PRELIMINARY STUDY OF THE WATER-TEMPERATURE REGIME OF THE NORTH SANTIAM RIVER DOWNSTREAM FROM DETROIT AND BIG CLIFF DAMS, OREGON

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ABSTRACT

The purpose of the study, done in cooperation with the Army Corps of Engineers, was to evaluate a riverine-temperature model and associated data collection system. The model is intended to help the Corps determine cost benefits of selective-withdrawal structures for future use with dams on the Willamette River system. A U.S. Geological Survey, Lagrangian reference frame, digital computer model was used to simulate stream temperatures on the North Santiam River below a multipurpose dam (Detroit) and a reregulating dam (Big Cliff), from river mile 45.6 to 2.9. In simulation, only available air temperature and windspeed information from a nearby National Weather Service station at Salem, Oregon, were used. This preliminary investigation found that the model predicted mean daily temperatures to within 0.4° C standard deviation. Analysis of projected selective-withdrawal scenarios showed that the model has the sensitivity to indicate water-temperature changes 42.7 miles downstream on the North Santiam River.

INTRODUCTION

Reservoirs are capable of releasing water to provide cooler or warmer temperatures downstream at critical times of fish spawning, rearing, or migration. Presently, dams on the Willamette River system do not have selective-withdrawal capabilities. Facilities to provide greater water temperature control would be costly to construct. To evaluate the cost benefits of modifying the outlet structures of various dams, it is necessary to have an accurate understanding of the temperature regime in the stream below a reservoir not only under present conditions, but also under planned withdrawal conditions. This study was conducted in cooperation with the Portland District Army Corps of Engineers and is a preliminary step for the Corps in defining the feasibility of using selective withdrawal from the reservoir in the North Santiam River to control river temperatures. The study measured necessary stream temperature and atmospheric conditions and calibrated a mathematical temperature model for the North Santiam River downstream from Detroit and Big Cliff Dams. Figure 1 shows the location of the study area.

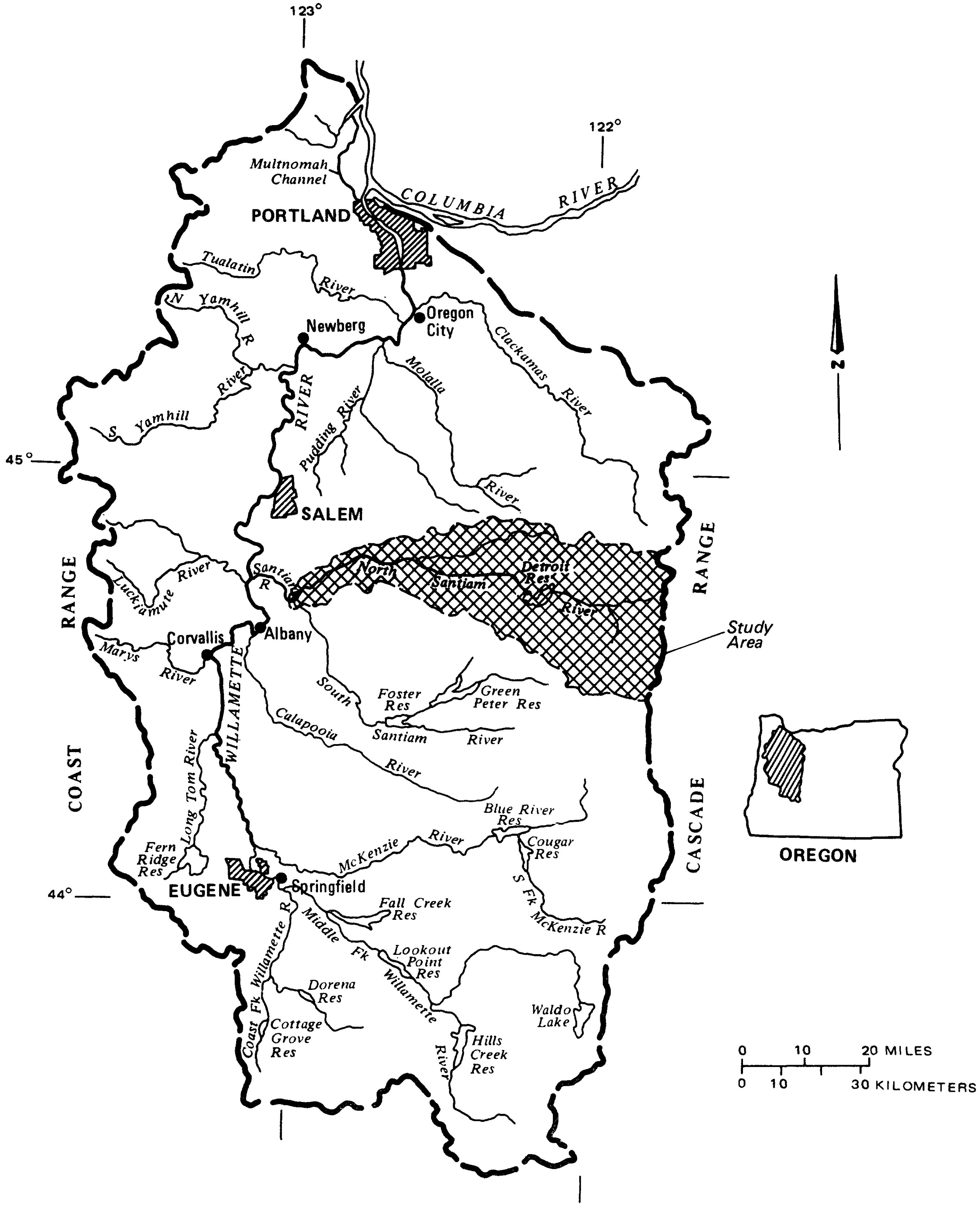

Figure 1.--Willamette River basin, Oregon, principal rivers and reservoirs, and study area

According to the Oregon Department of Fish and Wildlife (ODFW), the project area supports fish resources that contribute to important commercial and recreational fisheries in the Pacific Ocean, and in the Columbia, Willamette, and Santiam Rivers. Fall chinook salmon, summer and winter steelhead trout, and resident trout use the area for spawning, rearing, and migration. Spring chinook salmon and winter and summer steelhead trout are collected at the ODFW Minto Fish Trap (4 miles downstream from Big Cliff Dam) to supply eggs for the ODFW Marion Forks Fish Hatchery, 24 miles upstream from Detroit Dam (fig. 2). The holding ponds at Minto are used as the principal summer holding facility for spring chinook salmon returning to other hatcheries throughout the Willamette River system.

Problem

In general, evaluation of the influence of upstream releases on stream temperatures include (1) the determination of how far downstream water temperatures will be affected by releases from a dam, and (2) the determination of the effect on the maximum, minimum, and average daily water temperatures. Specific questions that this study is intended to answer are:

1. What type of data-collection network would best fill the requirements to accurately model water temperatures in this area?

2. How accurately will the U.S. Geological Survey temperature model predict stream temperatures?

3. What measured parameters are necessary for reasonable predictions?

4. How sensitive are model results to the measured parameters?

Objectives

The objectives of this study were to (1) define the existing water-temperature conditions in the stream and to reasonably predict them with a mathematical model using existing atmospheric data, and (2) determine the effect on and sensitivity of downstream temperatures by varying different parameters in the model. The objectives will be addressed using existing data and simplified model techniques because of time and economic constraints. Answers will be detailed enough to decide how further investigations should be implemented and to assess the probable accuracy of the predictions.

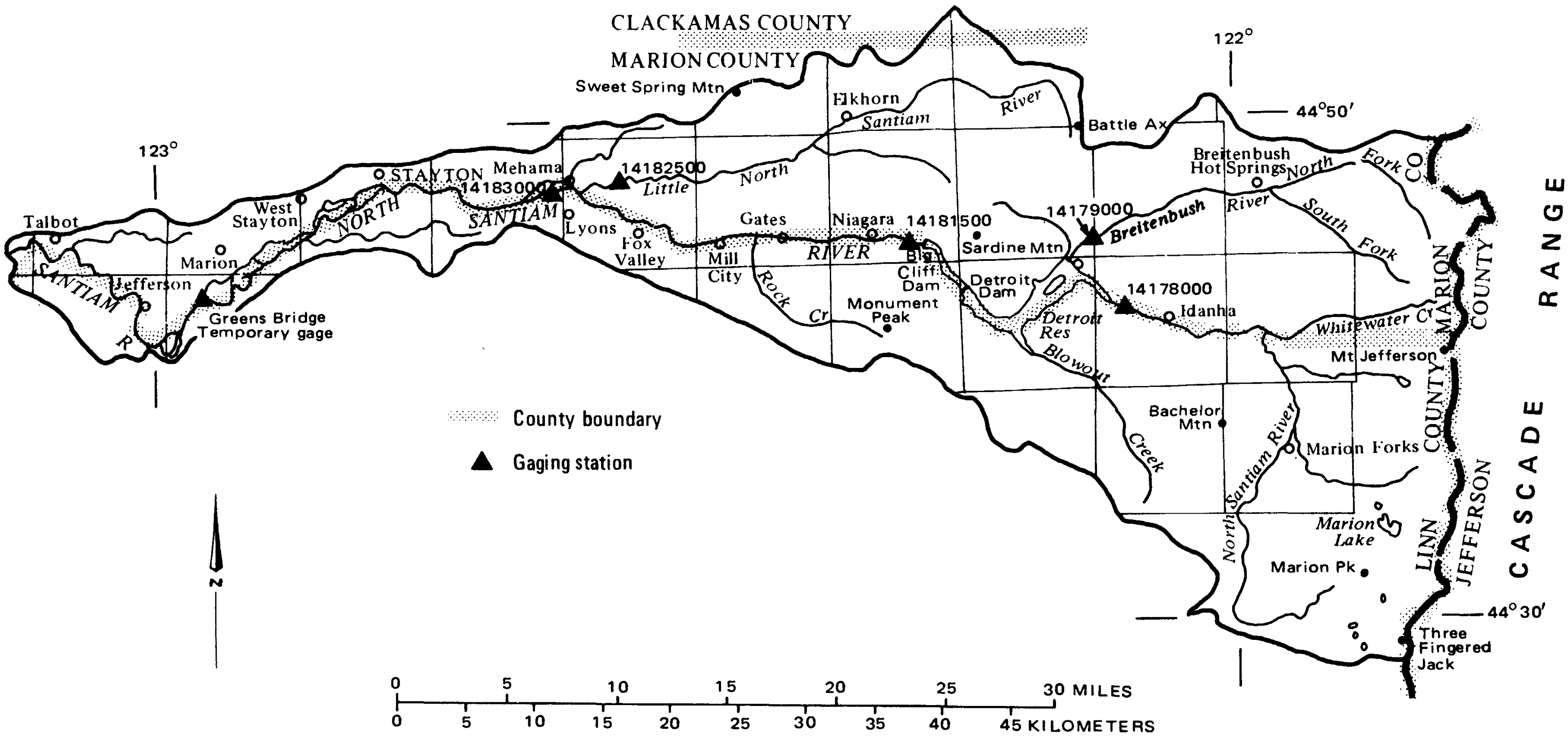

Figure 2.--Data collection network in the North Santiam River basin

Approach

The North Santiam River below Big Cliff Dam was used as a "pilot site" because of the large temperature data base on Detroit Reservoir and because of a special interest by the Army Corps of Engineers.

A temperature model as described by Jobson (1980) was calibrated with existing long-term temperature data and additional site-specific temperature data to define existing conditions. Because of the limited atmospheric data available, the model was used in its simplest form with only inputs of air temperature (to approximate equilibrium) and windspeed. Stream-width information was obtained from Geological Survey topographic maps and checked with minimal field data. Stream-velocity data were obtained from a report by Harris (1968). Various averaging combinations of air-temperature and windspeed data from Salem and Detroit were used in model simulations to test for variability. Comparisons were made with observed data to define accuracy. To determine windspeed sensitivity, wind data were eliminated as an alternative in model simulation. Finally, water-temperature conditions were imposed on the model to simulate various release conditions from the reservoir (including a pre-reservoir condition), and downstream water-temperature conditions were evaluated. These varying temperature-release scenarios were run to develop a feeling for the types of riverine changes that can be expected in future modeling and to identify future modeling problems.

PHYSICAL SETTING

Geography

The North Santiam River and its tributaries drain the western slopes of the Cascade Range from Olallie Butte to Three Fingered Jack (fig. 2). This basin occupies a drainage area of about 750 mi^2. It extends westward from the Cascade Range to the confluence with the South Santiam River near Jefferson.

The basin contains a large multipurpose reservoir, created by the completion of Detroit Dam in 1953, and a smaller reregulating reservoir (Big Cliff) just downstream. Both dams were constructed by the Army Corps of Engineers.

A large part of the basin downstream from Mehama is an alluvial plain, except where volcanic and marine sedimentary rocks of Eocene to Pliocene age are exposed in foothills. Agriculture is the principal occupation in the lower basin. Upstream from Mehama, the basin is steep, and the rocks are primarily composed of High Cascade volcanics of Pliocene age. Timber is the primary resource in the upper basin.

Streamflow is largely from precipitation; however, several large snowfields and some springflow help sustain spring and summer flows. There are hot springs in the area; however, the flow from these hot springs is insignificant relative to the total flow in the North Santiam River.

The upper part of the river reach, from Big Cliff Dam (RM 45.6) to Mehama (RM 27.0), is generally in a canyon about 150 ft in width, and falls at a rate of 30 ft/mi. The middle reach, from Mehama to Stayton (RM 16.7), is generally in an alluvial valley, with the river about 225 ft in width, and falls at a rate of 17 ft/mi. The lower reach, from Stayton to the mouth, meanders and has many islands. It is approximately 240 ft wide and falls 13 ft/mi. Many conifers and deciduous trees line the edge of the river. In the lower reach the deciduous trees overhang the river providing considerable shade.

Climate

The North Santiam River basin has a temperate marine climate characterized by dry summers and wet winters. About 80 percent of the normal precipitation falls between October and May. Mean annual rainfall ranges from about 45 inches near Jefferson to about 75 inches near Detroit.

The normal annual air temperature at Salem (the nearest first order weather station) is 52° F. Normal monthly air temperatures range from 39° F in January to 67° F in July. Table 1 shows some selected atmospheric statistics for Salem. The city of Salem lies outside the Santiam Basin, approximately 40 miles west northwest from Detroit Reservoir, and is at a lower elevation.

Some air-temperature and windspeed information was also available at Detroit Dam; however, the data-collection period is short, and the time increment of collection is not frequent enough for this analysis (3 hour average for air temperature and a daily total for windspeed). In general, the air temperatures were about 2° F cooler and windspeed about 5 mi/h slower than at Salem.

Reservoirs

Two reservoirs store waters of the North Santiam River, controlling runoff from about 450 mi^2 of drainage area. The major reservoir, Detroit Lake, provides 436,000 acre-feet of storage (at maximum pool elevation) for the purposes of flood control, irrigation, downstream navigational improvement, power generation, and recreation. Big Cliff, a small reservoir, is used to smooth out water releases made for power generation at Detroit. Detroit Dam rises 360 ft above the streambed and has a 100,000 kilowatt powerhouse. Big Cliff is 126 ft high and has an 18,000 kilowatt powerhouse.

Table 1.--Selected meteorological normals, means, and extremes for Salem, Oregon, 1939-78

[National Oceanic and Atmospheric Administration (NOAA) local climatological summary]

Month	Temperature (°F)					Precipitation, normal (in)	Relative humidity by hour (pct.)				Windspeed (mi/h)		Conditions for mean number of days		
	Monthly Normal	Recorded High	Recorded Low	Mean number of days Maximums +90°F	Mean number of days Minimums -32°F		04	10	16	22	Mean	Fastest	Clear	Partly cloudy	Cloudy
Jan.	38.8	64	-10	0	13	6.90	85	84	76	85	8.6	40	3	4	24
Feb.	42.9	72	-4	0	12	4.79	87	81	68	84	7.8	46	3	5	20
Mar.	45.2	80	12	0	11	4.33	85	75	60	80	8.1	40	4	6	21
Apr.	49.8	88	23	0	8	2.29	85	69	56	77	7.2	44	4	8	18
May	55.7	95	25	0	1	2.09	85	65	52	75	6.6	28	6	8	17
June	61.2	102	32	2	0	1.39	85	62	49	73	6.5	25	7	8	15
July	66.6	108	37	7	0	0.35	84	57	40	68	6.5	26	15	9	7
Aug.	66.1	106	38	6	0	0.57	85	59	41	71	6.3	24	14	8	9
Sept.	61.9	103	26	2	0	1.46	86	65	47	78	6.1	31	11	9	10
Oct.	53.2	93	23	0	3	3.98	89	77	61	85	6.2	58	6	8	17
Nov.	45.2	72	9	0	8	6.08	90	85	76	88	7.4	38	3	5	22
Dec.	40.9	64	-12	0	12	6.85	87	86	81	86	8.2	45	2	3	26
Total	52.3	108	-12	17	69	41.08	86	72	59	79	7.1	58	78	81	206

To compensate for the loss of fish-spawning area upstream from the dams, the Marion Forks Salmon Hatchery and the Minto Egg-collecting Station were constructed by the Corps of Engineers in 1950. Both facilities are now operated by the ODFW.

Detroit Lake is a very popular recreational area. Recreational uses on or near the lake include water skiing, swimming, fishing, camping, day use, and boating. In 1974 about 350,000 recreational visits were recorded in the area.

DATA NETWORK

Data used in this study included data from existing stream gage and temperature recording locations, data obtained at temporary collection sites, and miscellaneous field measurements. Figure 2 shows the location of existing stream gages and temporary temperature recorders.

Existing Long-term Stations

Existing sites included Geological Survey stream-gaging stations on the North Santiam River at Niagara (14181500), at Mehama (14183000), and on the Little North Santiam near Mehama (14182500). All sites provided hourly discharges, but only the Niagara site recorded hourly water temperatures. Hourly air-temperature and windspeed data were obtained from the National Weather Service station at McNary Air Field in Salem. Three-hour air temperatures and daily totals of windspeed were also available from the Detroit Dam site.

Additional Sites

Additional data were collected by installing Enviro-Labs[1/] temperature units with thermistor probes and Fisher-Porter digital recorders in existing stream-gage sites on the Little North Santiam and North Santiam near Mehama. Another recording temperature unit was placed in a temporary shelter on the North Santiam River at Greens Bridge (RM 2.9) near Jefferson. Water temperatures were collected at 15-minute intervals. The data-collection period was from August 25 to October 13, 1982, and March 24 to April 7, 1983.

1/ The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Field Surveys

To supplement the above data, two floating surveys were made at different stream discharges. The first trip was made during the period August 25 to September 2, 1982, when the discharge at Niagara was about 1,200 ft^3/s. The second trip was made September 16 to 22, 1982, when the discharge at Niagara was about 2,300 ft^3/s. These surveys were made to help define the channel characteristics throughout the project reach. Data collected include: water temperature at each riffle and pool, approximate channel width and depth at selected points, cross-sectional variation of water temperature at selected points, streambank canopy, island information, and inflow temperature and volume. Float-survey data can be found in table 8 in the back of this report. In general, an attempt was made to float with the stream current and record temperatures at regular intervals, thereby following the water parcel as it traveled downstream and observing how it was affected by heating and cooling. Temperature cross sections from several locations can be found in figure 16 in the back of the report. The temperature was always nearly uniform in the cross section, indicating good mixing and that a one-dimensional model, as used here, is adequate.

TEMPERATURE MODEL

A model developed by Jobson (1980) was used to simulate the temperature diffusion and transport in a river system. This one-dimensional model solves the convective-diffusion equation along a moving (Lagrangian) reference frame. The model was used in the steady-state discharge mode. Because very little meteorological data were available for this study, the simplified version of the model was used to predict water temperature. Air temperature (used to approximate equilibrium temperature) and windspeed were the only required inputs to the model.

In the Lagrangian framework, an individual fluid parcel is followed and those factors affecting temperature change are applied (fig. 3). Stream width, depth, and velocity are important parcel characteristics. Changes in temperature from tributary flow and (or) diversion and (or) ground water are input at grid points. Grid points define parcel boundaries.

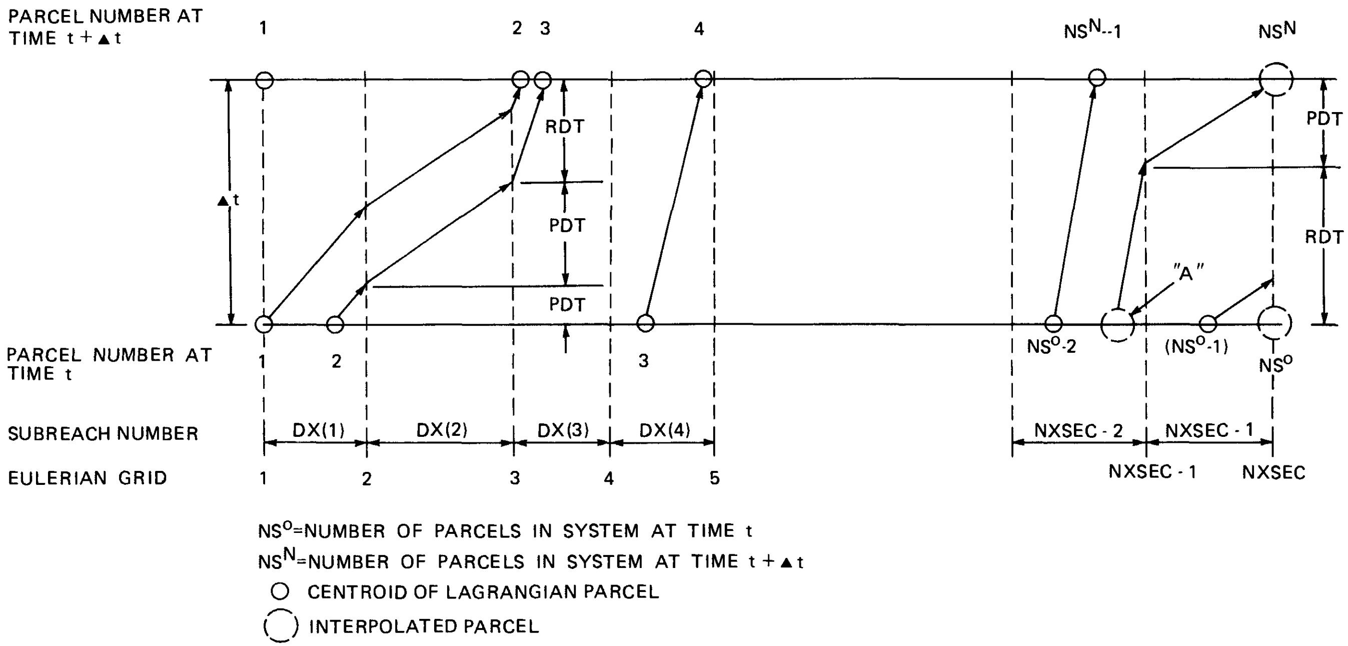

Figure 3.--Schematic diagram of the computational scheme for the Lagrangian transport model from Jobson (1980)

Convection-diffusion Equation

The following derivations are summarized from Jobson (1980) to help define the application of the model to our particular situation. The convection-diffusion equation solved by the model is:

$$T = To + \int_o^t \frac{\partial \overline{u'T'}}{\partial \xi} dt' + \int_o^t \frac{HW}{A_p c_p \rho} dt' + \int_o^t \Phi dt' \qquad (1)$$

where,

- T = the average water temperature in parcel at time t,
- To = the initial water temperature of parcel,
- ξ = Lagrangian distance coordinate,
- H = net addition of thermal energy to water from air-per-unit time and area (surface exchange term),
- $\overline{u'T'}$ = average of the product of instantaneous velocity and water temperature,
- W = width of river at location of parcel,
- A_p = cross-sectional area of river at location of parcel,
- ρ = density of water (g/cm^3),
- c_p = specific heat of water,
- Φ = additional source term to account for tributary inflow, and
- t = time.

Dispersion Term

Assuming the temperature in each parcel is well mixed and the flow rate from parcel k to k+1 is DQ_k, the heat flux across a boundary can be computed using continuity considerations. The dispersion term can be written:

$$\int_o^t \frac{\partial \overline{u'T'}}{\partial \xi} dt' = \frac{DQ_{k-1}\Delta t(T_{k-1} - T_k) + DQ_k \Delta t(T_{k+1} - T_k)}{V} \qquad (2)$$

where,

- DQ = flow rate between parcels,
- V = parcel volume, and
- Δt = time step.

Surface-exchange Term

Using the equilibrium temperature approach, the surface-exchange term can be written:

$$H = -K_e (T - Te) \quad (3)$$

where,

K_e = is a positive surface exchange coefficient, and
Te = equilibrium temperature, which is approximated here by the air temperature Ta.

The assumptions for the equilibrium temperature approach are (1) when T = Te there is no net heat exchange (H=0), (2) the water temperature will approach the equilibrium temperature, and (3) the air temperature (Ta) approximates the equilibrium temperature (Te).

According to Jobson (1980):

$$K_e = 4\varepsilon\sigma(T + 273.16)^3 + \rho L(\alpha + NV)(\gamma + \mu) \quad (4)$$

where,

ε = emissivity of water (0.97 unitless)
σ = Stefan-Boltzman constant 1.171×10^{-7} cal/cm^{2}d (K)^4
273.16 = converts to Kelvin temperature scale
L = latent heat of vaporization = 595.9 - 0.545(T) cal/g
α = constant in wind function (0.302 cm/d kPa)
N = mass-transfer coefficient of wind function 0.113 cm/d(m/s)kPa
V = windspeed m/s
γ = psychrometric constant = 0.06 kilopascals/degree Celsius
μ = slope of vapor-pressure curve in kPa/°C

The slope of the vapor-pressure curve is evaluated at the water temperature and empirically determined as:

$$\mu = \frac{1.1532 \times 10^{11} \left[\exp(-4271.1/(T + 242.63))\right]}{(T + 242.63)^2} \quad (5)$$

Table 2.--Average channel characteristics used in U.S. Geological Survey temperature model for specified North Santiam River segments and selected discharges

Segment	Grid points	Reach distance (mi)	Channel characteristics: Q = 1,000 ft^3/s Width (ft)	Velocity (ft/s)	Area (ft^2)	Q = 2,500 ft^3/s Width (ft)	Velocity (ft/s)	Area (ft^2)	Q = 9,200 ft^3/s Width (ft)	Velocity (ft/s)	Area (ft^2)
Niagara to Gates	1-2	6.3	100	1.91	619	125	3.07	888	165	2.81	1,290
Gates to Mill City	2-3	3.9	155	2.65	376	190	3.76	672	245	2.81	1,290
Mill City to Mehama	3-4	8.4	180	2.36	430	210	3.61	699	295	2.81	1,290
Mehama to Staton Island	4-5	7.3	200	2.39	441	245	4.24	699	330	4.07	1,510
Below Staton Island	5-6	8.6	220	1.78	640	270	3.95	861	330	5.17	1,775
Above Greens Bridge	6-7	8.2	210	0.84	893	260	3.05	1,020	310	6.38	1,510

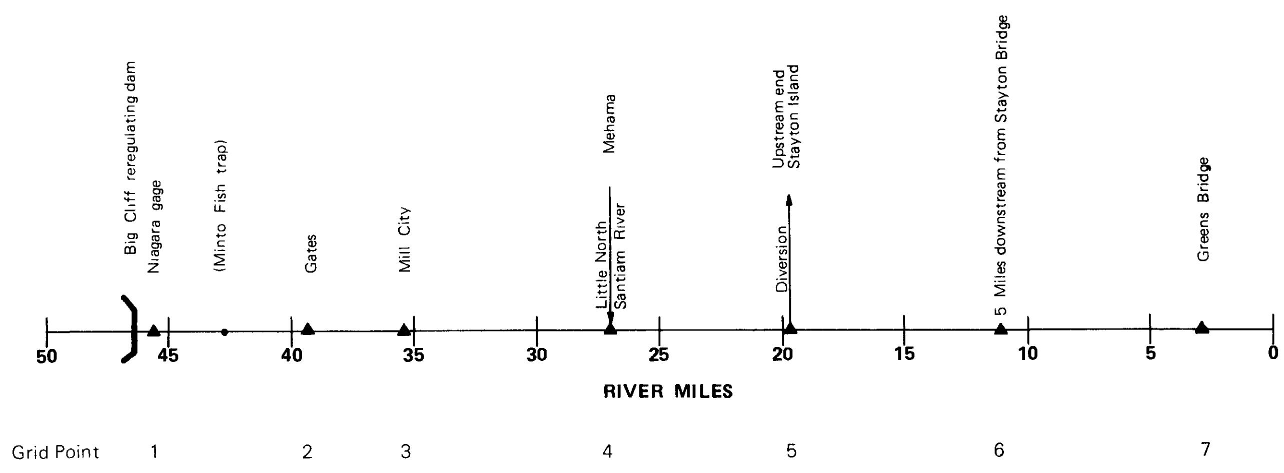

Figure 4.--Schematic diagram showing model segmentation.

Model Segmentation

Jobson's model requires meteorological, water temperature, water discharge, and stream cross-section inputs at discrete grid points to define parcel interactions.

For our model, the North Santiam River was divided into six subreaches to define various channel characteristics (fig. 4) and to facilitate input of tributary inflow and diversion outflow. Channel characteristics in each subreach were determined by averaging. The grid points are as follows: (1) Geological Survey gage site at Niagara, (2) Gates, (3) Mill City, (4) Geological Survey gage at Mehama, (5) Upper Staton Island, (6) 5 miles below Staton Bridge, and (7) the temporary gage site at Greens Bridge. Table 2 lists the channel characteristics used in the model for a series of stream discharges for model calibration. Stream-width information was obtained from Geological Survey topographic maps and checked with minimal field data. Stream-velocity data were obtained from a report by Harris (1968) and are summarized in figure 5.

Calibration/Verification

To begin calibration of the model, air-temperature and windspeed data from Salem were first used as the required atmospheric input, because these data were the most complete (air temperature and windspeed recorded each hour) available. In general, the use of these data yielded a very reasonable response, as shown in figure 6, where the observed water temperatures at Mehama and Greens Bridge can be compared to the modeled temperatures for a moderately low-flow period in late September. However, this initial calibration, using Salem atmospheric data, overpredicted the maximum water temperature during the low flow, maximum air-temperature condition on September 2, as can be seen in figure 7. This maximum air temperature, low-flow condition was not only the period of interest but the most difficult period to model accurately.

As the next step in calibration, modeled water temperatures using various combinations of atmospheric data from Salem and Detroit were tried in order to evaluate the response and improve the calibration. These trials, hampered by the lack of frequency in collection of the Detroit data, resulted in the following:

1. Use of Detroit air temperature tended to lower the mean of the simulated water temperatures below the mean of the observed, even in the upper reach of the river where these temperatures should be representative. A possible explanation for this discrepancy would be that Detroit Lake has a moderating influence on the air temperature, and it is not a good approximation of the equilibrium temperature without a correction. The decision was made not to incorporate the use of Detroit air temperature in the model input.

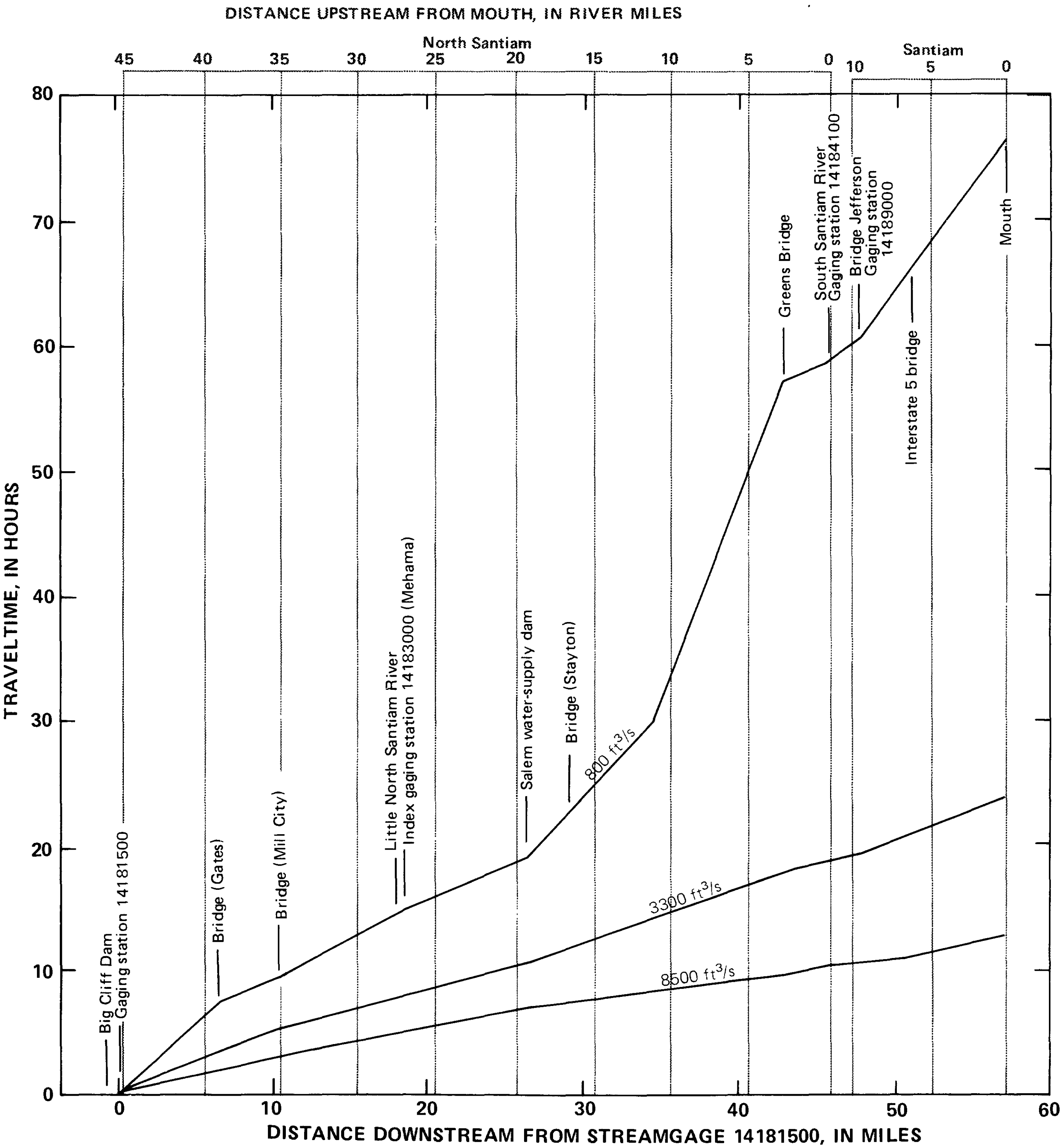

Figure 5.--Time of travel of North Santiam and Santiam Rivers for selected discharges, indexed by gaging station at Mehama (14183000), modified from Harris (1968).

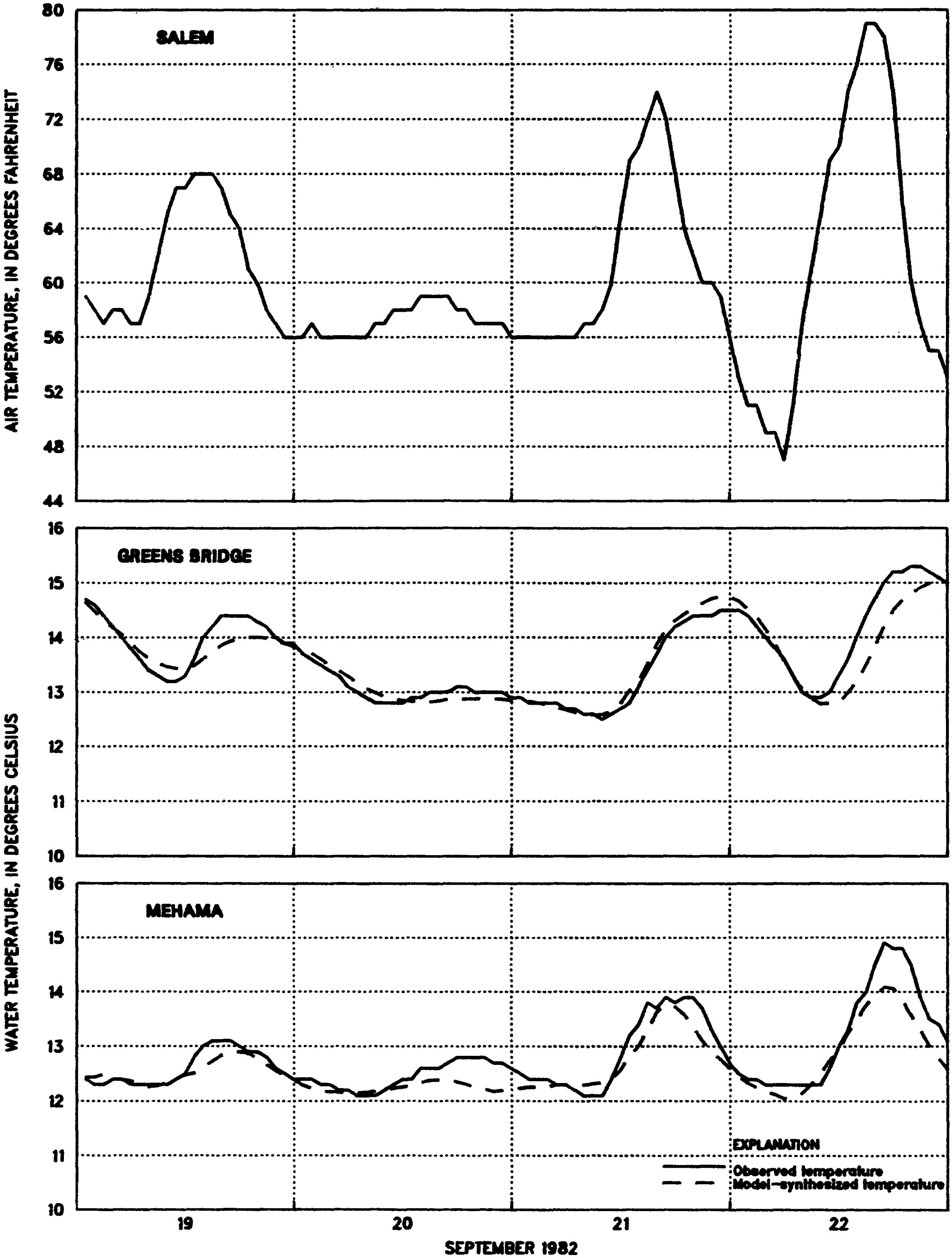

Figure 6.--Comparison of observed temperatures with model-simulated temperatures using Salem air-temperature and windspeed data (September 19-22, 1982)

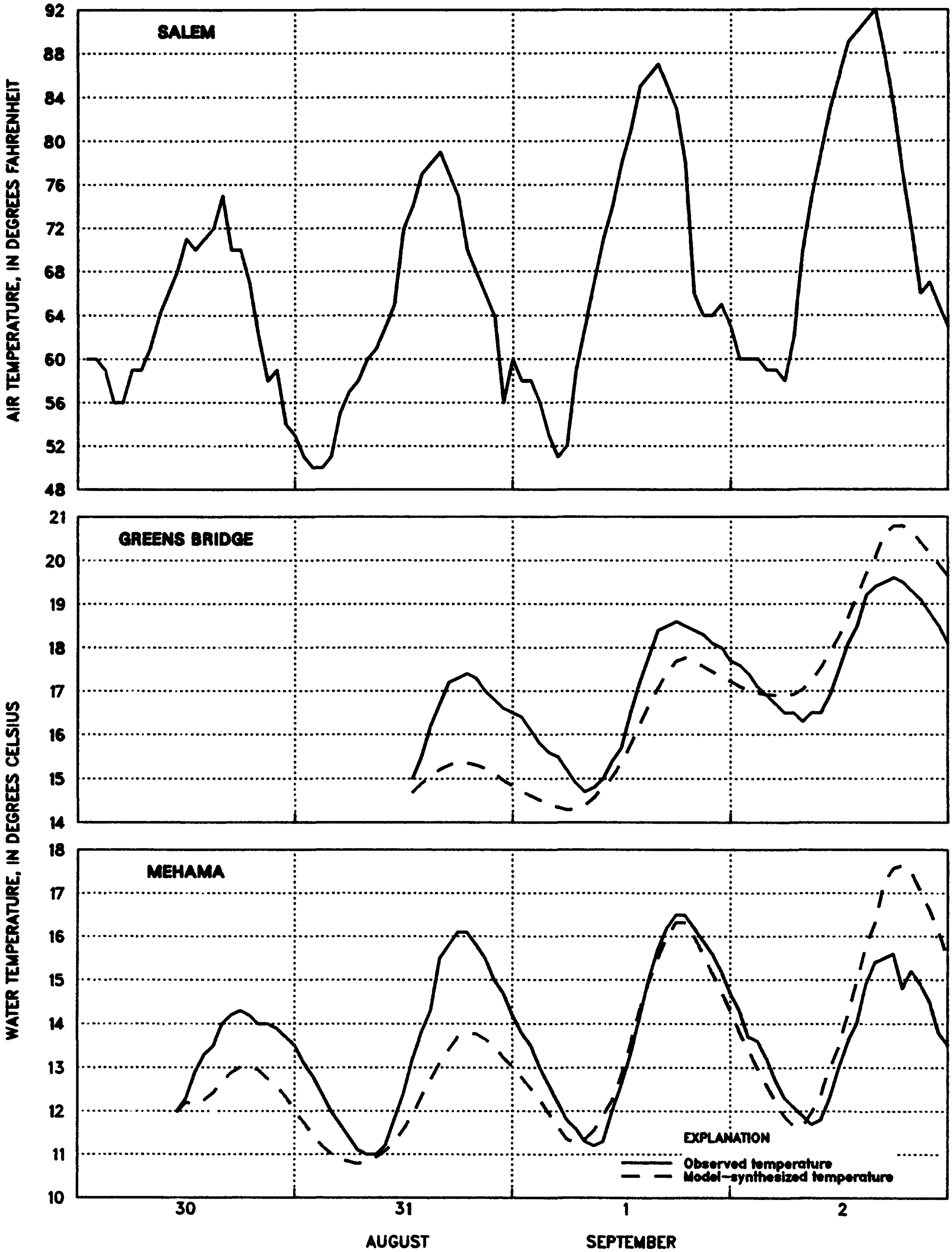

Figure 7.--Comparison of observed temperatures with model-simulated temperatures using Salem air-temperature and windspeed data (August 30 to September 2, 1982)

2. Daily totals of windspeed at Detroit were generally less than one-third that of Salem but fluctuated considerably on a day-to-day basis. Windspeed data at Salem were first reduced by two-thirds, but this reduction proved to be too drastic because daily maximums were significantly underpredicted. The best fit in calibration resulted from reducing Salem windspeed proportionately in each segment of the model on the basis of distance between Detroit and Salem. Windspeed used for Detroit was one-third of that in Salem.

This final trial yielded the best results in predicting water temperatures in the low-flow, maximum air-temperature period of interest. Figure 8 shows how simulated model temperatures using Salem air temperatures (unaltered) and a reduction in Salem windspeed (based on distance from Detroit) compare for the period of August 30 to September 2. There are still major deviations from the observed in the plot shown in figure 8, but this is probably the best fit with the atmospheric data available. For this modeling effort, no changes were made to air temperature to adjust for the relation between air and equilibrium temperature. Equilibrium temperature has a larger diel variation than air temperature. The September 2 maximum temperature is only 0.9° C higher than the observed at Greens Bridge, and the average temperature is within 0.5° C for this period. Atmospheric data of air temperature and windspeed collected at intermediate points along the river, plus a better understanding of the relation between air temperature and equilibrium temperature, should yield a better fitting curve.

To verify the calibration, air-temperature and windspeed data as defined above were used to predict water temperature for the entire period of data collection from August 25 to October 13, 1982, and March 24 to April 7, 1983. These predicted data were then compared to the observed. Refer to table 9 (at back of report) for a comparison of means, maximums, and minimums for the predicted and observed water temperatures. Model results were also verified with temperatures obtained in float surveys. Figure 9 shows a plot of time versus the temperature as collected by float survey compared to the modeled temperature at grid point intervals.

Sensitivity

The model can be analysed for sensitivity by varying the input parameters of air temperature and windspeed and the channel characteristics of stream discharge, channel width and area (depth), tributary inflow, and diversion outflow. This was done for two base periods when data were collected: (1) a warm period with low stream discharge (August 30 to September 2), and (2) a cooler period in the spring with higher stream discharge (March 29 to April 1).

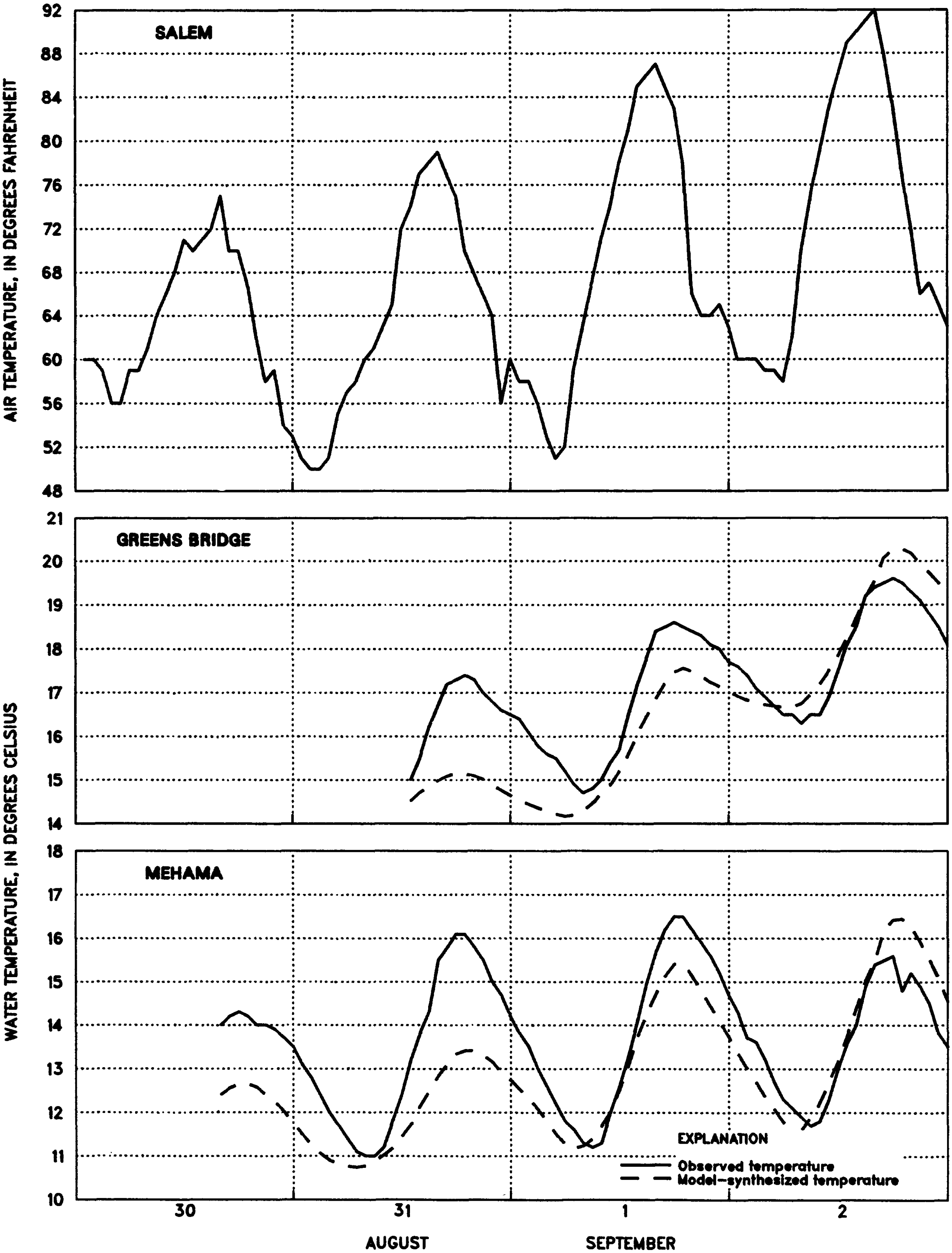

Figure 8.–Comparison of observed temperatures with model-simulated temperatures using Salem air-temperature and adjusted windspeed data (August 30 to September 2, 1982)

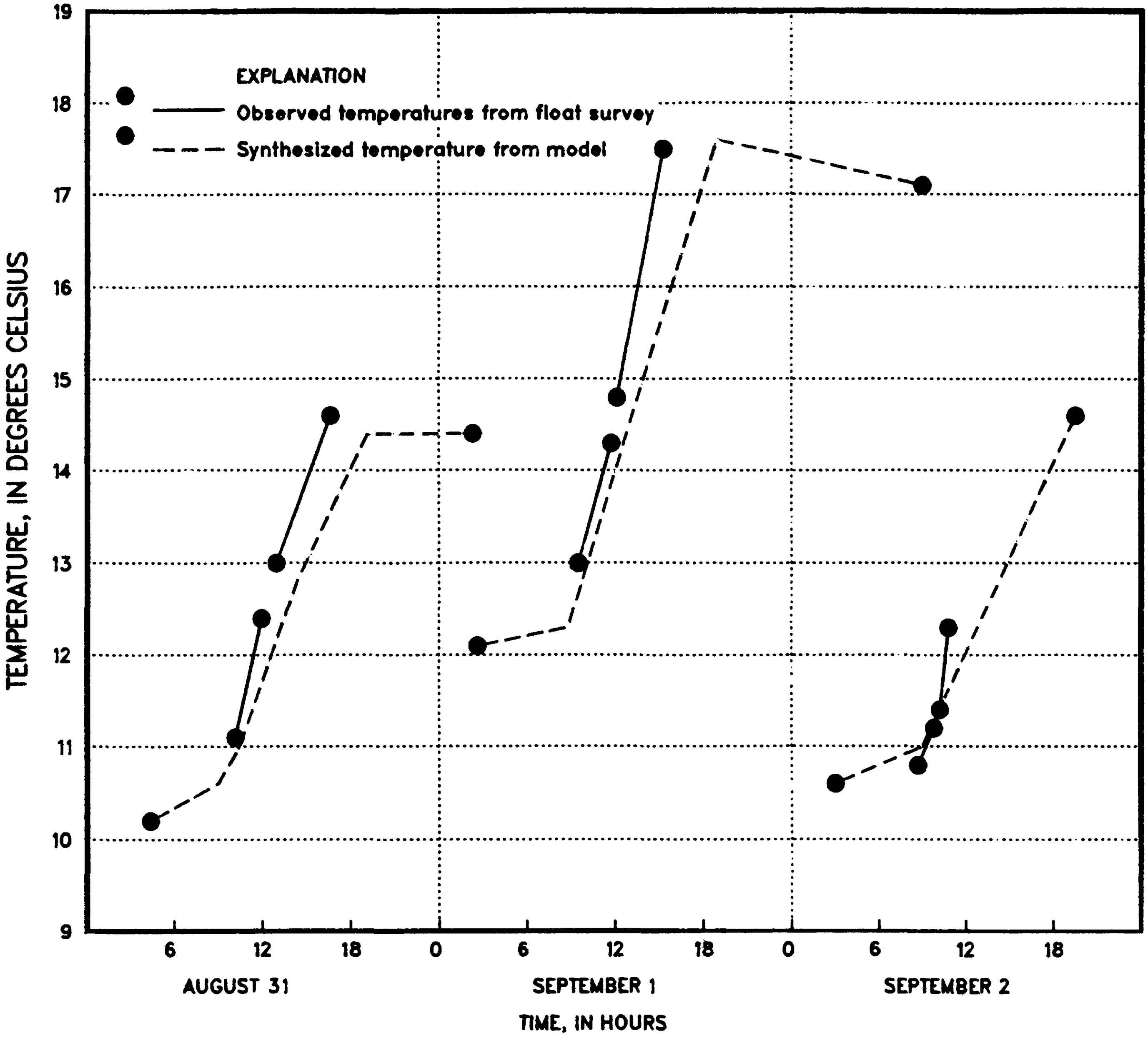

Figure 9.–Comparisons of water temperature obtained while floating with stream current with model-simulated temperatures

For the period of August 30 to September 2, the discharge at Niagara was 1,000 ft^3/s. The channel characteristics correspond to the heading Q = 1,000 ft^3/s in table 2. The average air temperature for the period was approximately 72° F and fluctuated as shown in figure 13. Average windspeed for the period was 4.2 mi/h with gusts up to 19.2 mi/h. Tributary inflow from the Little North Santiam was low at 83 ft^3/s.

For the period of March 29 to April 1, the discharge at Niagara was 3,700 ft^3/s. The channel characteristics correspond to the heading Q = 9,200 ft^3/s in table 2. The average air temperature for the period was approximately 50° F and fluctuated as shown in figure 14. Average windspeed for the period was 10.1 mi/h with gusts up to 23.5 mi/h. Tributary inflow from the Little North Santiam was 5,600 ft^3/s.

Table 3 lists the results of the sensitivity analysis. Small variations of air temperature and windspeed produced the greatest effects on water temperature. From Big Cliff Dam to Greens Bridge (42.7 miles downstream), an air-temperature change of approximately 9° F would change water temperatures approximately 2.6° C, and an increase in windspeed of about 5 mi/h increases water temperature about 1.9° C, for the period August 30 to September 2. The stream discharge had to be doubled or halved before any significant change took place. Increasing stream top widths by approximately 15 percent and doubling the diversion only yielded an average change of about 0.5° C. In contrast, doubling the tributary inflow did not significantly (less than 0.5° C) change downstream conditions. Neither did changing the cross-sectional area by 20 percent.

Accuracy

Stream temperature model accuracy is dependent on the accuracy of the atmospheric parameters, used to estimate the energy exchange between the air and water, and the accuracy of the stream parameters that approximate the physical boundaries of the system. As can be seen from the preceding section on sensitivity, variations of air temperature (equilibrium) and windspeed will have the greatest influence on model accuracy. It is preferable that air temperature and windspeed information be collected at selected points along the river reach to be modeled; however, for this study, the use of Salem air temperature and windspeed proved adequate, and a statistical analysis was performed.

Two data sets were used to simulate stream temperatures and were compared to observed data. The first data set, comprised of water temperatures simulated from air and windspeed from Salem, generally showed good agreement with observed water temperatures. Table 4 is a statistical summary of these results comparing maximums, minimums, and means. The standard deviation from the mean between simulated and observed data sets was approximately 0.42° C at Greens Bridge (a river reach of 42.7 miles).

Table 3.--Summary of model sensitivity analysis for selected minimum or maximum variances at Greens Bridge

Parameter varied	Minimum or maximum	Base value (August 30 to September 2, 1982)	Average resultant water temperature change (°C) (August 30 to September 2, 1982)	Average resultant water temperature change (percent) (August 30 to September 2, 1982)	Base value (March 29 to April 1, 1983)	Average resultant water temperature change (°C) (March 29 to April 1, 1983)	Average resultant water temperature change (percent) (March 29 to April 1, 1983)
Air temperature	+9°F	Salem hourly	+2.60	+16.5	Salem hourly	+0.79	+11.3
	-9°F		-2.43	-15.4		-.77	-11.0
Windspeed	+5 mi/h	Salem hourly	+1.89	+12.0	Salem hourly	+.12	+1.7
	0 mi/h		-1.21	-7.7		-.30	-4.3
Stream discharge	double base	1,000 ft^3/s	-1.83	-11.7	3,700 ft^3/s	-.40	-5.7
	half base		+1.11	+7.0		+.31	+4.5
Stream top-width	+30 ft	1/	+.45	+2.9	1/	+.06	+.9
	-30 ft		-.51	-3.2		-.06	-.9
Stream cross section	+100 ft^2	1/	-.11	-.7	1/	+.00	+.0
	-100 ft^2		+.03	+.2		+.00	+.0
Little North Santiam inflow	double base	83 ft^3/s	+.07	+.4	5,600 ft^3/s	-.02	-.3
	0		-.06	-.4		+.10	+1.4
Diversion outflow	double base	330 ft^3/s	+.43	+2.7	0 ft^3/s	----	----
	0		-.29	-1.8		----	----

1/ Refer to table 2 for widths and cross-sectional area for individual stream segments.

Table 4.--Statistical summary for daily maximums, minimums, and means predicted by the model using unaltered Salem air temperature and windspeed

Univariate Analysis for Greens Bridge

Number of values 48

Variable is difference between observed and predicted mean (in degrees Celsius)

Mean	0.1625
Standard Deviation	0.422064
Skewness	-0.0683782
Sum	7.8
Variance	0.178138
Kurtosis	-0.755593

Variable is difference between observed and predicted maximum (in degrees Celsius)

Mean	0.129167
Standard Deviation	0.616772
Skewness	0.236979
Sum	6.2
Variance	0.380408
Kurtosis	0.916976

Variable is difference between observed and predicted minimum (in degrees Celsius)

Mean	0.0375
Standard Deviation	0.382948
Skewness	-0.224527
Sum	1.8
Variance	0.146649
Kurtosis	-0.492172

Univariate Analysis for Mehama

Number of values 60

Variable is difference between observed and predicted mean (in degrees Celsius)

Mean	0.131667
Standard Deviation	0.427643
Skewness	0.937599
Sum	7.9
Variance	0.182879
Kurtosis	2.12885

Variable is difference between observed and predicted maximum (in degrees Celsius)

Mean	0.225
Standard Deviation	0.659385
Skewness	0.288307
Sum	13.5
Variance	0.434788
Kurtosis	2.93647

Variable is difference between observed and predicted minimun (in degrees Celsius)

Mean	0.0783333
Standard Deviation	0.348893
Skewness	0.311469
Sum	4.7
Variance	0.121726
Kurtosis	1.0623

The second data set was comprised of water temperatures simulated from Salem air temperature and modified windspeed (weighting based on distance from Detroit). This data set showed a better agreement for the low-flow, maximum air-temperature period, but was more positively skewed for the remainder of the prediction period. Table 5 is a statistical summary of these results. The standard deviation from the mean between the second simulated data set and the observed data set was approximately 0.39° C for the same reach.

ANALYSES

Three scenarios were analysed to determine if this type of temperature model could answer some of the general questions asked in the introduction. How far will temperature be affected downstream from the dam? How will the maximum, minimum, and average daily temperature be affected? The scenarios were as follows: (1) definition of the temperature regime in the stream during a low-flow, maximum air-temperature period for selected release conditions by the dam. (2) definition of the temperature regime during a spring-time flow with cooler temperatures for selected release conditions by the dam, and (3) to define the temperature regime before reservoirs were constructed for the above periods of interest.

Simulation of Various Temperature Releases August 30 to September 2

Using the same atmospheric and stream parameter values as in the final calibration, different uniform temperatures were used as initial input to the model. Water temperatures from 7.0° C to 15.0° C, available for release if selective-withdrawal facilities were constructed, were used. Figure 10 shows the resultant temperatures in two-degree increments at Greens Bridge.

Figure 10 shows that, in the length of the stream reach studied, the average water temperature (as well as the maximums and minimums) will be affected by changes in water temperature releases; however, the amplitude of the diel variance remains relatively constant. With a 1° C average water-temperature difference in reservoir release, the simulated average change in water temperature will be approximately 0.7° C at Mehama (18.6 miles downstream from Big Cliff Dam) and will be approximately 0.3° C at Greens Bridge (42.7 miles downstream). However, the diel fluctuation experienced at Greens Bridge on September 1 and 2 remains at about 3.5° C. Table 6 gives the average differences of synthesized water temperature shown in figure 10.

Figure 11 shows the temperature regime of the stream for a specific temperature release at the various grid points in the model. It is interesting to note that the diel fluctuation reaches a maximum in the vicinity of Mehama and is less at Greens Bridge.

Table 5.--Statistical summary for daily maximums, minimums, and means predicted by the model using unaltered Salem air temperature and modified windspeed data

Univariate analysis for Greens Bridge

Number of values 48

Variable is difference between observed and predicted mean (in degrees Celsius)

Mean	0.241667
Standard Deviation	0.392934
Skewness	0.0890895
Sum	11.6
Variance	0.154397
Kurtosis	-0.912077

Variable is difference between observed and predicted maximum (in degrees Celsius)

Mean	0.258333
Standard Deviation	0.57161
Skewness	0.711943
Sum	12.4
Variance	0.326738
Kurtosis	1.53443

Variable is difference between observed and predicted minimum (in degrees Celsius)

Mean	0.0708333
Standard Deviation	0.35727
Skewness	-0.261868
Sum	3.4
Variance	0.127642
Kurtosis	-0.556394

Univariate analysis for Mehama

Number of values 60

Variable is difference between observed and predicted mean (in degrees Celsius)

Mean	0.265
Standard Deviation	0.419372
Skewness	0.832296
Sum	15.9
Variance	0.175873
Kurtosis	1.46297

Variable is difference between observed and predicted maximum (in degrees Celcius)

Mean	0.536667
Standard Deviation	0.635921
Skewness	0.845885
Sum	32.2
Variance	0.404395
Kurtosis	1.79088

Variable is difference between observed and predicted minimum (in degrees Celsius)

Mean	0.0883333
Standard Deviation	0.345475
Skewness	0.397825
Sum	5.3
Variance	0.119353
Kurtosis	1.01785

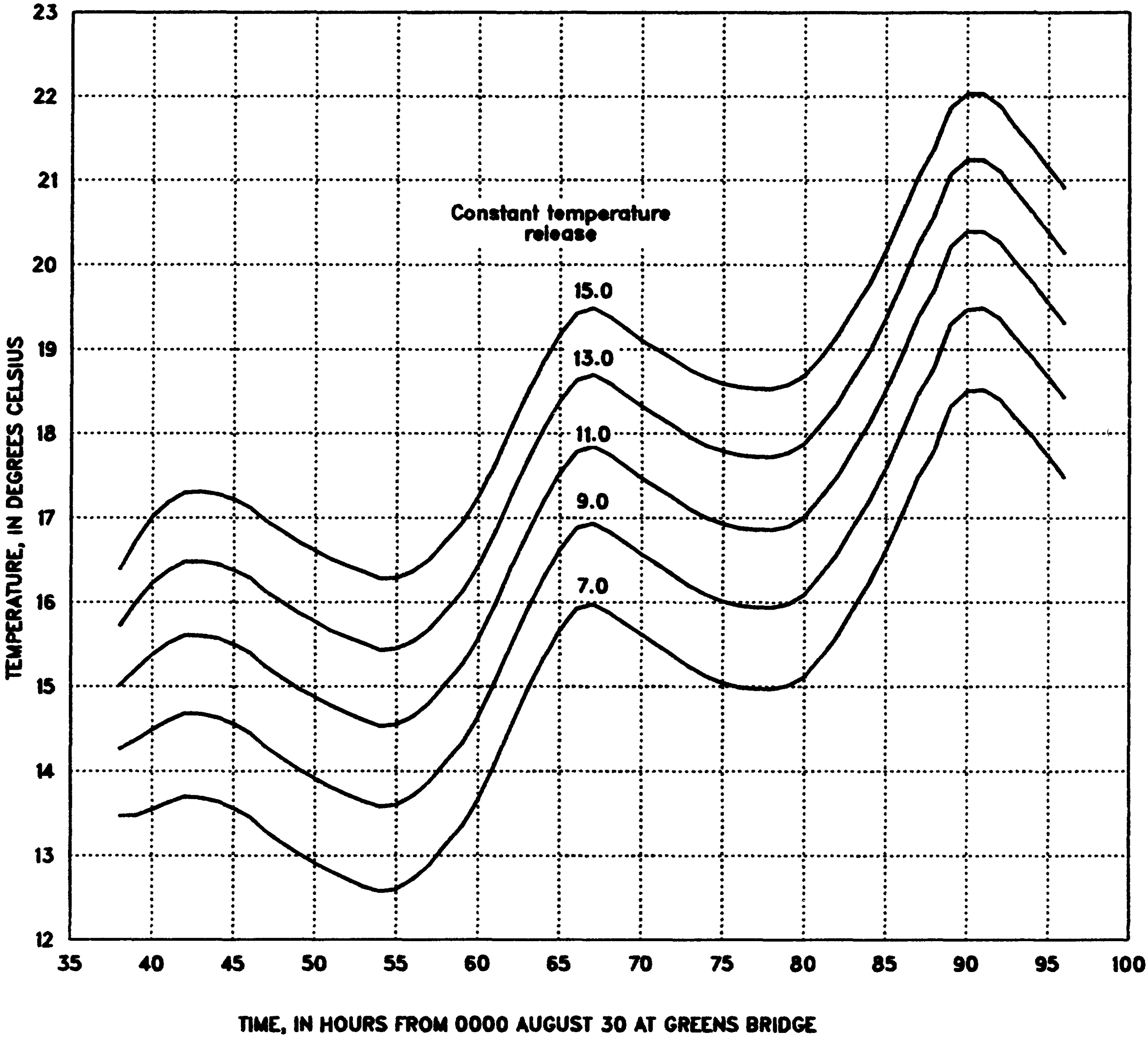

Figure 10.--Model-simulated water temperatures at Greens Bridge as defined by various approximated temperature releases for the period of August 30 to September 2, 1982

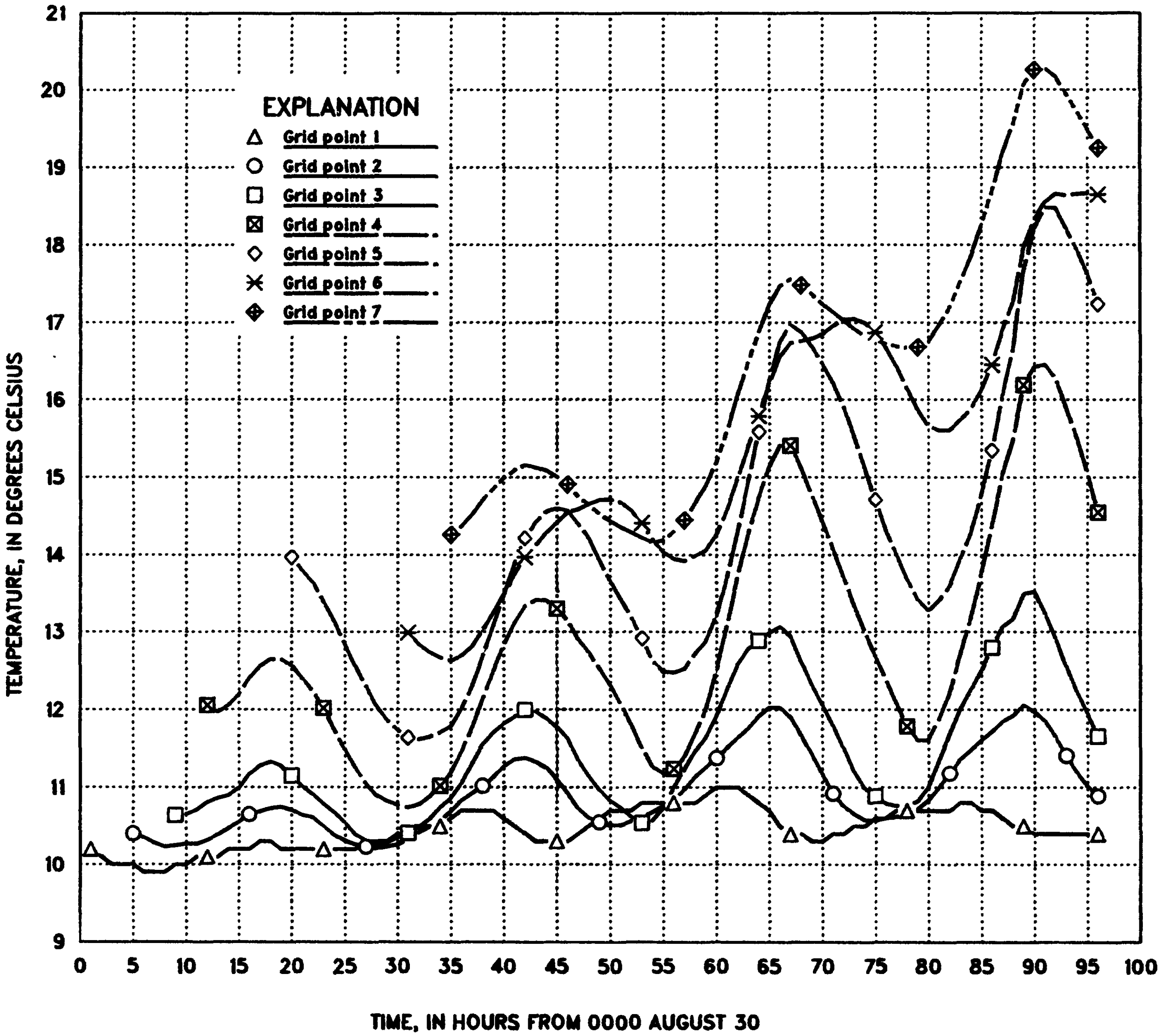

Figure 11.--The temperature change from Niagara to Greens Bridge by grid-point interval for the period of August 30 to September 2, 1982

Simulation of Various Temperature Releases
March 29 to April 1

Initial water temperatures, (depicting different release conditions) from 4.0° C to 7.0° C, in 1° C increments, were used to define a series of resultant temperature curves at Greens Bridge (42.7 miles downstream from Big Cliff Dam). Figure 12 shows these curves. Again, the average temperatures (as well as the maximums and minimums) will be affected by different temperature release conditions. For this period, a 1° C difference in water-temperature release conditions will change the simulated output by approximately 0.5° C at Mehama (18.6 mi downstream) and by approximately 0.3° C at Greens Bridge (47.7 mi downstream). The diel fluctuation for this period averaged 0.7° C at Greens Bridge. Refer to table 7 for averages.

Simulation of Nonreservoir Conditions

To simulate conditions in the stream reach before the creation of the reservoir, a stream segment had to be inserted to approximate the channel before 1953. This was accomplished by measuring stream widths from superseded USGS quadrangle maps and estimating stream velocity based on a relation of velocity-to-channel slope for the downstream section.

Next, the initial stream temperatures from the temperature gages on the North Santiam River below Boulder Creek (14178000) and the Breitenbush River above Canyon Creek (14179000) were input to the model. Figure 13 shows simulated water-temperature conditions at Mehama and at Greens Bridge for approximated nonreservoir conditions for the low-water, warm air-temperature condition. Figure 14 depicts the spring-time, cooler air-temperature condition.

Figure 15 shows how simulated mean daily water temperatures at Mehama and at Greens Bridge compare for current (reservoir) conditions and for nonreservoir conditions for the entire data-collection period. This scenario shows that the reservoir has generally decreased stream temperature in August and September by about 2° C, and that the stream temperatures in March and April were generally not affected.

Results

The results of the three scenarios indicate the model response 42.7 miles downstream to be sensitive to changes in inflow temperatures; however, average changes at the downstream grid point can be very close to model accuracy. The three scenarios represent only a short time-frame historically and therefore cannot be used to generalize impact on downstream riverine-temperature conditions.

Table 6.--Average differences of syntesized water temperature from the observed normal at Mehama, and Greens Bridge for the period August 30 to September 2, 1982, for selected input temperatures

Input water temperature	Difference at Mehama		Difference at Greens Bridge	
(°C)	(°C)	(pct)	(°C)	(pct)
7.0	-2.58	-20.2	-1.03	-6.5
8.0	-1.82	-14.3	-0.71	-4.5
9.0	-1.07	-8.4	-0.40	-2.6
10.0	-0.33	-2.6	-0.10	-0.6
10.3		NORMAL		
11.0	0.41	5.2	0.19	1.2
12.0	1.14	8.9	0.47	3.0
13.0	1.86	14.6	0.75	4.7
14.0	2.57	20.1	1.01	6.4
15.0	3.27	25.6	1.27	8.1

Table 7.--Average differences of syntesized water temperature from the observed normal at Mehama, and Greens Bridge for the period March 29 to April 1, 1983, for selected input temperatures

Input water temperature	Difference at Mehama		Difference at Greens Bridge	
(°C)	(°C)	(pct)	(°C)	(pct)
4.0	-0.61	-9.8	-0.56	-7.8
4.5	-0.35	-5.6	-0.42	-5.9
5.0	-0.09	-1.5	-0.29	-4.0
5.3		NORMAL		
5.5	0.16	2.6	-0.15	-2.2
6.0	0.42	6.7	-0.02	-0.3
6.5	0.67	10.8	0.11	1.6
7.0	0.93	14.9	0.24	3.4

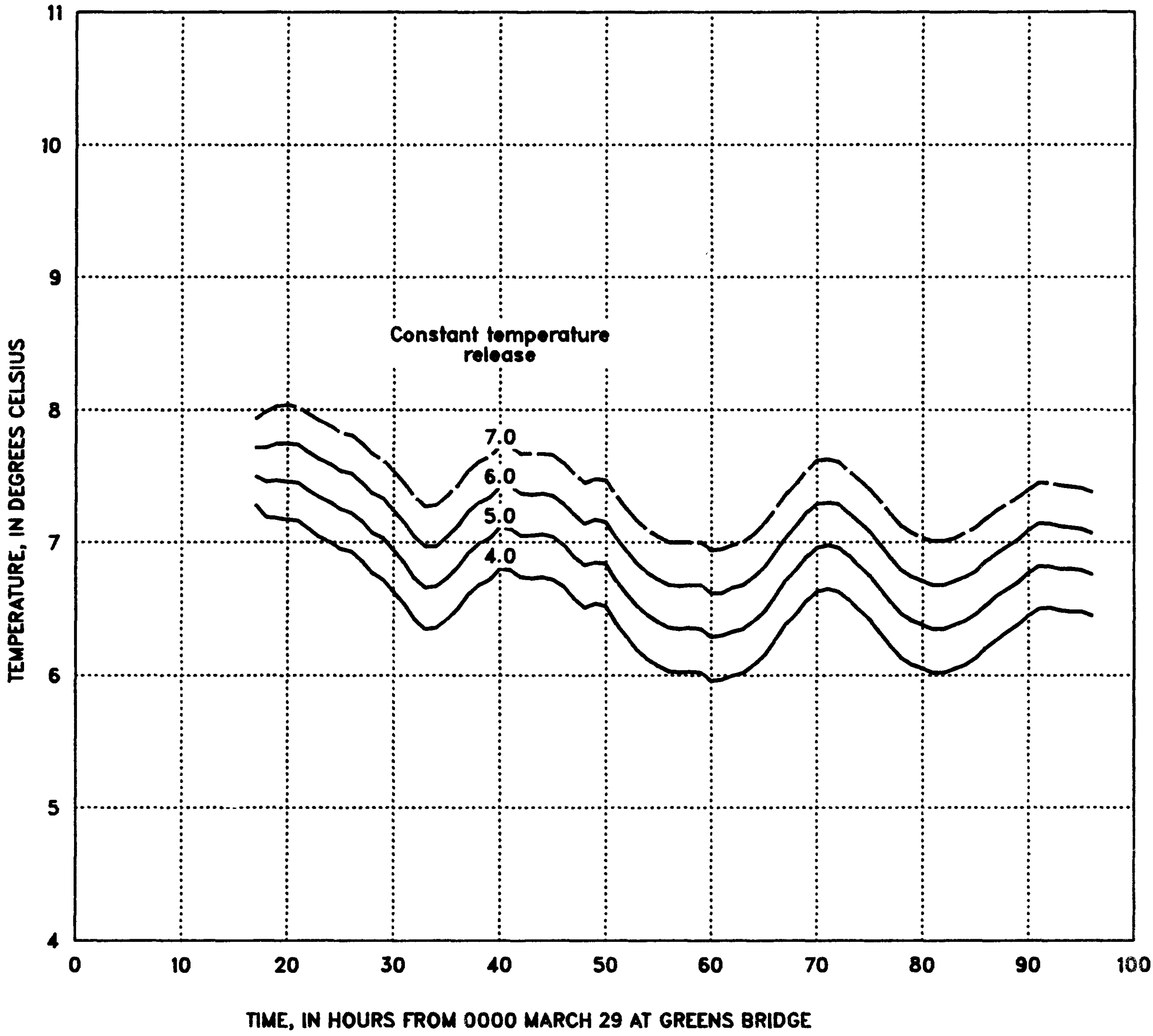

Figure 12.--Model-simulated water temperatures at Greens Bridge as defined by various approximated temperature releases for the period of March 29 to April 1, 1983

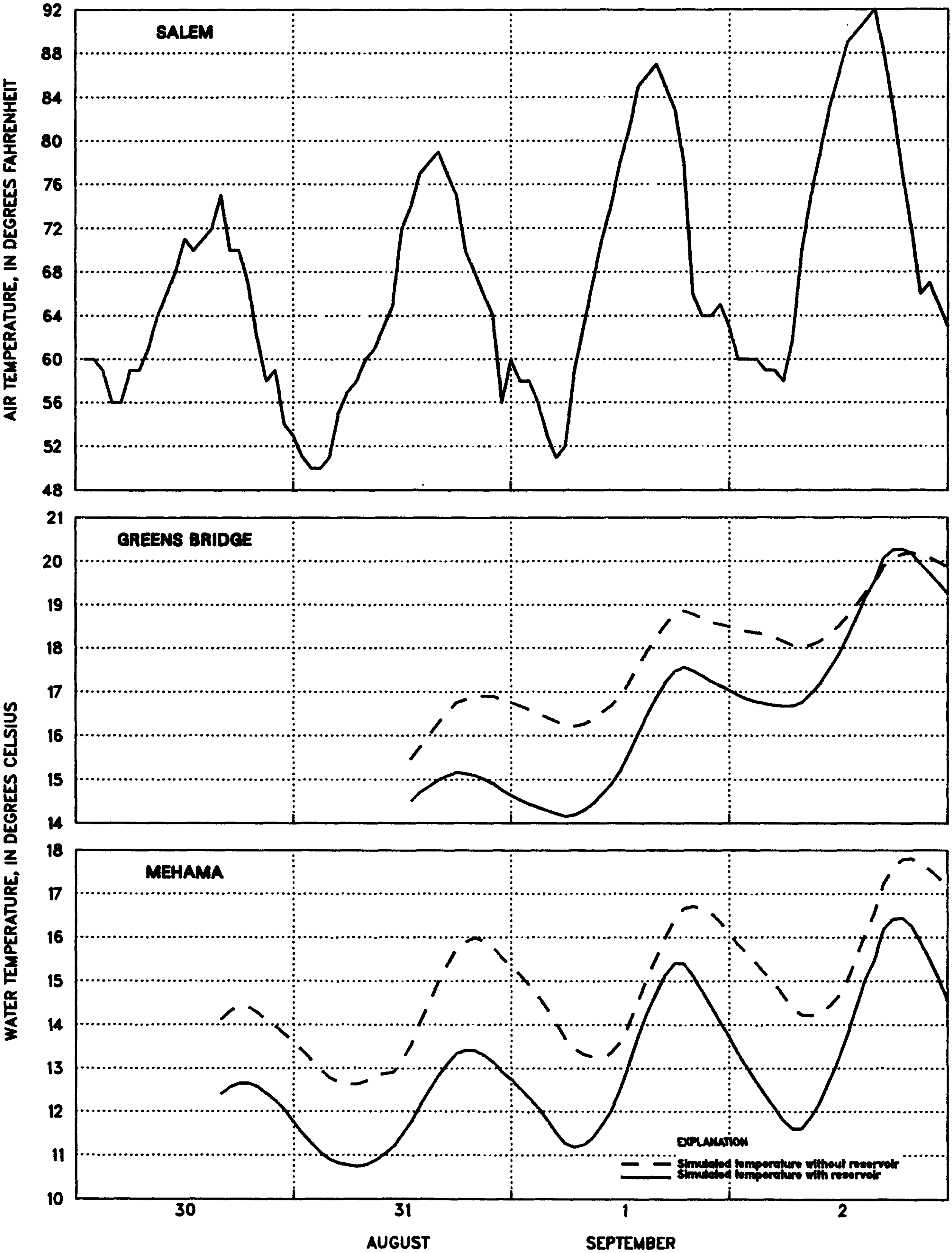

Figure 13.--Comparison of simulated water temperatures for approximated nonreservoir conditions with simulated water temperatures for existing reservoir condition for the period August 30 to September 2, 1982

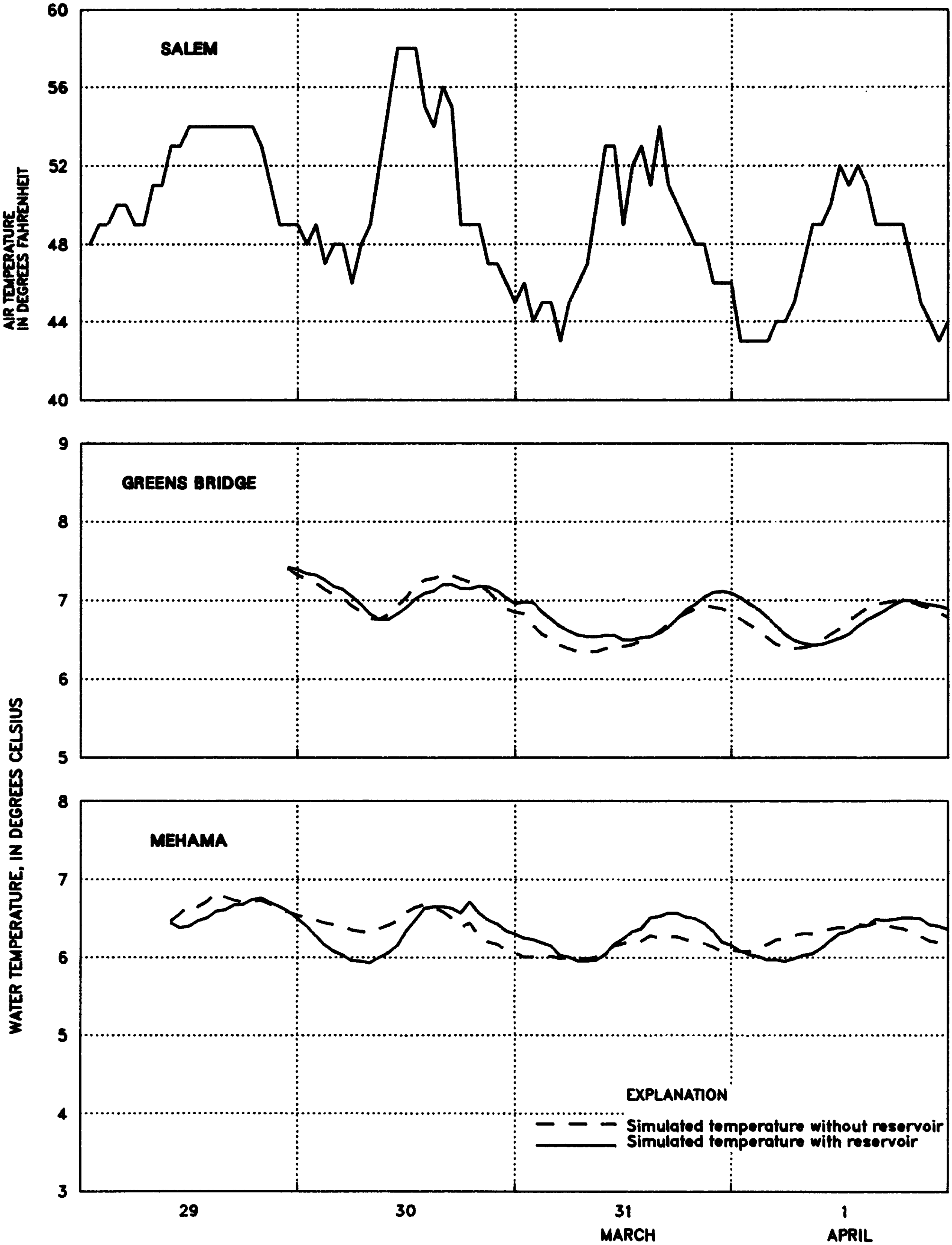

Figure 14.--Comparison of simulated water temperatures for approximated nonreservoir conditions with simulated water temperatures for existing reservoir conditions for the period March 29 to April 1, 1983

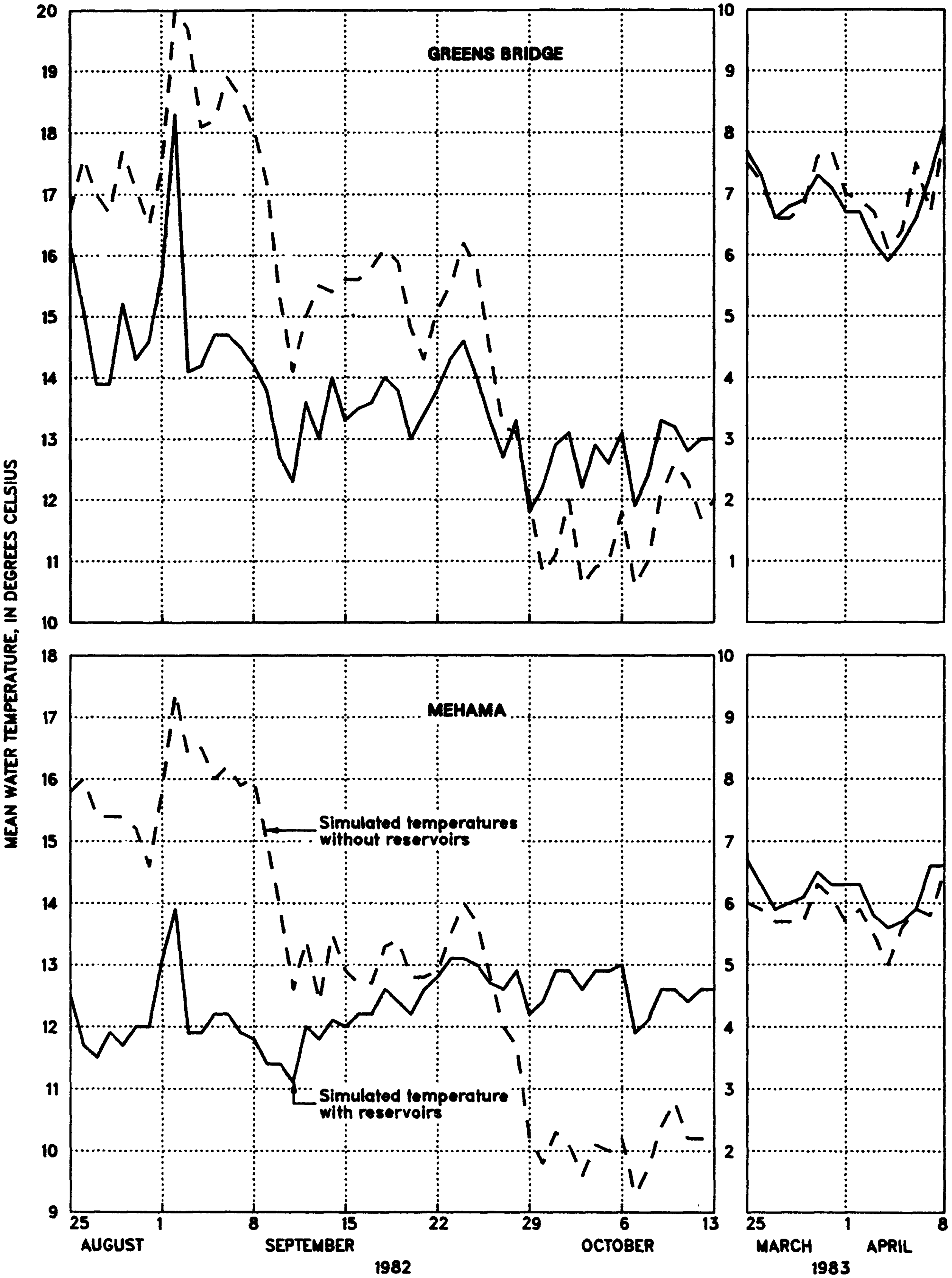

Figure 15.--Simulated mean-daily water temperatures at Mehama and Greens Bridge for current (reservoir) and approximated nonreservoir conditions for the periods August to October, 1982, and March to April, 1983

SUMMARY AND CONCLUSIONS

Evaluation of the Jobson (1980) simple model showed that it is reasonably accurate (± 0.5° C) in defining water temperature with existing atmospheric data in the North Santiam River downstream from Detroit Dam. The model is also sensitive enough to determine changes in the streamflow regime of the North Santiam River at a distance of 42.7 miles downstream with changes in release temperatures at Detroit Dam. Different verification periods show the model to be able to reliably predict maximum, minimum and mean daily water temperatures.

1. An air-temperature, a water-temperature, and a windspeed data-collection network will be adequate to define the model requirements stated in the problem section. However, the data needs to be collected at several representative locations along the stream for best accuracy.

2. Using atmospheric inputs of air temperature and windspeed from a location just outside the basin (McNary Air Field in Salem), the Jobson (1980) model was able to predict mean daily water temperature 42.7 miles downstream from Dig Cliff Dam to within 0.4° C standard deviation, maximum temperature to within 0.6° C standard deviation, and minimum temperature to within 0.4° C standard deviation.

3. Air-temperature and windspeed parameters should be all that is necessary to drive Jobson's temperature model in order to reasonably predict downstream water temperatures. However, if a good relation could be explained between equilibrium and air temperature then results would be more valid.

4. The model parameters that proved to be the most sensitive are as follows: (a) Air temperature -- A 9° F change in air temperature can produce a 2.5° C in water temperature change at Greens Bridge. (b) Windspeed -- A 5 mi/h increase in windspeed can produce a 1.9° C increase in water temperature at Greens Bridge. Other parameters of discharge, cross-section geometry, inflow and diversions proved not to be sensitive.

FUTURE STUDIES

Intensive temperature data are already being collected on the McKenzie River as the next step in obtaining a more accurate temperature model. Channel characteristics of width, depth, and velocity have been more accurately measured in the field. The atmospheric parameters of air temperature and windspeed are measured at several intermediate points. The results of this next model interpretation will determine if future studies will be made.

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Harris, D. D., 1968, Travel rates of water for selected streams in the Willamette River Basin, Oregon: U.S. Geological Survey Hydrologic Investigations Atlas, HA-273, 2 sheets.

Jobson, H. E., 1980, Temperature and solute-transport simulation in streamflow using a Lagrangian reference frame: U.S. Geological Survey Water Resources Investigations Report 81-2, 165 p.

SUPPLEMENTAL DATA

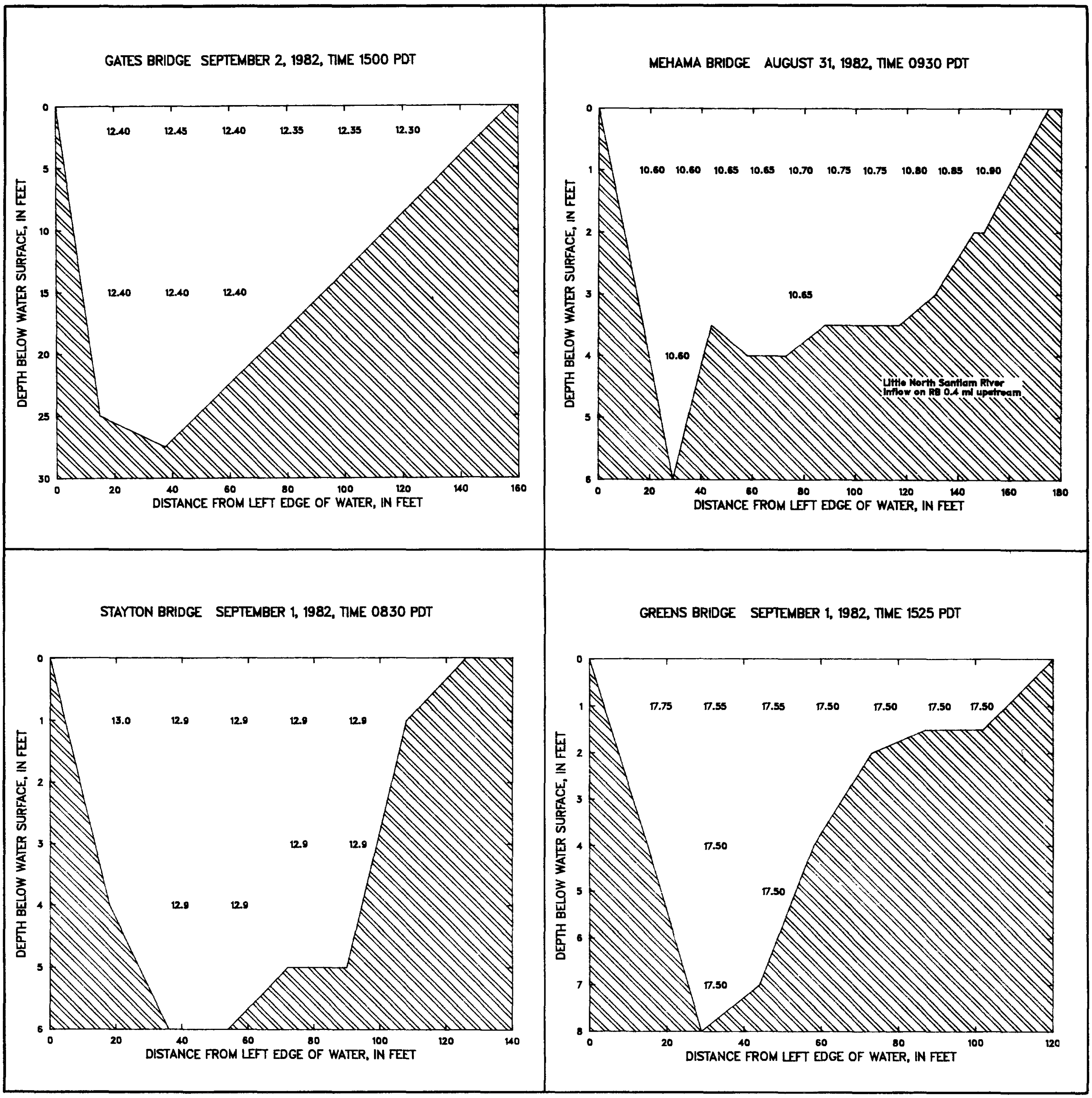

Figure 16.--Temperature cross sections at selected locations

Table 8.--Stream temperature survey and observations

River mile	Time	Water temp. (°C)	Air temp. (°F)	Relative humidity (pct)	Stream cross-section estimates Width (ft)	Depth (ft)	Characteristic	Remarks
Streamside measurements on right bank from river mile 46.4 to 42.3, August 25, 1982								
46.4	1600	10.0	84	45	50	12	Chute	Begin, sunny and warm, canyon in shade.
45.6	1615	10.2	82		155	5	Pool	At USGS stream gage site.
44.9	1630	10.2	82		10	25	Chute	2 ft^3/s inflow at 10.6°C.
44.3	1650	10.3	82		150	4	Riffle	5 ft^3/s inflow at 14.8°C, trees 40 ft high.
43.5	1710	10.5	78		4.5	40	Chute	At Niagara Park, Sevenmile Creek = 5 ft^3/s at 13.3°C.
42.9	1735	10.5	75		150	4	Riffle	3 ft^3/s inflow at 17.0°C.
42.3	1755	10.8	71	70	155	3	Riffle	Stop, at Packsaddle Park, sunny.
Float measurements from river mile 42.3 to 33.2, August 26, 1982								
42.3	1130	9.9	57	89	155	4	Riffle	Begin, Packsaddle Park, overcast.
	1135	9.9			80	5	Pool	Trees, 50-80 ft, sparse.
	1145	9.9			90	5		
	1148				30	--	Narrows	
	1150	9.3			80	--		
40.5	1155	9.7			80	6		At Minto Park.
	1200				200	4	Riffle	5 ft^3/s inflow on LB.
	1205	9.9			200	5	Pool	
	1210	9.6			60	--	Island	
39.3	1215	9.9	59	71	120	6		Stop, at Gates Bridge.
39.3	1225	10.2	59					Begin, at Gates Bridge.
	1230	10.2			100	3	Chute	Trees, 30-40 ft, sparse.
	1235	10.2			60	4	Chute	
	1250	10.2			100	>10	Pool	Just above Spencers Hole rapids.
	1300	10.2			120	6	Pool	Below rapids, time to bail out.
	1308	10.2			250	3	Boulder fld.	Clouds begining to break up.
	1312	10.3			100	4	Riffle	
	1320	10.4			200	3	Riffle	Trees, 30-80 ft, sparse, some sunshine.
	1325	10.3			300	4	Pool	
35.5	1330	10.4	62		200	6	Pool	Stop, Mill City Falls.
35.5	1400		64	69	100	6	Pool	Portage around Mill City Falls.
35.6	1415				60	>10	Narrows	Begin, at Mill City Bridge.
	1423				120	8	Pool	Temp. recorder malfunctioning.
	1430				250	5		Trees, 30-50 ft, sunshine.
	1435	11.6			200	2	Riffle	
	1445	11.7			250	3	Island	
33.2	1448	11.7	69	63	350	2	Riffle	Stop, at Fisherman's Bend Park.
Float measurement from river mile 33.2 to 27.0, September 2, 1982								
33.2	0830	10.85	54	96	350	2	Riffle	Begin, at Fisherman's Bend Park.
	0834	10.90			350	2	Riffle	Trees, 30-40 ft, sunny.
	0837	10.90			300	4	Pool	
	0841	10.90			100	2	Riffle	Riffle with islands.
	0845	10.90				>10		
	0847	10.85			1/4	4		Start diagonal meas.
		10.90			1/2	8	Pool	Width = 200 ft.
		10.85			3/4	3		
	0855	10.90			300	3	Riffle	
	0900	10.95	59	96	100	>10	Narrows	
	0905	10.95					Riffle	
	0910	10.95			180	6	Pool	
	0915	11.00			300	1.5	Riffle	
	0920	11.00			400	1.5	Riffle	
	0925	11.10			350	1.5	Riffle	Trees, 40-50ft.
	0930	11.10			200	>10	Pool	
29.8	0934	11.20	57		300	3	Fall	Stop, at N. Santiam State Park.
29.8	0950	11.35	58	72				Begin, at N. Santiam State Park.
	0952	11.35			100	>10	Narrows	
	0955	11.35					Pool	
	0958	11.35			300	1.5	Island	
	1000	11.40			200	1.5	Riffle	
	1002	11.45			250	2	Riffle	
	1007	11.50			300	2	Pool	
	1010	11.50					Riffle	
	1014	11.55					Fall	
	1016	11.60			200	4	Pool	
	1018	11.65				2	Riffle	
	1021	11.70					Island	
	1025	11.75			200	>10	Pool	
	1027	12.05					Pool	Confluence with L.N. Santiam R.
	1030	12.05					Pool	
	1032	12.10				3	Riffle	Trees, 30-50 ft.
27.0	1034	12.20	66		180	4	Pool	Stop, Mehama Bridge.

Float measurement from river mile 33.2 to 19.8, September 17, 1982

River mile	Time	Water temp. (°C)	Air temp. (°F)	Relative humidity (pct)	Stream cross-section estimates Width (ft)	Depth (ft)	Characteristic		Remarks
33.2	0930	11.45	60	90	RB		Pool	Shade	Begin, Fisherman's Bend Park.
		11.45			1/4			Shade	Sunny, width = 350 ft, depth = 2 ft.
		11.40			1/2				
	0933	11.40					Riffle	Sun	
	0934	11.40					Pool	Sun	
	0936	11.45					Riffle	Sun	
	0937	11.45					Pool	Shade	
	0938	11.45					Riffle	Sun	
	0940	11.45					Pool	Sun	
	0943	11.45					Riffle	Shade	90° bend in channel.
	0944	11.45					Pool	Shade	
	0945	11.45					Riffle	Shade	
	0946	11.45					Pool	Shade	
	0950	11.45					Rapids		White water.
	0955	11.45					Riffle	Sun	
	0957	11.45					Pool	Sun	
	1004	11.50					Pool	Sun	Long, quiet stretch.
	1006	11.50					Pool	Shade	Wide and shallow.
	1011	11.50					Riffle	Shade	
	1013	11.50					Pool	Sun	
29.8	1015	11.50	59	73			Falls	Shade	Stop, N. Santiam Park.
	1030	11.60	59	74			Pool	Ptly shade	Begin, N. Santiam Park.
	1033	11.60					Riffle		90° bend.
	1035	11.60					Pool		
	1036	11.65					Riffle		Island in center stream.
	1037	11.65					Pool		
	1039	11.65					Riffle		
	1042	11.65					Pool		Three channels join.
	1046	11.70					Riffle		
	1048	11.70					Riffle		Series of rapids.
	1051	11.75					Riffle		
	1055	11.80					Pool		
	1057	11.80					Riffle		Island.
	1101	11.90					Pool		
	1106	11.90					Riffle		Confluence with L.N. Santiam.
	1107	11.90					Pool		
	1108	11.90					Riffle		
	1109	11.95					Pool		
	1112	12.00					Riffle		
27.0	1115	12.00	65	46			Pool	Ptly shade	Stop, at Mehama Bridge.
27.0	1200	12.35	77	37	LB		Pool	Ptly sun	Begin, Mehama Bridge.
		12.35			1/4				High overcast.
		12.35			1/2				Diagonal.
		12.35			3/4				Depth = 7 ft.
		12.40			RB				
	1205	12.30					Pool	Sun	
	1208	12.30					Riffle		Wide, shallow.
	1210	12.35					Riffle	Sun	
	1211	12.35					Riffle	Sun	Island.
	1212	12.35					Pool	Shade	Bend, cooler.
	1215	12.35					Riffle	Shade	Begin long riffle, USGS cable.
	1218	12.40					Riffle	Ptly shade	End of riffle.
	1220	12.40					Pool	Shade	Depth = 6 ft.
	1224	12.40					Riffle	Ptly sun	Slight wind starting.
	1227	12.40					Riffle	Ptly sun	In bend with some deep pools.
	1230	12.45					Riffle	Ptly sun	Getting more overcast.
	1235	12.45					Riffle	Sun	
	1240	12.50					Riffle	Sun	
	1245	12.60			LB		Pool	Sun	Diagonal, sun returning.
		12.50			1/4				Depth = 3 ft.
		12.50			1/2				
		12.50			3/4				
		12.60			RB				
	1250	12.50					Pool-riffle	Sun	
	1252	12.55					Pool		Depth = 5 ft.
	1255	12.60					Riffle	Sun	Islands, stream width = 400 ft.
	1258	12.60					Falls		
	1302	12.60					Pool		
	1305	12.60					Pool		
	1308	12.60					Falls		
	1310	12.60					Pool		Depth = 7 ft.
	1313	12.65					Riffle		Sunshine.
	1317	12.70					Riffle		Bend.
	1320	12.70					Pool		
	1323	12.70					Riffle		
	1330	12.70					Pool-riffle		
	1335	12.75					Pool		Depth = 5 ft.
	1340	12.75					Island		Depth = 3 ft.
	1345	12.80					Riffle		Shallows.
	1350	12.80					Island		
	1357	12.80					Pool		
	1400	12.85					Riffle		
19.8	1402	12.90	78	54			Pool	Sun	Stop, Staton Island.

River mile	Time	Water temp. (°C)	Air temp. (°F)	Relative humidity (pct)	Stream cross-section estimates Width (ft)	Depth (ft)	Characteristic		Remarks
Float measurement from river mile 42.3 to 33.2, September 16, 1982									
42.3	1120	11.60	74	50	RB		Pool	Shade	Begin, Packsaddle Park, sunny.
		11.55			1/4			Shade	
		11.50			1/2			Shade	Depth = 4 ft.
	1126	11.50					Riffle	Ptly sh	
	1127	11.50					Pool	Ptly sh	
	1128	11.45					Riffle	Ptly sh	
	1129	11.60					Pool	Sun	
	1130	11.50					Riffle	Sun	
	1132	11.40					Riffle	Sun	
	1133	11.30					Pool	Shade	
	1135	11.60					Riffle	Shade	
	1136	11.65					Pool	Shade	
	1137	11.60					Rapids		
	1138	11.60					Pool	Sun	
	1139	11.55			RB		Pool	Sun	
		11.40			1/4			Sun	
		11.45			1/2			Sun	
		11.45			3/4			Sun	
		11.40			LB			Shade	
	1150	11.55					Riffle	Sun	3 ft^3/s inflow (waterfall).
	1152	11.60					Riffle	Sun	
40.5	1154	11.80	68	49			Riffle	Sun	Minto Park.
	1155	11.65					Pool	Sun	
	1156	11.60					Riffle	Shade	
	1158	11.55					Pool	Shade	
	1159	11.60					Pool	Shade	
	1200	11.65					Pool	Sun	
	1203	11.60					Riffle	Sun	
	1204	11.70					Riffle	Sun	
	1205	11.65					Pool	Shade	
	1208	11.70					Riffle	Shade	
39.3	1209	11.70	71	40			Pool	Sun	Gates Bridge.
	1211	11.70					Pool	Sun	
	1212	11.75					Riffle	Sun	
	1213	11.70					Pool	Sun	
	1214	11.65					Riffle	Sun	
	1216	11.80					Pool	Sun	
	1217	11.80					Riffle	Sun	
	1218	11.85					Pool	Sun	
	1220	11.90					Rapids	Sun	
	1224	11.85					Pool	Ptly sun	Above Spencers Hole.
	1226	11.90					Rapids	Sun	
38.1	1227	11.90	70	43			Pool	Sun	Stop, just below Spencers Hole.
	1300	12.05	76	36			Pool	Sun	Begin, Spencers Hole.
	1305	12.00					Riffle	Sun	
	1308	11.95					Pool	Sun	
	1310	12.05					Riffle	Sun	
	1315	12.20					Pool	Sun	
	1320	12.20					Riffle	Sun	
	1325	12.25					Pool	Sun	
	1330	12.25					Riffle	Sun	
	1335	12.35					Riffle	Sun	
	1337	12.35					Rapids	Sun	Carnivore Rapids.
	1339	12.35	74	33			Riffle	Sun	Stop, just above Mill City Falls.
35.5	1345						Pool	Ptly sun	Portaged around falls, Thermistor. Equipment got wet.
35.6	1410	12.4	80	30			Pool	Sun	Began, below Mill City Falls.
	1415	12.5					Riffle	Sun	Readings with hand-held thermometer.
	1420	12.6					Riffle	Sun	Long, wide, shallow riffle.
	1425	12.8					Pool	Sun	
	1430	12.8					Pool	Sun	Wide pool.
	1437	12.9					Riffle	Sun	Shallow riffle.
	1440	12.9					Riffle	Sun	
33.2	1445	12.9	78	39			Pool	Sun	Stop, Fisherman's Bend Park.

Table 8.--Stream temperature survey and observations--Continued

River mile	Time	Water temp. (°C)	Air temp. (°F)	Relative humidity (pct)	Stream cross-section estimates: Width (ft)	Depth (ft)	Characteristic	Remarks
Float measurement from river mile 27.0 to 19.8, August 31, 1982								
27.0	1015	11.15	62	85	180	4	Pool	Begin, at Mehama Bridge, trees, 30-40 ft.
	1025	11.20			250	2	Pool	30 ft^3/s inflow nr old bridge pier.
	1035	11.25			225	4	Pool	
	1045	11.30					Pool	Sunny weather.
		11.80			LB	2	Pool	Start of diagonal measurement.
		11.40			1/4	3		Width = 175 ft.
		11.50			1/2	8		
		11.60			3/4	6		
		11.80			RB	2		
	1055	11.60			200	-	Riffle	Stop, at rapids.
	1115	11.85			150	8	Pool	Begin, below rapids.
	1125	11.95			-	-	Riffle	
	1130	12.00			-	-		
	1135	12.05			500	-		
23.7	1150	12.45	70		LB	1	Pool	Start of diagonal measurement.
		12.40			1/4	4		Width = 300 ft.
		12.35			1/2	5		
		12.45			3/4	4		
		13.30			RB	1		Stop, at falls.
	1250	13.05			200	-		Begin, below falls.
	1255	13.15			175	6		
	1305	13.40			200	-		
	1340	13.65			LB	5	Pool	Start of diagonal measurement.
		13.70			1/4	8		Width = 150 ft.
		13.75			1/2	11		
		13.80			3/4	5		
		13.80			RB	3		
	1405	14.10			175	-	Pool	15-20 mi/h upstream wind.
	1415	14.05			175	-		
	1425	14.15			500		Riffle	
	1440	14.25			125	2	Riffle	Trees, 30-40 ft.
19.8	1450	14.55	72	67	250	5	Island	Stop, upper Staton Island.
Float measurement from river mile 16.7 to 2.9, September 1, 1982								
16.7	0915	13.00	78	90	126	6	Narrow	Begin, at Staton Bridge.
	0920	13.05			150	-		Sun just breaking through.
	0935	13.25			125	-	Riffle	Trees, 20-30 ft.
	0945	13.40			100	-		
	0950	13.50			125	-	Riffle	
	1000	13.10			175	-		Inflow from around island.
	1005	13.20			225	4	Pool	
	1010	13.50			225	-		
	1015	13.45			250	4	Pool	Trees overhang stream 15 ft.
	1025	13.50			-	7	Pool	
	1030	13.65			225	-	Pool	Diversion channel, pumps.
	1050	13.80			200	4		
	1100	13.85			-	4	Pool	More pumps.
	1110	13.80			125	-		
	1122	14.00			125	3	Pool	
	1130	14.20			80	16		
	1140	14.25						Stop, break.
	1210	14.85	85		150	-	Pool	Begin, after break.
	1215	14.90			300	-		
	1230	15.20			200	10	Pool	Brush overhanging river.
	1235							Large diversion channel, Sidney Ditch.
	1240							Begining of snags.
	1250				80	-		
	1300	15.80			175	-		
	1320	16.15			120	-		Many snags and stumps.
	1340	16.40			50	6	Pool	
	1355	16.65			225	6		
	1400	16.60			275	8	Pool	
	1405	16.70			80	2		
	1415	16.80			175	-		
	1430	17.15			150	-		
	1445							Inflow, Smallman Creek.
	1450	17.20			125	5	Pool	
	1500	17.40			125	5		
	1505	17.35			100	-		Trees, 20-40 ft, 15 ft overhang.
2.9	1510	17.40	77	53	124	8	Pool	Stop, at Greens Bridge.

River mile	Time	Water temp. (°C)	Air temp. (°F)	Relative humidity (pct)	Stream cross-section estimates Width (ft)	Depth (ft)	Characteristic	Remarks
Float measurement from river mile 16.7 to 2.9, September 22, 1982								
16.7	0948	12.40	64	90	LB	Pool	Shade	Begin, Staton Bridge.
		12.35			1/4			Overcast, with some fog.
		12.35			1/2			Diagonal.
		12.35			3/4			
		12.40			RB			
	0955	12.35				Riffle	Shade	
	1000	12.40				Pool		Shallow on LB.
	1005	12.40				Pool		
	1010	12.45				Riffle	Shade	
	1015	12.45				Pool		
	1020	12.45				Riffle		Two channels converge.
	1023	12.50				Pool		
	1025	12.50				Pool		Channel splits.
	1027	12.50				Riffle	Ptly sun	
	1030	12.50				Pool		
	1035	12.55				Riffle		Blue sky starting to show.
	1040	12.60				Pool		Long, calm, deep pool.
	1042	12.60				Riffle	Sun	Sun is out.
	1043	12.60				Pool		
	1045	12.60				Riffle		
	1046	12.60				Pool		In bend, sun behind cloud.
	1047	12.60				Riffle		
	1050	12.60				Pool		
	1052	12.60				Riffle		
	1055	12.65				Pool	Sun	Long, deep, pool, sun back out.
	1100	12.70				Pool		
	1101	12.70				Riffle		
	1105	12.70				Pool		
	1114	12.70	70			Pool		
	1120	12.75			LB	Pool	Shade	Cross section, depth t 10 ft.
		12.80			1/4		Shade	Depth = 8 ft.
		12.80			1/2		Sun	Depth = 6 ft.
		12.80			3/4		Sun	Depth = 3 ft.
		13.00			RB		Sun	Depth < 1 ft.
	1125	12.85				Pool	Sun	
	1130	12.85				Pool		
	1135	12.85				Pool		
	1140	12.90				Pool		Stop, break.
	1240	13.40				Pool		Begin, sunny and warm.
	1245	13.40				Pool	Sun	
	1248	13.40				Riffle		
	1252	13.45				Riffle		Very shallow.
	1255	13.50				Pool		
	1257	13.50				Riffle		Very shallow, had to pull boat.
	1300	13.50				Riffle		
	1302	13.50				Pool		
	1304	13.55				Pool		
	1306	13.60				Pool		Took left branch.
	1310	13.60				Pool	Sun	Begining of snags.
	1315	13.65				Pool		
	1317	13.70				Pool		Approaching swamped and broken canoe.
	1321	13.70				Riffle		Log jam.
	1325	13.70				Pool		Very sunny, getting hot.
	1327	13.75				Pool		Another log jam.
	1328	13.75				Pool		Large trees outcrop into channel.
	1331	13.80				Pool		Inflow on RB.
	1333	13.80						Log jam in main channel.
	1335	13.85				Pool	Sun	Small inflow on RB.
	1338	13.90				Pool		Long shallow pool.
	1340	13.95				Island	Ptly sun	Channel splits.
	1343	13.95				Island		
	1346	14.00				Riffle		
	1348	14.00				Island		
	1353	14.00				Pool		
	1400	14.05				Pool	Ptly sun	Long pool.
	1404	14.10				Riffle		
	1410	14.15				Pool		
	1415	14.20				Riffle		Long, broad riffle.
	1418	14.20				Pool		Long, broad pool.
	1420	14.20				Pool		
2.9	1425	14.20	67	62		Riffle	Ptly sun	Stop, Greens Bridge.

Table 9.--Maximums, minimums, and means of observed and model simulated water temperatures at Greens Bridge and Mehama for the entire data collection period

MO	DAY	YR	OBSERVED MEAN	OBSERVED MAX	OBSERVED MIN	SIMULATED MEAN	SIMULATED MAX	SIMULATED MIN	DIFFERENCE MEAN	DIFFERENCE MAX	DIFFERENCE MIN
GREENS BRIDGE											
AUG	26	82	15.5	16.5	14.5	15.1	16.0	14.1	0.4	0.5	0.4
AUG	31	82	15.4	17.4	13.5	14.6	15.2	14.2	0.8	2.2	-0.7
SEP	1	82	16.7	18.6	14.7	15.7	17.6	14.2	1.0	1.0	0.5
SEP	2	82	17.9	19.6	16.3	18.3	20.3	16.7	-0.4	-0.7	-0.4
SEP	15	82	12.9	13.9	11.5	13.3	14.6	12.0	-0.4	-0.7	-0.5
SEP	16	82	13.1	14.6	11.4	13.5	15.3	11.6	-0.4	-0.7	-0.2
SEP	17	82	13.3	14.2	12.1	13.6	14.9	12.1	-0.3	-0.7	0.0
SEP	18	82	13.7	14.9	12.4	14.0	15.0	13.0	-0.3	-0.1	-0.6
SEP	19	82	14.0	14.7	13.2	13.8	14.6	13.4	0.2	0.1	-0.2
SEP	20	82	13.1	13.7	12.8	13.0	13.6	12.8	0.1	0.1	0.0
SEP	21	82	13.3	14.5	12.5	13.4	14.6	12.5	-0.1	-0.1	0.0
SEP	22	82	14.2	15.3	12.9	13.8	14.9	12.6	0.4	0.4	0.3
SEP	23	82	14.4	15.5	13.1	14.3	15.3	13.4	0.1	0.2	-0.3
SEP	24	82	14.4	15.2	13.6	14.6	15.3	14.0	-0.2	-0.1	-0.4
SEP	25	82	13.7	14.4	13.3	14.0	14.6	13.7	-0.3	-0.2	-0.4
SEP	26	82	13.2	13.7	12.6	13.3	13.7	12.9	-0.1	0.0	-0.3
SEP	27	82	13.4	14.1	12.4	12.7	13.5	12.2	0.7	0.6	0.2
SEP	28	82	13.4	14.0	12.9	13.3	13.6	13.0	0.1	0.4	-0.1
SEP	29	82	12.8	13.7	11.8	11.8	12.8	11.0	1.0	0.9	0.8
SEP	30	82	12.9	14.0	11.7	12.2	13.4	11.1	0.7	0.6	0.6
OCT	1	82	13.2	14.3	11.8	12.9	14.0	11.9	0.3	0.3	-0.1
OCT	2	82	13.2	13.9	12.6	13.1	13.9	12.6	0.1	0.0	0.0
OCT	3	82	13.1	13.9	12.1	12.2	13.0	11.5	0.9	0.9	0.6
OCT	4	82	13.2	13.9	12.4	12.9	13.5	12.3	0.3	0.4	0.1
OCT	5	82	13.1	14.0	12.0	12.6	13.9	11.5	0.5	0.1	0.5
OCT	6	82	13.1	13.8	12.7	13.1	13.9	12.6	0.0	-0.1	0.1
OCT	7	82	12.4	12.8	12.0	11.9	12.7	11.4	0.5	0.1	0.6
OCT	8	82	12.4	12.8	11.9	12.4	13.0	11.8	0.0	-0.2	0.1
OCT	9	82	13.0	14.0	12.3	13.3	14.2	12.6	-0.3	-0.2	-0.3
OCT	10	82	13.1	14.2	11.9	13.2	14.5	11.8	-0.1	-0.3	0.1
OCT	11	82	13.1	14.1	11.9	12.8	13.7	11.7	0.3	0.4	0.2
OCT	12	82	13.2	14.3	12.0	13.0	14.4	11.5	0.2	-0.1	0.5
OCT	13	82	13.3	14.3	12.1	13.0	13.9	11.9	0.3	0.4	0.2
MAR	24	83	8.5	9.3	7.6	7.7	8.6	7.2	0.8	0.7	0.4
MAR	25	83	8.0	8.8	7.4	7.3	7.7	7.1	0.7	1.1	0.3
MAR	26	83	7.2	7.7	6.8	6.6	7.1	6.4	0.6	0.6	0.4
MAR	27	83	7.4	8.4	6.6	6.8	7.2	6.5	0.6	1.2	0.1
MAR	28	83	7.3	7.7	6.9	6.9	7.4	6.6	0.4	0.3	0.3
MAR	29	83	7.4	7.7	7.1	7.3	7.6	7.0	0.1	0.1	0.1
MAR	30	83	7.3	7.6	6.9	7.1	7.3	6.8	0.2	0.3	0.1
MAR	31	83	7.2	7.8	6.7	6.7	7.1	6.5	0.5	0.7	0.2
APR	1	83	6.6	6.8	6.3	6.7	7.0	6.4	-0.1	-0.2	-0.1
APR	2	83	6.5	6.6	6.3	6.2	6.5	6.0	0.3	0.1	0.3
APR	3	83	6.5	7.2	5.7	5.9	6.3	5.5	0.6	0.9	0.2
APR	4	83	6.8	8.0	5.8	6.2	7.2	5.4	0.6	0.8	0.4
APR	5	83	7.1	8.4	5.7	6.6	7.4	6.0	0.5	1.0	-0.3
APR	6	83	7.3	8.6	5.8	7.3	8.7	6.4	0.0	-0.1	-0.6
APR	7	83	7.9	8.2	7.8	8.1	8.7	7.5	-0.2	-0.5	0.3

Table 9.--Maximums, minimums, and means of observed and model simulated water temperatures at Greens Bridge and Mehama for the entire data collection period--Continued

MO	DAY	YR	OBSERVED			SIMULATED			DIFFERENCE		
			MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN
						MEHAMA					
AUG	25	82	13.0	15.3	10.9	12.5	14.0	11.2	0.5	1.3	-0.3
AUG	26	82	12.2	13.8	11.1	11.7	12.8	10.5	0.5	1.0	0.6
AUG	27	82	11.7	12.9	10.7	11.5	12.4	10.7	0.2	0.5	0.0
AUG	28	82	12.4	14.8	10.4	11.9	13.8	10.2	0.5	1.0	0.2
AUG	29	82	12.0	12.8	11.4	11.7	12.2	11.2	0.3	0.6	0.2
AUG	30	82	12.7	14.3	11.4	12.0	12.6	11.6	0.7	1.7	-0.2
AUG	31	82	13.4	16.1	11.0	12.0	13.4	10.7	1.4	2.7	0.3
SEP	1	82	13.8	16.5	11.2	13.1	15.4	11.2	0.7	1.1	0.0
SEP	2	82	13.7	15.6	11.7	13.9	16.4	11.6	-0.2	-0.8	0.1
SEP	3	82	11.9	13.1	11.5	11.9	13.3	11.4	0.0	-0.2	0.1
SEP	4	82	12.1	13.3	11.0	11.9	12.6	11.4	0.2	0.7	-0.4
SEP	5	82	12.4	14.7	10.8	12.2	13.9	11.1	0.2	0.8	-0.3
SEP	6	82	12.5	13.9	11.1	12.2	13.4	11.0	0.3	0.5	0.1
SEP	7	82	12.3	14.0	11.0	11.9	13.2	10.8	0.4	0.8	0.2
SEP	8	82	12.3	13.9	11.0	11.8	12.9	10.8	0.5	1.0	0.2
SEP	9	82	11.6	12.0	11.0	11.4	11.7	10.8	0.2	0.3	0.2
SEP	10	82	11.8	12.8	11.2	11.4	11.8	11.0	0.4	1.0	0.2
SEP	11	82	11.2	11.6	10.8	11.1	11.5	10.6	0.1	0.1	0.2
SEP	12	82	12.5	13.7	11.6	12.0	12.8	11.5	0.5	0.9	0.1
SEP	13	82	12.3	13.8	11.1	11.8	13.0	10.8	0.5	0.8	0.3
SEP	14	82	12.3	13.6	11.3	12.1	13.4	11.2	0.2	0.2	0.1
SEP	15	82	12.0	13.6	10.8	12.0	13.2	10.9	0.0	0.4	-0.1
SEP	16	82	12.3	13.7	11.3	12.2	13.7	11.2	0.1	0.0	0.1
SEP	17	82	12.1	13.1	11.5	12.2	13.3	11.3	-0.1	-0.2	0.2
SEP	18	82	12.7	13.8	11.8	12.6	13.5	11.9	0.1	0.3	-0.1
SEP	19	82	12.6	13.1	12.3	12.4	12.7	12.2	0.2	0.4	0.1
SEP	20	82	12.5	12.8	12.1	12.2	12.3	12.1	0.3	0.5	0.0
SEP	21	82	12.9	13.9	12.1	12.6	13.4	12.2	0.3	0.5	-0.1
SEP	22	82	13.2	14.9	12.3	12.8	13.8	12.1	0.4	1.1	0.2
SEP	23	82	13.3	14.8	12.4	13.1	13.9	12.3	0.2	0.9	0.1
SEP	24	82	13.2	13.7	12.7	13.1	13.4	12.9	0.1	0.3	-0.2
SEP	25	82	12.9	13.4	12.5	13.0	13.2	12.8	-0.1	0.2	-0.3
SEP	26	82	12.7	13.3	12.4	12.7	12.9	12.4	0.0	0.4	0.0
SEP	27	82	13.0	13.7	12.5	12.6	13.1	11.9	0.4	0.6	0.6
SEP	28	82	12.9	13.3	12.5	12.9	13.3	12.2	0.0	0.0	0.3
SEP	29	82	12.6	13.7	11.9	12.2	12.8	11.7	0.4	0.9	0.2
SEP	30	82	12.5	13.7	11.7	12.4	13.4	11.9	0.1	0.3	-0.2
OCT	1	82	12.7	13.7	11.9	12.9	13.7	12.1	-0.2	0.0	-0.2
OCT	2	82	12.8	13.2	12.3	12.9	13.2	12.6	-0.1	0.0	-0.3
OCT	3	82	12.9	13.7	12.3	12.6	13.1	12.0	0.3	0.6	0.3
OCT	4	82	12.9	13.5	12.6	12.9	13.4	12.6	0.0	0.1	0.0
OCT	5	82	12.9	13.7	11.9	12.9	13.8	12.1	0.0	-0.1	-0.2
OCT	6	82	12.8	13.2	12.4	13.0	13.2	12.5	-0.2	0.0	-0.1
OCT	7	82	11.8	12.3	11.4	11.9	12.3	11.7	-0.1	0.0	-0.3
OCT	8	82	11.6	12.0	11.3	12.1	12.5	11.8	-0.5	-0.5	-0.5
OCT	9	82	12.0	12.9	11.4	12.6	13.3	12.2	-0.6	-0.4	-0.8
OCT	10	82	12.2	13.1	11.6	12.6	13.6	11.9	-0.4	-0.5	-0.3
OCT	11	82	12.2	13.1	11.6	12.4	13.1	11.7	-0.2	0.0	-0.1
OCT	12	82	12.4	13.6	11.8	12.6	13.6	11.8	-0.2	0.0	0.0
OCT	13	82	12.7	13.6	12.0	12.6	13.4	12.1	0.1	0.2	-0.1
MAR	24	83	6.6	7.7	5.9	6.7	7.3	6.3	-0.1	0.4	-0.4
MAR	25	83	6.9	7.6	6.4	6.3	6.7	5.8	0.6	0.9	0.6
MAR	29	83	7.1	7.5	6.8	6.5	6.8	6.4	0.6	0.7	0.4
MAR	30	83	6.8	7.2	6.4	6.3	6.7	5.9	0.5	0.5	0.5
MAR	31	83	6.9	7.5	6.4	6.3	6.6	6.0	0.6	0.9	0.4
APR	1	83	6.9	7.1	6.6	6.3	6.5	5.9	0.6	0.6	0.7
APR	2	83	6.6	7.0	6.1	5.8	6.2	5.5	0.8	0.8	0.6
APR	3	83	6.6	7.2	6.0	5.6	5.8	5.4	1.0	1.4	0.6
APR	4	83	7.2	8.2	6.3	5.7	6.4	5.1	1.5	1.8	1.2
APR	5	83	7.3	8.6	6.1	5.9	6.4	5.5	1.4	2.2	0.6