TRINITY RESERVOIR WATER TEMPERATURE SIMULATION MODEL

By

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2119 Camino Court
Davis, CA 95616

Agreement Number TFG 97-10
Trinity County

Project Officer:

Tom Stokely
Senior Planner
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The main stem Trinity River provides critical habitat for numerous fish species, including chinook and coho salmon, and steelhead. These anadromous salmonid species have particular water temperature requirements for spawning and egg incubation, holding habitat, juvenile rearing, emigration of smolts, and immigration of spawning adults. The quality and quantity of water released from Trinity Reservoir define important upstream conditions for Lewiston Reservoir, releases to the Trinity River, and diversions to the Sacramento River Basin. Extra-basin diversions and releases to the Trinity River help maintain cool water temperatures for anadromous fishes in the Sacramento River and Trinity River, respectively.

This project updates and extends previous water temperature modeling efforts for Trinity Reservoir to define the water temperature regime of reservoir and reservoir releases for various hydrologic, climatic, and operational conditions. The completed Trinity Reservoir water temperature simulation model provides a practical tool that can be used to simulate release temperatures and assess temperature control alternatives in the Trinity and Sacramento River systems.

Principal project tasks included reviewing the computer models HEC-5Q and WQRRS to determine which model should be employed; model calibration and verification; formulating EIS year-type data sets; creating a framework for interpreting model output; and model application. This project report outlines each of these tasks as well as conclusions and recommendations for future work.

Initial strategies for switching to HEC-5Q were abandoned after determining that WQRRS was more flexible, easier to operate, provided a short development and application time, and produced numerically equivalent results. Model calibration and verification were completed for water year 1994 and 1993, respectively (water year extends from October 1 through September 30). Sufficient measured water temperature profile data for Trinity Reservoir were available for these periods and they were independent of the five hydrology based year-types selected for the Trinity River Mainstem Fisheries Restoration Environmental Impact Statement and Report (EIS). Model calibration and verification results were typically within 1°F to 2°F of measured values. Additional measured profiles from 1986, 1989, and 1990 were compared with simulated values to expand the range of available hydrologic, climatic and operation conditions. Computed results effectively reproduced field conditions for these additional simulations and increased confidence in the ability of the model to represent Trinity Reservoir.

To improve interpretation of model results, spreadsheets were designed to post-process model output. WQRRS was modified to produce a new output file for transfer into Microsoft Excel® spreadsheets. This output file contained semi-monthly data including reservoir surface elevation and associated water temperature profiles. When imported to the spreadsheet, water temperature profiles and time series of storage and water temperature at selected elevations are plotted. Semi-monthly reservoir storage and surface elevation, and water temperatures at selected elevations are tabulated as well. Figures, tables, and raw data can be copied from these spreadsheets to other software packages.

Model application was the final project task and included applying the calibrated and verified model with the formulated EIS year-type files. The post-processing spreadsheets were tested and refined during this task. To illustrate the application of WQRRS to Trinity Reservoir, fifteen simulations were completed to represent impacts of variable climatic, hydrologic, and operating conditions on the thermal regime of the reservoir. Three runs were completed for each year-type with initial October 1 storage (carryover storage) set at 750,000 acre-feet (low), 1,250,000 acre-feet (moderate), and 1,750,000 acre-feet (hihg). Inflow, reservoir operations, and meteorological conditions were assumed equivalent to historical data for each year-type.

Though no attempt was made to adjust historic operations to respond to initial carryover storage volumes, changing storage conditions, or to accommodate reservoir inflow, this abbreviated analysis illustrated that

- low carryover storage generally resulted in elevated mid- to late-summer water temperature in the vicinity of the intake structures
- moderate to high carryover storage typically maintained cool water temperatures in the vicinity of the intake structures throughout the simulation period.
- Continued draw down of the reservoir during October and November can result in elevated fall water temperatures in the vicinity of the intake structures

Development of the Trinity Reservoir Water Temperature Model, although successful, revealed certain needs to be realized beyond the present project. Recommendations include further model application to assess temperature control alternatives, monitoring of Trinity Reservoir inflow water temperature to improve modeling capabilities, review of meteorological data and improved representation of critical parameters, and further study of how power penstock and other outlet operations influence the thermal structure of the reservoir.

Trinity Reservoir, as a unique source of cold water, will play a key role in plans for protection and enhancement of anadromous fisheries of the Trinity River. To determine the most effective use of stored cold water it is necessary to provide the means to predict the thermal structure of impounded water – a capability achieved through this project.

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1.0 Introduction

The mainstem Trinity River provides critical habitat for numerous fish species, including chinook and coho salmon, and steelhead. These anadromous salmonid species have particular water temperature requirements for spawning and egg incubation, holding habitat, juvenile rearing, emigration of smolts, and immigration of spawning adults.

Trinity Reservoir is the principal component of the Trinity Division of the United States Bureau of Reclamation. Maximum reservoir storage capacity is 2,448,000 acre-feet and mean annual inflow is about 1,200,000 acre-feet. Trinity Reservoir discharges to Lewiston Reservoir that regulates Trinity River diversions to the Central Valley via Clear Creek Tunnel, and downstream releases to the Trinity River. The quality and quantity of water released from Trinity Reservoir define important upstream conditions for Lewiston Reservoir, releases to the Trinity River, and diversions to the Sacramento River Basin. Extra-basin diversions and releases to the Trinity River help maintain cool water temperatures for anadromous fishes in the Sacramento River and Trinity River, respectively.

The construction of Trinity and Lewiston Reservoirs and the diversion of a significant percentage of the river's water out of the basin have resulted in several changes in the river, including the river's temperature regime. Though water temperature changes in the river are due to several factors, releases from Trinity Reservoir have dramatically changed the seasonal water temperature regime. In the winter, the large thermal mass of the reservoir results in release of waters warmer than may have occurred in pre-dam periods. During summer and early fall periods Trinity Reservoir becomes strongly stratified, and releases are typically cooler than pre-dam periods. For example, prior to construction of Trinity and Lewiston Reservoirs, water temperatures in the Lewiston to North-Fork reach of the Trinity River were warmer during the migration, oversummering, and spawning periods for spring-run chinook salmon (Fredrickson and Kamine, 1980). However, temperature conditions in the Trinity River during the late summer periods have been more favorable than those prior to construction of the Trinity Project due to an increase in baseflow (Fredrickson and Kamine, 1980) and cooler water releases from Trinity Reservoir. In addition, because Trinity Reservoir becomes strongly stratified during summer and fall, the availability of cold water may be restricted at the fixed outlets of Trinity Dam. This can be of concern in years of low carryover storage when release temperatures may exceed desired levels.

This project updates and extends previous water temperature modeling efforts for Trinity Reservoir to define the water temperature regime of reservoir and reservoir release temperatures for various hydrologic, climatic, and operational conditions. The completed Trinity Reservoir water temperature simulation model provides a practical tool that can be used to simulate release temperatures and assess temperature control alternatives in the Trinity and Sacramento River systems.

1.1 Project Scope

The project consisted of five principal tasks:

- Transfer the existing computer files for WQRRS (Water Quality for River-Reservoir Systems) to HEC-5Q (Simulation of Flood Control and Conservation Systems Including Water Quality Analysis)

- Calibrate and verify the model using daily data from the recently installed meteorological station near Lewiston Dam

- Construct computer model input files for Critical, Dry, Normal, Wet, and Extremely Wet year types as prescribed by the Trinity River Mainstem Fisheries Restoration Environmental Impact Statement and Report (EIS/R).

- Complete a suite of illustrative model runs for different carryover storage volumes

- Provide spreadsheet templates to facilitate examination and interpretation of model output

This project updates and extends previous modeling work on Trinity Reservoir. Application of WQRRS to Trinity Reservoir was completed under a State Water Resources Control Board 205(j) Clean Water Act grant administered by Trinity County in conjunction with the California Department of Fish and Game Proposition 70 Salmon Restoration Fund. The final project report, *Sacramento River Temperature Modeling Project* (Deas, et al, 1997), outlined Trinity Reservoir definition, model selection criteria, description of WQRRS (i.e., theory, assumptions, structure, governing equations), and preliminary application of WQRRS. For details concerning the application of WQRRS to Trinity Reservoir, the reader is referred to Appendix A where information from the 205(j) study pertaining to the reservoir are reproduced. Additional sources of temperature modeling studies at Trinity Reservoir include Rowell (1990, 1979).

1.2 Report Organization

The report includes a presentation of project tasks: model transfer, model calibration and verification, formulation of EIS year-type data sets, processing model output, and EIS year-type simulations. Conclusions and recommendations are included as a last chapter. Several appendices are included and provide background information, historic data, data estimate techniques, technical details, computer programs and documentation, as well as other information. The main report is intended to be brief with the bulk of the technical detail included as Appendices.

1.3 Acknowledgements

Several agencies and individuals provided support for the project. In particular, Jack Rowell and Paul Fujitani of the United States Bureau of Reclamation (USBR) provided input on Trinity Reservoir inflow temperatures, and operations at Trinity Dam.; USBR staff at the offices in Sacramento, Shasta Dam, and Trinity Dam provided operations, temperature profile, and meteorological data; and Greg Kamman for supplied meteorological data sets and general support.

Thanks are due most to Tom Stokely, Senior Planner and the Trinity County Planning Department, Natural Resources Division for both funding the project and providing project guidance. This project was funded by Trinity County under agreement number TFG 97-10 with funding provided by the Trinity River Task Force through USBR Trinity River Basin Fish and Wildlife Restoration Grant Program Cooperative Agreement No. 4-FC-20-12350.

2.0 Computer Model Selection

The original work plan included transferring all available input and data files to HEC-5Q format. However, after securing the existing WQRRS input files for Trinity Reservoir, reviewing the model HEC-5Q, and discussing application of the model with U.S. Army Corps of Engineers, Hydrologic Engineering Center representatives, it was decided that transfer of the model from WQRRS to HEC-5Q was not in the best interest of Trinity County at this time. Several reasons led to this conclusion, including

1) The US Army Corps of Engineers, Hydrologic Engineering Center is not supporting the HEC-5Q model in its current form. They are in the process of updating the model and providing new features, including an improved user interface. Availability of the updated version of HEC-5Q was not expected prior to the completion of the Trinity Reservoir water temperature simulation modeling project.

2) HEC-5Q in its current form requires the operation of three sub-models to complete a simulation. First, a weather model is used to calculate a coefficient heat exchange with the water surface (the solar radiation term is addressed separately). Second, the reservoir model HEC-5 is applied to simulate the hydrology and operations of the system. Finally, the output from the weather model and HEC-5 is used as input to HEC-5Q to model water temperature. In contrast, all control parameters, meteorology, hydrology, operations, and temperature data are supplied in a single input file used to run WQRRS. It was concluded that start-up time and application would be more efficient by employing WQRRS.

3) The models WQRRS and HEC-5Q produce numerically equivalent results.

Given the above information, WQRRS was retained for modeling Trinity Reservoir.

3.0 Calibration and Verification

Calibrating and verifying WQRRS for Trinity Reservoir required selecting simulation periods, securing required data, and applying the model to selected periods. Water years (WY) 1994 and 1993 were selected for calibration and verification, respectively (a water year is defined as the period starting October 1 and ending September 30). Sufficient measured water temperature profile data were available for comparison with simulated results and these periods were independent of the EIS year-types. Required data included meteorological, hydrologic and operational, and water temperature data sets. Though the original proposal called for calibration and verification of the model using data from a newly installed weather station near Lewiston Dam, this data set limited in duration and was inconsistent with that used for EIS studies at Lewiston Reservoir and downstream in the Trinity River. After conferring with Trinity County Planning Department it was decided to use the data sets developed for the EIS. Required data and calibration and verification for the selected periods are outlined below.

3.1 Data

Daily meteorological, hydrological, operations, and water temperature data were obtained from available sources for WY 1994 and WY 1993. Where local data were not available, data from nearby locations was employed. If data at a particular time was required, but unavailable, data from similar periods were used to estimate parameter values. Sources for all data are outlined in Appendix B. Data sets are included as time series plots in Appendix C and a listing of all input files is included on diskette (Appendix D).

3.1.1 Meteorological Data

The original intent of the proposed project was to calibrate WQRRS for Trinity Reservoir using local data from a recently installed meteorological station installed near Lewiston Dam. However, due to the short meteorological record and to be consistent with other EIS analysis (e.g., at Lewiston Reservoir) data from previous studies were used. This included average daily air temperature and adjusted wind speed from the fish hatchery at Lewiston, dew point estimates, and barometric pressure and cloud cover from Redding municipal airport. Barometric pressure was corrected for elevation differences between Redding and Trinity Reservoir. Considerations and limitations of using non-local data and other details are included in Appendix E.

3.1.2 Hydrological and Operations Data

Daily inflows and operations (reservoir releases) were required to model Trinity Reservoir throughout the analysis periods and were derived from monthly USBR Report of Operations. The USBR aggregates all daily reservoir inflow to a single value. For application of WQRRS this single inflow value was used directly from the Report of Operations. Reservoir releases as defined in the Report of Operations are not aggregated to a single value. Daily hydropower releases and reservoir spill quantities are individually defined; however, the releases from the main and auxiliary outlets are aggregated.

Significant differences between the main and auxiliary intake elevations (invert elevations of 2100 ft mean sea level (msl)) and 1995.5 ft msl, respectively) required that daily release quantities be disaggregated and assigned to these intakes to properly simulate the reservoir thermal structure. The auxiliary intake is preferentially used to release water in excess of that diverted for hydropower because simultaneous releases from power and main outlets can cause cavitation under certain conditions and operators have greater control over releases using the auxiliary intake (P. Fujitani, pers. comm., 3/13/98). Therefore, it was assumed that releases in excess of those diverted for power generation were assigned to the auxiliary intake up to maximum capacity (2500 cubic feet per second (cfs)). Additional releases in excess of the auxiliary intake capacity were assigned to the main outlet. For modeling purposed the power and main release quantities were combined because water is drawn from the same intake. Intake capacities and elevations are discussed further under section 3.1.4 Physical System Data, below.

3.1.3 Water Temperature Data

Calibration, verification, and application of WQRRS for Trinity Reservoir required reservoir temperature profiles and time series of river inflow temperatures. Though reservoir temperature profile data were widely available for the calibration and verification period, profiles required to specify the initial thermal structure of the reservoir at the beginning of each simulation were typically unavailable. Measured inflow temperature data for Trinity Reservoir were unavailable and were estimated from previous studies and nearby streams.

Though reservoir temperature profiles were available throughout calibration and verification periods, measured October 1 profiles for both water years were unavailable. However, available reservoir profile data (including EIS year-type periods) provided sufficient data from neighboring time periods (September and October) to estimate October 1 conditions for a range of initial storage volumes. Estimation of October 1 thermal conditions has a minor impact on model results because Trinity Reservoir undergoes fall turnover and experiences isothermal conditions during the winter period; effectively erasing the previous summer season conditions. The onset of isothermal conditions is a function of meteorological conditions, hydrology, reservoir operations and reservoir storage, and may occur any time from December through February. Appendix F outlines the estimation of reservoir profiles for various initial reservoir storage volumes.

Ideally, daily inflow water temperatures would be represented by measured data. Instead, monthly inflow water temperatures estimated by Rowell (1990) were employed. After reviewing measured reservoir water temperature profiles and examining model results, estimated inflow water temperatures appeared too cold in winter months. An analysis of nearby streams and rivers was completed to estimate winter period water temperatures. These results were used to adjust winter inflow water temperatures reported by Rowell (1990). Final inflow temperatures utilized in model simulations and their method of determination are presented in Appendix G.

3.1.4 Physical System Data

Physical system data included reservoir geometry and intake structure elevation and size. Reservoir geometry, represented by a stage-area-capacity table, was available from the files supplied by Trinity County. The intake structures at Trinity Reservoir include a 28-ft diameter intake (invert elevation 2100 ft msl) that feeds the main outlet and power plant, a 7-ft diameter auxiliary intake (invert elevation 1995.5 ft msl), and a spillway (crest elevation 2370.0 ft msl.

The power/main intake structure splits to feed the power plant and the main outlet. The capacity of the main outlet is 7,200 cfs, while the capacity of the power plant is 4000 cfs. However, due to structural limitations and operations of this system, the maximum outflow is significantly less than the combined main and power plant capacities. Combined capacity has been estimated to be on the order of 8500 cfs; however, there is no physical evidence to support this large a value. A more conservative estimate would be in the range of 6000 cfs (P. Fujitani, pers. comm. 3/13/98). After reviewing records for water year 1983, the wettest year on record, it was determined that a value of 7000 acre-feet would accommodate historical flows through the system. Table 3.1 presents the size, invert elevation, and capacity for each structure. Appendix H includes further details on selection of intake invert elevations for modeling.

Table 3.1 Trinity Dam outlet specifications

Outlet	Diameter (ft)	Invert Elevation (ft msl)	Capacity (cfs)
Spill	n/a	2370.0	22,500[1]
Main	28	2100.0	7000
Power	28	2100.0	4000
Main/Power[2]	28	2100.0	7000
Auxiliary	7	1995.5	2500

[1]Set at 7100 cfs for modeling purposes

[2]Combined capacity assumed for modeling purposes

3.2 Model Calibration and Verification

Calibration of WQRRS for Trinity Reservoir required running the model for a selected period and comparing model output to observed historic conditions. Model input parameters and coefficients were adjusted to obtain the best agreement between the model and the physical system. Verification required application of the model to simulate system performance for an independent set of boundary conditions while maintaining the same coefficients derived in the calibration process. A total of twenty temperature profiles were available for the calibration and verification period – sixteen in WY1994 and four in WY 1993. WY 1994 was selected for calibration because extensive data availability allowed improved determination of calibration parameters. In addition, several temperature profiles for the EIS year-types were available for further comparison of simulated results versus measured values (water years 1190, 1989, and 1986). Calibration objective, selection of parameter values, and calibration and verification results are outlined below.

3.2.1 Calibration Objective

Of principal importance in modeling Trinity Reservoir was simulating the reservoir thermal regime such that release temperatures in the vicinity of the intake structures, and thus release water temperatures, could be reliably predicted. Previous studies of Trinity Reservoir have noted that withdrawals zones may not always coincide with the centerline elevation of the intake structures and may extend considerable distances above this elevation. It is clear that inflow to intake structures is non-uniform with depth. Depending on degree of thermal stratification, release rate, and location of intake with respect to the water surface the bulk of contributing flow can originate from below, at, or above the intake centerline elevation

(Tsaras, 1980). Appendix H includes additional details concerning the impacts of withdrawals from stratified reservoirs.

A calibration objective was selected to minimize discrepancy between simulated results and measured data in the region of the thermocline and cooler bottom waters in the vicinity of the intake structures for the period from June through September. After several trial runs three elevations were selected to compare simulated results and measured data:

- Elevation 2000 ft msl
- Elevation 2100 ft msl
- Elevation 2150 ft msl

Elevations 2000 ft msl and 2100 ft msl were selected to represent the approximate invert elevations of the auxiliary and power/main inlets, respectively. As introduced by Weidlein (1971) and discussed by Rowell (1979), the influence of reservoir withdrawals may extend a considerable distance above the invert elevation. Selection of a third calibration elevation at 2150 ft msl creates an envelope that addresses the thermal structure of the reservoir throughout the vicinity of the intake structures. Calibrating to reservoir surface water temperature was not emphasized, but may be important under extremely low storage conditions when surface waters could be entrained. Emphasis was placed on June through September because high water temperatures are most likely to occur during the warmer months of the year. Including October was not feasible due the selected water year simulation period (October 1 through September 30).

3.2.2 Calibration Parameters

Calibration parameters for WQRRS include evaporation, diffusion, and water column stability parameters. In addition, secchi depth, a measure of light transparency for distribution of light energy into the water column, is often used as a calibration parameter in WQRRS. Calibration parameters are presented in Table 3.2. Complete model and calibration parameter descriptions are included in Appendix I.

Table 3.2 WQRRS calibration parameters for Trinity Reservoir

Parameter
Evaporation coefficient*, a
Evaporation coefficient*, b
Critical water column stability, GSWH
Minimum water column stability, GMIN
Diffusion coefficient for water quality stability less than GSWH, A1
Constant to compute density based gradient diffusion coefficients, A3
Secchi depth

* Seasonal values were incorporated in WQRRS

Parameters GMIN and A1 were held constant during calibration as per the WQRRS User's Manual (USACOE-HEC, 1986). GSWH and GMIN were varied through a wide range of values to determine reservoir response.

WQRRS required that a single set of calibration parameter values be entered for the entire 12-month simulation. However, due to seasonal changes in the atmospheric boundary layer and the associated impact on evaporation, the model was modified to allow the user to enter two sets of evaporation coefficients. Distinct seasonal evaporation coefficients (a and b) for October through May, and for June through September were applied to reservoir simulation for calibration. This added flexibility improved calibration results, especially in critical summer months when water temperatures are of special concern. The WQRRS code listing is included in Appendix D, and specific modifications are addressed in Appendix J. Finally, secchi depth was set at 7.5 feet for the entire simulation period. Though much greater secchi depth values were observed at Trinity Reservoir, the model was not simulating algal growth and the associated reduction in lake clarity. Thus, approximate minimum annual values of secchi depth were assumed.

3.2.3 Calibration and Verification Results

Multiple simulations of Trinity Reservoir water temperatures were completed and calibration parameters adjusted to minimize differences between simulated values and measured data. Emphasis was placed on the period June through September 1994, but all of WY 1994 was analyzed. Results were examined graphically as well as tabulating deviations from measured data at the elevations specified in the calibration objective.

Selected profiles for June through September illustrating final calibration results are shown in Figure 3.1 and.Table 3.3 presents the average and absolute average difference for the months of June through September. Simulated water temperatures at the calibration elevations of 2000 ft msl and 2100 ft msl were within 1°F from June through September. Simulated water temperature at elevation 2150 ft msl were within 1°F to 2°F of measured with the exception of August 31 and September 15, when simulated values exceeded measured data by 3.3°F and 4.5°F, respectively.

Table 3.3 Difference between simulated and measured water temperature at elevations 2000 ft msl, 2100 ft msl, and 2150 msl for May through September, 1994

Date	Elevation 2000 (ºF)	Elevation 2100 (ºF)	Elevation 2150 (ºF)	Average (absolute)*
6/8/94	-0.4	0.6	0.5	0.2 (0.5)
6/23/94	-0.5	-0.3	0.3	-0.2 (0.4)
7/8/94	-0.9	-0.3	0.3	-0.3 (0.5)
7/22/94	-0.8	-0.2	-0.1	-0.4 (0.4)
8/14/94	-0.7	-0.1	-0.9	-0.6 (0.6)
8/31/94	-0.5	-0.6	-3.3	-1.5 (1.5)
9/15/94	-1.0	-1.0	-4.5	-2.2 (2.2)
Average (absolute)*	-0.7 (0.7)	0.4 (0.4)	-1.3 (1.4)	

Difference = simulated minus measured

*Average = Σ(difference)/n, absolute average = Σ(|difference|)/n

All summary statistics reported in ºF

Verification required applying the same calibration parameters to an independent period. For verification results for WY 1993 are shown in Figures 3.2 and Table 3.4. Fewer profiles were available for the verification period. Simulated temperatures at the calibration elevations were on the order of 1°F to 2°F lower than measured data for the months of June through September. For the verification period, simulated September water temperatures were consistently cooler than measured data, the opposite of the calibration period.

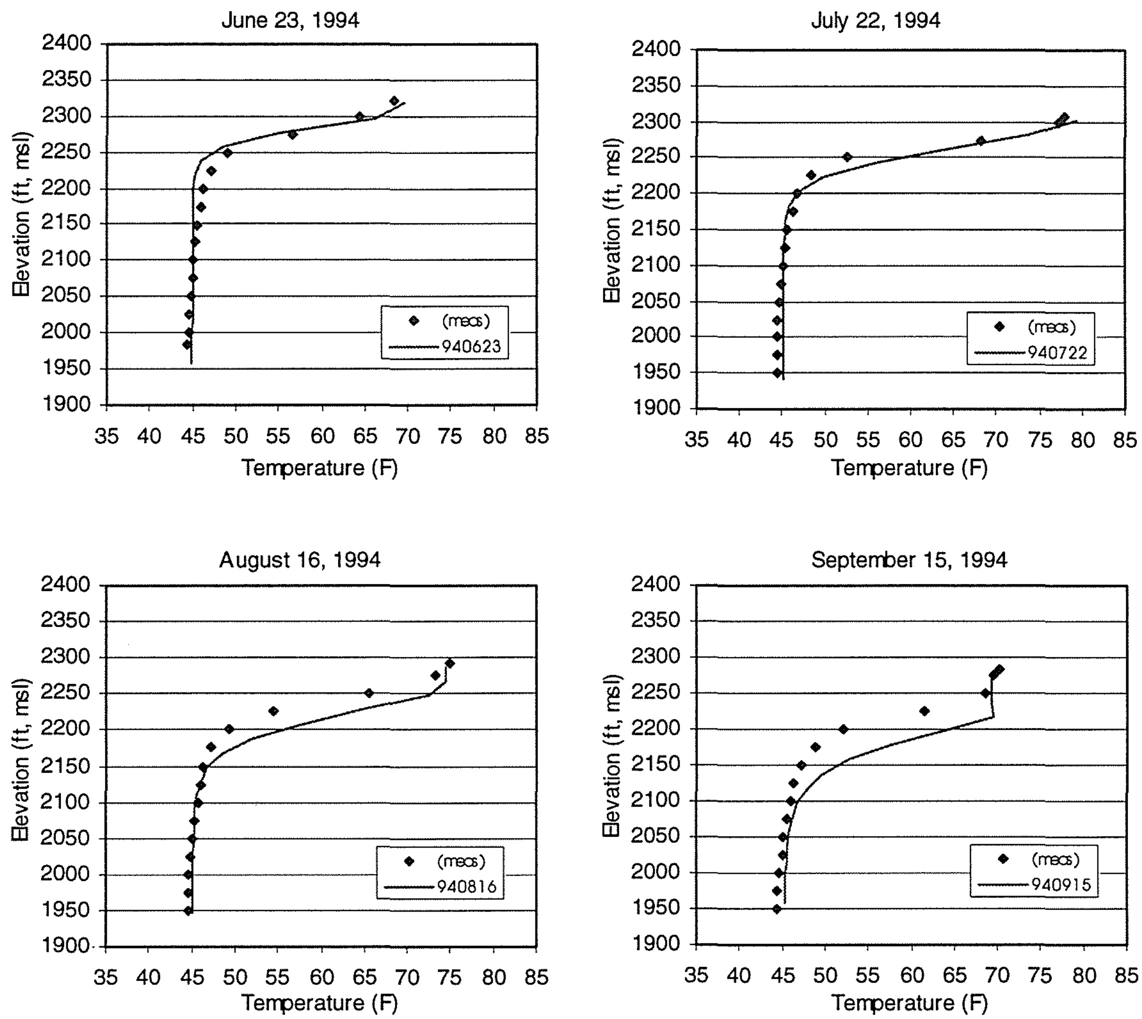

Figure 3.1 Calibration results for Trinity Reservoir, June through September, 1994

Table 3.4 Difference between simulated and measured water temperature at elevations 2000 ft msl, 2100 ft msl, and 2150 msl for May through September, 1993

Date	Elevation 2000 (ºF)	Elevation 2100 (ºF)	Elevation 2150 (ºF)	Average (absolute)*
7/16/93	0.8	0.2	1.1	0.7 (0.7)
8/9/93	2.2	1.5	2.0	1.9 (1.9)
9/22/93	1.9	1.4	1.4	1.6 (1.6)
Average (absolute)*	1.6 (1.6)	1.0 (1.0)	1.5 (1.5)	

*Average = Σ(difference)/n, absolute average = Σ(|difference|)/n
All summary statistics reported in ºF

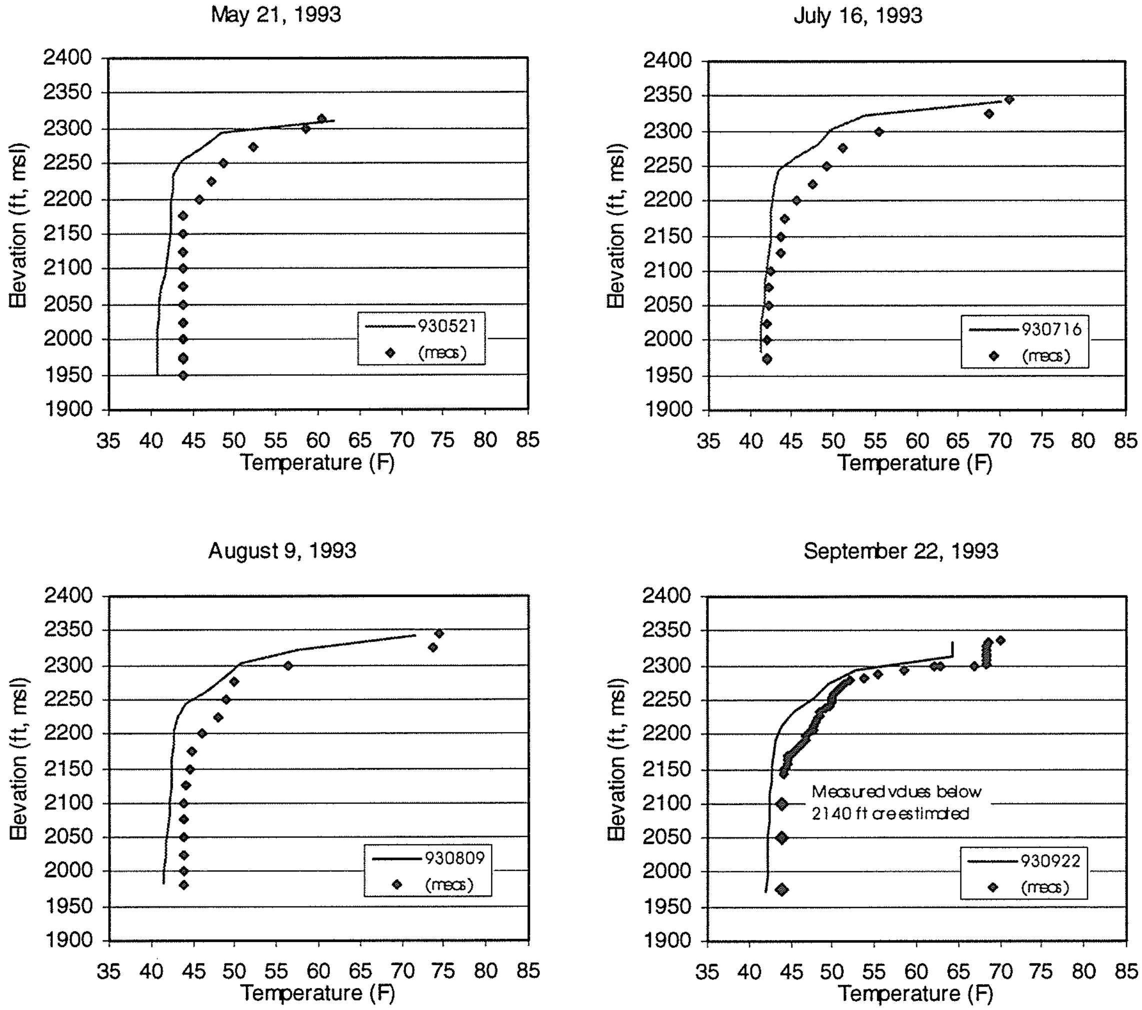

Figure 3.2 Verification results for Trinity Reservoir, May through September, 1994

To test the model over a wider range of climatic, hydrologic, and operational conditions simulated results versus measured data were examined for several months in WY 1986, WY 1989, and WY 1990. For the period June through September, five additional measured profiles were available: June 26, 1990; July 27, 1989; August 24, 1989; September 29, 1989; September 29, 1986.

Figure 3.3 compares these five measured profiles with simulated data for dates in the proximity of the measurements. With the exception September 29, 1989 all of the profiles are within 1°F at all calibration elevations. September 29, 1989 is within 1°F at elevations 2000 ft msl and 2100 ft msl, and approximately 2°F high at elevation 2150 ft msl. These additional runs increased confidence that the model could represent a wide range of conditions. Calibration and verification illustrate that the Trinity Reservoir water temperature model effectively reproduces water temperature in the vicinity of the intake structures. In all cases tested the model is within ±2°F in the region of the power/main and auxiliary inlet elevations. Simulated results for late summer (e.g., September) may overstate water temperatures in the region of the power/main intake at reduced reservoir storage.

Calibration and verification simulations, including additional simulations for 1990, 1989, and 1986, had minimum storage volumes typically greater than 1,000,000 AF during the summer period. Analysis of summer storage levels significantly below 1,000,000 AF may be subject to additional uncertainty.

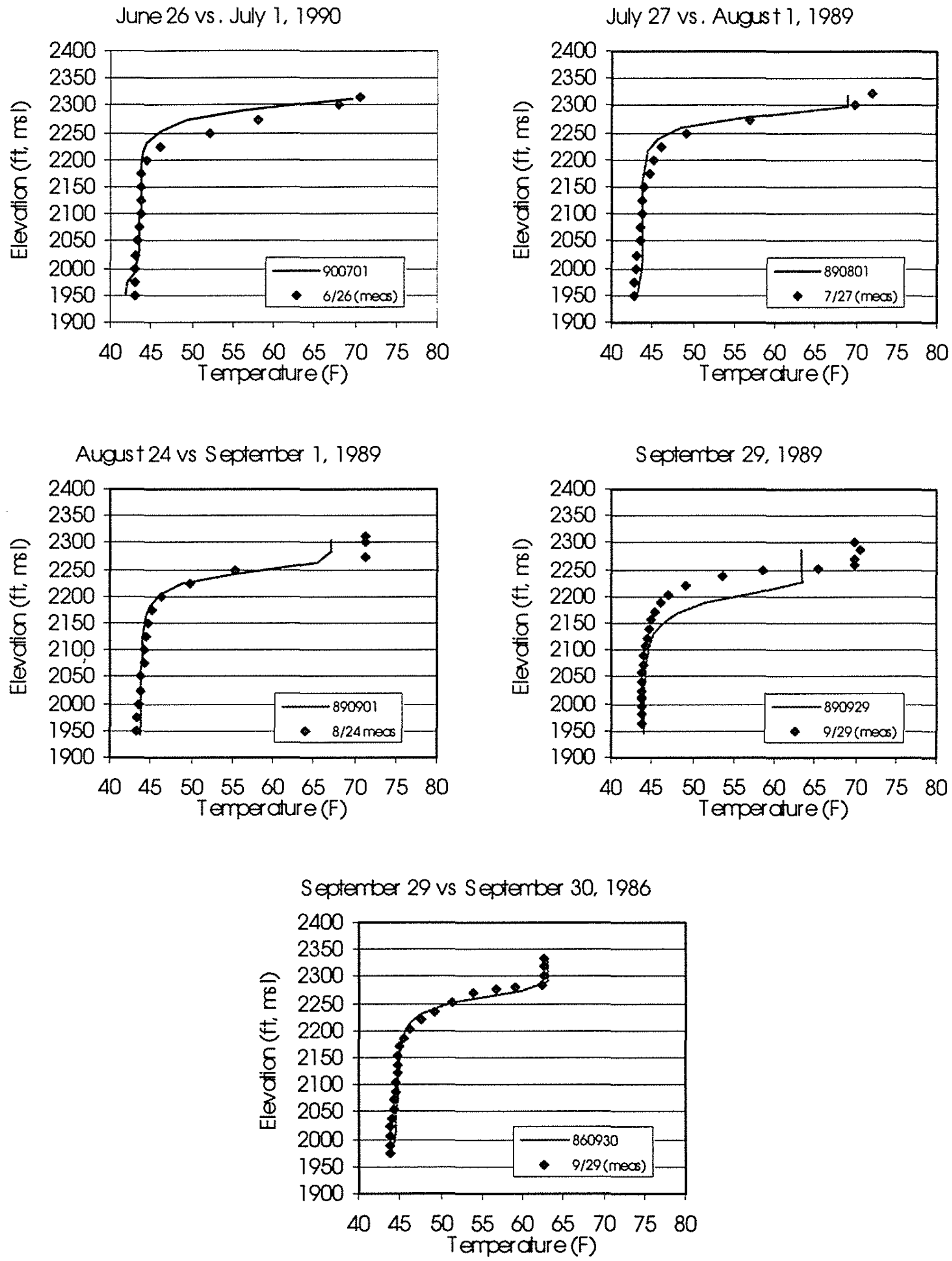

Figure 3.3 Simulated versus measured profiles for Trinity Reservoir for available June through September periods; WY 1986, WY 1989, and WY1990

4.0 Formulation of EIS Year-Type Data Sets

Meteorological, hydrological and operations, and water temperature data were assembled for the five hydrologically-based year-types identified in the EIS process these year types. Specifically,

Extremely wet:	WY 1983
Wet:	WY 1986
Normal:	WY 1989
Dry:	WY 1990
Critically Dry:	WY 1977

All data sets were constructed consistent with procedures described in Section 3, above. Time series of EIS Year-type input data are included in Appendix K, and files included on diskette are outlined in Appendix D.

For each year-type, model data were arranged in five basic categories: reservoir operations, reservoir inflow quantity and temperature, meteorological data, initial temperature reservoir temperature profile (October 1), and model control data. Model control data included parameters such as simulation period and time step; calibration coefficients; reservoir geometry; number, location, size, and capacity of reservoir outlets; and parameters controlling program logic. A pre-processor program was built that utilizes the five basic files to create the required input file for WQRRS. The individual year-type data files can be constructed in any spreadsheet or text editor. Formats for basin input data files and application and use of the pre-processor program are included in Appendix L.

5.0 Processing Model Output

The output produced by the original WQRRS code included all program information and was not conducive to efficient data examination and analysis. To improve the interface between the WQRRS model and the user, the computer code was modified to produce a file of profile temperature data at semi-monthly intervals (first and fifteenth of each month). This file can be imported to a Microsoft Excel® spreadsheet designed to provide summary statistics and figures. Currently, a spreadsheet exists for each year-type and includes:

- a location to import the WQRRS reservoir profile output data
- monthly and semi-monthly reservoir temperature profile plots
- simulation period graphs of reservoir storage, and water temperature at the power/main and auxiliary intakes
- summary statistics:
  - semi-monthly values for reservoir storage and associated reservoir elevation;
  - semi-monthly values for water temperature at the auxiliary outlet, power/main outlet, and surface
- summary statistics for maximum and minimum annual reservoir elevation/storage
- a listing of daily Trinity Reservoir outlet temperatures for input to a Lewiston Reservoir model (e.g. BETTER)

Figure 5.1 illustrates sample spreadsheet temperature profiles for July through September 1990. Water temperatures at 2000 ft msl, 2100 ft msl and 2150 ft msl are essentially stable through August at approximately 44°F, but change rapidly through the month of September as the reservoir is drawn down. Summary spreadsheet statistics for WY 1990 simulation are shown in Table 5.1, and agree with findings shown in Figure 5.1. Additional statistics include maximum and minimum storage and associated temperatures at selected elevations. Appendix M further describes the post-processor spreadsheet and Appendix D includes a listing of associated files.

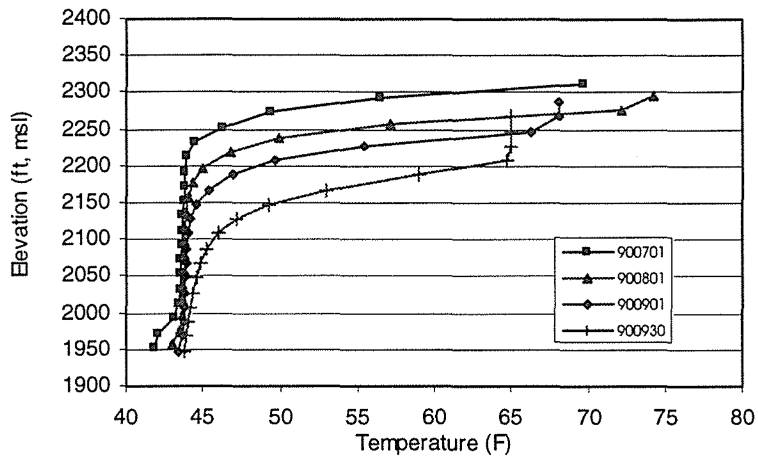

Figure 5.1 Simulated Trinity Reservoir water temperature profiles, July through September 1990.

Table 5.1 Semi-monthly summary statistics for Trinity Reservoir WY 1990 simulation

Date (yymmdd)	Elevation 2000 (ºF)	Elevation 2100 (ºF)	Elevation 2150 (ºF)	Reservoir Surface Elev. (ft, msl)	Reservoir Storage (AF)
891001	43.9	44.5	45.1	2291.86	1,368,630
891015	44.2	44.8	45.8	2284.25	1,285,269
891101	44.4	45.2	46.5	2283.59	1,278,154
891115	44.6	45.4	46.8	2282.79	1,269,531
891201	44.7	45.6	47.2	2282.11	1,262,200
891215	43.9	45.6	47.3	2282.00	1,261,015
900101	43.3	45.7	46.8	2281.35	1,254,008
900115	40.6	45.3	45.8	2285.85	1,302,517
900201	40.6	44.5	44.5	2286.56	1,310,170
900215	40.6	43.6	43.6	2287.31	1,318,255
900301	40.5	43.5	43.7	2288.99	1,336,365
900315	40.7	43.4	43.6	2293.16	1,383,571
900401	40.8	43.4	43.6	2296.96	1,427,244
900415	41.0	43.4	43.6	2300.30	1,465,824
900501	41.3	43.5	43.6	2302.43	1,491,683
900515	41.9	43.5	43.7	2301.94	1,485,734
900601	42.5	43.6	43.7	2310.95	1,595,730
900615	42.8	43.6	43.7	2313.41	1,627,176
900701	43.2	43.6	43.7	2312.57	1,616,438
900715	43.5	43.7	43.8	2307.40	1,552,021
900801	43.7	43.8	44.0	2298.83	1,448,735
900815	43.7	43.9	44.2	2292.52	1,376,215
900901	43.8	44.0	44.7	2287.72	1,322,675
900915	43.9	44.4	46.3	2279.69	1,236,329
900930	44.1	45.7	49.8	2270.46	1,143,261

6.0 EIS Year-Type Simulations

To illustrate the application of WQRRS to Trinity Reservoir, fifteen simulations were completed to represent impacts of variable climatic, hydrologic, and operating conditions on the thermal regime of the reservoir. Three runs were completed for each year-type with initial October 1 storage (carryover storage) set at 750,000 AF (elevation 2224.2 ft msl), 1,250,000 AF (elevation 2281.0 ft msl), and 1,750,000 AF (elevation 2322.9 ft msl). October 1 water temperature profiles were estimated to provide initial conditions (Appendix F). Inflow, reservoir operations, and meteorological conditions were assumed equivalent to historical data for each year-type. Appendix K contains time series plots of historical input data.

Under certain operations and hydrologic conditions certain simulations were infeasible because the reservoir was de-watered. Safety of dams criteria was examined, but was not an issue for the selected carryover storage volumes. For purposes of this analysis, minimum operating reservoir storage was set at 300,000 acre-feet (2141.8 ft msl). These runs were for illustrative purposes only and no attempt was made to adjust historic operations to avoid storage falling below 300,000 acre-feet. Table 6.1 represents a matrix of alternatives, defining simulations that were feasible and infeasible given designated year-type operations and hydrology. Simulations were infeasible for the critically dry year-type (WY 1977) for carryover storage volumes of 750,000 acre-feet and 1,250,000 acre-feet. During these simulations reservoir storage was reduced to well below 300,000 acre-feet.

Table 6.1 Feasibility matrix for simulation of EIS year-types for various starting conditions

	Initial October 1 Storage (acre-feet)		
Year-type	750,000	1,250,000	1,750,000
Extremely Wet (WY 1983)	0	0	0
Wet (WY 1986)	0	0	0
Normal (WY 1989)	0	0	0
Dry (WY 1990)	0	0	0
Critically Dry (WY 1977)	X*	X*	0

* Reservoir storage dropped below 300,000 acre-feet

6.1 Results

WQRRS was applied for each set of operating conditions to compute associated reservoir water temperatures. To assess the impacts of alternative carryover storage, reservoir storage and water temperature at elevation 2000 ft msl, 2100 ft msl, and 2150 ft msl were plotted for the period of simulation (water year). In addition, maximum and minimum reservoir storage and maximum intake water temperatures were tabulated. Water temperatures at the intake invert elevations may not correspond to actual Trinity Reservoir release temperatures. Rowell (1979) noted the tendency of reservoir releases to originate from elevations higher than that of the centerline intake elevation. Appendix H discusses the selective withdrawal issues in detail.

Significant findings include

- Low carryover storage generally resulted in elevated mid- to late-summer water temperature in the vicinity of the intake structures

- Moderate to high carryover storage typically maintained cool water temperatures in the vicinity of the intake structures throughout the simulation period. The exception was the Critically Dry year-type when insufficient winter runoff resulted in large draw down of the reservoir

- Draw down of the reservoir during October and November can result in elevated fall water temperatures in the vicinity of the intake structures

For the purposes of this analysis, temperatures at the selected elevations greater than 50°F were considered elevated. Results for Critically Dry (WY1977) and Normal (WY 1989) year-types are briefly discussed, herein. Results from the other year-types are included in Appendix N.

Critically Dry: WY 1977

The Critically Dry year-type simulations were only feasible for the highest carryover storage; 1,750,000 acre-feet. Figure 6.1 illustrates reservoir storage and water temperatures at elevation 2000 ft msl, 2100 ft msl, and 2150 ft msl throughout the simulation period. Water temperatures were on the order of 45°F through July. However, as storage dropped below approximately 1,000,000 acre-feet, the water temperatures begin to rise appreciably. Temperatures at the 2100 ft msl elevation were simulated in excess of 65°F in early September, prior to the onset of fall cooling. Simulated water temperatures at elevation 2000 ft msl lagged those at the power/main elevation, but still exceeded 65°F by late September. Significant to this analysis was the net draw down of Trinity Reservoir through the water year: 1,255,100 acre-feet. The final reservoir storage was approximately 475,000 acre-feet corresponding to a surface elevation of 2180 ft msl.

This simulation illustrates the thermal structure of the reservoir changes significantly through time. The volume of warm water above the thermocline increases from spring through mid-summer because net atmospheric heating during this period is positive. Associated with this increase in warm water volume is an increase in depth to the thermocline. Another condition that increases the depth to the thermocline is reservoir draw down. As reservoir levels decline the cross section of the reservoir decreases. To accommodate an equivalent volume of warm water above the thermocline requires a corresponding increase in depth. Depth to the thermocline is important with respect to intake elevations and entrainment of warmer surface waters.

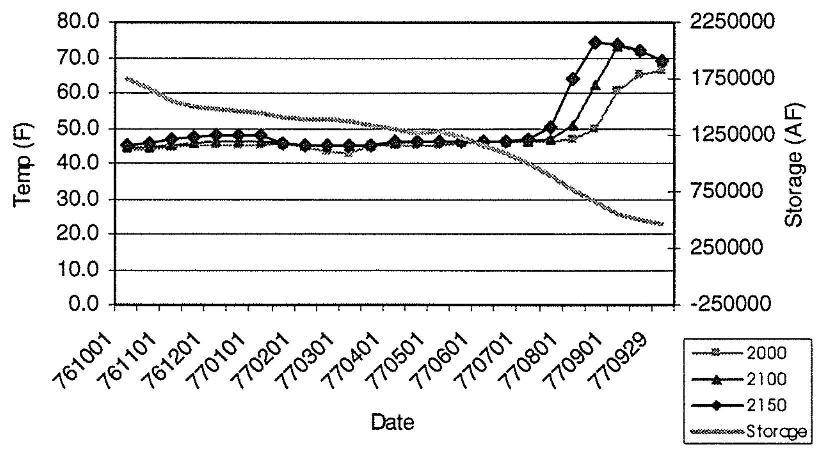

Figure 6.1 Simulated Trinity Reservoir storage and water temperature, Critically Dry year-type (WY 1977): Carryover - 1,750,000 acre-feet

Normal: WY 1989

Normal year-type conditions were simulated for all three designated carryover storage volumes and results are shown in figures 6.2, 6.3, and 6.4. Figure 6.2 illustrates that for low carryover storage (750,000 acre-feet) there were elevated temperatures in late September in the vicinity of the intakes, but cool water temperatures were maintained throughout the simulation periods for the two larger carryover storage volumes. Note that fall conditions in the 750,000 acre-feet and 1,250,000 acre-feet carryover cases exhibited fall heating at the intake elevations as the reservoir was drawn down for winter storage.

6.2 Discussion

Operations were not adjusted to respond to initial carryover storage volumes, changing storage conditions, or to accommodate reservoir inflow. Simply applying historic operations does not simulate operational flexibility that would occur under the various conditions. Thus, the reader is cautioned against drawing explicit conclusions from these analyses. Nonetheless, this abbreviated analysis illustrates that under certain operations low carryover storage conditions may present temperature problems in the late summer months at intake elevations.

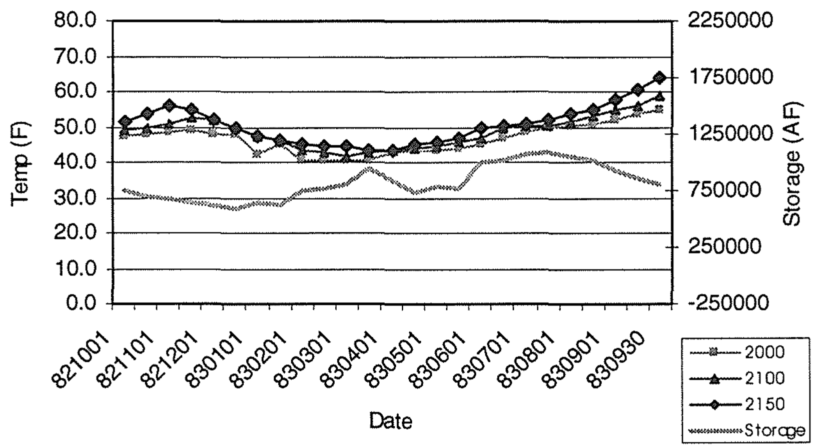

Figure 6.2 Simulated Trinity Reservoir storage and water temperature, Normal year-type (WY 1989): Carryover - 750,000 acre-feet

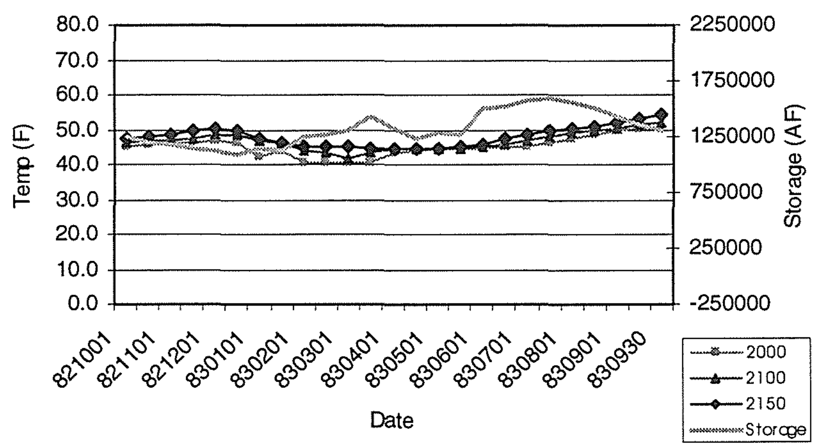

Figure 6.3 Simulated Trinity Reservoir storage and water temperature, Normal year-type (WY 1989): Carryover - 1,250,000 acre-feet

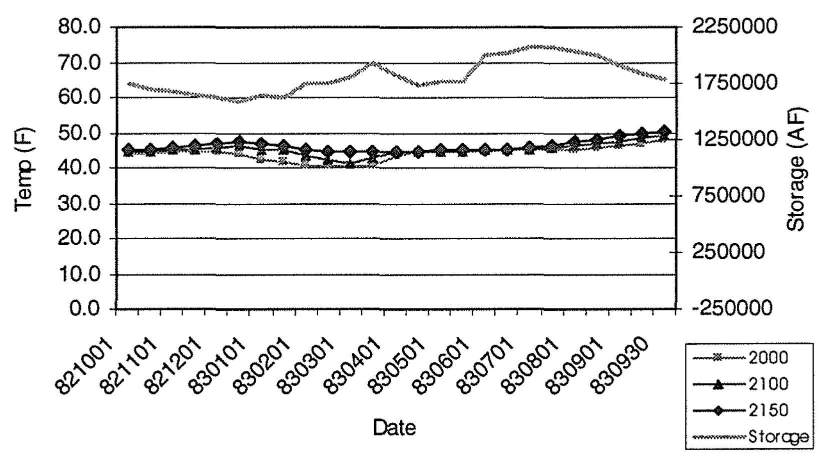

Figure 6.4 Simulated Trinity Reservoir storage and water temperature, Normal year-type (WY 1989): Carryover - 1,750,000 acre-feet

7.0 Conclusions and Recommendations

Trinity Reservoir, as a component of the Central Valley Project, will play a key role in plans for protection and enhancement of anadromous fisheries. This unique source of cold water contributes directly to the maintenance of anadromous fish propagation downstream reaches. To determine the most effective use of stored cold water it is necessary to provide the means to predict the thermal structure of impounded water for spring, summer and fall seasons. This capability was achieved through the combined tasks of model review, calibration and verification of WQRRS, year-type data acquisition and input file construction, pre- and post-processor program fabrication, and model application. The tasks of calibration, verification, and subsequent application of the model illustrated that WQRRS reliably simulates the thermal conditions of Trinity Reservoir under a wide range of hydrologic, climatic, and operational scenarios.

Development of the Trinity Reservoir Water Temperature Model, although successful, revealed certain needs to be realized beyond the present project. Recommendations addressing these needs are presented herein.

- Temperature Control Assessment
  The Trinity Reservoir Water Temperature Model is an effective and flexible tool for assessment of specific options for temperature control within the reservoir and in downstream river reaches; however, only preliminary, representative analyses have been completed. It is recommended that the model developed in this project be applied in assessment of additional year-type operations, selective withdrawal, and other temperature control measures.

- Trinity Reservoir inflow water temperature monitoring
  Inflow water temperature, especially in years when significant system inflow occurs, can potentially impact the overall thermal regime of Trinity Reservoir well into the summer months. It is recommended that inflow water temperature be monitored year-round on a daily or weekly basis to characterize the range of potential inflow temperatures for use in reservoir modeling.

- Trinity Reservoir water temperature profile monitoring
  Maintain and expand current water temperature profile monitoring program. Formalize the process of profile measurements such that field data is recorded at regular intervals (e.g., first and fifteenth of each month) such that year to year comparisons can be made and additional data is available for model application.

- Trinity Reservoir meteorological assessment
  The majority of meteorological data employed for temperature modeling at Trinity Reservoir was estimated from available local data or was derived from non-local data. It is recommended that these data sets be compared with available data from a newly installed weather station at Lewiston Dam to determine if estimated and non-local meteorological data assumptions are reasonable. A sensitivity analysis using the temperature model can be used to assess the relative importance of critical meteorological parameters.

- Withdrawal Zone Study
  The zone of influence for each intake is a function of withdrawal quantity, schedule of operations, time year, degree of stratification, and reservoir storage. Water may be preferentially drawn into an intake from above, below, or at the centerline elevation. It is recommended that a withdrawal zone study be completed to define potential intake envelopes to ensure proper model representation and that operational temperature control goals are attained.

8.0 References and Personal Communications

8.1 References

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Paul Fujitani, US Bureau of Reclamation, March 13, 1998

Appendix A Previous WQRRS Application: Trinity Reservoir

Summarized herein are the background, application, and results of previous work completed by Deas et al (1997) for hourly modeling of Trinity Reservoir using WQRRS. Significant changes between this previous application and the current project include the addition of the auxiliary outlet to the analysis, consistent meteorological data sets for calibration and verification years, seasonal evaporation coefficients, and different monthly tributary inflow temperatures.

A.1 Introduction

The quantity and quality of water released from a reservoir define important boundary conditions for modeling the river downstream. In the case of Trinity Reservoir the flows released to downstream river reaches are generally predetermined by project operating schedules designed to meet user demands. Temperatures, on the other hand, are governed largely by combinations of uncertain hydrologic, hydrodynamic, and climatic conditions affecting the thermal energy balance in the water body. An objective of this project was to select an appropriate mathematical model that can be used to reliably simulate the seasonal cycle of temperature change within the reservoir which, in combination with a specified operation schedule, will provide the needed boundary conditions for the models downstream.

Large water bodies like Trinity Reservoir are inherently complex in their circulation and in the distribution of internal thermal energy. In reality they are truly three-dimensional, that is, motions and properties of the water vary along all principal axes. However, with respect to temperature, such large and deep water bodies may become so strongly stratified that they may be modeled one-dimensionally. To determine whether the one-dimensional approach is appropriate for Trinity Reservoir, a criterion based on the relationship between inertial and gravitational forces developed by Water Resources Engineers, Inc. (1969) was applied. This criterion is in the form of a densimetric Froude number (Fr) and compares inertial forces, represented by an average flow-through velocity, to gravitational forces that tend to maintain stability, as given by the following expression:

$$Fr = 320\,[LQ/HV] \qquad (A.1)$$

where Q is the average flow through the reservoir, H is the average depth of the lake, L is lake length, and V is lake volume. The constant 320 includes gravitational and density effects and has units of time. A value of Fr greater than $1/\pi$ (approximately 0.318) indicates that inertial forces dominate the water body and complete mixing can be expected. A much lower value indicates a dominance of gravitational forces, i.e., a tendency toward stratification.

For Trinity Reservoir, a typical value of the densimetric Froude number can be derived from measured data for September 1993. Values for this month were: L=29,000 m (91,170 ft), H=123.7 m (406 ft), Q=98 m^3/s (3465 cfs), V=2.5×10^9 m^3 (2.03×10^6 acre-feet) which yields a densimetric Froude number of 0.0029. Based on the above criterion the reservoir is classified as subject to strong stratification seasonally and could be modeled one-dimensionally. Accordingly, the well documented finite difference model WQRRS (USCOE-HEC, 1978) was selected for simulation of Trinity Reservoir.

WQRRS is based on the principles of conservation of mass and thermal energy. The reservoir's geometric and volumetric properties are represented conceptually by a series of one-dimensional horizontal slices, or layers. Each layer is characterized by bounding areas, a thickness, and a volume of water. Water assumed to be fully mixed within each layer, i.e., homogeneous. Thus, properties of the system of layers are defined by discrete values identified with the vertical position of each successive layer based on densities determined primarily by temperature. Inflows enter this system of layers at elevations of corresponding temperature and outflows occur at temperatures identified with the level of the outlet structure. Internal transport of heat and mass occurs only in the vertical direction by advection and effective dispersion. Convective mixing, driven by density gradients such as occur with diurnal cooling of the reservoir surface layers or with net heat loss during the fall cooling period, may involve properties of several layers. Because water density is a function of temperature, a characteristic temperature profile develops in the reservoir, the form of which is governed by the seasonal changes in inflow, outflow, and surface heat exchange. Model results are considered representative of average conditions in the main reservoir body (away from tributary inflow and localized effects of outlets).

One of the advantages of this model is that the heat exchange routine it uses is well documented (TVA, 1974) and has been incorporated in other widely used models like QUAL2E (Brown and Barnwell, 1987). Additionally, it is detailed enough to predict climatic impacts on the thermal regime of the reservoir at daily, even hourly, intervals. It allows withdrawals to occur from multiple outlets at different elevations, which makes it especially useful for reservoir operation analysis where selective withdrawal may be an option. It is important to note that WQRRS is not a hydrodynamic model; flows between layers in the model occur as the consequence of imbalances in the water budget in accordance with mass conservation. The reservoir's water surface rises and falls depending on the net difference between inflow and outflow. Details concerning conceptual representation of WQRRS may be found in the User's Manual (USCOE-HEC, 1978).

A.2 Trinity Reservoir: Conceptualization and Implementation

Modeling Trinity Reservoir required conceptualizing the prototype as a one-dimensional longitudinally and laterally averaged system as described above. The reservoir was discretized into layers 1.52 meters (5.0 ft) in depth to provide sufficient detail of temperature profile output.

Implementation of WQRRS for Trinity Reservoir required specific data, including an elevation-capacity curve for the reservoir; initial conditions; hydraulic characteristics of outlet structures and their elevations, tributary inflows, operations, initial and boundary conditions, and meteorological data. Geometric data, i.e., stage-area-capacity relationships, were used in the model, together with temperature profiles and discharges, to calculate the hydraulic properties of the withdrawal layer. Initial temperature conditions for the reservoirs were usually specified as constant with depth, i.e., homogeneous, or, when available, measured profile information was used. Inflow temperatures were usually assumed to be at equilibrium levels, though inflow temperatures may at times be less than equilibrium. WQRRS required substantial data preparation. Hydrologic and meteorologic data, as well as boundary conditions and reservoir operations information were arranged in several individual data files. A "pre-processor" computer program was written to manipulate these files into the single WQRRS input file. Once these steps were completed the model was ready for calibration.

A.3 Trinity Reservoir: Calibration and Verification

Primary calibration parameters for these applications of WQRRS included evaporation and internal diffusion coefficients. The model was calibrated for Trinity Reservoir using measured data from 1987 and verified using measured data from 1993. Experience has shown that it is more difficult to calibrate for the colder months of the year due to uncertain mixing conditions associated with weak stratification and wind, a finding also observed in this exercise. Summer months are better characterized because of the typical stratified conditions that prevail during the warmer periods of the year.

Complete boundary and initial conditions for the calibration year (1987) were provided by the USBR (Rowell, 1994). Observed temperature profiles for the months of January, February, August, September, and October were provided by the USBR, Redding Office. Table A.1 outlines those coefficients used in calibration and their final values. The calibrated values for Trinity Reservoir were within the envelope recommended in the WQRRS user's manual (USCOE-HEC, 1978; pp 15). Figure A.1 illustrates modeled temperatures (solid line) versus measured temperatures (symbols) in the form of profiles for selected dates. Results indicate that the calibration is reasonable. WQRRS represents the uniformly mixed condition during the winter months and effectively models the transition to the stratified condition during the summer months.

Verification data were derived from several sources. Portions of the 1993 data were obtained from Balance Hydrologics Inc., and the remaining required information was obtained from published sources (e.g., DWR, USBR, NOAA). As a result of inconsistent data sources, specifically with respect to the available local meteorological information, the quality and frequency of measurements differed between the calibration and verification periods. Consequently, the initial set of calibration parameters did not produce a satisfactory simulation of 1993 observed water temperatures. The evaporation parameter b was revised for 1993 from 1.2×10^{-9} to 2.0×10^{-9}. Figure 4.2 presents calculated temperature profiles versus actual data obtained for the 1993 period.

Table A.1 WQRRS calibrated coefficients for Trinity Reservoir: January 1 through December 31, 1987

Parameter	Value
Evaporation Constant a (m/hr-mbar)	0.0
Evaporation Constant b (1/mbar)	1.2×10^{-9}
Water Column Minimum Stability ($Kg/m^3/m$)	0.0
Water Column Critical Stability (GSWH) ($Kg/m^3/m$)	1.0×10^{-6}
Maximum Allowable Dispersion (A1) (m^2/sec)	0.5×10^{-4}
Coefficient Relating Gradient to Dispersion (A3)	-0.70

It is expected that inconsistencies noted in meteorological data sets for Trinity Reservoir will be substantially reduced by data from a recently installed meteorological station near Trinity Reservoir at the Trinity River Fish Hatchery located at the base of Lewiston Dam. The models should be recalibrated and verified when sufficient data from the reservoir station becomes available.

A.4 References

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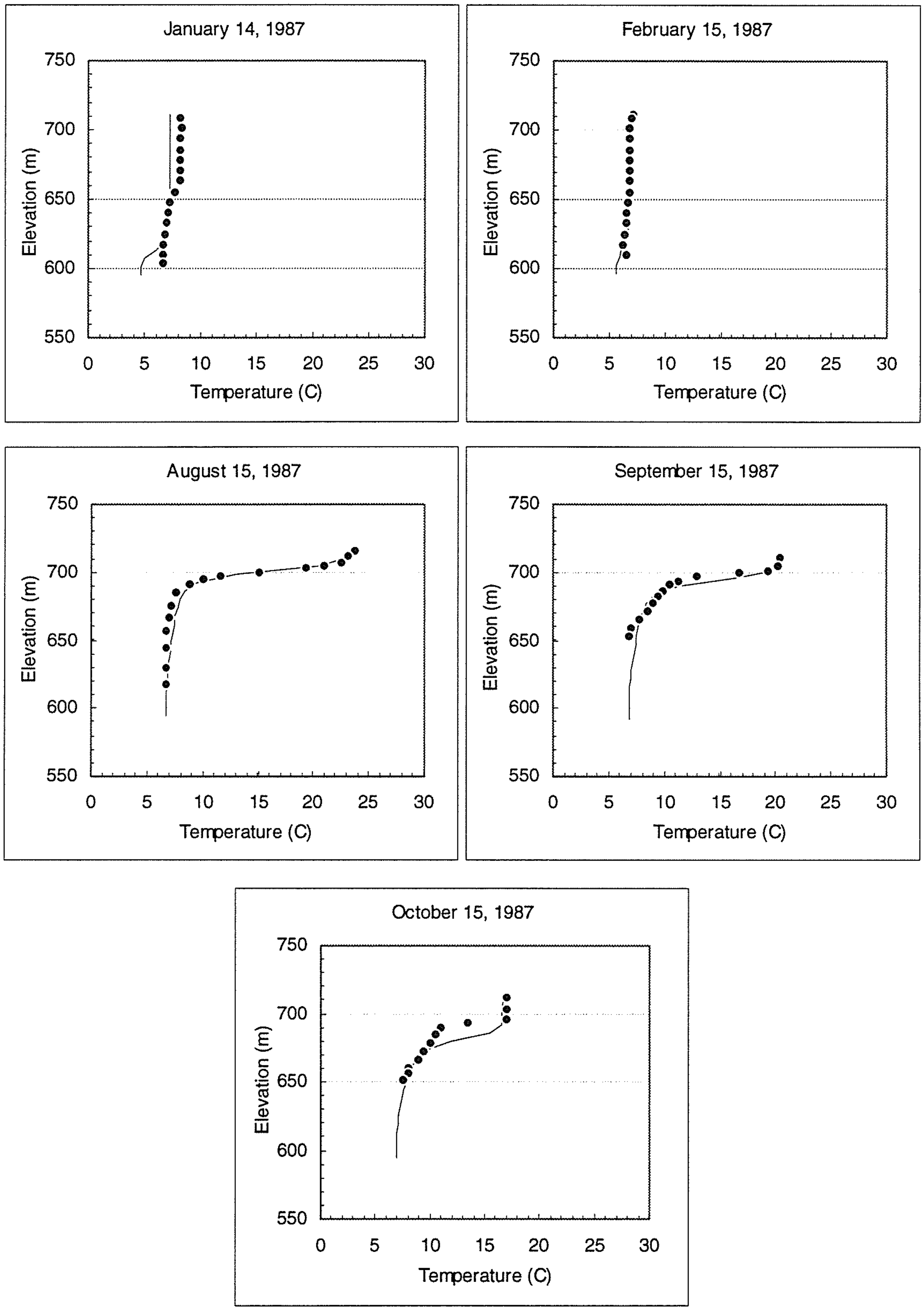


Figure A.1 WQRRS calibration results for Trinity Reservoir, 1987 (Deas, et al, 1997)

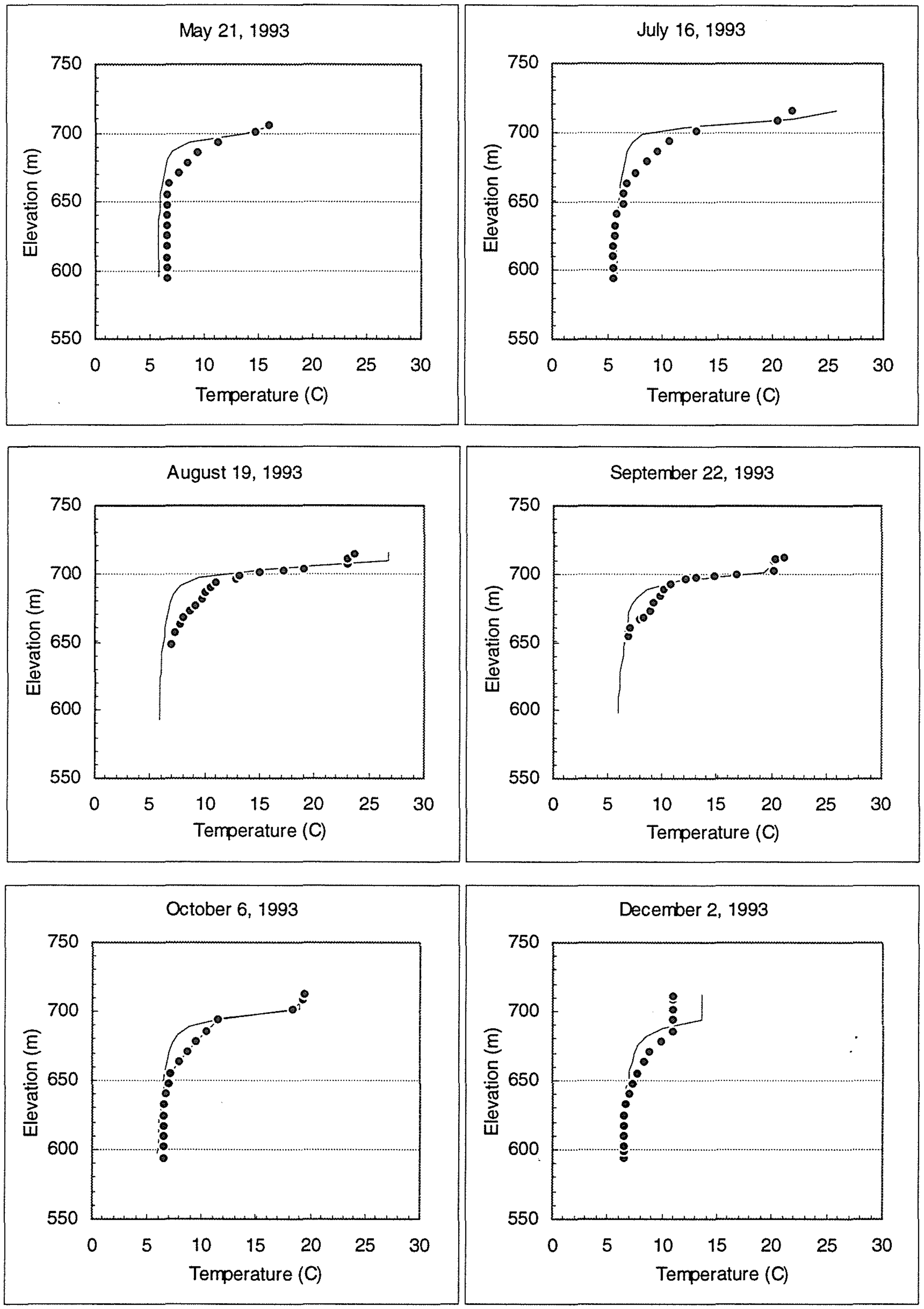


Figure A.2 WQRRS refined calibration results for Trinity Reservoir, 1993 (Deas et al 1997)

All data sets are daily data. For initial reservoir temperature profile data reconstruction and inflow water temperature estimation see Appendices F and G, respectively. Meteorological data considerations are discussed in Appendix D.

Hydrologic Data:

Trinity Inflow: USBR Report of Operations
Reservoir operations including spill: USBR Report of Operations
October 1 reservoir storage: USBR Report of Operations

Inflow Temperature

Monthly inflow temperatures: from Rowell (1990) and estimated (see Appendix G)

Reservoir Temperature Profile Data

Measured reservoir temperature profiles: USBR and DWR. October 1 profiles for all analyses were reconstructed from measured data.

Meteorological Data

Wind speed: derived from Lewiston Fish Hatchery anemometer
Air temperature: derived from maximum and minimum air temperature at Lewiston Fish Hatchery
Dew point: derived from air temperature data at Lewiston Hatchery
Barometric pressure: Red Bluff (pre-8/86) and Redding municipal airports
Cloudiness: Red Bluff (pre-8/86) and Redding municipal airports

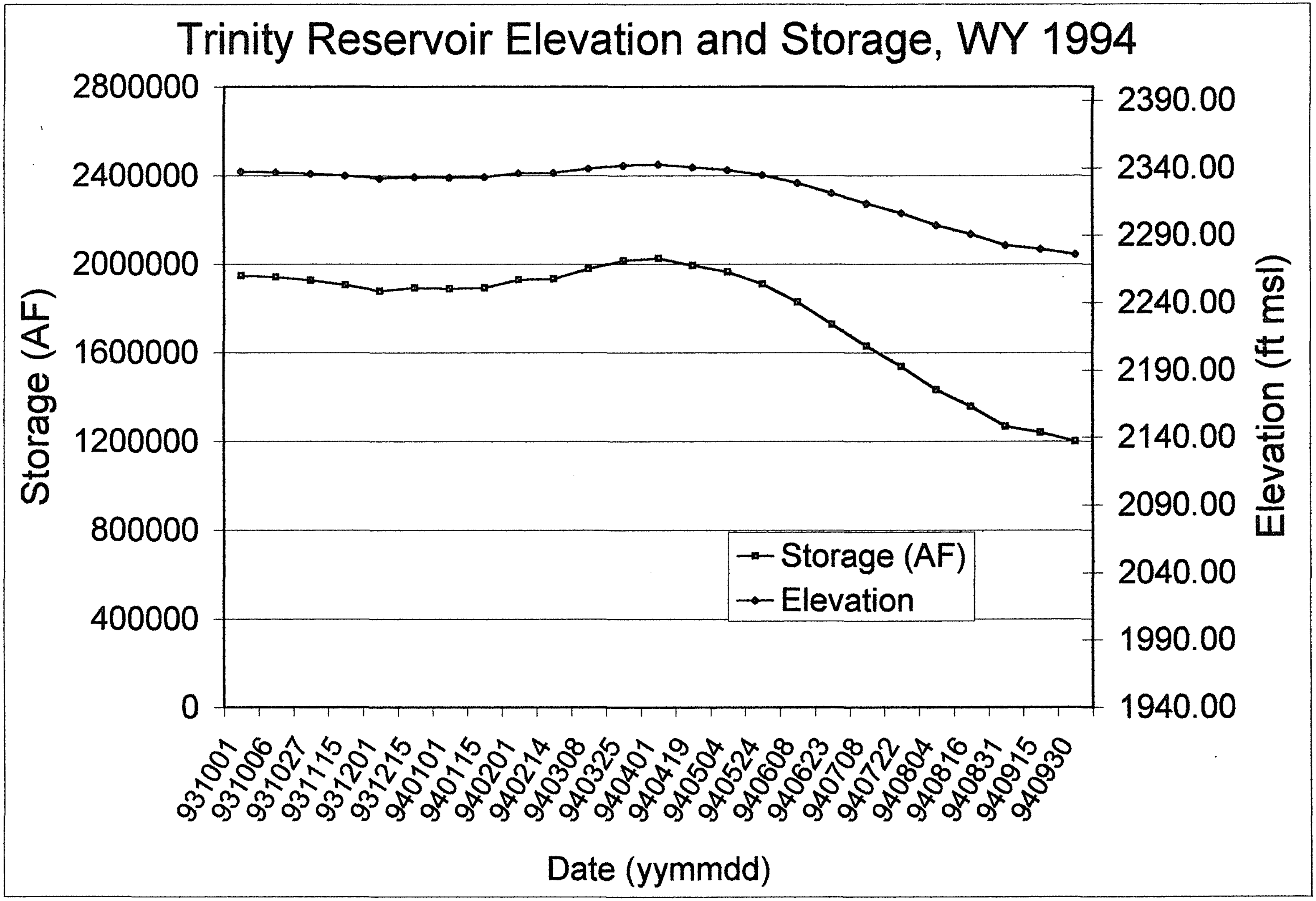
Appendix C Calibration and Verification Data: Figures

Water Year 1994 (Calibration):

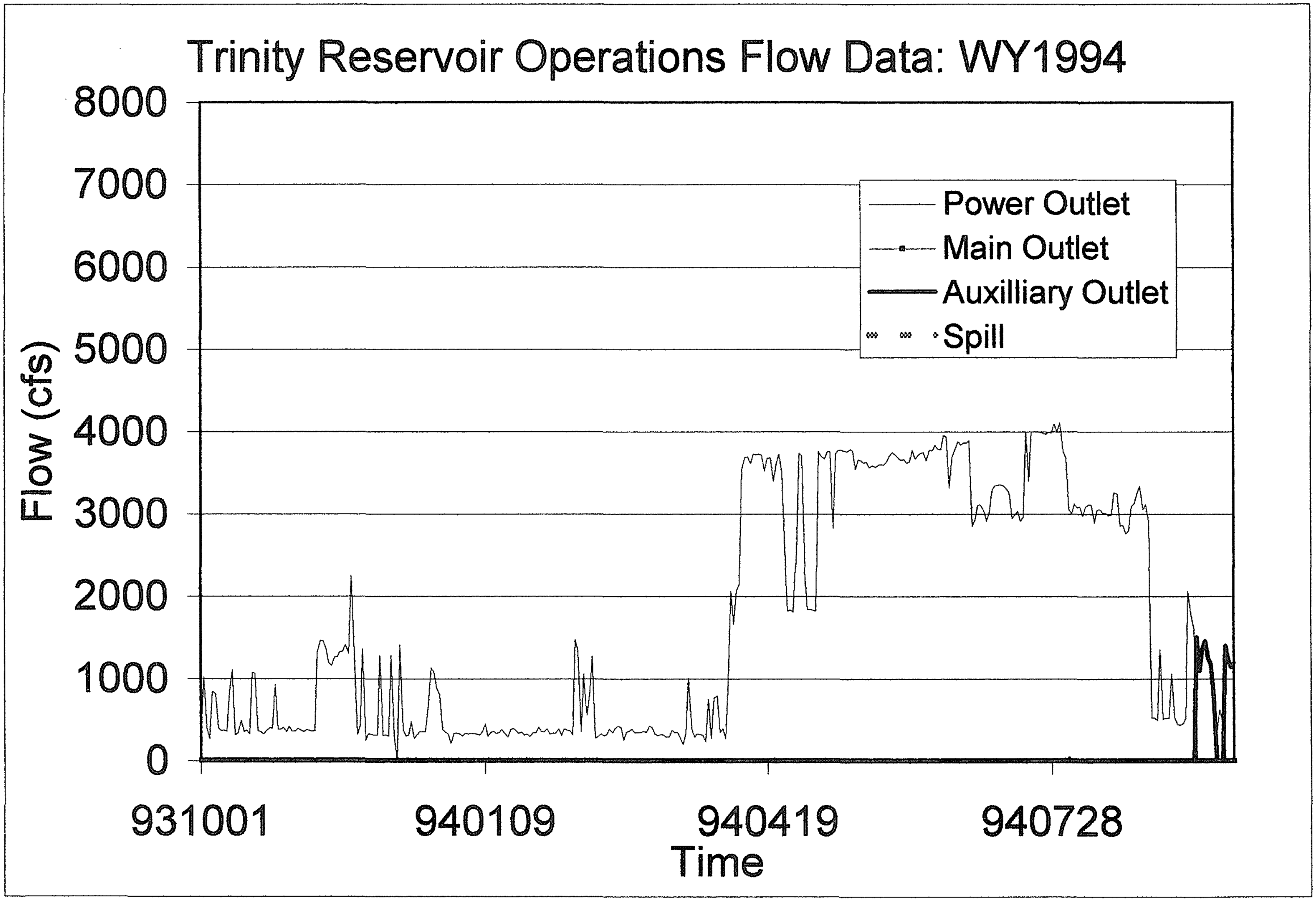
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover

Water Year 1993 (Verification):

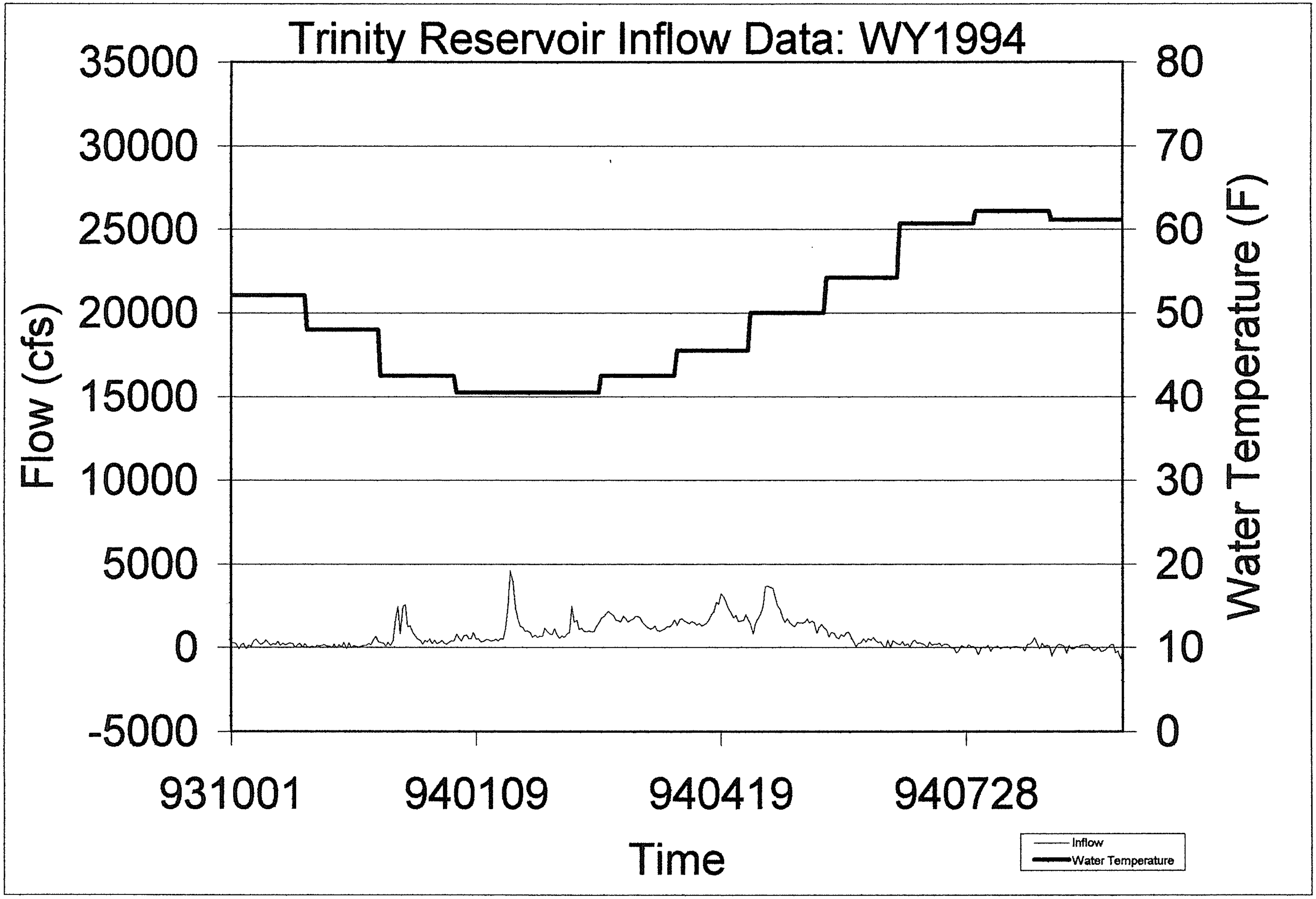
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover



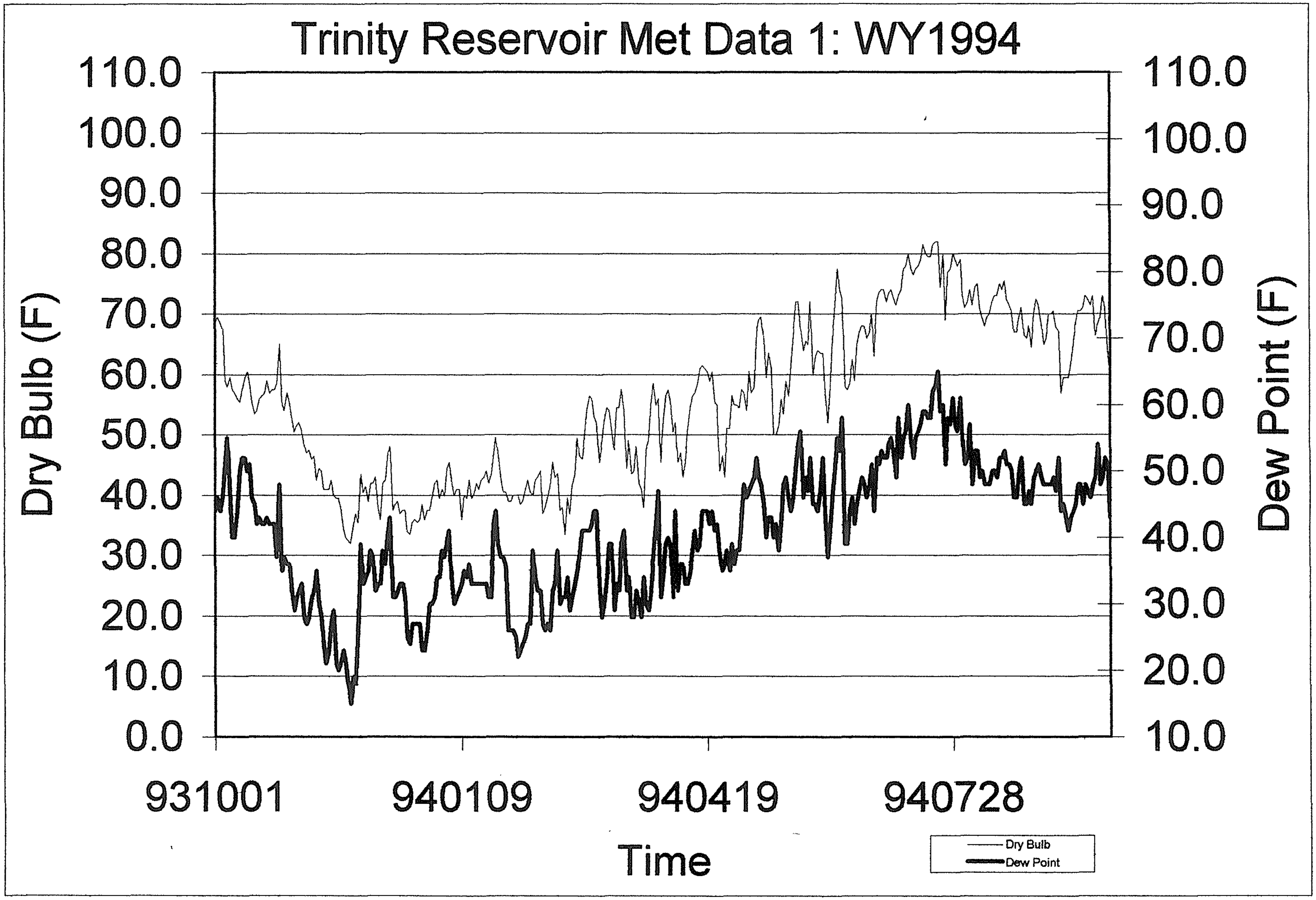
Trinity Reservoir Elevation and Storage, WY 1994
Storage (AF)
2800000
2400000
2000000
1600000
1200000
800000
400000
0
Elevation (ft msl)
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
Storage (AF)
Elevation
931001
931006
931027
931115
931201
931215
940101
940115
940201
940214
940308
940325
940401
940419
940504
940524
940608
940623
940708
940722
940804
940816
940831
940915
940930
Date (yymmdd)



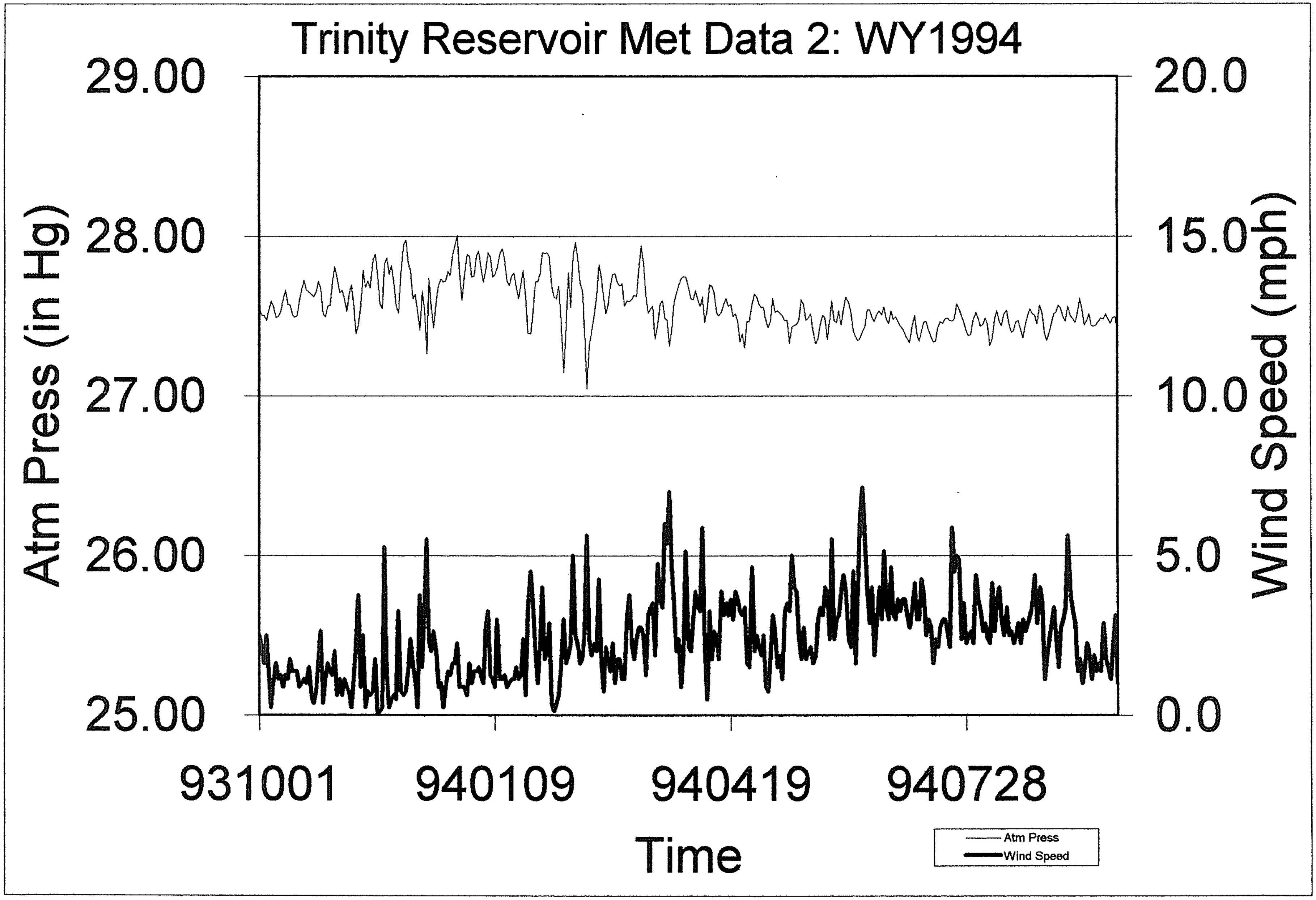
Trinity Reservoir Operations Flow Data: WY1994
Flow (cfs)
8000
7000
6000
5000
4000
3000
2000
1000
0
Power Outlet
Main Outlet
Auxilliary Outlet
Spill
931001
940109
940419
940728
Time



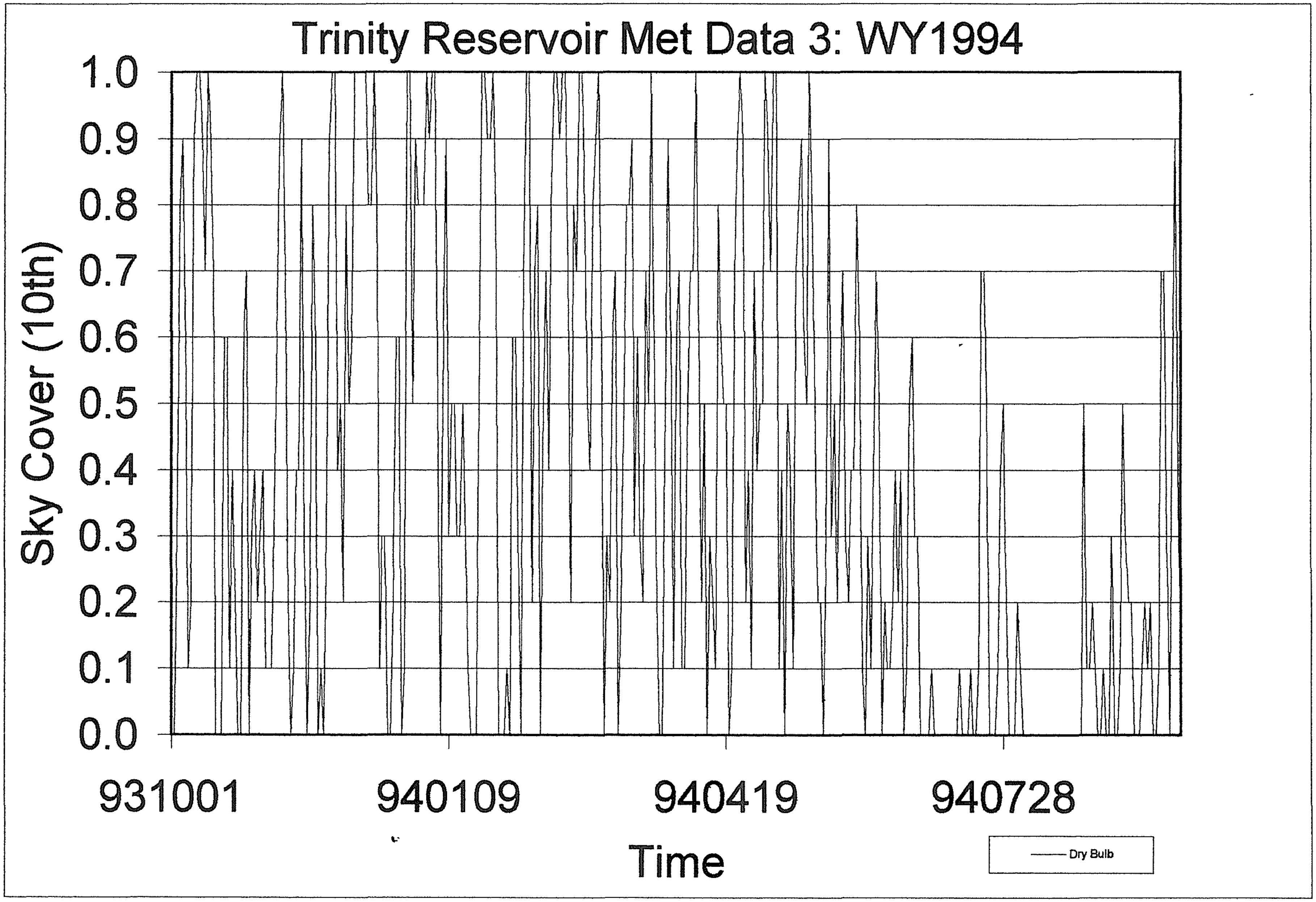
Trinity Reservoir Inflow Data: WY1994
Flow (cfs)
35000
30000
25000
20000
15000
10000
5000
0
-5000
Water Temperature (F)
80
70
60
50
40
30
20
10
0
931001
940109
940419
940728
Time
Inflow
Water Temperature

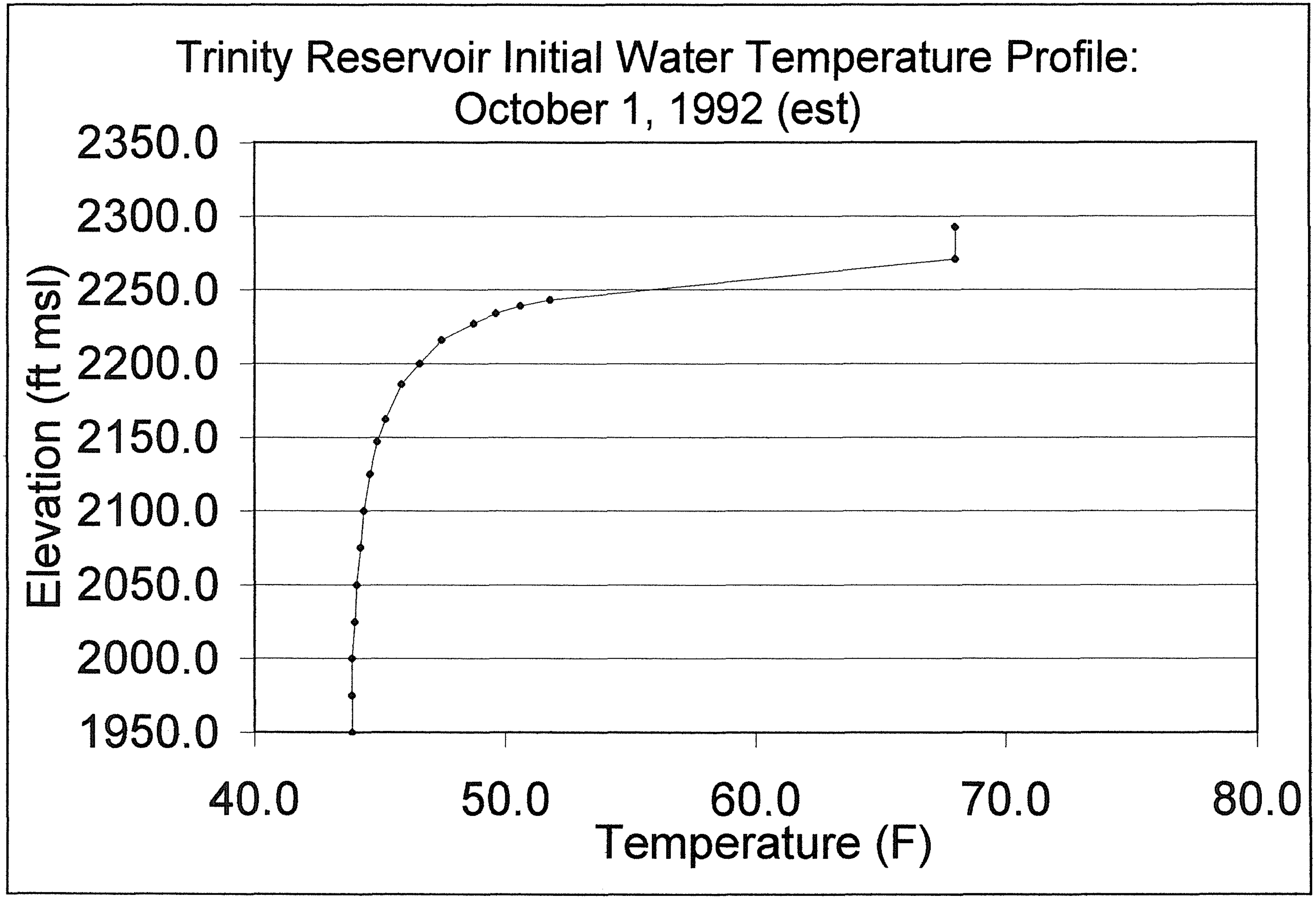


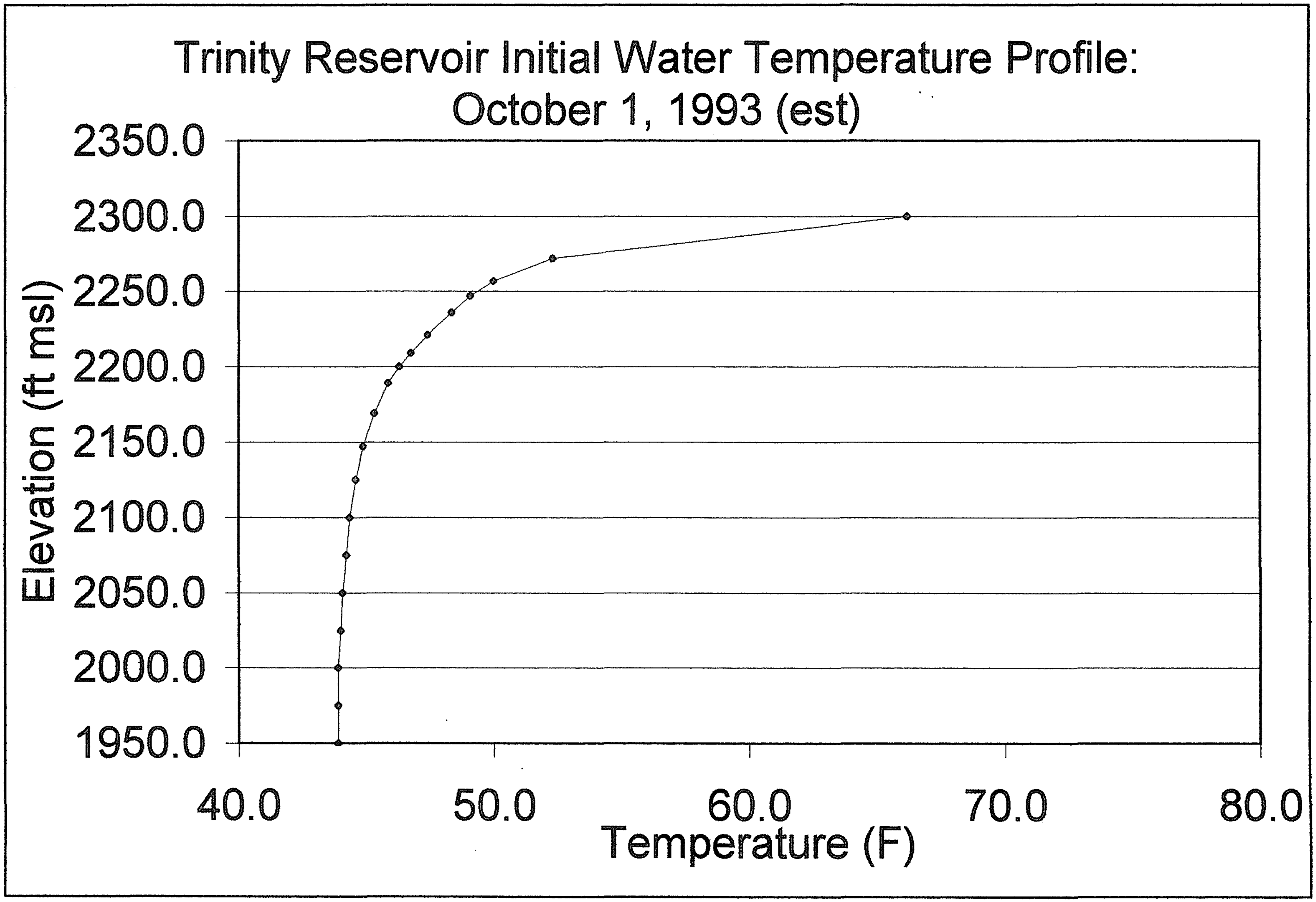
Trinity Reservoir Met Data 1: WY1994
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Dry Bulb (F)
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
Dew Point (F)
931001
940109
940419
940728
Time
Dry Bulb
Dew Point



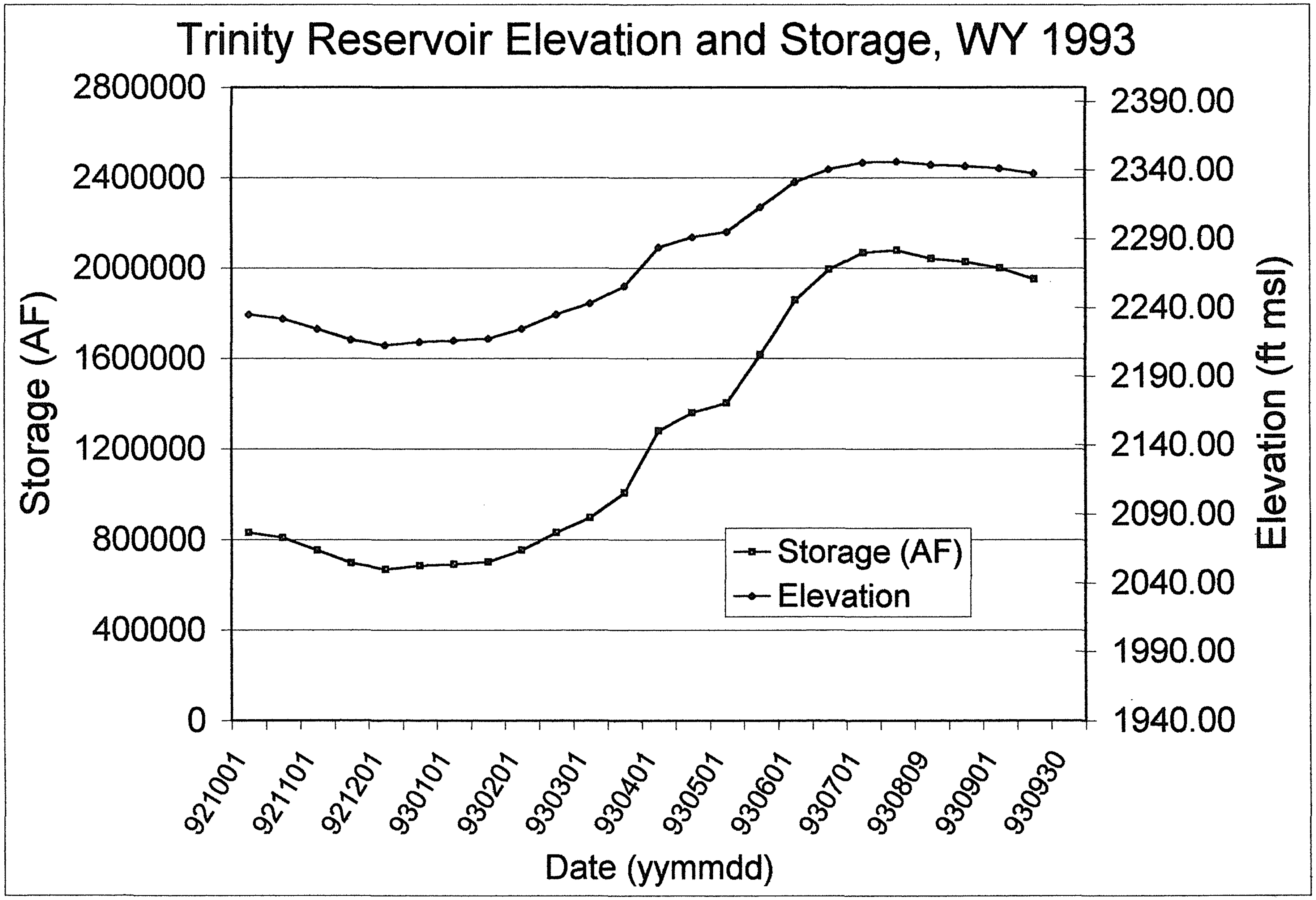
Trinity Reservoir Met Data 2: WY1994
29.00
28.00
27.00
26.00
25.00
Atm Press (in Hg)
20.0
15.0
10.0
5.0
0.0
Wind Speed (mph)
931001
940109
940419
940728
Time
Atm Press
Wind Speed

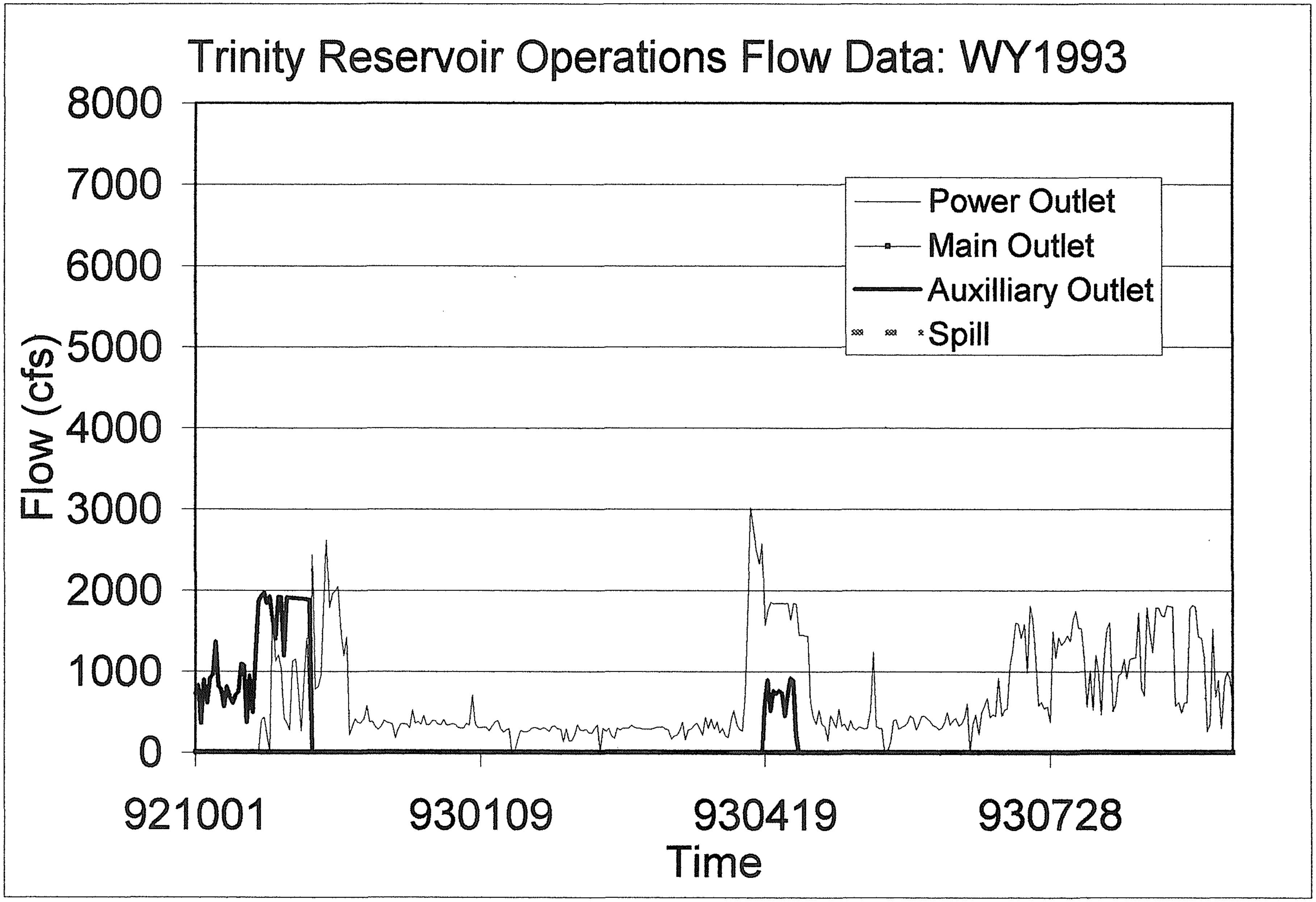

Trinity Reservoir Met Data 3: WY1994
Sky Cover (10th)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
931001
940109
940419
940728
Time
Dry Bulb


Trinity Reservoir Initial Water Temperature Profile:
October 1, 1992 (est)
Elevation (ft msl)
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
40.0
50.0
60.0
70.0
80.0
Temperature (F)

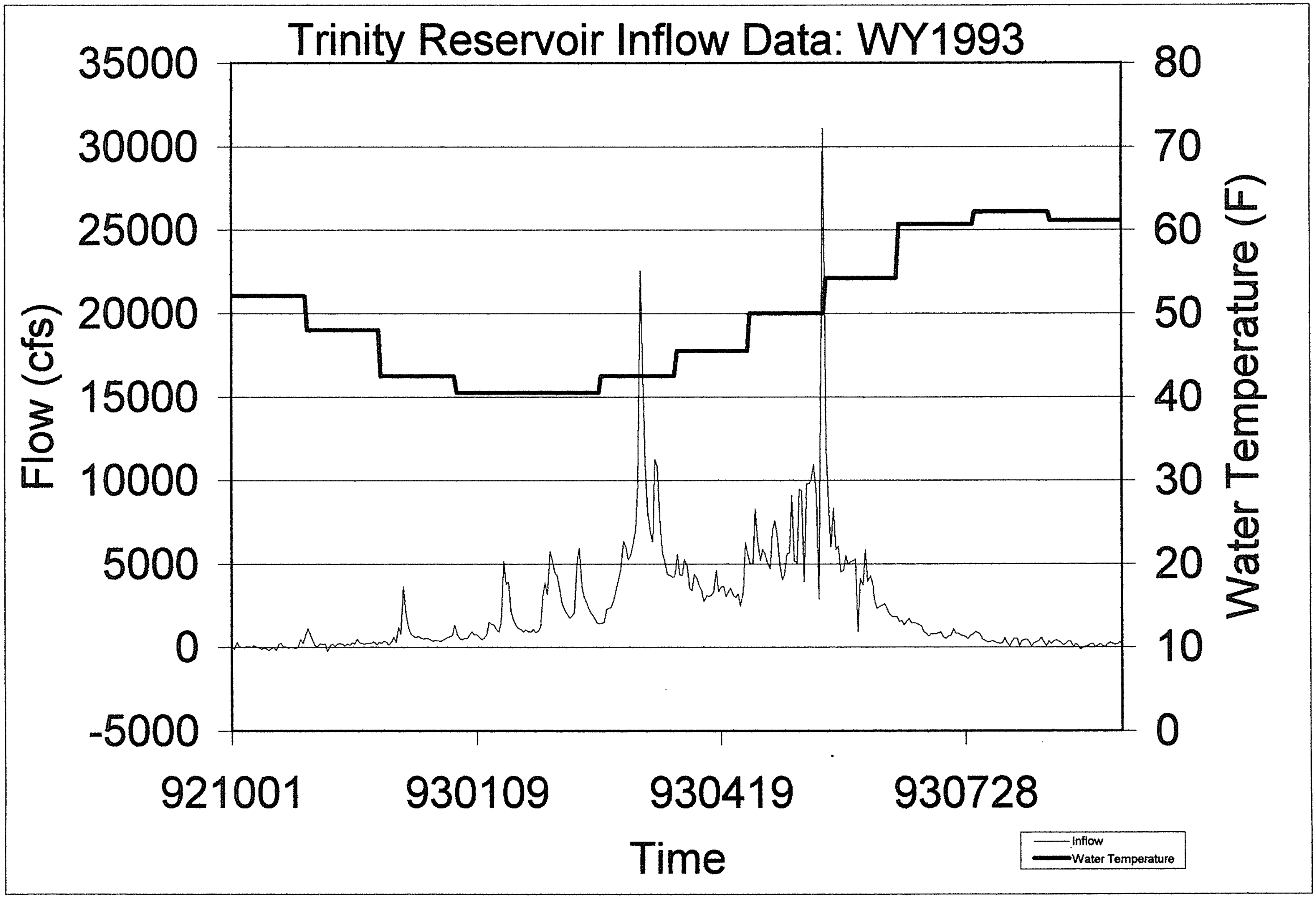


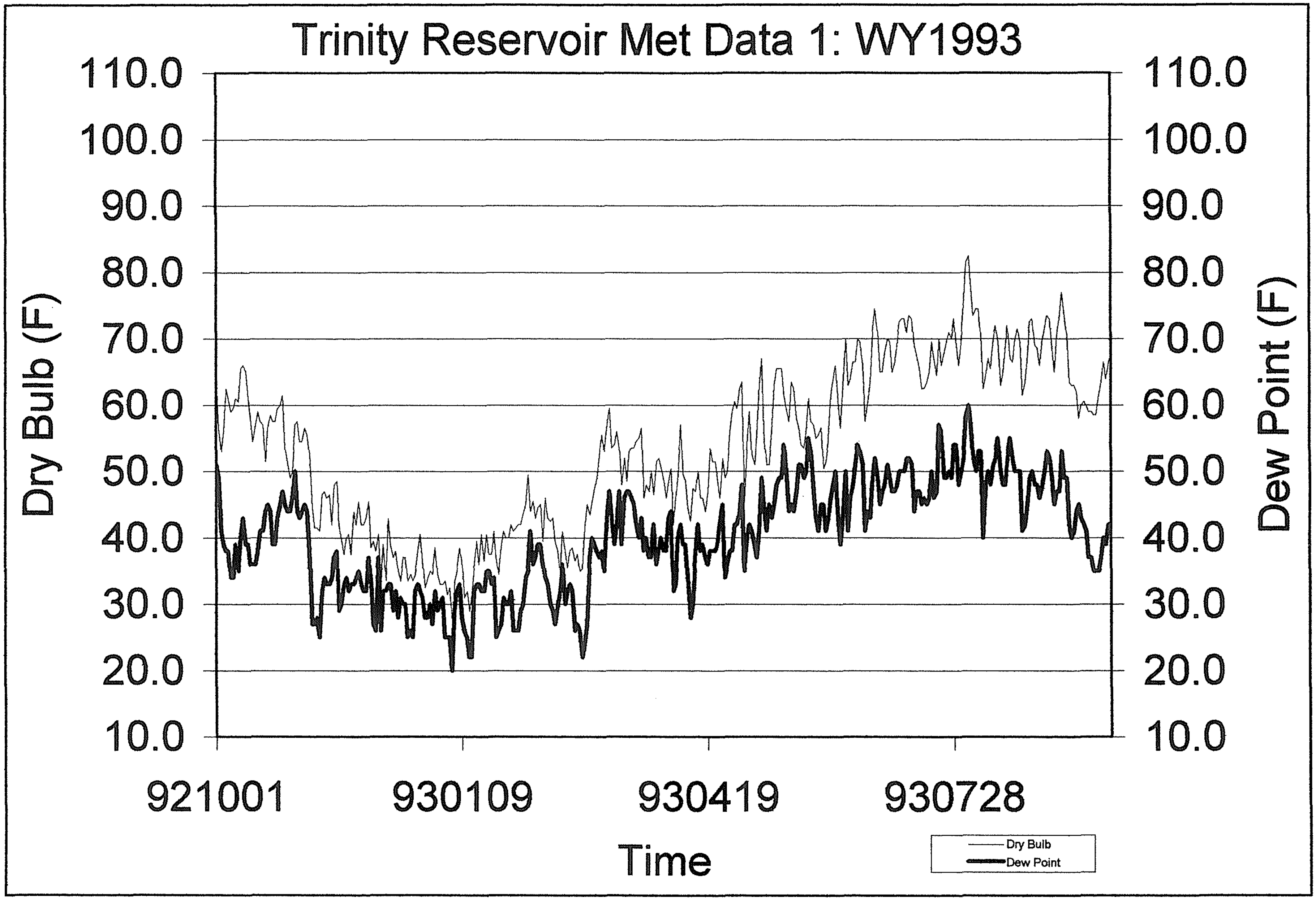
Trinity Reservoir Initial Water Temperature Profile:
October 1, 1993 (est)
Elevation (ft msl)
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
40.0
50.0
60.0
70.0
80.0
Temperature (F)


Trinity Reservoir Elevation and Storage, WY 1993
Storage (AF)
2800000
2400000
2000000
1600000
1200000
800000
400000
0
Elevation (ft msl)
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
921001
921101
921201
930101
930201
930301
930401
930501
930601
930701
930809
930901
930930
Date (yymmdd)
Storage (AF)
Elevation

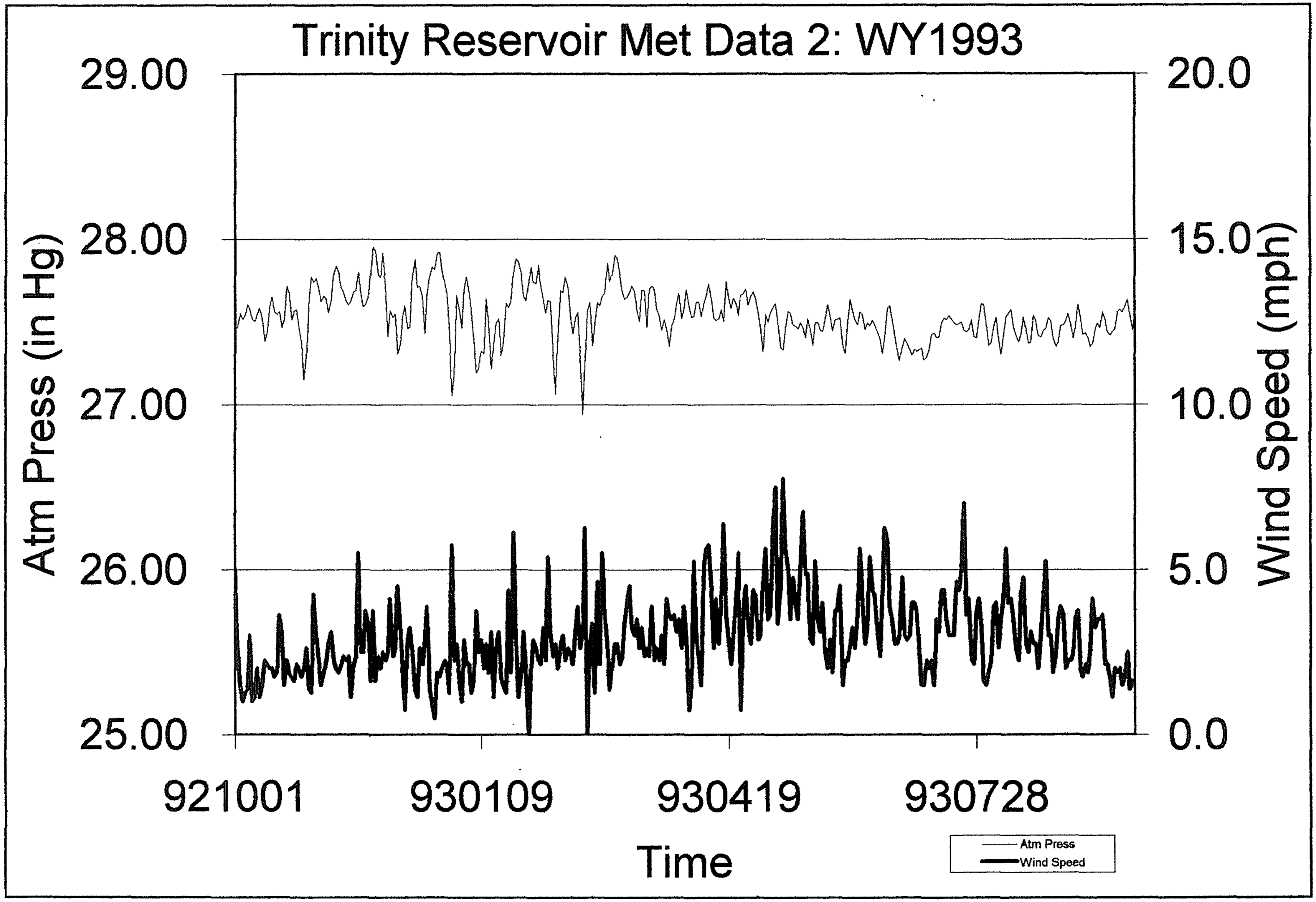


Trinity Reservoir Operations Flow Data: WY1993
8000
7000
6000
5000
4000
3000
2000
1000
0
Flow (cfs)
Power Outlet
Main Outlet
Auxilliary Outlet
Spill
921001
930109
930419
930728
Time

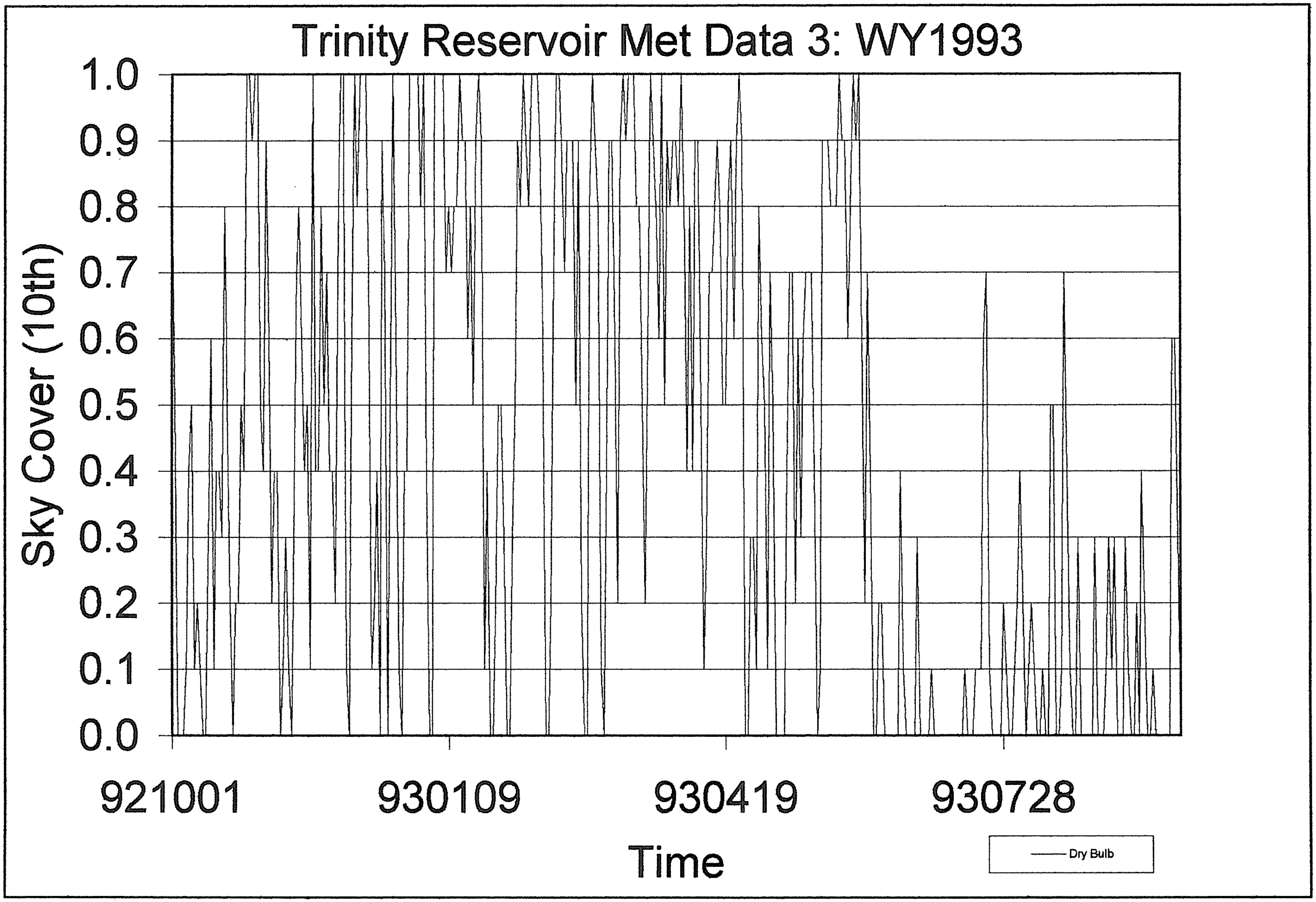

Trinity Reservoir Inflow Data: WY1993
Flow (cfs)
35000
30000
25000
20000
15000
10000
5000
0
-5000
Water Temperature (F)
80
70
60
50
40
30
20
10
0
921001
930109
930419
930728
Time
Inflow
Water Temperature



Trinity Reservoir Met Data 1: WY1993
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
Dry Bulb (F)
Dew Point (F)
921001
930109
930419
930728
Time
Dry Bulb
Dew Point



Trinity Reservoir Met Data 2: WY1993
29.00
28.00
27.00
26.00
25.00
Atm Press (in Hg)
20.0
15.0
10.0
5.0
0.0
Wind Speed (mph)
921001
930109
930419
930728
Time
Atm Press
Wind Speed


Trinity Reservoir Met Data 3: WY1993
Sky Cover (10th)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
921001
930109
930419
930728
Time
Dry Bulb

Appendix D Listing of Data Files and Files Included on Diskette

Much of the data are supplied on separate diskette (ZIP). Outlined herein is a listing input data, input files constructed for WQRRS, pre-processors, post-processing spreadsheets, and the WQRRS computer code modified for use on a personal computer (PC).

Input Data

No.	Filename	Description
1	inflwy77	WY1977 inflow and inflow water temperature
2	operwy77	WY1977 reservoir operations
3	metwy77	WY1977 meteorological data
4	profwy77	WY1977 initial water temperature profile data
5	param77	WY1977 WQRRS control parameters
6	inflwy83	WY1983 inflow and inflow water temperature
7	operwy83	WY1983 reservoir operations
8	metwy83	WY1983 meteorological data
9	profwy83	WY1983 initial water temperature profile data
10	param83	WY1983 WQRRS control parameters
11	inflwy86	WY1986 inflow and inflow water temperature
12	operwy86	WY1986 reservoir operations
13	metwy86	WY1986 meteorological data
14	profwy86	WY1986 initial water temperature profile data
15	param86	WY1986 WQRRS control parameters
16	inflwy89	WY1989 inflow and inflow water temperature
17	operwy89	WY1989 reservoir operations
18	metwy89	WY1989 meteorological data
19	profwy89	WY1989 initial water temperature profile data
20	param89	WY1989 WQRRS control parameters
21	inflwy90	WY1990 inflow and inflow water temperature
22	operwy90	WY1990 reservoir operations
23	metwy90	WY1990 meteorological data
24	profwy90	WY1990 initial water temperature profile data
25	param90	WY1990 WQRRS control parameters
26	inflwy93	WY1993 inflow and inflow water temperature
27	operwy93	WY1993 reservoir operations
28	metwy93	WY1993 meteorological data
29	profwy93	WY1993 initial water temperature profile data
30	param93	WY1993 WQRRS control parameters
31	inflwy94	WY1994 inflow and inflow water temperature
32	operwy94	WY1994 reservoir operations
33	metwy94	WY1994 meteorological data
34	profwy94	WY1994 initial water temperature profile data
35	param94	WY1994 WQRRS control parameters

Calibration/Verification Data

No.	Filename	Description
1	measprof.xls	spreadsheet of calibration/verification water temperature profile data and secchi depth measurements

Input Data Files for WQRRS

No.	Filename	Description
1	trin77.in	WY1977 WQRRS input file (historic conditions)
2	trin83.in	WY1983 WQRRS input file (historic conditions)
3	trin86.in	WY1986 WQRRS input file (historic conditions)
4	trin89.in	WY1989 WQRRS input file (historic conditions)
5	trin90.in	WY1990 WQRRS input file (historic conditions)
6	trin93.in	WY1993 WQRRS input file (historic conditions)
7	trin94.in	WY1994 WQRRS input file (historic conditions)

Pre-Processor

No.	Filename	Description
1	trinput	executable
2	trinput.for	pre-processor source code

Post-Processor (MS Excel® Spreadsheets)

No.	Filename	Description
1	profil77.xls	spreadsheet for analysis of WY1977 WQRRS results
2	profil83.xls	spreadsheet for analysis of WY1983 WQRRS results
3	profil86.xls	spreadsheet for analysis of WY1986 WQRRS results
4	profil89.xls	spreadsheet for analysis of WY1989 WQRRS results
5	profil90.xls	spreadsheet for analysis of WY1990 WQRRS results

WQRRS

No.	Filename	Description
1	Wq09	WQRRS executable
2	Wq09.for	program WQRRS
3	Wq11.for	block data
4	Wq12.for	subroutine banner
5	Wq13.for	function beta
6	Wq14.for	subroutine comput
7	Wq15.for	subroutine david
8	Wq16.for	subroutine dpform
9	Wq17.for	subroutine error
10	Wq18.for	subroutine factor
11	Wq19.for	subroutine fitit
12	Wq20.for	subroutine flowin
13	Wq21.for	subroutine flowout
14	Wq22.for	subroutine form
15	Wq23.for	subroutine former
16	Wq24.for	subroutine halt
17	Wq25.for	subroutine inconc
18	Wq26.for	subroutine inflo
19	Wq27.for	subroutine inhyd
20	Wq28.for	subroutine inpdr

21	Wq29.for	subroutine irate
22	Wq30.for	subroutine lakeco
23	Wq31.for	subroutine matrix
24	Wq32.for	subroutine object
25	Wq33.for	subroutine optiml
26	Wq34.for	subroutine outr
27	Wq35.for	subroutine outrw
28	Wq36.for	subroutine phco2
29	Wq37.for	subroutine prjnew
30	Wq38.for	subroutine prodct
31	Wq39.for	subroutine projct
32	Wq40.for	subroutine radiat
33	Wq41.for	subroutine rcoeff
34	Wq42.for	subroutine residu
35	Wq43.for	subroutine resim
36	Wq44.for	double precision function
37	Wq45.for	subroutine selecet
38	Wq46.for	subroutine solve
39	Wq47.for	subroutine subst
40	Wq48.for	subroutine wqfct
41	Wq49.for	subroutine pcfiles

Appendix E Meteorological Data Considerations

Though a complete weather station is operational at Lewiston Dam, the record is limited to only a few months of reliable data. To reconstruct a meteorological record of the Trinity Reservoir area data from several sources were compiled. Required data included daily mean air temperature, wind speed, dew point, cloudiness or sky cover, and barometric pressure. Each meteorological parameter is discussed below, but the reader is referred to Jones and Stokes (1992) for additional details on methods used to estimate daily mean air temperature, dew point, and wind speed, as well as the impact of averaging meteorological data over a single day.

Daily air temperature, wind speed, and dew point for all EIS year-types were supplied by Greg Kamman (derived from Jones and Stokes, 1992). Barometric pressure and sky cover for these periods were obtained from the National Climatic Data Center CD ROM (Earthinfo, Inc.). For the calibration and verification years (WY 1994, and WY 1993, respectively), air temperature and wind speed data was obtained from personnel at the Lewiston Hatchery, and barometric and sky cover data from National Climatic Data Center CD ROM.

Air Temperature

Mean daily air temperature was estimated by averaging the daily maximum and minimum air temperature measured at the Trinity Lake Hatchery. Jones and Stokes (1992) note that averaging daily maximum and minimum air temperature is reasonably accurate and discuss uncertainty associated with such an approach.

Wind Speed

Wind speed was estimated using an anemometer located at the Lewiston Hatchery. The anemometer, which has been in operation for several years, is located in a relatively sheltered location at the base of the dam and is only about two feet above the ground surface. As a result, wind speeds at this site do not accurately represent daily average wind speed conditions for Lewiston or Trinity Reservoirs (Jones and Stokes, 1992). Jones and Stokes (1992) attempted several methods for adjusting wind speed to obtain reasonable values and concluded that multiplying wind speed by a factor of three proved to be the best method. The same method was adopted for the Trinity Reservoir temperature model. Improvements in representation of this critical meteorological parameter should be pursued.

Dew Point

Neither relative humidity nor dew point data were available at Trinity Reservoir. Jones and Stokes (1992) report that minimum air temperatures are often close to dew point temperature because additional cooling creates fog and dew, which releases heat and tend to stabilize the air temperature. Previous modeling efforts at Lewiston Reservoir estimated dew point based on a regression relationship using McArthur Cimis Station based minimum air temperature data (Jones and Stokes, 1992). This relationship is reproduced in equation E.1.

$$DP = 0.7634T_{min} + 1.238 \qquad (E.1)$$

where: DP = dew point temperature (°C)

T_{min} = minimum air temperature (°C)

Lacking additional data and to remain consistent with other modeling efforts in the EIS process, the above relationship was employed. It should be noted that model results were moderately sensitive to changes in dew point temperatures. For example, setting dew point equal to minimum Lewiston air temperature (values which typically vary 2°F to 3°F from those calculated using Equation E.1) results in differences of about 0.2°F at the selected calibration elevations (2000, 2100, and 2150 ft msl) for the months June through September.

Given the uncertainty in applying a relationship developed from a non-local weather station in a different environment, improvements in dew point estimation using local air temperature should be pursued. (The McArthur California Irrigation Management Information System (CIMIS) station is located in a large open valley approximately 75 miles east-northeast of Trinity Reservoir.)

Cloud Cover

To incorporate incoming solar radiation (short wave) and atmospheric long wave radiation WQRRS uses cloud cover data. Daily cloud cover, or sky cover data was assumed equal to Red Bluff and Redding Municipal Airport conditions. Data is recorded in percentages (10 percent increments), with 100 percent representing completely cloudy conditions and zero percent clear skies. In August 1986 the weather station was moved from Red Bluff to Redding. Thus, cloud cover prior to August 24, 1986 was represented by Red Bluff data and after August 31, 1986 by Redding data. During this short period of about one week where data was absent clear sky conditions were assumed (0%).

Barometric Pressure

Barometric pressure data was derived from Red Bluff and Redding Municipal Airport data. Barometric pressure is a function of elevation. Because Red Bluff (elevation 349.2 ft msl) and Redding (502.1 ft msl) were significantly lower than Trinity Reservoir (2370.0 ft msl at spill way crest) barometric pressure was corrected for elevation. Barometric pressure at a known elevation can be estimated as from standard barometric pressure at sea level by

$$P_t = 1{,}013 - 3.436(E/100) - 0.0029\,(E/100)^2 + 0.0001(E/100)^3 \qquad (1)$$

Barometric pressure at Red Bluff and Redding were converted to sea level ($P_{sea\ level}$) and then corrected to account for the elevation of Trinity Reservoir ($P_{Trinity}$). Specifically,

$$P_{sea\ level} = P_{actual(Red)} - P_{t(Red)}$$

$$P_{Trinity} = P_{sea\ level} + P_{t(Trinty)}$$

The subscript "Red" represents Red Bluff and/or Redding, P_{actual} refers to measured barometric pressure, and P_t represents the application of equation (1). As with the cloud cover data there is a short period of about one week where data was absent in the last week of August 1986 when the weather station was moved from Red Bluff the Redding. During this period barometric pressure was assumed equal to the last reading at Red Bluff (29.4 in Hg); a reasonable assumption under the stable summer atmospheric conditions.

Appendix F Estimation of Initial Water Temperature Profiles

Application of WQRRS to the water year period (October 1 – September 30) required specification of an initial condition describing the water temperature with depth – a water temperature profile. Measured profiles were not available for any of the EIS year-types for September 30 or October 1. In addition, application of the model to various reservoir carryover storage quantities required specification of temperature profiles for various initial elevations – some elevations well out of the range of historic operations.

To determine initial conditions for model runs, water temperature profiles were estimated from measured data during the late September to early October period. Figure F.1 shows available September-October Trinity Reservoir measured temperature profiles between 1985 and 1994.

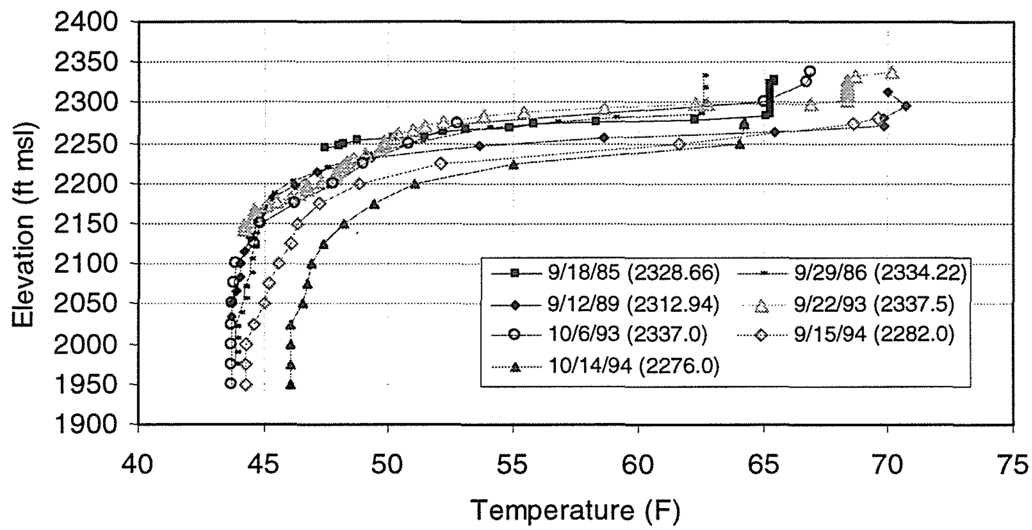


Figure F.1 September-October measured Trinity Reservoir water temperature profile data (date and reservoir elevation (ft msl) included in legend)

These data were used to estimate initial October 1 temperature profiles. For all of the EIS year-types all initial elevations were greater than 2290 ft msl and sufficient historical data was available to make reasonable estimates of profile temperatures using the data in Figure F.1. Figure F.2 shows the estimated initial temperature profiles for the EIS year-types. Because the thermal structure of the reservoir changes at elevations below 2300 ft msl, initial profiles were defined for starting elevations between 2290 ft msl and 2300 ft msl, and between 2300 ft msl and 2350 ft msl.

For carryover study simulations, there were no measured data available for 750,000 acre-feet (2224.2 ft msl) carryover, and limited measured data for 1,250,000 acre-feet (2281.0 ft msl) carryover. Estimated initial temperature profiles are shown in Figure F.3. Data for initial profiles are included in the computer input files outlined in Appendix D.

Suitable estimation of initial water temperature profiles was required, but not critical to analysis because winter cooling creates isothermal conditions of Trinity Reservoir: effectively erasing the previous summer thermal signal. Winter water temperatures and quantity and timing of inflows probably have a greater impact on the subsequent summer thermal structure than minor variations in initial reservoir temperature profiles.

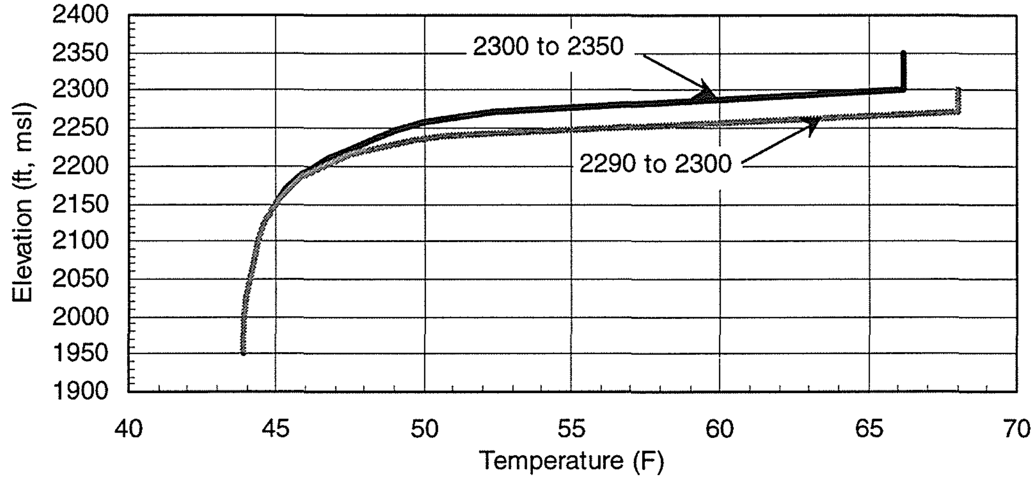


Figure F.2 Estimated October 1 Trinity Reservoir water temperature profiles for EIS year-types

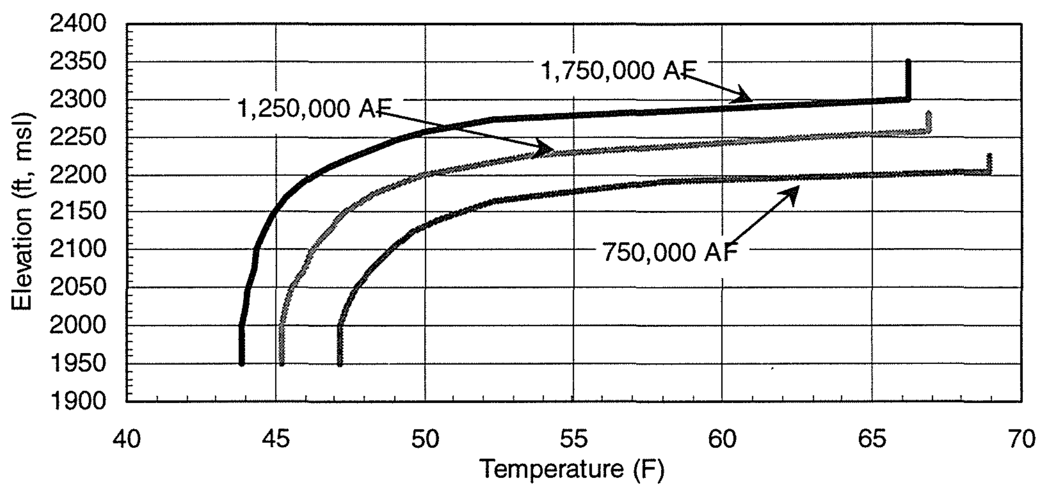


Figure F.3 Estimated October 1 Trinity Reservoir water temperature profiles for carryover storage simulations

Appendix G Trinity Reservoir Inflow Temperature Estimation

Available measured water temperature for Trinity Reservoir inflows was extremely limited. Table G.1 defines the available data from summer 1993 at four locations.

Table G.1 Trinity Reservoir inflow water temperature data

Location	Date	Time	T_{water} (ºF)	T_{air} (ºF)
Swift Creek	8/19/93	16:15	65.8	81.3
Swift Creek	9/22/93	12:10	59.0	69.4
E. Fork Trinity River	8/19/93	17:15	68.0	72.9
E. Fork Trinity River	9/22/93	11:00	55.4	66.2
Trinity River north of Coffee Ck.	8/19/93	18:45	67.5	76.1
Trinity River north of Coffee Ck.	9/22/93	11:50	54.0	71.6
Coffee Creek	8/19/93	16:45	65.3	75.6
Coffee Creek	9/22/93	11:35	53.2	70.7

Source: field work completed by UC Davis under Gabriella K. Meyer

The best available data were monthly estimated inflow temperatures from Rowell (1990) (Table G.2). Reviewing these estimated temperatures and comparing them with measured profile data indicated that winter inflow temperatures might be underestimated. Measured water temperature profile data illustrate that reservoir water temperature rarely dropped below 43°F – 47°F. Though approximately constant from the reservoir surface to the bottom, surface waters were typically slightly warmer. Figure G.1 illustrates these approximately isothermal conditions for February 14 and December 28, 1994 measured profile data.

Estimated winter monthly inflow temperatures by Rowell were significantly cooler, with December, January, and February mean monthly water temperatures of 37.7°F, 36.7°F, and 40.5°F, respectively. Appreciable inflow can enter the reservoir during these months. Though these inflows would contribute to overall reservoir cooling, along with seasonal atmospheric cooling, they may also pool in the bottom of the reservoir being cooler and denser than surface waters. Preliminary model results provided additional insight. Figure G.2 illustrates simulated versus measured data for Trinity Reservoir for February 14, 1994 using December, January and February inflow temperatures of 42.5°F, 40.5°F, and 40.5°F, respectively. Even under these "warmer" inflow conditions, simulated bottom water temperature deviates markedly from the measured profile, illustrating the impact of cooler, denser waters occupying the lowest levels of the reservoir. This preliminary examination of inflow temperature lead to exploration of potential inflow temperatures.

To assess possible winter inflow temperatures USGS water temperature data from nearby watersheds was investigated. Several stations were examined, including

- Sacramento River near Mt. Shasta (11341400)
- Sacramento River at Shasta Retreat near Dunsmuir (11341440)
- Grass Valley Creek near French Gulch Creek (11525556)
- Grass Valley Creek at Fawn Lodge near Lewiston (11525600)
- Little Grass Valley Creek near Lewiston (11525580)

Table G.2 Estimated Trinity Reservoir inflow water temperature, Rowell (1990)

Month	Temperature
October	52.1
November	41.3
December	37.7
January	36.7
February	40.3
March	40.3
April	41.3
May	43.8
June	54.2
July	60.7
August	62.2
September	61.1

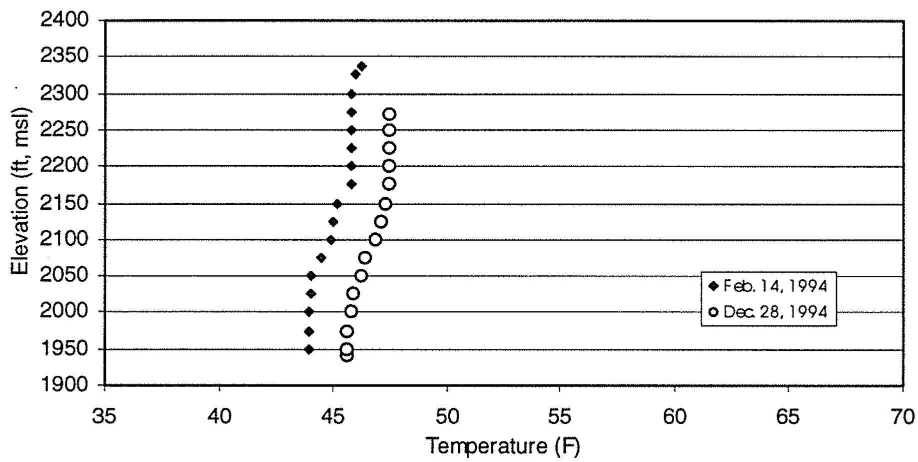


Figure G.1 Measured Trinity Reservoir water temperature, Feb. 14 and Dec. 28, 1994

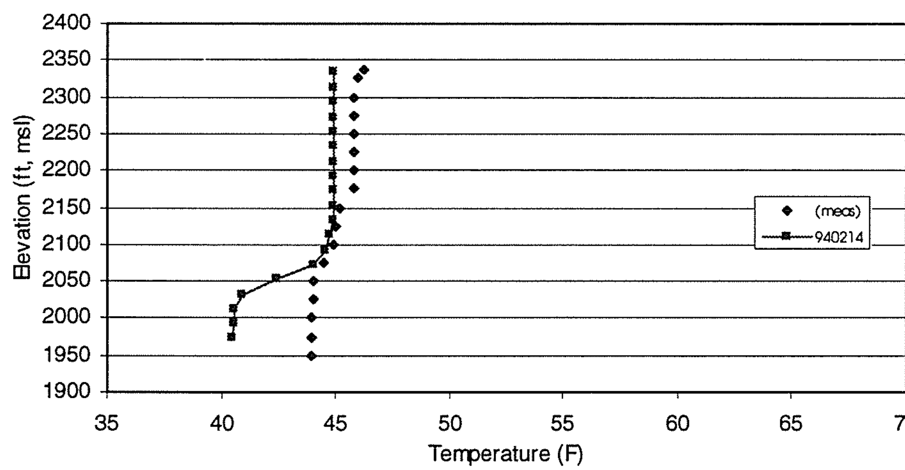


Figure G.2 Measured vs. simulated Trinity Reservoir water temperature, February 14, 1994

The Sacramento River stations are approximately 25 miles northeast of Trinity Reservoir and at similar elevation. The Grass Valley and Little Grass Valley Creek locations are approximately 4 miles south of Lewiston Reservoir and slightly lower in elevation. Data from all stations were examined; however, only Sacramento River near Mt. Shasta (11341400) and Grass Valley Creek at Fawn Lodge near Lewiston (11525600) were reviewed in detail.

Table G.3 outlines average monthly winter stream temperatures for the Sacramento River (1965-86) and Grass Valley Creek (1975-95) locations. Data were once daily measurements, typically taken between the hours of 8:00 a.m. and 5:00 p.m. It was determined that although winter temperatures in these systems did attain low values (32°F), they were typically short term events, and that average monthly temperatures were on the order of 40°F or greater.

Table G.3 Average monthly stream temperatures. November through April

Month	Grass Valley Creek [11525600] (ºF)	Sacramento River nr Mt. Shasta [11341400] (ºF)
November	45.7	48.2
December	42.8	42.5
January	42.0	40.5
February	42.9	40.4
March	42.4	42.2
April	47.8	45.4

Ultimately, Sacramento River temperature data were used to estimate winter water temperatures because the upper Sacramento River winter flow rates are probably more representative of the Trinity River above Trinity Reservoir than smaller Grass Valley Creek. Figure G.3 illustrates November through May upper Sacramento River water temperatures near Mt. Shasta for the period 1965-86. Although Box Canyon dam may moderate water temperatures to some extent during winter periods the effect is most likely small. Further, it was found that winter water temperatures in the Sacramento River near Dunsmuir were approximately the same magnitude. Table G.3 shows the final estimated monthly Trinity Reservoir inflow water temperatures. For comparison values from Rowell (1990) are included. Summer temperatures were not modified.

This analysis illustrates that Trinity Reservoir is sensitive to inflow temperature through the summer months. For these analyses it is assumed that inflow temperature does not vary from year to year. Rainfall driven events versus snowmelt events may provide variable inflow temperatures to Trinity Reservoir. Further, initial storage may impact thermal structure of the reservoir if significant increases in storage are due to rainfall or snowmelt runoff.

This complex process requires a more detailed examination than that included herein. Additional data are needed to more completely characterize inflow temperature to Trinity Reservoir. The selected winter inflow temperature values are only estimates and model runs and measured temperature profiles indicate that detailed field measurements and perhaps an equilibrium temperature model for inflows may improve prediction capabilities.

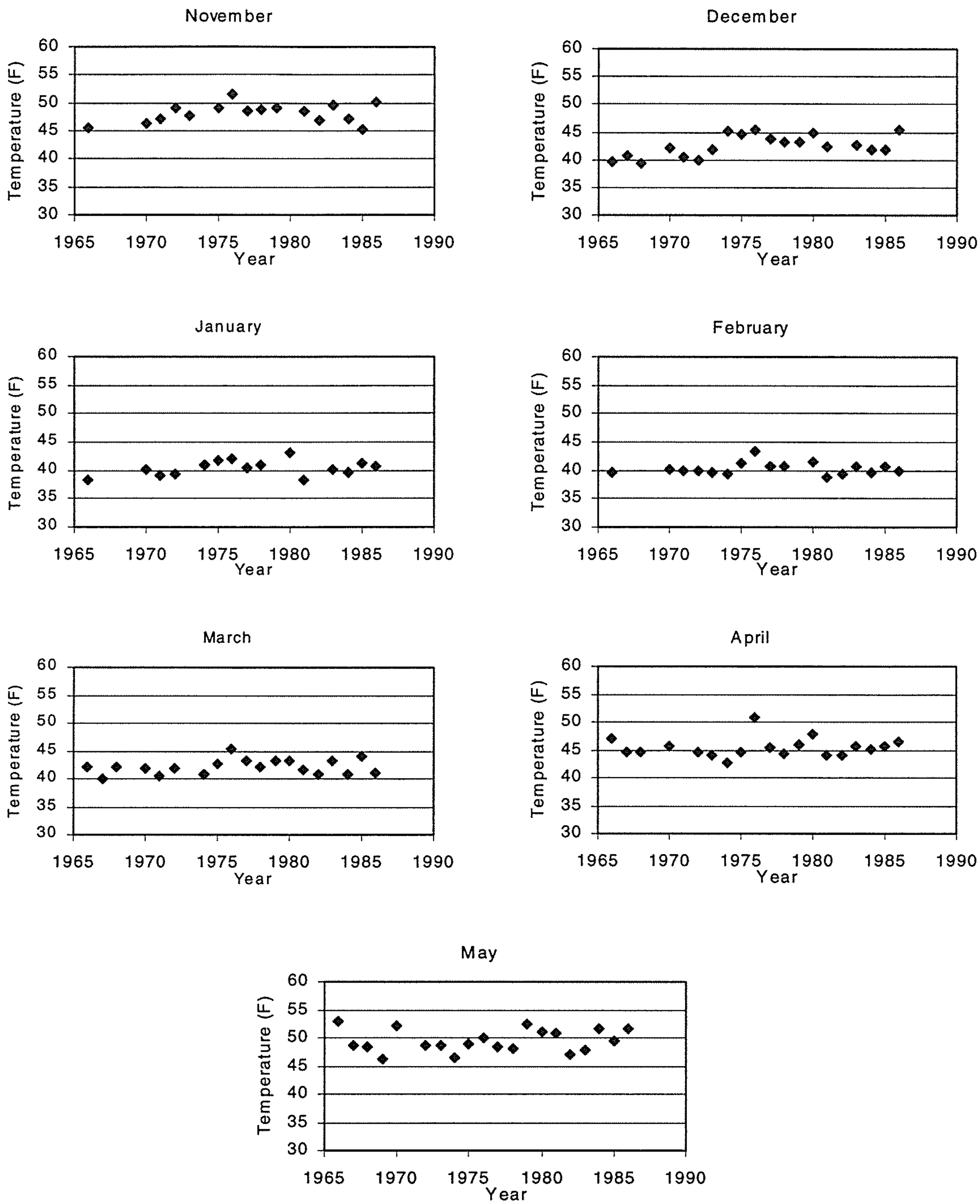


Figure G.3 Historic November through May water temperature, Sacramento River near Mt. Shasta (1965-86)

Table G.4 Original and revised estimated Trinity Reservoir inflow water temperature.

Month	Revised Water Temperature (revised values in bold)	Original Water Temperature (Rowell, 1990)
October	52.1	52.1
November	**48.0**	41.3
December	**42.5**	37.7
January	**40.5**	36.7
February	**40.5**	40.3
March	**42.5**	40.3
April	**45.5**	41.3
May	**50.0**	43.8
June	54.2	54.2
July	60.7	60.7
August	62.2	62.2
September	61.1	61.1

Appendix H Selective Withdrawal from Stratified Reservoirs

Outlined herein is a brief introduction to selective withdrawal, physical structures in place at Trinity Dam(intake elevations and diameters), previous references to withdrawal zones at Trinity Reservoir, and a discussion of assumptions used in this report.

Selective withdrawal is the withdrawal of water from a specified range in a stratified reservoir. Many large reservoirs develop significant temperature differences during warmer months of the year as much of the thermal energy entering a reservoir is absorbed in the upper layers where warmed waters are less dense, while the lower layers remain cool and more dense. The limited vertical movement of fluid imposed by the density stratification can permit the control of the quality of water released. While operation of a single intake port is sometimes adequate to meet release water quality objectives, multiple intake ports at different elevations can provide increased flexibility through selection of water of different qualities to achieve a desired result (Howington, 1990).

Trinity Reservoir has intakes located at two elevations: the power/main intake is located at invert elevation 2100.0 ft msl (diameter: 28 feet) and the auxiliary intake is located at invert elevation 1995.5 ft msl (diameter: 7 feet). For reference the spillway crest elevation is 2370.0 ft msl. The power/main intake is preferentially used due to hydropower considerations. Typically, reservoir storage is sufficient that releases from the power/main intake remain cool, even through the summer months. However, when reservoir draw down significantly reduces reservoir storage warmer waters from near surface layers can be entrained, leading to elevated release water temperatures.

Though formal studies have been conducted at Trinity Reservoir on the zone of entrainment for the power/main and auxiliary intakes, Weidlein (1971) estimated the withdrawal elevation for the power/main intake from historic data. Using data from September, October, and November 1968 Weidlein compared water temperature profile and release temperature data to estimate the apparent withdrawal level or source of water for the intakes. Weidlein found that water temperatures 39 feet above the centerline of the intake compared with release temperatures from the power/main intake – stating that there is a "tendency to draw water well above the penstock intake." One apparent error was that Weidlein assumed the reservoir invert (2100 ft msl) was the centerline elevation. Accounting for the diameter of the intake (28 feet), the apparent withdrawal level is reduced to 25 feet above the centerline elevation.

The issue of intake water origin becomes important when simulating lower operational reservoir volumes and potential impacts on release temperatures. Computer models require specification of intake elevations and associated intake diameters. Rowell (1979) modeled Trinity Reservoir and selected a centerline elevation of 2140 ft msl for the power/main intake based on Weidlein's studies (the discrepancy addressed in the previous paragraph was corrected in the Rowell studies). Limitations to the Weidlein study include limited available data (3 profiles from 1968), no discussion of heating through the power plant, and no review of rate of reservoir withdrawal or water column density considerations. Still, the report provides insight into a potentially important process. This author's brief review of 1994 water temperature profiles for Trinity Reservoir yielded additional information. Using the same method as Weidlein, power plant release temperatures were compared with reservoir profile temperatures to estimate a potential contributing elevation. Table H.1 outlines the results (all releases were via the power/main intake). The findings of this abbreviated analysis support Weidlein's findings to some degree; the average intake elevation for the available months corresponded to a reservoir temperature at elevation 2130 ft msl – 16 feet above the centerline elevation. Closer examination shows that several of the temperatures were associated with elevations within the approximate diameter of the penstock. It should be noted that this study suffers from every shortcoming outlined above (limited data, excludes power plant heating, and ignores operations and density considerations).

Table H.1 Summary of release temperatures and corresponding elevations within Trinity Reservoir, 1994

Date	Power Plant Discharge Temperature	Corresponding Temperature Elevation in Trinity Reservoir	Centerline of Power/Main Intake Elevation (28 ft diameter)
6/23/94	45.5	2137	2114
7/8/94	45.5	2133	2114
7/22/94	45.6	2153	2114
8/16/94	46.0	2119	2114
8/31/94	46.4	2129	2114
9/15/94	46.4	2128	2114
10/14/94	47.2	2115	2114
	Average:	2130	

Selection of a centerline elevation for the application of WQRRS to Trinity Reservoir was based on the above sources and review of available sources. Tsaras (1983) notes that withdrawal zone formed in the reservoir by the intake structure is not uniform. Depending on the location of the intake with respect to the water surface (reservoir volume), the degree of stratification, season, and system hydrology the intake envelop may be symmetrical about the centerline elevation, asymmetrical with a larger contributing area above the centerline elevation, or asymmetrical with a larger contributing area below the centerline elevation. Further, reservoir morphology, inflow hydrology, and dynamic state of operations (quantity/duration) also affect withdrawal zone shape and extent (Fischer, et al, 1979).

Given the uncertainties in estimating intake elevation for model use, actual centerline elevations for each intake were used in WQRRS.

References

Fischer, H.B, E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. *Mixing in Inland and Coastal Waters*. Academic Press, Inc. Harcourt Brace Jovanovisch. New York.

Howington, S.E. 1990. *Simultaneous Multiple-Level Withdrawal from a Density Stratified Reservoir*. Waterways Experiment Station, US Army Corps of Engineers. Technical Report W-90-1. June.

Rowell, J.H. 1979. *Mathematical Model Investigations: Trinity Dam Multilevel Outlet Prediction Study*. Prepared under the Trinity River Basin Fish and Wildlife Task Force, Interim Action Program. U.S Bureau of Reclamation, Sacramento, CA May.

Tsaras, Y.G. 1983. *Effects of Stratification on Temperature of Discharged Water from Deep Reservoir.* Master's Thesis, Department of Civil Engineering, University of California, Davis.

Weidlein, D.W. 1971. *Temperature Approximations for the Sacramento and Trinity Rivers under Year 2020 Water Demand Conditions.* California Department of Fish and Game, Region 1. Environmental Services Administrative Report 71-1, June.

Appendix I Model and Calibration Parameters

Outlined herein are general model operation and model calibration parameters. Model parameters include allocation of inflow, withdrawal option, representation of effective diffusion, atmospheric turbidity, and water solar radiation fraction. Details of this discussion are summarized from the WQRRS User's Manual (1986). For other model parameters the reader is referred to the input files and WQRRA user's manual.

I.1 General Model Operation Parameters

Though there are several parameters which control the computer program flow logic only four of principal interest will be covered herein: allocation of inflow, withdrawal option, effective diffusion method, heat exchange method, atmospheric turbidity, and water solar radiation fraction. The reader is referred to the input files (Appendix D) and the WQRRS user's guide for additional details and details on other model parameters.

Allocation of Inflow

The allocation of inflow is based on the assumption that inflow water will seek a level of similar density within the reservoir ("entry level"). The switch controlling allocation of inflow is provided on card PHYS4, variable RLEN. RLEN is effective reservoir length. For stratified conditions, a positive value of RLEN distributes inflows about the entry level with a uniform velocity distribution, and a negative value distributes water in proportion to element size down to the entry level. This latter method is applicable to reservoirs where the inflow is located several miles from the deepest part of the reservoir and was selected for this application.

Withdrawal Option

WQRRS contains two options for allocating reservoir withdrawal through an outlet gate to individual layers; Debler-Craya and WES. During calibration of the Trinity Reservoir water temperature model both allocation techniques were explored and minimal differences noted with the exception of late September results. Further, results of Tsaras (1980) indicate that for deep, well-stratified reservoirs differences of less than 1°C (1.8°F) are typical between the two methods. The WES withdrawal technique was employed for this application (JOB3, variable IWES = 0)

Effective Diffusion

Besides advection, effective diffusion is the other mechanism to transport heat and mass between the elements. Two methods are available to calculate effective diffusion: the stability method and wind method. Because Trinity Reservoir is strongly stratified and wind mixing does not dominate the reservoir, the stability method was selected (PHYS3A versus PHYS3B).

Water Surface Heat Exchange

Water surface heat exchange can be addressed using a heat budget or equilibrium temperature method in WQRRS. The heat budget method was used herein (JOB7, variable IEQF = 0)

Atmospheric Turbidity

Atmospheric turbidity is used in the determination of amount of scattering incoming short wave radiation. Data was available for estimating atmospheric turbidity and clear, unpolluted atmosphere assumed (PHYS1, variable TURB = 2.0). Though certain periods of the year may exhibit these conditions, other periods (e.g. summer) may exhibit increased turbidity. Currently WQRRS allows the user to enter a single value for the analysis period. Further definition of this parameter should be investigated.

Solar Radiation Absorption

Fraction of solar radiation absorbed with depth is addressed through two variables: XQPCT and XQDEP. XQPCT is the fraction of solar radiation absorbed in depth XQDEP. Variables XQPCT and XQDEP were set at 32.5% (0.325) and 1.0 meter, respectively (PHYS2).

I.2 Model Calibration Parameters

Calibration parameters outlined herein include secchi depth, water column stability and diffusion parameters, and evaporation coefficients. The final set of calibration parameters is included in Table I.1. For further description of model parameters the reader is referred to USACOE – HEC, (1986) (Appendix O).

Secchi Depth

The secchi depth is a measure of light transparency for distribution of light energy with depth in the reservoir. If algal dynamics are included in the simulation the secchi depth should be reflect non-bloom conditions since the program adjusts the light extinction coefficient to account for decreased light penetration as a function of the increased algal concentrations. During calibration, it may be necessary to adjust secchi depth to influence the location of the thermocline (USACOE-HEC, 1986).

For the Trinity Reservoir application of WQRRS only water temperature was modeled. Algal dynamics and associated reduction of light penetration into the reservoir was not simulated. It was found that adjustment of secchi depth had little or no impact on simulated reservoir water temperatures in winter months (when secchi depths are typically higher). However, simulated water temperatures responded significantly to changes in secchi depth during summer months, most likely in response to considerable increases in heat exchange at the air-water interface during this period compared to winter periods. Secchi depth was adjusted during calibration to accommodate diminished light penetration in summer months due to algal growth and other particulate material. The final value of 5 feet is within the range of measured data (Table I.1).

Table I.1 Trinity Reservoir secchi depth measurements (California Department of Water Resources)

Date	Location	Secchi Depth (ft)
10/27/93	near Ridgeville Islands	15.0
9/22/93	near Trinity Dam	20.0
4/24/90	near Trinity Dam	6.9
5/11/89	near Trinity Dam	10.8
9/12/89	near Trinity Dam	60.7
5/9/86	near Trinity Dam	6.9
9/18/85	near Trinity Dam	20.7
5/21/85	near Trinity Dam	5.0

Water Column Stability and Diffusion Coefficients

There are two mechanisms used in WQRRS to transport heat mass vertically through the reservoir system: advection and diffusion. Advection is the physical transport fluid particles (flow) in the vertical direction. Effective diffusion consists of molecular and turbulent diffusion and convective mixing. Effective diffusion is modeled in WQRRS using water column stability considerations based on thermally driven water density gradients. This method assumes that stronger thermal stratification (more stable) results in less mixing in the vertical direction. A relationship between effective diffusion and water column stability (WRE, 1969) defines several calibration coefficients incorporated in WQRRS. Specifically,

- Critical water column stability, GSWH
- Minimum water column stability, GMIN
- Diffusion coefficient for water quality stability less than GSWH, A1
- Constant to compute density based gradient diffusion coefficients, A3

The minimum water column stability GMIN) is the density gradient above which mixing of the water column will occur. A positive value will cause the thermocline to form more quickly and delay destratification (USACOE-HEC, 1986). Because a daily time step was used, the value was set to zero as per USACOE-HEC (1986). Although the constant A3, used to compute density based gradient diffusion coefficients, was varied to determine system sensitivity, the values was ultimately set to –0.7, the suggested calibration value as per USACOE-HEC (1986). The critical water column stability (GSWH) and diffusion coefficient (A1) were varied through a wide range of values prior to arriving at final values of 0.01×10^{-6} kg/m^3 m^{-1} and 2.0×10^{-4} kg/m^3 m^{-1}, respectively. During calibration it was found that there was not necessarily a unique set of parameters to achieve a particular calibration objective.

Evaporation Coefficients

In the model WQRRS evaporative is represented by

$$E = (a+bu)(e_s-e_a)$$

Where E is evaporation, a and b are coefficients, u is wind speed, and e_s and e_a are saturation and air vapor pressure, respectively. WQRRS, though supplied with data in English units, converts all data to metric units. Thus wind speed is in meters per second

($m\ s^{-1}$), vapor pressures are in millibars (mb), and coefficients a and b have units of $m\ s^{-1}\ mb^{-1}$ and mb^{-1}, respectively.

The original format of WQRRS requires that the user specify a single annual set of values for coefficients a and b. However, seasonal differences in these parameters occur due to atmospheric boundary layer thickness and stability. To accommodate seasonal differences, the original WQRRS code was modified to accept a two sets of evaporation coefficients: one for late fall, winter and early spring (October – May), and one set for the late spring, summer, and early fall (June – September). The seasonal periods October through June and May through September were also examined, but model results were not distinctly different than for the previously described seasonal breakdown. This additional flexibility allowed improved calibration of late summer months when water temperatures are of concern.

[The new evaporation parameters are included in the WQRRS input file under Physical Card 1. Fields 3 and 4, which originally represented annual coefficient values, represent October 1 through May 31 a and b values. Fields 8 and 9 have been added to this card to accept evaporation coefficient values aa and bb, representing the months June through September.]

Final Calibration Parameters

The final calibration parameters are summarized in Table I.2.

Table I.2 WQRRS calibration parameters and values for Trinity Reservoir

Parameter	Value
Evaporation coefficient; October – May, a ($m\ mb^{-1}\ s^{-1}$)*	1.5e-9
Evaporation coefficient; October – May, b (mb^{-1})*	2.0e-9
Evaporation coefficient; June - September, aa ($m\ mb^{-1}\ s^{-1}$)*	3.0e-9
Evaporation coefficient; June - September, bb (mb^{-1})*	2.0e-9
Critical water column stability, GSWH ($kg/m^3\ m^{-1}$)*	2.0e-4
Minimum water column stability, GMIN ($kg/m^3\ m^{-1}$)*	0.0
Diffusion coefficient for water quality stability < GSWH, A1 ($m^2\ s^{-1}$)*	0.01e-6
Constant to compute density based gradient diffusion coeff., A3 (-)	-0.7
Secchi depth (ft)	7.5

*WQRRS converts all data to metric units

Appendix J WQRRS Source Code Modification

The model WQRRS source code is included on diskette. The code includes modifications to allow the model to run on the PC version of Microsoft FORTRAN Powerstation V4.0. These changes are commented in the source files. Modifications to output, as well as evaporation parameters are included in within these files.

Modifications to the Output

When running the model, the user is prompted for an input file, and three output files. The three output files correspond to general information, a continuous listing of water temperature profiles, and a table of water temperature profiles. The general data file contains all data, including a printout of all input data and control parameters, as well as program output. This file has not been modified and was not used in this analysis. The continuous listing and tabular water temperature profile output was added to WQRRS. The tabular file is the primary output file and includes water surface elevation and temperature profile data for each selected printout date. This is the output file that is used by the post-processor spreadsheet.

Modifications to WQRRS Input

Seasonal evaporation coefficients were added to WQRRS for this analysis. These modifications affect one input line in the WQRRS input file. Line PHYS1, which originally consisted of 7 fields was modified to accommodate two additional evaporation coefficients for the period June 1 through September 30 of the simulation period. The original evaporation coefficients were assigned to the period October through May, and the added evaporation coefficients applied to June through September. These changes do not allow periods other than water years to be simulated for Trinity Reservoir. If simulation periods other than water years are selected, the model logic should be modified accordingly. The modified PHYS1 card is outlined below with bold lettering denoting changes. The reader is referred to the WQRRS User's manual for additional parameter information.

Field	Variable	Value	Description
1		PHYS1	Card Identification
2	IDEW	1	Wet Bulb temperature is required
		0	Dew point temperature is required
3	AA	+	Evaporation coefficient **(October – May)**
4	BB	+	Evaporation Coefficient **(October – May)**
5	XLAT	+	North latitude of reservoir site in degrees
6	XLON	+	West longitude of reservoir site in degrees
		-	East longitude of reservoir site in degrees
7	TURB	+	Atmospheric turbidity factor
8	**AA1**	+	**June – September evaporation coefficient**
9	**BB1**	+	**June – September evaporation coefficient**

Appendix K EIS Year-Type Data: Figures

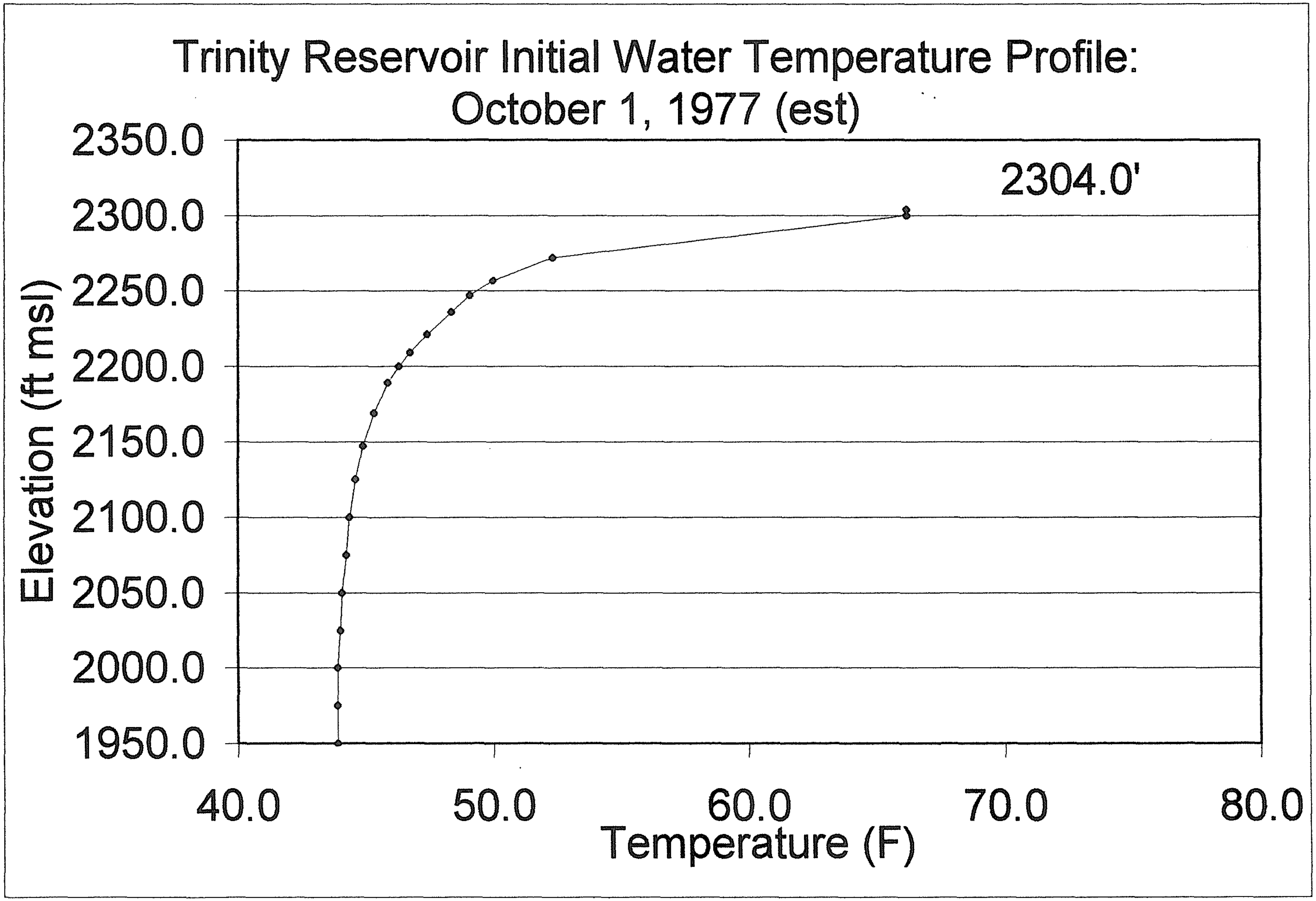
Water Year 1977 (Critically Dry):
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover

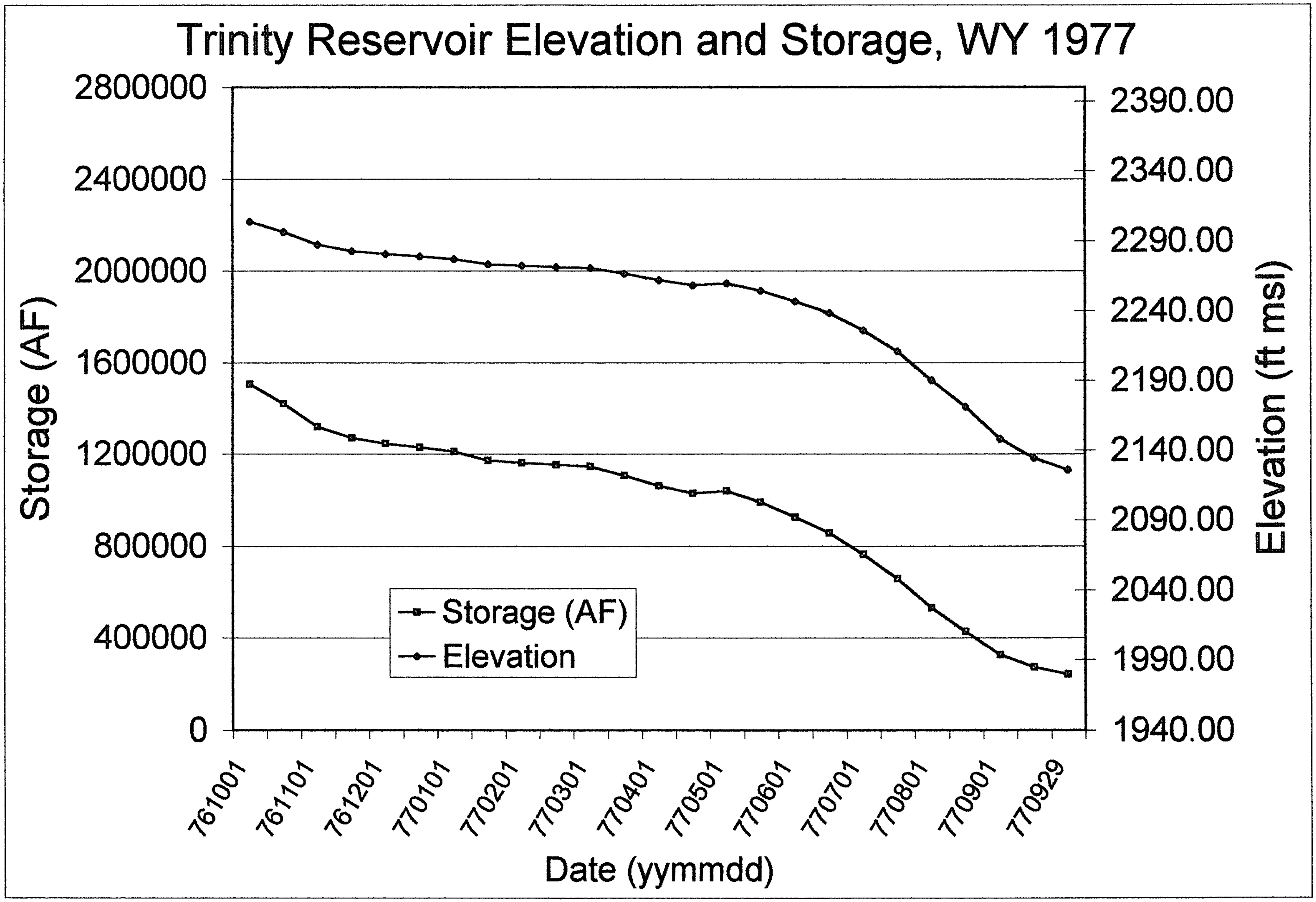
Water Year 1983 (Extremely Wet):
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover

Water Year 1986 (Wet):
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover

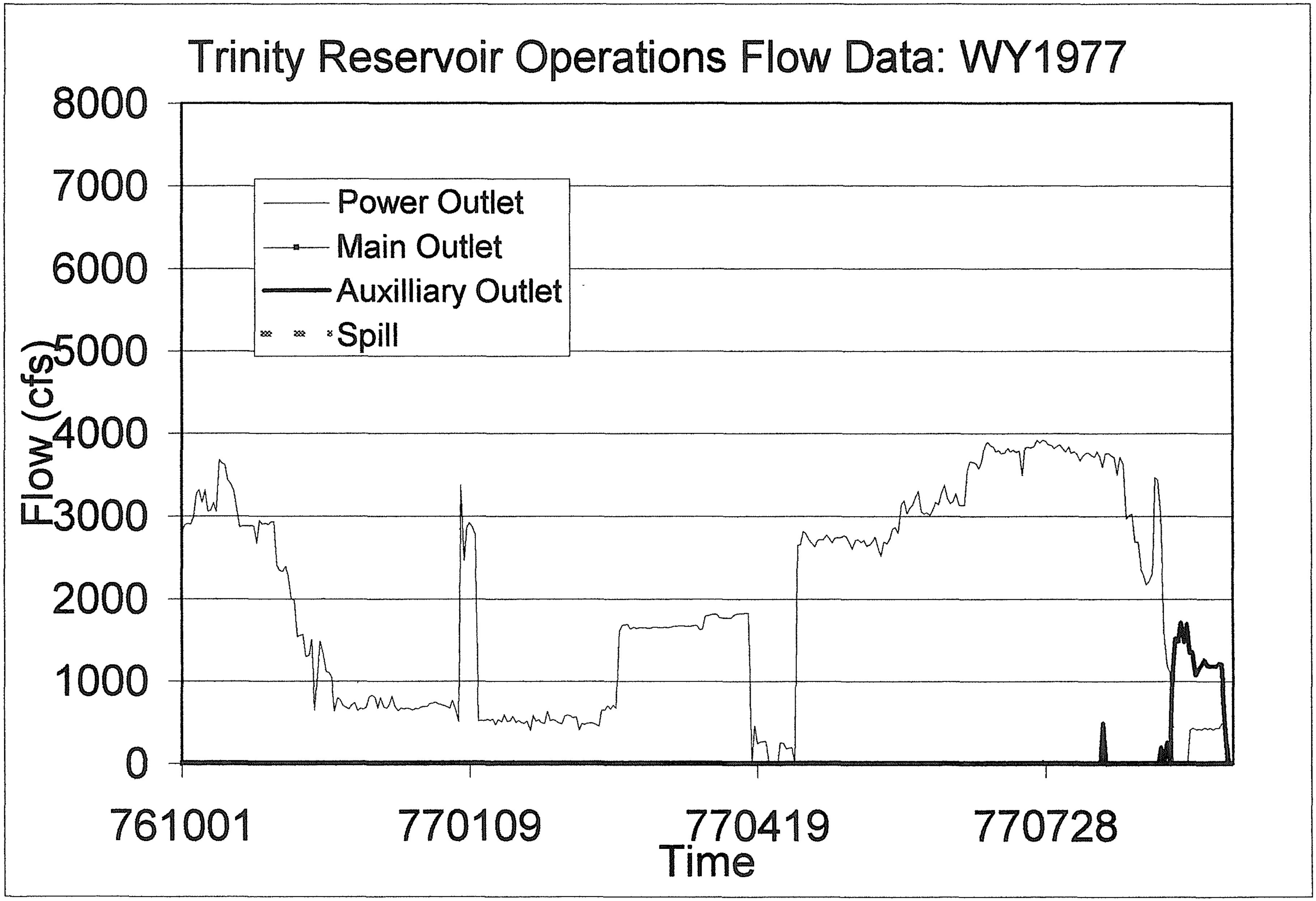
Water Year 1989 (Normal):
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover

Water Year 1990 (Dry):
- Trinity Reservoir Elevation and Storage
- Trinity Reservoir Operations
- Trinity Reservoir Inflow Data: Quantity and Temperature
- Trinity Reservoir Met Data 1: Dry Bulb and Dew Point Temperature
- Trinity Reservoir Met Data 2: Atmospheric Pressure and Wind Speed
- Trinity Reservoir Met Data 3: Sky Cover

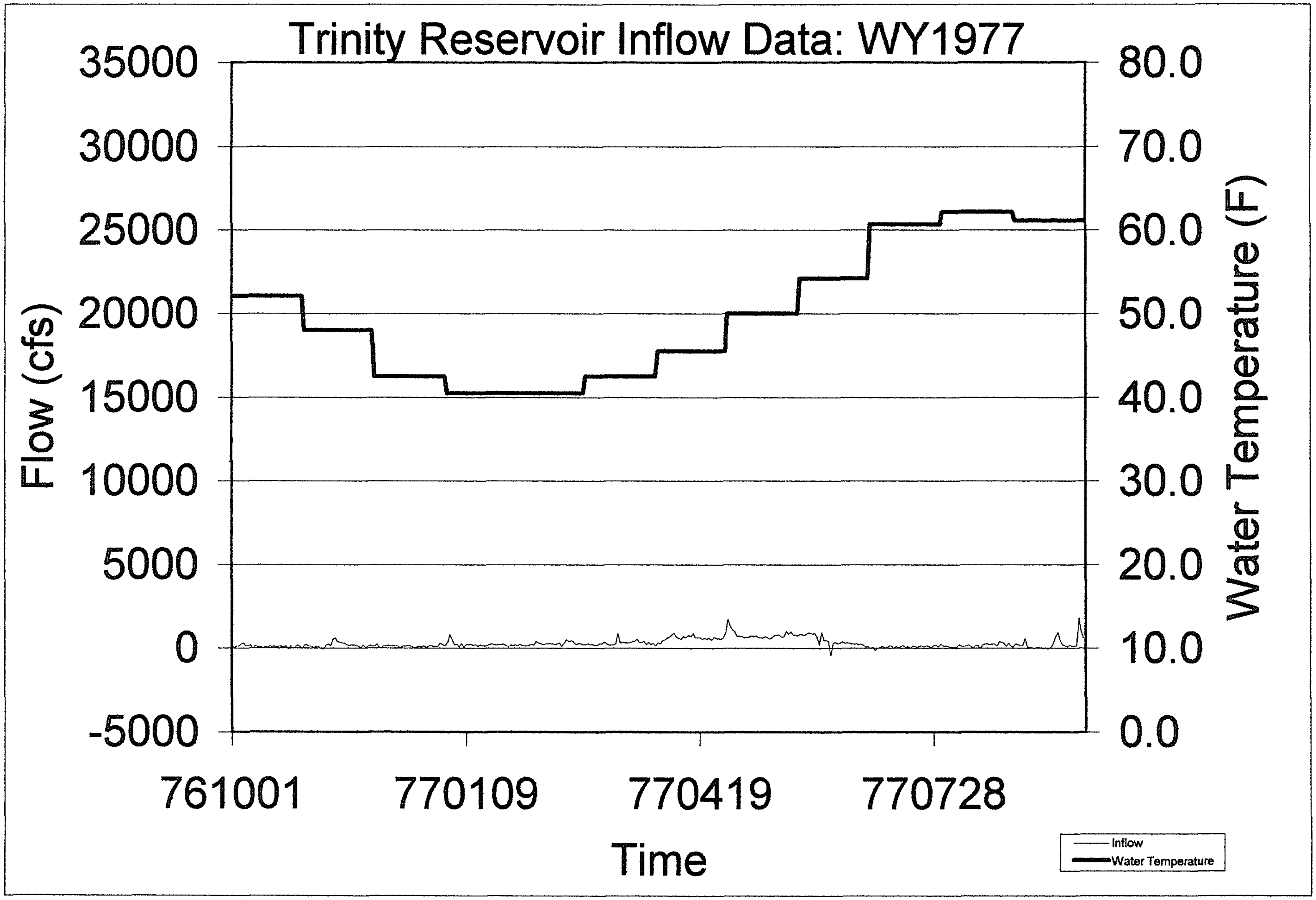

Trinity Reservoir Initial Water Temperature Profile:
October 1, 1977 (est)
2304.0'
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
Elevation (ft msl)
40.0
50.0
60.0
70.0
80.0
Temperature (F)



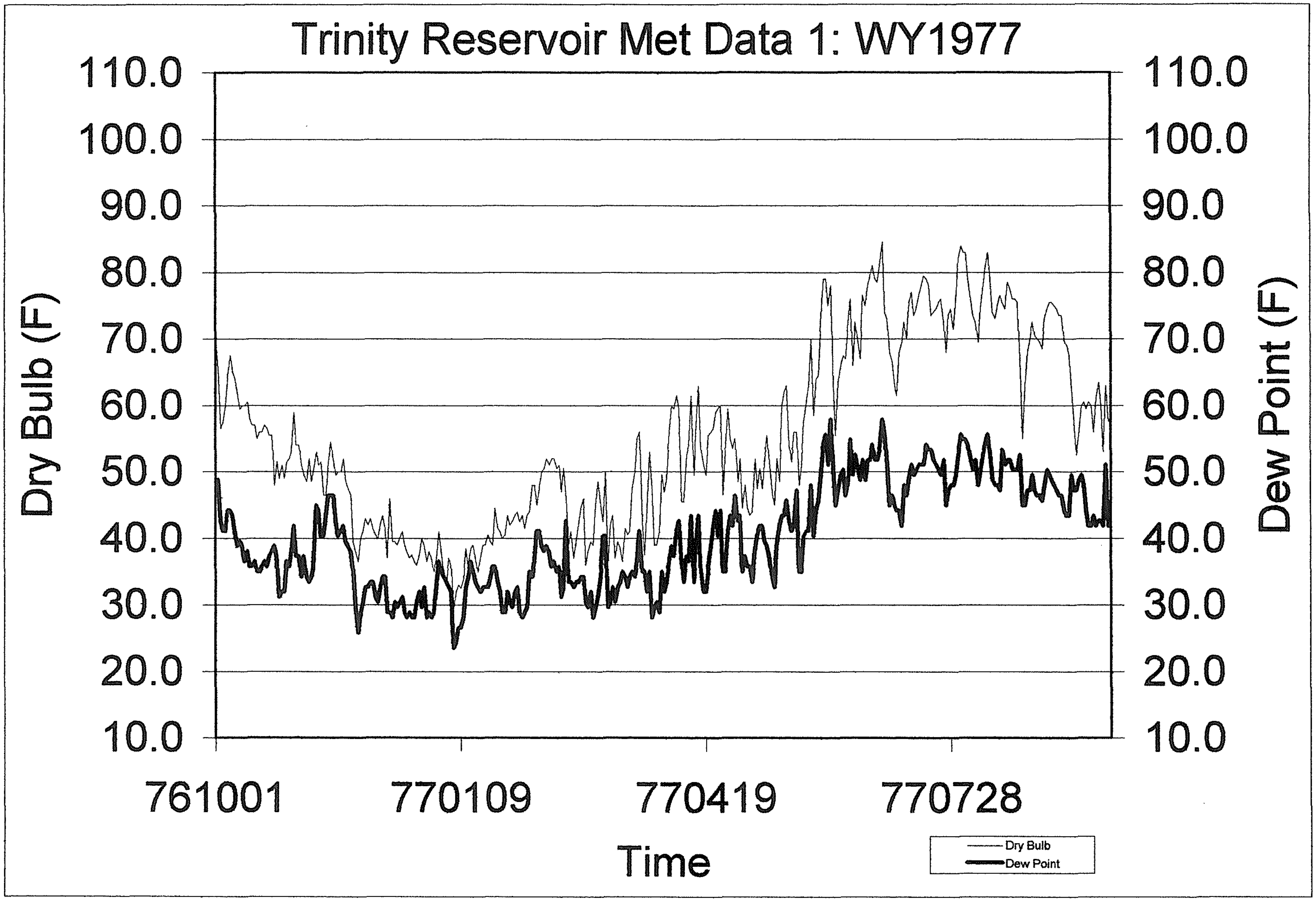
Trinity Reservoir Elevation and Storage, WY 1977
Storage (AF)
2800000
2400000
2000000
1600000
1200000
800000
400000
0
Elevation (ft msl)
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
Storage (AF)
Elevation
761001
761101
761201
770101
770201
770301
770401
770501
770601
770701
770801
770901
770929
Date (yymmdd)

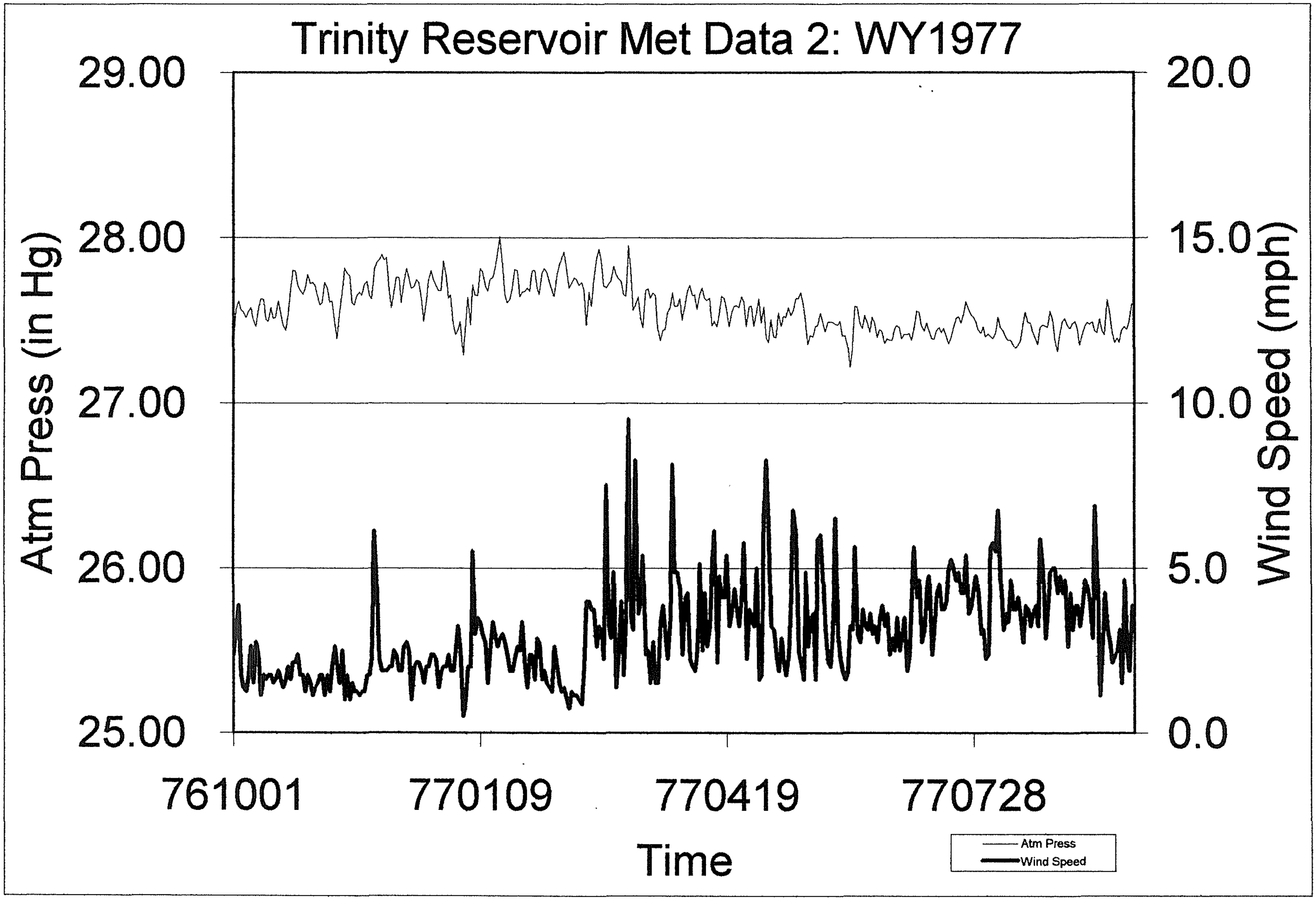


Trinity Reservoir Operations Flow Data: WY1977
Flow (cfs)
8000
7000
6000
5000
4000
3000
2000
1000
0
Power Outlet
Main Outlet
Auxilliary Outlet
Spill
761001
770109
770419
770728
Time

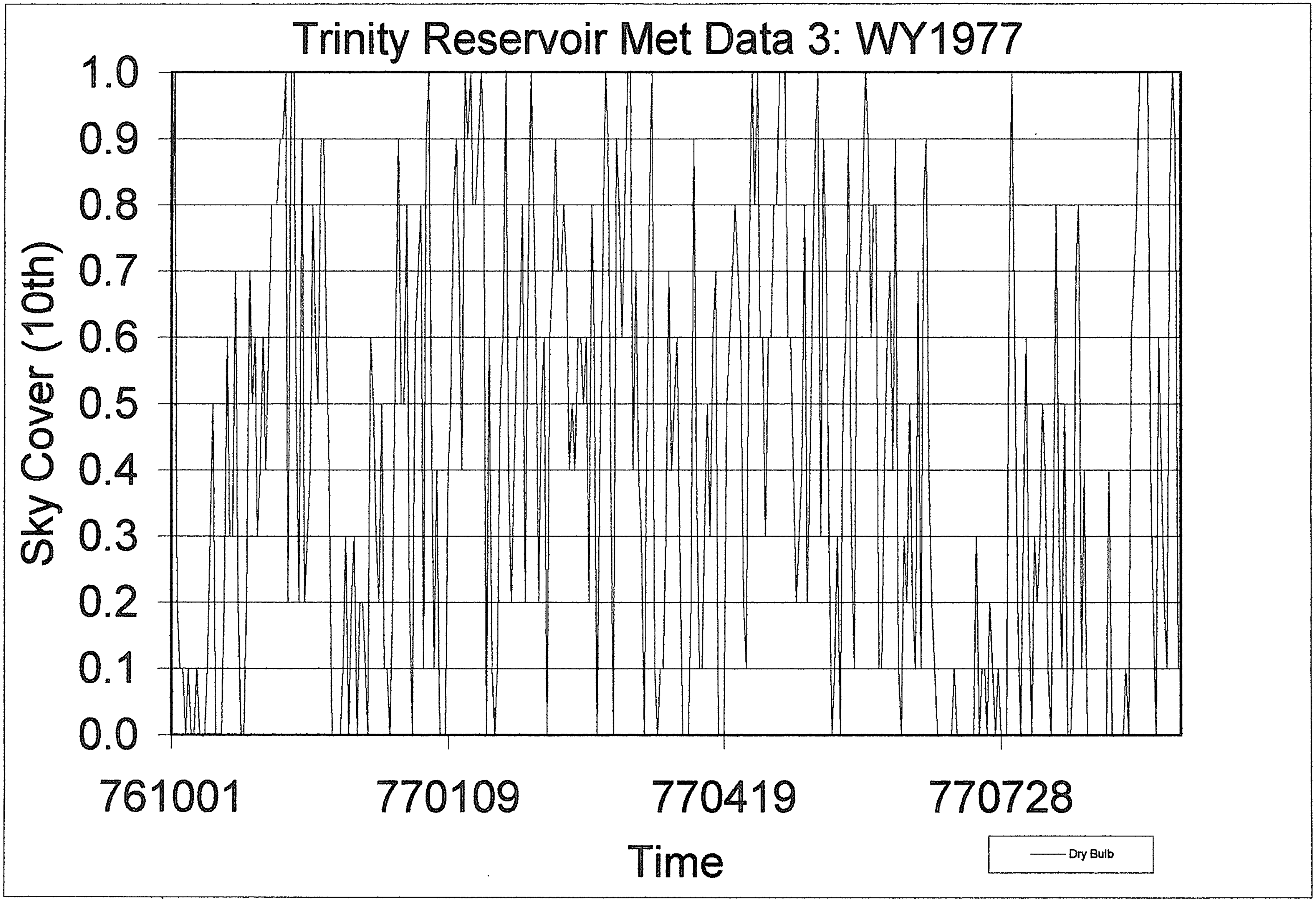


Trinity Reservoir Inflow Data: WY1977
Flow (cfs)
35000
30000
25000
20000
15000
10000
5000
0
-5000
Water Temperature (F)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
761001
770109
770419
770728
Time
Inflow
Water Temperature

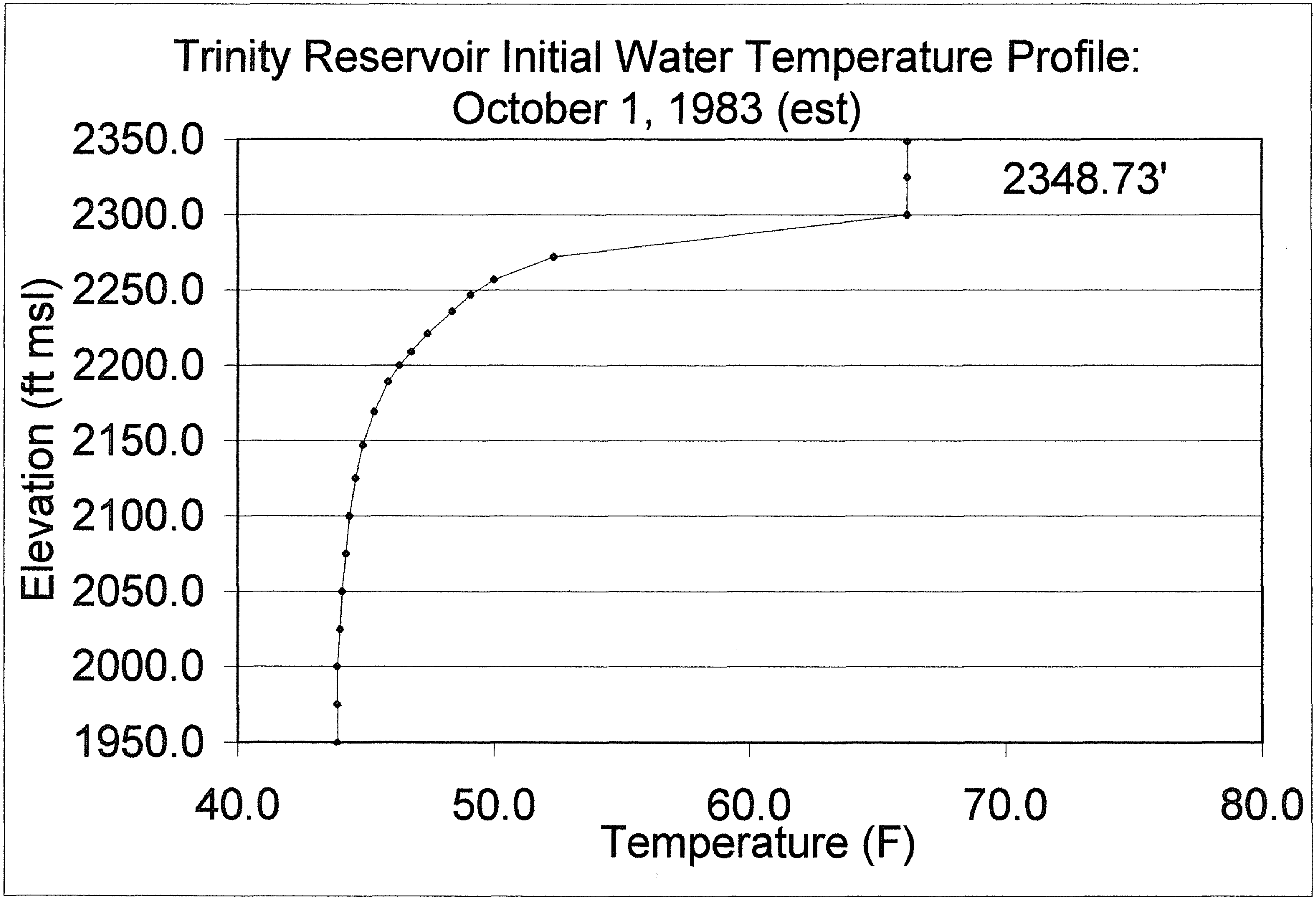

Trinity Reservoir Met Data 1: WY1977
Dry Bulb (F)
Dew Point (F)
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
761001
770109
770419
770728
Time
Dry Bulb
Dew Point

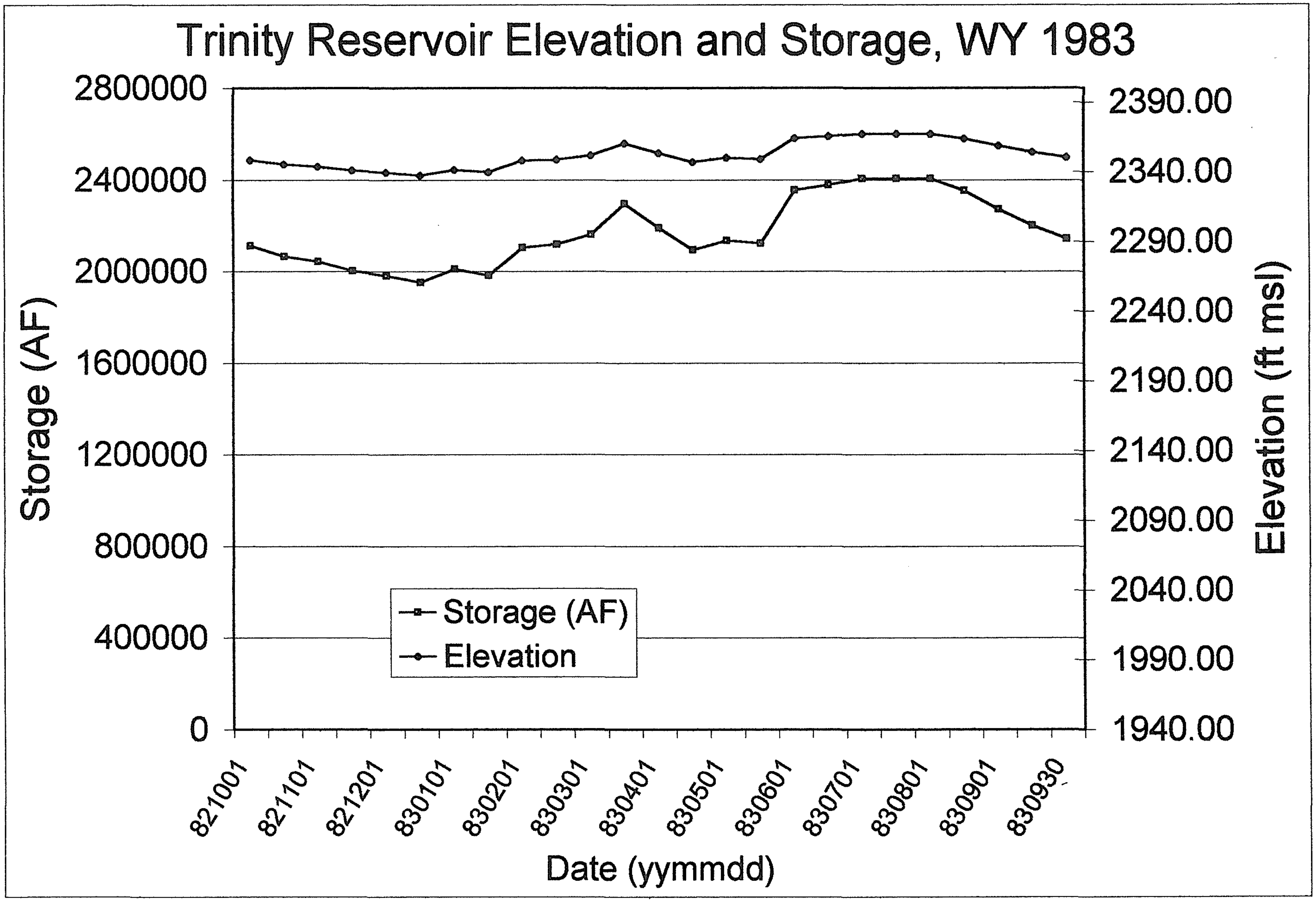


Trinity Reservoir Met Data 2: WY1977
29.00
28.00
27.00
26.00
25.00
Atm Press (in Hg)
20.0
15.0
10.0
5.0
0.0
Wind Speed (mph)
761001
770109
770419
770728
Time
Atm Press
Wind Speed

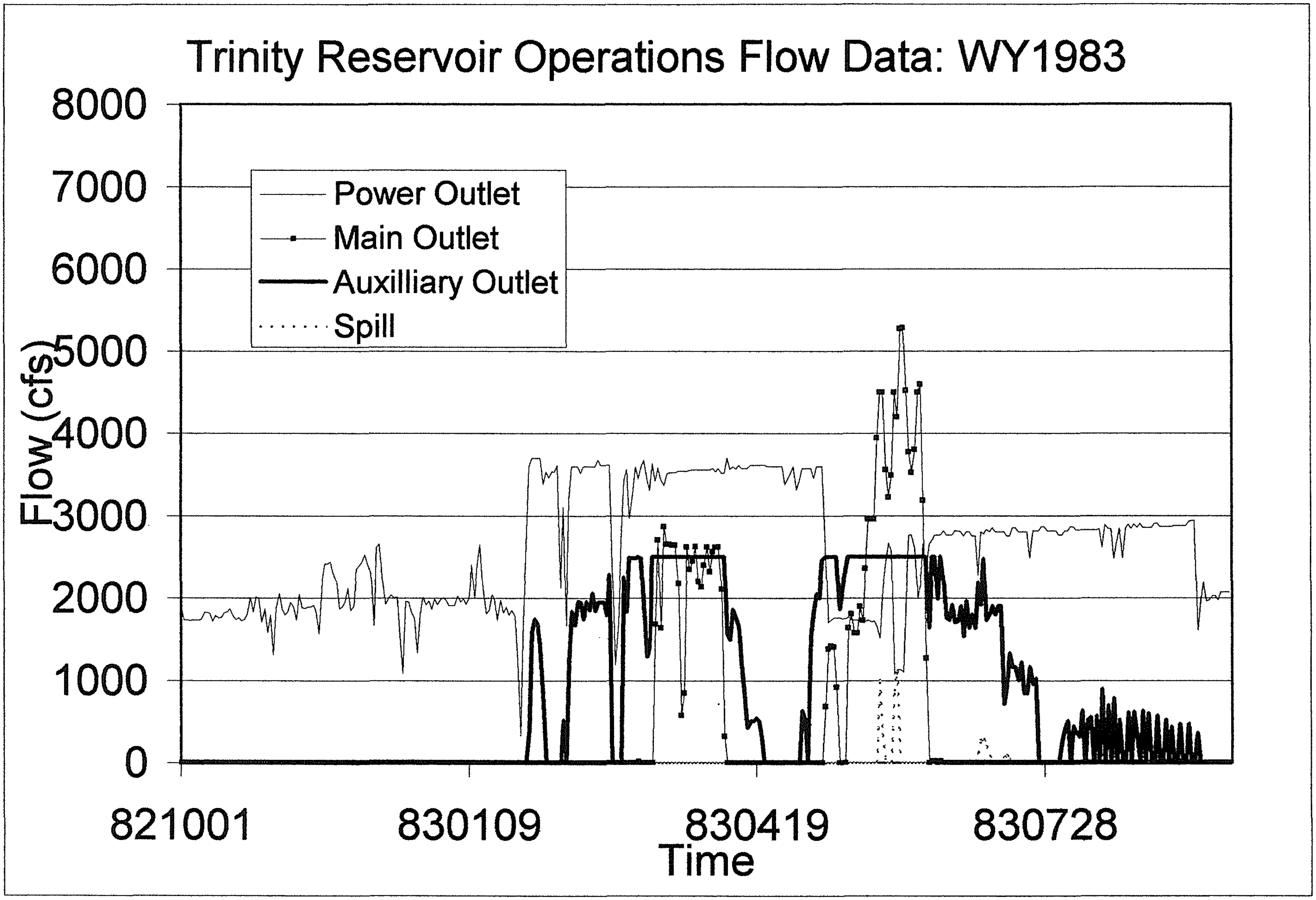


Trinity Reservoir Met Data 3: WY1977
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Sky Cover (10th)
761001
770109
770419
770728
Time
Dry Bulb

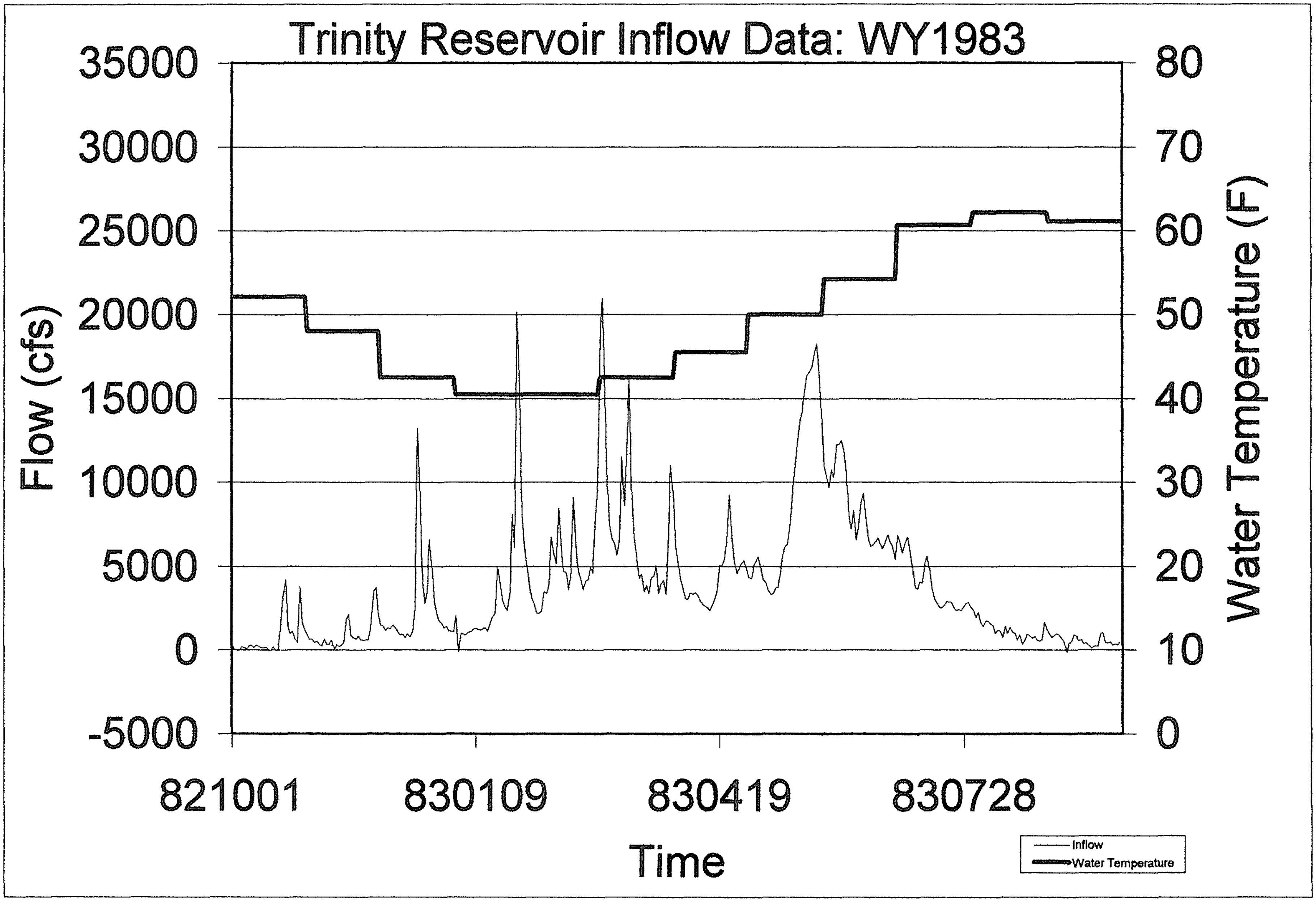

Trinity Reservoir Initial Water Temperature Profile:
October 1, 1983 (est)
2348.73'
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
Elevation (ft msl)
40.0
50.0
60.0
70.0
80.0
Temperature (F)



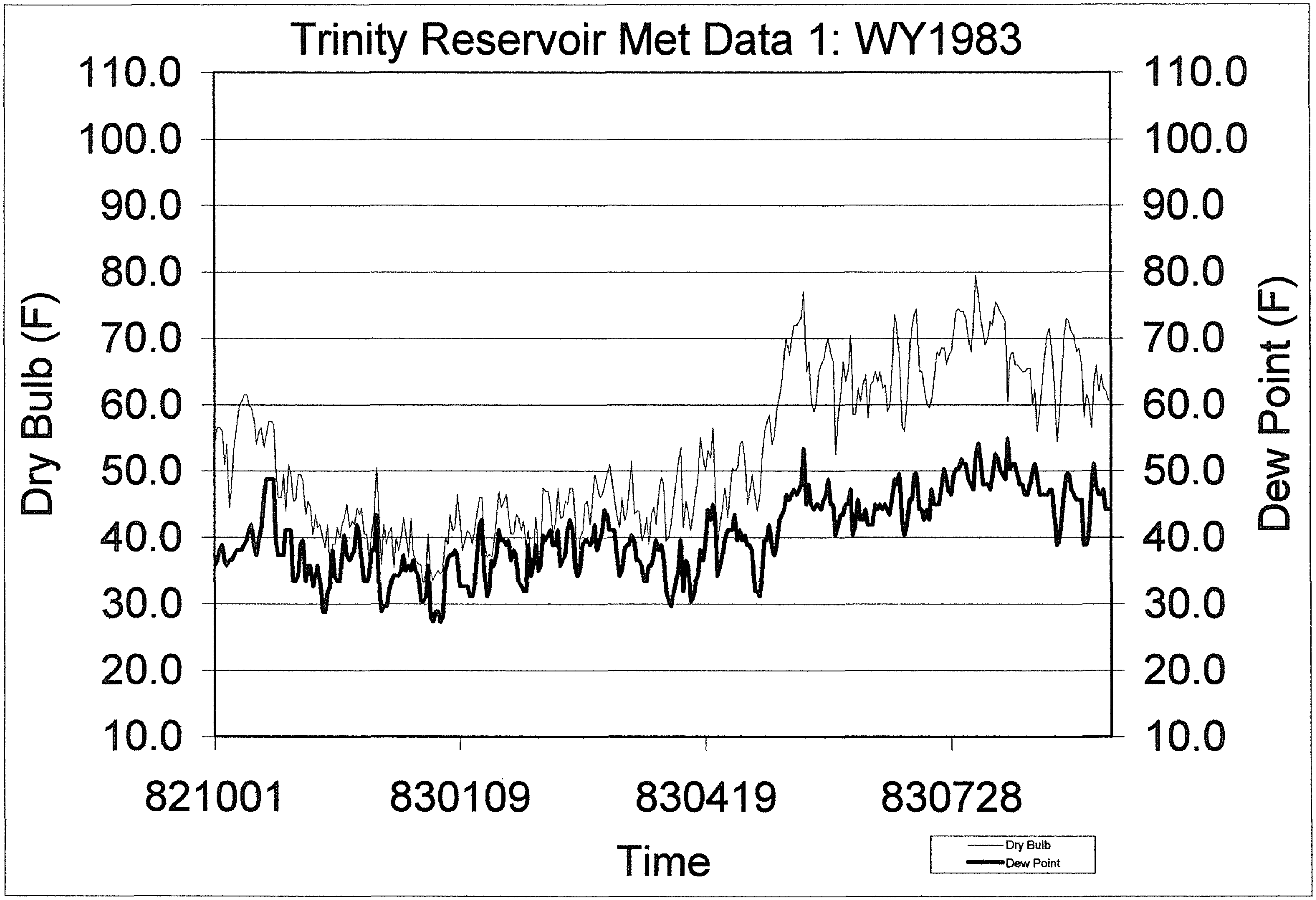
Trinity Reservoir Elevation and Storage, WY 1983
Storage (AF)
2800000
2400000
2000000
1600000
1200000
800000
400000
0
Elevation (ft msl)
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
Storage (AF)
Elevation
821001
821101
821201
830101
830201
830301
830401
830501
830601
830701
830801
830901
830930
Date (yymmdd)



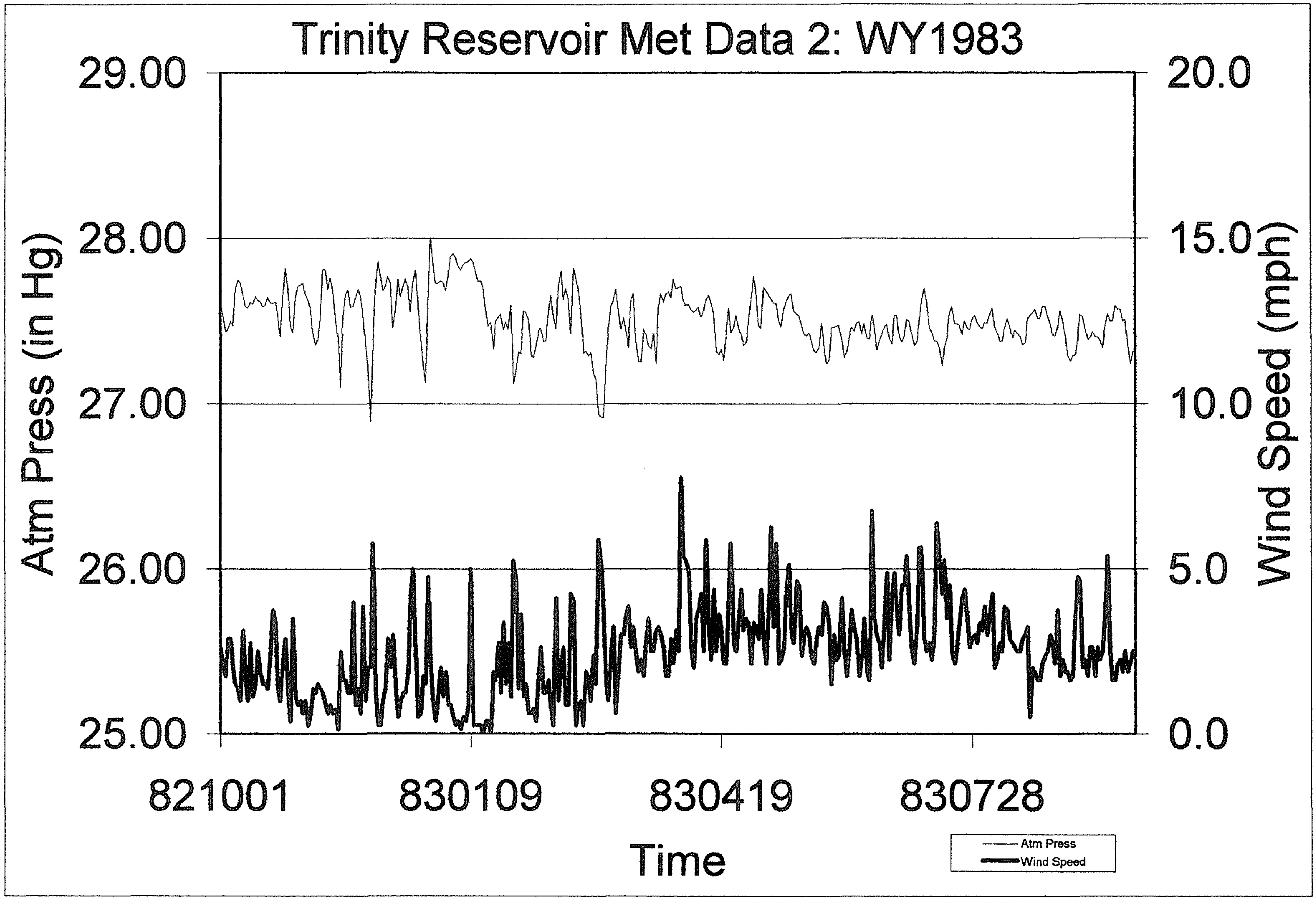
Trinity Reservoir Operations Flow Data: WY1983
Power Outlet
Main Outlet
Auxilliary Outlet
Spill
Flow (cfs)
8000
7000
6000
5000
4000
3000
2000
1000
0
821001
830109
830419
830728
Time

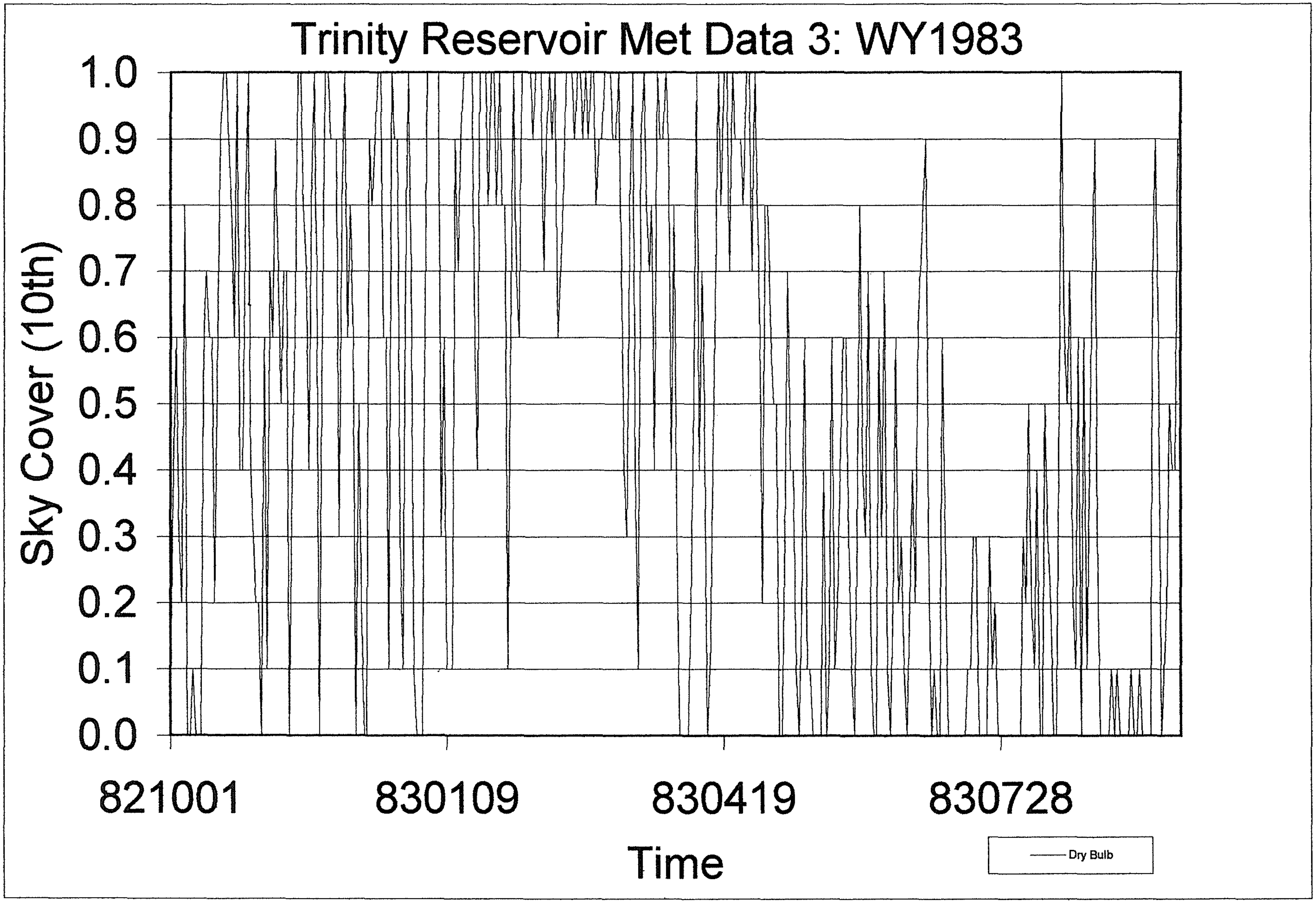


Trinity Reservoir Inflow Data: WY1983
Flow (cfs)
35000
30000
25000
20000
15000
10000
5000
0
-5000
Water Temperature (F)
80
70
60
50
40
30
20
10
0
821001
830109
830419
830728
Time
Inflow
Water Temperature

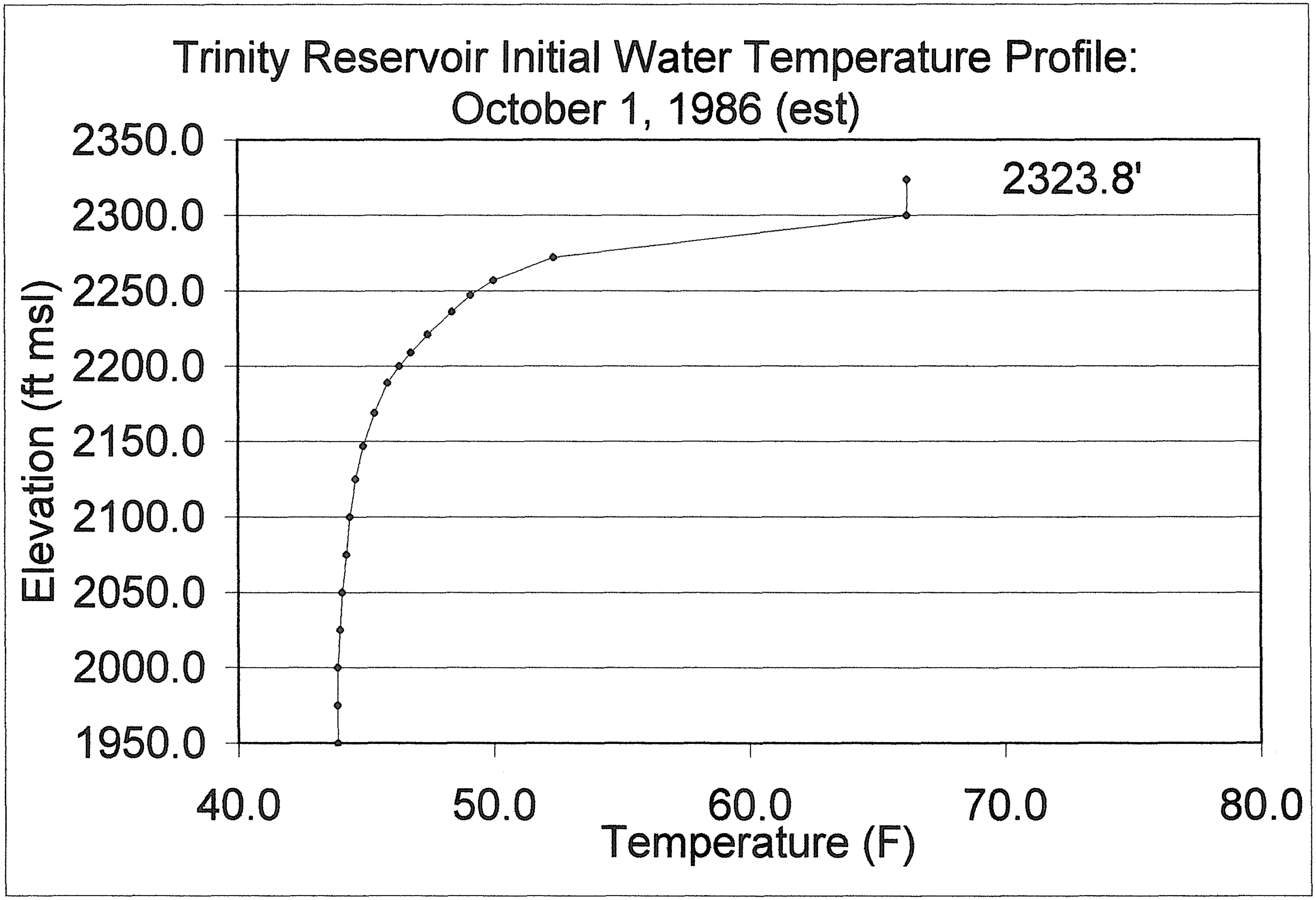


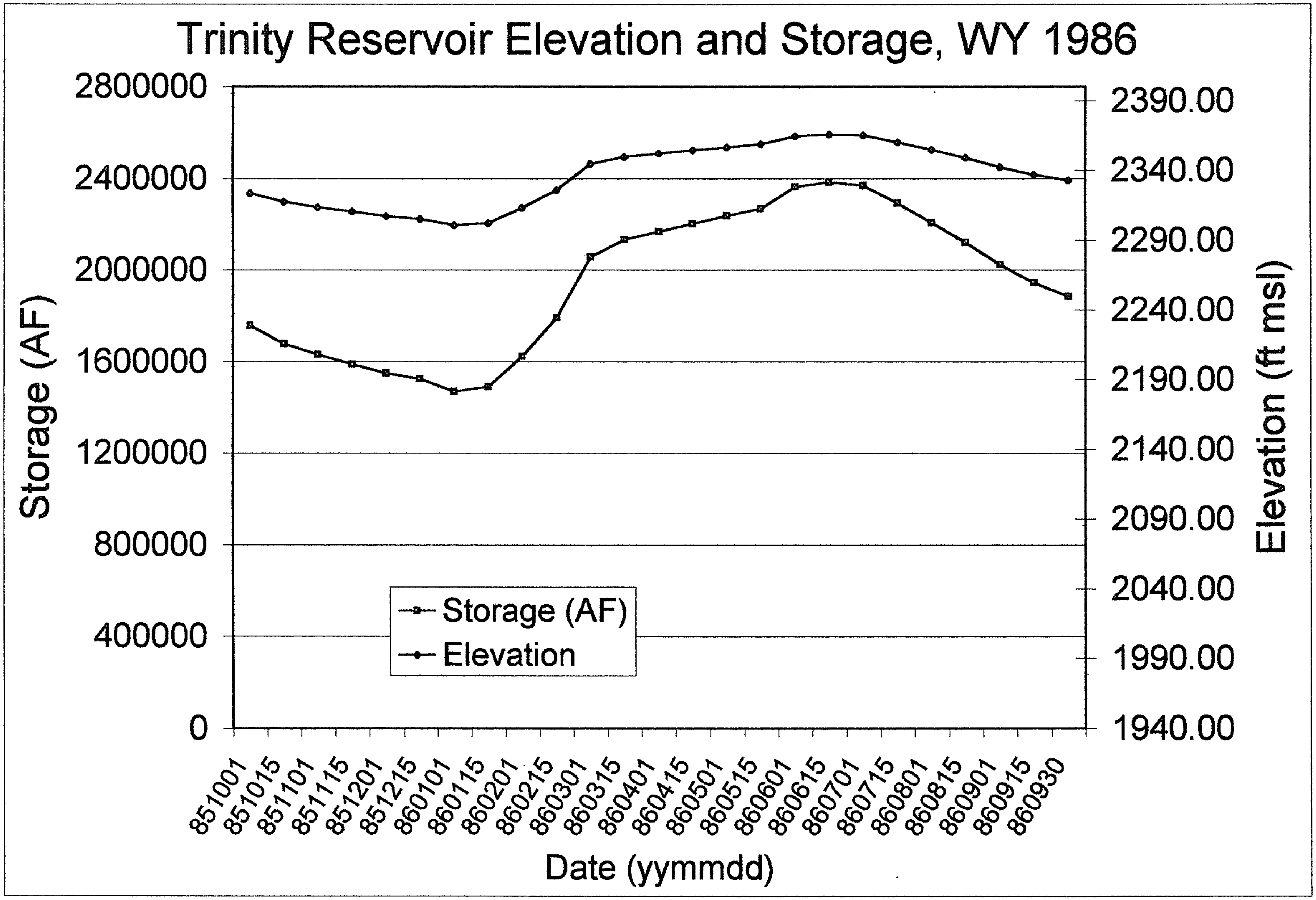
Trinity Reservoir Met Data 1: WY1983
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
Dry Bulb (F)
Dew Point (F)
821001
830109
830419
830728
Time
Dry Bulb
Dew Point


Trinity Reservoir Met Data 2: WY1983
29.00
28.00
27.00
26.00
25.00
Atm Press (in Hg)
20.0
15.0
10.0
5.0
0.0
Wind Speed (mph)
821001
830109
830419
830728
Time
Atm Press
Wind Speed

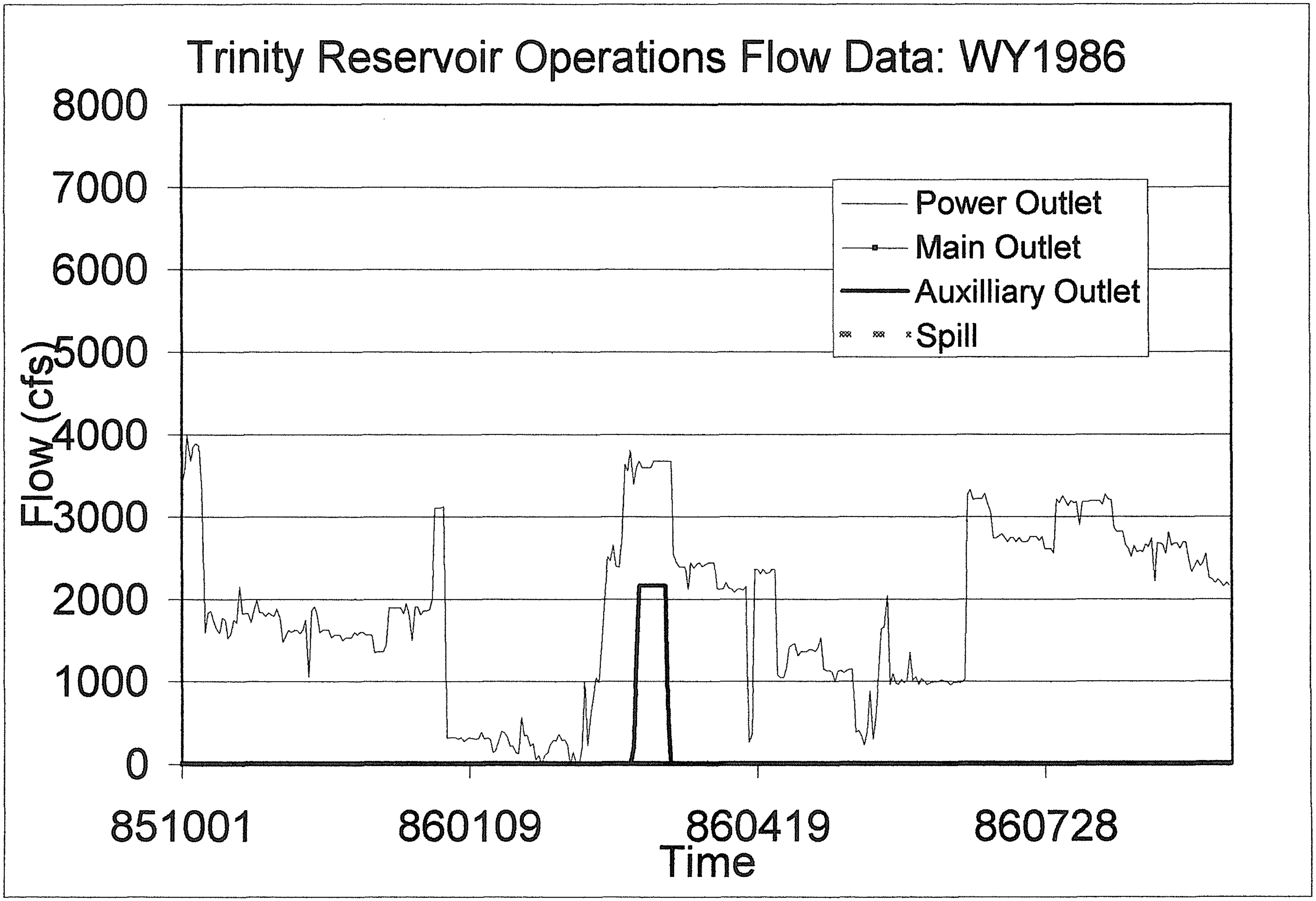


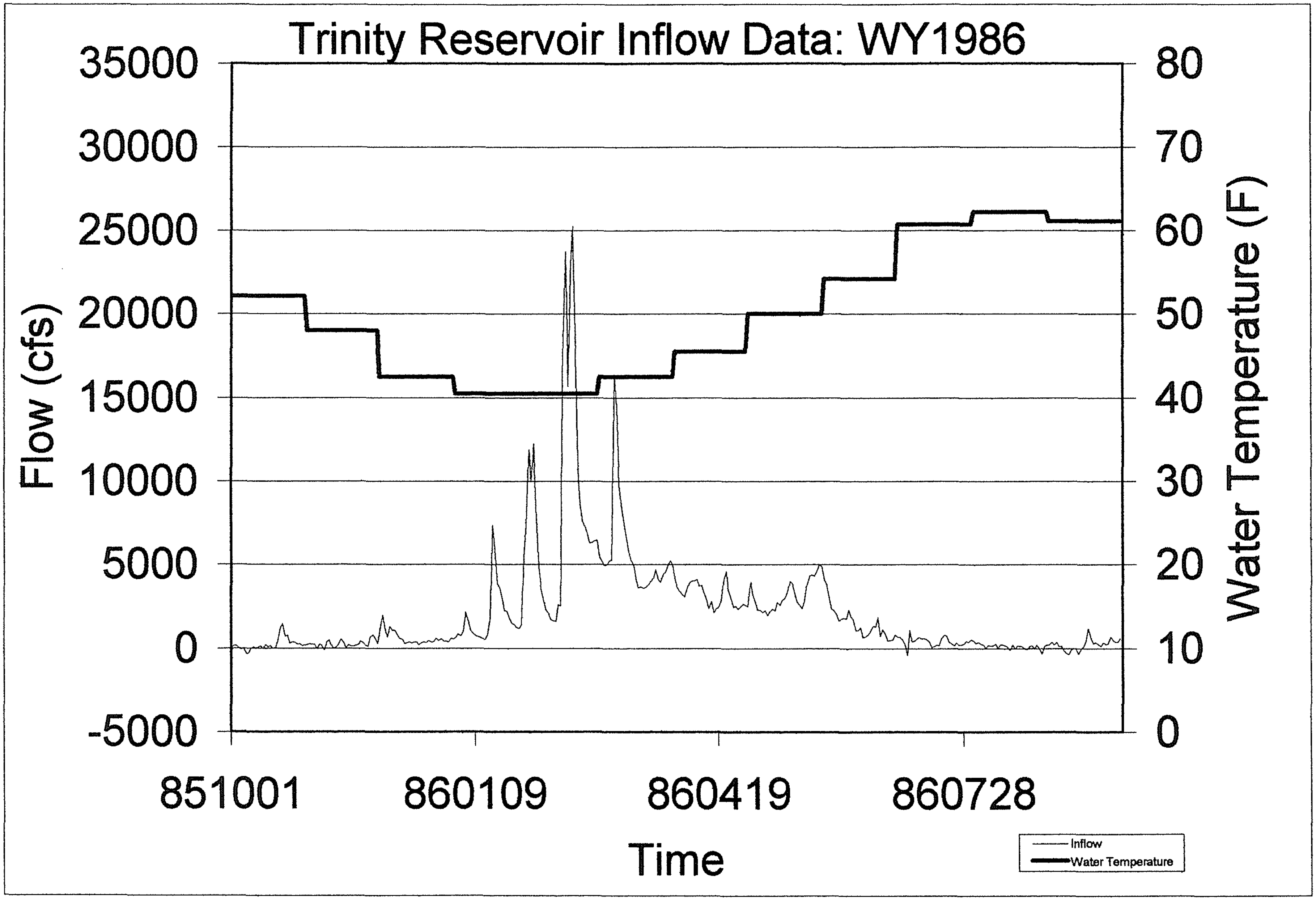
Trinity Reservoir Met Data 3: WY1983
Sky Cover (10th)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
821001
830109
830419
830728
Time
Dry Bulb

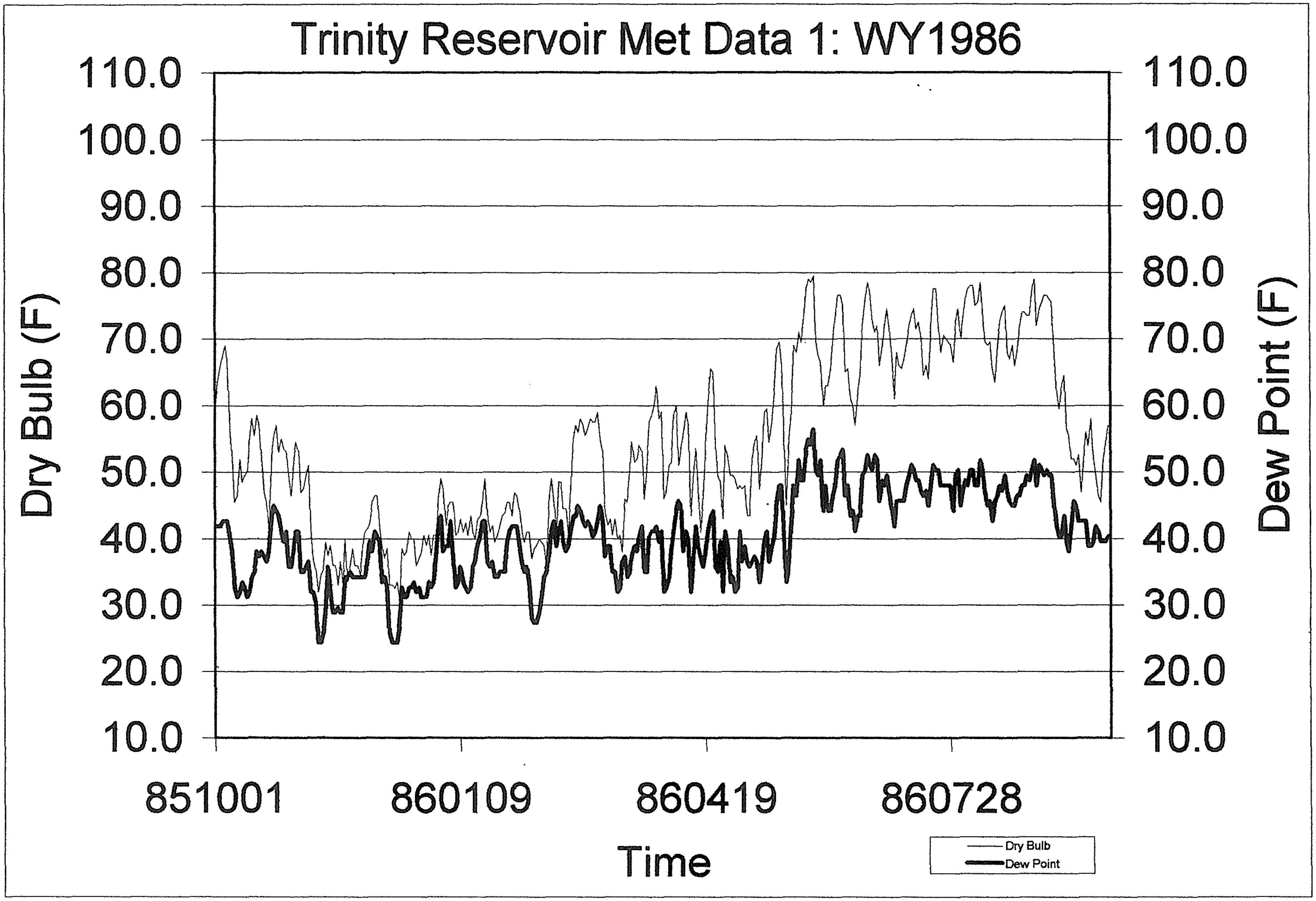

Trinity Reservoir Initial Water Temperature Profile:
October 1, 1986 (est)
2323.8'
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
Elevation (ft msl)
40.0
50.0
60.0
70.0
80.0
Temperature (F)



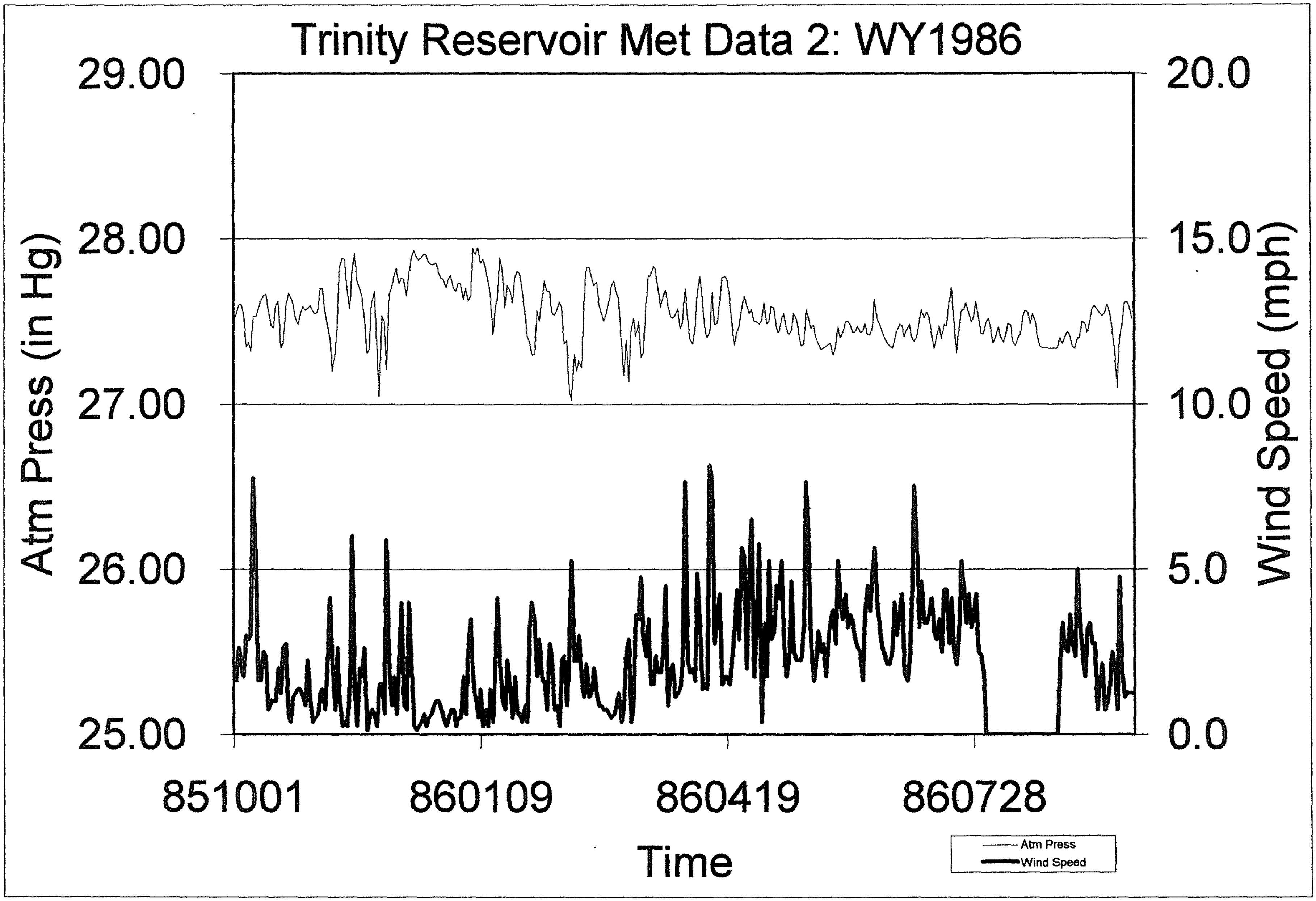
Trinity Reservoir Elevation and Storage, WY 1986
Storage (AF)
Elevation (ft msl)
Date (yymmdd)
Storage (AF)
Elevation
2800000
2400000
2000000
1600000
1200000
800000
400000
0
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
851001
851015
851101
851115
851201
851215
860101
860115
860201
860215
860301
860315
860401
860415
860501
860515
860601
860615
860701
860715
860801
860815
860901
860915
860930


Trinity Reservoir Operations Flow Data: WY1986
Flow (cfs)
8000
7000
6000
5000
4000
3000
2000
1000
0
851001
860109
860419
860728
Time
Power Outlet
Main Outlet
Auxilliary Outlet
Spill

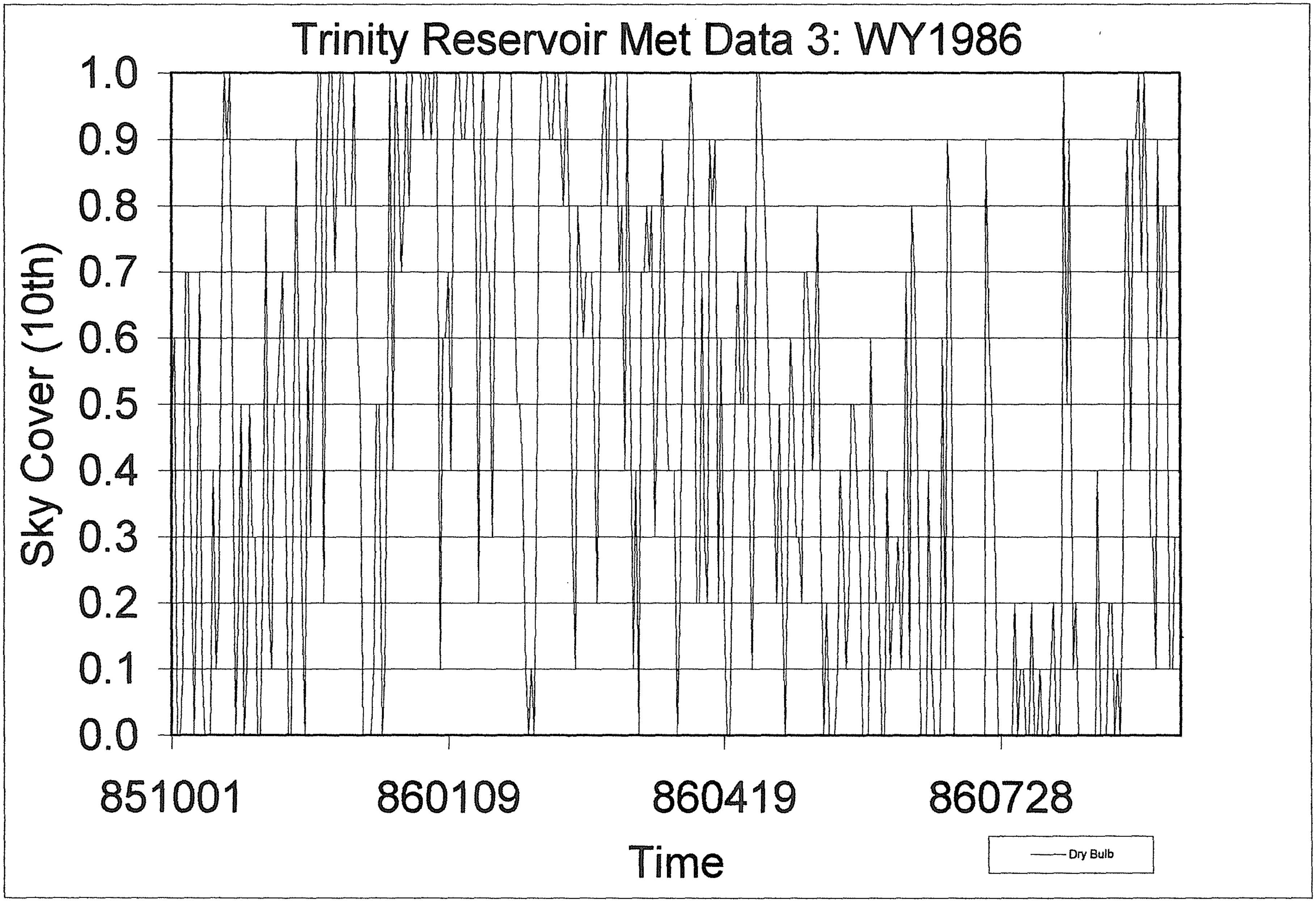

Trinity Reservoir Inflow Data: WY1986
Flow (cfs)
35000
30000
25000
20000
15000
10000
5000
0
-5000
Water Temperature (F)
80
70
60
50
40
30
20
10
0
851001
860109
860419
860728
Time
Inflow
Water Temperature



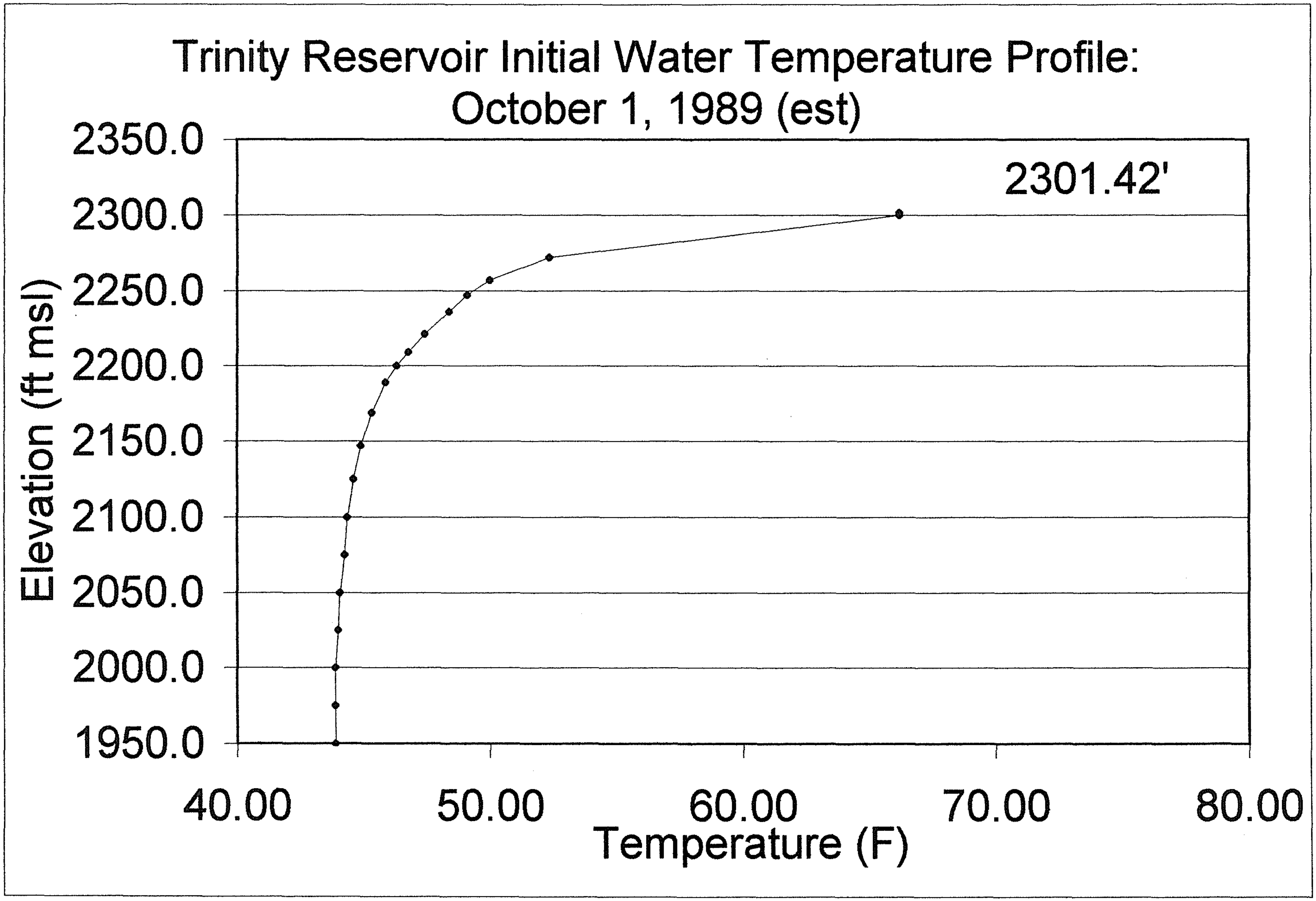
Trinity Reservoir Met Data 1: WY1986
Dry Bulb (F)
Dew Point (F)
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
851001
860109
860419
860728
Time
Dry Bulb
Dew Point

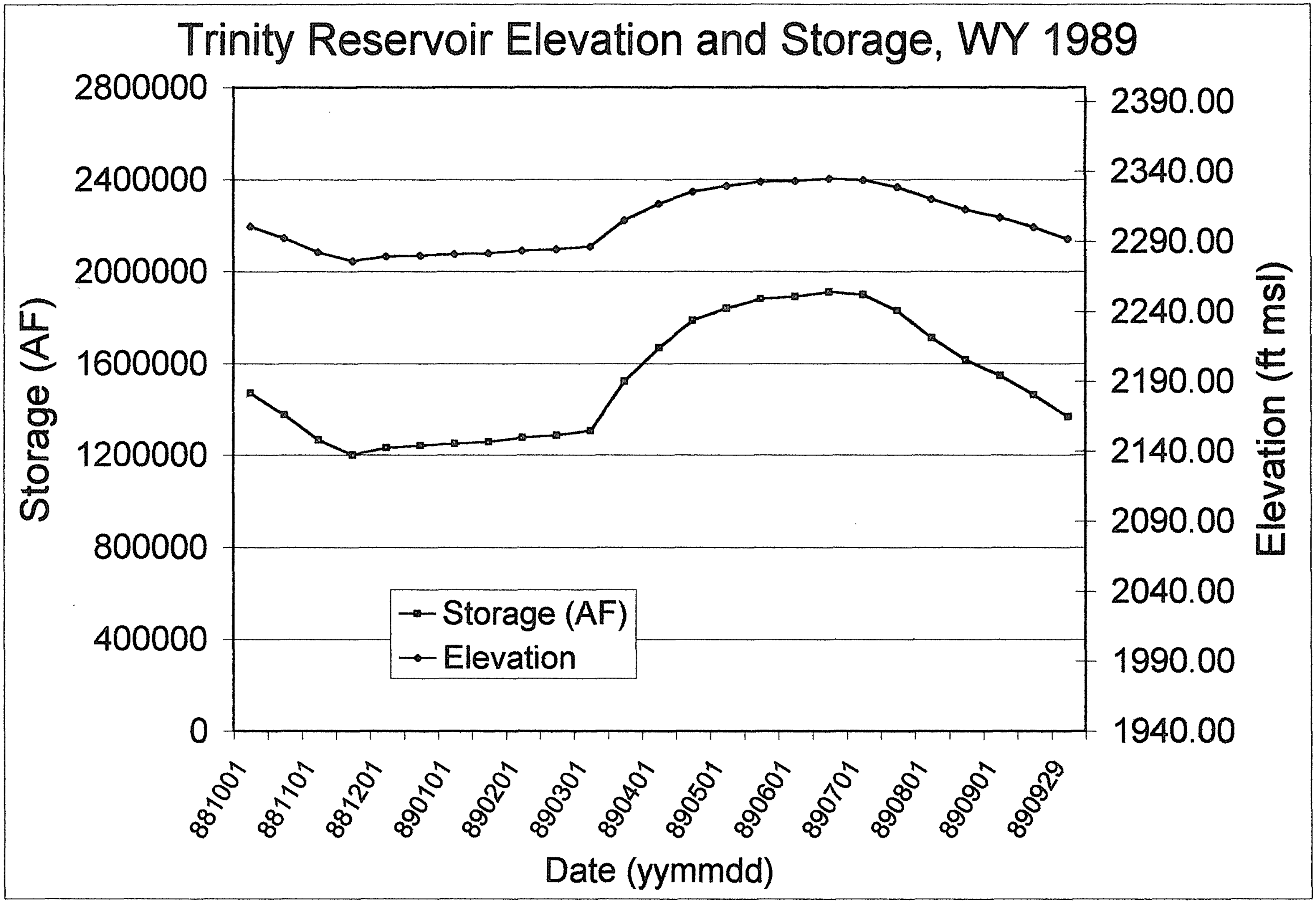


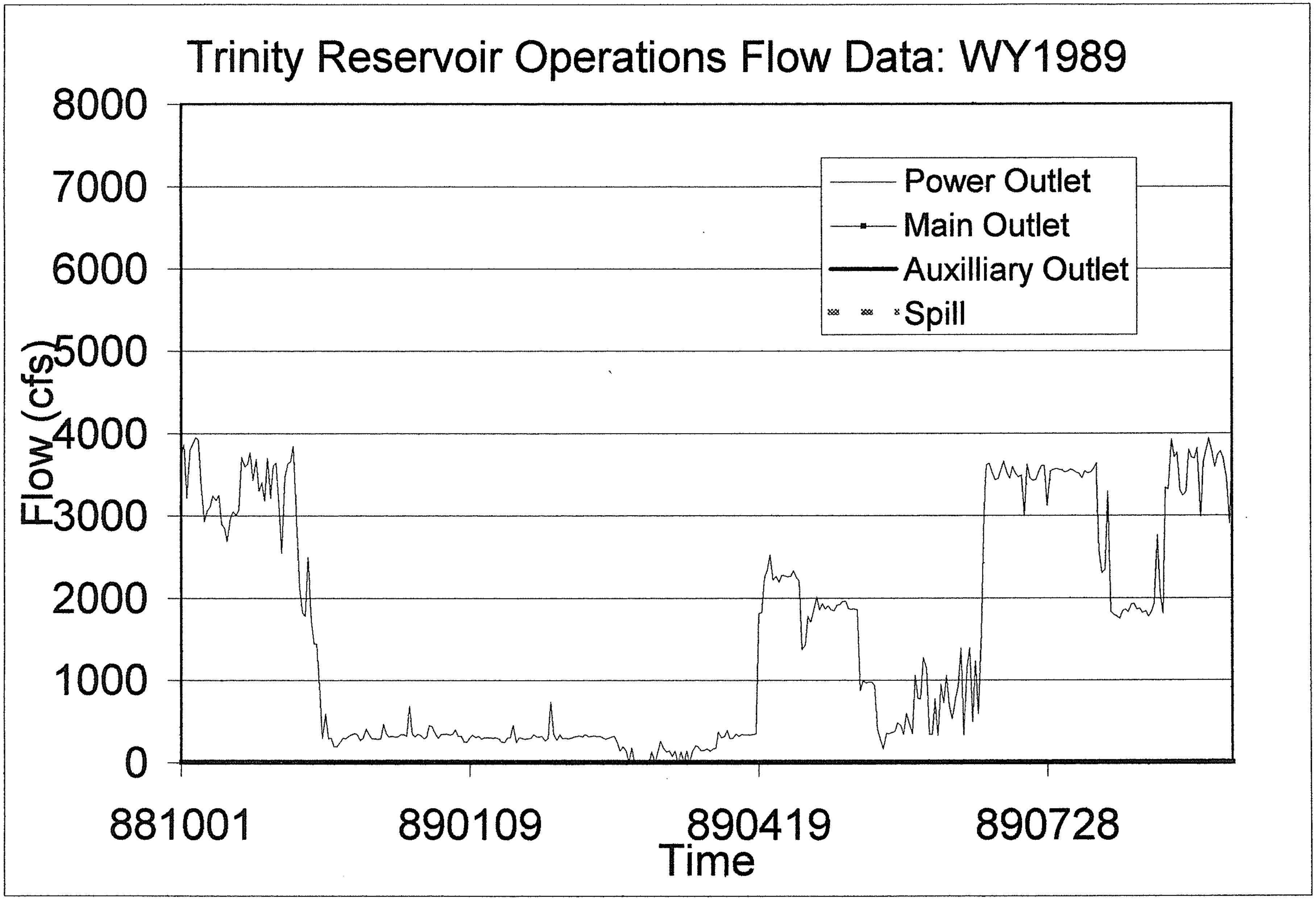
Trinity Reservoir Met Data 2: WY1986
Atm Press (in Hg)
29.00
28.00
27.00
26.00
25.00
Wind Speed (mph)
20.0
15.0
10.0
5.0
0.0
851001
860109
860419
860728
Time
Atm Press
Wind Speed



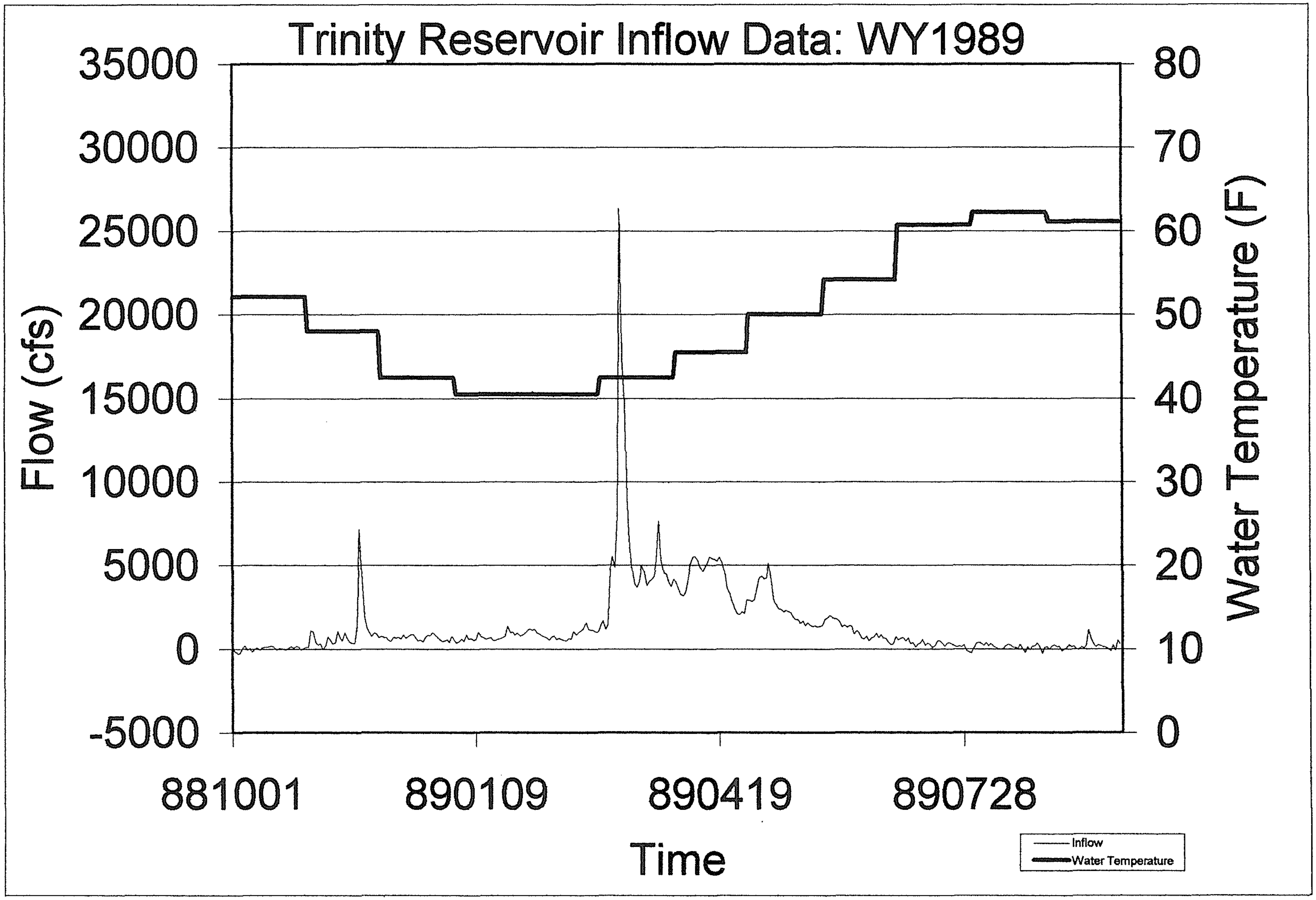
Trinity Reservoir Met Data 3: WY1986
Sky Cover (10th)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
851001
860109
860419
860728
Time
Dry Bulb


Trinity Reservoir Initial Water Temperature Profile:
October 1, 1989 (est)
2301.42'
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
Elevation (ft msl)
40.00
50.00
60.00
70.00
80.00
Temperature (F)

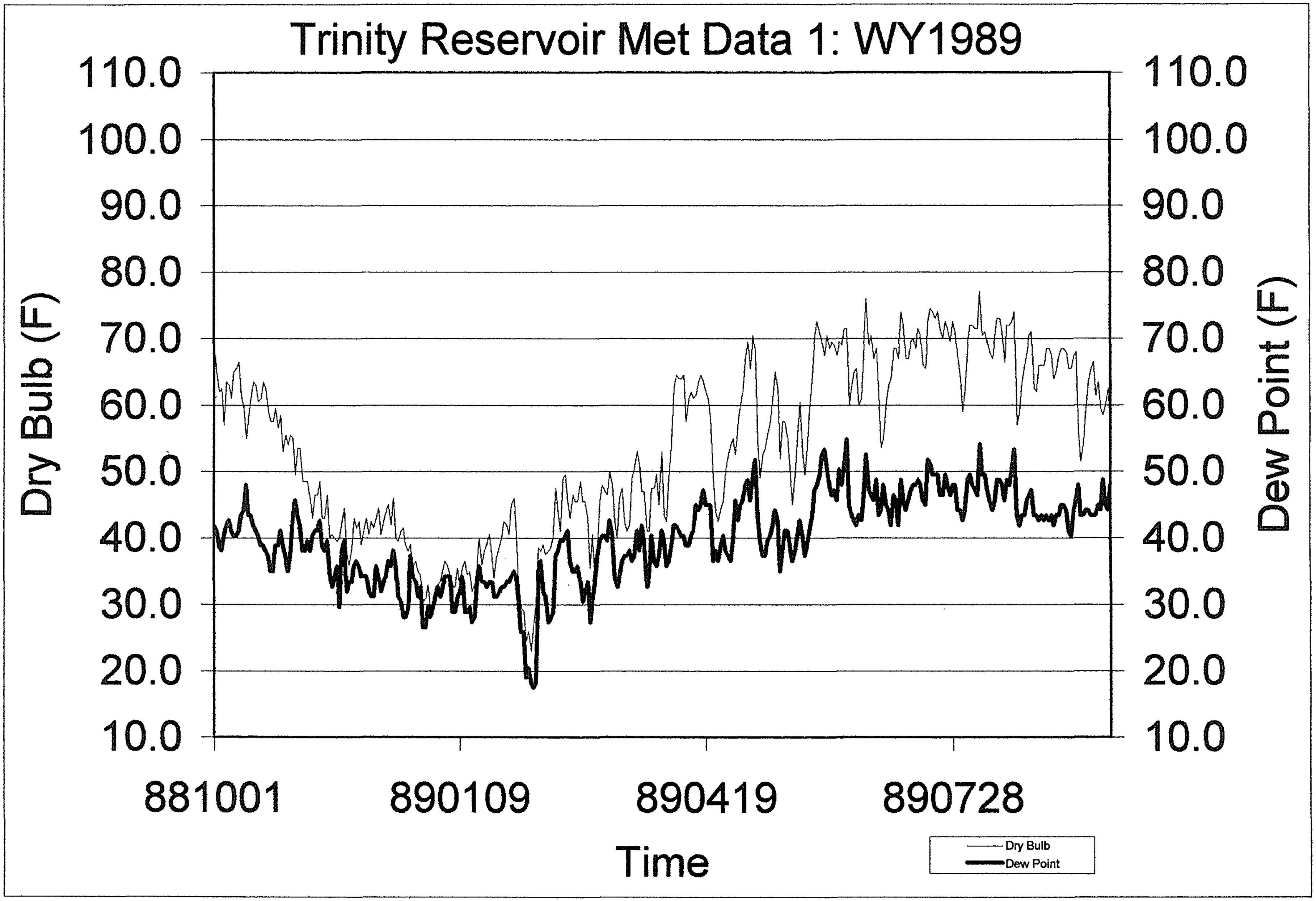

Trinity Reservoir Elevation and Storage, WY 1989
2800000
2400000
2000000
1600000
1200000
800000
400000
0
Storage (AF)
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
Elevation (ft msl)
Storage (AF)
Elevation
881001
881101
881201
890101
890201
890301
890401
890501
890601
890701
890801
890901
890929
Date (yymmdd)

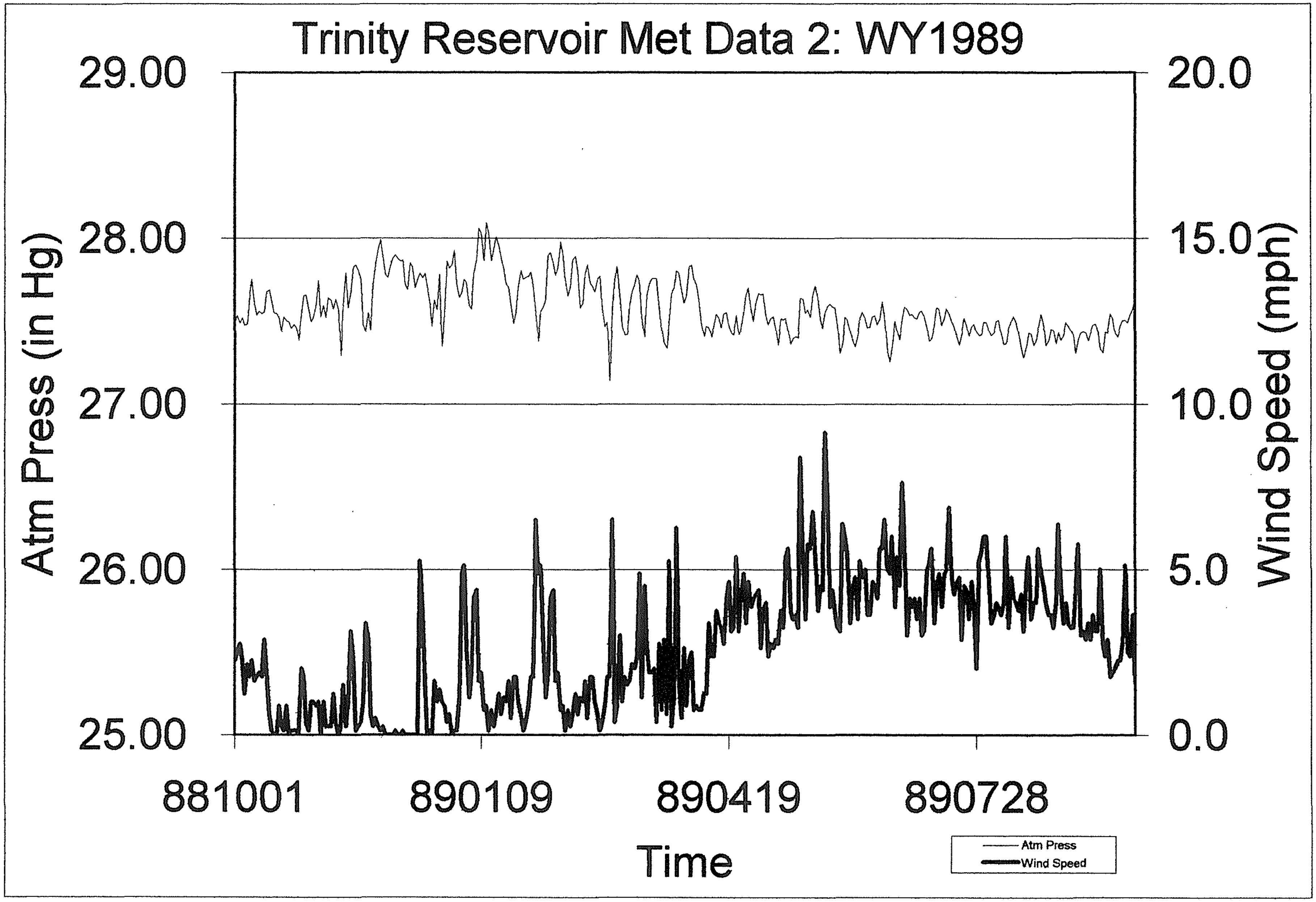


Trinity Reservoir Operations Flow Data: WY1989
8000
7000
6000
5000
4000
3000
2000
1000
0
Flow (cfs)
Power Outlet
Main Outlet
Auxilliary Outlet
Spill
881001
890109
890419
890728
Time

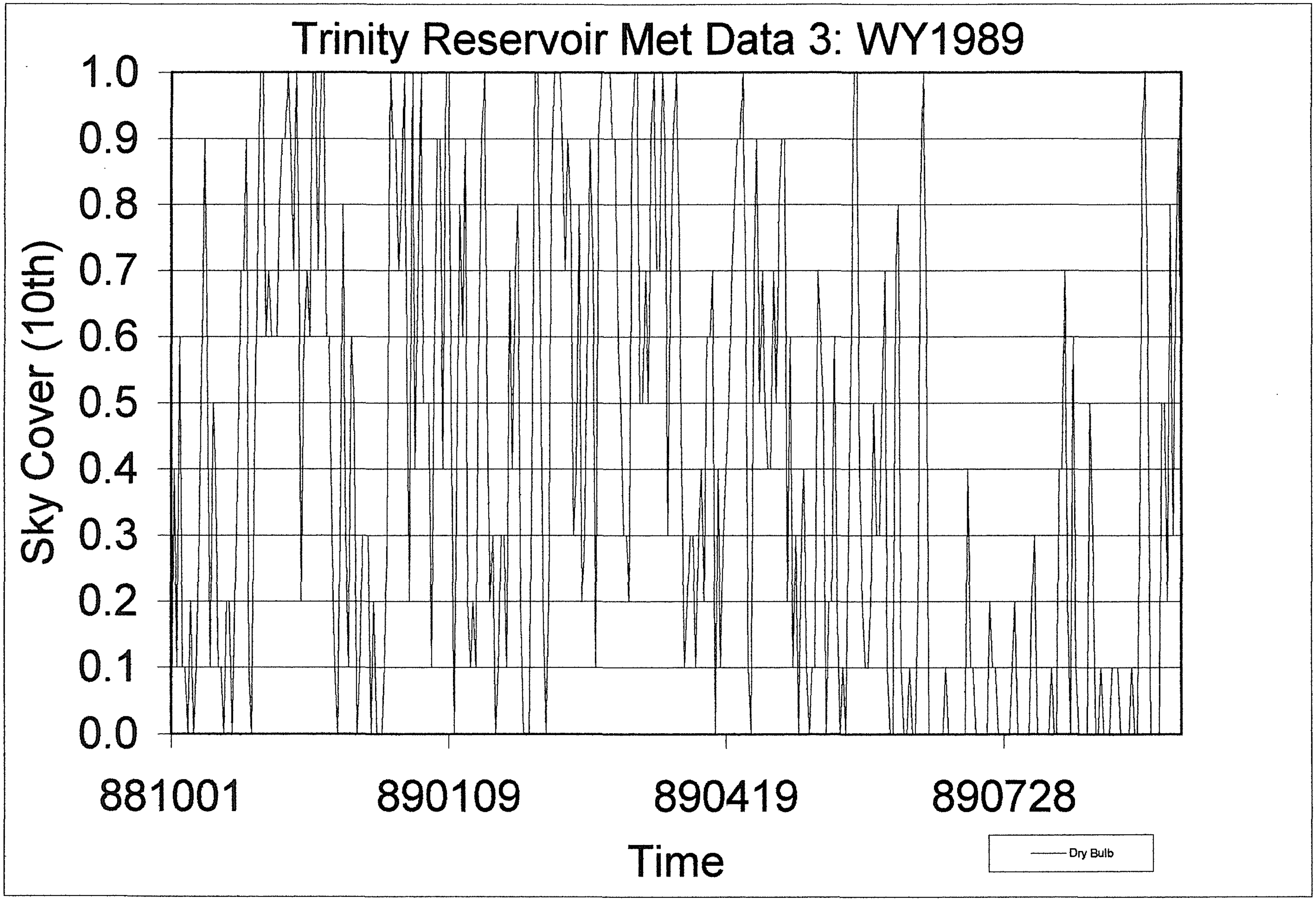


Trinity Reservoir Inflow Data: WY1989
Flow (cfs)
35000
30000
25000
20000
15000
10000
5000
0
-5000
80
70
60
50
40
30
20
10
0
Water Temperature (F)
881001
890109
890419
890728
Time
Inflow
Water Temperature

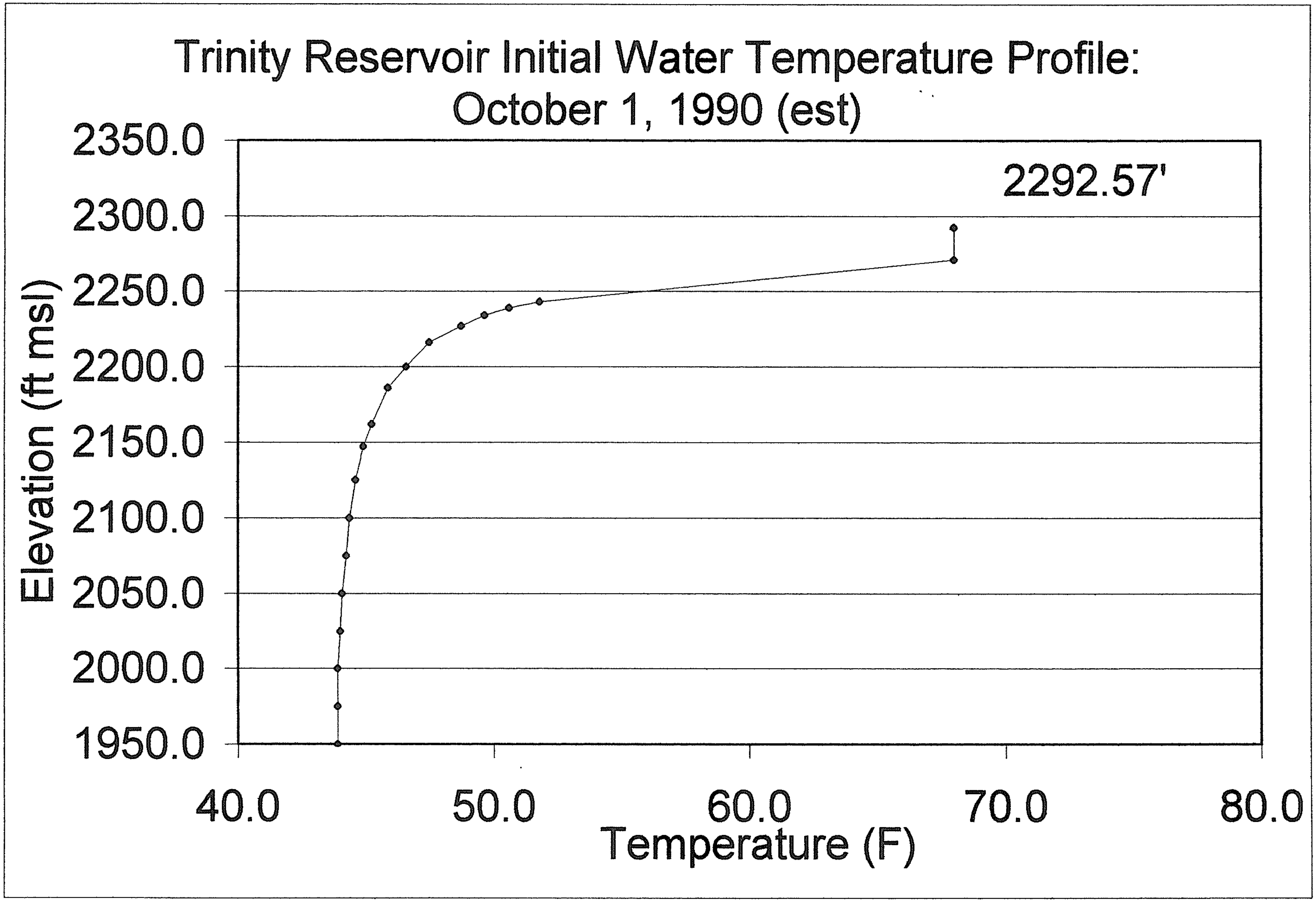

Trinity Reservoir Met Data 1: WY1989
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
Dry Bulb (F)
Dew Point (F)
881001
890109
890419
890728
Time
Dry Bulb
Dew Point

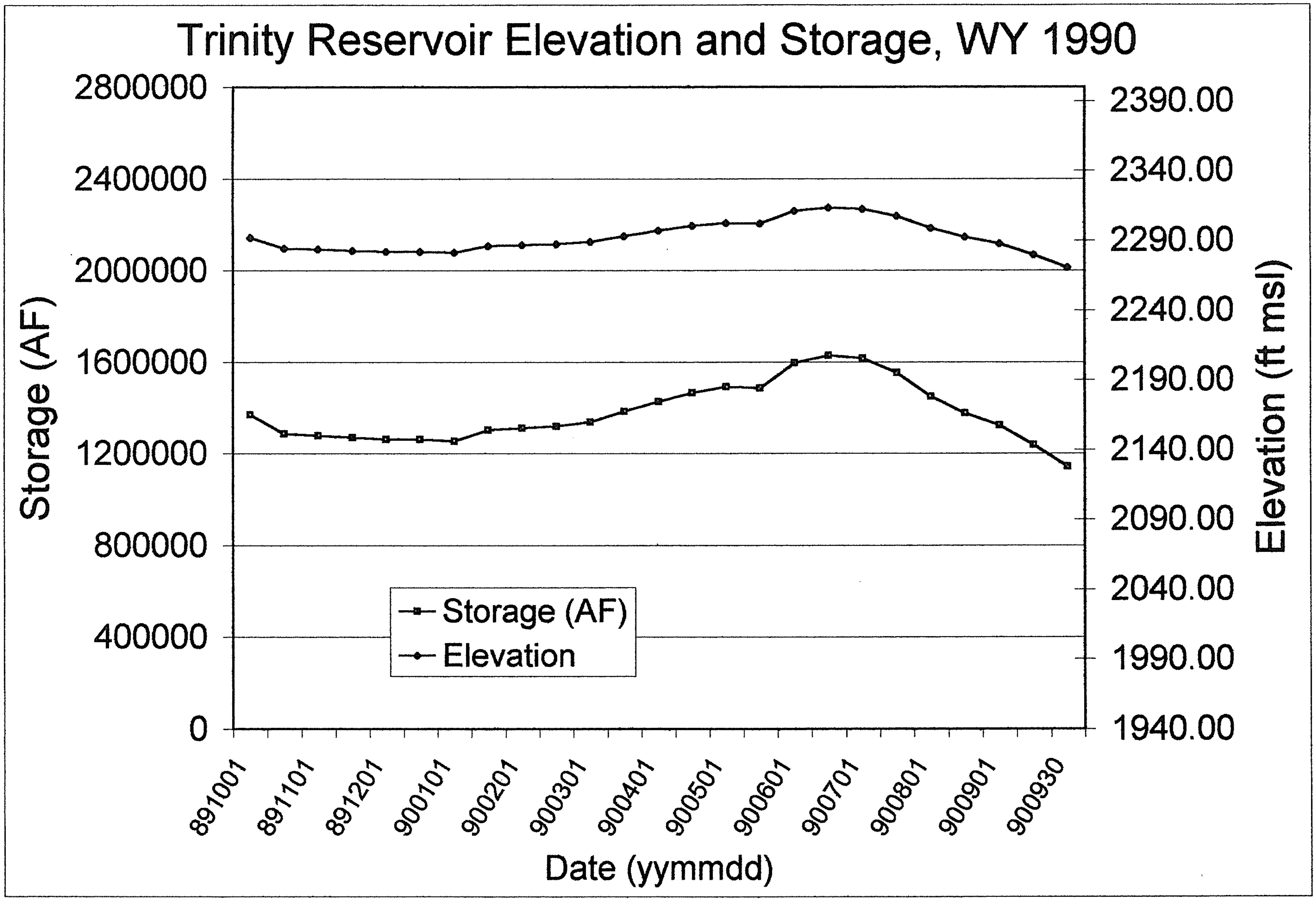


Trinity Reservoir Met Data 2: WY1989
Atm Press (in Hg)
29.00
28.00
27.00
26.00
25.00
Wind Speed (mph)
20.0
15.0
10.0
5.0
0.0
881001
890109
890419
890728
Time
Atm Press
Wind Speed

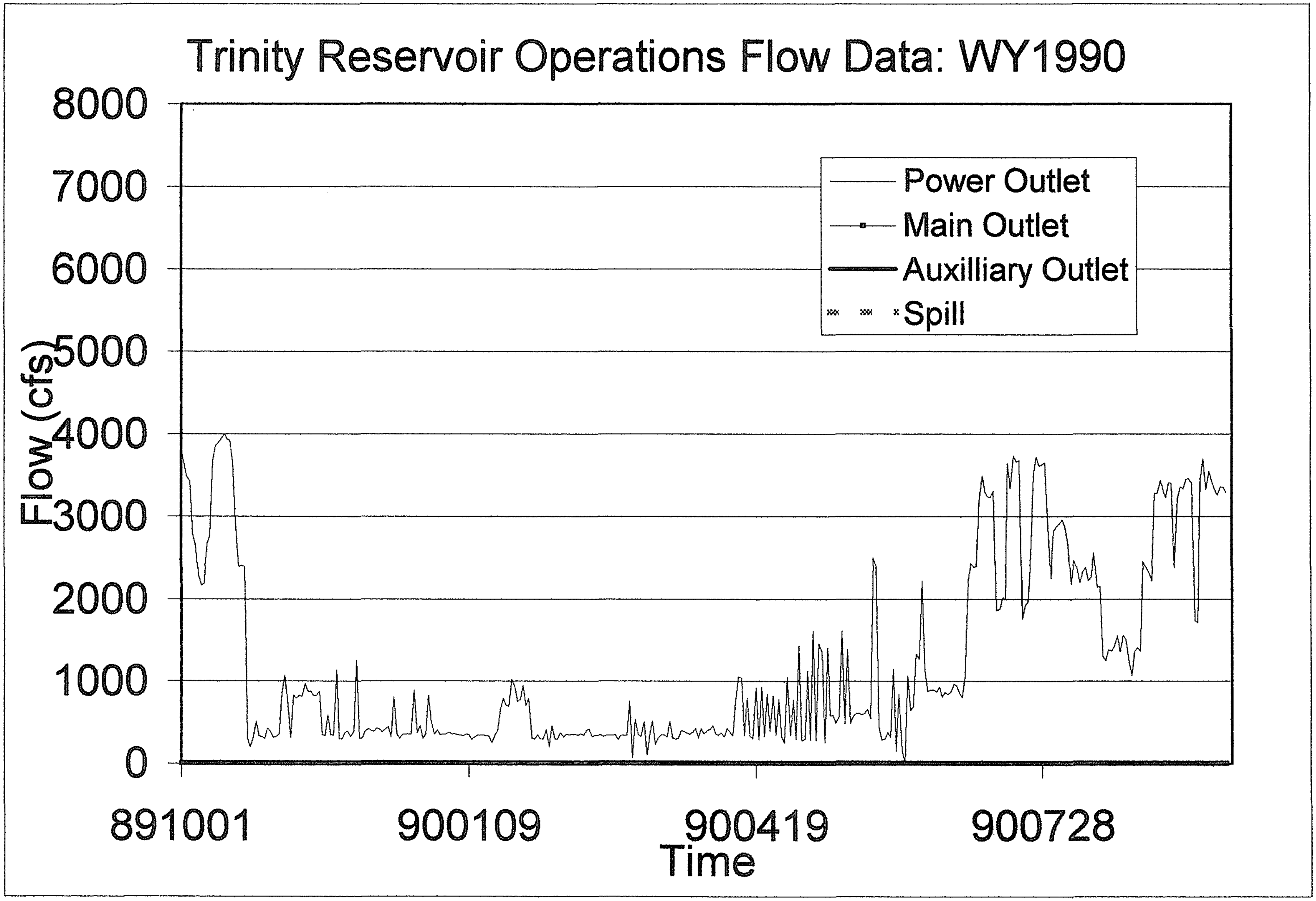


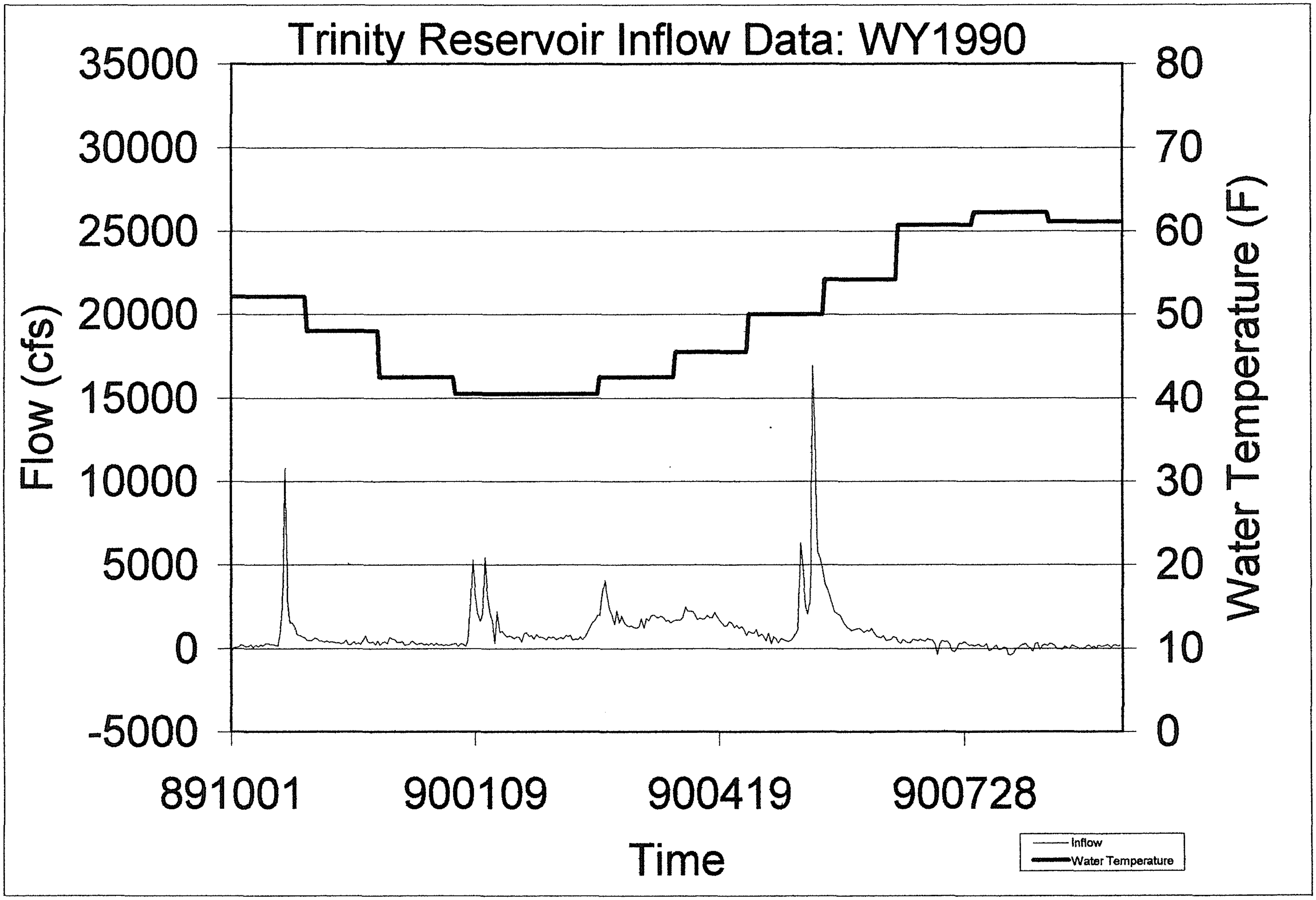
Trinity Reservoir Met Data 3: WY1989
Sky Cover (10th)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
881001
890109
890419
890728
Time
Dry Bulb


Trinity Reservoir Initial Water Temperature Profile:
October 1, 1990 (est)
2292.57'
Elevation (ft msl)
2350.0
2300.0
2250.0
2200.0
2150.0
2100.0
2050.0
2000.0
1950.0
40.0
50.0
60.0
70.0
80.0
Temperature (F)

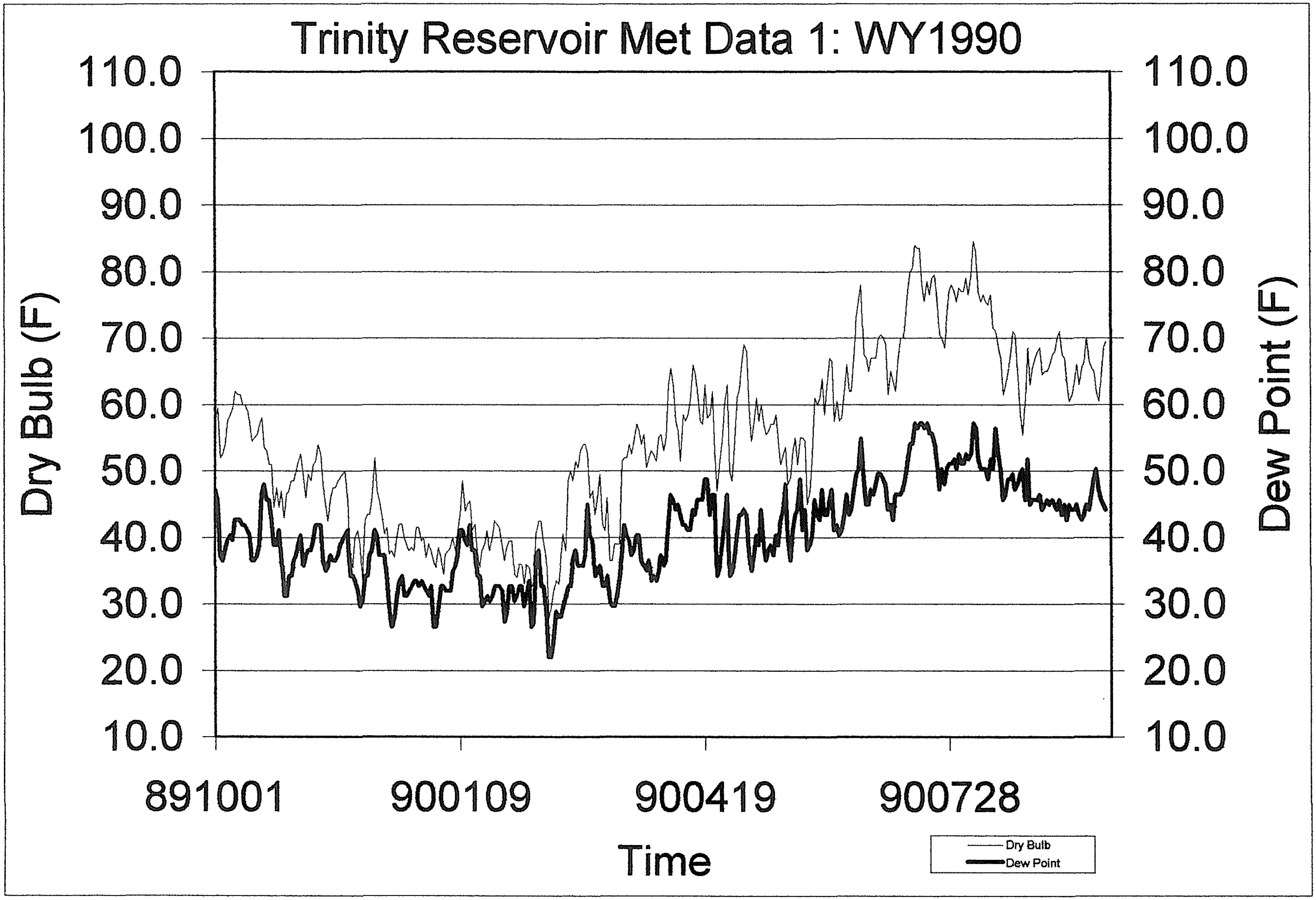


Trinity Reservoir Elevation and Storage, WY 1990
Storage (AF)
Elevation (ft msl)
2800000
2400000
2000000
1600000
1200000
800000
400000
0
2390.00
2340.00
2290.00
2240.00
2190.00
2140.00
2090.00
2040.00
1990.00
1940.00
Storage (AF)
Elevation
891001
891101
891201
900101
900201
900301
900401
900501
900601
900701
900801
900901
900930
Date (yymmdd)

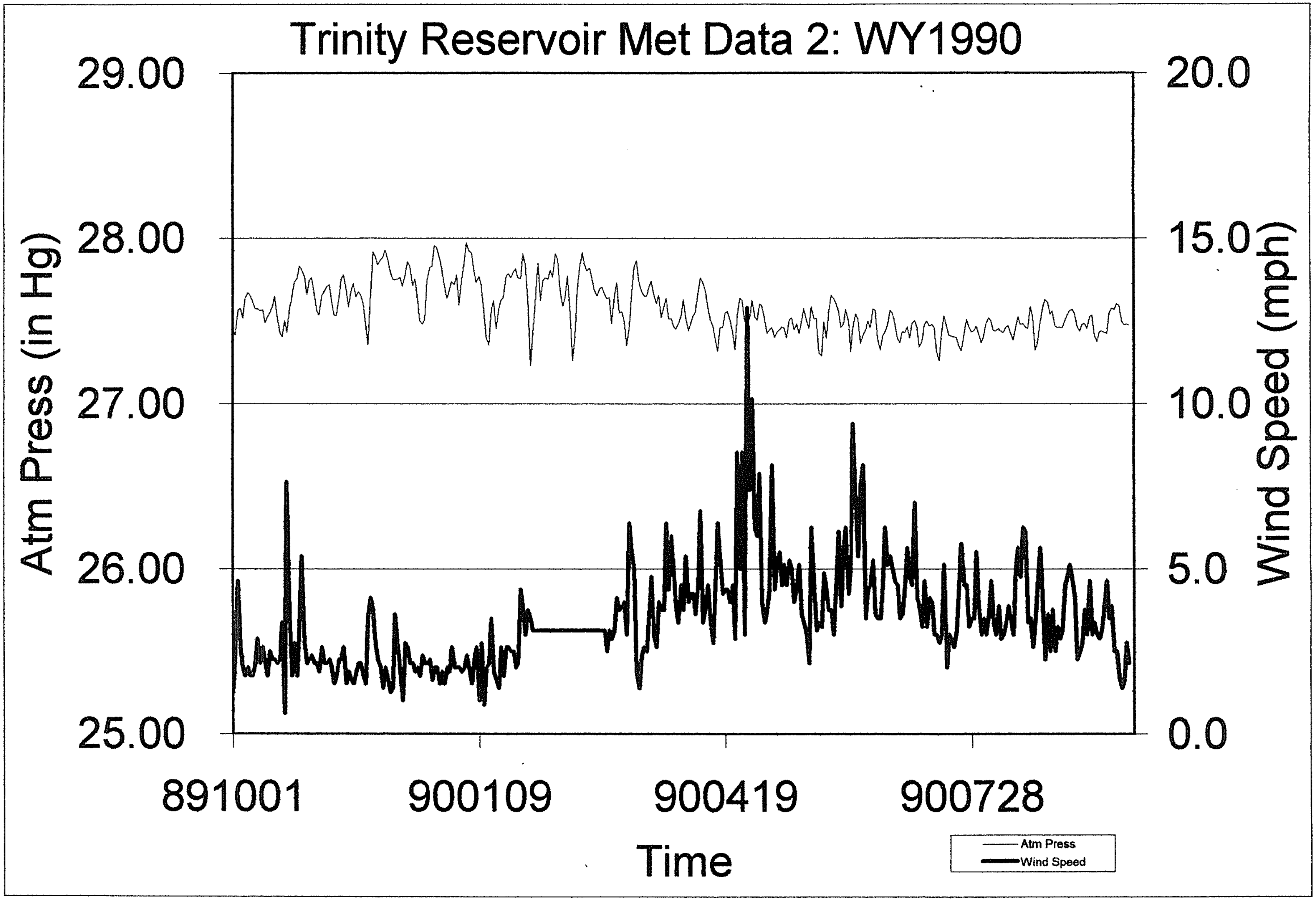

Trinity Reservoir Operations Flow Data: WY1990
Flow (cfs)
8000
7000
6000
5000
4000
3000
2000
1000
0
Power Outlet
Main Outlet
Auxilliary Outlet
Spill
891001
900109
900419
900728
Time



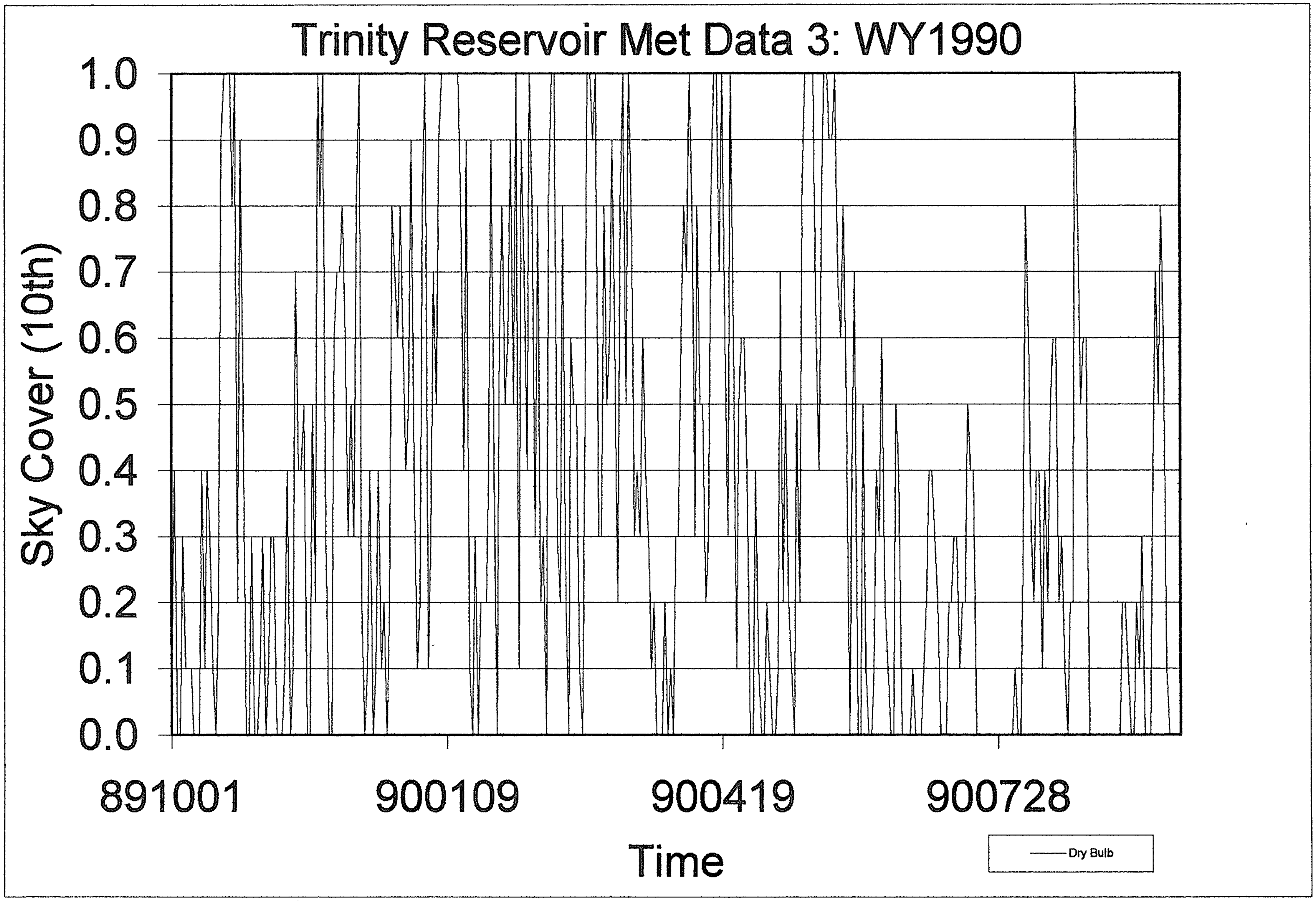
Trinity Reservoir Inflow Data: WY1990
35000
30000
25000
20000
15000
10000
5000
0
-5000
Flow (cfs)
80
70
60
50
40
30
20
10
0
Water Temperature (F)
891001
900109
900419
900728
Time
Inflow
Water Temperature



Trinity Reservoir Met Data 1: WY1990
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
Dry Bulb (F)
Dew Point (F)
891001
900109
900419
900728
Time
Dry Bulb
Dew Point



Trinity Reservoir Met Data 2: WY1990
29.00
28.00
27.00
26.00
25.00
Atm Press (in Hg)
20.0
15.0
10.0
5.0
0.0
Wind Speed (mph)
891001
900109
900419
900728
Time
Atm Press
Wind Speed


Trinity Reservoir Met Data 3: WY1990
Sky Cover (10th)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
891001
900109
900419
900728
Time
Dry Bulb

Appendix L WQRRS Pre-processor Program

To assemble the required inflow, operations, water temperature, and meteorological data a preprocessor computer program was written to assemble the required data into the format of a WQRRS input file. Data was arranged in five files:

Parameter file: program logic control parameters including calibration coefficients, system geometry, number of points in the initial water temperature profile, initial reservoir elevation, print dates, and several other parameters

Profile file: initial temperature profile data for Trinity Reservoir

Inflow file: total reservoir inflow and associated water temperature data

Operations file: reservoir release and spill schedule

Meteorological file: climate data

All input files include headers and list the total number of lines of data to be read by the preprocessor program. Data can be maintained in spreadsheets; however, the program reads text files. Data files maintained in spreadsheets should be saved as text files prior to processing. The program prompts the user for each input file name and the output file name (which will become the input file for WQRRS). There is an echo file that prints out input read from data files. If the user is experiencing difficulty reading in data files an examination of this file may help locate potential problems. The FORTRAN code is listed below. For input data file format, the reader is referred to accompanying data files included on diskette (a listing of input files is included in Appendix D).

Program TRINPUT.F

```
c Program to construct WQRRS input files
c  Requires the following input files
c   1) param__. (unit 1) control parameter and geometry file
c   2) prof__. (unit 2) initial temperature profile data
c   3) oper__. (unit 3) operations for Trinity Reservoir (outflow)
c   4) temp__. (unit 4) inflow and inflow temperature to Trinity Res.
c   5) met__. (unit 5) meteorlogical data file
c
c  See specific data files for format and requri-ea parameters
c
c  PROGRAM TRINPUT.F
c
c
c  Declare Variables
c
      real elevini
      real ptemp,elev,power,spill,outaux,inflow,intemp,dryb,dwpt,atmp,
     +     wind,cloud,outmain,pwrmain

      integer numlin1,numlin2,numlin3,numlin4,numlin5,zero,one,none
      integer hydtime,temptime,mettime,day1,day2
      integer i,icount,ileft

      character *8  i1,i2,i3,i4
        character *20 file1,file2,file3,file4,file5,file10,file11
```

```
      character *80 field

      dimension ptemp(100),elev(100),inflow(400),power(400),spill(400),
      +          outaux(400),intemp(400),dryb(400),dwpt(400),atmp(400),
      +          wind(400),cloud(400),hydtime(400),temptime(400),
      +          mettime(400),outmain(400),pwrmain(400)
      i1='INIT1'
      i2='INIT2'
      i3='INIT3'
      i4='INIT4'
      zero = 0
      one = 1
      none = -1
c
c   Prompt user for input and output filenames
c
      write(*,*)'ENTER PARAMETER FILENAME'
      read(*,*)file1
      write(*,*)'ENTER INITIAL TEMPERATURE PROFILE FILENAME'
      read(*,*)file2
      write(*,*)'ENTER OPERATIONS FILENAME'
      read(*,*)file3
      write(*,*)'ENTER INFLOW TEMPERATURE FILENAME'
      read(*,*)file4
      write(*,*)'ENTER METEOROLOGICAL FILENAME'
      read(*,*)file5
      write(*,*)'ENTER OUTPUT FILENAME'
      read(*,*)file10
c
c   file11 echos input
c
      file11 = 'echo.prn'
c
c   Open files  (units 1-5 = input, units 10-11 = output)
c
          open(unit=1,file= file1,status='unknown')
          open(unit=2,file= file2,status='unknown')
          open(unit=3,file= file3,status='unknown')
          open(unit=4,file= file4,status='unknown')
          open(unit=5,file= file5,status='unknown')
          open(unit=10,file= file10,status='unknown')
          open(unit=11,file= file11,status='unknown')
c
c   Write input filenames to echo file
c
        write(11,*)'INPUT FILES'
      write(11,110)file1
      write(11,110)file2
      write(11,110)file3
      write(11,110)file4
      write(11,110)file5
      write(11,*)'OUTPUT FILES'
      write(11,110)file10
cc    write(11,110)file11
c
c   Read param file as character strings
c
```

```
      do 210 i = 1,12
      read(1,100)
210   continue
      read(1,*)numlin1
    write(11,*)'total lines in param file =',numlin1
    read(1,100)
    read(1,100)
    do 212 i = 1,numlin1
      read(1,111)field
      write(10,111)field
212   continue
c
c  Read initial water temperature profile data, save
c    elevations and temperatures (numlin1)
c
    do 220 i = 1,3
      read(2,100)
220   continue
      read(2,*)numlin2
    if(numlin2.gt.100)then
      write(*,*)'NO. OF POINTS FOR PROFILE MUST BE LESS THAN 101'
      write(11,*)'NO. OF POINTS FOR PROFILE MUST BE LESS THAN 101'
      goto 1000
    endif
    write(11,*)'total lines in initial profile file =',numlin2
    read(2,*)elevini
    write(11,*)'initial reservoir elevation =',elevini
    do 222 i = 1,4
      read(2,100)
222   continue
    write(11,*)'INITIAL TEMP PROFILE'
    write(11,*)'ELEV     TEMP'
    do 224 i = 1,numlin2
      read(2,*) elev(i),ptemp(i)
      write(11,*)elev(i), ptemp(i)
224   continue
c
c  Assemble initial profile component of input file (numlin2)
c
    write(10,120)i1,zero,zero,zero,zero
    do 226 i=1,numlin2
      write(10,122)i2,elev(i),ptemp(i)
      write(10,124)i3
      write(10,124)i4
226 continue
c
c  Read hydrology file, operations  (numlin3)
c
      do 230 i = 1,3
      read(3,100)
230   continue
      read(3,*)numlin3
    if(numlin3.gt.400)then
      write(*,*)'HYDROLOGY FILE: NO. OF ENTRIES'
      write(*,*)' MUST BE LESS THAN 400'
      write(11,*)'HYDROLOGY FILE: NO. OF ENTRIES'
      write(11,*)' MUST BE LESS THAN 400'
```

```
        goto 1000
      endif
      write(11,*)'total lines in hydrology file =',numlin3
         do 232 i = 1,4
         read(3,100)
232      continue
      write(11,*)'INPUT OPERATIONS'
      write(11,*)'  TIME      POWER     SPILL     OUTLET '
         do 234 i = 1,numlin3
cc       read(3,*)hydtime(i),power(i),spill(i),outlet(i)
cc       write(11,130)hydtime(i),power(i),spill(i),outlet(i)
         read(3,*)hydtime(i),power(i),outmain(i),outaux(i),spill(i)
         pwrmain(i) = power(i) + outmain (i)
         write(11,130)hydtime(i),power(i),outmain(i),outaux(i),spill(i)
234      continue
c
c    Read inflow and inflow temperature file (numlin4)
c
         do 240 i = 1,4
         read(4,100)
240      continue
         read(4,*)numlin4
      read(4,*)day1
      read(4,*)day2
      if(numlin4.gt.400)then
        write(*,*)'INFLOW/TEMP FILE: NO. OF ENTRIES'
        write(*,*)' MUST BE LESS THAN 400'
        write(11,*)'INFLOW/TEMP FILE: NO. OF ENTRIES'
        write(11,*)' MUST BE LESS THAN 400'
        goto 1000
      endif
      write(11,*)'total lines in inflow and temp file =',numlin4
      do 242 i = 1,4
        read(4,100)
242      continue
      write(11,*)'INFLOW AND INFLOW TEMPERATURE'
      write(11,*)'  DATE      INFLOW    INFLOW TEMPERATURE'
         do 244 i = 1,numlin4
         read(4,*)temptime(i),inflow(i),intemp(i)
         write(11,140)temptime(i),inflow(i),intemp(i)
244      continue
c
c  Read meteorological file (numlin5)
c
         do 250 i = 1,3
         read(5,100)
250      continue
         read(5,*)numlin5
      if(numlin5.gt.400)then
        write(*,*)'METEOROLOGICAL FILE: NO. OF ENTRIES'
        write(*,*)' MUST BE LESS THAN 400'
        write(11,*)'METEOROLOGICAL FILE: NO. OF ENTRIES'
        write(11,*)' MUST BE LESS THAN 400'
        goto 1000
      endif
      write(11,*)'total lines in inflow and temp file =',numlin5
         do 252 i = 1,4
```

```
      read(5,100)
252   continue
    write(11,*)'METEOROLOGICAL DATA'
    write(11,*)' DATE    CLOUD     DRY   DEW   PRESS   WIND'
      do 254 i = 1,numlin5
      read(5,*)mettime(i),cloud(i),dryb(i),dwpt(i),atmp(i),wind(i)
      write(11,150)mettime(i),cloud(i),dryb(i),dwpt(i),atmp(i),
    +             wind(i)
254    continue
c
c  Assemble remainder of data file
c
c       INFLOW (numlin4)
c
    write(10,160)'INFL1    ',one,zero,zero,zero,zero,
     +                         zero,zero,zero,zero
    write(10,162)'INFL1A   ',zero,zero,zero,zero,zero,zero
    write(10,164)'INFL1B   ',zero,zero,zero,zero,zero
    write(10,166)'INFL2    ',day1,day2
    write(10,168)'INFL3    ',zero,'    INFLOW RATE'
    icount = nint(real(numlin4)/4.)
    itotal = icount*4
    ileft = mod(numlin4,4)
    k=1
      do 260 i=1,icount
      write(10,170)'INFL5    ',temptime(k),inflow(k),
     +              temptime(k+1),inflow(k+1),
     +                     temptime(k+2),inflow(k+2),
     +                         temptime(k+3),inflow(k+3)
      k = i*4+1
260   continue
      if(ileft.eq.1)then
      write(10,171)'INFL5    ',temptime(itotal+1),inflow(itotal+1)
    elseif(ileft.eq.2)then
      write(10,172)'INFL5    ',temptime(itotal+1),inflow(itotal+1),
    +                          temptime(itotal+2),inflow(itotal+2)
    elseif(ileft.eq.3)then
      write(10,173)'INFL5    ',temptime(itotal+1),inflow(itotal+1),
    +                          temptime(itotal+2),inflow(itotal+2),
    +                          temptime(itotal+3),inflow(itotal+3)
    endif
    write(10,174)'INFL5    ',none
c
c    TEMPERATURE (numlin4)
c
    write(10,168)'INFL3    ',zero,'    TEMPERATURE'
    icount = nint(real(numlin4)/4.)
    ileft = mod(numlin4,4)
    k=1
      do 262 i=1,icount
      write(10,170)'INFL5    ',temptime(k),intemp(k),
     +              temptime(k+1),intemp(k+1),
     +                     temptime(k+2),intemp(k+2),
     +                         temptime(k+3),intemp(k+3)
      k = i*4+1
262   continue
      if(ileft.eq.1)then
```

```
          write(10,171)'INFL5    ',temptime(itotal+1),intemp(itotal+1)
        elseif(ileft.eq.2)then
          write(10,172)'INFL5    ',temptime(itotal+1),intemp(itotal+1),
     +                             temptime(itotal+2),intemp(itotal+2)
        elseif(ileft.eq.3)then
          write(10,173)'INFL5    ',temptime(itotal+1),intemp(itotal+1),
     +                             temptime(itotal+2),intemp(itotal+2),
     +                             temptime(itotal+3),intemp(itotal+3)
        endif
        write(10,174)'INFL5    ',none
c
c   METEOROLOGICAL(numlin5)
c
         do 280 i=1,numlin5
        if(i.eq.numlin5)then
          write(10,180)'WEATH1   ',mettime(i),cloud(i),dryb(i),dwpt(i),
     +                             atmp(i),wind(i),zero,zero,none
        else
          write(10,180)'WEATH1   ',mettime(i),cloud(i),dryb(i),dwpt(i),
     +                             atmp(i),wind(i),zero,zero,zero
        endif
280     continue
c
c   HYDROLOGY/OPERATIONS - OUTFLOW (numlin3)
c
         do 290 i=1,numlin3
        if(i.eq.numlin3)then
            hydtime(i) = -hydtime(i)
        endif
c       write(10,190)'OUTL1    ',hydtime(i),power(i),outlet(i)
        write(10,190)'OUTL1    ',hydtime(i),pwrmain(i),outaux(i),spill(i)
290     continue
c
        do 295 i=1,3
            write(10,124)'TITLE    '
295 continue
         write(10,124)'JOB1     '
         write(10,124)'EOF..    '
c
c  Close files
c
        close(1)
        close(2)
        close(3)
        close(4)
        close(5)
        close(10)
        close(11)
c
c  Format statements
c
100     format()
110     format(a20)
111     format(a80)
120     format(a8,4i8)
122     format(a8,2f8.2)
124     format(a8)
```

```
130   format(i8,1x,4f8.0)
140   format(i8,1x,2f8.0)
150   format(i8,1x,6f8.0)
160   format(a8,9i8)
162   format(a8,6i8)
164   format(a8,5i8)
166   format(a8,2i8)
168   format(a8,i8,a15)
170   format(a8,i8,f8.2,i8,f8.2,i8,f8.2,i8,f8.2)
171   format(a8,i8,f8.2)
172   format(a8,i8,f8.2,i8,f8.2)
173   format(a8,i8,f8.2,i8,f8.2,i8,f8.2)
174   format(a8,i8)
180   format(a8,i8,5f8.2,3i8)
190   format(a8,i8,3f8.2)
1000  stop
      end
```

Appendix M Post-Processor Spreadsheet (MS EXCEL®)

MS Excel® (Excel) spreadsheets have been constructed for each EIS year-type to allow efficient review and interpretation of model output. The spreadsheet uses imported output files from WQRRS to graph water temperature profiles, reservoir storage, and elevation. Semi-monthly statistics for outlet temperatures at selected elevations are tabulated and graphed. Instructions for use of the spreadsheets are included in the first worksheet of each Excel file ("notes") and the user is assumed to have mastered the basic skills of operating spreadsheets. A brief outline of instructions is included herein for completeness.

The post-processor spreadsheet uses a file produced by WQRRS. Specifically, WQRRS prompts the user for three output file names prior to simulation: printed report file, profile 1 output file, profile 2 output file. The printed report file includes all model data and is difficult to use for interpreting output. The profile 1 output file is for debugging in case of errors. The profile 2 output has been constructed to tabulate all data for output interpretation. Each file is in text format. Profile 2 output file has been constructed to include the date, reservoir surface elevation, depth, and associated water temperature data in a format easily imported into a spreadsheet. This file can be opened in Excel as a text file.

The post-processor spreadsheet is actually a workbook consisting of several worksheets. The worksheet labels and individual contents are defined in Table M.1. The first six spreadsheets include information useful for use of the spreadsheets and output interpretation. Sheets seven through nine are for calculation of values in other sheets (e.g., reservoir storage at selected elevations, interpolation of water temperature at selected elevations). Further details are included in the spreadsheets.

Table M.1 Post-processor spreadsheet worksheet contents

Worksheet Name	Content
1. Notes	Worksheet instructions, misc. notes
2. Datafile	WQRRS output data file location
3. Stats	Summary statistics, figures
4. Monthly	Monthly reservoir profiles
5. Semimonthly	Semi-monthly reservoir profiles
6. BETTER	BETTER model input file data template
7. Calcs	Calculation spreadsheet
8. Interp	Calculation spreadsheet
9. s-table	Calculation spreadsheet

The post-processor spreadsheet is actually a template. The WQRRS output data is copied/pasted into the worksheet titled "datafile." All figures, graphs, tables, are updated automatically and the user can scan through the various sheets and examine the output data in various formats. For example, many of the figures and tables included in this report were imported directly from the post-processor spreadsheet

The spreadsheets have many formulas and external references. For maintenance purposes, the user should always keep a backup of the EIS year-type spreadsheets should any of the files become corrupted. As with all modeling applications, a measure of experience in system response is necessary to effectively interpret model output.

Post Processor Excel Files:

Filename	Description	Format
Profil77.xls	WY1977 post-processor spreadsheet	Excel v97, v95, v5.0
Profil83.xls	WY1983 post-processor spreadsheet	Excel v97, v95, v5.0
Profil86.xls	WY1986 post-processor spreadsheet	Excel v97, v95, v5.0
Profil89.xls	WY1989 post-processor spreadsheet	Excel v97, v95, v5.0
Profil90.xls	WY1990 post-processor spreadsheet	Excel v97, v95, v5.0

Appendix N Sample Application of the Trinity Reservoir Temperature Model

The Trinity Reservoir temperature model was applied for each of the five EIS year-types at three carryover storage volumes; 750,000 acre-feet, 1,250,000 acre-feet, and 1,750,000 acre-feet. These runs illustrate the ability of the model to simulate various year-types and estimate potential consequences of carryover storage selection. Operations were not adjusted to respond to initial carryover storage volumes, changing storage conditions, to accommodate reservoir inflow, or selectively withdraw water from different outlets to control temperature. Simply applying historic operations does not simulate operational flexibility that may potentially occur under various conditions. Table N.1 outlines the historic initial and final water surface elevations and storage volumes for the EIS year-types.

Table N.1 Historic initial and final water surface elevations and storage volumes for EIS water year-types

Water Year	Initial Elevation (ft (msl)	Final Elevation (ft msl)	Net Change (ft)	Initial Storage (acre-feet)	Final Storage (acre-feet)	Net Change (acre-feet)
1977	2,303.0	2,126.2	176.7	1,497,500	242,400	-1,255,100
1983	2,348.5	2,352.0	-3.5	2,111,600	2,164,100	52,500
1986	2,323.3	2,334.0	-10.7	1,754,800	1,901,000	146,200
1989	2,301.4	2,292.6	8.8	1,479,000	1,376,200	-102,800
1990	2,291.9	2,272.1	19.7	1,368,100	1,162,400	-205,700

A brief review of Table N.1 shows that only WY1977 experienced extreme draw down. Also, WY1983, defined as extremely wet, experienced the smallest net change in storage because there was significant storage at the beginning of the water year. These examples illustrate that initial conditions can significantly affect operations. Thus, the reader is cautioned against drawing explicit conclusions from these test runs.

The five year-types were simulated and summary statistics, as well as graphs of reservoir storage and water temperature at the 2000 ft msl, 2100 ft msl, and 2150 ft msl elevations for each carryover storage volume were determined. Table N.2 summarizes maximum and minimum storage for each year-type, and maximum water temperature at the selected elevations for the simulation period.

The lower two carryover storage volumes were infeasible for WY1977. The highest carryover storage volume still posed problems under WY1977 historic operations. The excessive draw down resulted in maximum water temperatures in the intake region exceeding 60°F during the late summer of the simulation period. In general, 1,250,000 acre-feet and 1,750,000 acre-feet carryover volumes had similar results; water temperatures in the mid to high forty degree range. An exception is 1983, where temperatures 50°F or greater occurred at the 2100 ft msl elevation for all carryover volumes. This result can be attributed to the fact that little water was stored under the WY1983 operations. In all likelihood at these lower carryover storage values operations under WY1983 hydrology would have differed from those used in the test simulation

Reservoir storage and maximum water temperatures at the 2000 ft msl, 2100 ft msl, and 2150 ft msl are shown in Figures N.1 through N.5 for all applicable carryover storage volumes. Maximum temperatures occur in the mid- to late-summer months and are especially pronounced for the 750,000 acre-feet carryover volume.

Table N.2 Summary of maximum and minimum reservoir storage and maximum water temperatures at 2000 ft msl, 2100 ft msl, and 2150 ft msl for EIS year-type test runs

Water Year	Carry-over Storage (1000 AF)	Maximum Storage (acre-feet)	Minimum Storage (acre-feet)	Maximum Tw at 2000 ft msl (°F)	Maximum Tw at 2100 ft msl (°F)	Maximum Tw at 2150 ft msl (°F)
1977	750K	n/a	n/a	n/a	n/a	n/a
	1250K	n/a	n/a	n/a	n/a	n/a
	1750K	1745221	472536	66.5	73.0	74.5
1983	750K	1090471	591004	54.8	58.7	63.7
	1250K	1582251	1089619	50.5	52.1	54.3
	1750K	2076372	1586910	47.7	49.2	50.6
1986	750K	1381157	462147	50.7	54.6	59.2
	1250K	1875280	959406	47.7	49.2	51.2
	1750K	2370574	1457010	45.3	46.6	47.4
1989	750K	1189241	471717	53.4	62.0	63.8
	1250K	1682910	970694	47.9	50.5	56.1
	1750K	2177858	1468738	45.2	46.5	48.0
1990	750K	1010068	536726	52.1	65.0	66.8
	1250K	1502610	1021267	46.7	48.0	51.6
	1750K	1995836	1508194	44.6	45.4	46.5

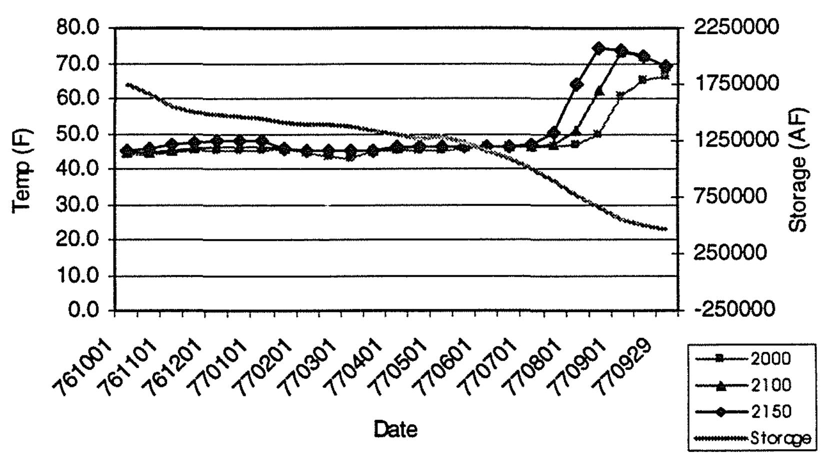


Figure N.1 Trinity Reservoir storage and water temperature; WY 1977 Conditions; carryover storage of 1,750,000 AF

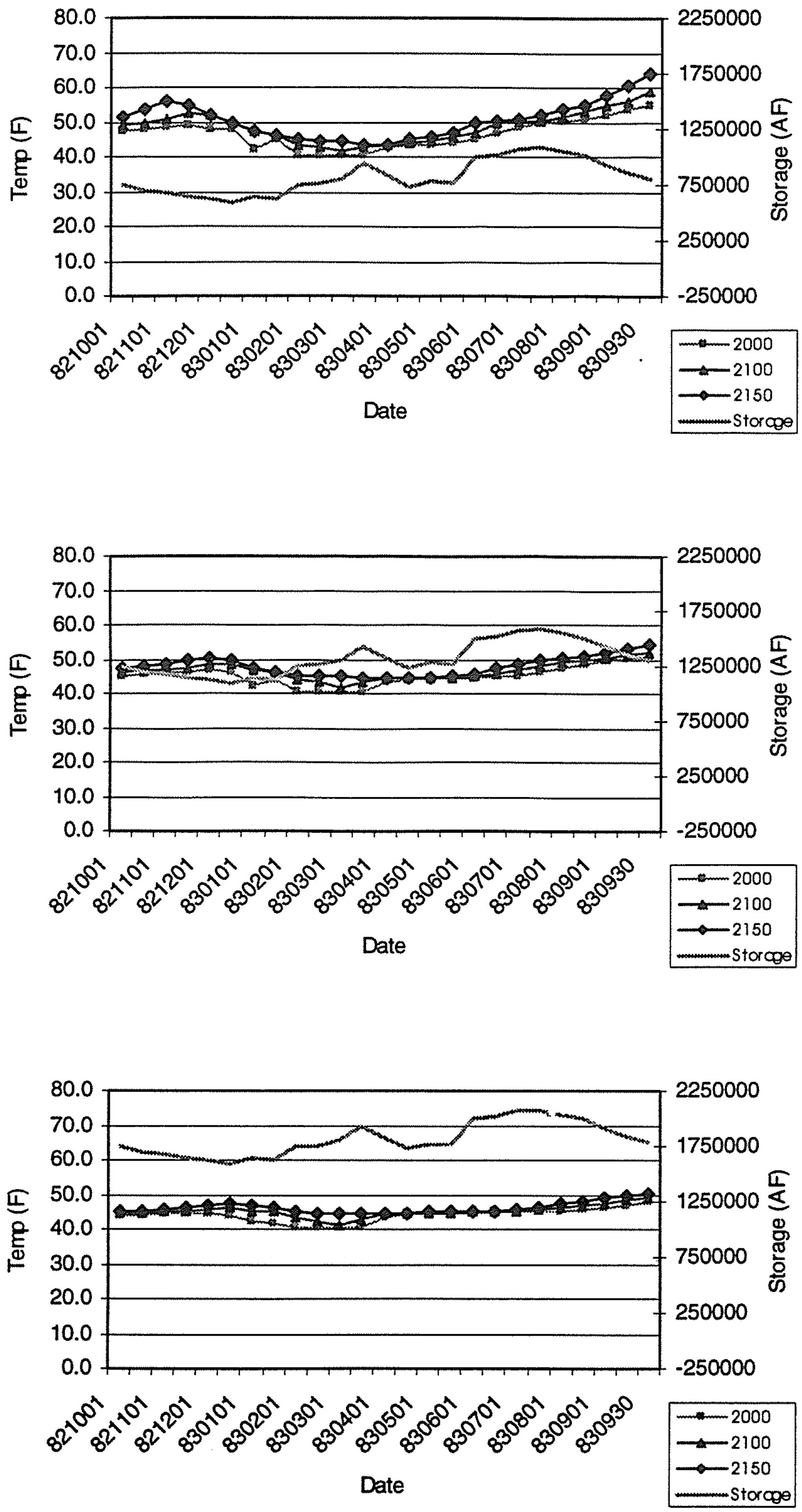
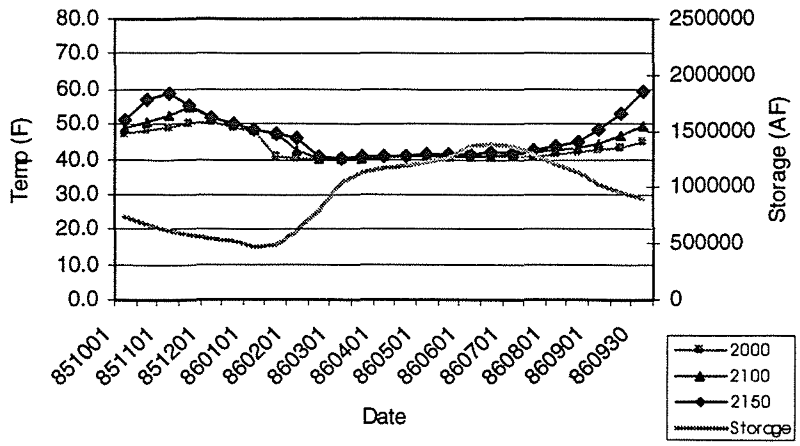
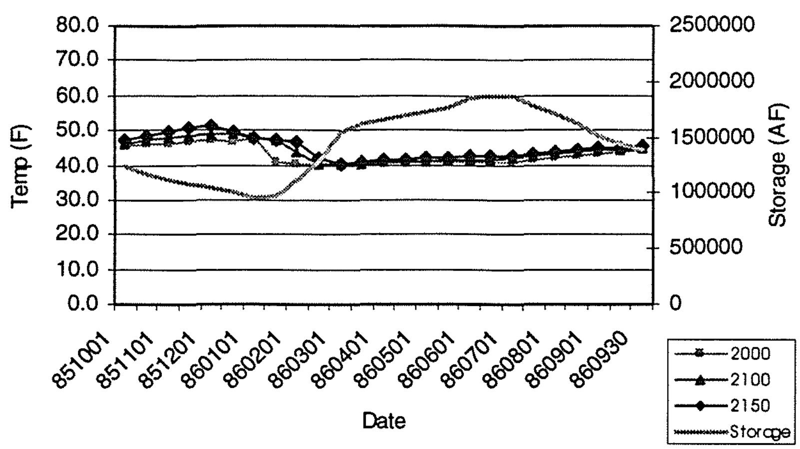


Figure N.2 Trinity Reservoir storage and water temperature; WY 1983 Conditions; carryover storage of 750,000 acre-feet, 1,250,000 acre-feet and 1,750,000 acre-feet (top to bottom)





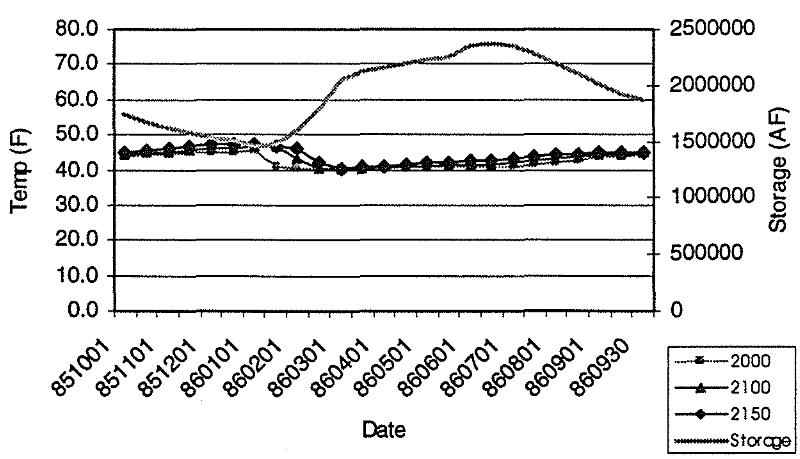


Figure N.3 Trinity Reservoir storage and water temperature; WY1986 Conditions; carryover storage of 750,000 acre-feet, 1,250,000 acre-feet and 1,750,000 acre-feet (top to bottom)

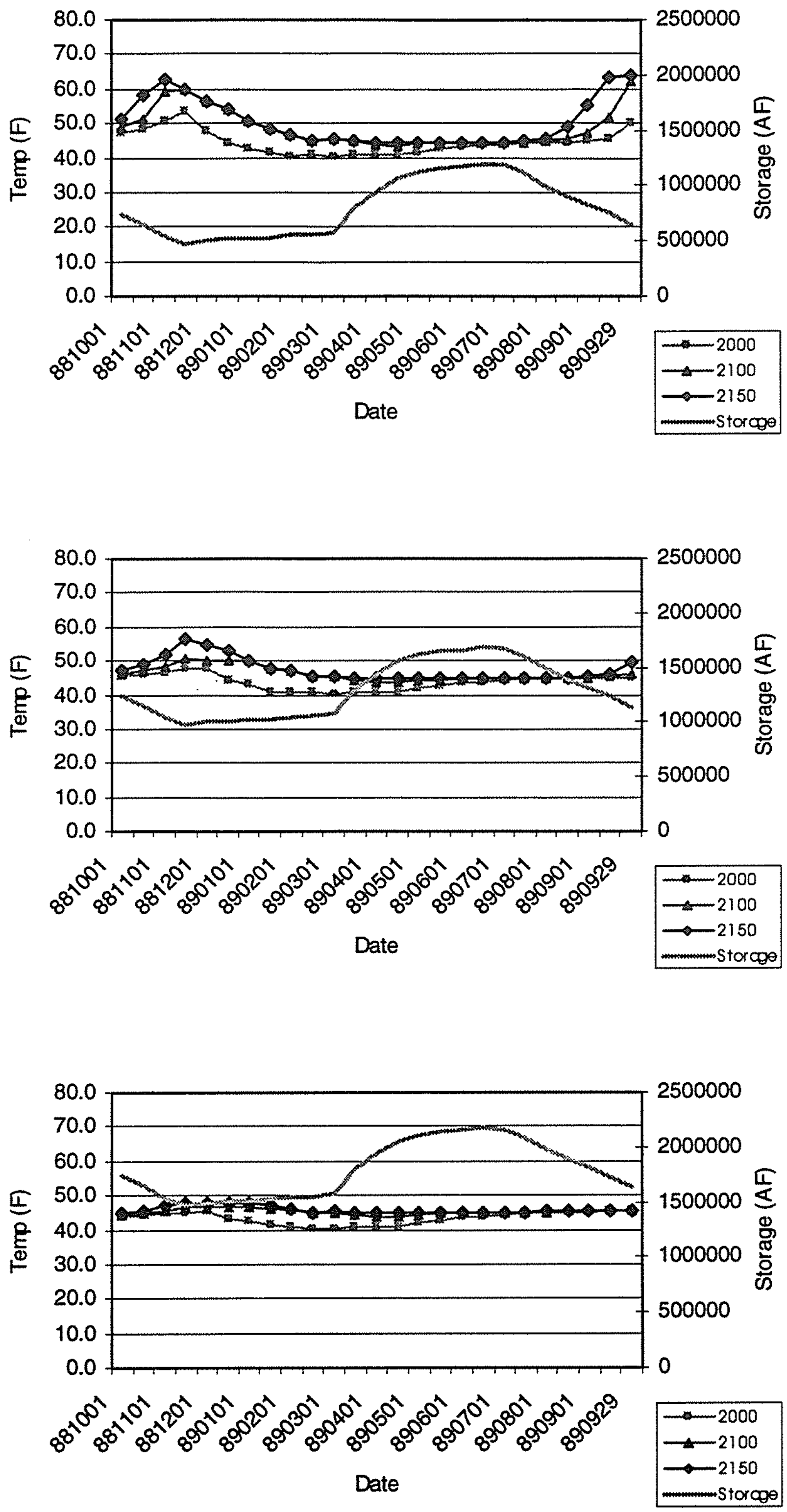


Figure N.4 Trinity Reservoir storage and water temperature; WY1989 Conditions; carryover storage of 750,000 acre-feet, 1,250,000 acre-feet and 1,750,000 acre-feet (top to bottom)

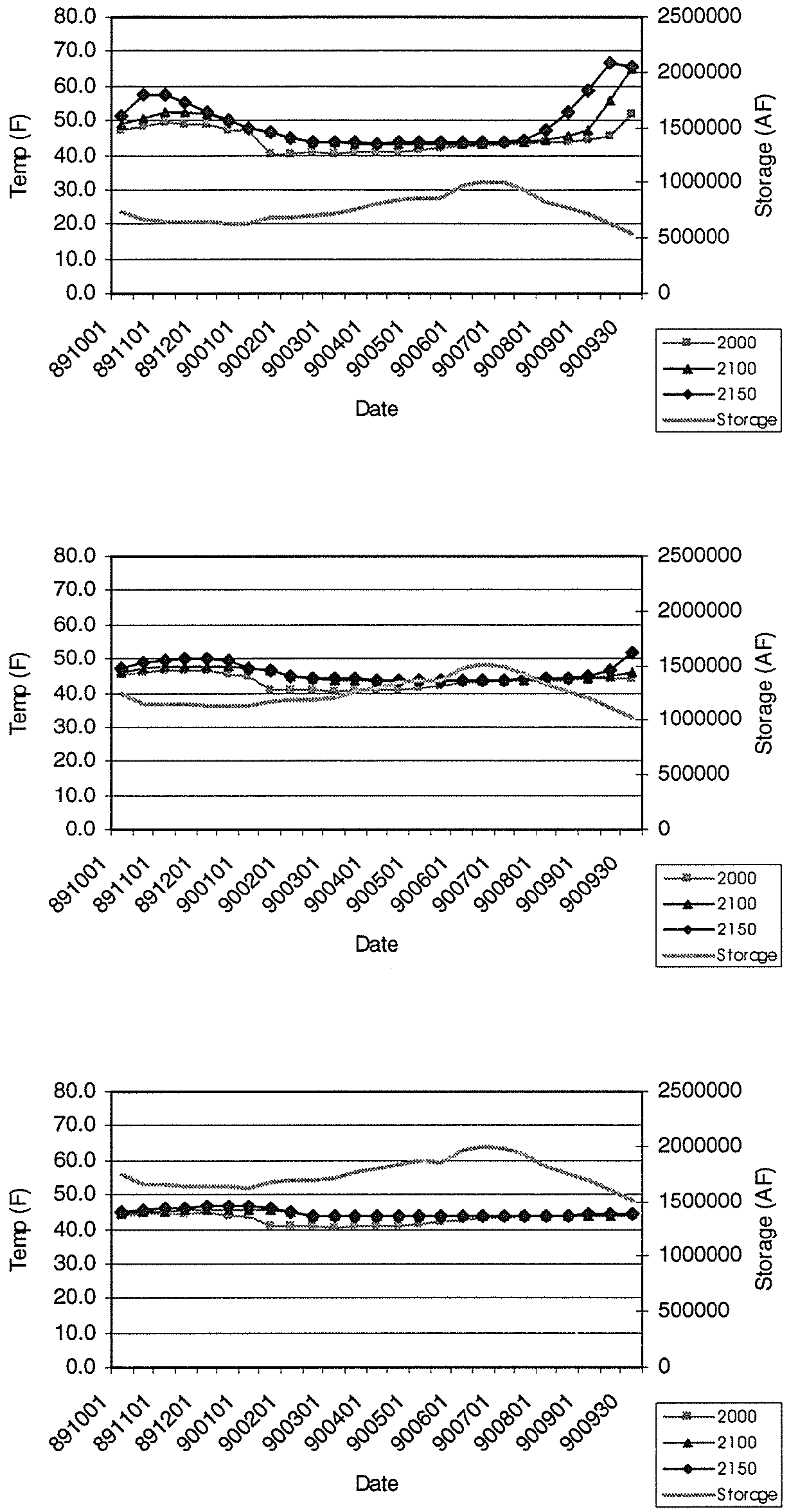


Figure N.5 Trinity Reservoir storage and water temperature; WY1990 Conditions; carryover storage of 750,000 acre-feet, 1,250,000 acre-feet and 1,750,000 acre-feet (top to bottom)

Appendix O WQRRS User's Manual

The WQRRS User's Manual (USACOE-HEC, 1986) is included as a separate attachment.