Evapotranspiration in Hong Kong: A Second Report[1]

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THE FIRST REPORT on evapotranspiration in Hong Kong (Ramage, 1953)[3] describes installation of an evapotranspirometer battery, twenty months' measurement of potential evapotranspiration (P.E.) from grass surfaces, and comparisons of P.E. from grass and some common vegetables.

Comparison of measured P.E. with that computed from Thornthwaite's (1948) formula reveals that the formula when applied in Hong Kong gives values consistently low in winter and high in summer.

This leads to two possible conclusions:

1) The site of the evapotranspirometers is not representative of the area.
2) Thornthwaite's formula is not valid for Hong Kong.

The present paper will summarise the first five years' P.E. measurements at Hong Kong (October 1951 through September 1956), present arguments on the two possibilities mentioned above, discuss Penman's (1948) transpiration formula, and, finally, describe the derivation of a simple P.E. formula for Hong Kong.

FIVE YEARS' POTENTIAL EVAPOTRANSPIRATION MEASUREMENTS

Table I shows monthly totals of P.E. measured for three grass-covered soil tanks at the King's Park Radiosonde Station (22°19′N., 114°10′E., 213 feet above mean sea level) together with relevant meteorological data. Each tank has an internal area of four square meters. To save material, the central tank has a wall in common with each of the others. The site was unchanged throughout the period and there were no variations in methods of watering or of measuring rainfall and overflow. Except when one or two tanks were used briefly for growing vegetables, the results are means derived from all three tanks in the battery. Readings varied insignificantly and randomly between tanks, indicating a satisfactory local exposure and unlikelihood of leaks. In wet weather the overflow tanks occasionally flooded. Resulting errors have been eliminated from the final values.

POTENTIAL EVAPOTRANSPIRATION OF VEGETABLES

Validity of P.E. relative to grass for tomatoes, Chinese cabbage, and lettuce determined during the 1952 winter (table 1 of first report) was tested in the winter of 1953–54. The results appear in Table 2. It can be seen that ratios of vegetable P.E. to grass P.E. varied little from one winter to the next. The method of comparison thus appears to give results of real value to irrigation planners.

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TABLE 1

MONTHLY POTENTIAL EVAPOTRANSPIRATION AND METEOROLOGICAL OBSERVATIONS MADE AT KING'S PARK (22°19'N., 114°10'E., 213 FT. ABOVE M.S.L.) AND AT ROYAL OBSERVATORY (22°18'N., 114°10'E., 109 FT. ABOVE M.S.L.) FOR THE FIVE-YEAR PERIOD, OCTOBER 1951–SEPTEMBER 1956, AND ALSO FOR OCTOBER 1956–DECEMBER 1956

	YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Potential evapotranspiration (King's Park) mm.	1951										144	100	91
	1952	74	79	80	88	120	95	113	104	81	139	100	76
	1953	72	49	73	72	99	130	133	100	119	122	93	81
	1954	72	77	88	80	140	102	148	147	161	133	136	83
	1955	79	81	106	107	110	116	118	101	125	147	121	87
	1956	64	84	95	131	142	157	157	124	140	141	116	78
	5-YEAR MEAN	72	74	88	96	122	120	134	115	125	137	110	84
Rainfall (King's Park) mm.	1951										104	75	15
	1952	26	32	40	183	184	560	189	376	838	17	9	24
	1953	27	64	135	95	354	407	138	374	564	48	41	76
	1954	53	30	58	160	89	207	147	294	171	20	133	0
	1955	2	0	61	162	446	322	546	580	115	11	49	18
	1956	67	80	7	79	299	367	170	455	165	37	34	7
	5-Year Mean	35	41	60	136	274	373	238	416	371	40	61	27
Mean temperature (King's Park) °F.	1951										77	70	64
	1952	62	61	65	72	80	82	83	81	80	77	73	61
	1953	61	61	65	66	76	82	83	83	80	79	71	64
	1954	63	61	61	71	80	82	83	83	81	76	70	61
	1955	57	64	69	72	79	81	82	82	83	77	68	66
	1956	58	61	66	75	79	83	84	82	83	77	68	62

REPRESENTATIVENESS OF THE KING'S PARK SITE

An oil-drum evapotranspirometer (see Garnier, 1954) was installed at Kai Tak Airport (22°20'N., 114°12'E., 12 feet above mean sea level)and readings began in September, 1954. The tank was turfed with and surrounded by grass clipped to 1–2 inches and was watered from above. The site being in an extensive flat area near sea level differs considerably from King's Park where the evapotranspirometer is atop a small isolated hill.

Figure 1 shows results of the first year's simultaneous readings. For this period it is safe to assume that the oil drum did not develop leaks. At Kai Tak, in moisture deficient

TABLE 1, *continued*

MONTHLY POTENTIAL EVAPOTRANSPIRATION AND METEOROLOGICAL OBSERVATIONS MADE AT KING'S PARK (22°19′N., 114°10′E., 213 FT. ABOVE M.S.L.) AND AT ROYAL OBSERVATORY (22°18′N., 114°10′E., 109 FT. ABOVE M.S.L.) FOR THE FIVE-YEAR PERIOD, OCTOBER 1951–SEPTEMBER 1956, AND ALSO FOR OCTOBER 1956–DECEMBER 1956

	YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.
	5-Year Mean	60	62	65	71	79	82	83	82	81	77	70	63
Mean dew point temperature (Royal Observatory) °F.	1951										68	61	50
	1952	52	55	61	68	75	77	77	77	75	68	62	47
	1953	51	56	60	60	71	77	77	78	74	73	61	55
	1954	57	54	53	67	74	77	77	77	73	65	59	48
	1955	41	53	62	64	72	75	77	76	76	64	53	53
	1956	46	55	59	67	73	76	77	76	72	65	52	51
	5-Year Mean	49	55	59	65	73	76	77	77	74	68	59	51
Sunshine duration (Royal Observatory) hours	1951										197	135	189
	1952	168	78	84	114	196	152	192	177	165	240	264	138
	1953	130	59	75	61	125	194	275	241	114	211	141	153
	1954	160	116	109	69	221	159	254	206	218	256	213	150
	1955	210	147	121	174	169	137	160	208	253	289	181	229
	1956	165	66	102	175	137	214	263	229	229	242	172	164
	5-Year Mean	167	93	98	119	170	171	229	212	196	239	187	172
Mean wind speed (Royal Observatory) knots	1951										9.5	10.9	9.9
	1952	9.6	11.7	13.2	10.8	8.9	8.1	8.1	7.0	9.0	9.8	7.5	8.4
	1953	10.2	11.5	10.9	11.3	9.5	8.8	6.4	5.7	10.3	9.5	8.3	9.4
	1954	9.3	9.4	9.1	11.0	6.7	7.7	5.9	7.3	10.5	8.8	10.6	9.3
	1955	9.4	11.6	11.1	9.3	8.0	9.1	6.8	4.7	6.5	11.2	11.6	10.8
	1956	9.3	12.1	12.5	10.4	9.5	8.2	6.6	9.6	9.1	9.9	9.4	7.8
	5-Year Mean	9.6	11.3	11.4	10.6	8.5	8.4	6.8	6.9	9.1	9.8	9.8	9.6

months, grass surrounding the tanks could not be watered, while some flooding possibly occurred in moisture-surplus months. Since King's Park is not subject to these mensural drawbacks they may account for some of the differences between the two curves. It seems reasonable then to conclude that the King's Park site is probably a representative one.

TABLE 2
COMPARISON OF POTENTIAL EVAPOTRANSPIRATION FROM VEGETABLES AND GRASS

CROP	TOMATOES	CHINESE CABBAGE	LETTUCE
Planting date	28 Oct. 1953	28 Oct. 1953	2 Jan. 1954
Days to reach maturity	128 (last fruit)	61	79
Total crop weight (lbs.)	85 (poor crop)	34½	
(1) Total P.E. (mm.)	838	282	271
Average daily P.E. (mm.)	6.5	4.6	3.4
(2) Total P.E. of grass in same period (mm.)	354	182	193
Average daily P.E. of grass in same period	2.8	3.0	2.4
Ratio $\frac{(1)}{(2)}$	2.4	1.5	1.4
Mean temperature during period (°F.)	65	68	62
Ratio $\frac{(1)}{(2)}$ for 1952 winter	2.3	1.6	1.7

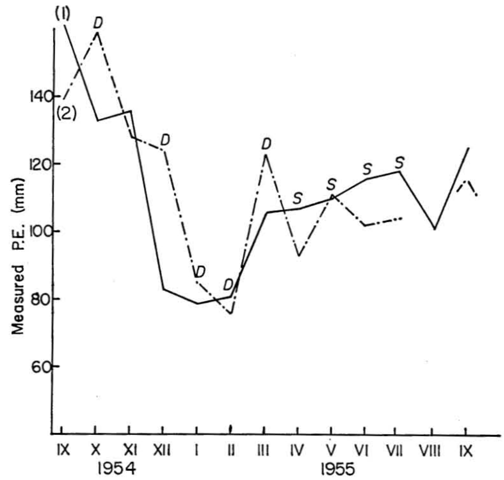

FIG. 1. Monthly potential evapotranspiration measured at King's Park (1), and at Kai Tak Airport (2). September 1954 through September 1955. "D" signifies that P.E. exceeded rainfall by at least 75 per cent and the letter "S" that rainfall was in excess by at least 35 per cent.

COMPARISON OF MEASURED POTENTIAL EVAPOTRANSPIRATION WITH VALUES DERIVED FROM THORNTHWAITE'S AND PENMAN'S FORMULAE

Thornthwaite's Formula

The conclusions of the first report are amply confirmed by the longer period of record. Figure 2 shows monthly means of P.E. derived from the five years' measurements. Again calculated values are too low in the dry winter and too high in the wet summer. Since investigators in Australia (Leeper, 1950), Nigeria (Garnier, 1954), and Trinidad (Smith, 1954) report similar shortcomings in the formula one must conclude that it should not be assumed to be valid for any monsoon or tropical maritime region.

Penman's Formula

Penman (1948, 1950), using energy conceptions, derives the following formula for estimating potential transpiration from vegetated areas. (It checks well with observations made in America and Europe.)

$$E_T = E_o \times f = f\,(\Delta H + 0.27 E_a) / (\Delta + 0.27) \text{ mm/day.}$$

Where E_T = potential transpiration

E_o = the hypothetical evaporation that would take place from an extended sheet of open water exposed to the weather conditions found over the site.

f, an empirically determined seasonal factor converting E_o to E_T, has the following values:

Nov. through Feb.	0.6
Mar., Apr., Sept., Oct.	0.7
May through Aug.	0.8

Δ = slope of vapor-pressure curve for water at mean air temperature T_a (mm mercury/°F)

$H = R_A\,(1-r)\,(0.18 + 0.55n/N) - \sigma T_a^4 (0.56 - 0.092\sqrt{e_d})/(0.10 + 0.90n/N)$

0.27 = the constant of the standard hygrometer equation (mm/°F)

$E_a = 0.35\,(e_a - e_d)\,(1 + u_2 \times 10^{-2})$ mm/day

R_A = theoretically calculable amount of radiation that would reach the earth in the absence of an atmosphere, converted to an evaporation equivalent by putting 59 cal/cm² = 1 mm. evaporation.

r = reflection coefficient, to be taken as 0.05. For standard evaporation tanks with light walls and clean water it may be very much greater.

n/N = actual/possible hours of sunshine. In the first term in H it is a factor limiting incoming short-wave radiation; in the second it is a transform of a cloudiness factor limiting outward long-wave radiation.

σT_a^4 = theoretical black-body radiation at mean air temperature T_a; this too is in evaporation units like R_A.

e_d = saturation vapor pressure at dewpoint (mm Hg).

e_a = saturation vapor pressure at mean air temperature; hence $(e_a - e_d)$ is the mean saturation deficit.

u_2 = average wind speed in miles/day at 2 m. above the ground.

Since the formula incorporates both humidity and wind parameters it appeared likely to give more reasonable results than Thornthwaite's formula when applied in Hong Kong. The data listed in Table 1 have been used to calculate mean monthly P.E. according to Penman's formula and the values are plotted in Figure 2. They approach the observed values more closely than those determined by Thornthwaite's formula but err in the same sense, overestimating summer and underestimating winter P.E.

POTENTIAL EVAPOTRANSPIRATION FORMULA FOR HONG KONG

Deriving the Formula

In Penman's formula, the expression $E_a = 0.35\ (e_a - e_d)\ (1 + u_2 \times 10^{-2})$ mm/day incorporates humidity and wind parameters.

Figure 3 shows a plot of both E_a and mean daily observed P.E. at Hong Kong derived from the monthly means for five years. From October through January and from February

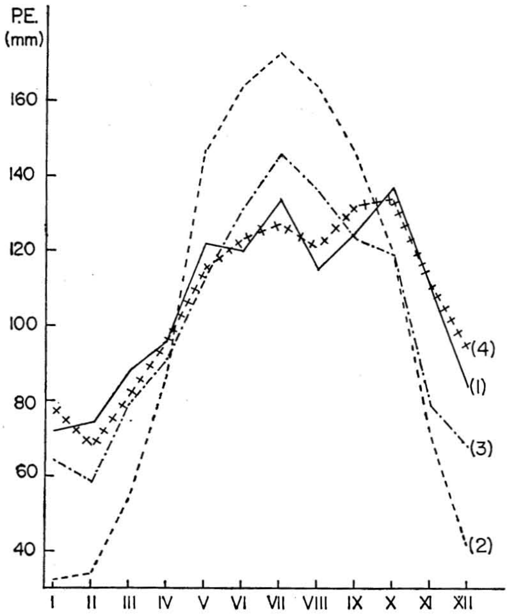

FIG. 2. Monthly means of potential evapotranspiration measured at King's Park (1), and calculated according to Thornthwaite's formula (2), Penman's formula (3), and the new formula (4). Based on five years' data.

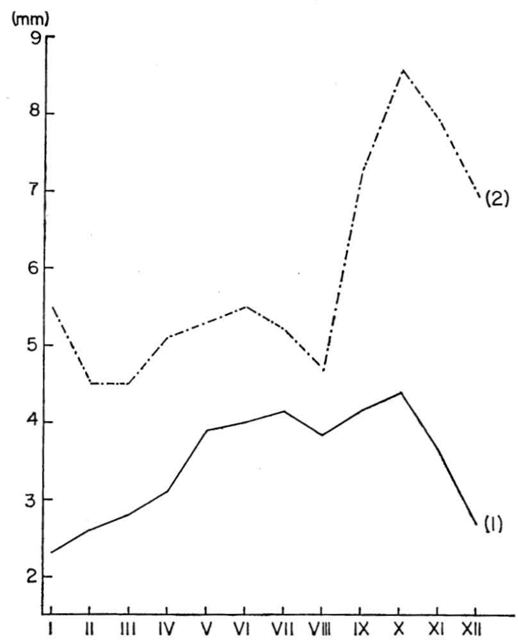

FIG. 3. Mean daily potential evapotranspiration measured at King's Park (1), and E_a (2). Based on five years' data.

TABLE 3

MEASURED AND CALCULATED MONTHLY POTENTIAL EVAPOTRANSPIRATION AT HONG KONG FOR 1953 AND OCTOBER THROUGH DECEMBER 1956 (MM.)

	1953												1956		
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Oct.	Nov.	Dec.
Measured......	72	49	73	72	99	130	133	100	119	122	93	81	141	116	78
Thornthwaite formula.....	35	33	53	59	122	165	175	168	138	135	73	45	115	58	38
Difference......	+37	+16	+20	+13	−23	−35	−42	−68	−19	−13	+20	+36	+26	+58	+40
Penman formula	64	46	65	76	106	140	160	144	114	104	69	59	125	85	57
Difference.....	+8	+3	+8	−4	−7	−10	−27	−44	+5	+18	+24	+22	+16	+31	+21
New formula...	81	57	78	81	106	126	127	121	129	124	105	84	142	111	81
Difference.....	−9	−8	−5	−9	−7	+4	+6	−21	−10	−2	−12	−3	−1	+5	−3

through August the curves are similar although between these periods they undergo sharp relative displacements. Nevertheless, E_a seems to bear some intraseasonal relationship to measured P.E. This may explain why Penman's formula approximates Hong Kong observations more closely than does Thornthwaite's formula which does not explicitly embody humidity and wind parameters.

Thornthwaite attaches great importance to temperature in the evapotranspiration process. This was allowed for by combining e_a with E_a in the form $\sqrt{E_a} + \sqrt{e_a}$. When this expression is plotted against mean daily measured P.E. (Fig. 4), a good fit is provided by a straight line whose equation is

$$\text{P.E.} = \sqrt{E_a} + \sqrt{e_a} - 3.5 \text{ mm/day}$$

Values calculated from this equation and plotted in Figure 2 are in reasonable agreement with mean monthly measured P.E.

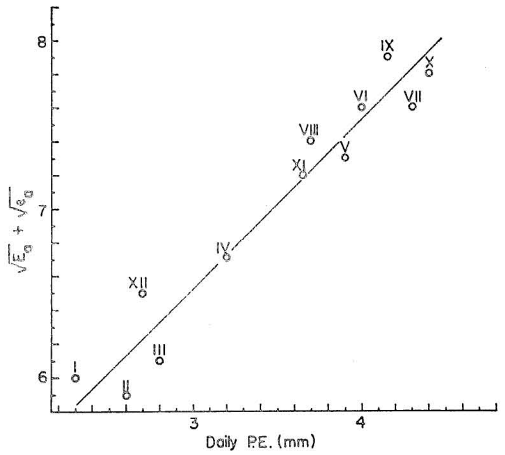

FIG. 4. Mean daily potential evapotranspiration measured at King's Park plotted against $\sqrt{E_a} + \sqrt{e_a}$. Based on five years' data.

Testing the Formula

1953 was the most abnormal year of the five-year period. Table 3 and Figure 5 depict

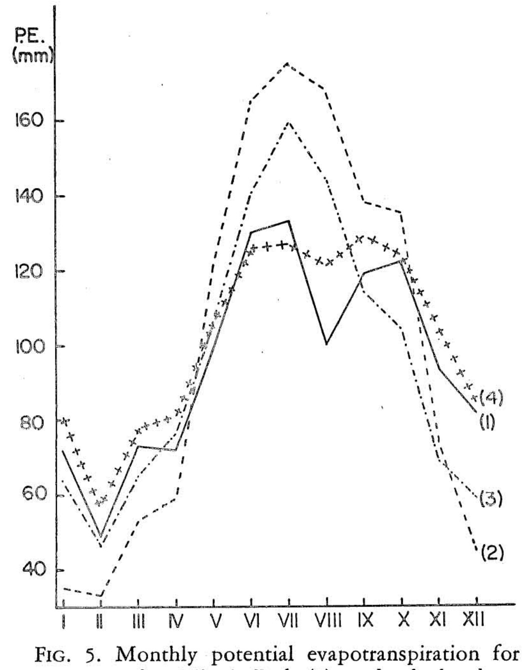

FIG. 5. Monthly potential evapotranspiration for 1953 measured at King's Park (1), and calculated according to Thornthwaite's formula (2), Penman's formula (3), and the new formula (4).

measured P.E. and P.E. calculated by the Thornthwaite, Penman, and new formulae. In addition, Table 3 compares the formulae for the three months following the five-year period. Again the new formula best approximates Hong Kong measurements.

CONCLUSIONS

Evapotranspiration formulae based on mid-latitude data should not be uncritically used in estimating P.E. for monsoonal or tropical maritime regions.

In such regions, humidity and wind may be as important parameters as temperature, and simple formulae similar to that derived for Hong Kong might fairly be used to calculate potential evapotranspiration.

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