PAPER No. 368

An Estimate of Evaporation from Free Water Surface in West Pakistan

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AND
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SYNOPSIS

Loss of water occurs by evaporation and by seepage. Evaporation takes place at all temperatures from a stretch of free water surface, from soil, plants and all other wet bodies exposed to air. The plants loose water by transpiration. Evaporation is heavy in an arid or semi-arid country like West Pakistan. An estimate of this loss and an effective means for its reduction, can make available large volume of water for beneficial use.

In West Pakistan an estimate of evaporation loss has now become all the more important due to limited water of only three rivers and construction of storage dams.

In this paper evaporation from free water surface (f.w.s.) for the various regions of West Pakistan has been estimated. Although this subject has been studied, extensively all over the world during the last 150 years, it has received little attention in this country till recently.

In this paper an estimate of f.w.s. evaporation has been made for 51 cities of West Pakistan. It is estimated by using Penman, Rohwer, Blaney Criddle and Hargreaves formulae. Actual measured evaporation from 19 sites is compared with the calculated one. It has been noted that none of the above mentioned relations can give an estimate of f.w.s. evaporation equal to the observed one. A new formula by using common meteorological parameters was tried by the authors. It was found that results calculated by this formula fitted more closely to West Pakistan conditions.

An estimate of water lost from the storages in existence or those under construction is also given. It is hoped that this information will prove useful for future planning of multi-purpose water projects in West Pakistan and for undertaking measures to reduce the loss of water.

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Evaporation is a result of Molecular Energy

The common parameters which account for f.w.s. evaporation and its intensity are:—

(*i*) The temperature; evaporation is directly related with the rise or fall of temperature.

(*ii*) Solar radiations as their intensity and duration supply heat energy to the water molecules.

(*iii*) Percentage relative humidity as more water vapours or molecules can be absorbed in the air if it is low.

(*iv*) Wind velocity as quick removal of air with water saturated vapour close to the surface increases evaporation.

(*v*) Decrease of barometric pressure lowers the boiling point and hence increases evaporation.

(*vi*) The nature of the liquids.

Practically all the above stated parameters are closely inter-related.

Molecules of a liquid are in constant agitation, moving at a very great speed and frequently colliding with each other. Some of these leave the water surface and escape into the air medium where after further collision, some diffuse into the air medium while others return back to the liquid surface. Heat is a source of energy for molecules and for this reason their agitation and movement has been explained on the basis of kinetic theory of gases and their collision on the mean free path.

If the temperature of air and water is different then convection currents similar to that in water are set in which cause diffusion of water molecules into the air medium. Heat radiation increases the temperature and both the molecular agitation and the kinetic energy of a gas increases. This causes increase in diffusion and generation of convection currents. If the air flow is laminar, the layer of the air close to water surface gets saturated, there being little intermixing, evaporation is reduced. Turbulent flow of air increases intermixing and quick removal of air saturated with water molecules increases evaporation.

Intermixing of water molecules with air has also been explained due to the difference of mean saturation vapour pressure of the liquid, e_s and the mean vapour pressure of the saturated air at the temperature of dew point, e_d. The ratio of e_d/e_s is the % relative humidity or $e_d = (e_s \times \text{percentage relative humidity})/100$.

For every change of state, from a liquid to vapour, heat energy is needed. This is the heat of vapourisation. It is supplied by the liquid, so that its own temperature falls. This is quite evident in case of quick evaporating liquids, such as spirit or ether. The sun radiations continue to make up the fall in temperature of water as a result of vapourisation.

Evaporation formulae

In 1802 Dalton[1] stated that evaporation, E, in a given time period is equal to the difference of mean vapour pressure of saturated vapour at the temperature of water surface, e_s, and the mean vapour pressure of saturated air at the temperature of dew point, e_d. He also stated that E was a direct function of the horizontal wind velocity (u).
Mathematically it was expressed as:—

$$E=(e_s-e_d)f(u) \ldots \ldots \ldots \quad (1)$$

Ever since Dalton stated his relation, scientists working in various localities, under different climatic conditions, have tried to bring in the affects of various climatic parameters and have empirically determined the constants and related them with the evaporation from a free water surface. A very detailed discussion of the various formulae is given by H. Oliver[2] in the book on Irrigation and Climate. A useful discussion can be seen in the Hydrology by Meinzer[3] and in many books on Irrigation[4] and Hydrology[4a].

Two types of evaporation formulae have been developed by various workers. One type is similar to Dalton in which various constants have been determined with the introduction of wind velocity or barometric pressure. Most well known of these are due to Rohwer and Penman. Rohwer[5] in 1931 put forth the following relation:—

$$E=(1.465-0.0186B)\ (0.44+0.118W)\ (e_s-e_d)$$

in which

B is barometric pressure and

W is wind velocity.

Penman[6] in 1948 put forth the relation:—

$$E=0.35\ (1+0.0098u)\ (e_s-e_d)$$

in which u is the wind velocity at 2 meters height. In the second type of formulae, solar radiation and humidity has been made use of. The most commonly used relations of this type are due to Blaney[7] Criddle, Hargreaves[8] and Penman. These are as under:—

(*i*) $f=c \quad \frac{t\times p}{100}$ .....(Blaney Criddle)

(*ii*) $E=m\ (t-32)$

$=d\ (0.38-0.0038h)\ (t-32)$ .....(Hargreaves)

$$(iii)\ E = \frac{\Delta H_o + \gamma E_a}{\Delta + \gamma} \qquad \ldots\ldots \text{(Penman)}$$

in which

t =mean monthly temperature

p=mean monthly percentage of day time hours.

H_o=heat budget or influx radiation—back radiation

Δ=slope of saturation vapour curve

γ=Pschyremeter constant

E, E_o, E_a, f represents evaporation, c, h, d are constants, some of these depending upon humidity.

The details of the constants and the examples of the use of these formulae are available in all textbooks on Irrigation and Hydrology.

Actual Recording of Evaporation in Pans in West Pakistan

True evaporation can only be recorded at a big natural stretch of water such as a lake or a storage pond. This determination, however, presents many indeterminate factors such as the seepage, inflow outflow, rainfall etc. which make the estimate very difficult and often approximate. Unless the site possess special facilities of observation, resort has often been made to small pans of various dimensions and depths, located under known conditions. The interrelation of their records, to represent the true evaporation has become a problem. However, the adoption of a standard pan called class 'A' pan of America is helpful to find out true evaporation by using coefficient which have been found to hold true. In our country all observations collected by WASID of WAPDA are by the class 'A' Pan. This data can be converted to give evaporation from a lake type reservoir.

At Niazbeg Field Research Station recording of evaporation has been in progress since 1960. In the beginning a Colorado type sunken pan, 3 ft. × 3 ft and 1.5 ft. deep was installed in 1960. Class 'A' pan was added in 1962 and a lake type pan 12 ft. diameter and 5 ft. depth was added in 1963. Evaporation from all these pans are being observed regularly.

The type of pan used at Kurrum Garhi was Colorado Sunken Pan. Recently 10 ft. diameter floating pan has been used on the reservoir itself.

The Meteorological Department at Lahore is observing evaporation in a 4×4 ft. sunken type pan with 18 inches deep water. Evaporation is also being recorded in the Directorate of Land Reclamation since 1941 in a lake type pan of 16 ft. diameter and 6.5 ft. depth.

Some data was collected at Lyallpur but its accuracy is doubtful.

Inter-relation of results of different types and sizes of pans

Much work has been done in America to interrelate the results obtained from various types of pans and to compute the true order of evaporation corresponding to that from a big span of water. Henery Oliver[2] has included in his book a detailed discussion on the pan variables which affects the evaporation. Table No. 3 is reproduced from this book. It can be used to determine the true lake evaporation from the data of various sizes and types of pans.

The variation of evaporation with size of pan diameter is illustrated in Fig. 2. With 12 ft. diameter of pan the evaporation is 1.1 time the lake evaporation. Some other authorities[3] have, however, stated that for this size the factor is one.

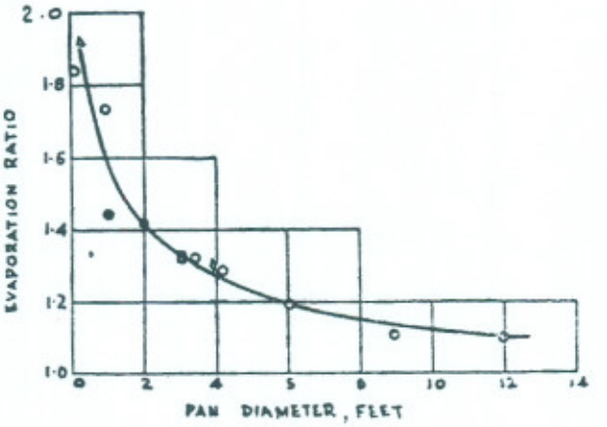


Fig. 2.—Variation of Coefficients with pan Diamete

○ Observations by Selight
◇ Observations by Rohwer
● Observations by Tomlinson
□ Observations by Keeling
△ Observations by Millar

Evaporation Ratio is Referred to Rohwer's 1,800 acre reservoir as unity

The colour of paint of a pan effects the rate of evaporation. A pan of galvanized iron is taken as a standard and those made of other metals or having different paints are compared with it. A pan painted black or made of copper, gives a high order of evaporation as compared to a pan made of galvanized iron. The coefficients for other paints are usually less than one which is taken as a standard for a pan of galvanized iron. Affects of depth of pan, its rim height or shelter of top screen have also been recorded. It is known that class A pan which is kept some distance above surface gives a high order of evaporation than a lake, so that its coefficient is low. Results with sunken type pan are closer to lake evaporation and its coefficient is high.

The evaporation from a floating pan kept on the surface of water has also been compared with a pan kept on the bank of a lake.

Recently Albertson[9] has studied the effects of laminar and turbulent flow of wind on evaporation and its inter-relations with the two conditions had been determined.

At Niazbeg Field Research Station, the actual evaporation recorded by Colorado sunken pan, class A pan and lake type pan during each month is given in Table No. 4. Using the mean annual pan coefficient as determined by various authorities mentioned in Table No. 3, lake evaporation was worked out. This is given in Table No. 6. A checking of the coefficient of a lake type and class A pan for Niazbeg data gave the mean annual coefficient equal to 0.709. It is very close to that determined by other authorities. The variation of this coefficient month by month is shown in Table No. 5.

It is interesting to note that besides the size of a pan and its other constructional conditions as already mentioned, its location and environments also effects the evaporation. An example is that of evaporation being recorded at Land Reclamation Laboratories, in Meteorological Office on Gulberg Road, Lahore and at Niazbeg. Comparative results of mean evaporation for these three sites situated in Lahore for the years 1960 to 1964 are given in Table No. 7. The pan at Meteorological Office is 4×4 ft. and is sunken so that a coefficient of 0.87 was used to compare its results with D.L.R. or Niazbeg for which no coefficient was used.

There is considerable variation in the results of the three sites although situated so close. Niazbeg is in the open. It has always a lower temperature and greater wind velocity, than the Meteorological Office which is surrounded by buildings.

Development of an Evaporation Formula on the basis of Niazbeg Data

A perusal of the information given in the note will show that if mean daily temperature, sun-shine hours, mean humidity, barometric and vapour pressure and wind velocity, are known for a site, it is possible to work out the evaporation by the use of Blaney Criddle, Penman, Rohwer and Hargreaves formulae. In case of Blaney Criddle, humidity and wind velocity is not made use of. In case of Penman, wind velocity is given weight and humidity enters indirectly when the value of e_s and e_d are used. The effect of temperature is indirectly taken care of while using these factors.

In case of Hargreaves direct use of humidity is not made nor that of the sun-shine hours. While using Rohwer relation, wind velocity is the main factor. The use of factors e_s and e_d is the same in all relations.

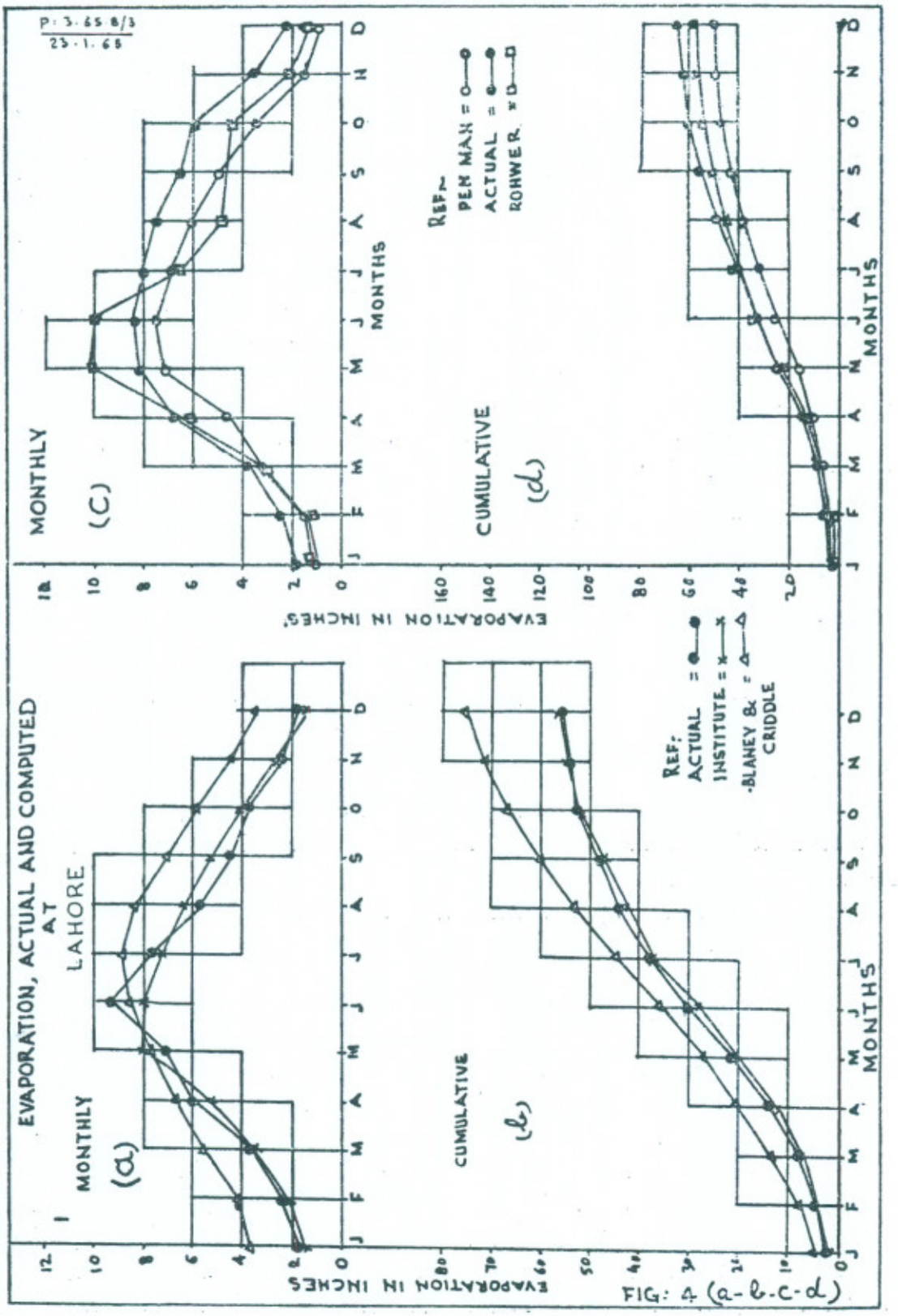

P: 3.65.8/3
23.1.65
EVAPORATION, ACTUAL AND COMPUTED AT LAHORE
MONTHLY
(a)
CUMULATIVE
(b)
MONTHLY
(c)
CUMULATIVE
(d)
EVAPORATION IN INCHES
MONTHS
J F M A M J J A S O N D
REF:
ACTUAL = ●—●
INSTITUTE = ×—×
BLANEY & CRIDDLE = △—△
REF:
PEN MAN = ○—○
ACTUAL = ●—●
ROHWER = □—□
FIG: 4 (a-b-c-d)

Fig. 4.—*a, b, c, d.*

When the pans were installed at Niazbeg recording of maximum/minimum temperature, dry and wet bulbs temperature and wind velocity was started to be noted. Daily mean temperature and % mean humidity at 8.00 A.M. was worked out. The mean daily percentage of sun-shine hours for the latitude of Lahore was noted from the tables given in all books[4] dealing with the subject of meteorology. This is reproduced in this note also as Table No. 2. Using these parameters monthly evaporation was worked out by Blaney Criddle formula. The data given in Revelle Report,[10] in which monthly potential evaporation is estimated by Penman and Rohwer relations, were noted. As noon humidity was not available Hargreaves relation was not made use of. All these estimates were compared with the actual observed evaporation at Niazbeg. It was noted that none of the formule gave results close enough to the actual. Next an attempt was made to use the mean monthly sun-shine hours, the mean monthly temperature and mean percentage humidity in a relation of the type:—

$$E=\phi\frac{P}{H}(t-32)$$

in which E was evaporation in inches.

ϕ was a constant taken equal to 0.879.

P was mean monthly % sun-shine hours.

H was mean monthly humidity observed at 8.00 A.M.

t was mean monthly temperature in °F.

The evaporation results thus obtained were very satisfactory. These compared closely to the actual as are shown in Table No. 8, the calculated results are also compared with those worked out by the three well known formulae. These are shown in Fig. 4 (abcd), both in the form of monthly variable and cumulative values. The agreement of the calculated results and the observed one is very close.

Evaluation of f.w.s. evaporation for West Pakistan

West Pakistan is a big country with considerable variation of meteorological factors varying from place to place. Certain sites are located at high elevations and possess low temperature throughout the year, others are close to sea and has its influence. There are large areas which are very dry with little precipitation while some have a fair quantity of rainfall. Thus f.w.s. evaporation must vary from site to site. It was decided to estimate it for as many sites as possible. There were 51 sites for which the meteorological parameters could be collected to work out the evaporation. Out of these, 19 sites were such, for which actual observed evaporation was also available.

The meteorological constants of the authors formula and that of Blaney Criddle are such which are determined at each observational centre, other parametres used in Penman, Rohwer, Hargreaves are not generally available.

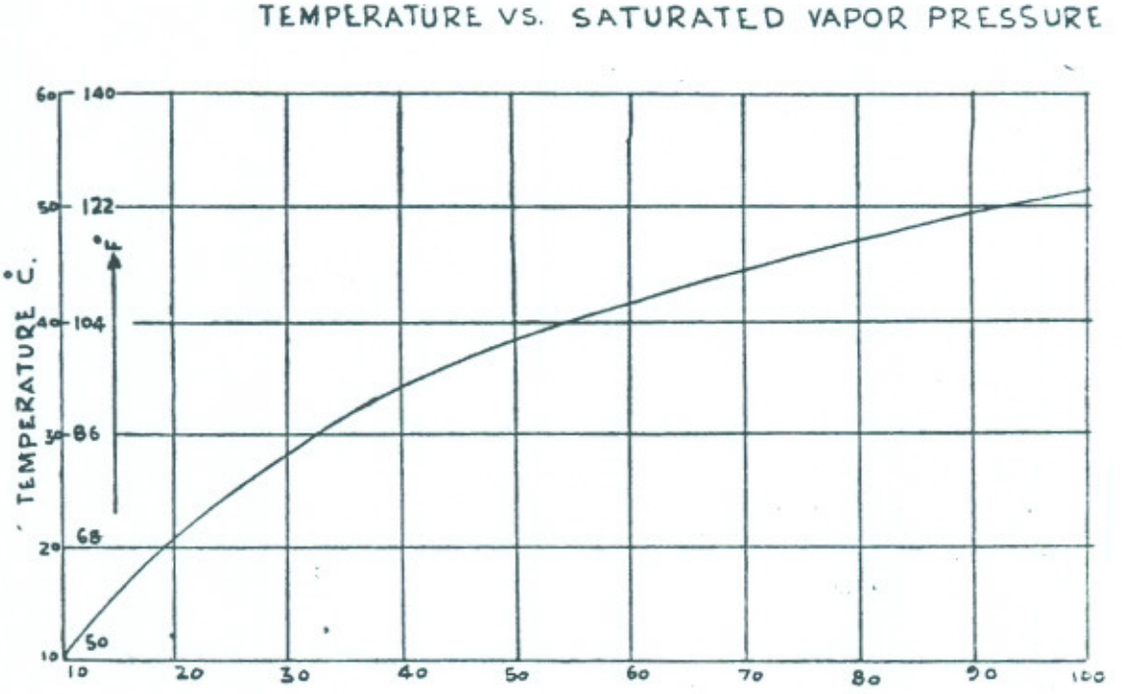


Fig. 5.—Saturated vapor pressure (e_s) m.m. of HG.

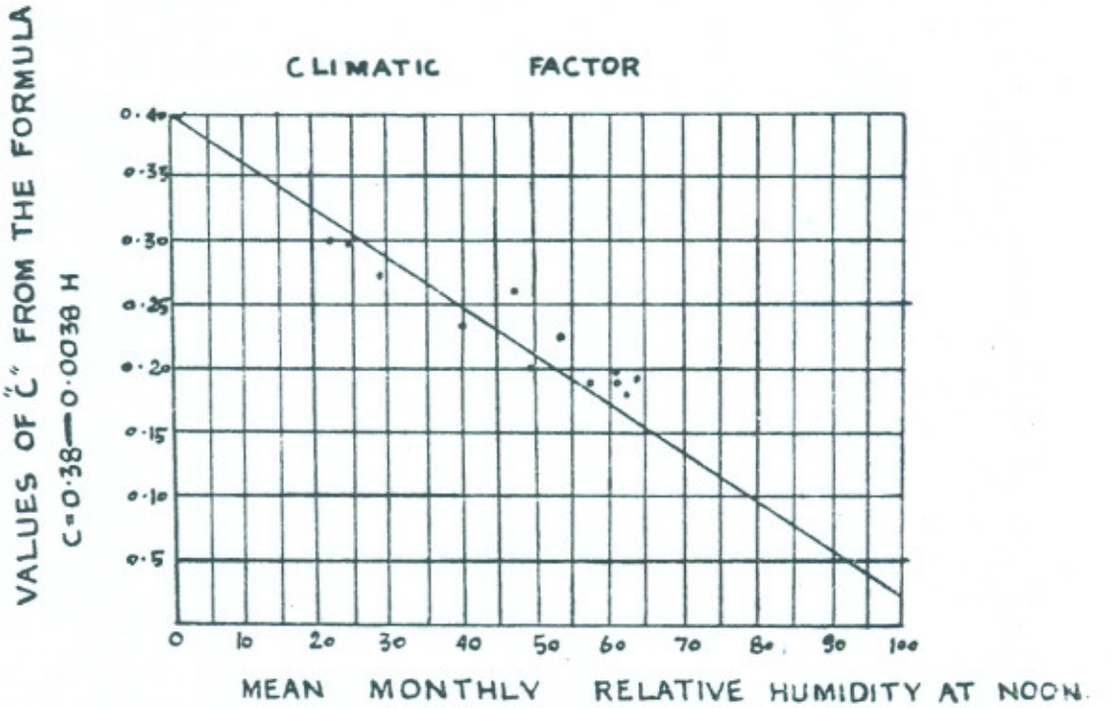


Fig. 1.—Determination of Climatic Factor "C" from mean percentage humidity observed at noon after Hargreaves

Hence for all these 51 stations, whereas evaporation could be worked out by the authors and B.C. formulae it was not possible to use the rest three formulae at all sites.

In the calculation e_s was taken from the standard curve shown in Fig. 5; using percentage humidity, e_d was determined as explained already. Similarly c and d, the constants of Hargreaves formulae were recorded from his own calculations as adopted in Fig. 1. It is plotted between % humidity and the factor c. Table 1 gives calculated mean monthly day time co-efficient, d for various latitudes. For the convenience of calculations all available meteorological constants were recorded for each station in tables. These however are not given in the paper but are available in the main report.

The evaporation was worked out for each month of the year. These results for all the 51 sites are not given in the paper. Only the plotted results for Mangla, Terbela, Hub and Baran Dam are given in Fig. Nos. 6/1, 6/2, 6/3 and 6/4 a and b. In this paper mean annual evaporation for 51 stations is given in Table No. 9. The monthly evaporation is however available in the actual report prepared on the study.

Fig. 6/1

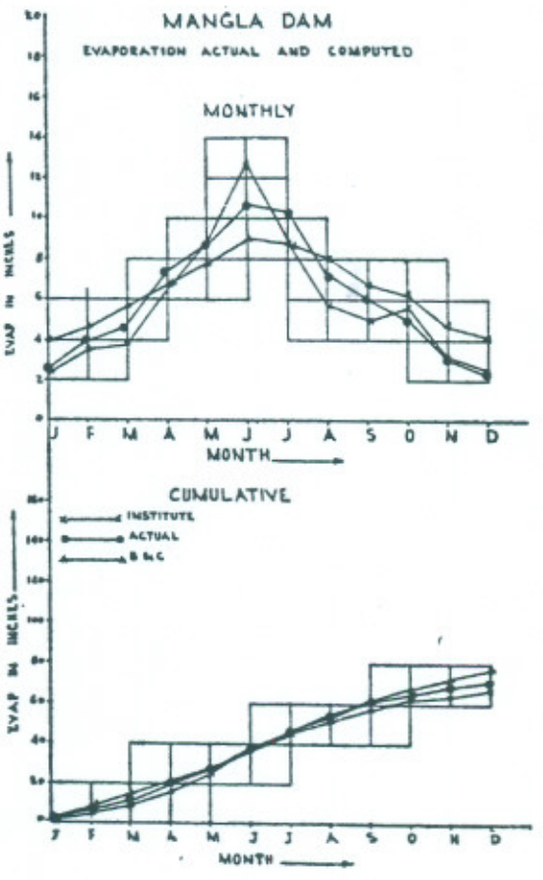


Fig. 6/2

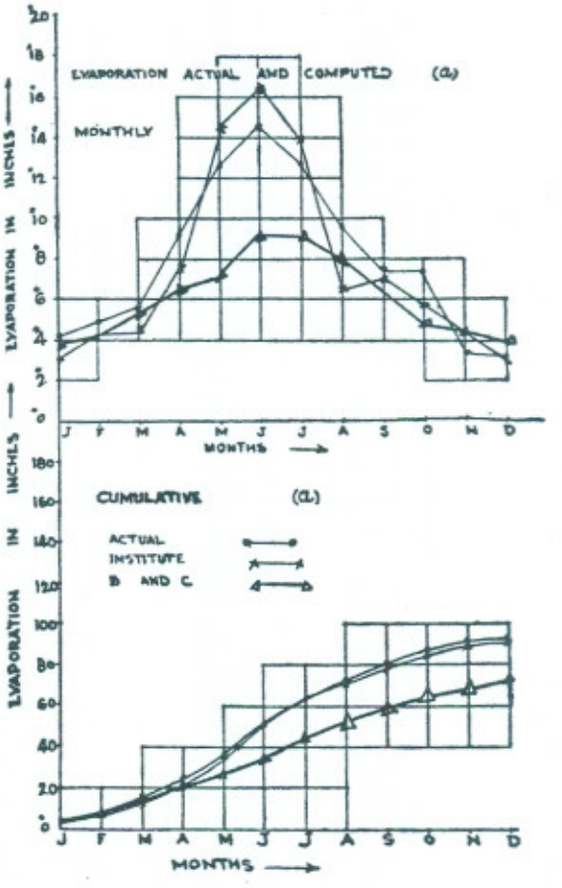


Fig. 6/3

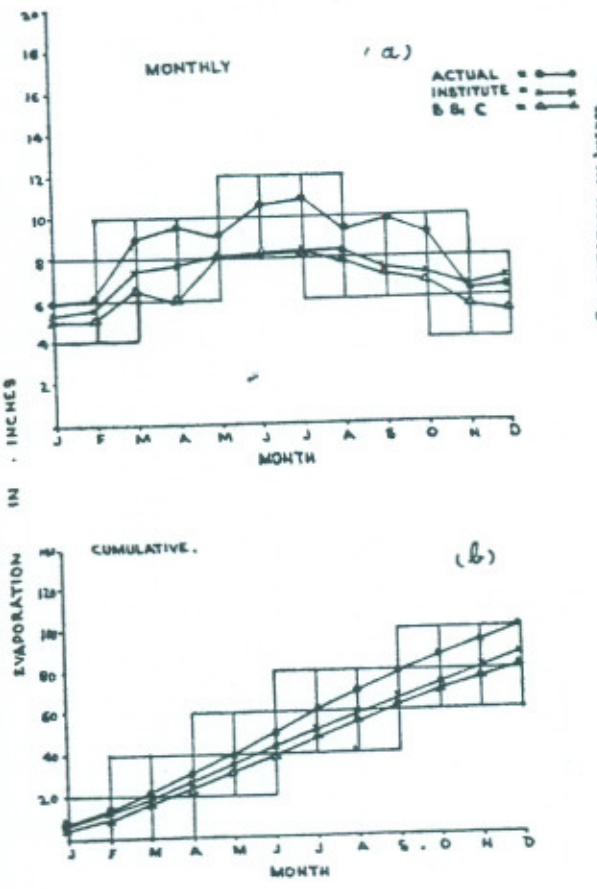
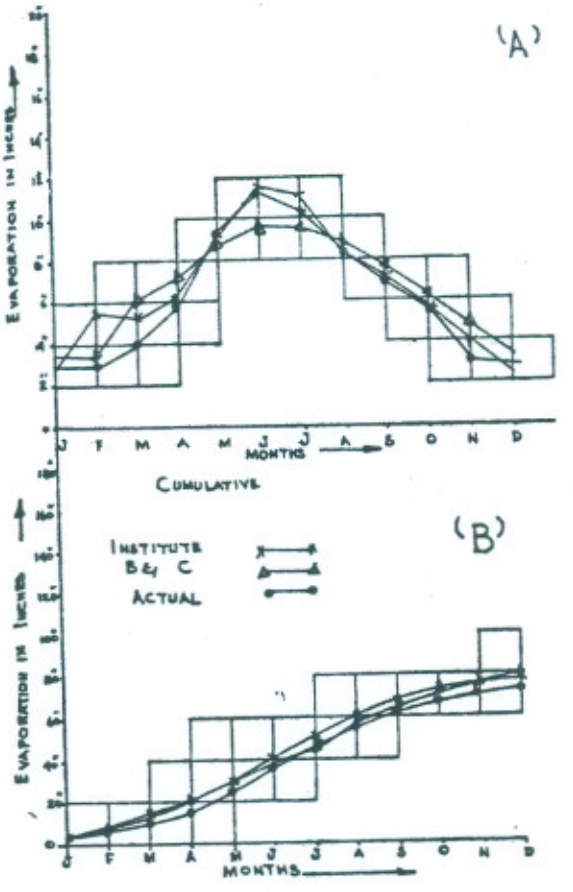


Fig. 6/4



Author's formulas give results closer to observed ones

In Fig. 7 actually observed lake evaporation is plotted against that calculated by author's formula for 19 stations in West Pakistan. The points all lie on a straight line proving the best fit. There is, however, some variation but it is due to the use of available data. In the calculations mean daily temperature is taken as mean of maximum and minimum temperature. Actually it often happens that on some day the temperature touches the maximum value only for a very short time and on another day it may remain at a high level for much longer period. Although the mean temperature will be the same in the two cases but the heat intensity causing evaporation will differ.

Again the percentage sun-shine hours is taken from the table of Latitudes but the actual fact is that each site has its own sun-shine hours. Two sites on the same latitude may not necessarily have the same sun-shine hours. One may remain more cloudy than the other.

Similarly we have supposed the morning record of humidity to present the mean daily humidity. It may not hold for all sites. Altitude and wind

velocity also, do effect the evaporation, but their affect is included in the co-efficient.

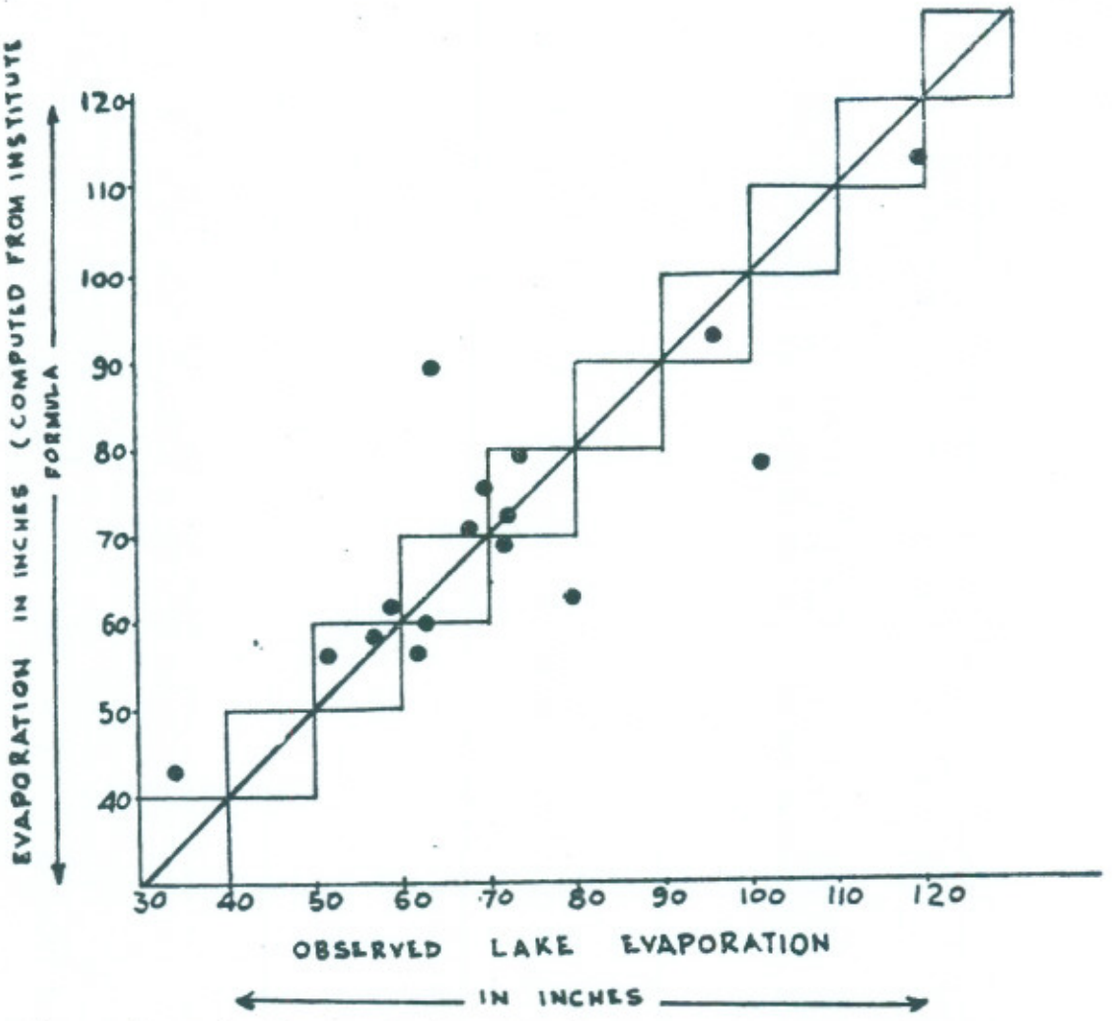


Fig. 7.—Comparison between the observed and computed evaporation at Different station

It may, however, be noted that the above stated meteorological parametres are not generally observed. Only those which are easily observed and are available for each site, are made use of in the formulae and closeness of fit of the results enhances its usefulness.

Evaporation contours of West Pakistan

So far we have some information of f.w.s. evaporation at individual sites. With the further utilization of water resources of the country small and big storages are being constructed and some are under planning stages. An estimate of f.w.s. evaporation from storage or barrages where these are proposed to be located, can be useful. With this ends in view evaporation contours are plotted for the whole of West Pakistan utilizing the calculated evaporation by

the author's formula for 51 stations in the country. Three types of maps are prepared. There are twelve maps in which monthly evaporation is recorded, two maps give the evaporation during the six summer months from first April to end of September and for the same period during the next winter months beginning first October to 31st of March. Another map depicts the annual evaporation in West Pakistan. In this paper annual and six monthly maps are only given in Figs. 3a, b and c.

A study of these maps leads to very useful results. There are some sites in West Pakistan which record very high order of potential evaporation throughout the year. Generally this order persists even during winter months. The regions of high f.w.s. evaporation are:—

	Site	Evaporation from f.w.s. in inches		
		Annual Max.	Kharif Max.	Rabi Max.
	Darwat near Hyderabad and Hub Dam Site ..	108	57.1	51.2
2.	Sibi ..	100.6	68.3	32.2
3.	Nokkundi ..	95.4	68.1	27.3
4.	Tarbela ..	92.7	66.9	25.9

Darwat is the highest f.w.s. evaporation site and it remains high even during winter. Sibi follows Darwat. Here winter evaporation is also high. Tarbela is the fourth among the high order f.w.s. evaporation sites in West Pakistan.

The lowest f.w.s. evaporation takes place at Murree followed by the sites located at high elevations in the ranges of Suleiman mountains such as Kalat, Quetta, Fort Sandeman, Wana, Parachinar, Dir and Drosh. The range of their annual f.w.s. evaporation is 50 inches.

During the summer six months the f.w.s. evaporation from these sites is 40 inches, the rest 10 inches is in the six winter months. Annual f.w.s. evaporation in the irrigated areas of the Punjab lies between 60 to 70 inches. This order persists in the Sukkur Region as well. Lahore and Sheikhupura Districts are low order evaporation zones, so that the annual evaporation at Lahore is 56 inches only. In the irrigated regions, the high order evaporation

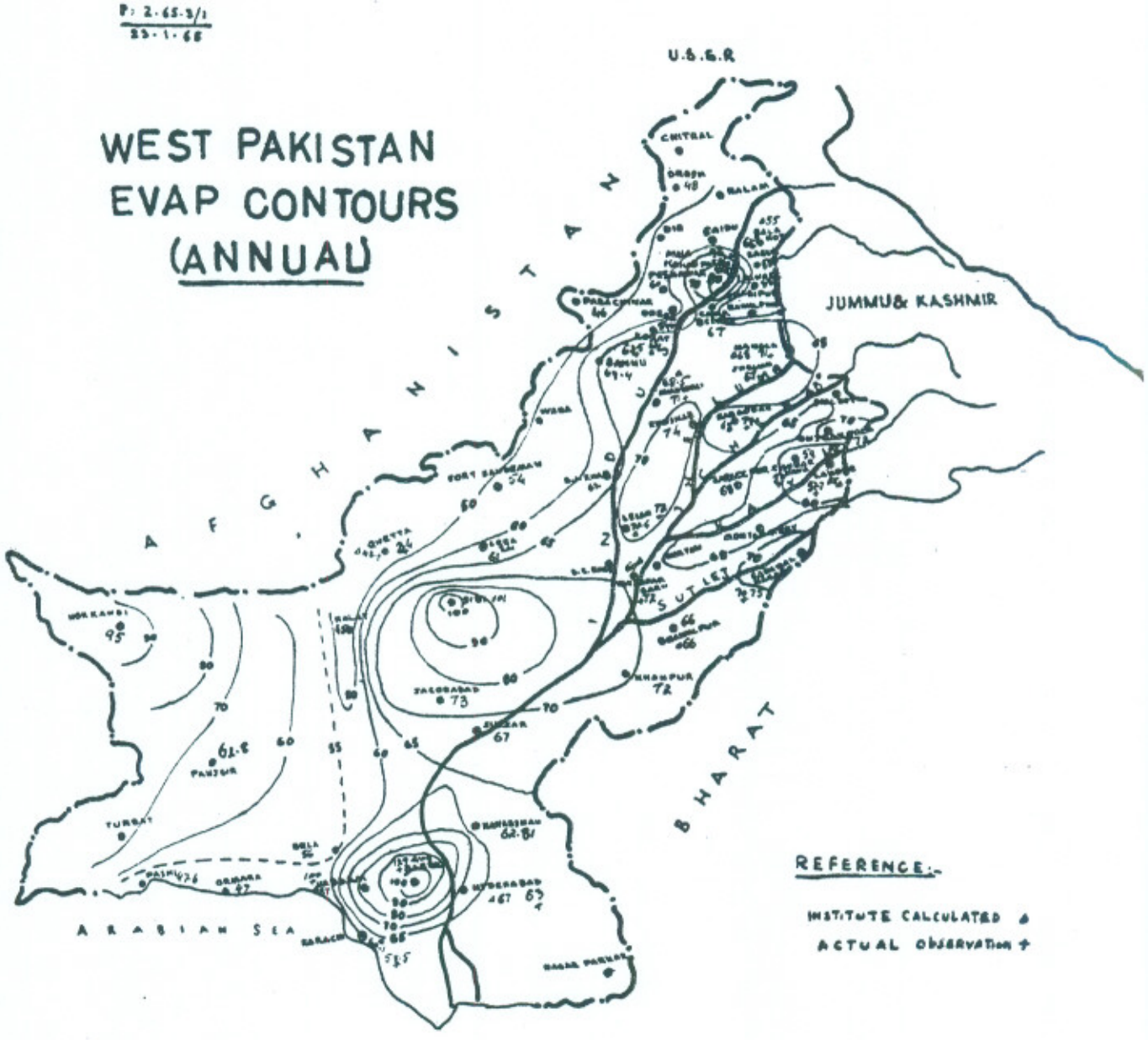

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23.1.68
WEST PAKISTAN
EVAP CONTOURS
(ANNUAL)
U.S.S.R
JUMMU& KASHMIR
AFGHANISTAN
BHARAT
ARABIAN SEA
REFERENCE:-
INSTITUTE CALCULATED Δ
ACTUAL OBSERVATION +

Fig 3—*a*

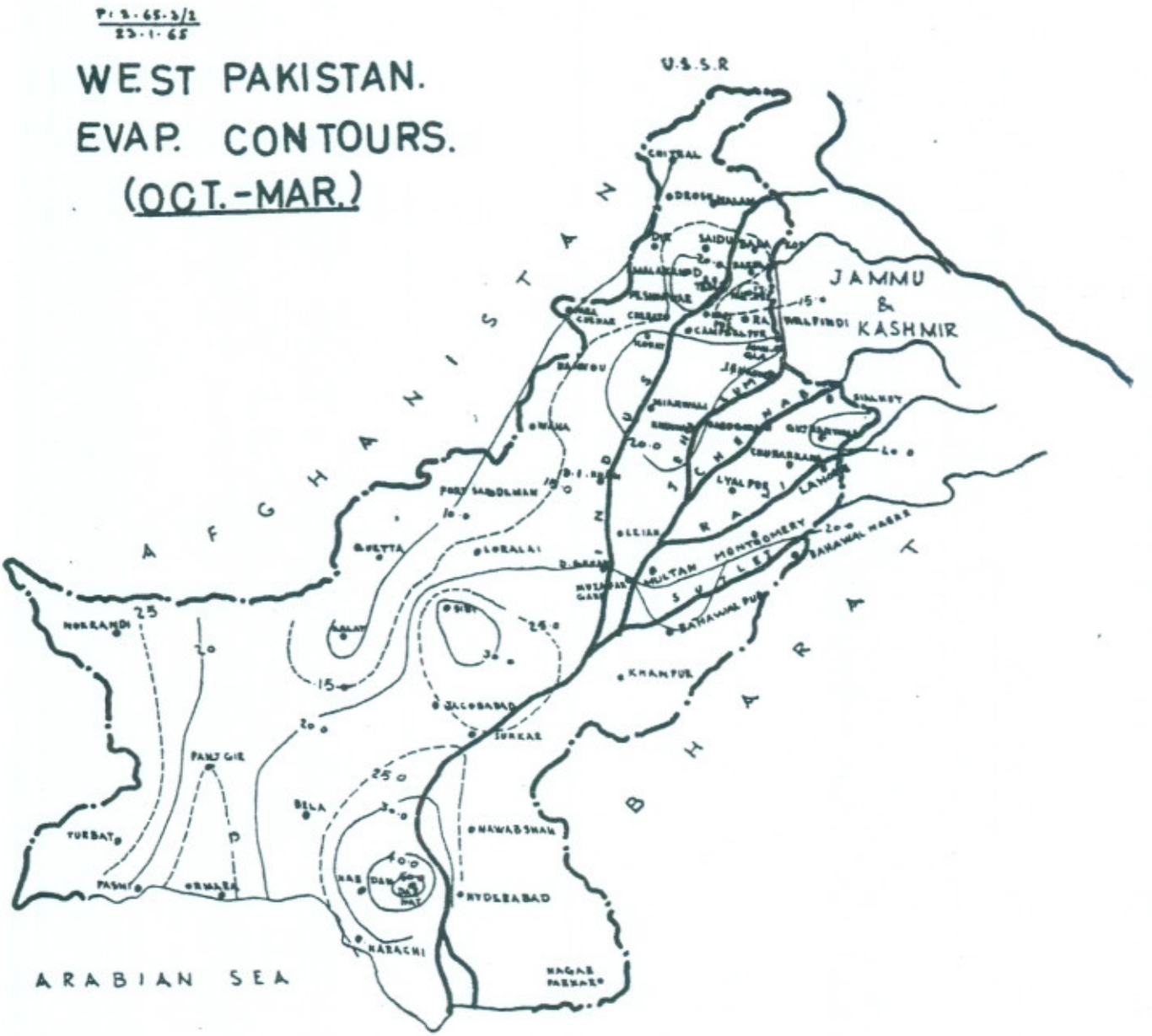

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23-1-65
WEST PAKISTAN.
EVAP. CONTOURS.
(OCT.-MAR.)
U.S.S.R
AFGHANISTAN
JAMMU & KASHMIR
BHARAT
ARABIAN SEA
CHITRAL
DROSH
SAIDU SHARIF
DIR
SWABI
PESHAWAR
RAWALPINDI
JHELUM
SIALKOT
GUJRANWALA
LYALLPUR
LAHORE
MONTGOMERY
SAHIWAL
MULTAN
BAHAWALPUR
KHANPUR
SUKKUR
JACOBABAD
QUETTA
LORALAI
PORT SANDEMAN
NOKKUNDI
PANJGUR
TURBAT
PASNI
ORMARA
BELA
LASBELA
NAWABSHAH
HYDERABAD
KARACHI
KHARAN
NAGAR PARKAR

Fig 3—*b*

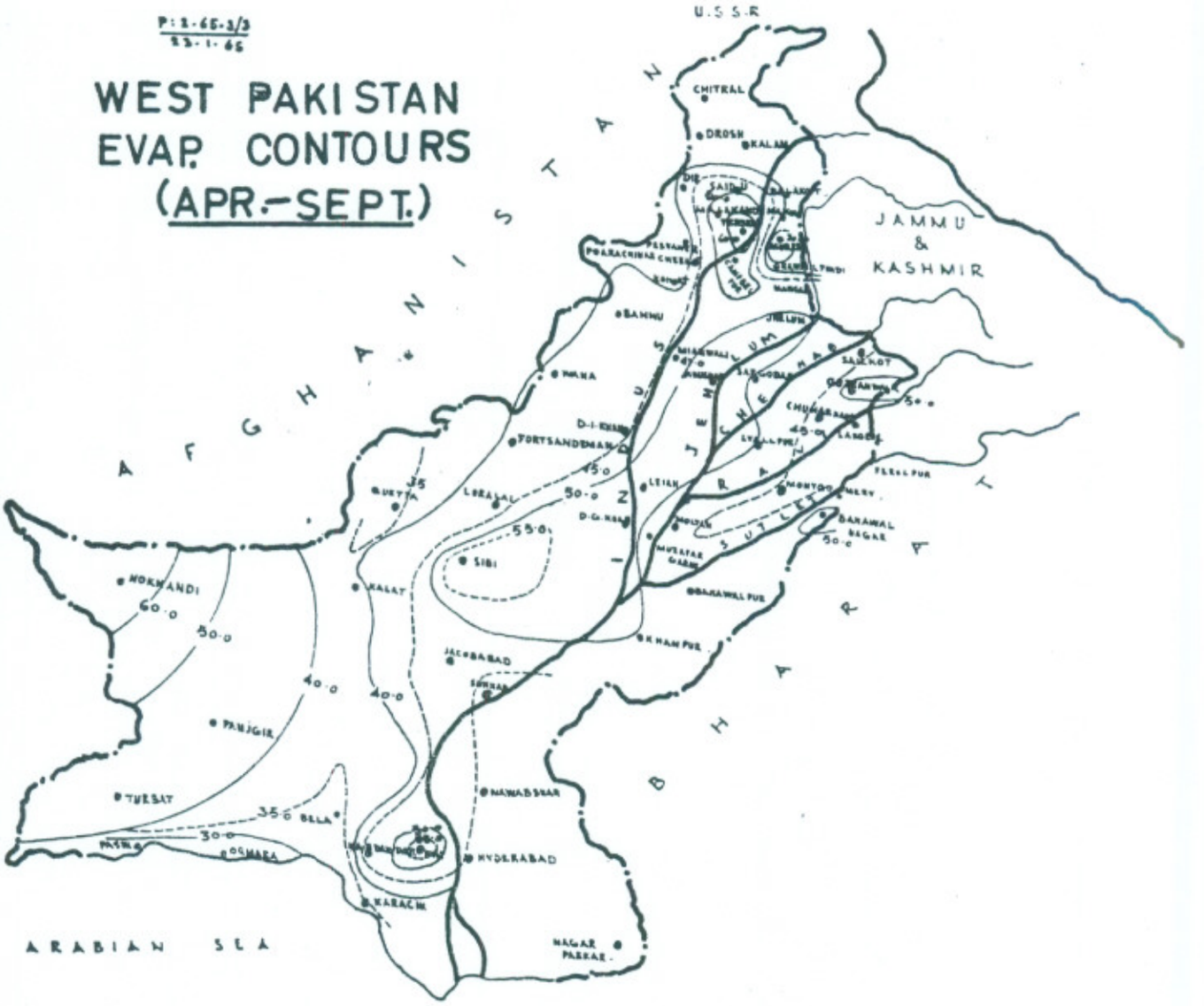

P:E-65-3/3
23-1-65
WEST PAKISTAN
EVAP. CONTOURS
(APR.-SEPT.)
U.S.S.R
AFGHANISTAN
CHITRAL
DROSH
JAMMU
&
KASHMIR
BANNU
MIANWALI
SARGODHA
SIALKOT
FORTSANDEMAN
QUETTA
LORALAI
SIBI
KALAT
LEIAH
MONTGOMERY
FEROZEPUR
BAHAWALNAGAR
BAHAWALPUR
KHANPUR
JACOBABAD
SUKKUR
NOKKUNDI
PANJGIR
TURBAT
BELA
PASNI
GWADAR
NAWABSHAH
HYDERABAD
KARACHI
NAGAR PARKAR
ARABIAN SEA
INDIA
60·0
50·0
40·0
35·0
30·0
55·0
45·0

Fig 3—*c*

zones are those of Bahawal Nagar, Khanpur, Jacobabad, Leiah and Muzaffargarh. During winter six months, the irrigated areas of the Punjab and Bahawalpur evaporate 20 inches and less. Bahawal Nagar and Khanpur again being toward the high order. Below Sukkur the free water surface evaporation in winter months increases to 25 and 30 inches rising to 51 inches at Darwat. Hyderabad and right side area of Ghulam Mohammad Barrage lie within a range of 30 to 40 inches of evaporation during winter.

The regions along the coast of Las Bela and Mekran in Baluchistan are of low order evaporation nearly equal to Quetta—Kalat area. It remains nearly the same throughout the year, the range for Kharif and Rabi periods being 30 and 20 inches.

A study of monthly evaporation contours similarly leads to very useful informative results but these are not discussed in this paper.

An estimate of loss of water from free water surface storage and ponds

The free water surface evaporation maps are useful for estimating the water which is lost from storage during Kharif, Rabi seasons and during the full year. Besides the reservoirs there are 15 to 17 Headworks where water is ponded to feed the canals. Very often the effect of pond extends to several miles upstream of the headworks. During winter in particular when the water is very precious, the smooth quite water surface of pond extends to many miles upstream of a head regulator.

Mangla storage will have a surface area of 75,000 acres or 117.2 sq. miles. Its annual loss will be 68 inches per unit area or 587.12 cusecs from the exposed surface. Tarbela on the other hand has 93 inches of annual evaporation and its 93.75 sq. mile of surface will lose 642.19 cusecs. (See Table No. 10).

Another such site is Kalari lake with surface area of 60 sq. mile and with 90 inches of annual evaporation. It loses 397.8 cusecs. Baran Dam with the present 0.3 sq. mile of surface area and 69 inches annual evaporation loses 1.53 cusecs. At its full development it will have 3 sq. miles of surface area and the loss will increase to 15.3 cusecs.

In Table No. 10 we have given the loss of water in cusecs per sq. mile from the probable and the existing storages. In this table annual loss and Rabi/Kharif loss in inches is also given. Knowing the surface area of the reservoir, evaporation expected can be worked out. Similarly in Table 11 evaporation from Barrages is given. Here also the loss is worked out in terms of cusecs per sq. mile. Knowing the pond area the total loss can be estimated.

Measures to reduce the loss

This report is the first of its kind giving a picture of the amount of water being lost from the free exposed water surfaces. If some effective measure is possible to reduce this loss, perhaps by the use of chemicals which produce mono-molecular[10] film on the surface of water, we may save 50 to 70 per cent of this water. This technique shall have to be actively utilized in the country in the future.

MAIN CONCLUSIONS

1. An estimate of evaporation from free water surface has been carried out for 51 stations in West Pakistan.
2. It is based upon the use of Penman, Rohwer, Blaney Criddle, Hargreaves and a formula developed by the authors. It is noted that this formula gives results closer to the actual measurements followed by Blaney Criddle. The estimate of evaporation with other formulae is not so close to the observed value. Comparative results of evaporation are put forth for 18 stations in West Pakistan for which the actual evaporation data are available. Figures for only four stations have been given.
3. On the basis of authors formula called the Institute formula, monthly, six monthly, and annual evaporation contours are plotted for West Pakistan. These are utilized to work out the loss of water by evaporation from the presently existing storages such as Warsak, Kurram Garhi, Rawal, Kalari lake and those to be constructed such as Mangla and Tarbela dam. An estimate of water lost per sq. mile of pond surface annually for 15 headworks of West Pakistan is also given.
4. This study points to the development of some measure to reduce evaporation and to conserve water from free water surface.

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TABLE NO. 1

Calculated Monthly day time Coefficients (d) for various latitudes after Hargreaves formula

North Latitude in degrees	January	February	March	April	May	June	July	August	September	October	November	December
5	1.01	0.91	1.02	0.99	1.03	1.00	1.03	1.03	0.98	1.02	0.98	1.00
10	0.98	0.89	1.02	1.01	1.05	1.03	1.06	1.05	0.99	1.00	0.95	0.97
15	0.96	0.88	1.01	1.01	1.08	1.06	1.08	1.06	0.99	0.99	0.93	0.95
20	0.93	0.87	1.01	1.02	1.10	1.08	1.11	1.08	0.99	0.98	0.91	0.92
25	0.91	0.86	1.01	1.03	1.12	1.11	1.13	1.09	1.00	0.97	0.89	0.89
30	0.88	0.84	1.00	1.05	1.14	1.14	1.16	1.11	1.00	0.96	0.86	0.86
35	0.85	0.83	1.00	1.06	1.17	1.17	1.19	1.12	1.00	0.94	0.84	0.82
40	0.81	0.81	1.00	1.08	1.20	1.21	1.23	1.14	1.01	0.93	0.81	0.78
45	0.77	0.79	0.99	1.09	1.24	1.26	1.27	1.17	1.01	0.91	0.77	0.74
50	0.72	0.76	0.99	1.11	1.28	1.32	1.32	1.20	1.01	0.89	0.73	0.68

TABLE No. 2

Monthly percentage of day time hours of the year, latitudes 26° to 40° North of the Equator

Latitudes	25	26	28	30	32	34	36	37	38	39	40
January ..	7.53	7.49	7.40	7.30	7.20	7.10	6.99	6.93	6.87	6.80	6.70
February ..	7.14	7.12	7.02	7.03	6.97	6.91	6.86	6.83	6.79	6.76	6.73
March ..	8.39	8.40	8.39	8.38	8.37	8.36	8.35	8.34	8.34	8.32	8.30
April ..	8.61	8.64	8.68	8.72	8.72	8.80	8.85	8.88	8.90	8.91	8.92
May ..	9.33	9.37	9.46	9.53	9.63	9.72	9.81	9.96	9.92	9.96	9.99
June ..	9.23	9.30	9.38	9.49	9.60	9.70	9.83	9.89	9.95	10.02	10.08
July ..	9.45	9.49	9.58	9.67	9.77	9.88	9.99	10.04	10.10	10.22	10.34
August ..	9.09	9.10	9.16	9.22	9.28	9.33	9.40	9.44	9.47	9.52	9.56
September ..	8.32	8.32	8.32	8.34	8.34	8.36	8.36	8.37	8.38	8.40	8.41
October ..	8.09	8.06	8.02	7.99	7.93	7.90	7.85	7.82	7.80	7.79	7.78
November ..	7.40	7.36	7.27	7.19	7.11	7.02	6.92	6.87	6.82	6.78	6.73
December ..	7.42	7.35	7.27	7.14	7.05	6.92	6.79	6.72	6.66	6.66	6.53

TABLE NO. 3

Summary of Conversion Co-efficients for Reducing Pan Evaporation to Equivalent Reservoir Evaporation

Pan No.	Pan Type and Size	AUTHORITY									Means Coefficient
		A	B	C	D	E	F	G	H	I	
1	Land: Circ. 4′×10″ (Class A).	.70	.69	.70	.70	.77	.77	.67	.69	.69	.71
2	Ground: Circ. 6′×2′ (Plant Industry).	.94	—	—	—	—	.94	—	.91	.94	.93
3	Sunk: Sq. 3′×18″ (Colorado).	.79	.75	.79	.78	—	.89	—	.81	—	.80
4.	Floating: Sq. 3′×18″	.89	—	.77	.80	—	—	—	.80	.83	.82
5	Floating: Circ. 4′×10″	—	.78	—	—	—	—	—	.88	.82	.83
6	Sunk: Circ. 2′×3′	.78	—	—	—	.98	.97	—	—	—	.91

Authorities

A	Sleight	D	Sub Committee	G	White
B	Rohwer	E	Young	H	Hall
C	Rohwer	F	Young	I	Follansbee.

TABLE NO. 4

Evaporation from various pans installed at Niazbeg—Period 1960 *to* 1964 (*in inches*)

Month	Colorado Sunken type pan (3′ × 3′ × 1½′)					U.S.A. Class A pan (3′ dia × 10″ depth)			Lake type pan (12′ dia × 5′ depth)	
	1960	1961	1962	1963	1964	1962	1963	1964	1963	1964
January ..	1.39	1.47	2.42	2.03	1.64	2.27	2.58	2.29	2.00	1.97
February ..	2.92	1.77	2.18	2.88	1.808	3.00	3.52	2.01	2.48	1.87
March ..	4.49	3.32	4.16	4.96	4.12	4.74	5.93	3.89	4.48	3.65
April ..	7.35	5.06	6.76	7.00	5.09	8.86	8.64	5.70	5.37	5.72
May ..	10.05	8.16	10.01	9.06	6.51	11.64	10.91	8.75	7.08	7.75
June ..	10.23	8.94	10.43	9.95	6.67	13.90	12.79	8.25	8.10	5.16
July ..	6.51	5.89	8.73	9.96	5.92	11.12	9.25	7.08	7.28	3.80
August ..	5.98	5.79	6.18	6.97	6.40	8.01	8.52	6.80	5.91	4.30
September ..	5.37	4.12	4.54	6.56	5.29	6.15	6.70	5.84	5.09	4.52
October ..	4.67	4.88	5.46	5.49	4.82	5.03	5.77	5.85	3.90	4.48
November ..	3.70	3.24	2.99	3.18	3.54	3.32	3.52	3.57	2.80	2.97
December ..	2.16	2.09	1.78	1.88	2.54	2.05	2.50	2.79	1.90	1.94
Total ..	64.82	54.73	85.11	68.95	54.35	80.09	80.63	60.22	56.97	48.93

TABLE NO. 5

Evaluation of Coefficient of Class 'A' pan from Observed Evaporation in Lake type pan at Niazbeg—Year of Observation 1963-64

Month		Evap. in inches from Class A pan	Evap. in inches from Lake type	Co-efficient
January	..	2.65	1.99	.751
February	..	2.70	2.17	.804
March	..	4.91	4.06	.827
April	..	7.17	5.56	.773
May	..	9.56	7.22	.755
June	..	10.52	6.63	.630
July	..	8.20	5.54	.675
August	..	7.66	5.10	.665
September	..	6.32	4.50	.759
October	..	5.82	4.19	.720
November	..	4.52	2.89	.639
December	..	2.66	2.89	.639
Total	..	72.69	51.54	Mean 0.709

TABLE No. 6

Lake Evaporation at Niazbeg. Computed from different pans, in inches

Month	Colorado pan (0.78 coefficient)					Class 'A' Pan, 0.70 Coeff.			Lake type pan		Mean
	1960	1961	1962	1963	1964	1962	1963	1964	1963	1964	
January ..	1.08	1.15	1.89	1.58	1.15	1.59	1.81	1.60	2.00	1.97	1.98
February ..	2.27	1.38	1.50	2.25	1.27	2.10	2.40	1.41	2.48	1.87	1.80
March ..	3.50	2.59	3.24	3.88	2.88	3.22	4.15	2.72	4.48	3.65	2.62
April ..	5.70	3.95	5.28	5.46	3.56	6.21	5.85	3.99	5.37	5.72	5.07
May ..	7.83	6.36	7.82	7.07	4.56	8.15	7.63	6.12	7.08	7.75	7.04
June ..	7.98	6.97	8.14	7.77	4.67	9.73	8.95	5.77	8.10	5.16	7.33
July ..	5.07	4.59	6.81	7.07	4.14	7.79	6.47	4.96	7.28	3.80	5.07
August ..	4.66	4.52	4.82	5.44	4.48	5.61	4.56	4.76	5.91	4.30	4.72
September ..	4.18	3.21	3.54	5.12	3.70	4.31	4.69	4.09	5.09	4.52	5.13
October ..	3.64	3.80	4.26	4.29	3.37	3.52	4.04	4.10	3.90	4.48	3.97
November ..	2.88	2.52	2.34	2.48	2.48	2.33	2.46	2.49	2.88	2.97	2.58
December ..	1.66	1.63	1.39	1.47	1.78	1.44	1.75	1.95	1.90	1.94	1.69
Total ..	50.45	42.67	51.03	53.90	38.04	56.00	54.82	43.91	56.39	48.07	48.60

TABLE NO. 7

Mean Monthly and Annual Evaporation at three sites at Lahore from 1960-1964

(*in inches*)

Month		Niazbeg Station	D.L.R. Station	Meteorology Office
January	..	1.58	2.23	1.41
February	..	1.80	2.09	1.72
March	..	2.62	3.42	3.13
April	..	5.07	5.39	4.34
May	..	7.04	5.98	5.54
June	..	7.33	8.60	6.10
July	..	5.07	6.98	5.12
August	..	4.72	4.65	4.49
September	..	5.13	5.07	3.95
October	..	3.97	4.73	2.67
November	..	2.58	3.26	2.17
December	..	1.69	2.27	1.43
Total	..	48.60	54.67	42.07

Note.—The data of meteorological station has been computed using Pan Coefficient equal to 0.87.

TABLE NO. 8

LAHORE

Monthly Annual and Cumulative f.w.s. evaporation

(in inches)

Month	Actual		Institute		Blaney and Criddle		Penman Revelle Rpt.		Rohwer Revelle Rpt.	
	Month	Cum	Month	Cum	Month	Cum	Month	Cum	Month	Cum
January ..	1.70	1.70	1.56	1.56	·3.72	3.72	1.06	1.06	1.15	1.15
February ..	2.28	3.98	2.14	3.70	4.15	7.87	1.46	2.52	1.46	2.61
March ..	3.78	7.71	3.51	7.21	5.65	13.5	3.26	5.78	3.44	6.05
April ..	6.13	13.84	6.27	13.48	6.67	20.19	4.62	10.40	6.55	12.60
May ..	7.13	20.96	8.19	21.67	7.72	27.41	7.22	17.62	10.25	22.85
June ..	9.34	30.31	8.06	29.73	8.57	36.48	7.49	25.11	10.11	32.96
July ..	7.60	37.91	7.33	39.08	8.87	45.35	6.70	31.18	6.62	39.58
August ..	5.78	43.70	6.38	43.44	8.34	53.69	6.03	37.84	4.80	44.38
September ..	4.50	48.20	5.29	48.73	7.13	60.82	4.94	42.78	4.67	49.05
October ..	3.78	51.98	4.17	52.90	6.08	66.90	3.56	46.34	4.39	53.45
November ..	2.39	54.38	2.55	55.45	4.50	71.40	1.58	47.92	2.04	55.49
December ..	1.59	55.97	1.53	56.98	3.64	75.04	0.97	48.89	1.29	56.77

TABLE No. 9

Annual Evaporation at various Stations in West Pakistan By different methods

(in inches)

					Penman Formula		Rohwer Formula		
		Actual Obs. Lake Evap.	Instt. Formula	Blaney Criddle Formula	Instt. calculations	Revelle Report	Instt. calculations	Revelle Report.	Hargreaves
1		2	3	4	5	6	7	8	9
Quetta	..	34.20	42.57	60.73	43.00	44.34	55.34	44.13	94.54
Lahore	..	51.77	55.87	78.27	—	48.89	—	56.77	—
Balakot	..	61.77	55.91	66.18	—	—	—	—	—
Churkana	..	57.08	58.14	81.31	—	—	—	—	—
Kohat	..	62.49	62.26	77.20	—	—	—	—	—
Karachi	..	58.57	60.01	79.27	126.45	48.79	163.76	70.24	105.74
Sargodha	..	79.22	63.48	76.65	97.57	—	—	—	136.28
Mangla	..	71.12	67.89	76.37	—	—	—	—	—
Mianwali	..	71.40	68.54	75.89	—	—	—	—	—
Gujranwala	..	67.42	71.96	71.52	—	—	—	—	—
Leiah	..	72.11	71.66	79.00	—	—	—	—	—
Muzaffargarh	..	71.64	69.59	78.12	—	—	—	—	—

Bahawalnagar	..	69.73	75.46	83.74	—	—	—	—	—
Hub dam	..	100.04	87.43	81.07	—	—	—	—	—
Baran dam	..	73.00	76.97	79.72	—	—	—	—	—
Hyderabad	..	63.60	67.42	84.38	—	64.65	—	113.11	—
Terbela	..	95.71	92.72	73.78	—	—	—	—	—
Darwat	..	129.16	108.21	83.83	—	—	—	—	—
Peshawar	..	—	—	74.43	60.80	42.64	—	—	—
Nawabshah	..	—	62.81	81.20	106.90	—	—	—	160.18
D. I. Khan	..	—	62.40	77.32	58.19	—	71.36	—	—
Kakul	..	—	55.62	65.65	—	—	—	—	95.12
Khanpur	..	—	71.92	79.68	127.86	62.14	157.28	—	172.92
Nokkundi	..	—	95.37	78.09	264.31	—	—	—	173.15
Drosh	..	—	48.31	64.53	61.62	—	—	—	—
Bahawalpur	..	—	66.22	79.10	90.58	56.04	113.55	—	154.13
Campbellpur	..	—	67.00	78.63	95.97	—	—	—	132.38
Kalat	..	—	45.67	55.85	65.35	—	81.89	—	62.49
Murree	..	—	38.02	56.58	49.48	—	62.67	—	54.97
Lyallpur	..	—	68.02	77.31	78.46	—	97.26	—	157.23
Lesbela	..	—	56.15	80.11	52.01	—	65.97	—	187.73
Jhelum	..	—	67.43	75.49	76.40	—	—	—	138.57
Ormara	..	—	47.51	79.61	59.07	—	—	—	96.68
Sibi	..	—	100.56	82.16	158.12	—	248.45	—	—
Montgomery	..	—	61.88	78.73	82.66	—	103.95	—	127.79
Sialkot	..	—	62.38	76.90	56.43	47.66	69.46	—	124.08

[*Contd.*

TABLE No. 9—[*Concld.*]

		Actual Obs. Lake Evap.	Instt. Formula	Blaney Criddle Formula	Penman Formula		Rohwer Formula		Hargreaves
					Instt. calculations	Revelle Report	Instt. calculations	Revelle Report	
1		2	3	4	5	6	7	8	
Pasni	..	—	47.66	77.57	54.41	—	69.56	—	83.28
Multan	..	—	64.90	78.78	67.55	53.10	86.47	68.38	153.56
Bannu	..	—	69.4	75.26	—	—	—	—	95.50
Panjgar	..	—	61.81	72.64	95.69	—	121.52	—	154.26
Fort Sandeman	..	—	54.00	67.83	61.45	—	76.10	—	136.44
Cherat	..	—	53.93	66.34	102.66	—	132.03	—	—
Haripur	..	—	60.59	73.48	88.77	—	—	—	—
Parachinar	..	—	45.83	60.67	43.01	—	53.80	—	85.79
Khushab	..	—	73.82	77.88	105.37	—	145.50	—	163.02
Sukkur	..	—	67.31	82.18	88.21	—	—	—	—
Loralai	..	—	60.93	65.32	83.56	—	—	—	159.28
Jacobabad	..	—	72.87	81.73	94.27	—	119.01	—	168.29
Wana	..	—	51.87	66.73	—	—	—	—	—
Rawalpindi	..	—	64.96	71.64	66.70	43.49	82.36	53.90	—

TABLE NO. 10

Evaporation losses from the water storages in West Pakistan

Name of storage	Annual loss in inches	Kharif/Rabi in inches	App. surface area in sq. miles	Loss in cusecs per sq. mile
Warsak ..	53	38/15	5.682	22.22/3.91
Baran Dam ..	69	50/19	3	15.3 /5.09
Rawal Dam ..	65	49/16	—	4.79
Kalari Lake ..	90	50/40	60	397.80/6.63
Bolan Dam ..	90	53/35	—	6.63
Mangla ..	68	47/21	117.19	587.12/5.01
Terbela ..	93	67/26	93.75	642.19/6.85
Hub Dam ..	87	47/40	One sq. mile	6.41
Gulkatch ..	60	42/18	,,	4.42
Kalam ..	50	38/12	,,	3.69
Kalargi ..	65	50/15	,,	4.79
Bunda Tunda ..	62	39/23	,,	4.57
Sargwal ..	67	51/16	,,	4.94
Naran Dam ..	50	40/10	,,	3.69
Dhok Pathar ..	67	50/17	,,	4.94
Mokhad ..	67	50/17	,,	4.94
Darwat Dam ..	108	57/51	,,	7.96
Dam near Turbat ..	70	40/30	,,	5.16
Dam near Pasni ..	50	30/20	,,	3.69
			Mean ..	5.16

TABLE NO. 11

Evaporation losses from water surface of the barrages in West Pakistan

Name of Barrage		Annual loss inches	Kharif/Rabi	Loss in cusecs per sq. mile
(*i*) *Indus River*—				
G. M. Barrage	..	75	45/30	5.53
Sukkur	..	67	43/24	4.94
Guddu	..	75	52/23	5.53
Taunsa	..	70	52/18	5.16
Kalabagh	..	64	45/19	4.72
(*ii*) *Jhelum River*—				
Rasul	..	67	51/16	4.94
Trimmu	..	69	51/18	5.09
(*iii*) *Chenab River*— Marala	..	65	46/19	4.79
Khanki	..	65	46/19	4.79
(*iv*) *Ravi River*—				
Balloki	..	65	46/19	4.79
Sidhnai	..	63	46/17	4.64
(*v*) *Sutlej River*—				
Panjnad	..	71	49/22	5.23
Islam	..	72	48/24	5.31
Suleimanki	..	75	50/25	5.53
			Mean	5.07