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A Pan Evaporimeter For Rainy Areas

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INTRODUCTION

Pan evaporation serves widely as a reference level for estimating water losses, by evaporation and transpiration, from surfaces of water, soil, and crops. In combination with a knowledge on rainfall, it can be used to estimate total irrigation requirements. Additional knowledge on the size of the soil moisture reservoir available to plants in the rooting zone allows pan evaporation to be used for timing irrigation applications. Particularly in a humid, tropical climate, as prevails in Hawaii, it has proved to be a useful tool in this respect (Chang, 1961).

The U.S. Weather Bureau Class A (W.B.) pan has been recommended by the World Meteorological Organization as the standard instrument for pan-evaporation measurement. This pan is 4 feet in diameter and 10 inches high. It is placed on 2- by 4-inch lumber on the ground surface. Water in it is maintained between 2 and 3 inches below the rim by periodic water replenishment or by removal of water after rain. Evaporation is measured by a depth gage with Vernier scale up to an accuracy of 0.01 inch. In the computation of evaporation, the difference between water levels measured on consecutive days is increased by rain measured by a nearby rain gage.

Errors are introduced in measurement from the following sources:

(1) incorrect reading of the depth gage,
(2) a fluctuating water level,
(3) overflow of the pan during heavy rain, and
(4) the assumption that rain intercepted by a pan is the same as that collected by a nearby rain gage.

Because of the requirement of daily attendance of the W.B. pan and the susceptibility of the measurements to errors, a need has been felt for a long time to develop an evaporation pan that could be handled as a rain gage, an instrument that would discharge rain automatically and could supply a record of accumulated evaporation over an extended period. Several attempts to develop such an instrument have been made in the past. The earlier attempts were discussed by van't Woudt (1960); the recent work in this field is reviewed below.

The attempts made to develop a recording evaporation pan have all entailed the creation of a constant water level in an evaporation pan. The only constant-water-level pans that have proved satisfactory are the ones operating during extended nonrainy periods, e.g., in the states of California and Washington (Pruitt, 1960; Jensen *et al.*, 1961). In the instruments in question, a simple float valve controls the water supply from a nearby tank and maintains a constant water level in a standard W.B. pan. In rainy areas this principle is unsuited, as water-level fluctuations are not only introduced by rain, but also by temperature fluctuations.

Mihara (1961) reported on an evaporimeter used in paddy fields in Japan in which, by an ingenious system of levers, corrections are made for contraction and expansion of the water body under the influence of temperature changes. This instrument, however, does not appear suitable for routine evaporation measurements under field conditions.

OBJECTIVE

The objective of this study has been to develop a pan evaporimeter with a constant water level during rainy as well as nonrainy periods. This required the automatic and instantaneous discharge of rain by a mechanism that can operate under field conditions without electricity and that is inexpensive, and corrosion- and dirtproof.

In developing the instrument, an attempt has been made not to alter the energy balance applying to a W.B. pan.

PROCEDURE

Water expansion and contraction

Volume changes occur in the water body within a pan due to daily and seasonal temperature fluctuations. For the 7- to 8-inch depth of water in the W.B. pan, the water level varies 0.019 inch for a change in temperature from 68 to 86 degrees F. (20 to 30 degrees C.). For this reason, it was considered unavoidable to reduce the size of the water body in a pan and, thus, the effect of temperature fluctuations on the water level. This consideration led to the development of a constant-water-level pan (University of Hawaii, or U.H., pan) with the same diameter as the W.B. pan (4 feet), but with a height of 2 instead of 10 inches. The water level in the U.H. pan is maintained at approximately 1 inch instead of 2 to 3 inches below the rim, as in the W.B. pan. The water depth was thus reduced from 7–8 inches to 1 inch. For 1-inch depth of water, the water-level fluctuation is reduced to 0.0023 inch for a change in temperature as above. This fluctuation was considered acceptable. However, the change in pan depth and water depth has necessitated calibration of the U.H. pan against the W.B. pan.

Water supply

A water-supply tank of 2 feet diameter and of 2 feet height was selected. This gives a convenient ratio of 4 between tank area and pan area. It allows the water level in the supply tank to be read from a gage in centimeters and to be recorded in inches of evaporation, on division by 10. The accurate conversion figure is: 1/2.54 × 4.00 = 0.984, so that long-term records and records for experimental purposes, obtained as described, should be multiplied by 0.984 for accuracy. A continuous record of drop in water level in the supply tank and, therefore, of evaporation, can be obtained by placing a float recorder on the supply tank.

Under Hawaiian conditions the tank holds supply for 1 to 2 months of evaporation.

Conversion of a fluctuating water level to a fixed one

For water-level control and rain discharge, a number of float-controlled mechanisms have been tested. These included the following:

(1) stainless steel and brass carburetor valves and their related valve seats,
(2) stainless steel, Nylon, and Teflon balls fitting into sharp-edged valve seats of the same materials in various combinations,
(3) Nylon and Teflon tapered plugs fitting into tapered valve seats of the same materials, and
(4) Styrofoam floats, some of them impregnated or painted to prevent water absorption.

Three years of work have gone into the testing of various types of materials and mechanisms. This considerable length of time required for testing resulted from different findings under laboratory than under field conditions. Materials and mechanisms which performed well under shelter, broke down under field conditions because of the effects of corrosion, dirt, and wind, effects which often only showed up after several months of field testing.

The most satisfactory results were obtained by the use of a tapered plug fitting into a tapered valve seat, but the choice of material turned out to be critical. Nylon corroded slowly under field conditions. Teflon was satisfactory but no leakproof Teflon-Teflon combination of plug and valve seat could be made to work without exercising pressure in excess of that which is practicable.

The following mechanism has been found satisfactory.

Water is fed from the supply tank to the pan via two float-controlled valves in series. One of these valves is an inexpensive, commercial one which gives approximate water-level control in a small container attached to the supply tank. Water from this container is fed to a second float valve in a stilling well attached to the pan rim. This valve consists of a conical stainless steel plug fitting into a tapered Teflon valve seat and ensures at any time a fixed water level within the pan with an accuracy of 0.005 inch.

Rain is automatically discharged with a general accuracy of 0.01 inch, via a third float valve of the same shape and material as the second float valve (used for accurate inflow control), but placed in an inverted position with respect to the latter. This float valve is similarly placed within a stilling well attached to the pan rim. The two stilling wells can be placed adjacent to each other on the pan rim. The two stilling wells are interconnected with the main water body in the pan by copper tubing, but are wave- and dirt-insulated by the introduction of plastic pan-scrubbing material within an intermediate compartment. The assembly view is shown in figure 1. Details of critical parts are shown in figures 2 to 13.

Critical points in the over-all water-level control mechanism have been found to be the following:

(1) The rod arm of the commercial float valve (figs. 4 and 5) must be reduced from the normal 8-inch length to 5 inches. Stickiness of the float mechanism, experienced during the early stages of experimentation (resulting in persisting closure of the float valve), was eliminated as a result of the shortening of the float rod.

(2) The Teflon valve seat and stainless steel plug must not be installed till after a laboratory test has proved that they are so well machined that the plug and seat combination is leakproof under minute pressure.

(3) The connections between the interior of the pan and the stilling wells must be made of ½-inch copper tubing. Tubing of larger size will not sufficiently dampen ripples at the water surface in the pan. Tubing of smaller size tends to become clogged by dirt. Connections made by noncuprous materials tend to become blocked by algal growth.

Collection of test data

During the first 2½ years, almost daily attendance was given to the pans to check on their performance under laboratory and field conditions. Field conditions were simulated by exposing the pans on the lawn of the Agricultural Engineering Institute.

From July 27, 1961, to March 13, 1962, covering a period when the mechanism had almost been perfected, measurements were taken more systematically but at longer intervals. At that time, the U.H. pan was set up in duplicate with two W.B. pans on the lawn, at a site where all pans appeared to have equal exposure (fig. 14). The height of the bottom of the two U.H. pans was approximately 1 foot above the ground surface. The ground surface was uniformly covered by grass over the extent of the lawn.

At that time, readings were taken at intervals varying between 1 day and 14 days, depending on the opportunity for attendance, on rain and wind storms, on the necessity for cleaning, and on water-level control in the W.B. pans. Except for the time of recording, the pans remained unattended.

Dirt accumulation due to algal growth was suppressed by applying once a week a few drops of Roccal, a commercial sterilant, commonly used for swimming pools. However, other dirt accumulating in the pans necessitated periodic cleaning of the pans, usually once in 3 weeks.

Measurement of rainfall at the test site was made by a standard W.B. rain gage (8-inch-diameter receptacle). Wind was recorded at pan level by an anemometer with totalizing record.

FIGURE I

ASSEMBLY VIEW
UNIVERSITY OF HAWAII
EVAPORATION PAN

LEGEND	FIGURES
1. Scale (plastic ruler, calibrated in cm.)	
2. Gage of leucite tubing	
3. 1 ¼″ st. galv. pipe	
4. Concrete base in soil	
5. ½″ nipple plus plug (drainage plug)	
6. Water supply to tank	
7. Water supply tank	
8. Float chamber	4 and 5
9. Bracket for holding float chamber	
10. ⅝″ copper tubing + connections	
11. ⅜″ set screw (4 places)	
12. 1″ st. galv. pipe	
13. ⅝″ o.d. copper tubing + connections	
14. Inflow float chamber	6, 7, 8, 9, 11, 13
15. 2″ deep 48″ diameter pan	2 and 3
16. Set screw	2
17. 1″ st. galv. pipe	
18. 1 ¼″ st. galv. pipe	2
19. Pan base	2 and 3
20. Rain discharge outlet	2 and 10
21. Outflow float chamber	6, 7, 8, 9, 10, 12
22. Weight for holding down lids	

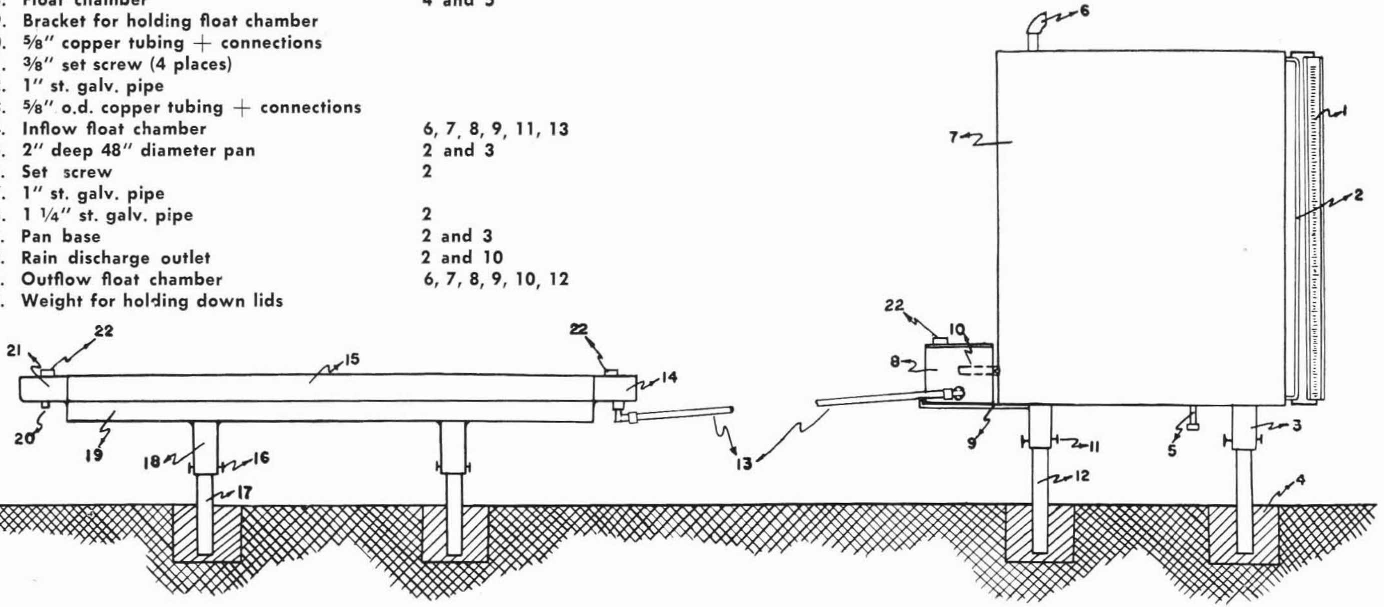


Figure 1. Assembly view, University of Hawaii evaporation pan.

FIGURE 2

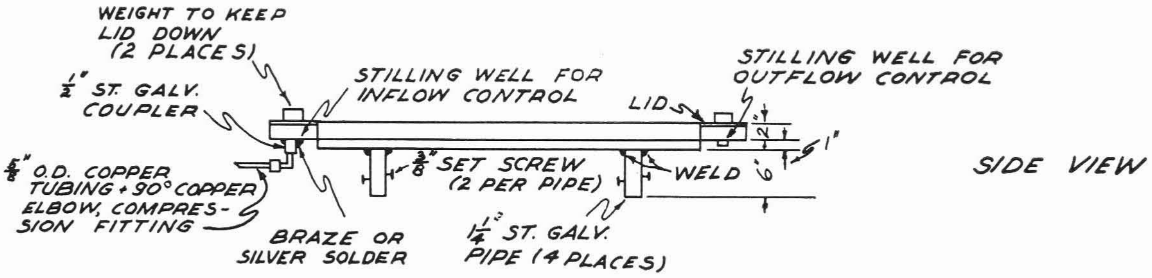
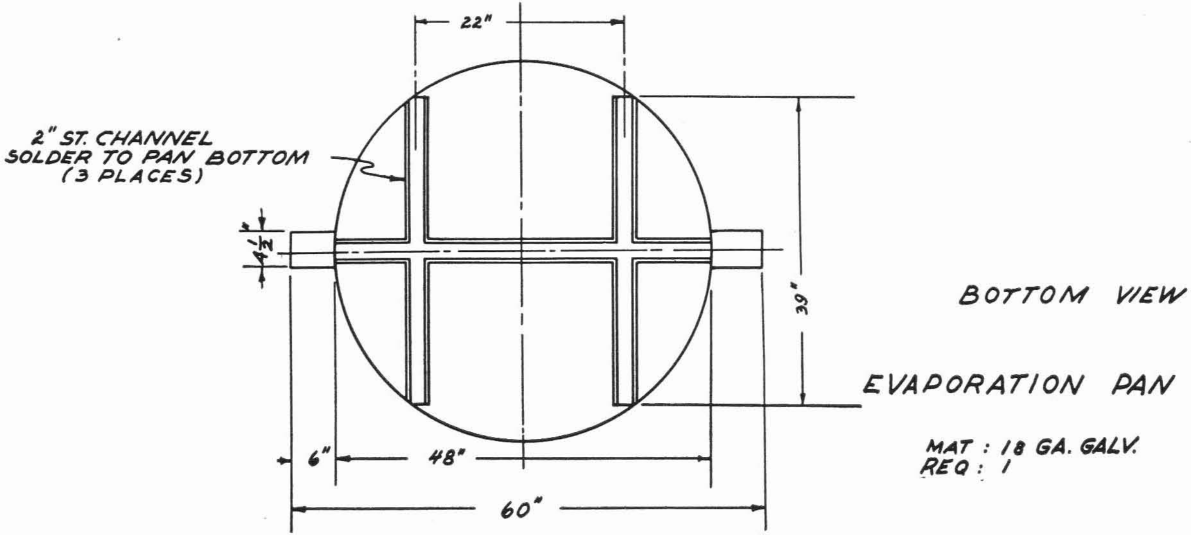


FIGURE 3



FIGURES 2, 3. Side view and bottom view, University of Hawaii evaporation pan.

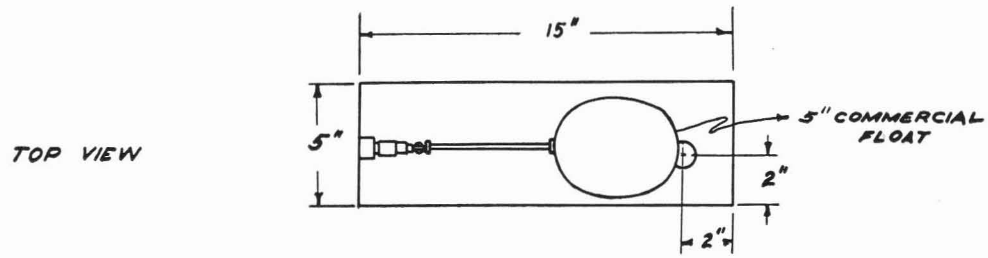


FIGURE 4

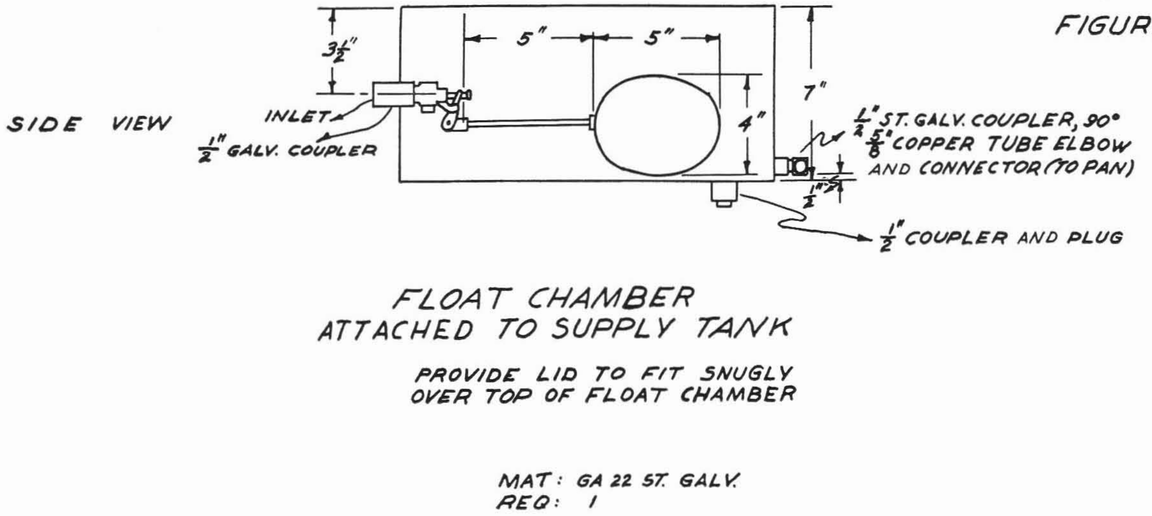


FIGURE 5

FIGURES 4, 5. Top view and side view of float chamber attached to supply tank, University of Hawaii evaporation pan.

FIGURE 6

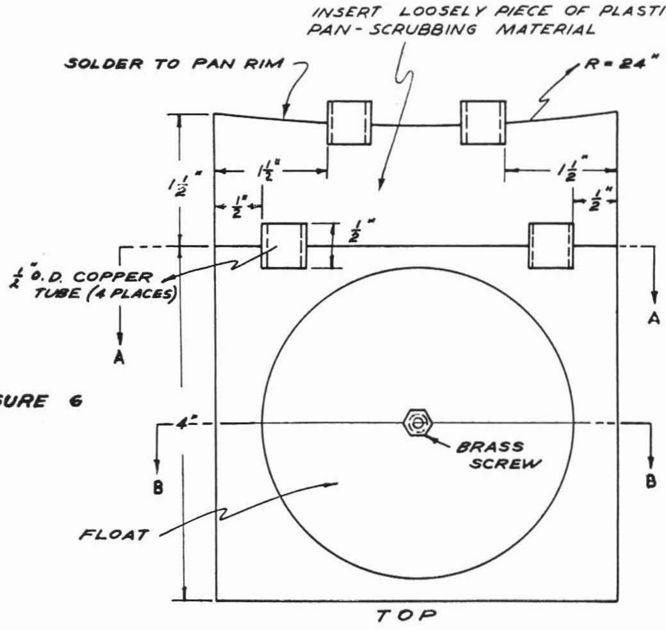
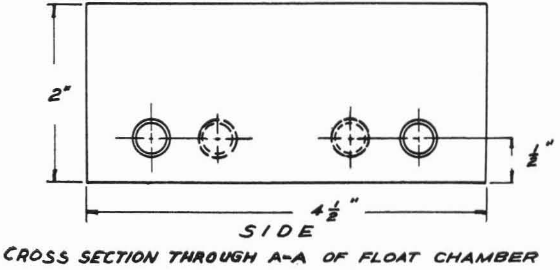


FIGURE 7



CROSS SECTION THROUGH A-A OF FLOAT CHAMBER

FIGURE 8

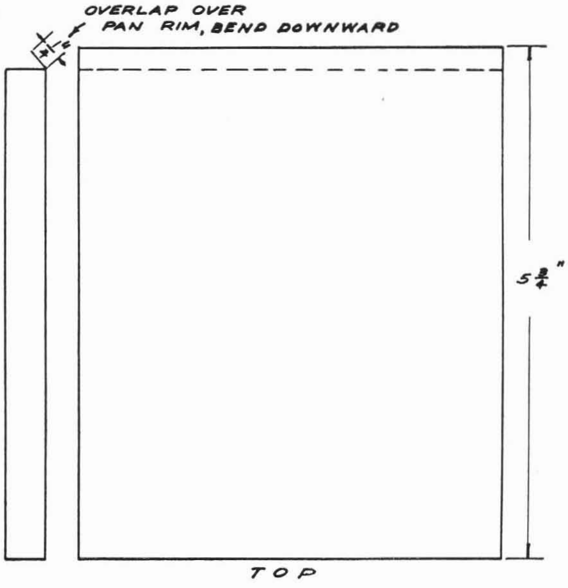
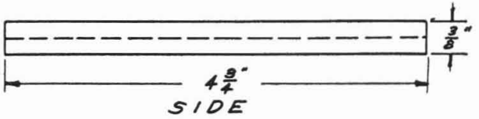


FIGURE 9



TOP AND SIDE VIEW LID FOR FLOAT CHAMBER

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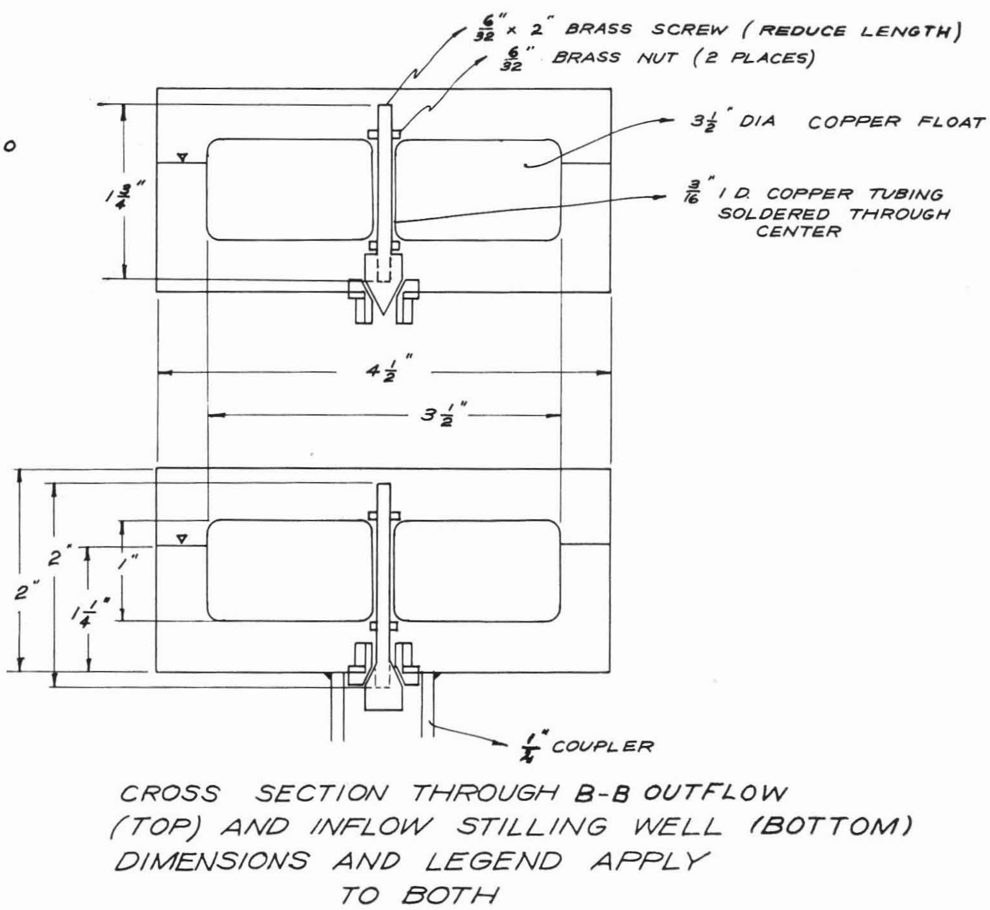
FIGURE 6. Top view of inflow and outflow float chambers, attached to pan rim.
FIGURE 7. Cross section through A-A of float chamber.
FIGURES 8, 9. Top view and side view of lid for float chamber.

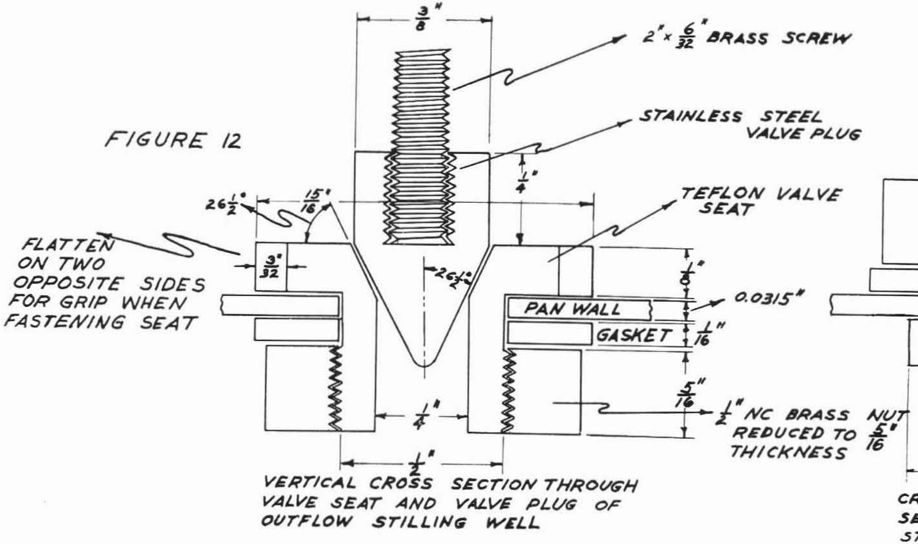
FIGURE 10

FIGURE 11



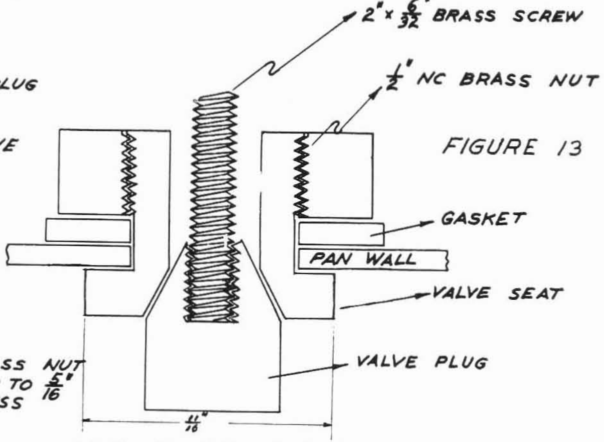
FIGURES 10, 11. Cross section through B-B outflow *(top)* and inflow float chamber *(bottom)*, attached to pan rim.

FIGURE 12



VERTICAL CROSS SECTION THROUGH VALVE SEAT AND VALVE PLUG OF OUTFLOW STILLING WELL

FIGURE 13



CROSS SECTION THROUGH VALVE SEAT AND VALVE PLUG INFLOW STILLING WELL. MATERIAL AND DIMENSIONS AS FOR OUTFLOW STILLING WELL. NOTE : VALVE SEAT AND PLUG IN UPSIDE-DOWN POSITION.

FIGURE 12. Vertical cross section through valve seat and valve plug of outflow float chamber attached to pan rim.
FIGURE 13. Cross section through valve seat and valve plug of inflow float chamber attached to pan rim.

FIGURE 14. Testing site on lawn of Agricultural Engineering Department.

A determination of possible variation in albedo (energy reflection) from the shallow U.H. and deep W.B. pan was at first unsuccessfully pursued by the use of a photometer and a photoelectric tube. Some results were obtained by suspending simultaneously two inverted pyrheliometers (actinometers) 4 feet above the centers of a U.H. and a W.B. pan. The instruments were provided with a 6-inch-long shield set at such an angle that a hypothetical extension of the sloping side coincided with the pan rim (fig. 14).

RESULTS

The readings taken with the various versions of the U.H. pan from October 27, 1959, to July 27, 1961, are shown in table 1.

The readings taken from July 27, 1961, to March 13, 1962, are given in table 2. Table 3 shows evaporation and rainfall records at the bauxite reclamation area, Kauai, from February, 1959, to September, 1960.

Table 4 shows evaporation records taken during 2 months by a U.H. and a W.B. pan under farm conditions by farm labor.

Figure 15 gives a graphical comparison of the average readings from two U.H. and two W.B. pans, and tables 5 and 6 give a summary of results and coefficients of correlation of the readings taken from July 27, 1961, to March 13, 1962.

Figures 16 and 17 show copies of the float record of the water level in the supply tank and W.B. pan expressed in inches of evaporation.

Figure 18 shows an example of the daily fluctuation in air- and pan-water temperature, of rate of evaporation, and of accumulative evaporation for a U.H. and a W.B. pan.

Figure 19 shows the rate of rain discharge from the U.H. pan, at various heads.

Figure 20 gives the time required for the completion of rain discharge from the U.H. pan.

DISCUSSION

Analysis of test data

The records taken from October 27, 1959, to July 27, 1961, (table 1) show a reasonable correlation between the U.H. and W.B. readings during 24 out of 27 nonrainy periods. During rainy periods 74 records appeared satisfactory. There were 27 records in which the U.H. readings were too low and 2 periods in which they were too high with respect to the W.B. readings.

In nearly all cases the unsatisfactory records were due to dirt interference with the water-level-control mechanisms. In the beginning of 1961 this difficulty was virtually overcome by the introduction of a dirt-settling compartment filled with plastic pan-scrubbing material between the two stilling wells and the main body of the pan (fig. 6). Installation of these compartments and other improvements were completed in July, 1961, and, therefore, the records taken from July 27, 1961, to March 13, 1962, (table 2) have been selected for analysis.

Even during this period a few records were missed, as indicated in the footnotes in table 2. On 7 days, records were missed for reasons not related to the satisfactory functioning of the evaporation pans. On 5 days, records

TABLE 1. Rainfall, and evaporation measured by U.H. pans and W.B. pans, from October 27, 1959, to July 27, 1961, in inches of water

DATE		RAINFALL	EVAPORATION[1]			
			U.H. Pan No. 1	U.H. Pan No. 2	W.B. Pan No. 1	W.B. Pan No. 2
1959						
Oct.	27	0.06	0.25		0.24	0.24
Nov.	2	0.71	0.29		0.38	0.37
	4	0.01	0.22		0.27	0.27
	5	0.09	0.21		0.17	0.13
	6	0.01	0.21*		0.26*	N.R.
	8	–	0.48		0.59	0.54
	10	–	0.34		0.31	0.33
	12	0.02	0.13		0.17	0.15
	13	–	0.06		0.06	0.07
	16	–	0.44		0.48	0.48
Dec.	17	0.03	0.16		0.16	0.17
	24	0.07	0.16		0.16	0.12
	27	0.03	0.18		0.17	0.18
	30	–	0.14		0.16	0.18
	31	0.01	0.11		0.12	0.11
1960						
Jan.	4	0.15	0.73		0.72	0.70
	6	0.02	0.33		0.37	0.39
	7	0.14	0.20		0.18	0.18
	8	0.04	0.23		0.19	0.17
	14	0.03	0.20		0.20	0.18
	15	0.02	0.11		0.13	0.10
	18	0.22	0.58		0.44	0.60
TOTAL—Excluding figures marked*[2]			5.55		5.67	5.66
Average					5.665	
1960						
Apr.	4– 5	0.02	0.21	0.22	0.26	0.26
	5– 7	0.05	0.34	0.37	0.38	0.38
	7–11	0.76	0.66	0.85	0.59	0.60
	11–14	0.13	0.53*	N.R.	0.68*	0.81*
	16–18	0.19	0.31	0.39	0.36	0.34
	18–20	0.02	0.49	0.42	0.51	0.49
	20–22	0.06	0.45	0.44	0.56	0.54
	22–25	0.21	0.48	0.50	0.67	0.70
	25–27	0.04	N.R.	0.50*	0.58*	0.54*
	27–29	0.02	0.46	0.49	0.49	0.55

(Continued)

TABLE 1. Rainfall, and evaporation measured by U.H. pans and W.B. pans, from October 27, 1959, to July 27, 1961, in inches of water (*Continued*)

DATE		RAINFALL	EVAPORATION[1]			
			U.H. Pan No. 1	U.H. Pan No. 2	W.B. Pan No. 1	W.B. Pan No. 2
1960						
May	2	0.02	0.75	0.74	0.72	0.89
	2– 4	–	0.46	0.43	0.46	0.51
	4– 9	0.13	1.26	1.33	1.32	1.46
	9–11	0.20	0.50	0.44	0.48	0.55
	11–13	1.80	0.39*	0.34*	0.45*	overflowed
	13–16	0.82	0.63*	0.56*	0.77*	N.R.
	16–18	0.08	N.R.	0.57*	0.45*	0.52*
	18–20	0.03	0.81	0.61	0.54	0.62
	20–23	0.06	0.42	0.74	0.71	0.79
	23–25	0.07	N.R.	0.32*	0.37*	0.42*
	25–27	–	0.80	0.50	0.55	0.65
	27–31	–	1.08*	1.22*	N.R.	N.R.
June	1	0.01	0.42	0.26	0.28	0.34
	1– 3	–	0.50	0.41	0.47	0.49
	3– 6	–	0.81*	0.80*	0.83*	N.R.
	6– 8	–	N.R.	0.60*	0.64*	0.73*
	8–10	0.05	0.47	0.57	0.63	0.68
	10–13	0.09	N.R.	0.80*	0.90*	0.98*
	13–15	0.07	0.51*	N.R.	0.62*	0.69*
	15–17	0.05	0.51	0.58	0.62	0.70
	17–20	0.03	0.91	0.90	0.96	1.07
	20–22	0.03	0.61	0.55	0.59	0.63
	22–24	0.27	0.33	0.36	0.46	0.47
	24–27	0.12	0.63	0.62	0.79	0.88
	27–29	0.20	0.25	0.49	0.54	0.54
July	1	0.07	0.24	0.34	0.43	0.47
	1– 5	0.30	0.95	0.71	0.98	1.10
	5– 6	–	0.20	0.18	0.28	0.31
	6– 8	–	0.24	0.26	0.32	0.35
	8–11	0.25	0.78	0.79	0.85	0.77
	11–13	0.18	0.30	0.35	0.48	0.54
	13–15	0.01	N.R.	0.50*	0.54*	0.58*
	15–18	0.01	0.80	0.83	0.96	1.07
	18–20	0.02	0.34	0.49	0.57	0.63
	20–22	–	0.40	0.43	0.50	0.53
	22–25	0.05	0.99	0.92	0.90	0.96
	25–27	–	0.43	0.72	0.59	0.68
	27–29	–	0.57	0.60	0.63	0.72

(Continued)

TABLE 1. *(Continued)*

DATE		RAINFALL	EVAPORATION[1]			
			U.H. Pan No. 1	U.H. Pan No. 2	W.B. Pan No. 1	W.B. Pan No. 2
1960						
August	1	0.02	0.89	0.81	0.83	0.82
	1– 3	0.06	0.51	0.52	0.57	0.63
	3– 5	0.16	0.30	0.36	0.52	0.57
	5– 8	0.03	0.84	0.79	0.85	0.94
	8–10	0.09	0.41	0.39	0.53	0.58
	10–12	–	N.R.	0.53*	0.54*	0.59*
	12–15	–	0.52*	0.71*	0.73*	N.R.
	15–17	–	0.97	0.55	0.58	0.62
	17–19	0.11	0.30	0.39	0.54	0.60
	19–22	0.02	0.58	0.78	0.81	0.83
	22–24	0.05	N.R.	0.42*	0.55*	0.60*
	24–26	0.06	0.43	0.65	0.64	0.69
	26–29	1.30	0.22*	0.28*	0.02*	overflowed
	29–31	0.09	0.48	0.42	0.58	0.59
Sept.	2	0.01	0.42	0.46	0.48	0.52
	2– 6	0.14	0.98	1.02	1.09	1.13
	6– 7	0.07	0.07	0.15	0.23	0.24
	7– 9	0.22	0.28	0.30	0.40	0.41
	9–12	0.12	0.49	0.68	0.80	0.82
	12–15	0.04	0.72	0.68	0.81	0.79
	15–19	0.14	1.16*	N.R.	1.03*	1.07*
	19–23	0.04	0.73	0.88	0.82	0.88
	22–26	0.01	N.R.	N.R.	0.85*	0.80*
Oct.	5– 8	0.17	0 92	1.22	0.77	0.77
	10	–	0.51	0.49	0.52	0.52
	17	0.48	1.48	1.49	1.46	1.41
	21	0.79	N.R.	0.90	1.09	1.11
	31	0.15	0.84	0.87	0.89	0.98
Nov.	4	0.11	0.47*	N.R.	0.61*	0.60*
	28	0.16	1.54	1.45	1.61	1.59
	12	1.38	1.13	1.18	1.28	1.30
	26	1.03	1.31	1.41	1.73	1.87
1961						
April 28–						
May	1	–	N.R.	0.51*	0.58*	0.53*
	15	0.12	1.56	1.56	1.68	1.58
	22	0.55	1.54	1.55	1.69	1.77
	24	–	0.73	0.78	0.70	0.73

(Continued)

TABLE 1. Rainfall, and evaporation measured by U.H. pans and W.B. pans, from October 27, 1959, to July 27, 1961, in inches of water (*Continued*)

DATE		RAINFALL	EVAPORATION[1]			
			U.H. Pan No. 1	U.H. Pan No. 2	W.B. Pan No. 1	W.B. Pan No. 2
1961						
June	5	0.42	1.55*	N.R.	N.R.	N.R.
	11	–	1.11*	0.90*	N.R.	N.R.
	20	0.04	1.27	1.11	1.17	1.27
	23	0.06	N.R.	0.83*	0.80*	0.92*
	26	0.03	0.68	0.87	0.74	0.81
	27	0.09	0.38	0.33	0.33	0.38
	29	–	N.R.	0.48*	0.48*	0.48*
	30	0.21	N.R.	N.R.	0.13*	0.16*
July	3	–	0.53	0.54	0.62	0.69
	7	–	N.R.	0.55*	0.52*	0.61*
	10	–	0.83	0.83	0.81	0.92
	17	1.01	1.65	1.62	1.66	1.82
	21	0.06	N.R.	0.86*	0.84*	0.96*
	27	0.02	N.R.	0.82*	0.72*	0.84*
TOTAL—Excluding figures marked*[2]			45.57	47.86	51.98	54.44
Average			46.715		53.210	

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[1] N.R.: No record.

[2] Figures marked with asterisk (*) excluded because data incomplete.

TABLE 2. Rainfall, and evaporation measured by 2 U.H. pans and 2 W.B. pans, from July 27, 1961, to March 13, 1962, in inches of water

DATE		NUMBER OF DAYS	RAINFALL	EVAPORATION				AVERAGE WIND AT PAN LEVEL MILES/DAY
				U.H. Pan No. 1	U.H. Pan No. 2	W.B. Pan No. 1	W.B. Pan No. 2	
1961								
July	31	4	0.04	0.89	0.88	0.89	1.03	103
Aug.	4	4	–	1.02	1.12	0.81	1.00	77
	9	5	0.02	0.92	1.14	1.03	1.13	
	12	3	–	0.64	0.66	0.63	0.67	93
	15	3	–	1.06	0.99	0.97	1.09	90
	18	3	–	0.96	0.91	0.97	1.05	49
	21		0.36	N.R.[1]	0.52*	0.60*	0.60*	
	22	1	–	0.25	0.22	0.25	0.26	111
	30		0.27	2.38*	2.39*	N.R.[1]	N.R.[1]	
NOTE: No record from August 30 to September 14; site of measurement changed.								
Sept.	18	4	–	0.59	0.65	0.69	0.70	70
	21	3	0.17	0.55	0.60	0.67	0.69	112
	25	4	0.11	0.89	0.97	0.98	0.97	55

(*Continued*)

TABLE 2. (*Continued*)

DATE	NUMBER OF DAYS	RAINFALL	EVAPORATION				AVERAGE WIND AT PAN LEVEL MILES/DAY
			U.H. Pan No. 1	U.H. Pan No. 2	W.B. Pan No. 1	W.B. Pan No. 2	
1961							
Oct. 9	14	0.81	2.24	2.26	2.48	2.29	55
16	7	0.05	0.85	0.93	0.83	1.10	61
23	7	1.76	0.96	0.94	1.04	1.04	40
27	4	0.45	1.27	1.64	1.60	1.49	112
30	3	0.03	0.55	0.47	0.46	0.57	54
Nov. 2		2.16	0.24*	0.24*	N.R.[2]	N.R.[2]	68
6	4	0.12	0.50	0.61	0.54	0.58	42
9	3	–	0.60	0.56	0.61	0.54	58
13	4	–	0.83	0.77	0.77	0.83	
18		0.62	1.48[6]*	0.83[5]*	1.27*	1.30*	116
20	2	0.32	0.62	0.58	0.63	0.54	
22		0.14	0.50*	N.R.[7]*	0.46*	0.44*	97
30		0.34	0.95*	0.93*	N.R.[3]	N.R.[3]	151
Dec. 4	4	0.01	0.70	0.67	0.68	0.62	
10		1.39	N.R.[4]	0.34*	0.50*	0.56*	136
18	8	0.10	1.09	1.16	1.13	1.21	27
22	4	0.11	0.72	0.61	0.76	0.72	80
30	8	0.06	1.15	1.22	1.31	1.24	41
1962							
Jan. 5	6	0.02	0.92	0.96	0.89	0.96	34
11	6	—	1.00	1.13[6]	0.92	0.98	83
15	4	0.06	0.64	0.77	0.72	0.74	52
23	8	0.23	0.80	0.95	1.01	1.05	42
29	6	0.33	0.77	0.73	0.72	0.75	46
Feb. 5	7	0.58	1.13	1.06	1.16	1.19	39
12	7	0.03	1.32	1.33	1.35	1.36	56
16	4	1.24	0.55	0.60	0.57	0.68	41
23	7	0.02	1.19	1.21	1.23	1.24	49
26	3	0.62	0.42	0.45	0.46	0.50	52
Mar. 1	3	0.61	0.32	0.37	0.42	0.34	59
5	4	0.18	0.75	0.86	0.76	0.90	98
13	8	1.06	0.91	1.02	1.04	1.08	62

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*Not analyzed.

[1] N.R.: No record, instrument being adjusted.

[2] N.R.: W.B. pan overflowed.

[3] Interference by sprinkler irrigation.

[4] N.R.: Level of pan setting shifted, causing emptying of pan.

[5] Commercial float blocked by dirt.

[6] Excess discharge due to 40- to 50-mile-per-hour wind.

[7] N.R.: Pan emptied because dirt particle lodged in outflow mechanism.

TABLE 3. Rainfall and pan evaporation at the Bauxite Reclamation Area, Wailua Game Reserve, Kauai, from February, 1959, to September, 1960 (altitude 500 feet)

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1959												
						inches of water						
Pan evaporation		2.80	3.72	3.30	3.72	4.80	4.34	4.96	missing	4.03	3.60	3.30
Rainfall		3.97	3.26	3.76	4.51	2.01	4.82	11.96	5.46	1.95	10.32	6.74
1960												
Pan evaporation	3.30	3.77	4.03	3.60	3.72	4.50	3.72	4.34	3.90			
Rainfall	5.21	6.59	11.95	3.85	4.10	3.98	3.93	4.51	5.37			

TABLE 4. Rainfall, and evaporation measured by a U.H. pan and a W.B. pan at Waimanalo Experimental Farm during February and March, 1962, in inches of water

DATE	RAINFALL	EVAPORATION		DATE	RAINFALL	EVAPORATION	
		U.H. Pan	W.B. Pan			U.H. Pan	W.B. Pan
February				**March**			
1	0.92	—	—	1	0.12	0.24	0.28
2	0.07	0.11	—	2	0.21		
3	0.02	0.07	0.18	3	0.02	0.14	0.18
4	—	0.12	0.12	4		0.30	0.31
5	—	0.17	0.16	5	0.06		
6	—	0.33	0.35	6	0.13		
7	—			7	0.03	0.30	0.32
8	0.37	—	—	8	1.58		
9	0.08	0.02	0.15	9	1.31		
10	—	0.18		10	0.14	0.28	0.32
11	—	0.20	0.19	11	0.07		
12	—	0.62	0.67	12	0.32		
13	—			13	0.62		
14	0.06			14	1.16	0.20	0.17
15	0.11			15	0.68		
16	0.21	0.14	0.11	16	0.02	0.12	0.17
17	1.23	—	—	17	0.04	0.15	0.23
18	0.02	0.21	0.29	18		0.20	0.18
19				19		0.45	0.48
20		0.14	0.20	20			
21		0.19	0.20	21		0.20	0.21
22		0.64	0.80	22		0.63	0.57
23				23			
24	0.26			24			
25	0.22			25	0.32	0.46	0.47
26				26	0.02		
27	1.05			27	0.02		
28				28		0.50	0.49
				29	0.28		
				30			
				31	0.02		
Total	4.62	3.14	3.42		7.17	4.17	4.38

TABLE 5. Summary of records of evaporation (from table 2) in inches by 2 U.H. pans and 2 W.B. pans, from July 27, 1961, to March 13, 1962[1]

DAYS OF MEASUREMENT	RAINFALL, INCHES	EVAPORATION						
		U.H. Pan No. 1	U.H. Pan No. 2	Average 2 U.H. Pans	W.B. Pan No. 1	W.B. Pan No. 2	Average 2 W.B. Pans	Average Percentage Difference
Nonrainy periods (including rain less than 0.05 inch)								
67	0.17	13.44	13.67	13.55	13.15	14.03	13.58	0.2
Rainy Periods								
112	7.91	17.13	18.33	17.73	18.83	19.10	18.97	6.5
Total								
179	8.08	30.57	32.00	31.28	31.98	33.13	32.55	3.9

[1] Figures marked with asterisk (*) in table 2 excluded from summary totals in table 5 because data incomplete.

TABLE 6. Coefficient of correlation between readings of U.H. pan No. 1 and U.H. pan No. 2; W. B. pan No. 1 and W.B. pan No. 2; and average of 2 U.H. pans and average of 2 W.B. pans, from July 27, 1961, to March 13, 1962

Nonrainy days		*Nonrainy days*	
U.H. pan No. 1 versus U.H. pan No. 2:	0.997	Average of 2 U.H. pans versus average of 2 W.B. pans:	0.994
W.B. pan No. 1 versus W.B. pan No. 2:	0.998		
Rainy days		*Rainy days*	
U.H. pan No. 1 versus U.H. pan No. 2:	0.980	Average of 2 U.H. pans versus average of 2 W.B. pans:	0.970
W.B. pan No. 1 versus W.B. pan No. 2:	0.994		
Nonrainy and rainy days			
Average of 2 U.H. pans versus average of 2 W.B. pans:	0.978		

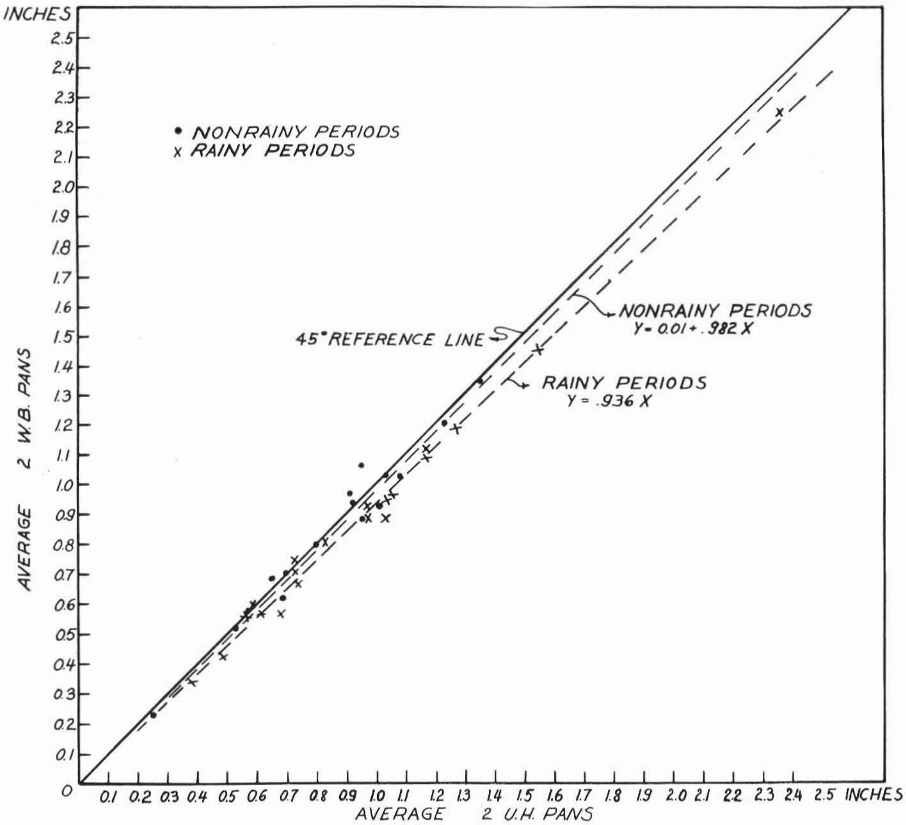


FIGURE 15. Average measured evaporation from two U.H. pans against that from two W.B. pans, from July 27, 1961, to March 13, 1962.

were missed due to weaknesses in the U.H. pan. Of these, two were permanently remedied (see footnotes in table 2). Three records showed up two persisting inherent weaknesses of the U.H. pan. These are:

(1) unwanted discharge due to float wobbling when winds exceed 40 miles per hour. This accounted for the measurement of excess evaporation of 0.18 inch during one period and 0.15 inch during another period. An error of this magnitude occurred on 1 day out of 181 days of measurement. Subsequent redesign of the lid on the stilling wells (fig. 8) will probably reduce the statistical incidence.

(2) emptying of the pan and supply tank because a dirt particle had lodged between the plug and valve seat in the discharge mechanism. This occurred on 1 out of 358 days, or during 1 out of 44 periods of measurement.

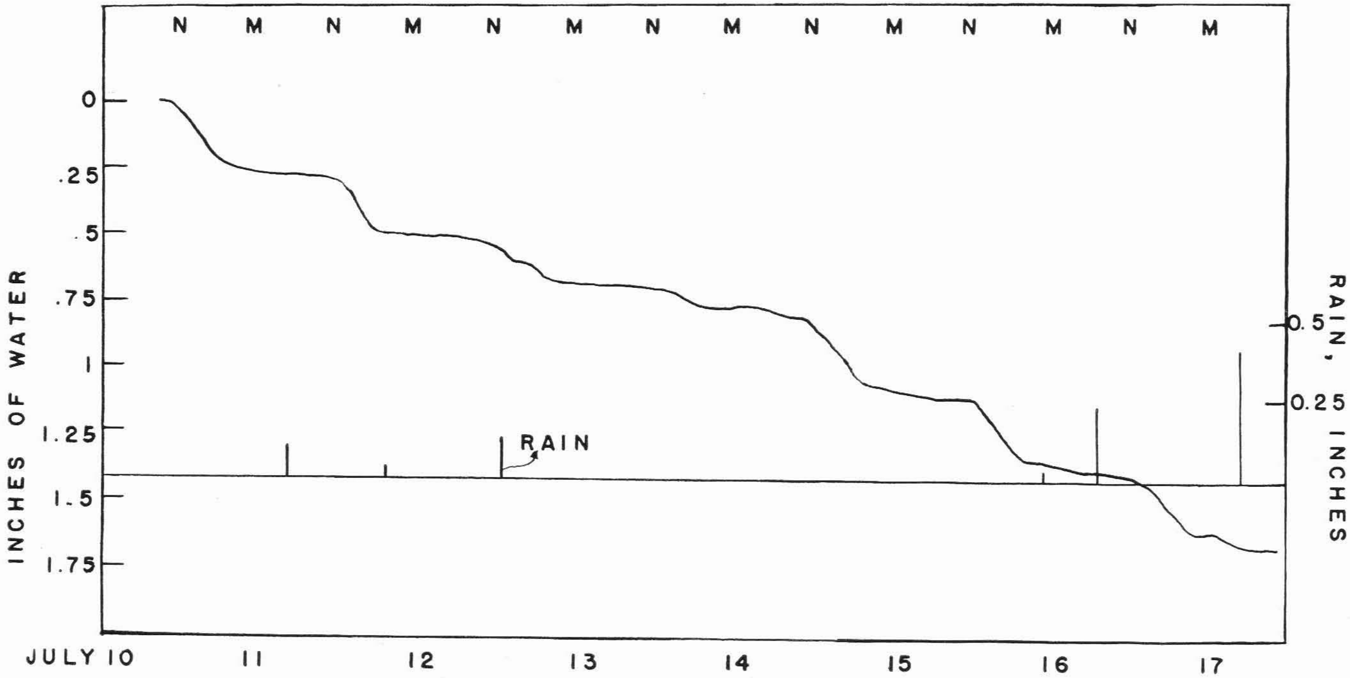


FIGURE 16. Copy of float record of water level in supply tank of U.H. pan, from July 10 to July 17, 1961, expressed in inches of evaporation.

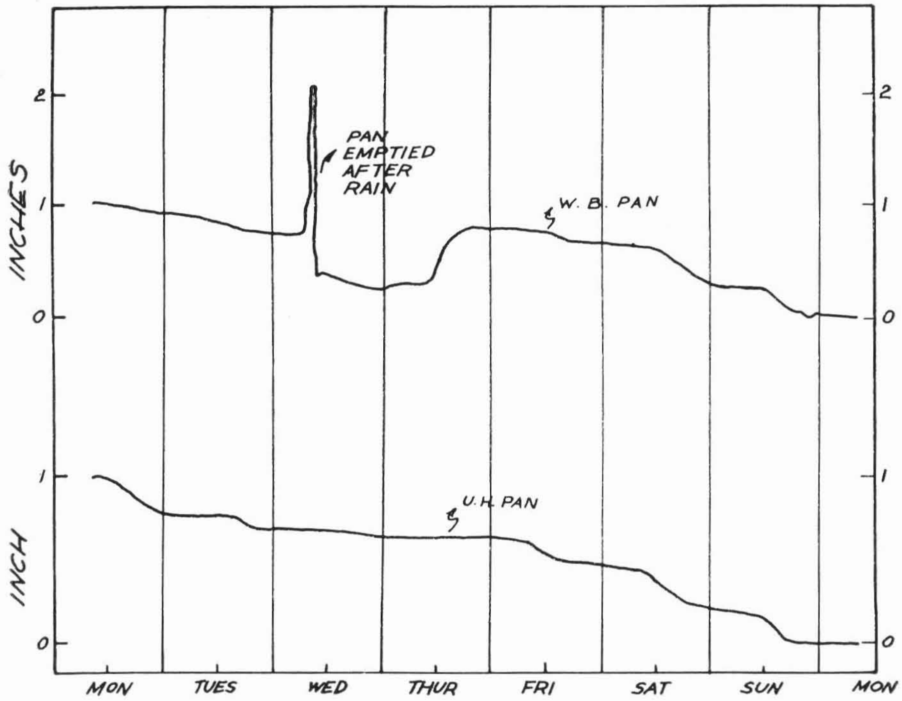


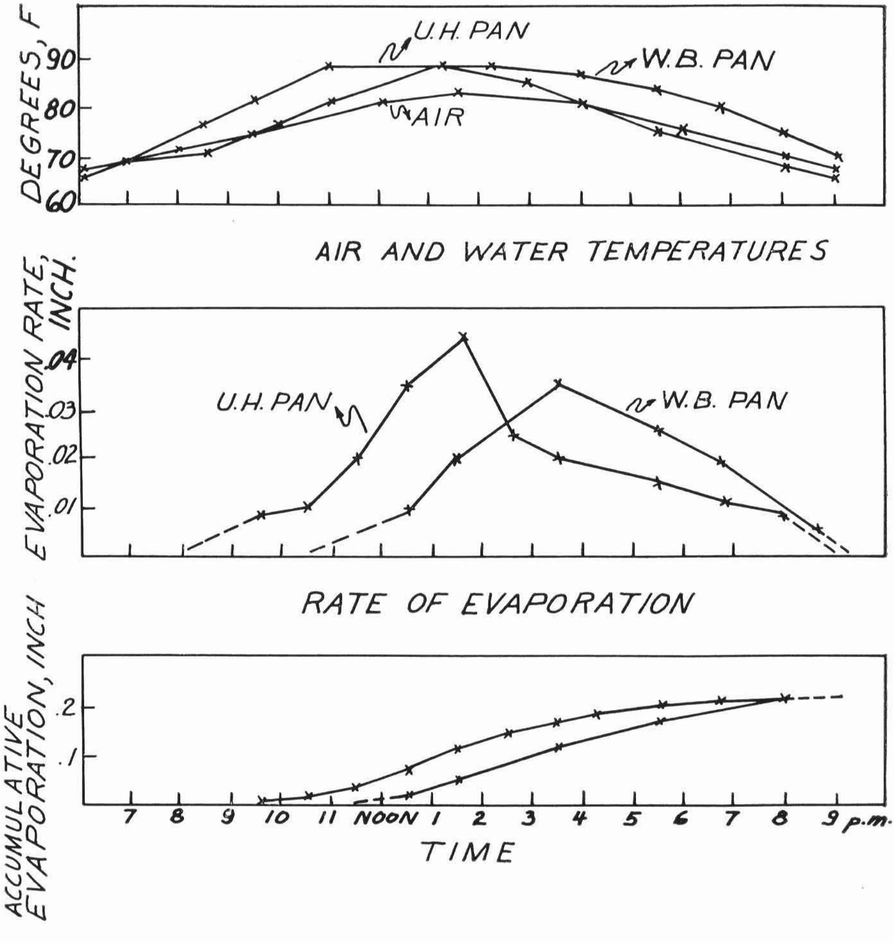
FIGURE 17. Copy of float record of water level in supply tank of U.H. pan and of water level variation in W.B. pan, from October 16 to 23, 1961, in inches of evaporation.

Record shows:

U.H. pan	0.97 inch evaporation
W.B. pan	1.04 inches evaporation
Rain	1.76 inches

Further analysis of the data showed a coefficient of correlation between the average of the two U.H. and the two W.B. pans (table 6) of 0.994 for nonrainy periods and 0.97 for rainy periods. During nonrainy periods the U.H. pan recorded evaporation within 0.2 percent of that measured by the W.B. pan, but during rainy periods evaporation from the U.H. pan was 6.5 percent lower than from the W.B. pan.

The 2-month record collected during rainy periods on the Waimanalo Farm (table 4) gave similar results. This discrepancy is further discussed in the following section.


AIR AND WATER TEMPERATURES

RATE OF EVAPORATION

FIGURE 18. Example of daily fluctuation in air- and pan-water temperature, of rate of evaporation, and of accumulative evaporation in inches for a U.H. and a W.B. pan.

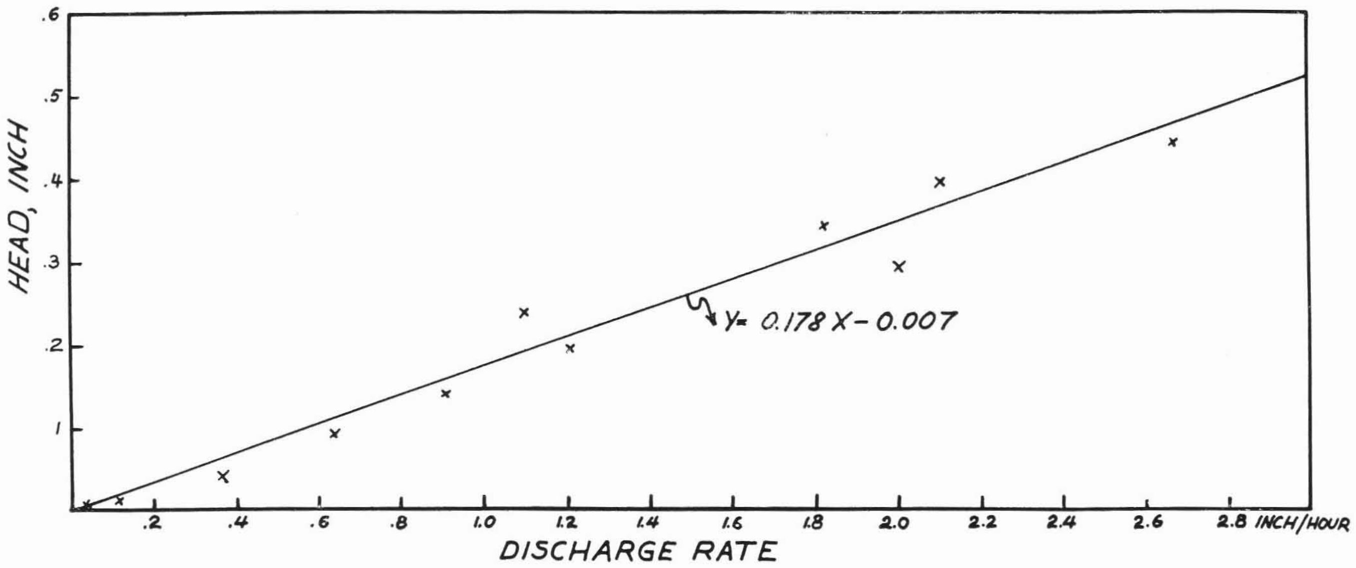


FIGURE 19. Rain-discharge rate at various heads above the equilibrium level in the U.H. pan.

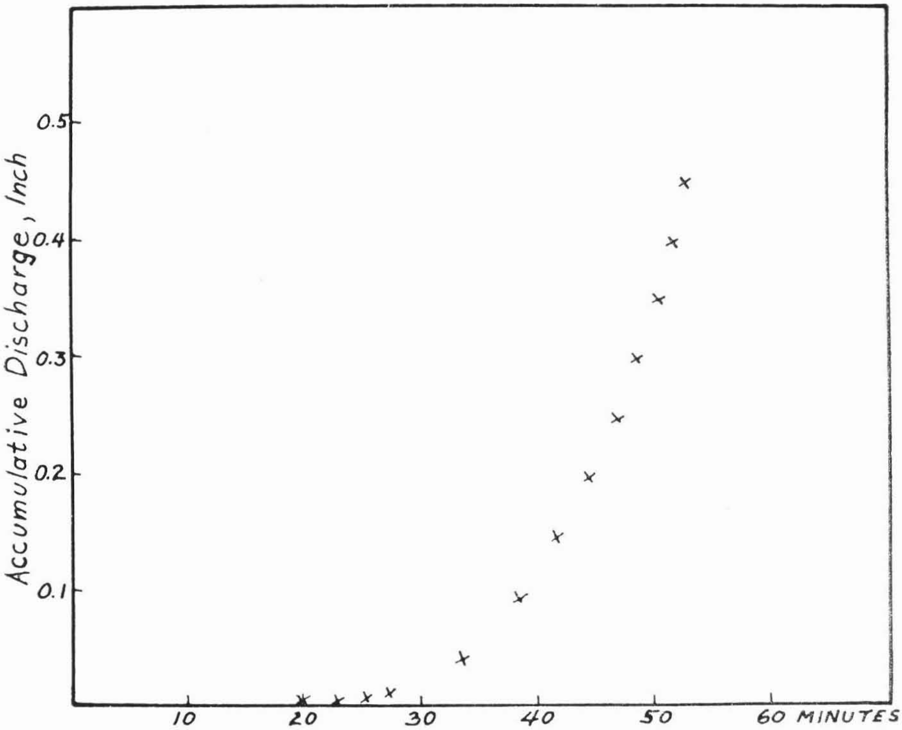


FIGURE 20. The time required for discharge of rain from the U.H. pan.

Rainfall interception by an evaporation pan

Data have been published recently (van't Woudt, 1960) which unwittingly predicted lower evaporation from a U.H. pan than from a W.B. pan during rainy periods, considering that evaporation readings by a W.B. pan are corrected for rain measured by a nearby gage. In an accurate and reliable manner it was shown that during 239 days a W.B. pan intercepted 5.6 percent less rain than a nearby rain gage. A recent scrutiny of the float records which have supplied this information confirm the correctness of these findings. A further attempt to check on rain interception by a rain gage and by a pan was subsequently made. However, it was found that rain was difficult to measure by an empty pan. Moisture adhering to the walls of a pan on emptying it for water measurement could readily account for any measured difference in rain interception. Only on two occasions were reliable records obtained. In both cases, rain was measured after it had started and before it had ceased to fall. Measurement of rain intercepted by the two W.B. pans was made with a depth gage, the water level in the two pans being at normal height.

The results are as follows:

Period of rain	*Rain intercepted by rain gage*	*Rain intercepted by*	
		W.B. pan 1	*W.B. pan 2*
5:00 P.M.–8:00 A.M.	0.47	0.410	0.405 inch
8:30 A.M.–3:35 P.M.	0.87	0.837	0.840 inch

In the first case, out of the difference of 0.06 and 0.065 inch, a maximum of 0.02 inch can be allowed for evaporation due to stored heat (fig. 18), leaving 0.04 and 0.045 inch, or 10 percent lower rain interception by a pan than by a rain gage. Similarly, in the second case, a 0.01-inch evaporation might have taken place during the rain. These data support the earlier information.

A scrutiny of the literature reveals little that supports these findings. The studies by Huff (1955) suggest that rain measured by a 1.15-inch and a 0.8-inch gage can be from 2 to 13 percent higher than from an 8-inch gage. Denison (1941) reported a similar trend in comparing a 3.5-inch gage with an 8-inch gage. Bac (1951) reported that measured rain decreases as the size increases of an interceptor placed near the ground surface. On the other hand, Wolfgang (1952) claimed a 1.5 percent increase in rain measured, due to lowering the height of a rain gage to ground level.

It is likely that differences in rainfall interception by a pan and by a gage vary according to the nature of the rain. It is considered likely that the findings on rainfall interception apply only to Hawaii or to other similar areas. It is known that almost all rain in Hawaii consists of unusually small drops (Chang, 1962).

The observed difference in rain interception largely explains the lower evaporation measured from a U.H. pan than from a W.B. pan during rainy periods. The evidence is that the U.H. pan gives the more accurate evaporation measurements during such periods.

However, a small error is introduced in measurement by the U.H. pan during rainy periods because of delay in rain discharge, as is discussed in the next section.

Rain discharge from a U.H. pan

A second, though minor, cause of discrepancies between evaporation readings taken by a U.H. and a W.B. pan arises out of continuation of discharge of rain after rain ceases to fall.

The rate of rain discharge at various water levels above that of the equilibrium level in the U.H. pan is shown in figure 19. Upon replotting the data in a different way in figure 20, it is seen that:

(1) Discharge continues for 20 minutes after rain ceases to fall. This applies to any rainfall. This is due to a very low rate of discharge

at heads of a few hundredths of an inch. At this stage, discharge takes place by the release of drops at several minutes interval.

(2) Rain of an intensity exceeding discharge time causes a further delay in discharge to be added to the 20 minutes delay for any rainfall.

For an assessment of the significance of the latter observation, rain data have been analyzed for a particular rainy area, that of the bauxite reclamation area on the island of Kauai. In this area, rain falls on 2 out of 3 days on the average, and, on rainy days, rain is usually from several showers.

Out of 319 rainfalls, 68 rainfalls were found to have an intensity in excess of that required for their discharge within 20 minutes from the U.H. pan. These data and their significance in time of evaporation lost after cessation of rain are shown in table 7.

Table 8 shows the correction factors to be applied to evaporation measurements by the U.H. pan per rainfall and for rainfalls of intensities shown in table 7.

Assuming a downward correction of 5.6 percent for rainfall to make the W.B. data more realistic, and an upward correction for delay in rain discharge to be applied to the U.H. data, the following comparisons result, based on the data in tables 4 and 5.

	Measured evaporation, U.H. pans, inches	*Corrected evaporation, U.H. pans, inches*	*Measured evaporation, W.B. pans, inches*	*Corrected evaporation, W.B. pans, inches*
Rainy periods at test site	17.73	18.03	18.97	18.53
Waimanalo Experimental Farm				
February 1962	3.14	3.17	3.42	3.20
March 1962	4.17	4.23	4.38	4.02

The applied corrections bring the two sets of data closer; the remaining small discrepancies can be due to three further factors:

(1) lack of complete discharge of rain or excess discharge from pan due to inaccurate float setting,

(2) rainfall interception by a pan and by a rain gage varies from the measured 5.6 percent, depending on the rainfall characteristics, and

(3) additional replication in measurement might have reduced the observed differences.

Of these three factors, rainfall is likely to be the most important one. In the absence of further information on the effect of differences in rainfall characteristics on catchment by a pan and by a rain gage, the above differences need be left unexplained.

TABLE 7. Details of 68 out of 319 rainfalls, at the Bauxite Reclamation Area, Kauai, from January 19 to December 7, 1959, that have such an intensity/duration relationship that their discharge from a U.H. pan cannot be completed in 20 minutes after cessation of rain

NUMBER OF RAINFALLS	INTENSITY, INCH/HOUR	DURATION, MINUTES	TOTAL RAIN, INCH	TIME REQUIRED FOR DISCHARGE FROM U.H. PAN, MINUTES	DISCHARGE TIME IN EXCESS OF 20 MINUTES AFTER CESSATION OF RAIN, PER RAINFALL, MINUTES	DISCHARGE TIME IN EXCESS OF 20 MINUTES AFTER CESSATION OF RAIN, FOR ALL RAINFALLS, MINUTES
4	0.18	10	0.03	32	2	8
5	0.24	5	0.02	29	4	20
9	0.24	10	0.04	34	4	36
6	0.30	10	0.05	35	5	30
5	0.36	5	0.03	32	7	35
6	0.36	10	0.06	35.5	5.5	33
5	0.48	5	0.04	34	9	45
4	0.48	10	0.08	38	8	32
1	0.54	10	0.09	39	9	9
2	0.54	20	0.18	44	4	8
1	0.60	5	0.05	35	10	10
6	0.60	10	0.10	39	9	54
1	0.60	20	0.20	45	5	5
2	0.66	10	0.11	40	10	20
1	0.72	5	0.06	35	10	10
3	0.72	10	0.12	41	11	33
2	0.84	10	0.14	42	12	24
1	0.88	30	0.44	53	3	3
1	0.90	10	0.15	42	12	12
1	0.96	5	0.08	38	13	13
1	1.08	10	0.18	44	14	14
1	1.50	10	0.25	47	17	17
68						471=44 minutes per month

TABLE 8. Upward corrections to be applied to evaporation measured by U.H. pan for each rainfall, and for rainfalls of high intensities (as given in table 7), in relation to prevailing rate of evaporation after cessation of rain

RATE OF EVAPORATION IN 24-HOUR DAY, INCH	AVERAGE RATE OF HOURLY EVAPORATION, INCH	UPWARD CORRECTION IN MEASURED EVAPORATION FOR EACH RAINFALL, INCH	POSSIBLE MONTHLY UPWARD CORRECTION IN MEASURED EVAPORATION FOR RAINFALLS OF GIVEN HIGH INTENSITY, INCH*
0.12	0.005	0.0017	0.01
0.18	0.0075	0.0025	0.01
0.24	0.01	0.003	0.01
0.30	0.0125	0.004	0.01
0.36	0.015	0.005	0.02
0.42	0.0175	0.006	0.02

*Assuming 10 high-intensity rainfalls per month.

The physical characteristics of the U.H. pan

One would have expected that readings from the U.H. pan would differ from those of the W.B. pan because of the reduction in depth of the pan, depth of water level, and length of rim above the water level, thus by the change from a "deep" to a "shallow" pan.

The assumption had been made that albedo would be higher from the shallow U.H. pan than from the deep W.B. pan, but that a lower evaporation arising out of a resulting lower energy supply might be offset by the smaller extent of the rim in the U.H. pan, thus by greater air movement around the U.H. pan.

The attempts to measure albedo from the U.H. pan merely resulted in a qualitative suggestion that its albedo is slightly higher than that from the W.B. pan, but the differences measured fall within the range of experimental errors of the pyrheliometers used for this purpose.

Although Wartena and Borghorst (1961) found a reflection of approximately 8 percent of incident, visible light from a pan comparable to a W.B. pan, Hall (1960) showed that all incoming energy is absorbed by a depth of water in excess of 3 millimeters and in line with this, Nordenson and Baker (1962) found only a 2 percent difference in evaporation between a W.B. pan with metal and black-painted bottom.

If a small difference in albedo does exist, it must be offset by other factors. Wave formation due to a given wind is much less in a shallow pan than in a deep pan and, in addition to exposure, this might well be another possible compensating factor.

Even though the total amount of evaporation from the U.H. and W.B. pans is the same during nonrainy periods, there is a distinct difference in pattern of daily evaporation, as is exemplified by figure 18; this also shows up in figures 16 and 17. Evaporation from the U.H. pan starts soon after sunrise and ceases at sunset. In the W.B. pan, incoming energy during the first few hours after sunrise is used up to increase water temperatures. Evaporation starts several hours after sunrise but continues after sunset at the expense of stored heat in the water body.

Limitations to the use of a U.H. pan due to expansion and contraction of water in the pan

As already mentioned, a reduction in depth of water surface in the U.H. pan has been necessitated by the effect of fluctuating temperature on the height of the water level. Table 9 shows that the maximum variation in water level under normal field conditions is 0.0077 inch for a U.H. pan.

TABLE 9. Increase or decrease in water level in U.H. pan at various temperatures, in relation to the water depth at 20 degrees C.*

DEGREES F.	DEGREES C.	SPECIFIC VOLUME	RELATIVE HEIGHT, INCH	DIFFERENCE IN HEIGHT, INCH
14	—10	1.00186	1.0002	+0.0002
32	0	1.0013	0.9996	—0.0004
39.2	4	1.000	0.9983	—0.0017
50	10	1.00027	0.999	—0.001
68	20	1.00177	1 inch	
86	30	1.00435	1.0026	+0.0026
104	40	1.00782	1.006	+0.006

*Maximum variation from 4 degrees to 40 degrees C.
0.0017 + 0.006 = 0.0077 inch.

Loss of water by splash and birds

From time to time the subject is brought up of the possible significance of loss of water from an evaporation pan by splash (for instance, Nordenson and Baker, 1962). "Splash" covers (1) discharge of water over the pan rim by wave action, and (2) loss of rain due to "spatters," when these are lodged beyond the pan.

Hawaii is reputed for strong winds, so that there has been ample opportunity during the several years of close observation of the behavior of the U.H. and W.B. pans to assess any significance of splash. Splash would be expected to be of greater significance in the shallow U.H. pan (with 1-inch rim above the water surface) than in the W.B. pan (with 2- to 3-inch rim above the water surface).

However, at no time has splash been observed.

As far as wind is concerned, lack of splash from the U.H. pan can be explained from the effect of wind on the water surface in this pan, which has already been referred to. Strong winds producing 1-inch-high waves in the W.B. pan merely produce ripples in the U.H. pan.

Spatter following raindrop impact has never been observed. This may be related to the small drop size in Hawaiian rains.

It is believed that splash is of no practical significance under Hawaiian conditions.

The shallowness of the water body invites birds to bathe and drink in the U.H. pan more than in the W.B. pan. Initially, it was believed that a bird screen for the shallow U.H. pan was unavoidable (fig. 21). However, a bird screen depressed evaporation about 5 percent below that from an unscreened pan, apparently because of decreased exposure of the water sur-

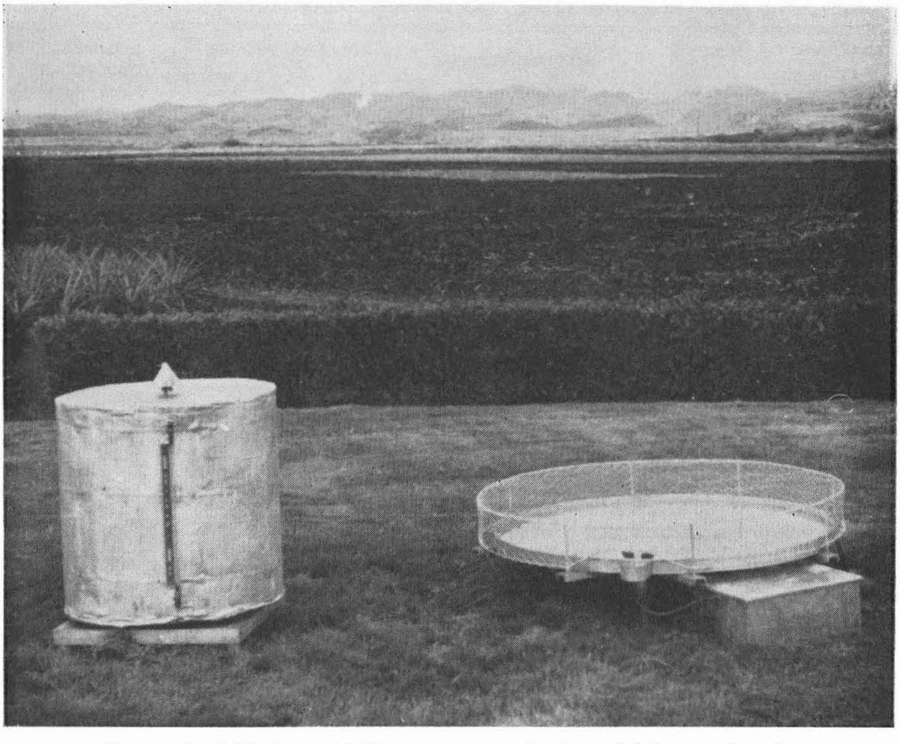


FIGURE 21. Initially the U.H. pan was tested with a "bird-screen" on it.

face. This caused divergence from W.B. measurements and this has led to the realization that 300 milliliters represent 0.01-inch depth of water in either the U.H. or W.B. pan. Subsequent observations and records have led to the conclusion that the small quantities of water removed by drinking by small birds is of negligible practicable significance under Hawaiian conditions.

Fencing of the site of measurement is essential where there is a chance of drinking by dogs or other large animals.

Usefulness of the U.H. pan

Provided:

(1) the instrument is manufactured according to the specifications given in figures 1 to 13,

(2) the instrument is installed according to the instructions given in Appendix 1, and

(3) normal maintenance care is given according to Appendix 1, the U.H. pan will give evaporation records which are the same as those obtained by the W.B. pan during nonrainy periods and more accurate than those from the W.B. pan during rainy periods.

However, a "chance" breakdown may be expected on 1 day per year due to a dirt particle becoming lodged between the valve plug and valve seat in the discharge mechanism. Also, during periods when winds above 40 miles per hour prevail, the reading may be in error.

Evaporation records can be obtained without daily readings or adjustment of the water level merely by reading the gage on the supply tank. The U.H. pan need not be cleaned more frequently than the W.B. pan. It is cleaned in a few minutes. The initial float setting remains unaffected by the cleaning if the cleaning is done with ordinary care.

Unnecessary breakdown of the mechanism may occur through undue accumulation of dirt in the pan bottom, water supply tank, or pan fittings.

The U.H. pan can be installed, with minor reservations, in isolated areas where only weekly attendance is possible by field men, as is evidenced by the 20 months' record collected on the island of Kauai (table 3). The evaporimeter used here was a still imperfected version of the U.H. pan. The pan was left unattended in an isolated area, except for periodic cleaning and weekly readings by a local foreman. The records obtained, on analysis, were found to be satisfactory during 19 out of 20 months.

Manufacture of the U.H. pan

The pan can be manufactured in a metal workshop at an expense which exceeds somewhat the cost of a W.B. pan. Its commercial manufacture in Hawaii costs approximately $175, compared with the cost of $100 for the W.B. pan (which includes the expense of a depth gage and a brass stilling well). The bulk of the pan is manufactured from galvanized sheet metal, standard copper tubing and copper fittings, standard float valve, and leucite tubing. The heart of the system consists of the two valves (in the stilling wells), which must be machined from stainless steel and Teflon stock. In addition, two small copper floats are needed. These are hard to make satisfactorily in a workshop and should be commercially obtained (Chicago Float Works, 2330 South Western Avenue, Chicago 8, Illinois, at $4.00 each).

All surfaces should be aluminum-painted where galvanized metal is subject to corrosion.

SUMMARY AND CONCLUSIONS

(1) An evaporation pan (University of Hawaii, or U.H. pan) has been developed with a water level that remains at a constant level during both rainy and nonrainy periods. Records are obtained from reading a gage on the outside of a water supply tank holding 1 to 2 months' supply. A continuous evaporation record can be obtained by using a float recorder on the supply tank.

(2) The record obtained with the U.H. pan during nonrainy periods is the same as that obtained by a U.S. Weather Bureau Class A (W.B.) pan, which has been recommended as the international standard for pan-evaporation measurement. During rainy periods, the U.H. pan records approximately 6 percent lower evaporation than the W.B. pan. This difference can be largely accounted for from findings that under Hawaiian conditions a pan intercepts some 5 percent less rain than a rain gage.

Differences in amounts of rainfall intercepted by a pan and a rain gage may vary according to the circumstances under which the rain falls. Findings in Hawaii may not necessarily apply elsewhere. However, under Hawaiian conditions the U.H. pan records evaporation more accurately than the W.B. pan during rainy conditions.

(3) An error is introduced in evaporation measurement by the U.H. pan during rainy periods, generally not exceeding 1 percent. A correction can readily be applied.

(4) The U.H. pan can be used more conveniently than the W.B. pan for routine evaporation measurements, but one may expect, with normal care, to lose one record on 1 day in a year due to interference by dirt with the level-control mechanism. Inaccurate records may possibly be obtained when winds of over 40 miles per hour prevail.

(5) But for the reservation mentioned under (4), the U.H. pan can be installed in isolated areas where only weekly attendance is possible.

(6) The cost of manufacture of the U.H. pan is approximately 1½ times that of the W.B. pan.

REFERENCES

BAC, S. 1951. (INFLUENCE OF METHOD OF MEASUREMENT ON THE INDICATION OF PRECIPITATION AMOUNTS.). Y. Przeglad Meteorologiczny Hydrologiczny, 1950/52: 16–32. (Meteorol. Abstr. 4. 4. 3. 27, 1953).

CHANG, JEN-HU. 1961. MICROCLIMATE OF SUGAR CANE. Hawaii. Planters' Rec. 56 (3) : 195–225.

————. 1962. THE ROLE OF CLIMATOLOGY IN THE HAWAIIAN SUGAR CANE INDUSTRY. Exp. Sta. Hawaii. Sugar Planters' Assn. Paper presented to Internatl. Geographic Conf., Meteorol. Sec., Kuala Lumpur.

DENISON, F. N. 1941. (RAINGAGE COMPARISON.). Bull. Amer. Meteorol. Soc. 22: 65–67.

HALL, C. W. 1960. THEORY OF INFRARED DRYING OF AGRICULTURAL PRODUCTS. Paper 60.813 presented to Dec. 4–7, 1960, meeting of Amer. Soc. Agr. Engin.

HUFF, F. A. 1955. COMPARISON BETWEEN STANDARD AND SMALL ORIFICE RAINGAGES. Trans. Amer. Geophys. Un. 36 (4): 689–694.

JENSEN, M. C., J. E. MIDDLETON, and W. O. PRUITT. 1961. SCHEDULING EVAPORATION FROM PAN EVAPORATION. Washington Agr. Exp. Sta. Circ. 386. 14 pp.

MIHARA, Y. 1961. THE MICROCLIMATE OF PADDY RICE CULTURE AND IMPROVEMENT OF WATER TEMPERATURE CONDITIONS BY SUPPRESSING EVAPORATION. (National Inst. of Agr. Sci. Division of Meteorology, Tokyo, Japan.) Paper presented to 10th Pacif. Sci. Congr., Honolulu. (Mimeo.)

NORDENSON, T. J., and D. R. BAKER. 1962. COMPARATIVE EVALUATION OF EVAPORATION INSTRUMENTS. J. Geophys. Res. 67(2): 671–679.

PRUITT, W. O. 1960. RELATION OF CONSUMPTIVE USE OF WATER TO CLIMATE. Trans. Amer. Soc. Agr. Engin. 3 (1) : 9–13, 17.

VAN'T WOUDT, B. D. 1960. WATER LEVEL CONTROL IN EVAPORATION PANS. J. Geophys. Res. 65(12): 4031–4035.

WARTENA, L., and A. J. W. BORGHORST. 1961. THE ENERGY BALANCE OF AN EVAPORATION PAN AND THE MEASUREMENT OF THE REFLECTIVITY OF ITS BOTTOM. Quart. J. Royal Meteorol. Soc. 87 (372) : 245–249.

WOLFGANG, M. 1952. VERGLEICH VON NIEDERSCHLAGSMESSUNGEN MIT EINEM FREISTEHENDEN UND EINEM IN DER ERDE VERSENKTE REGENMESSER. Deut. Wetterdienst (U.S. Zone) 35: 316–320. (Meteorol. Abstr. 4, 4-2–57, 1953.)

APPENDIX

Instructions for Installation and Operation of U.H. Pan

Installation

The bottom of the U.H. pan should be 1 foot above the ground surface. Short pipes should be set in concrete in the ground (fig. 1) at such spacings that the legs of the pan and of the supply tank fit over them. Initially, the legs of the pan and tank are loosely fitted over the pipes. At this stage the pan should be supported in four places by wooden blocks. The block on top should be wedge-shaped to allow fine adjustments to be made in the height of the pan.

The height of the supply tank and of the float valve in the chamber attached to this tank is then fixed in such a way (by tightening of the set screws on the legs and adjustment of the lever arm on the float valve) that the water level in the float chamber is 2 to 2½ inches above the bottom of the pan. The water level in this float chamber should be at half the height of this container (fig. 4).

Sufficient water is then introduced into the pan to lift the float from the valve seat in the inflow stilling well (fig. 11). The pan can then be leveled (while viewing the water level) by tightening of the set screws on the pan legs at the correct level. After that, 2 hours should be allowed for the water level in the pan to reach equilibrium. At the end of this period some adjustment may have to be made in the nuts fixing the height of the inflow float (fig. 11) to ensure a water level of approximately 1 inch in the pan.

The nuts on each side of the float, controlling outflow from the pan (fig. 10) are then so adjusted that, at equilibrium, slight pressure by hand on the peripheral side of the stilling well will cause dripping to occur. The accuracy of the outflow float setting should be checked on the next day, either by applying pressure to the stilling well, as described, or by adding water either to the pan or stilling well and measuring its recovery. The two nuts on the small floats should be securely tightened.

Once the correct water level in the pan has been established, and the inflow and outflow floats in the stilling wells have been coordinated, the setting of the two floats should be permanent and unaffected by cleaning of the pan.

Lack of proper coordination between the two float valves in the stilling wells will lead to unwanted or inadequate discharge of rain.

Operation

Water supply

The capacity of the supply tank and the variation in evaporation throughout the year is one of the factors that will determine the number of weeks the pan can be left unattended.

Remove periodically the plug in the bottom of the supply tank and flush out any sediment.

Suppression of algal growth

Apply once a week 2 or 3 drops of Roccal or equivalent sterilant to the pan water.

Cleaning

The pan is normally cleaned once in 2 or 3 weeks. A brush should be provided to rub the bottom to loosen dirt. The dirt is removed by placing a discharging garden hose in the pan for a few minutes, allowing the pan to overflow, or by splashing out excess water by palm of hand. The water level should automatically reach equilibrium within an hour. If the pan is allowed to empty, refill pan with enough water from hose to allow the float in the inflow stilling well to be lifted from the valve seat; otherwise, inflow will not take place from supply tank. When cleaning the pan do not place body weight on it, as this may cause change in water level, requiring renewed setting of outflow float.

To clean stilling wells and float chamber attached to supply tank, discharge jet of garden hose into them and let them overflow. Remove outflow float and grip inflow float in stilling wells between fingers during this process. Remove plastic wool from stilling wells, clean in jet stream of hose, and replace. Replace lids and weights on them.

Once in 2 or 3 months, screw off valve in float chamber attached to supply tank, clean valve and pipe inlet, and replace. Also remove copper connection between float chamber (figure 1, item 13) and inflow stilling well, clean, flush, and replace.

Under Hawaiian conditions, evaporation pans need to be aluminum-repainted once a year.

Trouble

Trouble can be expected from:

(1) Change in level of pan. Therefore, do not lean on pan.

(2) Excessive dirt. Once the pan gets very dirty, the plastic wool may no longer prevent excessive dirt from entering into the stilling wells. In that case it may happen that a dirt particle lodges between the valve plug and the Teflon valve seat in the outflow float mechanism, so that the pan empties. After excessive rain or a period of wind-blown dirt, check for unwanted discharge from the overflow stilling well. An extra cleaning may be required.

(3) Rough handling of the floats in the stilling wells may chip the valve seats, causing leakage. In that case the valve plug and seat need to be remachined.

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