ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

Report No. 6 and 7

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Semiannual Report

Report Period: 1 March 1968 through 28 February 1969

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FOREWORD

This summary report covers the progress and status of the Environmental Data Base for Regional Studies in the Humid Tropics. The project is sponsored by the Office, Secretary of Defense, Advanced Research Projects Agency (ARPA), Directorate of Remote Area Conflict, and by the Department of Army, Office of Chief of Research and Development, Army Research Office (ARO).

The study reported herein is being conducted under the guidance and with the direct participation of the Research Division of the US Army Tropic Test Center. Commanding Officer during the report period was Colonel John Zakel, Jr. The research program was carried out under the supervision of Dr. Guy N. Parmenter, Chief of the Division. The following individuals of the Research Division staff have been responsible for preparing the technical portions of the report; as noted: Dr. Thomas C. Crebbs, Mr. George Gauger, Dr. Robert S. Hutton, and Dr. Wilfried H. Portig. Mr. Michael A. Fradel is the Project Officer and has direct responsibilities in the meteorological field and for data processing. Other individuals participating in the preparation of the report were: Dr. Robert T. Allen, University of Arkansas, and Mr. Dennis C. Rankin, Duke University. The compilation, arrangement, and editing of the report has been accomplished by Mr. Edward E. Garrett, Physical Environmental Scientist of the Division.

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SUMMARY

This report, summarizes the activities of the Environmental Data Base Project for the period March 1968 through February 1969 and contains a brief statement on project background, scope, and observation sites, together with some analyses of the collected data. These analyses are not confined to data gathered within this reporting period.

The Climate Section (Part III) contains an operational description of the automatic data and recording system, a detailed analysis of the climatological and measurement aspects of evaporation.

The Soils and Hydrology Section (Part IV) presents the profile descriptions of the soils at the Fort Kobbe Satellite Sites.

The Vegetation Section (Part V) contains an analysis of litter fall at the Albrook Forest Site.

The section of Atmospheric Chemistry (Part VI) consists of a brief summarization of activities in this field for the reporting period.

The section on Macrofauna (Part VII) contains a tabulated listing of insects secured under the black-light sampling program.

ENVIRONMENTAL DATA BASE FOR REGIONAL STUDIES IN THE HUMID TROPICS

PART I. INTRODUCTION

Background

This progress report deals with the activities of the project from 1 March 1968 through 28 February 1969 and comprises semiannual reports number 6 and 7. The project is sponsored jointly by the Advanced Research Projects Agency, Office of the Secretary of Defense, and by the Army Research Office, Office of the Chief of Research and Development, Hqs., Dept of Army. The work has been performed by the US Army Tropic Test Center, US Army Test and Evaluation Command, Army Materiel Command, with contractual support of Maintenance International, Inc. Additional scientific support was provided through the cooperation of the National Center for Atmospheric Research and other individual scientists.

The investigational approach is made through an interdisciplinary study of the humid tropical climate as exemplified at the Canal Zone sites. These sites have analogies to regions of tropical monsoon climates in southeast Asia and other world climatic zones.

Project Objectives and Description

Objectives

The overall objective of the Data Base project is to provide increased knowledge concerning the militarily significant environmental factors of humid tropical environments. The project is designed to provide a bank of information and analyses derived from observations of selected physical and biological conditions at representative sites. A specific objective of the US Army Tropic Test Center is to obtain detailed information concerning the environments in which its tests are conducted, which information will be of direct value in the planning and accomplishment of tests as well as in the development of tropical test techniques and methods. The project will establish, at the chosen sites the spatial and temporal variations of a number of natural conditions that affect the durability and operability of materiel as well as such factors as movement, communication, visibility, and the physical performance of troops.

Scope

The basic program for the Data Base project provides for interrelated investigations in the following fields: (1) Climate, specifically the meteorological phenomena manifested below a height of approximately 50 meters; (2) Soils and hydrology, with emphasis on factors related to soil trafficability and ground water; (3) Vegetation, with emphasis on taxonomy, foliage canopy, plant succession, and the ground accumulation of forest debris; (4) Microbiology, with emphasis on numbers and kinds of bacteria and fungi and their transportation and deposition; (5) Macrofauna, currently limited to selected arthropods; and (6) Atmospheric chemistry, i.e., chemical and physical contaminants of the air.

Observational Approach

In order to demonstrate the relationships existing between these environmental factors, investigations are carried out synchronously at the selected sites. These locations, because of funding and manpower limitations, have been limited to two "main" sites, both in the Pacific region of lower and more seasonal rainfall. Additional "satellite" sites have been established where restricted data have been collected.

The project plan calls for the establishment of paired main sites, one site being under and within a typical forest canopy the other in an open area subject to the same climatic influences. This "paired site" approach has been followed since the various environmental factors differ markedly within forested and cleared areas. Furthermore, both forest and open areas occur extensively throughout the humid tropic regions, and they impose significantly different limitations on military activities.

The "main" sites are equipped with towers in order that temporal simultaneity may be matched with coordinated measurements throughout the vertical plane for both the climatic and the atmospheric chemical and biological fields. These include the standard meteorological parameters as well as sample determinations of atmospheric particulates and trace chemicals, airborne and surface-deposited microorganisms, and flying insects.

Some observations are made by Tropic Test Center personnel, however most of the routine work is carried by contractual arrangement. During the period of this report the contract was held by International Maintenance, Inc. Project scientists on the Tropic Test Center staff monitor all work and provide necessary guidance. The frequency of observation varies with the parameter measured, ranging from continuous reading, and/or automatic recording, of some meteorological instruments to the one-time observation of some soil factors.

PART II. OBSERVATION SITES

Site Locations

Two main observational sites are in current use. They are located on the Pacific side of the Canal Zone, which is characterized by a mean annual rainfall of approximately 70 inches, a pronounced three-month dry season, and semievergreen forest vegetation. The two sites are located in the Albrook Forest and at Chiva Chiva (see Figure II-1). The former is in a forest with a relatively dense canopy and understory vegetation; the latter is in an open, grassy area about four kilometers westward. Two satellite sites located at Fort Kobbe have been utilized for observation of soils and limited meteorological data.

Site Descriptions

The two main sites are each equipped with 46-meter walk-up towers. Physical descriptions of the sites with their installations have been given in some detail in the previous Data Base Semiannual Reports[1,2,3,4*] and will not be repeated here. The instrumental arrays for the towers and the ground installations have been modified and are currently as shown on Figures II-2, -3 and -4. The top of the forest canopy at the Albrook Forest Site has grown upward appreciably since the last reporting period.

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* References cited are listed at the end of this report.

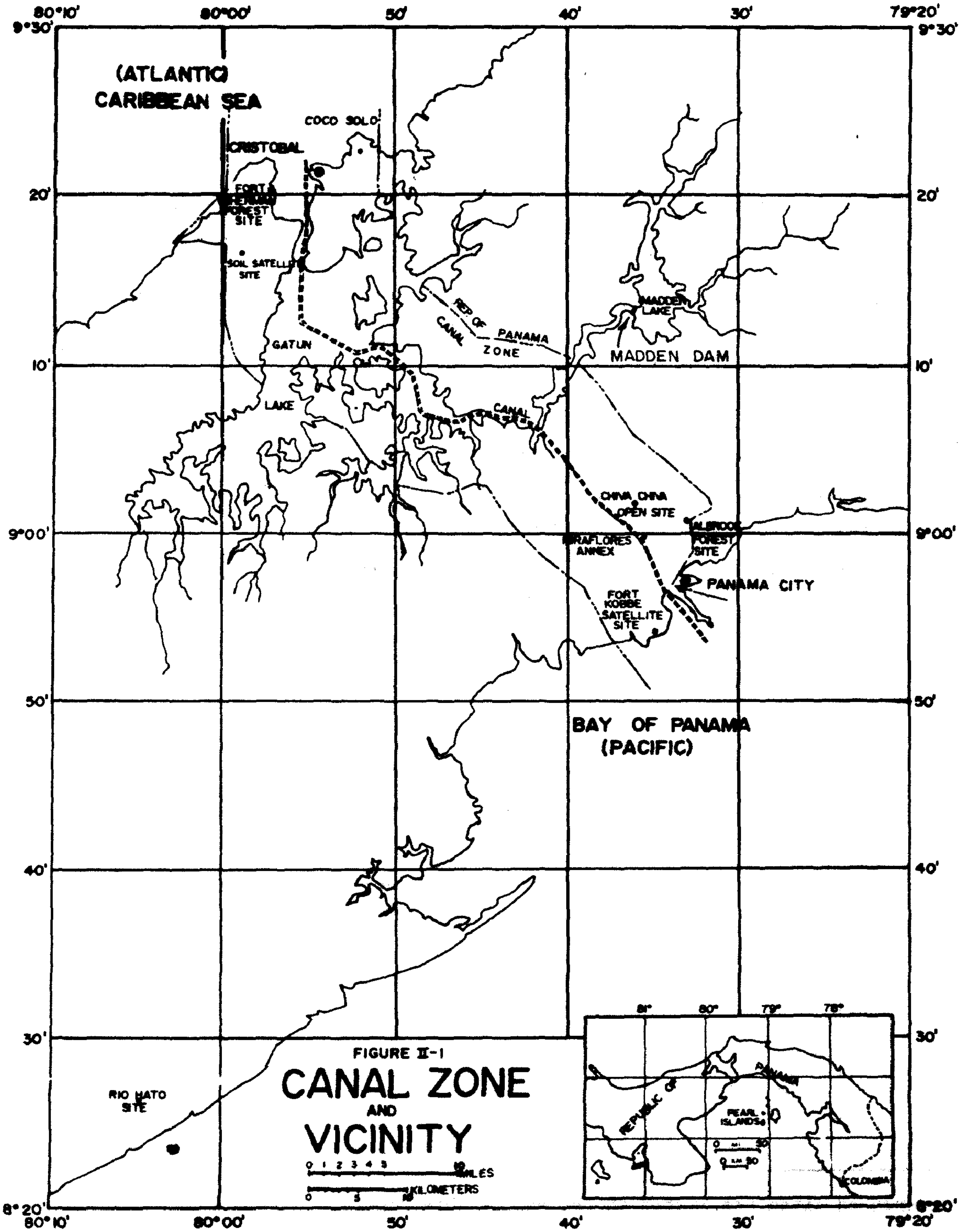

FIGURE II-1

CANAL ZONE AND VICINITY

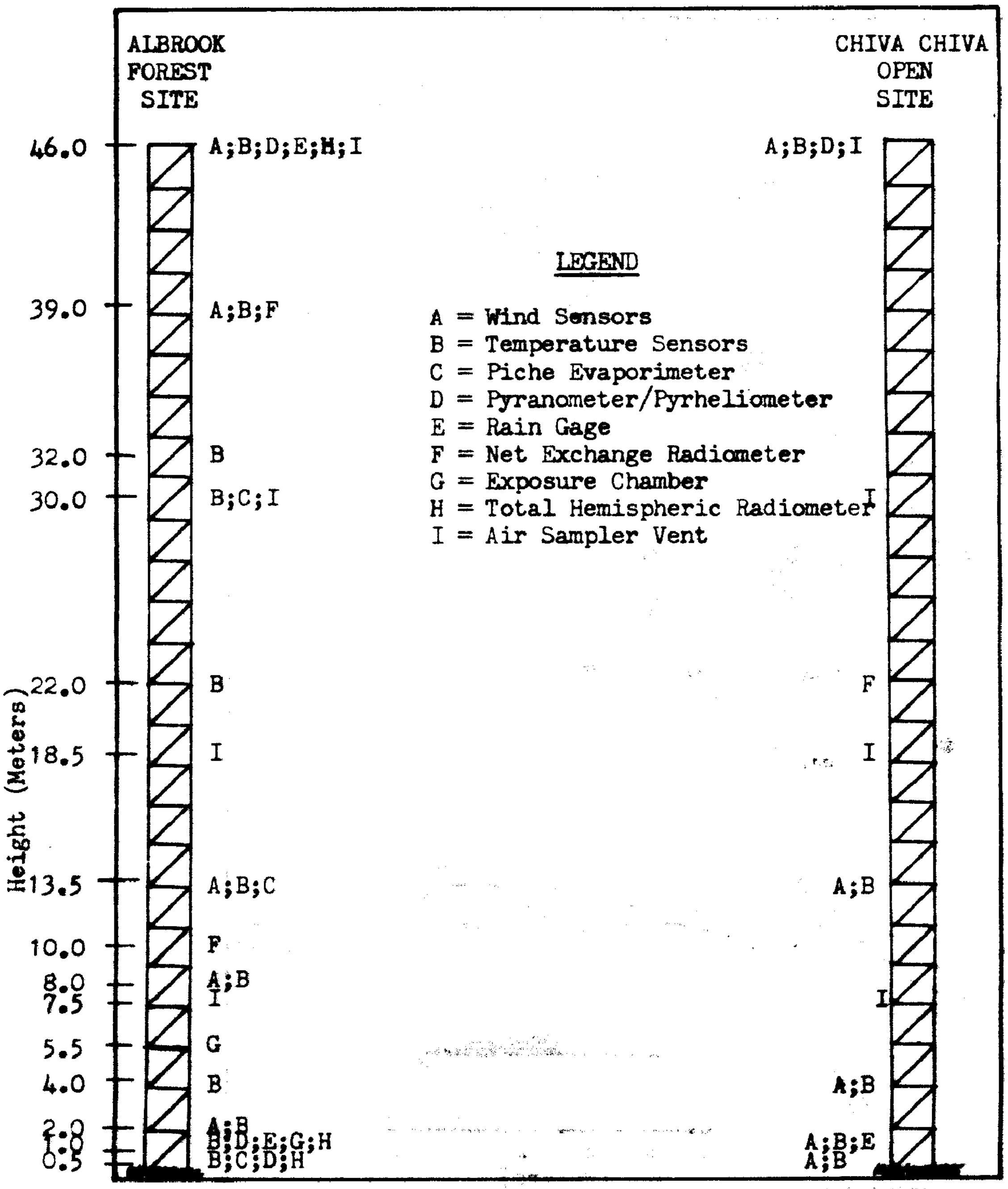

FIGURE II-2. INSTRUMENTATION ARRAY ON OBSERVATION TOWERS

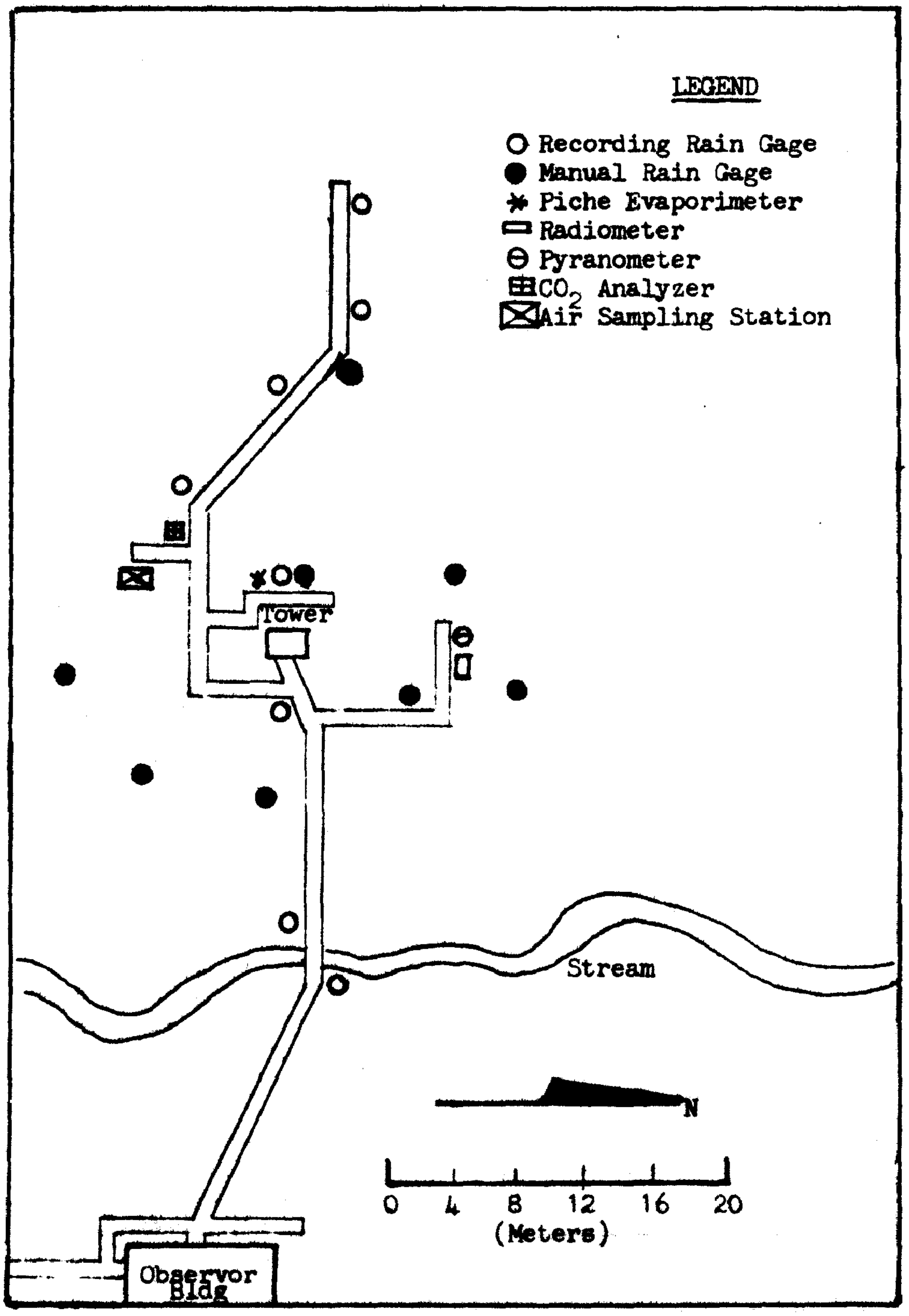

FIGURE II-3. ALBROOK FOREST SITE, GENERALIZED PLOT

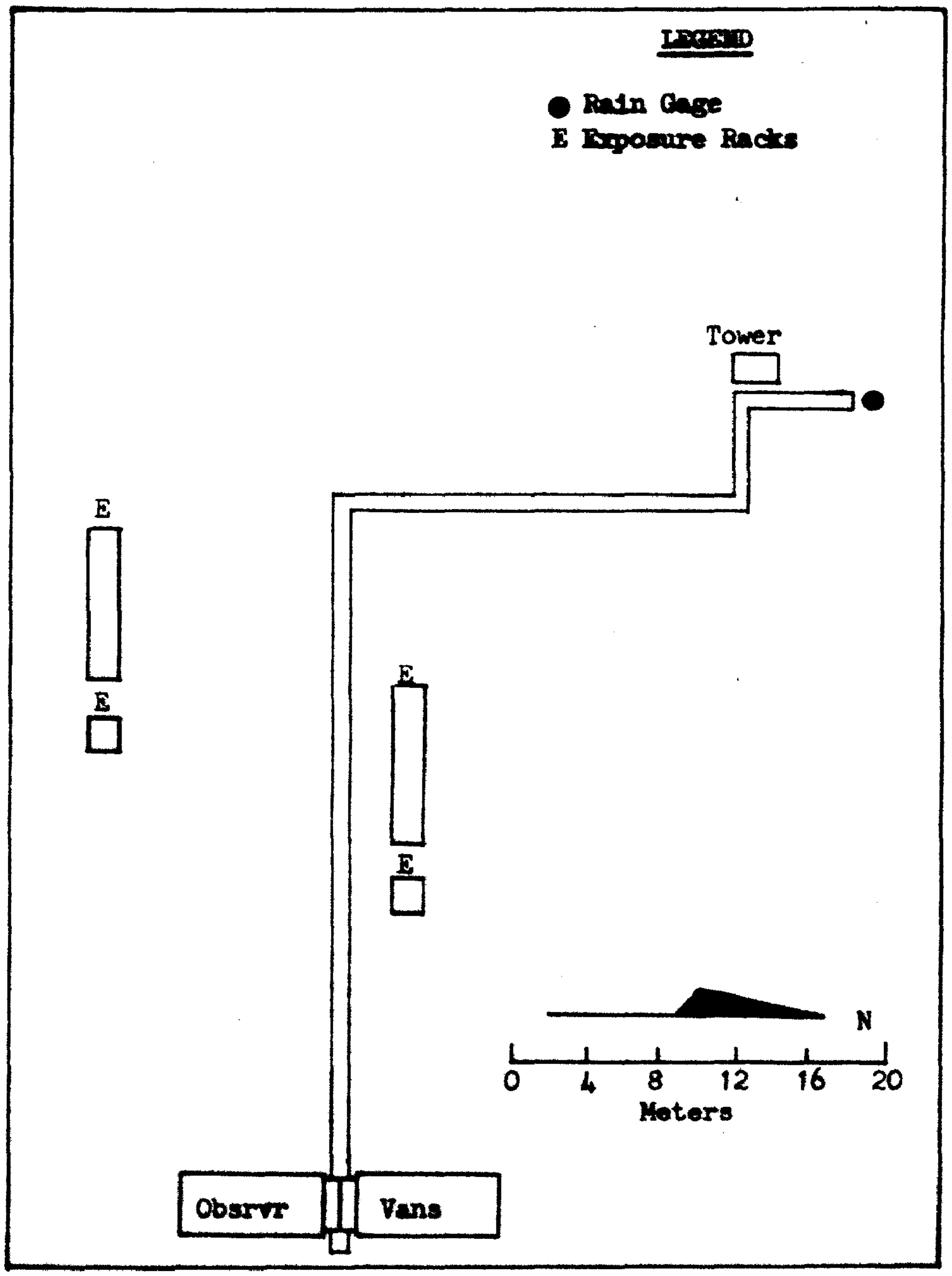

FIGURE II-4. CHIVA CHIVA OPEN SITE, GENERALIZED PLOT

PART III. CLIMATE

Introduction

The climatic subtask of the Data Base project is directed toward the compilation and dissemination of detailed micrometeorological information pertaining to the climate which prevails on the Pacific side of the Canal Zone. Measurements are made at two sites, one in a semievergreen forest, the other in a nearby open area. Both sites utilize instrumented 46-meter-high towers for acquisition of data extending through the vertical and horizontal planes. The information, which contributes to the development and improvement of testing techniques and provides a basis for extrapolation of information to other tropic regions and determination of their degree of analogy to the Canal Zone, is made available to governmental or other interested agencies through publication of periodic data summaries and technical reports. Limited analyses of the collected data are made, in consonance with availability of in-house resources and time, and are embodied in the semiannual reports. Such an analysis, of evaporation, is presented below.

Observations

General

The observational program for this reporting period has been significantly changed from previous periods of the Data Base project. Reductions in project funding necessitated a curtailment in the scope of work requiring contractual assistance. Consequently all manual measurements were eliminated at the Chiva Chiva open site. This action nullified the need for round-the-clock occupancy of the site and allowed a considerable reduction in contract costs. The Albrook Forest site continued to be manned 24 hours per day; the Chiva Chiva site was monitored through daily maintenance visits. The locations are shown in Figures II-2 through II-4.

Albrook Forest Site. The following determinations were made, all by automatic means at 15-minute intervals: five measurements each of dry and wet-bulb temperature, wind speed, and wind direction; six measurements of rainfall; and two measurements each of global total hemispheric, and net exchange radiation. In addition, the following measurements were made, using non-automatic methods: six measurements each of dry and wet bulb temperatures, made at half-hourly intervals; three measurements of rainfall made at hourly intervals; plus eight measurements of rainfall and three of evaporation made at six-hourly intervals.

Chiva Chiva Open Site. Measurements at this site consisted of dry and wet bulb temperatures, wind speed, and wind direction, five levels each; and one level each of rainfall, global radiation, total hemispheric radiation, and net exchange radiation. All observations were made at 15-minute intervals using automatic methods.

Instrumentation

The Meteorological Automatic Data Acquisition systems (briefly described in a previous semiannual report[2]) were placed in operation and used throughout this report period, one at each observation site. Each system consists of several sensors, namely, five wind speed sensors, five wind direction sensors, five dry bulb temperature sensors, five wet bulb temperature sensors, six tipping-bucket rain gages, two pyranometers and four radiometers, a means for converting the sensor output to measurable quantities, a measuring system, and a digital conversion system which ultimately punches the measured quantity on paper tape in an eight-level IBM compatible code.

The outputs of the wind speed and direction sensors are connected to a translator unit which conditions and filters the output signal to provide an output voltage proportional to a five-second average of each function. The dry and wet bulb temperature sensors are radiation-shielded platinum resistance bulbs. The wet bulb has a wick and a water reservoir attached, and the entire assembly is mechanically aspirated. Each platinum bulb is connected into an individual bridge circuit with zero and span adjustment. The output of the bridge is a voltage which is a linear function of temperature. Six integrating operational amplifiers are provided to receive the inputs from the pyranometers and radiometers.

Pulses emanating from the rain gages at the rate of one pulse for each .01 inch of rain are accumulated in three decade accumulators providing a capacity of 9.99 inches each. Provision is made to store a pulse while recording is taking place. Total count in the accumulator is visible from the front panel. The accumulators are reset each hour.

All voltages from the wind translator, temperature bridges, and integrating amplifiers are scaled to a common full-scale level and applied to the input scanner. The voltages are selected one at a time under programmed control and presented to an integrating digital voltmeter. The measured function at this point is converted to a digital code for recording. The voltmeter integrates the reading for a 16 milli-second reading which eliminates erroneous readings due to noise and transients. The measurements are also displayed on the front panel as a four digit decimal.

A system timer generates pulses independently from the power line and is used to operate a digital clock. The System Programmer synchronizes the entire recording sequence and provides the necessary control between scanning, measuring, and punching functions.

All digital outputs from the digital voltmeter, the clock, and the rain gage totalizers are converted to BCD code and gated to the punch driver circuit one digit at a time. A parity generator counts the number of bits in each character and inserts the appropriate parity bit for computer error detection. After the parity bit has been generated, the punch driver energizes the tape punch to translate the character to paper tape.

A control panel allows all functions of the system to be controlled manually if desired. Any input can be selected and displayed individually. The basic recording interval is 15 minutes, but a 5 or 10 minute interval may be selected by means of a switch on the control panel. The basic recording cycle requires approximately seven seconds.

Included as part of the system is an off-line tape reader and automatic typewriter combination. It provides a type-written copy of the information on the data tape so that the data can be inspected visually.

The circuitry is of modular design so that maintenance may be facilitated and the system expanded with a minimum of modification.

The Yellow Spring telethermometer, weighing rain gage, Clear-Vu rain gage and Piche evaporimeter continued to be used at the Albrook site for making the manual type measurements.

Data Reduction and Storage

With the adoption of nearly completely automatic measuring techniques, data reduction, as such, has been virtually eliminated. The automatically obtained data are directly presented on punched tape, and the manually obtained data are read from dials or graduations and subsequently entered on standard punch cards. Arrangements are being formulated to transfer these data onto magnetic disks for further automatic processing.

All data obtained through the period 1 May 1965 thru 31 Jan 1968 have been transferred to magnetic disks and will be further processed together with data being collected through this and subsequent periods.

Climatological Aspects of Evaporation*

Introduction

Evaporation is the meteorological process through which water is translated into the atmosphere. It is essentially the last stage in the transpiration cycle for plants, and it occupies the same position in the analogous physiological system for animals and, as such, is an essential element in the control of body heat. The physical properties of soil are dependent to a large extent on its moisture content which in turn is significantly affected and partially controlled by evaporation.

Data Collection

Table III-1 shows the periods and locations for which evaporation measurements from the Data Base sites are available. The table concludes with January 1968. The presentation of subsequent data is planned for a later report. Most of the data were obtained with Piche evaporimeters, i.e., with a vertical, water-filled glass tube from which the water evaporates through a piece of blotting paper which is attached to the lower end of the tube. The Standard pan was also used most of the time in Chiva Chiva. This is a circular metal pan, one foot high and four feet in diameter, which is almost completely filled with water. Changes in the height of the water level reflect evaporation and precipitation. Attempts to use the pan in the forest were relatively unsuccessful. The use of an open pan was a complete failure; because litter and debris falling into it impaired its accuracy, and because the rainfall under the canopy is too variable for accurate spot measurement(Read[5]). A series of measurements made with a pan provided with a plastic cover four feet above it were partially successful. (See p. 17). The measurements obtained with the pan in the open were less satisfactory than those from the Piche instrument. Whenever the control rain gage indicates a greater height of precipitation, it is obvious that a substantial amount of rain splashes out of the pan. As the adjustment for rainfall has to be made with the value obtained from the gage, the computed evaporation value is too high. Actually, the evaporation values computed from the pan readings during the rainy season are frequently higher on rainy days than on dry days, which seems unrealistic. The Piche data do not show this discrepancy. Some statistical data which illustrate the rainfall dependence of the pan were obtained during an approximate two-month period, as shown below.

The information for Table III-2 on page 13 was calculated from only 58 of the 68 days in the time period covered. The missing data are for days on which the computation for the pan resulted in condensation rather than in evaporation. While it is true (see section on Measurement of Evaporation) that condensation can occur on a water surface for short

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* This section has been prepared by Dr. Wilfried H. Portig, Research Meteorologist.

TABLE III-I LOCATIONS AND TIME PERIODS FOR WHICH DAILY EVAPORATION TOTALS ARE AVAILABLE

	CHIVA CHIVA		ALBROOK				
Level	Sfc	0.5m	Sfc	0.5m	13.5m	28.5m	46m
1965							
May-Aug	-	Pi	-	Pi	Pi	Pi	Pi
Sep	-	Pi	-	Pi	Pi	-	-
Oct	SP	Pi	-	Pi	Pi	-	-
Nov	SP	Pi	SP	Pi	Pi	-	-
Dec	SP	(Pi)	SP	Pi, (CPi)	Pi	-	-
1966							
Jan	SP	-	SP	Pi, CPi	Pi	-	-
Feb-Mar	SP	Pi	SP	Pi	Pi	-	-
Apr	SP	Pi	SP	Pi	(Pi)	(Pi)	(Pi)
May-Nov	SP	Pi	-	Pi	-	Pi	Pi
Dec	SP	Pi	-	Pi	(Pi)	Pi	Pi
1967-1968							
Jan-Jan	SP	Pi	-	Pi	Pi	Pi	Pi

SP = Standard Pan
Pi = Piche Evaporimeter
CPi = Piche under cover
Parentheses indicate incomplete data (Pi)

TABLE III-2. DAILY PAN AND PICHE EVAPORATION
7 OCTOBER - 13 DECEMBER 1965
CHIVA CHIVA OPEN SITE

Rain (inches)	0-0.02	0.03-0.49	0.50-3.49
Piche, mean (in^3)	0.145	0.104	0.086
Piche, standard deviation	0.059	0.062	0.061
Pan, mean (in)	0.121	0.096	0.173
Pan, standard deviation	0.063	0.073	0.137
Number of days	19	20	19

periods of time, it is considered impossible that condensation can be greater than evaporation over a 24-hour period for the sites under discussion.

If any computation of daily values resulted in negative evaporation the value was considered invalid and was cancelled. Also extremely high values of pan evaporation were cancelled. What was considered as "extremely high" was decided subjectively after comparison with other simultaneous measurements. It is sometimes very difficult to read the hook gage of the standard pan, while it is always easy to read the scale of the Piche.

Stations. In addition to the two Data Base sites, daily evaporation measurements were obtained at Madden Dam during the period May/June 1966 through April 1967. Beginning in May 1966 a Standard Pan on land and a floating pan nearby were in operation, supplemented in June by a Piche evaporimeter halfway between the pans. The floating pan indicated 10-20% less evaporation than the pan on land. In the subsequent discussion the floating pan is disregarded; all references to Madden Dam are to the land pan or to the Piche, as indicated. The Madden Dam station is located on the southern slope of the open Rio Chagres valley, 13 miles north of Chiva Chiva. The original readings are available for the Data Base stations (which can serve as checks for the computations) but only the results of the computations for the Madden Dam station are at the disposal of the writer.

Data Analysis

Correlation of Daily Evaporation Totals.

Like Instruments, Different Stations. Figures III-1 and -2

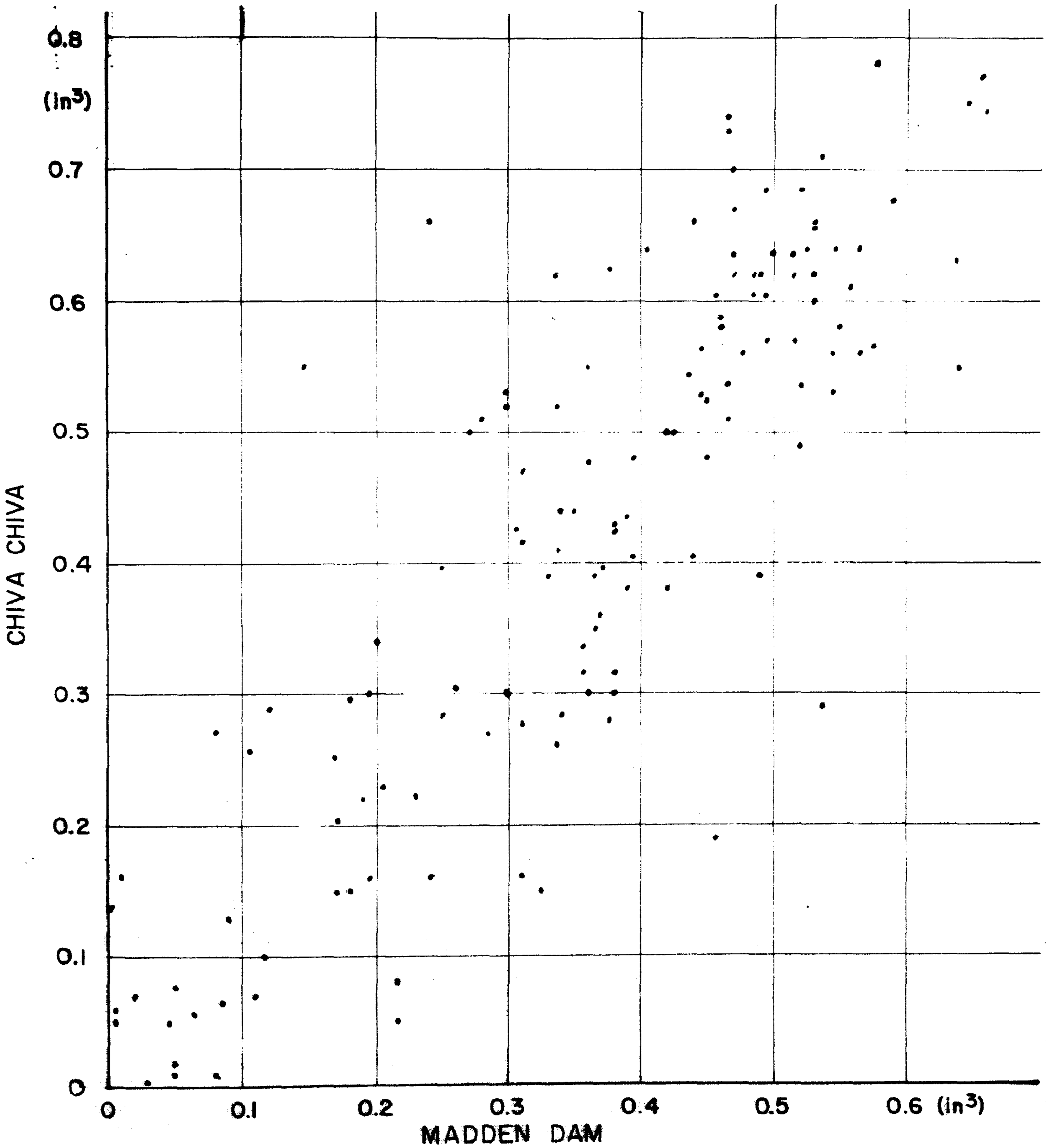


FIGURE III-1. CORRELATION BETWEEN PICHE MEASUREMENTS AT CHIVA CHIVA AND MADDEN DAM STATIONS

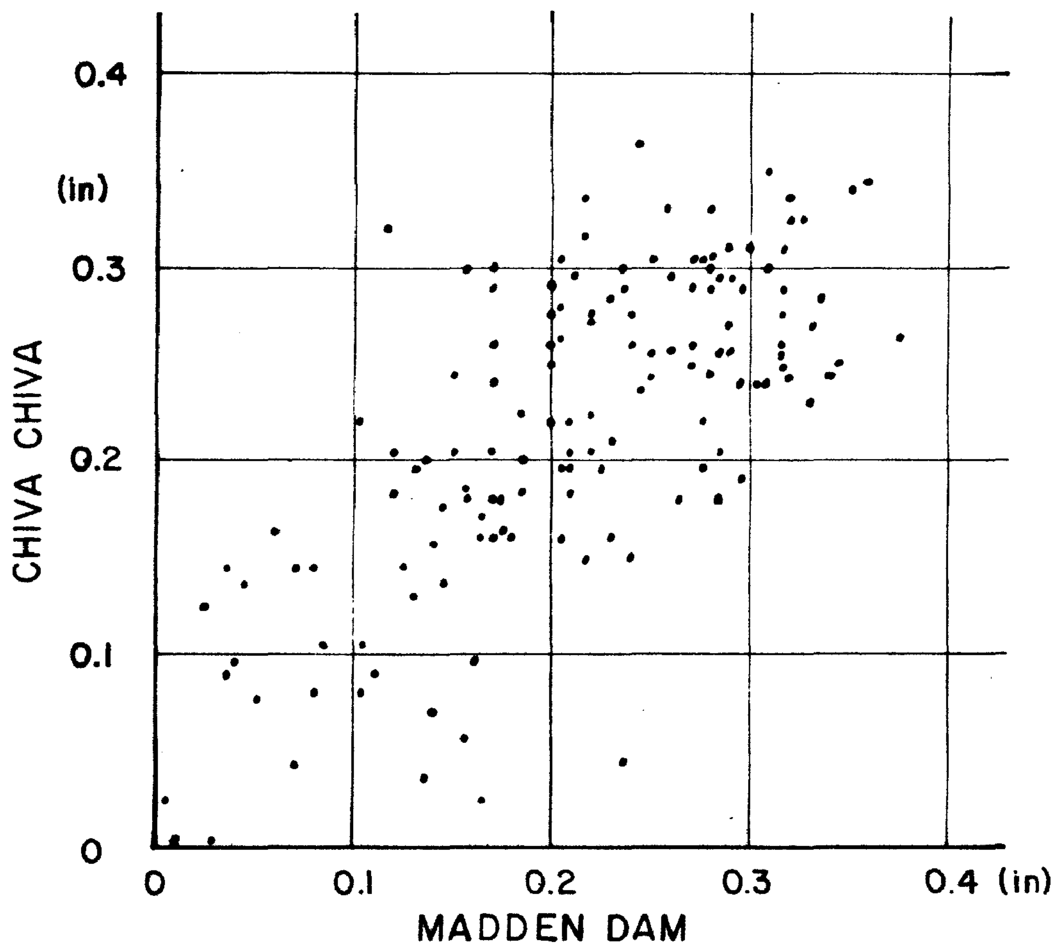


FIGURE III-2. CORRELATION BETWEEN STANDARD PAN MEASUREMENTS AT CHIVA CHIVA AND MADDEN DAM STATIONS present the correlation between the Piche measurements at the Chiva Chiva and Madden Dam stations, and that between the pans, respectively for the period December 1966 through April 1967. The correlation coefficients are 0.55 for the Piches and 0.41 for the pans. Since no conventional meteorological data have been collected at Madden Dam, Figures III-1 and -2 can be analyzed only superficially by stating that there is a fairly good correlation between the evaporation data of these stations located 13 miles apart.

The two Data Base stations are closer together and consequently show closer correlation. Also, it has been possible to check the data and eliminate errors. As examples, the correlation coefficients between the Piche measurements in Chiva Chiva (near the surface) and the Albrook Forest at 46 meters over the forest floor, were 0.61 in October 1966 and 0.98 in May 1967. The rainy season shows a lower correlation than the dry season because the data are spread over a small interval only, so that errors and accidental variations have relatively greater effect. The greatest spread is obtained in the transition months when dry and wet situations enter the computation. This was the case in May 1967 (normally April is the month with the greatest spread).

Like Instruments, Same Station. As Table III-1 shows, there were always several evaporimeters working on the Albrook tower at the same time. When the evaporation is not very close to zero, it is quite different at different levels, yet the correlation between simultaneous readings is excellent. R. G. Read[5] concluded from a few measurements that weather changes reach through the canopy down to the forest floor, though reduced in effect. The high correlation coefficients confirm this result for the much greater number of measurements used in this paper. Also the reduction factor derived from the Piche measurements corresponds exactly to that found by Read[5] when working with Livingstone atmometers. The somewhat tricky Livingstone (each instrument has a different calibration, and this calibration can change with time through obstruction of the pores by air contaminants) is superior to the Piche only when stripchart recordings are needed (see section on Evaporation Measurement).

The month of May 1967 may serve as an example for the good correlation between the evaporations of different levels on the Albrook tower. The correlation coefficients were:

between 46	and 28.5 m	. . . . 0.971
between 46	and 13.5 m	. . . . 0.930
between 46	and 0.5 m	. . . . 0.798
between 28.5	and 13.5 m	. . . . 0.952
between 28.5	and 0.5 m	. . . . 0.847
between 13.5	and 0.5 m	. . . . 0.877

These values rise slightly when the inaccuracies of measurement are considered. The greatest improvement is found in the correlation coefficient between the 46 and 0.5 meter levels which rises from 0.798 to 0.822, assuming a mean observational error of 0.1 ml (0.006 in^3) and using simple algebra (Portig[6]).

Figure III-3 presents the vertical distribution of the Piche evaporation for typical days and months. It shows the great increase of Piche evaporation with height; but it further shows that the evaporation near the ground can be quite large in a tropical semievergreen forest. (The extreme was measured at the beginning of the observation period when the vegetation was reduced by the disturbance of the tower construction.) The March value at 0.5 meters in the forest is very close to the mean summer value measured with the same instrument in the open in many places in Germany, with the difference, however, that the German measurements show a much greater dispersion up to an exceptional maximum of 22 ml. (1.3 in^3) in 24 hours. (Uhlig[7]). In tropical San Salvador, in Central America, the mean daily Piche evaporation oscillates between 2 ml, (0.12 in^3) in September and 8 ml (0.5 in^3) measured in the open (Lessmann[8]) over a five-year period. This is close to the values obtained immediately above the forest canopy in Albrook (see also below "Annual Variation").

Different Instruments, Same Station. There are three series of data when Piche readings and measurements with the Standard Pan were taken simultaneously. The most extensive series has been obtained in Chiva Chiva where parallel readings were taken during 26 out of 33 months (Table III-1). Similar readings were taken at Madden Dam during an 11-month period. Measurements with an open pan in the forest failed completely, but somewhat doubtful measurements were taken during a six-month period from a pan which had a plastic roof approximately 1.3 meters over the water surface.

Figure III-4 shows daily Piche evaporations for four months in relation to simultaneous pan measurements. (Typical rainy months have not been correlated because of the inaccuracies of the pan measurements.) It is obvious that the correlation is not very good; the deviations from the free-hand-drawn functional curves are very large. But, while there is doubt whether the differences between Chiva Chiva and Madden Dam are statistically significant, it is evident that the pan at the forest floor is much more sluggish with respect to the Piche than the pans in the open. Two reasons for this different behavior seem apparent: (1) The plastic cover as well as the leaves of the trees protect the pan in the forest from solar radiation and the corresponding warming. Since the pan evaporation depends more on the water temperature than the Piche (whose evaporating surface is usually at the wet bulb temperature, according to R. Roth[9], and Mukammal[10]), the relative pan evaporation in the forest will be less than in the open. (2) The Piche evaporimeter is known to react strongly even to wind of low velocity, while the pan is less sensitive in this respect. There may be enough wind at the forest floor to affect the Piche, but not sufficient to have much effect on the pan.

Hourly readings of the pan and the Piche were made in Chiva Chiva during three weeks in January 1968. Table III-3 shows the diurnal variation of the data. Both instruments act also as thermometers. When readings are taken every 24 hours, the thermal effect can be neglected

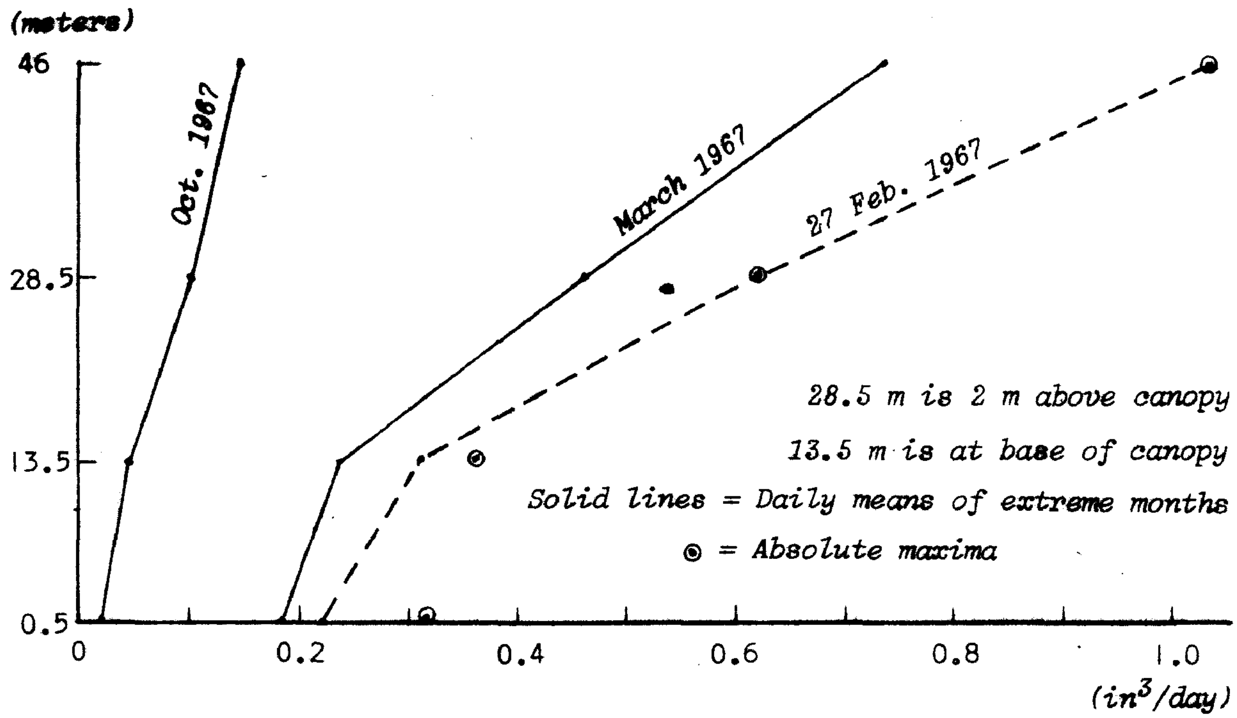


FIGURE III-3. PICHE EVAPORATION AS A FUNCTION OF HEIGHT

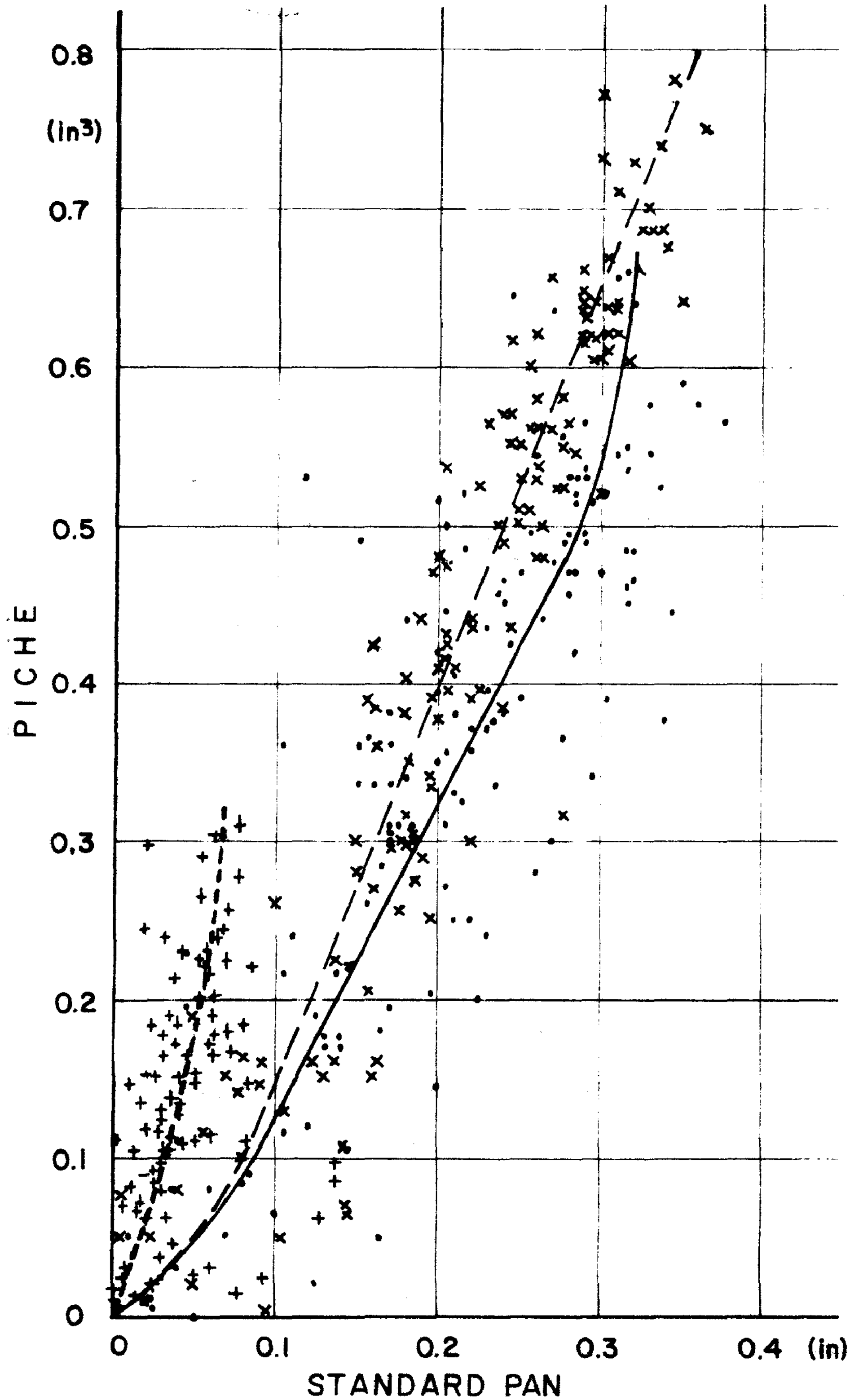


FIGURE III-4. COMPARISON OF PAN AND PICHE MEASUREMENTS

Solid line and dots: ***Madden*** *Dam, Dec. 1966 - March 1967*

Long dashes and ×'s: Chiva Chiva, Dec. 1966 - March 1967

Short dashes and +'s: Albrook, under canopy, Dec. 1965 - March 1966

TABLE III-3. DIURNAL VARIATION OF PAN AND PICHE EVAPORATION AT CHIVA CHIVA 11-31 JANUARY 1968 (IN PERCENTAGE OF DAILY TOTAL PER HOUR)

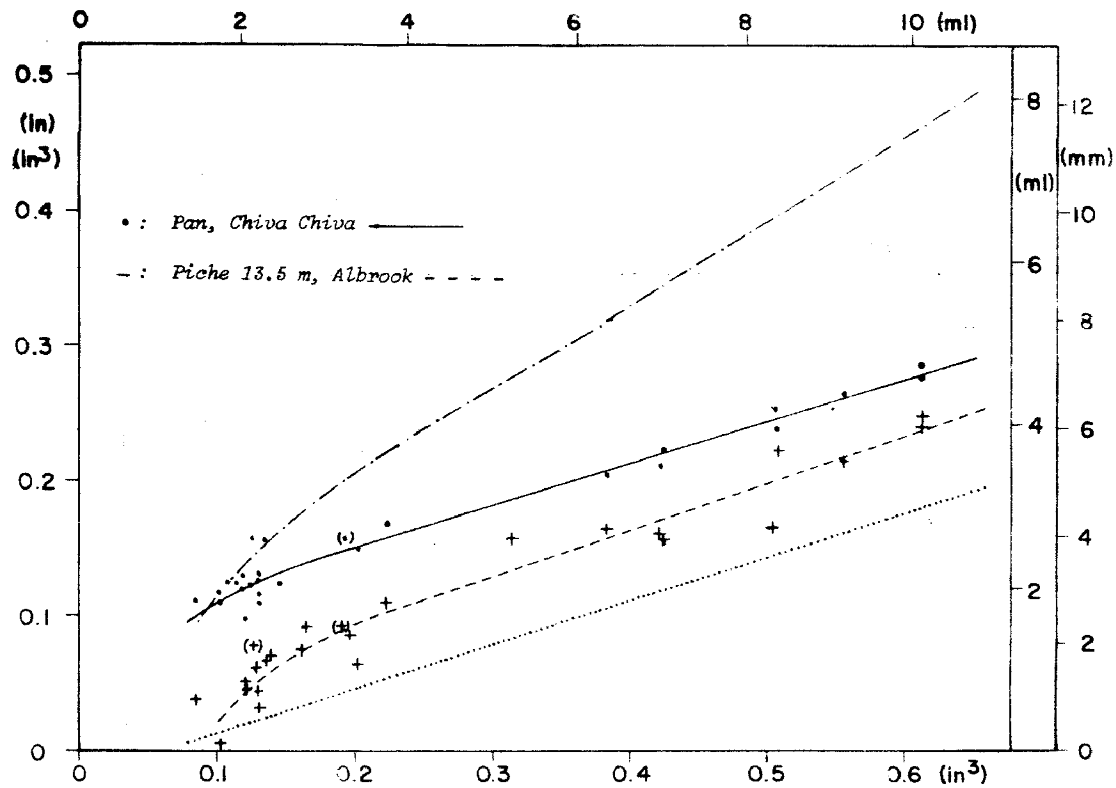
Hour of Day	1-6	6-8	8-9	9-10	10-11	11-12	12-13
Pan (%)	0.8	0.0	2.6	2.6	4.7	6.0	6.8
Piche (%)	0.3	0.1	1.8	4.8	9.5	10.3	9.2
Pan minus Piche	+0.5	-0.1	+0.8	-2.2	-4.8	-4.3	-2.4

Hour of Day	13-14	14-15	15-16	16-17	17-18	18-20	20-01
Pan (%)	10.2	17.1	12.0	10.7	7.3	4.3	1.7
Piche (%)	11.1	12.8	10.7	8.3	5.8	2.3	1.1
Pan minus Piche	-0.9	+4.3	+1.3	+2.4	+1.5	+2.0	+0.6

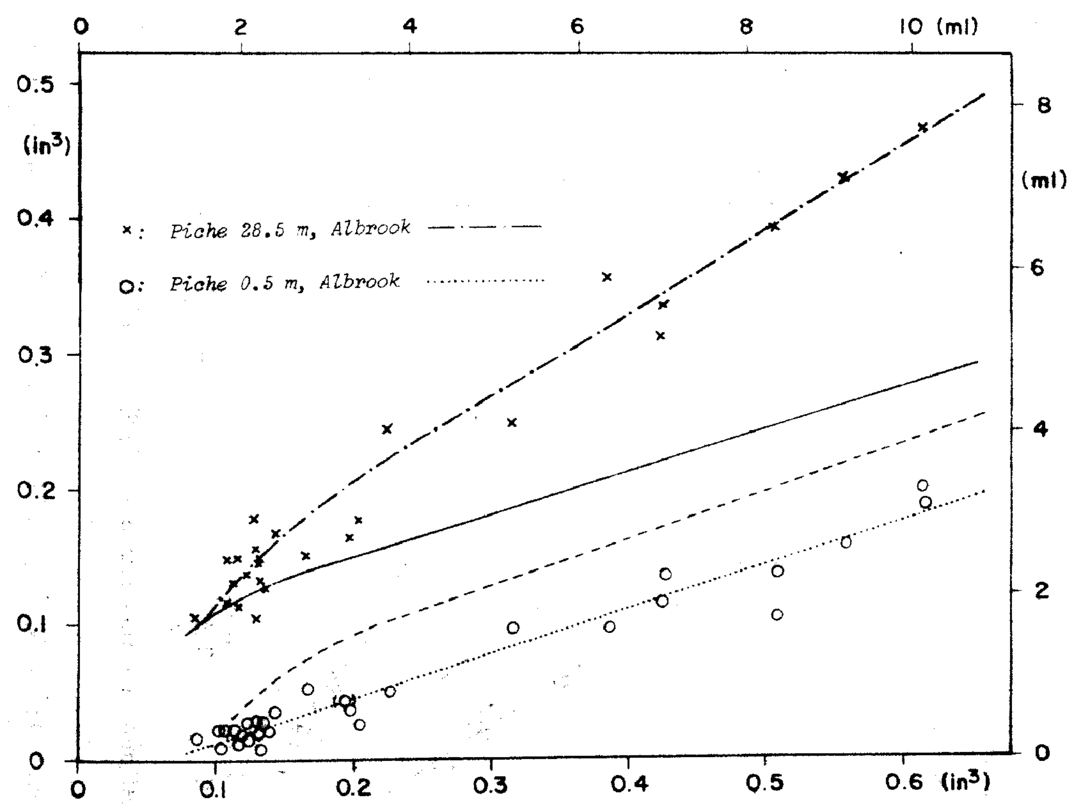
(especially in the tropics where the temperature variation from day to day is very small). In hourly observations, however, the readings should be corrected for the expansion or contraction of the water due to temperature changes. Since no simultaneous readings of the water temperatures have been made, no corrections can be computed. As this subject is dealt with more detail in the next section, it suffices here to say that the corrections would not alter the basic results: (1) The pan evaporates less than the Piche before midday, and more thereafter. This stems from the differences in the masses of water. The temperature of the water in the pan is much lower than the air over it as long as the temperature rises, and higher thereafter, while there is no such lag for the Piche temperature. (2) The low evaporation average for the period 1800-0600 hours is produced by a mixture of positive and negative evaporation measurements. As will be exemplified in the next section, at that time of the day condensation (negative evaporation) can occur on water surfaces. The hourly observations hold the key for the understanding of the often considerable differences between the simultaneous measurements made with different kinds of evaporimeters.

Correlation of Monthly Means. Figures III-5a, 5b and -6a, 6b, present the correlations between the monthly mean data obtained from different evaporimeters as indicated in the legend. Because of the great number of data points, the figures were divided into pairs. For clarity it must be explained that the two members of a pair contain the same four curves, but only two scatter diagrams. Figure III-5a, for example, contains the scatter diagrams from which the solid and the short-dashed curves were derived, while Figure III-5b contains all data points from which the "dash-dot" and the dotted curves were constructed. None of the fitting curves are straight lines through the origin. Since high evaporation values are typical for the dry season and small ones for the rainy season, it follows that the proportionality factor between the Piche in Chiva Chiva and other instruments is not the same throughout the year. (Note that this statement also holds true for the straight parts of curves as long as the extension of the straight lines does not go through the origin.)

It can be deduced from Figure III-5 that there are months with practically no evaporation at the forest floor, and, to a lesser extent, at the base of the canopy, while the instruments with free exposure show measurable amounts for all months. On the other hand, it follows from the same figure that the monthly evaporation within the forest is greater in the driest months than it is in the wettest months in the open. For better comparability both Figures III-5 and -6 present the correlation between the Piches in Chiva Chiva and at 28.5 meters on the Albrook tower. The steepening of the fitting curve for the 28.5 vs 46 meter correlation in the driest months is probably the consequence of the greater increase of wind speed with height in those months. The mean wind speed in the dry season at 46 meters is approximately three times the velocity over the canopy at 28.5 m. In the rainy season the ratio is closer to 2:1. Similar reasoning may also explain the curvature of the fitting curve for the 28.5 vs 13.5 m levels, while great dispersion of the data from the lowest level obviously allows

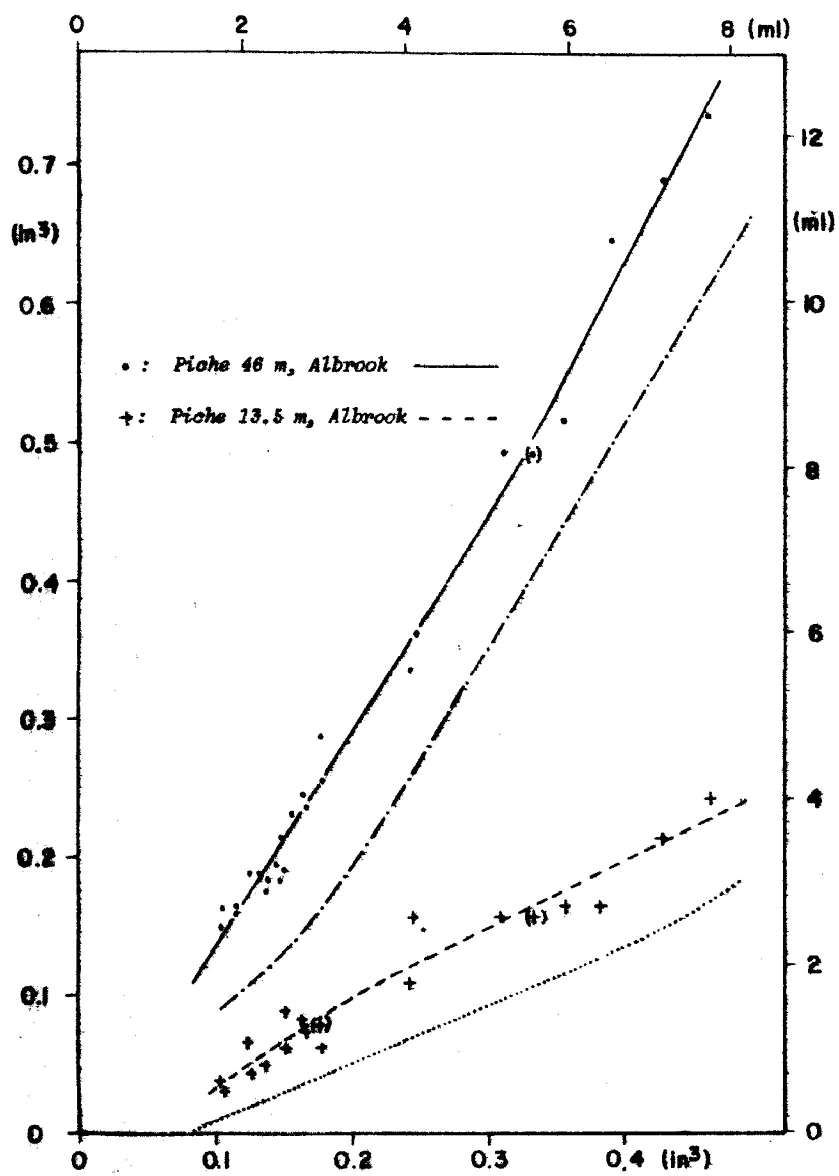


A. CORRELATION WITH PAN AT CHIVA CHIVA AND WITH PICHE AT 13.5 METERS ON ALBROOK TOWER

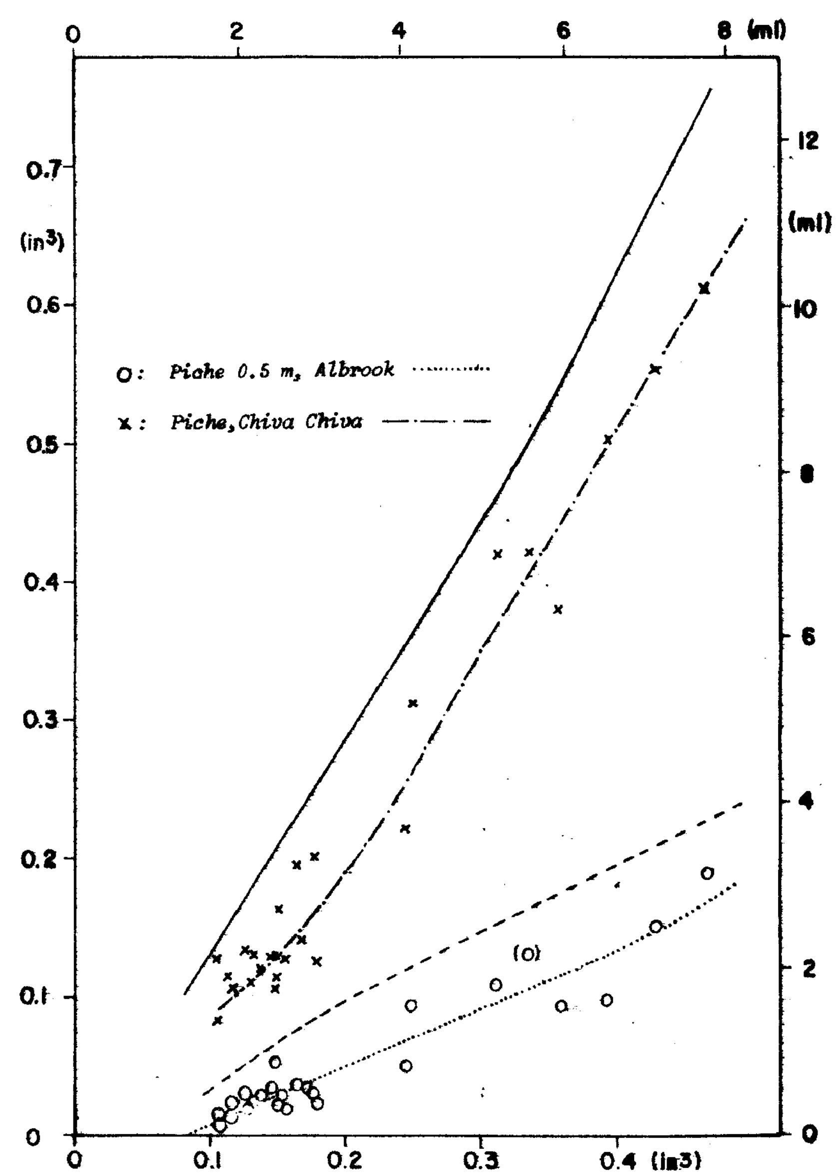


B. CORRELATION WITH PICHES AT 0.5 AND 28.5 METERS ON ALBROOK TOWER

FIGURE III-5. CORRELATION OF CHIVA CHIVA PICHE WITH OTHER EVAPORIMETERS



A. CORRELATION WITH ALBROOK PICHES AT 46 AND 13.5 METERS



B. CORRELATION WITH PICHES AT 0.5 METERS, ALBROOK AND AT CHIVA CHIVA

FIGURE III-6. CORRELATION OF ALBROOK PICHE AT 28.5 METERS WITH OTHER EVAPORIMETERS the drawing of different kinds of fitting curves.

The curves of Figures III-5 and -6 have been used to fill the gaps documented in Table III-1, and from this completed data the annual variations of six instruments have been computed and are listed in Tables III-4a and -4b. The former uses the units in which the data are recorded on punch cards. The latter gives percentages of the annual total. Table III-5 presents the seasonal variations of evaporation. The difference between the months of largest and smallest evaporation varies significantly and separates the six stations into three divisions. One division consists of the Piche at the forest floor. Tables III-4 and -5 indicate that changes occurring in the free atmosphere do not readily penetrate to the ground in the rainy season, whereas in the dry season they are easily discernible though attenuated, at the lowest layer. The second division consists of the Chiva Chiva pan, which behaves differently from the Piches. The remaining four stations have smaller differences among themselves and thus form the third division. Within this group, the instrument in the open at the surface is not strictly comparable to any one of the forest instruments, but it has one characteristic in common with one, another with another, member of this group. The correlation between rainfall totals and evaporation totals is small. The strong double wave which could be observed in the annual variation of rainfall in the period under consideration is only very faintly reflected in the evaporation, while, on the other hand, the evaporation increased very much from January to March, while the rainfall was close to zero in each of these months. This poor correlation was found for the pan as well as for the Piche. For example, there were 17 separate months, one May, two Junes, three Julies, three Augusts, three Septembers, three Octobers, two Novembers, when the pan evaporation was more than 3 and less than 4.5 inches, i.e., between 4.9 and 7.3 percent of the mean annual total. The rainfall totals of these months oscillated from 4.5 to 21.2 inches, i.e., between 5.3 and 24.9 percent of the mean annual total. There were six months with 0.5 inches rainfall or less, January (two), February (two), March (two), with pan evaporations ranging from 6.3 to 8.9 inches, and Piche evaporations of more than 11.9 and less than 19.1 cubic inches.

This result is not surprising because the amount of rainfall depends more on the vertical distribution of meteorological parameters than on the conditions near the ground. Also, evaporation is measured daily, but rainfall only when there is rain (which may be only once during a dry season month).

The correlation between global radiation and evaporation is good, that for the wind is fair. For global radiation the measurements of the Eppley pyrheliometer of the Army Meteorological Team on Gun Hill were used, and for wind the Data Base recordings at the 26.5 m level at Chiva Chiva. (Only at that level wind recordings were made during the entire period). Since wind and radiation have a similar annual variation, the correlation coefficients had to be corrected for this. Table III-6 shows these correlation coefficients.

TABLE III-4. ANNUAL VARIATION OF EVAPORATION

A. TOTALS, IN INCHES FOR THE PAN, IN CUBIC INCHES FOR THE PICHES

Chiva Chiva, Pan	6.4	7.3	8.7	6.5	4.9	3.7	4.1	3.8	3.6	3.7	3.9	4.8	61.4
Chiva Chiva, Piche	12.2	14.9	19.0	12.7	6.7	4.2	4.6	3.9	3.8	3.2	3.6	5.4	94.2
Albrook, 46 m	15.8	19.3	24.1	14.8	9.1	6.2	6.6	6.4	5.6	5.1	5.1	8.6	126.7
28.5 m	10.3	12.0	14.8	9.7	6.4	4.4	4.8	4.6	4.0	3.6	3.7	5.7	84.0
13.5 m	4.7	6.1	7.6	4.7	3.4	2.0	2.1	2.1	1.5	1.4	1.3	2.3	39.2
0.5 m	2.8	4.1	6.0	3.7	1.8	1.0	0.9	0.9	0.6	0.6	0.6	1.0	24.0

B. IN PERCENTAGE OF ANNUAL TOTAL

Chiva Chiva, Pan	10.4	11.9	14.2	10.6	8.0	6.0	6.7	6.2	5.9	6.0	6.4	7.8	100.0
Chiva Chiva, Piche	13.0	15.8	20.2	13.5	7.1	4.5	4.9	4.1	4.0	3.4	3.8	5.7	100.0
Albrook, 46 m	12.5	15.2	19.0	11.7	7.2	4.9	5.2	5.0	4.4	4.0	4.0	6.8	100.0
28.5 m	12.3	14.3	17.6	11.5	7.6	5.2	5.7	5.5	4.8	4.3	4.4	6.8	100.0
13.5 m	12.0	15.6	19.4	12.0	8.7	5.1	5.4	5.4	3.8	3.6	3.3	5.9	100.0
0.5 m	11.7	17.1	25.0	15.4	7.5	4.2	3.8	3.8	2.5	2.5	2.5	4.2	100.0

(In the conversion from means to totals the different lengths of the months have been considered.)

TABLE III-5. SEASONALITY OF EVAPORATION (IN PERCENT OF THE ANNUAL TOTAL, ARRANGED FOR DECREASING RANGE)

Station	Largest Evap. (1)	Smallest Evap. (2)	(1) Minus (2)	Secondary Max	Secondary Min
Albrook 0.5 m	25.0 (March)	2.5 (Sep, Oct, Nov)	22.5	(None)	(None)
Chiva Chiva Piche	20.2 (March)	3.4 (Oct)	16.8	4.9 (July)	4.5 (Jun)
Albrook 13.5 m	19.4 (March)	3.3 (Nov)	16.1	5.4 (Jul, Aug)	5.1 (Jun)
Albrook 46 m	19.0 (March)	4.0 (Oct, Nov)	15.0	5.2 (Jul)	4.9 (Jun)
Albrook 28.5 m	17.6 (March)	4.3 (Oct)	13.3	5.7 (Jul)	5.2 (Jun)
Chiva Chiva Pan	14.2 (March)	5.9 (Sep)	8.3	6.7 (Jul)	6.0 (Jun)

TABLE III-6. CORRELATION COEFFICIENTS BETWEEN MONTHLY TOTALS (MEANS) OF EVAPORATION, RADIATION, AND WIND SPEED FOR 31 MONTHS AT CHIVA CHIVA

	Radiation	Wind	Radiation Corrected For Wind	Wind Corrected For Radiation	Radiation Plus Wind
Standard Pan	.915	.884	.689	.515	.938
Piche	.908	.879	.658	.543	.936

The parameters obtained in the course of the correlation computation can be used to compute an equation of double regression, i.e., "Evaporation, best fit, equals factor A times radiation, plus factor B times wind, plus a constant." If we choose the units in such a way that A/B = 1 for the pan, then A/B = 0.79 for the Piche. This confirms the well-known fact that the Piche measurement reflects the radiation less, and the wind more, than the pan. However, the relatively small difference between 1 and 0.79 indicates that the difference between the measurements with these two instruments cannot be explained by saying that "the Piche atmometer is very sensitive to wind speed" (quoted from Middleton and Spilhaus[11], and other similar studies).

Conclusions

In the foregoing the difference between measurements with the Standard Pan and the Piche evaporimeter (and Livingstone atmometer) were described and documented. The user of evaporation data is not interested in what an instrument indicates but what the indication means. The discrepancy between the instruments calls for clarification through further work, part of which has been carried out in the Data Base program and is described in the next section.

Measurement of Evaporation*

Introduction and Background

Although evaporation is an important factor in natural processes, little precise quantitative information on it is known. There are many ways to find out how much water evaporates, all of them deficient in some respect or the other. Which way is taken depends on the details of the project: evaporation from a small body, from an area, from a region, from an ocean? Evaporation at a certain moment, during a day, in the course of a year? This discussion aims only at contributing to the understanding of evaporimeters for strictly local use on a time scale of hours.

With this objective in mind several series of measurement have been made at Chiva Chiva. Starting with readings of the Piche and Standard Pan, taken at four-hour intervals, the experiments progressed to strip-chart recordings of the Standard pan, the Wild weighing gage, the Livingstone atmometer in and out of shade, wind speed, dry and wet bulb temperatures at different levels, global radiation, and water temperature. The intention here is not to give a chronological rundown of what has been done, but rather to describe some essentials of the measurement study.

Arrangement and Description of Instrumentation

Standard Pan. The Standard Pan used was painted gray, stood on a low, sturdy grating, and was placed in a chicken wire cage 160 cm high and 185 by 190 cm wide (Figure III-7). This cage, designed to prevent animals and birds from drinking the water, was also large enough to house other instruments.

At certain sun angles the hook gauge was very difficult to read. It was also noted that the water level in the "still" well was rising and falling irregularly when the wind agitated the water surface of the tank. Since the mean wind velocity never exceeded 8 mi/hr (3.6 m/sec) considerable reading errors can be expected in a windy moist climate. These reading errors, however, cancel out in the computation of evaporation over some longer period of time. This is not the case with errors due to water spray-out from the pan produced by wind or hard rain. Such errors did not occur during the test series described here, but, in routine measurements, rain splash-out certainly occurs, and occasional wind splash-out cannot be completely ruled out.

Piche Evaporimeter. Several Piche evaporimeters were used during the experiments. Two of them can be seen in Figure III-7, one upwind from the pan, the other standing very close to a recording balance. For some time the blotting paper under one of the Piches was increased from 32 to 90 mm

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* This section has been prepared by Dr. Wilfried H. Portig, Research Meteorologist.

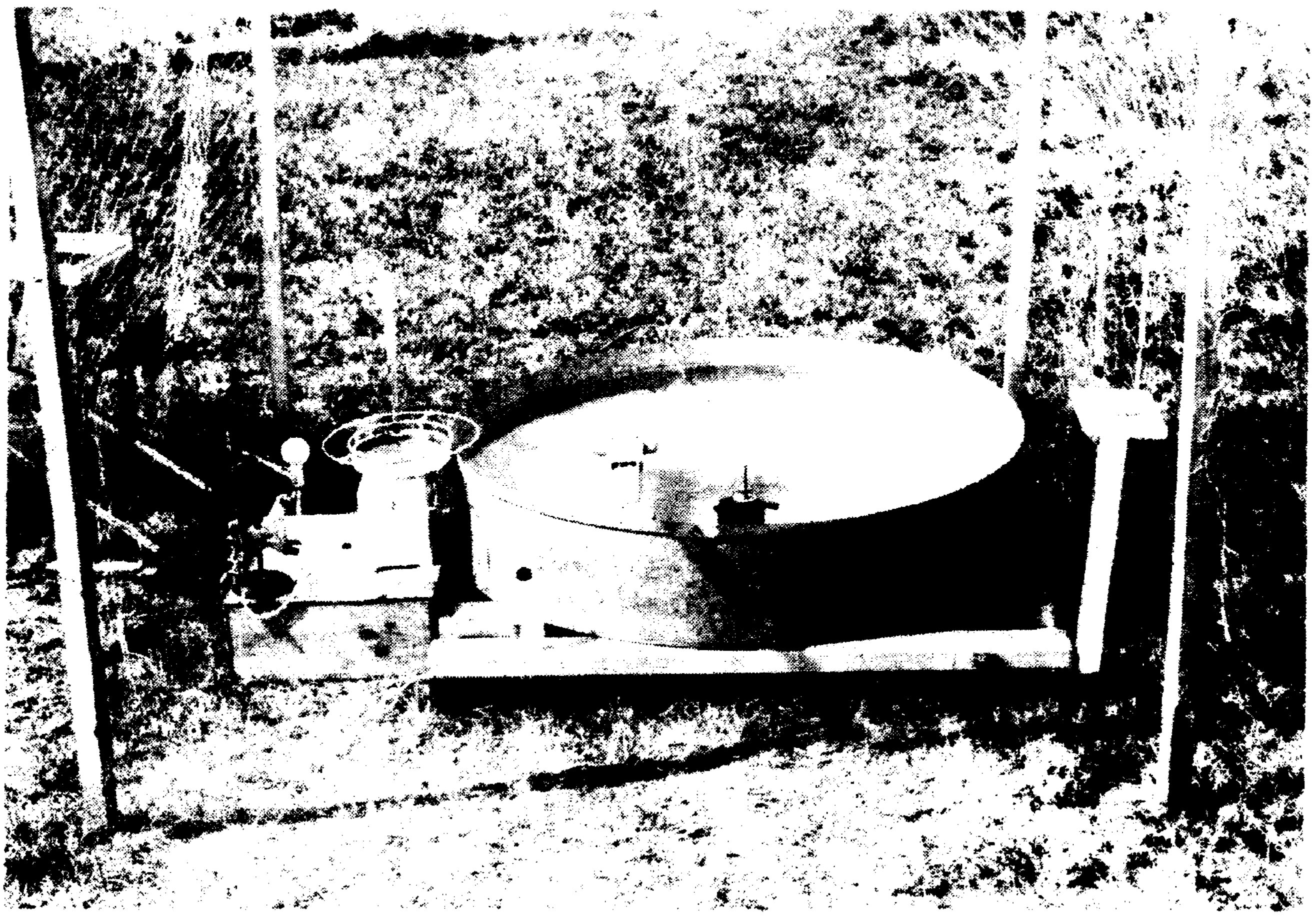


FIGURE III-7. INSTALLATION OF THE VARIOUS EVAPORATION GAGES USED WITHIN THE WIRE CAGE AT CHIVA CHIVA. (VIEW FROM NORTH).

in diameter in order to increase the evaporation rate and, thus, reduce the relative reading error. However, two disadvantages caused the rapid termination of this experimental phase. The mechanical stability of the modified Piche against wind stress was reduced too much, and the instrument had to be refilled too frequently. One normal Piche was hanging free from its upper ring; a second one was prevented from swinging by an additional clamp (Figure III-8). A third Piche stood in a Standard thermometer shelter.

Wild Evaporation Weighing Gage. Several evaporation weighing gages (of the type introduced by Wild in 1871) were used. They consist of a brass bowl of 250 cm^2 area, filled with water, and attached to the lever of a balance. The weight of the bowl produces a trace on a stripchart which is graduated in such a way that it indicates the change of water level rather than the weight. These gages were alternatively and/or simultaneously placed in the sun (as seen on Figure III-8), in the shade, and in the thermometer shelter. During the last series of experiments they were also used to obtain stripchart recordings of the pan and of the Livingstone atmometer. Details follow below. Regrettably, stripchart recordings of the Piche could not be obtained because the sensitivity of the balance is insufficient for the small weight changes of the Piche.

Livingstone Atmometer. The Livingstone atmometer consists of a porous porcelain ball filled with water. Water penetrates the porcelain at the rate of its evaporation from the ball's surface. The evaporated water will be replaced from some container, and the reduction of the water in the container is equal to the amount evaporated. Figures III-7 and -8 show the atmometer in its original exposure in the sun. At that time the water container for replenishment of the evaporated water was a burette. Later the probe was also used in the shade and it recorded on stripchart. (Details below, p.33).

Cup Anemometer. The wind was measured with different kinds of cup anemometers; however, during the experiment in April 1968 it was measured as depicted on Figure III-9. Later this instrument was elevated to the height of the thermometer shelter, and an automatic weather station manufactured by Meteorology Research Inc., was placed on the ground, its recording cup anemometer having the same height the non-recording instrument had before. Test runs before the rearrangement showed exact agreement of the instruments' calibrations.

Honeywell Hygrothermograph. A Honeywell Hygrothermograph recorded dry and wet bulb temperatures at the height of the water level of the pan, and the temperature of the pan water. Figure III-9 shows the instrument, but not the position normally used. The recorder with its three pens was fastened to the thermometer shelter. The temperature sensors were down-wind from the pan and facing into the main wind direction, i.e, they were outside the photo in Figure III-9 to the right side of the photo and pointing to the left (into the picture). The water thermometer (actually a soil thermometer) was in an inclined position in the tank (visible on Figures III-7 and -9). Frequent calibrations showed that the effect of solar radiation on the

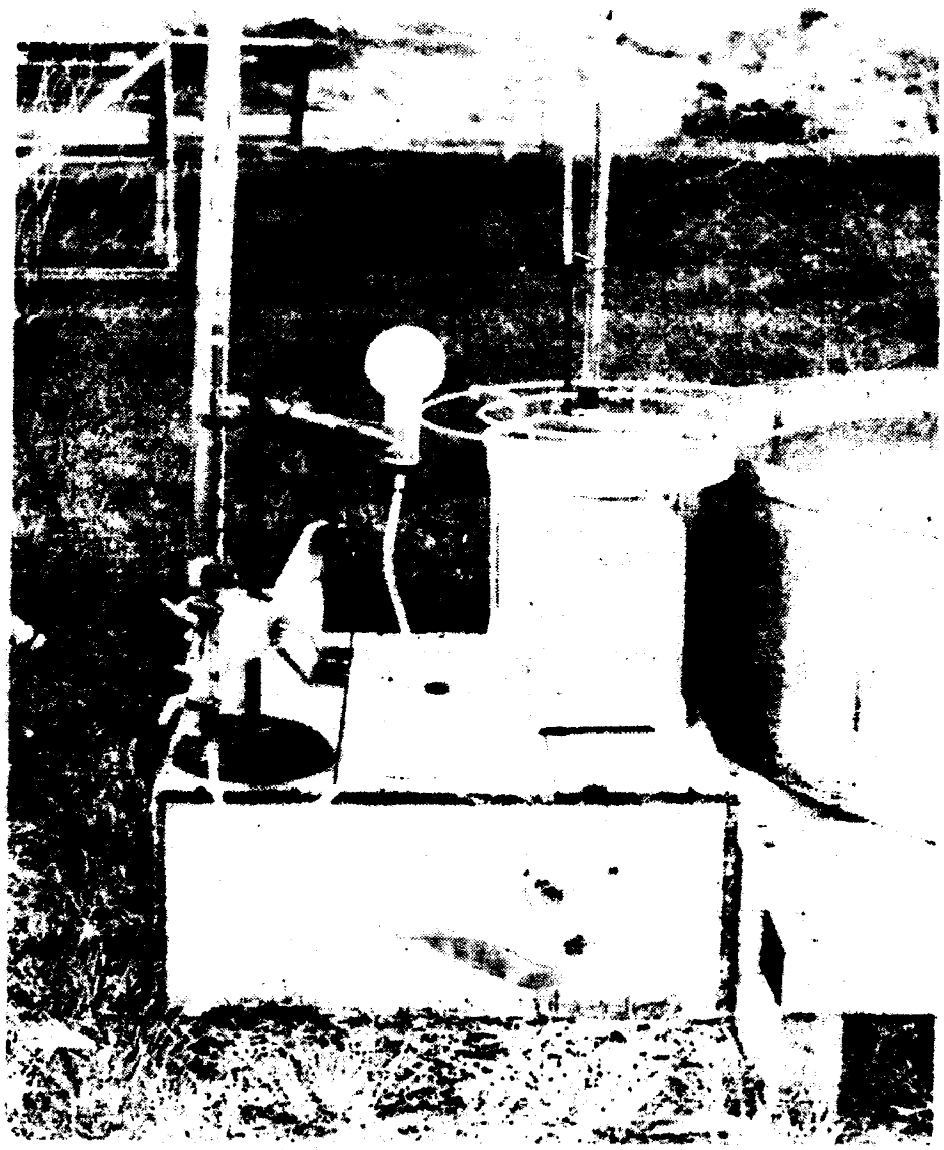


FIGURE III-8. VIEW OF WILD WEIGHING GAGE, LIVINGSTONE ATMOMETER AND PICHE EVAPORIMETER WITH CLAMP ATTACHED TO DAMPEN SWINGING, CHIVA CHIVA

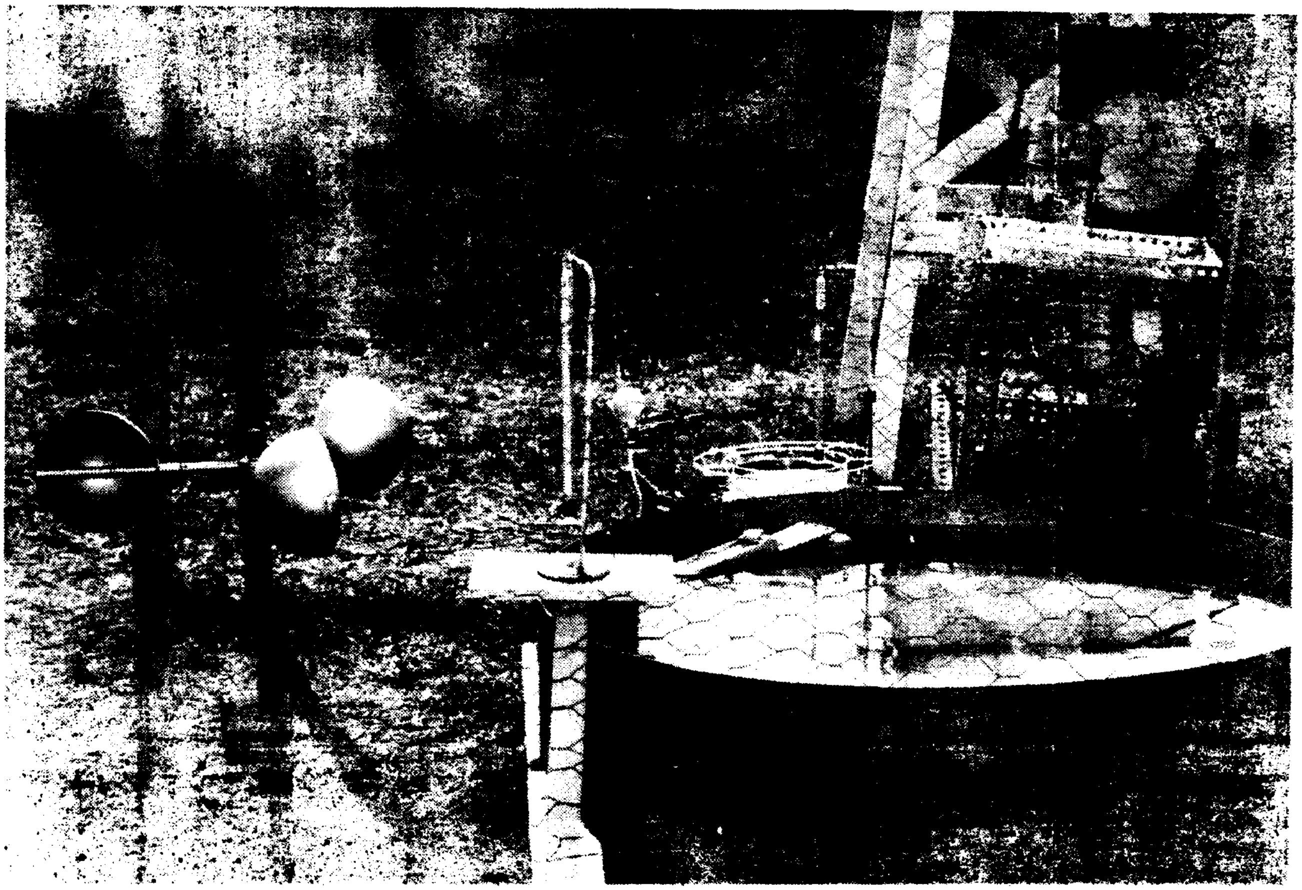


FIGURE III-9. INSTALLATION OF THE CUP ANEMOMETER
AT CHIVA CHIVA

instrument was too small to be measured while the floating thermometer (visible in Figures III-7 and -9) was several degrees too high during sunshine.

Belfort Hygrothermograph. A Belfort hygrothermograph with weekly stripchart was running in the thermometer shelter at all times.

Actinograph. Near the evaporimeters an Actinograph (pyranograph) was recording the global radiation. Its recording can be calibrated, to a certain extent, by means of the recordings obtained by the US Army Meteorological Team in Chiva Chiva Test Site (1400 meters NW of the Chiva Chiva Data Base tower) and on Gun Hill (1750 meters to the SSW).

Rain Gage. A tipping-bucket rain gage, recording on punch tape, was in operation most of the time, but periods with rain will be discarded in the analyses to follow.

Arrangements and Modifications of Instruments

Since the spatial relationships of the various instruments involved are of direct significance in the discussion following, Figure III-10 shows their basic arrangement during the first period of measurements during the dry season in 1969. During the last part of the experiments the entire station was moved close to the Data Base tower. Two of the Cardion West thermometers were taken down from the tower and placed in the space between the tower, the wire cage with the evaporimeters, and the thermometer shelter, at the height of the Belfort hygrothermograph. Every 5 minutes, the well aspirated thermometers recorded dry and wet bulb temperatures on punch tape.

In the last phases of the experiments, very simple siphons connected the Standard Pan and the Livingstone with recording evaporation weighing gages and provided excellent stripchart recordings. For the pan siphon, a wooden plate and a plastic collar separated the evaporation bowls from the ambient air. Because of the siphon, the water in the bowl had the same height as the water in the pan and reflected all its height changes. Since the siphon did not touch any moving part of the weighing gage, the recorded changes of the water level in the bowl were produced by the changes in the pan. For high accuracy it would be necessary to apply two corrections, one for different temperatures of the two water bodies involved, and another because the small bowl is an extension of the entire water mass but without exposure to the ambient air. It was expected that the accuracy of the weighing mechanisms would not warrant the application of such corrections. During data analysis, it turned out that the accuracy of the measurements could have been substantially improved had the temperature of the water in the bowl been recorded.

The Livingstone atmometer was connected with the weighing gage in nearly the same way as the Standard Pan, with only a difference in the siphon. The rubber hose that assured equal water levels of pan and gage was replaced with a brass tube leading from the water-filled bowl of the gage vertically up into the porcelain ball. Water evaporating from the latter

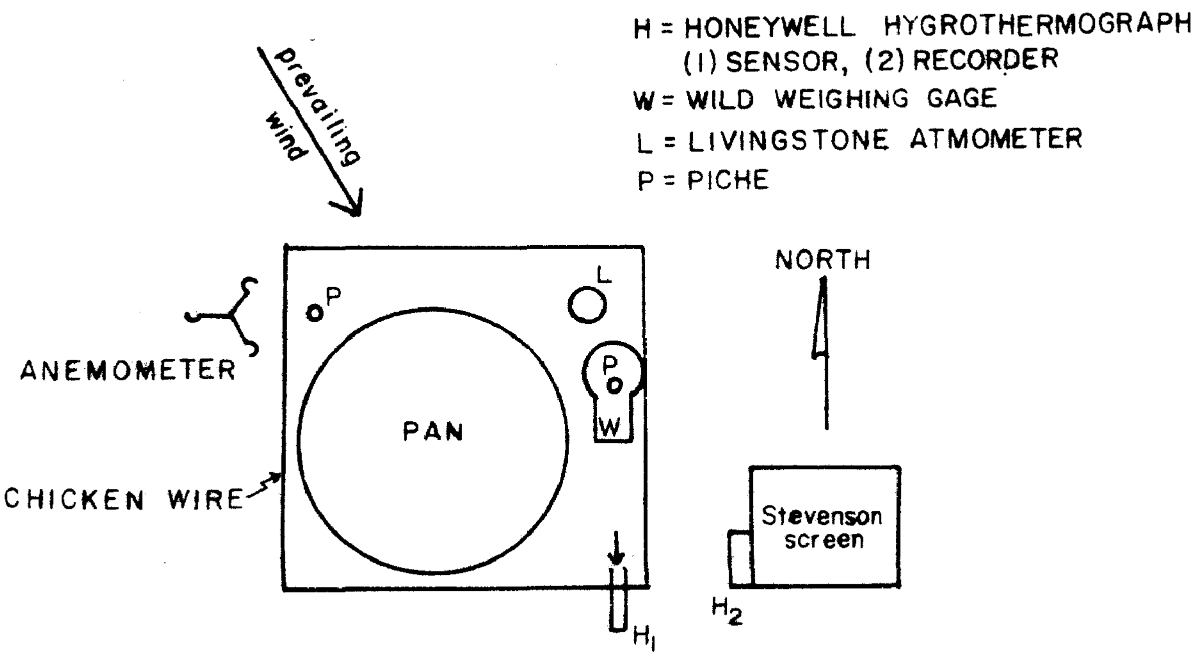


FIGURE III-10. POSITIONING OF INSTRUMENTS AT THE TIME WHEN THE PHOTOGRAPHS WERE TAKEN was replaced with water from the bowl by simple suction. The two corrections described in the previous paragraph do not apply here, because in the pan recording the height of the water level was measured and, in the Livingstone recording, the water mass was measured.

Results of Observational Program

Analysis of data may lead either to descriptions of what happens, or to the use or the development of theory which explains the causes and mechanisms of what happens. This section deals only with what actually took place during the evaporation experiments in Chiva Chiva, not with exposition of theory.

Different Exposures of Piche Evaporimeters. Several series of measurements were made to investigate the influence of the exposure on the measurements taken with Piche instruments.

One Piche was hanging in the NW corner of the cage,and a clamp prevented it from swinging. Another Piche was freely hanging directly over the bowl of the weighing gage. After several days the clamp was removed from the former and attached to the latter. No effect of the clamp change could be found; in both configurations the Piche over the bowl indicated 77 percent of the evaporation indicated by the Piche in the NW corner. Results: (a) There was no difference whether the instrument was swinging or not, but the wind was never so strong as to force water through the blotting paper by the centrifugal force of excessive swinging, or by bouncing against the stand. (b) The Piche evaporation was 23 percent lower over the bowl where it was slightly shielded against wind by the shelter provided by the pan, and by lower height. Differences in global radiation for both instruments can be assumed to have been insignificant.

This experiment shows that the method of suspending the Piche is less important than its location.

Since the two Piches with different sizes of blotting paper were never at the same place, the effect of difference in size cannot be properly assessed. An estimate can be obtained from a comparison between two series of measurements, one taken following the other, i.e., under slightly changed weather conditions. In both series one normal Piche was hanging over the bowl. In the first of the series, the Piche in the NW corner of the measuring plot had an oversize blotting paper of 90 mm diameter. During the subsequent series, the paper was replaced with one of normal size (32 mm diameter). From the measurements one can infer (though with a low degree of certainty) that the water loss increases more than the area of the paper. The paper area in the first series was 8.6 times greater than that of the second; the recorded water loss was estimated, using the second series as a base, to have been 9.8 times what it would have been with a blotting paper of normal size. The differences between 9.8 and 8.6 could be explained by the fact that the bigger paper reacts more to gusts, and has a greater tendency to lose drops in addition to the water loss by evaporation.

One Piche was hanging in the NW corner, another was located in the temperature shelter (Stevenson screen). The latter instrument recorded 79 percent of the former. One is tempted to conclude that the instrument in the shelter acts in almost the same way as the instrument over the bowl.

This, however, is not the case. While the quoted percentages of both instruments were practically equal on the basis of 24-hour periods, they were different for different parts of the day. Though the instrument over the bowl always recorded 77 percent of that in the NW corner, the sheltered Piche recorded 73 percent of the latter during daytime hours, and 98 percent during the night. (The average of 73 and 98 is not 79; the night evaporation is smaller than the day evaporation and enters 79 with a correspondingly smaller weight). Referring the evaporation in the shelter to that over the weighing gage, it was 91 percent during the day and 120 percent at night. Result: the ratio between in-shelter and out-of-shelter evaporation changes in the course of the day. It can be assumed that it also changes in the course of the year, especially in locations with definite seasonal changes.

Evaporation Weighing Gages and Livingstone Atmometer. The evaporation weighing gages reflect qualitatively the same conditions as reported for the Piche above, but quantitatively they are different, as can be seen in the following tabulation:

Ratio Between Evaporation in Thermometer Shelter to Evaporation in NE Corner of the Plot

	Daytime	Nighttime	24-hours
Piches	0.91	1.20	0.99
Wild Weighing Gage	0.48	4.00	0.55

Another series of comparisons helps to explain the contents of this tabulation. Two evaporation weighing gages were working in the open for several weeks. One was completely exposed to the weather, while the other stood on the ground close to a small stilted shelter with a wide overhanging roof, 190 cm above the ground. Though the shelter only produced a modification of the wind flow over the evaporation bowl, the roof drastically curtailed the radiation. Direct sunshine was shielded from 0930 to 1410 local time (approximately 0900 to 1340 true solar time). A substantial amount of sky radiation, including the entire flux from the zenith, was intercepted by the roof. The comparison of the measurements made by the free and by the sometimes shielded weighing gages gives some insight into the influence of radiation on the evaporation measurements with a Wild instrument.

The comparisons between the Piches in and out of the shelter are based on a limited number of readings per day. The comparison of the Wild is based on continuous stripchart recordings, which allows a finer analysis. The stripcharts show that at 0930, as soon as the shadow of the roof reached the evaporation bowl, the evaporation dropped to 59 percent of that under the sun, and it stayed at this percentage until the shadow left the bowl in the early afternoon. During the time of reduced evaporation, the water temperature of the shaded instrument was 7°F lower than that under the sun.

Some time after the shadow cast by the sun had left the bowl, the water temperatures of both Wilds were equal. Yet that which had been in the shadow before evaporated more than the other, sometimes more than twice as much. The reason for this could not be fully determined. The ruggedness of the curves suggests that the wind speed and/or the turbulence were greater near the stilted shelter than in the wire cage. The shelter may have produced a kind of Venturi effect beneath it, and the chicken wire may have reduced the wind. Lack of suitable anemometers precluded this determination. The difference in the evaporation rates of both instruments dropped to zero with the nocturnal decrease of wind speed, but since the relative humidity of the air also rose enough at the same time to prevent any evaporation, the last statement is not conclusive. Result: The Wild gage is highly sensitive to radiation and reacts strongly and quickly to changes in it.

Since only one Livingstone atmometer was available, no simultaneous recordings of such instruments could be obtained. The one instrument was recording side by side with the Wild gage within the cage for some weeks, and, for other weeks, side by side with the Wild gage under the roof. The shadow reduced the evaporation rate of the atmometer, but this reduction cannot be expressed by a numerical value because the weather during the first exposure period was not the same as during the second one, and no simple formula was found to relate the indication of the Livingstone to that of the evaporation weighing gage. (Such a formula may exist for daily totals, but hourly evaporation rates are under consideration here.)

Incidental Observations. Some phenomena that seem to be worth reporting were noted as by-products of the observation routine.

The change in the evaporation rate of the Wild gage when a shadow is cast on it is described above. This occurs because the water temperature drops when substantial amounts of the radiation are cut off. The change in water temperature was not spectacular when the shadow reached the bowl, while the ambient temperature rose sharply; but when the shadow moved away, approximately at the time of the highest ambient temperature, the temperature changes of the water in the bowl were interesting. In this case the water temperature rose sharply from approximately 83°to 87°F, causing the evaporation rate to go up, which in turn,lowered the temperature rapidly to 85°F and slowly to the upper 70's at sunset. After the transition from the rapid to the slow temperature drop, the water temperatures of both Wilds were equal. (Note: As mentioned above, the evaporation rates were not equal at that time).

The radiation effect on the water temperature depends on the height of water in the bowl, but this effect is not large enough to be detected in the observations under investigation. The correlation coefficients between height of water and rate of evaporation had the expected sign but were too small even for the 90 percent level of significance.

The temperature changes of the evaporating water clearly affect the evaporation rate, but the temperature changes of the non-evaporating water in the bowl of the pan recorder also had an influence on the recorded amount. When the temperature of the bowl water is higher than that of the pan water, thermal expansion causes some water flow from the bowl to the pan, which appears on the stripchart as increased evaporation. This effect was deemed insignificant when the experiments were carried out, but the data show a correlation between amount of water in the bowl and "evaporation" trace in the morning when the small water mass in the bowl warms up rapidly while the large water mass in the pan does so only slowly. It is estimated that the temperatures of the two water masses sometimes differ as much as 10°F, but measurements of this difference have not been made.

Dew formed on the water surfaces of the evaporimeters on certain days. For instance, on 11 April 1968, the grass was very wet with dew at sunrise. After sunrise the temperatures of the grass and the overlying air rose rapidly, and the dew evaporated in a very short time. Table III-7 shows some measurements taken on the day when this process was taking place and one can infer from it that the water temperature almost equalled the dew point at 0800. One may also assume that it was lower than that for some time and in this case, water would have to condense on the water. In fact, the pan (Table III-7) as well as the open Wild gage (Figure III-11) showed the condensation, which was minute in this case. Such a condensation on water may be of some importance when warm and very moist air is advected over cold water (as may happen in spring months over the Great Lakes during invasion of warm air from the South).

TABLE III-7. MEASUREMENTS ON 11 APRIL 1968

	0730	0800	0830	0930	
Air Temperature*	72.8	76.1	80.9	83.4	°F
Relative humidity*	100	91	77	68	%
Dew point*	72.8	73.2	73.1	71.8	°F
Water temperature of pan	72.5	73.3	75.0	76.3	°F
Water level in pan, raw	2.562	2.561	2.565	2.560	°F
Same, corrected for water temp.	2.562	2.560	2.563	2.556	in
Evaporation (+), Condensation (-)		+0.002	-0.003	+0.007	in

* At 50 cm above ground.

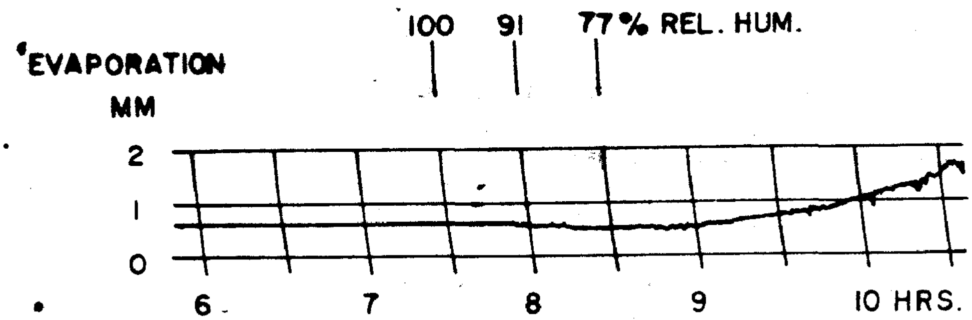


FIGURE III-11. RECORDING OF AN EVAPORATION WEIGHING GAGE AT THE TIME OF DEW FORMATION ON THE WATER, ON 11 APRIL 1968.
Relative humidity of the ambient air is noted above the curve, The small dip of the curve at 0755 indicates the beginning of the condensation on the water.

Diurnal Variations. The series of measurements were made in the dry season. In order to demonstrate those results which are typical for the season, only the days with considerable radiation were summarized for the comparison of diurnal changes. The first part of the following compares the results obtained simultaneously by different evaporimeters. The second part displays the average meteorological conditions for the same days.

Diurnal Variation in Evaporation. It has been shown above that the amount of evaporated water can change greatly from one instrument to another through a small change of location, (see Different Exposures of Piche Evaporimeters, p.36). Because of this, this section presents all results in relative units: hourly rates of evaporation are presented in percentages of the daily total. The measurements of all instruments that measure the mass of evaporated water could be used without correction. The measurements of instruments that measure the height of the evaporated water column need a reduction for water temperature, because the column expands and contracts with temperature changes. The errors introduced by temperature changes do not cancel out in the mean of many diurnal variations because temperature and evaporation are closely correlated. Numerical evaluation of the pertinent formulas shows that the temperature effect on the Piche is too small to be considered. The correction is, however, considerable for the pan, because the ratio of the evaporating surface to the cross section of the water container is 1 while it is 8.4 for the Piche- Table III-8 lists some of the corrections that had to be applied to the pan readings. Two other corrections described above (see Arrangement and Modifications of Instruments p.33) were not applied for the reasons given. The times given in Table III-8 and in the figures are local clock times. The true solar time differed during the period of the measurements by approximately 30 minutes, so that, for instance, 0700 corresponds to 0630 solar time. Under tropical dry season conditions all evaporimeters show a minimum of evaporation near sunrise, and a maximum a short time after noon. The height of the extremes, and the evaporation between them, differs with the type of instrument used.

TABLE III-8. EXAMPLES OF CORRECTIONS APPLIED TO THE PAN READINGS BECAUSE OF CHANGES OF WATER TEMPERATURE

Hour	4-5	9-10	13-14	17-18	20-21
Raw Evaporation Rate *	0.10	0.26	0.96	1.04	0.30
Corrected Evaporation Rate * **	0.07	0.50	1.09	0.85	0.19

* Scale divisions on the recorder, the unit is irrelevant.
** Under the assumption of a water depth of 10 inches. The correction is proportional to the water depth and to the temperature change during the time interval of rate computation.

Figure III-12 shows the slightly smoothed diurnal variations of evaporation during "radiation days" of the dry season on the Pacific side of the Canal Zone. All curves show a tendency for a secondary maximum to occur near midday. This is probably due to a secondary wind maximum in the forenoon (see below, p.44). In addition, the solar radiation has its maximum well ahead of the main wind maximum. This occurs because the accumulated heat, rather than the monentary insolation, is responsible for the air motion. The evaporation, however, reacts relatively quickly to the radiation and the wind speed. Hence, the disparity between the variations of solar radiation and wind produces the buckle in the evaporation curves before they reach their main maximum.

The time of the highest evaporation rate changes from 1330 (Wild and Livingstone) to 1430 (Piche) and 1445 (Standard Pan). The relative amount reflects the "peakedness" (also called "kurtosis" or "fourth moment", when numerically expressed using all measurements. The "peakedness" increases in the order: Standard pan - Wild in shelter - Livingstone - Wild in the open - Piche.

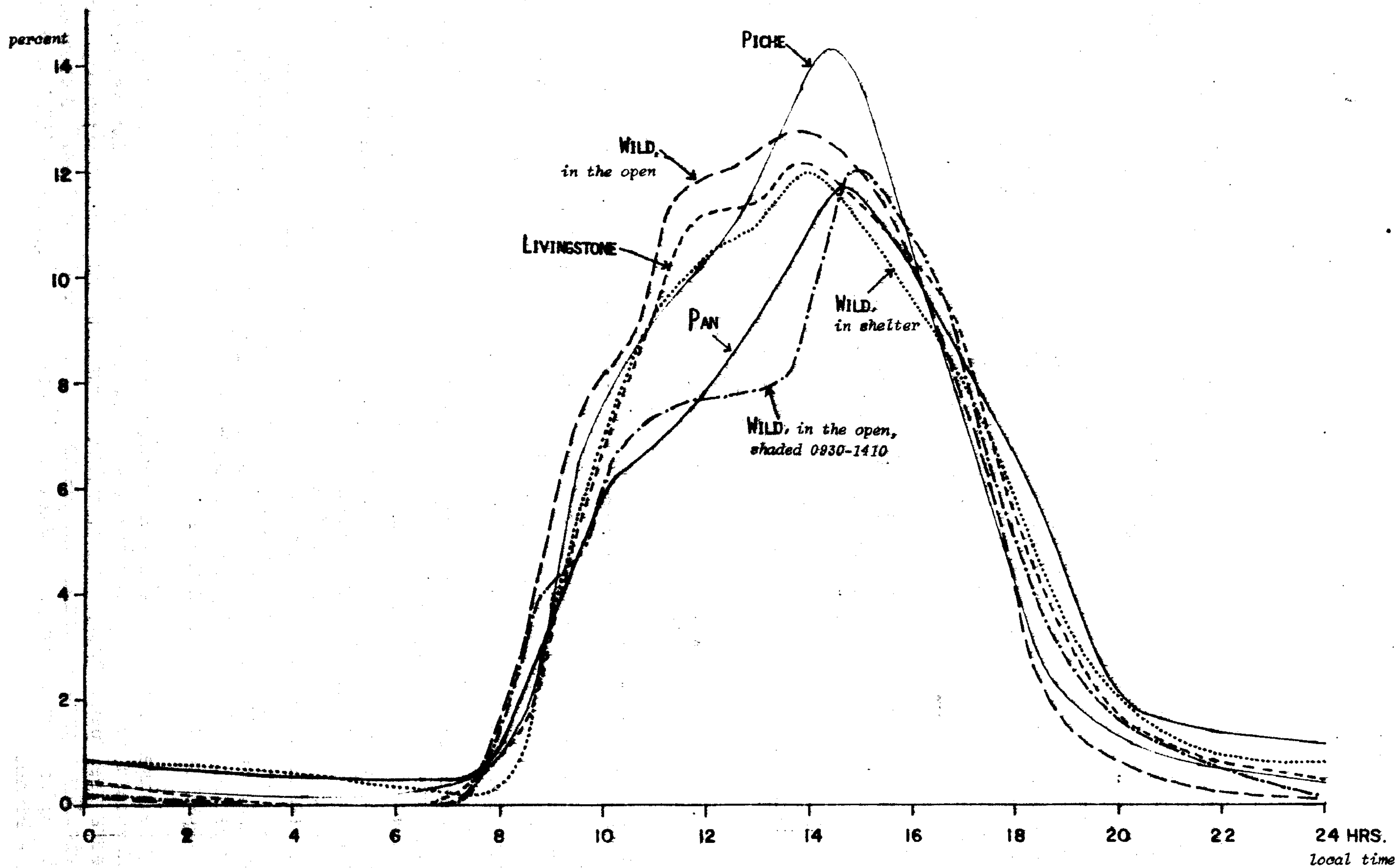


FIGURE III-12. DIURNAL VARIATION OF EVAPORATION MEASURED WITH DIFFERENT INSTRUMENTS (PERCENTAGE OF DAILY TOTAL)

Table III-9 shows a similar characteristic by comparing the percentages of daytime and nighttime evaporation.

TABLE III-9. PERCENTAGE OF TOTAL EVAPORATION DURING DAY AND NIGHT

Instrument	Day (07-19)	Night 19-07)
Standard Pan	87.9	12.1
Wild in shelter	87.9	12.1
Livingstone	93.5	6.5
Wild in the open	97.0	3.0
Piche	94.6	5.4

After reaching a maximum the evaporation rate decreases sharply and drops to zero, or close to zero, for all instruments except the Standard Pan. The heat capacity of the large water mass of the pan is such that enough energy is available to maintain the vaporization process through the entire night. On the other hand, the same reasoning applies to the sluggishness of pan evaporation before noon. Note: Because of some uncertainty in the data reduction, (see under Incidental Observations, p.38) the evaporation curve for the pan may be incorrect between 0800 and 1100. This is of no effect as long as the reader does not attempt an analysis more detailed than this discussion.

In addition to the five curves discussed so far, Figure III-12 also contains the evaporation curve of the Wild gage that was shaded during part of the day. In this case the percentages do not refer to the total measured with this instrument, but to the total measured with the unshaded Wild. The discussion of this curve can be found in the section on Evaporation Weighing Gages, p.37.

Diurnal Variation of Meteorological Parameters. Figure III-13 gives information on the diurnal variation of several meteorological parameters. The curves refer to the same radiation days as those of Figure III-12 with the exception that in the latter the Piche data have been taken 13 months earlier, i.e., in January 1968. The data were obtained by Data Base contractor personnel and were not part of the evaporation experiments described in this paper. However, these are the only hourly Piche data available for Chiva Chiva, and only those days were selected for averaging whose meteorological conditions came close to those presented in Figure III-12. Air temperature and saturation deficit are based on readings taken by the automatic data acquisition system at five-minute intervals. The other data are based on hourly evaluations of stripcharts.

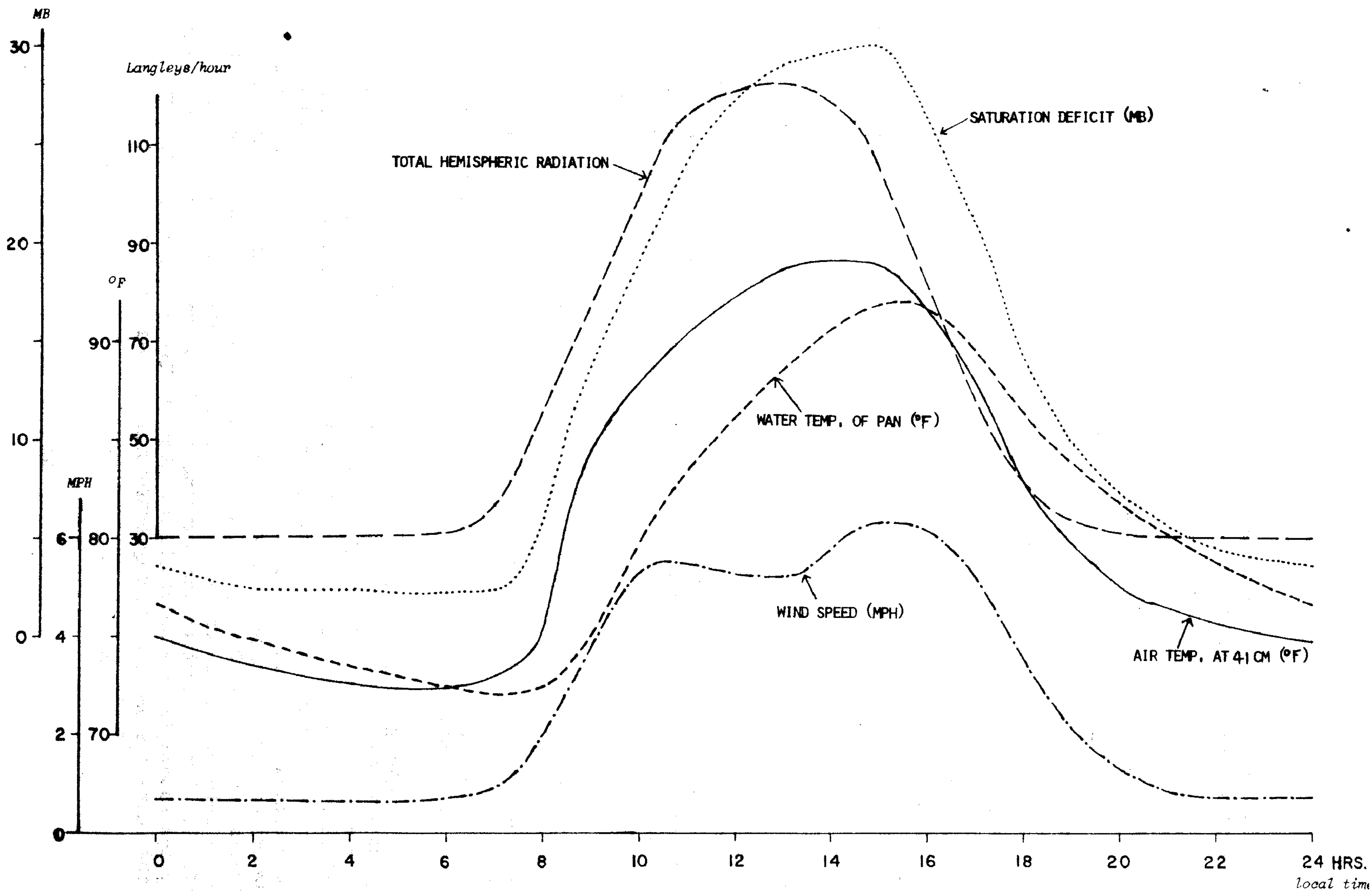


FIGURE III-13. DIURNAL VARIATION OF SOME METEOROLOGICAL PARAMETERS

The ambient temperature was taken at 41 cm and 141 cm above ground, the former being graphed in Figure III-13 and labelled "Air Temperature 41 cm." The rapid temperature increase between 0800 and 0900 and the occurrence of the flat maximum are typical for the humid tropics. A temperature peak one would expect from corresponding curves obtained in drier climates is cut off by the cloudiness which always develops.

The curve of the mean global radiation is given in Figure III-13, but since it is based on hourly increments and since the instrument was on Gun Hill at a distance of 1750 meters, it is appropriate to present a summary of the actinograph recordings although such an instrument gives relative, rather than absolute values. Figure III-14 shows the actinograph recording read every 7.5 minutes and averaged over the eight radiation days on which most of the curves of Figures III-12 and -13 are based. In addition, Figure III-14 also shows the highest and lowest values read within each 7.5 minute interval. The curve looks quite different from what most meteorologists expect to be typical for the days with greatest radiation in the dry season. Only in the late afternoon is the curve rather smooth and the range between extremes rather small. This is the same period when the evaporation curves of Figure III-11 required a minimum of smoothing.

The curve of the saturation deficit is generally parallel to the curve of the ambient temperature, with two exceptions. In the morning the temperature rises more strongly than the saturation deficit because the increasing heat vaporizes the nocturnal dew and the soil moisture brought to the surface during the night, and thus raises the absolute humidity of the air. Contrasting to this, the soil adds practically no more moisture to the air at noon and later, but the turbulence dilutes the low level moisture into higher levels. Through this mechanism the saturation deficit still rises when the ambient temperature has begun to drop. Figure III-15 shows the mean vapor pressure at the 41 cm level during the eight radiation days. It is interesting to notice the coincidence of the drop of radiation at 1345 (Figure III-14) and the simultaneous rise of absolute humidity (Figure III-15).

The comparison of the Cardion-West thermometers with the Honeywell hygrothermograph revealed that the latter gives too high readings of the wet bulb thermometer during periods of sunshine because its water reservoir heats up and feeds the wet bulb with water which is 10° and sometimes 20°F warmer than the wet bulb temperature. The resulting error is in the order of magnitude of 1.5°F, corresponding to approximately 5 percent relative humidity. The error is greater than at other wet bulb thermometers because (1) the big glass container warms the water like plants in a greenhouse, and (2) the water consumption of the big sensor is considerable so that there is little time for the water to cool at least to dry-bulb temperature on its way to the sensor.

The wind is a consequence of heat distribution and, hence, reflects the uneven radiation conditions by displaying a secondary maximum late in the morning and its main maximum one hour after the maximum of radiation.

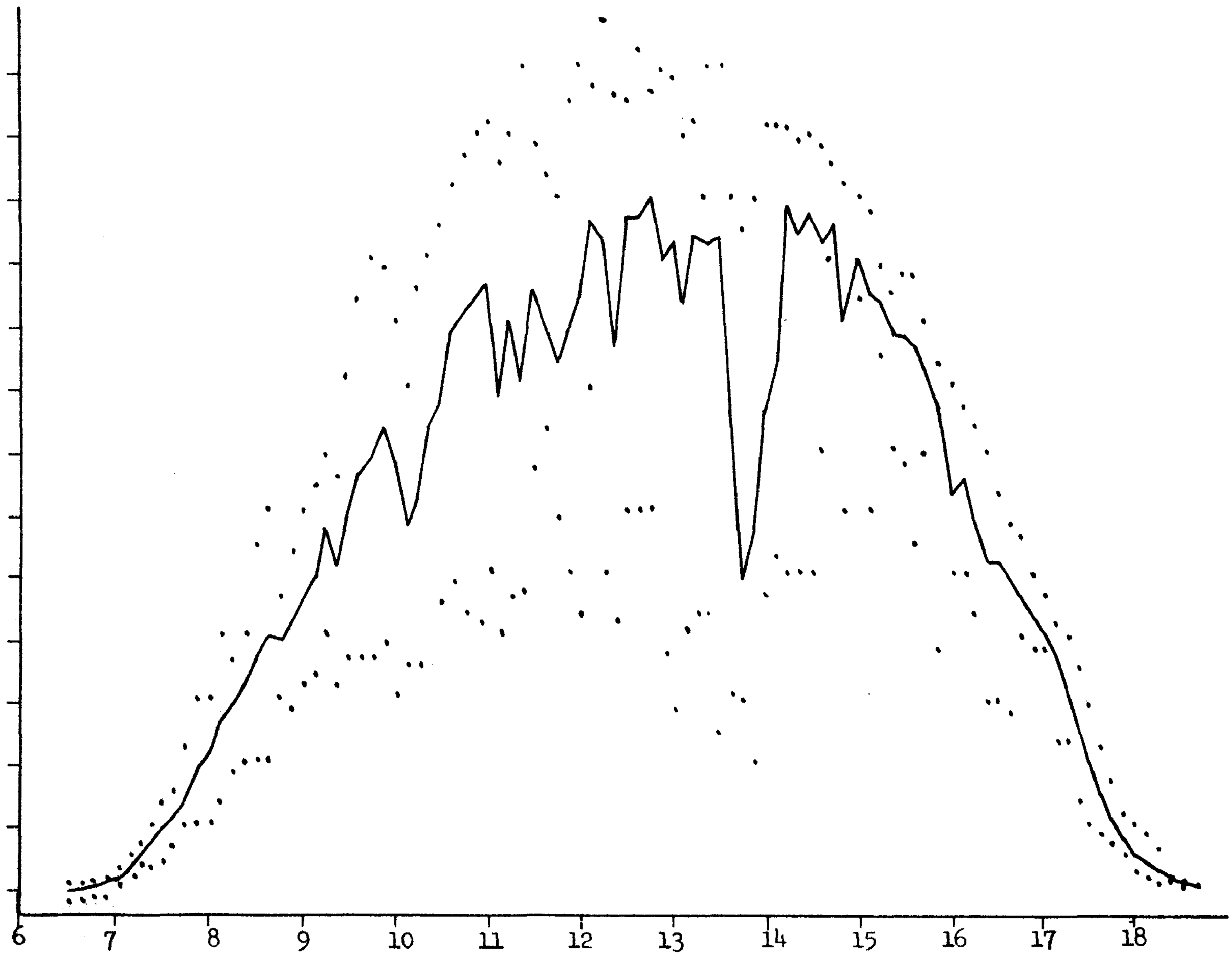


FIGURE III-14. MEAN (CURVE) AND EXTREME (DOTS) GLOBAL RADIATION DURING EIGHT RADIATION DAYS

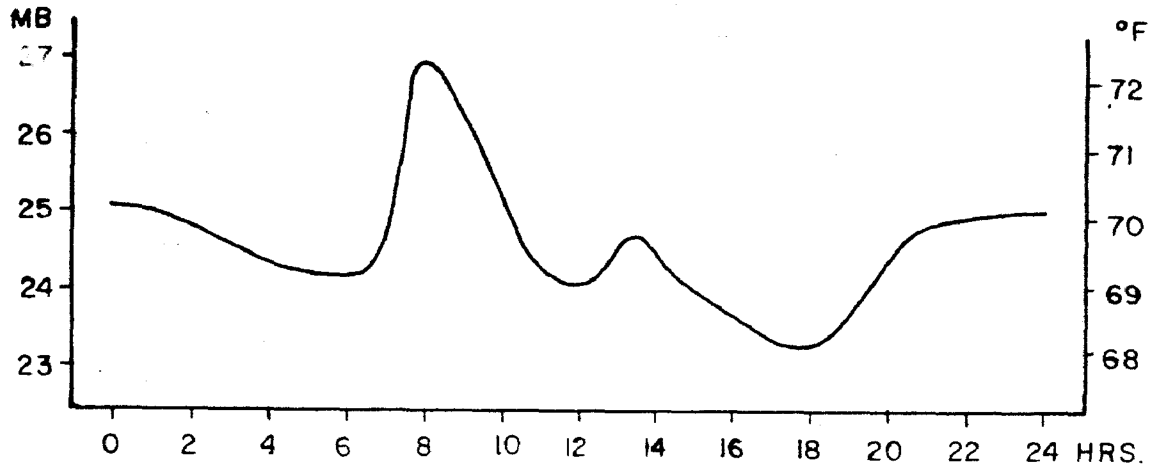


FIGURE III-15. DIURNAL VARIATION OF VAPOR PRESSURE AT 41 CM OVER GROUND
(Right scale equivalent dew point temperature)

As observations of this and previous years show, the double wind maximum develops gradually in the course of February and is typical for March. At that time, the global circulation (trade winds) becomes weaker and is more and more replaced with local developments.

The temperature of the water in the Standard Pan (Figure III-13) shows a considerable lag with respect to the temperature of the ambient air, and from 1600 to 0600 it is warmer than the latter. The mean daily water temperature was measured to be only 0.8 F lower than the mean air temperature at 41 cm over the ground. Under the assumption, however, that the water temperature at the place where it evaporates is at the wet bulb temperature, the corresponding difference of mean daily temperatures would be 8.2°F. This would be the case with the Piche (Mukammel[10]). Since the temperature of the evaporating water is of great influence on the amount of evaporation, this difference between the water temperatures is one of the main contributors to the discrepancy between measurements made with different types of evaporimeters. Though not measured, it can be assumed that the water temperatures of the Livingstone and Wild instruments lie between those of the pan and the Piche, because their involved water masses are greater than that of the Piche and smaller than that of the pan.

Theoretical Aspects of Evaporation

A complete general theory of evaporation does not yet exist, and it is doubtful that it ever will.[16] Simplification of the problem was attempted by dividing the evaporation processes into two groups, one in which the evaporating surface is always kept wet, and the other where the water supply is sometimes, or always, restricted. The first group is called "potential evaporation". It was hoped that methods of linking the actual evaporation to the potential evaporation might be found, through the understanding of the mechanism of water supply.

Actual Evaporation. Not much is known about actual evaporation because all attempts of measuring it affect the process itself. Attempts were made under project TREND* to measure the actual evaporation from soil as well as from branches of plants (the latter process called "transpiration"). Theoretical treatment of the process would involve an assessment of the balance between the suction force of the air ("evaporative power") and the pressure forces such as capillarity for soil and osmosis for plants It seems that we are still far from a solution of this problem, but there is no doubt that the understanding of actual evaporation processes would be beneficial in many fields of science, engineering, agriculture, to name only a few.

Potential Evaporation. Four different approaches to the understanding of potential evaporation are dealt with here.

Correlations. The most common approach to potential evaporation is a correlation of measured or estimated values with wind speed and saturation deficit over the evaporating surface. Usually the method is refined by replacing the saturation deficit with the difference between the actual vapor pressure of the air and the saturation vapor pressure at the water surface temperature. All these attempts end in an empirical formula of the general type $E = a\ (e_w - e_a)\ (1 + bv^c)$ in which E is the rate of evaporation; e_w and e_a are the saturation vapor pressure at water temperature and the actual vapor pressure of the air; v is the wind speed at some specified height over the water surface; and a, b, c, are constants. The latter three vary from author to author depending on how the E values were obtained. As will be shown below, such a formula can only be a rough approximation and cannot be generalized.

Water Balance. A more sophisticated approach towards the understanding of potential evaporation is the consideration of the water balance It is reasoned that the total of the water movements involved in precipitation, evaporation, run-off (at the soil surface), and seepage (into the soil) is zero. This reasoning is particularly applied in the study of entire watersheds; but the uncertainties of measurement are considerable and accumulative with respect to evaporation, because in the water balance equation, the evaporation is the small difference between relatively large amounts of precipitation on one hand, and run-off and seepage on the other

Energy Balance. The attempt is made to compute the thermal energ

* An environmental study, similar in many respects to the Data Base Project, being carried out in Thailand under the sponsorship of the US Army Natick Laboratories.

going into and coming out of a volume which consists of water in its lower part, and air in its upper. One of the heat flux components is the heat of vaporization which is directly proportional to the mass of evaporated water. Hence, when all other heat fluxes are known, the evaporation can be computed. Again, as in the case of the water balance, the individual fluxes are not well enough known to allow computation of the evaporation with a high degree of accuracy. The heat balance considerations can be applied to areas of any size and are not restricted to watersheds or entire lakes. A special difficulty in this type of computation lies in the proper assessment of the amount of heat carried away by the wind. This part of the problem is extremely difficult in its physical background as well as its mathematical treatment. A solution has been obtained only under the assumption that the atmosphere is adiabatically stratified right over the evaporating surface. This, however, is practically never the case. In the Chiva Chiva experiments described above, the temperature lapse rate between 41 and 141 cm over the ground at noon time was 100 times as great as the adiabatic and became negative at night. The assumption of adiabatic stratification of the air leads to a formula in which the potential evaporation is proportional to the decrease of water vapor with height. In Chiva Chiva, however, there was generally a slight increase of vapor pressure with height, yet evaporation occurred.

The actual problem of the heat balance method is more deeply rooted: No theory adequately describes the movement of air very close to the ground under any possible vertical temperature differences. While in the free atmosphere air rises through buoyancy when the lapse rate exceeds the adiabatic, lapse rates of more than 2,000 times the adiabatic have been measured immediately over the ground, and no special vertical movements were noted. Baum[12] computed, with the use of very simplifying assumptions that a lapse rate of $6^{\circ}C/cm$ would be the maximum possible in the one centimeter thick layer of air directly over the ground. This is 60,000 times the adiabatic lapse rate under which potential evaporation can be computed (in the present state of the art) by means of austausch and flux theory.

Figure III-13 shows the great differences between the water temperatures of the Standard Pan and the air at 41 cm over ground. When we assume that the height of the thermometer was 5 cm higher than the water surface of the pan, we arrive at lapse rates oscillating between $-2.5^{\circ}C/5\,cm = 0.5^{\circ}C/cm$ at 1900 and $+5.5^{\circ}C/5\,cm = +1.1^{\circ}C/cm$ at 0900, whereas the lapse rate used in the heat flux theory is the adiabatic which is $-0.001^{\circ}C/cm$. (The height between water surface and thermometer for the air temperature was variable because the water level changed through evaporation; also the air temperature was not measured over the pan, but approximately 2 meters away.) (Reference for this and the preceding subheading: Sutton[13]).

Hofmann's Approach. Hofmann[14] tried to explain the formation of dew, rime, and frost. But since evaporation is the reverse of dew formation, his reasoning can be and has been (Roth[9]) applied to evaporation processes. His work results in a formula of the form: $E = a\,(B + S) + b.v^{0.75}(100 - R.H)$. In this formula E is the rate of evaporation; B is the flux of sensible heat through matter other than air to the evaporating surface, S is the net radiation (= radiation balance) of that same surface; v is the wind speed; RH is the relative humidity of the air. The letters a and b do not denote constants as they do above under Correlations, but mathematical functions of the temperature; b is, in addition, very strongly dependent on the form and size of the evaporating surface.

Discussion of the formula reveals the basic difficulties in the evaluation of evaporation measurements. For instance, B represents the heat fluxes through the walls of the container as well as through the water itself to its surface. These fluxes depend on the radiation that hits the container and on the temperature difference between ambient air and water, a difference that changes rapidly in the course of the day. S depends on the amount of incoming radiation, the wavelength of this radiation (because the absorptivity of the evaporimeter is dependent on it), and the (constantly changing) temperature of the evaporating surface. Neglecting the relatively simple dependence of b on the ambient temperature, the form factor which is a part of b varies considerably and is not known in detail.

Considering all the factors condensed into Hofmann's formula, one must conclude that the real potential evaporation from any evaporating device, i.e., from any evaporimeter, differs with the form of the device and with its heat conduction (the meteorological conditions being equal). In other words, one may say that the evaporation from any surface is not a meteorological parameter alone, but is always strongly influenced by the evaporating body including the mass below the evaporating surface. The consequence is that measurements are only comparable if they have been made with the same kind of instrument in the same kind of exposure. The significance of such a comparison depends on the special conditions under which the comparison is made.

There are certainly correlations between pan and lake evaporation although these correlations are frequently applied in cases in which, in the opinion of the writer, they do not hold. Whether correlations between the instruments and evaporation processes of interest can be established, is open to question. One may conjecture that a correlation between Piche evaporation and perspiration or transpiration may be found. As long as such correlations have not been found, measurements of evaporimeters are meaningless, or, at least, they are of no greater importance than a meteorological parameter which combines saturation deficit and wind speed. Since some types of measurement are rather simple, it is hoped that correlations will be found that make the data useful. There is, nevertheless, no guarantee that this will happen.

PART IV. SOILS AND HYDROLOGY*

Introduction

The soils and hydrology task of the Data Base program, which has been directed to four primary types of data (soil strength measurements, soil sample measurements, soil temperature and moisture measurements, and ground water level measurements), has been brought to a conclusion within the current reporting period insofar as field data collection is concerned. Previous Data Base Semiannual reports[1,2,3,4] have presented detailed information on the types of data listed above and have analyzed some correlations between the data. It is recognized that these analyses are neither comprehensive nor exhaustive, but they have been carried out to the limit of time and personnel restrictions. Data collection methods and site descriptions have been given in detail in the previous semiannual reports and will not be repeated.

The data presented here were collected and prepared in order to provide more detailed information on the Fort Kobbe satellite sites and to determine the variability of the soils in-situ. Soil profile descriptions provide a comprehensive, systematic method of presenting soils information. The data are presented in a standardized form which contributed to the dissemination and understanding of the local pedalogic conditions, and aids in the establishment of a definitive base to which additional regional soils data may be correlated. In the absence of soil profile descriptions, the types of data previously collected can only be applied to the specific locations.

Data Collection

Pits were dug to expose the different soil horizons and detailed descriptions were prepared for all the Fort Kobbe satellite sites. These descriptions are given in Tables IV-1, -2, -3, -4. The profile description of Site I covers the same soil described in a previous semiannual report[2] (p. A7) but extends to a greater depth and utilizes a revised approach in descriptive terminology. The procedures used were developed by the US Department of Agriculture[15]. Each horizon was described on the basis of depth, color (Munsell notation), texture, structure, consistency, reaction, boundary, and other significant features. Diagrammatic sketches of each profile are appended to the descriptions as Figures IV-1, -2, -3, and -4. Figure IV-5 shows the topographic relationships of the three plots at Site II.

* This section has been prepared by Mr. Jackie L. Smith, Soil Scientist.

TABLE IV-1. SOIL PROFILE DESCRIPTION, FORT KOBBE SATELLITE SITE I

Location: Fort Kobbe Military Reservation, Canal Zone; grid coordinates PV 569848

Elevation: 20 meters

Slope: 2 percent

A_1	0-11"	Very dark gray (10YR 3/1) clay; few fine faint yellowish brown (10YR 6/8) mottles; many fine pores; many fine roots; many vertical to near vertical cracks 1/16" to 1/8" wide through horizon; strong medium subangular blocky structure; very firm; moderately alkaline; very slight effervescence; smooth wavy boundary.
B_{21}	11-18"	Dark grayish brown (2.5Y 4/2) clay; common fine distinct yellowish brown (10YR 5/8) mottles; many vertical to near vertical cracks, 1/16" to 1/8" wide; extending into above horizon; strong medium subangular blocky structure; very firm; mildly alkaline; smooth wavy boundary.
B_{22}	18-26"	Dark grayish brown (2.5Y 4/2) clay; common fine distinct yellowish brown (10YR 5/8) mottles; few small vertical cracks 1/16" wide; many medium soft $CaCO_3$ concretions; strong medium subangular blocky structure; very firm; moderately alkaline; smooth wavy boundary.
B_3	26-52"+	Light olive brown (2.5Y 5/4-5/6) clay; many medium distinct brownish yellow (10YR 6/8) mottles; many vertical cracks 1/8" to 3/8" wide extending to top of horizon; many large slickensides; few small hard $CaCO_3$ concretions; massive; very firm; moderately alkaline.

Remarks:

Profile described from pit.
All colors for moist soils.
pH determined by Hellige-Truog field kit.
B_{22} and B_3 horizons (18-26" and 26-52+") matrix will not effervesce.
Effervescence determined by .1N HCL

TABLE IV-2. SOIL PROFILE DESCRIPTION, FORT KOBBE SATELLITE SITE II, PLOT A

Location: Fort Kobbe Military Reservation, Canal Zone; grid coordinates PV 5650 8505

Elevation: 5 meters

Slope: 4 percent

A_1	0-9"	Yellowish red (5YR 4/6) silty clay loam; moderate medium subangular blocky structure; many fine and medium roots; many krotovinas; few fine Fe-Mn concretions; friable; slightly acid; clear wavy boundary.
A_2	9-12"	Yellowish red (5YR 4/6) silty clay; few fine faint red (2.5YR 4/8) mottles; few fine roots; few medium Fe-Mn concretions; moderate medium subangular blocky structure; friable; medium acid; clear wavy boundary.
B_1	12-32"	Red (2.5YR 4/8 & 10R 4/8) clay; many fine prominent brownish gray (10YR 6/2) and light gray (10YR 7/2) mottles; horizontal somewhat cemented layers of indurated and non-indurated plinthite making up 30-50 percent of the horizon; strong moderate to coarse subangular blocky structure; very firm; very strongly acid; clear wavy boundary.
B_{22t}	32-47"	Red (10R 4/8) clay; many medium prominent yellowish brown (10YR 6/6-6/8) and light gray (10YR 7/2) mottles; moderate medium subangular blocky structure; more than 5 percent non-indurated plinthite; thick discontinuous clay films; firm; very strongly acid; clear wavy boundary.
B_{23t}	47-65"+	Pale brown (10YR 6/3) clay; common medium faint yellowish brown (10YR 5/4) and yellow (10YR 6/8) mottles; strong coarse subangular blocky structure; thin discontinuous clay films; firm; medium acid.

Remarks:

Described from pit and auger boreings.
All colors for moist soils.
pH determined by Hellige-Truog field kit.

TABLE IV-3. SOIL PROFILE DESCRIPTION, FORT KOBBE SATELLITE SITE II, PLOT B

Location: Fort Kobbe Military Reservation, Canal Zone; grid coordinates PV 5648 8505

Elevation: 4 meters

Slope: 9 percent

A_{11}	0-7"	Reddish brown (5YR 4/4) sandy clay loam; moderate medium subangular blocky structure; many fine and medium roots; few medium pores; few fine Fe-Mn concretions; many worm casts and krotovinas; firm; medium acid; clear wavy boundary.
B_{1t}	7-15"	Yellowish red (5YR 4/8) sandy clay; moderate medium subangular blocky structure; few worm casts; many medium and large pores; few fine roots; many fine and medium Fe-Mn concretions; firm, medium acid; clear wavy boundary.
B_{21t}	15-25"	Yellowish red (5YR 4/6-4/8) clay; many fine prominent light yellowish brown (10YR 6/4) or very pale brown (10YR 7/4) and red (10YR 6/4) mottles; few large pores; thin continuous clay films; many medium Fe-Mn concretions; less than 5% non indurated plinthite; small near vertical cracks, 1/8" to 5/32" wide, throughout horizon; strong medium subangular blocky structure, firm; strongly acid; clear wavy to clear irregular boundary.
B_{22t} or B_{3t}	25-37"	Pale brown to very pale brown (10YR 6/3-7/3) clay; few fine faint brownish yellow (10YR 6/8) and few fine prominent yellowish red (5YR 4/8-5/8) mottles; near vertical cracks, 1/8" to 1/4" wide, throughout horizon; slickensides; many fine to medium Fe-Mn concretions few medium pores; strong coarse subangular blocky structure; firm; strongly acid; abrupt wavy boundary.
II C	37-60"+	Yellowish brown (10YR 5/4-5/6) clay stone or clay occurring in layers; few fine distinct strong brown (7.5YR 5/6) mottles; massive; very firm; slightly acid.

Remarks:

Described from pit and auger boreings.
All colors for moist soils.
pH determined by Hellige Truog field kit.
II C horizon (37-60+") does not disperse in calgon solution.

TABLE IV-4. SOIL PROFILE DESCRIPTION, FORT KOBBE SATELLITE SITE II, PLOT C

Location: Fort Kobbe Military Reservation, Canal Zone; grid coordinates PV 5644 8505

Elevation: 1 meter

Slope: Less than 1 percent.

A_1	0-5"	Dark grey to grey (7.5YR N4/, N5/) sandy clay loam; weak fine subangular blocky structure; very friable; many fine roots; many fine iron and manganese stains on ped faces; very strongly acid; abrupt wavy boundary.
A_2 or A_{12}	5-14"	Dark gray to gray (7.5YR N4/, N5/) sandy clay loam; many common distinct yellowish brown (10YR 5/8) and strong brown (7.5YR 5/8) mottles; weak fine subangular blocky structure; very friable; few fine roots; very strongly acid; abrupt wavy boundary.
B_{21t}	14-26"	Yellowish brown (10YR 5/4) clay; few fine faint brown (7.5YR 4/4-5/4) mottles; weak fine subangular blocky structure; many thick discontinuous clay films; many yellow (10YR 7/6) silt streaks on ped faces; friable; very strongly acid; abrupt wavy boundary.
B_{22t}	26-60"+	Yellow (10YR 7/6) sandy clay; common fine faint yellowish brown (10YR 5/8) and few fine prominent red (2.5YR 5/6) mottles; weak medium subangular blocky structure; thin discontinuous clay films; few Fe-Mn stains on ped faces; friable; very strongly acid.

Remarks:

Profile described from pit and auger boreings.
All colors for moist soils.
pH determined by Hellige-Truog field kit.

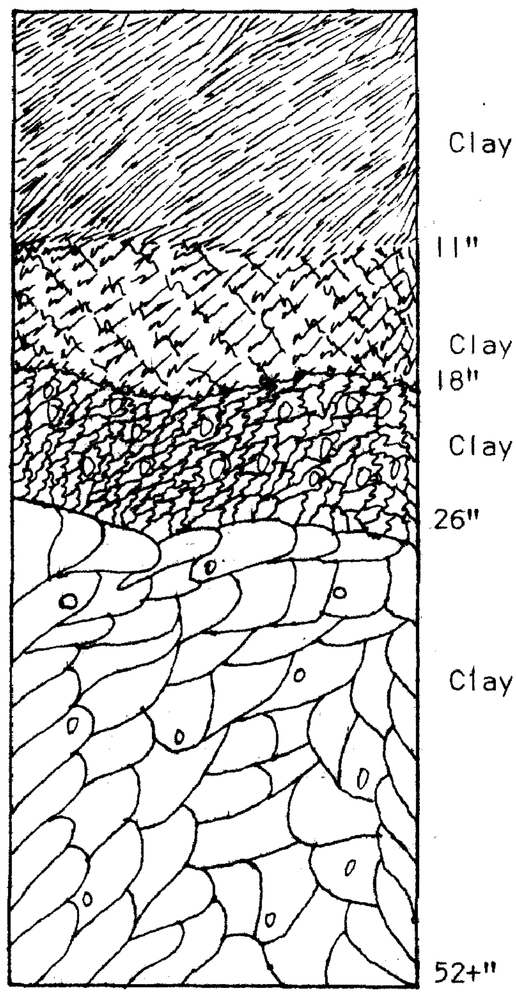


FIGURE IV-1. SOIL PROFILE, FORT KOBBE, SITE I

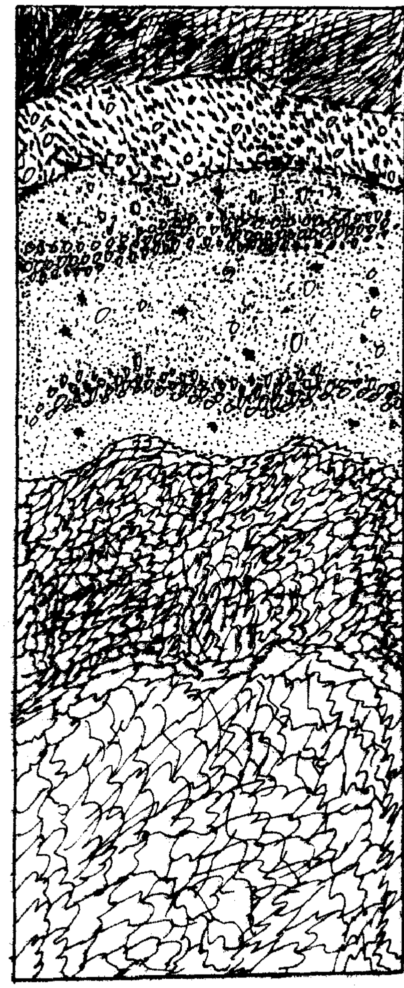


FIGURE IV-2, SOIL PROFILE, FORT KOBBE, SITE II A

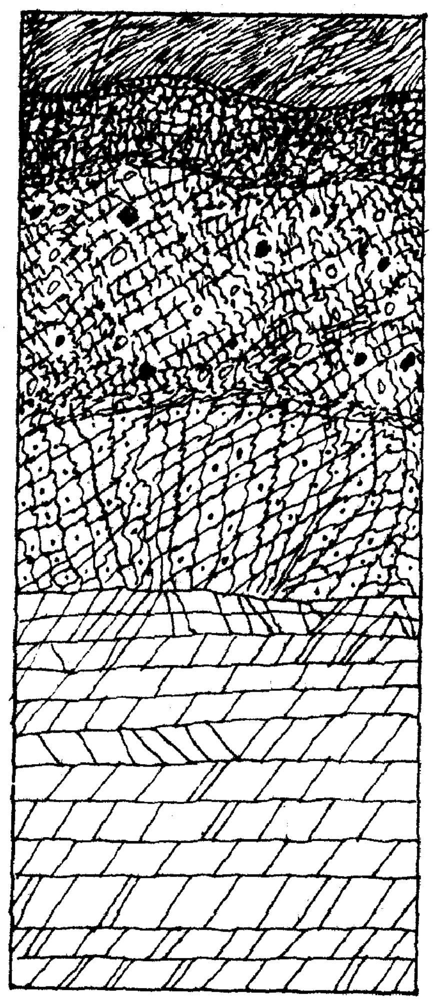


FIGURE IV-3. SOIL PROFILE, FORT KOBBE, SITE II B.

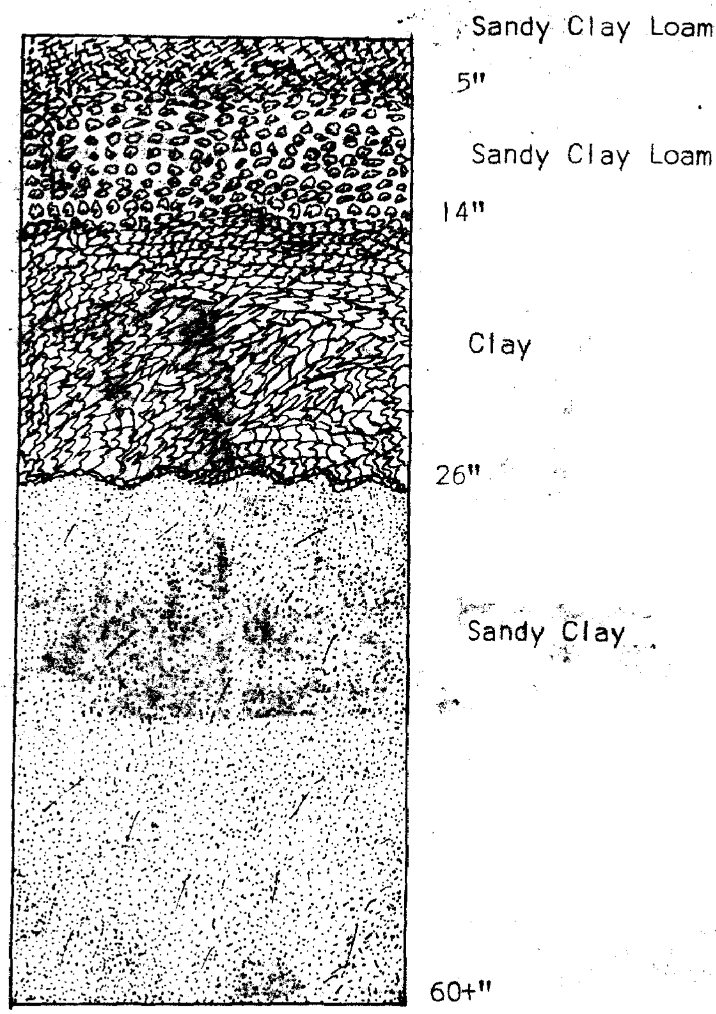
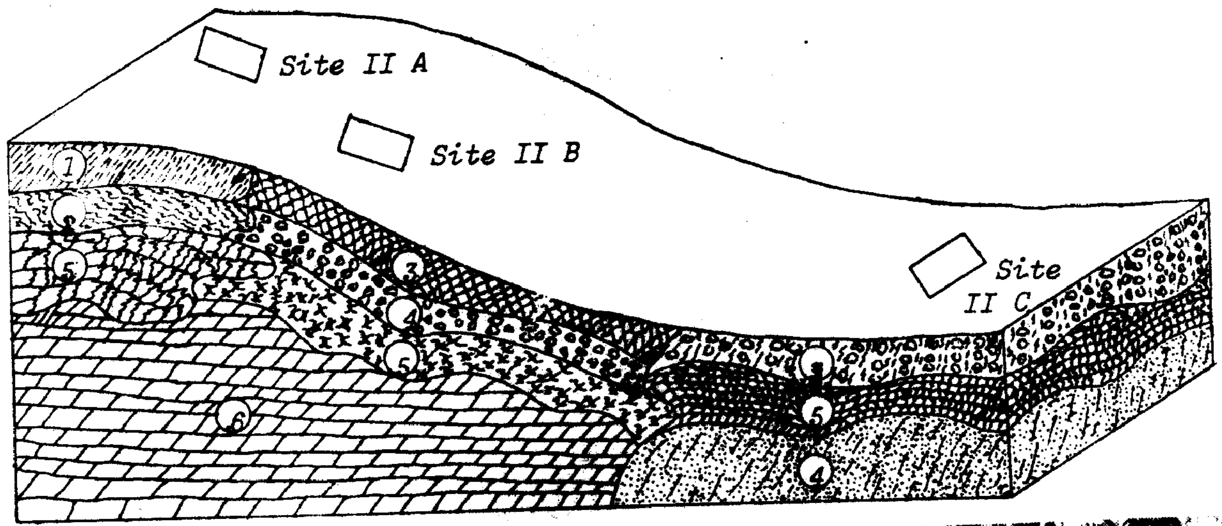


FIGURE IV-4. SOIL PROFILE, FORT KOBBE, SITE II C.



Site II A

Site II B

Site II C

LEGEND

1 - *Silty Clay Loam*
2 - *Silty Clay*
3 - *Sandy Clay Loam*
4 - *Sandy Clay*
5 - *Clay*
6 - *Clay or Clay Stone*

FIGURE IV-5. LANDFORM RELATIONSHIPS FOR FORT KOBBE SATELLITE SITE II A, B, AND C.

PART V. VEGETATION

Litter Fall Analysis*

Introduction

This report presents the results of a 15-month study of litter fall at the Albrook Forest site covering the period of November 1966 through January 1968. The study was undertaken to determine weights of various plant parts and species composition in litter fall. Litter is commonly defined as the vegetational and animal remains which accumulate on the soil surface. Litter fall in this paper refers to the vegetational matter which falls from canopies, tree trunks, and understory plants. The collection of litter samples and their weight determination, before decomposition has begun, is the basic approach followed in this study, the main purpose of which was to examine the component parts which make up litter, and to identify the principal canopy species which contribute to its deposition on the forest floor.

Methods and Materials

The Albrook Forest site has been classified as Semievergreen Seasonal Forest, though some 55% of the canopy tree species are deciduous. The composition of this forest site was described in detail in previous Environmental Data Base reports[1,2,3]. Three principal contributors to the litter are *Ficus spp.* (evergreen), *Anacardium excelsum* (evergreen), and *Luehea seemannii* (deciduous). Commonly occurring understory species contributing to the litter are *Annona purpurea* and *Bactris balanoidea*.

Litter fall was sampled with litter traps or pans. These traps had a horizontal area of one square meter inside the 3-inch deep frame. The wooden frames were floored with aluminum window screen and mounted eight inches from the ground. Thirty traps were used simultaneously. Randomization of the sample was achieved by assigning a number to each square meter in the entire 3,600 m^2 sampling area, then picking 30 numbers from a random number table. Traps were spaced 10 m apart, and moved to new locations weekly. The contents were collected each week, placed in plastic bags, and taken to the laboratory for separation and identification of components.

Results

The weight of the litter-fall at the Albrook Forest site, analyzed by components, is shown by weekly increments in Table V-1. Table V-2 summarises that information into weekly seasonal, and annual totals.

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* This section has been prepared by Dr. Thomas C. Crebbs, Biologist, and by Dennis C. Rankin, School of Forestry, Duke University.

TABLE V-1. WEIGHT OF LITTER COMPONENTS AT ALBROOK FOREST SITE (KILOGRAMS PER HECTARE)

Date of Collection from Litter Traps	Branches	Fruits and Seeds	Mixed Leaves	Anacardium Excelsum Leaves	Ficus S P Leaves	Luehea Seemannii Leaves	Debris	Total Litter Weight
1966								
November 7	67.6	1.1	43.7	8.2	8.1	12.9	29.3	170.9
14	4.8	0.4	46.4	6.4	2.5	10.3	10.2	81.0
21	42.4	0.6	89.6	17.0	2.6	19.6	18.8	190.6
28	19.8	0.3	50.4	30.3	3.5	18.7	17.7	140.7
Monthly Total	134.6	2.4	230.1	61.9	16.7	61.5	76.0	583.2
Weekly Average	33.6	0.60	57.5	15.5	4.18	15.4	19.0	146.0
December 5	19.8	0.4	37.7	11.6	3.5	14.7	27.5	115.2
12	5.4	0.2	34.3	8.9	2.9	10.8	17.4	79.9
19	12.7	0.1	70.8	13.4	4.4	15.2	13.9	130.5
26	19.0	0.2	59.1	41.3	6.1	15.6	11.2	152.5
Monthly Total	56.9	0.9	201.9	75.3	16.9	56.3	70.0	478.1
Weekly Average	14.2	0.225	50.5	18.8	4.22	14.1	17.5	120.0
1967								
January 2	10.9	0	78.3	39.1	4.1	20.0	12.6	165.0
9	5.0	1.0	96.6	137.8	16.3	30.8	21.3	308.8
16	53.3	0.5	91.8	278.4	16.5	17.3	26.7	484.5
23	26.4	0.3	126.4	222.7	17.3	10.7	35.3	439.1
30	5.8	0.2	101.0	180.7	6.1	15.7	35.0	344.5
Monthly Total	101.4	2.0	494.1	858.7	60.3	94.5	130.9	1741.9
Weekly Average	20.32	0.40	98.8	172.0	12.1	18.9	26.2	348.0
February 6	5.8	0.4	87.6	91.0	1.0	8.5	48.0	242.3
13	47.8	0.5	41.5	59.0	7.2	9.2	38.5	203.7
20	32.2	6.6	90.1	37.1	3.3	21.2	47.4	237.9
27	27.7	4.4	126.4	14.8	14.5	20.5	24.2	232.5

TABLE V-1. WEIGHT OF LITTER COMPONENTS AT ALBROOK FOREST SITE (KILOGRAMS PER HECTARE) cont'

Date of Collection from Litter Traps	Branches	Fruits and Seeds	Mixed Leaves	Anacardium Excelsum Leaves	Ficus S P Leaves	Luehea Seemannii Leaves	Debris	Total Litter Weight
1967								
Monthly Total	113.5	11.9	345.6	201.9	26.0	59.4	158.1	916.4
Weekly Average	28.4	2.98	86.4	50.5	6.5	14.8	39.5	229.0
March 6	24.7	1.0	46.8	13.9	2.8	14.5	26.1	129.8
13	14.0	4.7	69.5	3.0	22.6	15.3	31.1	160.2
20	80.8	4.8	102.4	14.7	6.9	18.6	28.3	256.5
27	13.7	18.0	75.2	2.5	7.0	22.4	30.5	168.3
Monthly Total	133.2	28.5	293.9	34.1	39.3	70.8	116.0	715.8
Weekly Average	33.3	7.12	73.5	8.52	9.82	17.7	29.0	179.0
April 3	10.5	6.0	54.5	11.0	4.7	11.2	29.4	128.2
10	9.7	16.5	70.1	4.6	9.5	17.4	18.3	146.1
17	5.2	4.8	26.4	16.5	9.2	16.3	30.3	108.7
24	38.5	12.3	46.5	17.0	6.1	21.9	22.9	165.2
Monthly Total	63.9	40.5	197.5	49.1	29.5	66.8	100.9	548.2
Weekly Average	16.0	10.1	49.4	12.3	7.38	16.7	25.2	137.0
May 1	83.4	16.8	40.2	8.2	0.8	15.9	20.7	186.0
8	27.3	13.0	21.4	8.2	0.3	10.0	18.6	98.8
15	9.8	10.9	26.1	4.0	3.2	22.1	16.2	92.3
22	35.8	17.2	23.8	15.7	14.8	70.6	17.2	195.1
29	29.4	2.5	27.7	3.6	0.1	69.1	11.4	143.8
Monthly Total	185.7	60.4	139.2	39.7	19.2	187.7	84.1	716.0
Weekly Average	37.1	12.1	27.8	7.94	3.84	37.5	16.8	143.0
June 5	58.2	22.7	34.2	11.9	11.3	59.9	16.3	216.5
12	17.9	5.2	67.1	6.9	0.2	68.1	13.9	179.3
19	9.4	3.8	25.5	11.7	0.8	47.8	8.9	107.9
27	30.0	5.7	38.2	9.2	1.5	39.5	15.9	140.0
Monthly Total	115.5	39.4	16.5	39.7	13.8	215.3	55.0	643.7
Weekly Average	28.9	9.85	4.12	9.92	3.45	53.8	13.8	161.0

TABLE V-1. WEIGHT OF LITTER COMPONENTS AT ALBROOK FOREST SITE (KILOGRAMS PER HECTARE) cont'd

Date of Collection from Litter Traps	Branches	Fruits and Seeds	Mixed Leaves	Anacardium Excelsum Leaves	Ficus S P Leaves	Luehea Seemannii Leaves	Debris	Total Litter Weight
1967								
July 3	66.8	7.8	38.2	10.2	0.5	19.0	17.5	160.0
10	26.1	6.1	22.0	8.0	4.7	23.1	23.4	113.4
17	4.4	2.6	37.8	7.3	0	18.8	15.0	85.9
24	55.0	9.1	38.4	10.7	2.1	29.4	19.5	164.2
31	16.5	4.2	40.5	16.3	0	23.7	18.5	119.7
Monthly Total	168.8	29.8	176.9	52.5	7.3	114.0	93.9	643.2
Weekly Average	33.8	5.96	35.4	10.5	1.46	22.8	18.8	129.0
August 7	3.6	1.2	11.5	11.8	0	6.1	4.1	38.3
14	6.8	3.0	20.0	19.8	0.5	7.8	14.9	72.8
21	47.8	12.5	36.0	27.5	5.2	16.3	19.1	164.4
28	21.8	7.0	24.3	8.1	10.5	10.6	10.1	92.4
Monthly Total	80.0	23.7	91.8	67.2	16.2	40.8	48.2	367.9
Weekly Average	20.0	5.92	23.0	16.8	4.05	10.2	12.0	92.0
September 5	6.9	2.7	28.1	15.9	5.5	9.5	9.8	78.4
11	18.2	1.0	39.0	16.6	1.5	7.6	10.8	94.7
18	1.3	3.4	27.5	5.5	0	7.3	7.2	52.2
25	8.8	0.8	34.8	12.4	6.2	7.9	9.2	80.1
Monthly Total	35.2	7.9	129.4	50.4	13.2	32.3	37.0	305.4
Weekly Average	8.8	1.98	32.4	12.6	3.30	8.08	9.25	76.4
October 2	19.3	1.3	43.1	18.8	0	7.2	12.5	102.2
9	30.3	1.0	43.3	18.1	6.9	8.5	8.5	116.6
16	3.5	0.6	25.5	7.5	7.3	10.3	10.2	64.9
23	19.7	0.8	26.5	41.5	2.5	9.0	8.4	108.4
30	49.2	0.7	22.7	7.8	4.3	10.5	7.6	102.8
Monthly Total	122.0	4.4	161.1	93.7	21.0	45.5	47.2	494.9
Weekly Average	24.4	0.88	32.2	18.7	4.2	9.10	9.44	99.0

TABLE V-1. WEIGHT OF LITTER COMPONENTS AT ALBROOK FOREST SITE (KILOGRAMS PER HECTARE) cont'd

Date of Collection from Litter Traps	Branches	Fruits and Seeds	Mixed Leaves	Anacardium Excelsum Leaves	Ficus S P Leaves	Luehea Seemannii Leaves	Debris	Total Litter Weight
1967								
November 6	8.1	0.2	62.0	7.2	13.3	18.9	10.8	120.5
13	80.1	0.2	33.6	9.6	12.2	25.8	12.6	174.1
20	43.7	0.5	38.7	2.8	11.5	13.0	11.2	121.4
27	87.8	0.4	27.9	10.5	3.9	19.5	15.0	165.0
Monthly Total	219.7	1.3	162.2	30.1	40.9	77.2	49.6	581.0
Weekly Average	54.9	0.325	40.6	7.52	10.2	19.3	12.4	145.0
December 4	24.4	0.2	33.0	20.7	0	10.2	12.1	100.6
11	53.5	1.0	28.6	21.5	0	34.5	19.9	159.0
18	24.7	0.2	73.8	11.3	10.7	29.7	8.9	159.3
26	30.2	25.8	72.5	50.5	6.2	29.2	15.7	230.1
Monthly Total	132.8	27.2	207.9	104.0	16.9	103.6	56.6	649.0
Weekly Average	33.2	6.8	52.0	26.0	4.22	25.9	14.2	162.0
1968								
January 2	20.6	8.5	97.0	68.9	0	32.1	17.4	244.5
8	21.9	0.6	90.3	100.1	14.2	20.4	16.6	264.1
15	8.8	0.2	41.3	57.5	12.4	16.4	7.8	144.4
22	40.0	0.5	67.2	131.7	1.7	27.3	22.0	290.4
29	17.7	0.3	66.3	96.4	9.4	21.3	15.2	226.6
Monthly Total	109.0	10.1	362.1	454.6	37.7	117.5	79.0	1170.0
Weekly Average	21.8	2.02	72.4	90.0	7.54	23.5	15.8	234.0

TABLE V-2. WEIGHT OF LITTER COMPONENTS AT ALBROOK FOREST SITE: WEEKLY, SEASONAL, AND ANNUAL TOTALS AND AVERAGES. (KILOGRAMS PER HECTARE)

Time Interval	Branches	Seeds	Leaves	Anacardium Excelsum Leaves	Ficus S P Leaves	Luehea Seemannii Leaves	Debris	Totals
Dry Season Totals*	543.7	78.8	1771.9	1665.8	190.7	431.9	533.7	5216.5
Dry Season Weekly Average	24.7	3.58	80.5	75.7	8.67	19.6	24.3	237
Wet Season Totals	1228.5	211.6	1438.3	547.0	184.2	911.3	668.8	5338.2
Wet Season Weekly Average	28.6	4.92	33.4	12.7	4.28	21.2	15.6	124
Grand Totals	1772.2	290.4	3210.2	2212.8	374.9	1343.2	1202.5	10554.7
1 Year Totals**	1470	277	2420	1620	304	1110	978	8320
1 Year Weekly Average	28.3	5.33	46.5	31.2	5.85	21.3	18.8	160
1 Year Monthly Average	122	23.1	202	135	25.3	92.5	81.5	693

* The dry season (for this period) began 13 Dec 1966 and ended 17 April 1967.
** Yearly totals for calendar year 1967.

The contribution to the total litter fall made by the leaves from the three major canopy species found at the Albrook site is graphically shown in Figure V, which also shows the rainfall figures for the same period of time. Rainfall is included to show the actual distribution of precipitation during the period of the study. Correlation between periods of rainfall extremes and litter fall extremes are readily apparent.

Conclusion

The yearly total of 8,320 kilograms per hectare of litter fall is of special significance. This figure represents the total annual amount of leaves, branches, fruits and seeds, and debris which reaches the forest floor. Of this total, leaves made up 5,454 kilograms per hectare or 65 percent. The three most significant tree species contributed a total of 3,034 kilograms per hectare of leaves or 56 percent to this amount. Of the three, note that Ficus spp. an evergreen, displayed a constant monthly contribution of leaf-fall to the total litter fall, This is expected of a truly evergreen species. However, Anacardium excelsum, also an evergreen, shows an increase of leaf-fall in January of over 16 times that of March to November. This casts serious doubt on the validity of application of the terms "evergreen" and "deciduous" to tropical species. The leaf contribution of Luehea seemannii, a deciduous species, shows a definite peak in June, which is the third month of the wet season. This reversal of seasons of maximum leaf-fall is also shown by Cordia alliodora, a common forest species which is bare-branched in the height of the wet season. Species of Cecropia, a common weed tree, lose all their leaves only if the dry season is severe and prolonged. The large forest trees Cavanillesia platanifolia and Pseudobombax barrigon lose their leaves at the beginning of the dry season, regularly and regardless of the severity of the dry season.

This study, plus other observations made by the senior author over the past two years, indicate the necessity of revising the terminology referring to rate and degree of leaf-abscission in tropical tree species. The following terminology is suggested as applicable to Panamanian forest species:

1. True evergreen: species which lose and replace leaves regularly throughout the year. Rate of loss monthly is never more than twice that of any other month.

2. Semievergreen: species which lose and replace leaves regularly. Occasional and erratic peaks of leaf loss may exceed twice that of average monthly loss.

3. True deciduous: species which lose over 50% of leaves during months of the dry season.

4. Semideciduous: species which lose over 50% of leaves only if the dry season is severe and prolonged.

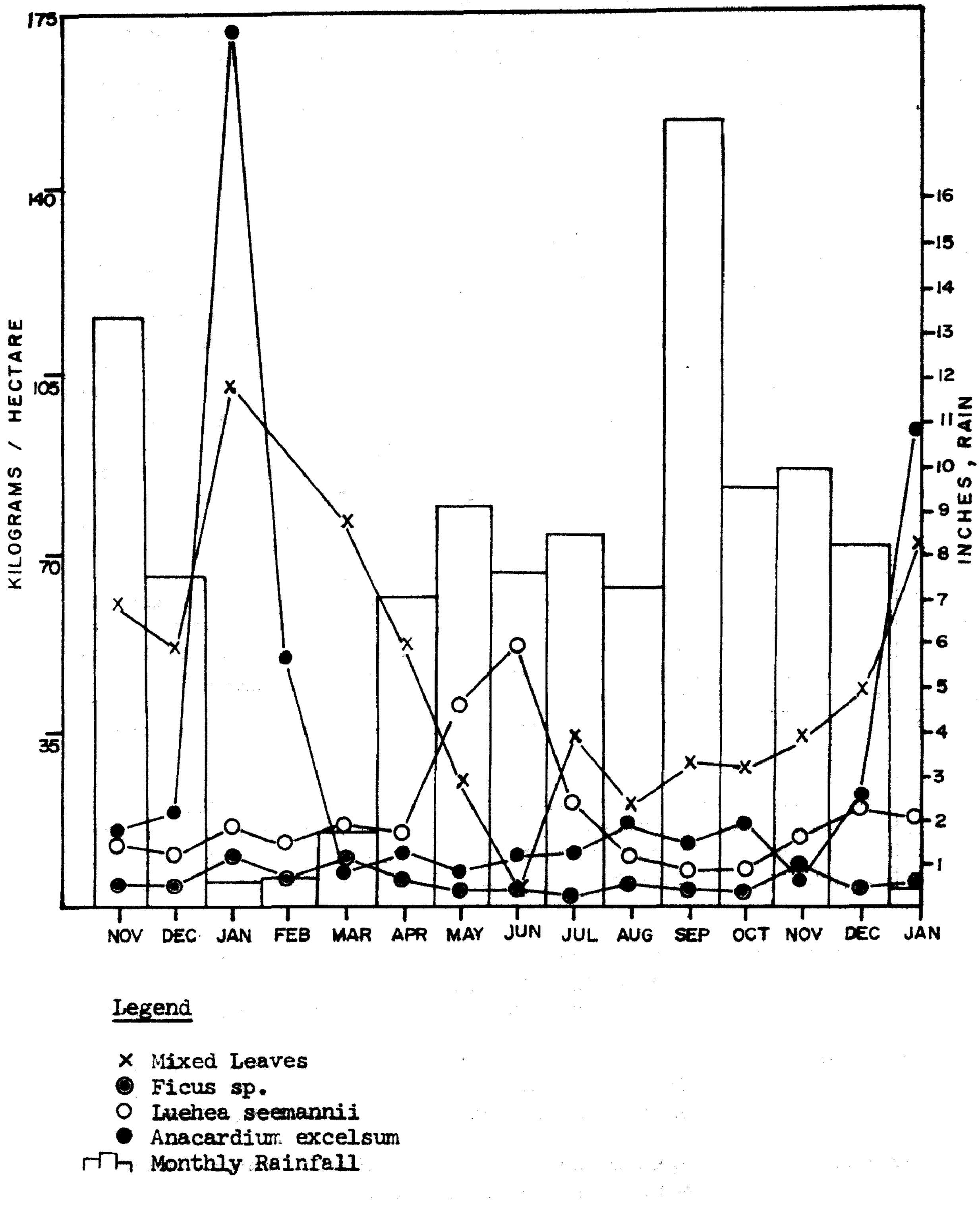

FIGURE V-1. AVERAGE WEEKLY LITTER FALL OF LEAVES: ALBROOK FOREST SITE, NOVEMBER 1966 THROUGH JANUARY 1968

5. Seasonal deciduous: species which lose over 50% of leaves at any season of the year other than the dry season.

This terminology allows for those abberrant patterns of leaf abscission which do not conform to the patterns of temperate zone species.

Summary

1. Data are presented to show amount of litter fall year-long under a second-growth Semievergreen Seasonal Forest.

2. Some 8,320 kilograms per hectare of litter fall on the forest floor in one year.

3. The seasonal aspects of litter fall as presented in this paper make it necessary to revise the present terminology in regard to "evergreen" and "deciduous" species. A new terminology is suggested.

PART VI. CHEMISTRY OF THE ATMOSPHERE*

Chemicals in the Atmosphere

Observations on the nitrogen compounds. NO, NO_2 and ammonia, the sulfur compound SO_2, and organic compounds, the aldehydes of the tropical atmosphere continued. The chemical data obtained by the National Center for Atmospheric Research personnel through a contract with ARO and cooperation of US Army Tropic Test personnel is being finalized. Most of these data have been calculated and transferred to magnetic tapes for printout by the computer.

The chemical data obtained will be published in scientific journals and in a 2 or 3 volume comprehensive report which will include all meteorology and site identification.

Papers will also be published on gas chromatography and hydrogen sulfide methodology.

Chemical Particulate Matter

Several of the particulate chemicals found in the tropical atmosphere will also be reported in published papers. This will include sulfate and chloride crystal size and count data as well as general particulate matter as determined by electron microscopy. A paper on the coefficient of haze data obtained in the tropical atmosphere will also be published.

Data on organic chemicals found in the tropical environment as detected with the gas chromatograph will also be published. This will be a joint NCAR and USATTC report.

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* This section was prepared by Mr. George W. Gauger, Microbiologist and Dr. Robert S. Hutton, Biological Scientist.

PART VII. MACROFAUNA

Insect Collections at Albrook Forest Site*

Introduction

The class Insecta contributes significantly to the biomass of any area, and often plays an important role in reduction and decay of vegetation. The authors decided to investigate the numbers and distribution of insects at the Albrook Forest site by using black-light traps. The traps would be set at two levels: at 30 meters on the tower, and at ground level. A comparison could then be made between numbers and groups of insects captured at the two levels.

Methods

The two black-light traps were constructed and sent to Panama in May of 1967. See Figure VII for details of black light trap. Both traps were in operation one night a week, between 6 P.M. and 6 A.M., except during occasional electrical failures. The traps have been in operation since May 25, 1967. The collected insects were preserved in alcohol and sent to the University of Arkansas for segregation and identification. The material has been segregated to insect orders, and the order Coleoptera further divided into families. During the first year, collections were made on 53 nights, and these collections have been counted and separated.

Results

Analysis of total insects captured in light traps can lead to erroneous conclusions. Light-trapping does not yield a random sample; it is highly selective. Many orders of insects are over-represented in the sample because they are nocturnal and are attracted strongly to light. Other insects may be present in even larger numbers but not represented in the sample, because they are diurnal or not attracted by light. Further, it is impossible to total numbers by month, as both traps were not in operation for all of the sampling nights of the month, due to mechanical failure. To obtain meaningful numbers, the monthly catch at each level was totaled then divided by the number of complete trap-nights, which gives an average nightly catch during that month. These data are shown in Tables VII-1 and -2. In terms of total insect activity, it is apparent that more insects were taken at the 30-meter level than at the ground level. Some orders seemed to fluctuate widely in numbers, while others contributed regularly and consistently to the total catch.

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* This section has been prepared by Dr. Thomas C. Crebbs, Biologist, and Dr. Robert T. Allen, Entomologist, University of Arkansas.

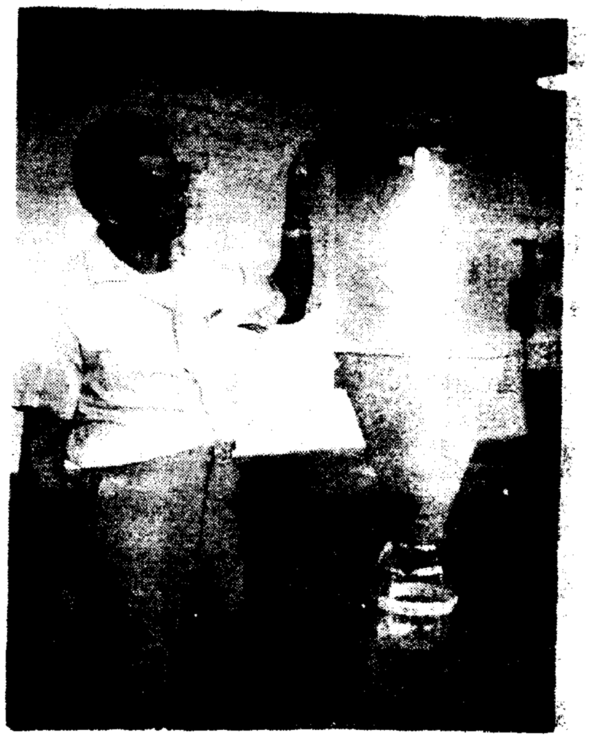

FIGURE VII-1. BLACK LIGHT INSECT TRAP.

TABLE VII-1. AVERAGE NUMBER OF INSECTS CAUGHT PER TRAP NIGHT: GROUND LEVEL

1967

Orders	May (1)	Jun (4)	Jul (3)	Aug (4)	Sep (4)	Oct (4)	Nov (5)	Dec (4)
Coleoptera	1219	314	290	584	174	133	1009	743
Dermaptera	0	1 T	1 T	0	0	1 T	2 T	1 T
Plecoptera	0	0	0	22	118	151	506	1 T
Ephemeroptera	26	18	27	99	12	7	171	125
Hemiptera	166	33	35	123	37	23	111	57
Homoptera	226	56	69	407	576	544	798	65
Hymenoptera	754	446	563	445	153	100	348	340
Isoptera	0	1 T	1	2 T	1 T	1 T	1 T	1 T
Lepidoptera	790	266	347	156	10	10	26	217
Neuroptera	0	1	0	2	1	2 T	2 T	1 T
Orthoptera	58	39	25	15	1 T	1 T	2 T	10
Psocoptera	12	2	2 T	2	12	13	49	0
Odonata	0	0	0	0	1 T	1	2 T	0
Embioptera	0	0	1 T	2 T	0	0	1 T	0
Thysanoptera	0	1 T	0	0	0	0	0	2 T
Trichoptera	39	39	22	10	0	0	0	72
Collembola	0	0	0	0	0	0	1 T	5 T

1968

	Jan (4)	Feb (4)	Mar (4)	Apr (4)	May (5)
Coleoptera	1030	1529	464	405	1483
Dermaptera	1 T	1 T	1 T	3 T	1 T
Plecoptera	0	0	0	0	8 T
Ephemeroptera	30	6	2 T	1 T	67
Hemiptera	57	33	63	75	307
Homoptera	81	19	21	28	275
Hymenoptera	146	344	204	391	3385
Isoptera	0	0	1	0	538
Lepidoptera	369	2266	389	565	425
Neuroptera	0	1 T	2 T	9 T	8 T
Orthoptera	12	9	10	9	29
Psocoptera	0	0	0	0	0
Odonata	1 T	2 T	1 T	1 T	1 T
Embioptera	0	0	1	0	0
Thysanoptera	10	5 T	34	10	70
Trichoptera	101	44	57	39	34
Collembola	0	0	13 T	6 T	2 T

NOTE: In parenthesis indicates number of trap nights per month.
T indicates total number.

TABLE VII-2. AVERAGE NUMBER OF INSECTS CAUGHT PER TRAP NIGHT - 30 METER LEVEL

1967

Orders	May (1)	Jun (3)	Jul (3)	Aug (5)	Sep (4)	Oct (4)	Nov (4)	Dec (4)
Coleoptera	873	4491	1370	1099	1383	1249	1547	1038
Dermaptera	5	4	2	2 T	1 T	0	2 T	0
Plecoptera	0	0	0	0	1 T	0	0	1 T
Ephemeroptera	7	1	2	5	6	7	356	257
Hemiptera	1122	206	149	114	92	37	76	249
Homoptera	695	390	395	175	131	84	90	69
Hymenoptera	574	969	477	291	308	129	625	1116
Lepidoptera	1410	1659	883	650	478	238	241	257
Isoptera	0	6	0	0	0	2 T	2 T	0
Neuroptera	10	12	3	2	1	1	3 T	5 T
Orthoptera	58	43	21	12	10	4	10	9
Psocoptera	23	6	4	2	4	3	3 T	10
Odonata	0	1 T	0	1 T	0	1 T	0	0
Embioptera	0	0	0	0	0	0	0	0
Thysanoptera	0	2 T	0	0	0	1 T	1	0
Trichoptera	49	14	16	9	13	3	32	37
Pseudoscorpion	0	6	0	0	0	0	0	0

1968

Orders	Jan (4)	Feb (4)	Mar (4)	Apr (4)	May (5)
Coleoptera	973	1869	506	774	2501
Dermaptera	3	0	0	0	4
Plecoptera	0	0	0	0	0
Ephemeroptera	139	12	2 T	3 T	21
Hemiptera	227	78	262	430	383
Homoptera	53	22	24	41	255
Hymenoptera	53	153	67	91	1130
Lepidoptera	313	253	324	474	554
Isoptera	0	2 T	0	6 T	255
Neuroptera	3 T	15 T	10 T	7 T	15 T
Orthoptera	12	10	12	15	31
Psocoptera	6	13 T	13 T	13 T	10
Odonata	0	0	0	1 T	5 T
Embioptera	0	0	0	0	0
Thysanoptera	2 T	14	32	15	9
Trichoptera	46	21	112	7	19
Pseudoscorpion	0	0	0	0	0

NOTE: In parenthesis indicates number of trap nights per month.
T indicates total number.

Data Base Semiannual Report #4 included a description and brief discussion of the insect orders represented in the sample. Of these orders, only a few were caught in large numbers.

A detailed analysis of these data will be included in a subsequent Data Base report.

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13. ABSTRACT

This report, summarizes the activities of the Environmental Data Base Project for the period March 1968 through February 1969 and contains a brief statement on project background, scope, and observation sites, together with some analyses of the collected data.

The Climate Section (Part III) contains an operational description of the automatic data and recording system, a detailed analysis of the climatological and measurement aspects of evaporation.

The Soils and Hydrology Section (Part IV) presents the profile descriptions of the soils at the Fort Kobbe Satellite Sites.

The Vegetation Section (Part V) contains an analysis of litter fall at the Albrook Forest Site.

The section of Atmospheric Chemistry (Part VI) consists of a brief summarization of activities in this field for the reporting period.

The section on Macrofauna (Part VII) contains a tabulated listing of insects secured under the black-light sampling program.

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