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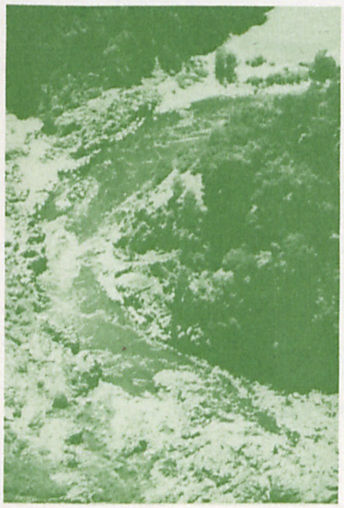

MISCELLANEOUS PAPER EL-87-15

DEVELOPMENT OF A MODEL TO PREDICT LONGITUDINAL WATER TEMPERATURES FOR THE ROGUE RIVER, OREGON

by

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This report documents efforts to modify and implement the riverine water quality model, QUAL II, as a predictive/management tool for assessing effects of Lost Creek Dam operation on downstream temperatures in the Rogue River. Some of the topics addressed in this report are data synthesis of missing or unavailable observed data, results of calibration/verification, model sensitivity to operational changes, and software development to increase usability of the model. Each topic is discussed as related to the study objective; recommendations are presented to avoid model misuse.

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PREFACE

This report was prepared within the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The study was sponsored by the US Army Engineer District, Portland, and was funded under Intra-Army Reimbursable Services Order No. E86850133, dated 10 January 1985, and No. E86860076, dated 1 November 1985.

The study was conducted and the report was written by Ms. Dorothy E. Hamlin and Dr. John M. Nestler of the Water Quality Modeling Group (WQMG), Ecosystem Research and Simulation Division (ERSD), EL, WES. This report was prepared under the direct supervision of Mr. Mark Dortch, Chief, WQMG, and under the general supervision of Mr. Donald L. Robey, Chief, ERSD, and Dr. John Harrison, Chief, EL. Technical reviews by Mses. Sandra L. Bird and Lillian T. Curtis, both of WQMG, are gratefully acknowledged. The report was edited by Ms. Jessica S. Ruff of the WES Information Products Division.

COL Dwayne G. Lee, CE, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

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

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

Multiply	By	To Obtain
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9	Celsius degrees*
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres

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

DEVELOPMENT OF A MODEL TO PREDICT LONGITUDINAL WATER TEMPERATURES FOR THE ROGUE RIVER, OREGON

PART I: INTRODUCTION

Background

1. The Rogue River in the southwestern part of the state of Oregon, with 84 miles* of the lower river designated as "wild and scenic," supports one of the most valuable salmon fisheries in the Pacific Northwest. The fishery resources of the Rogue River have made this area nationally famous, attracting approximately 9,000 anglers annually. Recent estimates place a value of $24 million on this fishery resource (US Army Engineer District (USAED), Portland 1983). The USAED, Portland, regulates flow in the Rogue River by operating Lost Creek and Applegate Dams.

2. The USAED, Portland, has sponsored studies to determine the effects of variables such as flow, temperature, and turbidity as potential factors causing the decline of the salmon fisheries since impoundment. These studies, conducted by the Oregon Department of Fish and Wildlife (ODFW), have tentatively identified the effects of flow, temperature, and other variables on salmon life-stages in the Rogue River. Since the salmon fishery is such a valuable resource, Lost Creek and Applegate Dams are operated in accordance with the recommendations of the ODFW whenever possible, to meet the temperature and flow requirements for different life-stages of salmonid species that use the Rogue River for spawning, rearing, and juvenile development.

3. To meet downstream temperature and water quality requirements, each project has incorporated a selective withdrawal system in its design. The selective withdrawal structures can mix release water from up to five different thermal layers, giving more control over water temperature released from the projects (USAED, Portland 1983).

4. During the last 3 years considerable controversy has arisen concerning the operation of Lost Creek Dam for improved fishery benefits. Much of

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

the controversy centers on the effects of Lost Creek Dam on downstream temperatures; water temperature in the Rogue River is thought to be one of the most critical factors determining the success of some salmonid species. Therefore, the availability of a highly accurate model would allow assessment of the operation of Lost Creek Dam for fisheries benefits.

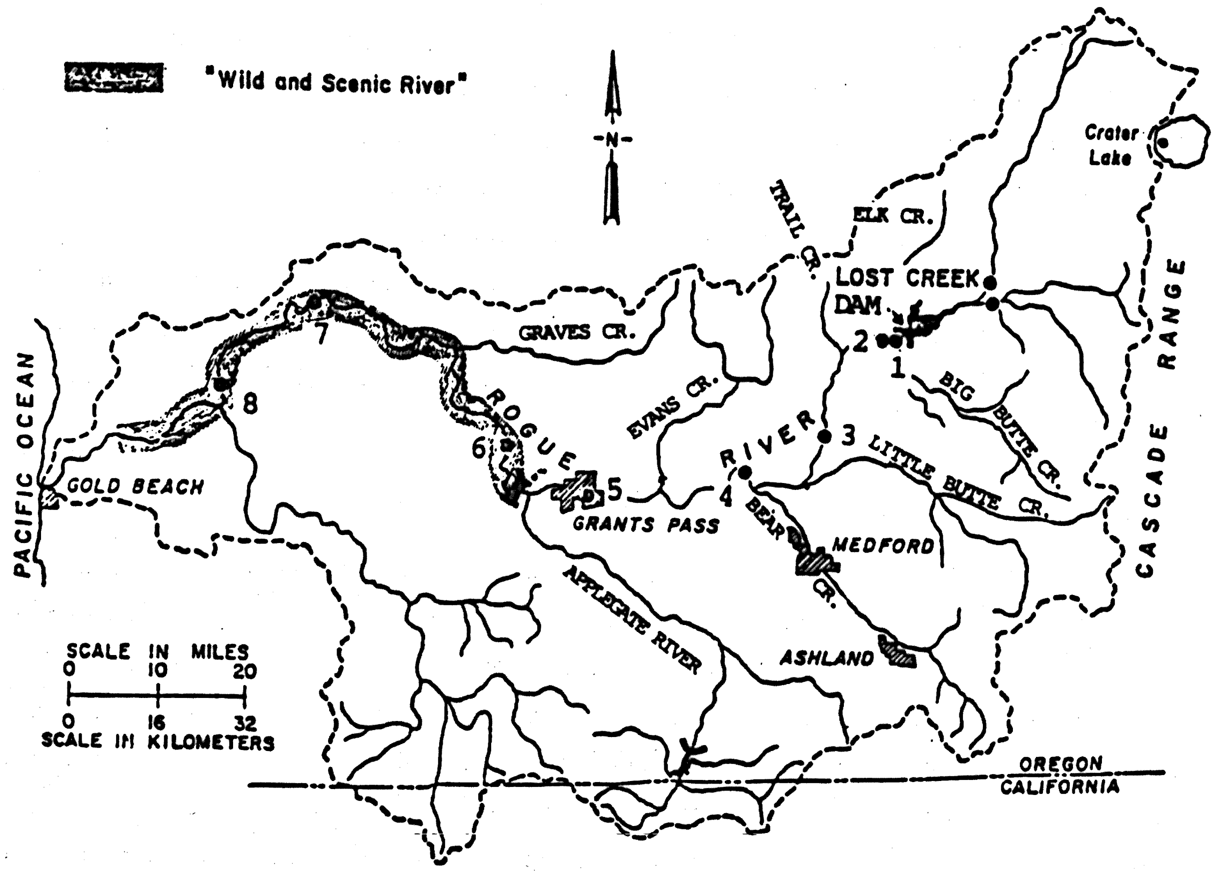
5. This report documents efforts by the US Army Engineer Waterways Experiment Station (WES) to modify and implement the riverine water quality model, QUAL II, as a predictive/management tool for assessing the effects of Lost Creek Dam operation on downstream temperatures in the Rogue River.

Objective

6. The objective of the work reported herein was to develop a numerical simulation model for predicting downstream effects of Lost Creek Dam operation on water quality variables critical to salmon abundance. Development of a numerical water quality model for the Rogue River will allow assessment of the effects of reservoir operation on the fishery, and the formulation of improved management strategies for this valuable resource. Thus far, efforts have focused on temperature simulation, although other water quality variables of interest (turbidity, for example) can be included as required.

Site Description

7. The Rogue River originates in the Cascade Mountains northwest of Crater Lake and flows south and west 210 miles to the Pacific Ocean at Gold Beach, Oreg. The portion of the Rogue River chosen for the application of QUAL II begins at Lost Creek Dam (river mile (RM) 157.4) and extends downstream to Marial, Oreg. (RM 49) (Figure 1). Within this study reach, a number of significant features occur. There are two existing Corp projects, Lost Creek Dam on the upper Rogue River and Applegate Dam (RM 56) on the Applegate River, a major tributary of the Rogue River at RM 94.5. Lost Creek Dam has a drainage area of 674 square miles (13 percent of the total area of the Rogue River basin) and a storage capacity of 465,000 acre-ft. It is currently operated to provide a minimum release flow of 700 cfs. In comparison, the Applegate Dam has a drainage area of 223 square miles (4.5 percent of the total basin drainage area), a storage capacity of 82,000 acre-ft, and is



Gaging Station	River Mile
1 - at McLeod	156.0
2 - near McLeod	154.2
3 - at Dodge Bridge	138.5
4 - at Raygold	125.2
5 - at Grants Pass	101.8
6 - at Merlin	86.0
7 - at Marial	49.0
8 - near Agness	29.7

Figure 1. Rogue River basin showing the gaging stations used in this study (USAED, Portland 1974)

operated to provide a minimum release flow of 100 cfs. Both dams are operated for flood control, fish protection and enhancement, and recreation. Lost Creek Dam is operated for hydropower production. A third dam, Elk Creek Dam (RM 1.7), is under construction on Elk Creek, a tributary of the upper Rogue River at RM 152. It has a drainage area of 133 square miles (3 percent of the total basin drainage area) with a storage capacity of 110,000 acre-ft. Elk Creek Dam is proposed to have a minimum release flow of 30 cfs. This new project will be operated for flood control, irrigation, fish and wildlife enhancement, water supply, recreation, and water quality control.

8. In general, the Rogue River is a meandering, steep-sloped channel with the upper reaches usually wider than the lower reaches. There are many deep pools in the narrow reaches (i.e., between Grants Pass (RM 101.8) and Gold Hill (RM 120)) where depths greater than 30 ft have been sounded during periods of low flow (Harris 1970). Two run-of-the-river dams, Raygold Dam (RM 125.4) and Savage Rapids Dam (RM 107.5), occur between Bear Creek (RM 126) and Grants Pass.

9. The climate for the study reach is characterized by mild, wet winters and hot, dry summers. The nearest weather station to the study site, at Medford, Oreg. (el 1,290 ft NGVD), has a monthly average temperature range from 3.0° C in January to 22.2° C in July and an annual precipitation of 19.78 in. Climatological data for Medford and other selected stations in the Rogue River basin are summarized in Table 1.

10. The streamflow regimen of the Rogue River and tributaries is very similar to the precipitation pattern. During June through October (periods of low precipitation), low flows prevail, while during the rest of the year medium to high flows usually occur. These flows can fluctuate widely depending upon meteorological conditions, snowmelt, etc. The topography and geology of the Rogue River basin result in rapid runoff, causing peak flows within hours after a rainstorm. The average annual runoff of the Rogue River below South Fork Rogue River (basin area, 650 square miles) near Prospect, Oreg. (near headwaters of Lost Creek Lake), for the period 1929 to 1972 is approximately 1,780 cfs or about 1.3 million acre-ft per year (USAED, Portland 1974).

Table 1

Summary of Climatological Data from Stations in the Rogue River Basin

Parameter	Ashland	Fish Lake	Gold Beach	Grants Pass	Illahe	Medford	Prospect	Waldo
Elevation	1780	4837	50	925	348	1298	2482	1650
Period of record	1879-1964	1918-56	1890-1964	1889-1964	1939-64	1911-64	1906-64	1913-35
Precipitation								
Normal annual, in.	19.99	42.23	81.41	31.07	87.13	19.78	41.69	49.23
Maximum annual, in.	29.33	59.32	119.26	43.83	126.99	28.78	61.51	64.03
Year of maximum annual	1948	1945	1953	1909	1953	1956	1953	1926
Minimum annual, in.	10.22	27.13	51.24	16.79	61.96	10.42	26.39	33.54
Year of minimum annual	1959	1928	1930	1949	1939	1959	1924	1923
Maximum monthly, in.	12.29	16.27	31.84	16.06	41.43	12.72	23.68	22.54
Month and year of maximum monthly	Jan 1881	Nov 1942	Jan 1890	Dec 1964	Dec 1964	Dec 1964	Dec 1964	Jan 1914
Maximum 24-hr recorded, in.	4.00	3.35	7.34	5.27	8.38	3.20	4.39	4.48
Month and year of 24-hr maximum	Oct 1908	Nov 1938	Dec 1955	Oct 1950	Dec 1945	Dec 1964	Dec 1964	Oct 1924
Snowfall								
Maximum seasonal, in.	69.8		3.5	44.2	51.0	31.6	146.4	
Season of maximum	1916-17		1934-35	1916-17	1949-50	1955-56	1936-37	
Temperature, °F								
Normal annual	52.6	44.3	52.3	54.2	55.1	54.0	49.8	51.0
Normal annual maximum	64.9	56.9	60.0	68.2	67.1	66.8	64.5	63.9
Normal annual minimum	40.0	31.3	44.7	39.2	43.2	41.1	34.9	37.4
Absolute maximum	106	100	98	114	112	115	106	109
Absolute minimum	-1	-15	20	0	15	-10	-12	-1
January mean	37.5	29.2	46.4	39.2	40.4	37.5	35.4	36.4
July mean	69.1	61.8	58.0	70.6	70.0	71.9	66.2	67.3
Difference, July-January	31.4	32.6	11.6	31.4	29.6	34.4	30.8	30.9

Source: USAED, Portland (1974).

Simulation Strategy

11. Development of a predictive/management tool as an aid for assessing the effects of operation of Lost Creek Dam on downstream water temperatures involved a sequence of interrelated steps. These steps are briefly outlined below as an overview of the organization of this report.

Modeling approach

12. This section identifies the criteria used in the selection of QUAL II for modeling Rogue River water temperatures, describes the operation of QUAL II, and presents modifications made to the code to increase its utility for this application.

Data collection

13. This section identifies data sources used in the study as well as how unavailable and missing data were synthesized. Data manipulations such as standardization, transformation, and conversions are also discussed.

Model calibration/verification

14. This section discusses steps involved in hydraulic and thermal calibration/verification of QUAL II for the Rogue River system. Also, the results of calibration/verification runs are presented and discussed.

Sensitivity

15. This section relates water temperatures downstream of Lost Creek Dam to Lost Creek Dam operation. Assessment of the regression equations for predicting ungaged tributary flows and temperatures is presented also.

Software development

16. This section discusses software developed to increase the usability of QUAL II by aiding the user in the development of new input data sets and the examination of simulation results.

PART II: MODELING APPROACH

Model Selection

17. Selection of a numerical model to represent a system is based on a number of factors, including issues to be addressed, characteristics of the system, and model availability.

18. Although several riverine water quality codes are available that can predict flow, temperature, and turbidity, QUAL II was selected for this application of the following reasons:

- a. It can simulate water quality conditions (in this case flow, temperature, and turbidity) in a stream network.
- b. It can be applied under varying meteorological conditions (at 3-hr intervals).
- c. It is relatively easy to use.
- d. It is well documented and supported by the US Environmental Protection Agency (USEPA).
- e. It is widely used and a generally accepted standard for use in modeling water quality under one-dimensional (longitudinal), steady-flow conditions.
- f. It is economical to use, thus allowing long-term simulations on Corps of Engineers (CE) mini- and micro-processors.
- g. It has the capability to model other water quality constituents that could be used in the future if required.

19. When the decision to use QUAL II for this study was made, one of the limitations of the model was that it applied the same meteorological conditions throughout the study reach. Thus, as in the case of the Rogue River, the predictions may not be totally accurate when the river crosses different climatological zones. However, the USEPA is in the process of changing the QUAL II code so that different meteorological conditions can be used as the river crosses different climatological zones. If necessary, the present application can be updated with the capability to handle more than one set of meteorological conditions.

20. Stream temperature models developed by the US Fish and Wildlife Service were also considered but not selected because they could neither perform dynamic temperature simulations nor model turbidity.

Model Description

21. QUAL II is a one-dimensional (longitudinal) stream water quality model with branching capability. It solves the time-dependent water quality constituent transport equation allowing for description of advection, dispersion, and sources/sinks. This equation is sometimes referred to as the energy equation for temperature or the differential mass balance equation for other constituents.

22. Hydraulic conditions (flow rate and depth) used within the energy and mass balance equations are determined from steady, nonuniform flow conditions by satisfying continuity and either using stage-discharge relationships or solving Manning's equation with channel geometry information. Steady flow implies that the flow, velocity, width, and depth at a given point in the stream network are constant with time. Nonuniform flow allows velocity, flow, width, and depth to change in the longitudinal direction from reach to reach.

23. In approximating the prototype, QUAL II subdivides the stream system into reaches (the basic division of the model). Reaches represent portions of the river having similar channel geometry, hydraulic characteristics, and chemical/biological coefficients. Reaches are further divided into equally spaced units called computational elements. Figure 2 shows how QUAL II conceptualizes a river basin (National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) 1982). Each computational element has inputs, outputs, and reaction terms. The energy and differential mass balance equations are solved simultaneously (implicitly) for each computational element.

24. Computational elements are connected in the direction of flow to form reaches; thus, the output from one element becomes the input to the next element downstream. QUAL II recognizes seven different element types depending on the type of input and/or output and the location in the stream network. The following tabulation identifies the flags (identifiers) for each computational element (NCASI 1982).

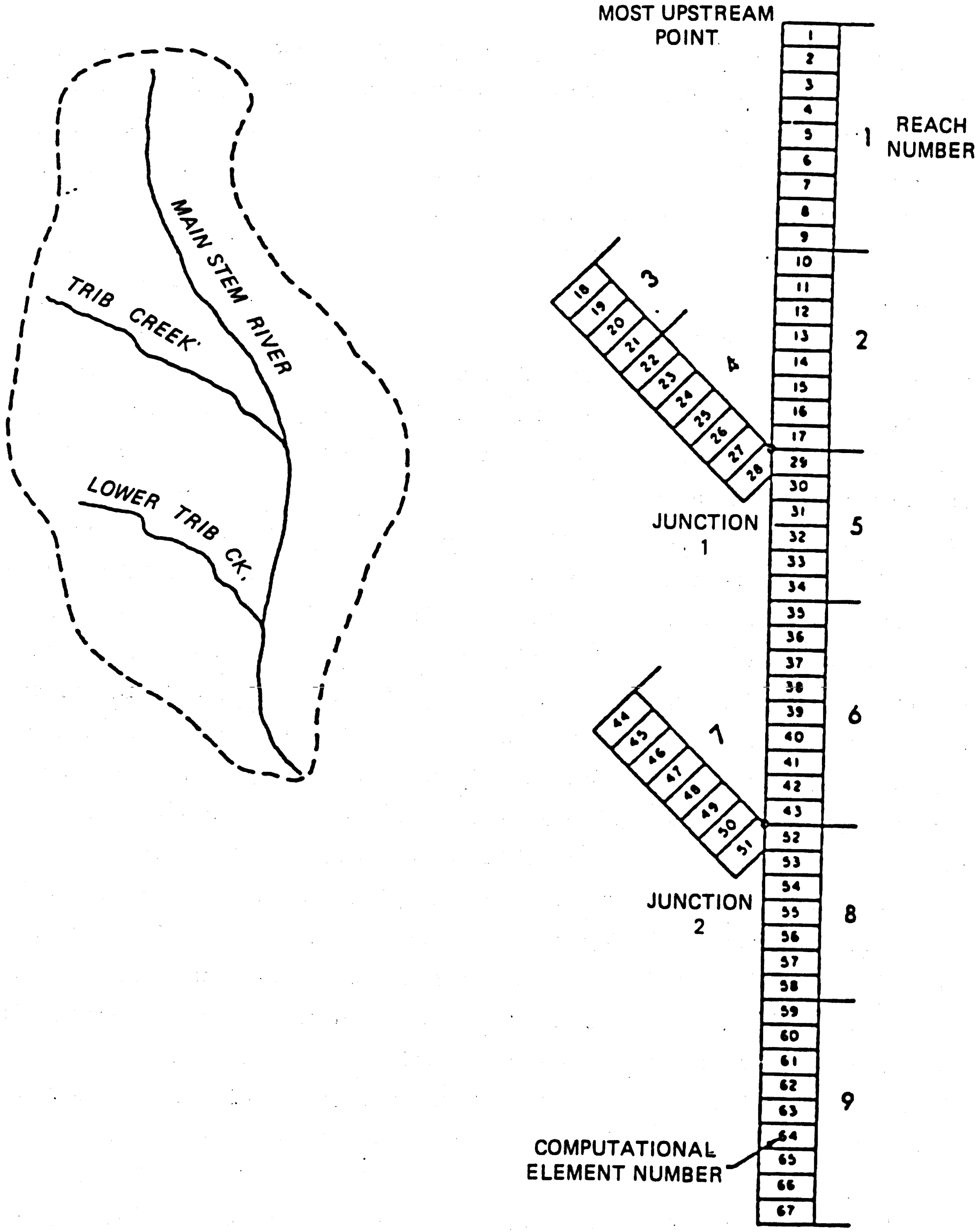


Figure 2. Schematic of a stream system showing computational elements and reaches (NCASI 1982)

Identifying Number	Type of Element
1	Headwater element
2	Ordinary element
3	Element upstream of junction on the main stem of river
4	Junction element
5	Last element in system
6	Element with a point source
7	Element with a withdrawal

25. A type 1 element represents a headwater element of a tributary as well as the main stem of the river system, and as such must always be the first element in a reach. An ordinary or standard element (type 2) is one that cannot be classified as any of the other types of elements. The only input permitted in a standard element is incremental inflow. The type 3 element is used to designate an element on the main stem of the river just before a junction element type 4 that has the simulated tributary entering it. Element type 5 represents the last element in the system, and there should be only one of this type. The remaining two types of elements (6 and 7) have inputs (wasteloads, returns, and unsimulated tributaries) and water withdrawals, respectively.

26. Longitudinal changes in water quality constituents are derived by solving the differential mass and/or energy balance equation at the beginning of one of the headwater reaches and continuing downstream until a junction is encountered. Once a junction is encountered, the mass balance equations are solved for all the computational elements in the other reaches entering the junction before continuing beyond the junction. The result is a set of partial differential equations equal to the number of computational elements in the system. These partial differential equations are linked through the inputs and outputs of each element and are solved using an implicit finite difference procedure employing the Thomas algorithm.

27. For this application of QUAL II on 108 miles of the Rogue River below Lost Creek Dam, there were 57 reaches subdivided into 378 elements, spaced 1,500 ft apart. Two headwaters (Lost Creek Dam and Elk Creek) and 11 point sources that represented tributaries comprised the Rogue River

system. Of all the tributaries included in the study, Elk Creek was the only one treated as a branched reach, since cross-section data were available. The other tributaries were treated as point sources. In addition, irrigation withdrawals and returns were not considered in the system because no daily averaged values for these variables were available, and sensitivity analysis showed no significant influence of these variables on water temperature of the Rogue River during critical time periods (summer flows).

Model Modifications

28. Several model modifications were made to QUAL II to accommodate study needs. One of the modifications to QUAL II was to allow for variable discharge and temperature updates at inflow boundaries on a daily basis. Because QUAL II is based on the steady-flow assumption and does not provide for an unsteady flow routing, updating the inflow rate results in changing the flow instantaneously throughout the reach. Use of the flow update feature provided acceptable results as long as discharge update intervals were large with respect to the travel time of the system and the percent change in flow was not too great. For example, suppose the travel time through the system was approximately 3 days and the discharge was updated from 1,000 cfs on Julian day 100 to 1,500 cfs on Julian day 101. In this case, a phase error would occur at the most downstream stations because the 1,500-cfs flow would be assumed instantaneously, when in fact this higher flow would not reach these stations until after about 3 days. Therefore, every time there is a flow update, some error is introduced for a period (equivalent to the reach travel time). However, if the flow update intervals are much larger than the travel time and the amount of flow change is relatively small, the error can be kept small.

29. Water quality constituents in QUAL II can be computed in either a steady-state mode (the time derivative of concentration is omitted from the mass balance equation, and the solution is computed in a single iteration) or dynamic mode (concentrations can change with time). In the dynamic mode, QUAL II uses a time step that is in hours (1 hr, 3 hr, etc.). The second modification to the code was to allow a time step as large as 24 hr and to provide daily average values for the output. The 24-hr time step decreased the

run time for a simulation of QUAL II, allowing efficient simulations of long time periods (entire year).

30. Finally, QUAL II was modified to calculate the values for water surface elevation and thalweg elevation for each element in the system. These variables were then used to aid in the hydraulic calibration efforts.

PART III: DATA REQUIREMENTS

Observed Data

31. Numerical models require observed data for formulation, calibration, and verification purposes. Observed data used in this study are listed and described in Table 2.

32. Channel geometry data were obtained from the US Geological Survey (USGS) for RM 76.5 to RM 157.4. However, cross-section data for approximately 25 miles of the study area (Galice (RM 76) to Marial (RM 49)) were unavailable from published sources. Cross-section data obtained by the WES in conjunction with the USAED, Portland, during a site inspection during July 1985 were used. However, in comparison to the cross-section data obtained from the USGS, the 1985 cross-section data were not measured as frequently or with the same accuracy.

33. Meteorological data required by QUAL II (cloud cover, dry bulb and wet bulb temperature, air pressure, and wind speed) were extracted from weather data tapes available at the weather station at Medford, Oreg., a first-order meteorological station. There were two first-order weather stations in or near the study area: Medford and North Bend, Oreg. The Medford station was chosen to represent weather conditions for the portion of the Rogue River being modeled since it was located approximately 26 miles southwest of Lost Creek Dam, while North Bend was located on the coast of Oregon north of Gold Beach.

Data Manipulations

34. Data manipulations were necessary to convert the data to the form required by QUAL II. Minimum and maximum observed water temperature values for the tributaries of the Rogue River (Table 2) were averaged to obtain mean daily temperature values, and 3-hr values of meteorological data were averaged to obtain mean daily values.

Table 2

Observed Data Used for the Rogue River Study

Data Type	Source	Gaged Station Name	Station Number	Location RM	Extent*	Comment
Stage/discharge*	USGS Portland	at McLeod	14335075	156	1978-81	
		near McLeod	14337600	154	1978-81	
		Dodge Bridge	14339000	138	1978-81	
		Raygold	14359000	125	1978-81	
		Grants Pass	14361500	102	1978-81	
		near Agness	14372300	30	1978-81	
Tributary stage/ discharge	USGS Portland	Big Butte Creek	14337500	0.6	1978-81	Variable name BBC
		Elk Creek	14338000	0.4	1978-81	Variable name ELK
		N Fork Little Butte	14343000	15	1978-81	Variable name NLB
		S Fork Little Butte	14341500	18	1978-81	Variable name SLB
		Bear Creek	14357500	10	1978-81	Variable name BCR
		W Fork Ashland Creek	14353000		1978-81	Variable name WAC
		E Fork Ashland Creek	14353500		1978-81	Variable name EAC
		Applegate Wilderville	14369500	6	1978-81	Variable name APA
		Graves Cr Pease Bridge	14371500	27	1978-81	Variable name GRC
		Illinois R near Agness	14379200	3	1978-81	Variable name IRA
		E Fork Illinois Takima	14372500	71	1978-81	Variable name EIR
		W Fork Illinois Rock Cr	14375500	13	1978-81	Variable name WIR
Temperature	USGS Portland	at McLeod	14335075	156	1978-81	
		near McLeod	14337600	154	1978-81	
		Dodge Bridge	14339000	138	1978-81	
		Raygold	14359000	125	1978-81	
		Grants Pass	14361500	102	1978-81	
		near Merlin	14370400	86	1978-81	
		near Marial	14372250	49	1978-81	
Tributary temperature	USGS Portland	Big Butte Creek	14337500	0.6	1978-81	Only maximum and minimum daily temperature values available
		Elk Creek	14338000	0.4	1978-81	
		Applegate Wilderville	14369500	6	1978-81	

(Continued)

* More data were available but not used for this application.

Table 2 (Concluded)

Data Type	Source	Gaged Station Name	Station Number	Location RM	Extent*	Comment
Cross sections	USGS Portland			157-102		
	USGS Stepback Water Analysis			102-76		
	Field notes			76-49		
Low-flow water surface elevations	USGS Open File Report			157-102		
Thalweg elevations	USGS Open File Report			157-102		
	USGS maps			102-49		
Rating curves	USAE Medford	near McLeod	14337600	154	1978-81	
		Dodge Bridge	14339000	138	1978-81	
		Raygold	14359000	125	1978-81	
		Grants Pass	14361500	102	1978-81	
		Near Agness	14372300	30	1978-81	
Tributary rating curves	USAE Medford	Big Butte Creek	14337500	0.6	1978-81	Variable name BBC
		Elk Creek	14338000	0.4	1978-81	Variable name ELK
		N Fork Little Butte	14343000	15	1978-81	Variable name NLB
		S Fork Little Butte	14341500	18	1978-81	Variable name SLB
		W Fork Ashland Creek	14353000		1978-81	Variable name WAC
		E Fork Ashland Creek	14353500		1978-81	Variable name EAC
		Applegate Wilderville	14369500	6	1978-81	Variable name APA
		Graves Cr Pease Bridge	14371500	27	1978-81	Variable name GRC
		Illinois R near Agness	14379200	3	1978-81	Variable name IRA
Meteorological	USAF Environmental Technical Applications Center	Medford, Oreg.			1978-81	QUAL II used cloud cover, dry bulb and wet bulb temp, air pressure, and wind speed

Data Synthesis

Background

35. QUAL II requires sufficient input data to calculate both a mass balance and heat budget throughout the system. However, the Rogue River temperature study was initially limited by a lack of observed data, particularly for many of the tributaries in the system. Additionally, gaps extending from 1 day to several months occurred in the available data for tributary temperature, which further hindered model implementation.

36. Knowledge of tributary inflows was considered an important element in properly assessing the effects of operation of Lost Creek Dam on downstream temperatures versus other factors in the system that could be affecting Rogue River water temperature. For example, comparison of readings at the Grants Pass gage with readings at the near McLeod gage indicated that approximately 30 to 50 percent of the flow in the Rogue River at Grants Pass was contributed by tributaries.

37. To overcome the problems caused by unavailable data, regression equations were developed to synthesize flow and temperature data for those tributaries that lacked data or for which the data contained gaps. The methods presented in the following text are not alternatives to monitoring and gaging but rather represent an attempt to synthesize data of sufficient quality to meet the objectives of this study. Other use of the equations presented below should be made with caution.

38. The approach used to synthesize tributary data was determined by the quantity and quality of available data. Flow data (Table 2) were available for most of the major tributaries of the Rogue River, whereas tributary water temperature data were generally available. Flow data were available for the following gaged tributaries: Big Butte, Elk Creek, Little Butte, Bear Creek, Applegate River, and Graves Creek. However, in the case of Little Butte and Graves Creeks, gages were located well upstream of the mouth of the tributary, and tributary flows had to be adjusted to account for runoff between the gage and the mouth of the tributary. Temperature data (Table 2) were available only for Big Butte, Elk Creek, and the Applegate River. Neither flow nor temperature data were available for Trail Creek (RM 148.6), Reese Creek (RM 139.2), Sams Creek (RM 123), Sardine Creek (RM 117.7), and Evans Creek (RM 110). Gaging and monitoring these creeks would be expensive

and time consuming, and would have resulted in unacceptable delays in completion of this study.

39. A survey of the tributary characteristics (Harris 1970) supplemented by a site evaluation and inspection of temperature data for Elk Creek and Big Butte Creek indicated further difficulties with obtaining flow and water temperature data for the Rogue River tributaries. The tributaries differed substantially in area, discharge, slope, elevation, geology, land use patterns, precipitation patterns, and other variables, all of which would be expected to cause tributary flows and water temperatures to vary considerably within the basin. The heterogeneity of the Rogue River tributaries, particularly their pronounced differences in elevation, precluded use of standard methods of synthesizing temperature data (Drummond and Robey 1975).

40. Regression analysis, described below, was performed to synthesize tributary flows and water temperatures needed to supplement data obtained from the USGS. The equations developed by regression analysis are embedded in the preprocessor program and are performed automatically to generate data necessary to run the Rogue River model.

Flow data synthesis

41. Synthesis of flow data for ungaged tributary streams can be broadly separated into three steps:

- a. Identify/develop independent variables appropriate for regression analysis.
- b. Perform multiple regression analyses to develop statistical relationships between a tributary flow and a set of independent variables.
- c. Implement regression results.

42. Independent variables. Lystrom (1970) identified many of the independent variables (Table 3) that could be used to develop regression equations for predicting tributary flows. In addition to Lystrom (1970), other data sources to develop the independent variables for regression analysis included USGS quad maps and US Weather Bureau (1961). Daily average flow in Big Butte Creek was also included as a independent variable. Correlation analysis (SAS Institute, Inc. 1982) indicated that Big Butte Creek flows were good predictors of flows in other gaged tributaries (Table 4) and, thus, should also be a good predictor of flows for ungaged tributaries.

Table 3

Basin Characteristics for Gaging Stations Used in the Regression Analysis

Station Number	Drainage Area, A	Slope S	Length L	Storage S_t	Elevation E	Forest F	Precipitation P	Precipitation Intensity $I_{24,2}$	Temperature Index T_1	Solids Index S_1
14335500	138	141	16.4	1.34	3.95	98	36	2.10	22	4.2
14337500	249	109	29.8	1.20	3.52	96	36	2.30	24	3.3
14338000	133	121	20.5	1.00	3.10	100	39	2.80	28	3.5
14339000	1,215	34.2	79.5	1.11	3.93	97	43	2.60	25	3.9
14339200	6.42	71.0	5.0	1.00	1.57	49	18	2.10	29	1.2
14339500	16.0	108	7.5	1.05	5.35	100	26	1.80	22	5.6
14341500	138	182	22.3	1.01	4.44	87	22	1.70	25	3.6
14353000	10.5	617	5.8	1.00	5.12	100	21	1.90	27	5.6
14353500	8.14	535	6.2	1.00	5.04	100	22	1.85	26	5.6
14359000	2,053	30.3	92.3	1.16	3.56	86	35	2.00	25	3.6
14361300	7.41	334	4.0	1.00	1.98	94	29	2.80	30	3.2
14362000	223	166	17.5	1.09	4.28	95	35	2.80	27	2.1
14363000	297	95.3	28.4	1.07	3.90	96	32	2.70	28	2.6
14366000	483	64.7	37.1	1.04	3.66	93	29	2.60	29	3.2
14368500	8.60	475	5.0	1.00	3.22	97	38	3.40	28	3.2
14369500	694	38.1	56.1	1.03	3.63	90	31	2.70	29	2.8
14369800	3.07	376	3.1	1.00	1.76	85	38	3.90	31	3.2
14370000	31.4	180	10.4	1.00	2.16	92	45	4.00	31	3.2
14370200	3.16	332	2.7	1.00	1.63	100	34	3.70	30	3.2
14371500	22.1	132	10.3	1.00	3.48	101	53	3.00	31	1.2
14372500	42.3	308	9.7	1.04	3.90	99	74	5.30	29	3.2
14375000	76	170	15.1	1.05	3.91	98	57	3.80	27	3.6
14375500	42.4	128	9.7	1.02	2.50	93	80	5.80	31	3.2
14377000	364	112	26.9	1.04	2.93	88	66	5.00	29	3.2
14377500	23	333	6.8	1.04	3.37	97	43	3.60	28	3.2
14377800	1.62	1,240	2.5	1.00	3.05	93	42	4.60	31	0.6
14378000	665	38.1	48.3	1.02	2.78	88	58	4.80	29	3.1
14378800	1.05	423	2.7	1.00	6.00	96	83	5.70	41	2.2
14378900	0.74	222	2.2	1.00	0.43	52	82	5.70	40	2.2

Source: Lystrom (1970).

Table 4

Results from Correlation Analysis Performed on Rogue River Tributaries

	BBC	ELK	SLB	NLB	BCR	WAC	EAC	APA	ORC	IRA	EIR	WIR
BBC	1.00000 0.0000	0.85832 0.0001	0.83582 0.0001	0.23182 0.0001	0.84772 0.0001	0.59962 0.0001	0.55988 0.0001	0.83276 0.0001	0.77552 0.0001	0.78767 0.0001	0.78679 0.0001	0.75930 0.0001
ELK	0.85832 0.0001	1.00000 0.0000	0.74342 0.0001	0.19424 0.0001	0.73219 0.0001	0.49766 0.0001	0.46975 0.0001	0.82823 0.0001	0.90605 0.0001	0.88222 0.0001	0.83964 0.0001	0.84550 0.0001
SLB	0.83582 0.0001	0.74342 0.0001	1.00000 0.0000	0.32478 0.0001	0.85814 0.0001	0.65078 0.0001	0.57365 0.0001	0.71141 0.0001	0.62270 0.0001	0.59203 0.0001	0.61673 0.0001	0.55499 0.0001
NLB	0.23182 0.0001	0.19424 0.0001	0.32478 0.0001	1.00000 0.0000	0.27025 0.0001	0.19697 0.0001	0.18657 0.0001	0.06832 0.0237	0.10577 0.0005	0.05973 0.0481	0.08643 0.0042	0.06795 0.0245
BCR	0.84772 0.0001	0.73219 0.0001	0.85814 0.0001	0.27025 0.0001	1.00000 0.0000	0.64877 0.0001	0.58285 0.0001	0.78197 0.0001	0.65408 0.0001	0.63983 0.0001	0.65649 0.0001	0.59919 0.0001
WAC	0.59962 0.0001	0.49766 0.0001	0.65078 0.0001	0.19697 0.0001	0.64877 0.0001	1.00000 0.0000	0.94676 0.0001	0.72142 0.0001	0.46480 0.0001	0.43779 0.0001	0.49129 0.0001	0.38475 0.0001
EAC	0.55988 0.0001	0.46975 0.0001	0.57365 0.0001	0.18657 0.0001	0.58285 0.0001	0.94676 0.0001	1.00000 0.0000	0.70305 0.0001	0.42774 0.0001	0.40716 0.0001	0.45143 0.0001	0.34653 0.0001
APA	0.83276 0.0001	0.82823 0.0001	0.71141 0.0001	0.06832 0.0237	0.78197 0.0001	0.72142 0.0001	0.70305 0.0001	1.00000 0.0000	0.78286 0.0001	0.78469 0.0001	0.78950 0.0001	0.71640 0.0001
ORC	0.77552 0.0001	0.90605 0.0001	0.62270 0.0001	0.10577 0.0005	0.65408 0.0001	0.46480 0.0001	0.42774 0.0001	0.78286 0.0001	1.00000 0.0000	0.95696 0.0001	0.93683 0.0001	0.92407 0.0001
IRA	0.78767 0.0001	0.88222 0.0001	0.59203 0.0001	0.05973 0.0481	0.63983 0.0001	0.43779 0.0001	0.40716 0.0001	0.78469 0.0001	0.95696 0.0001	1.00000 0.0000	0.95235 0.0001	0.96330 0.0001
EIR	0.78679 0.0001	0.83964 0.0001	0.61673 0.0001	0.08643 0.0042	0.65649 0.0001	0.49129 0.0001	0.45143 0.0001	0.78950 0.0001	0.93683 0.0001	0.95235 0.0001	1.00000 0.0000	0.95518 0.0001
WIR	0.75930 0.0001	0.84550 0.0001	0.55499 0.0001	0.06795 0.0245	0.59919 0.0001	0.38475 0.0001	0.34653 0.0001	0.71640 0.0001	0.92407 0.0001	0.96330 0.0001	0.95518 0.0001	1.00000 0.0000

Notes: Upper number represents correlation coefficient; lower number represents significance. Tributary variable names are defined in Table 2.

43. Multiple regression analysis. Stepwise multiple regression analysis (PROC STEPWISE - SAS Institute, Inc. 1982) of the independent variables was used to identify variables that were the best predictors of flow in the gaged tributaries. A maximum of five independent variables were kept for regression equation development. Further regression analysis (PROC REG - SAS Institute, Inc. 1982) was used to evaluate the equations identified by PROC STEPWISE. Analyses were performed iteratively using PROC STEPWISE and PROC REG to optimize correlation coefficients, improve significance levels, and eliminate undesirable patterns in the residuals. Best predictions of average daily tributary flows for the gaged tributaries were obtained by breaking the regression into four parts based on median flow (115 cfs) in Big Butte Creek and seasonal precipitation patterns. Separate regression equations were developed for the following cases:

a. Wet season (Julian days 1 to 121, 304 to 365) with Big Butte flows <115 cfs.

b. Wet season with Big Butte flows ≥115 cfs.

c. Dry season (Julian days 122 to 303) with Big Butte flows <115 cfs.

d. Dry season with Big Butte flows ≥115 cfs.

The regression models developed, significance values, regression coefficients, and correlation coefficients to predict flows in the gaged tributaries are listed in Table 5. The correlation coefficients are inflated to an unknown degree since the observations in the data are not independent. That is, the regression was performed on serial data. Of all the variables evaluated, the log of Big Butte flow and the log of tributary basin area proved to be significant for each case. Other significant variables in the regression equations were precipitation, precipitation intensity, and the log of the slope of the tributary.

44. Implementation of regression equations. The relationship between flow and independent variables identified by regression analysis of the gaged tributaries was applied to estimate the flows in the ungaged tributaries. Data necessary to develop the independent variables for the ungaged tributaries were obtained from a variety of sources. Slope and basin area of the ungaged tributaries were obtained from Lystrom (1970) or were measured directly from USGS quad maps. Precipitation and precipitation intensity values were obtained from Lystrom (1970) and US Weather Bureau (1961). If a

Table 5

Regression Equations to Predict Flow at Ungaged Tributaries Under Different Seasons and During Different Discharges of Big Butte Creek

Season/Big Butte Flow	Independent Variable	Regression Coefficient	Significance	R Square
Wet/ $Q < 115$ cfs	Intercept	-3.410360	0.0001	0.8652
	Log of Big Butte flow	1.522749	0.0001	
	Log of trib. basin area	0.878139	0.0001	
	Precipitation intensity	0.170101	0.0001	
Wet/ $Q \geq 115$ cfs	Intercept	-0.0872849	0.0001	0.9013
	Log of Big Butte flow	-0.904558	0.0001	
	Log of trib. basin area	0.749202	0.0001	
	Log of trib. slope	-0.458465	0.0001	
	Precipitation intensity	0.165061	0.0001	
Dry/ $Q < 115$ cfs	Intercept	-3.51502	0.0001	0.8072
	Log of Big Butte flow	1.89613	0.0001	
	Log of trib. basin area	0.58284	0.0001	
	Annual precipitation	0.03793	0.0001	
	Precipitation intensity	0.60308	0.0001	
Dry/ $Q \geq 115$ cfs	Intercept	-3.04233	0.0001	0.6980
	Log of Big Butte flow	1.43675	0.0001	
	Log of trib. basin area	0.88450	0.0001	

value for precipitation was unavailable for a tributary, it was assumed to be the same as that of a neighboring tributary of known value.

Temperature data synthesis

45. Methods used to develop tributary water temperatures were dictated by the sparsity of data available for tributary streams in the Rogue River basin. Long-term water temperature data were available for only three tributaries in the system: Elk Creek, Big Butte Creek, and the Applegate River. Water temperatures in the Applegate River are partly determined by reservoir operations (Applegate Dam), thus eliminating Applegate River water temperature data for use in determining water temperatures in the unregulated tributaries.

46. Regression techniques were used to synthesize daily average tributary water temperatures for Elk Creek. Independent variables, such as slope, simple channel characteristics, elevation, and 3-day running average equilibrium temperature (Edinger and Geyer 1965) were selected for use in this analysis because these variables could also potentially predict the water

temperature in other tributary creeks in the system. Optimum regression equations were developed for Elk Creek water temperature based on correlation coefficients, significance levels, and behavior of the residuals. The regression equation was then modified to represent Big Butte Creek conditions. That is, the Elk Creek regression equations were modified to represent the slope, elevation, and channel characteristics of Big Butte Creek, and the resulting predictions were tested against Big Butte water temperatures. Big Butte Creek differs from Elk Creek in mean basin elevation, discharge pattern, and channel characteristics.

47. Synthesis of temperature data for unmonitored streams can be broadly separated into five steps:

- a. Select regression models.
- b. Identify/develop independent variables appropriate for regression analysis.
- c. Perform multiple regression analyses to develop correlative relationships between stream temperature and independent variables.
- d. Verify regression predictions against water temperatures in a separate tributary.
- e. Implement regression equations.

48. Regression model. Temperature regression was based upon the analytical solution for one-dimensional water temperatures under steady-state flow conditions in uniform channels (Martin 1986) written as

$$To = Te + (Ti - Te) \exp\left(\frac{-K * As}{Gamma * Cp * Q}\right) \quad (1)$$

where

To = outflow temperature of a segment, °C

Te = equilibrium temperature, °C

Ti = initial inflow temperature of a segment, °C

K = coefficient of surface heat exchange, J/sec-m^2-°C

As = segment surface area, m^2

Gamma = density of water, kg/m^3

Cp = specific heat of water, J/kg-°C

Q = flow in segment, m^3/sec

Note that this equation contains terms for flow (Q) and meteorology (Te and K) and terms dependent on elevation (Ti) and channel characteristics (As) specific to Elk Creek. In fact, the second term of Equation 1 can be viewed as a correction for tributary-specific basin characteristics or

$$CT = (Ti - Te) \exp\left(\frac{-K * As}{Gamma * Cp * Q}\right) \qquad (2)$$

49. Independent variables. Estimates for the terms in Equation 1 came from a variety of sources. Flow data were obtained from the USGS for gaged tributaries. Flow values for ungaged tributaries or to replace data gaps for gaged tributaries were obtained by using the regression equations described in the previous section. Values for Te and K were obtained by employing the Heat Exchange Program (Eiker 1977). Necessary input to the program consisted of meteorological data (cloud cover, dew point, dry bulb temperature, and wind speed) and site characteristics (latitude, longitude, and site elevation). Meteorological data and site characteristics for the Medford, Oreg., weather station were obtained from the US Air Force Environmental Technical Applications Center at Asheville, N. C. Constant values for Gamma (1,000 kg/m^3) and Cp (4,186 J/kg-°C) were used for all tributaries.

50. Variable Te in Equation 1 can be approximated using either daily equilibrium temperature or running averages of daily equilibrium temperature. Correlation analysis (PROC CORR, SAS Institute, Inc. 1982) indicated that the 3-day running average of daily equilibrium was the best predictor of observed Elk Creek water temperature. Three-day running average values for heat exchange coefficients were employed to be consistent with the selected 3-day running average equilibrium temperature.

51. Inflow temperature is calculated separately for each tributary by reducing 3-day equilibrium temperature by an elevation correction term (Tc) whose maximum reduction (Tm) is calculated as

$$Tm = K * (ELEVT - ELEVM) \qquad (3)$$

where

Tm = maximum reduction in water temperature for specific tributary, °C

K = elevation correction of 1.78° C per 1,000 ft of elevation

ELEVT = mean elevation of tributary, ft

ELEVM = elevation of Medford weather station, ft

Next, the maximum reduction in 3-day equilibrium water is related to ambient equilibrium temperature at the Medford meteorological station. That is, at high equilibrium temperatures, the maximum elevation correction value is used, but as equilibrium temperatures approach 0.0° C, the elevation correction value also approaches 0.0 to prevent estimation of negative water temperatures. A variety of different functions (linear interpolation, power functions with different a and b coefficients, etc.) relating elevation correction values to ambient equilibrium temperature were evaluated in Equation 2 against temperature data from Elk Creek using PROC REG (SAS Institute, Inc. 1982). Best predictions were obtained using

$$Tc = a * Te ** b \tag{4}$$

where

Tc = elevation correction for a specific tributary, °C

Te = 3-day equilibrium temperature

a,b = coefficients specific to each tributary that allow Ti to vary between 0.0° C at low equilibrium temperatures to Tm (Equation 3) at high equilibrium temperatures

Initial water temperatures for a specific tributary are then calculated as

$$Ti = Te - Tc \tag{5}$$

where

Ti = initial water temperature specific for each tributary

Te = 3-day equilibrium temperature

52. An index of surface area (As) for Elk Creek was obtained by nonlinear regression of the stage/discharge data obtained from gage rating tables using

$$H = a * Q ** b \tag{6}$$

where

H = depth index, m

a,b = coefficients

to obtain estimates of coefficients a and b . Manning's equation,

$$v = \frac{(1.48 \times H^{**}2/3 \times slope^{**}1/2)}{n} \qquad (7)$$

where

v = water velocity, m/sec

slope = value from Lystrom (1970) or USGS quad maps

n = roughness coefficient (value of 0.04 used)

was used to estimate water velocity at the gage. Top width index was calculated as

$$w = \frac{Q}{H \times V} \qquad (8)$$

where

w = top width index, m

H = depth, from nonlinear regression of gage rating curve

Area (As) was obtained by multiplying the length of the tributary segment by the calculated value for top width index (w). Segment length was calculated as one-half the length of the tributary. A segment length of one-half the tributary length is generally consistent with an elevation correction factor based on average elevation of the basin.

53. Regression analysis. Although not absolute estimates, the relative estimates for the terms in Equation 2 should be adequate to predict tributary water temperatures if regression analysis is used to estimate coefficients to better fit Equation 1 to observed Elk Creek water temperatures. Preliminary regression analysis was performed using

$$ECT = a + (b)Te + (c)CT \qquad (9)$$

where

ECT = daily average Elk Creek water temperature

a,b,c = regression coefficients

Te = 3-day running average equilibrium temperature

CT = tributary-specific correction term (Equation 2)

Iterative regression analyses using PROC REG (SAS Institute, Inc. 1982) to evaluate the regression equations were used to develop an optimum regression equation based on correlation coefficients, significance values, and inspections of the residuals. Best estimates of coefficients a, b, and c in Equation 9 were 3.9055, 0.74823, and 2.1169, respectively. However, the optimal equation using the coefficients listed above exhibited a definite harmonic pattern of the residuals. Nonlinear regression of the residuals using

$$RES = a * \cos\left[\left(\frac{\text{Julian day} + b}{365}\right) * c * 3.1416\right] \qquad (10)$$

where

RES = residuals

a = amplitude coefficient

b = phase coefficient

c = periodicity coefficient

provided estimates for a , b , and c of 1.03, 0.4805, and 2.0, respectively.

54. The regression equation

$$To = 3.40066 + 0.76589*Te + 1.8038*CT + 1.0841*HAR \qquad (11)$$

where

To = water temperature at mouth of Elk Creek

HAR = harmonic function (Equation 10)

provided a correlation coefficient of 0.96 and a significance level of 0.0001. Equation 11 was also used to synthesize water temperature data for Elk Creek when gaps in the data occurred.

55. <u>Verification of regression.</u> Verification was necessary to determine if the regression equation developed for Elk Creek could be applied to other Rogue River tributaries. Verification was performed by determining values, specific for Big Butte Creek, for the terms in Equation 2 necessary to estimate CT . Data sources for verification on Big Butte Creek were the same as data sources for Elk Creek. Predicted values using the regression equation modified for Big Butte Creek conditions plotted against observed values are presented in Figure 3. Note that although Big Butte Creek differs substantially from Elk Creek in elevation, flow patterns, and channel

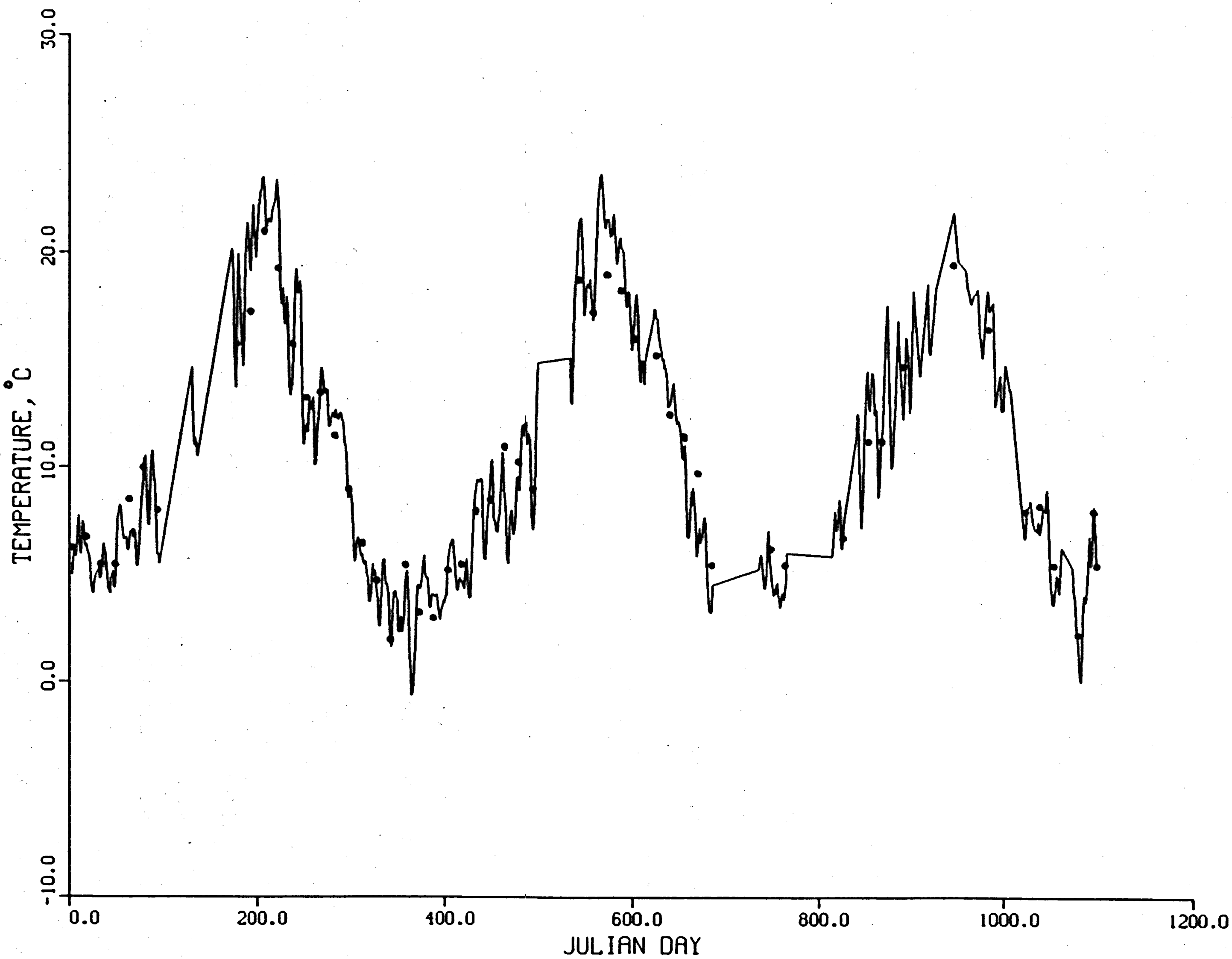


Figure 3. Predicted values (—), using the regression equation modified for Big Butte Creek, plotted against observed values (...) for the years 1978-1980

characteristics, the modified regression equation has a root mean square (RMS) error (an estimate of the error range) of only 1.48° C. The verification results indicated that the modified regression approach could provide estimates of tributary water temperatures.

56. <u>Implementation of regression equations.</u> Tributary water temperatures were estimated by determining tributary-specific values for the terms in Equation 2. Data to determine tributary-specific values for the terms in Equation 2 were generally obtained from the same sources as the data for Elk Creek regression analysis. For some of the ungaged tributaries, all variable values were not available. In some cases, necessary values were obtained from the nearest gaged tributary. For example, if estimates of top width index were not available for an ungaged tributary, a top width estimate from the nearest tributary of similar drainage area was used. The regression equations, necessary data, and supporting regression equations are built into the preprocessor program and automatically generate necessary tributary water temperatures and supporting data to complete the input data needs for the model application selected by the user.

57. <u>Cautionary comments.</u> Although data-synthesizing techniques provide information necessary to complete input data sets, their use is not without risk. ~~The user of this temperature model should be aware of the dangers of~~ using synthesized versus measured data. For some tributaries, both flow and temperature were synthesized using regression techniques. Therefore, the uncertainties in the flow regression are compounded in the temperature regressions. This is particularly true in the dry season during high flows when the flow regression equations are least dependable (correlation coefficient, 0.69). Overall model performance is probably most limited by the uncertainties in the regression methods used to synthesize the tributary water temperatures. The RMS error of 1.5° C for Big Butte water temperature indicates that water temperature predictions at and downstream of Grants Pass cannot be improved much beyond a RMS error of about 1.0° C since up to 50 percent of the flow in the Rogue River at this point is derived from tributary inflow. Improving model performance significantly above current levels would require additional gaging and monitoring of at least some of the major tributaries in the Rogue River system.

58. Use of the regression estimates for tributary flow and temperatures is probably adequate for evaluating operations against historical conditions.

Although temperature estimates for a given day may be off, general trends will be accurately portrayed, and the general effect of operating Lost Creek Dam can be realistically evaluated against other factors in the system. However, use of the model for real-time operations of Lost Creek Dam on a daily or weekly basis should be performed with caution since daily variability in tributary flow and temperature cannot be consistently predicted.

PART IV: MODEL CALIBRATION/VERIFICATION

Background

59. Model calibration required iterative comparisons of model output to historical data for refining and adjusting model parameters until optimal model predictions are obtained. Water quality model calibration can be broken into two phases. First, calibration of model hydraulics is performed until predicted behavior of the stream hydraulics is in agreement with observed hydraulic behavior. After the completion of hydraulic calibration, water quality calibration is performed until water quality predictions are in agreement with observed water quality values. A second data set, different from that used for calibration, is used after the completion of calibration to verify that the model produces acceptable predictions. A calibrated and verified model can then be used to simulate the behavior of the prototype under a variety of different operational and meteorological conditions.

Hydraulic Calibration

60. Hydraulic calibration of the model was performed by comparing predicted water surface elevations and depths with observed values. The model was not calibrated for conveyance times since travel time data were not available for the Rogue River. Additionally, data for hydraulic calibration were available only from Lost Creek Dam to Grants Pass. The model is not calibrated for hydraulics below Grants Pass.

61. Two sources of water surface elevation data were available for model calibration for water year 1979. Low-flow water surface elevations for each cross section between Lost Creek Dam and Grants Pass were obtained from Harris (1970). Stage and flow data were available from the four gages in this reach of river.

62. The model was calibrated under a range of discharges from the dam. Model hydraulics under medium and high discharge were calibrated using April 1979 (1,500 cfs) and July 1979 (2,400 cfs) releases compared to stage and flow data from the four gages. Model hydraulics under low-flow conditions were calibrated using October 1979 (1,000 cfs) releases from Lost Creek Dam compared to the water surface elevations in Harris (1970). Manning's n values

were adjusted until predicted and observed water surface elevations were in agreement using graphical and statistical comparisons. The average deviation of the predicted from the observed or absolute mean error (AME) calculated as

$$AME = \frac{\Sigma(\text{Predicted} - \text{Observed})}{\text{Number of observations}} \tag{12}$$

was used to evaluate calibration results. Final calibration under low-flow conditions produced a mean error for depth of 0.03 ft at a mean observed depth of 5.25 ft. The model is better calibrated under lower flows because much more data were available for calibration.

63. The study reach included several features that were difficult to model using the hydraulic formulations in QUAL II. Two small dams, Raygold and Savage Rapids, occurred on the upper Rogue River. The pools created by these dams were treated as riverine reaches since they were shallow and did not exhibit significant thermal stratification. The increased water depth of the pools was simulated in the model by using high values for Manning's n. Deep pools due to natural channel controls (adverse bed slopes) were also treated as riverine reaches although pools cannot be simulated as well as impoundments. Even though predicted and observed water surface elevations were in agreement in these reaches, predicted depths were not in agreement with observed depths because QUAL II does not allow for adverse (negative) slopes.

Temperature Calibration/Verification

Background

64. Manning's n, bottom width, and side slopes were adjusted to obtain optimal water temperature predictions during temperature calibration. Bottom width and side slopes were adjusted only after careful reexamination of cross-section data indicated that the variable values used for some reaches were initially incorrect and the new values were more representative. Minor adjustments of Manning's n values, not exceeding 0.010, were used to optimize water temperature predictions. At the conclusion of temperature calibration, the hydraulic calibration was rechecked to ensure that the model remained hydraulically calibrated.

Calibration

65. Temperature calibration of the model was performed by comparing mean daily water temperature predictions at the elements corresponding to the locations of six gaging locations to observed mean daily water temperatures at the gages. The "at McLeod" gaging station was excluded from the comparison because of its proximity to the dam. Plots of observed versus predicted water temperatures and comparison statistics for the 1979 water year are presented in Figure 4. Note that gaps in the observed data produce straight lines on the plots.

66. The accuracy of mean daily water temperature predictions was evaluated using the AME (Equation 10) and the RMS error calculated as

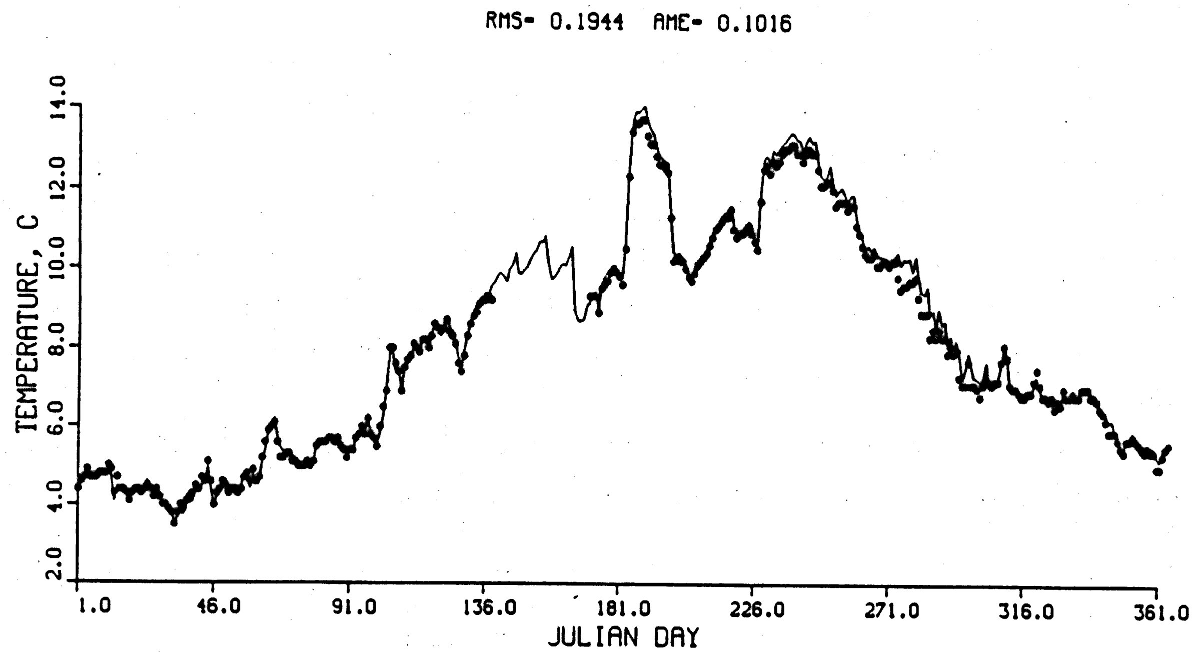
$$\text{RMS} = \left[\frac{\Sigma(\text{Predicted} - \text{Observed})^2}{(\text{Number of observations})} \right]^{0.5} \quad (13)$$

The sign of the AME indicates whether the predicted results average higher (+) or lower (-) than the observed data.

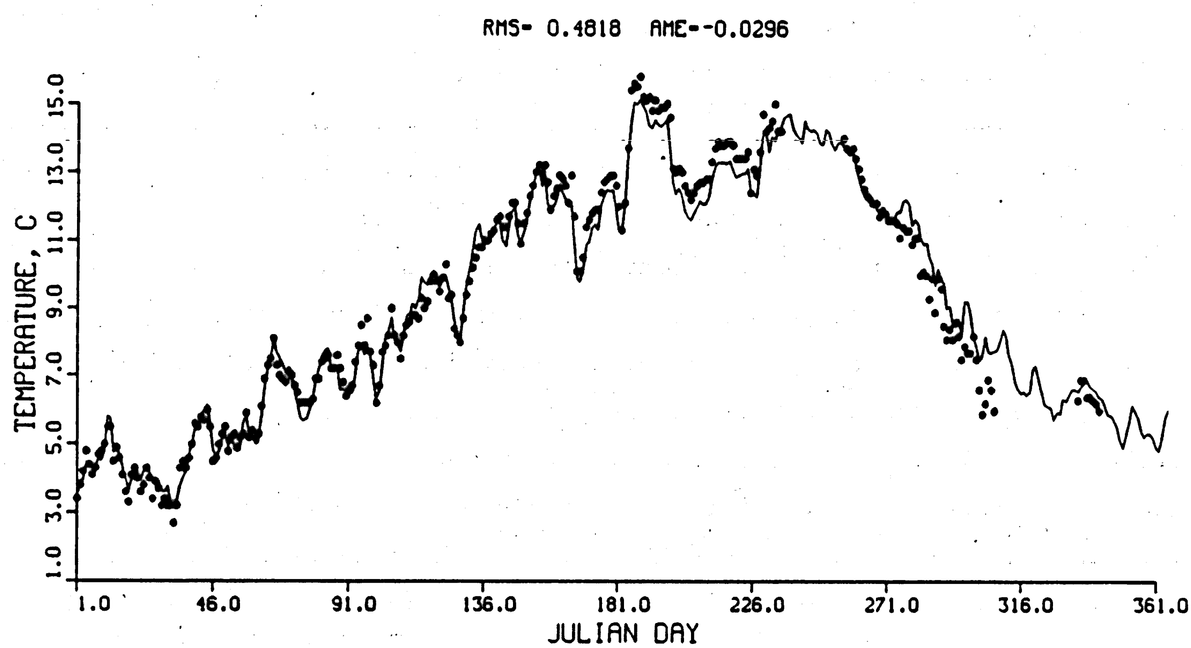
67. Inspection of Figures 4a-4f reveals several trends in errors in model predictions. First, RMS increases with increasing distance from Lost Creek Dam, except for the Merlin station, at RM 86 (Figure 4e). The error could be due to the use of synthesized water temperatures instead of actual values for the tributary flows coming into the Rogue River downstream of the dam. Predictions between Lost Creek Dam (RM 157.4) and Raygold (Figure 4c, RM 125.2) are in close agreement with observed data (RMS values less than 0.5° C). The reaches between the Raygold (RM 125.2) and Grants Pass (Figure 4d, RM 101.8) stations show a slight increase in RMS values (0.72° C). The slight increase in the RMS values could be due to the fact that these reaches contain the two run-of-the-river dams as well as a number of deep pools, both difficult to model using the model formulations in QUAL II.

68. Further examination of temperature data for the Merlin station (Figure 4e, RM 86) and Marial station (Figure 4f, RM 49) shows that the RMS value at Marial is almost double that at Merlin. The pronounced increase at Marial can be attributed to:

<u>a</u>. Insufficient cross-section data for the lower reaches in the system.

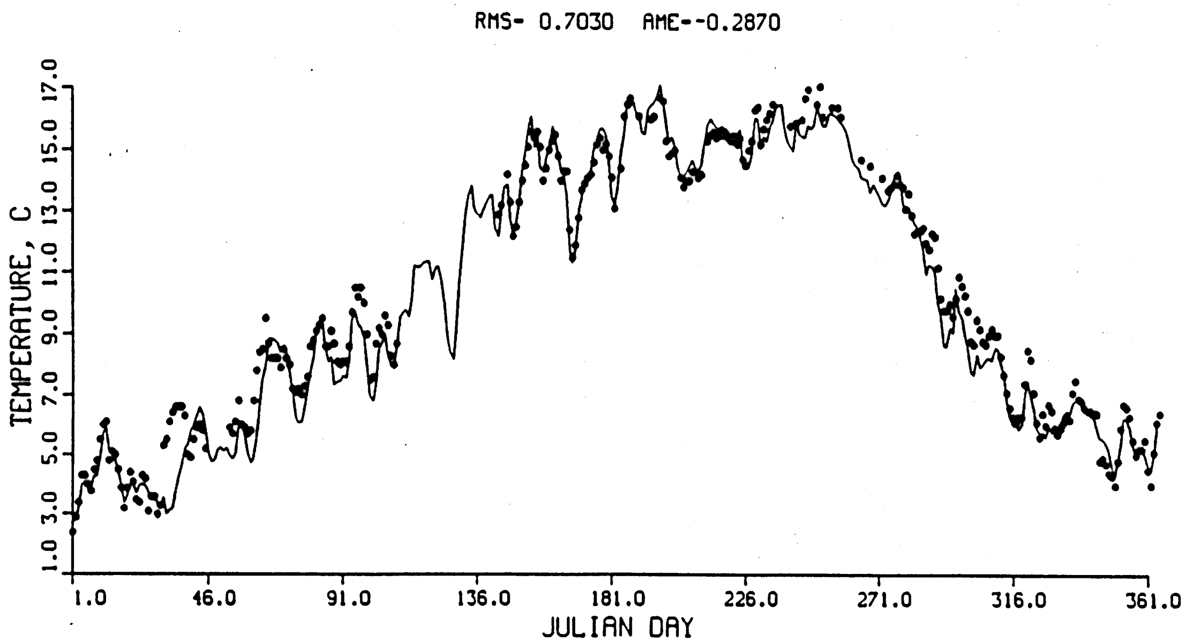


a. Near McLeod, RM 154.2

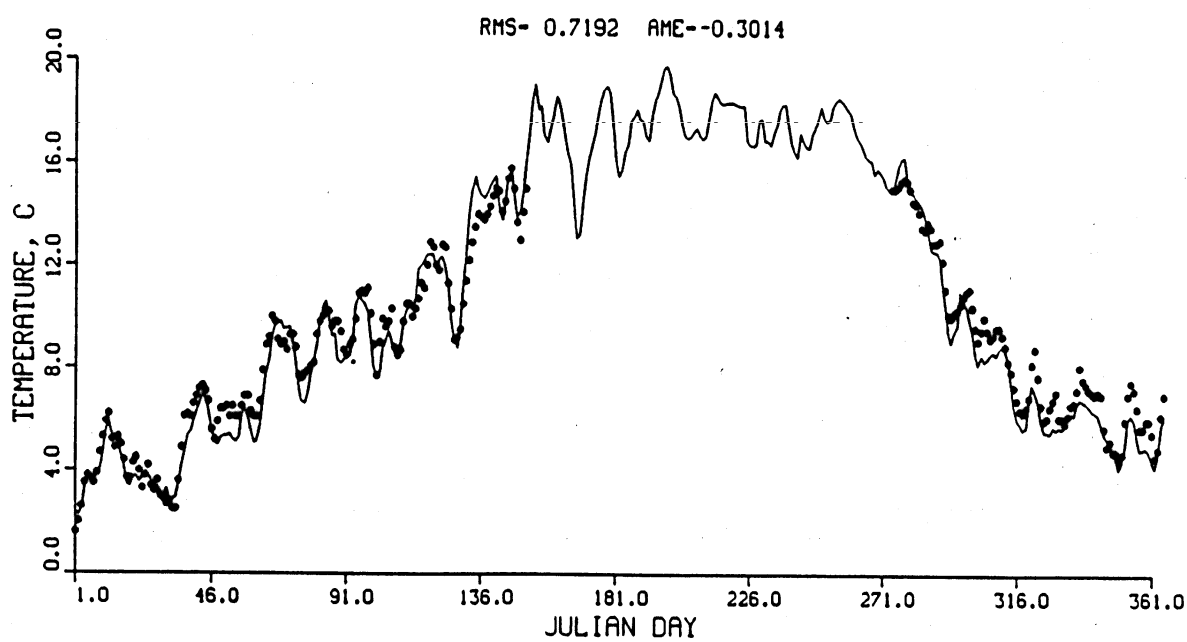


b. Dodge Bridge, RM 138.5

Figure 4. Predicted (—) and observed (...) stream temperature data for 1979 (Sheet 1 of 3)

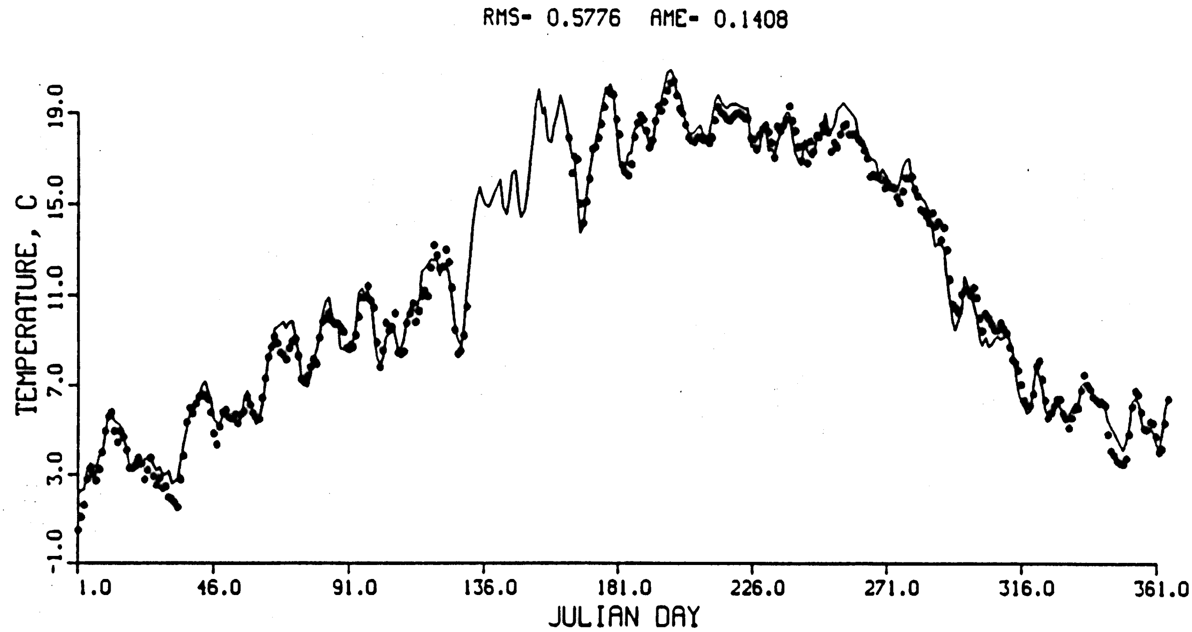


c. At Raygold, RM 125.2

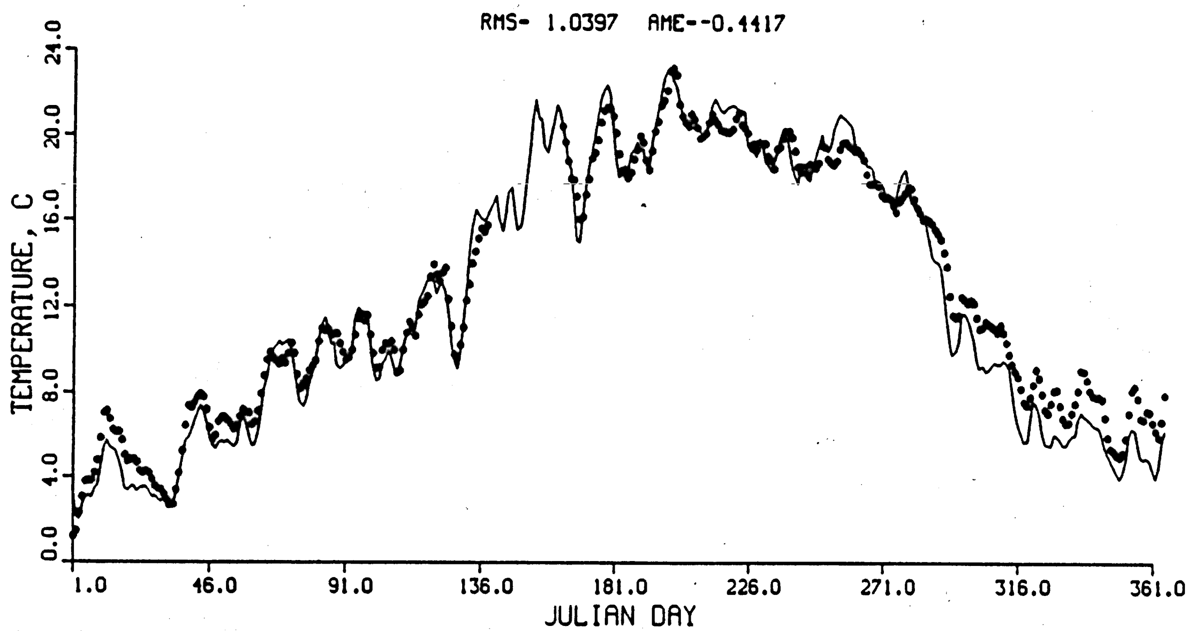


d. At Grants Pass, RM 101.8

Figure 4. (Sheet 2 of 3)



e. At Merlin, RM 86.6



f. At Marial, RM 49.0

Figure 4. (Sheet 3 of 3)

b. Phase error resulting from the violation of the steady-flow assumption; that is, the time step is less than travel time through the system (produced by daily updates of headwater and point source flows).

c. Lack of hydraulic calibration below Grants Pass, which compounded errors in model hydraulics at Marial.

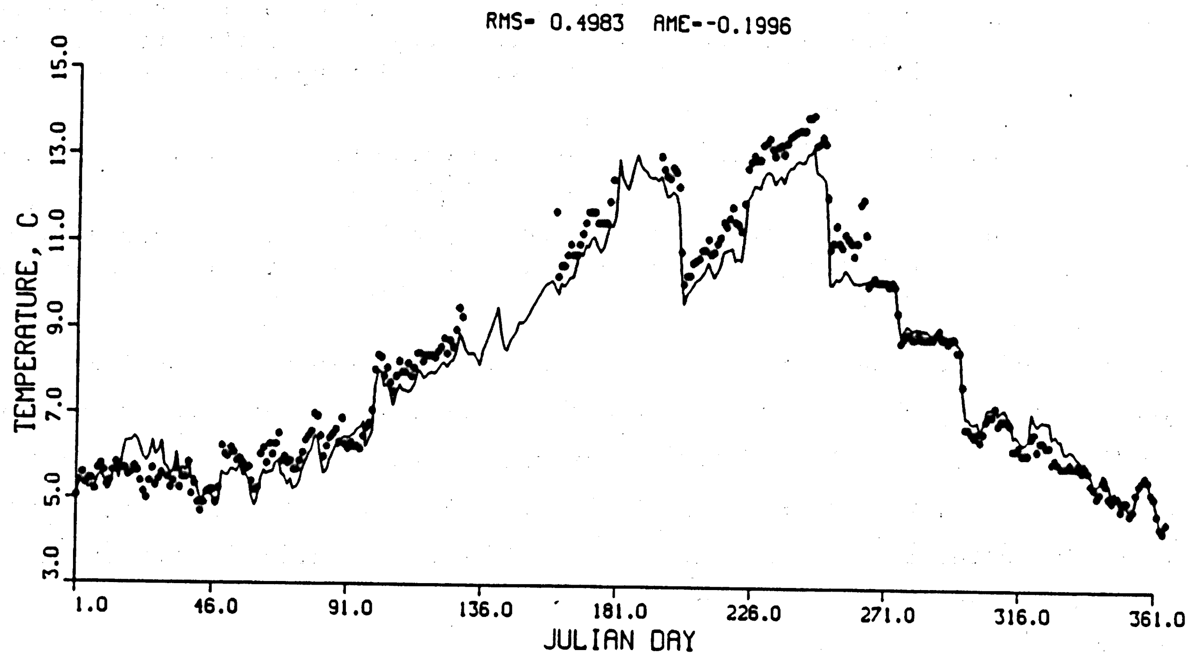
d. Overextension of the meteorological data from Medford, Oreg., to Marial, which is near the boundaries of a climatological zone.

In spite of increased error at Marial, model predictions for the 1986 water year were acceptable. The predictions for the 1979 calibration run were generally well within a RMS of 1.0° C for the six gaging stations, except the Marial station, with a RMS of 1.04° C. The AME values for the six gaging stations indicated that the model, in general, was predicting approximately -0.2° C cooler than the observed data.

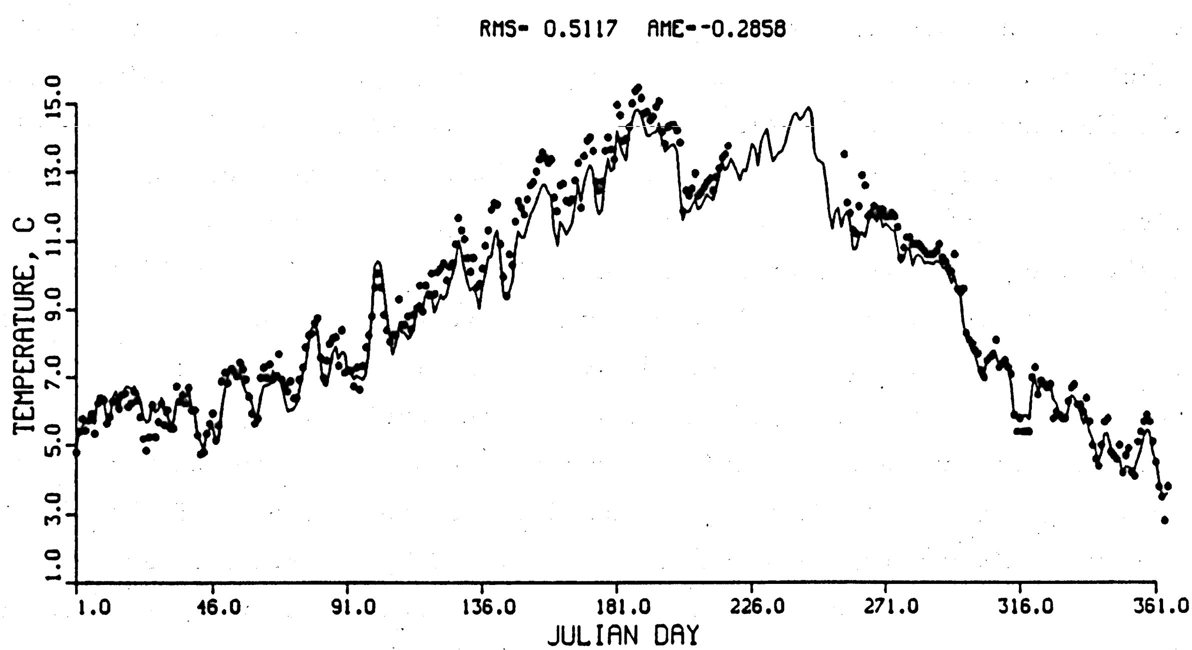
Verification

69. Model performance was verified against data from the 1978 water year (Figures 5a-5f). The RMS and AME values obtained for each station in the verification simulation were similar to the values for the 1979 calibration simulation except at the Merlin gaging station (Figure 5e). Examination of the flow and temperature data used for the headwaters and point sources in the verification data set indicated that the difference noted for the Merlin station was related to the lack of water temperatures for the Applegate River in 1978. The Applegate River is a major tributary (approximately 10 percent of the flow of the Rogue River) that empties into the Rogue River about 8 miles upstream of the Merlin station. In water year 1979, observed temperature data were available for the Applegate River for the entire year; whereas, in 1978, water temperature data for this tributary were available for only 3 months and were synthesized using the regression equations for the other 9 months. Since Applegate River water temperatures are affected by operation of Applegate Dam, the regression equations used to synthesize tributary water temperature are less effective on the Applegate than on other tributaries of the system. Use of observed water temperature values for the Applegate River, had they been available, would probably have decreased the errors in water temperatures at the Merlin station in 1978.

70. The model was also tested against data sets for water year 1980 and 9 months of the 1981 water year, not only to further verify the model but

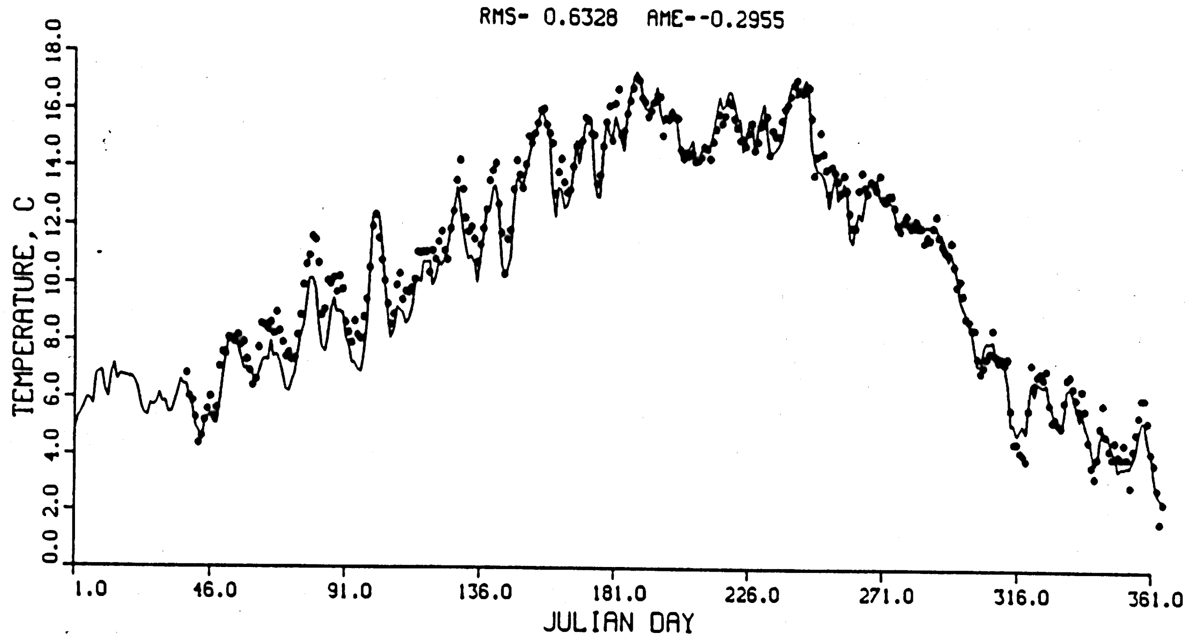


a. Near McLeod, RM 154.2

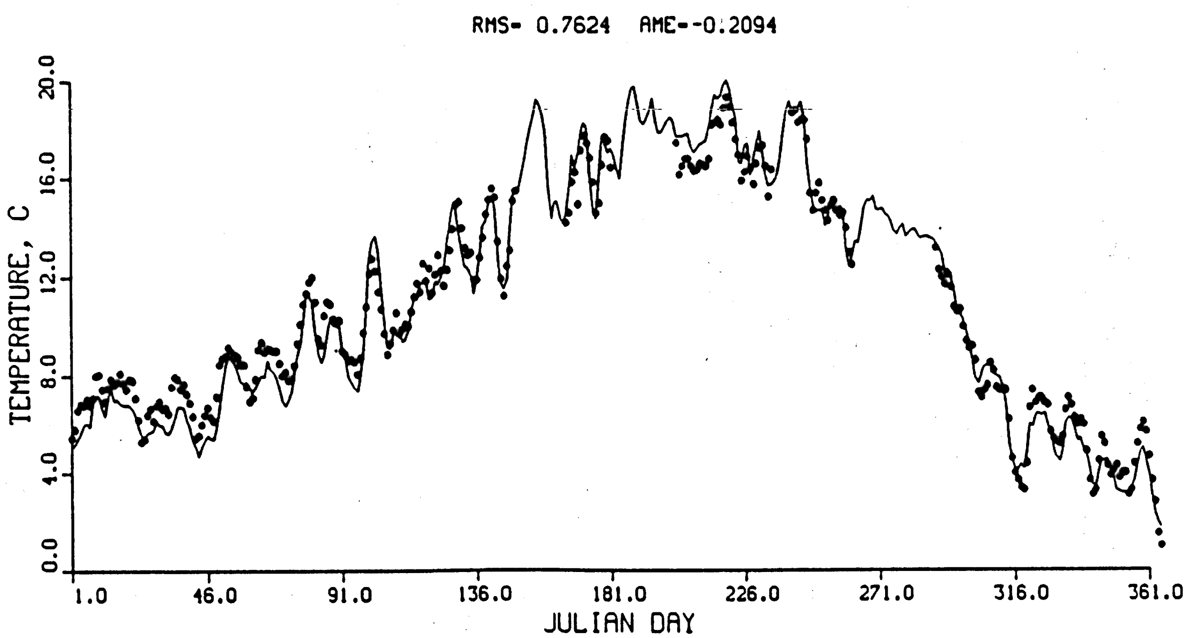


b. Dodge Bridge, RM 138.5

Figure 5. Predicted (—) and observed (...) stream temperature data for 1978 (Sheet 1 of 3)

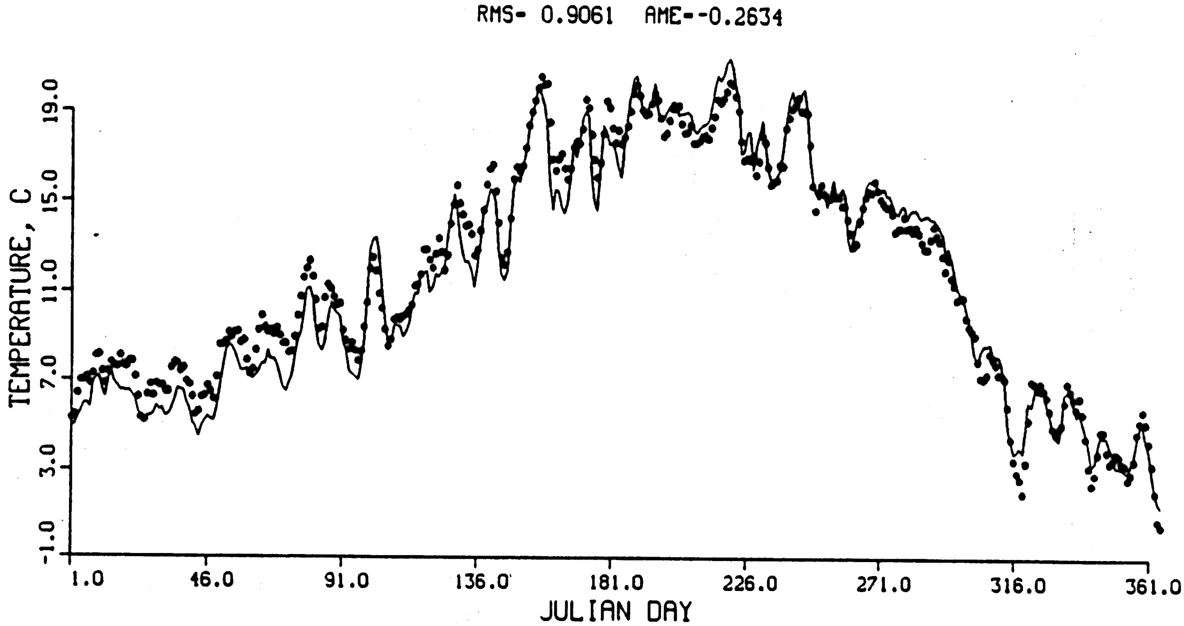


c. At Raygold, RM 125.2

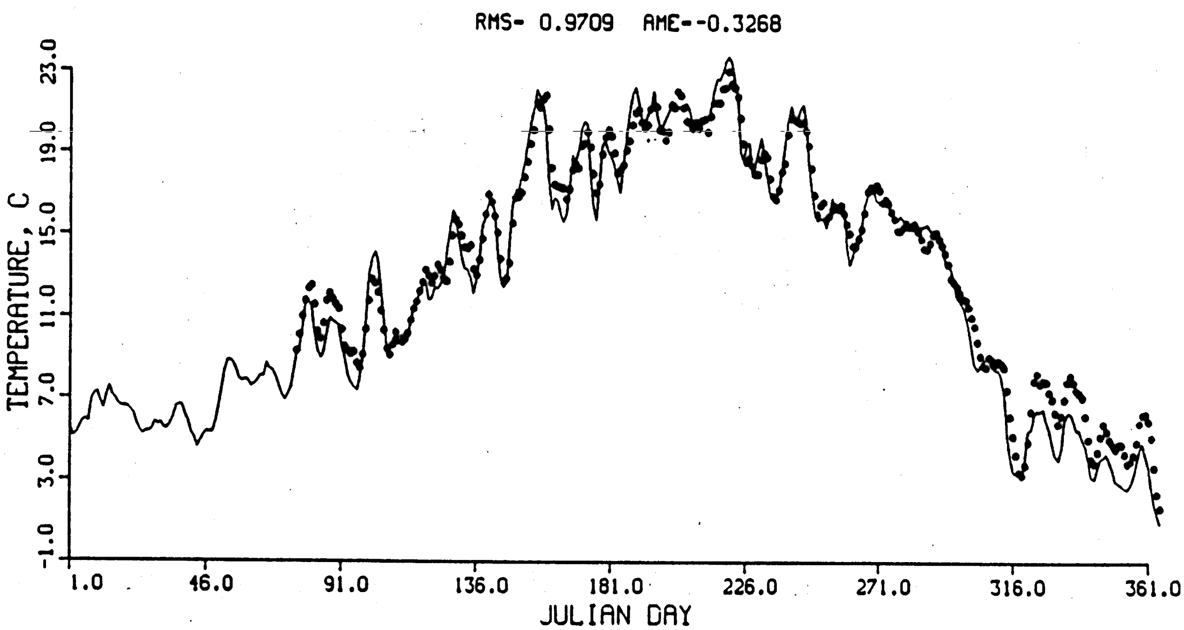


d. At Grants Pass, RM 101.8

Figure 5. (Sheet 2 of 3)



e. At Merlin, RM 86.6

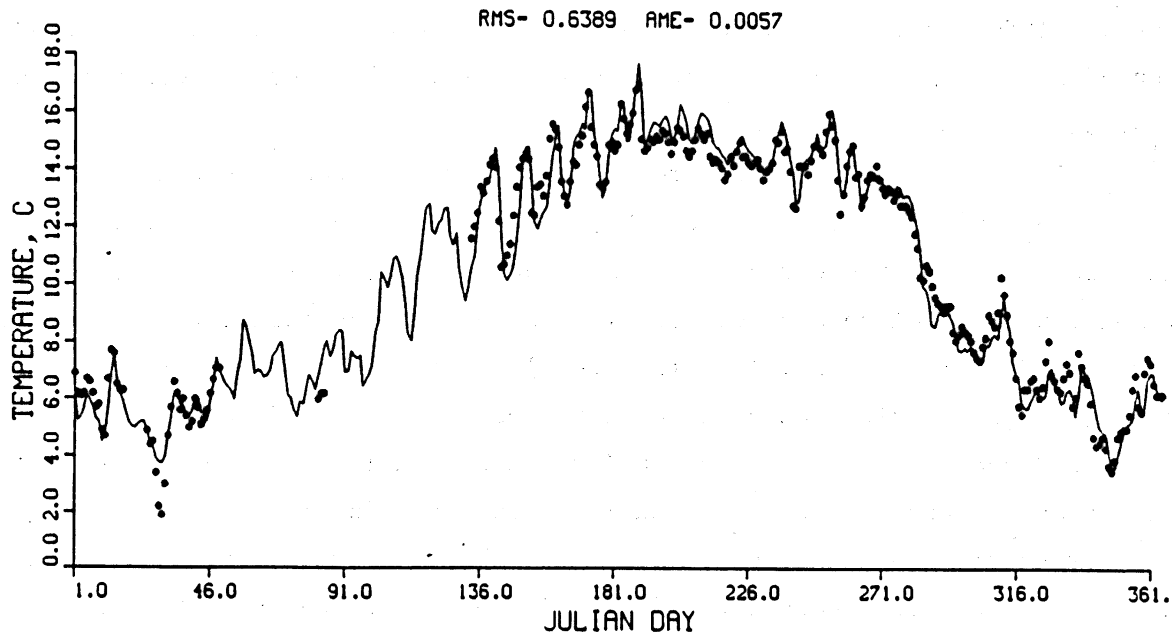


f. At Marial, RM 49.0

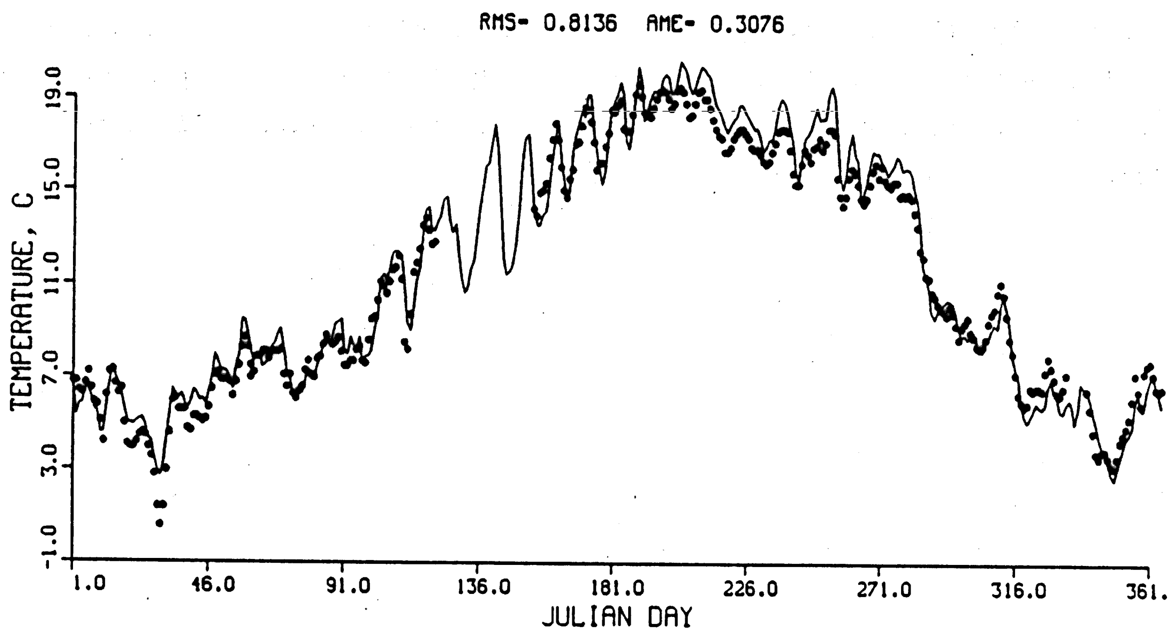
Figure 5. (Sheet 3 of 3)

also to check for anomalies in the data sets for these 2 years. The results for the 1980 and 1981 simulations at the Raygold and Merlin stations are presented in Figures 6 and 7, respectively. The results for the other gaging stations are shown in Appendix A.

71. In general, model errors in predicting water temperatures for water years 1980 and 1981, in terms of RMS, were similar to those observed during calibration, with two exceptions. Noticeable reductions in observed water temperature at Julian day 30, 1980 (Figure 6) were not simulated by the model, and around Julian day 25, 1981 (Figure 7), overprediction of water temperature occurred. An examination of headwater, point source, and meteorological data for the 2 years indicated no unusual condition in 1980. However, in 1981 around Julian day 25, there was an 11° C increase in air temperature at the weather station that was not reflected by observed water temperature values on the river. Several factors could explain this discrepancy. QUAL II may be unable to simulate water temperatures approaching 0° C. Alternatively, the regressed temperature values for the tributaries might be higher than actual values, causing the water temperature values on the Rogue River to be warmer. Additionally, the meteorological data for Medford may not be representative of conditions throughout the basin, particularly if a front were passing through the valley or if meteorological conditions changed substantially with altitude.

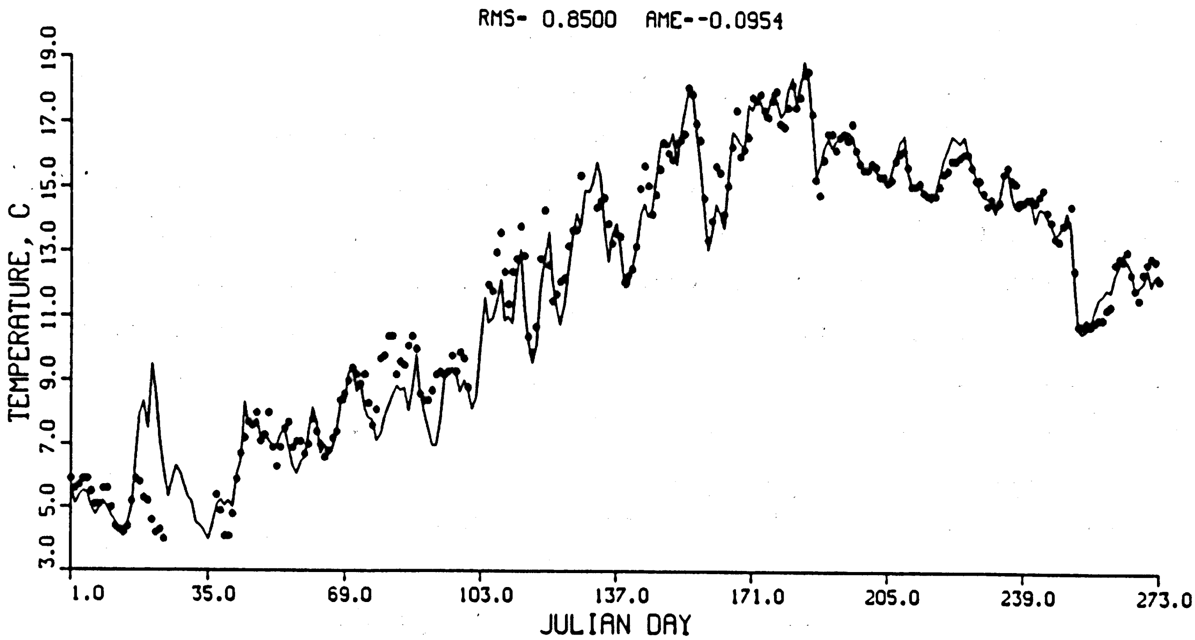


a. At Raygold, RM 125.2

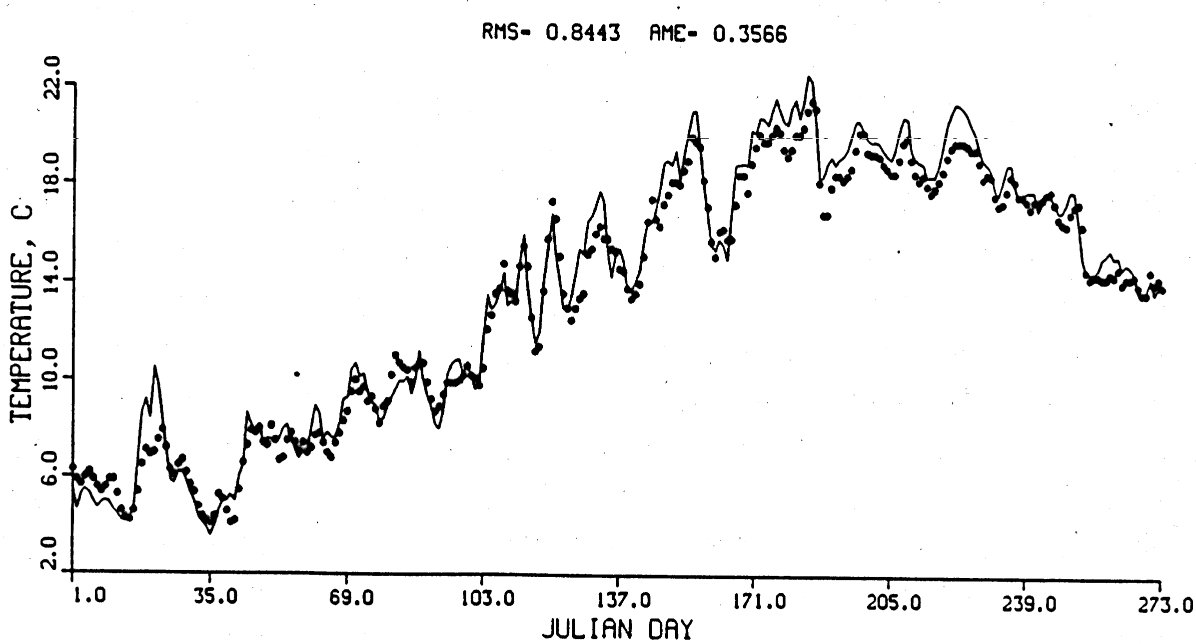


b. At Merlin, RM 86.6

Figure 6. Predicted (—) and observed (...) stream temperature data for 1980



a. At Raygold, RM 125.2



b. At Merlin, RM 86.6

Figure 7. Predicted (—) and observed (...) stream temperature data for 1981

PART V: SENSITIVITY

72. After successful calibration and verification, sensitivity analyses were performed to determine the relative effects of release discharge rate and release temperature on water temperatures downstream of Lost Creek Dam. The results of the sensitivity analyses also provided an estimate of the downstream extent of temperature control by Lost Creek Dam. In addition to sensitivity analyses, the utility of the regression equations for improving downstream water temperature predictions was also assessed. Predictions of river water temperatures using equilibrium temperature for tributary water temperature were compared to model predictions that used the regression equations for estimating tributary water temperatures.

Sensitivity to Operational Changes

Background

73. QUAL II was run at two release flows and two release temperatures to determine the effect of changes in these variables on water temperatures at the Dodge Bridge (RM 138.5) and Marial (RM 49) gaging stations. The Marial station was selected since it is the farthest downstream station (108 miles from Lost Creek Dam) and thus provides an estimate of the downstream extent of the temperature alterations resulting from operation of Lost Creek Dam. The downstream extent of water temperature effects caused by altering discharge or release temperature from Lost Creek Dam cannot be assessed with this model below the point where model error, as indicated by RMS, is approximately equal to the estimated temperature effect (1.0° C). Also, to more completely describe temperature alterations caused by operating Lost Creek Dam, the model should be run in dynamic mode so that predicted changes in water temperatures at 3-hr intervals can be compared to predicted changes in mean daily temperatures. For example, a 1.0° C increase in mean water temperature over a daily range of 2.0° C may have a different biological impact than a 1.0° C increase over a range of 8.0° C.

74. The Dodge Bridge station was selected to depict the effects of Lost Creek Dam operation on water temperatures nearer the dam. Results of the sensitivity analyses at the other gaging stations are presented in Appendix B. Time periods for sensitivity analyses were selected based on maximum

equilibrium temperature (July) and maximum river water temperature (October). Two data sets were developed for the sensitivity analyses: one for July 1979 with a constant release discharge of approximately 2,400 cfs from Lost Creek Dam, and the other for October 1979 with a constant release discharge of 1,000 cfs from Lost Creek Dam. The following four flow and release temperature conditions were evaluated for both months (note historical refers to regulated flows or temperatures):

a. Halved historical discharge/historical release temperature.

b. Doubled historical discharge/historical release temperature.

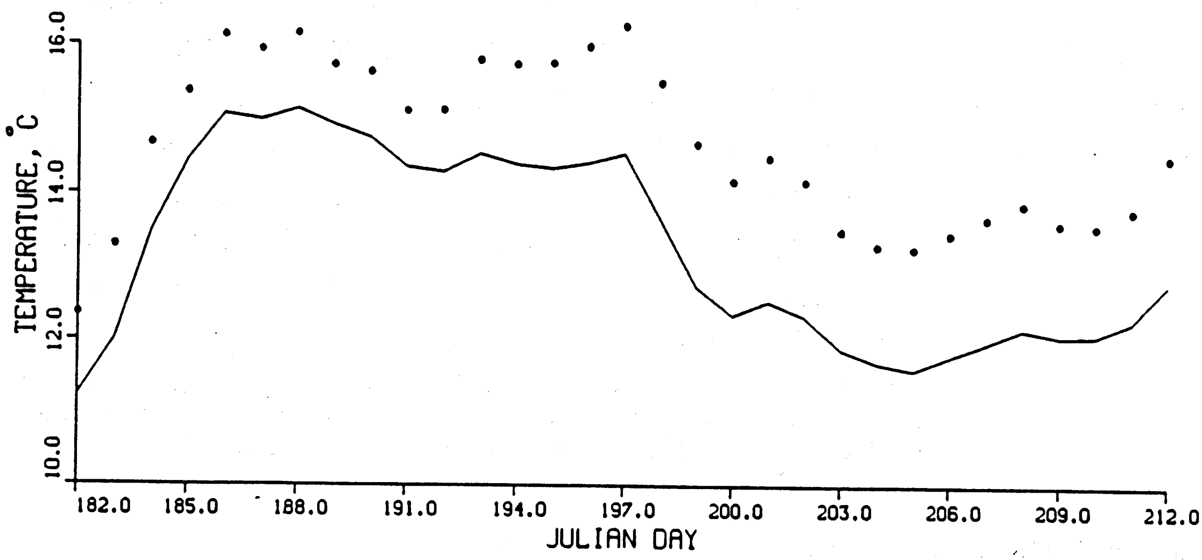
c. Historical discharges/decreased release temperature by 5.0° C.

d. Historical discharges/increased release temperature by 5.0° C. In all cases, comparisons are between simulations run under modified conditions and simulations using historical (regulated) conditions.

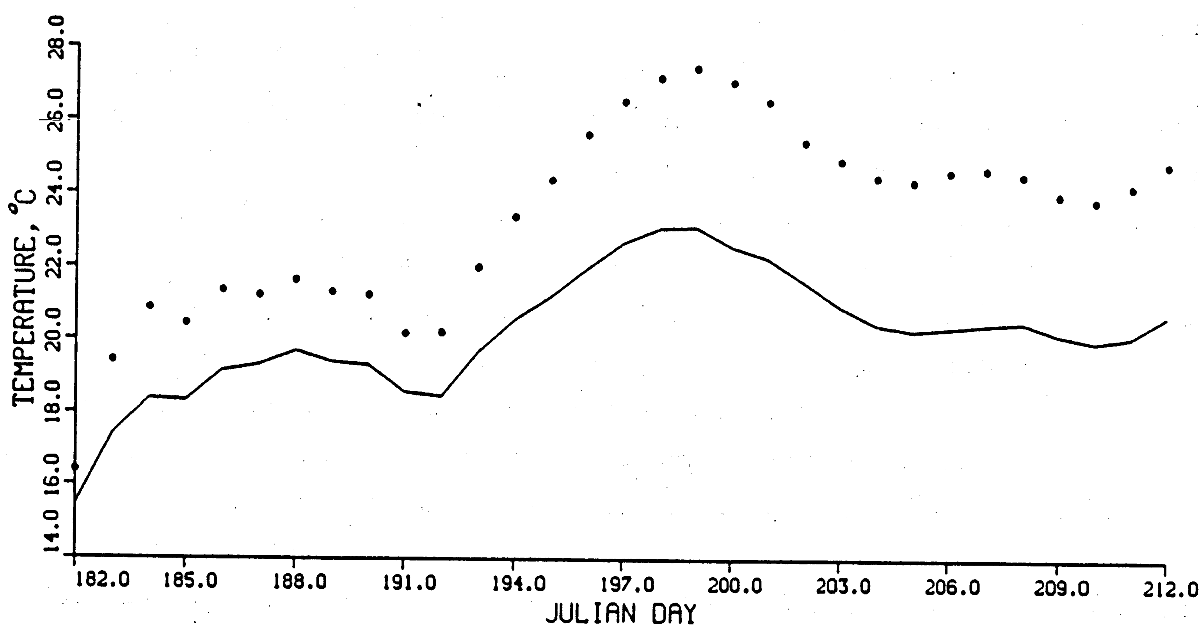
Altered discharge

75. Reducing historical discharges from Lost Creek Dam by one-half results in warming of Rogue River water temperatures during both months and at both gaging stations. For the July simulation, water temperatures at the Dodge Bridge gaging station (Figure 8a) were warmer by an average approximation of 1.0° C; at the Marial gaging station, temperatures were warmer by an average approximation of 3.5° C (Figure 8b). For October simulation, results were similar to July except that water temperatures at the Marial gaging station were warmer by only an average of 1.0° C (Figure 9b). The temperature effects were more pronounced during the first 10 days of the October simulation. Predicted effects during the latter half of the October simulation period were substantially less than model error.

76. Doubling historical discharges at the Lost Creek Dam resulted in a cooling of Rogue River water temperatures during both months and at both gaging stations. For the July simulation, water temperatures at Dodge Bridge (Figure 10a) were cooler by approximately 4.0° C; at the Marial gaging station, water temperatures were cooler by an average approximation of 1.0° C (Figure 10b). For the October simulation, water temperatures at both gaging stations were approximately 1.0° C cooler than simulations using historical conditions (Figure 11a and 11b).

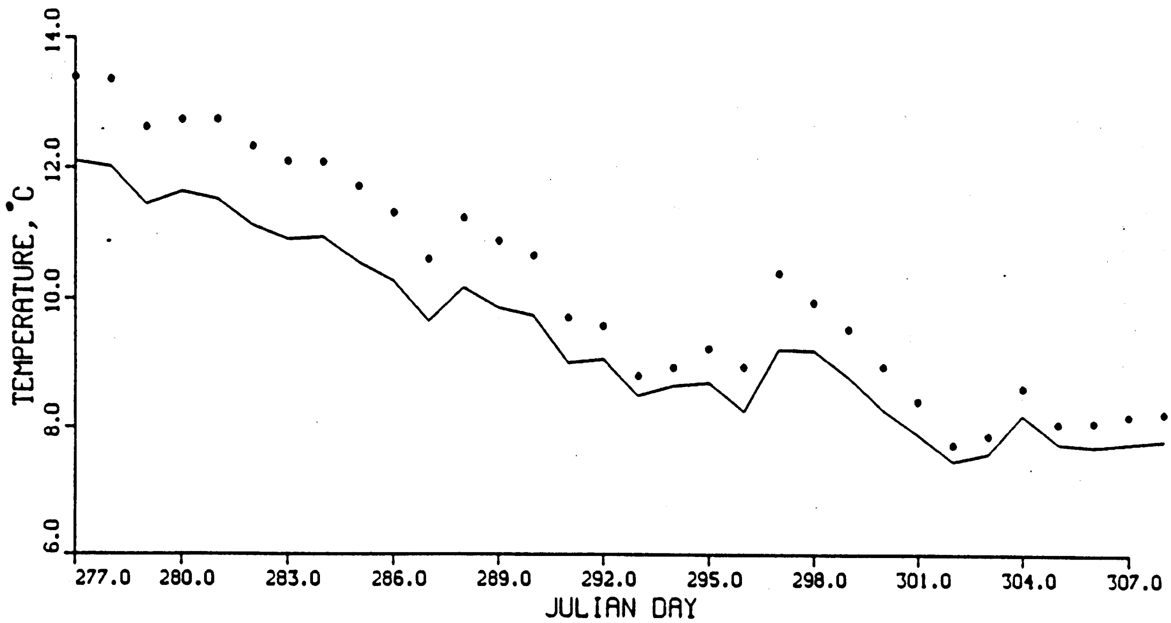


a. At Dodge Bridge, RM 138.5

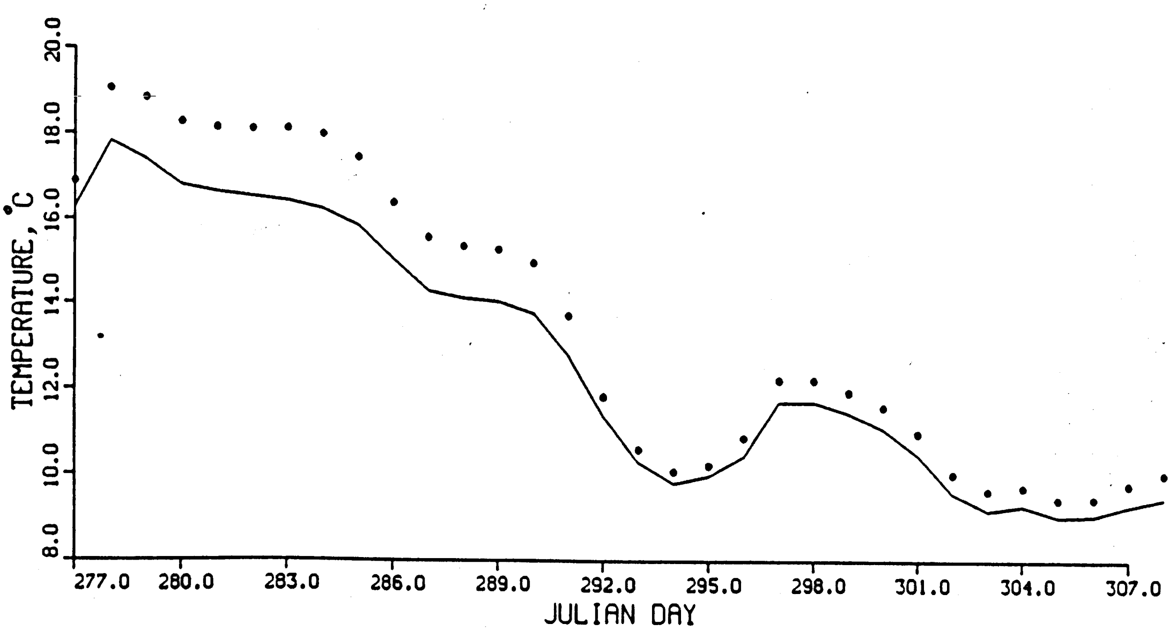


b. At Marial, RM 49.0

Figure 8. Computed stream temperatures for July 1979 using historical flows (—) compared to halved historical flows (...)

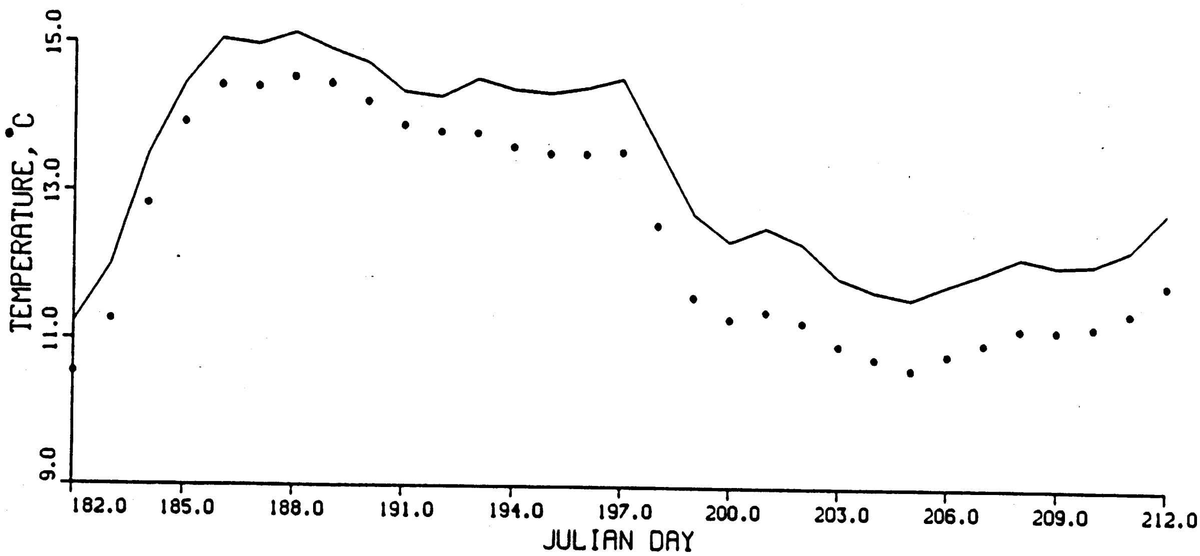


a. At Dodge Bridge, RM 138.5

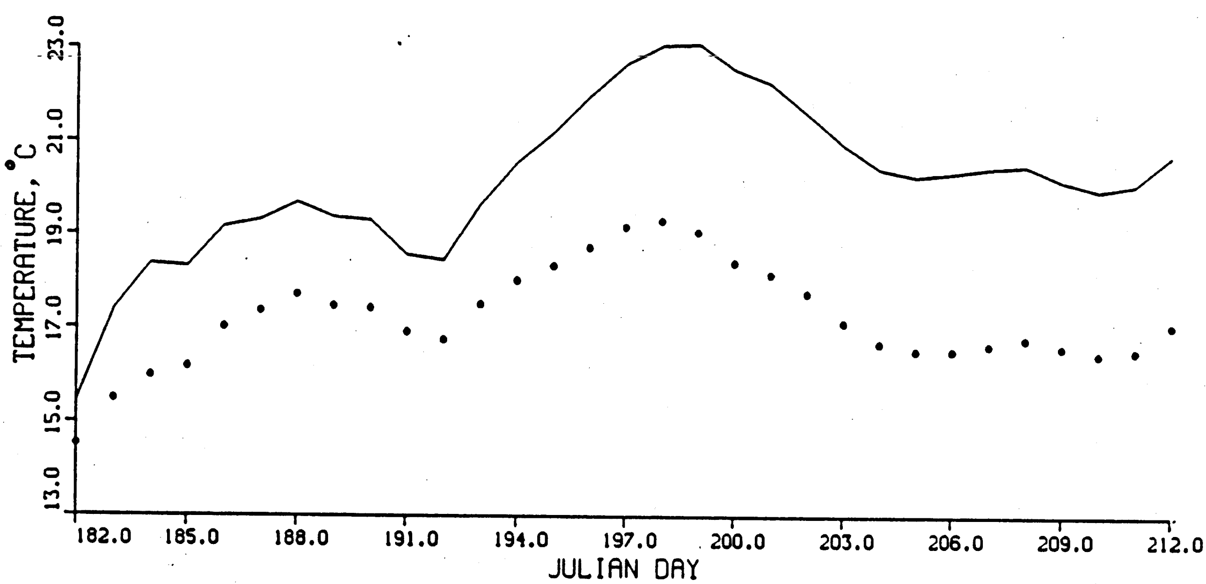


b. At Marial, RM 49.0

Figure 9. Computed stream temperatures for October 1979 using historical flows (—) compared to halved historical flows (...)

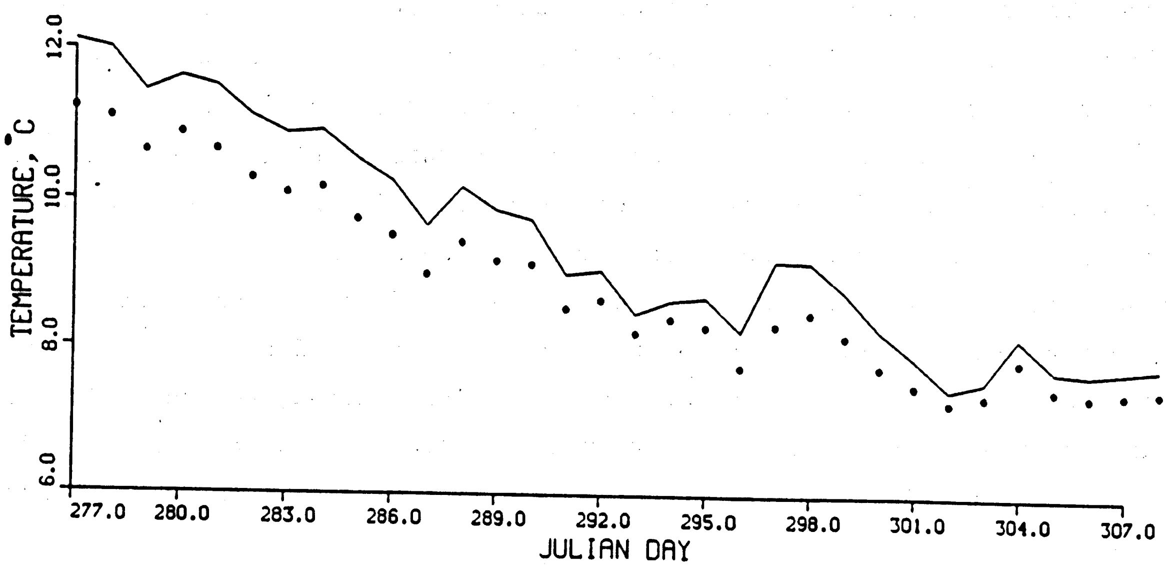


a. At Dodge Bridge, RM 138.5

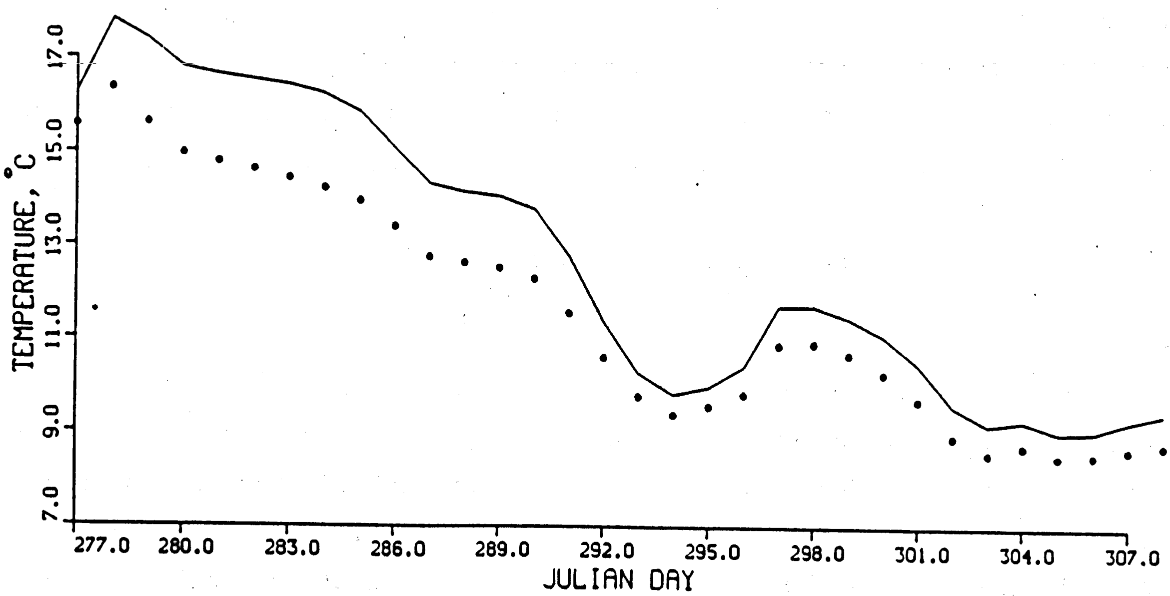


b. At Marial, RM 49.0

Figure 10. Computed stream temperatures for July 1979 using historical flows (—) compared to doubled historical flows (...)



a. At Dodge Bridge, RM 138.5



b. At Marial, RM 49.0

Figure 11. Computed stream temperatures for October 1979 using historical flows (—) compared to doubled historical flows (...)

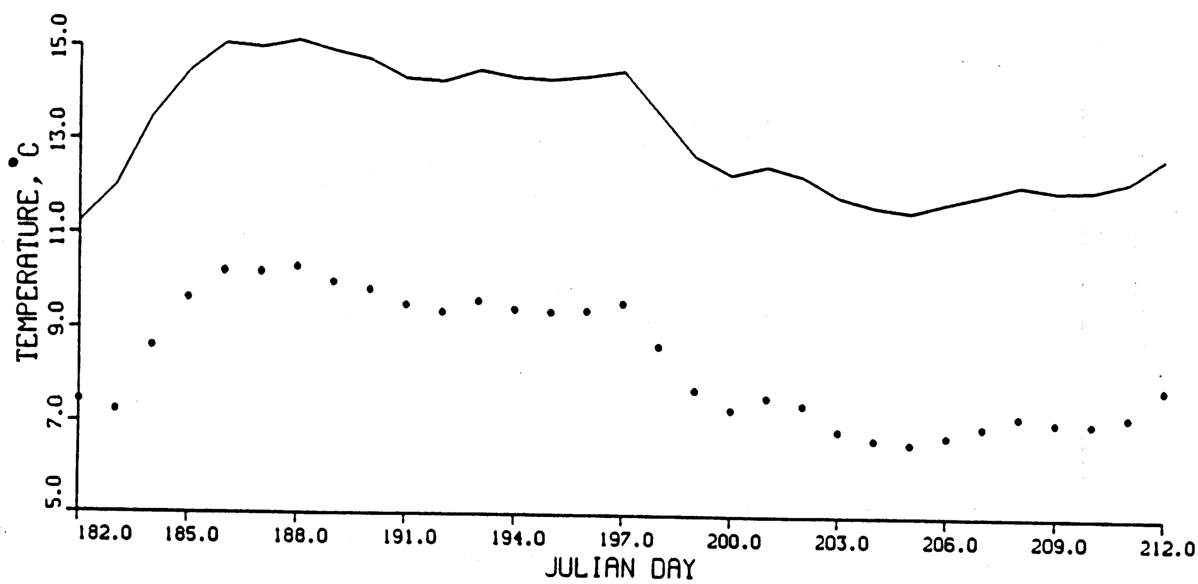
Altered release temperatures

77. Decreasing the water temperatures of the releases by 5.0° C at Lost Creek Dam decreased water temperatures at both stations and during both months (Figure 12 for July, Figure 13 for October), with the greatest temperature effect occurring at the Dodge Bridge gaging station (cooler by 3.0° C). Because of the short travel distance between this station and the dam, the water has not warmed sufficiently to reduce the difference caused by decreasing the release temperature at the dam. At the Marial gaging station, the resulting water temperature is partially affected on the second day of simulation for both months, and by the third day, the full effect of decreasing the release temperature can be seen. At the Marial station, the July simulation shows a greater temperature effect than the October simulation because differences between release temperatures and equilibrium temperatures are greatest in July.

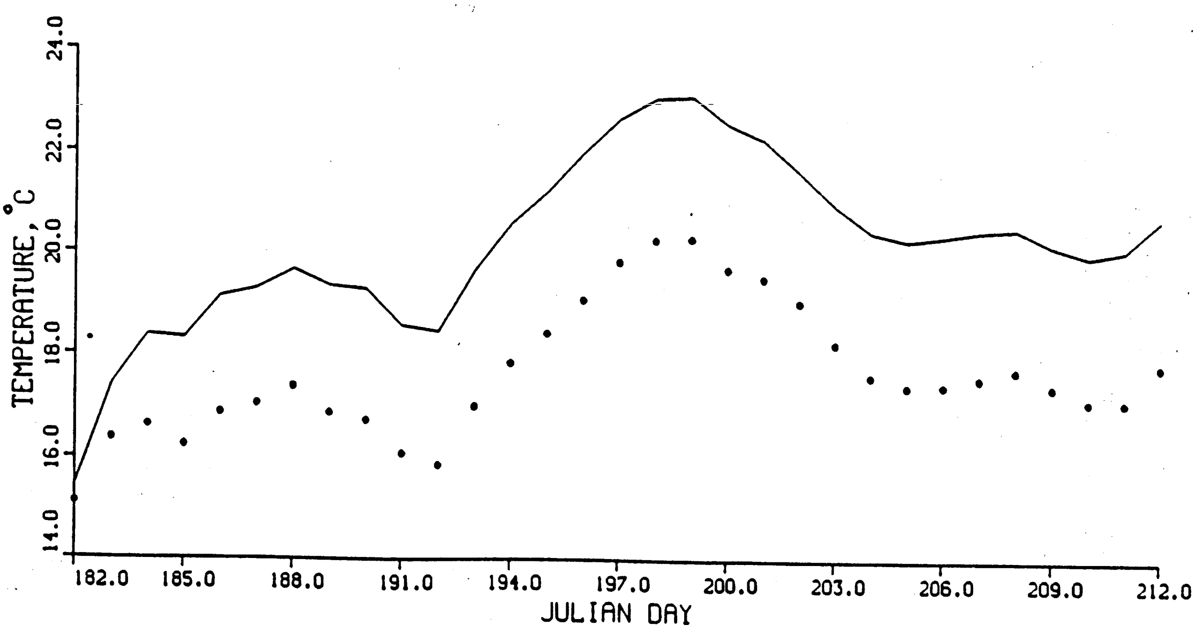
78. Increasing the release temperature by 5° C at Lost Creek Dam increased water temperatures at both stations and during both months (Figure 14 for July, Figure 15 for October), again with the greatest difference occurring at the Dodge Bridge station. Predicted water temperatures at both stations and during both months were similar to the previous analysis; however, instead of water temperatures being cooler, they were warmer. As before, the greatest difference at the Marial gaging station for both months occurred during July when maximum equilibrium temperatures occur.

Sensitivity to Method of Calculating Tributary Temperature Input

79. A simulation was performed to assess the utility of the regression equations for improving downstream water temperature predictions. Equilibrium temperature values (3-day running average) were substituted for the regressed temperature values used for the tributaries in the 1979 calibration data set. Figure 16 illustrates the results of the simulation at the Merlin gaging station. Comparison of the RMS and AME values from Figure 16 with the calibration results (Figure 4) for Merlin demonstrates that the tributary temperature predictions using regression equations do, in fact, result in better water temperature predictions: the RMS value from Figure 16 is almost double that

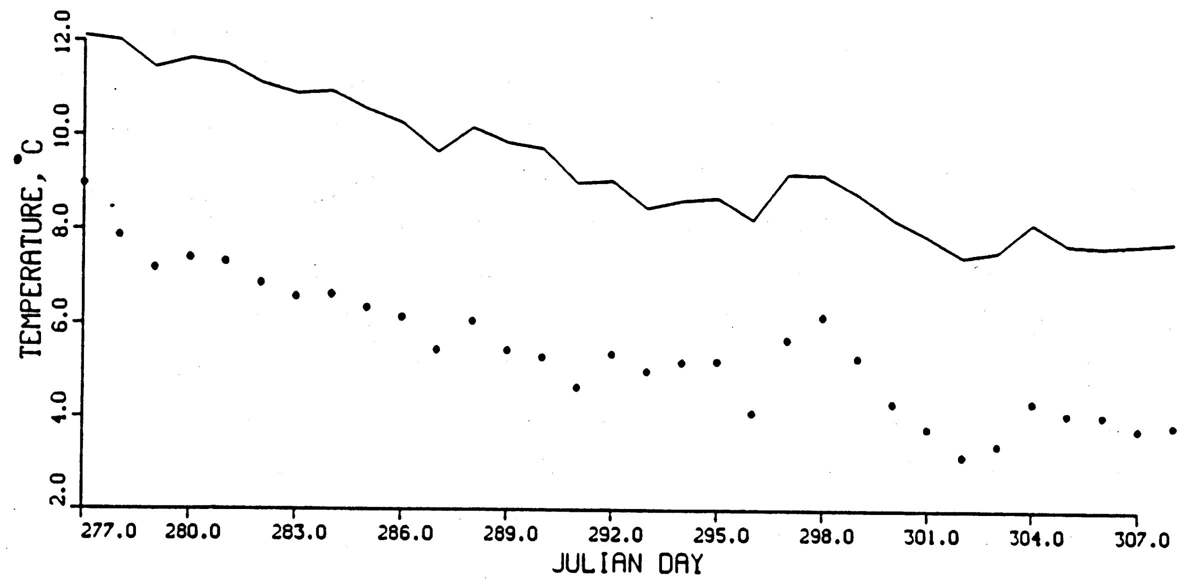


a. At Dodge Bridge, RM 138.5

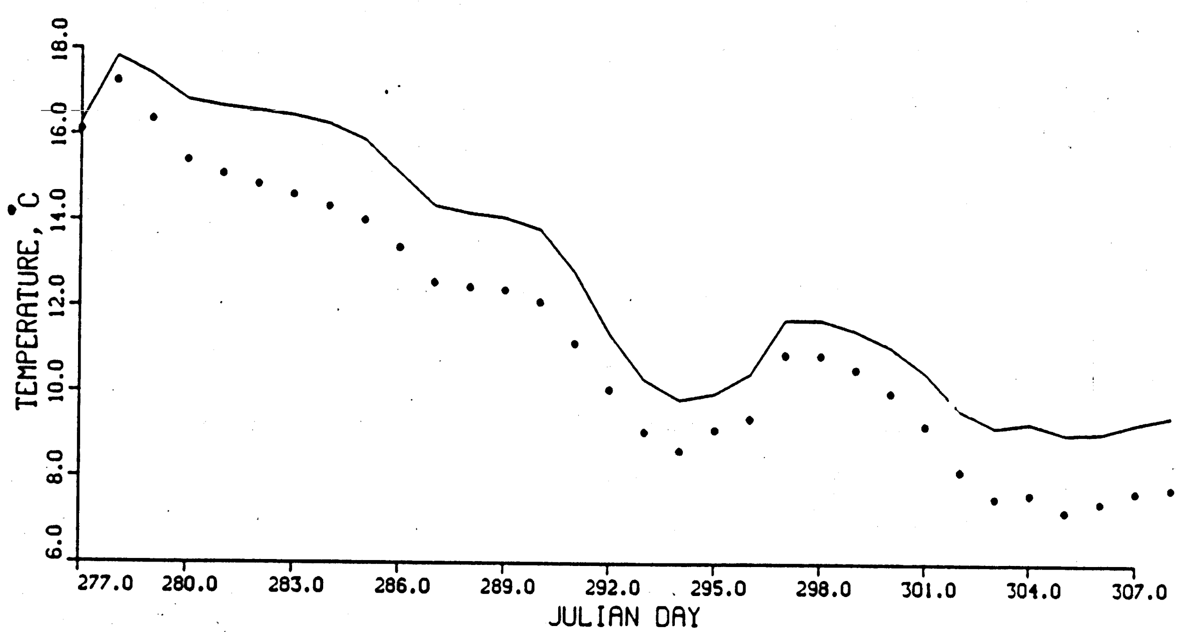


b. At Marial, RM 49.0

Figure 12. Computed stream temperatures for July 1979 using historical release temperatures (—) compared to 5° C decreases of historical release temperatures (...)

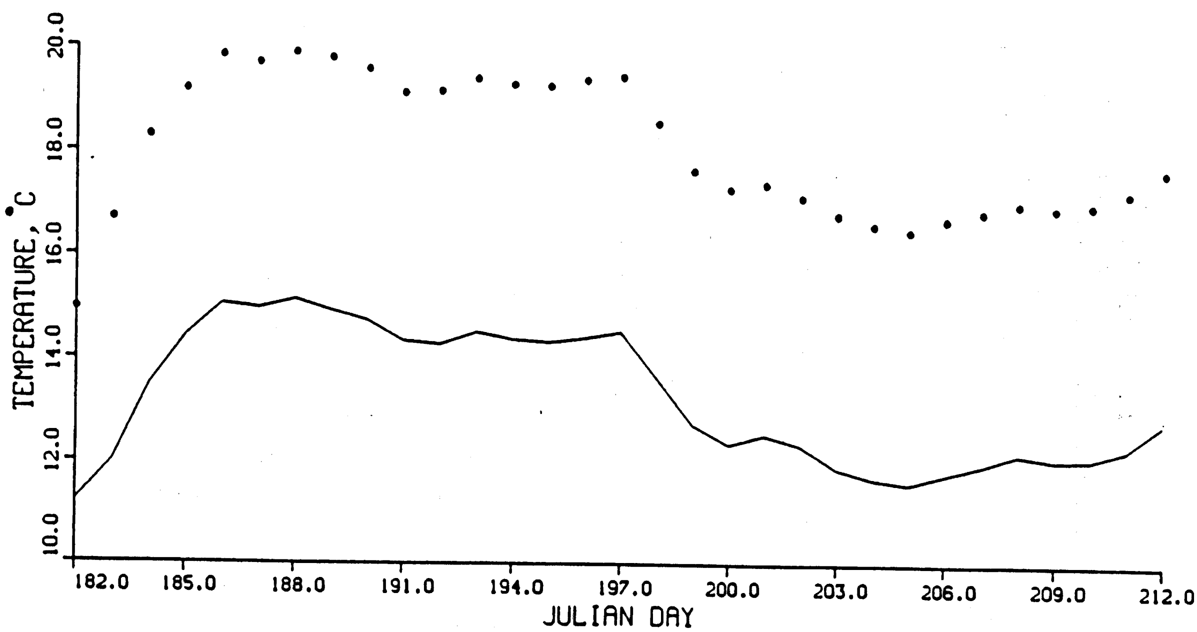


a. At Dodge Bridge, RM 138.5

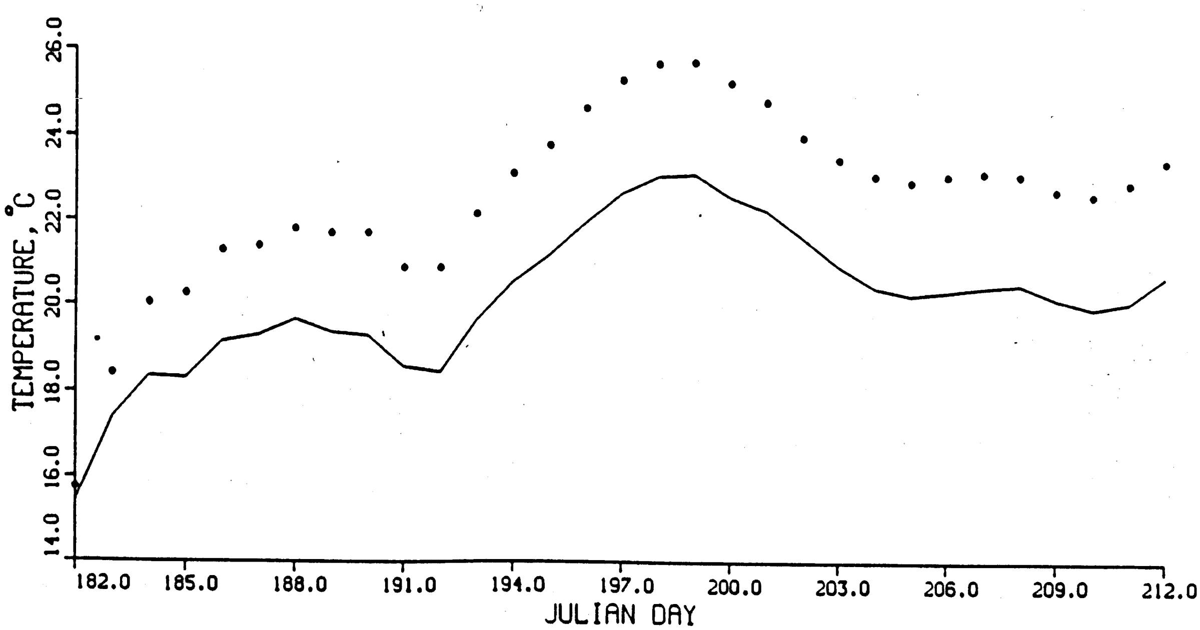


b. At Marial, RM 49.0

Figure 13. Computed stream temperatures for October 1979 using historical release temperatures (—) compared to 5° C decreases of historical release temperatures (...)

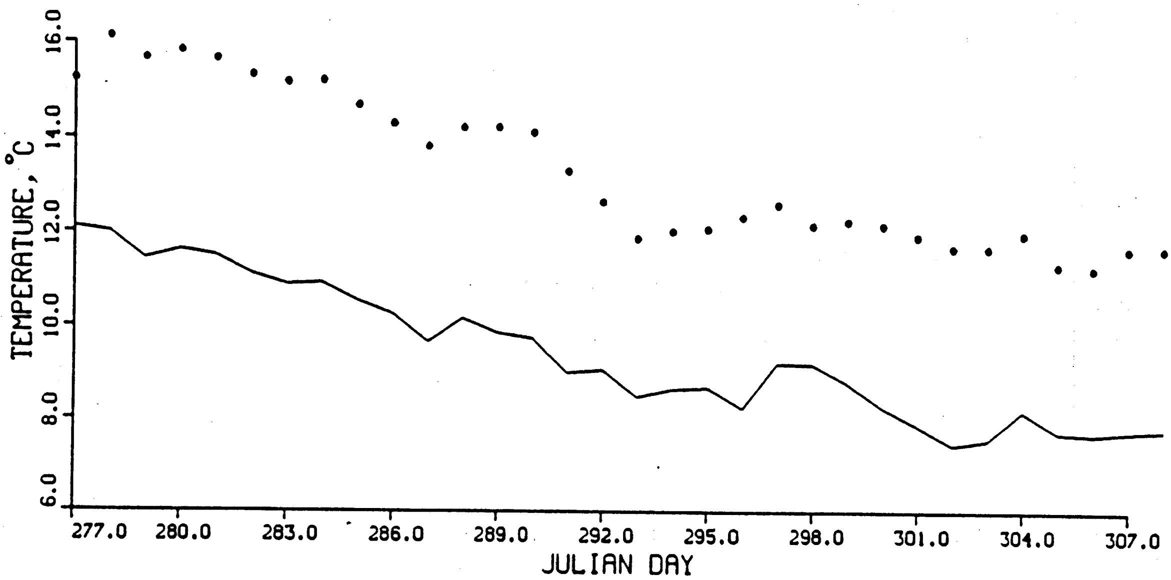


a. At Dodge Bridge, RM 138.5

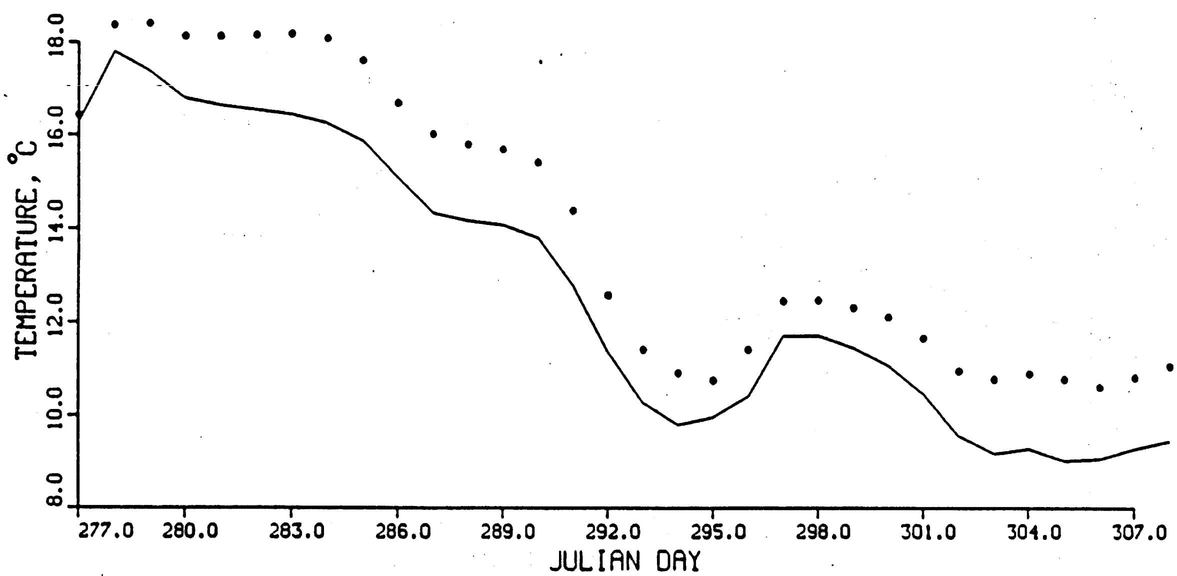


b. At Marial, RM 49.0

Figure 14. Computed stream temperatures for July 1979 using historical release temperatures (—) compared to 5° C increases of historical release temperatures (...)



a. At Dodge Bridge, RM 138.5



b. At Marial, RM 49.0

Figure 15. Computed stream temperatures for October 1979 using historical release temperatures (—) compared to 5° C increases of historical release temperatures (...)

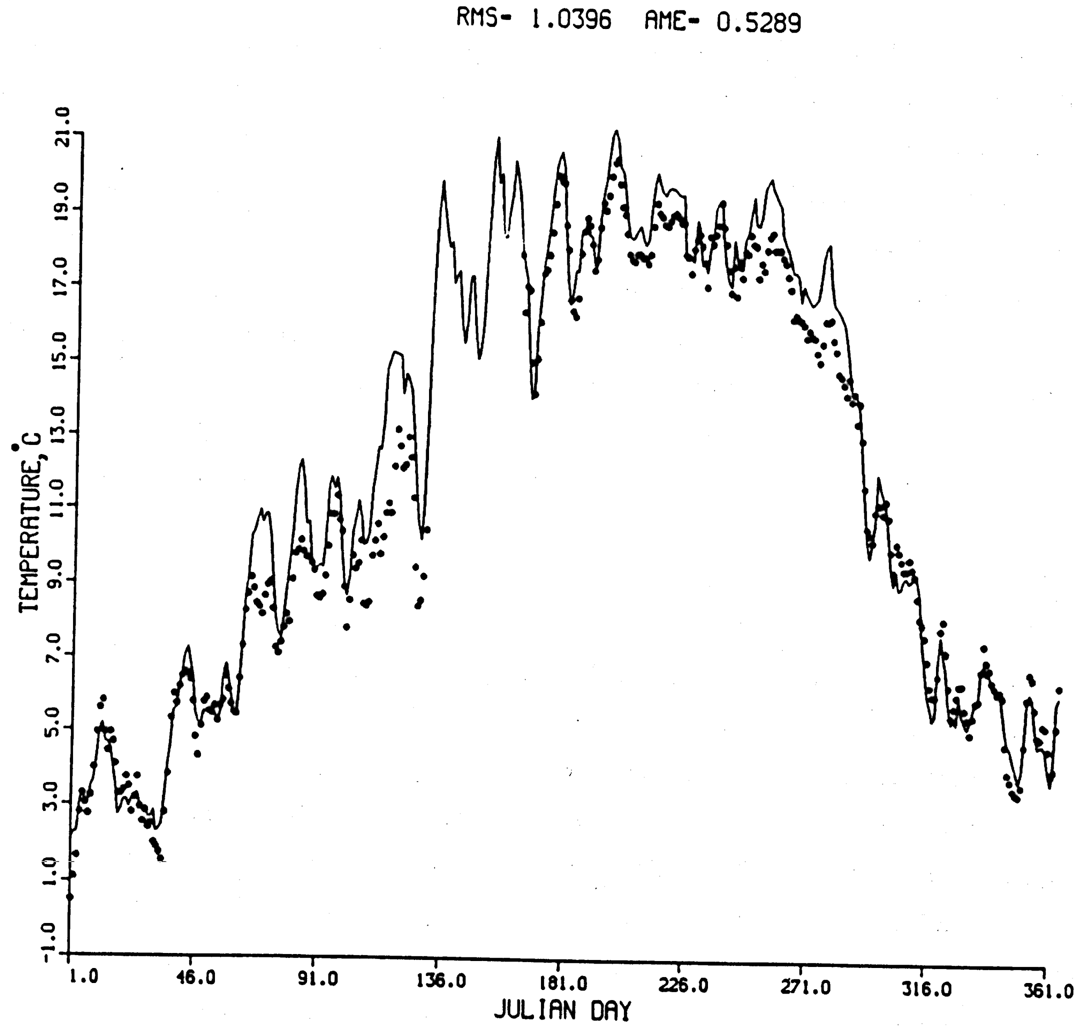


Figure 16. Predicted (—) and observed (...) temperature data at Merlin station for 1979 using equilibrium temperature instead of regression equations for estimating tributary temperatures

of Figure 4, and the AME increased 0.4° C (positive), indicating the model overpredicted temperature values to an even greater extent.

PART V: SOFTWARE DEVELOPMENT

80. Water quality modeling can be an extremely tedious and time consuming approach to evaluating water quality problems of a system because large input data sets may be required and large output data sets may be generated. To increase the usability of QUAL II, WES developed a user-friendly preprocessor program, INPUT, to aid the user in creating new input data sets for temperature simulations on the Rogue River system. Also a user-friendly graphics program, PLOT (which will eventually be developed into the postprocessor), was developed to aid in examining results from a simulation.

Preprocessor

Example

81. The preprocessor program, INPUT, allows the user to create an input data set as needed without directly manipulating variables in the input data set. This ensures that possible errors (i.e., adding extra spaces causing data to shift to the wrong column) to the input data set are eliminated. To use the interactive program, the user answers questions prompted by INPUT with appropriate responses. Depending upon the user's responses, the new input data set (NEWFILE) will be set up accordingly. An error could occur, however, if the user answers any question with an inappropriate or incorrect response. Some examples of questions prompted by INPUT during a session are shown below. Information and queries generated by the computer are outlined in asterisks. User responses are prefaced by a ">" symbol.

```
*****************************************************
*  CHOOSE THE MODELING OPTION FOR THIS SIMULATION   *
*  FROM THE LIST BELOW:                             *
*                                                   *
*   OPTION A : ROGUE RIVER WITHOUT DAM              *
*   OPTION B : ROGUE RIVER WITH LOST CREEK DAM ONLY *
*   OPTION C : ROGUE RIVER WITH LOST CREEK AND ELK  *
*              CREEK DAM                            *
*   OPTION D : APPLEGATE RIVER WITHOUT DAM          *
*   OPTION E : APPLEGATE WITH APPLEGATE DAM         *
*                                                   *
*  PLEASE ENTER A, B, C, ETC. FOR OPTION CHOSEN     *
*****************************************************

>B
```

```
*******************************************************
*                                                     *
*  WHAT YEAR DO YOU WANT TO MODEL - LAST TWO DIGITS   *
*          TIME PERIODS TO CHOOSE FROM ARE            *
*              JAN 1978 THRU SEPT 1981                *
*                                                     *
*******************************************************

>79

*******************************************************
* PICK OPTION THAT BEST FITS YOUR NEEDS               *
*                                                     *
* OPTION 1: SIMULATE WHOLE YEAR (1).                  *
* OPTION 2: SIMULATE TIME PERIODS LESS THAN A YEAR-   *
*           i.e. WEEK, 2 WEEKS, MONTH, ETC. (2).      *
* OPTION 3: SIMULATE A PARTICULAR DAY (3).            *
*******************************************************

>2
*******************************************************
* WILL HISTORICAL OR SYNTHESIZED DATA BE USED         *
* FOR THE DISCHARGE AND RELEASE TEMPERATURE AT        *
* LOST CREEK DAM?  (H OR S)                           *
*******************************************************

>H

************************************************************
* WHAT IS YOUR STARTING DATE OF SIMULATION (JULIAN DAY)? *
************************************************************

>151

*******************************************************
* WHAT IS THE LAST DAY OF SIMULATION (JULIAN DAY)?  *
*******************************************************

>300.
```

Organization

82. INPUT performs three important functions to enhance the usability of QUAL II. All of these functions are tedious and time consuming and could easily produce errors if routinely performed by the user. The tasks performed by QUAL II include:

a. Creation of the input data set required by QUAL II.

b. Data synthesis and handling.

c. Creation of one of several different headwater formulations as required for each scenario.

Input data files

83. Information requirements to generate the input file for QUAL II can be separated into two categories--data that are independent of the scenario being run and data that change with each scenario.

84. Data that are independent of the scenario being run are contained in a file named OPTABC. Some examples of this type of information are hydraulic reach data, stream reach data (river mile), element type, etc. INPUT reads this data file and writes the information to the input data set for QUAL II. If the user wishes to modify information that would remain constant for all applications of QUAL II on the Rogue River (i.e., add new reaches to the system or perhaps model new water quality constituents other than temperature, such as dissolved oxygen or algae), then OPTABC would have to be changed to accommodate the new information. In turn, INPUT would also need to be altered in order to read the new information, or an error would occur when running INPUT.

85. INPUT can obtain information that changes with each scenario from two sources. Historical information, such as was used for calibration and verification in this study, was compiled by the WES and placed into two data files, INP7879 and INP8081. INP7879 contains all necessary data for 1978 and 1979, and INP8081 contains all data for 1980 and the first 9 months of 1981. Some examples of these variables are daily averaged flow and temperature from Lost Creek Dam, Big Butte Creek, Elk Creek, and Applegate River; 3-day running average equilibrium temperature and coefficient of surface heat exchange (used in the flow and temperature regression equations); and daily averaged meteorological data. Depending upon the scenario being run, QUAL II will read either one of these input files and extract the necessary information. Use of historical information from other time periods requires that data be collected and compiled into new data files.

86. INPUT can also use flow and temperature information estimated by a reservoir water quality model (i.e., WESTEX or QUALR1) to generate headwater flows and temperatures for QUAL II. For this type of application the user must respond with "S" when INPUT queries whether historical or simulated (synthesized) data will be used. INPUT accesses simulated data one of two ways depending upon the length of time that is simulated. For time periods less than 2 weeks, the user enters the data when prompted by QUAL II. For time periods greater than 2 weeks, INPUT will read the necessary information from

one or both of two data files, SYNAMC and SYNELK. These files contain release discharge and temperature data for Lost Creek Dam and Elk Creek Dam, respectively.

Tasks performed by INPUT

87. To create new input data sets for the Rogue River system, INPUT performs many necessary tasks that would otherwise have to be performed by the user. For example, the regression equations discussed in previous sections have been embedded in INPUT. The user need not calculate missing temperature and flow data for the tributaries. INPUT also calculates other values associated with the regression equations, such as Ti (initial inflow temperature of the tributary) and As (surface area of the tributary).

88. INPUT has the capability to synthesize data when gaps occur in the historical data. On days for which historical data for Lost Creek Dam, Elk Creek, Big Butte Creek, or Applegate River are missing, a -2 value was entered. When INPUT encounters -2 for temperature values in Big Butte Creek, Elk Creek, or the Applegate River, temperature regression equations (discussed in a previous section) are solved to synthesize the missing data. Missing values for temperature at Lost Creek Dam, however, are set to the previous known value since release temperature does not generally change substantially from one day to another. For instance, if a temperature value was missing on Julian day 115, the value used for day 115 would be the value on Julian day 114 (if available).

89. Initial temperature conditions for each reach of the Rogue River system are also determined by INPUT. The temperature Equation 1 was applied to the four gaging stations on the Rogue River (Dodge Bridge, Raygold, Grants Pass, and Agness from Table 2) using observed temperature from the "near McLeod" station for Ti , observed flow data at each gaging station for Q , and the appropriate calculated value for As . Water temperatures at all elements downstream of the Dodge Bridge gage are obtained by linear interpolation between the gages. Initial conditions upstream of the Dodge Bridge station are obtained by interpolating between the observed temperature value at the "near McLeod" station (or "at McLeod" station when "near McLeod" station value was missing) and the predicted temperature for the Dodge Bridge station. Resulting temperature values for each reach are written to the new input data file (NEWFILE) as initial conditions of the Rogue River.

Headwater reach handling

90. INPUT will automatically set up headwater reaches depending upon the data type (historical or simulated) being used for discharge and release temperature at the dams. If historical data are used for discharge and release temperature at Lost Creek Dam, the headwater is assumed to begin at the "at McLeod" gaging station (RM 156) since data from this station are used by the Portland District in place of actual values measured at the dam. Two elements would be contained in this headwater reach. However, if synthesized (simulated) data are used, the headwater is assumed to begin at the actual damsite (RM 157.4) and the headwater reach would contain six elements. The Lost Creek Dam headwater reach is handled in this fashion because results from a preliminary simulation showed that a +0.2° C error in water temperature was introduced when the temperatures at the "at McLeod" gage were used as the release temperatures from Lost Creek Dam, causing slightly increased water temperatures downstream.

91. The headwater reach for Elk Creek is handled in a similar fashion. If synthesized data are being used, Elk Creek is modeled as having a dam with the headwater starting at the actual damsite (RM 1.7). Five elements would be contained in this headwater reach. However, if historical data are being used, Elk Creek is modeled as a tributary with the headwater starting at RM 0.4 (the gaging station near Trail, Oreg., from Table 2). This headwater reach would contain two elements.

Postprocessor

92. To aid in the evaluation and interpretation of model output, the WES developed a postprocessor program that would plot the results produced by QUAL II simulations. Under the original study plan, the postprocessor program would also contain fish regression equations developed by the Oregon Department of Fish and Wildlife. However, at the time the postprocessor was developed, the Portland District considered the regression equations too preliminary for inclusion in the program. The effort that would have gone into embedding the fish regression equations into the postprocessor was redirected to enhancing the graphics in the postprocessor program.

93. The fish regression equations can later be included into the postprocessor program to complete the development of this management tool for the

Rogue River fishery. Two examples (Cramer 1985) are provided to illustrate how these equations could be used by the postprocessor program. Prespawning mortality of spring chinook is given by:

Mortality of hatchery fish = -22.107 + 1.242 * Mean maximum temperature at Raygold during June (14)

Mortality of wild fish = 1.354 - 1.928 * 10E-03 * Mean flow at Raygold during June (15)

Note that values for the independent variables (Raygold mean maximum temperature in June and Raygold mean flow in June) for both these equations are predicted by QUAL II. The postprocessor program could be modified to calculate the necessary values to complete the regression equations, and mortality estimates (or other estimates of the status of the Rogue River fishery) could be output from the postprocessor.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

94. The dynamic temperature simulations of the Rogue River reported herein, which included sensitivity analyses performed by changing the input parameters of discharge and release temperature at Lost Creek Dam, and the evaluations of the importance of tributary flows and temperatures produced the following conclusions and recommendations:

a. QUAL II produced acceptable water temperature predictions that were within 1.0° C of observed temperatures most of the time.

b. To improve model predictions for the lower reaches of the Rogue River, more cross-section data should be obtained using the same measurement standards as practiced by the USGS. Gage information (such as stage, discharge, and rating curves at the Merlin and Marial stations) to verify hydraulic conditions between Grants Pass and Agness is also needed.

c. Sensitivity analyses show that water temperature changes as far downstream as the Marial gaging station are detectable due to changes in Lost Creek Dam discharge and release temperatures. This effect is most pronounced in July when the most extreme weather conditions occur (hot, dry summers).

d. The effects of ungaged tributaries were significant enough to warrant the inclusion of tributary flow and temperature estimates in the input data sets.

e. Regressed flow and temperature values for the ungaged tributaries were adequate to complete the simulations for the Rogue River; however, observed gaged data for these variables would be preferred if available. Gaging some of the larger tributaries (i.e., Evans Creek, Bear Creek, and Graves Creek) for flow and temperature should be considered for future model simulations.

f. The primary use of this model is to simulate the downstream temperature and flow effects of different Lost Creek Dam release flows and temperatures under historical meteorological conditions and tributary inputs. The model is not set up for real-time simulation, but could be modified. The development of a set of nomographs to relate discharge, release temperature, and downstream river temperatures for given sets of meteorological conditions as an aid to operations should be considered.

g. For simulation of water temperature on the Rogue River, Elk Creek and Applegate River were not modeled with dam conditions. Elk Creek was modeled as a tributary and Applegate River as a point source (no cross-section data required) using gage information as the boundary conditions for both. However, simply by changing the boundary conditions to the dams' operating schedules, both could be modeled with dam conditions. No additional information would be required for Elk Creek, but cross-section information for Applegate River would need to be included, and this stream reach would need to be calibrated.

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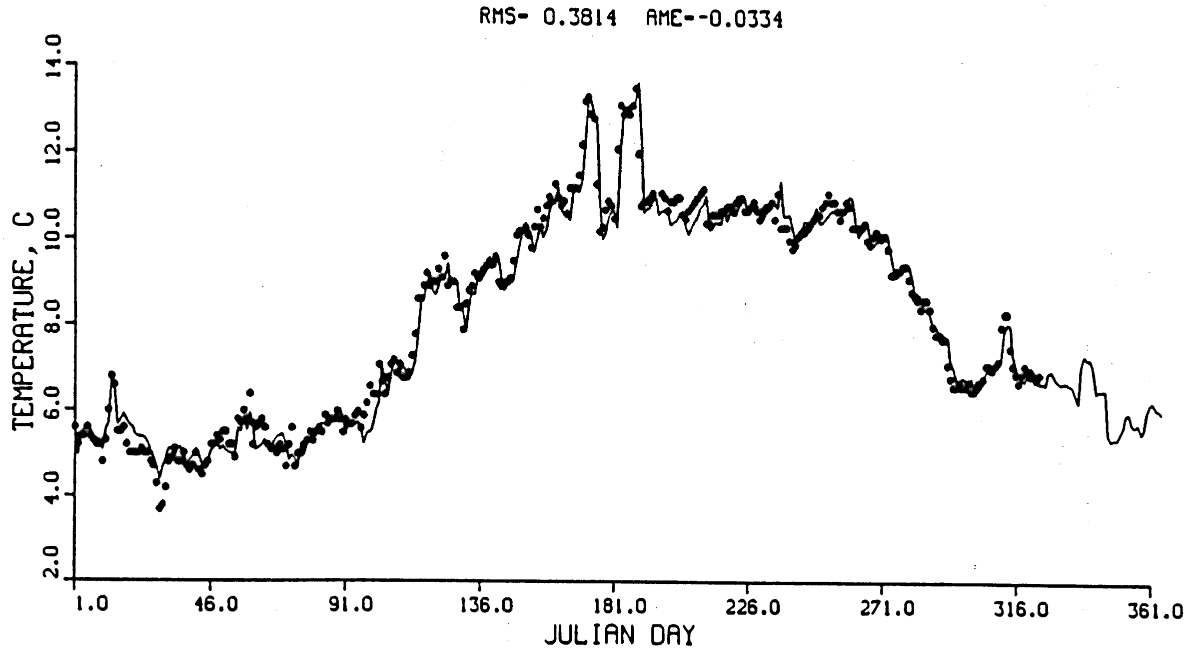
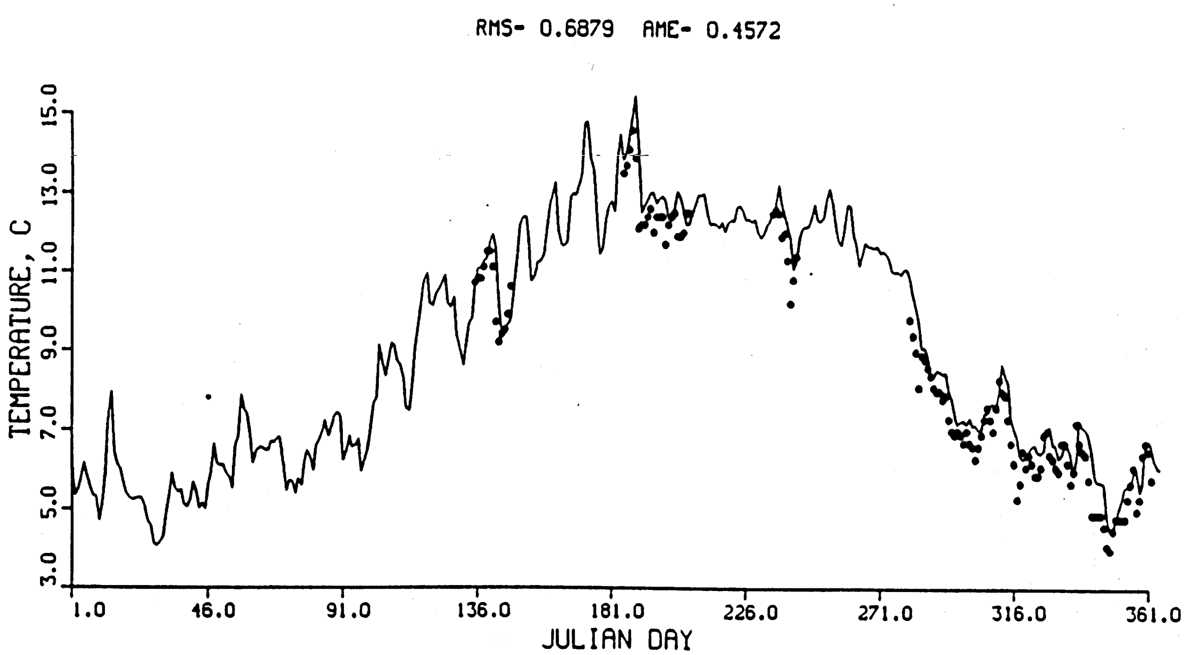
APPENDIX A: VERIFICATION RESULTS FOR 1980-1981

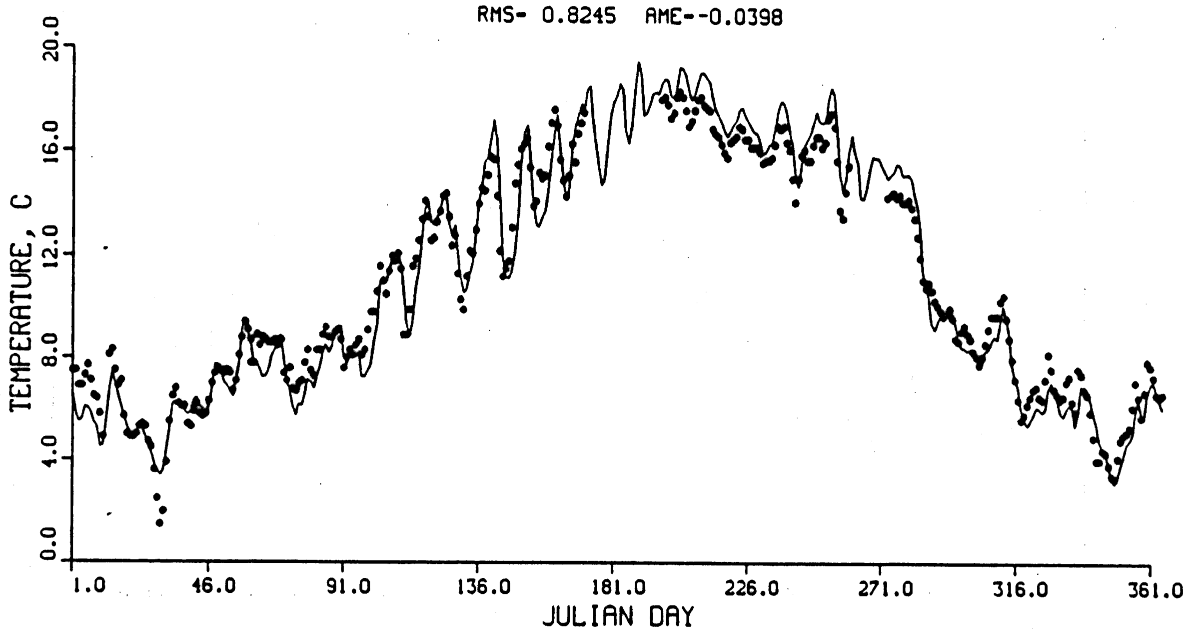


a. Near McLeod, RM 154.2

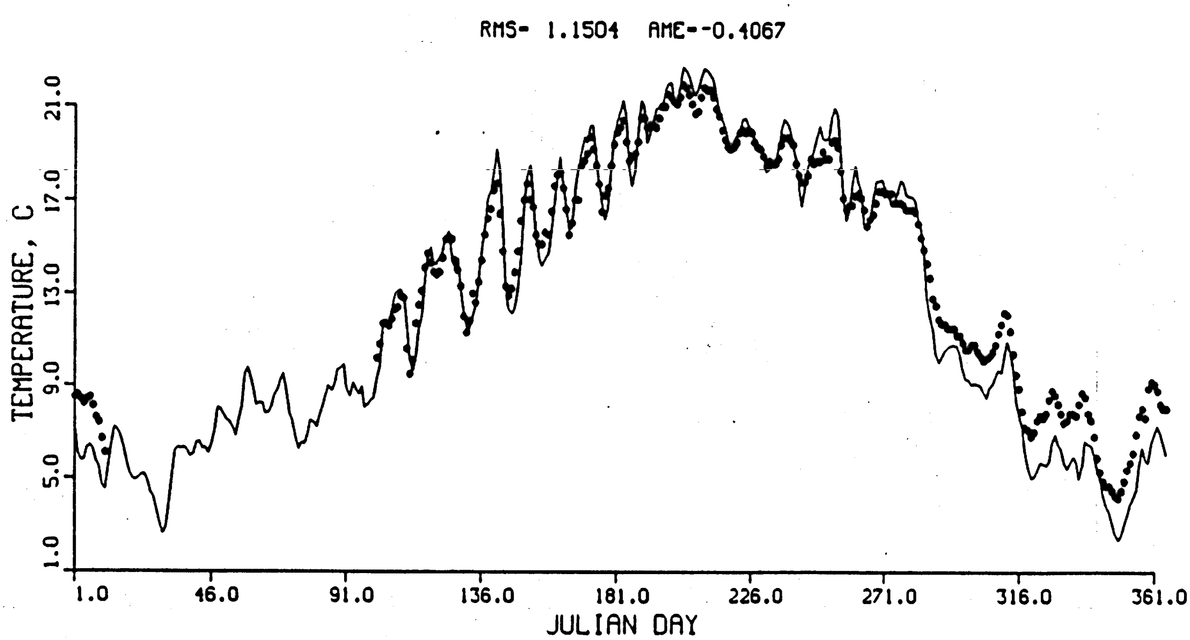


b. At Dodge Bridge, RM 138.5

Figure A1. Predicted (—) and observed (...) stream temperature data for 1980 (Continued)

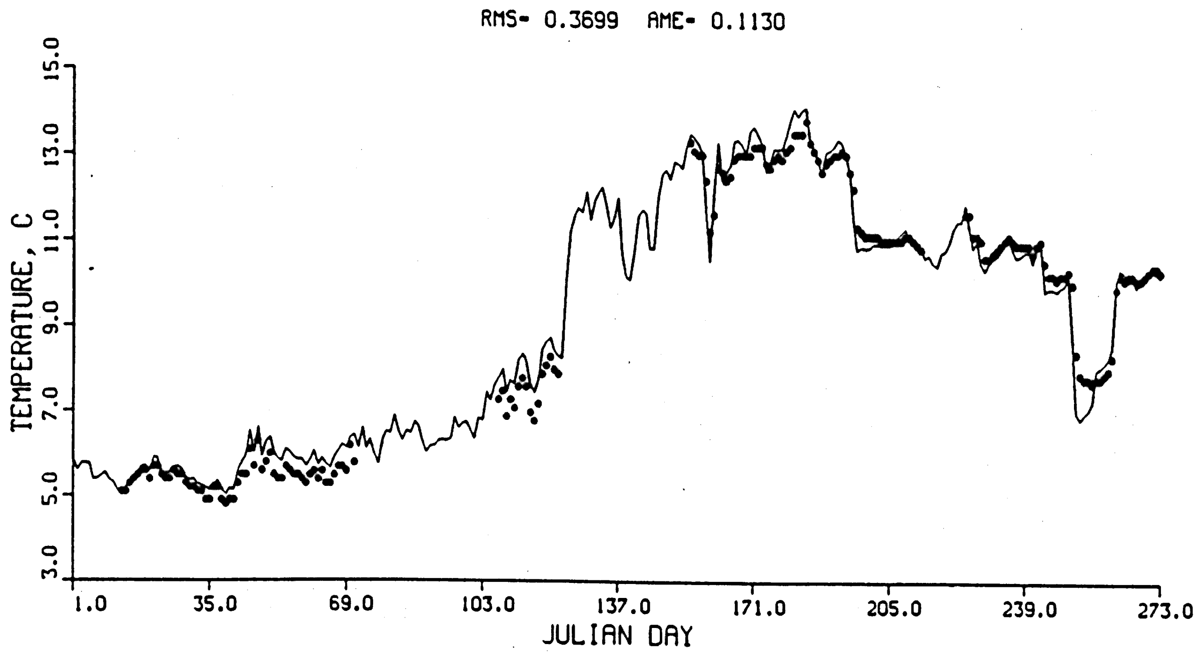


c. At Grants Pass, RM 101.8

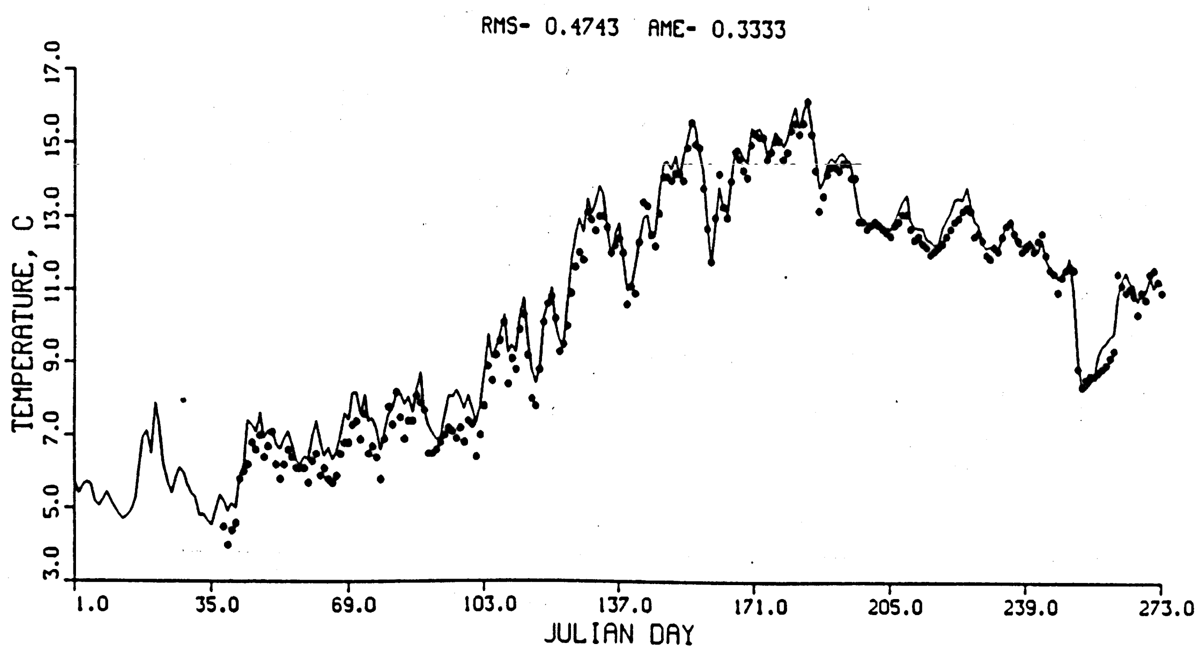


d. At Marial, RM 49.0

Figure A1. (Concluded)

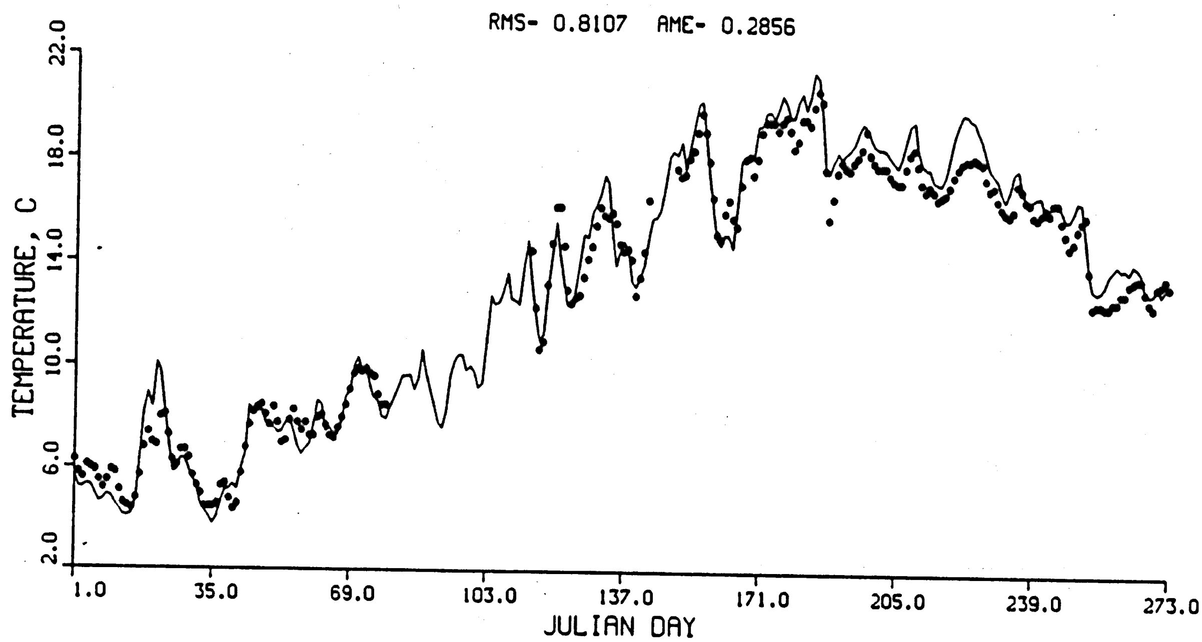


a. Near McLeod, RM 154.2



b. At Dodge Bridge, RM 138.5

Figure A2. Predicted (—) and observed (...) stream temperature data for 1981 (Continued)



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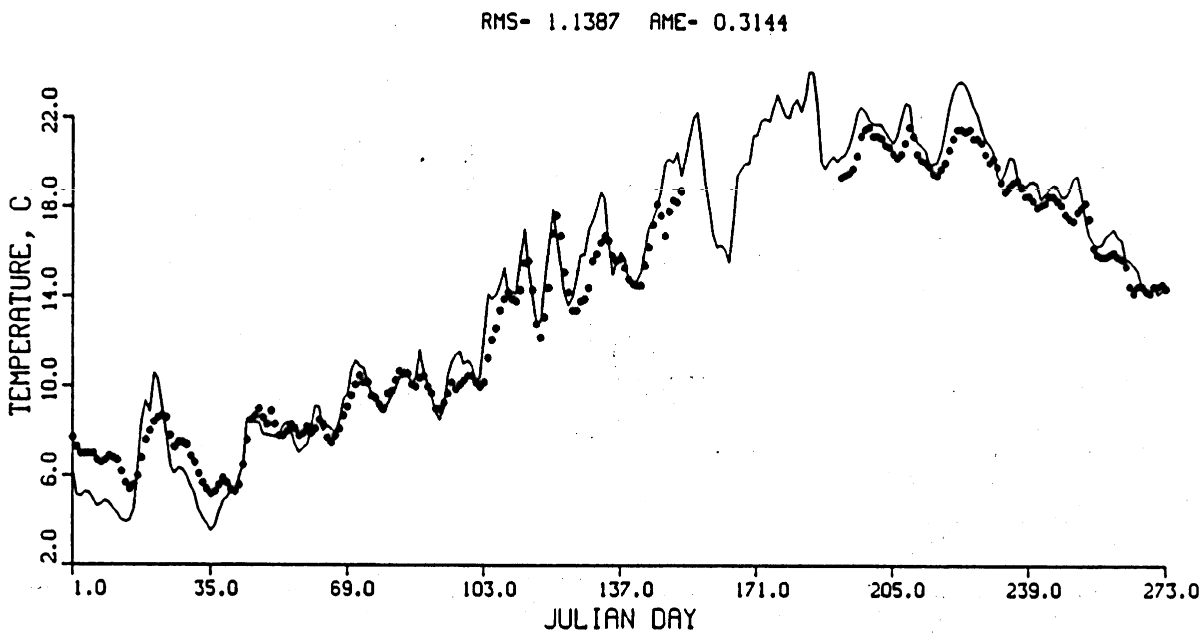

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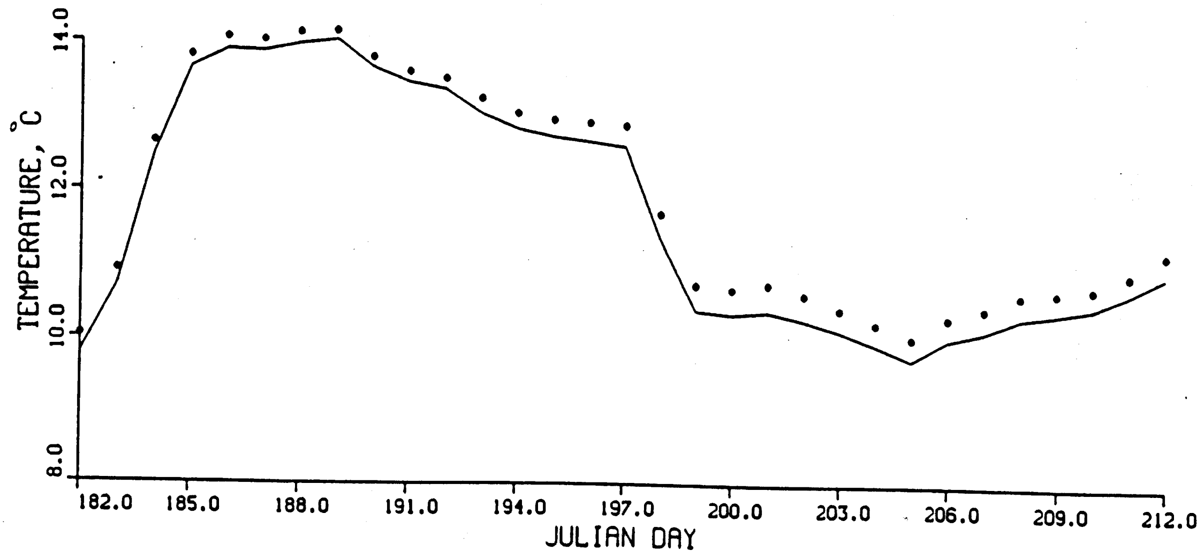
Figure A2. (Concluded)

APPENDIX B: SENSITIVITY ANALYSES RESULTS



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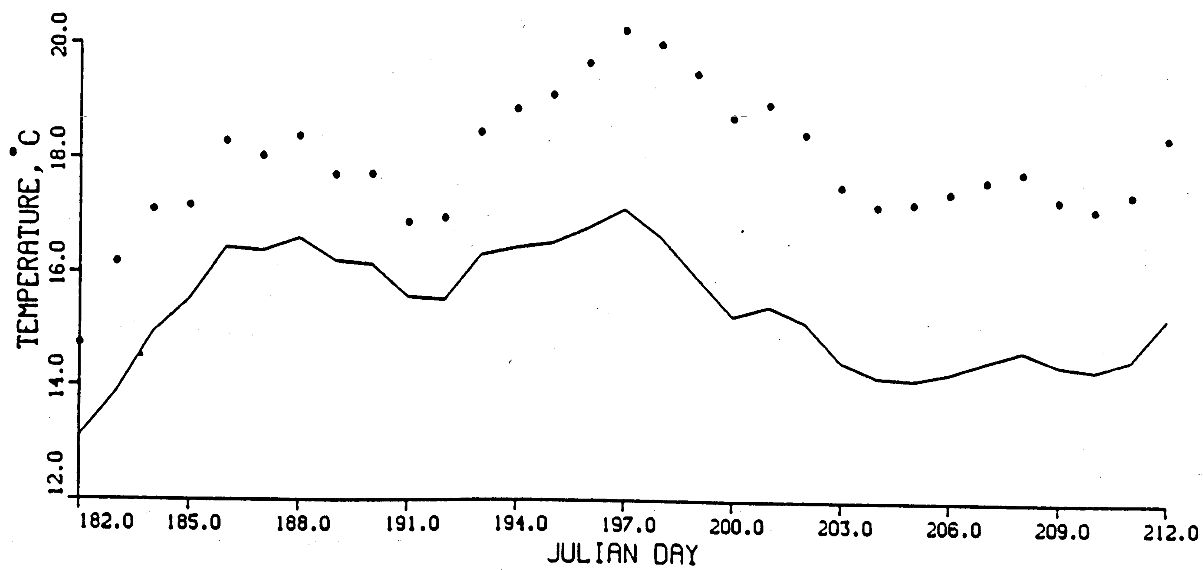
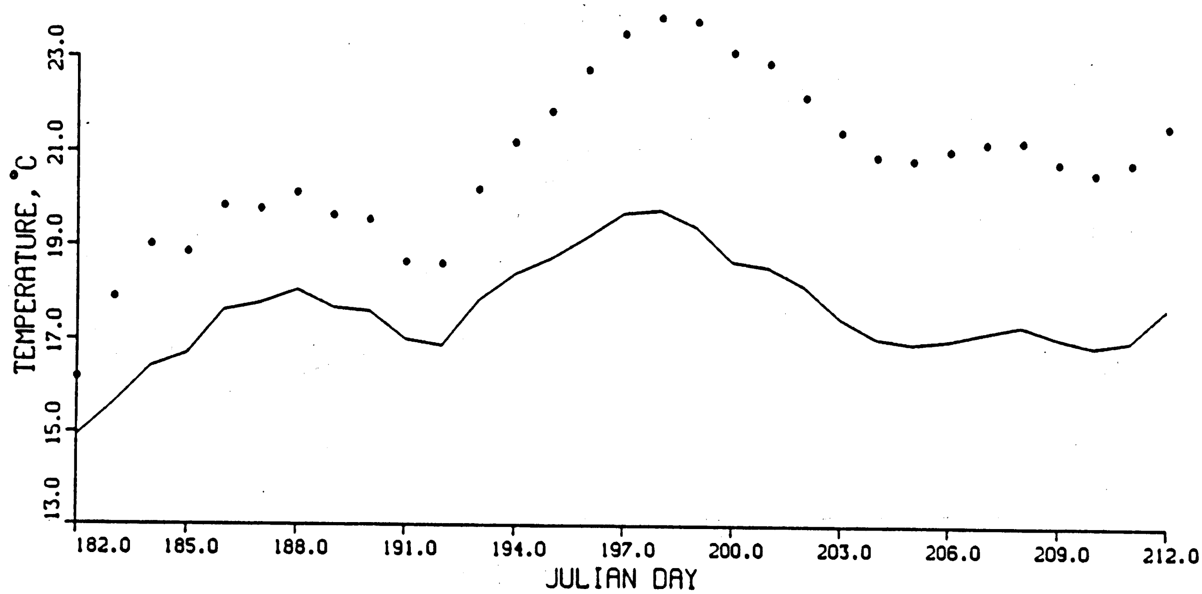


b. At Raygold, RM 125.2

Figure B1. Computed stream temperatures for July 1979 using historical flows (—) compared to halved historical flows (...) (Continued)



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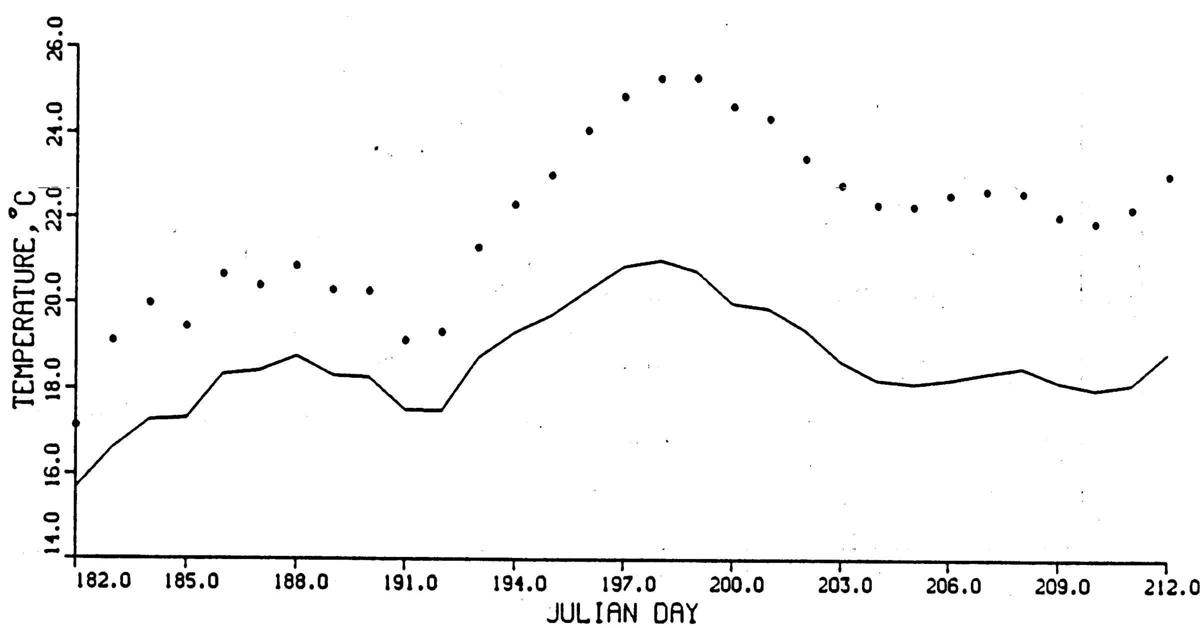
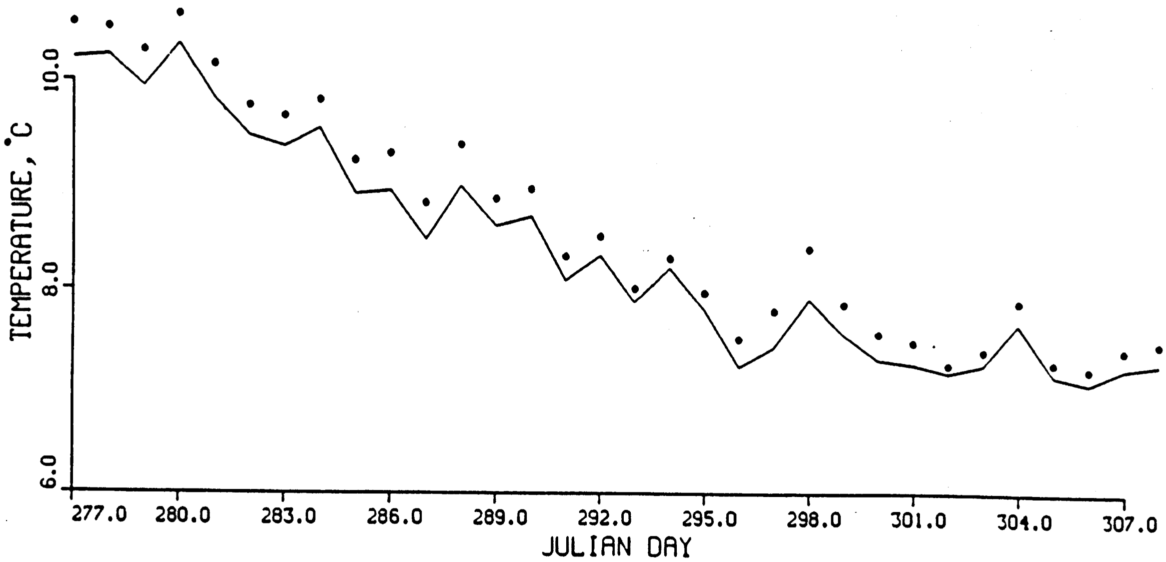
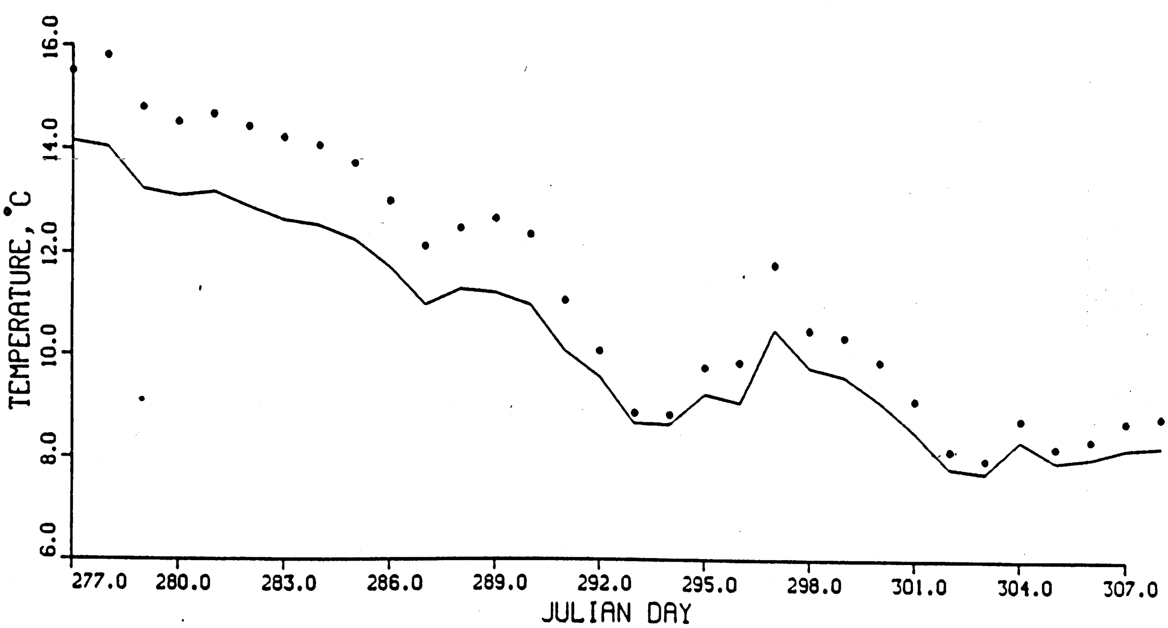


d. At Merlin, RM 86.6

Figure B1. (Concluded)

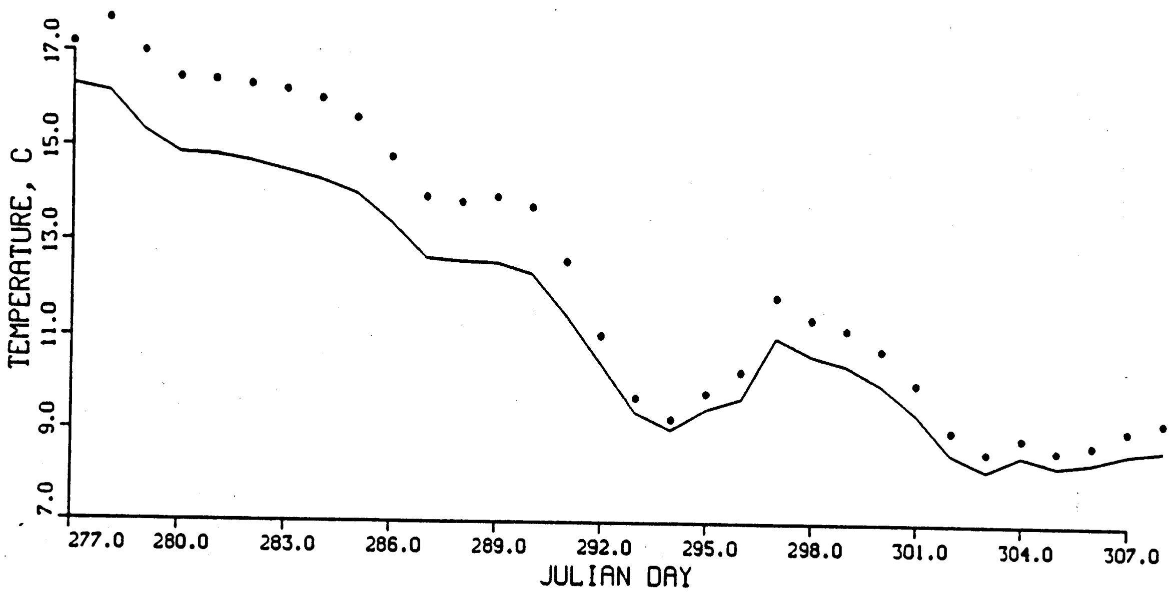


a. Near McLeod, RM 154.2



b. At Raygold, RM 125.2

Figure B2. Computed stream temperatures for October 1979 using historical flows (—) compared to halved historical flows (...) (Continued)



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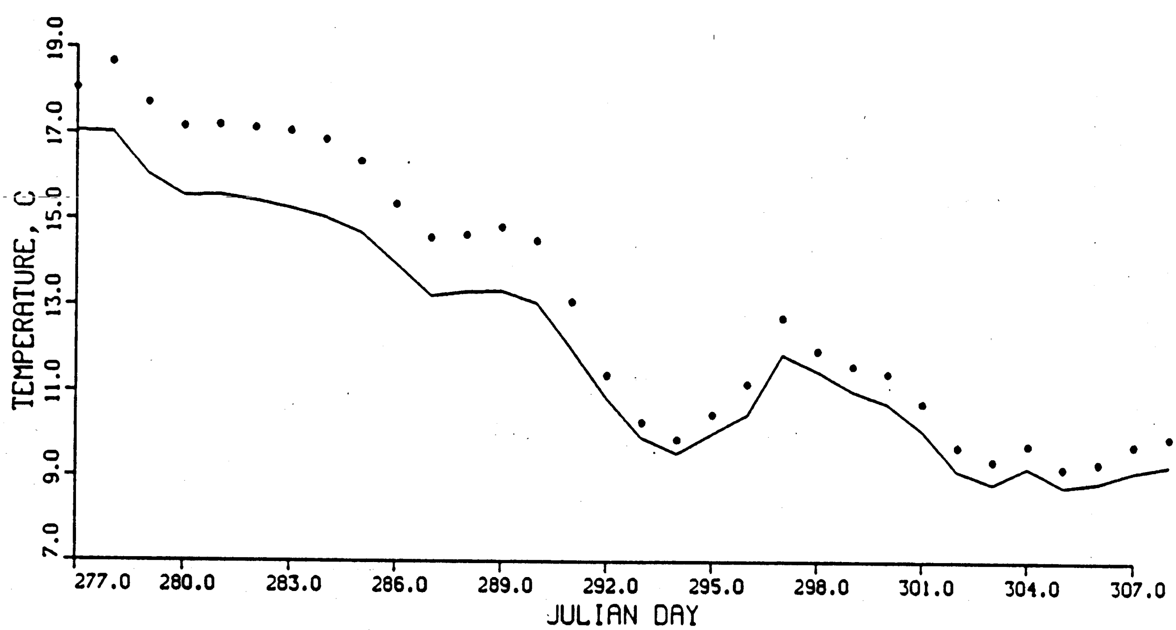

d. At Merlin, RM 86.6

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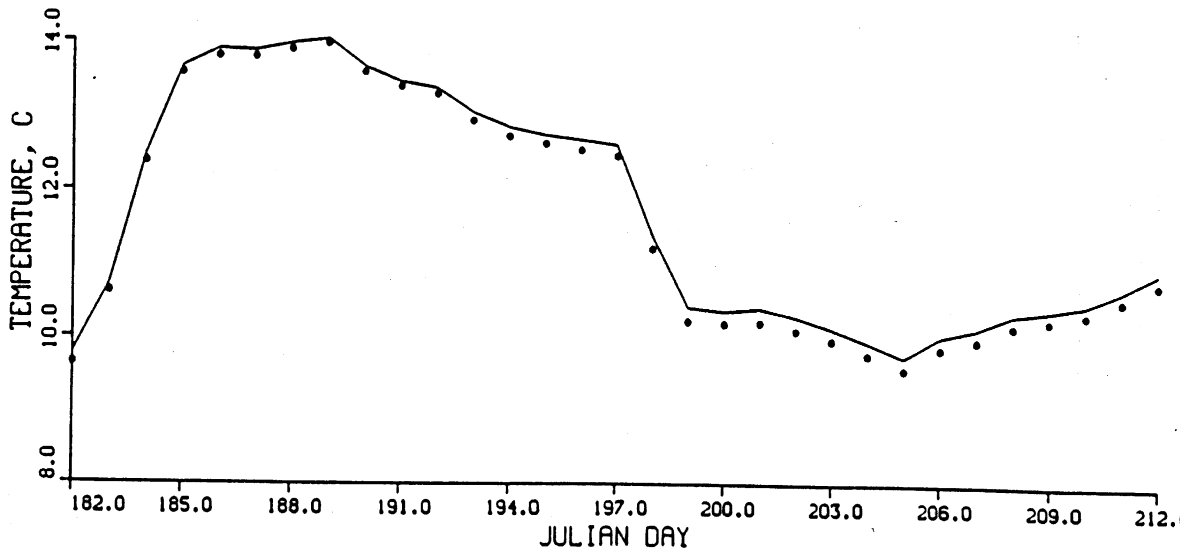

a. Near McLeod, RM 154.2

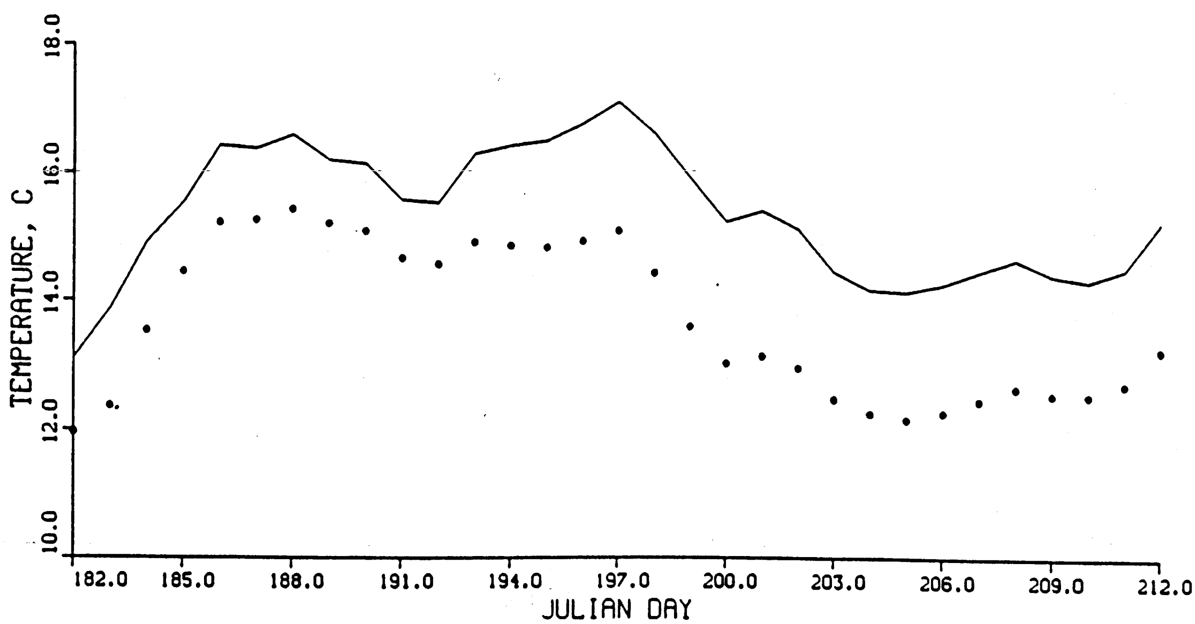

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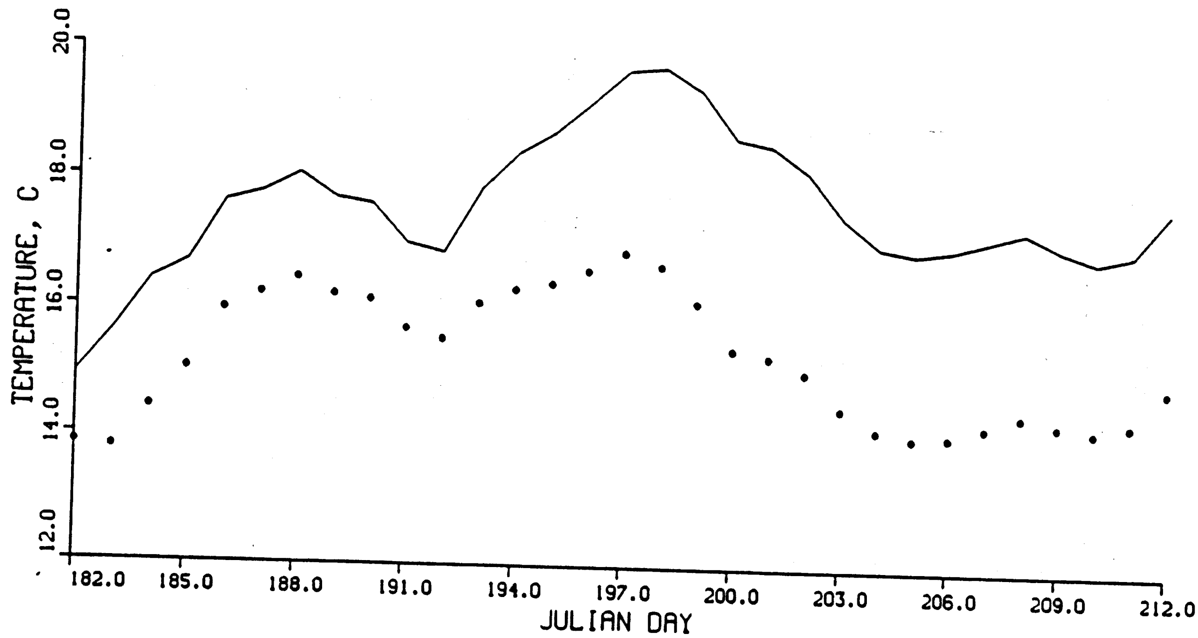
Figure B3. Computed stream temperatures for July 1979 using historical flows (—) compared to doubled historical flows (...) (Continued)



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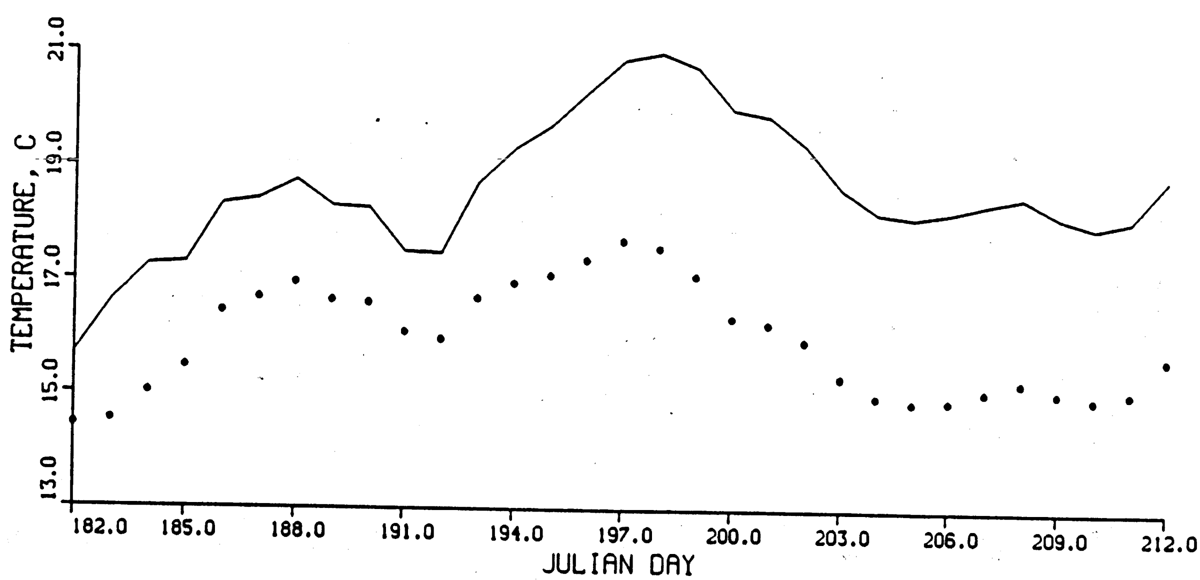

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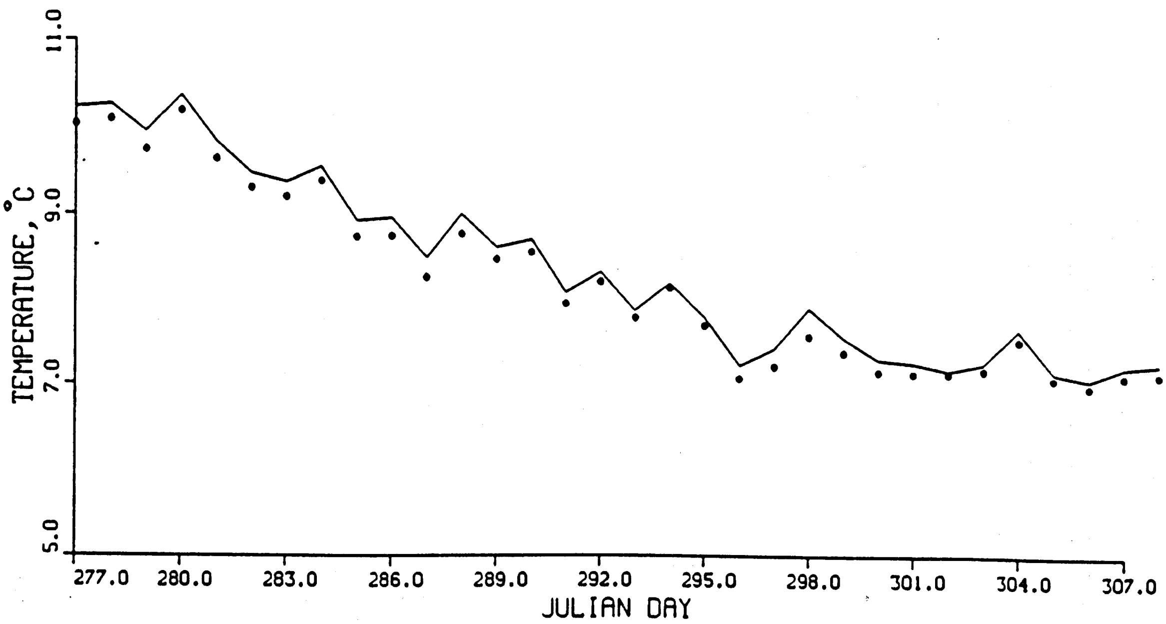

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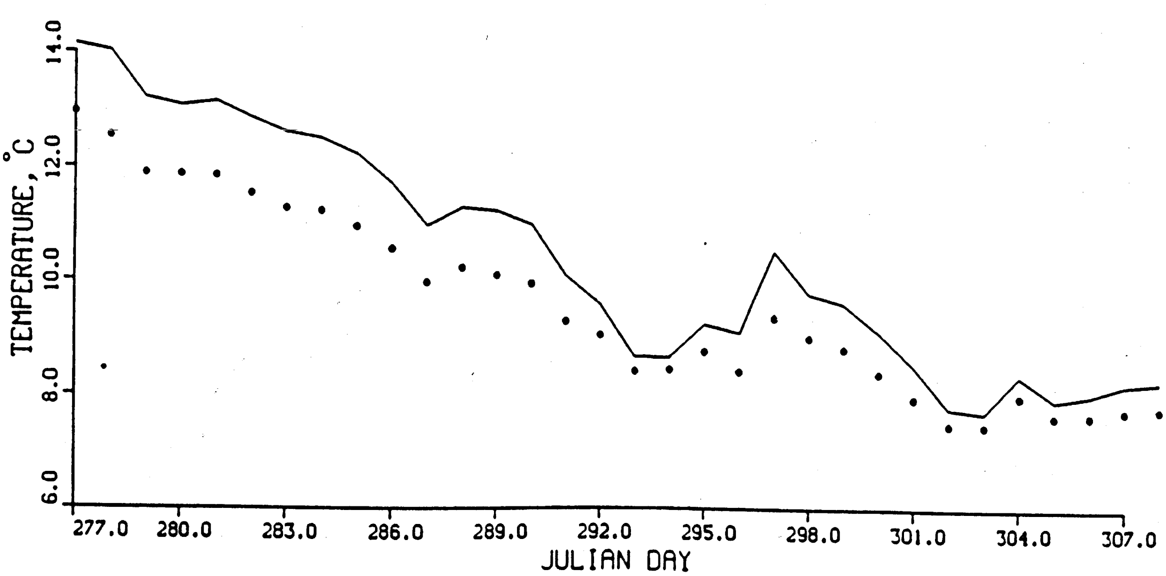

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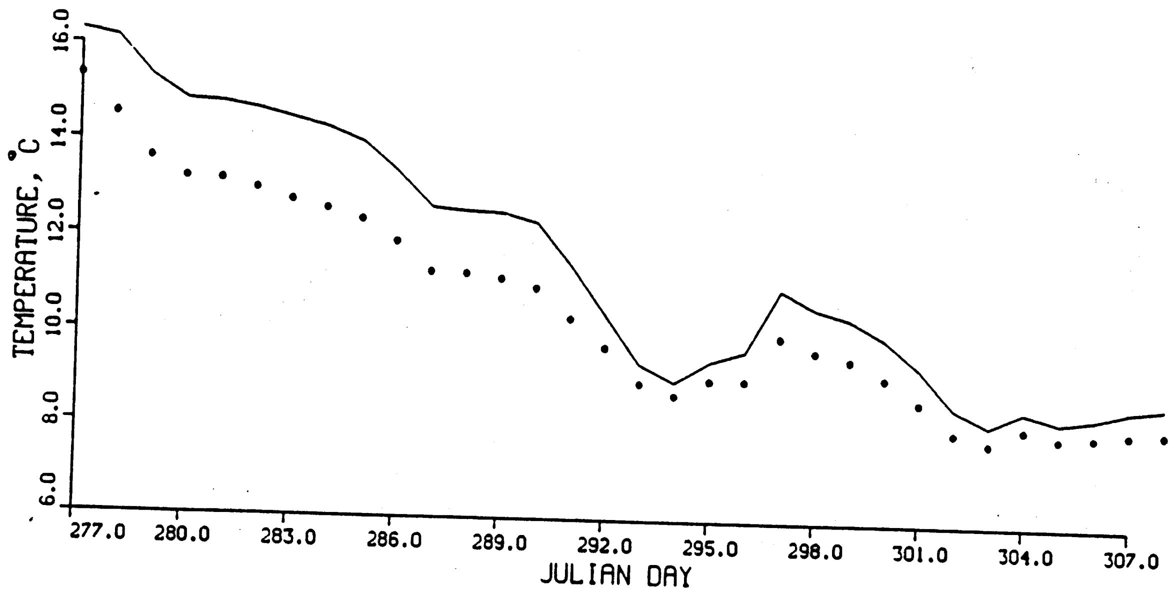
Figure B4. Computed stream temperatures for October 1979 using historical flows (—) compared to doubled historical flows (...) (Continued)



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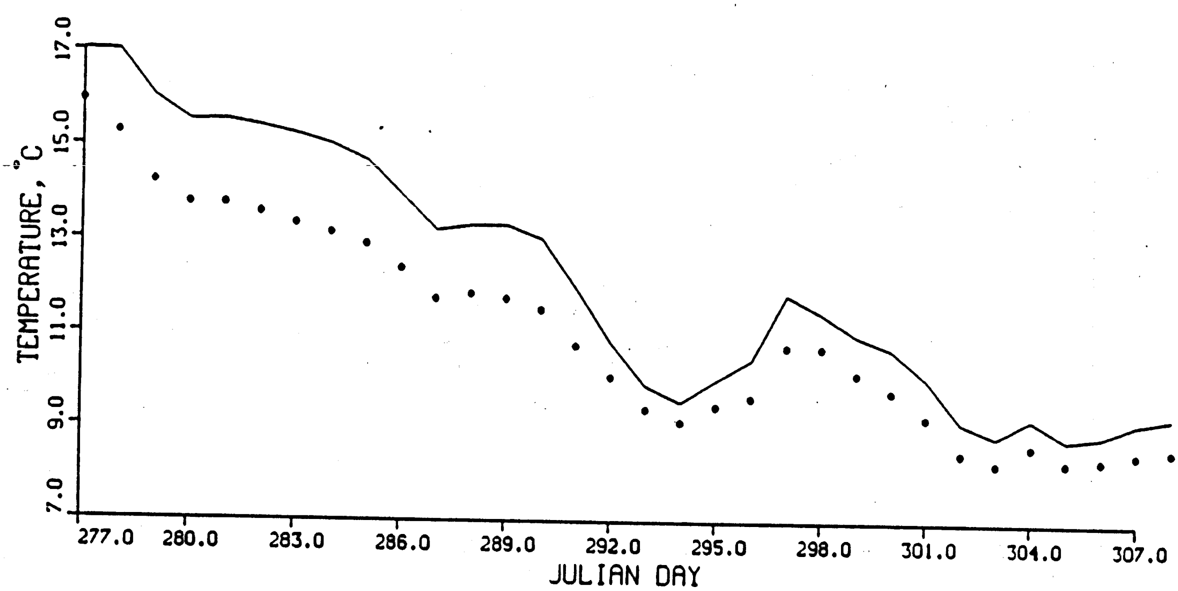

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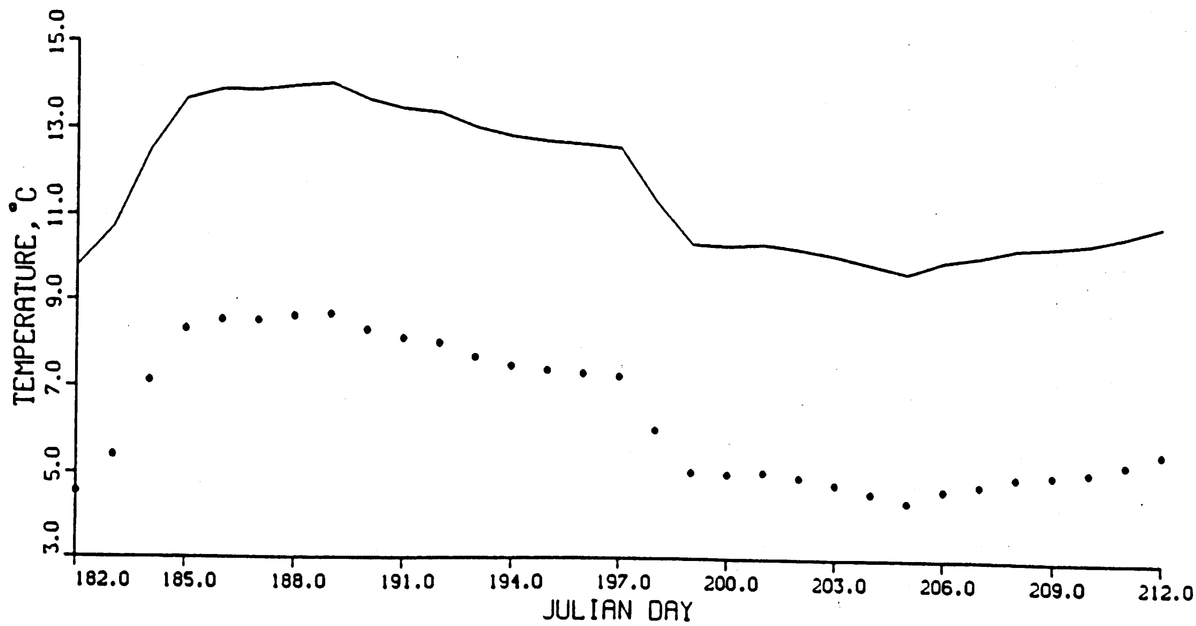

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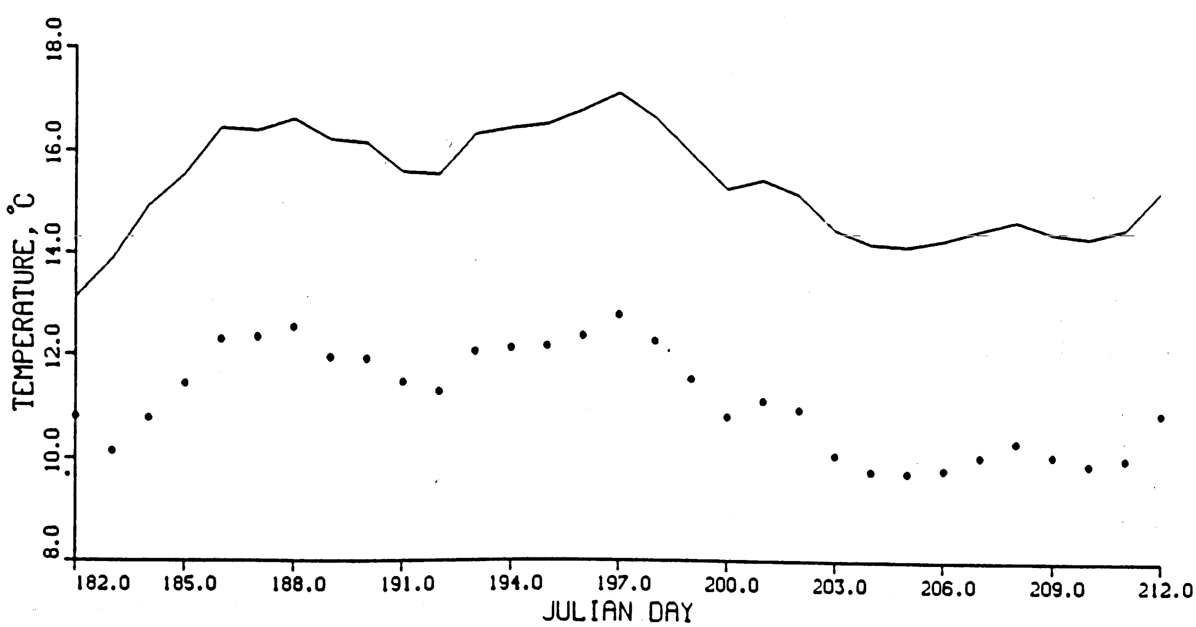
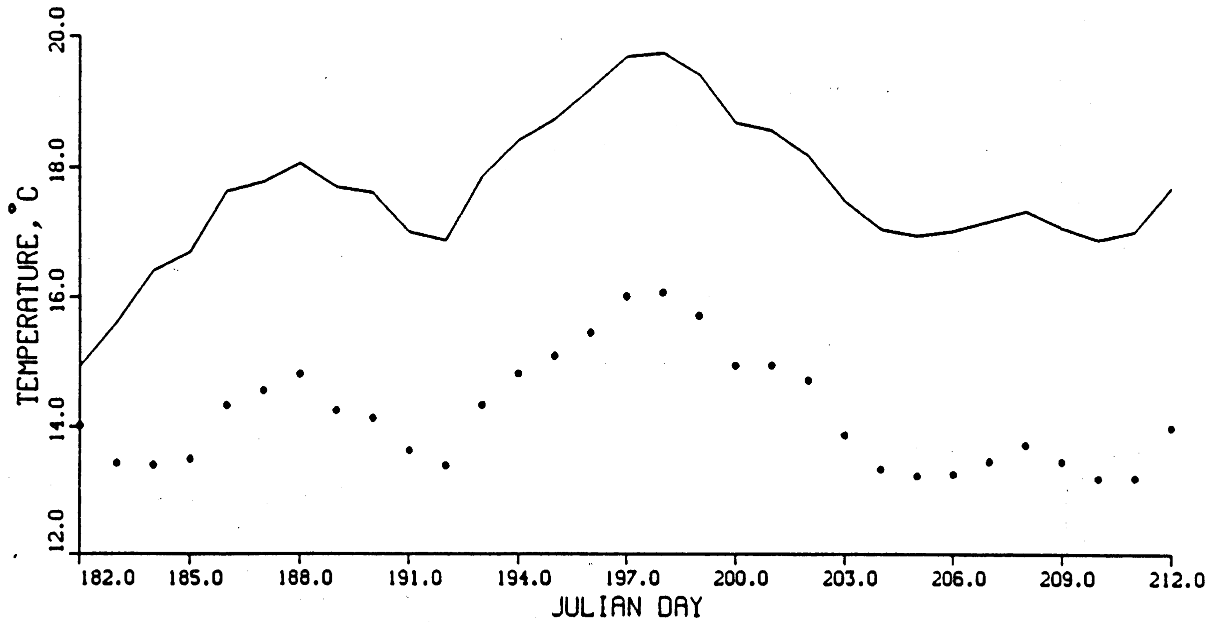


b. At Raygold, RM 125.2

Figure B5. Computed stream temperatures for July 1979 using historical release temperatures (—) compared to 5° C decreases of historical release temperatures (...) (Continued)



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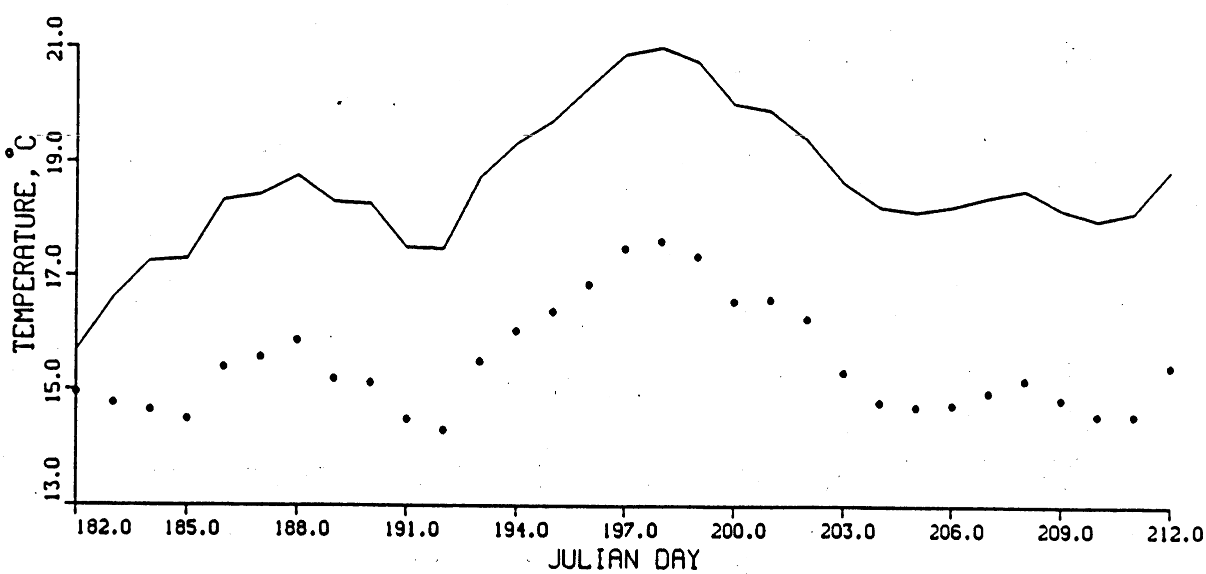

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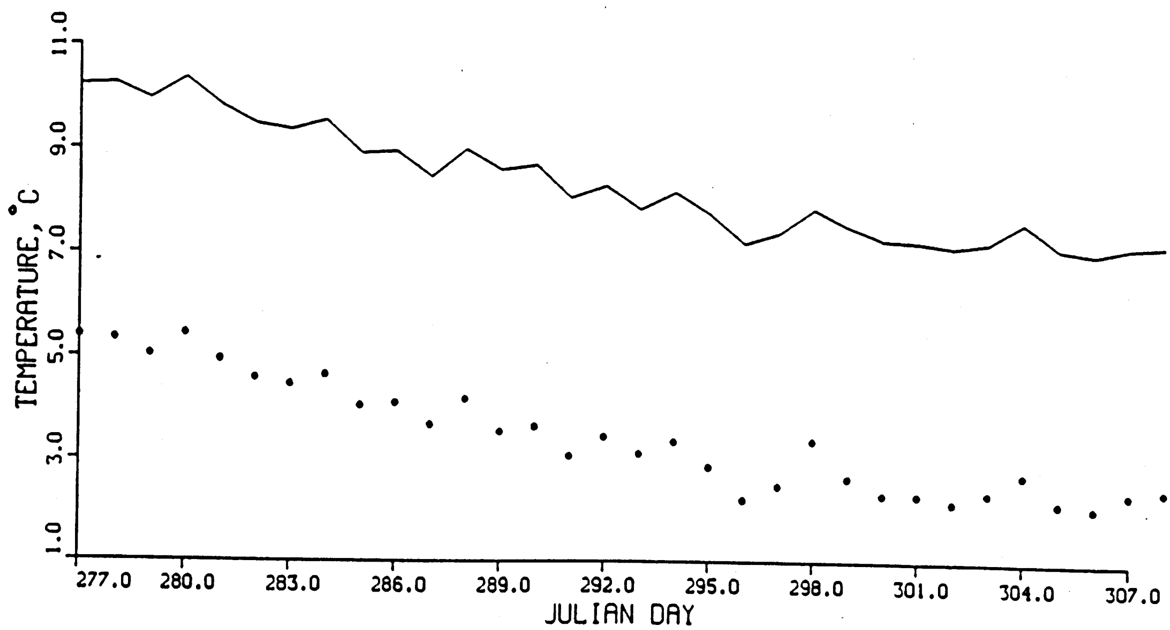

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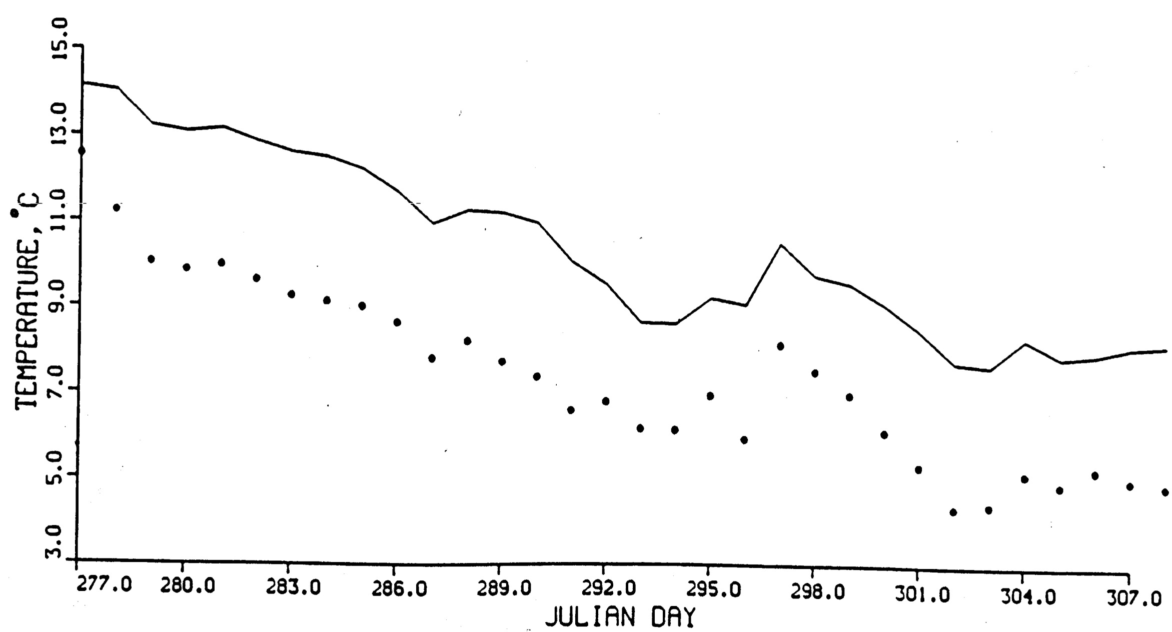

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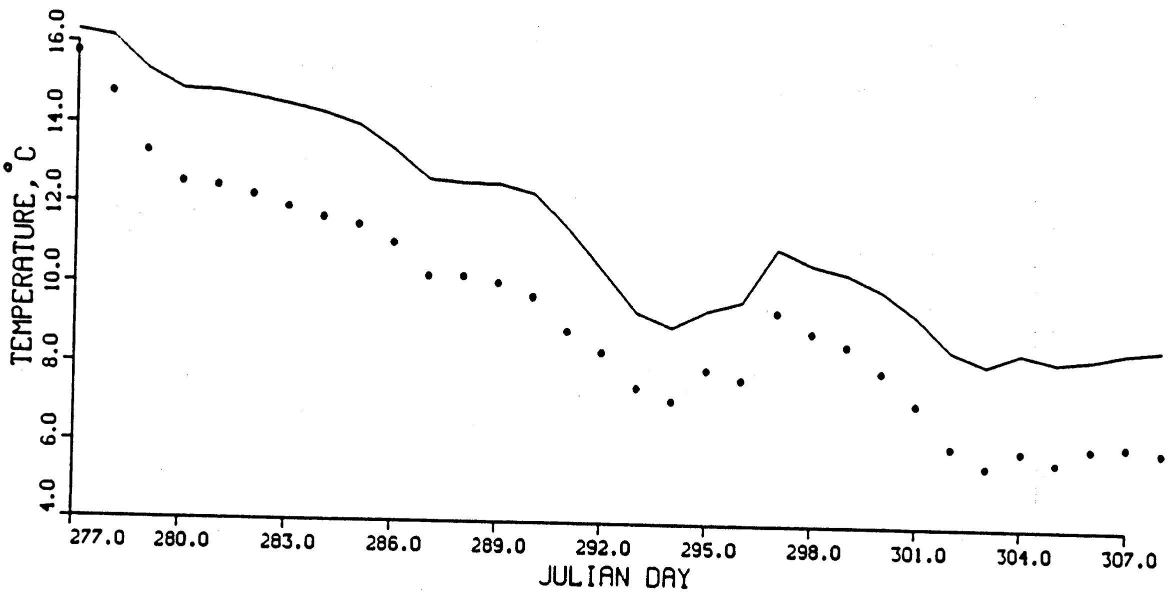
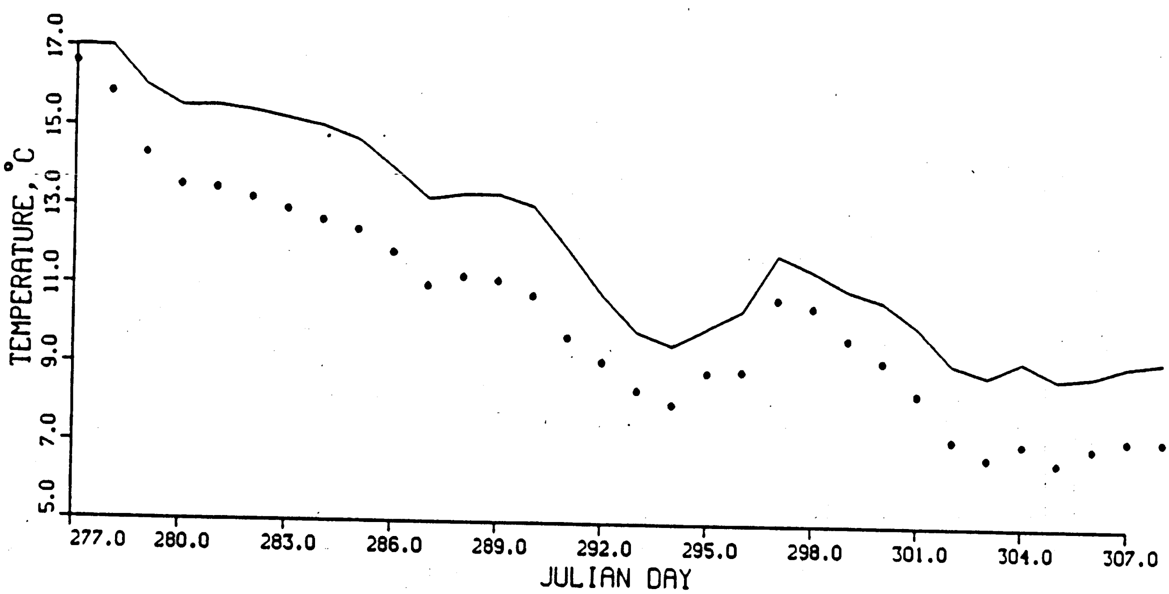
Figure B6. Computed stream temperatures for October 1979 using historical release temperatures (—) compared to 5° C decreases of historical release temperatures (...) (Continued)



c. At Grants Pass, RM 101.8



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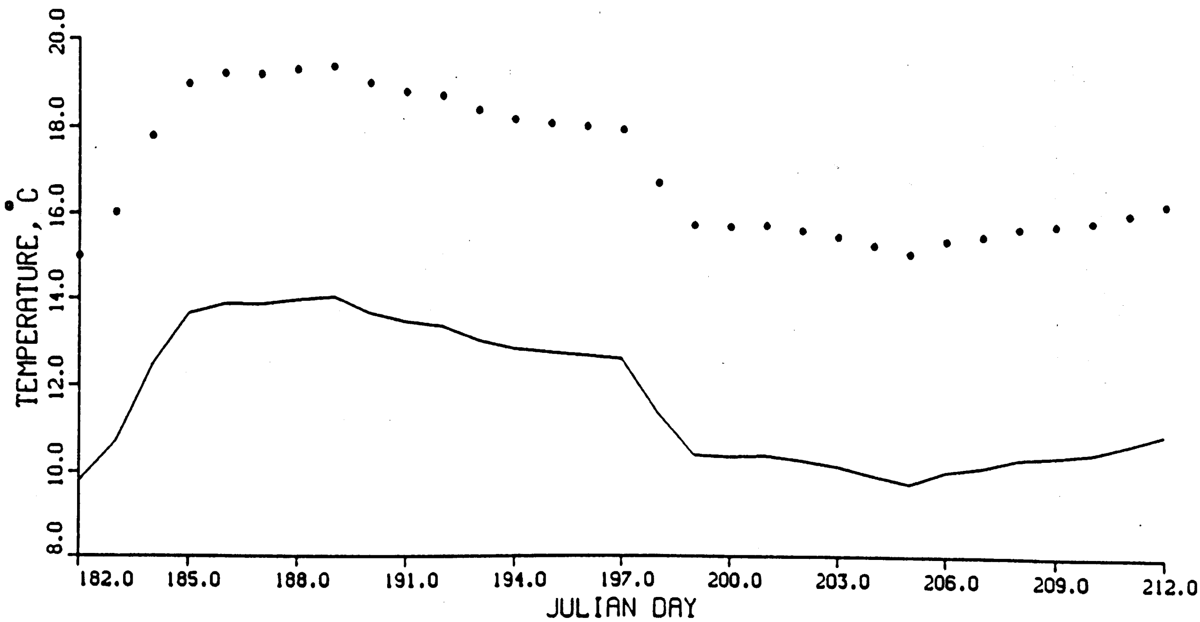

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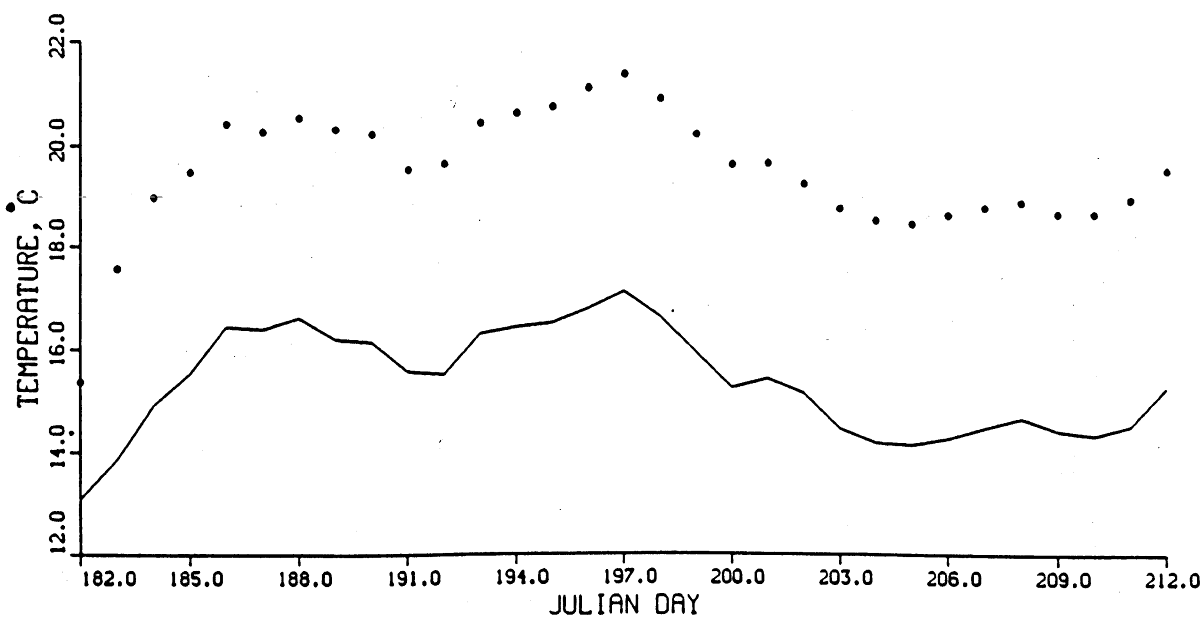

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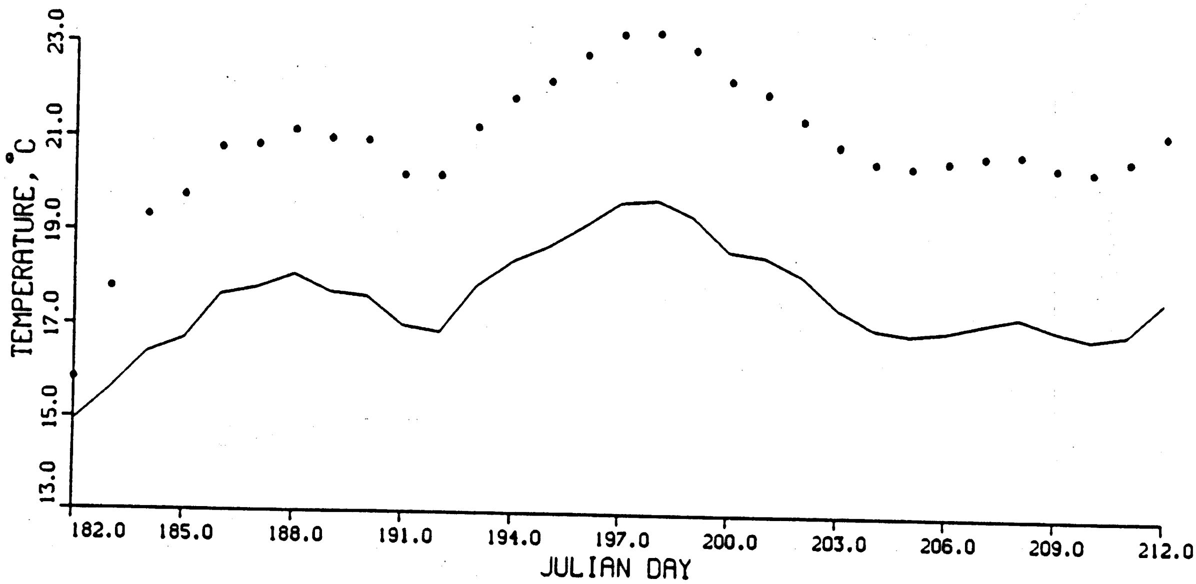
Figure B7. Computed stream temperatures for July 1979 using historical release temperatures (—) compared to 5° C increases of historical release temperatures (...) (Continued)



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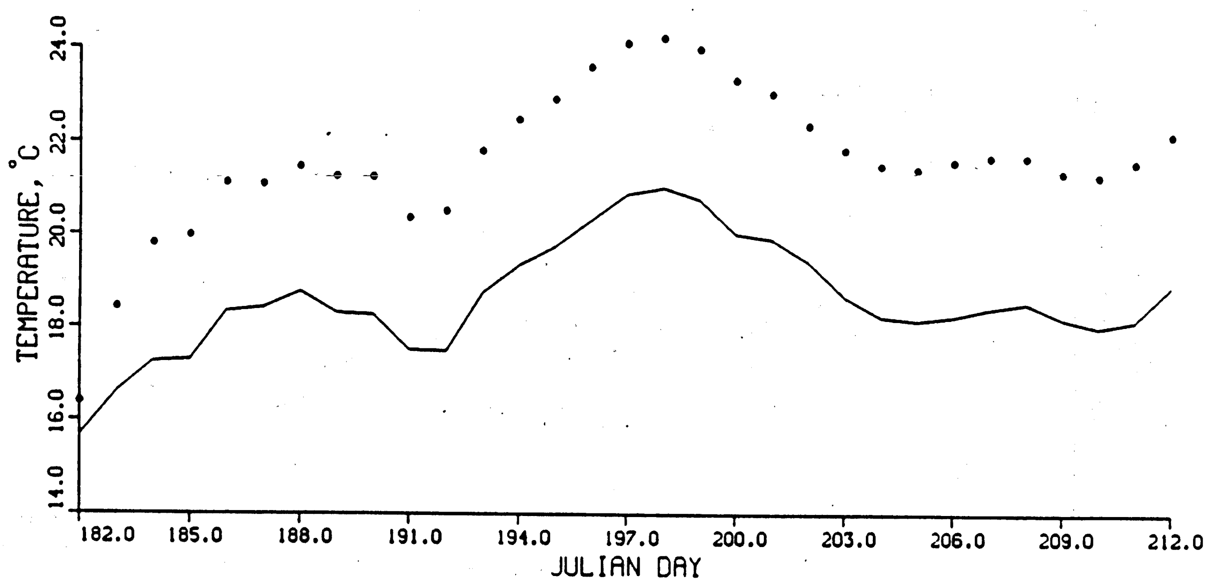

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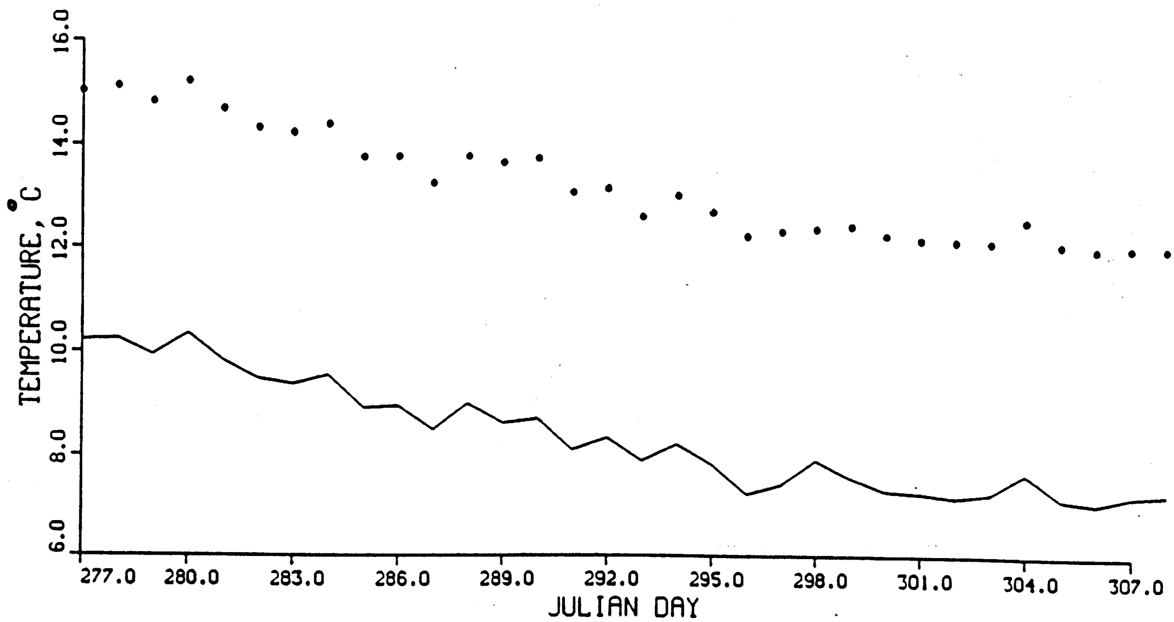

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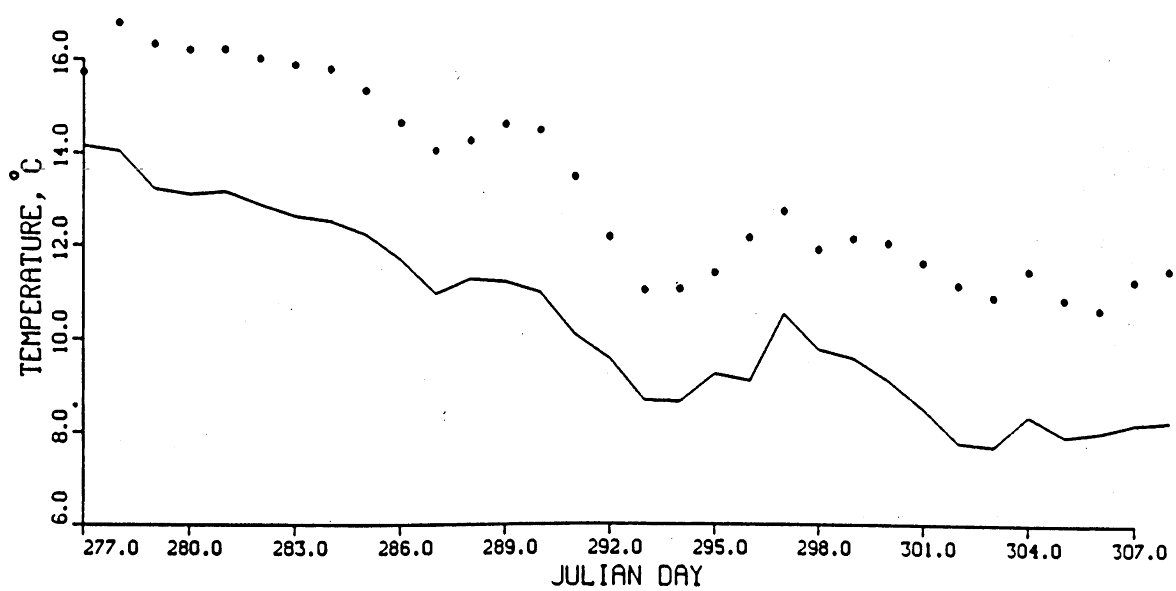
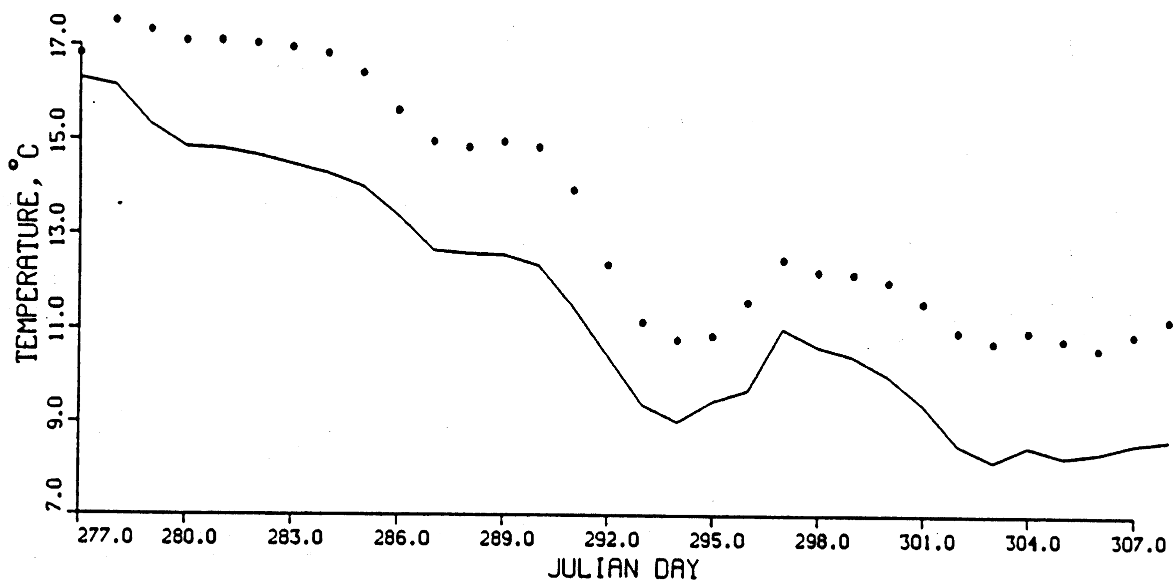


b. At Raygold, RM 125.2

Figure B8. Computed stream temperatures for October 1979 using historical release temperatures (—) compared to 5° C increases of historical release temperatures (...) (Continued)



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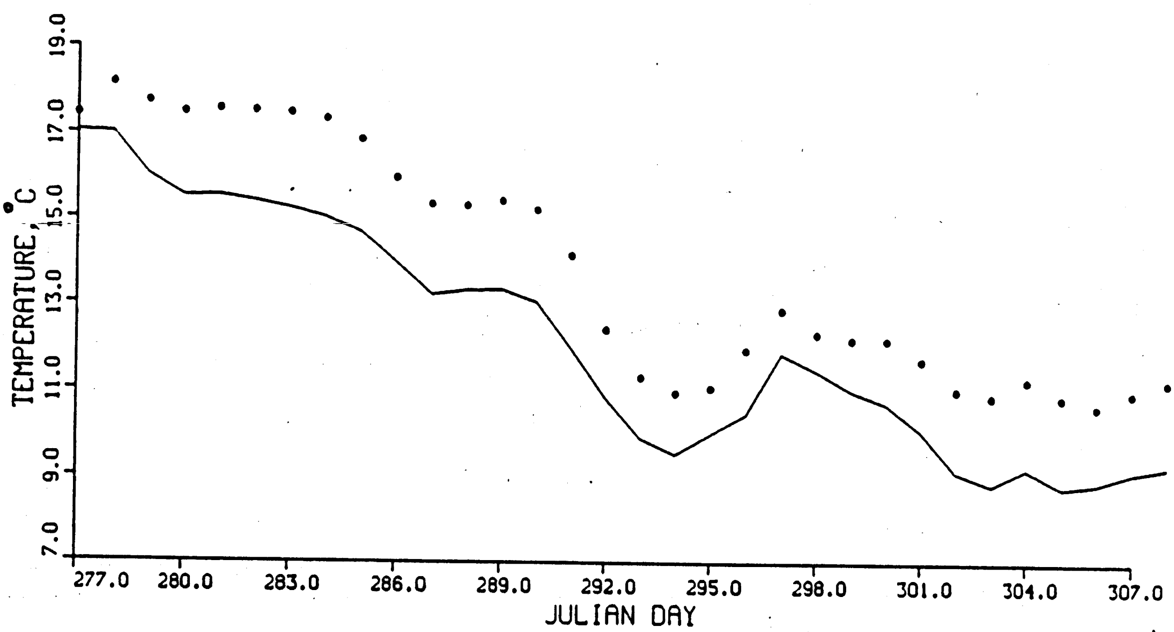

d. At Merlin, RM 86.6

Figure B8. (Concluded)