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HETAN: A SUBPROGRAM PACKAGE
FOR PREDICTING THE HEAT TRANSFER
ACROSS THE SURFACE OF A NATURAL BODY
OF WATER

Battelle

Pacific Northwest Laboratories
Richland, Washington 99352

JUNE 1974

MASTER

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HETRAN: A SUBPROGRAM PACKAGE FOR
PREDICTING THE HEAT TRANSFER ACROSS THE
SURFACE OF A NATURAL BODY OF WATER

By

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June 1974

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SUMMARY

A computer subprogram HETRAN was developed for prediction of atmospheric heat exchange across the air-water interface of a natural water body. The program uses standard meteorologic data and analytic-empirical relationships to calculate the component energy fluxes. Included in the general heat budget are net shortwave radiation, net atmospheric radiation, back radiation, evaporative heat loss, and convective loss or gain at the air-water interface. The program is capable of predicting diurnal patterns and long term temperature variations. The subprograms are designed so that they may be easily coupled to generalized programs for far field temperature predictions.

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NOTATION

- a = atmosphere transmission coefficient
- ABSORP = solar absorptivity of the water surface, averaged over time step
- C_1, C_2, C_3, C_4 = empirically derived coefficients
- D = time of year, measured in days from day 1 on January 1
- D_x, D_y = eddy diffusivities in the X and Y directions, respectively, m^2/sec .
- EQT YM = equation of time, obtained by linear interpolation in Table 3
- e_a = vapor pressure of the atmosphere, mb
- e_w = vapor pressure of water, mb
- H = total water depth of depth to the thermocline, m
- h = hour angle of the sun, degrees
- I = underwater radiation intensity, $K \text{ cal}/(m^2 \text{ hr})$
- J_o = solar constant, ca 1.94 Langley/min
- P = local atmospheric pressure, mb
- Q = total heat transferred to the water from the atmosphere, $K \text{ cal}/(m^2 \text{ hr})$
- Q_{at} = longwave radiation emitted by the atmosphere and absorbed by the water, $K \text{ cal}/(m^2 \text{ hr})$
- Q_c = energy transferred from the water to the atmosphere by conduction, $K \text{ cal}/(m^2 \text{ hr})$
- Q_e = energy transferred from the water to the atmosphere by evaporation, $K \text{ cal}/(m^2 \text{ hr})$
- Q_{sn} = daily total solar radiation, Langley

$\bar{Q}_{sn}$ = average solar radiation over a time step,
K cal/(m²hr)

Q_w = longwave radiation emitted by the water
surface to the atmosphere, K cal/(m²hr)

R = Bowen ratio

RBETA = fraction of solar radiation absorbed to depth H

r = distance from the center of the earth to the
center of the sun expressed in terms of the
length of the semimajor axis of the earth's
orbit

S = source term representing net heat transfer
across air-water interface

T_a = air temperature above the water surface, °C

T_w = water surface temperature, °C

TZONE = time zone number, defined as the standard
meridian in degrees divided by 15°. This
quantity is measured positive west of the
Greenwich Meridian, negative east of the
Greenwich Meridian

t = time of day, measured in hours from zero hours
at midnight standard time

t_m = mean solar time (hours)

t_s = true solar time (hours)

Δt = computational time step, hours

U = wind speed over water surface, knots

u,v = current velocities in the x and y directions,
respectively, m/sec.

z = vertical coordinate

α = solar altitude, measured in vertical degrees
from the horizon to the sun

β = atmospheric radiation factor

γ = latent heat of evaporation of water,
K cal/(m²hr)

Δ = phase angle for angle of declination of the
sun, degrees

ϵ = phase angle for radius vector of the earth,
degrees

θ = longitude of the site, measured in degrees as
positive west of the Greenwich Meridian, nega-
tive east of the Greenwich Meridian

δ = angle of declination of the sun, degrees

λ = light extinction coefficient, m⁻¹

ρ = density of water as a function of water
temperature, kgm/m³

σ = Stefan-Boltzman constant

τ = duration of daylight as a function of time of
year and latitude, hours

τ_1 = sunrise time, hours from midnight

τ_2 = sunset time, hours from midnight

ϕ = latitude of the site measured in degrees as
positive in the Northern Hemisphere, negative
in the Southern Hemisphere

HETTRAN: A SUBPROGRAM PACKAGE FOR PREDICTING THE HEAT TRANSFER ACROSS THE SURFACE OF A NATURAL BODY OF WATER

INTRODUCTION

The numerical modeling of physical processes in water systems for far field temperature prediction has received considerable attention over the last two decades. Particular emphasis has been placed on procedures for estimation of atmospheric heat exchange. By and large, most available temperature models have been developed from hydrodynamic and thermodynamic principles as expressed by the basic conservation equations. Generally, the form of the energy equation in two dimensions is expressed as:

Heat Equation (Vertically Averaged)

$$\begin{aligned} \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = & \frac{1}{H} \frac{\partial}{\partial x} [(\alpha + \epsilon_{hx}) H \frac{\partial T}{\partial x}] \\ & + \frac{1}{H} \frac{\partial}{\partial y} [(\alpha + \epsilon_{hy}) H \frac{\partial T}{\partial y}] + \frac{\dot{Q}}{\rho C_p} \end{aligned} \quad (1)$$

where

T = temperature

H = water depth, $H(x,y)$

α = thermal diffusivity (k/C_p)

$\epsilon_{hx}, \epsilon_{hy}$ = eddy thermal diffusivity

ρ = density

C_p = specific heat

$\dot{Q}$ = volumetric heat source or sink

The eddy diffusivity terms are generally used to account for the quasi-random turbulent mixing phenomena.

In the true three-dimensional problem, the heat transfer at the air-water interface is treated as a boundary condition. However, in two-dimensional models it is convenient to distribute the heat generation logarithmically with depth.

Another treatment utilizes a surface layer approximation and converts the net atmospheric energy flux to a volumetric heat source distributed over a finite surface layer. This is the fundamental idea underlying HETRAN.

Various energy transfer phenomena occur at the interface between the atmosphere and the water body. The external transfer of heat energy across the air-water interface is accomplished by three basic mechanisms: radiation (solar and atmospheric), evaporation, and convection. The net external heat exchange may be expressed as the algebraic sum of the component energy fluxes, namely

External Heat Balance

$$Q_n = Q_s - Q_{sr} + Q_a - Q_{ar} - Q_w - Q_e + Q_c \quad (2)$$

where

Q_s = shortwave radiation incident to the water surface

Q_{sr} = reflected shortwave radiation

Q_a = incoming longwave radiation from the atmosphere

Q_{ar} = reflected longwave radiation from the atmosphere

Q_w = back radiation emitted by the body of water

Q_e = energy utilized by evaporation

Q_c = energy convected to and from the body of water at the air-water interface

In general, the components Q_s , Q_{sr} , Q_a , Q_{ar} are independent of water surface temperature while Q_w , Q_e , and Q_c are explicit functions of water temperature. Most of these components present in atmospheric heat exchange are not routinely measured. However, the work of many investigators has provided a variety of theoretical and empirical relationships which represent the individual heat exchange mechanisms; Reference 1 is a comprehensive review of the literature. A relative comparison of the amount of heat loss or gain by each component of the heat balance is shown in Table 1.

TABLE 1. Comparison of Amounts of Heat Loss by Various Components of Atmospheric Heat Balance²

Component	Symbol	Range of Heat Loss or Gain (Btu/ft ² -day)
Shortwave solar radiation	Q_s	400 to 2800
Reflected shortwave	Q_{sr}	40 to 200
Net shortwave	$Q_{sn} = Q_s - Q_{sr}$	200 to 2860
Longwave atmospheric radiation	Q_a	2400 to 3200
Reflected longwave	Q_{ar}	70 to 120
Net longwave (incoming)	$Q_{at} = Q_a - Q_{ar}$	2280 to 3130
Net surface radiation	Q_w	2400 to 3600
Evaporative heat loss	Q_e	2000 to 8000
Convective heat loss or gain	Q_c	-320 to 400

DESCRIPTION OF THE SUBPROGRAM PACKAGE

It is known that heat flowing from a surface discharge remains primarily in the surface layer, above the thermocline, of a deep body of water but may occupy the full depth in a shallow vertically mixed body of water. A generalized far field temperature model coupled with the HETRAN subprogram could be used directly to simulate either condition. Figure 1 depicts a body of water and the two possible conditions that can be accounted for.

FIGURE 1. A Horizontal Finite Difference Grid on a Natural Body of Water

To calculate the water temperature change in a given computational cell as the result of the net heat transfer from the atmosphere to the water, HETRAN uses basic meteorologic parameters and initial surface water temperature as input variables. The required meteorologic parameters include air temperature, dew point temperature, wind speed, amount of cloud cover, and solar radiation. These data, with the exception of solar radiation, are available from the National Climatic Center in Ashville, North Carolina for over 290 local climatological data stations in the United States and U.S. territories. Data are supplied for one-hour intervals (through December 1964), for three-hour intervals (beginning in January 1965), or as daily averages. Stations for which data are available are shown in Table 2. Solar radiation data are available as daily totals at over 90 stations in the United States. These stations are shown in Figure 2.

Six different heat transfer phenomena have been taken into account in the water temperature change due to heat transfer across the air-water interface:

- 1) direct and diffuse shortwave radiation from the sun (solar radiation) incident on the water surface
- 2) solar radiation absorbed by the water
- 3) longwave atmospheric radiation
- 4) longwave radiation from the body of water
- 5) evaporation or condensation at the water surface
- 6) heat conducted from the air to the water as sensible heat

NET HEAT TRANSFER FROM THE AIR TO THE WATER

The HETRAN program calculates net heat flux across the air-water interface from the expression:

$$Q = \bar{Q}_{sn} + Q_{at} - Q_w - Q_e + Q_c \quad (3)$$

The term Q on the left side of this equation represents the net heat transferred into the body of water from the atmosphere. This equation accounts for the significant heat transfer characteristics across the air-water interface. The few other possible sources of heat, such as chemical

**U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE**

TABLE 2. Stations for Which Local Climatological Data are Issued, as of January 1, 1972

abc ALABAMA		FLORIDA		MASSACHUSETTS		NEW YORK (Contd.)		SOUTH DAKOTA
abc Birmingham	ac	Apalachicola	abc	Boston	abc	Buffalo	abc	Aberdeen
abc Huntsville	abc	Daytona Beach	ac	Blue Hill Obs.		New York	abc	Huron
abc Mobile	abc	Fort Myers	abc	Worcester	abc	Central Park	abc	Rapid City
abc Montgomery	abc	Jacksonville			abc	J.F. Kennedy Int'l AP	abc	Sioux Falls
	ac	Key West		MICHIGAN		LaGuardia Field		
abc ALASKA	abc	Lakeland	abc	Alpena	abc	Rochester		TENNESSEE
abc Anchorage	abc	Miami		Detroit	abc	Syracuse	abc	Bristol
abc Annette	abc	Orlando	abc	City Airport			abc	Chattanooga
abc Barrow	abc	Pensacola	abc	Detroit Metro AP		NORTH CAROLINA	abc	Knoxville
abc Barter Island	abc	Tallahassee	abc	Flint	abc	Asheville	abc	Memphis
abc Bethel	abc	Tampa	abc	Grand Rapids	abc	Cape Hatteras	abc	Nashville
abc Bettles	abc	West Palm Beach	abc	Houghton Lake	abc	Charlotte		Oak Ridge
abc Big Delta			abc	Lansing	abc	Greensboro	a	Area Stations
abc Cold Bay		GEORGIA	ac	Marquette	abc	Raleigh	ac	City
abc Fairbanks	abc	Athens	abc	Muskegon	abc	Wilmington		
abc Gulikana	abc	Atlanta	abc	Sault Ste. Marie				TEXAS
abc Homer	abc	Augusta				NORTH DAKOTA	abc	Abilene
abc Juneau	abc	Columbus		MINNESOTA	abc	Bismarck	abc	Amarillo
abc King Salmon	abc	Macon	abc	Duluth	abc	Fargo	abc	Austin
abc Kotzebue	ac	Rome	abc	International Falls	abc	Williston	abc	Brownsville
abc McGrath	abc	Savannah	abc	Minneapolis-St. Paul			abc	Corpus Christi
abc Nome			abc	Rochester		OHIO	abc	Dallas
abc St. Paul Island		HAWAII	abc	St. Cloud	abc	Akron-Canton	abc	Del Rio
abc Shemya	abc	Hilo				Cincinnati	abc	El Paso
abc Summit	abc	Honolulu		MISSISSIPPI	ac	Abbe Obs.	abc	Fort Worth
abc Talkeetna	abc	Kahului	abc	Jackson	abc	Airport	ac	Galveston
abc Unalakleet	abc	Lihue	abc	Meridian	abc	Cleveland	abc	Houston
abc Yakutat						Columbus	abc	Lubbock
		IDAHO	abc	MISSOURI	abc	Dayton	abc	Midland
abc ARIZONA	abc	Boise	abc	Columbia	abc	Mansfield	abc	Port Arthur
abc Flagstaff	abc	Lewiston	abc	Kansas City	abc	Toledo	abc	San Angelo
abc Phoenix	abc	Pocatello	abc	St. Joseph	abc	Youngstown	abc	San Antonio
abc Tucson			abc	St. Louis			abc	Victoria
abc Winslow		ILLINOIS	abc	Springfield		OKLAHOMA	abc	Waco
abc Yuma	ac	Chgo			abc	Oklahoma City	abc	Wichita Falls
		Chicago		MONTANA	abc	Tulsa		
abc ARKANSAS	abc	Midway Airport	abc	Billings				UTAH
abc Fort Smith	abc	O'Hare Airport	abc	Glasgow		OREGON	ac	Milford
abc Little Rock	abc	Moline	abc	Great Falls	abc	Astoria	abc	Salt Lake City
	abc	Peoria	abc	Havre	abc	Burns	abc	Wendover
abc CALIFORNIA	abc	Rockford	abc	Helena	abc	Eugene		
abc Bakersfield	abc	Springfield	abc	Kalispell	abc	Meacham		VERMONT
abc Bishop			abc	Miles City	abc	Medford	abc	Burlington
ac Blue Canyon		INDIANA	abc	Missoula	abc	Pendleton		
ac Eureka	abc	Evansville			abc	Portland		VIRGINIA
abc Fresno	abc	Fort Wayne		NEBRASKA	abc	Salem	abc	Lynchburg
abc Long Beach	abc	Indianapolis	abc	Grand Island	abc	Sexton Summit	abc	Norfolk
abc Los Angeles Airport	abc	South Bend	ac	Lincoln			abc	Richmond
ac Los Angeles			abc	Norfolk		PACIFIC ISLANDS	abc	Roadview
abc Civic Center		IOWA	abc	North Platte	abc	Cuam	ab	Walluys Island
abc Mt. Shasta	abc	Burlington	abc	Omaha	abc	Johnston		
abc Oakland	abc	Des Moines	abc	Scratchliff	abc	Korer		WASHINGTON
abc Red Bluff	abc	Dubuque	ac	Valentine	abc	Kwa-Jalein	abc	Olympia
abc Sacramento	abc	Sioux City			abc	Mar Jura	abc	Whilldgate Airport
abc Sandberg	abc	Waterloo		NEVADA	abc	Pago Pago	abc	Seattle-Tacoma AP
abc San Diego			abc	Elko	abc	Ponape	abc	Spokane
abc San Francisco	abc	KANSAS	abc	Ely	abc	Truk (Moon)	abc	Stampede Pass
ac Airport	abc	Concordia	abc	Las Vegas	abc	Wake	ac	Walla Walla
ac City	abc	Dodge City	abc	Reno	abc	Yap	abc	Yakima
abc Santa Maria	abc	Goodland	abc	Winnemucca				
abc Stockton	abc	Topeka				PENNSYLVANIA		WEST INDIES
	abc	Wichita		NEW HAMPSHIRE	abc	Allentown	abc	San Juan, P. R.
abc COLORADO			abc	Concord	abc	Erie		
abc Alamosa		KENTUCKY	ac	Mc. Washington	abc	Harrisburg		WEST VIRGINIA
abc Colorado Springs	abc	Lexington			abc	Philadelphia	abc	Beckley
abc Denver	abc	Louisville		NEW JERSEY	abc	Pittsburgh	abc	Charleston
abc Grand Junction			abc	Atlantic City	abc	Airport	abc	Elkins
abc Pueblo	abc	LOUISIANA	a	State Marina	abc	City	abc	Huntington
	abc	Alexandria	abc	Newark	abc	Scranton	ac	Parkersburg
abc CONNECTICUT	abc	Baton Rouge	abc	Trenton		Williamsport		
abc Bridgeport	abc	Lake Charles	abc					WISCONSIN
abc Hartford	abc	New Orleans	ac				abc	Green Bay
	abc	Shreveport		NEW MEXICO	abc	RHODE ISLAND	abc	La Crosse
abc DELAWARE	abc		abc	Albuquerque	abc	Bleek Island	abc	Madison
abc Wilmington	abc	MAINE	ac	Clayton		Providence	abc	Milwaukee
	abc	Caribou	abc	Roswell				
abc DISTRICT OF COLUMBIA		Portland				SOUTH CAROLINA		WYOMING
abc Washington-National AP			abc	NEW YORK	abc	Charleston	abc	Casper
abc Washington-Dulles Int'l AP	abc	MARYLAND	abc	Albany	abc	City	abc	Cheyenne
		Baltimore	abc	Binghamton	abc	Columbia	abc	Lander
						Greenville-	abc	Sheridan
						Spartanburg		

a. Monthly summary issued.

b. Monthly summary includes available 3-hourly observations.
Published if 5 or more available per day.

c. Annual Summary issued.

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FIGURE 2. Hemispheric Solar Radiation Stations--Daily Values

and biological processes within the control volume, conduction of heat from the earth beneath the control volume to the water, and the transformation of kinetic into thermal energy, are neglected because they are generally insignificant.

Each term in Equation 3 will be discussed individually.

SOLAR RADIATION

Outside the atmosphere of the earth radiant energy received from the sun on a surface normal to its rays is about 1.94 Langley per minute (1 Langley = 1 gm cal/cm²). This value, called the solar constant and referred to as J_0 , fluctuates slightly during the year because of sunspots and variations in the distance between the earth and the sun. However, these factors are minor when compared with the other factors that diminish the radiation received on the earth.

The plane normal to the sun's rays on the surface of the earth receives considerably less energy since moisture, gases, and solid particles in the atmosphere absorb and scatter the energy as it comes to the earth's surface. While part of this direct radiant energy is lost due to absorption and back scattering, some reaches the earth as diffuse or sky radiation.

The solar radiation received on a horizontal surface on the earth is so greatly affected by the sky condition (i.e., variations in cloud cover, smog, haze and dust) that the only accurate method available for estimating this quantity is through actual measurements. These measurements, supplied by the National Climatic Center as daily total solar radiation, are used by this program.

If diurnal variations in water temperature are desired, the daily total solar radiation must be apportioned throughout the day. The basic formula for computing the direct total solar radiation which falls on a horizontal area at the earth's surface is³

$$\frac{dQ_{sn}}{dt} = \frac{J_0}{r^2} a \cos \alpha \sin \alpha \quad (4)$$

Equation 4 is assumed to apply to total solar radiation although its derivation is strictly applicable only to monochromatic radiation. Refraction by the earth's atmosphere has also been neglected.

The radius vector of the earth, r , is the distance between the earth and the sun, normalized by the semimajor axis of the earth's elliptical orbit. It varies seasonally and may be considered constant for a given day. It is approximated by

$$r = 1 + 0.016735 \cos \left(\frac{2\pi}{365.25} D - \epsilon \right) \quad (5)$$

where D is the time measured in days, beginning with day one on January 1. The constant ϵ is the phase angle and can be calculated knowing that the radius vector of the earth is at its maximum on July 5.⁴

$$\epsilon = 186 \frac{2\pi}{385.25} \quad (6)$$

The constant a is the atmospheric transmission coefficient and is dependent on the moisture, dust, and smog content of the atmosphere. It normally ranges between 0.6 and 0.9.

The angle of incidence of the sun's rays, α , on the body of water is commonly referred to as the solar altitude. The solar altitude is a function of the time of day, the time of year, and the latitude of the body of water. It can be evaluated for any hour of any day of the year by the use of spherical trigonometry. This relationship can be expressed as

$$\sin \alpha = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h \quad (7)$$

The latitude, ϕ , is readily obtained as the average latitude of the body of water; it is positive in the Northern Hemisphere, negative in the Southern Hemisphere.

The declination of the sun, δ , can be approximated by a sine function with a period of one year. This function can be expressed as

$$\delta = 23.45 \frac{\pi}{180} \sin \left\{ \frac{2\pi}{365.25} D - \Delta \right\} \quad (8)$$

where the value of δ is in radians and D is the day number as previously defined. The constant, Δ , represents the phase angle and can be calculated knowing the declination of the sun is zero on March 21.

$$\Delta = 80 \frac{2\pi}{365.25} \quad (9)$$

The hour angle of the sun, h , is the angular distance measured in a westerly direction around the axis of the earth between the meridian of the observer and the meridian of the sun. At true solar noon (when the solar altitude is at maximum for that day), $h = 0$. In mornings h is negative and in afternoons h is positive. The value of h depends on three factors: 1) the local standard time (zone time); 2) the distance between the meridian of the observer and the standard meridian for that time zone; and 3) the variation in the length of a day due to seasonal variations in the orbital velocity of the earth. The third factor is accounted for by the equation of time which gives the difference between true solar time and mean solar time (this is computed on the basis of a yearly average). Table 3 lists values of the equation of time taken from a more complete table."

To compute the hour angle the true solar time must first be computed as follows:

- a) One-fifteenth hour is added to the local standard time (zone time) for each degree of longitude by which the point of observation is east of the standard meridian, or one-fifteenth hour is subtracted for each degree by which the observation point is west of the standard meridian. This gives the local mean solar time; this correction is made with the following equation:

$$t_m = t + \text{TZONE} - \frac{\theta}{15} \quad (10)$$

where TZONE is defined as the longitude of the standard meridian in degrees divided by 15° . TZONE is measured positive west of the Greenwich Meridian, negative east of the Greenwich Meridian. For example, the longitude of the standard meridian for Pacific Standard Time is 120° . The time zone number, TZONE, is 8.

- b) The equation of time obtained from Table 2 is added algebraically to the local mean solar time to obtain the true solar time. Linear interpolation is used between the dates given in Table 2. In equation form this becomes

$$t_s = t_m + \text{EQTYM} \quad (11)$$

TABLE 3. The Equation of Time

Equation of Time			Equation of Time		
Date	(min	sec)	Date	(min	sec)
Jan. 1	-3	14	July 1	-3	31
9	-6	50	9	-4	56
17	-9	54	17	-5	57
25	-12	14	25	-6	24
Feb. 1	-13	34	Aug. 1	-6	17
9	-14	17	9	-5	33
17	-14	10	17	-4	12
25	-13	19	25	-2	18
Mar. 1	-12	38	Sept. 1	-0	15
9	-10	51	9	+2	22
17	-8	42	17	+5	10
25	-6	20	25	+8	00
Apr. 1	-4	12	Oct. 1	+10	01
9	-1	52	9	+12	27
17	+0	13	17	+14	25
25	+1	53	25	+15	46
May 1	+2	50	Nov. 1	+16	21
9	+3	35	9	+16	12
17	+3	44	17	+15	10
25	+3	16	25	+13	15
June 1	+2	27	Dec. 1	+11	16
9	+1	06	9	+8	01
17	-0	33	17	+4	17
25	-2	17	25	+0	20

The hour angle is then given in degrees as

$$h = 15 t_s - 180 \quad (12)$$

The total daily solar radiation is simply the integral of Equation 4 over the duration of daylight

$$Q_{sn} = \frac{J_o}{r^2} \int_{\tau_1}^{\tau_2} a \csc \alpha \sin \alpha dt \quad (13)$$

where τ_1 and τ_2 represent the true solar times of sunrise and sunset, respectively.

The duration of daylight is a function of latitude and time of year and can be evaluated using

$$\tau = \frac{24}{\pi} \cos^{-1} (-\tan \phi \tan \delta) \quad (14)$$

or

$$\tau = 24 \text{ if } \phi + \delta \geq \frac{\pi}{2}$$

The latitude, ϕ , is readily determined and the declination of the sun can be evaluated from Equation 7.

The true solar times of sunrise and sunset can be calculated as

$$\begin{aligned} \tau_1 &= 12 - \frac{\tau}{2} \\ \tau_2 &= 12 + \frac{\tau}{2} \end{aligned} \quad (15)$$

Now, with the total daily solar radiation for a day, the daily average transmission coefficient, a , can be obtained by numerically solving the integral Equation 13. Using this daily average transmission coefficient in Equation 4, the solar radiation incident on the water body at any time of day can be calculated.

Equation 4 can now be integrated over the time step of interest and the average solar radiation over the time step can be evaluated as

$$\bar{Q}_{sn} = \frac{J_o}{r^2 \Delta t} \int_{t_s}^{t_s + \Delta t} a \csc \alpha \sin \alpha dt' \quad (16)$$

SOLAR RADIATION ABSORBED BY THE WATER

Of the total amount of shortwave radiation that reaches the water surface, a portion is reflected by the water surface and the balance is absorbed. A number of variables affect the absorptivity of the water surface, including the solar altitude, the type and amount of cloud cover, and turbidity of the atmosphere. Studies on Lake Hefner indicated that the absorptivity of a natural water surface is primarily a function of the sun's altitude and secondarily a function of atmospheric turbulence, including the effect of clouds.⁵ Figure 3 is a plot of these data.⁶ The absorptivity is assumed to be controlled by the solar altitude and the amount of cloud cover. Absorptivity values are taken from the curves shown in Figure 3 and are calculated for the average solar altitude at each time step. The amount of cloud cover for the curves shown in Figure 3 is given in Table 4. For cloud cover amounts between the values shown in Table 4, linear interpolation is used.

FIGURE 3. Effect of Solar Altitude and Cloud Cover on Absorptivity

TABLE 4. Cloud Cover

<u>Cloudiness</u>	<u>Amount (tenths of sky cover)</u>
Clear	0
Scattered	3.0
Average	5.0
Broken	7.5
Overcast	10.0

Most far field models are used to predict the heat transport in a surface layer of the water body (i.e., above the thermocline); however, the solar radiation may not be entirely absorbed in this layer but may penetrate to greater depths. If the water is clear the light will penetrate deeply before it is entirely absorbed, whereas if the water is turbid the light will be absorbed more rapidly.

A coefficient, defined by oceanographers as the light extinction coefficient, is used to define the rate at which the downward-traveling radiation is absorbed:⁷

$$\lambda = \frac{d \ln I(z)}{dz} \quad (17)$$

where I is the radiation intensity of an underwater horizontal surface as a function of z . The extinction coefficient is actually a function of the radiation wavelengths but is here defined as the average over the wavelength of the radiation.

Figure 4 describes extinction coefficients as a function of wavelength.⁸ The figure contains the extinction coefficients for pure water, the minimum, mean, and maximum coefficients observed in ocean water, and the minimum, mean, and maximum coefficients observed in coastal water. The extinction coefficients for shallow inland lakes and rivers may be much higher, on the order of 10 to 20 m^{-1} , due to high concentrations of plankton or sediments.

FIGURE 4. Light Extinction Coefficient as a Function of Wavelength in Pure Water and Different Types of Sea Water

Equation 17 can be used to show that the fraction of total radiation absorbed to depth H is just

$$RBETA = 1 - e^{-\lambda H} \quad (18)$$

This fraction, when multiplied by the total amount of solar radiation entering the water, yields the amount of radiant energy absorbed to depth H. Thus, the average amount of solar radiation that enters the water and is absorbed at depth H is

$$Q_{ABSORP} = RBETA \bar{Q}_{sn} \quad (19)$$

LONGWAVE ATMOSPHERIC RADIATION

Atmospheric radiation is the longwave radiation emitted by the atmosphere and is here defined as the amount that enters the water surface. It is a function of many variables in the column of air above the body of water, including the distribution of moisture, temperature, ozone and carbon dioxide, but is primarily dependent on the total amount of moisture in the air.

To evaluate the atmospheric radiation properly, it is necessary to sound the entire air column above the water and measure total moisture content and atmospheric temperature. Since upper air soundings are not always available, however, the following empirical relationship has been proposed to account for atmospheric radiation:⁹

$$Q_{at} = \sigma T_a^4 \beta \quad (20)$$

where the atmospheric radiation, β , factor is defined as

$$\beta = C_1 + C_2 e_a \quad (21)$$

The coefficients C_1 and C_2 are empirically determined and depend primarily on the amount of cloud cover and secondarily on the cloud height and type. The Lake Hefner data were used to compute the atmospheric radiation factor as a function of cloud amount and vapor pressure without regard to cloud height.¹⁰ This relationship is plotted in Figure 5.

The coefficients C_1 and C_2 listed in Table 5 were obtained from the family of curves shown in Figure 5. Linear interpolation is used in Table 5 when cloud cover is in fractions of a tenth.

Significant error can result if the reflection of longwave radiation at the water surface is not accounted for. Tests performed at the University of California showed that the absorptivity of a water surface in the usual ranges of air temperature is 0.970.¹¹ Thus the equation for atmospheric radiation absorbed by the water is modified to

$$Q_{at} = 0.970 \sigma T_a^4 \beta \quad (22)$$

FIGURE 5. Atmospheric Radiation Factor as a Function of Vapor Pressure and Cloud Cover

TABLE 5. Atmospheric Radiation Factor Coefficients

Cloud Amount (tenths of sky cover)	C_1	$C_2 - 1$ (in ⁻¹)
0	0.7406	0.1538
1	0.7492	0.1508
2	0.7598	0.1480
3	0.7703	0.1449
4	0.7813	0.1410
5	0.7910	0.1379
6	0.8000	0.1352
7	0.8109	0.1297
8	0.8254	0.1195
9	0.8457	0.1047
10	0.8648	0.0907

LONGWAVE RADIATION FROM THE BODY OF WATER

The Stefan-Boltzman law can be used to evaluate the longwave radiation emitted by the surface of a water body if suitable correction is made for the emissivity of the surface. This is necessary because a natural water surface does not behave as a perfect black body.

The Physical Standards Laboratory at the University of California determined the emissivity of samples of distilled water, Lake Hefner water, Lake Mead water, and sea water. It was concluded that emissivity of water was 0.970, to an estimated accuracy of ± 0.005 , and that it was independent of water temperature and dissolved solids.¹² Thus the longwave radiation emitted by the water surface can be expressed as

$$Q_w = 0.970 \sigma T_w^4 \quad (23)$$

EVAPORATION OR CONDENSATION AT THE WATER SURFACE

When the vapor pressure of the surrounding air is less than that of the air at the temperature of the water's surface, evaporation occurs, removing heat from the water in two ways. The more significant portion of the heat loss is utilized as energy for evaporating the water. Of secondary importance is the removal of the heat contained in the water that is evaporated. The heat transferred due to evaporation depends on the vapor pressure difference and the wind velocity across the air-water interface. An empirical equation is used to evaluate the loss of energy from the water due to evaporation.¹³ This equation is

$$Q_e = \gamma \rho C_3 U (e_w - e_a) \quad (24)$$

The latent heat of vaporization of water, γ , is computed by interpolating linearly in Table 6.¹⁴

The density of water is assumed to satisfy the following relationship.^{15,16}

$$\rho(T) = 1000 \left\{ 1 - \left[\frac{(T-3.9863)^2}{508929.2} \right] \left[\frac{T+288.9414}{T+68.12963} \right] \right\} \quad (25)$$

where T is given in degrees centigrade and ρ is in kilograms per cubic meter.

TABLE 6. Latent Heat of Vaporization of Water

<u>Temperature</u> <u>(°C)</u>	<u>γ</u> <u>(Cal/gm)</u>	<u>Temperature</u> <u>(°C)</u>	<u>γ</u> <u>(Cal/gm)</u>
0	595.9	90	545.8
10	590.4	100	559.55
20	584.9	110	532.9
30	579.5	120	525.7
40	574.0	130	518.5
50	568.5	140	511.1
60	563.2	150	503.5
70	557.5	160	495.6
80	551.7	170	497.2
		180	478.6

The constant C_3 has been evaluated using Lake Hefner data

$$C_3 = 4.19034 \times 10^{-6} \frac{\text{sec}}{\text{hr mb}} \quad (26)$$

The vapor pressure of water as a function of temperature is obtained from one of the two polynomials given below. These polynomials were developed from tabular data:^{17,18}

$$e = 33.863928 \sum_{k=0}^7 a_k (T + 30)^k \quad (27)$$

where the a_k are given in Table 7, T is measured in degrees Fahrenheit, and e is in millibars.

Note that if the vapor pressure of the atmosphere is greater than the vapor pressure of the atmosphere at the temperature of the water surface, Equation 24 indicates that condensation will occur and energy will be transferred to the water.

TABLE 7. Vapor Pressure Coefficients

<u>k</u>	<u>Temperature Range</u>	
	<u>-30° F to 25° F</u>	<u>25° F to 130° F</u>
	<u>a_k</u>	<u>a_k</u>
0	7.0045480 x 10 ⁻³	-1.5646350
1	4.2072376 x 10 ⁻⁴	1.0551908 x 10 ⁻¹
2	1.1393840 x 10 ⁻⁵	-2.9385150 x 10 ⁻³
3	2.2338811 x 10 ⁻⁷	4.5571050 x 10 ⁻⁵
4	5.7517723 x 10 ⁻¹⁰	-4.1023648 x 10 ⁻⁷
5	6.6754266 x 10 ⁻¹¹	2.2219889 x 10 ⁻⁹
6	-6.2660131 x 10 ⁻¹³	-6.4344569 x 10 ⁻¹²
7	4.6163819 x 10 ⁻¹⁵	8.0422282 x 10 ⁻¹⁵

HEAT CONDUCTED FROM THE AIR TO THE WATER AS SENSIBLE HEAT

Sensible heat is conducted to or from a body of water by the air whenever a temperature difference exists between the air and water. The amount of heat conducted depends on the temperature difference between the water and air and upon the wind velocity at the interface. Since these factors are also present in the equation representing heat loss by evaporation, the ratio proposed by Bowen has been used to evaluate the ratio of conducted heat to energy of evaporation.¹⁹ The Bowen ratio is expressed as

$$R = \frac{Q_c}{Q_e} = C_4 \frac{T_w - T_a}{e_w - e_a} \frac{P}{760} \quad (28)$$

Bowen determined the limiting values of C_4 as 0.442 and 0.501; in this program a value of 0.46 has been used.

Combining Equations 24 and 28, the equation for evaluating the energy lost from the water due to evaporation becomes

$$Q_c = \frac{C_3 C_4 \gamma \rho P}{760} U (T_a - T_w) \quad (29)$$

USE OF SUBPROGRAM HETRAN

PROGRAM DESCRIPTION

The subprogram package is designed to be used with a driving program. The driving program must set up the two-dimensional nodal points for the system to be modeled, calculate the convection and diffusion within the system, and call subprogram package HETRAN at each time step. A listing of the subprogram package is provided in Appendix A together with a simplified driving program.

HETRAN calculates the heat transfer from the water to the atmosphere in every cell at each time step. It calls seven subprograms directly or indirectly:

CNSTNT	defines the constants used in other sub-routines
QSOL	is responsible for the solar radiation calculations. It does this in two steps: first, it calculates the daily average atmospheric transmission coefficients; then, it distributes the solar radiation throughout the daylight hours and provides the average solar radiation energy incident on the water surface at each time step
ABSORP	returns the absorptivity of a natural water surface as a function of the average solar altitude and cloud cover for each time step (see Equation 19, Figure 3, and Table 4)
H20LHT	calculates the latent heat of vaporization of water as a function of water temperature by linear interpolation in Table 6
VAPRES	computes the saturation vapor pressure of water as a function of temperature (see Equation 27 and Table 7)
CLOUD	returns the atmospheric radiation factor, β , as a function of vapor pressure and cloud cover (see Equation 21, Figure 5, and Table 5)
DSOLTM	computes the difference between local standard time and true solar time. The correction accounts for both longitudinal and seasonal variations (see Equations 10 and 11)

COMMON Statements

The following labeled COMMON statements contain data essential to the HETRAN package:

Lable	List
IUNIT	IN, OUT
VARIABLE	NX, NY, MAXIN, KOUNT, DELT, H(NCEL), CIJ(NCEL), DELC(NCEL), IJBDY(NBDY), SNLMDA
LOCATN	PHI, THETA, TZONE, SINPHY, COSPHY, PHY
WEATHR	WEATIT(14), DAT1, TIME1, TAD1, RH1, WSPD1, CLOUD1, RAD1, IME1, DAT2, TIME2, TAD2, RH2, WSPD2, CLOUD2, RAD2, IME2, WEAEOF

The following labeled COMMON statement contains data which might be of interest to the user:

QOPUP Q, QSN, QAT, QW, QE, QC

Comments pertaining to each individual COMMON block are given below.

IUNIT	IN and OUT are logical input and output units, respectively. All input data required by HETRAN is read from IN. Similarly, any printed output is addressed to OUT.
VARIABLE	The dimensions of H, CIJ, DELC, and IJBDY are defined by the parameters NCEL and NBDY. MAXIN is the product of NX and NY. SNLMDA is the light extinction coefficient.
LOCATN	PHI, THETA are the latitude and longitude of the body of water under study. TZONE is the local time zone as defined earlier.
WEATHR	WEATIT is the title card of the weather card packet. It contains 14 six-character words of Hollerith information. The variables with terminal characters 1 and 2 are the weather parameters from the two most current weather cards. In time (1) cards precede (2) cards.

WEAEOF is a logical variable which is .FALSE. so long as weather data cards are present. It is set to .TRUE. when an end-of-file condition is encountered while attempting to read new weather data.

QOPUP This COMMON block contains the total heat transfer in $K \text{ cal}/(m^2 \text{ hr})$ during the current time increment, and the individual components as described by Equation 1.

Those variables not commented upon are used only by the various subprograms contained in the HETRAN package, and as such have no utility to the user.

DATA INPUT

Part of the input data is read directly into subprogram HETRAN and the remainder enters the subprogram through COMMON from the driving program.

A weather title card and the weather data are read directly into subprogram HETRAN. The weather data enter in the format shown in Table 8. These data can be obtained from the National Climatic Center in this format on punched cards or magnetic tape or can be assembled from other U.S. Weather Bureau or cooperative stations in this format.

The remainder of the data necessary for execution and read into the driving program are as follows:

<u>Name</u>	<u>Description</u>	<u>Units</u>
PHI	Latitude of the site	Degrees
THETA	Longitude of the site	Degrees
TZONE	Time zone number	
DELT	Time step size	Hours
NTIME	Number of time steps	
NX	Number of cells in X-direction	
NY	Number of cells in Y-direction	
SNLMDA	Light extinction coefficient	Meters ⁻¹
C(IJ)*	Initial water temperature	Degrees C
H(IJ)*	Water depth to bottom or to thermocline	Meters
IJBDRY ⁺	Boundary model points	
KDDNT	Number of boundary cells	

*These quantities may vary from cell to cell in a one-dimensional array.

⁺No calculations are done on boundary cells.

TABLE 8. Weather Data Format

<u>Name</u>	<u>Description</u>	<u>Format</u>	<u>Column</u>
DATE	Date (year/month/day)	I6	1 - 6
TIME	Time of day (hours from midnight, standard time)	I2	7 - 8
TAD	Air temperature (°F)	F7.1	13 -19
RH	Dew point (°F)	F6.1	26 -31
WSPD	Wind speed (knots)	F6.1	32 -37
CLOUD	Cloud cover (tenths of sky cover)	F3.0	38 -40
RAD	Daily total solar radiation (Langley's)	F5.0	41 -45
IME*	Time increment between weather data (hours)	I6	65 -70

*If IME is zero or blank, it is automatically set to 1 hour.

NUMERICAL EXPERIMENT

A set of numerical experiments has been conducted to determine the effect of varying the time step size. Local climatological data obtained at Fort Worth at three-hour increments and daily total solar radiation data have been used as input to calculate the diurnal temperature fluctuation in the upper 1.29 meters of Lake Arlington, a reservoir between Fort Worth and Dallas, Texas.

The time step size used for the calculation was varied from 0.5 hour to 3.0 hours with no significant effect on the temperatures calculated. The maximum temperature difference in runs using a 0.5 hour time step and a 3.0 hour time step was less than 0.1°C . Figure 6 is a plot of the predicted surface temperatures from 0000 hours central standard time on August 21, 1963, to 2100 hours central standard time on August 29, 1963, using a time step size of 0.5 hours.

Appendix B presents a listing of the weather data used for the prediction and the remainder of the data input to the driving program. Appendix C gives the calculated surface temperatures for the first 24 hours of the simulation.

FIGURE 6. Diurnal Surface Temperature Prediction for Lake Arlington, Texas

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ACKNOWLEDGMENT

The authors are grateful to R. G. Baca for his constructive criticism during the preparation of this document.

APPENDIX A

PROGRAM LISTINGS

PROGRAM LISTINGS

```

C---- THIS PROGRAM DRIVES THE HETRAN SUBPROGRAM PACKAGE
C
C---- PROGRAM AUTHCRS   DG DANIELS AND CA OSTER
C   PROGRAM DATE       JUNE 1972
C
    PARAMETER NCEL=1000, NBDY=250
    LOGICAL WEAECF
    INTEGER TZONE,OUT,TIME1,TIME2,DAT1,DAT2
    COMMON /IUNIT/IN,OUT
    COMMON /VARIABLE/NX,NY,MAXIN,KOUNT,DELT,H(NCEL),CIJ(NCEL),
1  IDELC(NCEL),IUBDRY(NBDY),SNLMDA
    COMMON /LOCATN/PHI,THETA,TZONE,SINPHY,COSPHY,PHY
    COMMON /WEATHR/WEATIT(14),DAT1,TIME1,TAD1,RH1,WSPD1,CLOUD1,RAD1,
    1  IME1,DAT2,TIME2,TAD2,RH2,WSPD2,CLOUD2,RAD2,
    2  IME2,WEAEOF
    COMMON /QOPUP/Q,QSN,QAT,QW,QE,QC
99  FORMAT(2E10.0,I5)
98  FORMAT(4H01 =I4,10F12.6/(8X10F12.6))
97  FORMAT(7H0TIME =F7.2)
96  FORMAT('0WEATHER DATA EXHAUSTED - ATTEMPTED TO READ THRU EOF')
95  FORMAT(1X,F7.2,8F13.7)
94  FORMAT(14A6)
93  FORMAT(1H 14A6)
92  FORMAT(1H+23X14A6)
C
C---- DEFINE LOGICAL I/O UNITS
    IN=5
    OUT=6
C
C---- THE FOLLOWING PARAMETERS DEFINE THE SITE LOCATION OF THE STUDY
C   PHI   IS THE LATITUDE              (DEGREES)
C   THETA IS THE LONGITUDE              (DEGREES)
C   TZONE IS THE TIME ZONE NUMBER
C
    READ (IN,99) PHI,THETA,TZONE
C
C---- SNLMDA IS THE LIGHT EXTINCTION COEFFICIENT (1/METERS)
    READ (IN,99) SNLMDA
C
C---- FIRST CARD OF WEATHER DATA PACKET IS A DESCRIPTIVE TITLE CARD.
    READ (IN,94) WEATIT
    NREF=0
    DELT=0.50

```

DRIV0000
 DRIV0010
 DRIV0020
 DRIV0030
 DRIV0040
 DRIV0050
 DRIV0060
 DRIV0070
 DRIV0080
 DRIV0090
 DRIV0100
 DRIV0110
 DRIV0120
 DRIV0130
 DRIV0140
 DRIV0150
 DRIV0160
 DRIV0170
 DRIV0180
 DRIV0190
 DRIV0200
 DRIV0210
 DRIV0220
 DRIV0230
 DRIV0240
 DRIV0250
 DRIV0260
 DRIV0270
 DRIV0280
 DRIV0290
 DRIV0300
 DRIV0310
 DRIV0320
 DRIV0330
 DRIV0340
 DRIV0350
 DRIV0360
 DRIV0370
 DRIV0380
 DRIV0390
 DRIV0400
 DRIV0410
 DRIV0420

KOUNT=0
 NX=1
 NY=1
 MAXIN=NX*NY
 NTIME=432
 DO 1 IJ=1,MAXIN
 CIJ(IJ)=32.5
 1 H(IJ)=1.292
 TYM=0.
 IF(MAXIN.NE.1) GO TO 2
 WRITE (OUT,95) TYM,CIJ(1)
 WRITE (OUT,92) WEATIT
 GO TO 4
 2 WRITE (OUT,93) WEATIT
 WRITE (OUT,97) TYM
 NYP1=NY+1
 J2=0
 DO 3 II=1,NY
 I=NYP1-II
 J1=J2+1
 J2=J2+NX
 3 WRITE (OUT,98) I,(CIJ(J),J=J1,J2)
 4 DO 7 IT=1,NTIME
 CALL HETRAN(NREF)
 IF(WEAECF) GO TO 6C
 TYM=FLOAT(IT)*DELT
 IF(MAXIN.NE.1) GO TO 5
 WRITE (OUT,95) TYM,CIJ(1),DELC(1),G,QSN,QAT,QW,QE,QC
 GO TO 7
 5 WRITE (OUT,97) TYM
 J2=0
 DO 6 II=1,NY
 I=NYP1-II
 J1=J2+1
 J2=J2+NX
 6 WRITE (OUT,98) I,(CIJ(J),J=J1,J2)
 7 CONTINUE
 50 CALL EXIT
 60 WRITE (OUT,96)
 GO TO 50
 END

DRIV0430
 DRIV0440
 DRIV0450
 DRIV0460
 DRIV0470
 DRIV0480
 DRIV0490
 DRIV0500
 DRIV0510
 DRIV0520
 DRIV0530
 DRIV0540
 DRIV0550
 DRIV0560
 DRIV0570
 DRIV0580
 DRIV0590
 DRIV0600
 DRIV0610
 DRIV0620
 DRIV0630
 DRIV0640
 DRIV0650
 DRIV0660
 DRIV0670
 DRIV0680
 DRIV0690
 DRIV0700
 DRIV0710
 DRIV0720
 DRIV0730
 DRIV0740
 DRIV0750
 DRIV0760
 DRIV0770
 DRIV0780
 DRIV0790
 DRIV0800
 DRIV0810
 DRIV0820
 DRIVEND-

```

SUBROUTINE HETRAN(NREF)
C
C----- PROGRAM AUTHORS    CA OSTER AND DG DANIELS
C    PROGRAM DATE    JUNE 1972
C
C----- THIS SUBPROGRAM COMPUTES THE WATER TEMPERATURE CHANGE DUE TO
C    ATMOSPHERIC HEAT TRANSFER.  ATMOSPHERIC HEAT TRANSFER IS A
C    FUNCTION OF WATER SURFACE TEMPERATURE, AIR TEMPERATURE, DEW POINT
C    TEMPERATURE, WIND SPEED, CLOUD COVER, AND SOLAR RADIATION.
C
    PARAMETER NCEL=1000, NBDY=250
    INTEGER OUT,DATE,TIME,DAT1,DAT2,TIME1,TIME2
    LOGICAL FIRST,WEAEOF,XSFRAC
    COMMON /SETQNT/DELTA0,OMEGA,DEL,RADEG,
1EN,ZEROJ,PI,CAPK,DTMAX,QSUM,SPSD,CPCD,A,PIO2,TWOPI,N
    COMMON /QOPUP/Q,QSN,QAT,QW,QE,QC
    COMMON /LOCATN/PHI,THETA,TZONE,SINPHY,COSPHY,PHY
    COMMON /IOUNIT/IN,OUT
    COMMON /WEATHR/WEATIT(14),DAT1,TIME1,TAD1,RH1,WSPD1,CLOUD1,RAD1,
1    IME1,DAT2,TIME2,TAD2,RH2,WSPD2,CLOUD2,RAD2,
2    IME2,WEAEOF
    COMMON /VARIBL/NX,NY,MAXIN,KOUNT,DELT,H(NCEL),CIJ(NCEL),
1DEL(NCEL),IJBDRY(NBDY),SNLMDA
    COMMON /DADATA/IDASAV,SOLIN
    COMMON /CONSTS/SBCON,EMISS,BOWEN,QECCON,PRESS,C,FKNT,ABSOLW
    COMMON /COMADD/CP,QCFACR,QWFAC,QATFAC
C
C----- SURFACE WATER DENSITY FUNCTION - RHOH20
C    SEE LW TILTON AND JK TAYLOR, ACCURATE REPRESENTATION OF
C    REFRACTIVITY AND DENSITY OF DISTILLED WATER AS A FUNCTION OF
C    TEMPERATURE, J.RES.NAT.BUR.STD. VOL 18, 1937 PP 205-214
C
    RHOH20(TW)=(1.-((((TW-3.9863)**2/508929.2)*(TW+288.9414)/
1(TW+68.12963))))*1.E3
C
99  FORMAT(I6,I2,4X,F7.1,6X,F6.1,F6.1,F3.0,F5.0,23X,I2)
    NREF=NREF+1
    IF(NREF.GT.1) GO TO 2
    CALL SETEOF($70)
    WEAEOF=.FALSE.
C
C----- MAKE SURE THE CONSTANTS ARE LOADED INTO THIS PROGRAM
C

```

```

HETRO000
HETRO010
HETRO020
HETRO030
HETRO040
HETRO050
HETRO060
HETRO070
HETRO080
HETRO090
HETRO100
HETRO110
HETRO120
HETRO130
HETRO140
HETRO150
HETRO160
HETRO170
HETRO180
HETRO190
HETRO200
HETRO210
HETRO220
HETRO230
HETRO240
HETRO250
HETRO260
HETRO270
HETRO280
HETRO290
HETRO300
HETRO310
HETRO320
HETRO330
HETRO340
HETRO350
HETRO360
HETRO370
HETRO380
HETRO390
HETRO400
HETRO410
HETRO420

```

C	CALL CNSTNT	HETR0430
		HETR0440
	PHY=PHI*RADEG	HETR0450
	SINPHY=SIN(PHY)	HETR0460
	COSPHY=COS(PHY)	HETR0470
C----	READ IN INITIAL WEATHER PARAMETERS	HETR0480
C	WEATHER PARAMETERS ARE READ IN THIS ORDER -	HETR0490
C	DAT2,DATE DATE IN THE FORM OF YEAR/MONTH/DAY	HETR0500
C	TIME2,TIME TIME OF DAY IN HOURS FROM MIDNIGHT	HETR0510
C	TAD2,TAD AIR TEMPERATURE IN DEGREES F	HETR0520
C	RH2,RH DEW POINT TEMPERATURE IN DEGREES F	HETR0530
C	WSPD2,WSPD WIND SPEED IN KNOTS	HETR0540
C	CLOUD2,CLOUD CLOUD COVER IN TENTHS	HETR0550
C	RAD2,RAD DAILY TOTAL SOLAR RADIATION IN LANGLEYS	HETR0560
C	I.E. (CAL/CM**2)	HETR0570
C	THE TIME IN HOURS BETWEEN WEATHER PARAMETER INPUT IS CALLED IME	HETR0580
C		HETR0590
	READ (IN,99) DAT2, TIME2,TAD2,RH2,WSPD2,CLOUD2,RAD2,IME2	HETR0600
	IDASAV=DAT2-1	HETR0610
C		HETR0620
C----	WINDSPEED IS CONVERTED FROM KNOTS TO METERS/SEC	HETR0630
C		HETR0640
	U22=WSPD2*FKNT	HETR0650
C		HETR0660
C----	AIR TEMPERATURE IS CONVERTED TO DEGREES K	HETR0670
C		HETR0680
	T22=273.15+5.*(TAD2-32.)/9.	HETR0690
C		HETR0700
C----	DEWPOINT IS CONVERTED TO DEGREES C	HETR0710
C		HETR0720
	DEW2=5.*(RH2-32.)/9.	HETR0730
	SUMDEL=0.0	HETR0740
	FRAC=0.	HETR0750
	XSFRAC=.FALSE.	HETR0760
C		HETR0770
C----	READ ADDITIONAL WEATHER PARAMEMERS FOR INTERPOLATION TO GIVEN TIME	HETR0780
C	PLANE	HETR0790
C		HETR0800
	1 READ (IN,99) DATE,TIME,TAD,RH,WSPD,CLOUD,RAD,IME	HETR0810
	U2=WSPD*FKNT	HETR0820
	T2=273.16+5.*(TAD-32.)/9.	HETR0830
	DEWPTC=5.*(RH-32.)/9.	HETR0840
C		HETR0850

C---- WEATHER PARAMETERS ARE LOADED INTO APPROPRIATE REGISTERS

C

DAT1=DAT2
 DAT2=DATE
 DATE=DAT1
 TIME1=TIME2
 TIME2=TIME
 TIME=TIME1
 IME1=IME2
 IME2=IME
 IME=IME1
 TAD1=TAD2
 TAD2=TAD
 T21=T22
 T22=T2
 RH1=RH2
 RH2=RH
 DEW1=DEW2
 DEW2=DEWPTC
 U21=U22
 U22=U2
 CLOUD1=CLOUD2
 CLOUD2=CLOUD
 RAD1=RAD2
 RAD2=RAD

HETR0860
 HETR0870
 HETR0880
 HETR0890
 HETR0900
 HETR0910
 HETR0920
 HETR0930
 HETR0940
 HETR0950
 HETR0960
 HETR0970
 HETR0980
 HETR0990
 HETR1000
 HETR1010
 HETR1020
 HETR1030
 HETR1040
 HETR1050
 HETR1060
 HETR1070
 HETR1080
 HETR1090
 HETR1100
 HETR1110

C

C---- FNAME REFERS TO CHANGE IN WEATHER PARAMETERS IN THE TIME IME HOURS

C

FU2 =U22 -U21
 FT2 =T22 -T21
 FDEW =DEW2 -DEW1
 FCLOUD=CLOUD2-CLOUD1
 FLIME =TIME2 -TIME1
 IF((FLIME.EQ.0.).AND.(IME.EQ.0)) FLIME=1.
 IF(IME.GT.0) FLIME=IME
 IF(FLIME.LT.0.) FLIME=FLIME+24.
 IF(XSFRAC) SUMDEL=FRAC*FLIME-DELT
 IF(DAT1.EQ.IDASAV) GO TO 2
 IDASAV=DAT1
 SOLIN=RAD1
 FIRST=.TRUE.
 T1=SUMDEL+FLOAT(TIME1)

HETR1120
 HETR1130
 HETR1140
 HETR1150
 HETR1160
 HETR1170
 HETR1180
 HETR1190
 HETR1200
 HETR1210
 HETR1220
 HETR1230
 HETR1240
 HETR1250
 HETR1260
 HETR1270


```

      CALL QSOL(FIRST,T1,RAD,ALPHA)
      FIRST=.FALSE.
C
C----- DELT IS THE TIME STEP IN HOURS.  IT MAY BE A FUNCTION OF TIME.
C
      2 SUMDEL=SUMDEL+DELT
      FRAC=SUMDEL/FLIME
      IF(FRAC.GT.1.0) GO TO 6
C
C----- WEATHER PARAMETERS ARE CALCULATED USING LINEAR INTERPOLATION
C
      U2 =U21 +FRAC*FU2
      T2 =T21 +FRAC*FT2
      DEWPTC=DEW1 +FRAC*FDEW
      CLOUD =CLOUD1+FRAC*FCLOUD
      T1=T1+DELT
      CALL QSOL(FIRST,T1,RAD,ALPHA)
C
C----- QSNENT IS THE AVERAGE SOLAR RADIATION ENTERING THE WATER SURFACE
C      DURING THE TIME STEP
C
      QSNENT=10.*RAD*ABSORF(ALPHA,CLOUD)
C
C----- QAT IS THE LONG WAVE ATMOSPHERIC RADIATION ENTERING THE WATER
C
      VP2=VAPRES(DEWPTC)
      QAT=QATFAC*CLOWD(VP2,CLOUD)*T2**4
      QEFAC=QECCON*U2
      QCFAC=QCFACR*U2
C
C----- THE TEMPERATURE CHANGE IN EACH CELL DUE TO TOTAL ATMOSPHERIC HEAT
C      TRANSFER IS CALCULATED
C
      DO 5 IJ=1,MAXIN
      IF(KOUNT.LE.0) GO TO 4
      DO 3 K=1,KOUNT
      IF(IJ.EQ.IJBDRY(K)) GO TO 5
      3 CONTINUE
C
C----- TW IS THE SURFACE WATER TEMPERATURE IN DEGREES C FROM THE PREVIOUS
C      TIME PLANE
C

```

```

HETR1280
HETR1290
HETR1300
HETR1310
HETR1320
HETR1330
HETR1340
HETR1350
HETR1360
HETR1370
HETR1380
HETR1390
HETR1400
HETR1410
HETR1420
HETR1430
HETR1440
HETR1450
HETR1460
HETR1470
HETR1480
HETR1490
HETR1500
HETR1510
HETR1520
HETR1530
HETR1540
HETR1550
HETR1560
HETR1570
HETR1580
HETR1590
HETR1600
HETR1610
HETR1620
HETR1630
HETR1640
HETR1650
HETR1660
HETR1670
HETR1680
HETR1690

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```

      4 TW=CIJ(IJ)
      RHOH=RHOH20(TW)
C
C----- RBETA IS THE FRACTION OF SOLAR RADIATION (RAD) TO BE ABSORBED IN
C         THE LAYER OF WATER H(IJ) IN DEPTH
C
      RBETA=1.-EXP(-SNLMDA*H(IJ))
C
C----- QSN IS THE AVERAGE SOLAR RADIATION ABSORBED IN THE TOP LAYER OF
C         OF WATER DURING THE TIME STEP
C
      QSN=RBETA*QSNENT
C
C----- WATER TEMPERATURE IS CONVERTED TO DEGREES K
C
      TWK=273.16+TW
      TW4=TWK**4
C
C----- QW IS THE LONG WAVE RADIATION LEAVING THE WATER
C
      QW=QWFAC*TW4
      DVPRES=VAPRES(TW)-VP2
      ELW=H2OLHT(TW)
      ELRHO=ELW*RHOH
C
C----- QE IS THE ENERGY OF EVAPORATION
C
      QE=QEFAC*DVPRES*ELRHO
C
C----- QC IS THE ENERGY CONDUCTED FROM THE AIR TO THE WATER
C
      QC=QCFAC*(T2-TWK)*ELRHO
C
C----- Q IS THE TOTAL ENERGY ENTERING THE WATER (KCAL/(M**2*HR))
C
      Q=QSN+QAT-QW-QE+QC
C
C----- DELTW IS THE CHANGE IN WATER SURFACE TEMPERATURE DUE TO
C         ATMOSPHERIC HEAT TRANSFER
C
      DELTW =Q*DELT/(CP*RHOH*H(IJ))
      DELC(IJ)=DELTW

```

```

HETR1700
HETR1710
HETR1720
HETR1730
HETR1740
HETR1750
HETR1760
HETR1770
HETR1780
HETR1790
HETR1800
HETR1810
HETR1820
HETR1830
HETR1840
HETR1850
HETR1860
HETR1870
HETR1880
HETR1890
HETR1900
HETR1910
HETR1920
HETR1930
HETR1940
HETR1950
HETR1960
HETR1970
HETR1980
HETR1990
HETR2000
HETR2010
HETR2020
HETR2030
HETR2040
HETR2050
HETR2060
HETR2070
HETR2080
HETR2090
HETR2100
HETR2110

```

```
      CIJ(IJ)=CIJ(IJ)+DELC(IJ)
5  CONTINUE
      IF(FRAC.LE.1.0) GO TO 7
6  FRAC=FRAC-1.0
      XSFRAC=.TRUE.
      GO TO 1
7  RETURN
70 WEAEOF=.TRUE.
      GO TO 7
      END
```

HETR2120
HETR2130
HETR2140
HETR2150
HETR2160
HETR2170
HETR2180
HETR2190
HETR2200
HETREND-

```

SUBROUTINE QSOL (FIRST, TONE, QOUT, ALPH)
C
C----- PROGRAM AUTHOR      CA OSTER
C      PROGRAM DATE      JUNE 1972
C
C----- THIS SUBROUTINE PERFORMS TWO FUNCTIONS.  THE FIRST IS THE APPROX.
C      OF THE ATMOSPHERIC TRANSMISSION COEFFICIENT A.  THE SECOND
C      FUNCTION IS THE DISTRIBUTION OF THE TOTAL SOLAR RADIATION
C      THROUGHOUT THE DAYLIGHT HOURS AND PROVIDING THE AVERAGE SOLAR
C      RADIATION AND AVERAGE SOLAR ALTITUDE OVER ANY TIME STEP.
C
      LOGICAL FIRST
      INTEGER DATE, DAYS, OUT
      COMMON /IOUNIT/IN, OUT
      COMMON /DADATA/DATE, SOLIN
      COMMON /LOCATN/PHI, THETA, TZONE, SINPHY, COSPHY, PHY
      COMMON /SETQNT/DELTA0, OMEGA, DEL, RADEG,
      1EN, ZEROJ, PI, CAPK, DTMAX, QSUM, SPSD, CPCD, A, PIO2, TWOPI, N
C
C----- THE FOLLOWING FUNCTION RETURNS THE JULIAN DATE FROM THE GREGORIAN
C      DATE      I IS YEAR, J IS MONTH, K IS DAY
C      REF...  H.F.FLIEGEL AND T.C.FLANDERN, COMM ACM VOL 11, NO.10,
C      OCT 68, PAGE 657
C      DAYS(I, J, K) = K - 32075 + 1461 * ((I + 4800 + (J - 14) / 12) / 4 + 367 * (J - 2 - (J - 14) / 12
      1 * 12) / 12 - 3 * ((I + 4900 + (J - 14) / 12) / 100) / 4
C
      99 FORMAT('NO SOLUTION - - - MAXIMUM RADIATION IS '1PE15.7,' LANGL
      1EYS.      A = 'E15.7)
      IF(.NOT.FIRST) GO TO 9
      IYEAR = DATE / 10000
      IDY = DATE - 10000 * IYEAR
      IMO = IDY / 100
      IDY = IDY - 100 * IMO
C----- LOCATE THE DAY-ZERO
      IYR = 1900 + IYEAR
      JDZERO = DAYS(IYR, 1, 1) - 1
C----- LOCATE THE SPRING EQUINOX
      EQNX = DAYS(IYR, 3, 21) - JDZERO
      DEL = EQNX * OMEGA
      A0 = .75
      ITDAY = DAYS(IYR, IMO, IDY) - JDZERO
      TDAY = ITDAY
      DELTA = DELTA0 * SIN(OMEGA * TDAY - DEL)

```

```

QSOL0000
QSOL0010
QSOL0020
QSOL0030
QSOL0040
QSOL0050
QSOL0060
QSOL0070
QSOL0080
QSOL0090
QSOL0100
QSOL0110
QSOL0120
QSOL0130
QSOL0140
QSOL0150
QSOL0160
QSOL0170
QSOL0180
QSOL0190
QSOL0200
QSOL0210
QSOL0220
QSOL0230
QSOL0240
QSOL0250
QSOL0260
QSOL0270
QSOL0280
QSOL0290
QSOL0300
QSOL0310
QSOL0320
QSOL0330
QSOL0340
QSOL0350
QSOL0360
QSOL0370
QSOL0380
QSOL0390
QSOL0400
QSOL0410
QSOL0420

```

IF (ABS (DELTA+PHY).LT.PI02) GO TO 1	QSOL0430
C---- LAND OF THE MIDNIGHT SUN	QSOL0440
TAU=24.	QSOL0450
GO TO 2	QSOL0460
1 SPSD=SINPHY*SIN(DELTA)	QSOL0470
CPCD=COSPHY*COS(DELTA)	QSOL0480
TAU=ACOS(-SPSD/CPCD)/(7.5*RADEG)	QSOL0490
C---- TUP IS SUN-UP TIME	QSOL0500
C TDN IS SUN-DOWN TIME	QSOL0510
2 TUP=12.-TAU/2.	QSOL0520
TDN=12.+TAU/2.	QSOL0530
DTAU=TAU/EN	QSOL0540
C---- COMPUTE THE TIME CORRECTION TO GET TRUE SOLAR TIME	QSOL0550
TCOR=DSOLTM(ITDAY,IYEAR)	QSOL0560
C---- DISTANCE FROM SUN TO EARTH (ASTRONOMICAL UNITS)	QSOL0570
RR=1.+0.016735*COS(OMEGA*(TDAY-186.))	QSOL0580
ZROJGR=ZEROJ/RR	QSOL0590
C---- FIRST SOLVE FOR TRANSMISSION COEFFICIENT (A)	QSOL0600
TOTAL=SOLIN/ZROJOR	QSOL0610
A=A0	QSOL0620
ITNO=0	QSOL0630
T0=TUP-DTAU/2.	QSOL0640
3 BOT=0.	QSOL0650
TOP=TOTAL	QSOL0660
DO 4 I=1,N	QSOL0670
T=T0+FLOAT(I)*DTAU	QSOL0680
H=CAPK*T-PI	QSOL0690
SINALF=SPSD+CPCD*COS(H)	QSOL0700
CSCALF=1./SINALF	QSOL0710
FACTR=A**CSCALF*DTAU	QSOL0720
BOT=BOT+FACTR	QSOL0730
TOP=TOP-FACTR*SINALF	QSOL0740
4 CONTINUE	QSOL0750
ANEW=A*(1.+TOP/BOT)	QSOL0760
ITNO=ITNO+1	QSOL0770
IF (ITNO.LT.3) GO TO 5	QSOL0780
IF (A*ANEW-1.) 5,7,7	QSOL0790
5 TEST=(ANEW-A)/ANEW	QSOL0800
IF (ABS (TEST)-.5E-7) 8,8,6	QSOL0810
6 A=AMINI (ANEW,1.)	QSOL0820
IF (ITNO.LT.10) GO TO 3	QSOL0830
7 IF (A.LT.1.) GO TO 8	QSOL0840
SOLIN=(TOTAL-TOP)*ZROJOR	QSOL0850

WRITE (OUT,99) SOLIN,A	QSOL0860
8 CONTINUE	QSOL0870
DTMAX=DTAU	QSOL0880
QSUM=0.	QSOL0890
DT=1.	QSOL0900
T0=0.	QSOL0910
IF(TONE.LE.0.) GO TO 22	QSOL0920
C---- AT ENTRY QSUM IS THE ACCUMULATED Q SO FAR. ON LEAVING Q IS THE	QSOL0930
C ADDITIONAL SOLAR ENERGY FOR THIS PANEL OF INTEGRATION.	QSOL0940
9 Q=0.	QSOL0950
T1=TONE+TCOR	QSOL0960
ALPHA=0.	QSOL0970
IF(T1-TUP) 21,21,10	QSOL0980
10 IF(T0-TDN) 11,21,21	QSOL0990
11 IF(T1-TDN) 12,19,19	QSOL1000
12 IF(T0-TUP) 13,14,14	QSOL1010
13 START=TUP	QSOL1020
GO TO 15	QSOL1030
14 START=T0	QSOL1040
15 RANGE=T1-START.	QSOL1050
NSTEPS=RANGE/DTMAX	QSOL1060
REM=RANGE-FLCAT(NSTEPS)*DTMAX	QSOL1070
IF(REM) 17,17,16	QSOL1080
16 NSTEPS=NSTEPS+1	QSOL1090
17 STEP=RANGE/NSTEPS	QSOL1100
C---- INTEGRATE OVER THIS PANEL	QSOL1110
TINIT=START-STEP/2.	QSOL1120
STPJOR=STEP*ZROJOR	QSOL1130
DO 18 I=1,NSTEPS	QSOL1140
T=TINIT+FLOAT(I)*STEP	QSOL1150
H=CAPK*T-PI	QSOL1160
SINALF=SPSD+CPCD*COS(H)	QSOL1170
SINALF=SIGN(AMIN1(ABS(SINALF),1.),SINALF)	QSOL1180
C---- COMPUTE AVERAGE SOLAR ANGLE ALPHA	QSOL1190
ALPHA=ALPHA+ASIN(SINALF)*STEP	QSOL1200
CSCALF=1./SINALF	QSOL1210
FACTR=A**CSCALF*STPJOR*SINALF	QSOL1220
18 Q=Q+FACTR	QSOL1230
GO TO 20	QSOL1240
19 Q=SOLIN-QSUM	QSOL1250
20 QSUM=QSUM+Q	QSOL1260
21 CONTINUE	QSOL1270

DELT=T1-T0
T0=T1
ALPH=ALPHA/DELT/RADEG
QOUT=Q/DELT
22 RETURN
END

QSOL1280
QSOL1290
QSOL1300
QSOL1310
QSOL1320
QSOLEND-

```

SUBROUTINE CNSTNT
C
C----- PROGRAM AUTHORS   CA OSTER AND DG DANIELS
C      PROGRAM DATE       JUNE-1972
C
C----- THIS SUBPROGRAM IS USED ONLY TO ESTABLISH CONSTANTS REQUIRED BY
C      OTHER SUBPROGRAMS IN THIS PACKAGE.
      LOGICAL BENHER
      COMMON /CONSTS/SBCON,FMISS,BOWEN,QECCON,PRESS,C,FKNT,ABSOLW
      COMMON /COMADD/CP,QCFACR,QWFAC,QATFAC
      COMMON /SETQNT/DELTA0,OMEGA,DFL,RADEG,
1FN,ZEROJ,PI,CAPK,DTMAX,QSUM,SPSD,CPCD,A,PIO2,TWOPI,N
C
C      SBCON  - STEFAN-BOLTZMANN CONSTANT          (KCAL/DEG K**4*M**2*HR))CNST0130
C      EMISS  - EMISSIVITY FOR BLACK BODY RADIATION (DIMENSIONLESS)CNST0140
C      BOWEN  - CONSTANT RELATED TO THE BOWEN RATIO (1/DEG C)CNST0150
C      QECCON - EMPIRICAL CONSTANT IN EVAPORATION EQUATION (1/MILLIBARS)CNST0160
C      PRESS  - LOCAL ATMOSPHERIC PRESSURE          (MILLIBARS)CNST0170
C      STANDARD SEA LEVEL PRESSURE HAS BEEN USED HERE. LOCAL CNST0180
C      ATMOSPHERIC PRESSURES SHOULD BE USED. CNST0190
C      CP     - SPECIFIC HEAT OF WATER AT CONST. VOL  KCAL/(KGM DEG C)CNST0200
C      FKNT   - CONVERSION CONSTANT                ((M/SEC)/KNOTS)CNST0210
C      ABSOLW - LONG WAVE RADIATION ABSORPTIVITY OF WATER SURFACE AT CNST0220
C      USUAL AIR TEMPERATURE (DIMENSIONLESS)CNST0230
C      DELTA0 - MAXIMUM DECLINATION OF THE SUN      (DEGREES)CNST0240
C      YEAR   - NUMBER OF DAYS IN A YEAR            CNST0250
C      CAPK   - ROTATION RATE OF THE EARTH          (DEGREES/HOUR)CNST0260
C      ZEROJ  - SOLAR CONSTANT                      (LANGLEYS/MINUTE)CNST0270
C      N      - NUMBER OF INTEGRATION STEPS USED IN COMPUTING ATMOSPHERICCNST0280
C      TRANSMISSION COEFFICIENT AND SOLAR RADIATION CNST0290
C      PI     - UNIVERSAL CONSTANT                  CNST0300
C      BENHER - LOGICAL CONSTANT INITIALLY .FALSE. BUT SET .TRUE. AFTER CNST0310
C      FIRST CALL. USED TO PREVENT MULTIPLE UNIT CONVERSIONS. CNST0320
C
C      DATA          SBCON /4.875066E-8 /,EMISS /.97 /, CNST0340
1BOWEN /.46 /,QECCON/4.19034096E-6/,PRESS /1013.25 /, CNST0350
2CP /1.000 /,FKNT /.514994404 /,ABSOLW/.970 /, CNST0360
3DELTA0/23.45 /,YEAR /365.25 /,CAPK /15. /, CNST0370
4ZEROJ /1.94 /,N /25 /,PI /3.141592654/, CNST0380
5BENHER/.FALSE. / CNST0390
C
C      IF(BENHER) GO TO 1
      BENHER=.TRUE.
CNST0400
CNST0410
CNST0420

```


QCFAC=BOWEN/760.*PRESS*QECCON
 QATFAC=ABSOLW*SBCON
 QWFAC=EMISS*SBCON
 EN=N
 ZEROJ=ZEROJ*60.
 RADEG=PI/180.
 TWOPI=2.*PI
 PIO2=PI/2.
 DELTA0=DELTA0*RADEG
 CAPK=CAPK*RADEG
 OMEGA=TWOPI/YEAR
 1 RETURN
 FND

CNST0430
 CNST0440
 CNST0450
 CNST0460
 CNST0470
 CNST0480
 CNST0490
 CNST0500
 CNST0510
 CNST0520
 CNST0530
 CNST0540
 CNSTEND-

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      FUNCTION DSOLTM(ITDAY,IYR)
C
C----- PROGRAM AUTHOR      CA OSTER
C      PROGRAM DATE        JUNE 1972
C
      PARAMETER NDAYS=48
C----- THIS FUNCTION COMPUTES THE DIFFERENCE IN LOCAL STANDARD TIME AND
C      LOCAL MEAN SOLAR TIME
C
C----- REFERENCE RJ LIST, SMITHSONIAN METEOROLOGICAL TABLES, SMITHSONIAN
C      INSTITUTION PRESS, CITY OF WASHINGTON, 1968, TABLE 169 EPHEMERIS
C      OF THE SUN. PP 495-496
C
      INTEGER DAYS,TZONE
      COMMON /LCCATN/PHI,THETA,TZONE,SINPHY,COSPHY,PHY
      DIMENSION JULDAT(NDAYS),MODY(NDAYS),DT(NDAYS)
C
C----- THE FOLLOWING FUNCTION RETURNS THE JULIAN DATE FROM THE GREGORIAN
C      DATE      I IS YEAR, J IS MONTH, K IS DAY
C      REF... H.F.FLIEGEL AND T.C.FLANDERN, COMM ACM VOL 11,NO.10,
C      OCT 68, PAGE 657
      DAYS(I,J,K)=K-32075+1461*((I+4800+(J-14)/12)/4+367*(J-2-(J-14)/12
1*12)/12-3*((I+4900+(J-14)/12)/100)/4
C
      DATA (MODY(I),DT(I),I=1,NDAYS)/
1  0101,-0.0538889, 0109,-0.1138889, 0117,-0.1650000,
2  0125,-0.2038889, 0201,-0.2261111, 0209,-0.2380556,
3  0217,-0.2361111, 0225,-0.2219444, 0301,-0.2105556,
4  0309,-0.1808333, 0317,-0.1450000, 0325,-0.1055556,
5  0401,-0.0700000, 0409,-0.0311111, 0417,+0.0036111,
6  0425,+0.0313889, 0501,+0.0472222, 0509,+0.0597222,
7  0517,+0.0622222, 0525,+0.0544444, 0601,+0.0408333,
8  0609,+0.0183333, 0617,-0.0091667, 0625,-0.0380556,
9  0701,-0.0586111, 0709,-0.0822222, 0717,-0.0991667,
A  0725,-0.1066667, 0801,-0.1047222, 0809,-0.0925000,
B  0817,-0.0700000, 0825,-0.0383333, 0901,+0.0041667,
C  0909,+0.0394444, 0917,+0.0861111, 0925,+0.1333333,
D  1001,+0.1669444, 1009,+0.2075000, 1017,+0.2402778,
E  1025,+0.2627778, 1101,+0.2725000, 1109,+0.2700000,
F  1117,+0.2527778, 1125,+0.2208333, 1201,+0.1877778,
G  1209,+0.1336111, 1217,+0.0713889, 1225,+0.0055556/
      DATA IYRLST,K/-1000,2/,NTZON/0/
      IF(IYR.EQ.IYRLST) GO TO 2

```

```

DSOL0000
DSOL0010
DSOL0020
DSOL0030
DSOL0040
DSOL0050
DSOL0060
DSOL0070
DSOL0080
DSOL0090
DSOL0100
DSOL0110
DSOL0120
DSOL0130
DSOL0140
DSOL0150
DSOL0160
DSOL0170
DSOL0180
DSOL0190
DSOL0200
DSOL0210
DSOL0220
DSOL0230
DSOL0240
DSOL0250
DSOL0260
DSOL0270
DSOL0280
DSOL0290
DSOL0300
DSOL0310
DSOL0320
DSOL0330
DSOL0340
DSOL0350
DSOL0360
DSOL0370
DSOL0380
DSOL0390
DSOL0400
DSOL0410
DSOL0420

```

```

        IYRLST=IYR
        JDZERO=DAYS(IYRLST,1,1)-1
        DO 1 J=1,NDAYS
        MO=MODY(J)/100
        IDY=MODY(J)-100*MO
        1 JJLDAT(J)=DAYS(IYRLST,MO,IDY)-JDZERO
        IF(NTZON.LE.0) GO TO 10
C----- EQUATION OF TIME
        2 I=ITDAY
        3 IF(I-JJLDAT(K)) 4,8,5
        4 K=K-1
        IF(K.GT.0) GO TO 3
        K=1
        GO TO 8
        5 IF(K.LT.NDAYS) GO TO 6
        K=NDAYS-1
        GO TO 8
        6 IF(I-JJLDAT(K+1)) 8,8,7
        7 K=K+1
        GO TO 5
        8 A=DT(K)
        B=DT(K+1)
        DELTA=FLOAT(I-JJLDAT(K))/FLOAT(JJLDAT(K+1)-JJLDAT(K))
        EQNTYM=A+DELTA*(B-A)
        DSOLTM=EQNTYM+ADDTYM
        RETURN
C----- CORRECT FOR LOCATION WITHIN TIME ZONE
        10 NTZON=NTZON+1
C----- STANDARD MERIDIAN FOR TIME ZONE
        ZONE=15.*FLOAT(TZONE)
        ADDTYM=(ZONE-THETA)/15.
        GO TO 2
        END

```

```

DSOL0430
DSOL0440
DSOL0450
DSOL0460
DSOL0470
DSOL0480
DSOL0490
DSOL0500
DSOL0510
DSOL0520
DSOL0530
DSOL0540
DSOL0550
DSOL0560
DSOL0570
DSOL0580
DSOL0590
DSOL0600
DSOL0610
DSOL0620
DSOL0630
DSOL0640
DSOL0650
DSOL0660
DSOL0670
DSOL0680
DSOL0690
DSOL0700
DSOL0710
DSOL0720
DSOL0730
DSOL0740
DSOLEND-

```

FUNCTION ABSORP(ALPHA,CL)	ABS00000
C	ABS00010
C---- PROGRAM AUTHOR CA OSTER	ABS00020
C PROGRAM DATE JUNE 1972	ABS00030
C	ABS00040
PARAMETER NAB=14	ABS00050
C---- THIS FUNCTION RETURNS THE ABSORPTIVITY OF A NATURAL WATER SURFACE	ABS00060
C SEE FIGURE 7 IN J.M. RAPHAEL, THE EFFECT OF WANAPUM AND	ABS00070
C PRIEST RAPIDS DAMS ON THE TEMPERATURE OF THE COLUMBIA RIVER,	ABS00080
C SEPT. 1961	ABS00090
C---- ALPHA IS THE AVERAGE SOLAR ALTITUDE ANGLE IN DEGREES	ABS00100
C CL IS THE PERCENT CLOUD COVER MEASURED IN TENTHS.	ABS00110
C 0 IS CLEAR --- 10 IS OVERCAST	ABS00120
DIMENSION AB(NAB,5),SA(NAB)	ABS00130
DATA (SA(I),I=1,NAB)	ABS00140
1 0., 2.5, 5., 7.5, 10., 15.,	ABS00150
2 20., 30., 40., 50., 60., 70., 80., 90./	ABS00160
DATA ((AB(I,J),I=1,NAB),J=1,5)/	ABS00170
1 .000,.218,.460,.720,.775,.830,	ABS00180
2 .870,.921,.935,.951,.949,.950,.950,.950,	ABS00190
3 .000,.220,.480,.730,.780,.840,	ABS00200
4 .875,.921,.935,.950,.965,.970,.973,.974,	ABS00210
5 .000,.225,.500,.750,.800,.850,	ABS00220
6 .880,.922,.935,.950,.954,.960,.962,.962,	ABS00230
7 .000,.425,.713,.780,.825,.870,	ABS00240
8 .890,.926,.935,.950,.953,.960,.962,.962,	ABS00250
9 .000,.610,.780,.840,.870,.890,	ABS00260
A .910,.930,.935,.943,.949,.950,.950,.950/	ABS00270
DATA K/6/	ABS00280
IF(ALPHA.LE.0.) GO TO 11	ABS00290
IF(CL.LT.3.0) GO TO 1	ABS00300
IF(CL.LT.5.0) GO TO 2	ABS00310
IF(CL.LT.7.5) GO TO 3	ABS00320
C---- BROKEN OVERCAST	ABS00330
J=4	ABS00340
CL0=7.5	ABS00350
DENDCL=2.5	ABS00360
GO TO 4	ABS00370
C---- CLEAR SKY	ABS00380
1 J=1	ABS00390
CL0=0.0	ABS00400
DENDCL=3.0	ABS00410
GO TO 4	ABS00420

C----- SCATTERED CLOUDS

2 J=2

CL0=3.0

DENDCL=2.0

GO TO 4

C----- AVERAGE SKY COVER

3 J=3

CL0=5.0

DENDCL=2.5

4 IF (ALPHA-SA(K)) 5,9,6

5 K=K-1

IF (K.GT.0) GO TO 4

K=1

GO TO 9

6 IF (K.LT.NAB) GO TO 7

K=NAB-1

GO TO 9

7 IF (ALPHA-SA(K+1)) 9,9,8

8 K=K+1

GO TO 6

9 A=AB(K,J)

B=AB(K+1,J)

C=AB(K,J+1)

D=AB(K+1,J+1)

DANGL=(ALPHA-SA(K))/(SA(K+1)-SA(K))

DCL=(CL-CL0)/DENDCL

FIRST=A+DANGL*(B-A)

SECND=C+DANGL*(D-C)

ABSOR=FIRST+DCL*(SECND-FIRST)

10 ABSORP=ABSOR

RETURN

11 ABSOR=0.

GO TO 10

END

ABS00430

ABS00440

ABS00450

ABS00460

ABS00470

ABS00480

ABS00490

ABS00500

ABS00510

ABS00520

ABS00530

ABS00540

ABS00550

ABS00560

ABS00570

ABS00580

ABS00590

ABS00600

ABS00610

ABS00620

ABS00630

ABS00640

ABS00650

ABS00660

ABS00670

ABS00680

ABS00690

ABS00700

ABS00710

ABS00720

ABS00730

ABS00740

ABS00750

ABSOEND-

```

      FUNCTION H2OLHT(T)
C
C----- PROGRAM AUTHOR      CA OSTER
C      PROGRAM DATE      SEPTEMBER 1971
C
C----- THIS FUCTION HAS T IN DEG C AS INPUT.  IT RETURNS THE VALUE OF
C      LATENT HEAT OF VAPORIZATION OF WATER IN (CAL(15 DEG C)/GM) AS
C      OUTPUT
C
C----- LINEAR INTERPOLATION IS USED FOR 0 .LE. T .LE. 180  DEG. C.
C      LINEAR EXTRAPOLATION IS USED OUTSIDE THIS RANGE.
C
C----- REFERENCE :  CD HODGMAN, RC WEAST, AND SM SELBY,  HANDBOOK OF
C      CHEMISTRY AND PHYSICS, 42-ND EDITION, CHEMICAL RUBBER PUBLISHING
C      CO., CLEVELAND OHIO, 1962-63.  PP 2412-2413.
C
      DIMENSION H(19)
      DATA H(1),H(2),H(3),H(4),H(5),H(6),H(7),H(8),H(9),H(10),H(11),
1H(12),H(13),H(14),H(15),H(16),H(17),H(18),H(19)/
2  595.9,  590.4,  584.9,  579.5,  574.0,  568.5,  563.2,  557.5,
3  551.7,  545.8,  559.55, 532.9,  525.7,  518.5,  511.1,  503.5,
4  495.6,  497.2,  478.6/
C
      R=T/10.
      I=R
      I=MINO(MAXO(I,0),17)
      F=R-FLOAT(I)
      I=I+1
      ELW=H(I)+F*(H(I+1)-H(I))
      H2OLHT=ELW
      RETURN
      END

```

```

H2OL0000
H2OL0010
H2OL0020
H2OL0030
H2OL0040
H2OL0050
H2OL0060
H2OL0070
H2OL0080
H2OL0090
H2OL0100
H2OL0110
H2OL0120
H2OL0130
H2OL0140
H2OL0150
H2OL0160
H2OL0170
H2OL0180
H2OL0190
H2OL0200
H2OL0210
H2OL0220
H2OL0230
H2OL0240
H2OL0250
H2OL0260
H2OL0270
H2OL0280
H2OL0290
H2OL0300
H2OLEND-

```

```

FUNCTION VAPRES(TC)
C
C----- PROGRAM AUTHOR      CA OSTER
C      PROGRAM DATE      MARCH 21,1969
C
C----- THIS FUNCTION RETURNS THE SATURATION VAPOR PRESSURE IN MILLIBARS
C      FOR THE CENTIGRADE TEMPERATURE TC.
C----- THESE POLYNOMIALS WERE OBTAINED FROM EZ BLOCK WHO FITTED TABULAR
C      DATA GIVEN IN JOHN H PERRY, CHEMICAL ENGINEERS HANDBOOK 3RD ED
C      PP. 762-764.
C----- POLYNOMIAL COEFFICIENTS FOR TEMP. (-30F TO 25F)
C      DATA C1,C2,C3,C4,C5,C6,C7,C8/7.004580E-03,4.2072376E-04,
1      1.1393840E-05,2.2338811E-07,5.7517723E-10,6.6754266E-11,
2      -6.2660131E-13,4.5163819E-15/
C----- POLYNOMIAL COEFFICIENTS FOR TEMP. (+25F TO 130F)
C      DATA D1,D2,D3,D4,D5,D6,D7,D8/-1.5646350E 00,1.0551908E-01,
1      -2.9385150E-03,4.5571050E-05,-4.1023648E-07,2.2219889E-09,
2      -6.4344569E-12,8.0422282E-15/
C----- CONVERSION CONSTANT FROM (INCHES OF HG) TO (MILLIBARS)
C      DATA BARS/33.863928/
C----- CONVERT TO FAHRENHEIT
C      TF=TC*1.8+32.
C      T=TF+30.
C      IF(TF-25.) 1,1,2
1      VP=C1+T*(C2+T*(C3+T*(C4+T*(C5+T*(C6+T*(C7+T*C8))))))
C      GO TO 3
2      VP=D1+T*(D2+T*(D3+T*(D4+T*(D5+T*(D6+T*(D7+T*D8))))))
C----- CCNVERT FROM (INCHES OF HG) TO (MILLIBARS)
3      VAPRES=VP*BARS
C      RETURN
C      END

```

```

VAPR0000
VAPR0010
VAPR0020
VAPR0030
VAPR0040
VAPR0050
VAPR0060
VAPR0070
VAPR0080
VAPR0090
VAPR0100
VAPR0110
VAPR0120
VAPR0130
VAPR0140
VAPR0150
VAPR0160
VAPR0170
VAPR0180
VAPR0190
VAPR0200
VAPR0210
VAPR0220
VAPR0230
VAPR0240
VAPR0250
VAPR0260
VAPR0270
VAPR0280
VAPR0290
VAPREND-

```

```

      FUNCTION CLOWD(VP2,CL)
C
C----- PROGRAM AUTHOR      CA OSTER
C      PROGRAM DATE      MARCH 21,1969
C
C----- THIS FUNCTION RETURNS THE CLOUD COVER CORRECTION FACTOR USED
C           IN THE ATMOSPHERIC (LONG WAVE) RADIATION TERM OF QR
C           SEE FIGURE 12 IN J.M. RAPHAEL, THE EFFECT OF WANAPUM AND
C           PRIEST RAPIDS DAMS ON THE TEMPERATURE OF THE COLUMBIA RIVER,
C           SEPT. 1961
C----- VP2 IS THE VAPOR PRESSURE IN MILLIBARS AND CL IS THE PERCENT
C           CLOUD COVER MEASURED IN TENTHS.(0 IS CLEAR --- 10 IS OVERCAST)
C           DIMENSION A(11),B(11)
C----- SET OF Y-INTERCEPTS, BETA AS A FUNCTION OF VAPOR PRESSURE (IN HG)
C           DATA A(1),A(2),A(3),A(4),A(5),A(6),A(7),A(8),A(9),A(10),A(11)/
C           1 .7406,.7492,.7598,.7703,.7813,.7910,.8000,
C           2 .8109,.8254,.8457,.8648/
C----- SET OF SLOPES, BETA AS A FUNCTION OF VAPOR PRESSURE (IN HG)
C           DATA B(1),B(2),B(3),B(4),B(5),B(6),B(7),B(8),B(9),B(10),B(11)/
C           1 .1538,.1508,.1480,.1449,.1410,.1379,.1352,
C           2 .1297,.1195,.1047,.0907/
C----- CONVERT VP2 FROM MILLIBARS TO INCHES OF HG.
C           V=VP2/33.863928
C           I=IFIX(CL)+1
C           IF(I.GT.10) GO TO 2
C           AB=A(I)+V*B(I)
C           BB=A(I+1)+V*B(I+1)
C           BBB=AB+(CL-FLOAT(I-1))*(BB-AB)
C           1 CLOWD=BBB
C           RETURN
C           2 BBB=A(11)+V*B(11)
C           GO TO 1
C           END

```

```

CLOW0000
CLOW0010
CLOW0020
CLOW0030
CLOW0040
CLOW0050
CLOW0060
CLOW0070
CLOW0080
CLOW0090
CLOW0100
CLOW0110
CLOW0120
CLOW0130
CLOW0140
CLOW0150
CLOW0160
CLOW0170
CLOW0180
CLOW0190
CLOW0200
CLOW0210
CLOW0220
CLOW0230
CLOW0240
CLOW0250
CLOW0260
CLOW0270
CLOW0280
CLOW0290
CLOW0300
CLOW0310
CLOWEND-

```


APPENDIX B
SAMPLE INPUT DATA

SAMPLE INPUT DATA

	32.6 20.0	97.	6				PHI, THET SNLMDA
WEATHER DATA...	FORT WORTH, TEXAS			AUG 21, 63 THRU AUG 29, 63 3 HR INCREMENTS			
63082100	80.0	56.0	6.0	0	632	LKARL	
63082103	75.0	62.0	4.0	0		LKARL	
63082106	73.0	66.0	6.0	0		3 LKARL	
63082109	81.0	71.0	8.0	0		3 LKARL	
63082112	92.0	78.0	4.0	2		LKARL	
63082115	98.0	61.0	7.0	3		3 LKARL	
63082118	97.0	60.0	7.0	0		LKARL	
63082121	88.0	61.0	8.0	0		LKARL	
63082200	82.0	65.0	6.0	0	641	LKARL	
63082203	77.0	68.0	6.0	0		LKARL	
63082206	75.0	69.0	7.0	0		LKARL	
63082209	83.0	71.0	10.0	0		LKARL	
63082212	94.0	68.0	13.0	2		LKARL	
63082215	98.0	69.0	10.0	4		LKARL	
63082218	98.0	68.0	11.0	0		LKARL	
63082221	89.0	69.0	9.0	0		LKARL	
63082300	85.0	66.0	8.0	0	670	LKARL	
63082303	83.0	71.0	11.0	0		LKARL	
63082306	79.0	69.0	9.0	0		LKARL	
63082309	81.0	70.0	9.0	0		LKARL	
63082312	93.0	67.0	12.0	0		LKARL	
63082315	100.0	62.0	8.0	0		LKARL	
63082318	100.0	61.0	10.0	0		LKARL	
63082321	89.0	61.0	7.0	0		LKARL	
63082400	85.0	62.0	7.0	0	652	LKARL	
63082403	82.0	68.0	8.0	0		LKARL	
63082406	78.0	70.0	7.0	0		LKARL	
63082409	86.0	67.0	12.0	0		LKARL	
63082412	97.0	71.0	8.0	1		LKARL	
63082415	102.0	63.0	9.0	6		LKARL	
63082418	100.0	60.0	10.0	4		LKARL	
63082421	90.0	61.0	6.0	3		LKARL	
83082500	87.0	62.0	6.0	8	649	LKARL	
83082503	84.0	63.0	7.0	10		LKARL	
83082506	79.0	65.0	6.0	4		LKARL	
83082509	86.0	68.0	10.0	10		LKARL	
83082512	96.0	68.0	7.0	10		LKARL	
83082515	101.0	64.0	6.0	3		LKARL	
83082518	102.0	61.0	6.0	0		LKARL	
83082521	93.0	61.0	5.0	0		LKARL	

63082600	87.0	62.0	3.0	2	570	LKARL
63082603	82.0	63.0	5.0	0		LKARL
63082606	77.0	64.0	4.0	1		LKARL
63082609	80.0	67.0	7.0	4		LKARL
63082612	97.0	64.0	9.0	6		LKARL
63082615	103.0	65.0	8.0	4		LKARL
63082618	98.0	63.0	7.0	1		LKARL
63082621	89.0	62.0	7.0	0		LKARL
63082700	85.0	61.0	6.0	0	626	LKARL
63082703	82.0	60.0	3.0	0		LKARL
63082706	76.0	61.0	5.0	0		LKARL
63082709	84.0	63.0	7.0	1		LKARL
63082712	99.0	63.0	9.0	0		LKARL
63082715	103.0	63.0	10.0	1		LKARL
63082718	101.0	62.0	10.0	0		LKARL
63082721	91.0	62.0	7.0	0		LKARL
63082800	88.0	60.0	8.0	0	596	LKARL
63082803	83.0	62.0	7.0	0		LKARL
63082806	80.0	63.0	7.0	0		LKARL
63082809	89.0	68.0	10.0	5		LKARL
63082812	98.0	65.0	11.0	7		LKARL
63082815	103.0	60.0	10.0	8		LKARL
63082818	101.0	60.0	10.0	0		LKARL
63082821	92.0	60.0	8.0	0		LKARL
63082900	98.0	61.0	10.0	0	593	LKARL
63082903	84.0	65.0	8.0	0		LKARL
63082906	79.0	65.0	6.0	0		LKARL
63082909	88.0	55.0	6.0	0		LKARL
63082912	95.0	55.0	4.0	0		LKARL
63082915	100.0	50.0	10.0	2		LKARL
63082918	99.0	51.0	9.0	2		LKARL
63082921	87.0	66.0	12.0	5		LKARL

APPENDIX C
SAMPLE OUTPUT

SAMPLE OUTPUT

		WEATHER DATA...FORT WORTH, TEXAS AUG 21,63 THRU AUG 29,63 3 HR INCREMENTS							
.00	32.5000000								
.50	32.3585040	-1414960	-363.7597900	-1.0000000	308.6323900	412.7681100	232.4636500	-27.1597220	
1.00	32.2248730	-1336316	-343.5576700	-1.0000000	307.7247500	412.0041100	212.4055700	-26.8720430	
1.50	32.0988290	-1230436	-324.0648600	-1.0000000	306.8454900	411.2844600	193.1743200	-26.4507700	
2.00	31.9801060	-1137230	-305.2543600	-1.0000000	305.9949900	410.6058600	174.7546900	-25.8888040	
2.50	31.8684450	-1110611	-287.1080000	-1.0000000	305.1734600	409.9674700	157.1344800	-25.1795170	
3.00	31.7635950	-1048510	-269.6073300	-1.0000000	304.3812800	409.3677000	140.3044400	-24.3164700	
3.50	31.6550460	-1085487	-279.1247300	-1.0000000	304.3756100	408.8051200	141.0636200	-26.6115900	
4.00	31.5430750	-1119702	-287.9326800	-1.0000000	304.3632400	408.2233300	152.1574700	-28.9351200	
4.50	31.4278670	-1151085	-296.0133400	-1.0000000	304.4043300	407.6238300	161.5085100	-31.2853210	
5.00	31.3100100	-1175570	-303.3455400	-1.0000000	304.4390300	407.0082300	167.1145800	-33.6607610	
5.50	31.1895010	-1205099	-309.9263600	-1.0000000	304.4674900	406.3781100	171.9754400	-36.0603240	
6.00	31.0667390	-1227610	-315.7300700	-1.0000000	304.5494300	405.7351100	171.0016600	-38.4832190	
6.50	30.9458170	-1209215	-311.0067700	-1.0000000	308.6740700	405.0808800	178.3482700	-36.4569110	
7.00	30.8404270	-1095389	-271.0716800	34.2581280	312.6699200	404.4372300	171.7624300	-34.0001260	
7.50	30.7677680	-0726593	-186.8919900	111.6194350	317.1394400	403.8768900	180.5872500	-31.1867130	
8.00	30.7350970	-0326710	-84.0371500	207.3310700	321.4841900	403.4908900	181.2373900	-28.1241280	
8.50	30.7449870	.0096900	25.4396510	309.6879600	325.9061700	403.3174300	181.9571200	-24.8799310	
9.00	30.7960490	.0510612	131.3420200	408.7118900	330.4072700	403.3694300	187.9063100	-21.5007030	
9.50	30.8974740	.1014259	260.8382600	500.5571500	337.5709100	403.6411000	152.3033300	-14.2953846	
10.00	31.0453090	.1470354	390.2510400	585.4426300	344.3931400	404.1801200	137.9742100	-8.3305915	
10.50	31.2336250	.1380153	425.1195760	659.4456300	352.3771100	404.9687500	111.6250500	-3.5120635	
11.00	31.4570930	.2231669	573.9576100	720.3203700	360.3231300	405.9720400	100.9674670	.2536223	
11.50	31.7089970	.2519035	647.8133800	768.2242500	368.4484000	407.1631300	84.7463180	3.0509870	
12.00	31.9831960	.2741996	705.0954300	801.6557000	376.7575500	408.5124300	69.7592970	4.9509050	
12.50	32.2520830	.2688856	691.3727300	819.1317000	374.6467400	409.9640700	57.9539190	6.5322535	
13.00	32.5085440	.2564614	659.3674000	820.7193600	372.9451500	411.4310700	131.2130500	8.3470192	
13.50	32.7455940	.2370497	609.4090400	806.2285500	371.6289400	412.8147500	103.0849300	10.4309434	
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15.00	33.2743330	.1393573	358.1372000	600.9830000	369.7710200	416.2092400	261.1618200	18.6035490	
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16.50	33.4850860	.0329064	84.5699050	416.5766100	362.0260900	417.9360400	291.7262400	15.6293954	
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20.00	32.7873000	-.1477930	-379.8943900	-1.0000000	340.8365700	415.1254400	304.6895600	-.9175618	
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21.00	32.4819810	-.1542600	-396.5862400	-1.0000000	333.8663100	413.5050200	307.6314700	-9.2860723	
21.50	32.3348170	-.1471656	-378.3320700	-1.0000000	332.2339800	412.6712700	288.6527100	-11.2429582	
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23.00	31.9333000	-.1274239	-327.6296300	-1.0000000	327.4463800	410.4008800	227.5696100	-16.1055180	
23.50	31.8119620	-.1213178	-311.9425800	-1.0000000	325.8862700	409.7154800	210.7451900	-17.3682860	
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24.50	31.5821770	-.1143758	-294.1147200	-1.0000000	323.0021000	408.4457200	188.6377700	-20.0333720	
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25.50	31.3566040	-.1122554	-288.6830300	-1.0000000	320.3488100	407.2208400	178.5726100	-23.2323980	
26.00	31.2454150	-.1111888	-285.9502800	-1.0000000	319.0387000	406.6269200	173.5222300	-24.8398330	
26.50	31.1352990	-.1101175	-283.2050000	-1.0000000	317.7396000	406.0333700	168.4586600	-26.4525710	
27.00	31.0262570	-.1090412	-280.4466900	-1.0000000	316.4514700	405.4461600	163.3814100	-28.0705910	

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