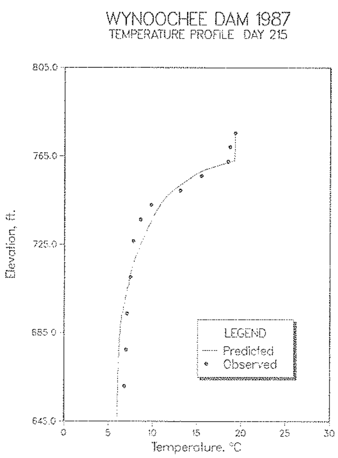
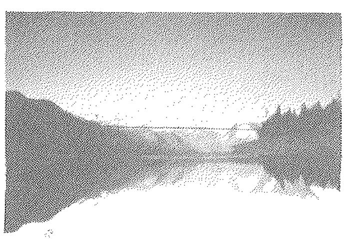
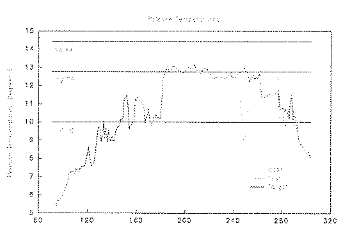
US Army Corps of Engineers







HYDRAULICS LABORATORY

MISCELLANEOUS PAPER HL-90-7

WYNOOCHEE DAM WATER TEMPERATURE CONTROL STUDY

by

Sandra K. Martin, Stacy E. Howington

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

August 1990

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for US Army Engineer District, Seattle
Seattle, Washington 98124-2255

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Miscellaneous Paper HL-90-7	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Hydraulics Laboratory 6b. OFFICE SYMBOL (If applicable) CEWES-HS-R	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 3909 Halls Ferry Road Vicksburg, MS 39180-6199	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Seattle 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) PO Box C-3755 Seattle, WA 98124-2255	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Wynoochee Dam Water Temperature Control Study

12. PERSONAL AUTHOR(S)
Martin, Sandra K.; and Howington, Stacy E.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM ______ TO ______	August 1990	77

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Fish passage
Hydropower
Selective withdrawal
Single wet well blending
Thermal stratification
Wynoochee Lake and Dam

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
The US Army Engineer Waterways Experiment Station was tasked with evaluating the water temperature release capabilities of a proposed hydropower intake structure at Wynoochee Dam near Montesano, WA. The existing dam structure has passageways for juvenile fish migrating downstream and has flexible operation capabilities due to multilevel ports to meet downstream target temperatures. The hydropower developers have proposed a single wet well intake structure with two variable-opening gates. The study objective was to demonstrate the ability of the proposed structure to meet water temperature objectives at least equal to that of the existing structure. All objectives were accomplished by modifying and using the one-dimensional thermal simulation model, WESTEX. After verification of WESTEX to 2 years of historical temperature release data, prediction runs were made using an assumed range of intake loss coefficients and withdrawal angles for 3 years of data. The study concluded that the combination of the existing and proposed structures can meet downstream target temperatures as well as the existing structure alone.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

PREFACE

This numerical model investigation was conducted for the US Army Engineer District, Seattle, in compliance with a Federal Energy Regulatory Commission requirement for the City of Aberdeen, WA. A water temperature model control study was conducted for Wynoochee Lake, Washington, to evaluate a proposed hydropower intake structure.

The study was conducted by personnel of the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), during the period December 1987 to February 1990. The study was conducted under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL; R. A. Sager, Assistant Chief, HL; and G. A. Pickering, Chief, Hydraulic Structures Division (HSD), HL. The study was conducted and this report prepared by Mr. Stacy E. Howington and Ms. Sandra K. Martin, Reservoir Water Quality Branch (RWQB), HSD, under the supervision of Dr. J. P. Holland, Chief, RWQB.

COL Larry B. Fulton, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
degrees (angle)	0.1745329	radians
Fahrenheit degrees	5/9*	Celsius degrees or kelvins
gallons	3.785412	cubic decimetres
inches	25.4	millimetres
miles (US statute)	1.609344	kilometres
pounds per cubic foot	16.01846	kilograms per cubic metre
square miles	2.589998	square kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

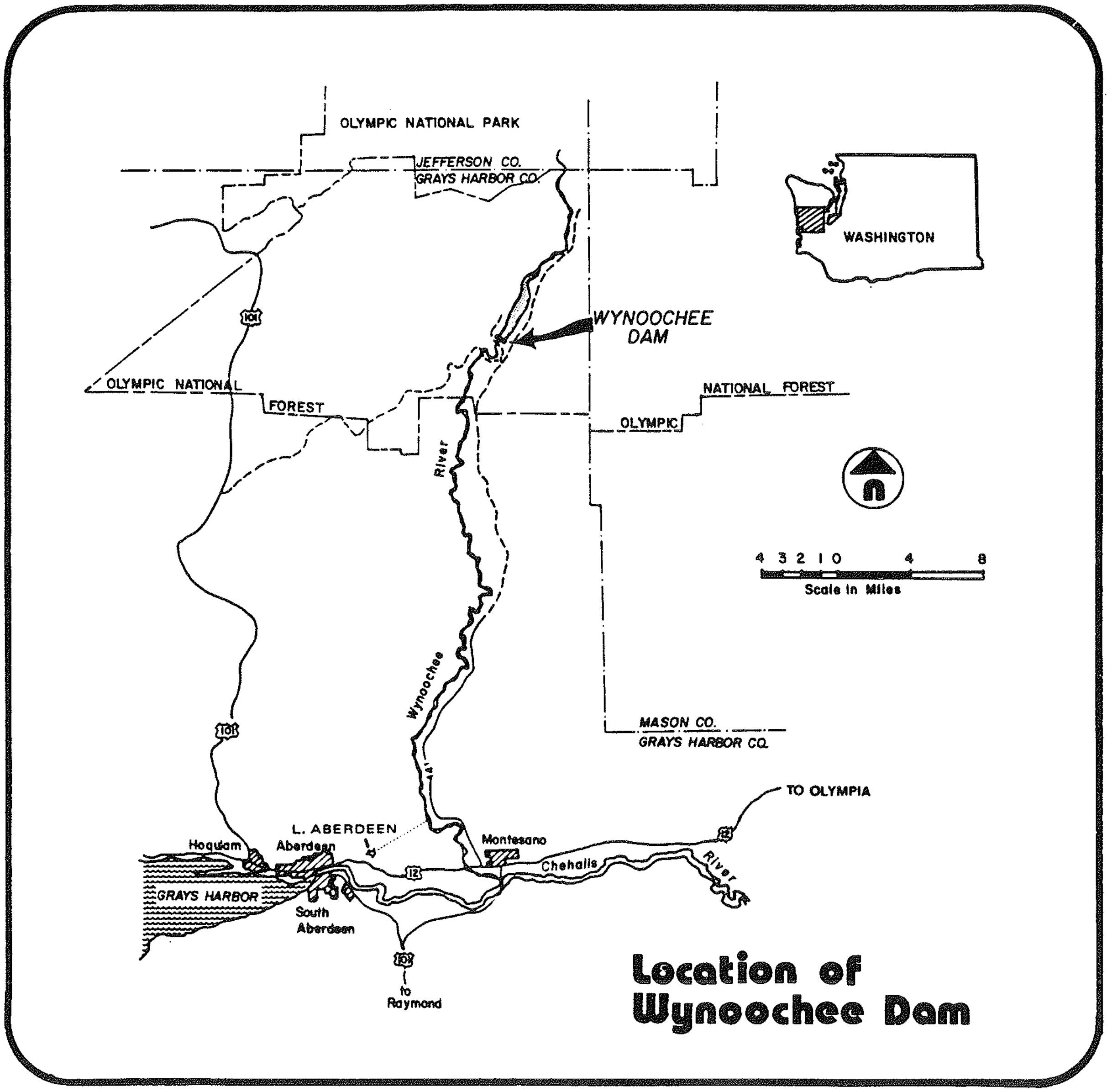


Figure 1. Location and vicinity map

WYNOOCHEE DAM WATER TEMPERATURE CONTROL STUDY

PART I: INTRODUCTION

Background

1. The Wynoochee River is approximately 67 miles* long and drains an area of 195 square miles at its confluence with the Chehalis River. It originates on the southern slopes of the Olympic mountains and flows southerly to its confluence with the Chehalis River near Montesano, Washington.

2. Wynoochee Dam and Lake Project, as shown in Figure 1, is located at approximately mile 52 on the Wynoochee River. At normal pool, Wynoochee Lake is approximately 4.4 miles long and has a maximum capacity of 70,000 acre-ft. The average annual precipitation at the dam is 153 in. (US Army Engineer District, Seattle, 1982).

3. Constructed in 1972 and operated by the US Army Engineer District, Seattle (NPS), the project's original multipurpose objectives of water supply, flood control, and fisheries are being extended to include hydropower for the joint developers, the cities of Aberdeen and Tacoma.

4. The existing structure (Figure 2) has six low-flow conduits at different elevations with an approximate capacity of 200 cfs each, plus two flood control sluices with a combined capacity of 9,200 cfs giving the existing structure a maximum discharge capacity of approximately 10,400 cfs. There is also a gated spillway which, to date, has not been operated. The existing multi-level conduits are designed as passageways for the downstream migrating juvenile fish native to the Wynoochee River.

5. The developers have proposed a hydropower retrofit which includes a single wet-well intake structure with upper and lower gate openings, each capable of variable opening. The upper gate provides up to a 30-ft opening extending from el 800 to 770** with weir-type withdrawal characteristics.

---

* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 3.

** All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

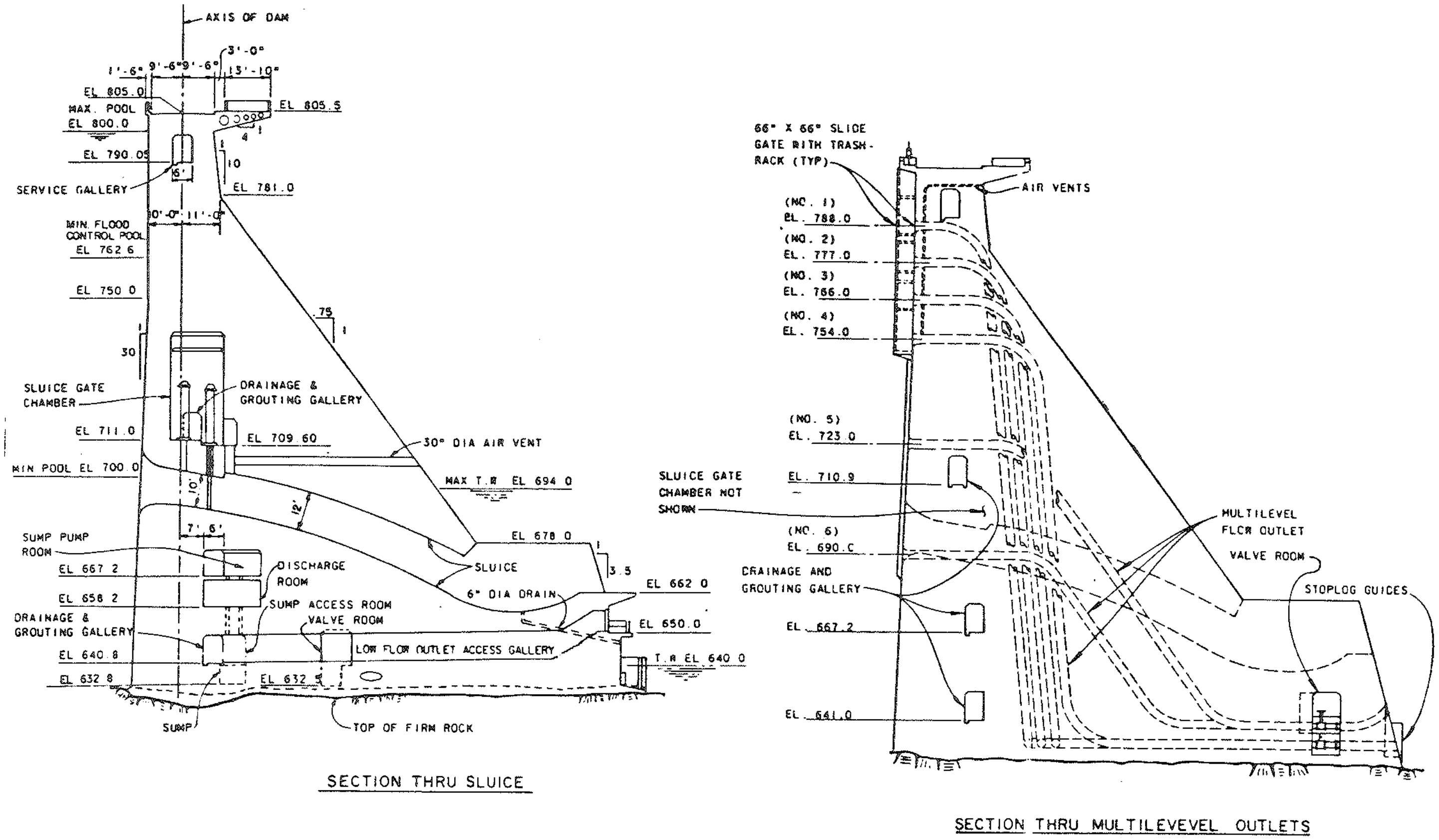


Figure 2. Section through the existing dam structure

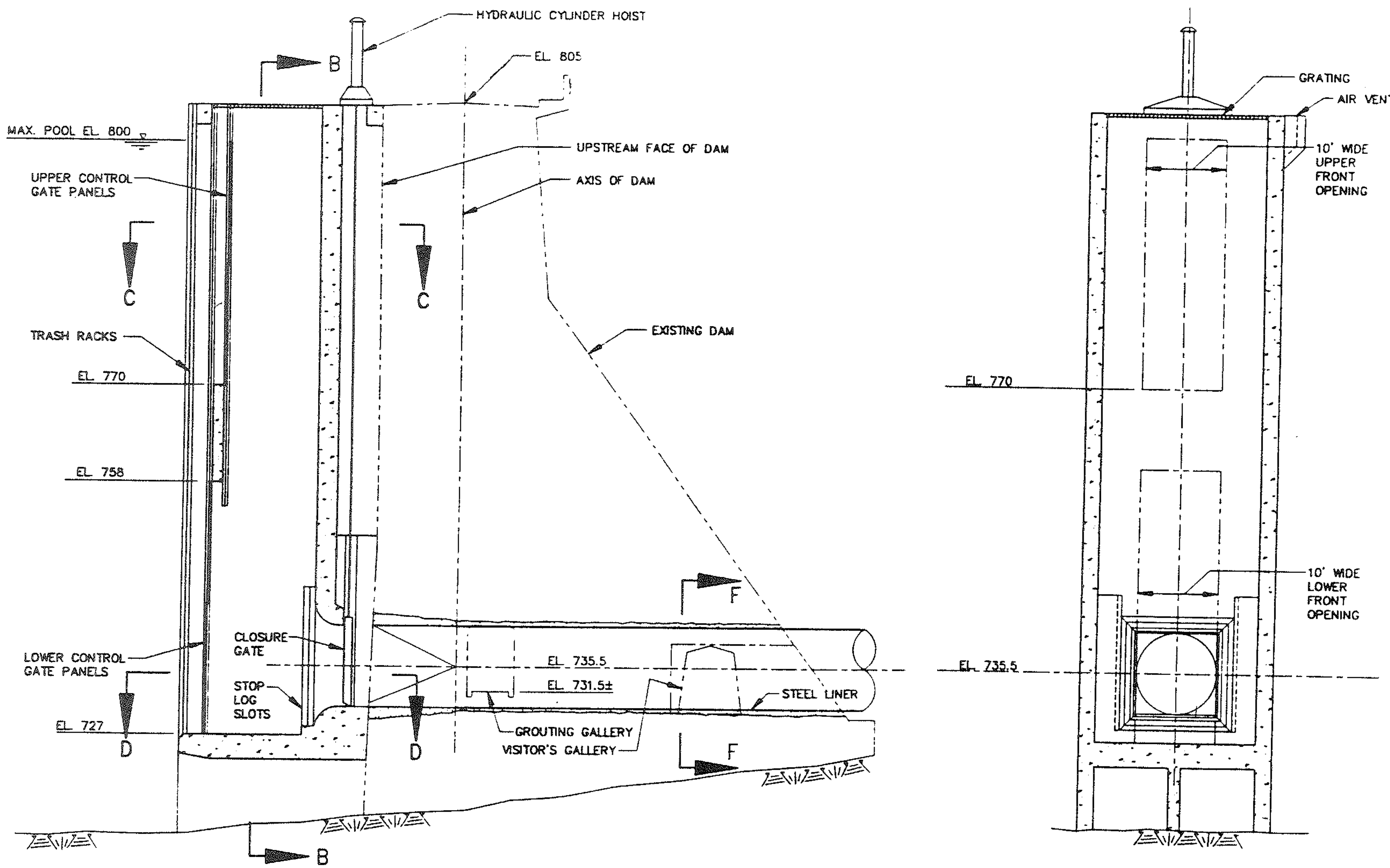


Figure 3. The proposed intake structure

The lower gate behaves like a port with a maximum 30-ft opening (Figure 3). The nominal well width, or port opening, is 10 ft. A trash rack will be installed at the entrance of the wet well. An alternative which may be investigated at a future date is a fish screen and bypass structure.

6. The US Army Engineer Waterways Experiment Station (WES) was requested by the NPS to evaluate the ability of the proposed intake structure to meet the Corps' water temperature regulation objectives. Further, the developer, or licensee, is required by the Federal Energy Regulatory Commission (FERC) to conduct a temperature computer model study which demonstrates the ability of the proposed structure to meet water temperature objectives at least equal to that of the existing structure (Hosey and Associates, 1988).

Purpose and Scope

7. The overall study objective, as alluded to above, is to verify that operation of the licensee's proposed hydropower intake structure during the stratification period will not alter the thermal characteristics of the reservoir in a manner that would jeopardize the water temperature control capabilities of the existing multilevel outlet structure. Specifically, the proposed structure should permit blending of withdrawals, provide as much flexibility as the existing structure to meet objectives, and not initiate any adverse conditions in the pool which would prohibit effective temperature control operations by the existing structure.

8. The scope of work undertaken by WES for NPS was to perform a one-dimensional numerical thermal analysis of the Wynoochee reservoir using the WESTEX computer model. WES provided NPS with the following services during this study:

- a. Review and comment on the licensee's December 1988 report (Hosey and Associates, 1988).
- b. Assistance in developing procedures, objectives and hydrologic/meteorologic scenarios to be used in conducting the reservoir temperature numerical model analysis.
- c. Assistance in constructing a reasonable range of assumed intake loss coefficients and selective withdrawal characteristics to be used in WESTEX.
- d. Regression analyses as needed to fill gaps in the existing hydrologic/meteorologic data records.

e. Incorporation of site-specific modifications and special operating constraints into the WESTEX source code.

f. Verification of the WESTEX code's ability to simulate the existing structure using the 1987 and 1982 data sets.

g. Simulation and analysis of the licensee's proposed intake structure for an assumed range of intake loss coefficients and withdrawal angles using the 1975, 1980, and 1983 data sets.

PART II: MODEL DESCRIPTIONS

HEATEX

9. The heat exchange program called HEATEX (US Army Engineer District, Baltimore, 1977) uses the day-to-day variations in meteorologic variables at a given location to compute equilibrium temperatures and coefficients of surface heat exchange for use in estimating net heat exchange between a water surface and the atmosphere. The equilibrium temperature is defined as the water temperature at which the net rate of heat exchange between a water surface and the atmosphere is zero. The surface heat exchange coefficient is the rate at which the heat transfer processes will proceed. Output from this model is used in WESTEX, the reservoir thermal analysis model. Mean daily inputs to HEATEX include cloud cover, wind speed, air temperature, dew point temperature, and optionally, the total shortwave solar radiation. Coefficients used in HEATEX are the reflected shortwave radiation (RFS), reflected long wave radiation (RFA), and reflectivity of the ground (RFG). Outputs are daily equilibrium temperature, heat exchange coefficient, and shortwave radiation.

WESTEX

10. The one-dimensional thermal simulation model, WESTEX, was selected to evaluate the thermal characteristics and release temperatures of Wynoochee dam reservoir. This model computes dynamic changes in thermal content of a reservoir through simulation of heat transfer at the air-water interface, heat advection due to inflow and outflows, and internal dispersion of thermal energy. Time-history computations of thermal energy are made for a series of conceptually homogeneous vertically stacked layers by solving for the conservation of mass and energy at each time increment subject to an equation of state regarding density (Holland 1982).

11. Inputs to the model are geometric data regarding the physical characteristics of the structure, the outputs from HEATEX, the hydrologic conditions at the project, and coefficients which characterize certain reservoir processes. Discussions regarding these inputs will follow in the model verification section of this report.

PART III: DEVELOPMENT OF DATA

12. The Seattle district furnished WES with the input data for the thermal analysis. These data included drawings of the existing and proposed structures, meteorological data, historical reservoir data, water temperatures, and operations criteria.

Study Years

13. The years selected for study were 1975, 1980, 1982, 1983, and 1987. The year for which the most complete set of daily information was available regarding temperature inflow and outflow data at Wynoochee was 1987. That year was chosen for the initial verification, and the Seattle District selected 1982 for the final verification. The other years were also selected by NPS based on total precipitation and temperatures during May through October compared to the historical average. Based on this criteria, 1975, 1980, and 1983 data (wet year, dry year, and average year, respectively) were selected for the simulation of the Licensee's proposed structure.

Meteorologic Data

14. The meteorologic data were collected from the Seattle-Tacoma Airport Class A weather station, hereafter referred to as Sea-Tac. Climatological conditions are different at the project than at this station due to a 400-ft change in elevation and the location of the project on the Olympic peninsula relative to the station location across the Puget Sound. Sensitivity analysis performed during model verification, however, validated the applicability of these data to the project site.

15. The meteorological data included maximum and minimum air temperatures, wet bulb and dry bulb temperatures, cloud cover, solar radiation, and wind speed. Additionally, maximum and minimum air temperatures at the project site were provided by the NPS. Daily average air temperatures are needed to compute the equilibrium temperatures for input to WESTEX. NPS did not have actual 24-hour average air temperatures readily available, but provided instead the average of the maximum and minimum air temperatures, or in this case, the dry bulb temperatures. Analyzing a set of random records at the

project and at the Sea-Tac station, NPS determined that this "average" was representative of the actual 24-hour average.* The equilibrium temperature's sensitivity to air temperature was checked during model verification.

16. Values labeled "percent of total" solar radiation were provided with the meteorological data, but not used because of the highly erratic readings. Values of the daily shortwave solar radiation were, instead, calculated in HEATEX for use in this study based on a method after Edinger and Geyer, 1965.

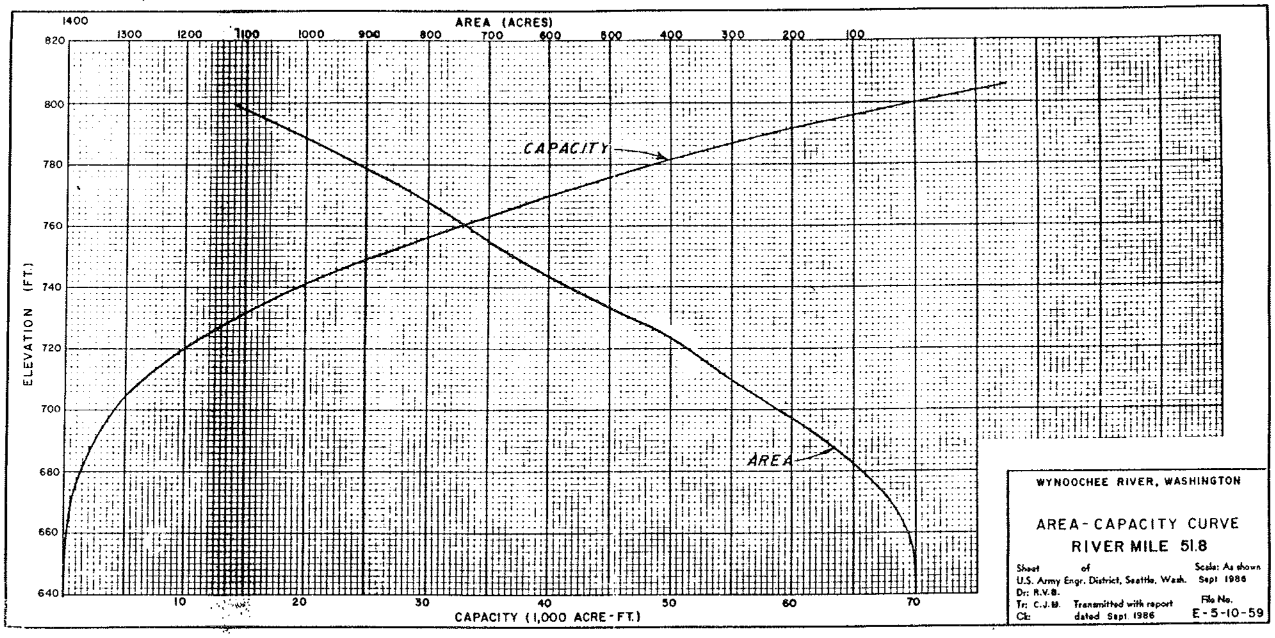
Hydrologic/Hydraulic Inputs

17. Hydraulic data provided by NPS were an area-capacity curve (Figure 4a), a reservoir rule curve (Figure 4b), rating curves and pertinent data regarding each outlet. For data years 1975, 1980, 1982, 1983, and 1987 daily inflows (calculated but not gaged), discharges, and pool elevations were provided. Historical discharges from each port were also provided.

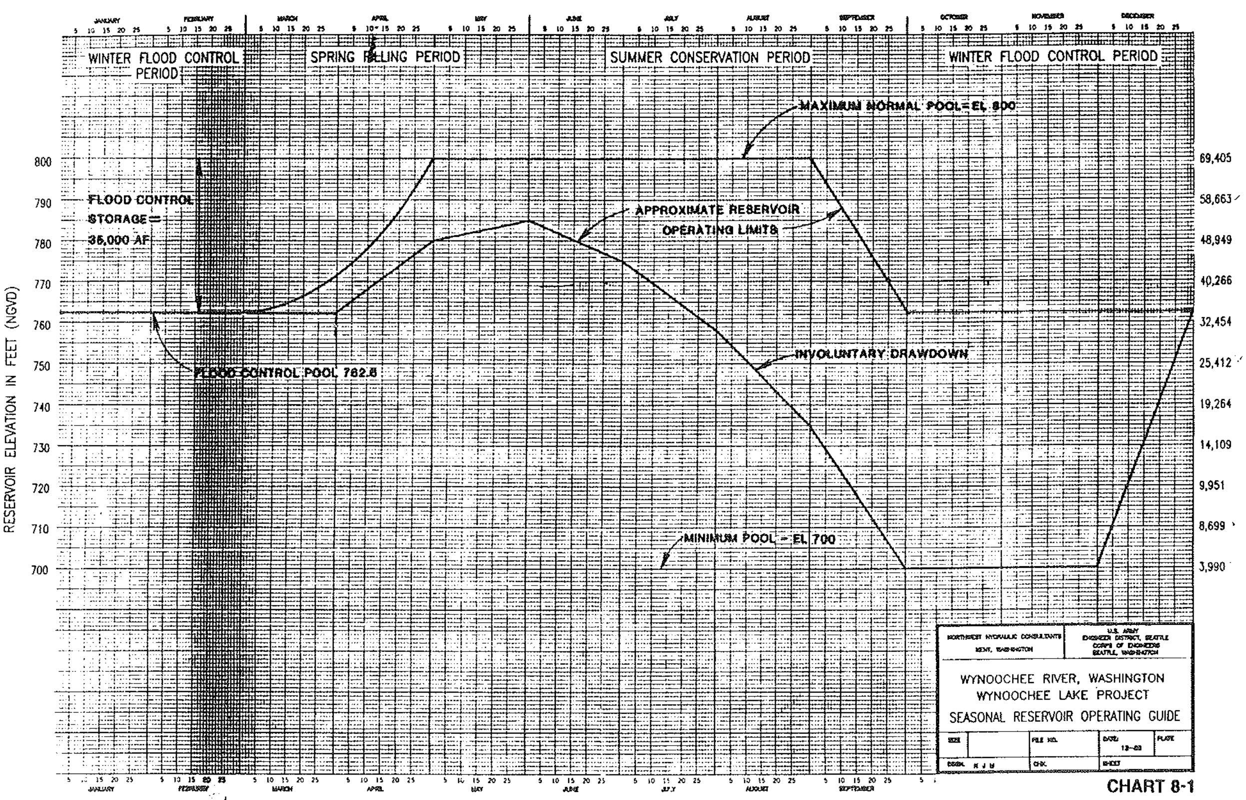
18. WESTEX performs a mass balance of the reservoir given the total inflow, outflow, and storage curve. Initial model runs produced pool elevations which did not agree within reasonable limits with the historical records provided by the district. The originally provided inflows were calculated using the change in storage (based on the change in pool) from the previous day plus the outflow occurring at the time of the calculation (usually the 8:00 AM reading). Since the outflow was an instantaneous discharge and not a 24-hour total, a discrepancy occurred in the mass balance. Because of this, NPS sent revised historical outflows based on a total daily discharge for all data years. WES backed out the daily inflows by performing a mass balance with the revised outflows, the elevation-storage curve, and the historical pool elevations. This "revised" set of inflows and outflows were used for the verification simulations of WESTEX. Historical inflows were calculated in the same manner for the simulation years 1975, 1980, and 1983. However, to reflect the present reservoir operations criteria which mandates a minimum downstream discharge, NPS sent outflow revisions incorporating this criteria for use in the prediction runs. Thus, the inflows for 1975, 1980, and 1983 are "historical"; the outflows are not historical and reflect downstream

---

* Data sent by Mr. Glen Singleton, NPS, 6 September 1989.



a. Area-capacity curve



b. Wynoochee Dam Reservoir rule curve

Figure 4. Reservoir hydraulic data

discharge considerations. Therefore, pool elevations calculated during the prediction runs will not necessarily match historical records.

Inflow Temperatures

19. Hourly inflow temperatures were available for 1987 only. Typically, in this situation, a linear regression equation developed from the observed, complete data can be used to predict the inflow temperatures for the other data years. Numerous regression attempts at using inflows and/or equilibrium temperatures resulted in poor correlations. Figure 5 is just one attempt, of many, to regress inflow temperatures with equilibrium temperatures. The regression coefficient, R-squared, was less than 0.50 for all attempted regressions. Failure to find a correlation is somewhat explained by the difference in the curves shown in Figure 6. Close evaluation of this curve reveals that the temperatures are relatively constant during the summer months. This condition most likely occurs because the inflows are largely influenced by groundwater (Heath 1983). This groundwater component was ungaged, and no method of accounting for its impact on inflowing river temperatures was available.

20. Hourly release temperatures were provided by NPS beginning 1 April through 21 December 1987. Supplemental data were provided from a USGS gage downstream of the dam for the period 1 January through 30 April 1987. These data were 8:00 AM readings.

21. In addition to providing the hourly inflow temperatures for 1987, NPS also furnished "biweekly" data for all data years. Approximately 10 to 14 additional days of data per data year were provided, and included temperature information on inflows, outflows and reservoir profiles (see Table 1). A plot of all the observed inflow temperatures can be found in Figure 7. Since regression analysis was unsuccessful, temperature curves were fitted to each set of the biweekly data. A portion of each curve was developed using a polynomial fit to the data, while remaining portions of the curve were smoothed in by hand. The actual hourly temperature data were averaged and used for the daily inflow temperatures in 1987. Additionally, a smooth curve was also determined for 1987 based on the biweekly data. During initial verification, a sensitivity test was performed with WESTEX using both the actual daily inflow temperatures and those fitted to the biweekly data.

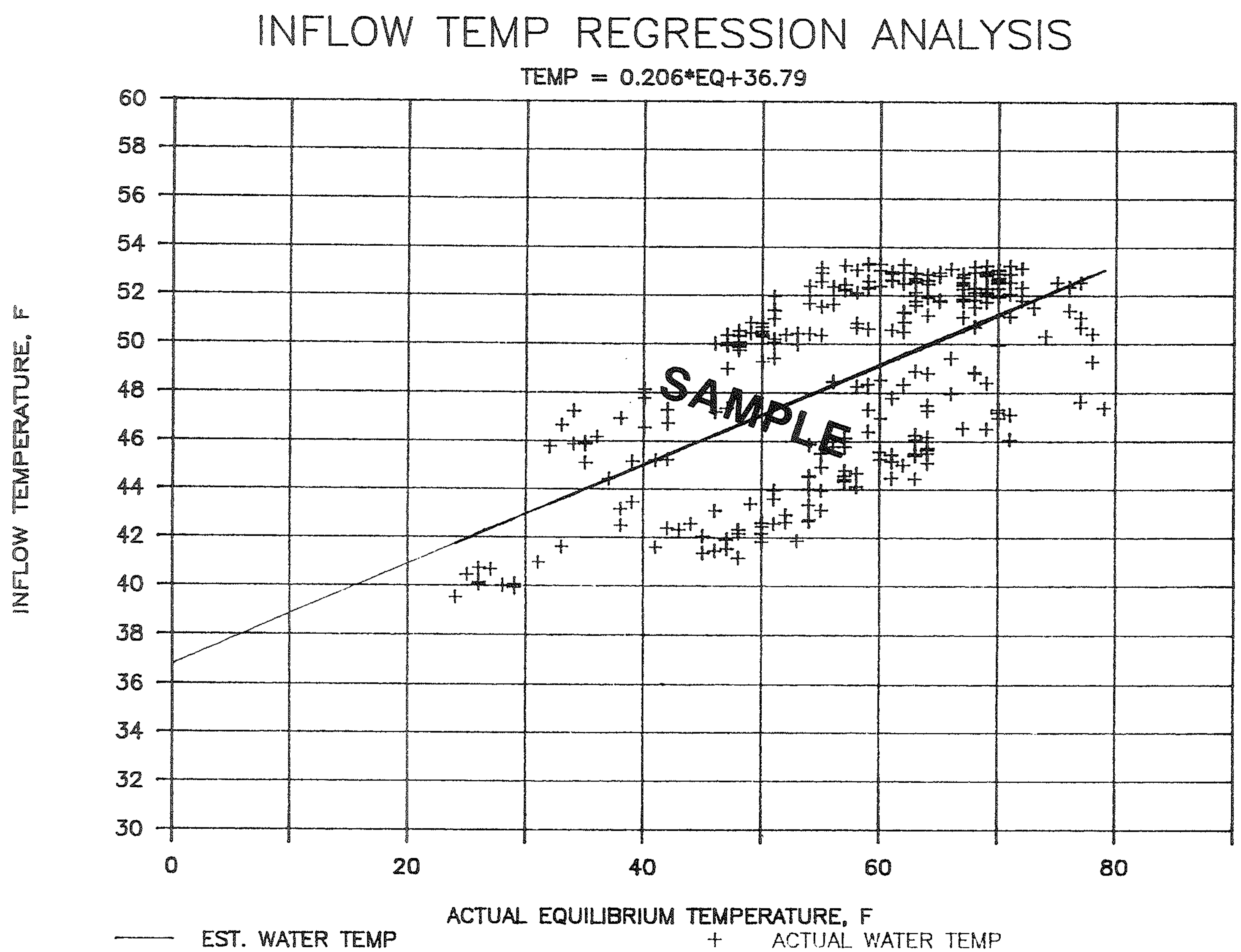


Figure 5. Example of attempted regression analysis

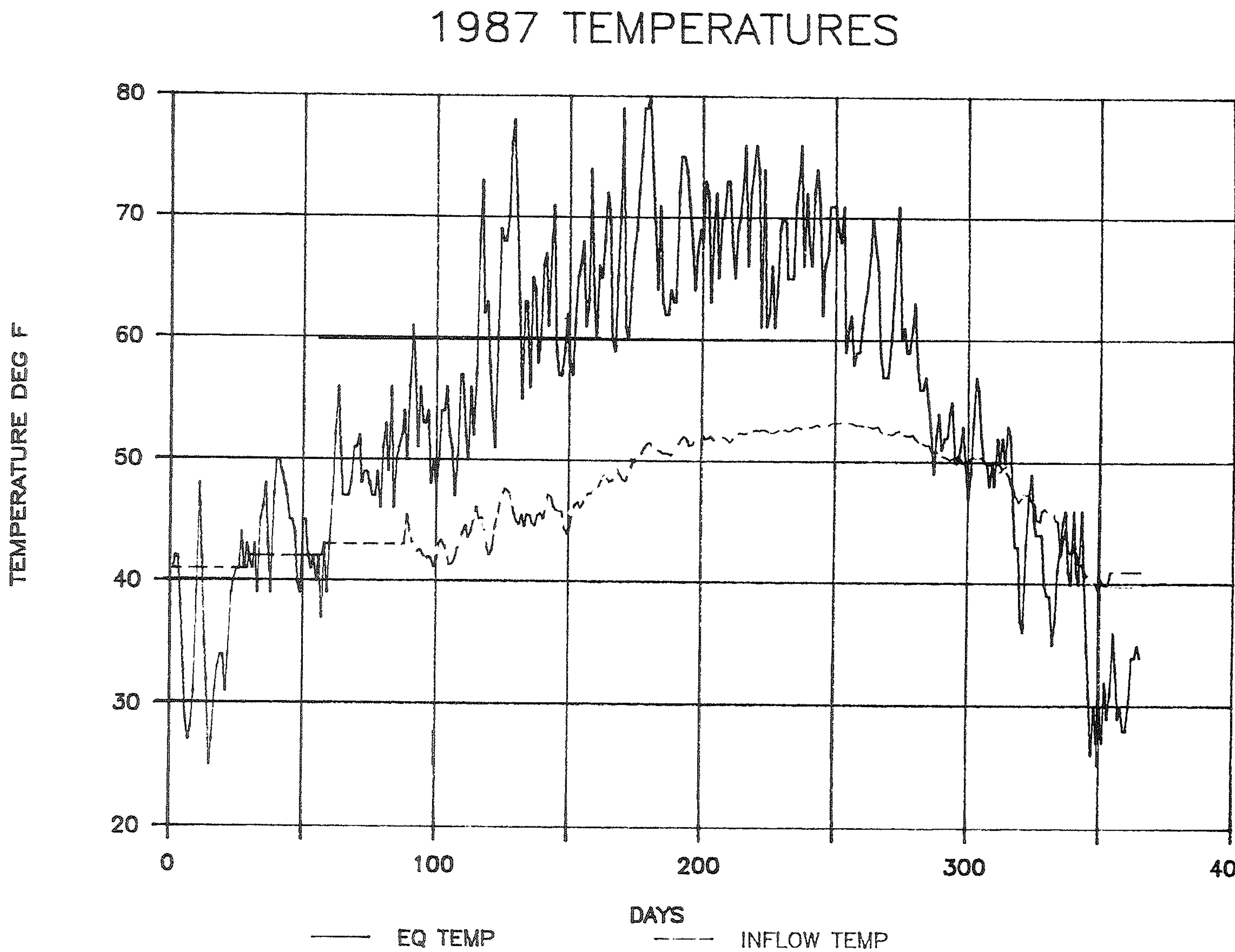


Figure 6. Comparison of actual inflow water temperatures to calculated equilibrium temperatures

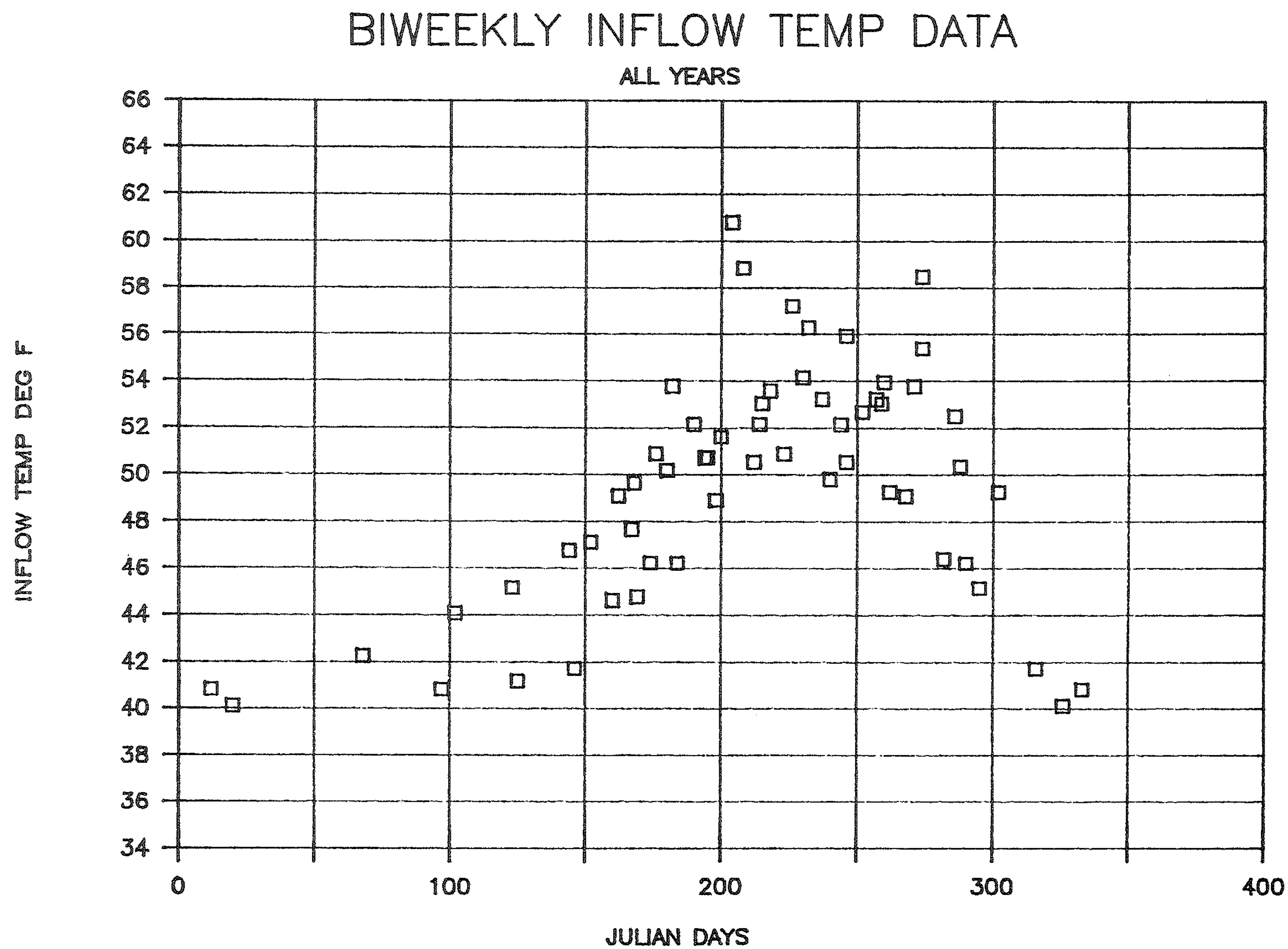


Figure 7. "Biweekly" inflow temperatures for all data years

Results for the fitted inflow temperatures were not greatly different than the actual temperatures. The resulting inflow temperature curves used for each data year can be seen in Figure 8.

22. There were several data discrepancies found between the data sets for inflow and outflow temperatures. For instance, temperatures taken from the hourly information on a specific date did not match those provided with the biweekly data. This discrepancy and others exist because the temperatures were taken at different upstream or downstream locations, with different instruments, and/or at different times of the day. In all cases, NPS recommended which set of data or values to use.

Operations Considerations

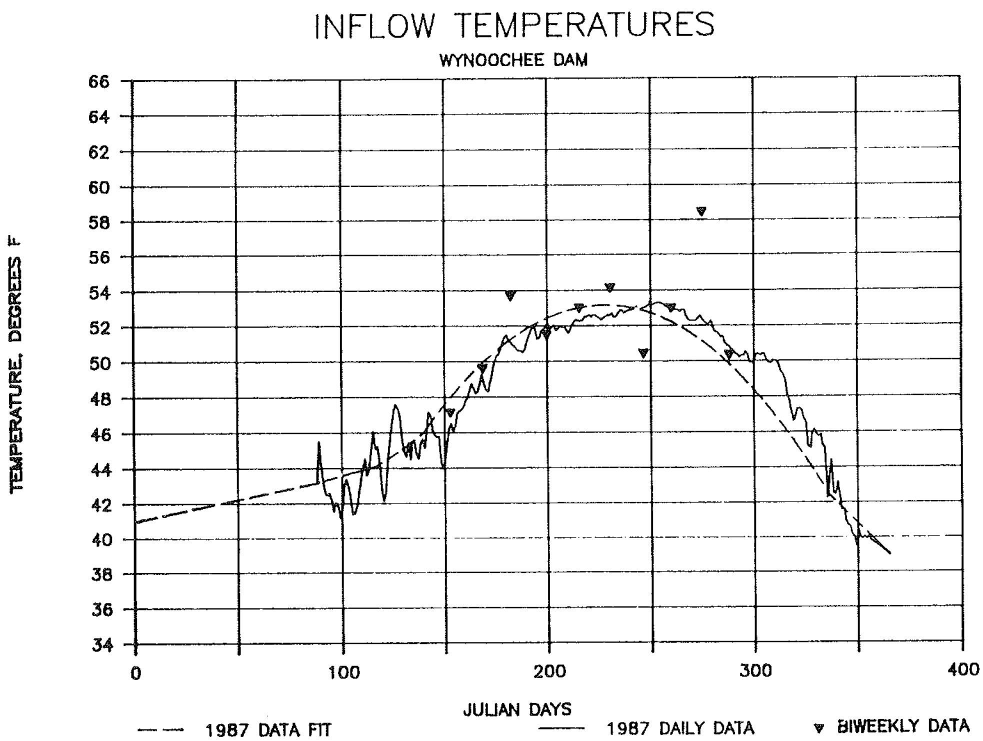
23. The fundamental operational guidance is that both structures should have the capability together to meet downstream target release temperatures. The acceptable range of target temperatures is 50 to 58° F. The target outflow temperature is 55° F. During the prediction runs, when the new system cannot meet this range of temperatures, WESTEX should switch operation to the existing structure. If neither can meet the target range, then operation returns to the new structure.

24. The Wynoochee Dam operations criteria for the existing structure, which was incorporated in WESTEX, is mandated by the Water Control Plan provided by Seattle.* In general, the criteria for the existing structure is as follows:

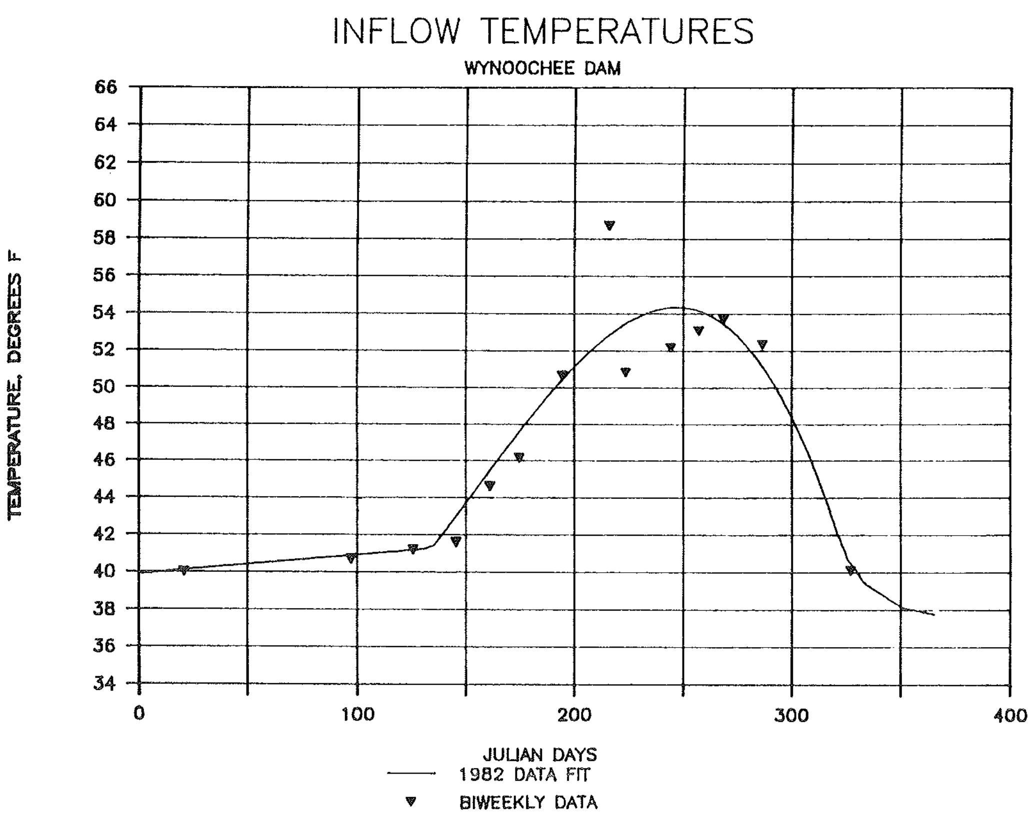
- a. The topmost submerged port of ports 1-4 must be fully opened during the months of January through July for fish passage. After July these gates can be throttled as needed to meet target release temperatures. Additionally, if target temperatures cannot be met by the uppermost submerged gate, then the next lower submerged gate could be fully opened, the first staying fully closed.
- b. Operation of the sluice by the project manager is determined from experience based on anticipated inflows. One method for operation would be to determine if the next day inflows would raise the pool above the rule; if so, then excess discharges would be released. However, if the next day inflows could be

---

* A section of this document was provided to WES by NPS on 12 December 1989.

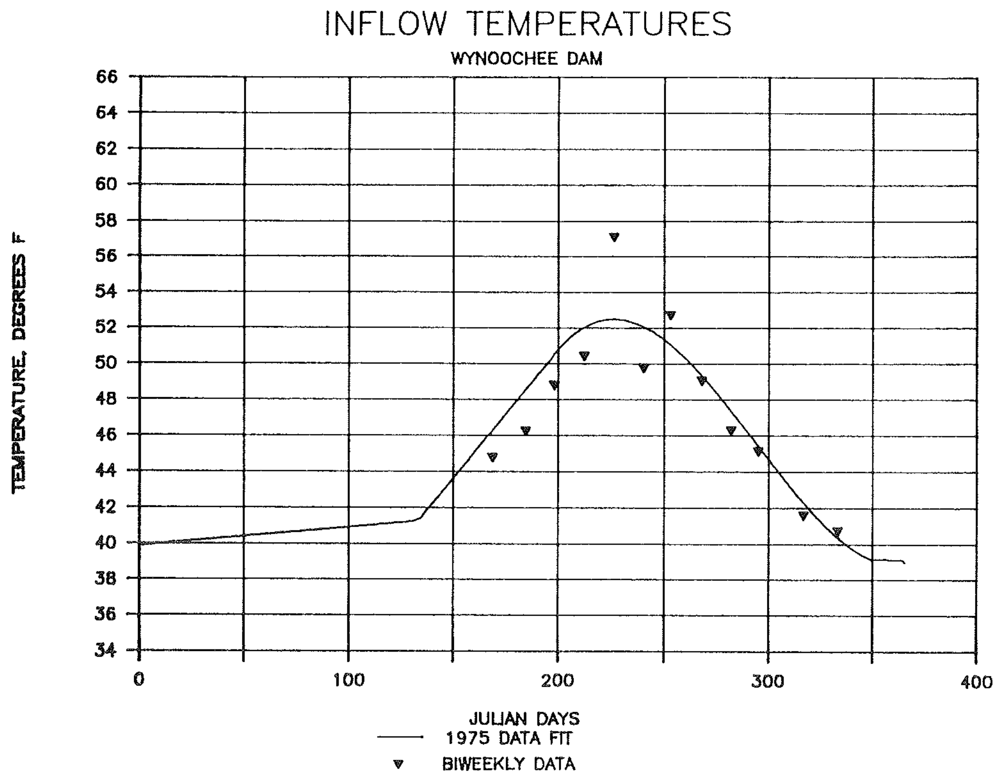


a. 1987

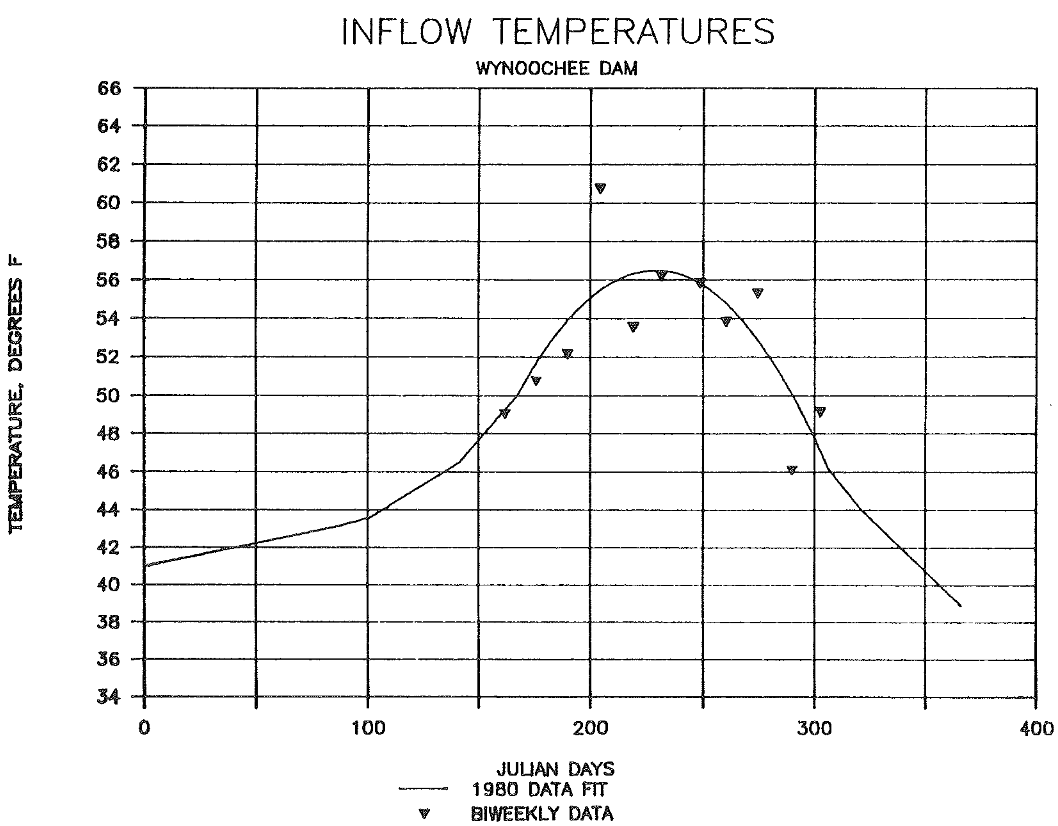


b. 1982

Figure 8. Inflow temperature curves used in WESTEX (Continued)

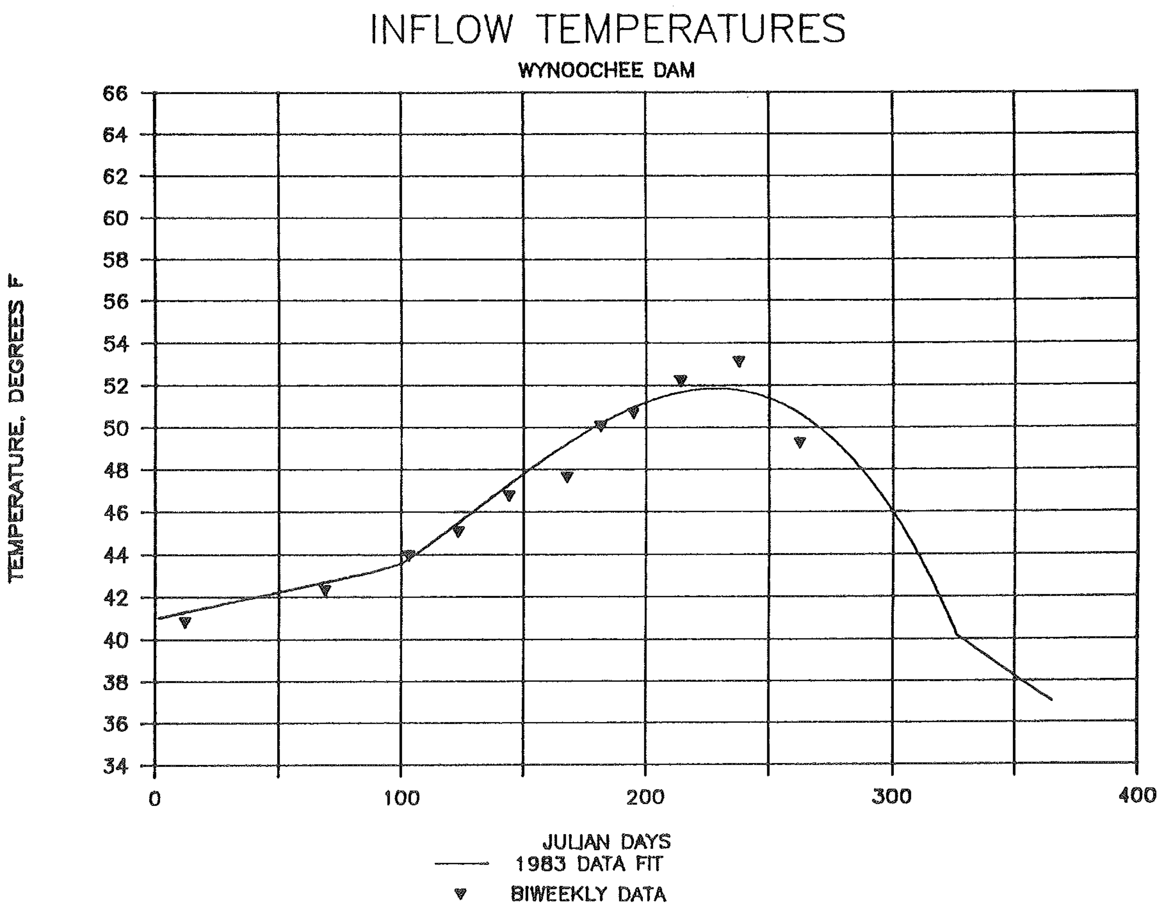


c. 1975



d. 1980

Figure 8. (Continued)



e. 1983

Figure 8. (Concluded)

stored without exceeding the rule curve, then they should be. Operation based on the rule curve was not done in this study since it had already been decided to use historical (predetermined) releases. Although the sluices are not generally operated for temperature control, WESTEX was modified to operate as many as three ports and the sluices for temperature control.

c. Because the fish spawn from May through July, the minimum flow requirement for this period increases from approximately 200 cfs to 300 cfs. This number is dependent on a minimum discharge of 400 cfs at Save Creek.

d. Ports 5 and 6 operate as necessary for minimum flows and/or temperature control.

25. The new structure must operate to meet target temperatures and minimum discharge criteria. The FERC application specifically calls for the proposed structure to shut down for 77 days beginning approximately on 15 April or the licensee must provide an approved fish bypass structure. This is a requirement for fish passage.

PART IV: MODEL VERIFICATION

The Heat Exchange Program Verification

26. Sensitivity runs were made using HEATEX to determine the effect, if any, the meteorological data have on the resulting equilibrium temperatures, exchange coefficients, and shortwave solar radiation. The coefficients for the RFS and the RFA were selected to be 0.03 and 0.05 based on values established from previous studies. Values of the RFG were checked during sensitivity. Simulations varying the RFG, air temperature data, and cloud cover were performed for the sensitivity analysis.

27. Specifically, the sensitivity runs included the following:

Test No.	RFG	Air Temps	Station	Cloud Cover
1	0.08	Average	Wynoochee	Sea-Tac
2	0.08	Average	Sea-Tac	Sea-Tac
3	0.50	Average	Wynoochee	Sea-Tac
4	0.08	Minimum	Wynoochee	Sea-Tac
5	0.08	Maximum	Wynoochee	Sea-Tac
6	0.08	Average	Wynoochee	50 percent of values at Sea-Tac

Comparisons of monthly average outputs for variable inputs are provided in Figure 9.

28. Final data selected for use in this study were all meteorologic data (other than solar radiation) provided at Sea-Tac, including the average air temperatures at Sea-Tac, and an RFG of 0.08 based on information in the "Thermal Simulation of Lakes, Users Manual" (US Army Engineer District, Baltimore, 1977). Sea-Tac air temperatures were selected over the Wynoochee air temperature data for two reasons. First, since all other meteorological data were taken at Sea-Tac, using those air temperatures resulted in a homogeneous data set in which, for instance, relationships between air temperature and dew point temperature were in agreement. Secondly, Sea-Tac produced slightly higher equilibrium temperatures which were needed during the initial verification of WESTEX for warming the pool to match historical profiles.

1987 DATA

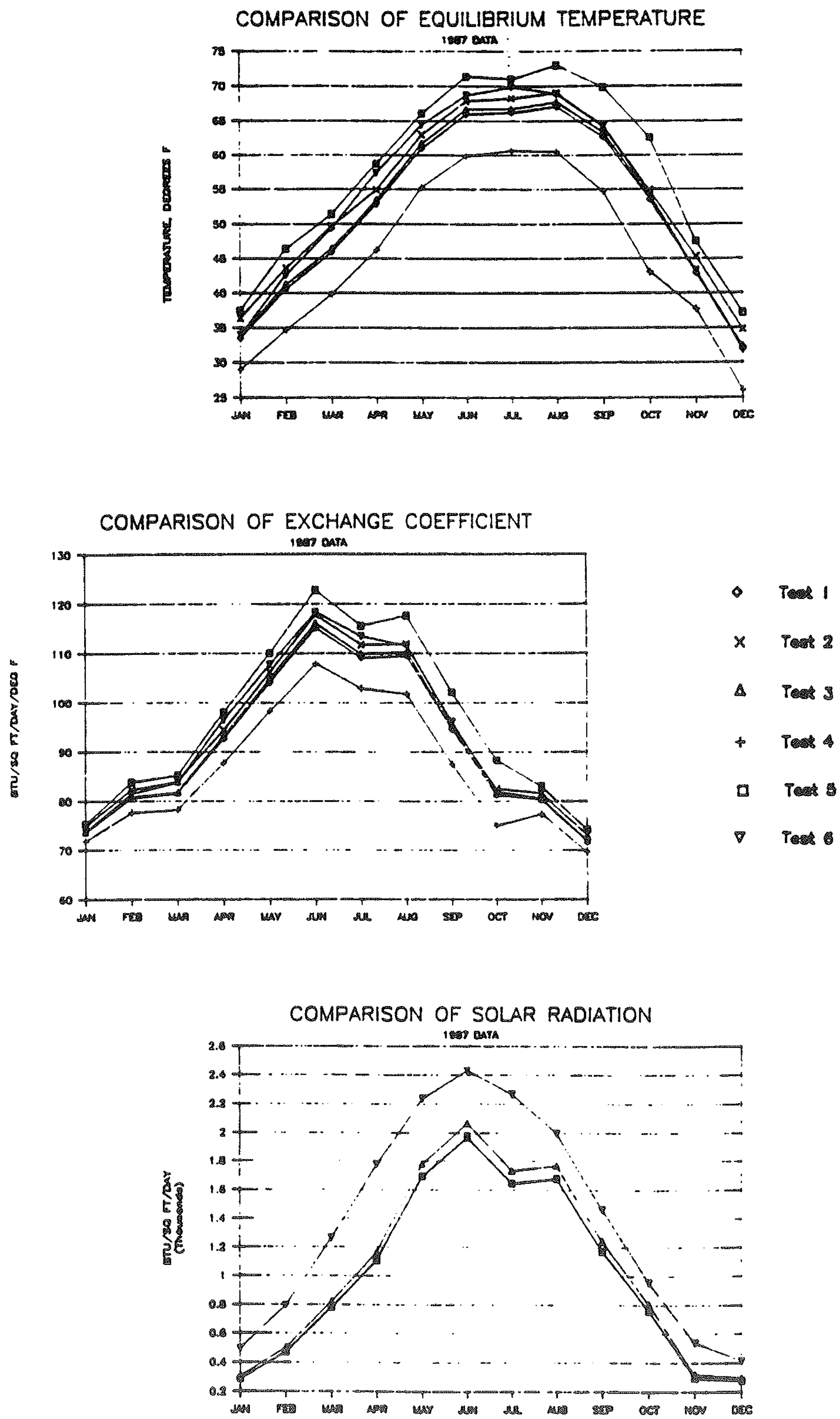


Figure 9. HEATEX sensitivity runs

WESTEX Model Verification for 1987 Study Year

29. The WESTEX one-dimensional model characterizes certain reservoir processes with four dimensionless coefficients and an entrainment value. In the initial verification of the model the coefficients and the entrainment are adjusted, within reasonable bounds, until the model produces reservoir profiles and release temperatures which more nearly match the historical records. The four coefficients include two mixing coefficients, α_1 and α_2, a light extinction coefficient, λ, and the percentage of short wave radiation absorbed in the top 2 ft of the pool, β. The entrainment, E, is a percentage of the surface water entrained by the inflowing river water. The coefficients selected for the initial verification resulting in the best comparisons between model and prototype were:

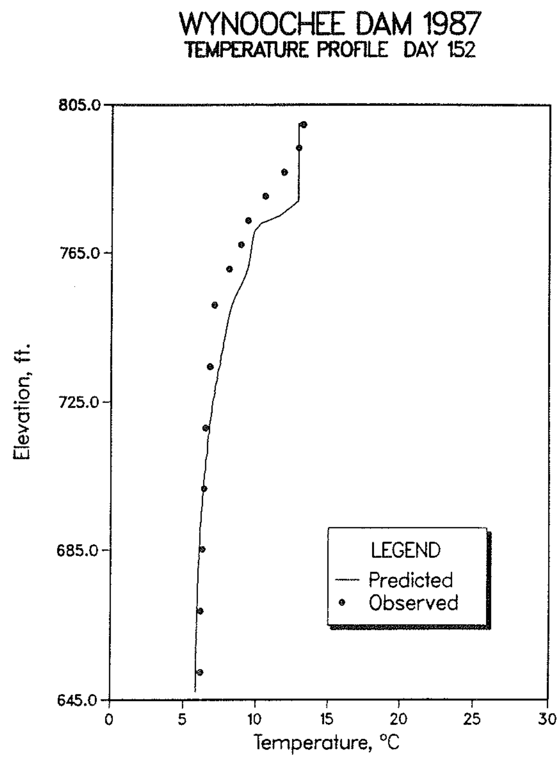
$$\alpha_1 = 7.00$$
$$\alpha_2 = 10^9$$
$$\lambda = 0.10$$
$$\beta = 0.70$$
$$E = 0.55$$

The verification results were very sensitive to α_1, λ, β, and E; the results were totally insensitive to α_2.

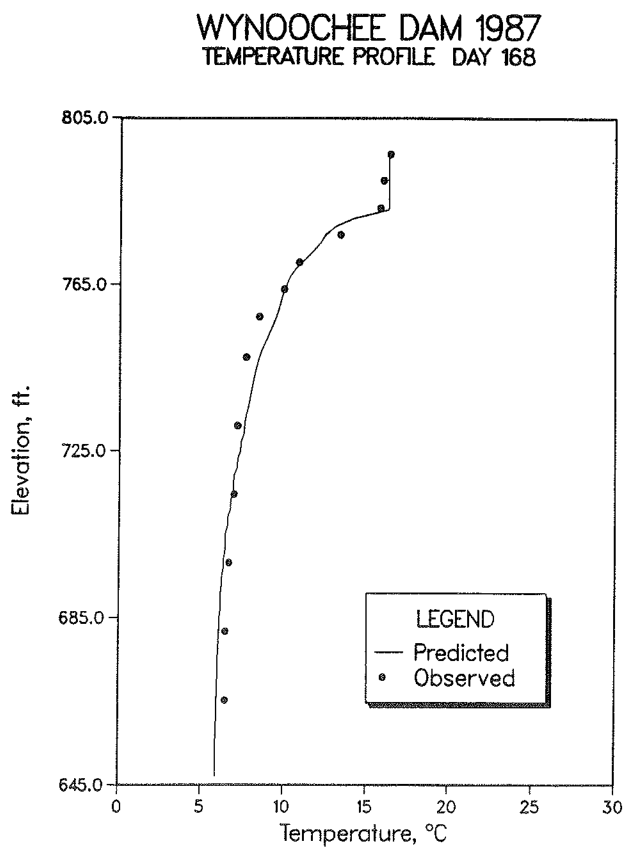
30. In addition to the model coefficients, the withdrawal angle of the existing structure was set at 3.14 radians. This parameter is used to account for topographic effects on the withdrawal zone.

31. Predicted and observed temperature profiles for the 1987 data year are found in Figures 10-12. As can be seen, the WESTEX model was extremely effective in matching the observed profiles. Table 2 contains the reliability index (RI) for each of the profiles. The RI is a measurement of the agreement between predicted and observed values. Perfect model-prototype agreement is an RI of 1.0; as the value increases (no values can be less than 1.0) the model's predicted values diverge from those observed (Howington 1989). The highest value of RI, 1.134, occurs on 3 September. The average value of RI is 1.088.

32. Observed release temperatures were compared to the computed temperatures for the 1987 data (Figure 13). Again, data were available such that

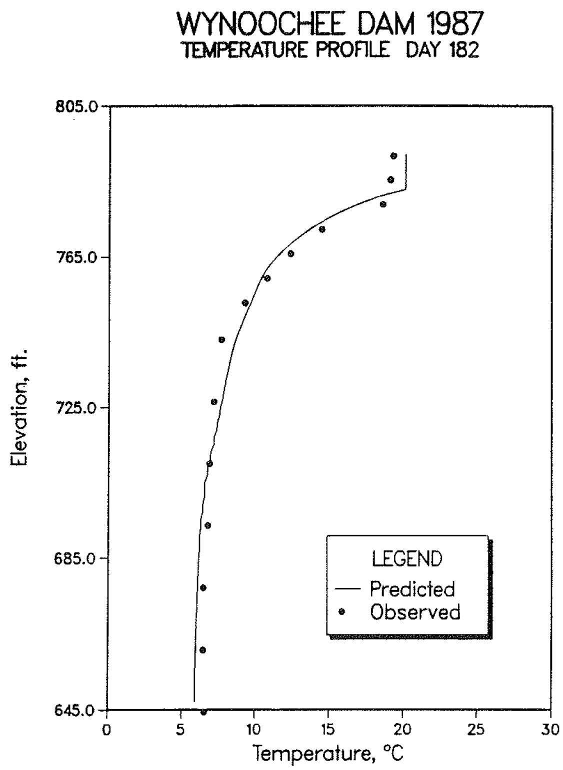


a. Day 152

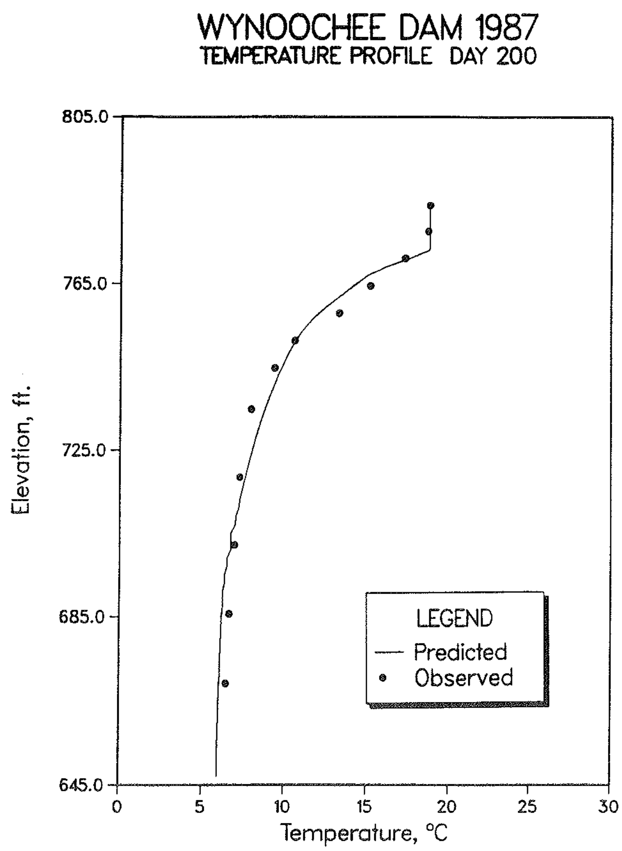


b. Day 168

Figure 10. Wynoochee Dam temperature profiles for 1987 (Continued)

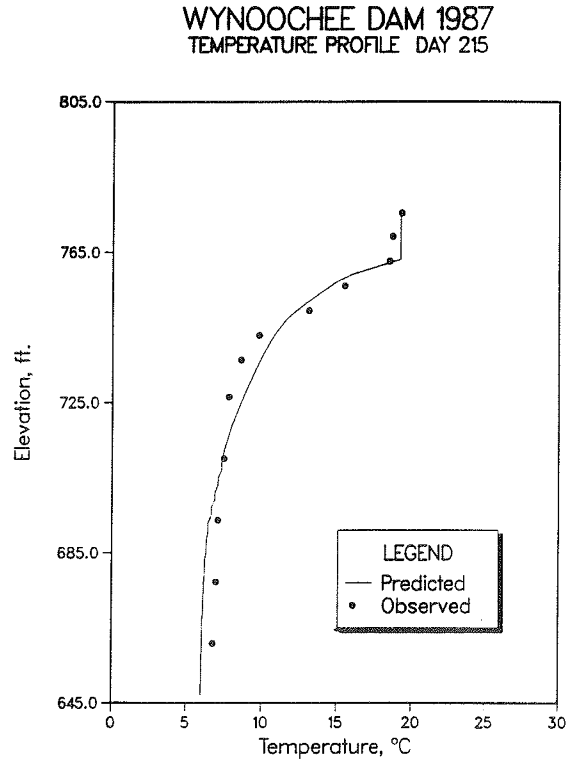


c. Day 182

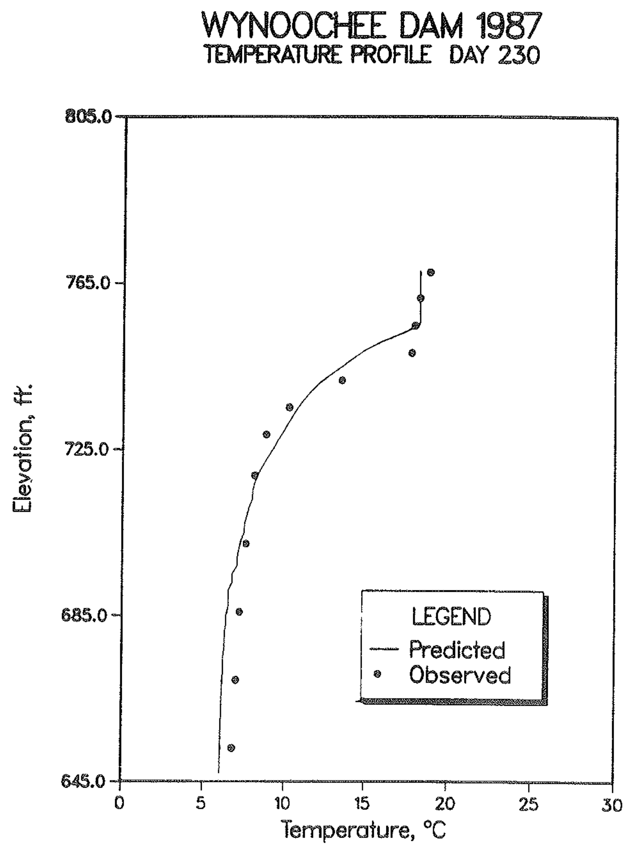


d. Day 200

Figure 10. (Concluded)

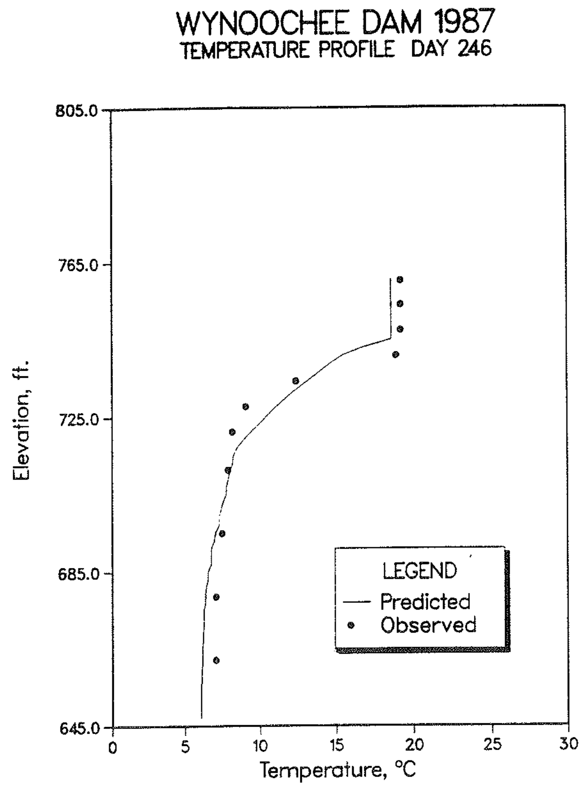


a. Day 215

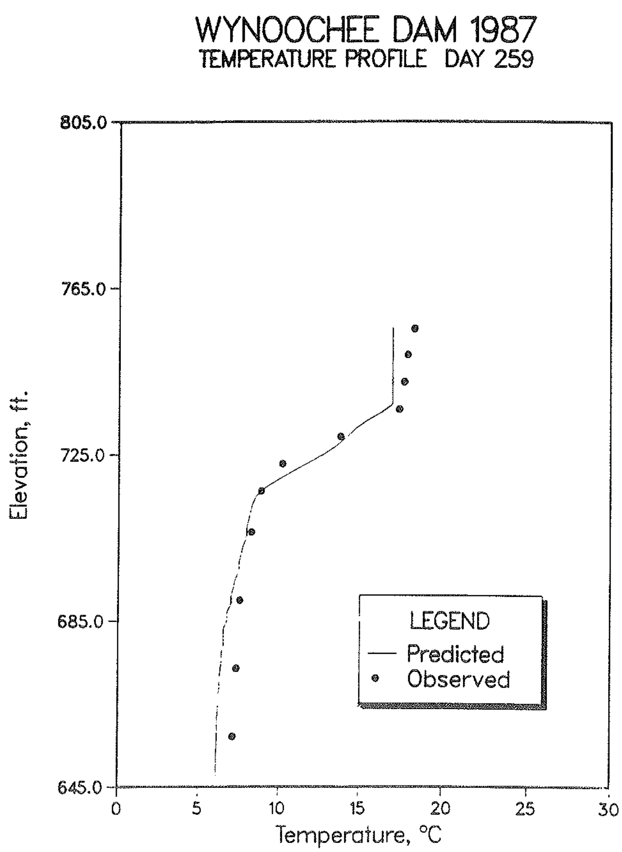


b. Day 230

Figure 11. Wynoochee Dam temperature profiles for 1987 (Continued)

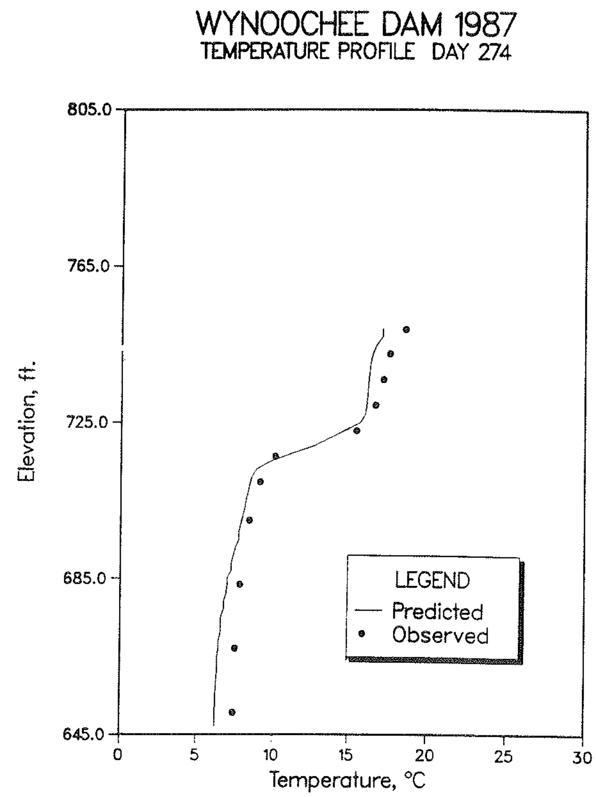


c. Day 246

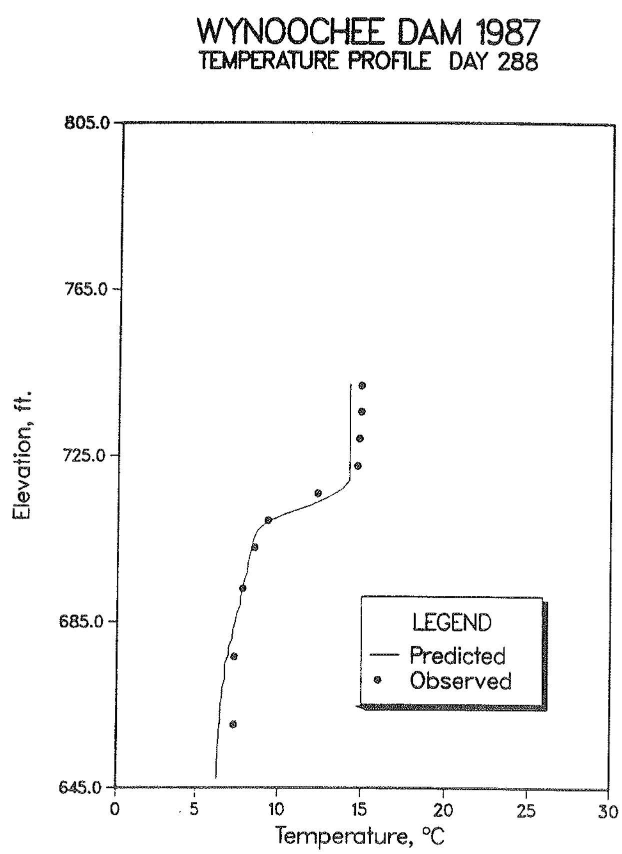


d. Day 259

Figure 11. (Concluded)



a. Day 274



b. Day 288

Figure 12. Wynoochee Dam temperature profiles for 1987

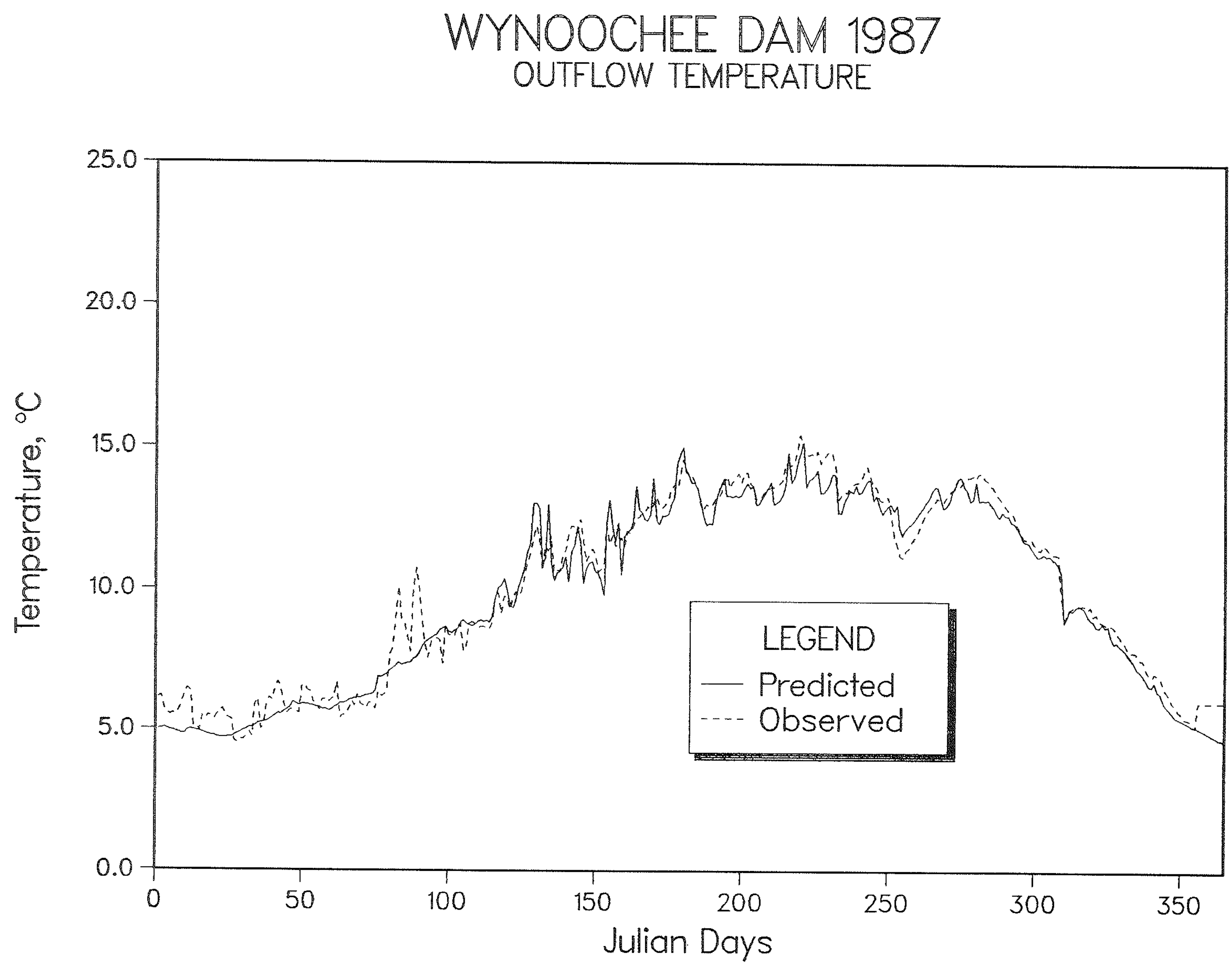


Figure 13. Outflow temperatures for 1987 - predicted vs. observed

daily average outflow temperatures could be used for the comparison. The maximum difference in outflow temperatures was less than 1.5° C, with the exception of two data points which occurred in March.

33. Historical hydraulic conditions for the 1987 data such as the inflows, outflows, and pool elevations are found in Figure 14.

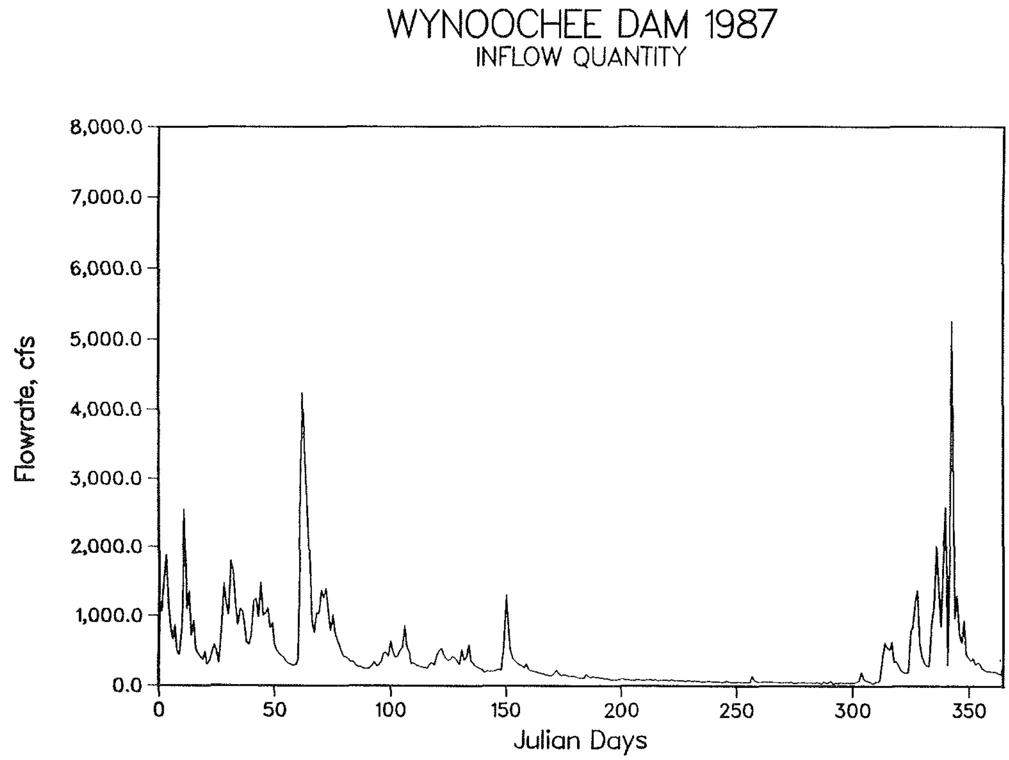
34. As discussed earlier, the inflow temperatures for years other than 1987 were developed based on a few isolated measurements during the year. To test the sensitivity of the model to inflow temperatures developed using these measurements, an inflow temperature curve was developed for the 1987 data. The model was run using these data, and results were compared to the simulation generated from the more specific set of inflow temperatures. The reliability indices for this simulation are in Table 2. As shown, smoothing the inflow temperatures did not significantly change the model results, indicating little sensitivity to inflow temperature values.

Final Verification with 1982 Study Year

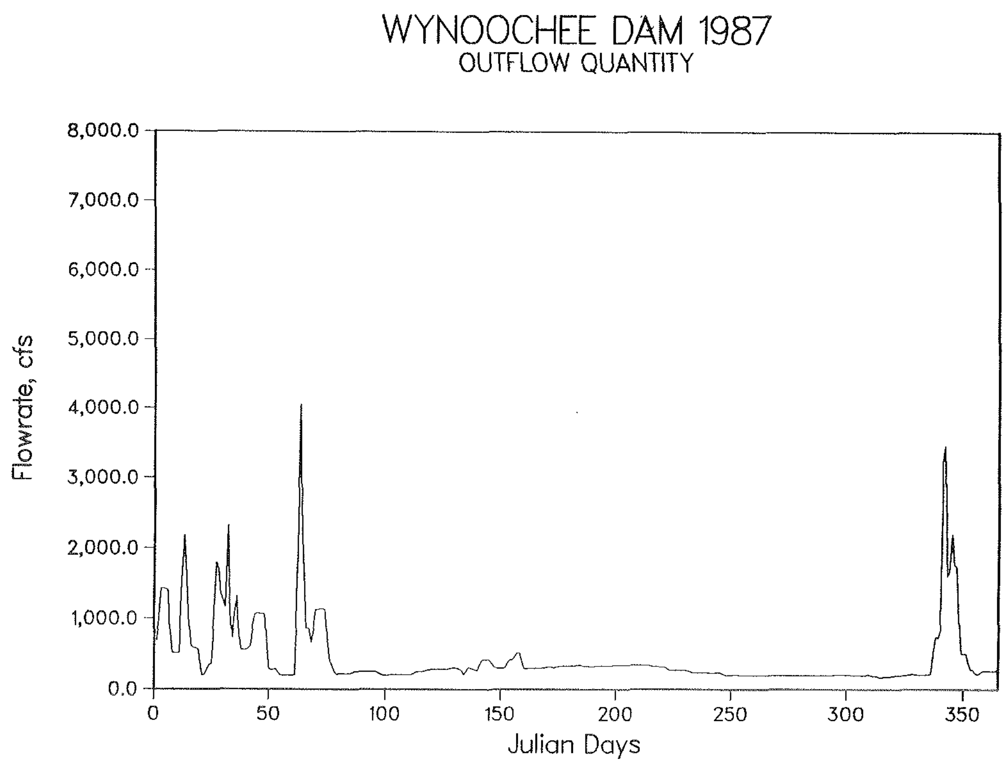
35. After adjusting the model coefficients to the 1987 data, the final verification was performed to determine if, given a different data set, WESTEX would continue to accurately predict reservoir profiles and release temperatures.

36. Table 3 contains the RI's for the 1982 data. Although an RI of 1.194 occurred in January on day 20, during the period of stratification the RI did not exceed 1.165. The average RI for these 14 points was 1.113. Figures 15-18 show the reservoir profiles. There were only 14 observed outflow temperatures (see Table 1) to compare outflow temperatures and they are overplotted onto the daily computed outflows from WESTEX (Figure 19). Figure 20 shows the hydraulic conditions plots. Comparisons between observed and predicted are in general worse than the 1987 data comparisons, but still in excellent agreement.

37. In summary, because the RI's are low, the shape of the profiles are similar, and the magnitude of the temperatures are in agreement, the conclusion can be drawn that Wynoochee Lake can, with some degree of confidence, be modeled with the one-dimensional thermal stratification model WESTEX.

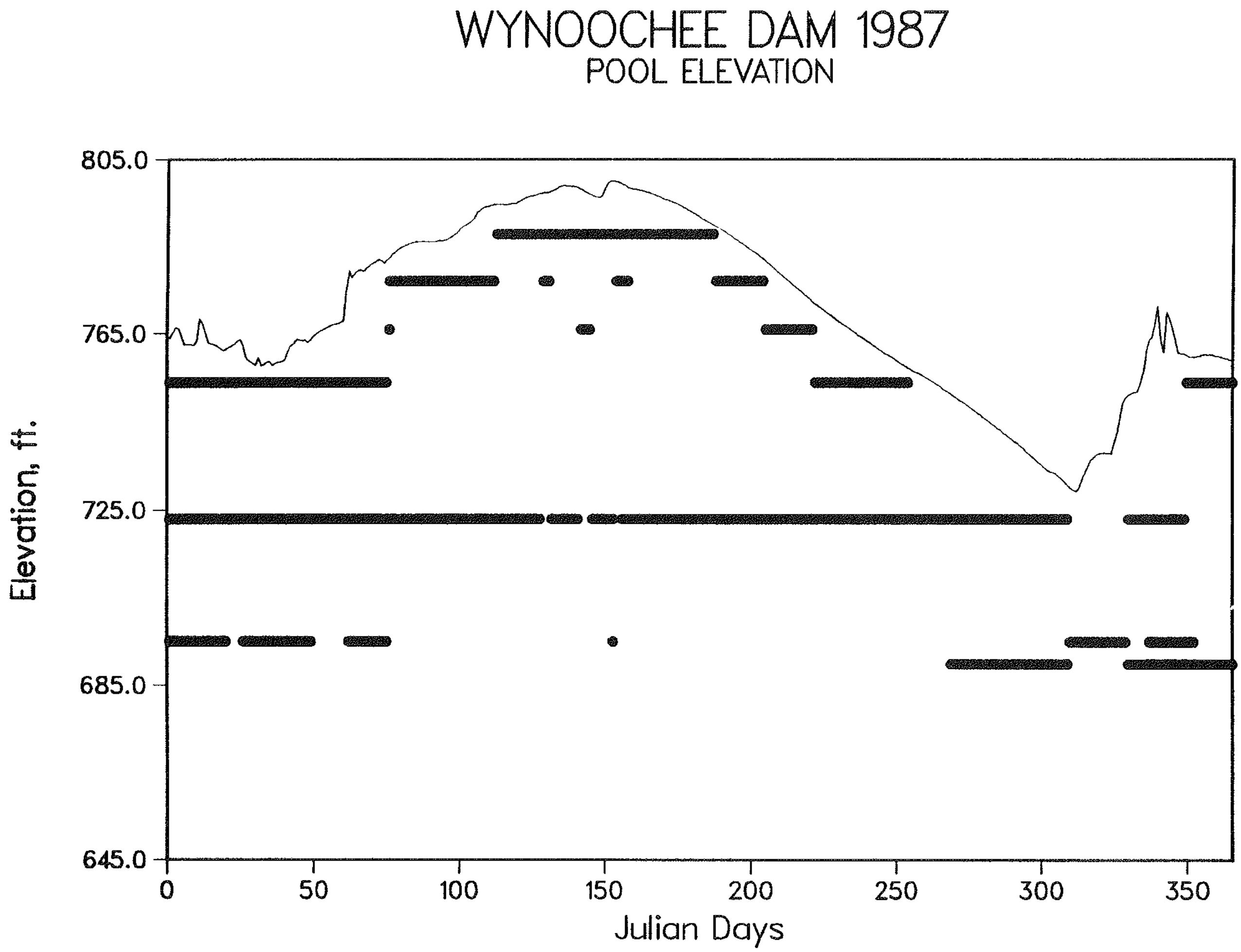


a. Inflow quantity



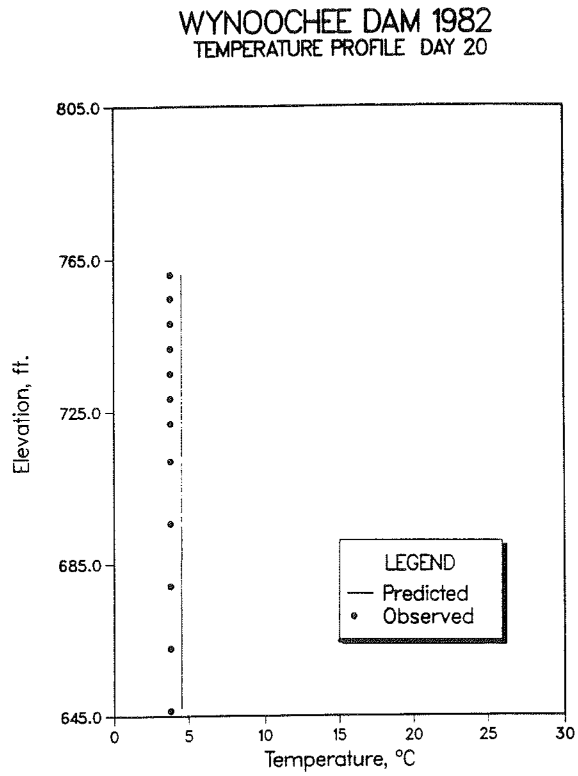
b. Outflow quantity

Figure 14. Hydraulic conditions 1987 (Continued)

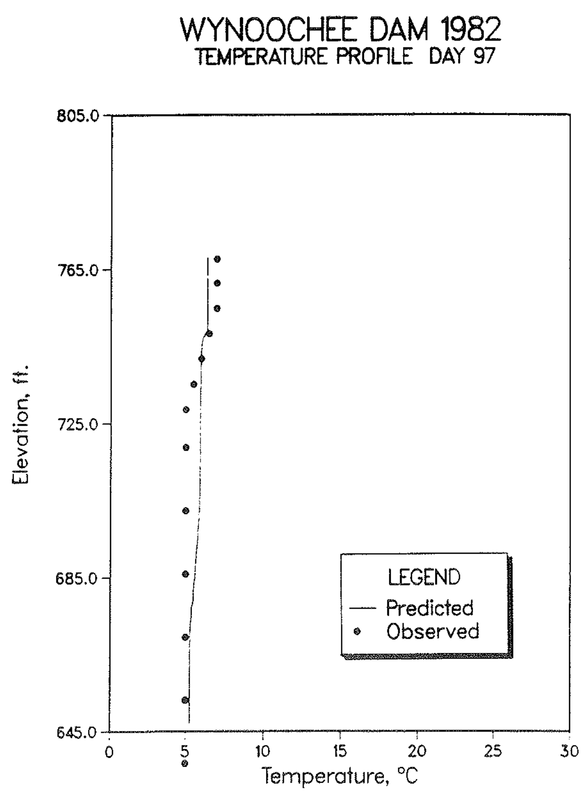


c. Pool elevation

Figure 14. (Concluded)

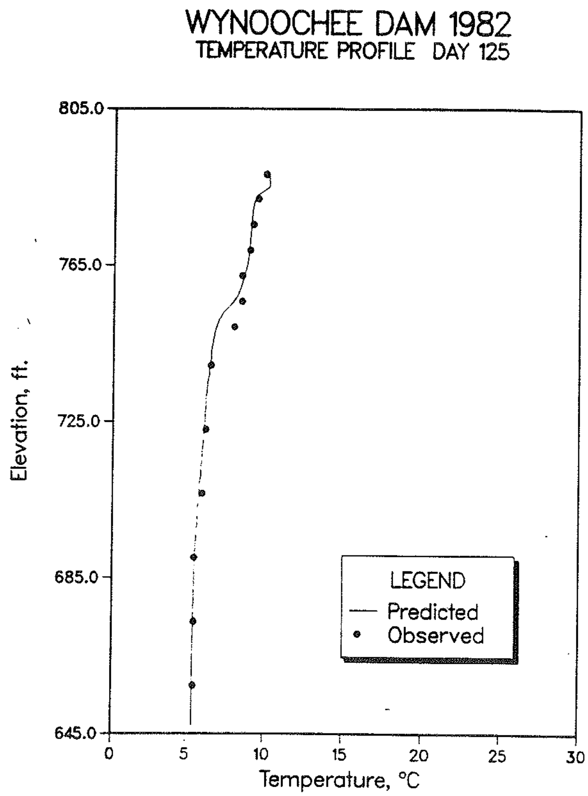


a. Day 20

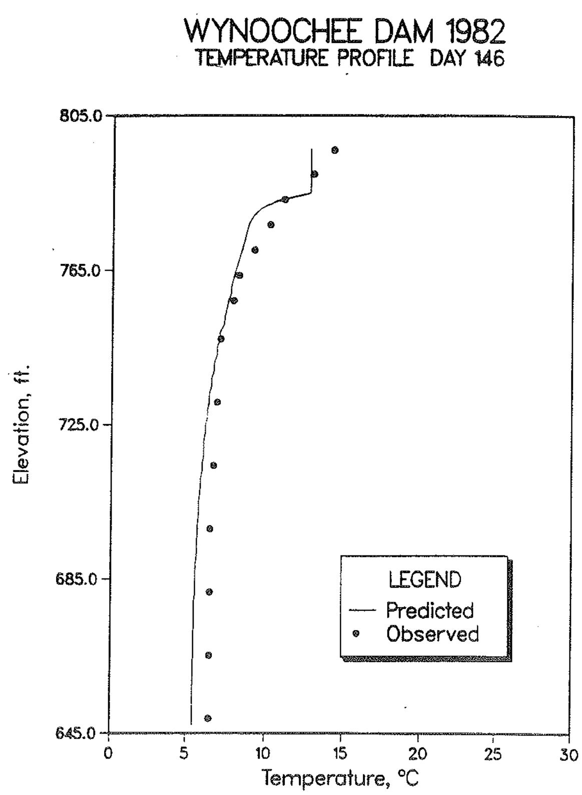


b. Day 97

Figure 15. Wynoochee Dam temperature profiles for 1982 (Continued)

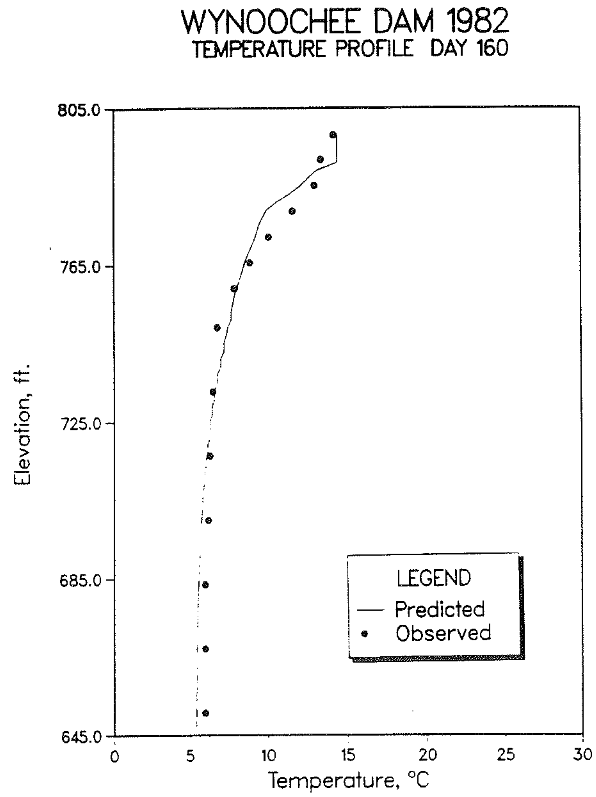


c. Day 125

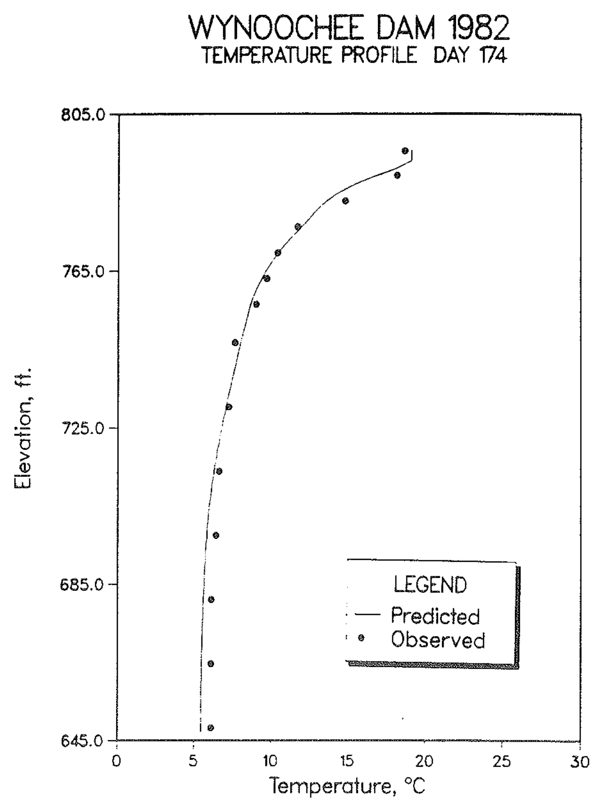


d. Day 146

Figure 15. (Concluded)

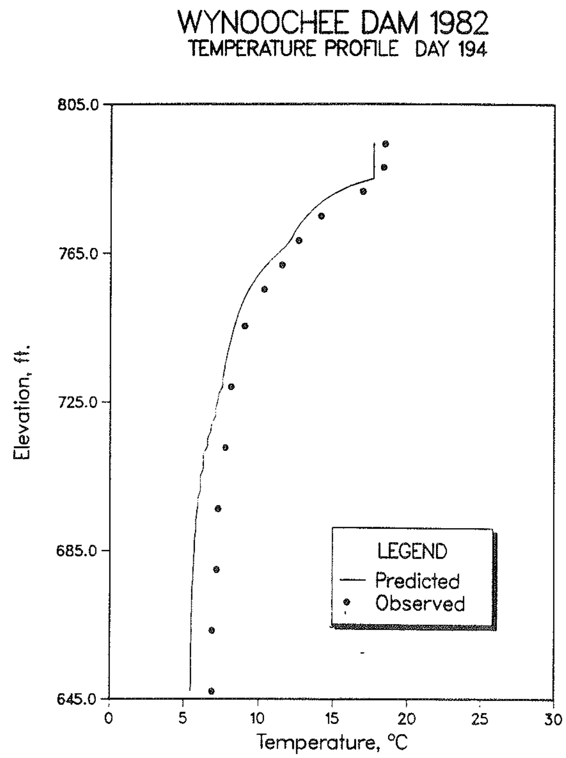


a. Day 160

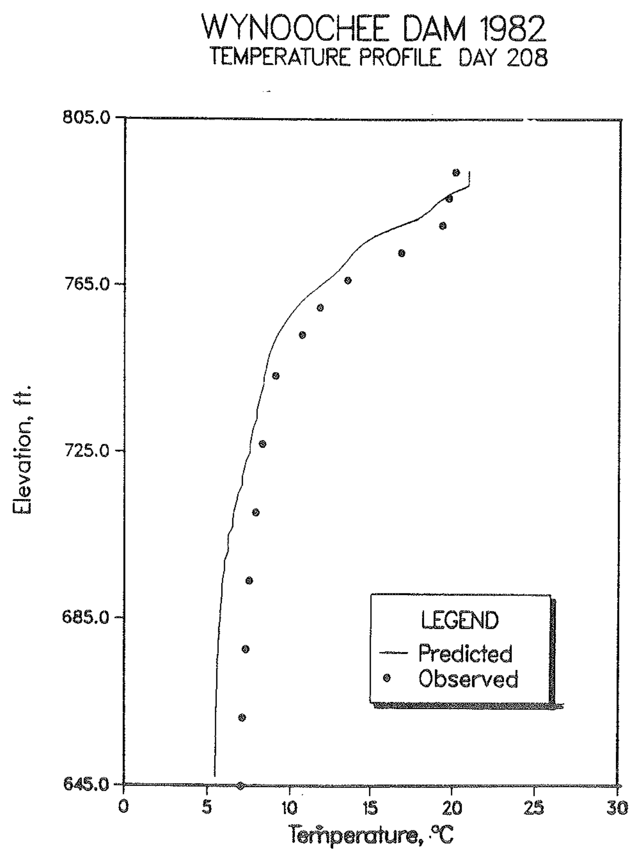


b. Day 174

Figure 16. Wynoochee Dam temperature profiles for 1982 (Continued)

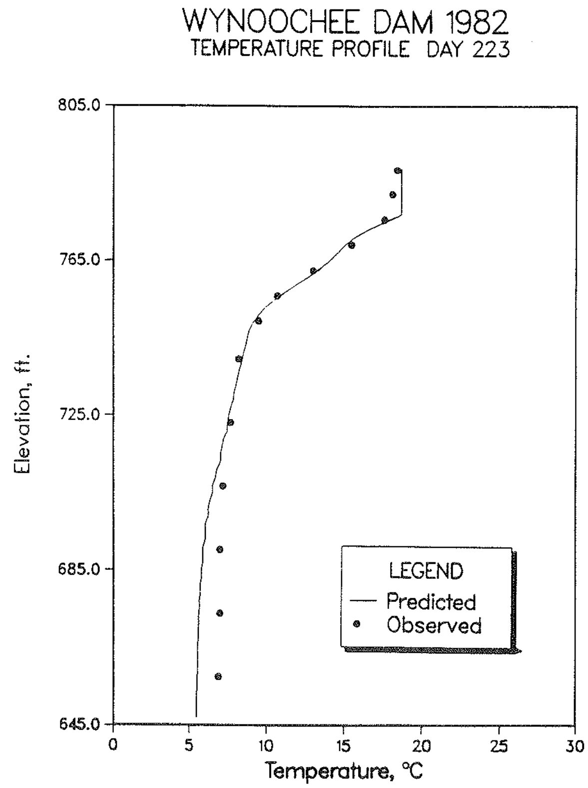


c. Day 194

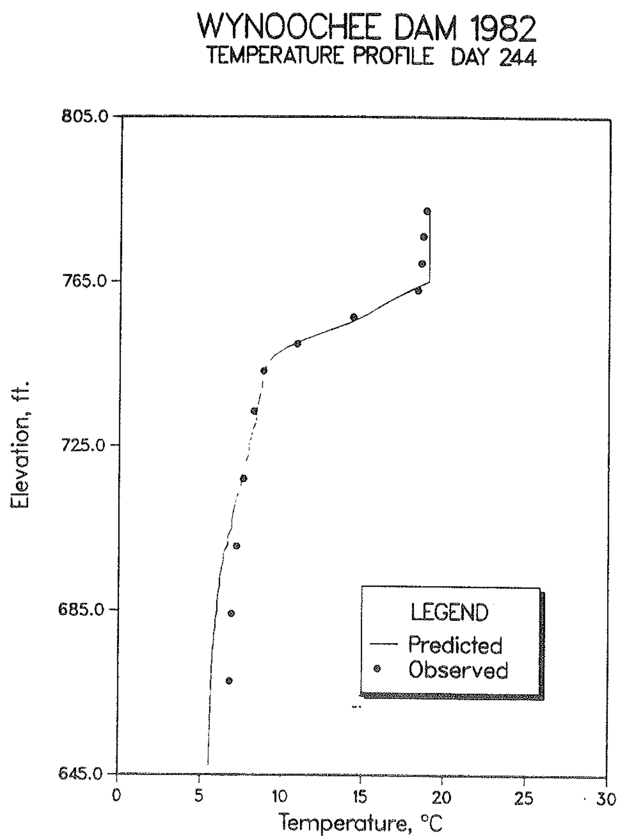


d. Day 208

Figure 16. (Concluded)

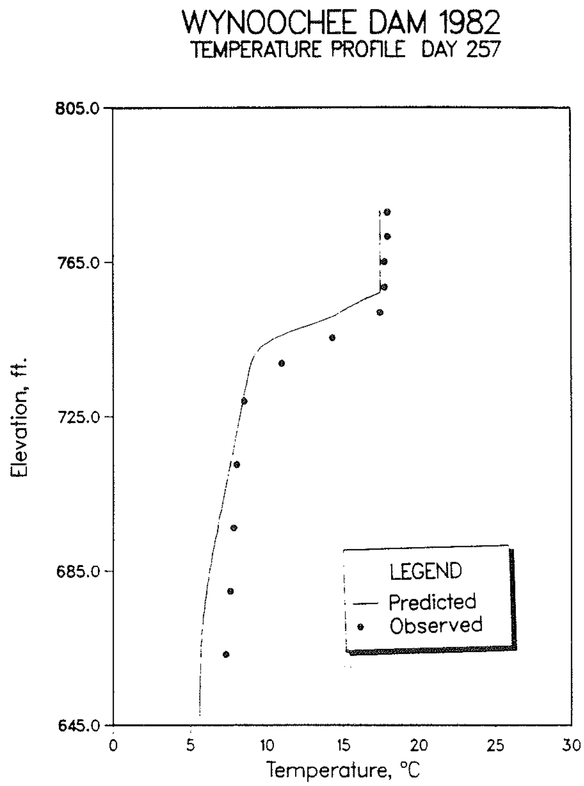


a. Day 223

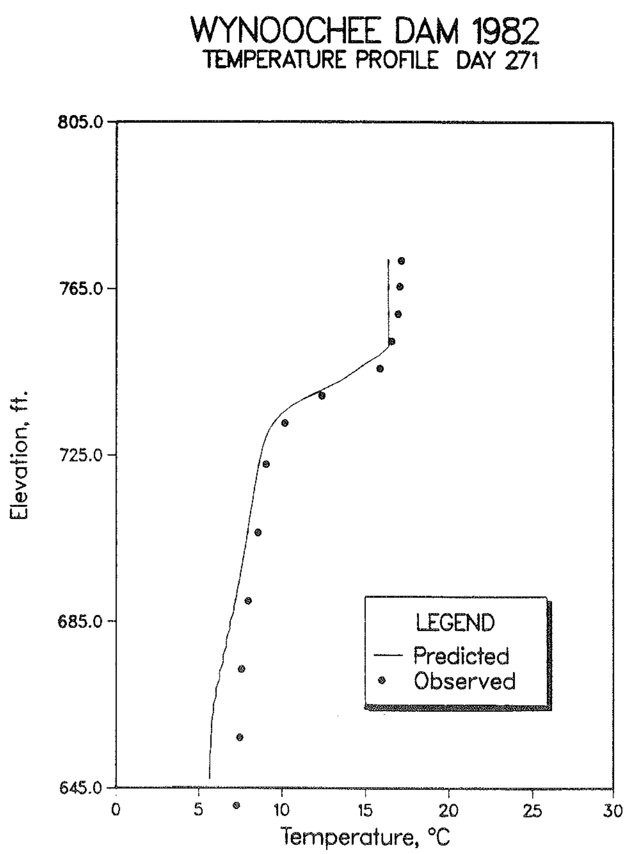


b. Day 244

Figure 17. Wynoochee Dam temperature profiles for 1982 (Continued)

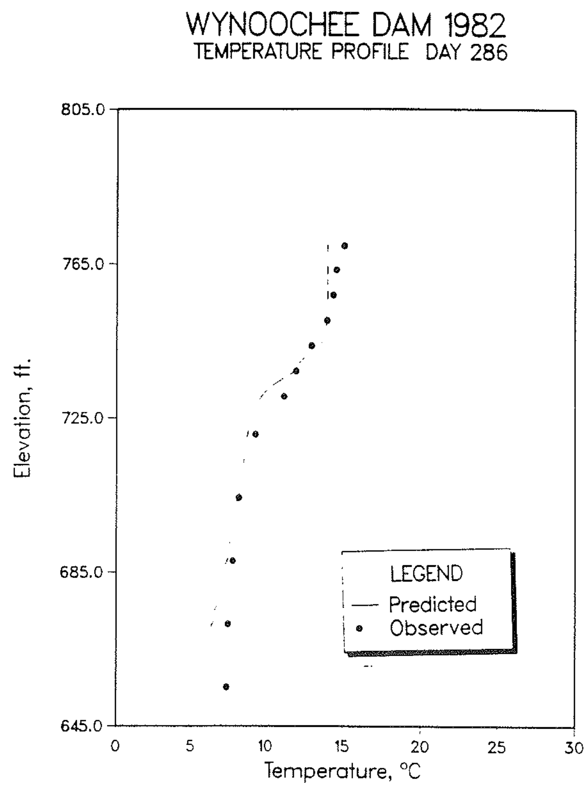


c. Day 257

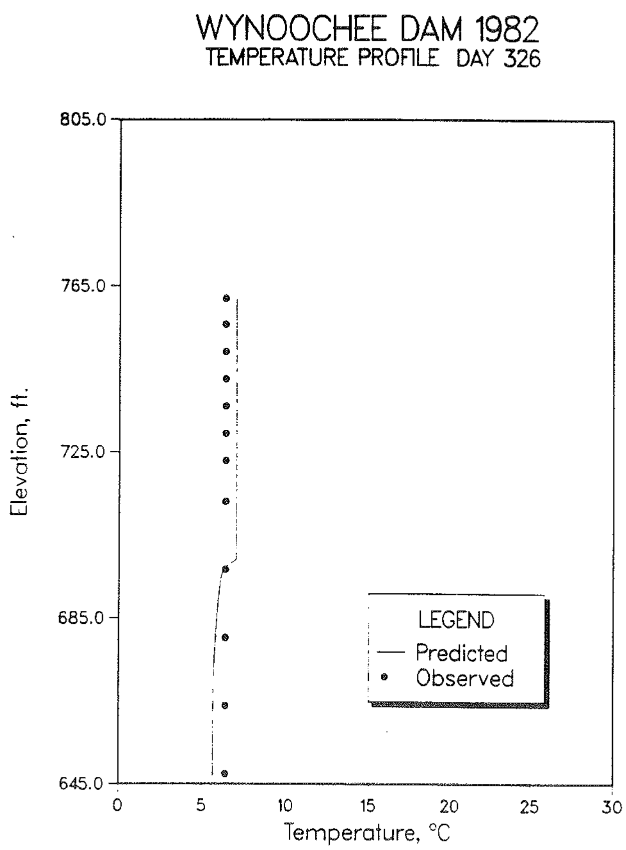


d. Day 271

Figure 17. (Concluded)



a. Day 286



b. Day 326

Figure 18. Wynoochee Dam temperature profiles for 1982

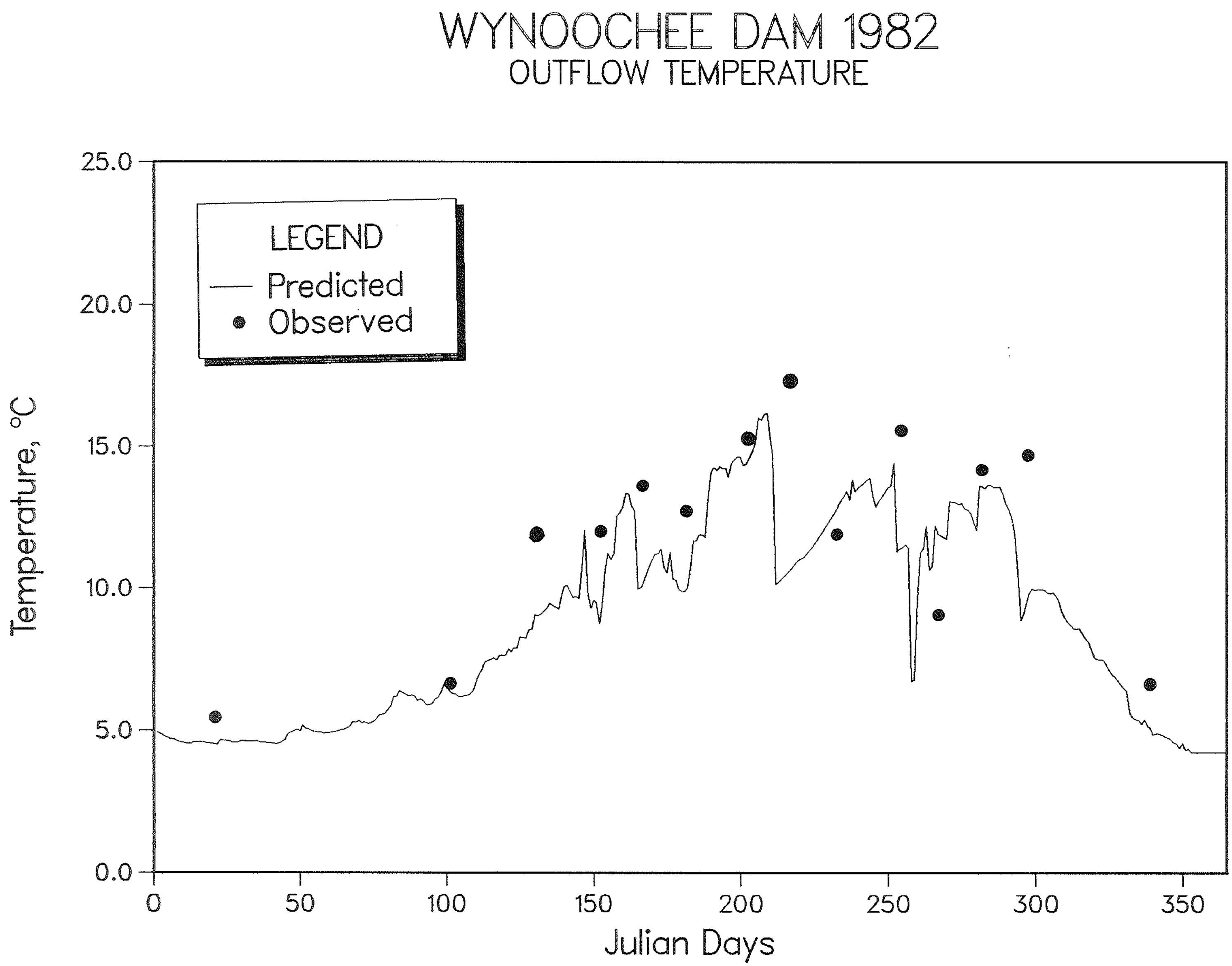
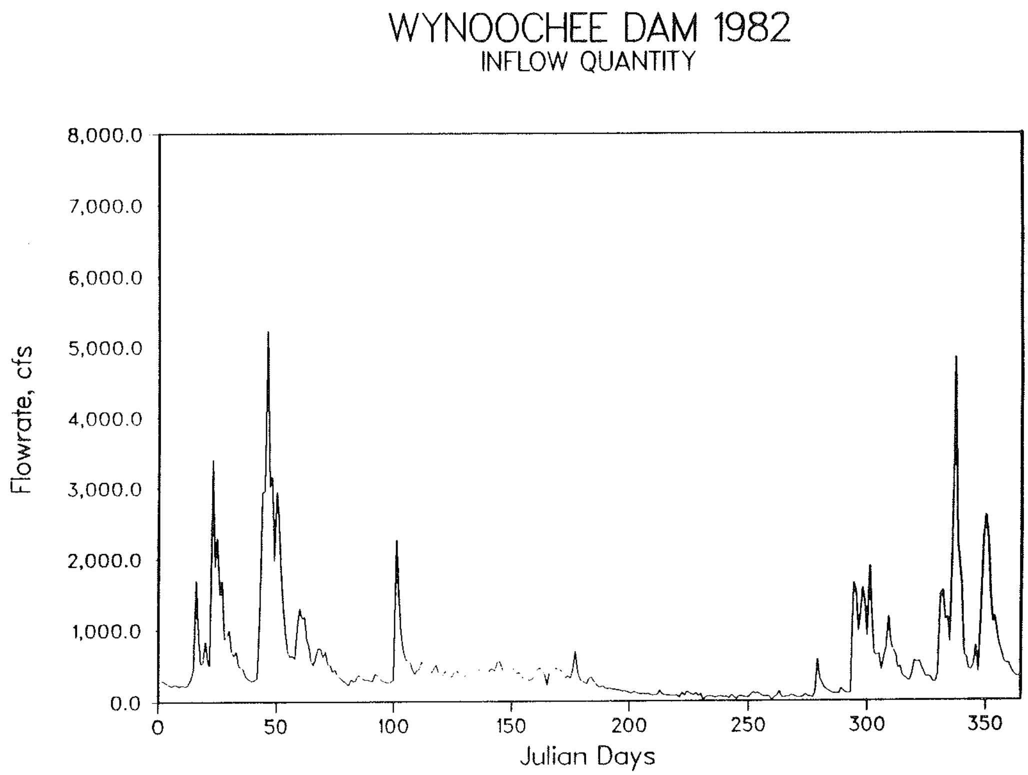
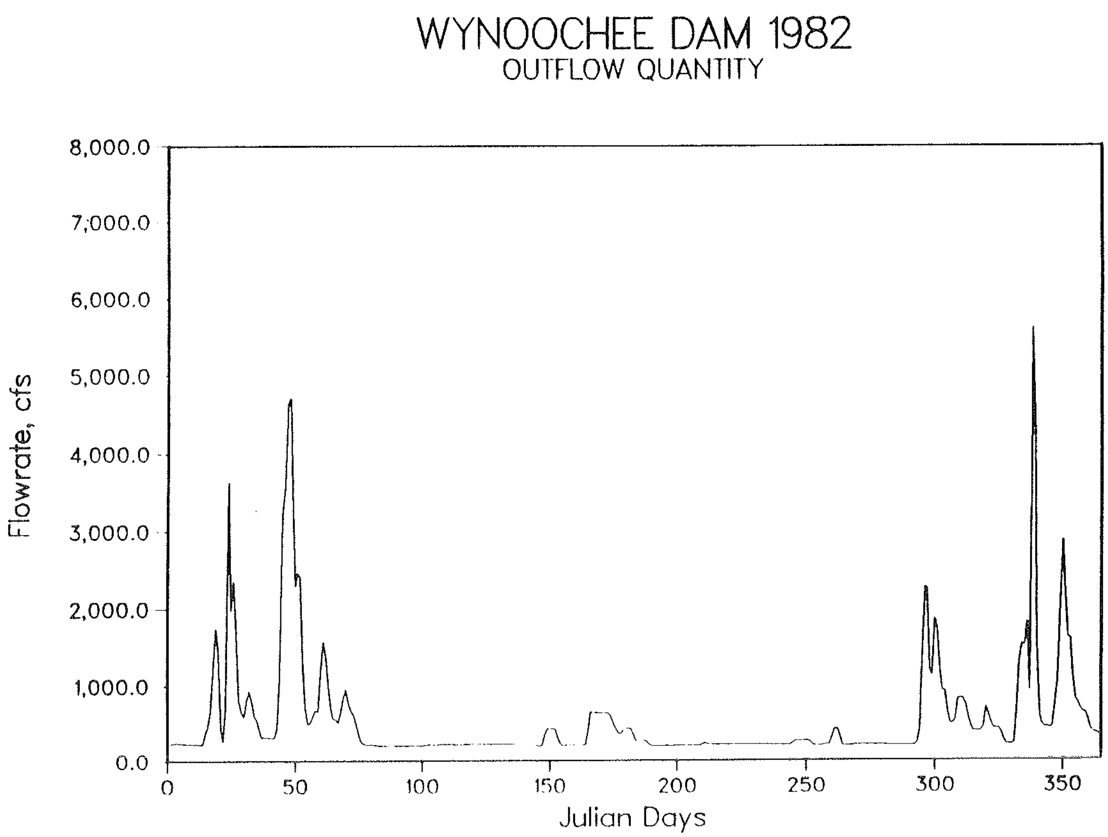


Figure 19. Outflow temperatures for 1982 - predicted vs. observed

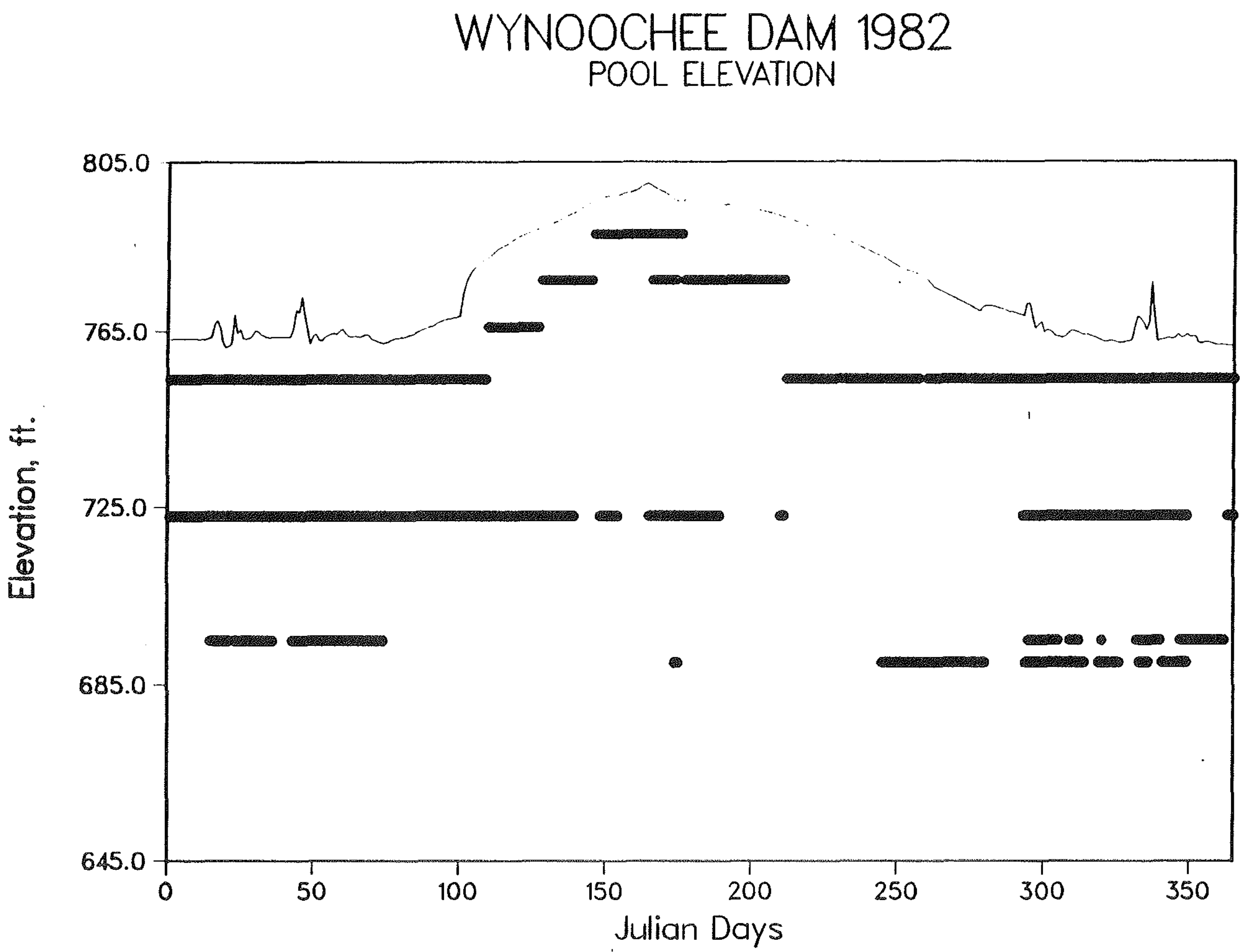


a. Inflow quantity



b. Outflow quantity

Figure 20. Hydraulic conditions for 1982 (Continued)



c. Pool elevation

Figure 20. (Concluded)

PART V: EVALUATION OF THE PROPOSED STRUCTURE

WESTEX Code Modifications

38. The WESTEX model was modified to accommodate several unusual aspects of the Wynoochee study including switching operation between the existing and proposed structures, establishing maximum flows, single-wet-well blending, fish passage restrictions on operation, and operating a weir and port simultaneously.

39. For selecting the appropriate intake structure to operate each day, an iteration procedure was installed in the WESTEX model. The proposed intake structure was given priority over the existing structure. The proposed structure was used for all days that it predicted a release temperature within the acceptable band (10-14.44° C), even if the existing structure might yield a temperature closer to the actual 12.78° C target. However, if the temperature criterion would be violated by using the proposed structure for a given day, that day's hydrologic and meteorologic conditions were simulated again, using the existing structure. If the existing structure failed to meet the acceptable release temperature range, the simulation with the proposed structure was used, regardless of which simulation was closer to the target temperature.

40. Flow rate was not a determining factor for structure selection. However, for flows greater than 1200 cfs (the maximum discharge of the proposed structure as provided by the developer) when using the proposed structure, the excess was taken through the sluices of the existing structure. Maximum flow for the weir in the proposed structure was limited such that the average velocity over the weir could not exceed a maximum prescribed by NPS of 5.0 fps. For the existing structure, the normally fixed values for maximum flow through each port were made variable with the water surface.

41. In simulating the proposed structure, several modifications were required. Although single-wet-well blending had been simulated with the WESTEX model in previous work, these applications had been site specific and the model had not been generalized. Building upon the prior applications, a version of the model suitable for simulating the proposed intake structure at Wynoochee was constructed. The resulting algorithm used the total flow through the structure, the desired release temperature, and the port and weir

loss coefficients to determine the gate setting of the port and the weir crest elevation that would most closely approximate the target temperature. As the weir crest is raised, the amount of water over the weir will decrease, but the water temperature over the weir will increase. Since for much of the year this is a warm water limited reservoir, the model needed to examine these tradeoffs. The potentially nonmonotonic solution of the weir elevation and the total release temperature precluded use of the simple search routine normally used in the single wet-well blending algorithm (Howington 1989). Therefore, the weir crest elevation was determined by examining the release temperature with five appropriately selected weir elevations and then retaining the one that produced the best release temperature.

42. From a selective withdrawal perspective, the weir would act as a port for a larger submergence and as a weir for a smaller submergence. The division between these two scenarios was established to be at a submergence equal to the weir length (10 ft).* Therefore, weir submergence greater than 10 ft triggered use of the port equations within the selective withdrawal routine and submergence less than 10 ft triggered use of the weir equations.

43. To simulate the existing structure, the operational constraints for fish passage were included. These constraints were described previously. Therefore, the model was modified to open the uppermost submerged port and permit no partial openings of the other three ports during the passage period. If the release temperature through the uppermost port exceeded 14.44° C, the uppermost submerged port was closed and the next lower port was opened fully. During the nonpassage parts of the year, the model was free to select any of the ports and to use partial openings.

Loss Coefficients and Withdrawal Angles

44. Typically in studies of this nature a physical model is used in conjunction with the numerical model to evaluate the hydraulic characteristics of the new structure. Specifically, the values associated with the loss coefficients through the structure and the withdrawal angles can be determined in the physical model. Since a physical model investigation was

---

* Information taken from unpublished data by Mr. M. S. Dortch, US Army Engineer Waterways Experiment Station.

not performed in this study, a range of loss coefficients and withdrawal angles had to be selected to test the sensitivity of the structure to meet objective temperatures.

45. There were three sets of loss coefficients to be determined for the proposed hydropower intake. These were losses associated with the trash rack upstream of the intakes, the variable height upper weir, and the variable opening lower port. Sidewall drag losses within the wet well will be very small in comparison to the port entrance head loss and can, within the context of this sensitivity analysis, be considered a part of the variable height upper weir loss. The coefficients were selected by WES and NPS to represent reasonable extremes. Loss coefficients are typically applied in the form:

$$\Delta H \text{ (head loss)} = k(v^2/2g) \qquad (1)$$

and in this study, where the terms are defined as:

ΔH = the difference in pool elevation and the elevation in the wet well, ft

k = the loss coefficient

v = velocity through the opening, fps

g = gravitational constant

46. NPS provided two values, 1.2 and 1.5, for the loss coefficient of the trash rack. These coefficients relate to the contracted area of the trashrack. The highest of the two values, 1.5, was used during all prediction runs. This value was selected since it was the most conservative, and since the scope of work did not include evaluation of multiple trash rack coefficients. This loss was used to establish the elevation of the water surface in the upstream pool between the trashrack and the intake gates.

47. Losses through an orifice are generally expressed in terms of the percent of gate opening. Logically, losses decrease as the gate opening increases. Since the actual losses associated with the proposed structure are not known, maximum and minimum values were selected from a curve provided by NPS expressing k in terms of gate opening. The value of k selected from this curve at approximately 100 percent gate opening was 0.60, and at the extreme confidence limits for approximately 10 percent gate opening was 3.30.

48. Determination of the upper gate losses was complicated by the fact that the gate is not an orifice but a weir. The weir equation does not

evaluate head loss in terms of k but uses a weir coefficient, C , and a total head to describe discharge over the weir. The equation given in the general form is:

$$Q = CLH_1^{3/2} \qquad (2)$$

where

Q = discharge, cfs

C = weir coefficient

L = weir length, ft

H_1 = height of the upstream pool over the weir, ft

This relationship is appropriate for weir length-to-depth ratios of approximately three or greater. Since the proposed upper gate can have depths of 30 ft with a weir length of ten, reducing this ratio to 0.33, the upper gate can behave more like a port than a weir. For this reason, maximum values of C were selected conservatively to reflect losses due to the sides of the rectangular opening.

49. In WESTEX, the head loss equation for the upper and lower ports is solved simultaneously to determine the discharge through the ports. Therefore, it was necessary to somehow express the weir coefficient, C , in terms of the loss coefficient, k . The problem was resolved by making the following calculations and assumptions:

a. A maximum and minimum value for C was selected from a curve provided by NPS (Figure 21) in much the same manner as k was determined for the lower port. The values selected were 3.0 and 0.6.

b. It can be seen from Figure 21 that C is a function of submergence, defined as R , such that $R = H_2/H_1$ and H_2 equals the height of the pool over the weir in the wet well. Then from this curve, R equals 0.98 for C equal 0.60 and 0.833 for C equal 3.0 (here, the minimum value of C results in the minimum discharge and the highest k).

c. To relate C to k , the following equations were solved simultaneously for k :

$$Q = CLH_1^{3/2}$$

$$Q = vH_1L$$

$$\Delta H = k(v^2/2g)$$

$$\Delta H = H_1 - H_2$$

$$R = H_2/H_1$$

d. Given R and C , the value of k can be computed using Equation 3:

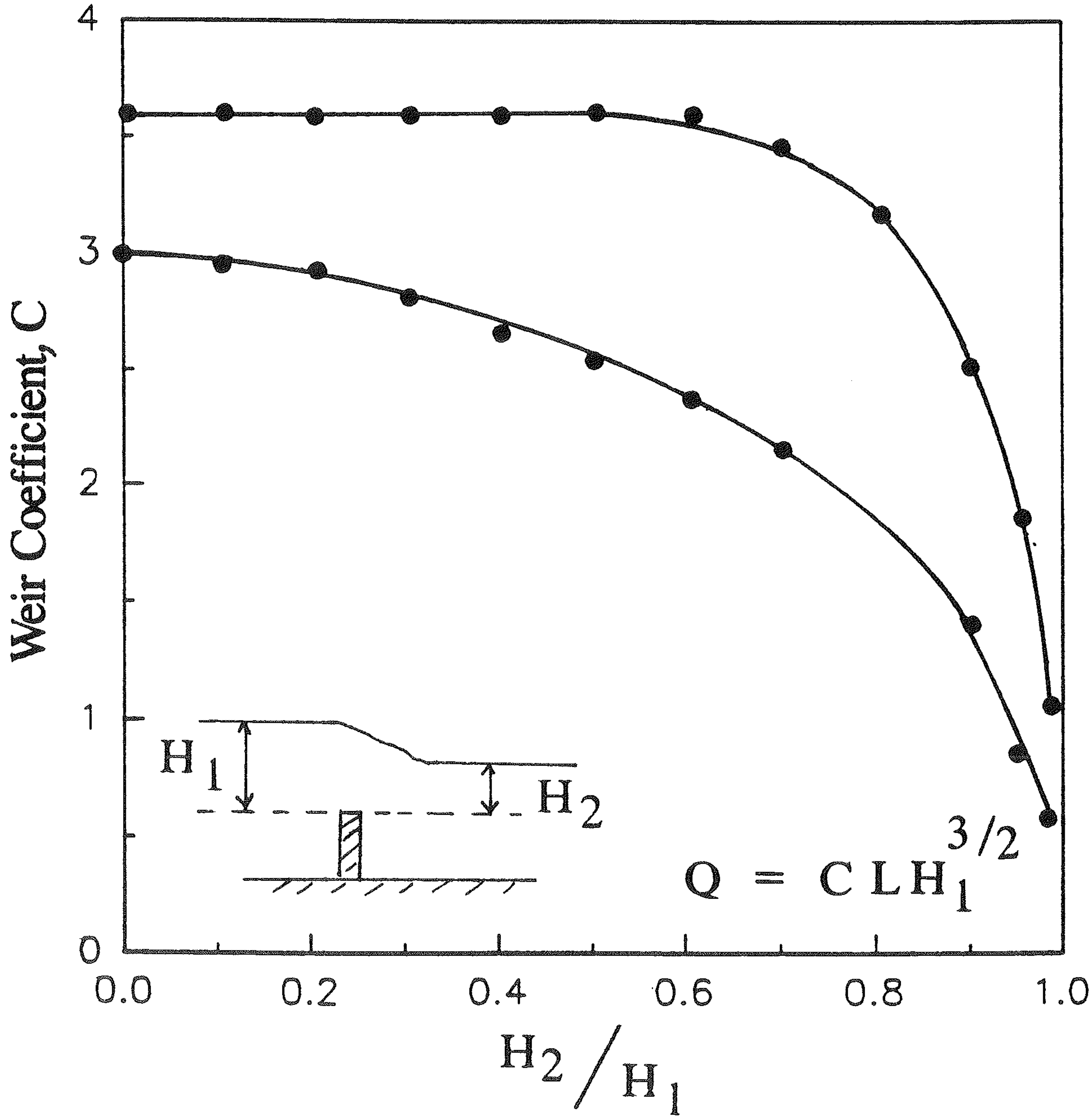


Figure 21. Weir coefficients for the upper port

for $C = 0.6$ and $R = 0.98$, then $k = k_{max} = 3.6$

for $C = 3.0$ and $R = 0.833$, then $k = k_{min} = 1.195$

The velocity used in these equations assumes that the depth of water over the weir is H_1 when, in fact, it is somewhat less than H_1. Therefore, the velocity is slightly underestimated. However, as will be subsequently established in this document, the water surface differential between the pool and the wet well is substantially restricted by the velocity criterion and the coefficient used in the weir equation. This limited differential in water surface permits the acceptable approximation of velocity in the manner shown. Resulting in the relationship:

$$k = \frac{(1-R)(2g)}{C^2} \tag{3}$$

50. By fixing the value of C we are making the assumption that Q is no longer a function of H_1 when, in fact, it is. We are also establishing a maximum value of Q and ΔH for each k. Flow through the upper port cannot exceed the weir equation, $Q_{max} = CLH_1^{3/2}$. The maximum head loss is determined from the relationship, $R = H_2/H_1$ and $\Delta H = H_1 - H_2$, for a value of H_1 equal to a maximum of 30 ft (based on a maximum pool el of 800 and a minimum weir el of 770) such that:

at $k = 3.6$, $\Delta H_{max} = 30 - 30(0.98) = 0.6$ ft

and

at $k = 1.195$, $\Delta H_{max} = 30 - 30(0.833) = 5.0$ ft

For the lower value of k, however, the velocity criteria of 5 fps would be exceeded long before the head loss would reach 5.0 ft. WESTEX was modified such that discharge through the upper ports could not exceed either the maximum resulting from the weir equation or the maximum imposed by the velocity criteria.

51. The two withdrawal angles that were selected for the prediction runs were 3.14 and 1.05 radians. The withdrawal angle describes the lateral confinement of the withdrawal zone due to topographical boundaries and adds a certain amount of quasi-multidimensionality to an otherwise one-dimensional evaluation of the reservoir's withdrawal characteristics (Howington 1989).

Establishing a Base Condition

52. The existing structure only was simulated in WESTEX using the new operations criteria for the study years 1975, 1980, and 1983. This was done to establish a base condition prior to prediction runs using both structures in order to have a viable means of comparing prehydropower and posthydropower conditions.

53. To answer the questions which prompted this study, several parameters were easily evaluated as a means to measure performance. Some of these items include the number of days target temperatures were met, the absolute value of the difference in daily temperatures from the target temperature of 12.78° C, the actual release temperature when the target range was not met, and the number of days the existing and proposed structures operated. However, the ability of the existing structure to compensate for any deficiencies established in the pool as a result of operating the proposed structure could only be assessed by knowing what the existing structure could have done alone. Therefore, values determined from the base condition runs were used as a means to evaluate the efficiency of the proposed structure.

54. All analyses pertaining to the efficiency and performance of the existing and the proposed structure relate only to 214 days from 1 April through 31 October (or Julian days 91 through 304), which hereafter will be referred to as the stratification period. While this time period may or may not be the actual stratification period, it approximates this period and was recommended by NPS as the time period for which releases should attempt to meet the target temperature of 12.78° C.* During January through March, and November through December, the warmest water available was drawn from the pool. Considering also that the proposed structure cannot operate during the 77 day period beginning approximately on Julian day 105 through 181 (15 April through 30 June), there is a maximum of 137 days during the stratification period that the proposed structure can operate.

55. Two efficiency values were constructed in terms of percentages to compare model results. The value, E_1 , relates to the efficiency of the combined new structure to meet target temperatures relative to the base

---

* This information based on a telephone conversation between Mr. Glen Singleton, NPS, and Dr. Jeffrey P. Holland, WES, on 2 March 1990.

condition. The second value, E_2 , relates to the number of days the new structure operates out of the possible 137 days. They are constructed as follows:

$$E_1 = \frac{\text{(Days met during test) - (Days met during base)}}{\text{(Days met during base)}} \times 100$$

$$E_2 = \frac{\text{Days the new structure operates}}{\text{137 days}} \times 100$$

E_1 is a percentage which evaluates the ability of the combined structure to meet the objective temperature range (10.0° C to 14.44° C). "Days met during base" describes the number of days out of the possible 214 included in the analysis that the base condition (existing structure only) met the target range. Likewise, "days met during test" describes the number of days of the 214 that the combined structure met the target range. E_2 describes the percentage of time the new structure operates during the stratification period normalized for the time period it is allowed to operate.

Prediction Runs

56. Based on the above selection of losses and withdrawal angles, the prediction tests were conducted for each study year by varying combinations of these parameters. The tests were such that combinations of all the following were either simulated in WESTEX or determined to have no bearing on the results.

Parameter	Values		
k(upper port)	3.6	1.195	
k(lower port)	3.3	0.6	
withdrawal angle	3.14	1.05	
study year	1975	1980	1983

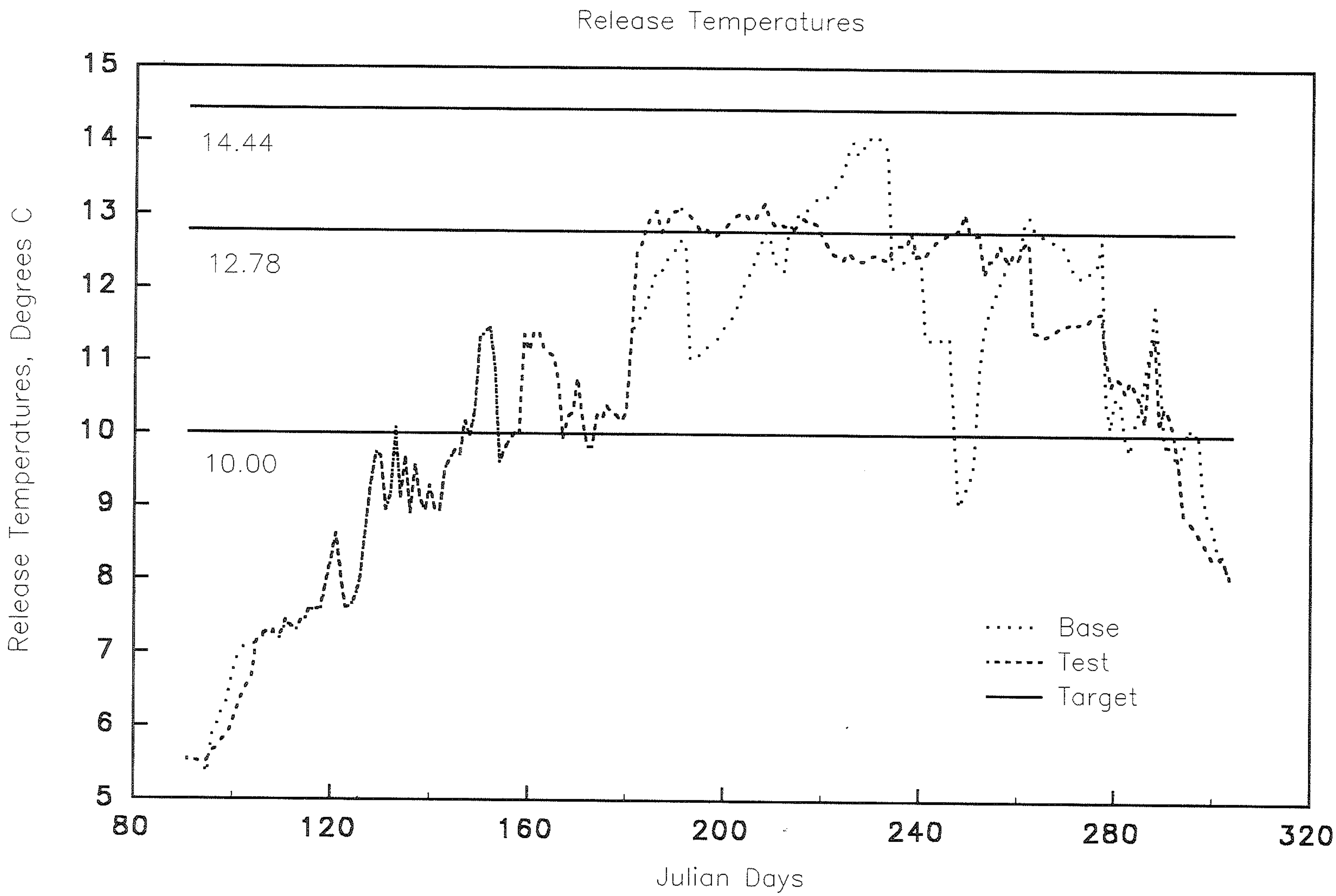
PART VI: RESULTS

57. The general test results are summarized in Table 4. Some of the tests outlined in the scope of work were eliminated when insignificant effects were observed due to changing a variable. For instance, E_1 , E_2 , the number of days of operation, the absolute average temperature difference from the target, the average release temperature, and the days target was met did not change at all between the following tests: 1 and 10, 4 and 7, 2 and 11, 5 and 8, 6 and 9, and 16 and 17. In these tests only, the lower port coefficient was changed from a maximum value of 3.3 to a minimum value of 0.6. Because of the unlimited throttling capabilities proposed by the developer, the range of lower port loss coefficients used in this study does not substantially affect the operation of the new structure.

58. Similarly, other parameters were determined to be insensitive in changing the ultimate output of the prediction runs and were consequently eliminated from further testing. The value of the withdrawal angle sometimes affected the number of days the new structure was allowed to operate, or E_2 , and marginally affected the absolute average temperature difference. The ability of the combined project (existing and proposed structure) to meet target temperatures, however, was not affected. These results can be seen by comparing the following tests: 10 and 18, 11 through 14, 3 and 15, 6 and 16, and 9 and 17.

59. The upper port coefficient, like the withdrawal angles, had small effects on the absolute average difference in temperature, and caused some variation in the number of days the new structure could operate. These affects can be seen by comparing results of the following tests in Table 4: 1 and 4, 7 and 10, 2 and 5, 8 and 11, 3 and 6, and 15 and 17.

60. The three sample plots in Figures 22-24 represent the release temperatures during the prediction runs for each study year compared to the releases if the existing structure only had operated (the base condition). All tests of the same data year resulted in similar release temperatures, therefore, tests 4, 2, and 16 were selected since these tests produced the least number of days the new structure was allowed to operate for 1975 data, 1980 data, and 1983 data, respectively. These plots compare the test releases to the target temperature of 12.78° C and to the base condition for the period beginning 1 April and continuing through 31 October.



a. Release temperatures

Figure 22. Comparison of 1975 release temperatures using Test No. 4 (Continued)

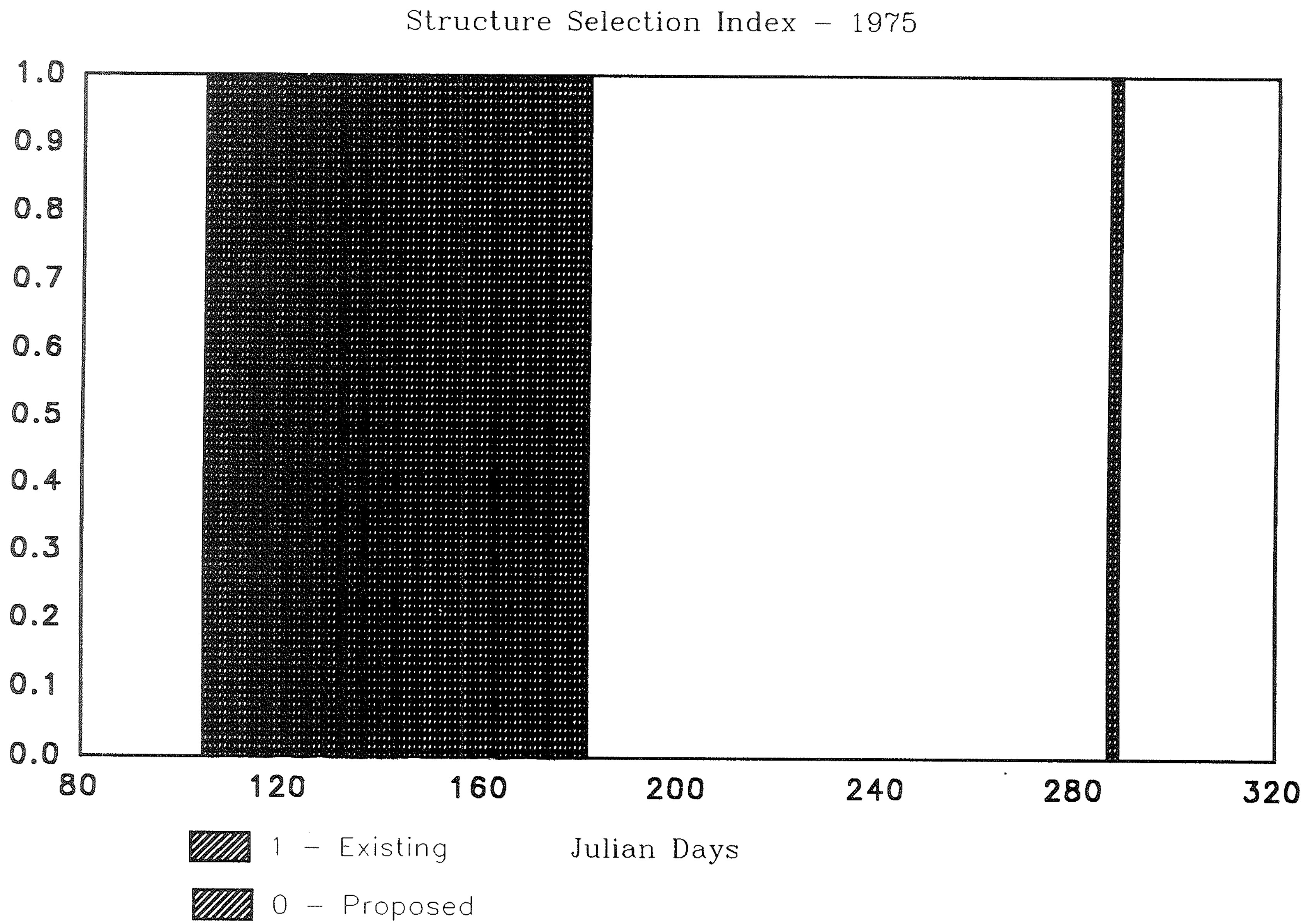
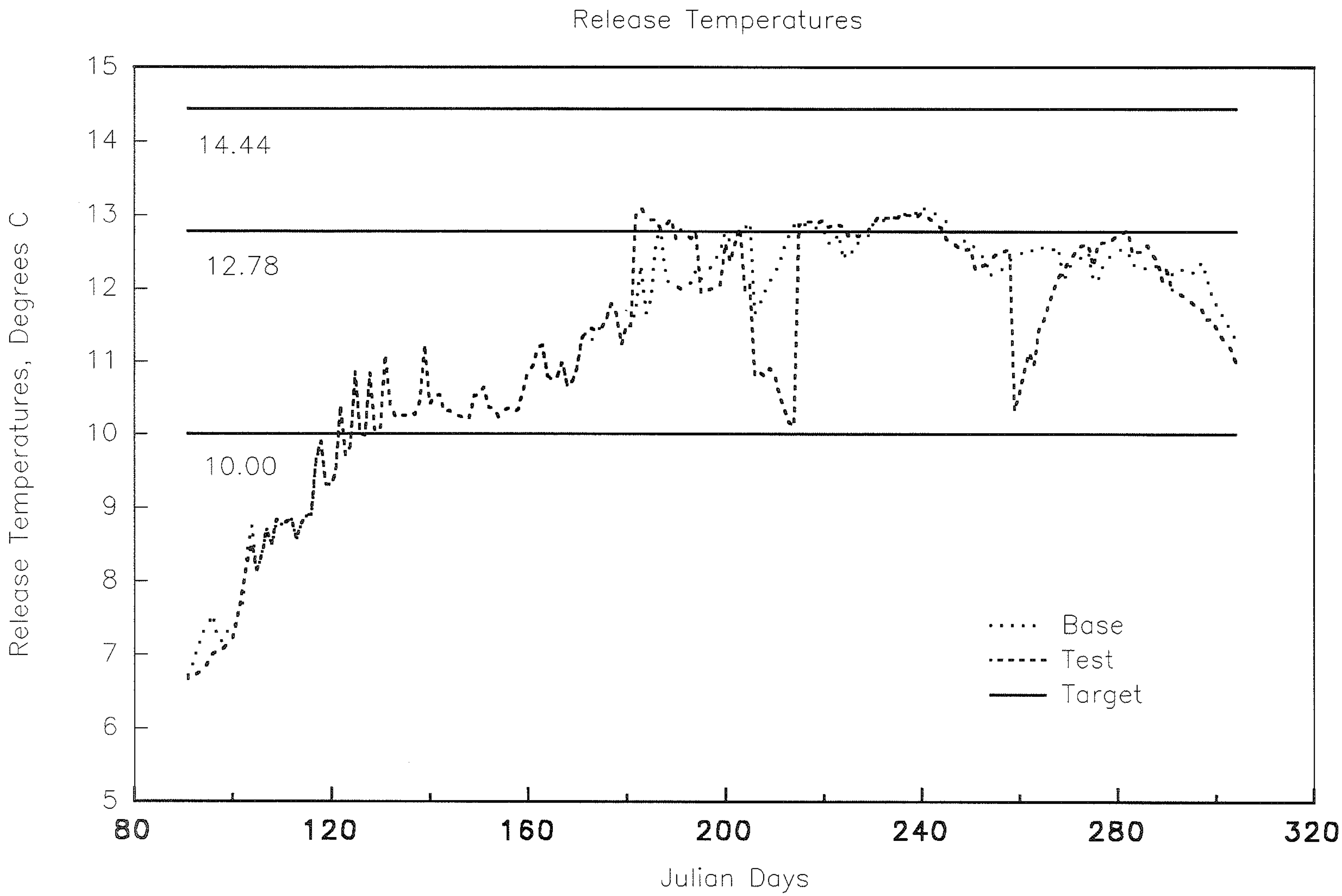
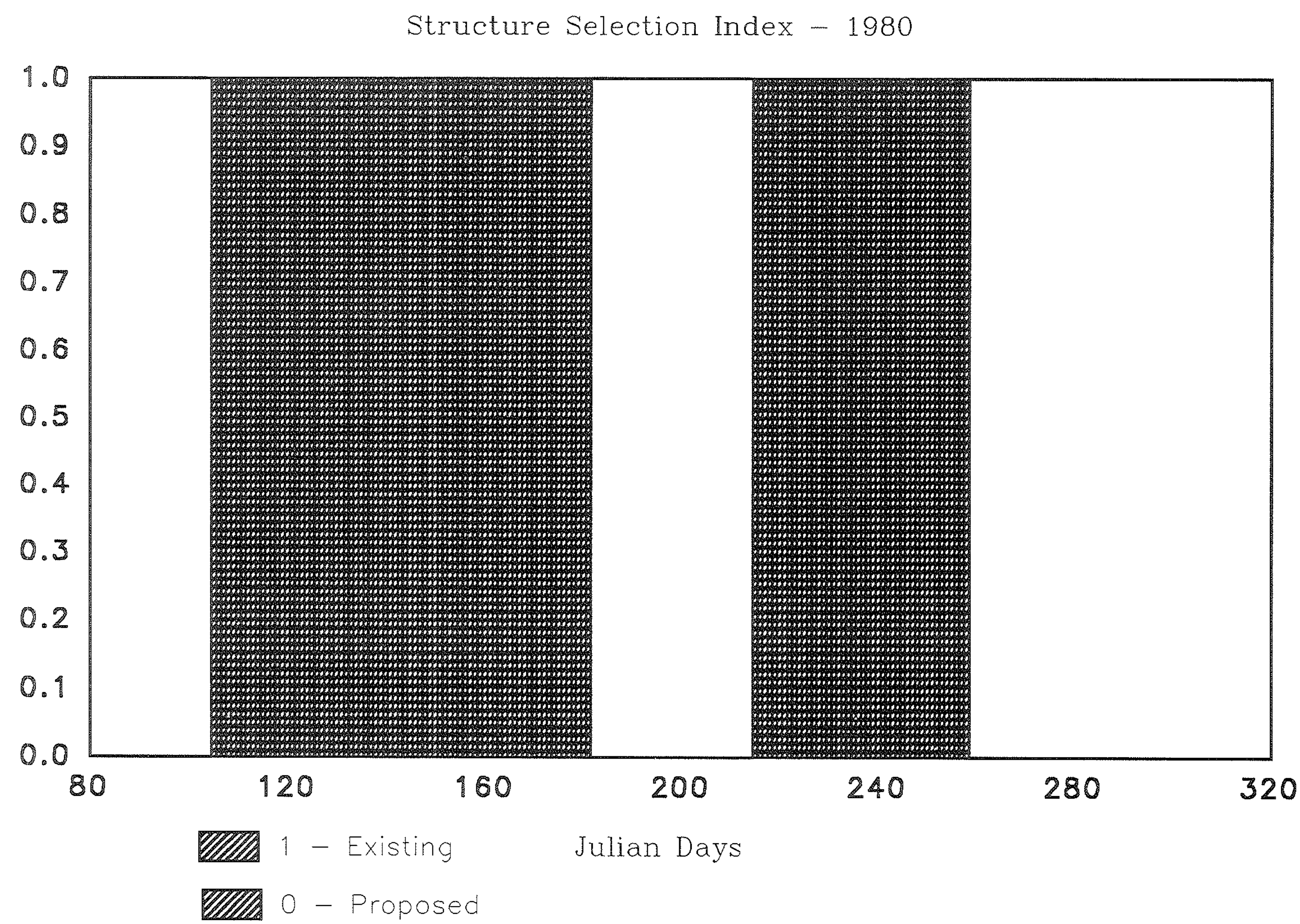


Figure 22. (Concluded)



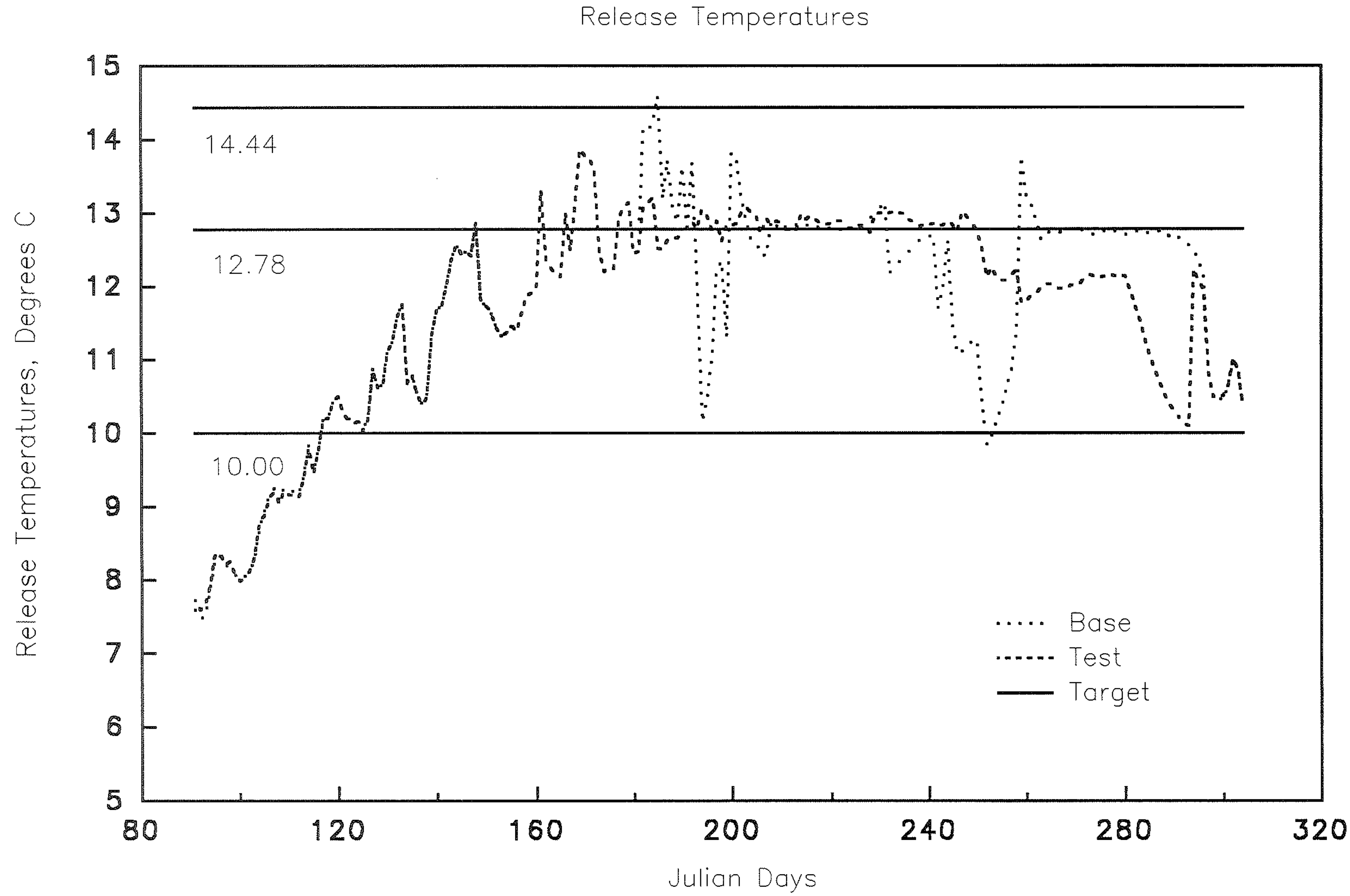
a. Release temperatures

Figure 23. Comparison of 1980 release temperatures using Test No. 2 (Continued)



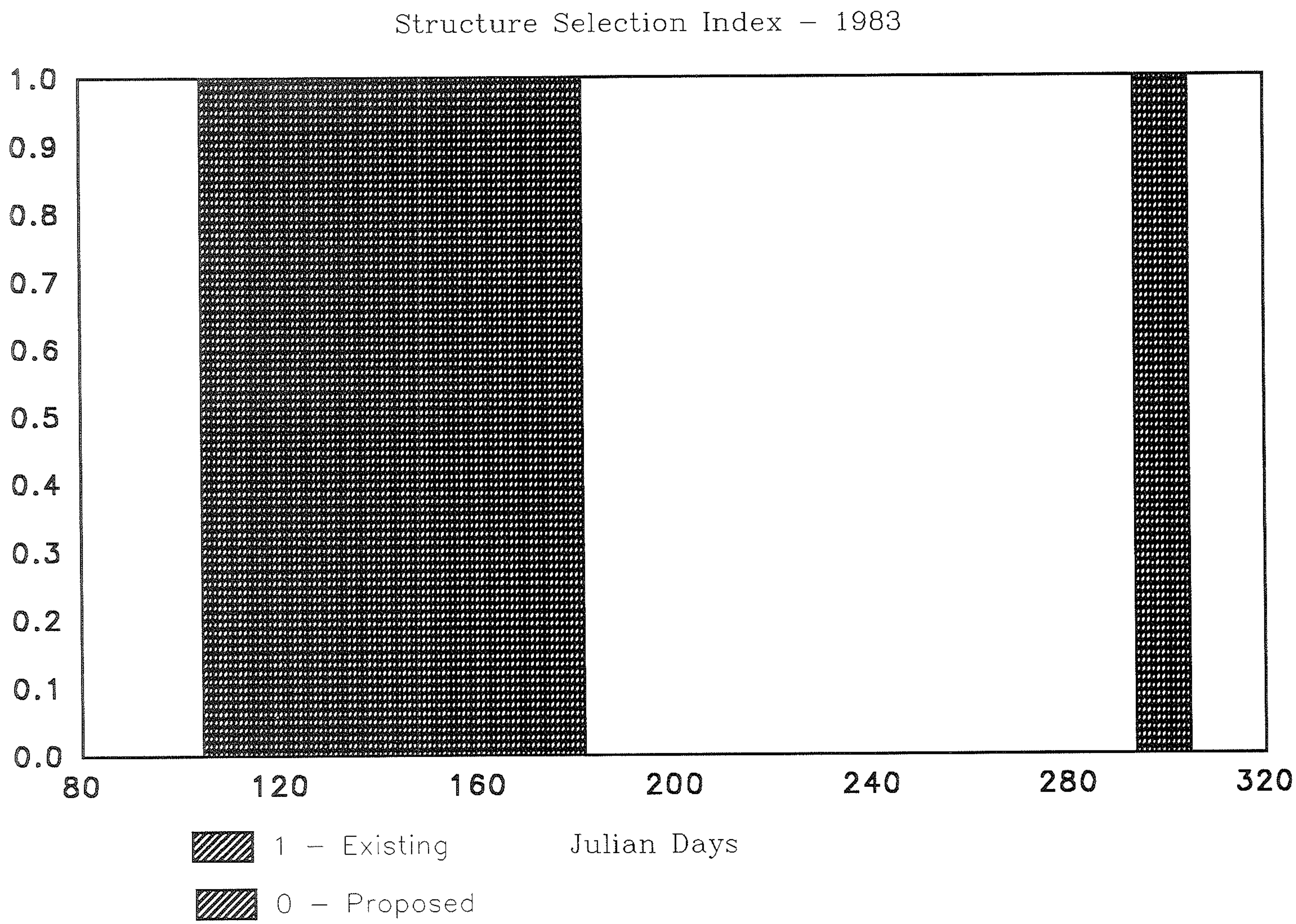
b. Structure used during Test No. 2

Figure 23. (Concluded)



a. Release temperatures

Figure 24. Comparison of 1983 release temperatures using Test No. 16 (Continued)



b. Structure used during Test No. 16

Figure 24. (Concluded)

61. Data year 1980 resulted in the least number of days the proposed structure could operate. Figure 23 shows that on day 215 when the existing structure takes over operations because the new structure cannot meet the target range, it quickly brings the release temperatures up to the target temperature. Table 5 shows the release temperatures in 1980 beginning with day 181 for the base condition, the simulation run, and the temperatures had the proposed structure continued operation. Two conclusions can be deduced from this information: (1) the old structure can use the reservoir temperature regime initiated by the proposed structure and still meet objective temperatures; and (2) had the proposed structure continued operations during this time period the releases would have been less than 1.5° from the minimum target limit of 10.0° C.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

62. In summary, three basic model tests were conducted:

   a. Simulations of the existing structure to verify WESTEX thermal modeling capabilities using 1987 and 1982 data sets.

   b. Base conditions were established using the existing structure only for 1975, 1980, and 1983 hydrologic/meteorologic inputs.

   c. Prediction runs that simulate and analyze the combined use of the existing and proposed structures for the same data years and using an assumed range of intake loss coefficients and withdrawal angles for the licensee's proposed structure.

63. The parameter having the least effect on the results was the lower port loss coefficient. This stems from the developer's contention that the lower port will have no lower limit on gate opening (the condition used for these analyses). In practice, however, the gate will be controllable only down to a finite opening, introducing a real lower bound for port operation. This limit will necessarily be determined in prototype testing. The withdrawal angles and the upper port coefficient had nominal effects on the number of days the new structure could operate and the absolute average temperatures, and no effect on the days target temperatures were met by the combined project. The hydrologic and meteorological inputs for each data year had the most significant effect on the study results. Of the tests conducted, 1975 had the worst absolute average difference in temperature of approximately 2.3° C during the stratification period and consequently, target temperatures were met the least amount of days (141) during this data year. However, it had the highest values of E_1 (2.92 to 3.65%), indicating that the combined structure performed better than the existing structure alone for 1975. Data year 1980 resulted in the least number of days (93) the new structure could operate during the stratification season, resulting in the lowest value of E_2 (67.9%). The 1983 data produced the lowest average absolute difference from the target temperature during the stratification period of approximately 1.3° C and met the target range 188 of the 214 days.

64. In all prediction runs when operation had to be returned to the old structure, it was because the proposed structure released water with temperatures less than the minimum target of 10.0° C. Although the proposed structure release was not warm enough to meet the 10° C criteria, had it continued operating, its releases would not have fallen below 8.7° C as shown in

Table 5. This table compares the release temperatures of the 1980 base condition, the Test 2 releases (either structure), and the release temperatures (last column) of the proposed structure if operations had not switched back to the existing structure. In 1975, during the two to three days the old structure was operating, the new structure would have released temperatures less than 0.5° C below the minimum target temperature. Similarly in 1983, during approximately days 295 through 304, the lowest temperature the new structure would have released was 9.3° C. Only once, during the base condition run with the 1983 data, did the objective exceed the upper target of 14.44° C, and that was for day 185 with a temperature of 14.6° C.

65. In conclusion, all items undertaken in the scope of work were completed. All data were developed and prepared for model input. The WESTEX code was modified to incorporate all site-specific constraints of the existing and proposed structures. WESTEX was verified and applied to evaluate the thermal capabilities of the proposed structure.

66. Results from this study in no way can be used as an operations guide. The obvious reason for this is that historical data were used to simulate the reservoir profiles and releases. Further prototype tests will be required to determine appropriate loss coefficients, rating curves for ports, limits of practical gate control, and other performance characteristics. Further, the results are not valid if fish passage facilities are added to the structure.

67. The overall study objective requiring that a model study be conducted to demonstrate the ability of the proposed project to meet water temperature objectives was accomplished. That is, for the range of coefficients and conditions examined in this study, the combination of the existing and proposed structure can meet downstream target temperatures as well as the existing structure alone. Furthermore, the combined operations does not prohibit the old structure from resuming operations when the new structure cannot meet release temperature requirements.

REFERENCES

Edinger, J. E., and Geyer, J. C. 1965. "Heat Exchange in the Environment," Publication No. 65-902, Edison Electric Institute, New York.

Heath, R. C. 1983. "Basic Ground-Water Hydrology," U.S. Geological Survey Water-Supply Paper 2220, Alexandria, Virginia.

Holland, J. P. 1982 (Apr). "Effects of Storage Reallocation on Thermal Characteristics of Cowanesque Lake, Pennsylvania," Technical Report HL-82-9, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Howington, S. E. 1989 (Jul). "Intake Structure Operation Study, Lost Creek Dam, Oregon," Technical Report HL-89-13, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Hosey and Associates, Engineering Company. 1988 (Dec). "Wynoochee Dam Hydroelectric Project, FERC No. 6842, Temperature Model Study Report, In Compliance with FERC License Article 402," City of Aberdeen and City of Tacoma.

US Army Engineer District, Seattle. 1982 (Sep). "Feasibility Report and Environmental Impact Statement, Wynoochee Hydropower/Fish Hatchery," Seattle, Washington.

US Army Engineer District, Baltimore. 1977 (Nov). "Thermal Simulation of Lakes, Users Manual," author, Earl Eiker, Baltimore, Maryland.

Table 1

Wynoochee Dam Water Temperatures, Degrees Celsius

DATE	IN	OUT	Reservoir Forebay Profile, Depth in Meters														
			0.1	2	4	6	8	10	12	15	20	25	30	35	40	45	50
Year 1975																	
6/18	7.1	10.9	15.2	15.0	14.6	11.8	10.0	8.9	7.9	7.4	7.0	6.9	6.6	6.4	6.4	6.4	
7/3	7.9	15.3	15.4	14.9	14.5	12.3	10.4	9.5	8.8	7.7	7.4	7.0	6.9	6.6	6.5		
7/17	9.4	14.9	18.5	18.5	17.6	13.5	11.5	10.0	9.1	8.0	7.5	7.2	7.0	6.7	6.6		
7/31	10.3	17.0	19.1	19.0	18.8	14.0	11.4	9.8	8.6	8.0	7.5	7.3	7.0	6.9	6.8		
8/14	14.0	18.5	19.7	19.0	18.7	16.2	12.4	9.8	8.1	8.0	7.6	7.3	7.1	6.9	6.9		
8/28	9.9	14.5	16.6	15.6	14.3	12.7	11.2	9.8	8.9	8.3	8.0	7.6	7.4	7.1	7.1		
9/9	11.5	12.4	18.1	16.5	15.7	13.2	11.8	11.1	10.4	9.5	8.5	8.0	7.5	7.2	7.2		
9/25	9.5	14.0	16.6	16.3	16.0	12.8	11.8	11.0	10.4	9.5	8.6	7.9	7.6	7.5			
10/9	8.0	10.0	13.6	13.6	13.5	13.5	12.5	11.5	11.0	10.5	9.5	8.5	8.2	8.0			
10/22	7.3	9.5	10.6	10.1	10.0	10.0	9.9	9.6	9.5	9.4	9.0	9.0	8.9	8.9			
11/12	5.4	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.5	6.4	6.4	6.4			
12/2	4.9	5.4															
Year 1980																	
6/11	9.5	13.5	13.9	13.7	13.2	12.7	11.2	9.3	8.2	7.7	7.0	6.5	6.5	6.2	6.2	6.2	6.3
6/25	10.5	15.3	15.5	15.5	15.5	14.0	12.4	9.6	8.2	7.5	7.0	6.7	6.5	6.5	6.5	6.5	
7/9	11.2	15.4	16.4	16.2	16.0	14.0	11.5	10.0	8.5	7.5	7.1	6.9	6.6	6.5	6.5	6.5	
7/23	16.0	17.1	18.8	18.4	18.0	17.5	13.3	11.0	8.9	7.9	7.3	6.9	6.6	6.5	6.4		
8/6	12.0	18.0	19.0	18.9	18.6	18.4	13.6	10.5	9.0	8.0	7.5	7.1	7.0	6.8	6.9		
8/20	13.5	12.9	18.0	18.0	17.8	17.4	15.0	11.3	8.6	8.0	7.4	7.0	6.9	6.8	6.8		
9/3	13.3	15.0	16.9	16.5	16.4	16.0	14.5	10.0	8.2	7.7	7.4	7.0	7.0	6.8	7.0		
9/17	12.2	15.5	17.0	17.0	16.8	16.3	13.9	9.0	8.1	7.7	7.4	7.1	7.0	7.0	7.2		
10/1	13.0	13.6	15.6	15.0	14.9	14.4	12.5	10.0	8.5	7.8	7.5	7.0	7.0	7.0	7.0		
10/17	7.9	12.0	13.5	13.2	13.2	13.0	12.3	10.8	9.3	8.0	7.5	7.1	7.0	7.0			
10/29	9.6	11.4	11.4	11.0	11.0	11.0	10.8	10.0	9.1	8.0	7.5	7.1	7.0	7.0			

(Continued)

Table 1 (Continued)

DATE	IN	OUT	Reservoir Forebay Profile, Depth in Meters														
			0.1	2	4	6	8	10	12	15	20	25	30	35	40	45	50
Year 1982																	
1/20	4.5	5.4	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8		
4/7	4.9	6.6	7.0	7.0	7.0	6.5	6.0	5.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0		
5/5	5.1	11.7	10.0	9.5	9.2	9.0	8.5	8.5	8.0	6.5	6.2	6.0	5.5	5.5	5.5		
5/26	5.4	11.9	14.3	13.0	11.1	10.2	9.2	8.2	7.9	7.1	6.9	6.7	6.5	6.5	6.5	6.5	6.3
6/9	7.0	13.5	14.2	13.4	13.0	11.6	10.1	8.9	7.9	6.8	6.5	6.3	6.2	6.0	6.0	6.0	5.8
6/23	7.9	12.6	18.7	18.2	14.8	11.7	10.4	9.7	9.0	7.6	7.2	6.6	6.4	6.1	6.1	6.1	
7/13	10.4	15.2	18.5	18.4	17.0	14.2	12.7	11.6	10.4	9.1	8.2	7.8	7.3	7.2	6.9	6.9	
7/27	14.9	17.3	20.1	19.7	19.3	16.8	13.5	11.8	10.7	9.1	8.3	7.9	7.5	7.3	7.1	7.0	
8/11	10.5	11.8	18.4	18.1	17.6	15.5	13.0	10.7	9.5	8.2	7.7	7.2	7.0	7.0	6.9		
9/1	11.2	15.5	18.9	18.7	18.6	18.4	14.4	10.9	8.8	8.2	7.6	7.2	6.9	6.8			
9/14	11.8	9.0	18.0	18.0	17.8	17.8	17.5	14.3	11.0	8.5	8.0	7.8	7.6	7.3			
9/28	12.1	14.1	17.2	17.1	17.0	16.6	15.9	12.4	10.2	9.1	8.6	8.0	7.6	7.5	7.3		
10/13	11.4	14.6	15.1	14.6	14.4	14.0	13.0	12.0	11.2	9.3	8.2	7.8	7.5	7.4			
11/22	4.5	6.6	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4			
Year 1983																	
1/12	4.9	5.9	5.7	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.2	5.2	5.2	5.2	5.2		
3/9	5.7	5.8	8.0	6.2	6.0	5.8	5.8	5.8	5.8	5.8							
4/12	6.7	7.9	8.5	8.0	7.9	7.8	7.5	6.5	6.5	6.5	6.3	6.0	6.0	6.0	6.0	6.0	
5/3	7.3	10.4	11.2	11.0	10.5	9.5	7.5	6.6	6.3	6.1	6.0	5.9	5.8	5.8	5.8	5.8	
5/24	8.2	14.1	17.6	15.4	12.8	11.2	8.9	7.6	7.5	7.1	7.1	6.9	6.7	6.7	6.7	6.7	
6/16	8.7	13.4	17.5	16.8	15.9	14.1	12.2	10.7	9.1	8.3	7.8	6.8	6.8	6.8	6.8	6.8	
6/29	10.1	13.9	18.2	17.8	17.5	15.4	12.9	12.0	10.1	8.4	7.9	7.7	7.5	7.4	7.3	7.3	6.6
7/14	10.4	10.6	16.5	16.1	16.0	14.0	12.4	11.8	11.3	8.6	7.7	7.4	7.2	7.2	7.2	7.2	
8/2	11.2	13.6	19.5	18.8	18.2	15.4	12.6	11.3	10.1	9.2	8.0	7.6	7.3	7.1	6.8	6.8	
8/25	11.8	11.2	19.8	19.7	19.5	17.1	14.1	11.8	9.6	8.5	7.9	7.6	7.3	7.1	6.9	7.0	
9/19	9.6	12.9	16.8	16.5	16.4	16.3	14.3	13.8	13.1	10.3	9.0	8.3	7.8	7.6	7.5		

(Continued)

Table 1 (Concluded)

DATE	IN	OUT	Reservoir Forebay Profile, Depth in Meters																
			0.1	2	4	6	8	10	12	15	20	25	30	35	40	45	50
								Year 1987									
6/1	8.4	11.0	13.2	12.9	11.9	10.6	9.4	8.9	8.1	7.1	6.8	6.5	6.4	6.3	6.2	6.2	
6/17	9.8	13.4	16.4	16.0	15.8	13.4	10.9	10.0	8.5	7.7	7.2	7.0	6.7	6.5	6.5		
7/1	12.1	14.2	19.3	19.1	18.6	14.5	12.4	10.8	9.3	7.7	7.2	6.9	6.8	6.5	6.5	6.6	
7/19	10.9	13.6	18.8	18.7	17.3	15.2	13.3	10.6	9.4	8.0	7.3	7.0	6.7	6.5			
8/3	11.7	15.0	19.3	18.7	18.5	15.5	13.1	9.8	8.6	7.8	7.5	7.1	7.0	6.8			
8/18	12.3	15.0	18.9	18.3	18.0	17.8	13.5	10.2	8.8	8.1	7.6	7.2	7.0	6.8			
9/3	10.3	13.3	19.2	19.2	19.2	18.9	12.4	9.1	8.2	7.9	7.5	7.1	7.1				
9/16	11.7	11.9	18.3	17.9	17.7	17.4	13.8	10.2	8.9	8.3	7.6	7.4	7.2				
10/1	14.7	15.5	18.6	17.6	17.2	16.7	15.5	10.1	9.1	8.4	7.8	7.5	7.4				
10/15	10.2	13.4	14.9	14.9	14.8	14.7	12.3	9.3	8.5	7.8	7.3	7.3					

Table 2

Reliability Index

Initial Verification - 1987 Data

Day	RI (Actual)	RI (Sensitivity)
152	1.112	1.141
168	1.066	1.085
182	1.067	1.077
200	1.054	1.068
215	1.086	1.099
230	1.092	1.087
246	1.134	1.144
259	1.091	1.092
274	1.101	1.091
288	1.073	1.071

Table 3

Reliability Index

Final Verification - 1982 Data

Day	RI
20	1.194
97	1.112
125	1.043
146	1.123
160	1.079
174	1.066
194	1.148
208	1.165
223	1.108
244	1.077
257	1.151
271	1.106
286	1.096
326	1.110

Table 4

Summary of Tests

Test No.	C Weir	Losses k_u	Losses k_l	Withdrawal Θ_u	Withdrawal Θ_l	Data Year	Abs. Ave. Temp. Dif. ° C	Average Release Temp, ° C	No. of Days Operations Old	No. of Days Operations New	No. of Days Target Met	Percent E_1	Percent E_2
Base	---	---	---	---	---	1975	2.41	10.52	214	---	137	---	---
1	0.6	3.6	3.3	3.14	3.14	1975	2.30	10.53	78	136	142	3.65	99.3
4	3.0	1.195	3.3	3.14	3.14	1975	2.22	10.61	79	135	141	2.92	98.5
7	3.0	1.195	0.6	3.14	3.14	1975	2.22	10.61	79	135	141	2.92	98.5
10	0.6	3.60	0.6	3.14	3.14	1975	2.30	10.53	78	136	142	3.65	99.3
18	0.6	3.60	0.6	1.05	1.05	1975	2.32	10.52	78	136	142	3.65	99.3
Base	---	---	---	---	---	1980	1.48	11.34	214	---	181	---	---
2	0.6	3.6	3.3	3.14	3.14	1980	1.60	11.22	121	93	181	0.00	67.9
5	3.0	1.195	3.3	3.14	3.14	1980	1.61	11.22	111	103	181	0.00	75.2
8	3.0	1.195	0.6	3.14	3.14	1980	1.61	11.22	111	103	181	0.00	75.2
11	0.6	3.60	0.6	3.14	3.14	1980	1.60	11.22	121	93	181	0.00	67.9
12	0.6	3.60	0.6	1.05	3.14	1980	1.61	11.22	121	93	181	0.00	67.9
13	0.6	3.60	0.6	3.14	1.05	1980	1.65	11.18	115	99	181	0.00	72.3
14	0.6	3.60	0.6	1.05	1.05	1980	1.65	11.18	116	98	181	0.00	71.5
Base	---	---	---	---	---	1983	1.25	11.74	214	---	186	---	---
3	0.6	3.6	3.3	3.14	3.14	1983	1.31	11.59	78	136	188	1.08	99.3
6	3.0	1.195	3.3	3.14	3.14	1983	1.21	11.69	87	127	188	1.08	92.7
9	3.0	1.195	0.6	3.14	3.14	1983	1.21	11.69	87	127	188	1.08	92.7
15	0.6	3.60	0.6	1.05	1.05	1983	1.34	11.56	78	136	188	1.08	99.3
16	3.0	1.195	3.3	1.05	1.05	1983	1.22	11.68	88	126	188	1.08	92.0
17	3.0	1.195	0.6	1.05	1.05	1983	1.22	11.68	88	126	188	1.08	92.0

Note: All averages, percentages and values were determined for a period of 214 days between 1 April and 31 October. Definitions for E_1 and E_2 are found in paragraph 55.

Table 5

Comparison of Base to Test 2, 1980

Julian Days	Release Temperatures Base	Release Temperatures Test 2	Actual Temperature Difference from 12.78° C Base	Actual Temperature Difference from 12.78° C Test 2	Absolute Temperature Difference Base	Absolute Temperature Difference Test 2	Temperature of Proposed Structure on Days Old Operates
181	11.5	11.5	-1.28	-1.28	1.28	1.28	
182	11.7	13.0	-1.08	0.22	1.08	0.22	
183	12.3	13.1	-0.48	0.32	0.48	0.32	
184	11.7	13.0	-1.08	0.22	1.08	0.22	
185	11.9	12.9	-0.88	0.12	0.88	0.12	
186	12.7	12.9	-0.08	0.12	0.08	0.12	
187	12.8	12.8	0.02	0.02	0.02	0.02	
188	12.1	12.9	-0.68	0.12	0.68	0.12	
189	12.0	13.0	-0.78	0.22	0.78	0.22	
190	12.0	12.7	-0.78	-0.08	0.78	0.08	
191	12.0	12.8	-0.78	0.02	0.78	0.02	
192	12.0	12.8	-0.78	0.02	0.78	0.02	
193	12.1	12.7	-0.68	-0.08	0.68	0.08	
194	12.2	12.8	-0.58	0.02	0.58	0.02	
195	12.1	12.0	-0.68	-0.78	0.68	0.78	
196	12.2	12.0	-0.58	-0.78	0.58	0.78	
197	12.3	12.0	-0.48	-0.78	0.48	0.78	
198	12.4	12.0	-0.38	-0.78	0.38	0.78	
199	12.5	12.1	-0.28	-0.68	0.28	0.68	
200	12.8	12.6	0.02	-0.18	0.02	0.18	
201	12.6	12.4	-0.18	-0.38	0.18	0.38	
202	12.7	12.6	-0.08	-0.18	0.08	0.18	
203	12.8	12.8	0.02	0.02	0.02	0.02	
204	12.8	12.0	0.02	-0.78	0.02	0.78	
205	12.9	12.1	0.12	-0.68	0.12	0.68	
206	11.7	10.8	-1.08	-1.98	1.08	1.98	
207	11.8	10.8	-0.98	-1.98	0.98	1.98	
208	12.0	10.8	-0.78	-1.98	0.78	1.98	
209	12.1	10.9	-0.68	-1.88	0.68	1.88	
210	12.2	10.8	-0.58	-1.98	0.58	1.98	
211	12.4	10.5	-0.38	-2.28	0.38	2.28	
212	12.6	10.3	-0.18	-2.48	0.18	2.48	
213	12.7	10.2	-0.08	-2.58	0.08	2.58	
214	12.9	10.1	0.12	-2.68	0.12	2.68	
215	12.8	12.9	0.02	0.12	0.02	0.12	9.8

(Continued)

Table 5 (Continued)

Julian Days	Release Temperatures Base	Release Temperatures Test 2	Actual Temperature Difference from 12.78° C Base	Actual Temperature Difference from 12.78° C Test 2	Absolute Temperature Difference Base	Absolute Temperature Difference Test 2	Temperature of Proposed Structure on Days Old Operates
216	12.9	12.9	0.12	0.12	0.12	0.12	9.6
217	12.9	12.9	0.12	0.12	0.12	0.12	9.4
218	12.8	12.9	0.02	0.12	0.02	0.12	9.2
219	12.8	12.9	0.02	0.12	0.02	0.12	9.1
220	12.8	12.9	0.02	0.12	0.02	0.12	8.9
221	12.6	12.8	-0.18	0.02	0.18	0.02	8.9
222	12.6	12.9	-0.18	0.12	0.18	0.12	8.8
223	12.7	12.9	-0.08	0.12	0.08	0.12	8.7
224	12.4	12.8	-0.38	0.02	0.38	0.02	8.7
225	12.6	12.7	-0.18	-0.08	0.18	0.08	8.7
226	12.5	12.8	-0.28	0.02	0.28	0.02	8.7
227	12.6	12.7	-0.18	-0.08	0.18	0.08	8.7
228	12.7	12.7	-0.08	-0.08	0.08	0.08	8.8
229	12.7	12.8	-0.08	0.02	0.08	0.02	8.8
230	12.9	12.9	0.12	0.12	0.12	0.12	8.8
231	12.9	13.0	0.12	0.22	0.12	0.22	8.8
232	12.9	13.0	0.12	0.22	0.12	0.22	8.8
233	12.9	13.0	0.12	0.22	0.12	0.22	8.9
234	13.0	13.0	0.22	0.22	0.22	0.22	8.9
235	13.0	13.0	0.22	0.22	0.22	0.22	8.9
236	13.0	13.0	0.22	0.22	0.22	0.22	8.9
237	13.0	13.0	0.22	0.22	0.22	0.22	9.0
238	13.0	13.0	0.22	0.22	0.22	0.22	9.0
239	13.0	13.0	0.22	0.22	0.22	0.22	9.0
240	13.1	13.0	0.32	0.22	0.32	0.22	9.0
241	13.1	13.0	0.32	0.22	0.32	0.22	9.1
242	13.1	12.9	0.32	0.12	0.32	0.12	9.1
243	13.0	12.9	0.22	0.12	0.22	0.12	9.1
244	13.0	12.8	0.22	0.02	0.22	0.02	9.1
245	12.9	12.7	0.12	-0.08	0.12	0.08	9.1
246	12.8	12.6	0.02	-0.18	0.02	0.18	9.2
247	12.7	12.6	-0.08	-0.18	0.08	0.18	9.2
248	12.7	12.5	-0.08	-0.28	0.08	0.28	9.2
249	12.6	12.5	-0.18	-0.28	0.18	0.28	9.3
250	12.6	12.6	-0.18	-0.18	0.18	0.18	9.3
251	12.6	12.3	-0.18	-0.48	0.18	0.48	9.4

(Continued)

Table 5 (Continued)

Julian Days	Release Temperatures Base	Release Temperatures Test 2	Actual Temperature Difference from 12.78° C Base	Actual Temperature Difference from 12.78° C Test 2	Absolute Temperature Difference Base	Absolute Temperature Difference Test 2	Temperature of Proposed Structure on Days Old Operates
252	12.5	12.3	-0.28	-0.48	0.28	0.48	9.5
253	12.4	12.3	-0.38	-0.48	0.38	0.48	9.5
254	12.2	12.4	-0.58	-0.38	0.58	0.38	9.6
255	12.2	12.5	-0.58	-0.28	0.58	0.28	9.7
256	12.2	12.5	-0.58	-0.28	0.58	0.28	9.8
257	12.3	12.5	-0.48	-0.28	0.48	0.28	9.9
258	12.4	12.5	-0.38	-0.28	0.38	0.28	9.9
259	12.4	10.3	-0.38	-2.48	0.38	2.48	
260	12.5	10.6	-0.28	-2.18	0.28	2.18	
261	12.5	10.9	-0.28	-1.88	·0.28	1.88	
262	12.5	11.1	-0.28	-1.68	0.28	1.68	
263	12.6	10.9	-0.18	-1.88	0.18	1.88	
264	12.6	11.4	-0.18	-1.38	0.18	1.38	
265	12.6	11.6	-0.18	-1.18	0.18	1.18	
266	12.5	11.8	-0.28	-0.98	0.28	0.98	
267	12.5	12.0	-0.28	-0.78	0.28	0.78	
268	12.6	12.2	-0.18	-0.58	0.18	0.58	
269	12.1	12.3	-0.68	-0.48	0.68	0.48	
270	12.3	12.4	-0.48	-0.38	0.48	0.38	
271	12.4	12.5	-0.38	-0.28	0.38	0.28	
272	12.4	12.6	-0.38	-0.18	0.38	0.18	
273	12.5	12.6	-0.28	-0.18	0.28	0.18	
274	12.5	12.6	-0.28	-0.18	0.28	0.18	
275	12.1	12.3	-0.68	-0.48	0.68	0.48	
276	12.1	12.6	-0.68	-0.18	0.68	0.18	
277	12.3	12.6	-0.48	-0.18	0.48	0.18	
278	12.4	12.6	-0.38	-0.18	0.38	0.18	
279	12.5	12.7	-0.28	-0.08	0.28	0.08	
280	12.5	12.7	-0.28	-0.08	0.28	0.08	
281	12.5	12.8	-0.28	0.02	0.28	0.02	
282	12.5	12.8	-0.28	0.02	0.28	0.02	
283	12.3	12.5	-0.48	-0.28	0.48	0.28	
284	12.3	12.5	-0.48	-0.28	0.48	0.28	
285	12.3	12.5	-0.48	-0.28	0.48	0.28	
286	12.3	12.6	-0.48	-0.18	0.48	0.18	

(Continued)

Table 5 (Concluded)

Julian Days	Release Temperatures Base	Release Temperatures Test 2	Actual Temperature Difference from 12.78° C Base	Actual Temperature Difference from 12.78° C Test 2	Absolute Temperature Difference Base	Absolute Temperature Difference Test 2	Temperature of Proposed Structure on Days Old Operates
287	12.3	12.5	-0.48	-0.28	0.48	0.28	
288	12.3	12.4	-0.48	-0.38	0.48	0.38	
289	12.3	12.1	-0.48	-0.68	0.48	0.68	
290	12.2	12.2	-0.58	-0.58	0.58	0.58	
291	12.2	12.0	-0.58	-0.78	0.58	0.78	
292	12.3	11.9	-0.48	-0.88	0.48	0.88	
293	12.3	11.9	-0.48	-0.88	0.48	0.88	
294	12.2	11.9	-0.58	-0.88	0.58	0.88	
295	12.2	11.8	-0.58	-0.98	0.58	0.98	
296	12.2	11.8	-0.58	-0.98	0.58	0.98	
297	12.4	11.7	-0.38	-1.08	0.38	1.08	
298	12.2	11.6	-0.58	-1.18	0.58	1.18	
299	11.9	11.6	-0.88	-1.18	0.88	1.18	
300	11.8	11.5	-0.98	-1.28	0.98	1.28	
301	11.7	11.3	-1.08	-1.48	1.08	1.48	
302	11.5	11.3	-1.28	-1.48	1.28	1.48	
303	11.4	11.2	-1.38	-1.58	1.38	1.58	
304	11.3	11.0	-1.48	-1.78	1.48	1.78	
305	10.9	10.3	-1.88	-2.48	1.88	2.48	
306	10.4	10.7	-2.38	-2.08	2.38	2.08	9.8
307	11.1	11.4	-1.68	-1.38	1.68	1.38	9.5
308	10.9	11.1	-1.88	-1.68	1.88	1.68	9.3
309	9.7	9.3	-3.08	-3.48	3.08	3.48	