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IRRIGATION REQUIREMENTS AND WATER BALANCE

ARENAL PROPOSED PROJECT COSTA RICA

by

George H. Hargreaves

A study prepared for the United Nations World Meteorologic Organization, WMO; the WMO-UNDP Proyecto Hidrometeorologico Centroamericano, PHCA; and the Instituto Costarricense de Electricidad, ICE

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IRRIGATION REQUIREMENTS AND WATER BALANCE
ARENAL PROPOSED PROJECT, COSTA RICA

Introduction

The Instituto Costarricense de Electricidad, ICE, has completed a preliminary study for the construction of a dam and reservoir on the Rio Arenal, a tunnel to the Rio Santa Rosa in the headwaters of the Rio Bebedero and other appertinant works. The principal purpose is the production of electrical energy.

The eventual construction of this major power facility will make available an adequate supply of irrigation for a large area of agricultural lands in Guanacaste. The needs for irrigation in this area have long been recognized. During more than thirty years various studies have been carried out relative to the possibility of irrigating a large area. Previously the main emphasis was on the possibility of using waters from the Tempisque river.

Neither time nor data availability permit the completion of a detailed analysis of irrigation requirements in this report. Requirements are defined in a general manner and methodology presented so that the study can be easily improved and refined as more information becomes available relative to soils, future crops to be grown, and to the average climatic conditions in the area.

Some elements essential to a water balance study are analyzed. However, rainfall and other data are not adequate for a complete water balance analysis.

Soils

The soils of Costa Rica have been mapped at a scale of 1:750,000 as shown on the map "Uso Potencial de la Tierra, Costa Rica," published in April 1970 by Ministerio de Agricultura y Ganaderia. For the area proposed for consideration for development to irrigated agriculture the potential use is approximately as follows:

Area I Intensive Use

7,800 Ha | $I-P_p$ | Areas planas o casi planas, de origen aluvial, con suelos ligeramente pesados de textura limosa a limo-arcillosa. Son aptas para CULTIVOS PERMANENTES y GANADERIA INTENSIVA; requieren de facilidades de drenaje y el empleo de metodos sencillos de conservacion.

Alluvial soils, plane or nearly plane, medium to slightly heavy in texture. Suitable for permanent crops and intensive livestock use and requiring simple drainage and conservation practices.

Area II Extensive Use

7,800 Ha | $II-P_p$ | Areas planas o casi planas, con suelos pesados de textura arcillo-limosa a arcillosa. Son aptas para CULTIVOS PER

MANENTES y GANADERIA EXTENSIVA; requieren de algunas practicas simples de conservacion.

Plane and nearly plane heavy soils. Suitable for permanent crops and intensive livestock and requiring simple conservation practices.

21,400 Ha | $II\text{-}P_{sl}$ | Areas-de lomerios bajos, con suelos pesados en proceso de laterizacion, de textura arcillosa. Son aptas para CULTIVOS PERMANENTES y GANADERIA EXTENSIVA; requieren de algunas practicas simples de conservacion.

Areas of undulating heavy soils in the process of laterization of clay texture. They are suitable for permanent crops and extensive livestock use and require simple conservation practices.

<u>Area IV Very Extensive Use</u>

41,300 Ha | IV-P | Areas con pendientes muy variables, con suelos de muy escaso desarrollo y en algunos casos de dificil acceso. Son aptas unicamente para una GANADERIA MUY EXTENSIVA.

Areas with very irregular slopes with soils that are not well developed and in some cases of difficult access. They are only suitable for very extensive livestock use.

14,100 Ha | IV-M | Areas pantanosas cubiertas permanentemente de agua dulce o agua salada, con vegetacion de mangle. No son aptas para usos agropecuarios.

Swampy areas permanently wet with mangrove vegetation in either salty or fresh water. Not suitable for agriculture or livestock.

17,100 Ha | IV-S | Areas pantanosas de agua dulce, aptas, durante una parte de la epoca seca, para una GANADERIA MUY EXTENSIVA.

Swampy areas with fresh water, dry during part of the dry season and suitable for very extensive livestock use.

Of the area proposed for irrigation development, a total of approximately 37,000 hectares are mapped as being suitable for permanent crops and for livestock production. An additional 58,400 hectares are considered to be suitable for very extensive livestock use. By extending the proposed area west to the Tempisque river a total of from 5,000 to 10,000 additional hectares of lands mapped as suitable for annual crops might be included within the project area.

The soils mapping at a scale of 1: 750,000 is of necessity very approximate. However, both from an inspection of the area and from the soils map it appears that use of the area for annual crops will be quite limited. The principal irrigation use should be for irrigated pasture both for livestock and dairy production. Probably the total area under irrigation at the stage of full project development will not exceed 40,000 hectares.

Climate

Weather data are fairly adequate for defining the climate of the area. Additional humidity and wind speed data would be most desirable. Data on temperature and precipitation are quite adequate for this study. Based upon the available data, an attempt is made to define the irrigation requirements for the area that may in the future be irrigated and the water use relationships for the watershed above the proposed dam.

The mean temperature for the proposed irrigated area is given in °C as follows:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Liberia	26.7	27.3	27.4	28.9	28.6	26.6	27.4	27.7	26.4	26.3	27.2	26.4
La Pacifica	27.2	27.6	28.2	28.7	28.7	26.7	27.2	26.5	26.3	26.1	25.8	26.9
Puntarenas	28.1	28.2	29.0	28.8	28.0	27.4	27.3	26.8	26.6	26.6	26.4	26.7
Average	27.3	27.7	28.2	28.8	28.4	26.9	27.3	27.0	26.4	26.3	26.5	26.7

The mean values of relative humidity for the area are estimated, based upon the available data, from readings at 0700, 1300 and 1800 hours as follows:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average at 0700, 1300 and 1800 hrs	76	71	73	74	81	87	86	84	91	90	83	82

Class A pan evaporation data used in this study are summarized as follows:

Evaporation in mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Hda. Tempisque Five-year Average	202	235	279	254	227	144	125	133	120	120	109	153	2101
Hda. Tempisque 1970	170	244	245	185	228	210	113	133	102	130	121	145	2026
Puntarenas 1970	118	203	189	176	126	101	94	101	97	115	102	119	1541
Arenal 1964-70	74	86	115	111	103	94	86	99	102	77	60	68	1075
Arenal 1970	83	62	100	104	110	107	92	113	97	61	41	61	1031

The available precipitation records were summarized for eleven locations as shown in Table 1. The average values for Liberia, La Pacifica and Puntarenas appear to be representative for the proposed irrigation area and are considered suitable for developing estimates of irrigation requirements. The mean of three stations: Monte Verde, Pueblo Nuevo and Cano Negro is shown as estimated mean precipitation for the Arenal basin. Data coverage is not adequate for estimating the mean precipitation of the basin with confidence. Rainfall in higher elevations can be quite variable. The usual tendency is to underestimate the rainfall for the ungauged higher elevation areas. It is therefore possible that the average precipitation for the Arenal drainage basin is significantly greater than the values shown. Table 1 gives mean values for precipitation for the full period of record available at each station.

Table 1. Mean Precipitation in mm

Station	Station Number	Latitude	Longitude	Elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Arenal	069-514	10°28'	84°51'	520	138	62	62	70	154	298	345	280	323	317	255	231	2535
Pueblo Nuevo	069-522	10°27'	84°46'	516	346	240	185	207	365	396	389	521	415	389	274	434	4161
Cano Negro	069-525	10°24'	84°50'	1027	547	340	244	244	306	375	399	577	392	484	569	591	5068
Liberia	074-001	10°37'	85°26'	144	2	1	2	16	197	271	159	140	356	339	104	13	1600
Hacienda Tempisque	074-011	10°30'	85°34'	22	1	6	4	56	212	329	213	197	367	400	87	11	1883
Tiliran	076-002	10°28'	84°59'	562	65	27	28	41	184	344	350	250	364	381	182	131	2347
La Pacifica (Canas)	076-005	10°25'	85°07'	95	4	27	11	44	92	327	123	163	322	307	100	24	1544
Tierras Morenas	076-006	10°34'	85°02'	650	123	68	39	48	180	351	264	290	321	447	232	326	2688
Las Juntas (Abangares)	078-001	10°17'	84°58'	140	3	2	23	101	223	336	265	361	440	404	186	31	2375
Monte Verde	078-002	10°19'	84°49'	1380	66	45	27	46	221	363	213	261	372	460	198	155	2427
Puntarenas	078-003	09°58'	84°50'	3	2	11	8	46	157	223	248	212	293	285	100	25	1610
*Mean Precipitation for proposed irrigation area					3	13	7	35	149	274	177	172	324	310	101	21	1588
**Estimated mean precipitation for Arenal basin					320	208	152	166	297	378	334	453	393	444	347	393	3885

*Average for Liberia, La Pacifica and Puntarenas.

**Average for Monte Verde, Pueblo Nuevo and Cano Negro.

Irrigation Requirements

Irrigation requirements may be estimated from measured Class A pan evaporation, EVPM, and from computed potential evapotranspiration, ETP. Potential evapotranspiration as used in this study is evapotranspiration equivalent to the amount of water transpired by and evaporated from an actively growing stand of short grass with a continuously adequate moisture supply. An equation for estimating ETP can be written

$$ETP = .35 \times RMM \times CT \times CH \times CW \times CE \qquad (1)$$

in which

RMM = monthly extraterrestrial radiation expressed in equivalent mm of evaporation by dividing the radiation ($cal/cm^2/day$) by the heat of vaporization at the mean monthly temperature, TM, and converting to mm per month (Table 2)

$$CT = .40 + .024 \times TM \qquad (1a)$$

(TM = mean monthly temperature in $^{\circ}C$)

$$CH = .05 + 1.42\ (1.00 - HM)^{1/2} \qquad (1b)$$

(HM = mean monthly relative humidity, expressed decimally, measured as the mean of readings at 0700, 1300 and 1800 hours)

$$CW = .80 + .028 \times W6 \qquad (1c)$$

(W6 = mean monthly wind speed from totalized wind movement at an instrument height of 6 meters converted to km/hr)

$$CE = 1.00 + .00004 \times EL \qquad (1d)$$

(EL = elevation in meters)

Table 2. Mean monthly values of extraterrestrial radiation

Latitude Degrees	Expressed as Equivalent Evaporation in Millimeters Per Day											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North												
60	1.41	3.36	6.88	11.31	15.14	17.06	16.25	13.03	8.67	4.58	1.92	0.96
55	2.55	4.62	8.08	12.18	15.55	17.18	16.50	13.71	9.77	5.85	3.11	2.02
50	3.77	5.89	9.23	12.98	15.93	17.30	16.73	14.34	10.79	7.09	4.35	3.21
45	5.04	7.14	10.30	13.69	16.23	17.38	16.91	14.87	11.74	8.30	5.63	4.46
40	6.32	8.36	11.30	14.31	16.45	17.38	17.01	15.32	12.59	9.45	6.90	5.75
35	7.59	9.53	12.21	14.82	16.58	17.30	17.01	15.66	13.35	10.54	8.15	7.04
30	8.84	10.64	13.03	15.23	16.60	17.13	16.92	15.90	14.01	11.55	9.36	8.32
25	10.05	11.68	13.75	15.52	16.51	16.85	16.72	16.02	14.56	12.48	10.53	9.56
20	11.20	12.64	14.37	15.70	16.32	16.48	16.42	16.04	15.00	13.33	11.63	10.76
15	17.29	13.51	14.88	15.77	16.02	16.00	16.02	15.93	15.33	14.07	12.66	11.91
10	13.30	14.28	15.27	15.72	15.61	15.42	15.51	15.72	15.54	14.71	13.61	12.98
5	14.23	14.96	15.55	15.55	15.09	14.74	14.90	15.39	15.63	15.24	14.47	13.98
0	15.07	15.53	15.71	15.27	14.47	13.97	14.19	14.95	15.61	15.66	15.23	14.90

Table 2. (Continued)

Latitude Degrees	Expressed as Equivalent Evaporation in Millimeters Per Day											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South												
- 5	15.81	15.98	15.75	14.88	13.76	13.12	13.39	14.41	15.46	15.96	15.89	15.72
-10	16.45	16.33	15.67	14.37	12.95	12.18	12.51	13.76	15.20	16.15	16.45	16.44
-15	16.98	16.55	15.48	13.76	12.06	11.17	11.54	13.01	14.82	16.21	16.89	17.06
-20	17.40	16.66	15.16	13.05	11.09	10.10	10.51	12.17	14.33	16.16	17.22	17.57
-25	17.71	16.65	14.73	12.24	10.05	8.97	9.42	11.25	13.73	15.99	17.43	17.97
-30	17.91	16.52	14.19	11.34	8.95	7.80	8.28	10.25	13.03	15.70	17.54	18.27
-35	17.99	16.27	13.54	10.36	7.80	6.61	7.10	9.18	12.23	15.29	17.52	18.46
-40	17.98	15.92	12.79	9.31	6.61	5.40	5.89	8.06	11.33	14.78	17.40	18.54
-45	17.86	15.46	11.94	8.19	5.41	4.19	4.69	6.89	10.35	14.16	17.18	18.54
-50	17.66	14.90	11.00	7.02	4.20	3.02	3.49	5.68	9.29	13.45	16.87	18.46
-55	17.40	14.25	9.98	5.81	3.01	1.90	2.34	4.46	8.16	12.64	16.49	18.33
-60	17.12	13.54	8.88	4.57	1.88	0.91	1.28	3.24	6.97	11.76	16.07	18.20

Potential evapotranspiration, ETP, can also be estimated from Class A pan evaporation, EVPM. For climatic conditions similar to those in Guanacaste the relationship is approximately

$$ETP = .82\ EVPM \qquad (2)$$

The Class A pan evaporation data from the station at Puntarenas are somewhat lower than typical for the area. The location is close to the ocean, is in a low area and the pan is protected from the wind by trees, vegetation, a wall and the station building.

The average values for evaporation from the record at Hacienda Tempisque appear to be somewhat above typical for the area. This is more noticeable during the dry months and probably can be explained as the result of increased advection during dry months.

Dependable precipitation, PD, is defined as that equaled or exceeded during three years out of four. It is best determined from a gamma distribution analysis of a long period of record. The 75 percent probability of precipitation, PD, can be approximated from the equation

$$PD = -10 + .70\ PM \qquad (3)$$

in which

PM = mean monthly precipitation in mm from the full period of available records

Dependable precipitation is used in evaluating the dependability of rainfall in meeting moisture requirements of crops or native vegetation.

The soils map of Costa Rica indicates that about 37,000 hectares in the proposed irrigation service area are suitable for permanent crops. This area could be somewhat expanded, and since the soils map is very general, some relatively inextensive areas of soils suitable for annual crops are included. Under full development some annual crops will be grown.

In view of the lack of precise soils information and of projections of possible future crops it seems safer to base an estimate of future irrigation requirements upon those necessary for pasture. Pasture requires more water than annual crops and therefore the analysis will be on the conservative side.

Crop coefficients for a considerable variety of crops are given in Table 3. These coefficients are suggested for use when more detailed soils information and better projections of future crop patterns become available.

Wind data are not given in the climatic summary. Data are not available. An estimate of monthly values in km/hr was made based upon data from other similar areas. These estimates are given as "W6" and are estimated values for an instrument height of 6 meters.

Table 4 summarizes average temperature for the project area, TM; mean humidity, expressed decimally (average of readings at 0700, 1300 and 1800 hours), HM; estimated wind speed in km/hr at an instrument height of 6 meters, W6; mean precipitation for the area, PREC; calculated

TABLE 3. CROP COEFFICIENTS, K

CROP	Root Depth in Meters	Full Crop Cover		Seasonal K	
		Range in K	Average K	Range	Mean
Field and Oil Crops	1.00-1.30	1.10-1.32	1.22	.73-.99	.89
Fruits					
Grapefruit	1.20		.79		.79
Naval Oranges	1.07		.65		.65
Grain and Forage Crops	1.12-1.35	1.08-1.70	1.37	.95-1.15	1.04
Grass Crops					
Bermuda Lawn	1.19		1.05		1.05
Blue Panicium Grass	1.20		1.11		1.11
Green Manure Crops	.86-1.31	.97-1.22	1.11	.85-1.18	.96
Winter Vegetables	.64-.95	1.22-1.86	1.45	.85-1.18	1.01
Summer Vegetables	.86-.95	1.22-1.40	1.28	.82-.84	.83

Notes: Root depth is zone from which 90 percent of soil moisture depletion occurred. Coefficients are to be used with estimated potential evapotranspiration, ETP.

Source: [1]Erie, L.J., Orrin F. French and Karl Harris, "Consumptive Use of Water by Crops in Arizona". (Tech. Bulletin 169: University of Arizona Agricultural Experiment Station, 1965), 44 pp.

[2]Middleton, J.E., O. W. Pruitt, P. C. Crandall and M. C. Jensen, "Central and Western Washington Consumptive Use and Evaporation Data, 1954-62", (Bulletin 681: Washington State University Agricultural Experiment Station, 1967), 7 pp.

Table 4. Analysis of Moisture Availability

PROJECT AVERAGE CR LAT 10 25 LONG 85 15 ELEV 30

MO	TM	HM	W6	PREC	RMM	EVPC	EVPC2	ETP	ETP2	PD	ETDF	MAI
1	27.3	.76	10.0	3.	418.	142.	157.	115.	124.	0.	124.	.00
2	27.7	.71	10.5	13.	405.	151.	171.	123.	135.	0.	135.	.00
3	28.2	.73	10.5	7.	478.	175.	197.	142.	155.	0.	155.	.00
4	28.8	.74	10.0	35.	475.	173.	192.	141.	152.	14.	137.	.10
5	28.4	.81	7.0	149.	486.	152.	151.	123.	123.	94.	29.	.77
6	26.9	.87	5.5	274.	464.	117.	110.	96.	91.	182.	-91.	1.99
7	27.3	.86	5.0	177.	483.	128.	122.	104.	100.	114.	-13.	1.13
8	27.0	.84	6.0	172.	490.	137.	130.	111.	108.	110.	-3.	1.03
9	25.4	.91	5.0	324.	469.	100.	91.	81.	76.	217.	-141.	2.85
10	26.3	.90	5.0	310.	460.	102.	93.	83.	78.	207.	-129.	2.65
11	26.5	.83	7.0	101.	413.	117.	116.	95.	95.	61.	34.	.64
12	26.7	.82	9.5	21.	408.	119.	130.	97.	103.	5.	99.	.05
AVE	27.3	.81	7.7	132.	454.	134.	138.	109.	112.	84.	28.	.93

extraterrestrial radiation for latitude 10°25' North and for the mean temperatures, expressed in mm of evaporation per month, RMM; evaporation calculated without correcting for wind speed, EVPC; evaporation corrected for estimated wind speed, EVPC2; potential evapotranspiration calculated without using wind, ETP; potential evapotranspiration corrected for estimated wind speed, ETP2; dependable precipitation, PD; the evapotranspiration deficit, ETDF = ETP2 - PD; and the moisture availability index, MAI = PD/ETP2.

The computer program, including the equations used in printing out Table 4, is given as Appendix 1.

Irrigation requirements may be calculated from ETP2 by use of crop coefficients given in Table 3. For irrigated pasture a coefficient of 1.25 is assumed. Water requirements are summarized as follows:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1. ETP2	124	135	155	152	123	91	100	108	76	78	95	103	1340
2. ETP2 x 1.25	155	168	194	190	154	114	125	135	95	98	119	129	1676
* Deficit	155	168	194	176	60	-68	11	25	-122	-109	58	124	672
Irrigation Deficit	155	168	194	176	60						58	124	935
**Irrigation Req	310	336	388	352	120						116	248	1870

*Deficit = (ETP2 x 1.25) - PD
**Assumes 50 percent overall efficiency including transportation, application and use.

The above analysis indicates a gross requirement of 1.87 meters depth of annual irrigation water or 748 millions of m^3 per annum. This value is considered to be a maximum requirement under conditions of full project development to a high water use crop. It assumes surface irrigation. For much of the area land preparation for surface irrigation will be difficult. Consideration needs to be given to the use of sprinkler equipment. This will permit irrigation efficiencies in the order of 70 to 80 percent, thereby materially reducing irrigation requirements.

Although the available water supply appears to be roughly twice the possible requirements under full development to irrigated agriculture, the timing of power releases is of importance. Peak power demands may not necessarily coincide with maximum irrigation requirements. Irrigation requirements occur in only seven months, and 21 percent of the annual demand is estimated for the month of March. If power releases are at a uniform rate then during the month of March irrigation requirements could exceed power releases.

Water Balance - Arenal Watershed

Data are inadequate for defining the water balance for the watershed above the proposed dam on the Arenal river. Some conditions can, however, be defined in order to promote a better understanding of the hydrologic conditions.

The Arenal station is not located so as to provide representative weather data for the watershed. Its location in the lower portion next to the river would normally be expected to result in lower than typical values of evaporation. This location is somewhat protected from the wind and measured wind velocities are quite low.

From an inspection of the area by auto and by plane it appears that about two-thirds of the drainage basin remains fairly green the year around, and therefore water use remains fairly high throughout the year. The existing Laguna de Arenal is more like a marsh than a lake and is covered over most of its area by dense vegetative growth. It is roughly estimated that water use from this vegetation will be about 1.3 times the measured evaporation at Arenal weather station.

Lake evaporation is normally less than pan evaporation. This is largely due to the effect of advective heating of the evaporation pan. Advective effects on the existing pan are rather minimal. Under these conditions it would be expected that lake or reservoir evaporation would be in the order of .80 to .85 times pan evaporation. The net result of creating a storage reservoir can thus be expected to be an increase in water yield. Present evapotranspiration losses or uses from the proposed reservoir area may be in the order of 10 to 20 percent higher than future evaporation from the water surface area.

Considering the pan location, the dry months for part of the area and their effect on reduced water use, it would seem logical to assume that evapotranspirational losses from the watershed area are about equal to the measured evaporation at the Arenal station which averages 1075 mm annually. Probably this estimate will be within plus or minus ten percent of the true value. If this is true then either the mean annual rainfall exceeds 3885 mm as given in Table 1, or measured values of streamflow are somewhat on the high side. Although evidence is currently inconclusive, it is believed that the mean annual precipitation for the watershed is probably about 4200 mm. With this value for mean rainfall an approximate water balance can be developed.

Summary and Conclusions

Soils and crop information are currently less than adequate for a satisfactory irrigation requirement study of the proposed irrigation project area. When such data become available this study should be updated.

Wind data are not available. Future availability of wind data will permit more precise estimates of potential evapotranspiration.

Currently available soils information indicate that probably not more than 30,000 to 40,000 hectares are suitable for development to irrigated agriculture and that the principal use should be for permanent crops. For that reason the analysis is based upon requirements for irrigated pasture, a high water use crop. Assuming that the entire area of 40,000 hectares could be planted to pasture, then the available water supply is fairly adequate for the area proposed for irrigation.

Additional study and investigation is required on the feasibility of irrigation development. Assuming that the hydroelectric development will proceed through the normal steps of feasibility studies, approval, design and construction, then it is not too soon to initiate pre-feasibility studies relative to irrigation of the proposed project area.

Acknowledgments

The methodology for "dependable precipitation" and "moisture availability index" was developed in cooperation with Jerald E. Christiansen, Professor Emeritus, Agricultural and Irrigation Engineering, Utah State University. The research leading to the development of the equations used was financed by the Agency for International Development Contract AID/csd-2167 and carried out at Utah State University.

The data required were made available by the Instituto Costarricense de Electricidad and the WMO-UNDP Proyecto Hidrometeorologico Centroamericano.

APPENDIX 1

Fortran Computer Program Used

```
      REAL MAI
      DIMENSION NAME(6),TM(12),HM(12),PREC(12),W6(12),DEC(12),ES(12),
     2DM(12),AV(12)
      DATA (DM(M), M=1,12)/31.,28.,31.,30.,31.,30.,31.,31.,30.,31.,30.,
     131./
      DATA (DEC(M),M=1,12)/-20.949,-13.553,-2.683,9.207,18.606,23.016,21
     $.195,13.523,2.789,-9.565,-18.854,-23.040/
      DATA (ES(M),M=1,12)/.97104,.98135,.99653,1.01313,1.02625,1.03241,1
     $.02987,1.01916,1.00347,.98693,.97369,.96812/
C     PROGRAM 20 GHH TO COMPUTE POTENTIAL EVAPOTRANSPIRATION FOR CENTRAL
C     AMERICA   INCLUDING CLIMATIC DATA
C         NAME = STATION ID FROM FIRST 40 COLUMNS OF FIRST CARD OF SET OF FIVE
C         TM = MEAN MONTHLY TEMPERATURE SECOND CARD 5X,12F5.1
C         HM = MEAN MONTHLY HUMIDITY    THIRD CARD 5X,12F5.2
C         PREC=MEAN MONTHLY PRECIPITATION  FOURTH CARD 5X,12F5.0
C         EVPM = MEAN MONTHLY PAN EVAPORATION  FOURTH CARD 5X,12F5.0
C         W6=MEAN MONTHLY WIND IN KM/HR AT 6M  5X,12F5.1
C         EVPC = MEAN MONTHLY PAN EVAPORATION CALCULATED
C         DP=CALCULATED PRECIPITATION AT 75 PERCENT PROBABILITY
C         DEC AND ES ARE MONTHLY CONSTANTS
C         DEC IS THE ANGLE OF THE SUN AND ES IS EXPECTED SUNSHINE
C         DM = NUMBER OF DAYS IN THE MONTH
C         RMM = MEAN MONTHLY RADIATION
C         CT = COEFFICIENT FOR TEMPERATURE
C         CH = COEFFICIENT FOR HUMIDITY
C         CE = COEFFICIENT FOR ELEVATION
C         CW= COEFICIENT FOR WIND
C         ETP = EVAPOTRANSPERATION CALCULATED
C         RMC = EVPM/EVPC
C         RPM = ETP/EVPM
C         AV = THE AVERAGE ACROSS MONTHS
C         LD,LDM = LATITUDE IN DEGREES AND MINUTES
C         LO,LOM = LONGITUDE IN DEGREES AND MINUTES
C         LE = ELEVATION
C         XLA = LATITUDE IN RADIANS
C******************************************************************************
```

```
00110      C
00110      C       CONVERT DEC FROM DEGREES TO RADIANS
00112              DO 1 I=1,12
00115            1 DEC(I)=DEC(I)/57.2958
00115      C
00117              DATA AV/12*0./
00117      C*****************************************************************************
00117      C  MAIN LOOP   READ DATA FIRST
00121              JJ=0
00122            2 READ(5,100,END=99) NAME,LD,LDM,LO,LOM,LE,TM,HM,PREC,W6
00155              JJ=JJ+1
00156        100 FORMAT(6A6,4X,I2,I3,5X,I2,I3,T52,I4/
00156           15X,12F5.1/5X,12F5.2/5X,12F5.0/5X,12F5.1)
00156      C       AT END OF DATA STOP
00157              XLA=(FLOAT(LD)-FLOAT(LDM)/60.)/57.2958
00160              IF(MOD(JJ,2).EQ.1) PRINT 104
00163        104 FORMAT('1')
00164              PRINT 101,NAME,LD,LDM,LO,LOM,LE
00177        101 FORMAT(' '//6A6,'   LAT ',I2,I3,'   LONG ',I2,I3,'   ELEV ',I4//
00177            1 '0 MO    TM      HM      W6    PREC     RMM   EVPC  EVPC2    ETP   ETP2      PD
00177            1 ETDF    MAI'/)
00177      C*****************************************************************************
00177      C
00177      C       CALCULATE AND PRINT MONTHLY VALUES AND SUM FOR AVERAGES
00200              DO 3 I=1,12
00203              Z=-TAN(XLA)*TAN(DEC(I))
00204              OM=ATAN(SQRT(1.-Z*Z)/ABS(Z))
00205              DL=OM/.1309
00206              IF(Z.LT.0.) DL=24.-DL
00210              RLD=120.*(DL*SIN(XLA)*SIN(DEC(I))+7.6394*COS(XLA)*COS(DEC(I))*
00210             *SIN(OM))/ES(I)
00211              RMM=DM(I)*10.*RLD/(595.9-.55*TM(I))
00212              CT=.4+.024*TM(I)
00213              CHV=.05+1.42*SQRT(1.-HM(I))
00214              CH=CHV
00215              IF(CH.GT.1.) CH=1.
00217              CW=.80+.028*W6(I)
00220              CHV=.72+.039*W6(I)
```

```
00221            IF(W6(I).LT..01) CW=1.00
00223            IF(W6(I).LT..01) CWV=1.00
00225            CF=1.+.00004*FLOAT(LE)
00226            CEV=1.+.00007*FLOAT(LE)
00227            EVPC=.43*RMM*CT*CHV*CEV
00230            EVPC2=EVPC*CWV
00231            ETP=.35*RMM*CT*CH*CE
00232            ETP2=ETP*CW
00233            PD=-10.+.70*PREC(I)
00234            IF(PD.LT.1.0) PD=0.0
00236            ETDF=ETP2-PD
00237            MAI=PD/ETP2
00240            AV( 1)=AV( 1)+TM(I)
00241            AV( 2)=AV( 2)+HM(I)
00242            AV( 3)=AV( 3)+W6(I)
00243            AV( 4)=AV( 4)+PREC(I)
00244            AV( 5)=AV( 5)+RMM
00245            AV( 6)=AV( 6)+EVPC
00246            AV( 7)=AV( 7)+EVPC2
00247            AV( 8)=AV( 8)+ETP
00250            AV( 9)=AV( 9)+ETP2
00251            AV(10)=AV(10)+PD
00252            AV(11)=AV(11)+ETDF
00253            AV(12)=AV(12)+MAI
00254            PRINT 102,I,TM(I),HM(I),W6(I),PREC(I),RMM,EVPC,EVPC2,ETP,ETP2,PD,
00254           1ETDF,MAI
00273        102 FORMAT(2X,I2,F6.1,F6.2,F6.1,8F6.0,F6.2)
00274          3 CONTINUE
00274      C
00274      C*************************************************************************
00274      C     COMPUTE AND PRINT AVERAGES
00276            DO 4 I=1,12
00301          4 AV(I)=AV(I)/12.
00303            PRINT 103,(AV(I),I=1,12)
00311        103 FORMAT('0AVE',F6.1,F6.2,F6.1,8F6.0,F6.2,//
00311      C
00311      C     REINITIALIZE AV AND LOOK FOR NEXT DATA SET
00312            DO 5 I=1,12
00315          5 AV(I)=0.
00317            GO TO 2
00320         99 STOP
00321            END
```