**US Army Corps
of Engineers**
Hydrologic Engineering Center

Generalized Computer Program

THERMS
Thermal Simulation of Lakes

User's Manual

July 1970

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14. ABSTRACT

This user's manual provides information on the simulation of reservoir temperatures using two computer programs - Heat Exchange Program (HEATX, Appendix A, 722-F5-E1010), and Thermal Simulation Program (THERMS, Appendix B, 722-F5-E1011). HEATX assembles the meteorologic data and performs the necessary calculations to determine the climatologic input to the reservoir heat balance. This output is then used as a portion of the input to THERMS.

HEATX performs all the computations necessary to determine the net rate of heat exchange at the air-water interface. Input to the program consists of measured values of a cloud cover, wet and dry bulb temperatures, and wind speed. See Appendix A for more details about the HEAT programs.

THERMS takes the required hydrologic and meteorologic data, assembles it, and performs the necessary calculations to determine the annual temperature cycle for the reservoir that is being studied. Input requirements may be divided into four categories: site characterization, hydrologic, meteorologic, and water temperature data. See Appendix B for more details about the THERMS program.

15. SUBJECT TERMS

722-F5-E1010, 722-F5-E1011, HEATX, Heat Exchange Program, THERMS, Thermal Simulation Program, annual temperature cycle, impoundment, heat balance, inflow, outflow, heat transfer, water surface, reservoir, meteorological variables, equilibrium temperature, mean daily values, air temperature, wet bulb temperature, wind speed, coefficients of surface heat exchange

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PREFACE

This computer program description as well as the associated source code were developed by Mr. Earl Eiker formerly of the U.S. Army Corps of Engineer District, Baltimore. Since he transferred from the District to the Office of the Chief of Engineers, the Hydrologic Engineering Center has been requested to distribute this program. Several versions of this program presently exist. The version HEC is distributing was obtained from the Ohio River Division. Some recent revisions have been made by HEC.

Extra copies of this publication and/or copies of the source code may be obtained from Ms. Penni Baker by calling (916) 756-1104. Questions regarding its application should be referred to one of the following:

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INTRODUCTION

When a dam is built across a stream, a totally different regime is established which profoundly affects the water quality within and downstream of the impoundment for many miles. The temperature structure within the reservoir is the most important consideration when establishing a management plan for water quality control.

When a study of reservoir temperatures is undertaken, it is important that all of the physical and meteorological heat exchange processes are included, so that consideration of the overall heat balance of the reservoir is assured. A sound theoretical approach will insure this. The analysis should provide a realistic assessment of the inter-relationship between project operations and the thermal variations within the reservoir. The use of input data which cannot be measured "in situ" should be kept to a minimum in order to insure that possible bias in results is eliminated. Finally, application should be straightforward and follow standard accepted procedures in order to provide confidence and guarantee uniformity in results.

CONSERVATION OF HEAT

The simulation of the annual temperature variations within an impoundment begins with the formulation of a mathematical description of the pertinent heat transfer mechanisms. The solution of the mathematical formulation results in an accounting of the external and internal heat balance for the reservoir over the yearly cycle.

The annual temperature cycle of a reservoir is the result of a complex inter-relationship among the many hydrodynamic and thermodynamic processes by which heat enters, is distributed within, and leaves an impoundment. Strictly speaking, the only mathematical descriptions which would be universally applicable would be the three dimensional equations of conservation of heat and mass. However, solution of the three dimensional equations is virtually impossible. There are many instances, though, when the reservoir heat balance can be adequately determined by considering only the vertical distribution of heat and the heat transfer mechanisms associated with movement along the vertical axis. Prototype data are available to support this assumption. The annual temperature cycle for the Beltzville Reservoir in northeastern Pennsylvania is shown on figures 1 through 3. Examination of these figures shows that the assumption of horizontal isotherms (layers of equal temperatures) is indeed valid. Very little variation was measured in either the longitudinal or lateral directions at Beltzville. A large number of Corps reservoirs exhibit this same characteristic and are readily analyzed by considering heat transfer in only the vertical dimension. It should be emphasized, however, that each impoundment is different and before this simplifying assumption is accepted, it should be scrutinized.

Some general guidance is available on the applicability of the one dimensional assumption to a particular reservoir. Orlob (15) has suggested a method of reservoir classification based on a ratio of inflow volume to storage volume in the reservoir.

1) Low flow/volume ratio. - Reservoirs in this class are extremely large and have detention times greater than one year. Little seasonal variation in storage occurs and outflow is generally from surface layers.

2) Medium flow/volume ratio. - Reservoirs in this class are large and detention times are in the range of from four months to one year. These reservoirs show strong patterns of stratification and variations in storage may be large.

3) High flow/volume ratio. - Reservoirs in this class are generally run of river types with detention times of less than four months. Patterns of stratification are difficult to access and longitudinal variations in temperature are common. Along with these longitudinal temperature variations, conditions of underflow may develop.

Reservoirs in the first and second class can be expected to exhibit a strong pattern of thermal stratification. In order to mathematically evaluate the applicability of the one dimensional assumption, Orlob (11) suggests the use of a densimetric Froude number computed as follows:

$$F_D = \frac{LQ}{HV} \sqrt{\frac{1}{g\ e}} \qquad (1)$$

where:

F_D = densimetric Froude number

L = length of the reservoir in ft. @ conservation pool

H = mean reservoir depth in ft.

V = volume of the reservoir in $ft.^3$ @ conservation pool

Q = flow through rate in cfs (check mean annual and spring mean monthly)

g = gravitational constant 32.2 ft/sec^2

e = average normalized density gradient taken as 0.3×10^{-6}/ft.

According to this theory, if the computed value of F_D is less than $^1/\P$ a strong stratification pattern will exist in the reservoir.

MATHEMATICAL FORMULATION

Several approaches to the simulation of reservoir temperatures have been utilized by various Corps offices (2, 11, 16). These methods have been analyzed by Eiker (6) and each was determined to be lacking in one or more areas. The simulation approach outlined below was developed by the **Baltimore** District and has been applied in several analyses of existing and proposed reservoirs. The basis of the analysis is the simultaneous solution of the time varying, one-dimensional equations for conservation of heat and conservation of mass.

The equations describing conservation of heat and mass for the reservoir are derived in the classical manner. The reservoir is idealized and a control volume is established as shown on figure 4. The control volume is of thickness (ΔZ) and has an average area (A) which is a function of elevation Z. Conservation of mass for the control volume is described by:

$$\frac{\partial Qv}{\partial Z} = \frac{Qin - Qout}{\Delta Z} \qquad (2)$$

where:

$\frac{\partial Qv}{\partial Z}$ = change in vertical flow per unit between the bottom and top of the control volume in cfs/ft.

Qin = inflow to the control volume in cfs.

Qout = outflow from the control volume in cfs.

ΔZ = thickness of control volume in ft.

The equation to describe the conservation of heat within the control volume is:

$$\frac{\partial T}{\partial t} + \frac{1}{A}\frac{\partial (Q_V \cdot T)}{\partial Z} = \frac{1}{A}\frac{\partial}{\partial Z}KA\frac{\partial T}{\partial Z} + \frac{TinQin}{A \cdot \Delta Z} - \frac{ToutQout}{A \cdot \Delta Z} + \frac{1}{\rho C_p A} \cdot \frac{\partial H}{\partial Z} \qquad (3)$$

where:

T = temperature in ^oF.

t = time in sec.

A = horizontal area of the control volume in ft^2

Q_v = vertical flow in cfs.

Z = elevation in ft.

K = diffusion coefficient (molecular and turbulent) in ft^2/sec.

T_{in} = temperature of inflow in ^{o}F.

Q_{in} = inflow to the control volume in cfs.

T_{out} = temperature of outflow = T in ^{o}F.

Q_{out} = outflow from the control volume in cfs.

ρ = density of water in LBS/ft^3.

C_p = specific heat of water in BTU/LBS/^{o}F.

$\partial H/\partial Z$ = external heat source in BTU/sec.

An examination of equation (3) confirms that all of the pertinent heat transfer mechanisms are included in the formulation. The first term on the left hand side of the equation represents the change in temperature with respect to time. The second term on the left hand side of the equation accounts for the vertical transfer of head due to advective processes. The first term on the right side of equation (3) is the measure of heat transfer related to diffusion. The remaining three terms account for the external heat balance of the reservoir, that is, inflow, outflow, and interfacial heat transfer. Heat transfer at the solid boundaries, if significant, may be included with an additional term having the same form as the external heat source term.

The next step in the simulation is to incorporate the conservation of mass equation into the conservation of heat equation. This is accomplished by expanding the second term (vertical advection) by the product rule and substituting equation (2) into the result as follows:

$$\frac{1}{A}\,\frac{\partial(Q_v \cdot T)}{\partial Z} = \frac{1}{A}\left[Q_v\frac{\partial T}{\partial Z} + \frac{T(Q_{in} - Q_{out})}{\Delta Z}\right] \qquad (4)$$

Now, when equation (4) is substituted back into equation (3) and simplified the result is:

$$\frac{\partial T}{\partial t} + \frac{Qv}{A} \frac{\partial T}{\partial Z} = \frac{1}{A} \frac{\partial}{\partial Z} KA\frac{\partial T}{\partial Z} + \frac{Qin(Tin - T)}{A \bullet \Delta Z} + \frac{1}{\rho C\ A} \frac{\partial H}{\partial Z} \qquad (5)$$

ADDITIONAL CONSIDERATIONS

Before proceeding with the solution of equation (5), functional descriptions for the inflow-outflow relationship, diffusion processes and the external heat source term must be developed.

The vertical outflow distribution used in the model is developed, based on methods presented in WES reports (3, 8). These methods enable an accurate prediction of the vertical variation in outflow to be made for either a weir or an orifice type outlet. The velocity distribution is first computed using the WES procedures. The outflow per foot is then developed by multiplying the velocity at each elevation by the reservoir width. A complete explanation of the application is contained in the above references.

When inflow enters a reservoir it tends to seek residence at a depth of similiar temperature (density). Velocity measurements of inflows at Fontana Reservoir, taken by Elder and Wunderlich (7), show that there is a vertical distribution of inflow. This distribution is approximately parabolic and is centered about the elevation where reservoir temperature is equal to inflow temperature. The vertical limits of the inflow distribution are dependent upon the quantity of flow and the degree of thermal stratification existing in the reservoir pool. Orlob (11) has suggested a method for determining the vertical limits of the inflow distribution as a function of densimetric Froude number following Debler's criteria. This relationship is as follows:

$$D = 2.88 \left[\frac{Q}{W \sqrt{gE}} \right]^{\frac{1}{2}} \qquad (6)$$

where:

D = thickness of the inflow distribution in ft.

Q = inflow in cfs.

W = reservoir width in ft.

g = gravitational constant = 32.2 ft/sec^2.

E = stability = $\frac{1}{\rho} \frac{d\rho}{dZ}$

The model uses equation (6) to estimate the thickness of the inflowing layer, fits a parabolic distribution of inflow velocity between the limits and centers this distribution about the point of corresponding density of inflow and reservoir water. If the reservoir surface or bottom restricts the distribution, the center-line is moved up or down as required and the thickness of the inflowing water is kept constant. The inflow quantity distribution is next computed by multiplying the computed velocity distribution by the reservoir width at each elevation. Some mixing of the reservoir inflow occurs as it enters the pool. Based on model studies conducted at WES, this phenomenon is handled by assuming a quantity of water from the top layer of the reservoir is entrained and mixed with the inflow current. A modified volume and volume-weighted temperature for the inflow is computed, based on the assumed quantity of entrainment, prior to placement within the reservoir.

Now, with a knowledge of the inflow and outflow distributions at any point in time, the vertical flows (Q_v) at any elevation are uniquely established. The relationship may be written as:

$$Q_v (Z) = \int_{Z_o}^{Z} \left[Q_{in} (Z) - Q_{out} (Z) \right] dZ \qquad (7)$$

where:

$Q_v (Z)$ = vertical flow at elevation Z in cfs.
Z_o = elevation of reservoir bottom in ft.
$Q_{in} (Z)$= inflow of distribution function in cfs/ft.
$Q_{out} (Z)$= outflow distribution function in cfs/ft.

Relating equation (7) to the control volume the net vertical flow through the control volume (Q_v) is evaluated as:

$$Q_v = Q_v (Z + \ Z) - Q_v (Z) \qquad (8)$$

The external heat sources that are considered in the model are the seven heat exchange processes which operate at the air-water interface and may be written as:

$$H_n = H_s - H_{sr} + H_a - H_{ar} \pm H_c - H_{br} - H_e \qquad (9)$$

where:

H_n = the net heat transfer in BTU/ft^2/DAY
H_s = the short wave solar radiation arriving at the water surface in BTU/ft^2/DAY.
H_{sr}= the reflected short wave radiation in BTU/ft^2/DAY.

H_a = the long wave atmospheric radiation in BTU/ft^2/DAY.

H_{ar} = the reflected long wave radiation in BTU/ft^2/DAY.

H_c = the heat transfer due to conduction in BTU/ft^2/DAY.

H_{br} = the back radiation from the water surface in BTU/ft^2/DAY.

H_e = the heat loss due to evaporation in BTU/ft^2/DAY.

Complete discussions of the individual terms have been presented by Anderson (1) and in Tennessee Valley Authority report No. 14 (14). All of the heat transfer mechanisms at the water surface, with the exception of short wave solar radiation, affect only the top one or two feet of the reservoir. Short wave radiation, however, penetrates the water surface and may affect water temperatures at great depths. This depth of penetration varies from reservoir to reservoir and is a function of absorption and scattering properties of the water (9).

The method used in the model to evaluate the net rate of heat transfer at the air-water interface has been developed by Edinger and Geyer (5). Their method utilized the concepts of equilibrium temperature and coefficient of surface heat exchange. The equilibrium temperature may be defined as that water temperature at which the net rate of heat exchange between a water surface and the atmosphere will be zero. The coefficient of surface heat exchange is the rate at which the heat transfer process will proceed. The equation to describe this relationship may be written as follows:

$$H_n = K_e\ (T_e - T_s) \qquad (10)$$

where:

H_n = the net rate of heat transfer in BTU/ft^2/TIME.

K_e = the coefficient of surface heat exchange in BTU/ft^2/TIME.

T_e = the equilibrium temperature in ^oF.

T_s = the surface temperature in ^oF.

Computation of T_e's and K_e's is dependent solely on meteorological variables and is outlined in the literature (5).

The evaluation of the external heat source term is completed by establishing a relationship for the heating effects of short wave solar radiation penetration. Based on laboratory and analytical studies, Dake and Harlemen (4) have developed an equation to describe the distribution of heat input due to solar radiation penetration below the water surface. Their approach is based on a surface absorption of the longer wave lengths of radiation and an exponential decay with depth for the remaining wave lengths of radiation. The equation to describe this exponential decay is:

$$\phi(Z) = (1 - \beta) \quad \phi_o \ e^{-\lambda Z} \qquad (11)$$

where:

ϕ (Z) = the quantity of radiation arriving at a horizontal plane (Z feet below the water surface) in BTU.

β = the fraction of radiation absorbed by the top 2 feet of water in the reservoir.

ϕ_o = total incoming radiation in BTU.

λ = the average absorption coefficient of the water in ft^{-1}

Z = depth below the water surface in ft.

Guidance in the selection of β and λ is provided by Dake and Harlemen and also in TVA Report No. 14 (14).

The final and perhaps the most difficult consideration to be made is with regard to the diffusion term. At this time, there is no adequate functional representation by which the variations over time and space in the diffusion coefficient (K) can be computed "a priori". The approach used in the model follows the arguments of Dake and Harleman and Stefan and Ford (13). That is, diffusion of heat in the epilimnion is handled indirectly by a combination of wind induced and convective mixing processes. In the model a coefficient may be used to increase or decrease wind speed effects due to fetch length, sheltering and water surface roughness (see App. B). The result of this procedure is the computation of a uniformly mixed eplimnion. Diffusion in the hypolimnion is considered constant and may be assumed as equal to molecular diffusion in the absence of better data.

SOLUTION TECHNIQUE

Analytical solutions of equation (5) have been accomplished, but their practical application is restricted. Numerical methods are the

the only means by which a workable solution to equation (5) may be obtained. The numerical technique used in the model is of the implicit type. The solution requires the stipulation of an initial condition and two boundary conditions. The initial condition may be taken as isothermal at some time during the spring. The lower boundary condition used in the model assumes no heat is transferred across the bottom boundary. The upper boundary condition assumes the heat exchange at the reservoir surface is equal to the net heat transfer at the air-water interface minus the quantity of heat attributable to the short wave solar radiation that penetrates into the water body. The mechanics of the solution are carried out by beginning from a known or assumed initial condition and stepping forward in time, using constant increments for hydrologic and meteorologic input.

In order to effect the solution, the reservoir is first segmented into a finite number of layers along the vertical axis. These layers may be thought of as a number of control volumes stacked vertically between the reservoir bottom and the surface. Each element has a thickness of ΔZ and an average horizontal area dependent on the reservoir elevation-area relationship. Heat and mass balances are next developed for each layer using central differences to approximate the derivatives in equation (5). The differences are substituted into equation (5) and a difference equation is developed for each layer. The resulting equations have the following general form:

$$\left\{A_{i+1,\ t+1}\right\} T_{i+1} + \left\{A_{i,\ t+1}\right\} T_i + \left\{A_{i-1,\ t+1}\right\} T_{i+1} = T_{i,\ t} + A_v + E_x \tag{12}$$

where:

$A_{i,\ t+1}$ = coefficient describing internal mixing processes

T_i = temperature of each layer at time t+1

$T_{i,\ t}$ = temperature of each layer at time t

A_v = temperature rise in layer i due to inflow

E_x = temperature rise in layer i due to external heat sources.

When equation (12) is written for each layer, there results N equations (one for each layer) in N unknowns. In matrix notation, the equations are written:

$$\left[A_{ij}\right] \left[T_j\right] = \left[C_j\right] \tag{13}$$

where:

$\left[A_{ij}\right]$ = a tri-diagonal matrix of coefficients

$\left[T_j\right]$ = a column matrix of temperatures at time t+1

$\left[C_j\right]$ = a column matrix of terms on the right side of equation (12).

Equation (13) is solved and the result is the temperature profile at time t+1. A more complete discussion of the numerical technique is presented by Keller (10).

COMPUTER PROGRAM

The simulation of reservoir temperatures as described above is accomplished by use of computer programs 722-F5-E1010, Heat Exchange Program and 722-F5-E1011, Thermal Simulation Program. The Heat Exchange Program assembles the meteorologic data needed to describe the interfacial heat exchange mechanism. The program then performs the necessary calculations to determine the climatologic input to the reservoir heat balance. The output from the first program is then used as a portion of the input for actual thermal modeling of the impoundment.

HEAT EXCHANGE

The Heat Exchange Program performs all the computations necessary to determine the net rate of heat exchange at the air-water interface. Computations to determine Equilibrium Temperature and Coefficients of Surface Heat Exchange are carried out using the methods of Edinger and Geyer (5), which have been discussed previously. In addition, if no measured values of short wave solar radiation are available the appropriate computations are made, using methods presented in TVA report No. 14 (14). Input to the program consists of measured values of cloud cover, wet and dry bulb temperatures, and wind speed. Also, physical characteristics such as latitude and longitude, and site elevation are furnished. Details of the program including a flow chart, variable definitions, input description and sample output are contained in Appendix A.

THERMAL SIMULATION

The Thermal Simulation Program takes the required hydrologic and meteorologic data, assembles it, and performs the calculations necessary to determine the annual temperature cycle for the reservoir under study.

The computations are made, based on methods and assumptions discussed previously. Input requirements of the model may be divided into four categories as site characterization, hydrologic, meteorologic, and water temperature data. Site characterization data are composed of reservoir width-elevation and area-elevation tables for the reservoir, project latitude and longitude, and site elevation. The hydrologic input requirements are daily average reservoir inflow and outflow, and daily pool elevation of the impoundment. Meteorologic data consists of mean daily values of Equilibrium Temperature, wind speed, Coefficient of Surface Heat Exchange and short wave solar radiationfrom the Heat Exchange Program. Input data for water temperature consists of daily average values of inflow water temperature and the temperature objective of release water. The geometric configuration of the outlet structure is required with reference to the location of various levels available for withdrawal. Details of the program including a flow chart, variable definitions, input description and sample output are contained in Appendix B.

CONCLUSION

A mathematical model capable of reservoir temperature prediction that is relatively easy to use has been presented. Consideration has been given to maintaining an accurate representation of the physical characteristics of the reservoir under study while adhering to the principles of conservation of heat and mass. Results of model verification studies are included in Appendix C. It is felt that the model presented offers the best combination of approaches to separate phases of the total problem that have been studied by various investigators.

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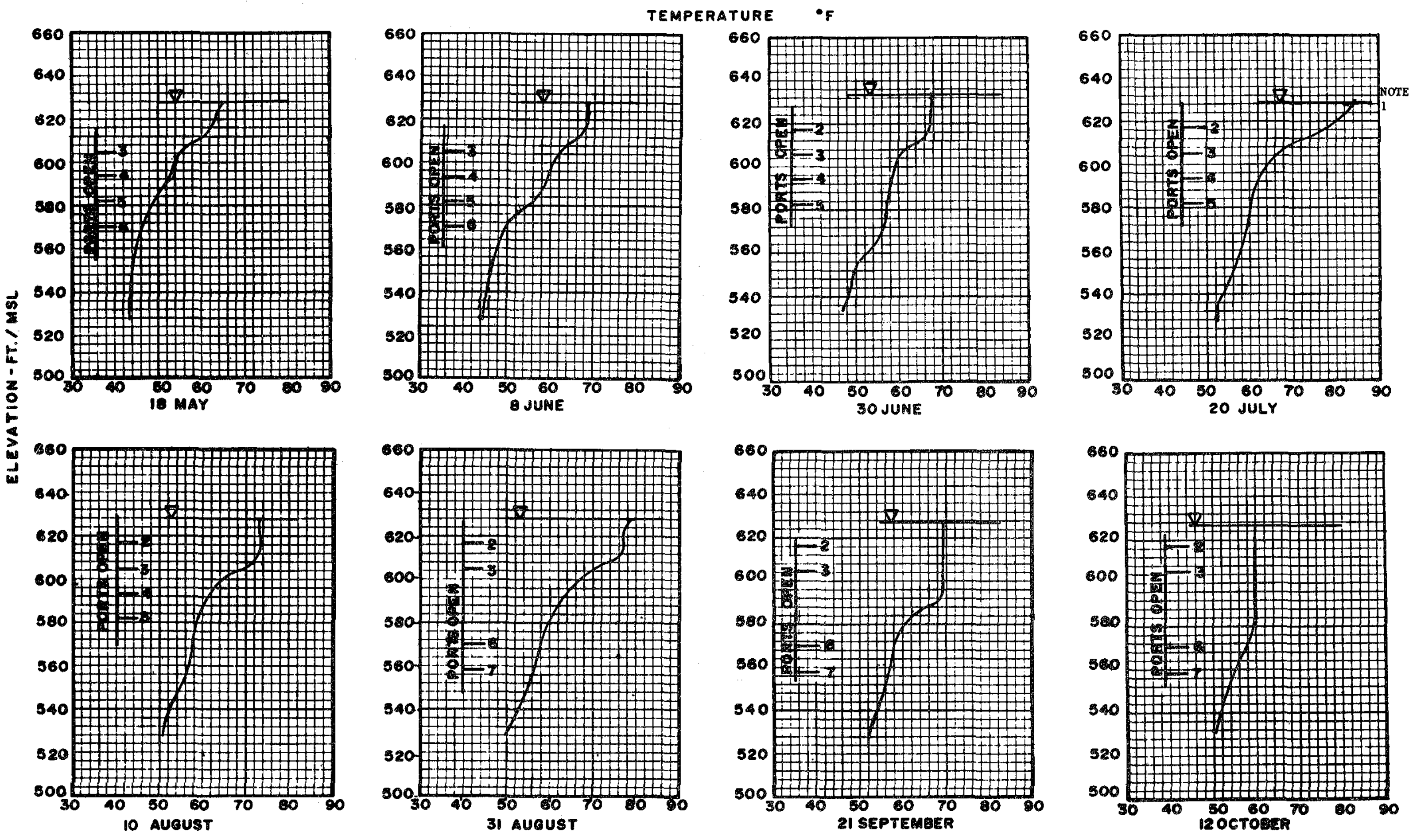
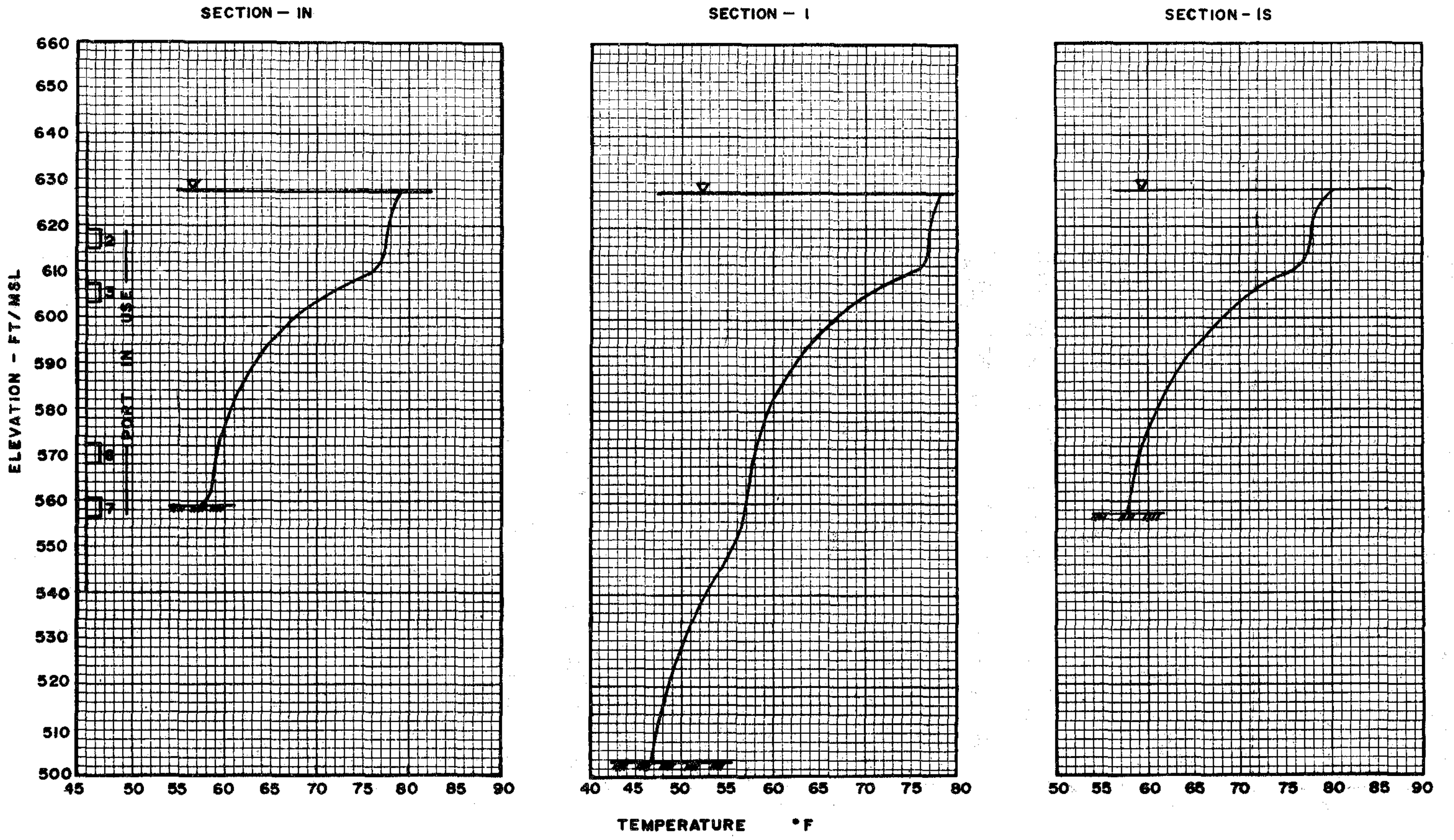


NOTE:
1 ALL MEASUREMENTS TAKEN APPROXIMATELY 100 YARDS UPSTREAM FROM INTAKE TOWER

**LEHIGH RIVER BASIN
POHOPOCO CREEK PENNSYLVANIA
BELTZVILLE LAKE
THE ANNUAL CYCLE OF
HEATING AND COOLING - 1972**

FIGURE I

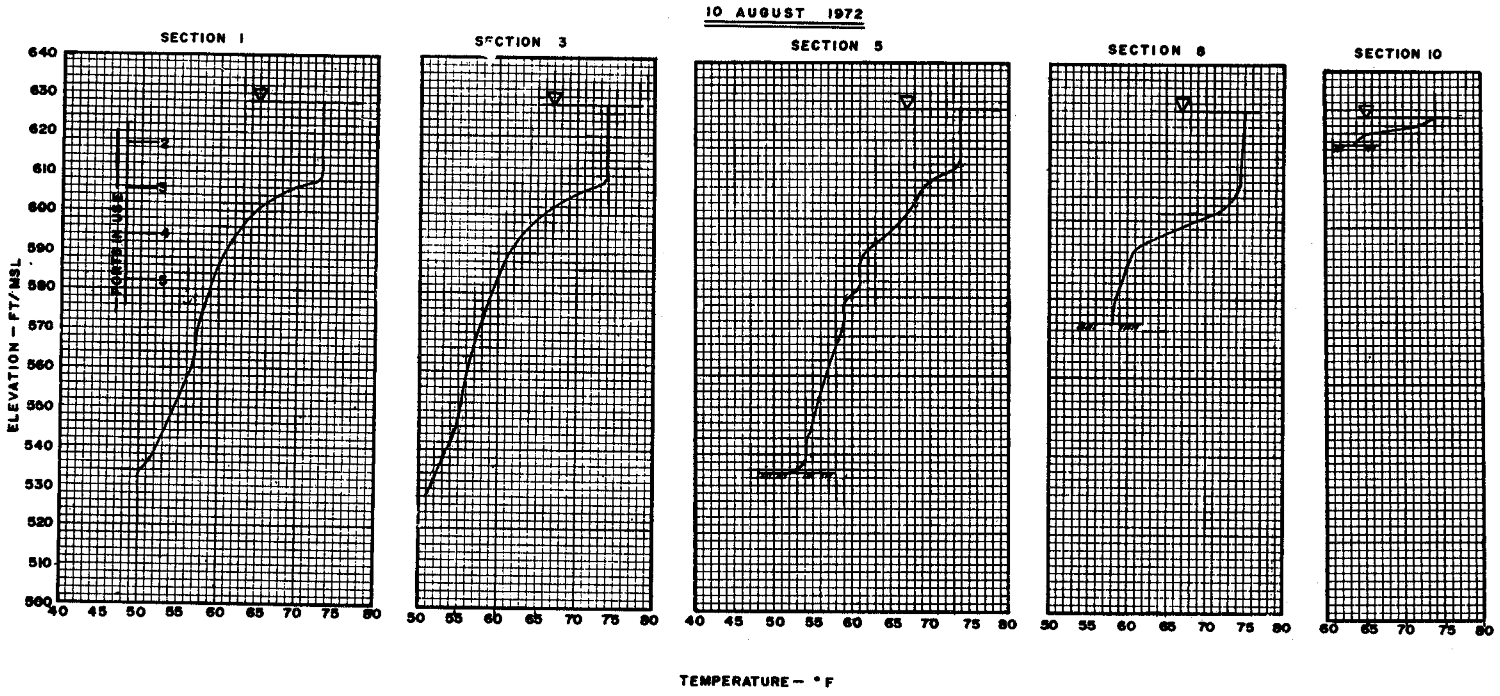


NOTES.

1. STATION 1 IS LOCATED APPROXIMATELY 100 YARDS UPSTREAM OF INTAKE TOWER ALONG CENTER LINE OF LAKE.
2. STATIONS 1N AND 1S ARE APPROXIMATELY 100 YARDS NORTH AND SOUTH OF STATION 1 ON A LINE PERPENDICULAR TO CENTER-LINE OF LAKE.

LEHIGH RIVER BASIN
POHOPOCO CREEK PENNSYLVANIA
BELTZVILLE LAKE
LATERAL TEMPERATURE VARIATION
31 AUGUST 1972

FIGURE 2



NOTES:
1. ALL STATIONS ALONG CENTER LINE OF LAKE.
2. STATION 1 IS APPROXIMATELY 200 YARDS ABOVE TOWER.
3. STATION 3 IS APPROXIMATELY 1.3 MILES ABOVE TOWER.
4. STATION 5 IS APPROXIMATELY 2.3 MILES ABOVE TOWER.
5. STATION 8 IS APPROXIMATELY 4.2 MILES ABOVE TOWER.
6. STATION 10 IS APPROXIMATELY 6.0 MILES ABOVE TOWER.

LEHIGH RIVER BASIN
POHOPOCO CREEK PENNSYLVANIA
BELTZVILLE LAKE

LONGITUDINAL TEMPERATURE PROFILES

FIGURE 3

CONTROL VOLUME REPRESENTATION

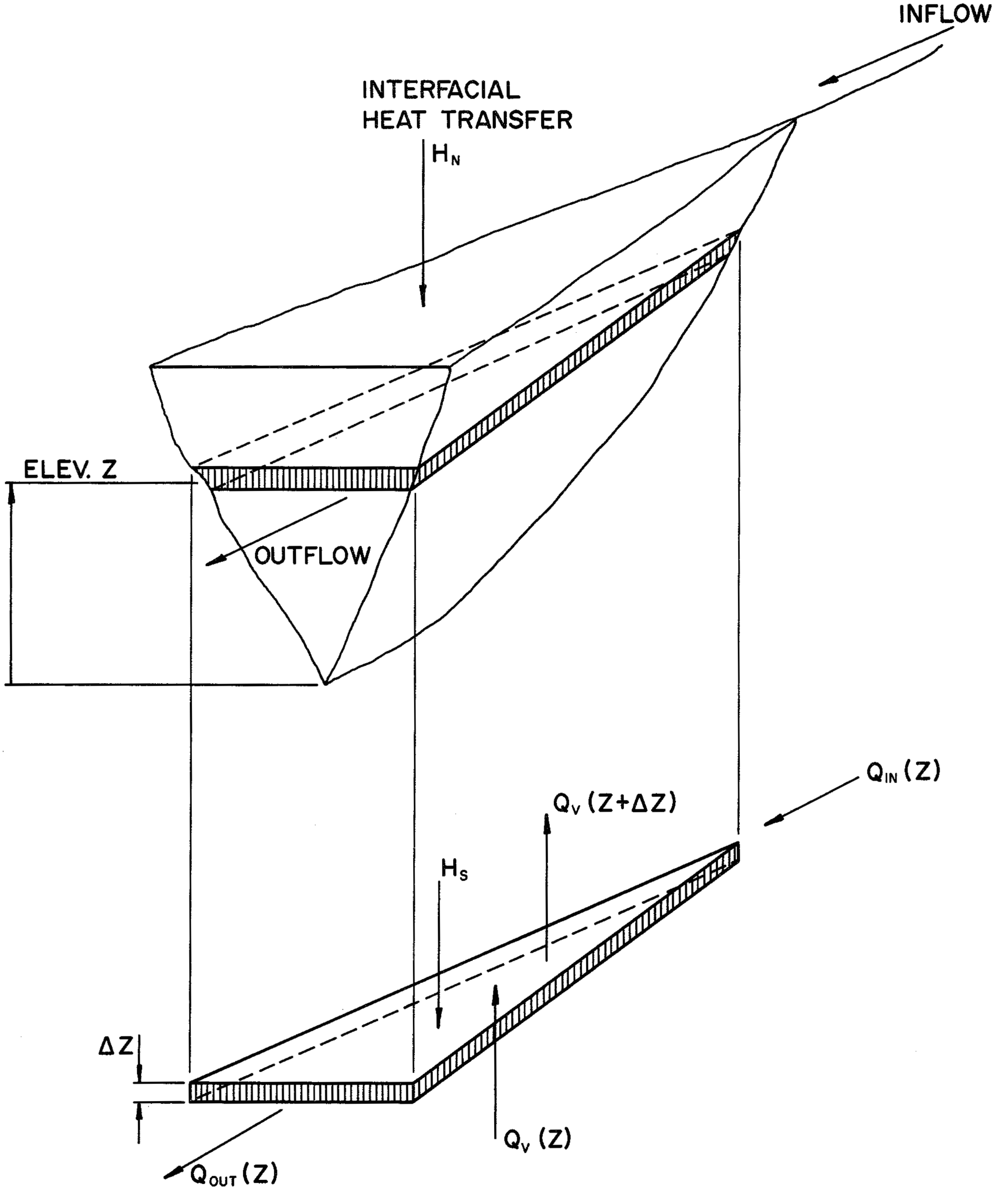


FIGURE 4

APPENDIX A

HEAT EXCHANGE PROGRAM

722-F5-E1010

APPENDIX A

HEAT EXCHANGE PROGRAM

TABLE OF CONTENTS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM Heat Exchange Program	**PROGRAM NO.** 722-F5-E1010

PREPARING AGENCY Water Quality Section, Engineering Division, U.S.A.E.D.
Baltimore District, P.O. Box 1715, Baltimore, Md. 21203

AUTHOR(S)	**DATE PROGRAM COMPLETED**	**STATUS OF PROGRAM**	
		PHASE	**STAGE**
Earl E. Eiker	Dec. 1972	Revised	Nov. 1977

A. PURPOSE OF PROGRAM

To analyze the day to day variations in meteorologic variables at a given location and using these variables to compute Equilibrium Temperatures and Coefficients of Surface Heat Exchange for use in estimating net heat exchange between a water surface and the atmosphere.

B. PROGRAM SPECIFICATIONS

1. Language - Fortran IV
2. Input - card only
3. Output- printer and punched card at users option
4. Size of Program - 8500 words
5. External storage - none
6. Restrictions - none

C. METHODS

Reference:

Edinger, J. E. and Geyer, J. C., "Heat Exchange in the Environment" Dept. of Sanitary Engineering, Research Project no. 49, The Johns Hopkins University, Baltimore, Md., June 1965.

D. EQUIPMENT DETAILS

Program is written for the Univac 1108 computer but can be adapted to comparable system. Normal configuration of reader/punch and printer required. Program is written for batch mode of time share operation.

E. INPUT-OUTPUT

Input consists of physical data to describe the site and mean daily values of air temperature, wet bulb temperature, wind speed and cloud cover. Output consists of computed values of Equilibrium Temperature and Coefficients of Surface Heat Exchange for any time period from one hour to one day. Punched card output is compatible with input requirements of program no. 722-F5-E1011, "Thermal Simulation Program."

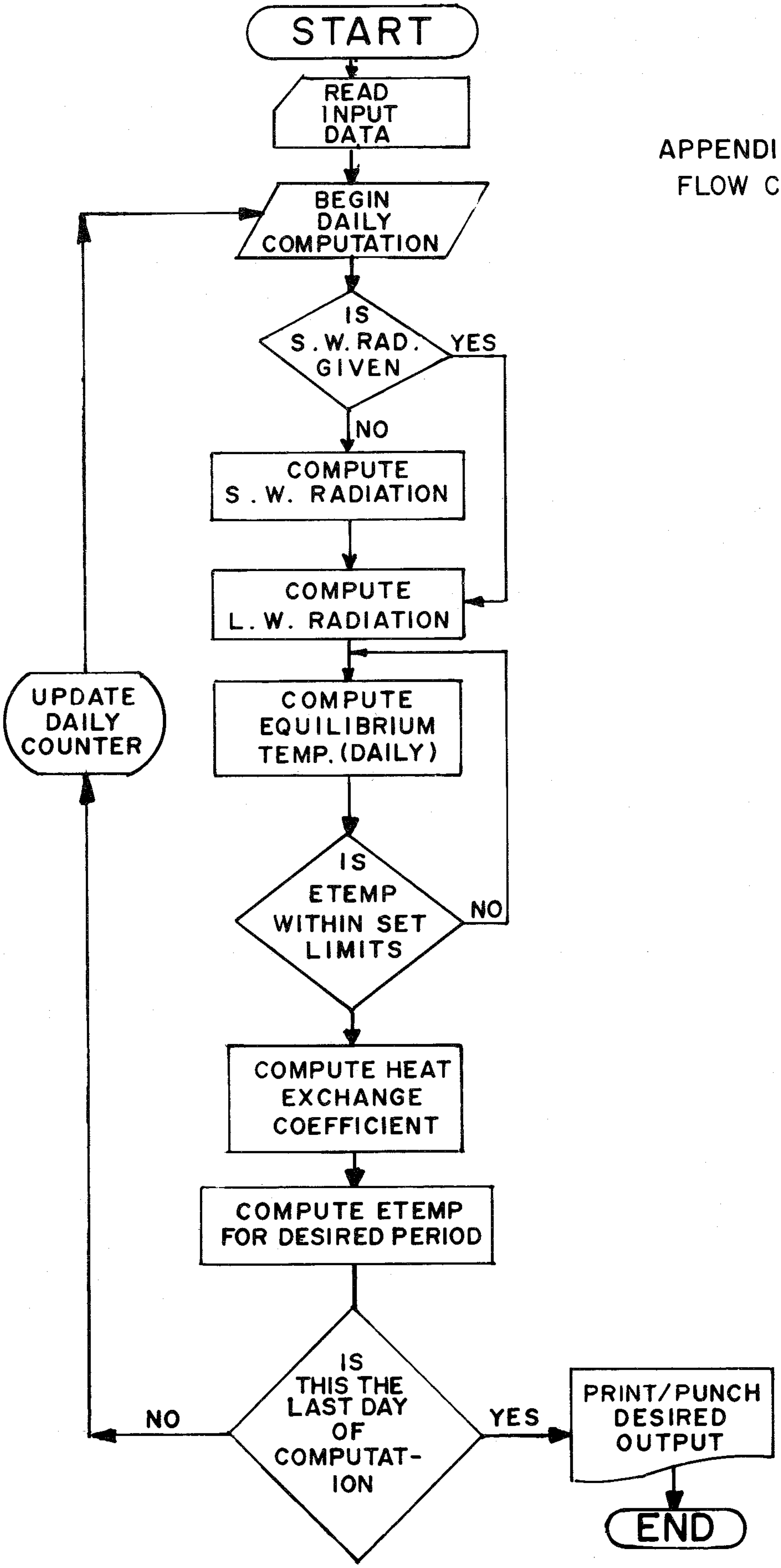
F. ADDITIONAL REMARKS

Complete documentation is available from The Hydrologic Engineering Center. Source deck available upon request.

ENG FORM 2883
1 AUG 60

PREVIOUS EDITIONS ARE OBSOLETE.

APPENDIX A.2
FLOW CHART



HEAT EXCHANGE PROGRAM

APPENDIX A.2

Appexdix A.3
HEAT EXCHANGE PROGRAM
DEFINITION OF VARIABLES

Variables	
A1	Constant in S.W. radiation computation.
A11	Constant in S.W. radiation computation.
AEV	Constant in wind speed equation.
AIRT (365)	Average daily air temperature in $^{\circ}$F.
AMASS	Optical air mass, dimensionless.
AMP	Amplitude of Equilibrium Temperature variation.
BEV	Constant in wind speed equation.
BOTEL	Project elevation in ft. above msl.
CBR	Constant in Bowen Ratio.
CL	Cloud cover function.
CLOUD (365)	Average daily cloud cover in tenths.
DEC	Declination of sun in radians.
DEWT (365)	Average daily dew point temperature in $^{\circ}$F.
DSTL	Time difference between local and standard meridians in hrs.
DUST	Constant in S.W. radiation computation.
EA	Atmospheric vapor pressure in inches of Hg.
EK (365)	Coefficient of Surface Heat Exchange in BTU/FT^2/DAY/$^{\circ}$F.
ES	Saturation vapor pressure in inches of Hg.
ETEMP (365)	Equilibrium Temperature in $^{\circ}$F.
ETEMP1	Initial Equilibrium Temperature (IDAY) in $^{\circ}$F.
FWIND	Wind speed equation.
HA	Atmospheric radiation in BTU/FT^2/DAY.
HAB	Hour angle at beginning of time period in radians.
HAE	Hour angle at end of time period in radians.
HAN	Net atmospheric radiation in BTU/FT^2/DAY.
HHS (24)	Hourly solar radiation (hemispheric) in BTU/FT^2/HR.
HR	Absorbed radiation in BTU/FT^2/DAY.
HSD (365)	Daily solar radiation in BTU/FT^2/DAY.
HSDAY	Daily solar radiation in BTU/FT^2/DAY.
HSN (24)	Hourly solar radiation at site in BTU/FT^2/HR.
IDAY	First day of computation (Julian).
IPNCH	Eq. 2 if punched card output desired, Eq. 1 otherwise.
ISW	Eq. 1 if S.W. radiation is furnished, Eq. 2 otherwise.
LDAY	Last day of computation (Julian).
NDAY	Day number for computations.
NLAST	Number of bits of meteorologic data furnished.
NPER	Length of one period in hours.
NSW	Number of bits of S.W. data furnished.
PETEMP (24)	Period Equilibrium Temperature in $^{\circ}$F.
PHI	Latitude of project in radians.

PHHS (24)	Period solar radiation (hemispheric) in BTU/FT^2/PERIOD.
PHSN (24)	Period solar radiation (net) in BTU/FT^2/PERIOD.
RATIO	Relative distance between earth and sun.
RFA	Water surface reflection of atmospheric radiation in hundredths.
RFG	Reflectivity of ground in hundredths.
RFS	Water surface reflection of S.W. radiation in hundredths.
SGDAY	Mean daily solar radiation (hemispheric) in BTU/FT^2/DAY.
SIG	Stefan-Boltzmann constant.
SLOPE	Slope of temperature vs. saturation vapor pressure curve.
STR	Standard time of sunrise in hours.
STS	Standard time of sunset in hours.
SW (365)	Daily solar radiation in BTU/FT^2/DAY.
TABS	Absolute temperature - 460 °F.
TIME	Time of day in hours.
WAT	Mean daily precipitable water content in CM.
WIND (365)	Mean daily wind speed in knots.
XDAY	Day number for computations.
XLAT	Latitude of project in degrees.
XLONG	Longitude of project in degrees.
XPER	Length of time period in hours.
XXLONG	Longitude of standard meridian in degrees.

WORKING VARIABLES

AL, ALF, ALT, AN, B, ETRY (3), KE, KNT, LE, M, NEX, SIGN, ST, STT, SUMH, SUMQ, X1, X2, X3, XI, XM, XTEM, XX, Y1, Y2, Y3, YM.

Appendix A.4
HEAT EXCHANGE PROGRAM
Input Description

Card No.

1 FORMAT (2I10)

NDATA - Number of jobs to be run
IHCJ - Output format; 0 for printer, 1 for LARM model input file, -1 for HEC-5Q input file, -2 for WQRRS input file

2 FORMAT (20A4) Job title - one card.

3 FORMAT (8F10.0)

ADDC - constant to be added to cloud cover (default=0)
ADDW - constant to be added to wind speed (default=0)
ADDT - constant to be added to dry bulb temperature (default=0)
ADDD - constant to be added to dew point temperature (default=0)
CMULT - factor to be multiplied times cloud cover (default=1)
WMULT - factor to be multiplied times wind speed (default=1)
TMULT - factor to be multiplied times dry bulb temperature (default=1)
DMULT - factor to be multiplied times dew point temperature (default=1)

4 FORMAT (6I10)

NLAST - Number of bits (e.g., days) of meteorological data furnished. Usually 365.
ISW - Equals 1 if short wave radiation furnished, equals 2 otherwise.
NSW - Number of bits of short wave data furnished.
IDAY - First day of computation. Usually one.
LDAY - Last day of computation. Usually 365.
IPNCH - Equals 2 if punched card output desired, equals 1 otherwise.

5 FORMAT (2F10.2)

ETEMP1 - Estimated initial Equilibrium Temperature in °F. Usually use air temperature.
XPER - Length of computation period and output interval for solar radiation only. Usually 24.

6 FORMAT (4F10.2)

AEV - Evaporation formula constant (0 for daily data).
BEV - Evaporation formula constant (426 for daily data from Lake Colorado City Studies).
RFS - Reflected S.W. radiation in hundredths. Only used if ISW equals 1. (0.05 from Lake Hefner Studies).
RFA - Reflected long wave radiation in hundredths (0.03 from Lake Hefner Studies).

7 FORMAT (4F10.2) - omit this card if card 12 is used.

BOTEL - Elevation of project in feet above sea level.
XLAT - Latitude of project in degrees.
XLONG - Longitude of project in degrees.
RFG - Reflectivity of ground surrounding the lake. This variable effects refluted solar radiation into the lake. See table on Appendix A.6.

8 FORMAT (12X, 34F2.0)

CLOUD (NLAST) - Mean daily cloud cover in tenths.

9 FORMAT (12X, 34F2.0)

WIND (NLAST) - Mean daily wind speed in knots. Can be be used in m.p.h. if WMULT on card 3 is equal to 0.8684.

10 FORMAT (12X, 22F3.0)

AIRT (NLAST) - Mean daily air temperature in °F.

11 FORMAT (12X, 22F3.0)

DEWT (NLAST) - Mean daily dew point temperature in °F.

12 FORMAT (12X, 11F6.1) - OPTIONAL

SW (NLAST) - Total daily short wave solar radiation in Langleys/day.

13 FORMAT (12X, 13F5.0) - OPTIONAL

BP(NLAST) - Barometric pressure needed if output is for WQRRS model. (Card 1.2 is -2)

Note: Skip to card 2 for next job.

APPENDIX A.5

HEAT EXCHANGE PROGRAM

INPUT SET UP

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
NDATA	IHCJ						
TITLE(20)		(1 CARD)					
ADDC	ADDW	ADDT	ADDD	CMULT	WMULT	TMULT	DMULT
NLAST	ISW	NSW	IDAY	LDAY	IPNCH		
ETEMPI	XPER						
AEV	BEV	RFS	RFA				
BØTEL	XLAT	XLØNG	RFG				
CLØUD(365)							
WIND(365)							
AIRT(365)							
DEWT(365)							
SW(365)							
BP(365)							

Appendix A.6
HEAT EXCHANGE PROGRAM
Table of Values for RFG

Meadows and fields	0.14*
Leave and needle forest	0.07 - 0.09*
Dark, extended mixed forest	0.045*
Heath	0.10*
Flat ground, grass covered	0.25 - 0.33
Flat ground, rock	0.12 - 0.15
Sand	0.18
Vegetation early summer, leaves with high water content	0.19
Vegetation late summer, leaves with low water content	0.29
Fresh Snow	0.83
Old Snow	0.42 - 0.70

*May be too low

Reference:

Tennessee Valley Authority, Division of Water Control Planning, Engineering Laboratory, "Heat and Mass Transfer Between a Water Surface and The Atmosphere," Water Resources Research, Lab. Rept. No. 14, Norris, Tennessee, July 1967, Rev. May 1970.

APPENDIX A.7

HEAT EXCHANGE PROGRAM

SAMPLE INPUT

```
1     1
2     1974 CHARLESTON / SUTTON LAKE, W. VA. AIR % DEW - 2.5 DEG. F
3     0          0        -2.5       -2.5        1          1          1          1
4   365          2          0          1       365          2
5   33.        24.
6    0.       426.          0.       0.03
7  925.     38.661     80.694       0.25
      101   10 41010101010101010 8 810 710 6 610 710 610101010 710 8 3 2 71010
      102   10 6101010 9 9 4 0 910 010 110 7 9 710 3 5 8 11010 51010101010 8 7 9
      103    91010 1 31010 9 910 710 0 7 8 5 71010 8 8 810 3 91010 6 910 8 3 910
      104    9 810 2 8 7 7 01010 6 8 6 2 5 8 5 5 810 9 810 5 510 7 6 7 8 6 0 9 2
      105   10 7 8 3 4 9 8 8 710 2 810101010 7 210 8 6 4 8 1 6 5 3 4 4 9 7 7 4 8
8*    106    8 91010 8 9 8 910 7 6 6 1 1 31010 7 81010 8 9 6 1 9 6 4 710 7 3 610
      107    8 510 6 7 8 8 3 3 810 71010 7 7 9101010 8 1 2 7 710 5 8 4 3 4 5 8 7
      108    6 9 910101010 5 41010101010 7 9 910 7 9 7 4 11010 7 3 2 8 3 7 710
      109    1 1 7 4 2 0 010 4 2 0 010 9 91010 010 710 0 0 4101010 0 010 9 5 7 6
      110   10 9 9 610 6 3 9 9 9 710 2 6 51010 710 7 0 810 4 5 0 7101010 310 0 2
      111   1010 9 0101010 910 9101010 7 8 3 610 9 51010 910 9
      201    6 6 3 6 3 5 7 5 6 4 8 7 4 61010 8 6 7 6 8 3 6 4 3 412 8 3 210 4 7 5
      202    9 4 6 9 6 6 9 9 8 6 6 5 4 9 3 9 7 716 9 510 7 6 9 5 71010 9 4 5 4 8
      203    8 6 7 7 2 61314 8 6 5 9 4 3 8 5 7 2 4 810 9 8 6 9 910 9 5 7 8 4 5 7
      204    7 911 5 4 5 6 2 61011 8 4 3 2 5 7 9 6 8 9 4 6 7 3 5 8 3 4 6 8 5 7 4
      205    6 5 1 3 4 5 4 6 5 4 3 3 7 5 7 5 3 3 5 6 4 7 5 3 9 7 4 2 3 9 7 5 5 6
9*    206    7 8 6 5 5 4 3 4 4 4 8 6 3 5 5 4 3 3 1 1 6 3 2 3 4 4 2 2 4 7 3 3 3 5
      207    4 3 2 2 2 7 5 3 1 4 6 6 2 3 2 3 3 3 3 4 3 2 3 3 5 2 4 3 4 3 3 2 1 1
      208    4 2 6 8 4 4 4 6 7 4 4 1 2 2 0 3 5 6 4 4 2 3 4 3 3 4 6 4 4 7 3 3 410
      209    9 5 5 3 3 3 1 2 2 1 2 1 1 1 6 6 4 7 4 5 4 1 3 3 2 6 3 0 0 3 3 0 2 3
      210    3 7 9 4 4 1 1 2 6 81110 9 3 6 1 41011 5 3 7 8 3 7 8 4 7 6 8 9 4 2 2
      211    5 7 8 4 2 4 2 3 7 6 6 7 9 1 6 5 8 5 8 3 3 3 2 5 5
      301   30 31 35 30 31 33 33 30 42 44 42 24 23 39 50 56 56 59 60 61 53 52
      302   51 37 39 51 62 49 45 44 50 41 49 34 27 23 41 37 25 22 28 30 43 51
      303   40 35 40 37 40 50 38 45 52 37 34 21 26 37 47 46 59 68 71 58 52 68
      304   67 69 55 43 43 32 34 45 44 37 42 51 48 42 37 51 31 31 46 51 55 59
      305   49 44 67 62 68 68 45 40 49 52 33 41 56 64 68 69 49 52 50 54 54 58
      306   70 66 54 46 48 59 64 71 75 73 63 55 63 55 52 51 45 57 61 59 65 62
      307   59 70 72 73 75 72 72 72 73 71 69 69 60 59 59 60 68 69 72 65 62 66
      308   69 70 72 76 76 77 77 68 64 63 68 69 66 58 66 71 78 77 73 64 61 59
10*   309   62 62 62 62 72 78 76 79 79 76 73 75 76 77 75 73 68 70 74 72 71 72
      310   78 73 72 70 70 70 72 71 73 75 74 74 71 71 71 73 74 72 67 68 72 72
      311   73 73 71 72 75 74 74 73 75 68 72 70 71 71 73 74 75 76 76 73 75 74
      312   73 71 67 63 58 59 59 65 68 67 69 72 72 73 59 58 60 66 66 68 68 59
      313   54 47 50 58 57 61 69 63 54 49 42 37 46 55 57 50 44 48 54 58 62 65
      314   69 57 50 52 48 42 36 34 43 50 58 61 53 47 53 63 63 64 64 66 63 66
      315   55 46 42 39 42 50 58 45 42 40 34 36 39 38 54 53 34 36 44 56 38 28
      316   33 39 34 35 34 32 32 28 26 33 42 42 25 25 34 43 39 38 39 40 32 28
      317   39 30 38 36 50 55 42 29 39 41 44 47 47
      401   27 24 34 28 28 32 29 24 40 43 40 14 14 31 44 44 47 46 55 52 46 41
      402   42 34 37 47 43 42 37 35 31 18 43 32 20 16 33 32 22 15 20 18 20 37
      403   39 26 30 24 24 37 31 30 39 20 26 13 14 17 30 32 48 47 42 47 49 57
      404   54 52 40 35 42 14 15 29 35 27 24 47 38 39 21 29 19 10 29 36 44 47
      405   41 35 40 43 48 56 36 28 26 44 29 28 31 42 52 52 34 30 34 34 40 34
      406   43 51 38 30 28 33 39 46 52 54 47 49 55 40 38 38 30 40 52 47 55 54
      407   40 46 57 60 67 66 65 62 61 65 60 58 46 48 44 48 62 64 66 63 58 56
      408   56 54 62 65 65 66 63 55 51 49 54 61 56 49 51 59 67 68 67 62 54 54
11*   409   54 58 60 58 60 64 67 67 68 67 69 68 69 69 69 66 57 57 60 66 63 64
      410   67 67 64 61 60 65 66 64 68 67 67 67 61 59 59 65 67 62 60 62 65 68
      411   67 67 65 68 68 64 66 68 67 66 64 63 62 63 65 66 68 69 68 69 69 69
      412   68 66 63 60 50 51 57 61 63 65 67 66 66 67 56 54 56 59 60 60 62 57
      413   49 38 41 47 50 56 63 52 41 37 27 27 29 37 42 45 36 36 41 44 49 56
      414   53 50 48 41 37 28 28 24 25 34 47 52 43 31 31 44 55 54 54 55 55 52
      415   47 31 35 32 32 32 31 39 27 29 20 23 32 35 48 44 27 27 27 37 33 17
      416   20 23 20 25 31 30 25 20 19 21 26 37 20 15 23 34 34 34 29 34 26 20
      417   30 25 30 24 28 42 36 18 34 39 39 41 43
```

---

* The first twelve columns of this card have been used for identification. They can be left blank if desired.

APPENDIX A.8

HEAT EXCHANGE PROGRAM

SAMPLE OUTPUT

```
          1974 CHARLESTON / SUTTON LAKE, W. VA. AIR & DEW = 2.5 DEG. F


CLOUD COVER           = CLOUD COVER X 1.00 +  0.00

WIND SPEED            = WIND SPEED X  1.00 +  0.00

DRY BULB TEMPERATURE  = DRY BLLB TEMPERATURE X  1.00 + -2.50

DEW POINT TEMPERATURE = DEW PCINT TEMPERATURE X 1.00 + -2.50
```

```
DAY    EQ TEMP    EX COEFF    SW DAY        LW    LW NET   SKY  WIND   AIRT  DEWT

  1     24.8        60.7       318.1     1883.6   1827.1   10    7.    28.   25.
  2     28.6        61.0       779.8     1674.1   1623.9    4    7.    29.   22.
  3     29.9        40.1       318.1     2002.5   1942.4   10    3.    33.   32.
  4     25.1        61.1       322.2     1883.6   1827.1   10    7.    28.   26.
  5     25.1        38.4       323.9     1906.9   1849.7   10    3.    29.   26.
  6     28.4        55.4       324.1     1954.2   1895.6   10    6.    31.   30.
  7     28.0        70.0       327.2     1954.2   1895.6   10    8.    31.   27.
  8     24.2        52.4       331.0     1883.6   1827.1   10    6.    28.   22.
  9     38.0        70.2       326.0     2179.4   2114.1   10    7.    40.   38.
 10     40.3        53.8       326.3     2232.3   2165.4   10    5.    42.   41.
 11     38.2        88.5       330.3     2179.4   2114.1   10    9.    40.   38.
 12     19.6        63.2       557.9     1657.2   1607.5    8    8.    22.   12.
 13     19.2        42.8       562.4     1636.7   1587.6    8    5.    21.   12.
 14     33.4        64.7       342.1     2102.1   2039.0   10    7.    37.   29.
 15     46.1       117.0       642.7     2219.8   2153.2    7   12.    48.   42.
 16     48.7       119.7       340.3     2572.6   2495.4   10   12.    54.   42.
 17     51.4       103.8       730.6     2333.4   2263.4    6    9.    54.   45.
 18     53.7        82.7       738.7     2416.4   2343.9    6    7.    57.   44.
 19     55.8       103.6       340.0     2695.2   2614.4   10    8.    58.   53.
 20     56.6        89.3       660.3     2524.6   2448.8    7    7.    59.   50.
 21     47.9        99.8       353.4     2483.7   2409.2   10    9.    51.   44.
 22     50.6        46.6       774.4     2226.4   2159.6    6    3.    50.   39.
 23     45.6        75.1       363.1     2425.9   2353.1   10    7.    49.   40.
 24     32.9        49.0       371.4     2051.8   1990.2   10    5.    35.   32.
 25     35.4        41.7       373.4     2102.1   2039.0   10    3.    37.   35.
 26     47.7        58.1       370.4     2425.9   2353.1   10    5.    49.   45.
 27     52.7       144.6       723.1     2553.9   2477.3    7   14.    60.   41.
 28     44.2        93.9       381.8     2369.2   2298.2   10    9.    47.   40.
 29     43.6        43.6       639.8     2141.0   2076.8    8    3.    43.   35.
 30     48.5        34.9      1022.0     1937.2   1879.0    3    2.    42.   33.
 31     44.4       105.3      1075.5     2063.0   2001.1    2   12.    48.   29.
 32     38.2        46.9       788.8     1993.8   1934.0    7    5.    39.   16.
 33     44.8        85.2       402.0     2369.2   2298.2   10    8.    47.   41.
 34     30.7        56.1       413.5     1978.2   1918.9   10    6.    32.   30.
 35     22.5        79.7       423.5     1815.1   1760.6   10   10.    25.   18.
 36     25.8        44.1       929.1     1566.4   1519.4    6    5.    21.   14.
 37     36.6        66.7       426.8     2153.4   2088.8   10    7.    39.   31.
 38     33.1        89.7       432.2     2051.8   1990.2   10   10.    35.   30.
 39     21.5        58.6       441.9     1770.6   1717.5   10    7.    23.   20.
 40     19.7        56.6       608.0     1658.5   1608.7    9    7.    20.   13.
 41     24.9        80.6       612.3     1786.9   1733.3    9   10.    26.   18.
 42     30.1        82.0      1142.9     1653.7   1604.1    4   10.    28.   16.
 43     40.9        80.2      1289.6     1885.3   1828.7    0    9.    41.   18.
 44     46.5        73.1       620.7     2359.0   2288.2    9    7.    49.   35.
 45     38.0        69.8       462.5     2127.6   2063.8   10    7.    38.   37.
 46     40.2        57.4      1327.5     1711.5   1660.2    0    6.    33.   24.
 47     36.5        48.9       478.8     2127.6   2063.8   10    5.    38.   28.
 48     37.7        88.3      1353.4     1756.6   1703.9    1   10.    35.   22.
```

DAY	EQ TEMP	EX COEFF	SW DAY	LW	LW NET	SKY	WIND	AIRT	DEWT
49	36.4	39.6	492.6	2127.6	2063.8	10	3.	38.	22.
50	46.6	101.9	947.9	2219.8	2153.2	7	10.	48.	35.
51	36.1	74.1	675.9	2019.5	1958.9	9	8.	36.	29.
52	43.1	77.2	978.3	2091.8	2029.0	7	8.	43.	28.
53	45.1	169.3	504.8	2454.7	2381.1	10	18.	50.	37.
54	37.5	86.4	1379.3	1780.5	1727.1	3	10.	35.	18.
55	39.2	57.0	1233.9	1762.6	1709.8	5	6.	32.	24.
56	20.6	83.6	889.3	1596.2	1548.3	8	12.	19.	11.
57	32.2	66.9	1511.9	1534.8	1488.8	1	8.	24.	12.
58	32.0	60.2	545.4	2051.8	1990.2	10	7.	35.	15.
59	40.8	93.2	544.3	2313.7	2244.2	10	10.	45.	28.
60	49.1	62.9	1294.9	2037.1	1976.0	5	6.	44.	30.
61	54.3	96.0	540.0	2664.1	2584.2	10	8.	57.	46.
62	57.9	134.0	546.6	2955.1	2866.4	10	12.	66.	45.
63	58.0	128.7	557.1	3057.7	2966.0	10	12.	69.	40.
64	52.8	116.3	560.5	2633.3	2554.3	10	10.	56.	45.
65	52.0	60.9	565.4	2454.7	2381.1	10	5.	50.	47.
66	66.2	88.7	924.6	2800.5	2716.5	8	6.	66.	55.
67	67.2	72.9	1098.6	2705.0	2623.9	7	5.	65.	52.
68	62.0	120.5	784.7	2906.5	2819.3	9	9.	67.	50.
69	50.7	97.6	810.9	2472.5	2398.3	9	9.	53.	38.
70	41.0	69.4	609.7	2205.8	2139.6	10	7.	41.	33.
71	42.7	83.2	609.4	2205.8	2139.6	10	8.	41.	40.
72	39.3	69.6	1761.7	1652.7	1603.1	1	8.	30.	12.
73	54.3	33.4	1686.5	1716.6	1665.1	3	2.	32.	13.
74	41.4	67.3	638.2	2259.2	2191.4	10	7.	43.	27.
75	40.1	131.2	639.7	2232.3	2165.4	10	15.	42.	33.
76	34.4	128.0	882.1	1995.1	1935.3	9	16.	35.	25.
77	39.4	81.1	893.3	2119.3	2055.7	9	9.	40.	22.
78	50.5	81.1	646.0	2425.9	2353.1	10	7.	49.	45.
79	52.5	67.0	1284.6	2167.8	2102.8	7	6.	46.	36.
80	41.1	99.0	667.2	2179.4	2114.1	10	10.	40.	37.
81	51.9	51.6	1933.6	1753.7	1701.0	0	5.	35.	19.
82	58.1	46.1	1336.4	2246.2	2178.8	7	3.	49.	27.
83	33.3	76.3	1166.3	1807.1	1752.9	8	9.	29.	17.
84	41.7	54.1	1682.6	1699.1	1648.1	5	6.	29.	8.
85	47.7	79.4	1373.0	2116.9	2053.4	7	8.	44.	27.
86	53.8	36.1	706.6	2425.9	2353.1	10	2.	49.	34.
87	54.6	60.0	703.8	2542.7	2466.4	10	5.	53.	42.
88	57.6	110.0	1176.2	2524.8	2449.0	8	9.	57.	45.
89	49.1	117.4	1198.4	2245.3	2177.9	8	12.	47.	39.
90	45.2	99.4	1218.6	2115.6	2052.1	8	10.	42.	33.
91	57.6	104.0	731.6	2921.5	2833.8	10	9.	65.	38.
92	64.9	90.1	1959.4	2393.6	2321.8	3	7.	60.	41.
93	61.0	127.3	991.1	2873.5	2787.3	9	10.	66.	46.
94	62.7	139.9	725.0	2955.1	2866.4	10	10.	66.	54.
95	42.6	107.3	758.0	2259.2	2191.4	10	12.	43.	34.

DAY	EQ TEMP	EX COEFF	SW DAY	LW	LW NET	SKY	WIND	AIRT	DEWT
96	44.5	94.6	1686.6	1929.8	1871.9	6	10.	38.	26.
97	49.2	60.9	1051.7	2303.8	2234.7	9	6.	47.	24.
98	50.8	90.1	764.7	2454.7	2381.1	10	8.	50.	42.
99	38.3	82.7	1311.7	1852.0	1796.4	8	9.	31.	27.
100	58.0	55.9	2120.1	1868.7	1812.6	3	5.	39.	26.
101	54.9	65.4	1074.3	2501.6	2426.5	9	6.	54.	29.
102	57.6	94.4	787.5	2822.7	2738.0	10	8.	62.	40.
103	64.2	109.9	1052.1	2873.5	2787.3	9	8.	66.	50.
104	64.3	137.0	1307.3	2832.6	2747.6	8	10.	67.	50.
105	44.7	116.7	810.8	2369.2	2298.2	10	13.	47.	32.
106	62.6	69.5	2274.0	2112.3	2048.9	2	6.	50.	28.
107	56.6	57.2	1370.8	2272.0	2203.9	8	5.	48.	32.
108	58.9	68.9	1608.7	2326.9	2257.0	7	6.	52.	32.
109	58.3	82.5	1604.6	2326.9	2257.0	7	7.	52.	38.
110	80.4	44.2	2362.5	2250.7	2183.2	0	2.	56.	32.
111	62.5	87.9	827.7	3023.2	2932.5	10	7.	68.	41.
112	60.0	142.0	822.8	2888.2	2801.6	10	12.	64.	49.
113	54.1	130.5	1846.5	2279.4	2211.0	6	13.	52.	36.
114	47.9	89.2	1428.3	2166.7	2101.7	8	9.	44.	28.
115	60.0	56.8	1886.7	2123.6	2059.9	6	5.	46.	26.
116	75.0	54.7	2389.4	2292.5	2223.7	2	3.	57.	31.
117	80.9	45.7	2048.3	2515.1	2439.6	5	2.	62.	37.
118	69.2	83.2	1428.4	2897.8	2810.9	8	6.	69.	44.
119	72.2	120.7	2020.1	2850.6	2765.1	5	8.	73.	50.
120	69.8	149.0	2019.9	2787.0	2703.4	5	10.	71.	52.
121	63.9	92.1	1446.8	2644.4	2565.0	8	7.	61.	45.
122	54.7	108.8	867.8	2542.7	2466.4	10	9.	53.	47.
123	62.2	137.7	1164.0	2713.3	2631.9	9	10.	61.	53.
124	62.1	62.3	1482.9	2409.7	2337.4	8	5.	53.	38.
125	51.2	76.4	894.7	2454.7	2381.1	10	7.	50.	36.
126	58.7	92.6	2136.5	2161.6	2096.7	5	8.	49.	36.
127	65.8	49.3	2166.3	2013.0	1952.6	5	3.	43.	28.
128	56.1	70.0	902.9	2602.8	2524.7	10	6.	55.	38.
129	63.8	122.8	1729.5	2524.6	2448.8	7	9.	59.	50.
130	73.5	59.2	1970.5	2416.4	2343.9	6	3.	57.	45.
131	72.9	78.3	1730.8	2643.7	2564.4	7	5.	63.	53.
132	65.9	100.0	1491.9	2614.0	2535.6	8	7.	60.	52.
133	61.1	107.7	2014.2	2416.4	2343.9	6	9.	57.	38.
134	75.9	90.0	2587.2	2583.9	2506.4	0	6.	68.	44.
135	68.9	121.7	1211.0	3007.2	2917.0	9	8.	70.	55.
136	82.4	92.2	2471.3	2691.5	2610.8	2	5.	71.	58.
137	73.5	125.1	874.7	3199.3	3103.3	10	7.	73.	65.
138	77.4	110.9	1717.1	2863.5	2777.6	7	6.	70.	64.
139	85.7	52.9	1480.3	2930.9	2842.9	8	2.	70.	63.
140	85.8	77.8	2403.7	2683.7	2603.2	3	3.	70.	60.
141	81.7	92.3	2300.2	2746.1	2663.7	4	5.	71.	59.
142	73.8	104.9	1207.0	2973.3	2884.1	9	6.	69.	63.

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DAY      EQ TEMP      EX COEFF      SW DAY          LW      LW NET   SKY  WIND   AIRT  DEWT

143       74.8          83.9        1517.5        2832.6    2747.6    8    5.    67.   58.
144       70.8         110.0        1529.1        2832.6    2747.6    8    7.    67.   56.
145       66.8          81.2        1834.5        2495.5    2420.6    7    6.    58.   44.
146       61.3          65.5         938.5        2664.1    2584.2   10    5.    57.   46.
147       79.0          61.5        2630.6        2292.5    2223.7    2    3.    57.   42.
148       70.7          57.9        1575.8        2554.2    2477.6    8    3.    58.   46.
149       67.6         126.1         913.4        2955.1    2866.4   10    8.    66.   60.
150       70.6          99.9         909.5        2989.0    2899.3   10    6.    67.   62.
151       71.2         137.6         905.2        3092.6    2999.8   10    8.    70.   64.
152       68.3          96.2         915.1        2855.3    2769.6   10    6.    63.   61.
153       76.2          66.7        1814.0        2553.9    2477.3    7    3.    60.   56.
154       83.7          71.6        2599.3        2485.4    2410.8    2    3.    64.   54.
155       67.9          89.5         936.2        2989.0    2899.3   10    6.    67.   54.
156       70.3         105.2        1575.5        2865.1    2779.1    8    7.    68.   52.
157       80.1          91.3        2027.0        2805.0    2720.9    6    5.    70.   60.
158       78.5         149.5        2343.9        2840.6    2755.4    4    8.    74.   63.
159       77.8         110.4        1534.6        3066.2    2974.2    8    6.    74.   63.
160       90.0          85.6        2595.5        2801.4    2717.3    1    3.    75.   64.
161       74.8         174.7        2028.5        2967.8    2878.7    6   10.    75.   61.
162       71.8         123.5        2258.8        2633.0    2554.1    5    8.    66.   53.
163       77.6          80.0        2563.1        2449.4    2376.0    3    5.    62.   49.
164       86.2          51.8        2450.2        2449.8    2376.3    4    2.    61.   47.
165       82.9          69.8        2426.1        2594.4    2516.6    4    3.    66.   52.
166       68.0         156.7        1260.9        2906.5    2819.3    9   10.    67.   59.
167       69.2         120.9        1844.3        2674.2    2594.0    7    8.    64.   54.
168       66.9          83.3        1872.6        2438.2    2365.0    7    6.    56.   47.
169       74.7          92.6        2444.4        2535.7    2459.6    4    6.    64.   49.
170       72.3         113.1        1569.3        2897.8    2810.9    8    7.    69.   57.
171       76.8         149.6        1532.4        3135.9    3041.8    8    8.    76.   65.
172       74.9         166.4        1234.4        3181.7    3086.3    9    9.    75.   66.
173       72.9         124.1         915.4        3127.8    3034.0   10    7.    71.   65.
174       67.4          94.4         929.5        2822.7    2738.0   10    6.    62.   60.
175       67.7          87.7        1587.1        2584.0    2506.5    8    6.    59.   52.
176       66.2          72.2        1282.5        2590.6    2512.9    9    5.    57.   52.
177       73.3          62.4        1585.6        2614.0    2535.6    8    3.    60.   52.
178       69.0          77.0        1268.9        2682.2    2601.7    9    5.    60.   56.
179       66.8          76.7         932.4        2758.3    2675.6   10    5.    60.   58.
180       73.3          80.8        1829.2        2553.9    2477.3    7    5.    60.   56.
181       72.8         148.2        2043.5        2805.0    2720.9    6    9.    70.   58.
182       78.9         129.8        2018.3        3001.2    2911.2    6    7.    76.   62.
183       89.8          86.2        2581.4        2770.1    2687.0    1    3.    74.   65.
184       84.6         123.5        2578.6        2864.9    2778.9    1    6.    77.   65.
185       84.3         124.4        2432.5        2903.7    2816.6    3    6.    77.   66.
186       76.6          91.9         906.8        3235.5    3138.4   10    5.    74.   65.
187       77.7          75.3         899.4        3127.8    3034.0   10    3.    71.   67.
188       84.5          81.2        1759.9        2962.2    2873.3    7    3.    73.   66.
189       89.0          57.1        1500.7        3066.2    2974.2    8    2.    74.   67.
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DAY	EQ TEMP	EX COEFF	SW DAY	LW	LW NET	SKY	WIND	AIRT	DEWT
190	83.9	53.7	895.5	3272.0	3173.9	10	2.	75.	67.
191	74.6	129.7	894.1	3199.3	3103.3	10	7.	73.	67.
192	81.2	76.3	1508.6	2964.2	2875.3	8	3.	71.	64.
193	78.0	50.2	1249.4	2873.5	2787.3	9	2.	66.	55.
194	81.3	70.2	2022.5	2742.1	2659.8	6	3.	68.	55.
195	83.5	93.6	2587.6	2708.3	2627.1	1	5.	72.	58.
196	76.2	90.6	1210.6	3007.2	2917.0	9	5.	70.	64.
197	87.7	58.9	1977.5	2773.4	2690.2	6	2.	69.	61.
198	90.9	61.9	2291.5	2715.2	2633.7	4	2.	70.	62.
199	82.3	98.9	1729.2	3063.7	2971.8	7	5.	76.	65.
200	72.0	140.5	883.9	3127.8	3034.0	10	8.	71.	65.
201	81.8	75.3	1737.2	2863.5	2777.6	7	3.	70.	62.
202	84.8	76.0	2404.2	2623.5	2544.8	3	3.	68.	59.
203	81.5	72.2	1964.7	2742.1	2659.8	6	3.	68.	58.
204	71.3	101.8	880.3	3023.2	2932.5	10	6.	68.	63.
205	77.8	92.3	1462.9	2930.9	2842.9	8	5.	70.	64.
206	83.7	77.2	2094.9	2724.5	2642.8	5	3.	69.	62.
207	79.7	56.1	863.9	3127.8	3034.0	10	2.	71.	66.
208	89.5	62.5	1894.6	2901.8	2814.7	6	2.	73.	65.
209	87.3	60.8	1679.9	2929.0	2841.1	7	2.	72.	65.
210	74.7	145.5	1434.6	2997.9	2908.0	8	8.	72.	65.
211	73.6	100.5	1456.2	2897.8	2810.9	8	6.	69.	59.
212	84.1	74.0	2338.9	2653.4	2573.8	3	3.	69.	57.
213	91.5	54.0	2329.8	2653.4	2573.8	3	2.	69.	57.
214	77.5	91.1	1422.8	2964.2	2875.3	8	5.	71.	63.
215	72.9	124.0	842.9	3163.4	3068.5	10	7.	72.	65.
216	74.0	119.1	1662.0	2863.5	2777.6	7	7.	70.	60.
217	73.4	49.1	854.1	2921.5	2833.8	10	2.	65.	58.
218	71.7	65.8	845.8	2955.1	2866.4	10	3.	66.	60.
219	85.2	58.2	1625.8	2863.5	2777.6	7	2.	70.	63.
220	81.7	78.3	1602.3	2863.5	2777.6	7	3.	70.	66.
221	78.3	74.3	1111.8	3041.5	2950.2	9	3.	71.	65.
222	76.0	72.4	818.3	3127.8	3034.0	10	3.	71.	65.
223	74.2	69.5	820.0	3057.7	2966.0	10	3.	69.	63.
224	74.1	90.2	808.2	3092.6	2999.8	10	5.	70.	66.
225	81.2	77.8	1340.6	3031.9	2941.0	8	3.	73.	66.
226	90.9	61.9	2283.2	2708.3	2627.1	1	2.	72.	62.
227	85.8	80.8	2213.7	2722.1	2640.5	2	3.	72.	64.
228	81.5	78.1	1538.3	2896.1	2809.2	7	3.	71.	66.
229	77.7	112.6	1533.8	2962.2	2873.3	7	6.	73.	65.
230	74.8	52.4	789.5	2955.1	2866.4	10	2.	66.	64.
231	79.2	92.0	1877.7	2755.6	2672.9	5	5.	70.	62.
232	76.8	70.2	1310.8	2865.1	2779.1	8	3.	68.	61.
233	78.8	89.8	1999.5	2684.5	2604.0	4	5.	69.	60.
234	82.7	75.5	2083.1	2653.4	2573.8	3	3.	69.	61.
235	83.2	77.5	1958.9	2746.1	2663.7	4	3.	71.	63.
236	87.4	60.3	1814.4	2818.7	2734.1	5	2.	72.	64.

DAY	EQ TEMP	EX COEFF	SW DAY	LW	LW NET	SKY	WIND	AIRT	DEWT
237	85.1	54.0	1254.0	3031.9	2941.0	8	2.	73.	66.
238	87.6	56.0	1449.4	2995.7	2905.8	7	2.	74.	67.
239	80.6	97.7	1625.1	2934.6	2846.6	6	5.	74.	66.
240	80.6	57.2	993.2	3041.5	2950.2	9	2.	71.	67.
241	74.6	129.7	987.0	3110.9	3017.6	9	7.	73.	67.
242	72.0	162.1	725.0	3163.4	3068.5	10	9.	72.	67.
243	73.8	89.9	722.9	3127.8	3034.0	10	5.	71.	66.
244	71.9	86.1	723.1	3057.7	2966.0	10	5.	69.	64.
245	68.6	80.4	725.3	2921.5	2833.8	10	5.	65.	61.
246	63.4	103.2	726.7	2790.3	2706.6	10	7.	61.	58.
247	62.3	105.8	1760.1	2346.4	2276.0	5	8.	56.	48.
248	69.0	72.5	1865.2	2339.0	2268.8	4	5.	57.	49.
249	61.5	70.6	717.2	2664.1	2584.2	10	5.	57.	55.
250	70.7	43.9	704.1	2855.3	2769.6	10	2.	63.	59.
251	72.4	49.8	694.6	2955.1	2866.4	10	2.	66.	61.
252	72.2	50.6	684.9	2921.5	2833.8	10	2.	65.	63.
253	74.8	47.9	674.9	2989.0	2899.3	10	2.	67.	65.
254	78.0	73.4	1307.3	2863.5	2777.6	7	3.	70.	64.
255	72.2	104.0	901.7	3007.2	2917.0	9	6.	70.	64.
256	72.2	123.0	891.2	3041.5	2950.2	9	7.	71.	65.
257	60.6	69.4	675.3	2664.1	2584.2	10	5.	57.	54.
258	64.6	71.0	1308.0	2438.2	2365.0	7	5.	56.	52.
259	67.1	44.9	898.1	2620.8	2542.2	9	2.	58.	54.
260	72.2	64.4	1268.6	2674.2	2594.0	7	3.	64.	57.
261	72.7	81.8	1633.2	2535.7	2459.6	4	5.	64.	58.
262	77.3	68.7	1793.7	2530.0	2454.1	1	3.	66.	58.
263	69.0	63.9	630.0	2955.1	2866.4	10	3.	66.	60.
264	60.4	69.9	633.1	2664.1	2584.2	10	5.	57.	55.
265	57.3	87.6	1240.1	2326.9	2257.0	7	7.	52.	47.
266	57.6	59.1	1710.0	2007.7	1947.5	3	5.	45.	36.
267	60.1	61.6	1742.9	2063.0	2001.1	2	5.	48.	39.
268	56.6	97.3	1035.8	2495.6	2420.7	8	8.	56.	45.
269	67.5	57.0	1622.0	2258.7	2190.9	3	3.	55.	48.
270	67.2	59.5	1160.9	2524.6	2448.8	7	3.	59.	54.
271	71.6	83.1	1126.6	2767.5	2684.5	7	5.	67.	61.
272	57.4	139.6	593.8	2790.3	2706.6	10	12.	61.	50.
273	54.4	112.4	1668.8	2151.6	2087.0	1	10.	52.	39.
274	55.5	68.2	1663.0	2028.4	1967.6	1	6.	47.	35.
275	44.7	59.3	1157.3	2017.9	1957.4	7	6.	40.	25.
276	49.5	43.0	1488.9	1801.4	1747.3	4	3.	35.	25.
277	56.7	45.6	1599.3	1967.4	1908.3	2	3.	44.	27.
278	63.1	50.1	1602.3	2173.2	2108.0	0	3.	53.	35.
279	70.3	38.6	1574.2	2224.6	2157.9	0	2.	55.	40.
280	51.3	37.2	553.9	2397.4	2325.5	10	2.	48.	43.
281	57.5	37.0	1400.6	1959.9	1901.1	4	2.	42.	34.
282	62.8	35.4	1506.8	2014.7	1954.3	2	2.	46.	34.
283	65.8	40.3	1513.7	2147.9	2083.5	0	2.	52.	39.

DAY	EQ TEMP	EX COEFF	SW DAY	LW	LW NET	SKY	WIND	AIRT	DEWT
284	69.7	38.9	1490.2	2250.7	2183.2	0	2.	56.	42.
285	61.9	37.7	520.0	2758.3	2675.6	10	2.	60.	47.
286	67.6	41.2	684.7	2776.5	2693.2	9	2.	63.	54.
287	62.9	96.0	682.8	2906.5	2819.3	9	7.	67.	51.
288	53.8	85.6	503.0	2602.8	2524.7	10	7.	55.	48.
289	49.3	59.2	499.9	2397.4	2325.5	10	5.	48.	46.
290	52.7	89.6	1404.3	2098.0	2035.1	0	8.	50.	39.
291	44.7	53.3	499.1	2341.3	2271.1	10	5.	46.	35.
292	42.2	58.7	966.5	2017.9	1957.4	7	6.	40.	26.
293	33.1	47.7	494.2	2027.0	1966.2	10	5.	34.	26.
294	48.5	31.1	1373.1	1690.8	1640.1	0	2.	32.	22.
295	49.9	42.8	1356.4	1885.3	1828.7	0	3.	41.	23.
296	53.9	45.9	1190.0	2104.8	2041.7	4	3.	48.	32.
297	56.4	38.9	459.6	2633.3	2554.3	10	2.	56.	45.
298	56.5	89.2	449.6	2726.6	2644.8	10	7.	59.	50.
299	50.0	47.0	453.2	2483.7	2409.2	10	3.	51.	41.
300	56.2	33.2	1272.8	1977.5	1918.2	0	2.	45.	29.
301	60.1	34.0	1258.3	2122.9	2059.2	0	2.	51.	29.
302	57.6	50.1	437.7	2790.3	2706.6	10	3.	61.	42.
303	61.5	56.0	571.2	2713.3	2631.9	9	3.	61.	53.
304	67.7	40.7	974.4	2515.1	2439.6	5	2.	62.	52.
305	65.4	43.6	797.8	2613.5	2535.1	7	2.	62.	52.
306	65.4	58.0	884.2	2619.7	2541.1	6	3.	64.	53.
307	60.1	55.3	404.1	2790.3	2706.6	10	3.	61.	53.
308	59.1	104.2	544.9	2808.5	2724.2	9	8.	64.	50.
309	50.4	113.7	545.2	2472.5	2398.3	9	10.	53.	45.
310	44.8	51.6	884.6	2073.7	2011.5	6	5.	44.	29.
311	37.9	50.6	402.8	2179.4	2114.1	10	5.	40.	33.
312	42.9	31.1	864.1	1906.6	1849.4	6	2.	37.	30.
313	47.4	31.8	1027.2	1891.3	1834.5	3	2.	40.	30.
314	46.9	34.1	530.2	2331.3	2261.3	9	2.	48.	30.
315	48.7	71.6	525.4	2560.6	2483.8	9	7.	56.	29.
316	41.2	89.8	514.0	2196.8	2130.9	9	9.	43.	37.
317	36.5	105.3	733.0	2017.9	1957.4	7	13.	40.	25.
318	33.9	96.6	377.7	2127.6	2063.8	10	12.	38.	27.
319	31.4	83.3	006.1	1702.3	1651.2	2	10.	32.	18.
320	35.6	39.3	402.1	1838.5	1783.4	6	3.	34.	21.
321	37.4	66.7	835.5	1873.0	1816.8	5	7.	37.	30.
322	33.5	30.3	360.5	2076.8	2014.5	10	2.	36.	33.
323	49.9	59.5	349.0	2513.1	2437.7	10	5.	52.	46.
324	48.0	119.0	666.5	2299.7	2230.7	7	12.	51.	42.
325	28.8	100.4	354.9	1978.2	1918.9	10	13.	32.	25.
326	33.1	55.4	671.6	1876.8	1820.5	7	6.	34.	25.
327	43.3	41.5	957.2	1908.0	1850.7	0	3.	42.	25.
328	48.0	83.7	558.3	2438.0	2364.9	8	8.	54.	35.
329	33.2	81.9	341.4	2076.8	2014.5	10	9.	36.	31.
330	27.8	37.4	837.8	1613.4	1565.0	4	3.	26.	15.

DAY	EQ TEMP	EX COEFF	SW DAY	LW	LW NET	SKY	WIND	AIRT	DEWT
331	29.3	67.6	775.5	1741.2	1689.0	5	8.	31.	18.
332	34.8	78.4	921.5	1796.6	1742.7	0	9.	37.	21.
333	30.1	45.5	639.0	1831.6	1776.7	7	5.	32.	18.
334	28.7	68.9	333.0	2002.5	1942.4	10	8.	33.	23.
335	29.2	63.3	328.6	1978.2	1918.9	10	7.	32.	29.
336	27.6	78.0	327.0	1930.4	1872.5	10	9.	30.	28.
337	29.3	84.4	835.5	1675.2	1624.9	3	10.	30.	23.
338	21.4	43.9	326.9	1837.7	1782.5	10	5.	26.	18.
339	27.8	30.3	885.9	1532.2	1486.3	0	2.	24.	17.
340	33.2	31.0	854.6	1681.6	1631.2	2	2.	31.	19.
341	34.4	55.5	320.1	2179.4	2114.1	10	6.	40.	24.
342	37.0	77.3	314.1	2179.4	2114.1	10	8.	40.	35.
343	20.3	71.9	432.0	1721.7	1670.0	9	9.	23.	18.
344	24.2	43.7	870.8	1513.3	1467.9	0	5.	23.	13.
345	26.6	30.5	316.0	1978.2	1918.9	10	2.	32.	21.
346	36.8	50.0	310.8	2205.8	2139.6	10	5.	41.	32.
347	33.0	32.3	309.9	2102.1	2039.0	10	2.	37.	32.
348	33.5	40.8	418.1	2019.5	1958.9	9	3.	36.	32.
349	32.5	71.8	310.4	2102.1	2039.0	10	8.	37.	27.
350	35.2	66.5	416.3	2068.9	2006.8	9	7.	38.	32.
351	26.1	60.8	310.3	1930.4	1872.5	10	7.	30.	24.
352	21.7	65.2	311.8	1837.7	1782.5	10	8.	26.	18.
353	32.7	88.4	308.2	2102.1	2039.0	10	10.	37.	28.
354	27.1	28.7	588.9	1744.0	1691.7	7	2.	28.	23.
355	33.1	64.3	501.7	1968.2	1909.1	8	7.	36.	28.
356	32.7	54.5	796.5	1759.0	1706.2	3	6.	34.	22.
357	41.7	84.1	660.5	2174.5	2109.3	6	9.	48.	26.
358	47.9	66.3	303.4	2542.7	2466.4	10	6.	53.	40.
359	37.2	85.6	415.4	2119.3	2055.7	9	9.	40.	34.
360	26.5	37.3	716.3	1657.8	1608.0	5	3.	27.	16.
361	33.2	40.7	309.4	2102.1	2039.0	10	3.	37.	32.
362	36.2	42.3	307.9	2153.4	2088.8	10	3.	39.	37.
363	40.0	34.0	417.9	2170.7	2105.6	9	2.	42.	37.
364	41.8	63.1	308.9	2313.7	2244.2	10	6.	45.	39.
365	43.1	64.5	417.9	2249.8	2182.3	9	6.	45.	41.

1974 CHARLESTON / SUTTON LAKE, W. VA. AIR & DEW = 2.5 DEG. F

MONTH	EQUILIBRIUM (DEG F)	SURFACE HEAT EXCHANGE (BTL/SQ FT/DAY/DEG F)	SHORT WAVE SOLAR (BTU/SQ FT/DAY)	SHORT WAVE SOLAR (LANGLEYS/DAY)
1	39.0	72.0	496.	135.
2	34.9	74.0	781.	212.
3	49.7	84.5	984.	267.
4	59.5	91.9	1436.	390.
5	69.3	91.9	1581.	429.
6	73.9	102.4	1740.	472.
7	81.5	86.7	1682.	456.
8	79.5	81.3	1395.	378.
9	66.8	76.7	1104.	300.
10	55.9	50.7	1019.	277.
11	41.8	66.5	648.	176.
12	32.3	56.5	460.	125.

APPENDIX B

THERMAL SIMULATION PROGRAM

722-F5-E1011

APPENDIX B

THERMAL SIMULATION PROGRAM

TABLE OF CONTENTS

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM Thermal Simulation Program	**PROGRAM NO.** 722-F5-E-1011

PREPARING AGENCY Water Quality Section, Engineering Division, U.S.A.E.D.
Baltimore District, P.O. Box 1715, Baltimore, Md. 21203

AUTHOR(S)	**DATE PROGRAM COMPLETED**	**STATUS OF PROGRAM** **PHASE**	 **STAGE**
Earl E. Eiker Terry Clayton	June 1973	Revised	Nov. 1977

A. PURPOSE OF PROGRAM

To determine the annual temperature cycle of an impoundment by means of a mathematical accounting of the external and internal heat balance of the reservoir due to variations in inflow, outflow and heat transfer between the water surface and the atmosphere.

B. PROGRAM SPECIFICATIONS

1. Language - Fortran IV
2. Input - card only
3. Output - printer and punched card at users option
4. Size of Program - 30,000 words (approximately)
5. External Storage - none
6. Restrictions - none

C. METHODS

The one-dimensional partial differential equations describing the vertical variations in temperature within a reservoir are solved using numerical techniques.

D. EQUIPMENT DETAILS

Program is written for the Univac 1108 computer but can be adapted to any comparable system. Normal configuration of reader/punch and printer are required. Program is written for batch mode operation.

E. INPUT-OUTPUT

Input consists of the hydrologic, meteorologic and physical parameters unique to the site and year under study. Meteorologic input is developed by program no. 722-F5-E1010, "Heat Exchange Program."
Output consists of a daily summary of pertinent hydrologic, meteorologic and thermal data and vertical temperature structure of the reservoir at selected time intervals.

F. ADDITIONAL REMARKS

Complete documentation of this program is available from The Hydrologic Engineering Center. Source deck available upon request.

ENG FORM 2883
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PREVIOUS EDITIONS ARE OBSOLETE.

APPENDIX B.2

THERMAL SIMULATION PROGRAM

DISCUSSION

The Thermal Simulation is divided into a main program and five subroutines as follows.

1. Main Program - The main program is used for assimilation of input and set up of the hydrologic, meteorologic and physical data required for the simulation. The main program acts as a control for the entire simulation. Computations are performed to establish the elevation-area and elevation-width relationships for the reservoir. Also, the short wave solar radiation distribution is calculated for each time step. All subroutines are called from the main program with the exception of subroutine WEIR.

2. Subroutine REG - This subroutine performs the day by day regulations of the reservoir in order to meet a specified downstream release temperature. Regulation is accomplished by an algorithm which scans existing temperature witin the lake and makes the selection of outlets to regulate. Regulation is made by using either one outlet, two adjacent outlets or an outlet and the flood control conduit. Maximum and minumum release capability of the selective withdrawal system and maximum capacity of each outlet are considered for regulation.

3. Subroutine EJM - This subroutine computes the inflow distribution, the outflow distribution and quantity of vertical flow generated by the inflow-outflow relationship. Outflow velocities for orifice type outlets are computed. If outflow from the reservoir is over a weir the actual velocities are computed by subroutine WEIR which is called from EJM.

4. Subroutine WEIR - This subroutine computes the outflow velocity distribution due to outflow over a weir. Weir flows are considered if ungated spillway flow occurs, if a skimmer weir is utilized as the top outlet or if the outlet being regulated is not completely submerged.

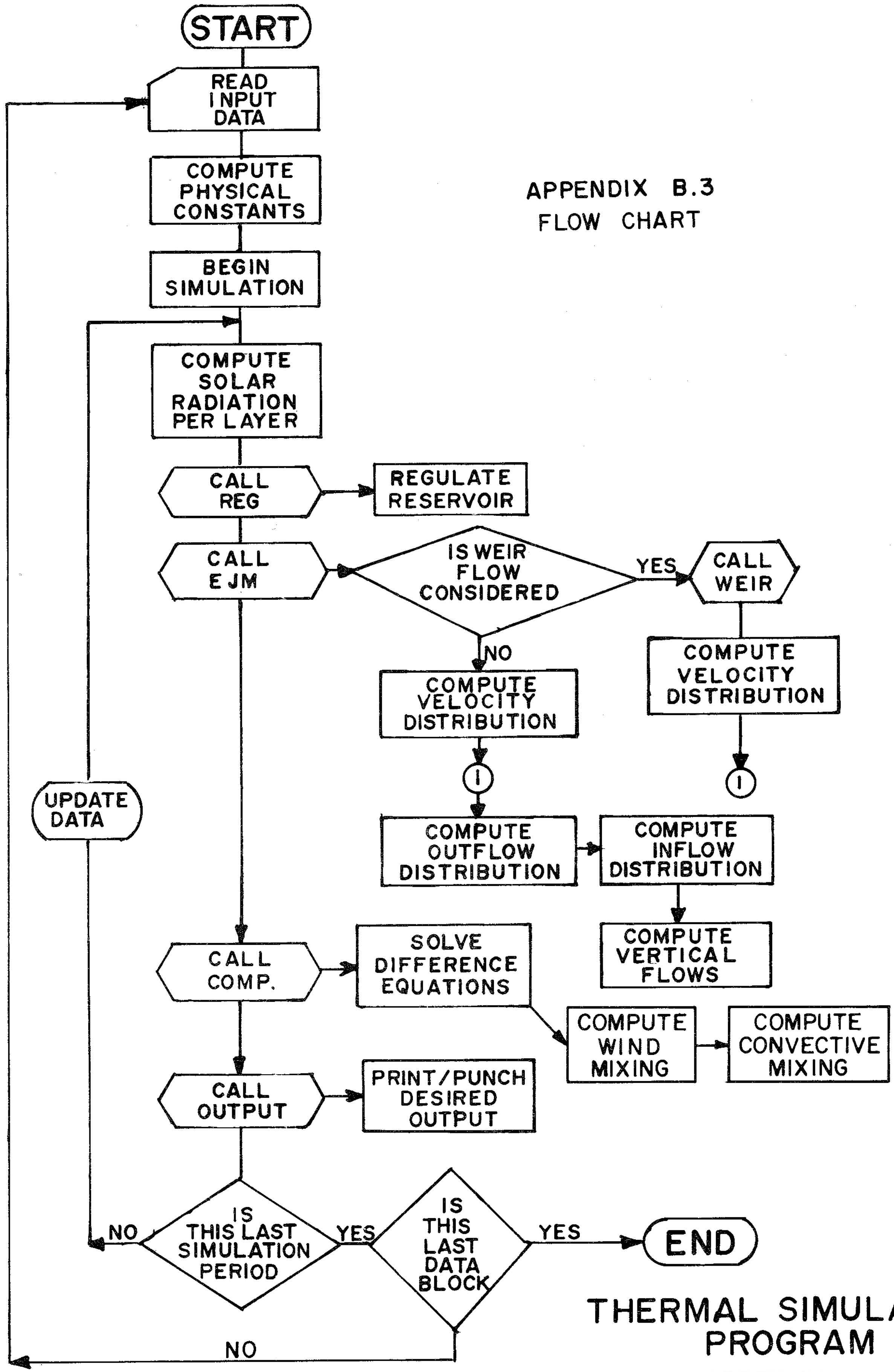
5. Subroutine COMP - This subroutine sets up and solves the simultaneous equations for each layer within the reservoir. After the temperature profile has been calculated wind stress is applied to the surface and mixing due to wind is computed. If an unstable profile exists at this point a convective mixing routine is performed to eliminate the unstable conditions.

6. Subroutine OUTPUT - This subroutine prints the daily summary table, the selected amplified output and the plot of the reservoir temperature profile. The frequency of the amplified and profile output are selected by the program user.

The major input parameters selected by the user are CDIFF, BETA, XNU, UPMIXand WCOEF. Final selection should be based on the model verification runs presented in Appendix C of this manual and comparisons of the simulation output with measured data available in the area under study. If enough data is available at a nearby impoundment a verification study should be made. The effect of every parameter change has a definite effect on the shape of the computed profiles. An increase in CDIFF will result in a smoother profile with a less clearly defined thermocline. An increase in BETA will result in a cooler epilimnium. An increase in XNU will result in a thinner epilimnion. An increase in UPMIX will result in a warmer metalimnion. An increase in WCOEF will result in a deeper epilimnion. Note that only one of the studies in Appendix C utilizes WCOEF. At present very little information is available to estimate this coefficient. It has been included in the model in anticipation of the completion of ongoing work at WES. In the meantime if the user desires to consider wind in the analysis a value of 1.0 should be used (0.0 will eliminate wind from the computations however wind data is still required as input).

If output is desired for use in graphical post-processor routines, tape 11 and tape 12 are formatted output tapes which can be saved for later processing.

APPENDIX B.3
FLOW CHART



THERMAL SIMULATION PROGRAM

APPENDIX B.3

Appendix B.4
THERMAL SIMULATION PROGRAM
DEFINITION OF VARIABLES

MAIN PROGRAM

Variables

A (100)	Planar areas at center of layer in ft^{2}.
AE (J)	Outlet area in S.F. (J-NOUTS).
AMP	Amplitude of daily variation in equilibrium temperature.
AR (100)	Planar areas at top of layers in ft^{2}.
AREA (K)	Area points, maximum K=100 (K=NAREA).
BETA	Amount of short wave radiation retained in top layer in percent/100.
BOTEL	Bottom elevation of reservoir in ft/sld.
CDIFF	Constant diffusion coefficient in ft^{2}/day.
CP	Specific heat of water - 1.0 BTU/ft^{3}/^{o}F.
CRSTEL	Spillway crest elevation in ft/sld.
CTEMP	Constant initial temperature of reservoir in ^{o}F.
DELZ	Thickness of top layer in ft.
DEL1	Thickness of top layer in ft.
DEPTH	Depth of water in ft.
DIFF (100)	Diffusion in ft^{2}/hr.
EKK (365)	Mean daily coefficient of surface heat exchange in BTU/ft^{2}/day.
EK (24)	Coefficient of surface heat exchange in BTU/ft^{2}/period.
EL (K)	Elevation Points, maximum K=100 (K=NAREA).
ELEV (100)	Average elevation of layers in ft/sld.
ETEM (365)	Mean daily equilibrium temperature in ^{o}F.
ETEMP (365)	Equilibrium temperature for simulation period in ^{o}F.
FLIN (3,365)	Mean daily inflows in cfs.
FLOT (365)	Mean daily inflows in cfs.
GAT (365)	Gate opening in ft. (controlled spillway) For an uncontrolled spillway - 0 = No spillway flow 1 = Spillway flow
GATOP (N)	Gate operation in ft. or whether or not spillway flow occurs.
GHT (J)	Port height in ft. (J=NOUTS).
GWT (J)	Port width in ft. (J=NOUTS).
HSN	Net short wave radiation in BTU/ft^{2}/period.
IDATA	Number of jobs to be run.
INPER	Counter for daily print cycle.
IPNCH	Set equal to 1 if punched card output. Set equal to 0 if no punched card output.
ITYPE	Set equal to 1 for uniform temperature conditions (initial). Set equal to 2 for variable initial temperature conditions.
JECHO	Set equal to 0 for no input data listing. Set equal to 1 if input data listing desired.
JJFMT	Set equal to 1 for hydrologic data in 8 F 10.2 format. Set equal to 2 for hydrologic data in USGS format.

JJGAT	Set equal to 0 if no GAT data furnished. Set equal to 1 if GAT data furnished.
JWEIR	Set equal to 0 if weir coef. claculated. Set equal to 1 if submerged weir flow coefficient to be used. Set equal to 2 if free weir flow coefficient to be used.
KDATA	Count of job being executed for multiple job runs.
KWEIR	Print control for type of weir flow.
LOL (J)	Layer number at center line of each outlet (J=NOUTS).
N	Counter of periods per day (24 maximum).
NAREA	Number of points on area - elevation table. (maximum - 100).
NDATA	Number of hydrologic data bits furnished.
NDAY	Counter of day number (365 - maximum).
NDDD	Counter of days between specified selected printout.
NDPN	Counter of days between selected printout.
NDPT	Frequency of selected printout in days, equals 0 if day numbers are specified.
NIFLO	Number of tributary inflows.
NL	Present period number of layers.
NLAST	Last day of simulation.
NLAY1	Number of layers on first day of simulation.
NLPNT	Frequency of vertical printout.
NNL	Previous period number of layers.
NOUTS	Number of outlets (Maximum = 16)
NPER	Number of periods - periods per day (Maximum = 24)
NPRE	Eq. 1 if multiple jobs change CDIFF, XNU, BETA, WCOEF and UPMIX Eq. 0 for complete data sets.
NSTRT	First day of simulation.
NDSEL (48)	Specified days for selected printout.
NSP	Equals 1 for controlled spillway, equals 2 for uncontrolled.
NWR	Equals 0 for orifice at top outlet, equals 1 for weir.
NVER	Equals 0 for simulation, 1 for verification.
OCAP	Maximum outlet capacity in cfs.
OMIN	Minumum flood control conduit outflow in cfs.
OTEMP (19)	Temperature at center line of each outlet in °F.
PCAP (J)	Maximum port capacity in cfs. (J-NOUTS)
PER	Number of periods per day (PER = NPER)
PFLOW(J)	Peak flow for hydropower generation in cfs.
PLEL (N)	Pool elevation in ft/sld per period.
QIN (N)	Inflow per period in cfs.
QOUT (N)	Outflow per period in cfs.
REW (K)	Reservoir width points, maximum K = 100 (K = NAREA).
RO	Specific weight of water 62.4 lb/ft^3.
ROW (I)	Reservoir widths at delz increments in ft.
SCAP	Selective withdrawal system capacity in cfs.
SFCE (365)	Mean daily pool elevation in ft/sld.
SMIN	Minimum selective withdrawal system release in cfs.
SPWTH	Effective spillway width in ft.
SRT (100)	Temperature rise due to S.W. radiation in each layer in °F.
SSW (365)	Daily total short wave radiation in BTU/ft^2/day.
SW (24)	Period total short wave radiation in BTU/ft^2/period.
TAR (365)	Mean daily target temperature in °F.

TARGET (N)	Target temperature per period in ^{o}F.
TEMP (100)	Present period temperature profile in ^{o}F.
TEMP1 (I)	Initial Temperature if variable in ^{o}F (I = NLAY1)
TFLI (3,365)	Mean daily inflow temperature in ^{o}F.
TIN (N)	Inflow temperature per period in ^{o}F.
TITLE (100)	Array of job titles (5 Cards).
TW	Reservoir width at spillway elevation in ft.
UPMIX	Inflow mixing coefficient
WCOEF	Wind speed coefficient - direct multiple of wind speed to account for effects of sheltering, fetch, water surface roughness, etc.
WIND (365)	Mean daily wind speed in mph.
WR (J)	Reservoir width at each outlet in ft. (J=NOUTS)
XNU	Light extinction coefficient in ft^{-1}.
XPER	Length of simulation period in hours.
XWIND	Average wind speed per period in mph.
YTEMP (100)	Previous period temperature profile in ^{o}F.
Z (100)	Distance from surface to bottom of layer in ft.
ZCLE (J)	Outlet centerline elevation in ft/sld (J=NOUTS).

<u>WORKING VARIABLES</u>

AFL, ARF, ATRY, HOLDB, HQ(200), IDON, IJJ, IKK, IKE, J, JCNT, JSTR, KA, KAR, KNL, KOEL, LN, LNL, LOC, LPER, M, MOO, NA, NAP, NAPT, NDDD, NDEL, NHL, NIFL, NIFP, NLR, NPSAV, NRISE, NSLC, SAAV, SLL, SUM, TOT, U(200), W, X, SDAY, XPSAV, XNL, ZAP, ZSOL

<u>Subroutines called</u>:

1.	REG	Determines outlets to regulate temperature to meet downstream objectives.
2.	EJM	Computes withdrawal zone thickness for an orifice outflow.
3.	COMP	Solves simultaneous equations.
4.	OUTPUT	Prints output.
5.	WEIR	Computes withdrawal zone for outflow over a weir; called from EJM.

SUBROUTINE REG

Variables

DELT	Difference between TMIX and TARGET.
KOUT (2)	Number of outlets being regulated.
NNN	Number of outlets open.
NOO	Number of outlets open.
NOS	Number of outlets open.
NOUTS1	(NOUTS + 1) Outlet number assigned to spillway.
OFLOW	Outflow, conduit only, in cfs.
OTEM (19)	Temperature at center line of each outlet in ^{o}F.
QMIX (2)	Flow from each outlet in cfs.
QZZ (2)	Specified flow from each outlet in cfs.
SPILL	Spillway flow in cfs.
TMIX	Estimate of mixed temperature due to regulation of outlets in ^{o}F.

WORKING VARIABLES - REG

CHECK, KLAY, LO, LOO1, NLOO, NV, NVER, QT, QX1, QX2, XI, XX, YY.

SUBROUTINE EJM

Variables

AO	Area of orifice opening in s.f.
AV	Average velocity through orifice in ft/sec.
CREST	Elevation of top of weir in ft/sld.
CD	Coefficient of discharge for weir.
DOC	Vertical shift of the withdrawal limit in ft.
DRHOS1 DRHOS2	Density difference of fluid between the layers of the original withdrawal limit and the shifted withdrawal limit.
DRHOB	Density difference between orifice center line and bottom boundary of withdrawal zone.
DRHOS	Density difference between orifice center line and free surface.
DRHO1	Density difference between maximum velocity and local velocity in withdrawal layer.
DRHO1M	Density difference between max. velocity and lower limit of withdrawal zone.
DRHO2M	Density difference between max. velocity elevation and upper limit of withdrawal zone.
DRHO1P	Density difference between orifice center line and lower limit.
DRHO2P	Density difference between orifice center line and upper limit.
G	Acceleration due to gravity (32.2 ft/sec^2)
GBT	50% of the height of an orifice gate in ft.
H	Total thickness of withdrawal zone in ft.
HLIM	Vertical distance of overlap of velocity profiles in layers.
HOR	Vertical distance between orifice centerlines in layers.
HRATIO	Extent of overlap of the two withdrawal zones.
HTEST	Densimetric froude number.
HTRY	Densimetric froude number.
IADD	Number of layers inflow distribution is shifted.
LAYER	Layer with density corresponding to density of inflow.
LIL	Layer of lower limit of inflow distribution.
LIU	Layer of upper limit of inflow distribution.
NCLD	No. of layers from water surface to center line of orifice.
NHLIM	Vertical distance of overlap of velocity profiles in layers.
NHOR	Vertical distance between orifice centerlines in layers.
NOVER	Number of layers where outflow exceeds layer volume.
NWAT	Vertical shift of the withdrawal limit in layers.
NWHO	Vertical shift of the withdrawal limit in layers.
NZLL	Elevation of lower limit of withdrawal zone in ft/sld.
NZUL	Elevation of upper limit of withdrawal zone in ft/sld.
OVER	Quantity of outflow in excess of layer volumes.
PARAM (100)	Density array of the reservoir by layers.
PLA	Vertical distance from pool elevation to top of the orifice in ft.
POOL	Elevation of water surface in ft/sld.
Q	Total discharge through orifice in cfs.

QLAY	Layer inflow in ft^3/period.
QOUTL (365)	Array of discharge per layer in cfs.
QOT (2, 100)	Array of discharges for 2 outlets in cfs.
QVERT (100)	Array of discharges along vertical axis in cfs.
RHOO	Density at orifice center line elevation.
RHOS1 RHOS2	Density of fluid at the layer of the original withdrawal limit.
RHOVM	Density at maximum elevation in the withdrawal zone.
RW	Width of reservoir in ft.
SQ	Total discharge for all ports open in cfs.
STAB	Stability of reservoir.
THD	Vertical dimension of inflow in layers.
THICK	Vertical dimension of inflow in ft.
VAVG	Average Velocity in any layer in ft/sec.
V (100)	Array of velocities in entire layer system in ft/sec.
V1 (100)	Array of velocities at any layer below max. velocity in ft/sec.
V2 (100)	Array of velocities at any layer above max. velocity in ft/sec.
VH1	Average velocity in the zone of overlap of the lower withdrawal zone in ft/sec.
VH2	Average velocity in the zone of overlap of the upper withdrawal zone in ft/sec.
VLAY	Layer volume in ft^3.
VRA1	The ratio of a local velocity to the max. velocity below the maximum velocity elev.
VRA2	The ratio of a local velocity to the max. velocity above the maximum velocity elev.
VV (2, 100)	Array of outflow velocity for two outlets in ft/sec.
WHAT	Vertical shift of the withdrawal limit in layers.
WHERE	Vertical shift of the withdrawal limit in layers.
WHO	Vertical shift of the withdrawal limit in ft.
WTEMP (100)	Previous period temperature plus solar radiation in ^oF.
XLW	Width of spillway or width of gate used as weir in ft.
XPL	Vertical distance from pool elev. to a point above the top of a gate.
ZB	Vertical distance from orifice center line to bottom boundary in ft.
ZCLO	Elevation of orifice center line in ft/sld.
ZDEL	The elev. of the max. velocity in withdrawal zone in layers.
ZMV	Elevation of max. velocity in withdrawal zone in ft.
ZS	Vertical distance from orifice center line to free surface in ft.
Z1H	Z1/H
Z1	Vertical distance from orifice to lower limit in ft.
Z2	Vertical distance from orifice to upper limit in ft.
ZONE	Vertical distance of overlap of velocity profiles in ft.

WORKING VARIABLES - EJM

ASQ, B, BIGED, BSQ, BTEST, BTRY, C, DELIN, DELQ, DISTR, DZ, FIFJ, ID, INEX, IS, JJ, K, KK, KR, K1, LIP, LL, L1, MEAN, ML,MLL, MUL, MMM, MMN, MN, NASQ, NBSQ, NH, NLL, NLL2, NNN, NOX, NUL, NULZ, NY1, NY1M, NYI, NZD, NZD1, NZMV, STEST, STRY, SUM, SUM1, SUM2, SUMIN, SUMIQ, SUMQ, TEST, TRY, VLAY, XD, XI, XLEFT, XML, XR, XRAT, XNH, XHY, Y1, Y2, Y1M, Y1MH, Y2M, YD1M, YD2M, YI, Z1LL, Z1LU, ZZLL, ZZLU.

SUBROUTINE WEIR

Variables

AW	Cross sectional area of flow over weir in ft^2.
DELD	Density difference between the crest of the weir and the lower limit of the withdrawal zone.
DEPL	The distance from the free surface to the lower limit of the withdrawal zone in layers.
DRHO	Density difference between the layer of maximum velocity and the corresponding layer of local velocity.
HW	The head on the weir or the depth of flow over the weir.
KWEIR	Equals 1 if submerged weir flow considered, equals 2 if free weir flow considered.
LVM	The layer number that contains the maximum velocity.
ML	The distance in layers from the weir crest to the lower limit of the withdrawal zone.
QW	Discharge over the weir.
RHOW	Density at the weir crest.
SUM1 (100)	The dimensionless velocity distribution for the portion below the maximum velocity.
SUM2 (100)	The dimensionless velocity distribution for the portion above the maximum velocity.
VM	The maximum velocity in the zone of withdrawal in ft/sec.
VW	The average velocity over the weir in ft/sec.
Y1F	The vertical distance in feet from the maximum velocity to the lower limit of the withdrawal zone.
Y2F	The vertical distance in feet from the maximum velocity to the upper limit in the withdrawal zone.
Y1L	The vertical distance in layers from the maximum velocity to the lower limit of the withdrawal zone.
ZO	The distance from the elevation of the weir crest to the lower limit of the withdrawal zone in feet.

WORKING VARIABLES - WEIR

BDFR, DEN, DENZ, DEPF, DEF, EXZ, LDEP, LL, LVM1, LY1F, NY1L, SAM, SAM1, SAM2, Y1, Y2, YS1

SUBROUTINE COMP

Variables

ALG 1 (100)	Computed coefficient for solution algorithm.
ALG 2 (100)	Computed coefficient for solution algorithm.
AVT	Average reservoir temperature in ^{o}F.
COEF (100, 3)	Matrix coefficients.
EKIN	Kinetic energy in wind mixing computation.
EPOT	Potential energy in wind mixing computation.
FORCE (100)	Computed values for right side of difference equations.
MIX1	Mixing depth for epilimnion in layers.
MIX2	Mixing depth for hypolimion in layers.
MIX3	No. layers to be mixed internally to produce stable profile.
QHEAT	Temperature rise of reservoir due to advection in ^{o}F.
SHEAR	Shear stress on surface due to wind.
SHEAT	Temperature rise of reservoir due to surface heating in ^{o}F.
SHVEL	Shear velocity on surface due to wind.
SUMV	Reservoir volume in ft^3.
TOUT	Outflow temperature in ^{o}F.
TSURF	Surface temperature in ^{o}F.
YAVT	Average reservoir temperature for previous time period in ^{o}F.

WORKING VARIABLES - COMP

CNTR, D, DEN1, DEN2, DIST, ETE, HOLDL, HOLDU, K, KFLAG, KL, KLOOP, KN, KNL, LM, LN, LNM, M, QVBOT, QVL, QVTOP, QVU, SMT, SUMVT, T1, T2, TEMPL, TEMPU, TFN, TMPMX, V2, VLA, VLEFT, VO, VO1, VOLL, VOLU, W1, XI, ZD

SUBROUTINE OUTPUT

Variables

PLOT (71)	Variable in plot routine.
SAVE (71)	Variable in plot routine.
B(100)	Layer areas in AC-FT.

WORKING VARIABLES - OUTPUT

ITP, KPLOT, KXX, LINES, LN, LNP, NN, NOU, NTO, SCALE

APPENDIX B.5
THERMAL SIMULATION PROGRAM
Input Description

Card No.

1 FORMAT (I10) No. jobs to be run.

2 FORMAT (20A4) Job title - five cards.

CODE INPUT

3 FORMAT (8I10)

1. NSTRT - 1st day of simulation. Usually in the spring; about 90.
2. NLAST - Last day of simulation. Usually in the fall; about 300.
3. NOUTS - Number of outlets for selective withdrawal (max. 16)
4. NAREA - Number pts. furnished for elev., area, width curves.
5. NDPT - Number days between profile output (0 if day numbers specified by card no. 16)
6. NLPNT - Vertical frequency of profile output. Usually one.
7. IPNCH - Equals 1 for punched card output, equals zero otherwise. Usually zero.
8. NPRE - Equals 1 for data change of CDIFF, XNU, BETA, UPMIX and WCOEF for additional job runs, equals 0 if additional data is read in complete sets. If 1 is used, on the next job following cards 22 read 5 title cards and 1 card with CDIFF, XNU, BETA, UPMIX, WCOEFF (5F10.2)

4 FORMAT (8I10)

1. NLAY1 - Number layers 1st day of simulation. The top layer will always be greater than or equal to 2 feet.
2. ITYPE - Equals 2 for variable initial temperature condition, equals 1 otherwise.
3. NPER - Number periods per day. Usually one.
4. NDATA - Number hydrologic & meteorologic data points. furnished. Usually 365.
5. NSP - Code to describe spillway, 1 for controlled, 2 for uncontrolled. Defines type of flow; tainter gate is treated like an orfice flow.

6. NWR - Code to describe top outlet, 1 for weir, 0 for orifice. (Spillway is not defined as an outlet).
7. NVER - Equals 1 for verification, equals 0 for simulation. This value controls the input of card 22.
8. NIFLO - Number of tributary inflows. At least one is is required. (maximum of 3 tributaries)

5 FORMAT (4I10)

1. JJGAT - Equals 1 if card 12 included, equals 0 otherwise.
2. JJFMT - Equals 1 for 8F10.2 format, equals 2 for USGS format on cards 8-13
3. JECHO - Equals 1 if input data listing desired, equals 0 otherwise.
4. JWEIR - Code to describe weir coefficient, equals 0 for computed, 1 for submerged, 2 for free weir flow.

PHYSICAL INPUT

6 FORMAT (8F10.5)

1. XPER - Length of one time period in hrs. Usually 24.
2. DELZ - Depth of one layer in ft.
3. BOTEL - Bottom elevation of reservoir in feet above sea level.
4. XNU* - Light extinction coefficient in ft^{-1}
5. BETA* - Fraction of SW RAD placed in top layer. BETA at 2 feet.
6. TW - Effective reservoir width at spillway crest in ft.
7. CDIFF* - Diffusion coefficient in ft^2/day.
8. CTEMP - Initial reservoir temperature if constant in °F. Only used if ITYPE=1.

7 FORMAT (8F10.2)

1. CRSTEL - Spillway crest elevation in feet above sea level.
2. SPWTH - Effective spillway width in ft. Subtract for pier width.
3. OCAP - Outlet works capacity (max) for flood control in cfs. This is the bottom outlet.
4. SCAP - Selective withdrawal system capacity (max.) in cfs.
5. OMIN - Minimum flood control conduit release in cfs.
6. SMIN - Minimum selective withdrawal system release in cfs.

7. UPMIX*+ - Inflow mixing coefficient indicating quantity of top layer water to be entrained (e.g. if UPMIX equals 0.5 a quantity of water equal to 1/2 the inflow volume will be withdrawn from the top layer and mixed with the inflow)
8. WCOEF*+ - Coefficient to modify wind speed to account for fetch, sheltering, over water effects, etc.

* Several values derived in field office application are shown in Appendix C.8.

\+ Use zero if this value is not to be considered in the calculation.

HYDROLOGIC INPUT

8-13	FORMAT (8F10.2) or (15X, 8F7.0, 9X) - Defined on Card 5; JJFMT	
8	FLIN (NIFLO, NDATA)	- inflows beginning Jan. 1 (daily) in cfs.
9	TFLI (NIFLO, NDATA)	- inflow temperature in °F.
10	FLOT (NDATA)	- outflows in cfs.
11	TAR (NDATA)	- outflow temperatures in °F.
12	GAT (NDATA) (Optional)	- spillway operations, a positive value indicates spillway flow, a 0.0 indicates no spillway flow for day, if spillway is gated, positive value should be gate opening in ft. (include only if JJGAT equals 1 on card 5)
13	SFCE (NDATA)	- pool elevations in ft. above sea level.

Note: Cards 8-13 are read in complete sets.
Cards 8-9 are repeated for each tributary inflow.

RESERVOIR GEOMETRY - Not necessarily at the top of each layer. These cards are input from the ground elevation to the highest water surface expected.

14 FORMAT (3F10.2) Note: 1 card for each point

EL (NAREA) - Elevation of area with width pts. in feet feet above sea level.
AREA (NAREA) - Surface area at EL in acres Should not be zero.
REW (NAREA) - Effective reservoir width at EL in ft.

OUTLET DESCRIPTION - These cards are input from the lowest outlet first to the highest outlet.

15 FORMAT (6F10.2) Note: 1 card for each outlet (max. 16)

ZCLE (NOUTS) - Elevation center line of outlet in ft. above sea level or invert of weir if top oulet is an overflow weir.
AE (NOUTS) - Area of outlet in ft^2.
GHT (NOUTS) - Height of outlet in ft.

GWT (NOUTS) - Width of outlet in ft.
WR (NOUTS) - Reservoir width at center line of outlet in ft.
PCAP (NOUTS) - Maximum Port capacity in cfs.
PFLOW(NOUTS) - Peak flow in cfs occuring during hydropower generation. If this value is positive, it will define the reservoir withdrawal zone. If this value is blank or zero, the withdrawal zone is defined by the flow data on either card 10 or 22.

SPECIFIED DAYS FOR SELECTED PRINTOUT (OPTIONAL)

16 FORMAT (16I5)

NDSEL (48) - Julian day numbers for selected output.

Note: 3 cards always needed with last specified day always equal to day number 365. Set NDPT=0 on card 3 if card 16 is used.

INITIAL TEMPERATURE

17 FORMAT (8F10.2)

TEMP1 (NLAY 1)- Initial temperature values for each layer in °F. (Read from bottom to top)

Note: Card 17 to be deleted for isothermal initial condition (i.e., ITYPE=1)

METEOROLOGICAL INPUT

18 FORMAT (16F5.1)

ETEMP (NDATA) - Equilibrium Temperatures in °F.

19 FORMAT (16F5.1)

EKK (NDATA) - Surface heat exchange coefficients in BTU/ ft^2/day.

20 FORMAT (16F5.1)

XWIND (NDATA) - mean daily wind speed in mph.

21 FORMAT (10F8.1)

SSW (NDATA) - Short wave solar radiation in BTU/ft^2/period.

Note: Cards 18, 19, 20 and 21 are output from HEAT EXCHANGE PROGRAM.

STIPULATED OUTFLOWS - Omit these cards if NVER=0.

22 FORMAT (16F5.0)

QZZ (NOUTS) - Outflow for each outlet (one card per day) in cfs. First card is for first day of verification (i.e., NSTRT).

Note: Card 22 for verification runs for daily time periods only. Outlets are numbered from bottom to top with discharge from outlet no. 1 placed in first 5 column field. If less than 16 outlets are specified only that number (NOUTS) of columns are used.

APPENDIX B.6

THERMAL SIMULATION PROGRAM INPUT SET UP

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
IDATA							
TITLE(100)	(5 CARDS)						
NSTRT	NLAST	NØUTS	NAREA	NDPT	NLPNT	IPNCH	NPRE
NLAYI	ITYPE	NPER	NDATA	NSP	NWR	NVER	NIFLØ
JJ6AT	JJFMT	JECHO	JWEIR				
XPER	DELZ	BØTEL	XNU	BETA	TW	CDIFF	CTEMP
CRSTEL	SPWTH	ØCAP	SCAP	ØMIN	SMIN	UPMIX	WCOEF
FLIN(3,365)							
TFLI(3,365)							
FLØT(365)							
TAR(365)							
GAT(365)							
SFCE(365)							
EL(100)	AREA(100)	REW(100)					
ZCLE(16)	AE(16)	GHT(16)	GWT(16)	WR(16)	PCAP(16)		
NDSEL(48)							
TEMPI(100)							
ETEMP(365)							
EKK(365)							
XWIND(365)							
SSW(365)							
QZZ(16)							

APPENDIX B.7

THERMAL SIMULATION PROGRAM

SAMPLE INPUT

```
1 ——  1              1
   ┌─ 2             POMMEI DE TERREI
   │  3             VERIFICATION STUDY
2  │  4             CALENDAR YEAR 1970
   │  5             K.C.
   └─ 6             AEV # 0.0  BEV # 289.0
3 ——  7              161        334       1        59        0        1        0        0
4 ——  8              29         2.        1        365       2        0        0        1
5 ——  9              1          1
6 —— 10     24.      3.0        750.      0.15     0.8       10965.   .13      0.0
7 —— 11     874.     180.       999999.   999999.  0.0       0.0      1.0      1.75
   ┌─12     150.     150.       150.      150.     150.      150.     150.     100.
   │ 13     100.     100.       100.      100.     100.      100.     100.     100.
   │ 14     200.     300.       200.      300.     200.      150.     150.     150.
   │ 15     250.     450.       400.      350.     350.      350.     250.     200.
   │ 16     250.     200.       200.      200.     200.      200.     200.     150.
   │ 17     150.     150.       100.      100.     100.      100.     100.     110.
   │ 18     110.     115.       115.      113.     115.      165.     115.     115.
   │ 19     150.     150.       125.      210.     760.      1160.    710.     510.
   │ 20     460.     385.       360.      235.     235.      260.     410.     310.
   │ 21     310.     335.       335.      710.     560.      910.     3160.    2290.
   │ 22     1710.    1250.      1060.     840.     840.      720.     570.     560.
   │ 23     535.     535.       510.      1010.    810.      600.     570.     510.
   │ 24     430.     430.       370.      350.     350.      290.     260.     240.
   │ 25     235.     215.       300.      260.     2380.     1340.    640.     470.
   │ 26     365.     4400.      885.      530.     410.      1115.    610.     5550.
   │ 27     35450.   10900.     2000.     1200.    500.      460.     240.     320.
   │ 28     200.     200.       500.      330.     180.      320.     1400.    1000.
   │ 29     550.     400.       300.      270.     270.      170.     120.     170.
   │ 30     170.     130.       110.      90.      90.       240.     150.     110.
8  │ 31     350.     410.       170.      150.     135.      120.     80.      80.
   │ 32     75.      75.        250.      200.     130.      150.     190.     100.
   │ 33     100.     560.       550.      300.     200.      170.     70.      60.
   │ 34     60.      60.        60.       60.      60.       50.      40.      30.
   │ 35     20.      20.        20.       20.      15.       15.      15.      15.
   │ 36     155.     80.        70.       60.      50.       20.      15.      10.
   │ 37     10.      10.        10.       10.      10.       10.      10.      10.
   │ 38     20.      40.        40.       40.      160.      100.     40.      20.
   │ 39     20.      15.        260.      25.      15.       10.      10.      10.
   │ 40     10.      10.        10.       10.      10.       10.      10.      10.
   │ 41     10.      10.        10.       10.      10.       10.      10.      10.
   │ 42     10.      10.        10.       20.      30.       330.     260.     315.
   │ 43     870.     220.       390.      2320.    800.      250.     200.     80.
   │ 44     700.     250.       270.      200.     860.      750.     310.     280.
   │ 45     150.     4050.      7670.     2670.    760.      700.     550.     480.
   │ 46     440.     430.       400.      280.     150.      130.     230.     200.
   │ 47     110.     5125.      5900.     1100.    750.      350.     460.     1470.
   │ 48     680.     580.       400.      330.     370.      330.     240.     220.
   │ 49     325.     320.       270.      2650.    4320.     1850.    890.     660.
   │ 50     570.     550.       420.      580.     320.      350.     250.     240.
   │ 51     1400.    950.       650.      550.     500.      500.     500.     400.
   │ 52     400.     380.       370.      560.     300.      300.     300.     300.
   │ 53     250.     200.       200.      190.     190.      190.     190.     190.
```

```
 54   190.      190.      150.      140.      130.      130.      130.      130.
 55   130.      120.      120.      120.      110.      350.      310.      260.
 56   210.      210.      410.      560.      510.      510.      300.      300.
 57   250.      240.      230.      250.      400.
 58        45.95     41.41     37.92     38.07     38.89     37.43     33.40     32.00
 59        32.00     32.00     38.29     40.35     43.61     43.68     45.63     48.97
 60        47.13     41.62     33.89     32.00     32.00     34.42     37.60     44.94
 61
 62        51.05     53.53     55.78     56.41     52.94     52.09     47.54     49.31
 63        47.34     41.59     40.40     42.40     48.08     51.98     49.76     49.29
 64        47.47     44.72     46.56     43.60     43.11     41.32     41.55     46.32
 65        48.87     49.59     45.45     45.49     49.17     53.23     53.82     50.09
 66        49.28     49.44     52.89     57.86     58.96     61.06     59.48     56.04
 67        53.94     53.59     53.99     55.47     53.67     50.51     45.17     41.65
 68        41.61     41.01     42.83     43.52     45.44     45.01     44.96     43.44
 69        42.84     44.18     48.06     49.89     50.86     49.94     48.22     48.25
 70        55.66     61.05     60.53     62.45     60.81     63.19     60.06     58.66
 71        57.03     60.11     63.85     64.70     62.61     60.49     58.45     62.28
 72        61.02     61.32     60.56     62.69     66.07     67.49     70.71     67.39
 73        60.96     56.18     53.71     56.30     60.27     62.54     65.20     65.72
 74        65.87     66.73     68.29     69.66     71.61     71.35     67.13     62.57
 75        60.22     62.76     64.53     68.18     69.49     70.87     71.81     72.03
 76        70.27     67.86     66.79     69.21     71.36     72.63     72.43     70.70
 77        68.96     65.72     65.20     65.63     67.10     67.74     69.08     70.14
 78        78.00     75.41     73.44     71.40     70.95     70.07     72.49     74.30
 79        72.18     72.85     73.17     75.31     76.49     78.59     78.11     78.51
 80        75.14     72.74     72.95     73.91     76.22     79.11     79.55     79.10
 81        75.50     72.77     69.71     72.17     75.06     76.05     75.99     74.13
 82        74.72     75.98     76.68     76.25     74.89     75.12     75.37     78.33
 83        73.03     71.22     65.96     68.55     70.83     73.54     75.11     76.64
 84        76.40     78.18     77.81     79.87     78.96     80.12     79.99     80.74
 85        80.62     79.96     79.29     80.01     78.65     78.34     74.17     73.23
 86        71.98     74.14     76.14     78.14     79.25     79.96     79.95     79.29
 87        77.73     73.22     73.88     71.52     70.81     70.73     72.45     74.22
 88        75.83     77.40     78.18     78.63     76.73     75.71     73.29     75.43
 89        75.64     78.67     76.26     77.16     72.56     70.97     69.26     70.50
 90        73.73     74.31     76.86     76.80     74.28     73.42     74.57     76.19
 91        76.08     72.06     68.64     67.79     64.90     64.86     61.19     63.79
 92        65.64     67.46     69.33     67.29     66.49     65.25     65.18     68.40
 93        65.24     58.93     52.68     51.91     56.80     59.63     59.21     57.47
 94        55.00     53.66     53.69     55.81     57.17     59.69     61.14     61.73
 95        62.56     62.83     64.09     60.31     56.91     53.52     54.15     53.55
 96        54.31     50.15     47.82     47.08     48.62     51.26     54.56     58.10
 97        57.18     56.28     53.78     52.13     51.31     49.16     47.05     46.31
 98        46.79     50.67     53.30     53.03     54.79     51.67     47.03     40.90
 99        40.57     48.47     54.91     57.72     58.00     60.56     62.18     62.50
100        59.86     57.54     55.47     50.10     49.63     50.83     54.99     59.03
101        56.29     52.13     45.53     46.47     49.69     49.30     51.08     52.88
102        52.07     51.12     47.66     51.75     51.83     49.91     42.68     41.77
103        42.81     46.26     47.96     48.75     47.96
104   100.      100.      100.      100.      100.      100.      100.      100.
105   100.      100.      100.      100.      100.      100.      100.      100.
106   100.      100.      100.      100.      100.      100.      100.      100.
107   100.      100.      300.      400.      400.      400.      400.      400.
```

9

10	108	400.	400.	400.	400.	400.	400.	400.	400.
	109	150.	100.	100.	100.	100.	100.	100.	100.
	110	100.	100.	100.	100.	100.	100.	100.	100.
	111	100.	100.	100.	100.	100.	100.	100.	100.
	112	100.	625.	700.	700.	700.	700.	700.	700.
	113	500.	400.	400.	400.	400.	400.	400.	1180.
	114	1500.	1500.	1500.	1500.	1310.	1500.	1170.	1000.
	115	1000.	1000.	1000.	1000.	1000.	554.	500.	500.
	116	500.	500.	310.	250.	150.	100.	100.	100.
	117	100.	100.	100.	100.	100.	100.	100.	100.
	118	100.	475.	600.	600.	600.	600.	600.	600.
	119	600.	600.	600.	600.	600.	5525.	5800.	5800.
	120	4800.	4800.	4800.	4600.	4800.	4700.	4700.	4600.
	121	4500.	4400.	1483.	500.	500.	500.	250.	200.
	122	200.	200.	200.	138.	100.	100.	100.	100.
	123	100.	100.	100.	100.	100.	100.	100.	100.
	124	100.	100.	100.	100.	100.	100.	100.	100.
	125	100.	100.	100.	100.	100.	100.	100.	170.
	126	200.	200.	200.	200.	60.	25.	25.	25.
	127	25.	25.	25.	25.	25.	25.	25.	25.
	128	25.	25.	25.	25.	25.	25.	25.	25.
	129	25.	25.	25.	25.	25.	25.	25.	25.
	130	25.	25.	25.	25.	25.	25.	25.	25.
	131	25.	25.	25.	25.	25.	25.	25.	25.
	132	25.	25.	25.	25.	25.	25.	25.	25.
	133	25.	25.	25.	25.	25.	25.	25.	25.
	134	25.	25.	25.	25.	25.	25.	25.	25.
	135	25.	25.	25.	25.	25.	25.	25.	25.
	136	25.	25.	25.	25.	25.	342.	500.	500.
	137	500.	500.	500.	500.	833.	2830.	3000.	3000.
	138	3000.	3000.	2330.	580.	500.	500.	140.	25.
	139	25.	25.	25.	25.	25.	1500.	3500.	3500.
	140	3500.	2500.	1000.	1000.	1000.	666.	100.	100.
	141	100.	100.	100.	233.	300.	1490.	2000.	2000.
	142	2000.	2000.	2000.	733.	100.	100.	260.	300.
	143	300.	766.	1000.	1000.	1000.	580.	500.	500.
	144	300.	500.	300.	260.	260.	250.	260.	260.
	145	260.	260.	260.	186.	150.	150.	150.	150.
	146	150.	150.	150.	150.	150.	150.	105.	100.
	147	100.	100.	100.	100.	100.	100.	100.	100.
	148	100.	100.	100.	100.	100.	100.	275.	300.
	149	300.	300.	300.	300.	300.			
11	150	40.	40.	40.	40.	40.	40.	40.	40.
	151	40.	40.	40.	40.	40.	40.	40.	40.
	152	40.	40.	40.	40.	40.	40.	40.	40.
	153	40.	40.	40.	40.	40.	40.	40.	40.
	154	40.	40.	40.	40.	40.	40.	40.	40.
	155	40.	40.	40.	40.	40.	40.	40.	40.
	156	40.	40.	40.	40.	40.	40.	40.	40.
	157	40.2	40.4	40.5	40.7	40.9	41.1	41.3	41.4
	158	41.6	41.9	42.2	42.5	42.8	43.1	43.4	43.7
	159	44.0	44.3	44.7	45.0	45.3	45.6	46.0	46.3
	160	46.6	46.9	47.3	47.6	48.0	48.3	49.6	49.9
	161	49.3	49.6	50.0	50.3	50.6	50.9	51.3	51.6

11	162	51.9	52.2	52.6	52.9	53.2	53.5	53.9	54.2
	163	54.5	54.8	55.0	55.3	55.6	55.8	56.1	56.3
	164	56.6	57.0	57.3	57.7	58.0	58.4	58.7	59.1
	165	59.4	59.7	60.0	60.3	60.7	61.0	61.3	61.6
	166	61.9	62.2	62.4	62.7	62.9	63.2	63.4	63.7
	167	63.9	64.2	64.5	64.7	65.0	65.3	65.5	65.8
	168	66.1	66.3	66.6	66.8	67.1	67.3	67.5	67.8
	169	68.0	68.2	68.5	68.7	68.9	69.1	69.4	69.6
	170	69.9	70.1	70.3	70.5	70.8	71.0	71.2	71.4
	171	71.6	71.8	72.0	72.2	72.4	72.6	72.8	73.0
	172	73.2	73.4	73.7	73.9	74.1	74.3	74.6	74.8
	173	74.7	74.9	75.0	75.2	75.3	75.5	75.6	75.8
	174	75.9	76.0	76.1	76.2	76.4	76.5	76.6	76.7
	175	76.8	76.9	77.0	77.1	77.2	77.3	77.4	77.4
	176	77.5	77.5	77.4	77.4	77.4	77.3	77.3	77.3
	177	77.3	77.2	77.1	76.9	76.8	76.7	76.6	76.4
	178	76.3	76.1	75.8	75.6	75.3	75.1	74.9	74.6
	179	74.3	73.9	73.6	73.2	72.8	72.4	72.1	71.7
	180	71.3	70.9	70.6	70.2	69.9	69.5	69.1	68.8
	181	68.2	67.8	67.5	67.2	66.9	66.5	66.2	65.8
	182	65.5	65.1	64.8	64.4	64.0	63.6	63.3	62.9
	183	62.5	62.2	61.8	61.5	61.2	60.8	60.5	60.1
	184	59.8	59.5	59.2	58.9	58.6	58.2	57.9	57.6
	185	57.3	57.0	56.7	56.4	56.2	55.9	55.6	55.8
	186	55.0	54.7	54.4	54.1	53.8	53.4	53.1	52.8
	187	52.5	52.2	51.8	51.5	51.2	50.8	50.5	50.1
	188	49.8	49.5	49.2	48.8	48.5	48.2	47.9	47.5
	189	47.2	46.8	46.5	46.1	45.8	45.4	45.0	44.7
	190	44.3	44.0	43.6	43.3	43.0	42.6	42.3	41.9
	191	41.6	41.4	41.3	41.1	41.0	40.8	40.6	40.5
	192	40.3	40.3	40.2	40.2	40.2	40.1	40.1	40.0
	193	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	194	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	195	40.0	40.0	40.0	40.0	40.0	40.0		
12	196								
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13	242	839.07	839.09	839.10	839.11	839.12	839.14	839.14	839.15
	243	839.14	839.13	839.13	839.13	839.14	839.14	839.14	839.15
	244	839.17	839.23	839.25	839.29	839.31	839.33	839.35	839.36
	245	839.40	839.48	839.51	839.50	839.50	839.47	839.43	839.38
	246	839.34	839.29	839.24	839.18	839.13	839.07	839.03	838.95
	247	838.95	838.96	838.98	838.97	838.98	838.98	838.99	838.99
	248	838.99	838.98	838.99	838.99	838.99	839.01	839.02	839.01
	249	839.04	839.02	839.03	839.05	839.23	839.49	839.63	839.74
	250	839.82	839.76	839.67	839.55	839.43	839.32	839.24	839.15
	251	839.09	839.06	839.06	839.13	839.17	839.29	839.98	840.26
	252	840.30	840.24	840.13	839.96	839.84	839.65	839.50	839.38
	253	839.26	839.15	839.02	839.02	838.97	838.97	838.98	838.97
	254	838.93	838.90	838.90	838.92	838.95	838.97	839.02	839.02
	255	839.05	839.07	839.11	839.13	839.70	839.99	840.12	840.20
	256	840.25	841.21	841.27	841.26	841.20	841.31	841.30	842.48
	257	850.02	852.02	852.28	852.39	852.44	851.37	850.26	849.23
	258	848.15	847.21	846.29	845.33	844.28	843.27	842.50	841.66
	259	840.66	839.57	839.35	839.27	839.19	839.09	839.05	839.03
	260	839.01	838.98	838.94	838.91	838.89	838.92	838.91	838.90
	261	838.96	839.04	839.05	839.06	839.06	839.05	839.03	839.00
	262	838.99	838.96	838.98	838.99	839.00	839.01	838.99	839.00
	263	838.97	839.09	839.19	839.23	839.25	839.25	839.23	839.20
	264	839.15	839.09	839.04	838.98	838.96	838.95	838.94	838.93
	265	838.91	838.88	838.85	838.83	838.81	838.79	838.77	838.75
	266	838.77	838.77	838.76	838.73	838.73	838.71	838.69	838.67
	267	838.63	838.61	838.58	838.55	838.53	838.51	838.49	838.47
	268	838.46	838.44	838.42	838.40	838.41	838.41	838.39	838.37
	269	838.35	838.32	838.36	838.35	838.34	838.32	838.30	838.28

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     270   838.27   838.24   838.22   838.20   838.18   838.19   838.14   838.11
     271   838.09   838.07   838.05   838.02   838.00   837.98   837.95   837.93
     272   837.91   837.89   837.87   837.86   837.85   837.92   837.97   838.04
     273   838.25   838.27   838.35   838.93   839.09   839.14   839.17   839.17
     274   839.34   839.39   839.44   839.48   839.68   839.78   839.73   839.66
     275   839.56   840.44   842.16   842.66   842.64   842.13   841.53   840.92
     276   840.28   839.62   839.15   839.06   838.96   838.85   838.86   838.90
13   277   838.91   840.19   841.88   842.11   842.27   842.00   841.27   840.77
     278   840.05   839.58   839.43   839.26   839.09   839.00   839.03   839.05
     279   839.10   839.16   839.20   839.79   840.78   840.86   840.59   840.26
     280   839.90   839.52   839.11   839.03   839.08   839.14   839.13   839.11
     281   839.39   839.43   839.34   839.22   839.08   839.02   839.01   839.03
     282   839.00   838.97   838.98   839.05   839.06   839.06   839.07   839.05
     283   839.05   839.02   839.00   838.98   838.99   839.01   839.02   839.03
     284   839.07   839.04   839.03   839.02   839.02   839.00   838.99   839.00
     285   839.03   839.02   839.03   839.04   839.04   839.11   839.16   839.19
     286   839.22   839.25   839.32   839.43   839.54   839.63   839.63   839.63
     287   839.61   839.60   839.58   839.35   839.38
     288   750.     0.0      0.0
     289   750.5    6.       10.
     290   751.     12.      25.
     291   752.     24.      75.
     292   753.     36.      125.
     293   754.     48.      126.
     294   755.     60.      130.
     295   756.     72.      135.
     296   757.     84.      140.
     297   758.     96.      152.
     298   759.     108.     158.
     299   760.     120.     165.
     300   761.     130.     210.
     301   762.     180.     225.
     302   763.     210.     230.
14   303   764.     240.     235.
     304   766.     300.     415.
     305   768.     360.     925.
     306   770.     420.     1700.
     307   772.     506.     1705.
     308   774.     592.     1890.
     309   776.     678.     2050.
     310   778.     764.     2063.
     311   780.     850.     2080.
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     313   784.     1134.    2145.
     314   786.     1323.    2215.
     315   788.     1512.    2465.
     316   790.     1700.    2590.
     317   792.     1922.    2680.
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     319   796.     2366.    2975.
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     321   800.     2810.    3115.
     322   803.     3092.    3245.
     323   805.     3374.    3440.
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    *24     909.        3556.       3550.
    *25     912.        3998.       3770.
    *26     915.        4345.       4155.
    *27     918.        4702.       4885.
    *28     921.        5092.       5625.
    *29     924.        5520.       6400.
    *30     927.        5955.       8370.
    *31     930.        6390.        8670
    *32     933.        6867.       8925.
14  *33     936.        7344.       9135.
    *34     939.        7820.       9265.
    *35     942.        8420.       9425.
    *36     945.        9050.       9570.
    *37     948.        9680.       9700.
    *38     951.        10321.      9810.
    *39     954.        10984.      9970.
    *40     957.        11647.      10245.
    *41     960.        12310.      10460.
    *42     964.        13354.      10650.
    *43     968.        14398.      10770.
    *44     972.        15510.      10860.
    *45     976.        16667.      11070.
    *46     978.5       17374.      11130.
15  *47     758.2       214.        16.         13.375      153.
    *48        161   199   201   221   241   260   273   281   301   334   365
16  *49
    *50
    *50.2           52.0        52.0        52.0        52.0        52.2        52.5        52.8        53.1
17  *50.3           53.4        53.8        54.3        54.9        55.6        56.5        57.4        58.2
    *50.4           59.1        60.0        61.3        63.3        66.0        69.8        74.3        75.0
    *50.5           75.3        75.7        75.9        76.2        75.5
    *55       25.7  16.9  19.9  27.4  21.0  10.3   7.8   3.7  15.8  13.8  28.8  25.1  28.6  32.1  38.7  42.4
    *56       24.7   7.0   2.2  10.2   3.9  19.9  30.0  41.6  49.6  44.4  45.1  52.2  32.7  35.2  37.9  37.6
    *57       21.2  18.6  30.2  44.8  36.0  47.0  35.6  28.2  43.0  28.2  36.1  27.2  26.2  22.1  39.0  48.3
    *58       41.0  31.3  39.2  46.8  42.8  44.3  46.7  34.0  41.0  52.8  46.7  52.8  58.5  56.5  46.8  47.8
    *59       48.7  44.4  55.7  53.1  35.4  30.9  28.4  35.7  39.7  34.5  31.6  33.1  36.9  37.7  33.6  35.1
    *60       39.6  42.7  48.8  44.6  42.0  50.2  38.5  38.4  43.3  45.5  44.5  49.2  57.6  40.7  54.0  61.6
    *61       59.8  60.3  55.8  64.4  65.0  60.4  44.3  55.4  56.1  64.9  62.9  64.4  54.9  59.0  64.3  64.7
    *62       54.6  65.5  61.9  72.4  73.6  74.0  72.1  65.4  55.4  69.6  69.6  72.3  73.7  73.6  68.8  68.6
    *63       64.9  74.3  76.0  75.6  75.5  73.7  61.1  69.0  73.7  76.3  77.2  77.7  78.4  75.5  78.7  79.8
    *64       72.3  80.2  67.9  75.9  72.4  75.6  76.8  70.4  67.9  71.6  67.2  66.9  79.4  81.0  78.3  72.9
    *65       74.0  71.8  77.0  84.7  83.0  83.5  82.4  81.0  84.3  75.0  84.0  73.5  81.5  77.2  80.5  83.1
18  *66       80.5  84.8  78.1  82.9  85.4  88.6  88.5  82.4  74.8  82.5  77.1  79.3  83.9  88.0  82.4  78.0
    *67       86.4  86.2  85.3  80.7  90.2  87.2  78.9  82.6  62.0  73.7  75.2  74.2  81.9  81.0  80.2  83.7
    *68       81.7  84.5  83.7  86.8  86.5  91.9  91.0  85.1  83.0  81.2  81.5  82.7  77.9  78.8  75.6  82.7
    *69       83.9  81.4  82.3  84.2  82.3  81.9  82.6  79.4  79.7  76.8  79.9  77.7  85.4  81.8  81.5  81.6
    *70       81.2  83.2  81.1  81.1  74.3  74.8  75.5  79.9  81.0  82.0  79.8  74.2  68.0  73.5  76.5  76.0
    *71       80.9  81.9  80.8  78.0  75.8  83.3  79.5  77.6  71.5  66.0  74.4  68.9  52.4  68.2  70.3  69.9
    *72       75.2  69.3  71.4  64.3  64.9  67.2  67.5  65.6  49.1  38.5  54.5  56.2  58.9  54.5  49.2  48.6
    *73       60.4  48.2  48.3  55.6  59.7  59.8  58.1  56.5  60.0  64.7  60.0  47.5  49.2  50.3  52.5  43.0
    *74       37.8  35.4  35.0  33.9  45.5  49.4  55.3  51.5  43.0  51.3  42.2  39.7  39.0  31.4  30.4  39.4
    *75       39.6  48.8  41.5  42.5  44.8  32.2  18.5  20.7  43.3  52.4  45.0  47.4  57.3  56.9  50.7  50.5
    *76       46.6  43.1  35.1  36.0  39.6  46.7  54.6  48.1  31.2  23.6  35.1  40.0  37.3  34.1  44.7  42.7
    *77       51.2  32.9  41.8  46.5  32.6  26.9  22.7  30.5  30.4  35.5  40.8  34.9  26.8
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     380     93.0 60.7 76.7 58.2 82.8 77.4 79.2 73.9 66.5 65.3 62.5 73.5 69.4 66.8 49.4 97.5
     381    103.7 66.7 47.7 62.1 75.9 62.0 64.4 86.1 67.9 69.5 92.0105.3132.2125.8 92.1 73.3
     382     70.0 53.6 71.3 90.3 88.3 85.5 82.2 56.4 67.3 51.8 66.4 68.0 70.7 66.8 67.5 54.3
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     390    109.1123.5123.4113.2 66.1105.8135.8166.5103.8 93.2 87.9 85.8106.8130.7123.1130.7
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     395     65.9 69.2 71.8 67.2 99.8123.5159.4172.5109.4 83.7 75.2 89.6 63.6 76.4 73.4 77.2
     396     35.3 46.6 53.5 42.7 51.9100.6124.0121.9 71.0102.6 92.2 73.4 67.2 69.1 63.0 53.5
     397     51.2 55.9 61.4 63.6 64.6 74.5 51.1103.6 80.4 52.0 82.7 66.1 63.0 82.7 61.5 61.7
     398     63.2 52.0 93.7 73.8 88.5 77.5 73.5 44.8113.8140.9 72.5 62.7 93.1 98.1 84.9 72.7
     399     97.4 46.6 60.0 38.8 72.0102.7 66.5 91.3 83.9 50.3 43.9 62.3 97.3 65.0 86.1 92.3
     400     62.3 62.1 61.8 61.9 63.4 44.8 60.6 55.4 38.3 48.5 31.0 80.2 51.3
     401     10.4 12.7  9.2 10.4 15.0 16.1 11.5 15.0 12.7 17.3 15.0  9.2 11.5  9.2 10.4 10.4
     402     12.7 13.8  8.1 13.8 10.4 16.1 11.5 15.0 11.5  9.2 12.7 18.4 17.3 12.7 15.0 16.1
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     404     19.6 13.8  8.1 10.4 12.7  9.2  9.2 18.4 12.7 10.4 15.0 15.0 17.3 17.3 16.1 12.7
     405     11.5  8.1 10.4 13.8 17.3 17.3 17.3 10.4 12.7  9.2 12.7 12.7 12.7 11.5 12.7  9.2
     406      9.2 13.8 11.5 18.4 16.1  9.2 15.0 12.7 11.5 12.7 17.3 17.3 10.4 12.7  9.2 11.5
     407     15.0 18.4  8.1  9.2 13.8 18.4 21.9 15.0 18.4  8.1 15.0 19.6 17.3 15.0 10.4 20.7
     408     13.8 10.4 15.0 12.7 18.4 16.1 15.0 12.7 16.1  6.9  9.2  9.2 10.4 11.5 16.1 17.3
     409     19.6 13.8 16.1 17.3 13.8 16.1 10.4 10.4 10.4 10.4 10.4 11.5 11.5  9.2 11.5 10.4
     410     11.5  6.9 12.7 13.8 13.8 12.7 10.4  9.2  8.1 10.4 11.5 12.7  9.2  8.1 11.5 16.1
20   411     18.4 18.4 17.3 11.5 10.4 11.5 13.8 16.1  9.2 12.7  9.2 10.4  6.9 12.7 16.1  8.1
     412     12.7  6.9 15.0 15.0 11.5  9.2  9.2 13.8 12.7  6.9 11.5 13.8 11.5  5.7  6.9  9.2
     413      8.1  9.2  9.2  9.2  4.6  8.1 11.5 13.8 12.7 10.4  9.2  8.1  9.2 11.5 10.4 10.4
     414     10.4 12.7 10.4  9.2  8.1  5.7  6.9 11.5 12.7 12.7 13.8 13.8 15.0 12.7  9.2  6.9
     415      6.9 11.5 12.7  9.2 11.5 16.1 12.7 11.5 11.5  8.1  8.1  8.1  4.6  6.9  8.1  9.2
     416     11.5 10.4  6.9  9.2 12.7 13.8 11.5 11.5 15.0 12.7  6.9 13.8 11.5 12.7 15.0  6.9
     417      9.2 10.4  9.2  9.2  9.2  5.7 12.7 15.0 13.8 13.8  9.2 11.5 12.7  4.6  5.7  8.1
     418      5.7  6.9  8.1  8.1 11.5 13.8 17.3 19.6 18.4 15.0 10.4 11.5  6.9 10.4 11.5 12.7
     419      3.5  5.7  6.9  4.6  5.7 12.7 16.1 16.1  8.1 11.5 11.5 11.5 10.4 10.4  9.2  8.1
     420      8.1  9.2 10.4 11.5 10.4 11.5  5.7 16.1 13.8  6.9 13.8 10.4 10.4 17.3 11.5 10.4
     421     10.4  6.9 17.3 12.7 16.1 17.3 17.3  8.1 18.4 21.9 11.5  8.1 11.5 13.8 12.7 10.4
     422     18.4  6.9 11.5  5.7 12.7 16.1  8.1 16.1 17.3  9.2  6.9 10.4 18.4 11.5 13.8 17.3
     423     11.5 10.4  9.2 10.4 12.7  8.1 12.7 10.4  5.7  8.1  3.5 15.0 10.4
     424        758.8     636.0     923.4     824.7     334.1     942.3     891.9     958.2     960.2     349.9
     425        346.6     463.7     868.3     761.6     975.9     759.9     362.3     609.7     377.9     504.0
     426        385.8     384.8     383.0     877.3     878.8     843.7     350.0     518.4    1005.9    1147.1
     427        902.4     417.4     428.6    1212.8     583.5    1196.7     436.0     433.5     742.6     612.3
21   428       1274.0     456.6    1240.7     477.1     481.2     498.4    1369.1    1383.5    1169.7    1437.9
     429       1450.5    1305.9     516.5     517.5     519.9    1530.0    1541.2    1186.0     545.3     539.7
     430        538.2     738.7    1453.8    1508.9     977.9     589.3    1670.9    1410.8     609.6     619.7
     431        629.9    1504.2    1799.8    1078.0     653.5     657.6     561.4     665.8     677.4     682.0
```

432	924.2	1152.9	594.9	595.6	1183.5	1397.4	720.9	726.6	728.5	729.8
433	735.3	2121.8	1909.7	760.7	1669.1	2166.2	2189.9	1499.4	1062.3	1720.7
434	2217.3	1530.5	1090.6	2051.2	1086.4	1075.9	1337.3	784.6	805.0	1611.9
435	2239.9	1357.0	832.5	1999.7	1121.2	2287.2	2176.2	1091.3	804.9	827.5
436	1895.3	2488.0	2475.0	2462.5	2409.2	2455.8	2227.7	2080.1	867.6	2199.8
437	1872.1	1872.3	1432.2	1441.8	1213.1	2590.6	2556.1	2546.3	2540.3	2527.6
438	2387.8	1203.0	2121.6	2282.2	1758.9	2626.5	1252.3	2176.0	897.1	1497.7
439	1509.9	904.2	921.3	2048.4	1258.9	1266.4	2629.6	2625.5	2621.0	1535.1
440	1787.3	1239.8	2169.6	1941.8	1481.1	1736.0	2300.7	2519.4	1982.3	1531.8
441	2318.1	1818.6	2381.4	1780.9	2299.6	1986.8	2591.3	2628.1	2590.7	2833.1
442	2265.0	2459.9	2519.2	2400.5	2644.7	2647.5	2567.5	2319.3	2554.8	2600.6
443	1758.0	880.8	2459.5	2445.9	2091.1	1718.6	2570.2	2516.2	1182.0	2422.1
444	905.2	2602.7	2585.3	1201.4	2443.0	2420.9	1676.9	2175.9	1859.4	2322.2
445	2004.3	2244.3	1973.3	2103.8	2278.9	2080.5	1782.6	1352.8	1564.5	1562.7
446	1080.7	1768.0	1351.6	2079.2	2308.9	2262.1	2191.9	2014.2	1860.1	1965.1
447	1827.5	1496.2	1673.0	752.9	2159.9	2210.1	2197.6	2173.1	2147.8	2115.0
448	2030.3	1841.7	714.8	1186.1	713.8	1192.4	938.3	1153.9	1732.1	1884.3
449	918.8	1997.7	1670.6	1860.2	1831.5	648.6	1417.3	1799.2	1393.5	853.9
450	1052.0	1467.6	1690.2	1444.5	617.1	1045.9	1692.5	1476.4	626.2	1338.3
451	1522.8	1581.2	1628.7	951.3	1657.8	1638.7	1577.2	1070.6	1043.6	720.5
452	560.9	557.2	1494.0	711.2	516.7	525.8	714.8	1330.0	1458.9	507.2
453	500.0	666.9	1062.9	1196.9	469.3	464.4	617.0	1250.9	608.6	462.9
454	1283.0	1263.1	958.8	445.9	442.5	437.3	431.5	431.1	1178.2	1121.9
455	772.8	405.0	406.4	1106.2	395.2	389.3	390.2	393.6	834.5	1034.0
456	375.9	979.9	371.4	1008.0	1004.6	848.7	1005.0	685.4	649.4	555.0
457	344.5	331.0	325.8	332.6	910.0	536.5	929.9	891.2	721.5	908.2
458	900.6	519.2	714.2	431.2	324.2	323.3	392.4	872.2	317.3	317.4
459	853.5	318.9	424.9	312.9	310.5	739.3	394.4	800.3	870.5	893.4
460	322.4	697.0	889.6	321.1	331.3					

Appendix B.8
THERMAL SIMULATION PROGRAM
SAMPLE OUTPUT

```
WATER QUALITY SECTION

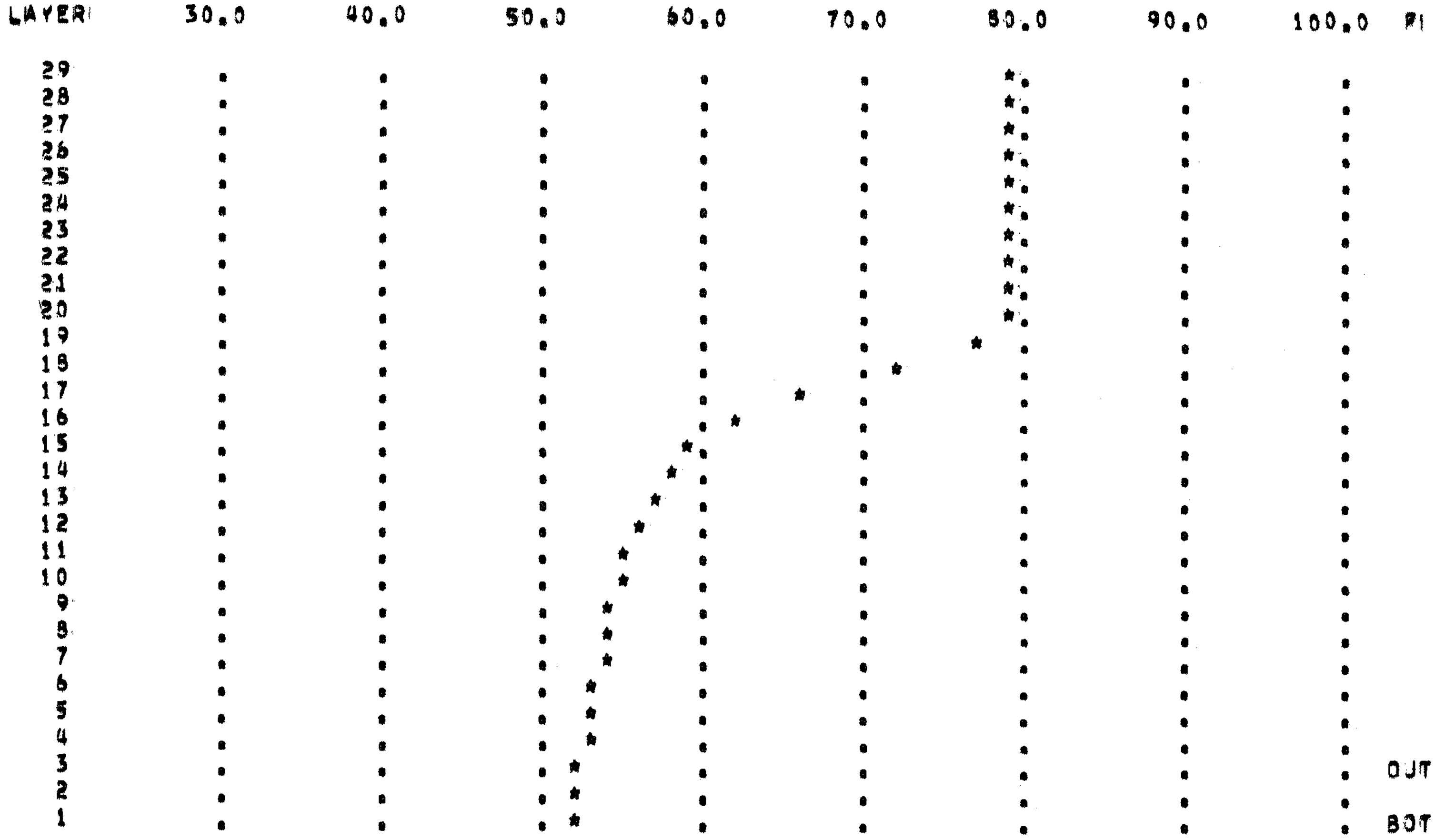
DAY NUMBER 189  PERIOD NUMBER  1

 LAYER   ELEV    TEMP    INFLOW   OUTFLOW    VEL 1      VEL 2     RES WDTH   RES AREA  SW DEG  SW PCT

   29   836.41  79.24     0.00     0.00   0.000000  0.000000   9090.00    7166.8   7.34   13.75
   28   832.50  79.24     0.00     0.00   0.000000  0.000000   8865.00    6640.5    .79   11.08
   27   829.50  79.24     0.00     0.00   0.000000  0.000000   8595.00    6184.5    .50    7.06
   26   826.50  79.24     0.00     0.00   0.000000  0.000000   7738.33    5749.5    .32    4.50
   25   823.50  79.24     0.00     0.00   0.000000  0.000000   6166.67    5313.0    .21    2.87
   24   820.50  79.24     0.00     0.00   0.000000  0.000000   5403.33    4904.0    .13    1.83
   23   817.50  79.24     0.00     0.00   0.000000  0.000000   4666.67    4535.5    .08    1.17
   22   814.50  79.24     0.00     0.00   0.000000  0.000000   4051.67    4178.5    .05     .74
   21   811.50  79.24     0.00     0.00   0.000000  0.000000   3721.67    3834.0    .03     .47
   20   808.50  79.24     0.00     0.00   0.000000  0.000000   3538.33    3527.0    .02     .30
   19   805.50  77.00    30.00     0.00   0.000000  0.000000   3400.00    3245.0    .01     .19
   18   802.50  72.43     0.00     0.00   0.000000  0.000000   3226.67    2963.0    .01     .12
   17   799.50  66.22     0.00     0.00   0.000000  0.000000   3110.00    2655.5    .01     .08
   16   796.50  61.62     0.00     0.00   0.000000  0.000000   3000.00    2322.5    .00     .05
   15   793.50  59.07     0.00     0.00   0.000000  0.000000   2810.00    1989.5    .00     .03
   14   790.50  57.66     0.00     0.00   0.000000  0.000000   2615.00    1673.5    .00     .02
   13   787.50  56.72     0.00     0.00   0.000000  0.000000   2365.00    1382.3    .00     .01
   12   784.50  55.99     0.00     0.00   0.000000  0.000000   2170.00    1114.3    .00     .01
   11   781.50  55.40     0.00     0.00   0.000000  0.000000   2110.00     903.5    .00     .01
   10   778.50  54.90     0.00     0.00   0.000000  0.000000   2090.00     754.5    .00     .00
    9   775.50  54.47     0.00     0.00   0.000000  0.000000   1995.00     625.5    .00     .00
    8   772.50  54.11     0.00     0.00   0.000000  0.000000   1730.00     496.5    .00     .00
    7   769.50  53.77     0.00     3.51   0.000000   .001321   1337.50     387.0    .00     .00
    6   766.50  53.42     0.00     4.52   0.000000   .005176    440.00     297.0    .00     .00
    5   763.50  53.06     0.00     4.90   0.000000   .009672    255.00     207.0    .00     .00
    4   760.50  52.72     0.00     4.64   0.000000   .012283    190.00     135.0    .00     .00
    3   757.50  52.43     0.00     4.14   0.000000   .012648    165.00      90.0    .00     .00
    2   754.50  52.21     0.00     2.93   0.000000   .009774    151.00      54.0    .00     .00
    1   751.50  52.08     0.00      .36   0.000000   .003592     50.00      18.0    .00     .00
```

WATER QUALITY SECTION

TEMPERATURE PROFILE FOR DAY 189   PERIOD NUMBER 1



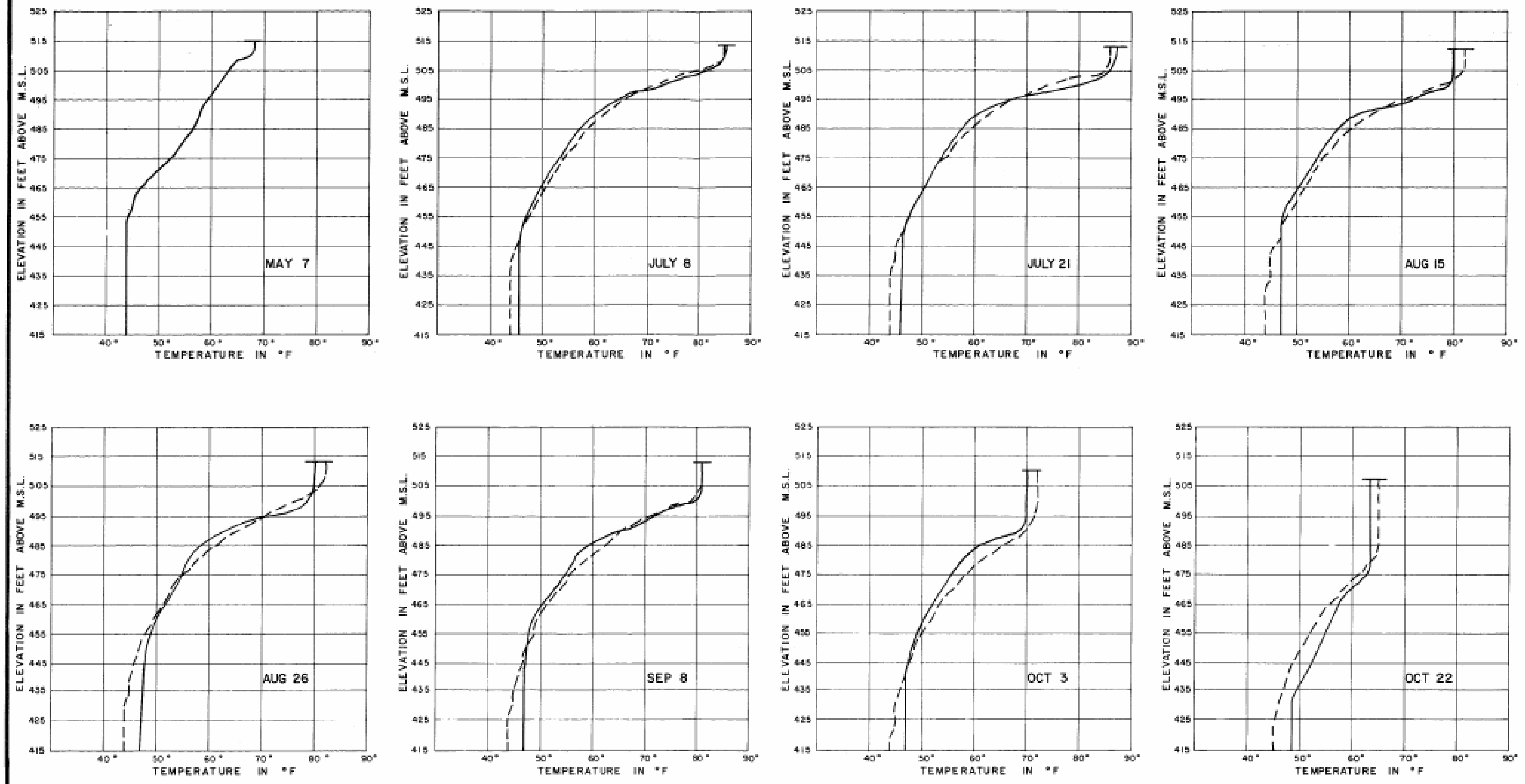
OUTLET NUMBER 1

BOTTOM ELEV = 750.0

```
WATER QUALITY SECTION

DAY PERI POOLI  INFLOW  ITEMPI OUTFLOWI  OUTLET  NO  OUTLET  NOI OTEMPI TARGET EQTEMP EXCOEFI TSURFI AVTEMPI BETA

190   1  838.8    15.0  76.0      25.0      0.   0     25.0  1  55.0  75.5   88.0    76.5  79.8  75.2  .86
191   1  838.8    15.0  76.0      25.0      0.   0     25.0  1  55.0  75.6   82.4    87.1  79.8  75.3  .86
192   1  838.8    15.0  74.1      25.0      0.   0     25.0  1  55.0  75.8   78.0   111.6  79.6  75.2  .86
193   1  838.8   155.0  74.7      25.0      0.   0     25.0  1  55.0  75.9   86.4   109.1  80.1  75.5  .86
194   1  838.8    80.0  76.0      25.0      0.   0     25.0  1  55.0  76.0   86.2   123.5  80.5  75.8  .86
195   1  838.8    70.0  76.7      25.0      0.   0     25.0  1  55.1  76.1   85.3   123.4  80.8  76.0  .86
196   1  838.8    60.0  76.3      25.0      0.   0     25.0  1  55.1  76.2   80.7   113.2  80.7  76.0  .86
197   1  838.7    50.0  74.9      25.0      0.   0     25.0  1  55.1  76.4   90.2    66.1  81.3  76.2  .86
198   1  838.7    20.0  75.1      25.0      0.   0     25.0  1  55.1  76.5   87.2   105.8  81.5  76.4  .86
199   1  838.7    15.0  75.4      25.0      0.   0     25.0  1  55.1  76.6   78.9   135.8  81.1  76.3  .86
200   1  838.7    10.0  78.5      25.0      0.   0     25.0  1  55.1  76.7   82.6   166.5  80.9  76.3  .86
201   1  838.6    10.0  73.0      25.0      0.   0     25.0  1  55.2  76.8   62.0   103.8  79.7  75.5  .86
```



NOTES :

COMPUTED — — —
MEASURED ———
FIRST DAY OF SIMULATION — MAY 7

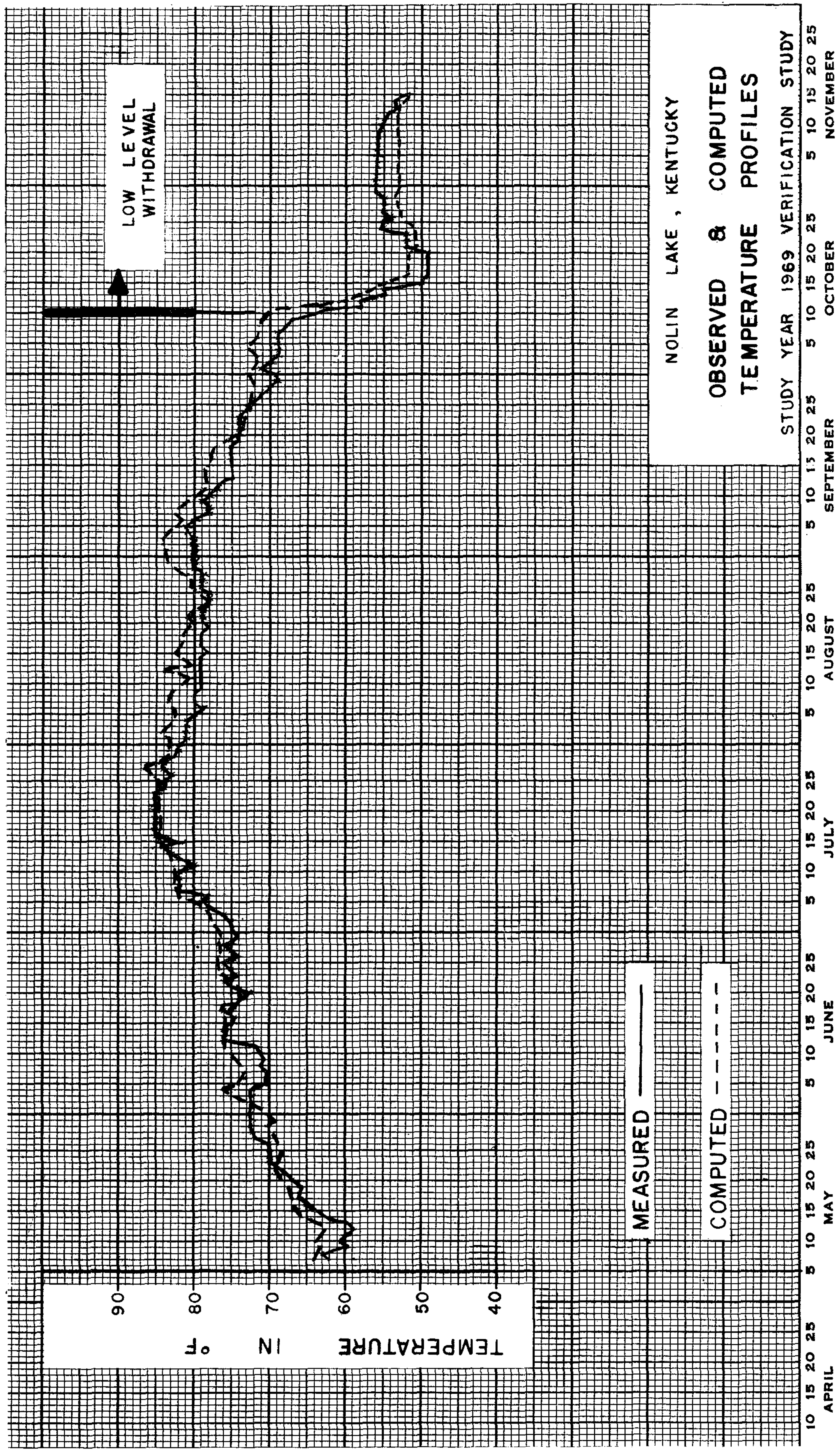
DEPARTMENT OF THE ARMY
BALTIMORE DISTRICT, CORPS OF ENGINEERS
BALTIMORE, MARYLAND

NOLIN LAKE, KENTUCKY

OBSERVED & COMPUTED TEMPERATURE PROFILES

STUDY YEAR 1969 VERIFICATION STUDY

EXHIBIT I



NOLIN LAKE, KENTUCKY

OBSERVED & COMPUTED TEMPERATURE PROFILES

STUDY YEAR 1969 VERIFICATION STUDY

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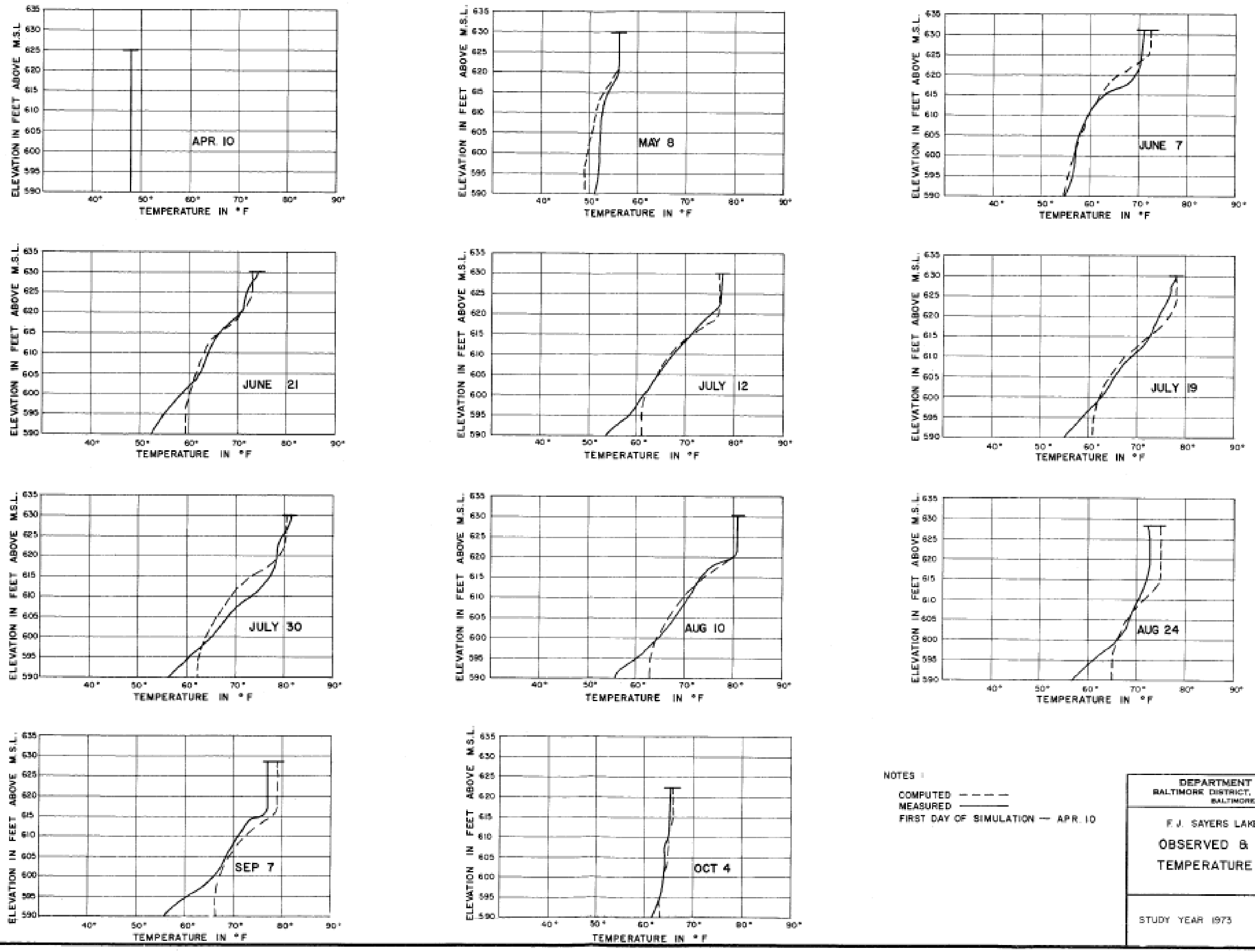


NOTES :

COMPUTED – – – –
MEASURED ———
FIRST DAY OF SIMULATION — APR. 10

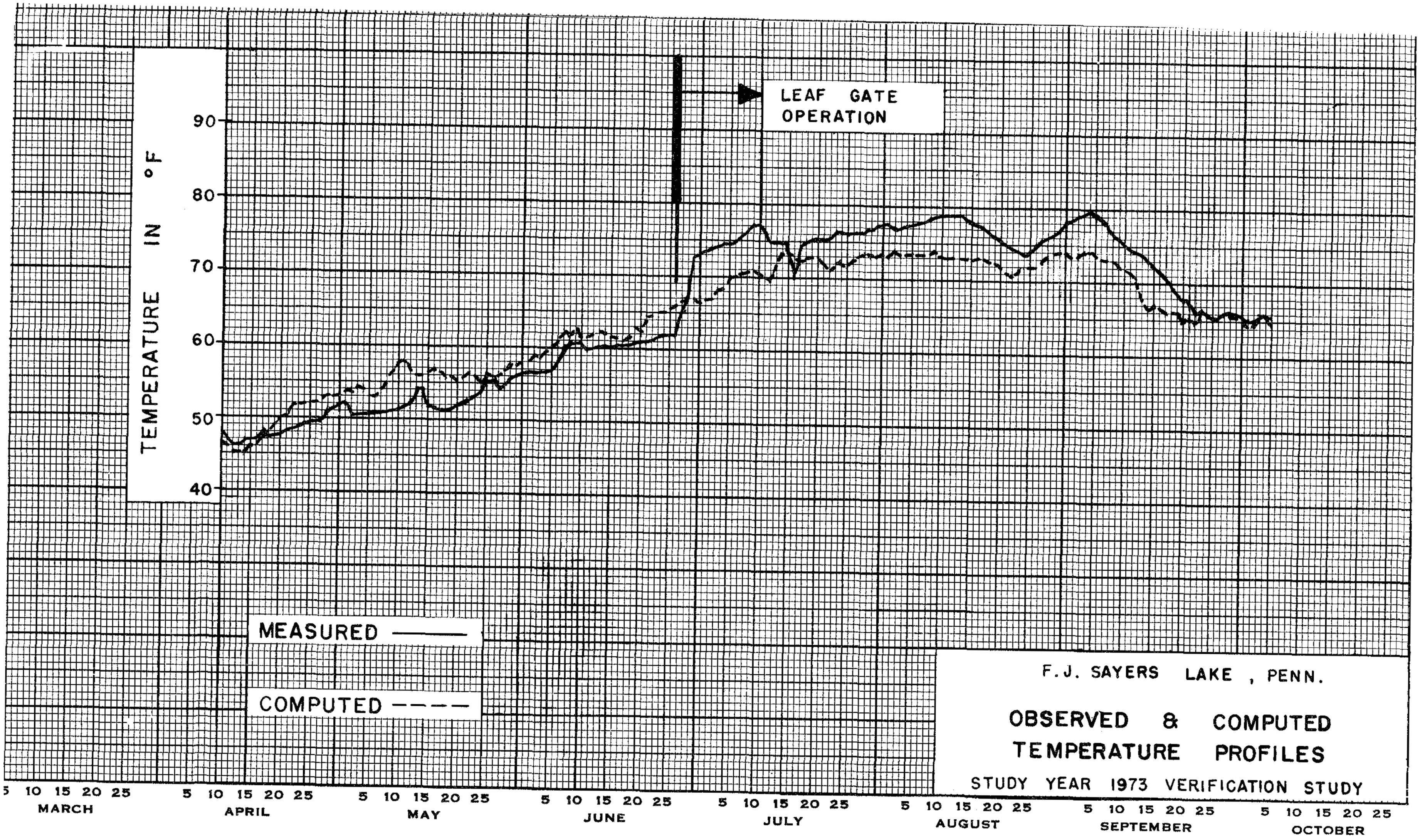
DEPARTMENT OF THE ARMY
BALTIMORE DISTRICT, CORPS OF ENGINEERS
BALTIMORE, MARYLAND

F. J. SAYERS LAKE, PENNSYLVANIA

OBSERVED & COMPUTED
TEMPERATURE PROFILES

STUDY YEAR 1973 VERIFICATION STUDY

EXHIBIT 3

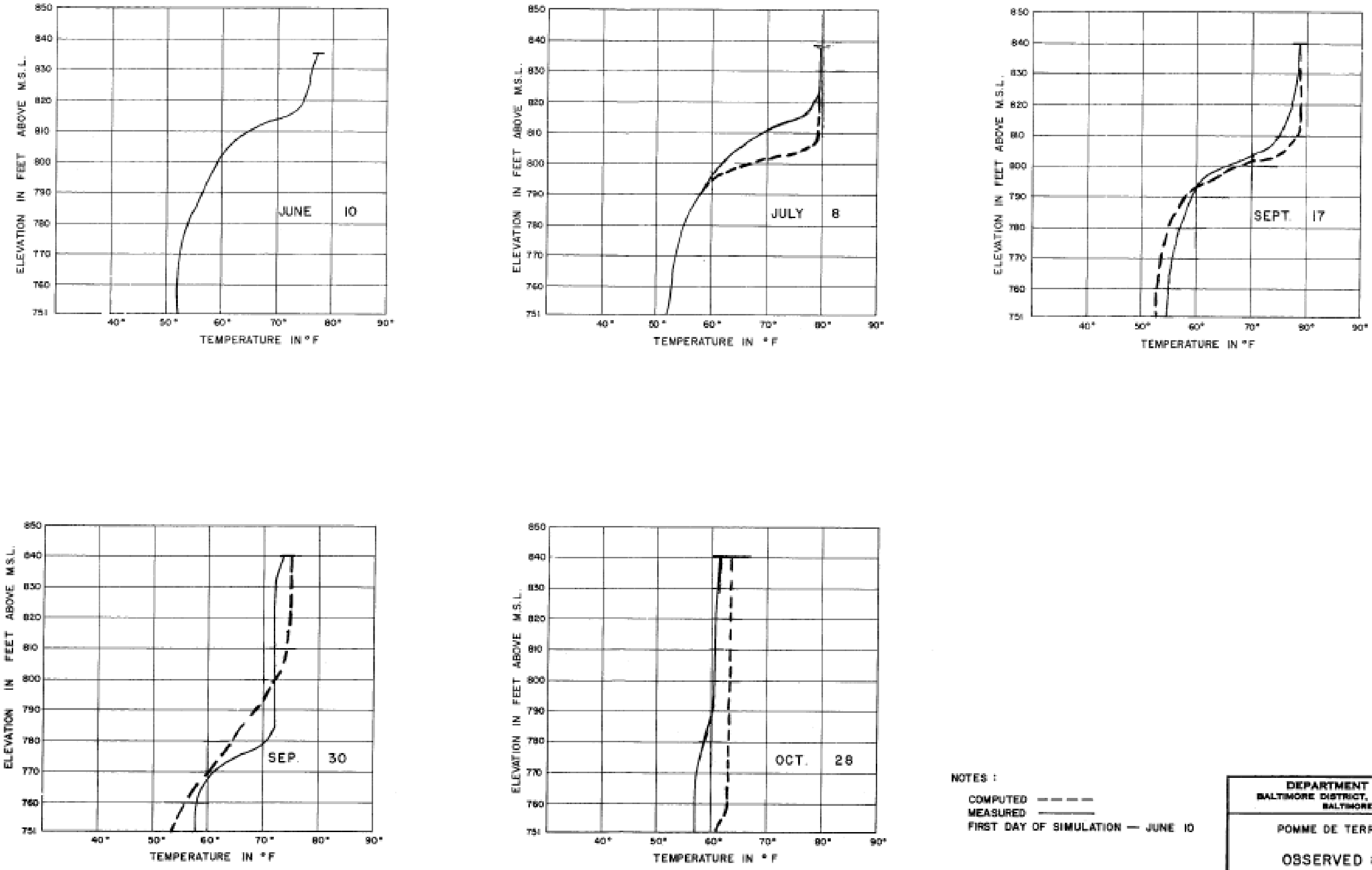


F.J. SAYERS LAKE , PENN.

OBSERVED & COMPUTED TEMPERATURE PROFILES

STUDY YEAR 1973 VERIFICATION STUDY

EXHIBIT 4



NOTES :

COMPUTED – – – –
MEASURED ————
FIRST DAY OF SIMULATION — JUNE 10

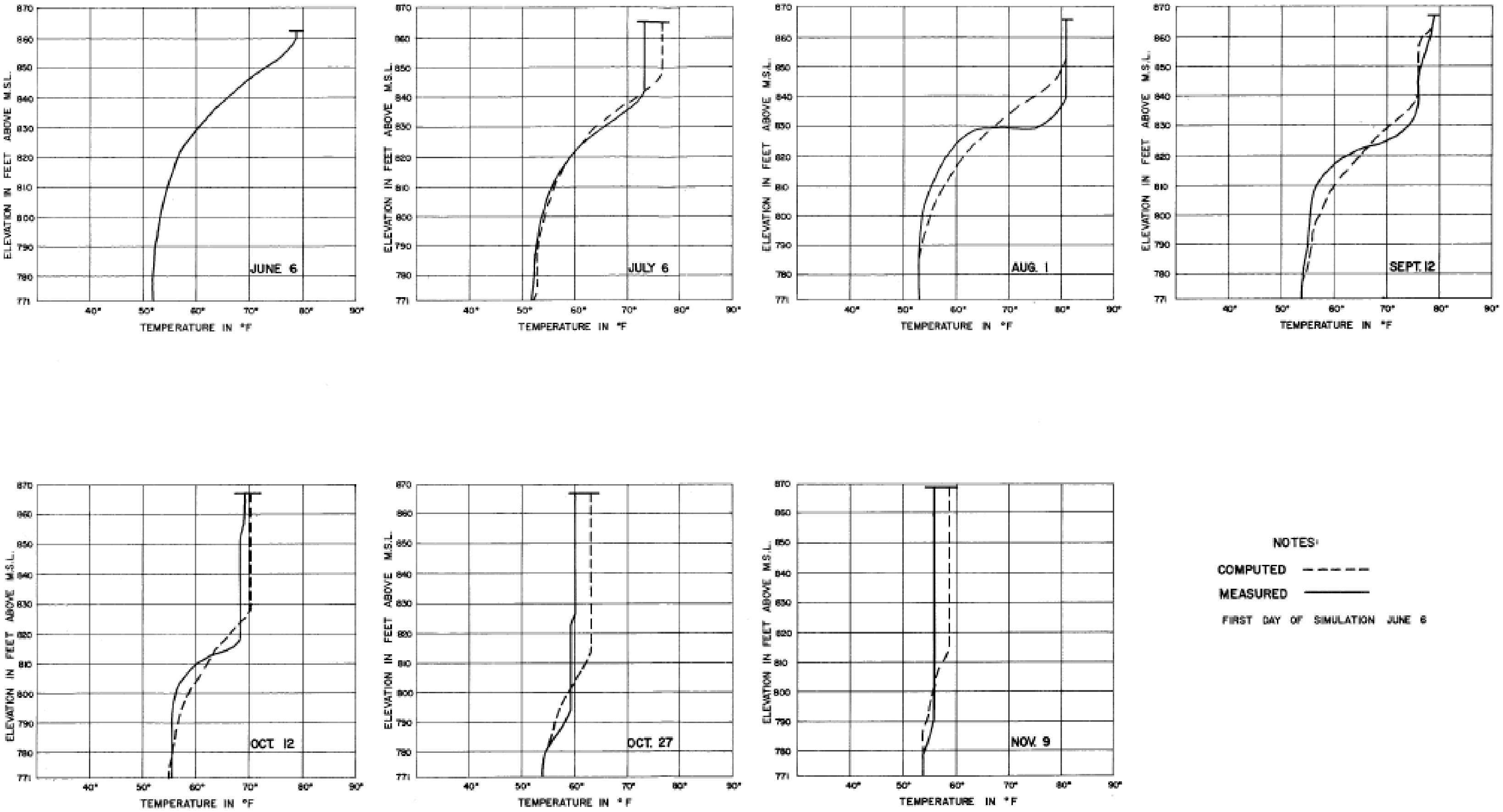
DEPARTMENT OF THE ARMY
BALTIMORE DISTRICT, CORPS OF ENGINEERS
BALTIMORE, MARYLAND

POMME DE TERRE LAKE, MISSOURI

OSSERVED & COMPUTED
TEMPERATURE PROFILES

STUDY YEAR 1970 VERIFICATION STUDY

EXHIBIT 5



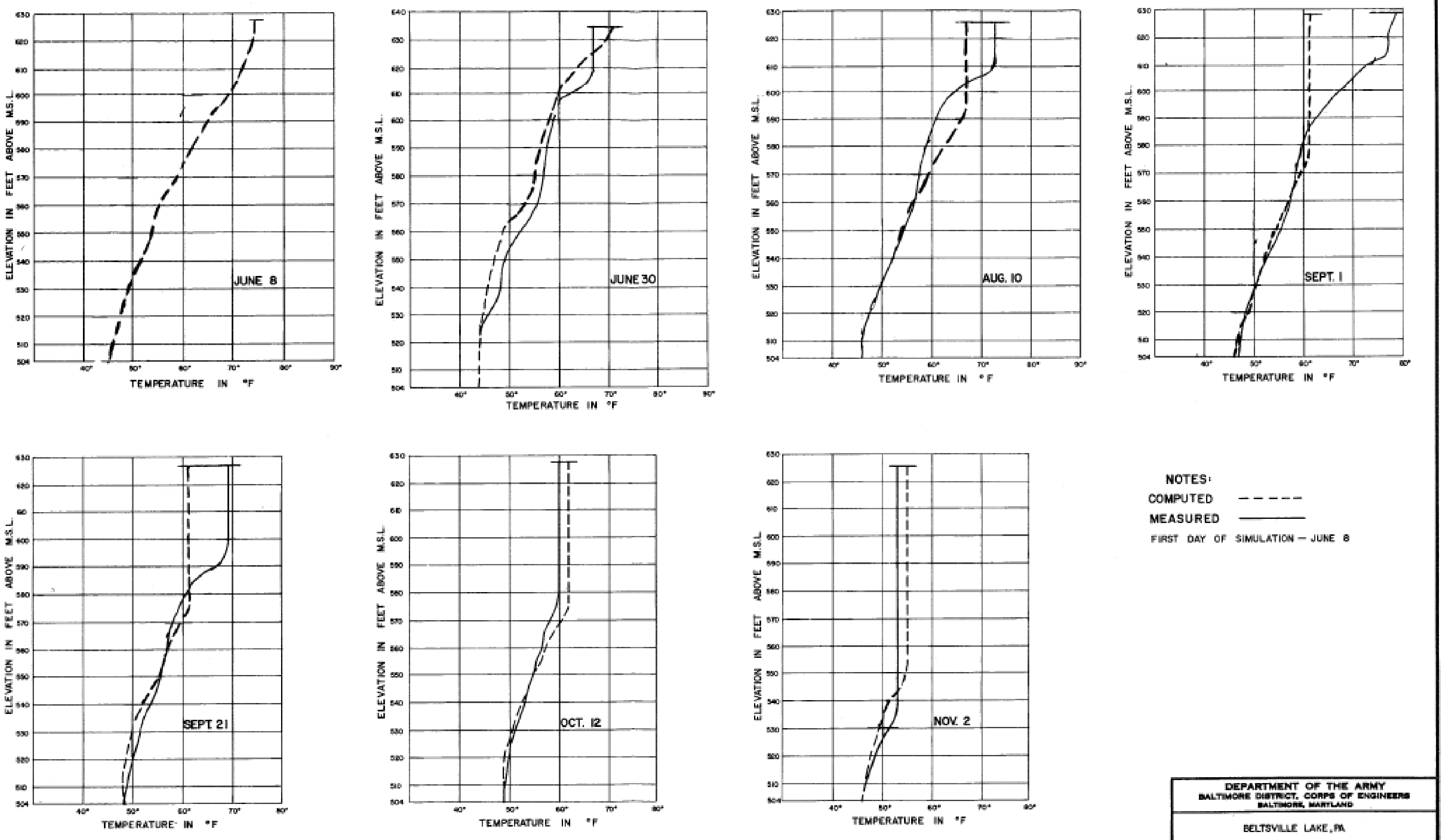
DEPARTMENT OF THE ARMY
BALTIMORE DISTRICT, CORPS OF ENGINEERS
BALTIMORE, MARYLAND

STOCKTON LAKE, MISSOURI

OBSERVED & COMPUTED
TEMPERATURE PROFILES

STUDY YEAR 1972 VERIFICATION STUDY

EXHIBIT 6



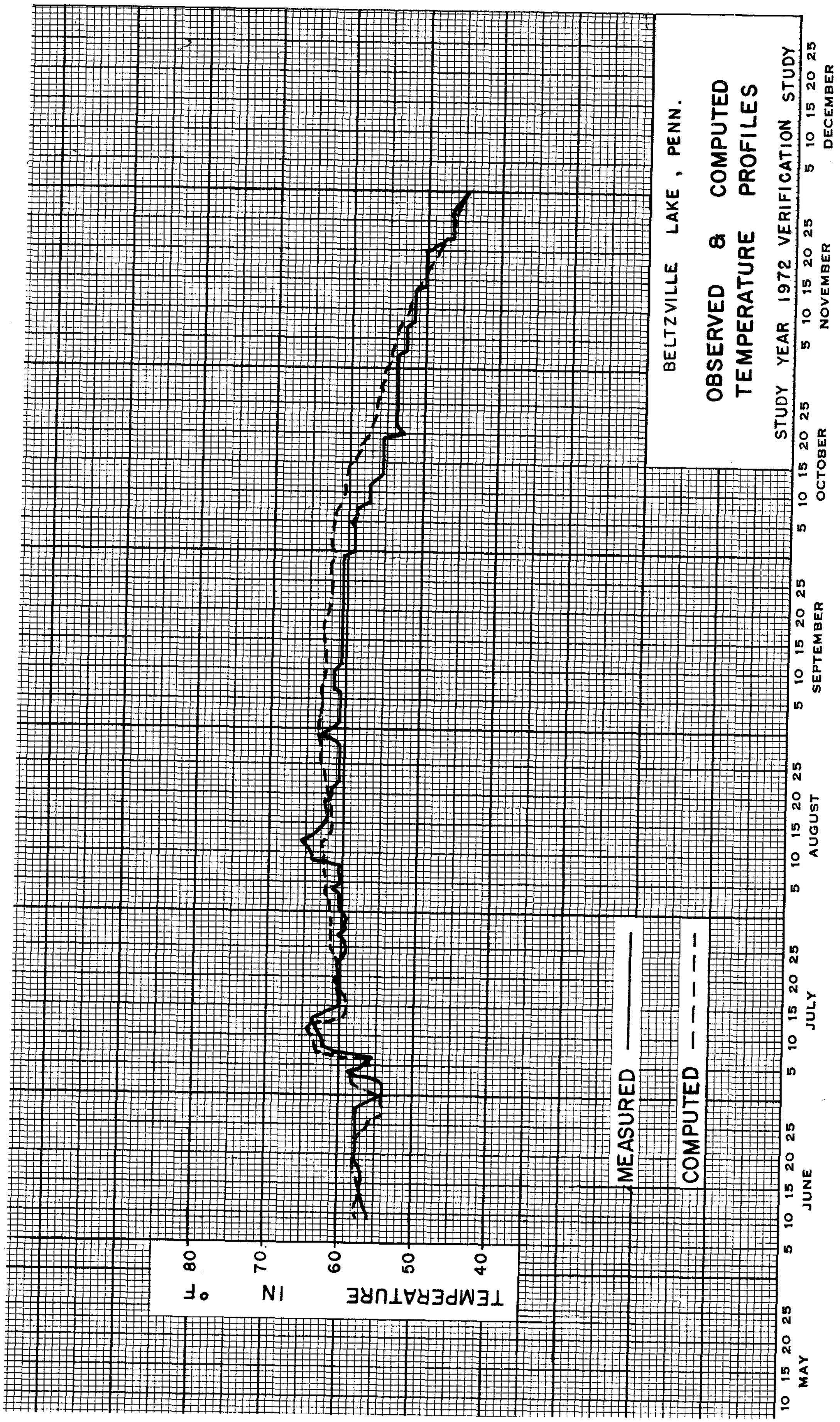
DEPARTMENT OF THE ARMY
BALTIMORE DISTRICT, CORPS OF ENGINEERS
BALTIMORE, MARYLAND

BELTSVILLE LAKE, PA.

OBSERVED & COMPUTED
TEMPERATURE PROFILES

STUDY YEAR 1972 VERIFICATION STUDY

EXHIBIT 7

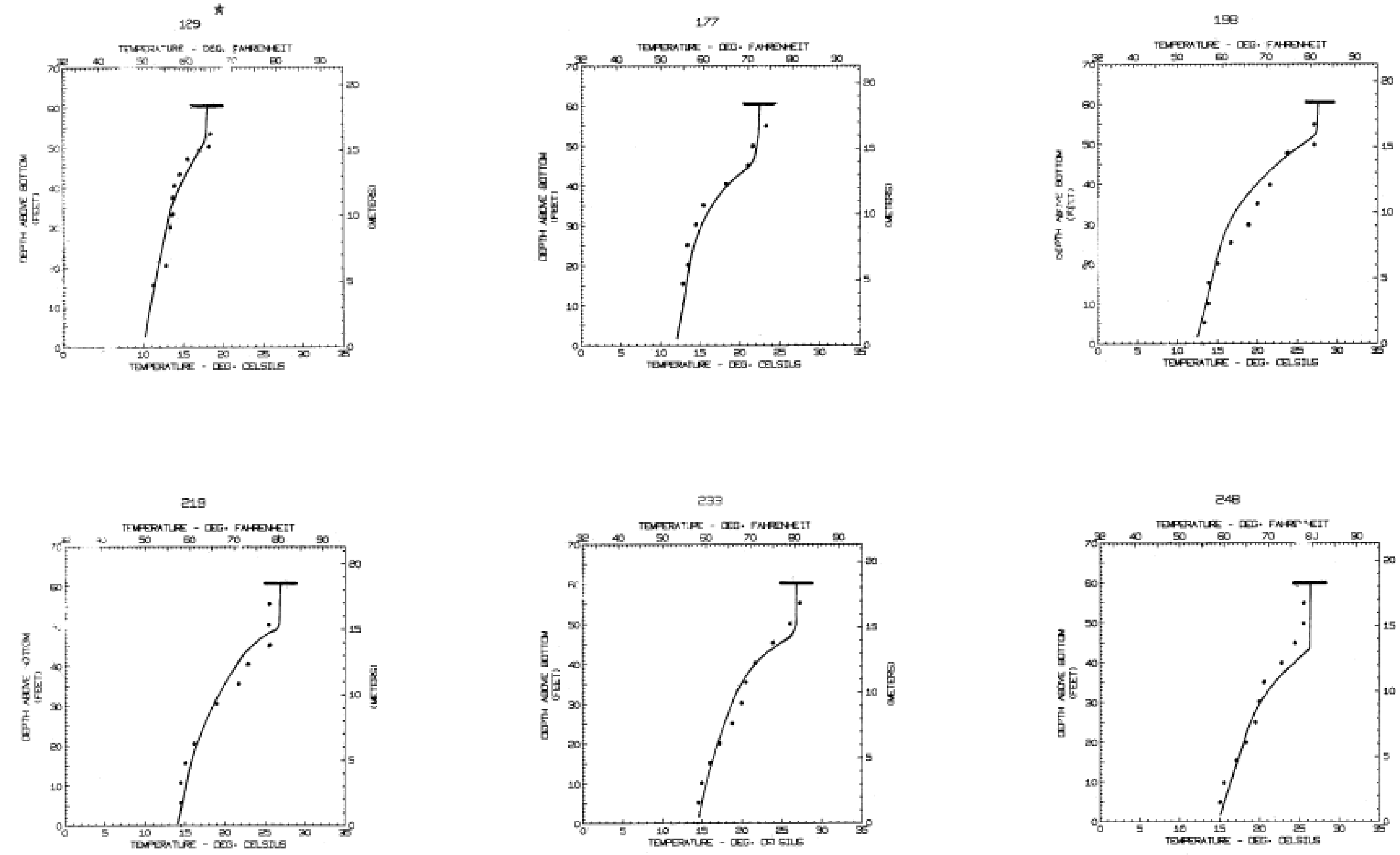


BELTZVILLE LAKE, PENN.

OBSERVED & COMPUTED TEMPERATURE PROFILES

STUDY YEAR 1972 VERIFICATION STUDY

EXHIBIT 8



U.S. ARMY ENGINEER DIVISION, OHIO RIVER
RESERVOIR CONTROL CENTER
CINCINNATI, OHIO

GRAYSON LAKE, KENTUCKY

OBSERVED & COMPUTED TEMPERATURE PROFILES

STUDY YEAR 1972

VERIFICATION STUDY

EXHIBIT 9