Everett 531-1150

UC-434

SEP 19 1986

Mr. Gerald R. Zimmerman
Executive Director
Upper Colorado River Commission
355 South 400 East
Salt Lake City, Utah 84111

Dear Mr. Zimmerman:

The final report on the methods of computing evaporation from Lake Powell is enclosed. A draft of this report was sent to you on October 30, 1984. The results of this report may be used in further studies to improve our determination of inflow to Lake Powell and bank storage. The results of these studies may help to further refine the methods of computing evaporation. Also, we hope sometime in the future to develop a procedure to determine evaporation for use in near real-time operations. This will probably involve pan evaporation measurements and weather data.

If you have any comments or questions, call Lee Morrison at 524-5573.

Sincerely yours,

FOR Harl Noble
Clifford I. Barrett
Regional Director

Enclosure

cc: Regional Director, Boulder City, Nevada

bc: Chief, Division of Planning Technical Services, E&R Center
Attention: D-752
Power Operations Manager, Page, Arizona

bcc: UC-434, UC-750

LMorrison:ch:9/16/86

UNITED STATES OF AMERICA
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LAKE POWELL
EVAPORATION

AUGUST 1986

UPPER COLORADO REGIONAL OFFICE
SALT LAKE CITY, UTAH

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INTRODUCTION

In the early 1950's it was expected that a highly credible determination of evaporation from reservoirs in the Colorado Basin was required because of the need to divide the water between the Upper and Lower Basins according to the Colorado River Compact of 1922. The average evaporation from Colorado River Storage Project Reservoirs (Lake Powell, Flaming Gorge, Navajo, Blue Mesa, Morrow Point and Crystal) is estimated at about 600,000 acre-feet per year. About 80 percent of this is evaporated from Lake Powell. Therefore, a plan was developed to measure and collect data. Since that time it has been determined that the Upper Basin will probably not be able to develop the 7,500,000 af per year allotted by the Colorado River Compact*. Therefore, at the present time, the accuracy of the evaporation determination is not so critical. But the determination is still needed for several purposes including water use and availability studies, streamflow forecasting, and water budget studies.

This report describes and comparies several methods of determining evaporation from Lake Powell.

METHODS OF DETERMINATION

Although evaporation from a reservoir cannot be measured directly, there are several ways of determining it indirectly. One way is termed the water budget method. In this method, the inflow must equal the outflow plus or minus the change in storage. But this method cannot be applied to Lake Powell because not all of the inflow can be measured and because the bank storage cannot be measured.

Evaporation pan measurements can be used. This method is being used as a check but it has disadvantages in that pans do not account for the change in energy storage nor for advected energy.

A third way is the energy-budget method. If all of the energy entering and leaving the Lake can be measured then the energy required to balance the energy-budget is that needed for evaporation. This method is used as a check at Lake Mead for annual values. This method requires data which is expensive to obtain for periods of time shorter than 1 year. Since surface area is changing during the year it was desirable to use a method for which it was practical to obtain data to complete evaporation for periods of time shorter than a year.

Another method is based on Dalton's law which says that the rate of evaporation is a function of the differences in the vapor pressure at the water surface. This is termed the mass transfer method and the one used in this study.

*Nothing in this report is intended to interpret the provisions of the Colorado River Compact (45 Stat. 1057), the Upper Colorado River Basin Compact (63 Stat. 31), the Water Treaty of 1944 with the United Mexican States (Treaty Series 994, 59 Stat. 1219), the Decree entered by the Supreme Court of the United States in Arizona v. California et al. (379 U.S. 340), the Boulder Canyon Project Act (45 Stat. 1057), the Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a), the Colorado River Storage Project Act (70 Stat. 105.; 43 U.S.C. 620), or the Colorado River Basin Project Act (82 Stat. 885; 43 U.S.C. 1501). Pursuant to the Colorado River Basin Project Act (Public Law 90-537) of 1968.

PROCEDURE

In the late 1950's several evaporation pans were installed near Lake Powell, Flaming Gorge, and Navajo Reservoirs. Data from pans at the following locations were collected for the May-October period for 1958 through 1962 and converted into an average annual evaporation rate.

Location of Pan	Average Annual Gross Evaporation Rate in Inches
Hite	59.87
Mexican Hat	73.17
Moab	58.52
Page	69.13
Total	260.73
Average	65.18

A pan was established at Green River, Utah, but the data was not used. A pan was installed at Wahweap in 1962, but the data was not available when the average annual evaporation rate was determined.

A method was established to determine the evapo-transpiration from the pre-reservoir Lake Powell area and data was collected before the Lake started to fill. The amount of evaporation caused by Lake Powell was estimated by multiplying the evaporation rate (65.18 inches) by the lake area and subtracting the evapo-transpiration from the equivalent pre-reservoir area. This evaporation has been used to the present time (Table 8). The method and the computations for determining the evaporation from the equivalent pre-reservoir is in the files of the Water Operations Branch of the Upper Colorado Region.

Studies of several methods of determining evaporation had been made at Lake Hefner in Oklahoma and Lake Mead. It was decided that collecting data for the energy-budget method would be very expensive for periods of time less than 1 year. Since it was desirable to determine evaporation for shorter periods of time, it was decided not to use the energy-budget method. It was also desirable to make a determination independent of the pan method. Therefore, the mass-transfer method was selected.

Three rafts were constructed, instrumented, and placed at Wahweap Bay, Padre Bay, (also called Crossing-of-the-Fathers), and Bullfrog Bay as shown in Figure 1. The data was processed in the early 1970's but there was some concern as to the coefficient to use in the equation. At that time scientists from several universities were investigating several aspects of Lake Powell. The studies, sponsored by the National Science Foundation, were named the Lake Powell Research Project. A cooperative agreement was made to make an evaporation study as part of their water budget analysis. The Bureau furnished instruments and another raft which was installed at Hite. The Bureau participated in this to obtain data to calibrate a mass-transfer coefficient for the data we had collected. New cassette recorders and sensors were installed on the rafts along with the old equipment which was still being used. Data was collected for about 2 years and analyzed by the energy-budget and mass-transfer methods and compared with pan measurements.

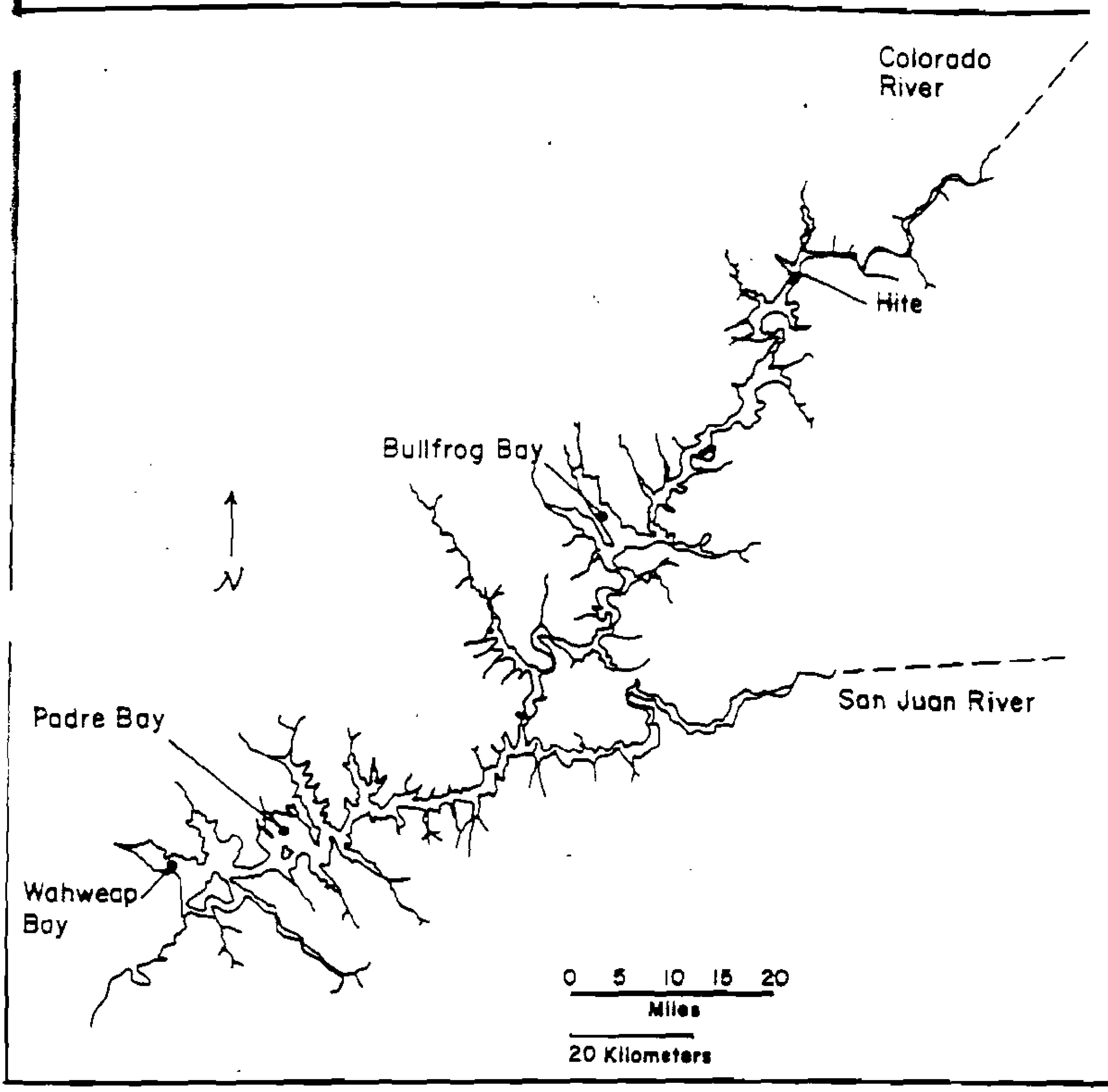


Figure 1: Locations of Data Collection System Rafts for Evaporation Study of Lake Powell

MASS TRANSFER METHOD

The following is a brief description of the mass-transfer method. A simple example of the same type as the Lake Hefner quasi-empirical equation is

$$E=Nu(e_o-e_a), \quad (1)$$

in which E=evaporation, in inches per day;

N=a coefficient of proportionality, hereafter called the mass-transfer coefficient;

u=wind speed, in miles per hour, at some height above the water surface; a numerical subscript, if used, indicates the height in meters;

e_o=saturation vapor pressure in millibars, corresponding to the temperature of the water surface;

e_a=vapor pressure of the air, in millibars; a numerical subscript, if used, indicates the height in meters.

Nearly all the mass-transfer equations to be found in the literature have one thing in common: evaporation is considered to be proportional to the product of the wind speed, u, and the vapor-pressure difference, e_o-e_a. In a few equations, the wind speed, u, has an exponent, usually less than unity.

The mass-transfer coefficient, N, represents a combination of many variables in the published mass-transfer equations. Among these are the manner of the variation of wind with height, the size of the lake, the roughness of the water surface, atmospheric stability, barometric pressure, and density and kinematic viscosity of the air.

The following mass-transfer equation was developed for Lake Mead and used to make monthly determinations of evaporation rates. These determinations have been checked on an annual basis by the energy-budget and pan-evaporation methods.

$$E = 2.65 \times 10^{-3} U_2 (e_o-e_2) \quad (2)$$

E = evaporation in inches per day.

U_2= is wind speed in knots.

e_o= is saturation vapor pressure at the temperature of the water surface.

e_2= is the vapor pressure of the air computed in millibars at 2 meters above the water surface.

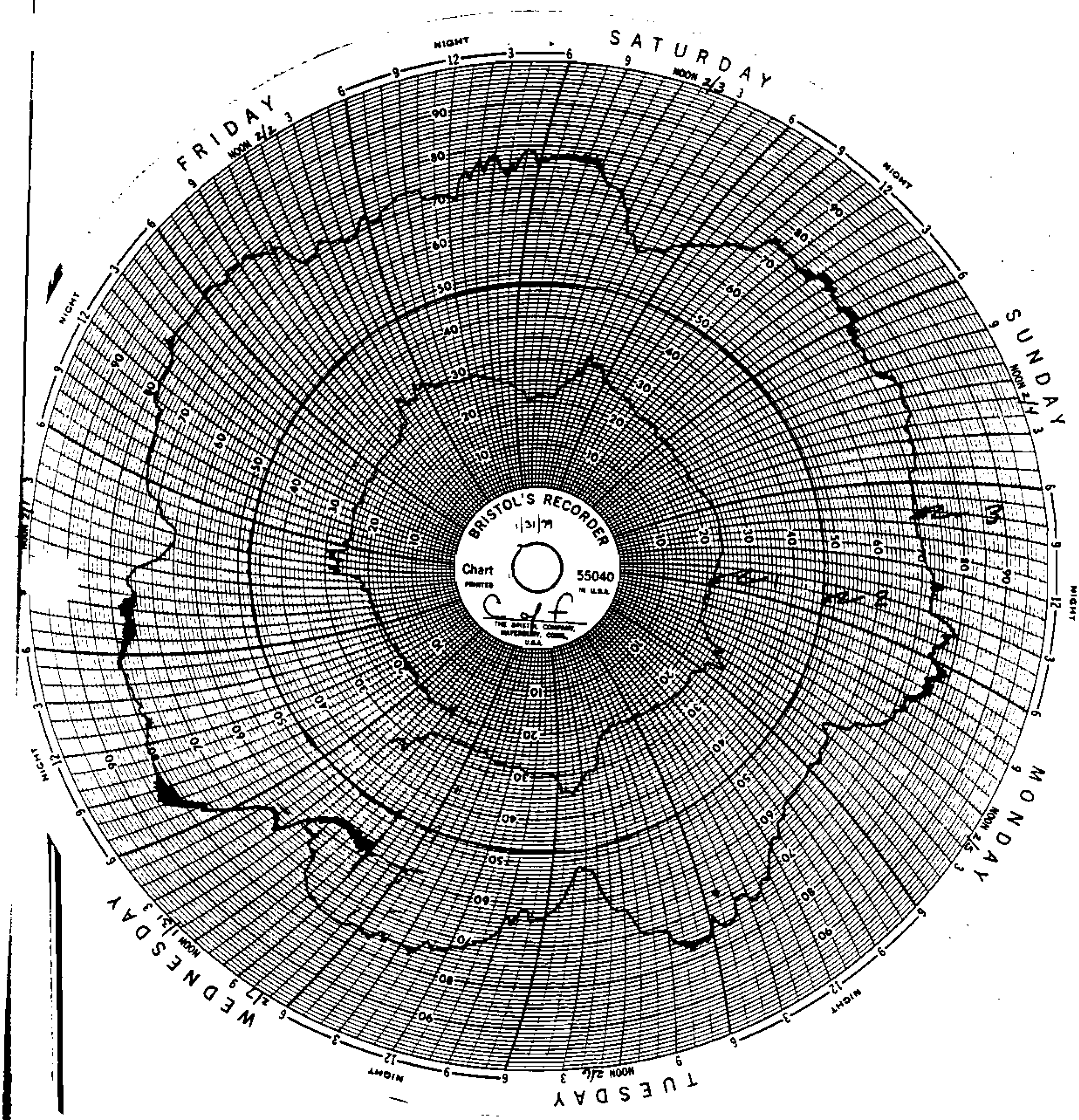


FIGURE 2

1. Air Temperature
2. Water Temperature
3. Relative Humidity

LAKE POWELL MEASUREMENTS

The following data was collected from each of the three rafts; water surface temperature, air temperature, and relative humidity. The wind was measured by an anemometer placed two meters above the water surface. The anemometers were read once each week. At each of the three rafts, water surface temperature, air temperature, and relative humidity were recorded on 7 day circular charts as shown in Figure 2. Wind was measured and recorded by anemometers placed 2 meters above the water surface which were read once each week. The data was manually read and recorded on the form shown in Figure 3.

ADJUSTMENTS TO DATA

The wind run was required on a daily basis but the raft anemometers were only read weekly on the rafts. Therefore, the daily wind run from anomemeters at the Wahweap Marina and Page were used to pro rate the weekly raft wind run readings for each day.

Some of the data was not recorded or was obviously wrong. Therefore, methods were developed to estimate missing data either by interpolation, observing trends before and after the missing data, or by correlation with data from other rafts. Wind has a large effect on evaporation and is highly variable. Therefore, a procedure was developed to estimate missing wind data using a hierarchy of options starting with the most preferred method. This procedure is explained in the files of the Water Operations Branch. Other details and computer printouts are also available in these files.

CALIBRATION OF COEFFICIENT

The evaporation rate as determined by the Lake Powell Research Project (LPRP) was used to calibrate a mass-transfer coefficient. For those days in 1974 when there was concurrent data as collected by the LPRP instruments and Bureau instruments a regression analysis was made for each of the three data stations. Thus there were 295 data sets at Wahweap Bay, 143 data sets at Bullfrog Bay and 133 data sets at Padre Bay. The regression coefficients were; .53 at Wahweap; .72 at Padre Bay, and .55 at Bullfrog Bay. These coefficients are not very high mainly because of the determined distribution of wind data. If the regression analysis were done for weekly or longer periods, the regression coefficients would be much higher. A comparison of monthly rates is shown in Table 1. From the regression analysis a mass transfer coefficient of 3.27 was determined and used in equation (3).

DATA FOR CO
A
BY MAS

MO.	DAY	YEAR	LAKE POWELL ELEVATION	WAHWEAP						CROSS	
				AIR TEMP.		WATER TEMP	HUMIDITY		ANEMOMETER READING	AIR TEMP.	
				MAX.	MIN.		MAX.	MIN.		MAX.	MIN
1 2	3 4	5 6 7 8	9 10 11 12 13 14	15 16 17	18 19 20	21 22	23 24	25 26	27 28 29 30 31	32 33 34	35 36

COMPUTATION OF EVAPORATION AT LAKE POWELL M/ ~-TRANSFER METHOD

WATER AND POWER RES
DIVISION OF WATER AND
RESERVOIR REGULA

CROSSING OF THE FATHERS						BULLFROG BASIN							PAGE	WAHWEAP	
TEMP.	WATER	HUMIDITY		ANEMOMETER	AIR TEMP.		WATER	HUMIDITY		ANEMOMETER		WIND	WIND	
MIN	TEMP.	MAX.	MIN.	READING	MAX.	MIN.	TEMP.	MAX.	MIN.	READING		MILES	MILES	
35 36 37	38 39	40 41	42 43	44 45 46 47 48	49 50 51	52 53 54	55 56	57 58	59 60	61 62 63 64 65		66 67 68	69 70 71	72 73 74 7

BY: DATE: CHECKED:

FIGURE 3

OF EVAPORATION
ELL
R ··THOD

WATER AND POWER RESOURCES SERVICE
DIVISION OF WATER AND LAND OPERATIONS
RESERVOIR REGULATION BRANCH

·HERS		BULLFROG BASIN						PAGE WIND MILES	WAHWEAP WIND MILES	
	ANEMOMETER READING	AIR TEMP. MAX.	AIR TEMP. MIN.	WATER TEMP.	HUMIDITY MAX.	HUMIDITY MIN.	ANEMOMETER READING			
3	44 45 46 47 48	49 50 51	52 53 54	55 56	57 58	59 60	61 62 63 64 65	66 67 68	69 70 71	72 73 74 75 76 77 78 79 80

	BY:	DATE:	CHECKED:

COMPUTATIONS

Equation (3) was used to compute a daily evaporation rate. It was developed from equation (2) which was developed specifically for Lake Mead.

$$E = 3.27 \times 10^{-3} u(e_o - 0.005(H_{max} + H_{min}) e_{as}) \qquad (3)$$

Where

E = evaporation in inches per day

u = average wind speed in miles per hour

e_o = saturation vapor pressure at water surface temperature in millibars

H_{max} = maximum relative humidity as percentage

H_{min} = minimum relative humidity as a percentage

e_{as} = saturation vapor pressure in millibars at average daily air temperature.

The vapor pressure of the air is approximated by multiplying the average daily humidity by the saturation vapor pressure at the average daily air temperature. Thus the .005 in the equation is from dividing by 100 to convert from percentage and dividing by 2 to get an average. The computations were done by a computer program termed EVAP. The daily evaporation rates were totaled for each month. They are shown in Table 2.

COMPARISON OF EVAPORATION RATES

Table 3 is pan evaporation as measured at Wahweap. Table 4 is the Lake Powell evaporation rate in inches from the adjusted class A pan at Wahweap Arizona. This adjustment is described in Lake Powell Research Bulletin Number 48. The average annual evaporation rate for the evaporation pan method was 69.44 inches for the 1962-1975 period while the rate for the mass-transfer method was 68.32 inches for the same period.

GROSS EVAPORATION

The gross evaporation is computed by multiplying the lake surface area by the evaporation rate in Table 2. This is shown in Table 5 and column (1) of Table 8.

NET EVAPORATION

Net evaporation which is the amount of increased evaporation caused by the reservoir is needed for some purposes. It is needed to establish water supply data that is homogeneous for the period before and after Lake Powell started to fill. It is also needed to determine depletion.

Net evaporation is determined by subtracting from the gross evaporation the evapotranspiration that would have occured from the reservoir basin if the

TABLE 1 COMPARATIVE EVAPORATION RATES FOR CALIBRATION PERIOD

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wahweap LPRP 1/	3.09	3.75	3.26	4.70	5.52	7.73	7.98	9.11	9.07	5.27	4.88	4.59
Bay Bureau 2/	4.76	4.18	4.06	5.29	5.83	7.07	8.19	8.46	8.23	4.32	5.26	5.70
Padre LPRP 1/	3.65	3.15	4.13	5.72	7.61	8.17	8.36	7.73	5.67	4.44	4.44	
Bay Bureau 2/	4.17	4.17	3.32	3.15	4.18	4.42	-	-	4.33	3.49	3.57	
Bullfrog Bay Bureau 2/	3.04	2.35	2.61	3.84	5.24	5.65	8.46	8.36	7.54	5.44	3.95	3.96
Adjusted Pan 3/				4.66	5.55	7.85	8.24	8.89	8.36	5.65	4.74	

1/ As computed by Lake Powell Research Project
2/ As computed using equation (3) using mass-transfer coefficient derived by regression analysis.
3/ Based on adjusted class a pan data from the class a pan at Wahweap.

TABLE 2
LAKE POWELL EVAPORATION RATE
(IN INCHES)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1965	2.25	3.02	3.76	4.46	7.29	6.71	6.37	8.57	8.98	2.83	3.10	3.53	60.87
1966	3.24	2.38	3.49	5.06	6.28	8.06	7.70	9.18	6.83	6.12	3.21	2.99	64.54
1967	2.03	1.79	2.86	4.68	5.13	7.00	7.73	7.44	6.75	5.93	3.35	4.13	58.82
1968	2.07	.87	2.72	3.90	6.48	8.79	9.42	10.58	8.66	5.38	5.28	4.04	68.19
1969	1.86	2.26	2.58	3.92	5.06	7.14	6.84	7.68	6.73	8.19	4.29	3.31	59.86
1970	2.36	1.54	3.35	4.04	7.76	9.94	10.18	10.97	11.96	7.53	4.94	3.94	78.51
1971	2.13	2.71	3.43	4.70	7.18	7.86	9.81	10.36	11.85	7.22	5.28	4.75	77.28
1972	3.24	2.21	3.75	4.90	5.15	7.71	9.17	9.24	8.02	6.58	5.68	5.18	70.83
1973	3.75	1.75	3.15	4.79	5.64	7.20	8.64	11.02	8.60	6.90	5.70	5.55	72.69
1974	3.99	3.28	3.27	4.44	5.65	6.36	8.33	8.41	7.63	4.70	4.24	4.41	64.71
1975	3.54	2.27	3.71	4.00	4.76	6.35	7.23	8.65	7.79	7.81	6.00	4.15	66.26
1976	2.91	2.75	4.26	4.96	4.53	6.93	8.06	10.51	5.70	5.17	4.19	3.89	63.86
1977	2.66	2.64	4.93	4.23	7.48	8.85	12.00	8.01	7.75	6.75	6.84	4.70	76.84
1978	3.05	2.89	3.22	6.29	6.40	7.70	6.42	8.75	9.05	6.05	7.11	6.28	73.21
1979	4.49	2.52	2.88	4.03	5.76								
MONTHLY MEAN	2.90	2.33	3.42	4.56	6.04	7.61	8.42	9.24	8.31	6.23	4.94	4.35	ANNUAL MEAN 68.32

Table 3 Total Pan Evaporation in Inches at Wahweap, Arizona (1962-1975)[a]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1962	2.08	2.93	6.07	12.01	15.83	17.36	19.96	18.28	12.21	6.82	3.07	2.69	119.31
1963	2.08[b]	3.15	6.99	10.38	16.17	17.39	20.72	13.90	10.31	7.43	3.65	2.69[b]	114.86
1964	2.08[b]	3.03[b]	6.25	9.89	14.68[b]	16.40	17.96	17.22	13.14	9.55	3.90	2.69[b]	116.79
1965	2.08[b]	3.66	6.19	8.62	14.54	14.36	15.33	16.39	13.06	7.49	3.72	2.69[b]	108.13
1966	2.08[b]	2.11	7.49	11.96	15.88	19.22	18.52	18.13	11.67	7.98	4.11	2.69[b]	121.84
1967	2.08[b]	3.03[b]	6.51[b]	10.92	13.02	15.54	16.41	14.18	10.50	8.16	4.37	2.69[b]	107.41
1968	2.08[b]	3.03[b]	6.79	9.00	14.63	17.41	15.93	12.71	12.76	6.99	4.19	2.69[b]	108.21
1969	2.08[b]	3.31	5.97	9.74	15.76	15.57	15.89	14.88	11.12	7.09	3.76[b]	2.69[b]	107.87
1970	2.08[b]	3.03[b]	7.70	10.86	16.55	17.16	15.78	14.62	12.79	7.24	3.76[b]	2.69[b]	114.26
1971	2.08[b]	3.03[b]	6.51[b]	10.82	13.77	17.42	20.05	15.06	10.98	7.11	3.76[b]	2.69[b]	113.28
1972	2.08[b]	3.03[b]	6.51[b]	12.16	15.95	15.54	16.64	12.67	11.13	7.51[b]	3.76[b]	2.69[b]	109.67
1973	2.08[b]	3.03[b]	5.15	9.59	13.06	15.04	15.43	15.36	11.22	8.05	3.84	2.69[b]	104.54
1974	2.08[b]	3.03[b]	6.51[b]	10.60	15.41	17.07	15.25	14.58	11.30	6.62	3.02	2.69[b]	108.16
1975	2.08[b]	3.03[b]	6.51[b]	8.32	10.26	14.71	15.40	12.79	10.26	7.16	3.76[b]	2.69[b]	96.97
Mean	2.08	3.03	6.51	10.23	14.68	16.44	17.08	15.05	11.60	7.51	3.76	2.69	110.66
Number of Years in the Mean													
	1	5	9	14	13	14	14	14	14	13	9	1	

a = The pan was usually not operated all 12 months of each year. When there was no measurement available the mean of the rest of the years for that month was used in calculating the estimated values. Original pan data from U.S. Weather Bureau Climatological Data for Arizona.

b = Estimated data.

Table 4 Evaporation at Lake Powell Based on Adjusted Pan Data from the Class A Pan at Wahweap, Arizona[a]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total
1962	2.08	2.05	3.04	5.28	5.70	7.99	10.78	11.15	9.04	5.79	4.82	5.38	73.1
1963	2.08[b]	2.20	3.50	4.57	5.82	8.00	11.19	8.48	7.63	6.32	5.73	5.38[b]	70.9
1964	2.08[b]	2.12[b]	3.12	4.35	5.28[b]	7.54	9.70	10.50	9.72	8.12	6.12	5.38[b]	74.03
1965	2.08[b]	2.56	3.10	3.79	5.23	6.61	8.28	10.00	9.66	6.37	5.84	5.38[b]	68.9
1966	2.08[b]	1.48	3.74	5.26	5.72	8.84	10.00	11.06	8.64	6.78	6.45	5.38[b]	75.43
1967	2.08[b]	2.12[b]	3.26[b]	4.80	4.69	7.15	8.86	8.65	7.77	6.94	6.86	5.38[b]	68.56
1968	2.08[b]	2.12[b]	3.40	3.96	5.27	8.01	8.60	7.75	9.44	5.94	6.58	5.38[b]	68.53
1969	2.08[b]	2.12	2.98	4.29	5.67	7.16	8.58	9.08	8.23	6.03	5.90[b]	5.38[b]	67.5
1970	2.08[b]	2.12[b]	3.85	4.78	5.96	7.89	8.52	8.92	9.46	6.15	5.90[b]	5.38[b]	71.01
1971	2.08[b]	2.12[b]	3.25[b]	4.76	4.96	8.01	10.83	9.91	8.12	6.04	5.90[b]	5.38[b]	70.64
1972	2.08[b]	2.12[b]	3.25[b]	5.35	5.74	7.15	8.99	7.73	8.24	6.38[b]	5.90[b]	5.38[b]	68.31
1973	2.08[b]	2.12[b]	2.58	4.22	4.70	6.92	8.33	9.37	8.30	6.84	6.03	5.38[b]	66.87
1974	2.08[b]	2.12[b]	3.25[b]	4.66	5.55	7.85	8.24	8.89	8.36	5.63	4.74	5.38[b]	66.75
1975	2.08[b]	2.12[b]	3.25[b]	3.66	3.69	6.77	8.32	7.80	7.59	6.09	5.90[b]	5.38[b]	62.56
Monthly Mean	2.08	2.12	3.26	4.50	5.28	7.56	9.22	9.18	8.58	6.38	5.90	5.38	Annual Mean 69.44

a = The pan was usually not operated all 12 months of each year. When there was no measurement available the mean of the rest of the years for that month was used in calculating the adjusted values. Original pan data from U.S. Weather Bureau Climatological Data for Arizona."

b = Based on estimated values as per note a above.

TABLE 5
LAKE POWELL GROSS EVAPORATION
(IN ACRE-FEET)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1965	9753	13093	16284	19347	31686	30226	33546	47651	49088	15586	17092	19755	303107
1966	10316	13374	19643	29179	37007	48336	45478	52326	37846	33069	17085	15674	367333
1967	7905	7605	14140	22582	24148	35897	42760	41102	36725	32060	18128	22215	305267
1968	11097	4621	14329	19661	32754	50258	57305	50275	52410	32170	31154	23525	379559
1969	10793	13236	15347	23801	33655	51280	50463	55895	47867	58190	30604	23343	414474
1970	16457	10673	23454	27846	54727	78263	84000	89807	97444	61516	40656	32436	617279
1971	17389	22546	28497	39157	60953	70200	90432	94118	105832	63960	46528	41307	680919
1972	27913	18958	32798	42856	44672	69462	82904	81099	68049	55809	49077	44464	618061
1973	31424	14389	25891	37907	47439	68525	88019	114360	97898	80503	72203	58493	737051
1974	41985	34630	34846	47623	62652	73154	95474	94045	82829	50314	45177	46760	709489
1975	37039	23706	38702	41864	50718	72126	86256	103092	91344	90272	69379	48146	752644
1976	33714	31736	48814	56700	52072	81437	80869	99529	65551	58625	46787	42763	698597
1977	28892	28362	52722	45565	80915	76212	98500	83542	78142	66994	67540	45981	753367
1978	28939	27012	29830	58941	61763	79207	69054	92946	92911	60810	71042	61838	734293
1979	43360	23997	27972	40820	62819								
MONTHLY MEAN	24331	19195	28217	36923	49198	63184	71790	78556	71709	54277	44460	37621	

reservoir did not exist. For this study the evapotranspiration that must be subtracted was determined in four parts.

EVAPORATION FROM THE PRE-RESERVOIR WATER SURFACE

The first part was the evaporation from the pre-reservoir river water surface. It is computed by multiplying the area of the river by the gross evaporation rate. The river water surface area was determined using the following criteria.

(1) The aerial photographs from which the Lake Powell topography came were flown in September and October of 1958 and 1959 when the river was at a very low stage.
(2) The average flow of the river over the period of record was about 18,000 c.f.s. at Lees Ferry.
(3) Tail water curves taken in the vicinity of Glen Canyon Dam indicate a rise of only about 5 feet for an increase in flow of 15,000 c.f.s.
(4) Since the water line shown on the topography represents a flow of about 6,000 c.f.s., it was assumed that the contour closest to this water line would represent average flow conditions.
(5) Where a contour crossed the river on a given topography sheet, a line representing the average flow line was drawn in and the area planimetered accordingly.
(6) Sandbars that did not show vegetation were assumed to be included in the water surface area at 18,000 c.f.s. average flow.

The river-elevation relationship is shown in Figure 4. The gross evaporation rate from Table 4 was used. The resulting river evaporation is shown in Table 8 Column 2.

STREAMSIDE EVAPOTRANSPIRATION

The second part was the evapotranspiration that would have occurred from the vegetation, which is mostly phreatophyte, and evaporation from the wetted soil on the streambank if the reservoir did not exist. It was computed by multiplying the evapotranspiration rate by the streamside area. The evapotranspiration rate was computed by the Blaney - Criddle method 7/ as shown in Table 7 and described below. The streamside areas were determined under a contract between the University of Utah and the Bureau of Reclamation in the late 1950's before Lake Powell started to fill 9/. The vegetation density was measured along transects. These were used as an index to make ocular estimates of the remaining areas. The areas were measured by planimeter from maps which were prepared from overlay maps and tabular data from the field. The area-elevation relationship is shown in Figure 5. The main source of water for this part is from percolation with a small contribution from precipitation. The streamside evapotranspiration is shown in Table 8 Column 3.

FIGURE 4

RIVER WATER SURFACE AREA
ACCUMULATED ABOVE GLEN CANYON DAM

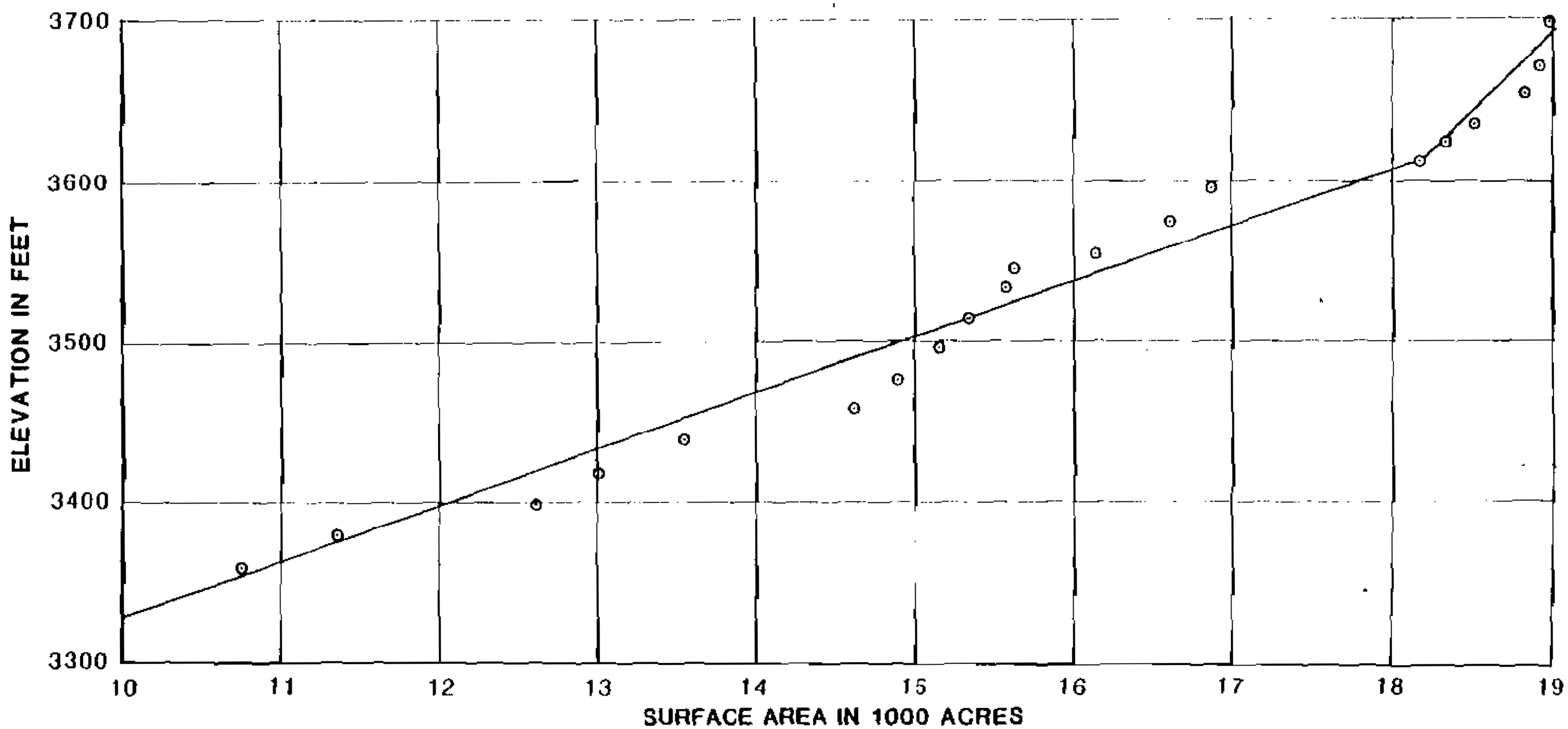


FIGURE 5

STREAMSIDE AREA
ACCUMULATED ABOVE GLEN CANYON DAM

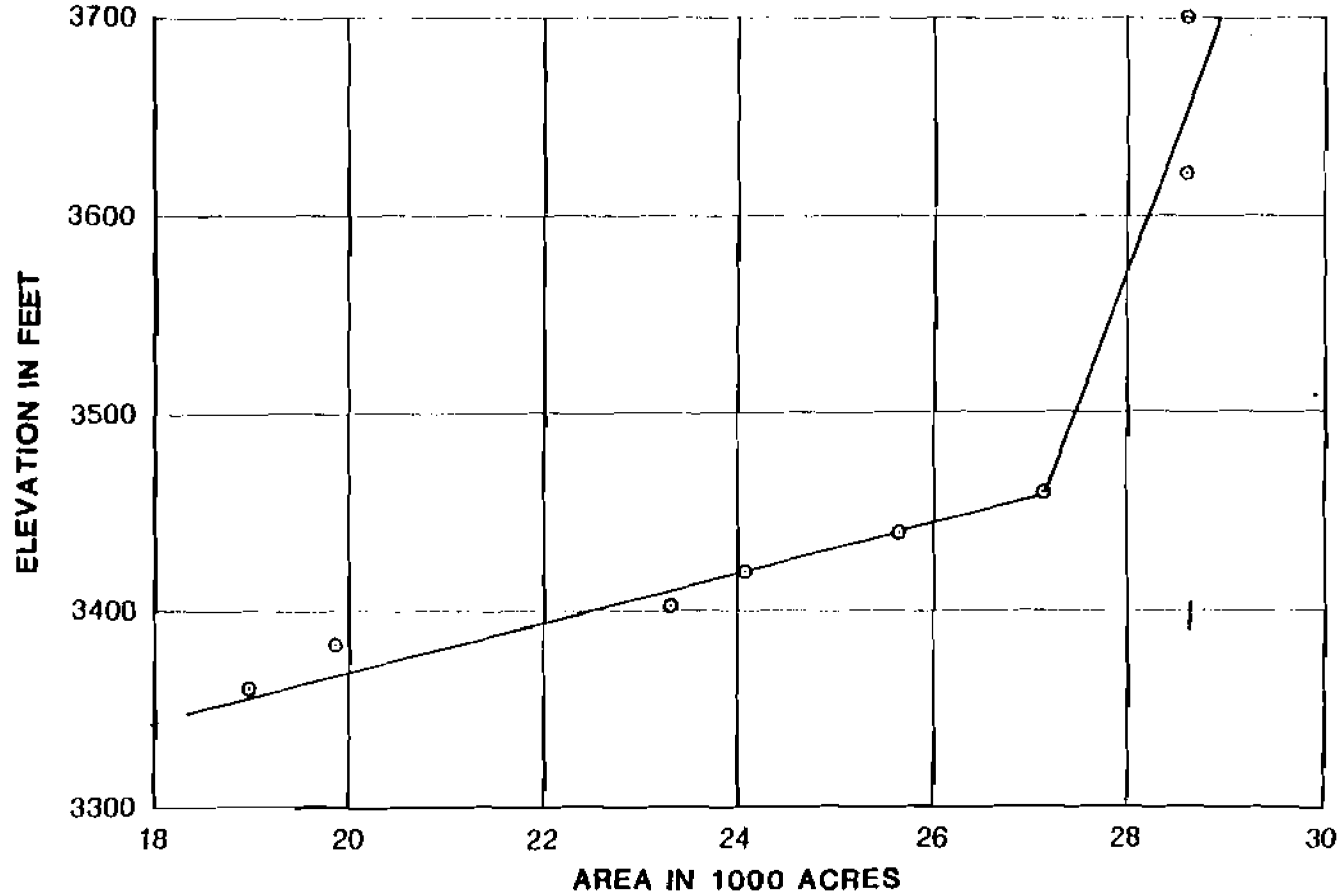
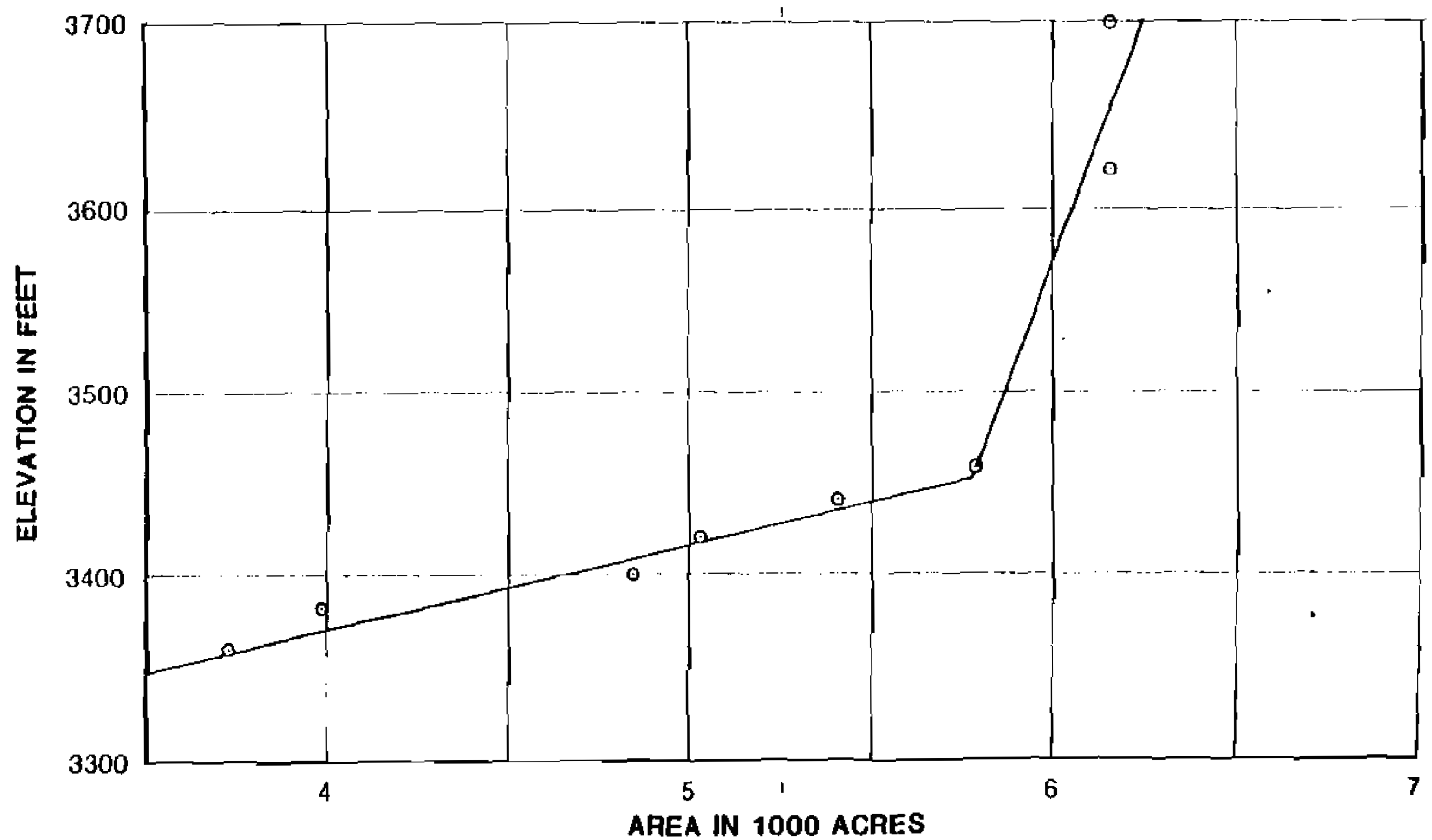


FIGURE 6

TERRACE AREA ACCUMULATED
ABOVE GLEN CANYON DAM



TERRACE EVAPOTRANSPIRATION

The third part is the evapotranspiration from the terrace areas under pre-reservoir conditions. It was computed by multiplying the evapotranspiration rate by the terrace area. The evapotranspiration rate was determined by the Blaney-Criddle method 7/ described below. The areas were determined by the same survey referred to above. This water reaches the root zone mostly by capillary action with some by precipitation. The terrace area-elevation curve is shown in Figure 6. The resulting evapotranspiration is shown in Table 8 Column 4.

BLANEY-CRIDDLE METHOD

The Blaney-Criddle method of computing evapotranspiration (consumptive-use) was chosen because of the minimal data requirements and accuracy acceptable for this purpose. The basic equation is:

$$u=fk$$

Where u is the evapotranspiration rate in inches. k is an emperical coeffecient dependent on the type of vegetation. Consumptive use coefficients have been determined mostly for irrigated crops so there has been little investigation of native vegetation.

From values given for k by Blaney 10/ for native vegetation for several densities of vegetation 1.1 was selected for the streamside area and 0.9 was used for the terrace area. The variable f is calculated as $(t)(p)/100$. Where t is the mean monthly air temperature in degrees farenheit and p is the monthly percent of annual daylight hours and is dependent upon the latitude. 39° north latitude was used. Therefore $u=(t)x(p)x(k)/100$. Table 6 shows the computation of $(p)x(k)/100$ for the streamside area and the terrace area. This was multiplied by the average temperature for the month to obtain the evapotranspiration rates.

EVAPOTRANSPIRATION OF REMAINING AREAS

The fourth part is the evapotranspiration from the remaining area of the reservoir under pre-reservoir condition.

Most of the precipitation falling on the area of Lake Powell would not have produced runoff because it would have evaporated from the vegetation and soil or it would have transpired from the vegetation. In consumptive use studies this is termed effective precipitation. It does not include precipitation that causes runoff. The method of determining the effective precipitation used is described in a report by R. A. Schleusener 8/. The precipitation was computed from seven stations: Page, Wahweap, Bullfrog, Canyonlands, Hite, Mexican Hut, and Natural bridges. Since each of these stations were located above the maximum elevation of Lake Powell, and since precipitation increases with elevation, it was necessary to reduce the precipitation to an equivalent for Lake Powell at a representative elevation of 3,600 feet. This was done by plotting the average annual precipitation for 1963 through 1980 against the elevation for the seven stations and drawing a curve throught the points. The resulting average annual precipitation from this curve is 6.33 inches. The ratio of 6.33 to the average annual precipitation at each station was multiplied by the monthly precipi-

TABLE 6
BLANEY-CRIDDLE
COMPUTATION OF $\frac{p \times k}{100}$

		Streamside		Terrace	
	%	K	$\frac{p \times k}{100}$	K	$\frac{p \times k}{100}$
January	6.92	1.1	.0761	0.9	.0623
February	6.87	1.1	.0756	0.9	.0618
March	8.34	1.1	.0917	0.9	.075
April	8.87	1.1	.0975	0.9	.0798
May	9.85	1.1	.1083	0.9	.0886
June	9.89	1.1	.1088	0.9	.089
July	10.05	1.1	.1105	0.9	.0904
August	9.44	1.1	.1034	0.9	.085
September	8.37	1.1	.0921	0.9	.0829
October	7.83	1.1	.0861	0.9	.0775
November	6.88	1.1	.0757	0.9	.0681
December	6.69	1.1	.0736	0.9	.0621
Total	100.00				

tation to reduce it to the equivalent precipitation at 3,600 feet. The equivalent precipitation for all stations was then totaled and divided by the number of stations on a monthly basis.
Table 6 was adapted from the report by R. A. Schleusener 8/.

TABLE 7
Effective Precipitation in Inches

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	.6	.6	.8	.8	.8	.8	1.0	1.0	1.0	.8	.8	.8

The precipitation up to the limit shown in Table 7 was multiplied by the remaining area. This is shown as column 5 in Table 8. The remaining area is the total area of the reservoir for the month minus the total of the water surface area, the streamside area, and the terrace area. From these computations it was determined that about 95 percent of the precipitation on the reservoir area would have evaporated and transpired.

RESULTS

Table 8 shows the computed monthly evaporation for each of the four parts and the resulting net evaporation for the period January 1965 through May 1979.

Table 9 shows the net annual evaporation, as described under PROCEDURE, which has previously been used on a preliminary basis, compared to the net annual evaporation computed from this study (Table 8). The net evaporation is less under this study when the reservoir is low but greater when the reservoir is high. The average evaporation under this study is 5 percent higher than the preliminary figures. This is mostly due to the 3 percent higher gross evaporation rate of 68.3 inches per year compared to 66.2 inches from the former estimates.

RECOMMENDATIONS

It is recommended that the results of this study be used to make a water budget analysis for Lake Powell. This will improve the estimate of the amount of water stored in the banks. It might also help to determine the amount of bank storage that is recoverable.

It is also recommeneded that the results of this study be used to determine a simpler method of estimating evaporation. A method that could be used in operations would be beneficial. One method that should be considered is to use pan evaporation at Wahweap.

TABLE 8
LAKE POWELL NET EVAPORATION
(IN ACRE-FEET)

YEAR	MONTH	NO. OF DAYS	(1) GROSS EVAPORATION	(2) EVAPORATION FROM RIVER	(3) EVAPORATION FROM STREAMSIDE	(4) EVAPO-TRANSPIRATION FROM TERRACE	(5) EVAPO-TRANSPIRATION FROM REMAINING AREA	(6) (2+3+4+5) TOTAL ADJUSTMENT	(7) (1-6) NET EVAPORATION
			ACRE-FEET						
1965	1	31	9753	2731	671	1685	1030	6117	3636
1965	2	28	13093	3666	677	1704	865	6912	6181
1965	3	31	16284	4565	930	2338	1660	9493	6791
1965	4	30	19347	5415	1170	2938	257	9780	9567
1965	5	31	31686	8857	1469	3690	93	14109	17577
1965	6	30	30226	8242	1670	4189	124	14225	16001
1965	7	31	33322	8191	1971	4905	1137	16204	17118
1965	8	31	47651	11255	1840	4540	3448	21083	26568
1965	9	30	49088	11733	1548	3495	2116	18892	30196
1965	10	31	15586	3704	1273	2874	1425	9276	6310
1965	11	30	17092	4060	915	2067	715	7757	9335
1965	12	31	19755	4641	616	1482	34	6773	12982
CALENDER YEAR TOTALS:			302883	77060	14750	35907	12904	140621	162262
1966	1	31	18316	4276	554	1374	282	6486	11830
1966	2	28	13374	3135	585	1452	104	5276	8098
1966	3	31	19643	4600	1002	2486	1299	9387	10256
1966	4	30	29179	6717	1287	3186	1778	12968	16211
1966	5	31	37007	8389	1609	4207	1535	15830	21177
1966	6	30	48336	10827	1879	4646	655	18007	30329
1966	7	31	45478	10292	2033	5042	978	18345	27133
1966	8	31	52326	12148	1907	4706	1108	19869	32457
1966	9	30	37846	8958	1645	3708	650	14961	22885
1966	10	31	33069	7966	1236	2791	0	11993	21076
1966	11	30	17085	4159	884	2001	967	8011	9074
1966	12	30	15674	3857	614	1482	1577	7530	8144
CALENDER YEAR TOTALS:			367333	85324	15325	37081	10933	148663	218670
1967	1	31	10373	2596	551	1373	728	5248	5125
1967	2	28	8993	2277	705	1757	1212	5951	3042
1967	3	31	14140	3622	1049	2619	1676	8966	5174
1967	4	30	22582	5885	1140	2848	2230	12103	10479
1967	5	31	24148	6391	1530	3831	2128	13880	10268
1967	6	30	35897	8977	1748	4357	1288	16370	19527
1967	7	31	42760	10132	2036	5057	3416	20641	22119
1967	8	31	41102	9752	1851	4574	1980	18157	22945
1967	9	30	36725	8808	1591	3592	2236	16227	20498
1967	10	31	32060	7723	1258	2839	2217	14037	18023
1967	11	30	18128	4363	895	2022	2649	9929	8199
1967	12	31	22215	5369	474	1141	2624	9608	12607
CALENDER YEAR TOTALS:			309123	75895	14828	36010	24384	151117	158006

TABLE 8
LAKE POWELL NET EVAPORATION
(IN ACRE-FEET)

YEAR	MONTH	NO. OF DAYS	(1) GROSS EVAPORATION	(2) EVAPORATION FROM RIVER	(3) EVAPORATION FROM STREAMSIDE	(4) EVAPO-TRANSPIRATION FROM TERRACE	(5) EVAPO-TRANSPIRATION FROM REMAINING AREA	(6) (2+3+4+5) TOTAL ADJUSTMENT	(7) (1-6) NET EVAPORATION
			ACRE-FEET						
1968	1	31	11097	2685	431	1073	357	4546	6551
1968	2	29	4621	1126	755	1881	1933	5695	-1074
1968	3	31	14329	3513	1009	2512	31	7065	7264
1968	4	30	19661	4969	1156	2880	297	9302	10359
1968	5	31	32754	8261	1576	3927	952	14716	18038
1968	6	30	50258	11639	1873	4639	71	18222	32036
1968	7	31	57305	12701	1771	4377	2708	21557	35748
1968	8	31	50275	14309	1736	4263	2427	22735	27540
1968	9	30	52410	11662	1594	3581	2418	19255	33155
1968	10	31	32170	7218	1238	2781	1226	12463	19707
1968	11	30	31154	7057	831	1875	1653	11416	19738
1968	12	31	23525	5379	522	1254	2954	10109	13416
CALENDER YEAR TOTALS:			379559	90519	14492	35043	17027	157081	222478
1969	1	31	10793	2473	652	1613	293	5031	5762
1969	2	28	13236	3015	657	1628	148	5448	7788
1969	3	31	15347	3455	911	2252	227	6845	8502
1969	4	30	23801	5282	1278	3157	351	10068	13733
1969	5	31	33655	6991	1699	4181	2964	15835	17820
1969	6	30	51280	10120	1853	4538	2228	18739	32541
1969	7	31	50463	9775	2069	5058	1438	18340	32123
1969	8	31	55895	10924	1963	4784	1914	19585	36310
1969	9	30	47867	9511	1692	3777	2834	17814	30053
1969	10	31	58190	11568	1175	2625	195	15563	42627
1969	11	30	30604	6066	830	1854	588	9338	21266
1969	12	31	23343	4664	652	1550	3864	10730	12613
CALENDER YEAR TOTALS:			414474	83844	15431	37017	17044	153336	261138
1970	1	31	16457	3311	623	1527	473	5934	10523
1970	2	28	10673	2158	767	1883	895	5703	4970
1970	3	31	23454	4709	986	2418	1242	9355	14099
1970	4	30	27846	5656	1169	2875	2110	11810	16036
1970	5	31	54727	10915	1690	4144	335	17084	37643
1970	6	30	78263	14462	1905	4645	333	21345	56918
1970	7	31	84000	15040	2089	5092	4464	26685	57315
1970	8	31	89807	16171	1976	4793	5125	28065	61742
1970	9	30	97444	17811	1645	3639	410	23305	74139
1970	10	31	61516	11094	1233	2732	1763	16828	44694
1970	11	30	40656	7290	902	2000	1185	11377	29279
1970	12	31	32436	5818	641	1514	1721	9694	22742
CALENDER YEAR TOTALS:			617279	114235	15626	37262	20056	187179	430100

TABLE 8
LAKE POWELL NET EVAPORATION
(IN ACRE-FEET)

YEAR	MONTH	NO. OF DAYS	(1) GROSS EVAPORATION	(2) EVAPORATION FROM RIVER	(3) EVAPORATION FROM STREAMSIDE	(4) EVAPO-TRANSPIRATION FROM TERRACE	(5) EVAPO-TRANSPIRATION FROM REMAINING AREA	(6) (2+3+4+5) TOTAL ADJUSTMENT	(7) (1-6) NET EVAPORATION
			ACRE-FEET						
1971	1	31	25113	4525	615	1499	3534	10173	14940
1971	2	28	27692	4958	734	1785	3598	11075	16617
1971	3	31	28497	5079	1038	2524	2164	10805	17692
1971	4	30	39157	6963	1285	3123	180	11551	27606
1971	5	31	60953	10692	1605	3907	1661	17865	43088
1971	6	30	70200	11875	1968	4776	2559	21178	49022
1971	7	31	90432	14903	2193	5314	6186	28596	61836
1971	8	31	94118	15704	1969	4741	5188	27602	66516
1971	9	30	105832	17933	1694	3737	1056	24420	81412
1971	10	31	63960	10896	1236	2721	5221	20074	43886
1971	11	30	46528	7955	836	1842	3888	14521	32007
1971	12	31	41307	7128	578	1362	2419	11487	29820
CALENDER YEAR TOTALS:			693789	118611	15751	37331	37654	209347	484442
1972	1	31	27913	4846	648	1572	879	7945	19968
1972	2	29	18958	3302	764	1856	1563	7485	11473
1972	3	31	32798	5634	1209	2938	5126	14907	17891
1972	4	30	42856	7366	1358	3298	2313	14335	28521
1972	5	31	44672	7725	1720	4180	190	13815	30857
1972	6	30	69462	11674	1964	4767	1397	19802	49660
1972	7	31	82904	13900	2178	5270	2413	23761	59143
1972	8	31	81099	13906	1934	4663	3870	24373	56726
1972	9	30	68049	11949	1669	3693	3149	20460	47589
1972	10	31	55809	9793	1232	2727	2212	15964	39845
1972	11	30	49077	8505	825	1824	2274	13428	35649
1972	12	31	44464	7735	571	1343	1373	11022	33442
CALENDER YEAR TOTALS:			618061	106335	16072	38131	26759	187297	430764
1973	1	31	31424	5562	514	1250	484	7810	23614
1973	2	28	14389	2584	692	1690	949	5915	8474
1973	3	31	25891	4651	957	2333	475	8416	17475
1973	4	30	37907	6993	1233	3004	282	11512	26395
1973	5	31	47439	8351	1697	4123	1081	15252	32187
1973	6	30	68525	10974	1921	4647	143	17685	50840
1973	7	31	88019	13269	2152	5184	703	21308	66711
1973	8	31	114360	16961	1990	4757	6639	30347	84013
1973	9	30	97898	13244	1706	3730	2416	21096	76802
1973	10	31	80503	10626	1344	2939	6446	21355	59148
1973	11	30	72203	8782	930	2034	2663	14409	57794
1973	12	31	58493	8556	690	1611	4728	15585	42908
CALENDER YEAR TOTALS:			737051	110553	15826	37302	27009	190690	546361

TAB.
LAKE POWELL NE EVAPORATION
(IN ACRE-FEET)

YEAR	MONTH	NO. OF DAYS	(1) GROSS EVAPORATION	(2) EVAPORATION FROM RIVER	(3) EVAPORATION FROM STREAMSIDE	(4) EVAPO-TRANSPIRATION FROM TERRACE	(5) EVAPO-TRANSPIRATION FROM REMAINING AREA	(6) (2+3+4+5) TOTAL ADJUSTMENT	(7) (1-6) NET EVAPORATION
			ACRE-FEET						
1974	1	31	41985	6151	589	1416	0	8156	33829
1974	2	28	34630	5059	666	1604	0	7329	27301
1974	3	31	34846	5049	1174	2817	0	9040	25806
1974	4	30	47623	6859	1306	3135	167	11467	36156
1974	5	31	61213	8591	1823	4373	86	14873	46340
1974	6	30	73154	9911	2126	5078	7280	24395	48759
1974	7	31	95474	12973	2166	5188	2448	22775	72699
1974	8	31	94045	13056	1990	4750	3332	23128	70917
1974	9	30	82829	11807	1751	3823	3299	20680	62149
1974	10	31	50314	7261	1007	2198	6661	17127	33187
1974	11	30	45177	6547	718	1566	6375	15206	29971
1974	12	31	46760	6806	616	1437	6574	15433	31327
CALENDER YEAR TOTALS:			708050	100070	15932	37385	36222	189609	518441
1975	1	32	37039	5454	712	1712	4203	12081	24958
1975	2	28	23706	3495	846	2038	2334	8713	14993
1975	3	31	38702	5713	1135	2731	6285	15864	22838
1975	4	30	41864	6163	1461	3512	3317	14453	27411
1975	5	31	50718	7350	1929	4627	5717	19623	31095
1975	6	30	72126	9874	2133	5108	4914	22029	50097
1975	7	31	86258	11314	2099	5012	1520	19945	66311
1975	8	31	103092	13537	1806	4292	3140	22775	80317
1975	9	30	91344	12165	1406	3057	3262	19890	71454
1975	10	31	90272	12177	1007	2188	1374	16746	73526
1975	11	30	69379	9355	760	1654	2933	14702	54677
1975	12	31	48146	6474	632	1466	1195	9767	38379
CALENDER YEAR TOTALS:			752644	103071	15926	37397	40194	196588	556056
1976	1	31	33714	4537	827	1977	5514	12855	20859
1976	2	29	31736	4285	869	2079	730	7963	23773
1976	3	31	48814	6634	1240	2991	1812	12685	36129
1976	4	30	56700	7721	1610	3853	2260	15444	41256
1976	5	31	52072	7055	2008	4795	0	13858	38214
1976	6	30	81437	10828	2172	5195	0	18195	63242
1976	7	31	80869	12600	2122	5068	3480	23270	57599
1976	8	31	99529	16404	1767	4205	1393	23769	75760
1976	9	30	65551	8882	1410	3060	1455	14807	50744
1976	10	31	58625	8039	1054	2295	7153	18541	40084
1976	11	30	46787	6504	681	1485	5088	13758	33029
1976	12	31	42763	6029	626	1456	1636	9747	33016
CALENDER YEAR TOTALS:			698597	99518	16394	38459	30521	184892	513705

TABLE 8
LAKE POWELL NET EVAPORATION
(IN ACRE-FEET)

YEAR	MONTH	NO. OF DAYS	(1) GROSS EVAPORATION	(2) EVAPORATION FROM RIVER	(3) EVAPORATION FROM STREAMSIDE	(4) EVAPO-TRANSPIRATION FROM TERRACE	(5) EVAPO-TRANSPIRATION FROM REMAINING AREA	(6) (2+3+4+5) TOTAL ADJUSTMENT	(7) (1-6) NET EVAPORATION
			ACRE-FEET						
1977	1	31	28892	4116	778	1868	1860	8622	20270
1977	2	28	28362	4081	832	2001	3846	10760	17602
1977	3	31	52722	7616	1329	3193	6658	18796	33926
1977	4	30	45565	6538	1501	3603	6365	18007	27558
1977	5	31	80915	11569	2068	4967	3209	21813	59102
1977	6	30	76212	13702	2140	5141	1191	22174	54038
1977	7	31	98500	18540	2142	5145	8348	34175	64325
1977	8	31	83542	12335	1831	4383	1769	20318	63224
1977	9	30	78142	11896	1479	3233	1932	18540	59602
1977	10	31	66994	10338	1084	2378	1587	15387	51607
1977	11	30	67540	10470	861	1890	2631	15852	51688
1977	12	31	45981	7183	707	1656	2071	11617	34364
CALENDER YEAR TOTALS:			753367	110384	16752	39458	41467	216061	537306
1978	1	31	28939	4648	769	1861	428	7706	21233
1978	2	28	27012	4395	915	2214	4190	11714	15298
1978	3	31	29830	4891	1263	3061	3043	12258	17572
1978	4	30	58941	9571	1510	3646	1755	16482	42459
1978	5	31	61763	9770	2022	4884	5098	21774	39989
1978	6	30	79207	11838	2164	5213	236	19451	59756
1978	7	31	69054	9924	2137	5133	4776	21970	47084
1978	8	31	92946	13504	1762	4217	1070	20553	72393
1978	9	30	92911	13914	1516	3320	4808	23558	69353
1978	10	31	60810	9281	1033	2259	1230	13803	47007
1978	11	30	71042	10896	594	1304	304	13098	57944
1978	12	31	61838	9608	544	1270	0	11422	50416
CALENDER YEAR TOTALS:			734293	112240	16229	38382	26938	193789	540504
1979	1	31	43360	6854	621	1500	1972	10947	32413
1979	2	28	23997	3840	839	2032	787	7498	16499
1979	3	31	27972	4399	1259	3042	586	9286	18686
1979	4	30	40820	6186	1555	3738	77	11556	29264
1979	5	31	62819	8913	1944	4670	1016	16543	46276

TABLE 9
LAKE POWELL NET EVAPORATION
1,000 ACRE-FEET

Calendar Year	Preliminary* Net Evaporation	Net Evaporation This Study
1965	200	162
1966	236	219
1967	215	158
1968	237	222
1969	300	261
1970	348	430
1971	398	484
1972	392	431
1973	441	546
1974	512	518
1975	523	556
1976	544	514
1977	486	537
1978	464	541
Total	5,296	5,579
Average	378	398

* Computed from pan evaporation rate as described under PROCEDURE.

REFERENCES

1. U.S. Geological Survey, 1954a, Water-Loss Investigations: Lake Hefner Studies, Technical Report: U.S. Geol. Survey Prof. Paper 269. Previously published as U.S. Geol. Survey Circ. 229 (1952) and as U.S. Navy Electronics Laboratory Report 327.

2. U.S. Geological Survey, 1954b, Water-Loss Investigations: Lake Hefner Studies, Base Data Report: U.S. Geol. Survey Prof. Paper 270; also published as U.S. Navy Electronics Laboratory Report 328.

3. NOAA Technical Report NWS33, 1959, "Evaporation Atlas for the Contiguous 48 States" Dept. of Comm. NWS, June 1982.

4. Harbeck et al. U.S. Geological Survey, 1958, Water Loss Investigations: Lake Mead Studies, Professional Paper Number 298.

5. Jacoby, Gordon C. Jr., et al. 1977, Lake Powel Research Project Bulletin, Number 48, National Science Foundation Institute of Geophysics and Planetary Physics University of California, Los Angeles.

6. G. Earl Harbeck, Jr., U.S. Geological Survey, 1962, A Practice Field Technique for Measuring Reservoir Evaporation Utilizing Mass-Transfer Theory, U.S.G.S. Professional Paper No. 272-E.

7. Blaney, H.F., Criddle, W. D., 1962, Determining Consumptive Use and Irrigation Water Requirements, U.S. Department of Agriculture Tech. Bulletin 1275.

8. Schleusener, R.A., Crow, L.W., 1961, Analysis of Precipitation Data in the Upper Colorado River Basin, Colorado State University.

9. Woodbury, A. M., Durrant S. D., Flowers, S., 1959, A Survey of Vegetation in the Glen Canyon Reservoir Basin Anthropological Papers Number 36, University of Utah Press.

10. Blaney H. F., Criddle, 1948, Final Report Engineering Advisory Committee to Upper Colorado River Basin Compact Commission.

11. Jensen, M.E., Editor, 1973, Consumptive Use of Water and Irrigation Water Requirements, American Society of Civil Engineers.