WATER TEMPERATURES IN THE LOWER DESCHUTES RIVER, OREGON

Prepared for Portland General Electric

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2. ABSTRACT

We combined detailed analyses of data available from public agencies, water temperature and weather data we collected, and a widely used stream temperature model (SNTEMP) to assess the effects of the Pelton Round Butte Project (PRB) on thermal regimes in the lower Deschutes River, Oregon. Multiple analytical methods were used, to ensure that our results would be strongly supported by available data.

Statistical analyses of historical data suggest that there have been functional, PRB-related changes in the temperature regime of the Deschutes River below PRB. Although changes in annual maximum and minimum temperatures since PRB completion have been small and statistically insignificant, there have been noticeable shifts in the timing of annual temperature cycles and extremes. Temperatures immediately below PRB are lower in the winter, spring, and early summer than they would be without PRB. A shift toward somewhat higher temperatures in the late summer and fall has also occurred. Annual temperature maxima immediately below PRB have been more than a month later post-PRB than they were pre-PRB. Smaller delays in annual maxima appear to have occurred farther downriver.

For a 1-year period starting in late May 1997, we used SNTEMP to simulate PRB's effects on water temperatures along the 100.1-mi. length of the lower Deschutes River. This was done by making paired sets of model runs, one using measured PRB release temperatures as input and the other using pre-PRB statistical relationships to predict what river temperatures at the release point would have been without PRB. Our simulations indicate that PRB has seasonally variable temperature effects that 1) attenuate downstream and 2) extend to the river's mouth.

Our simulations suggest that, during the period modeled, PRB decreased river temperatures from late May to early August, increased them (relative to an undammed condition) until about mid-December, then decreased them again until mid-May. This pattern of PRB influence is nearly identical to pre- versus post-PRB differences in river temperatures evident in historical data. The SNTEMP simulations suggest that immediately below PRB, weekly mean temperatures were elevated by an average of approximately 0.7°C (range: +0.2 to +1.5°C) from early August to mid-December and reduced by an average of about 1.7°C (range: -0.2 to -3.5°C) during the remainder of the annual cycle. Downstream at Colorado Rapids, 4.0 mi. above the river's mouth, the estimated PRB effect for the same periods was to raise temperatures by an average of about 0.5°C (range: -0.1 to +1.0°C) and to decrease them by approximately 0.6°C (range: -0.1 to -1.7°C).

Post-PRB changes in river temperatures are likely to have had mixed effects on coldwater biota. Observed changes in river temperatures appear likely to have delayed the emergence of incubating

steelhead embryos by about 10–14 days immediately below PRB and to have had quantifiable but statistically insignificant effects on the emergence timing of fall chinook in the river. However, by releasing slightly cooler than "natural" water at the time of year (early to mid-summer) when river temperatures would otherwise be warmest, PRB may cause a small reduction in annual peak 7-day mean maximum temperatures along much of the lower Deschutes River. This would slightly reduce the length of the lower river that exceeds Oregon's temperature standard for coldwater biota (7-day mean maximum temperature <17.8°C).

3. INTRODUCTION

Streamflows in the Deschutes River, Oregon, have historically been more uniform than those of other large rivers in the United States (USGS 1914). The uniformity of these flows has been attributed to unique geological formations within upper portions of the river's 27,200 km^2 watershed and an abundance of springs in areas inundated by or upstream of the Pelton Round Butte Project (PRB; Figure 1). Naturally stable Deschutes River flows in the vicinity of PRB were historically coupled with relatively moderate water temperatures. The moderate temperatures were also due to the presence of springs.

Water developments and stream channel changes in the drainage upstream of PRB have been substantial over the last 150 years (Nehlsen 1995). Storage of spring runoff, diversion of summer flows, and degradation of riparian systems have combined to reduce streamflows and elevate summer water temperatures at many locations. The effect of these changes on the volume and temperature of water entering PRB has been buffered by the strong influence of the springs described earlier, particularly along the Metolius and lower Crooked rivers.

Recent, cursory examinations of historical temperature data for the lower Deschutes River (that portion of the mainstem below PRB) raised questions about the extent to which PRB may have modified the river's temperature regime (Beaty 1995). In response to this issue, Portland General Electric Company (PGE) contracted us to review historical water temperature data from the Deschutes River drainage and to examine how PRB may have affected water temperatures in the river. Of interest to PGE were five key questions, three related to evaluating the degree to which PRB has changed the lower river's temperature regime and two directed toward the effects any such changes might have on coldwater biota. All five of these questions, listed below, are addressed in this report:

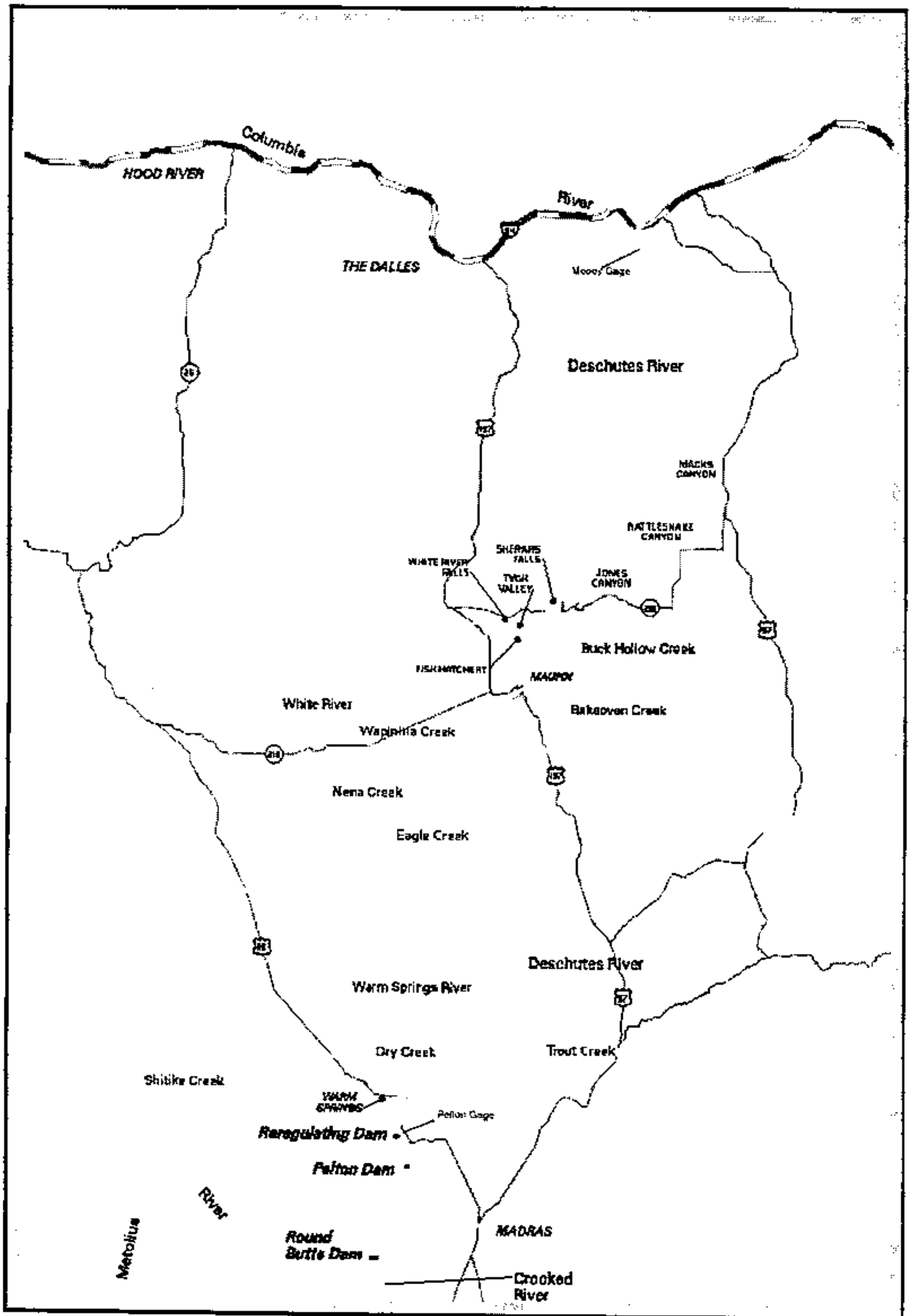

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Figure 1. Lower Deschutes River and major tributaries.

- Changes in Lower River Temperatures

1. Have there been changes in Deschutes River temperatures below PRB?

2. If so, how large have any temperature changes in the river below PRB been, particularly for those changes that may have been caused by PRB?

3. How far down the Deschutes River might any PRB-related changes in water temperatures extend?

- Effects on Coldwater Biota

4. If there have been PRB-related changes in river temperatures below PRB, what effect might those changes have had on the emergence timing of anadromous salmonid embryos incubating in the river?

5. What effect has PRB had on the occurrence or severity of high temperatures that Oregon's water quality standards identify as stressful for the lower river's coldwater biota (including salmonids)?

4. METHODS

4.1. CHANGES IN LOWER RIVER TEMPERATURES

We used three different analytical methods to assess PRB's effects on temperatures downstream in the lower Deschutes River. These methods included: (1) period-of-record comparisons of pre- versus post-PRB data on river temperatures; (2) analyses of historic temperature patterns and relationships; and (3) SNTEMP-based modeling of temperatures in the lower river. The multiple-method approach was used to ensure that any conclusions drawn would be strongly supported by available information.

4.1.1. Differences in Pre- Versus Post-PRB River Temperatures

Temperature information on the Deschutes River and selected tributaries was obtained from available sources (Table 1). Digital gage records for several important locations were acquired from the U.S. Geological Survey's (USGS's) Water Resources Division in Portland, Oregon. Various digital records of historical temperature measurements were obtained through a retrieval of all information for the Deschutes watershed stored in the U.S. Environmental Protection Agency's (USEPA's) STORET database. Temperature records for a number of important locations along the Deschutes, Metolius, Crooked, and White rivers, as well as on several other streams, were obtained directly from biologists who have conducted water temperature studies within the watershed. Temperature data for the Warm Springs River and Shitike Creek were acquired from published literature.

Once acquired, stream temperature data most relevant to assessing the potential thermal impacts of PRB were summarized to provide a clearer understanding of how temperatures have varied within the river system. Particular attention was paid to differences in temperature regimes within the lower mainstem Deschutes River before (pre-1958) and after (post-1964) the hydroelectric project. This focused attention on USGS temperature records for gages immediately below PRB [Pelton Gage, at river mile (RM) 100.1 and at Moody (RM 1.4)] because prior to our study there had been no continuous water temperature data collected at other locations on the lower river. We excluded data for construction years 1958 through 1964 from our analysis of conditions in the Deschutes below PRB because configurations of PRB during that time were variable and different from those since its completion. T-tests (or Mann-Whitney rank sum tests when parametric assumptions were not met) were used to examine the statistical significance of any post-PRB shifts in river temperatures at Pelton Gage, with alpha values set at 0.05.

4.1.2. Changes in Temperature Patterns and Relationships

In a particular section of stream and for a given time of year, temporal variations in stream temperature are most often related to the temperature of water flowing into the section, prevailing air temperatures, and the volume of water flowing through the section. We carefully examined

Table 1. Water temperature data for the Deschutes River and its tributaries.

Location	Temperature data			Period	Source
	daily means	max-min	sporadic		
Deschutes R. at Benham Falls	yes	yes		1967-1980	USGS - Portland
Deschutes R. at Bend	yes	yes	yes	1994-1995	Dean Grover, USFS
Deschutes R. at Tumalo Br.			yes	1958-1974	STORET data
Deschutes R. near Redmond	yes	yes		1994-1995	Dean Grover, USFS
Deschutes R. below Cline Falls	yes	yes		1992-1995	Jim Eisner, BLM
Deschutes R. below Cline Falls	yes	yes	yes	multiple years	Oregon DEQ/STORETdata
Deschutes R. at Tethro Crossing	yes	yes		1994-1995	Dean Grover, USFS
Deschutes R. at Steelhead Falls	yes	yes		1994-1995	Dean Grover, USFS
Deschutes R. near Geneva	yes	yes		1992-1995	Jim Eisner, BLM
Deschutes R. near Culver	yes	yes		1954-1974	USGS - Portland
Deschutes R. above Billy Chinook			yes	1958-1995	STORET data
Deschutes R. above Billy Chinook	yes	yes		1994-1995	Dean Grover, USFS
Deschutes R. above Billy Chinook	yes	yes		1994-1998	PGE
Deschutes R. below RB Dam	yes	yes		1994-1996	PGE
Deschutes R. below Pelton Dam	yes	yes		1994-1996	PGE
Deschutes R. at Pelton Gage	partial	yes		1952-1988	USGS - Portland
Deschutes R. below. Rereg Dam	yes	yes	yes	1994-1998	PGE
Deschutes R. at Wrm Spr. Bridge	yes		yes	June-Aug 95	Oregon DEQ/STORET data
Deschutes R. above Trout Cr.	yes	yes		1995-1996	Chris Zimmerman, OSU
Deschutes R. at Maupin			yes	1962-1995	STORET data
Deschutes R. at Moody	partial	yes		1954-1981	USGS - Portland
Deschutes R. at Moody		yes		July-Sept 86	Jim Newton, ODFW - The Dalles
Deschutes R. near mouth	yes			May-Aug 95	Oregon DEQ
Paulina Cr. near LaPine	yes	yes		1991-1995	USGS - Portland
Metolius R. near Grandview	yes	yes		1954-1974	USGS - Portland
Metolius R. near mouth	yes	yes		1988-1994	Mike Riehle, USFS
Metolius R. near mouth	yes	yes		1994-1998	PGE
Squaw Cr.	yes	yes		1995	Dean Grover, USFS
Crooked R. below Bowman Dam	yes	yes		1992-1995	Jim Eisner, BLM
Crooked R. at Dry Canyon	yes	yes		1992-1995	Jim Eisner, BLM
Crooked R. above Smith Rocks	yes	yes		1992-1995	Jim Eisner, BLM
Crooked R. at Terrebonne			yes	1962-1995	STORET data
Crooked R. below Opal Springs	yes	yes		1963-1974	USGS - Portland
Crooked R. near Culver	yes	yes		1954-1963	USGS - Portland
Crooked R. at Cove State Park			yes	1958-1975	STORET data
Crooked R. at Cove State Park	yes	yes		1994-1998	PGE
Willow Cr.	yes	yes		1994-1995	Dean Grover, USFS
Willow Cr.	yes	yes		1992-1995	Jim Eisner, BLM
Shitike Cr. at Warm Springs	yes*	yes*		1986-1992	Fritsch (1995)
Trout Cr. near Mouth	yes	yes		1992-1995	Jim Eisner, BLM
Trout Cr. near Ashwood	yes	yes		1992-1995	Jim Eisner, BLM
Warm Springs R. near Kahneeta	yes*	yes*		1988-1992	Fritsch (1995)
Wapinitia Cr.	yes	yes		1992-1995	Jim Eisner, BLM
White R. below Tygh Valley	yes	yes		1981-1982	USGS - Portland
White R. below White R. Falls	yes	yes		1992-1995	Jim Eisner, BLM
Miscellaneous locations			yes	multiple years	Agency files; STORET data

* thermograph data available only from visual inspection of plots of monthly values given in a published report

historical data on stream temperatures, flows, and air temperatures in the vicinity of PRB (Table 2). The purpose of this examination was to identify the degree to which selected post-PRB shifts in river temperatures at Pelton Gage might be related to factors other than the hydroelectric project, or conversely, how clearly these shifts were related to the presence of PRB.

Table 2. Historical water temperature, streamflow, and air temperature data used for detailed evaluations of the potential effects of the Pelton Round Butte Project on water temperatures in the Deschutes River at Pelton Gage (RM 100.1).

DATA TYPE/STATION	WATER YEAR (WY)
Water temperature data	
Deschutes R. near Culver (USGS #14076500)	WY 1955–1974
Deschutes R. at Pelton (USGS #14092500)	WY 1953–1956, 1972–1988
Crooked R. near Culver (USGS #14087500)	WY 1955–1963
Crooked R. below Opal Springs (USGS #14087400)	WY 1963–1974
Metolius R. near Grandview (USGS #15091500)	WY 1955–1974
Air temperature data	
Redmond, Oregon (Oregon Climate Center)	WY 1953–1988
Streamflow data	
Deschutes R. near Culver (USGS #14076500)	WY 1954–1974
Deschutes R. at Pelton (USGS #14092500)	WY 1953–1956, 1972–1988
Crooked R. near Culver (USGS #14087500)	WY 1954–1963
Crooked R. below Opal Springs (USGS #14087400)	WY 1963–1974
Metolius R. near Grandview (USGS #15091500)	WY 1954–1974

4.1.2.a. Selected Months. Daily data for each of the parameters identified in Section 4.1.2 were converted to mean weekly values, and grouped by month of the year. Mean weekly values were used because they accounted for temporal variation in river temperatures without having the strong edge effects associated with daily values (i.e., river temperatures one day might significantly reflect those of the previous day). We then selected the months of October, April, May, and August as representative of the range of pre- versus post-PRB changes in river temperatures evident in USGS data collected at Pelton Gage.

Mean weekly water temperature, streamflow, and air temperature data for the selected months were examined for differences between the pre- and post-PRB periods that might be explained by factors other than the presence of PRB. These examinations included graphical analyses and multiple regressions (with alpha values again set at 0.05) of historic stream temperatures versus streamflows and air temperatures. Statistically significant pre-PRB regressions for mean weekly data for all but one of the four months (October) allowed us to evaluate the degree to which observed post-PRB changes in river temperatures could be explained by variations in streamflow or weather:

April: $\text{Water Temperature}_{Pelton} = 10.3 + (0.29)(\text{Air Temperature}_{Redmond}) - (0.000305)(\text{Flow}_{into\ LBC})$, $n=16$, $r^2 = 0.73$

May: $\text{Water Temperature}_{Pelton} = 10.0 + (0.21)(\text{Air Temperature}_{Redmond})$, $n=16$, $r^2 = 0.81$

August: $\text{Water Temperature}_{Pelton} = 11.0 + (0.14)(\text{Air Temperature}_{Redmond})$, $n=16$, $r^2=0.75$

We also used historic USGS data on water temperatures and streamflows in the three rivers (Deschutes, Crooked, and Metolius) immediately above what is now Lake Billy Chinook (LBC; the uppermost PRB reservoir) to develop flow-weighted estimates of mean weekly temperatures for the water mass flowing into the area now occupied by LBC. For each selected month, graphical methods were then used to compare pre- versus post-PRB relationships (direction and magnitude of differences) between the temperature of the water mass entering the area now occupied by PRB and temperatures downstream at Pelton Gage.

4.1.2.b. <u>Annual Temperature Cycle</u>. For 90 weeks during the pre-PRB period, we were able to find complete sets of flow and temperature data for the three rivers flowing into LBC, for air temperatures at Redmond Airport, and for Deschutes River temperatures at Pelton Gage. The data covered multiple weeks within each month of the year. Stepwise, multiple regression of weekly Pelton Gage temperatures on weekly LBC inflow temperatures (flow-weighted) and air temperatures at Redmond Airport were highly significant ($p<0.001$) and yielded a pre-PRB relationship that was an excellent predictor of river temperatures immediately below PRB (Figure 2):

$$\text{Water Temperature}_{Pelton} = 2.8 + (0.79)(\text{Water Temperature}_{into\ LBC}) + (0.071)(\text{Air Temperature}_{Redmond}),\ n=90,\ r^2=0.98$$

Establishing this statistical relationship for the pre-PRB period allowed us to identify and model post-PRB patterns of temperature change in the lower Deschutes River that were attributable to PRB.

We applied the relationship to data from eight post-PRB years (1971–1974 and 1995–1998) to compare observed river temperatures at Pelton Gage versus those that would have been expected in the absence of PRB. *Such comparisons provide a reasonable yet imperfect estimate of PRB-related temperature effects at Pelton Gage because 2–6 mi. (upstream) shifts in post-PRB sampling locations on the three rivers tributary to LBC (because of inundation of historic sites) may cause the predictive equation to underestimate "natural" temperatures at Pelton Gage by as much as several tenths of a degree centigrade during some weeks in the spring or summer.*

4.1.3. Model-based Estimates of PRB Effects on Lower River Temperatures

4.1.3.a. <u>The SNTEMP Model</u>. SNTEMP is a steady-state temperature model that incorporates all of the significant sources of heat gain and loss in a moving stream (Theurer et al. 1984). Initially developed over a period of years by Dr. Fred Theurer of the U.S. Soil Conservation Service, it is available from the Ecological Services Center, USGS Biological Resources Division, Fort Collins, Colorado. The SNTEMP model has been widely applied to a variety of impact analyses, and most frequently to assessments of the effects of man-made reservoirs on downstream water temperatures. We selected the model for use in this study because it allowed detailed analyses of the downstream extent of potential changes in river temperatures caused by PRB and because it is familiar to the public agencies reviewing all of PGE's relicensing studies. Use of the model also allowed us to develop a mechanism for evaluating the downstream temperature effects of possible future changes in discharge timing or release temperatures below PRB.

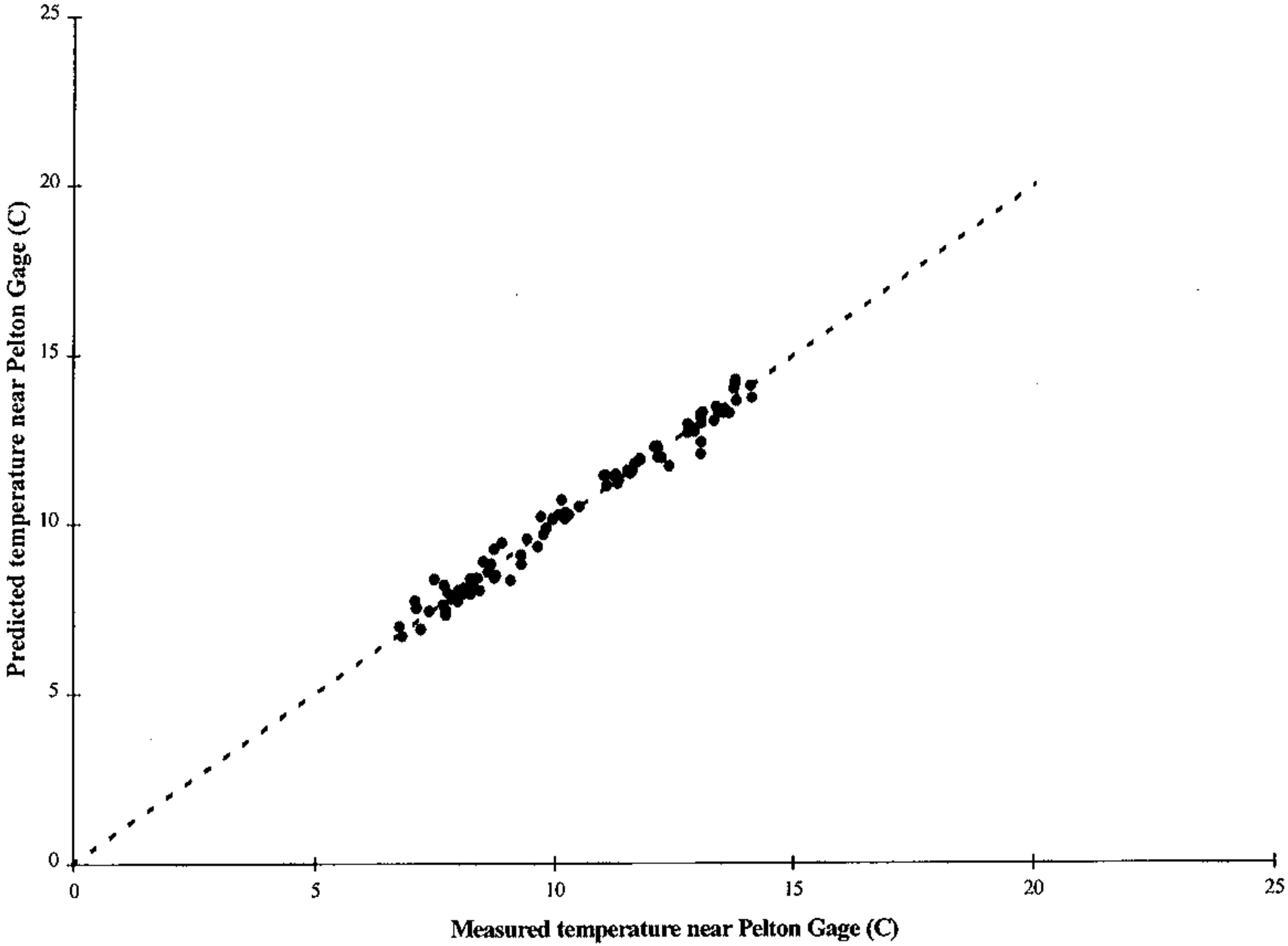


Figure 2. Measured water temperatures for the Deschutes River near Pelton Gage versus regression-based predictions based on the mean temperature of combined tributaries to LBC and the mean weekly temperature at Redmond Airport, 1954–1956.

4.1.3.b. Model Inputs. We applied the SNTEMP model to the Deschutes River for a 1-year period extending from late May 1997 through mid-May 1998. This was done by assembling data on spatial aspects of the drainage network, meteorology, flow, shade, and stream morphology into a group of interrelated files as follows:

- Study file: The study file defined the spatial aspects of the drainage network, headwater locations, important tributary junctions, and other sites of interest within the Deschutes system (Table 3).

- Meteorology file: This file contained information on average weekly values for air temperature, wind speed, relative humidity, and cloud cover (percent possible sun) for the 1-year modeling period. All of this information was obtained directly, or derived from, a weather station PGE established along the Deschutes River at Oak Springs (RM 47.6). SNTEMP utilized this information to help simulate conditions along the entire length of river between PRB's Reregulating Dam (RM 100.1) and the Columbia River (RM 0.0).

- Stream geometry file: Stream width, latitude, and elevation were entered for various points along the stream network. Widths for specific stream segments were either interpreted from 1:600-scale aerial photographs or obtained from USGS rating curve data. The widths were assumed to be constant over the range of flows modeled. Latitude and elevation information came from 7.5-minute topographic maps.

- Shade file: All of the factors influencing the amount of sunlight that might reach the stream were part of this file. Included were stream azimuth, topographic shade, and the height, density, and offset of riparian vegetation. Azimuth data were measured from 7.5-minute topographic maps, while data on riparian vegetation and topographic shade were measured in the field at a subsample of points along more than a third of the Deschutes River and expanded to remaining areas through interpretation of aerial photographs and topographic maps.

Table 3. Drainage network considered during SNTEMP simulations of water temperatures in the Deschutes River, Oregon. Flow data were entered for each headwater and junction. Temperature data were entered for headwaters and simulated for other locations within the network.

Location	Miles upstream from Columbia River	Description
Deschutes R. at Reregulating Dam	100.1	headwater for truncated model
Deschutes R. above. Shitike Cr.	96.8	above confluence
Shitike Cr. at USGS site near Warm Springs	97.1	headwater
Shitike Cr. above Deschutes R.	96.8	tributary
Deschutes R. below Shitike Cr.	96.8	junction
Deschutes R. at Mecca	95.4	
Deschutes R. at Dry Cr.	93.0	validation node
Deschutes R. at Trout Cr. Campground	89.0	PGE/OSU site
Deschutes R. above Warm Springs R.	84.8	above confluence
Warm Springs R. at USGS site near Kahneeta	89.2	headwater
Warm Springs R. above Deschutes R.	84.8	tributary
Deschutes R. below Warm Springs R.	84.8	junction
Deschutes R. at Kaskela	79.0	validation node
Deschutes R. at Whitehorse Rapids	76.0	
Deschutes R. at Eagle Cr.	64.5	
Deschutes R. at Nena	59.0	validation node
Deschutes R. at Bakeoven Cr.	51.1	
Deschutes R. above White R.	46.4	above confluence
White R. at USGS site below Tygh Valley	48.4	headwater
White R. above Deschutes R.	46.4	tributary
Deschutes R. below White R.	46.4	junction
Deschutes R. at Sandy Beach	45.0	validation node
Deschutes R. at Sherars Falls	43.9	
Deschutes R. at Jones Canyon	34.4	
Deschutes R. at Mack's Canyon	24.0	validation node
Deschutes R. at Harris Canyon	12.2	
Deschutes R. at Colorado Rapids	4.0	validation node
Deschutes R. at USGS site at Moody	1.4	
Deschutes R. at mouth	0.0	

■ Hydrology and water temperature file: Data on average weekly streamflows and water temperatures for headwaters and other key locations within the drainage network were obtained from the USGS and several of the sources of temperature information outlined earlier (Table 4). For the 1-year modeling period, USGS flow data were available for the Deschutes River at Pelton Gage and at Moody (RM 1.4), as well as for Shitike Creek and Warm Springs River. White River was the only major tributary for which concurrent flow data were lacking. White River flows were estimated on the basis of historical averages, adjusted for weekly exceedance values in the other tributaries.

Table 4. Water temperature and streamflow information used as input data for SNTEMP-based modeling of the lower Deschutes River, Oregon, late May 1997 through mid-May 1998.

Site	Water temperature information	Streamflow information
Deschutes R. above Lake Billy Chinook **	mean weekly temperatures obtained from PGE (Madras)	mean weekly flows obtained from USGS (Portland)
Metolius R. above Lake Billy Chinook **	mean weekly temperatures obtained from PGE (Madras)	mean weekly flows obtained from USGS (Portland)
Crooked R. above Lake Billy Chinook **	mean weekly temperatures obtained from PGE (Madras)	mean weekly flows obtained from USGS (Portland)
Deschutes R. at Pelton Gage (immediately below the Reregulating Dam)	mean weekly temperatures obtained from PGE (Madras)	mean weekly flows obtained from USGS (Portland)
Shitike Cr. at Warm Springs	substituted mean monthly temperatures for 1986–1992 from Fritsch (1995) because of a lack of 1997 and 1998 data	mean weekly flows obtained from USGS (Portland)
Warm Springs R. near Kahneeta	substituted mean monthly temperatures for 1988–1992 from Fritsch (1995) because of a lack of 1997 aand 1998 data	mean weekly flows obtained from USGS (Portland)
White R. below Tygh Valley	substituted mean monthly temperatures for 1983–1984 from ODFW et al. (1985) because of a lack of 1997 and 1998 data	substituted mean weekly flows estimated from historic USGS data for this location and correlations with flow exceedance data for Shitike Cr. and Warm Springs R.

** The data for these sites were used to predict temperatures that would have occurred in the Deschutes R. at Pelton Gage (immediately below PRB) in the absence of PRB.

The SNTEMP model requires that flows balance at all sites throughout the river system. During some weekly time periods between late May 1997 and mid-May 1998, USGS gaging records for the Deschutes River at Moody were less than the sum of gaged flows upstream. The differences were more than could be accounted for by water withdrawals or evaporation. In these instances, we reduced the estimated flows at Moody to balance the model. Adjustments at Moody averaged about 1% of total flow, with a maximum weekly adjustment of 11%.

For the period modeled, continuous water temperature data were collected at 21 sites along the mainstem Deschutes River below PRB and at sites immediately above PRB in each of the three rivers (Deschutes, Crooked, and Metolius) flowing into PRB. Water temperature data from seven sites on the lower mainstem Deschutes were used as inputs or to validate and calibrate our SNTEMP modeling. These mainstem sites included one at Pelton Gage (RM 100.1) as well as locations at Dry Creek (RM 93.0), Kaskela (RM 79.1), Nena (RM 59.0), Sandy Beach (RM 45.0), Mack's Canyon (RM 24.0), and Colorado Rapids (RM 4.0). Data on mean weekly water temperatures in selected lower river tributaries were to be collected by agency and tribal partners during our modeling effort, but were unavailable when we ran SNTEMP. Historic monthly data were used to estimate mean weekly temperatures for the tributaries.

4.1.3.c. Model Calibration. Once the input datafiles were assembled, we calibrated SNTEMP to conditions along the lower Deschutes River through an iterative process. Predicted temperatures were compared to measured values and small adjustments were made to the model to bring about better correspondence between SNTEMP output and actual river temperatures measured along the Deschutes.

After minor adjustments were made to the model, lower Deschutes River temperatures simulated by SNTEMP showed very close correspondence to the water temperatures measured at six validation sites (Table 5). Over the 52 weeks modeled, the average simulation error at individual validation sites ranged from approximately -0.1°C to +0.4°C, the mean error at all sites was less than +0.1°C, and the average of the absolute values of all errors was less than 0.3°C. Final modeling results were well within the general guidelines given in Bartholow (1997). SNTEMP consistently overpredicted Deschutes River temperatures at Kaskela (RM 79.1) and Nena (RM 59.0), and tended to underpredict them at Dry Creek (RM 93.0) and Colorado Rapids (RM 4.0). These difficulties were minor, but might be eliminated through further model refinements, the most significant of which would be inclusion of actual water temperature data for White River.

Table 5. Calibration statistics for SNTEMP modeling of water temperatures in the Deschutes River, Oregon, late May 1997 through mid-May 1998.

Validation site	Weeks simulated	Mean error in simulation (°C)	Mean absolute error in simulation (°C)
Dry Creek (RM 93.0)	52	- 0.1	0.2
Kaskela (RM 79.0)	52	0.4	0.4
Nena (RM 59.0)	52	0.3	0.3
Sandy Beach (RM 45.0)	52	< 0.1	0.1
Mack's Canyon (RM 24.0)	52	- 0.1	0.3
Colorado Rapids (RM 4.0)	52	- 0.2	0.3
All sites combined	**302**	**< 0.1**	**< 0.3**

4.1.3.d. Temperature Simulations. Once calibrated, we used SNTEMP to simulate two scenarios for the Deschutes River below PRB Reregulating Dam. One scenario, "simulated (with PRB)," used actual (measured) release temperatures for the Reregulating Dam site. The other scenario, "simulated (without PRB)," used the strong historical (i.e., pre-PRB) relationship between the temperature of the water mass flowing into PRB, air temperatures at Redmond Airport, and river temperatures immediately below the site of the Reregulating Dam as a basis for predicting what temperatures immediately below the damsite would have been during our modeling period without the presence of PRB (see Section 4.1.2.b). Differences in temperatures estimated for the lower Deschutes under the two scenarios reflect estimates of the downriver temperature effects of PRB.

4.2. EFFECTS ON COLDWATER BIOTA

The potential effects of post-PRB temperature changes on coldwater biota in the lower Deschutes River were evaluated by (1) assessing possible changes in the incubation period and emergence timing of fall chinook and summer steelhead embryos, and (2) evaluating the degree to which PRB influences peak 7-day mean maximum temperatures downriver. Multiple alternative analyses were available, but these two seemed of particular interest to agency, tribal, and public participants in the planning of this study. Peak 7-day mean maximum temperatures were of interest to PGE and others because they provide a basis for evaluating compliance with temperature standards the Oregon Department of Environmental Quality has established for coldwater biota (including salmonids).

4.2.1. Changes in the Emergence Timing of Anadromous Salmonids

Like all fish, anadromous salmonids are cold-blooded species whose rates of development and growth are strongly influenced by temperature. Incubating embryos of these species are particularly influenced by changes in water temperatures because they lack significant behavioral mechanisms that might allow them to mediate the influence of such changes upon their rates of development. This tends to make temperature-influenced changes in the emergence timing of anadromous salmonids reasonably simple to predict.

We evaluated temperature data collected in the Deschutes River at Pelton (RM 100.1) and Moody (RM 1.4) gages to see whether water temperature changes might have effected shifts in the timing of emergence for incubating fall chinook and summer steelhead embryos. Pre- versus post-PRB differences in dates of emergence for each species were evaluated for each of these gage sites. The statistical significance of differences in emergence timing between the pre- and post-PRB periods was determined using T-tests with alpha set at 0.05.

4.2.1. a. Timing of Fall Chinook Emergence. Assuming a reasonable date of spawning for fall chinook in the Deschutes River (01 November) and that chinook embryos must accumulate 1600 Temperature Units (TUs) before emergence (Piper et al. 1982), we estimated the date of emergence for this species at Pelton Gage and at Moody for each year in which adequate data on river temperatures were available for analysis. Years in which there were missing daily temperature values during the chinook incubation period were included, provided data were available for at least four days per week. Where needed, daily temperature values for missing dates were interpolated from values for dates bracketing the data gap.

4.2.1.b. Timing of Summer Steelhead Emergence. We estimated the date of steelhead emergence at Pelton and at Moody gages for each year in which adequate data on river temperatures were available for analysis. To do this, we assumed the date of spawning each year was the median value (10 April) that Zimmerman and Reeves (1996, 1997, 1998) found for Deschutes River steelhead and that Deschutes steelhead embryos must accumulate 900 TUs before emergence (B. Nyara, ODFW, pers comm.). Data gaps in historic temperature records were treated the same way in this analysis as they were in our evaluation of fall chinook emergence.

Because data available on the timing of steelhead spawning in the lower Deschutes River are more detailed than those for fall chinook, we thought it might be instructive to examine how changes in the river's thermal regime at Pelton Gage might affect steelhead embryos spawned at differing times during the known spawning period. Using the same form of analysis as that for the median date of spawning (10 April), we also evaluated pre- versus post-PRB differences in dates of emergence for the offspring of fish spawning on the 10^{th}- (19 March) and 90^{th}-percentile (30 April) dates of the steelhead spawning distribution found by Zimmerman and Reeves (1996, 1997, 1998).

4.2.2. Changes in Peak 7-Day Mean Maximum Temperatures

We calculated the peak 7-day mean maximum temperatures for each of 21 sites monitored in the lower Deschutes River during 1997. These temperatures were then compared to State water quality standards for coldwater biota. Output from our SNTEMP-based simulations (see Section 4.1.3.d) were used to evaluate how PRB had affected these temperatures.

5. RESULTS

5.1. CHANGES IN LOWER RIVER TEMPERATURES

5.1.1. Pre- Versus Post-PRB River Temperatures

5.1.1.a. **Seasonal Changes.** USGS data for the Deschutes at Pelton Gage (RM 100.1) suggest a shift in river temperatures following completion of PRB (Figure 3). Water temperatures recorded at Pelton Gage during ten post-PRB years were generally lower in the winter, spring, and early summer than those measured during four pre-PRB years. The differences in mean temperatures were greatest in April and May (more than 2.5°C cooler in each month). The reverse condition was observed during late summer and fall, when post-PRB temperatures tended to be somewhat higher than those observed at Pelton Gage during pre-PRB years. For instance, mean temperatures recorded during October were about 1.5°C warmer in post-PRB years than in pre-PRB years. Diurnal and interannual fluctuations in spring and summer water temperatures appear to have been smaller during the post-PRB years.

Mean weekly temperatures the USGS measured in the Deschutes River at Pelton Gage during the pre-PRB period were significantly different than those it measured there during the post-PRB period (Table 6). Differences in mean weekly temperatures between the two periods were highly significant ($p \leq 0.002$) for all months except December and August. Although suggestive of a causative relationship, these differences do not by themselves indicate that PRB has effected statistically significant shifts in river temperatures because changes in streamflow or weather patterns could have played a role in the observed shifts.

Deschutes River at Pelton (RM 100.1; USGS Gage #14092500)

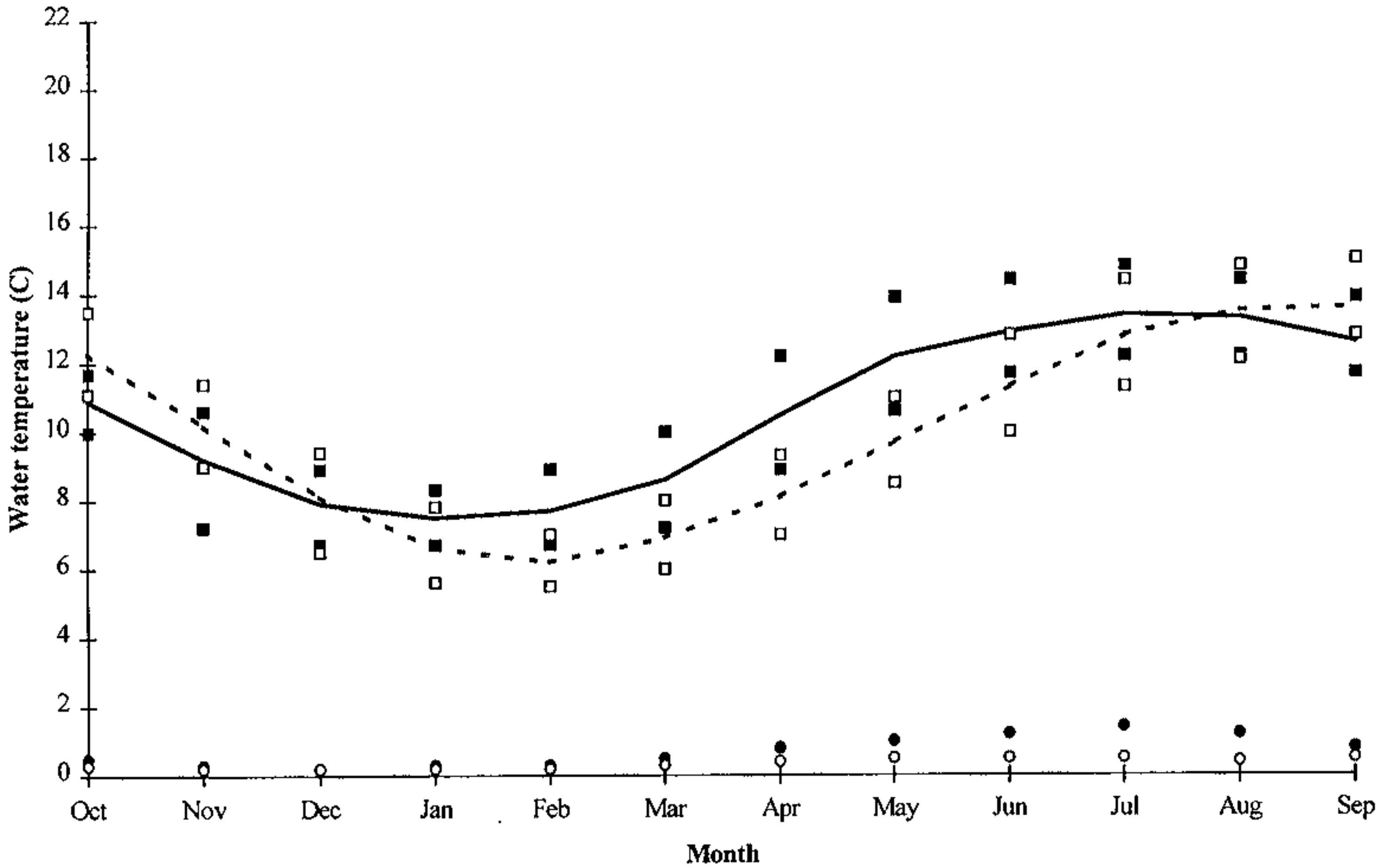


Figure 3. Deschutes River temperatures at Pelton Gage before (WY 1953–1956; solid lines/symbols) and after (WY 1972–1981; dashed lines/open symbols) construction of PRB. Given are monthly means (lines), 90th percentile extremes (squares), and mean daily fluctuations (circles).

Table 6. Comparisons of mean weekly temperatures, by month, for the Deschutes River at Pelton Gage (USGS Gage #14092500) before (WY 1953–1956) and after (WY 1972–1988) PRB. Tests of significance were by T-test unless otherwise noted, with alpha set at 0.05. Between-period differences in water temperatures reflect the combined effects of PRB, runoff patterns, and variable weather conditions.

Month	Period	Number of weeks	Mean	S.E.	p	95% C.I. of difference between means
October	before	16	10.9°C	0.11	< 0.001	1.2 to 1.9°C
	after	54	12.5°C	0.10		
November	before	17	9.2°C	0.25	< 0.001	0.6 to 1.5°C
	after	59	10.3°C	0.10		
December	before	17	8.0°C	0.16	N.S.	—
	after	61	8.1°C	0.11		
January	before	17	7.5°C	0.14	< 0.001	-0.5 to -1.3
	after	63	6.6°C	0.09		
February	before	17	7.7°C	0.17	< 0.001	-1.2 to -1.8
	after	60	6.2°C	0.07		
March	before	17	8.6°C	0.15	< 0.001	-1.4 to -2.1
	after	68	6.9°C	0.08		
April	before	16	10.6°C	0.24	< 0.001	-2.1 to -2.9
	after	68	8.0°C	0.09		
May	before	16	12.2°C	0.17	< 0.001	-2.1 to -3.0
	after	68	9.6°C	0.10		
June	before	17	12.9°C	0.11	–a–	—
	after	69	11.3°C	0.13		
July	before	17	13.4°C	0.10	–b–	—
	after	62	12.7°C	0.14		
August	before	16	13.4°C	0.09	N.S.	—
	after	58	13.5°C	0.11		
September	before	17	12.7°C	0.13	–c–	—
	after	52	13.6°C	0.09		

–a– non-normal distributions with heterogeneous variances prevented the use of parametric statistics; median temperatures before (13.0°C) and after (11.2°C) the dams were significantly different ($p<0.001$; rank sum test).

–b– non-normal distributions with heterogeneous variances prevented the use of parametric statistics; median temperatures before (13.4°C) and after (12.6°C) the dams were significantly different ($p=0.002$; rank sum test).

–c– non-normal distributions prevented the use of parametric statistics; median temperatures before (12.7°C) and after (13.6°C) the dams were significantly different ($p<0.001$; rank sum test).

USGS data for the Deschutes River at Moody (RM 1.4) show seasonal shifts in water temperatures that were similar to, but much smaller than, those observed between the pre- and post-PRB periods at Pelton Gage (Figure 4). The greatest differences between the two periods were water temperature increases of more than 1.0°C in October and decreases of about 1.0°C in July. As with the changes seen at Pelton Gage, these differences may reflect between-period differences in runoff patterns and weather as well as the influence of PRB.

5.1.1.b. Annual Temperature Extremes. Available data indicate that there have been post-PRB changes in the timing of annual temperature extremes in the lower Deschutes River (Figure 5) but show little change in the magnitude of these extremes (Figure 6). Annual maxima for daily temperatures have occurred significantly ($p<0.05$) later in the year at Pelton Gage (mean = 53 d) and at Moody (mean = 30 d) since completion of PRB. Between-period differences in the magnitude of these annual maxima have been statistically insignificant ($P<0.05$), averaging 0.3°C lower post-PRB at Pelton Gage (14.1°C versus 14.4°C) and an identical 20.0°C for the pre- and post-PRB periods at Moody. Annual temperature minima have not been significantly different ($p>0.05$) post-PRB at either Pelton Gage (5.9°C versus 6.6°C pre-PRB) or Moody (3.4°C versus 2.7°C pre-PRB), although temperatures close to the annual minimum now appear to occur for a longer period each year at Pelton Gage than they did during the pre-PRB period.

5.1.2. Changes in Temperature Patterns and Relationships

5.1.2.a. Selected Months. Patterns and relationships evident in historic data for the months of October, April, May, and August suggest that pre- versus post-PRB differences in Deschutes River temperatures at Pelton Gage are strongly related to PRB. Results of our examinations of patterns in historical data for each of these months are summarized below.

- **October.** Analyses of pre- and post-PRB datasets suggest that the greatest post-PRB increases (about 1.5°C) in mean river temperatures at Pelton Gage occurred during October (see Section 5.1.1.a). These changes do not appear to have been related to variations in streamflow or air temperatures. Mean weekly river temperatures at Pelton Gage were consistently higher during the post-PRB period when weeks of similar local air temperatures

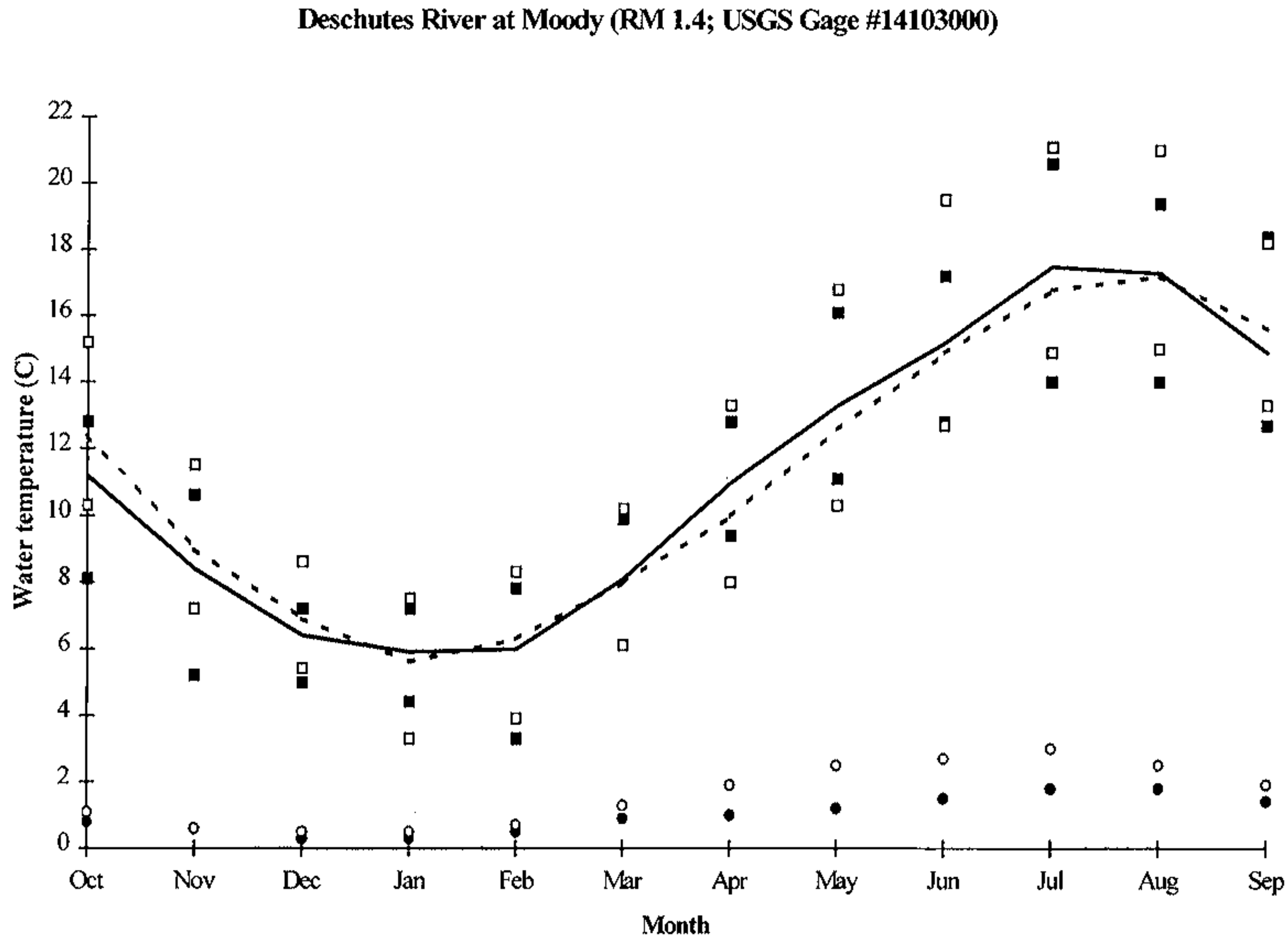


Figure 4. Deschutes River temperatures at Moody before (WY 1954–1956; solid lines/symbols) and after (WY 1972–1981; dashed lines/open symbols) construction of PRB. Given are monthly means (lines), 90th percentile (squares), and mean daily fluctuations (circles).

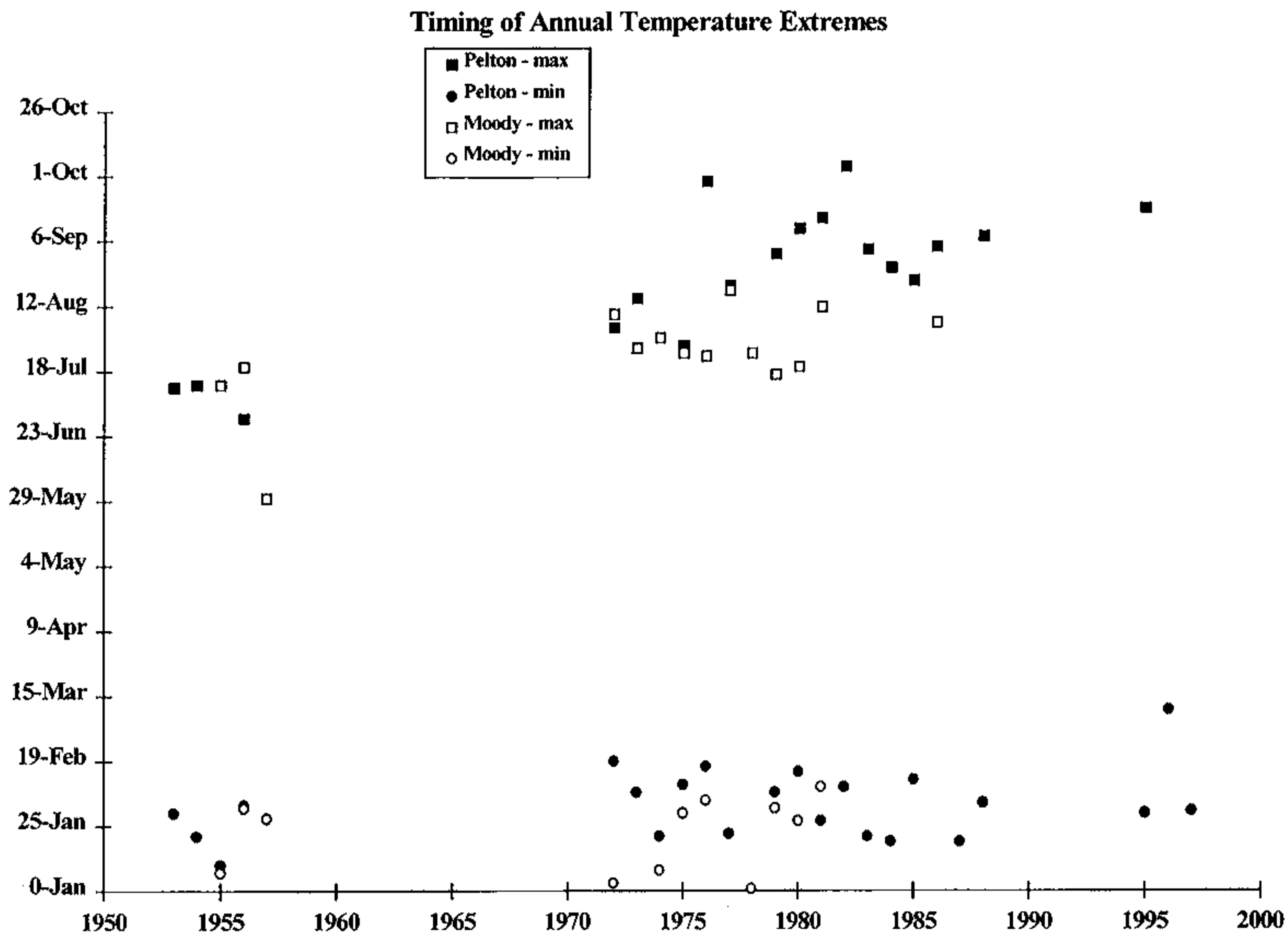


Figure 5. Timing of annual temperature extremes in the lower Deschutes River near Pelton Gage and at Moody, 1953–1998.

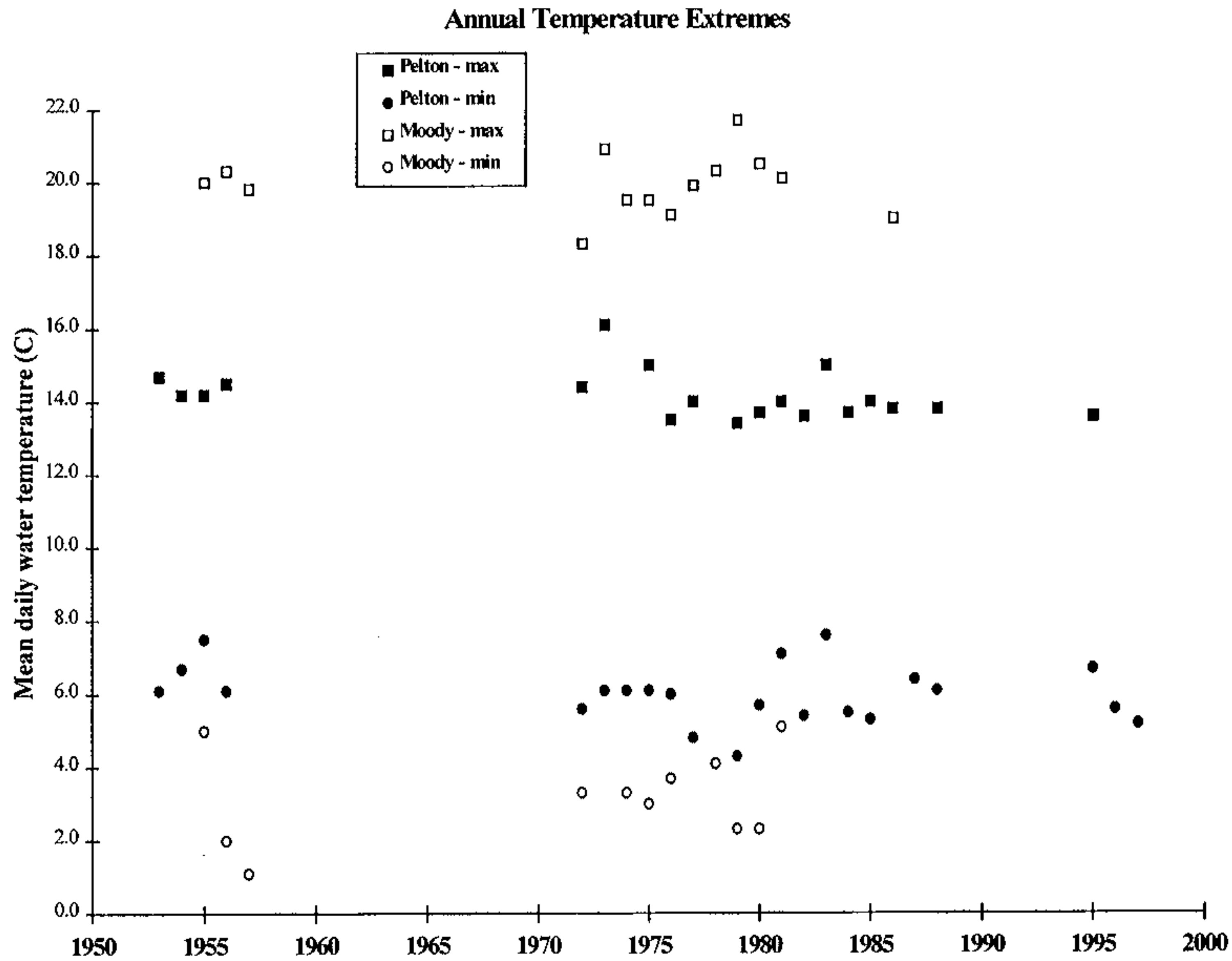


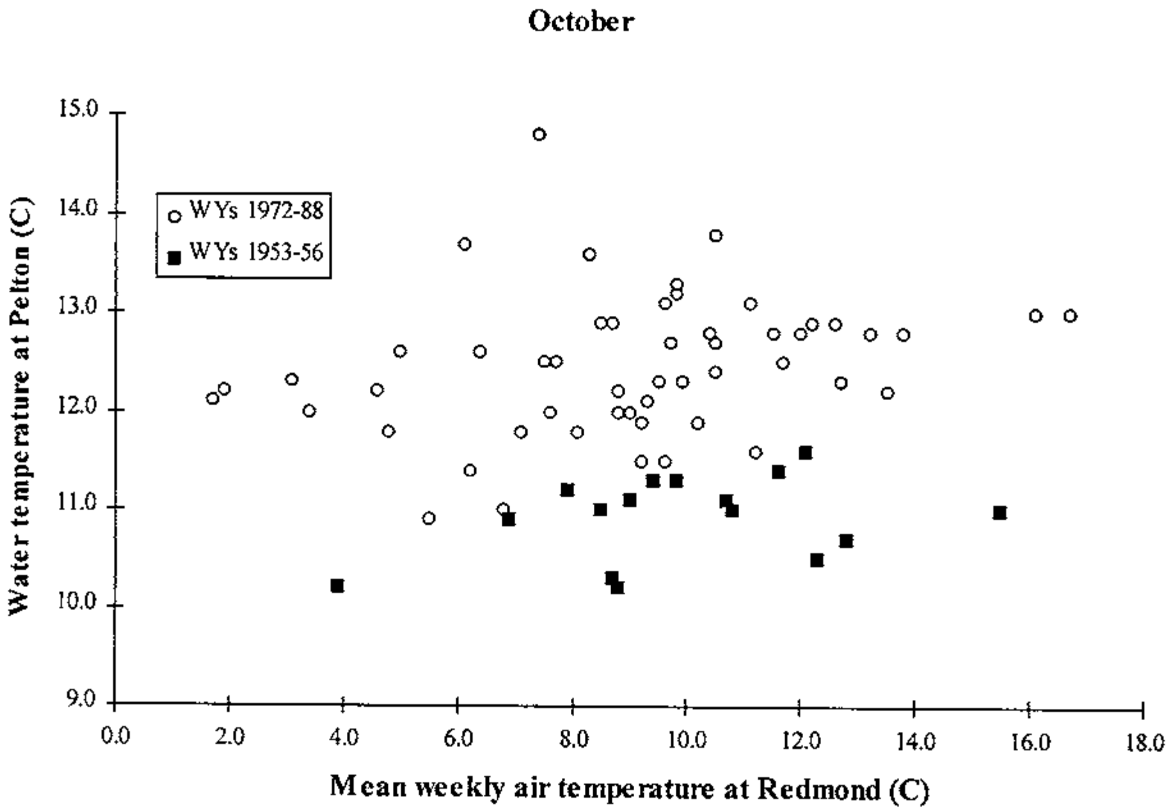
Figure 6. Annual temperature extremes in the lower Deschutes River near Pelton Gage and near Moody, 1953–1998.

or streamflows were considered (Figure 7). Water discharged at Pelton Gage was consistently warmer (during a limited post-PRB period) than might have been expected without PRB, based on the degree to which water warmed in the natural river channel (during a limited pre-PRB period) prior to inundation by PRB (Figure 8).

- **<u>April and May</u>.** Our full, period-of-record analyses of USGS data collected at Pelton Gage during the months of April and May suggest substantial shifts (of more than 2.5°C) toward colder temperatures between the pre- and post-PRB periods (see Section 5.1.1.a). Mean weekly river temperatures at Pelton Gage during these months were consistently lower during the post-PRB period, particularly when comparing weeks of similar local air temperatures or streamflows (Figures 9 and 10).

  Water temperatures leaving PRB (i.e., those at Pelton Gage) during April and May are no longer related to upstream temperatures in the same way they were prior to PRB. For the relatively short period of time for which concurrent pre-PRB data are available, water temperatures at Pelton Gage during April were consistently warmer than those above the site of LBC (see Figure 8). The reverse relationship is evident in post-PRB data for April, with water temperatures at Pelton Gage consistently cooler than those of the water mass entering LBC. Available temperature data for May show a pattern similar to that for April, with the inflowing water mass warming between the site of the upper end of LBC and Pelton Gage during the pre-PRB period, but being cooler at the lower of those two locations during the post-PRB period.

  Post-PRB variations from the predictive equations for mean weekly river temperatures at Pelton Gage were very strongly skewed toward lower water temperatures. Mean post-PRB deviations from predicted values were -2.7°C ($n = 68$; S.E.= 0.14) for April and -2.6°C ($n = 68$; S.E.= 0.09) for May. This clearly suggests that PRB's average effects on springtime water temperatures at Pelton Gage were of a magnitude similar to the observed differences between mean temperature conditions at that site during the pre- versus post-PRB periods.



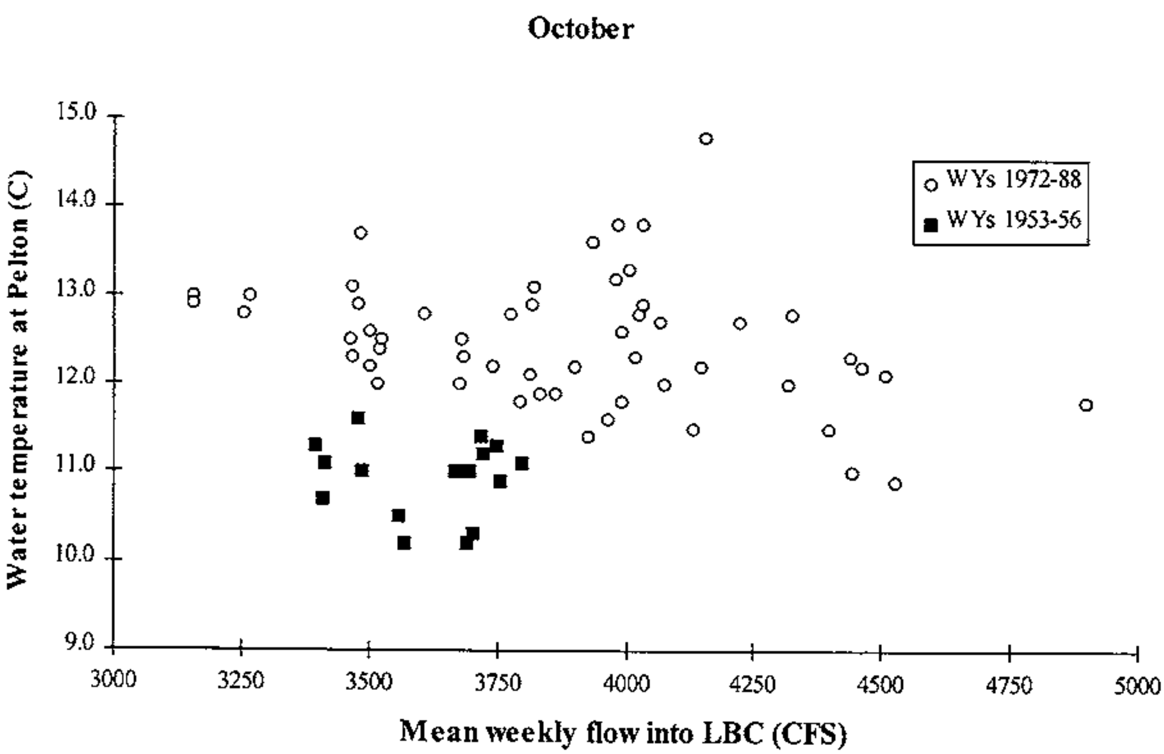


Figure 7. Mean weekly water temperatures at Pelton Gage versus mean weekly air temperatures at Redmond (upper) and mean weekly flows (CFS = cubic feet per second) into Lake Billy Chinook (LBC; lower), October, WYs 1953–1956 and WYs 1972–1988.

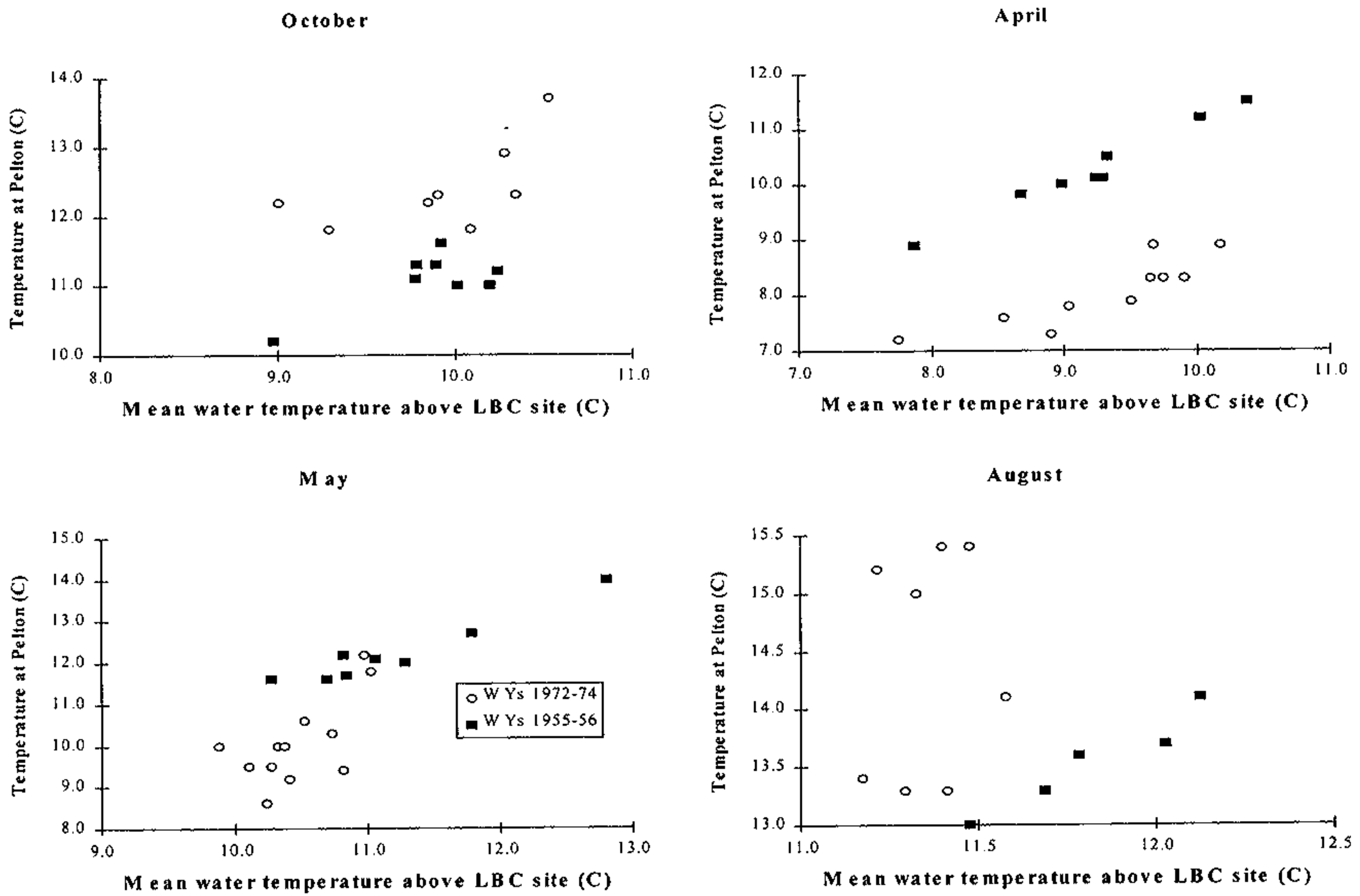
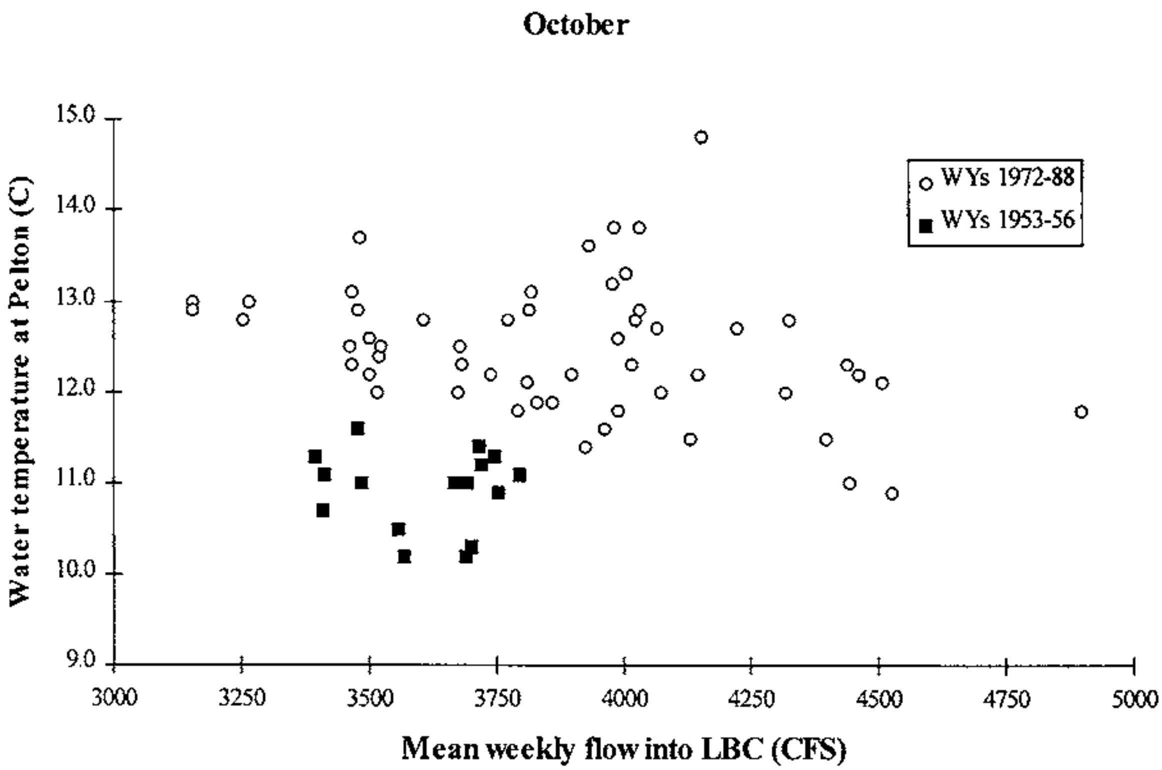


Figure 8. Mean weekly water temperatures in the Deschutes River at Pelton Gage versus mean weekly water temperatures above the site of Lake Billy Chinook (LBC), selected months, WYs 1955–1956 and WYs 1972–1974.



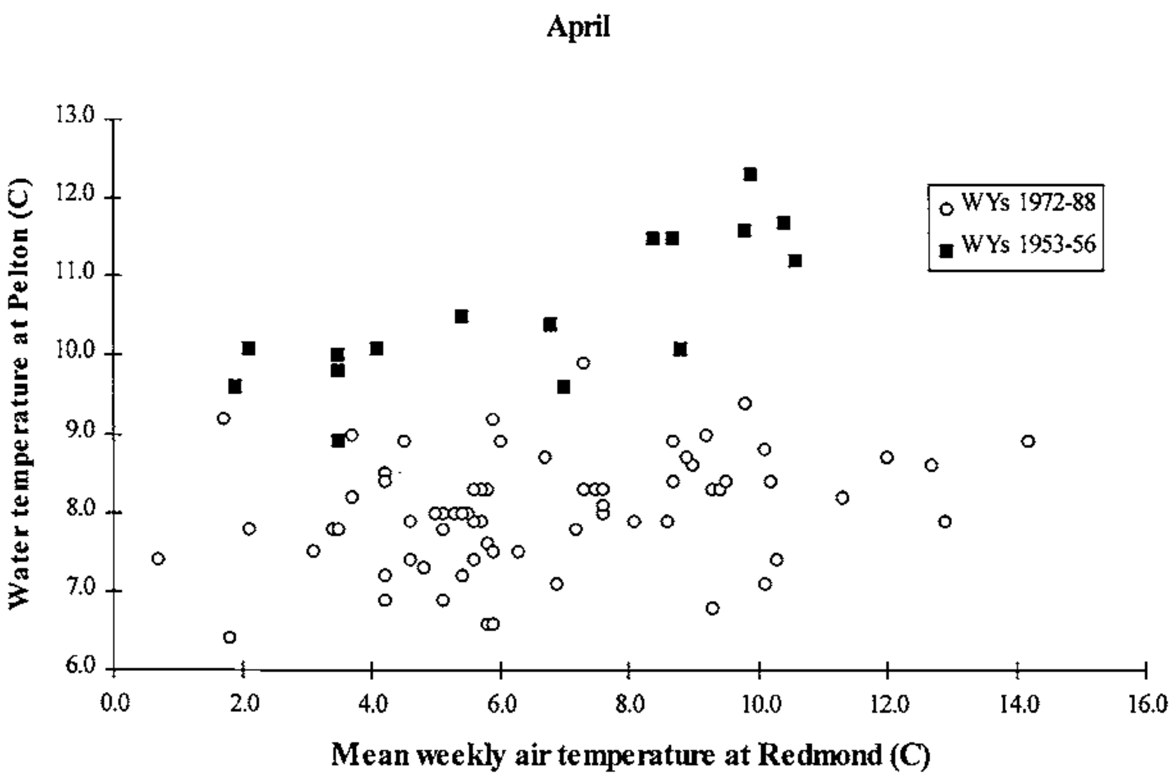
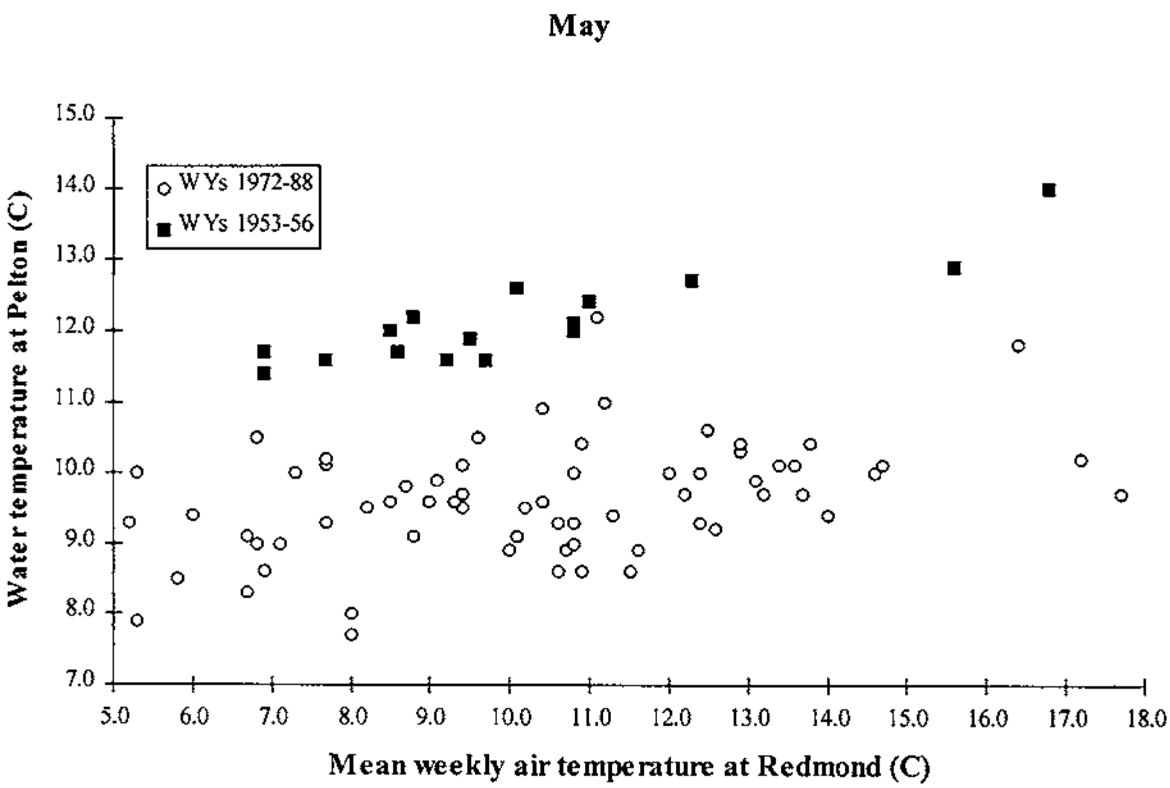


Figure 9. Mean weekly water temperatures at Pelton Gage versus mean weekly air temperatures at Redmond (upper) and mean weekly flows (CFS = cubic feet per second) into Lake Billy Chinook (LBC; lower), April, WYs 1953–1956 and WYs 1972–1988.



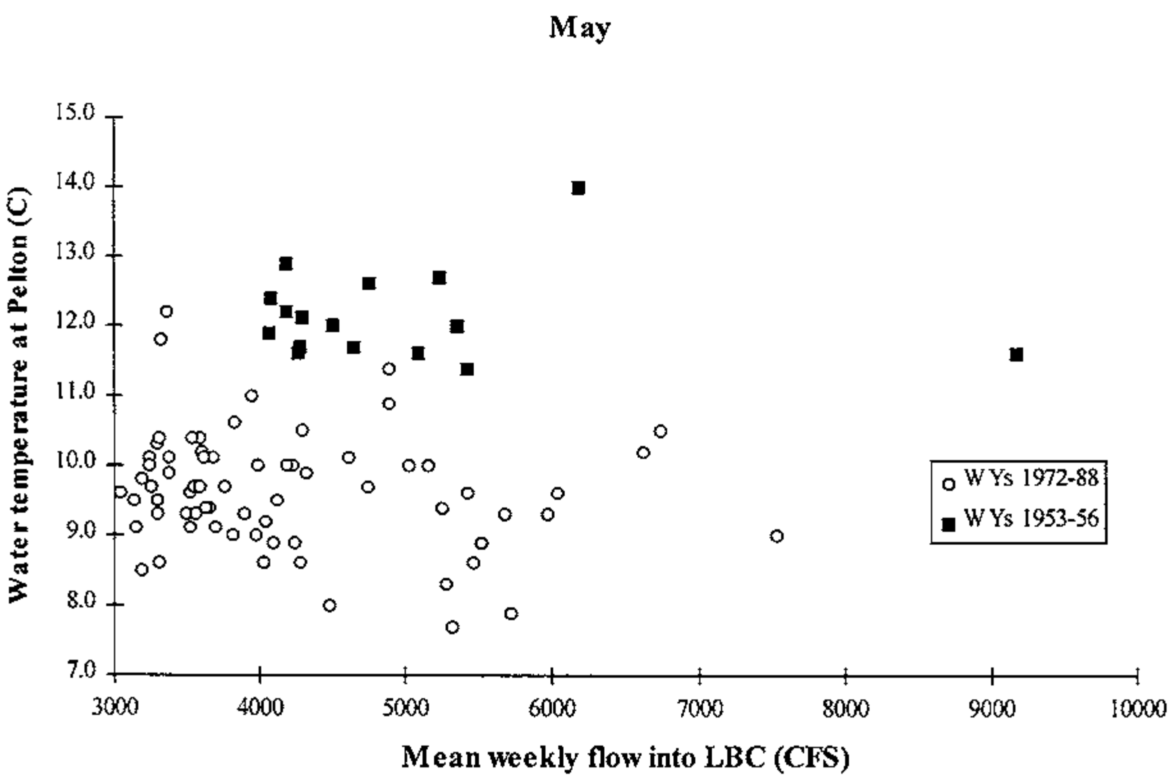


Figure 10. Mean weekly water temperatures at Pelton Gage versus mean weekly air temperatures at Redmond (upper) and mean weekly flows (CFS = cubic feet per second) into Lake Billy Chinook (LBC; lower), May, WYs 1953–1956 and WYs 1972–1988.

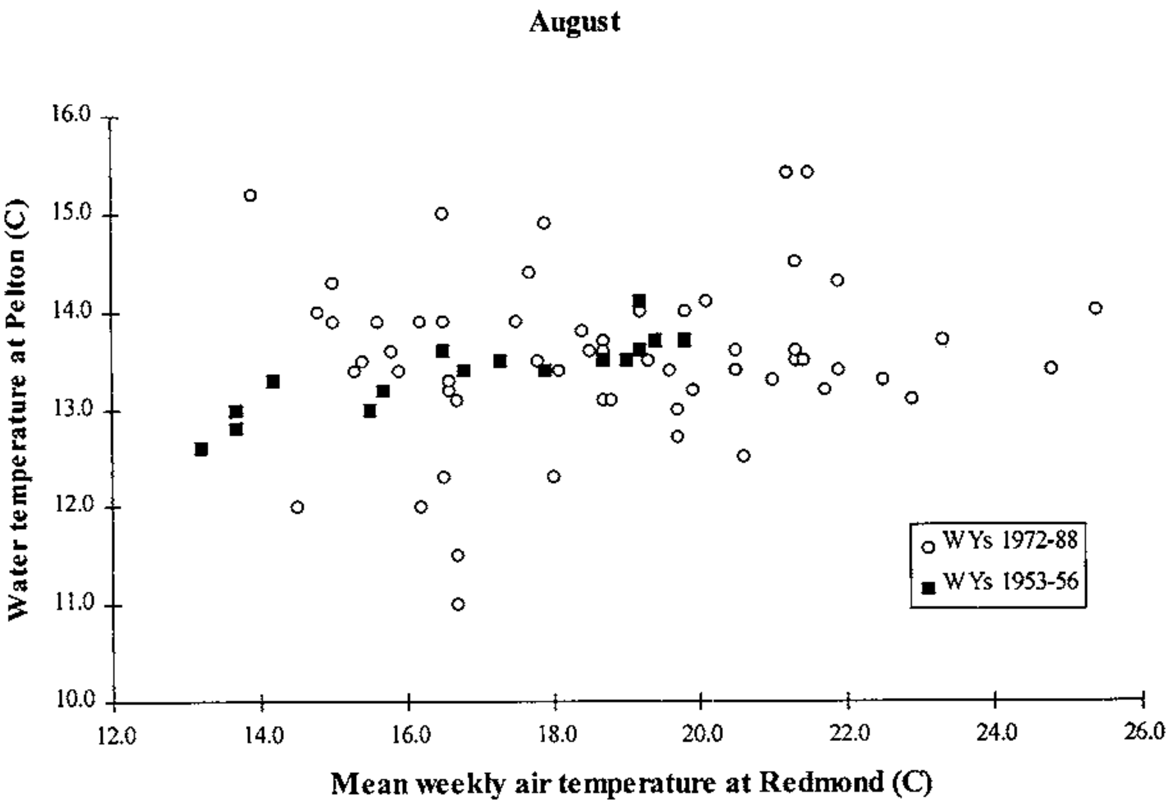
- **August**. River temperatures at Pelton Gage frequently reach some of their highest levels in August, a month during which there have been no more than small differences in mean weekly water temperatures between the pre- and post-PRB periods. Graphical analyses of the interaction of mean weekly water temperatures at Pelton Gage, Redmond air temperatures, and flows into LBC show little pre- versus post-PRB changes in general relationships among these factors (Figure 11).

  Post-PRB variations from the predictive equation for mean weekly river temperatures at Pelton Gage during August were relatively insignificant. The mean post-PRB deviation from predicted values was -0.1°C. This suggests that PRB's average effect on August water temperatures, like those for April and May, were similar to the mean difference between the pre- versus post-PRB periods.

5.1.2.b. Annual temperature cycles. Analyses based on the strongest predictive equation we were able to develop (see METHODS, Section 4.1.2.b) indicate that in the eight post-PRB years for which suitable data were available for evaluation, the effects of PRB followed patterns consistent with observed pre- versus post-PRB shifts in river temperatures recorded at Pelton Gage (Figures 12 and 13). PRB lowered river temperatures immediately downstream (i.e., at Pelton Gage) during the winter, spring, and early summer, then raised them during the late summer and fall. The increase in late summer and fall temperatures in the river at Pelton Gage appears to have been particularly pronounced in 1974, for reasons which have yet to be determined.

5.1.3. Model-based Estimates of PRB Effects on Lower River Temperatures

We used SNTEMP and the pre-PRB predictive equation for Deschutes River temperatures at Pelton Gage (see METHODS, Section 4.1.3.d.) to estimate PRB effects on water temperatures downstream. For the period from late May 1997 through mid-May 1998, it appears PRB decreased river temperatures (relative to an undammed condition) from late May to early August (statistical weeks 21 to 32 or 33), then increased them until about mid-December (week 50), at which time river temperature was decreased by PRB until the annual cycle was completed in mid-May (week 20). The magnitude of these estimated PRB effects on weekly mean temperatures in the lower Deschutes



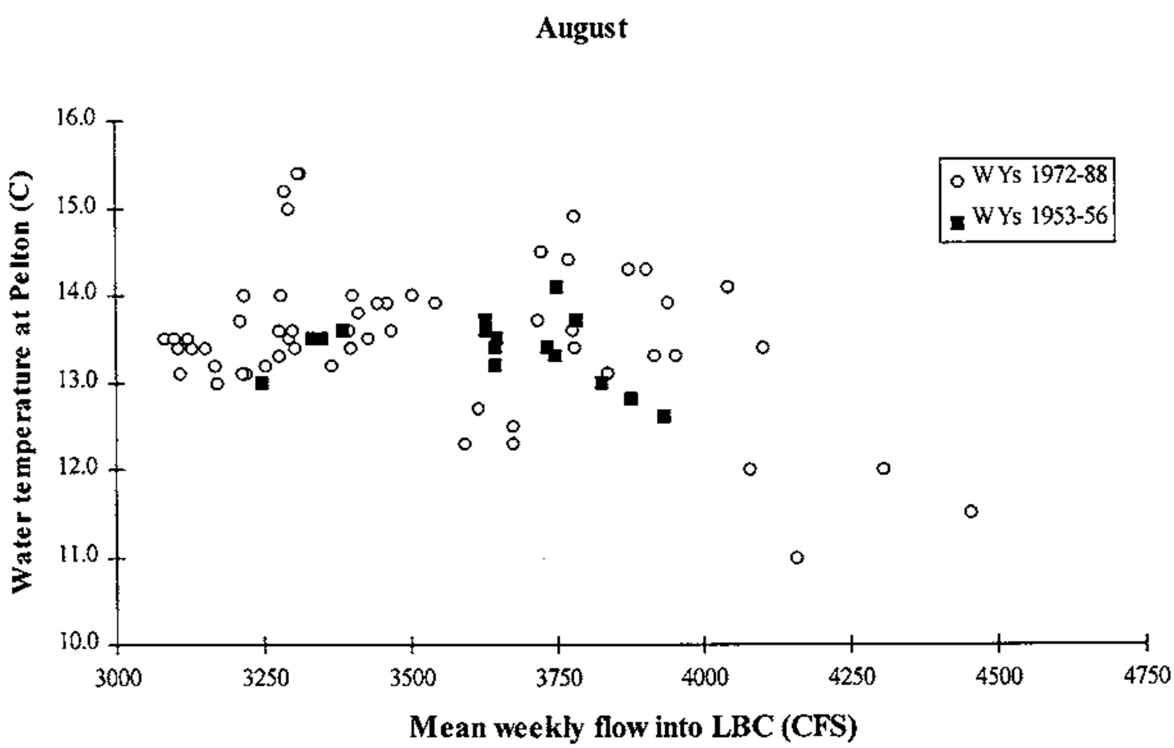


Figure 11. Mean weekly water temperatures at Pelton Gage versus mean weekly air temperatures at Redmond (upper) and mean weekly flows (CFS = cubic feet per second) into Lake Billy Chinook (LBC; lower), August, WYs 1953–1956 and WYs 1972–1988.

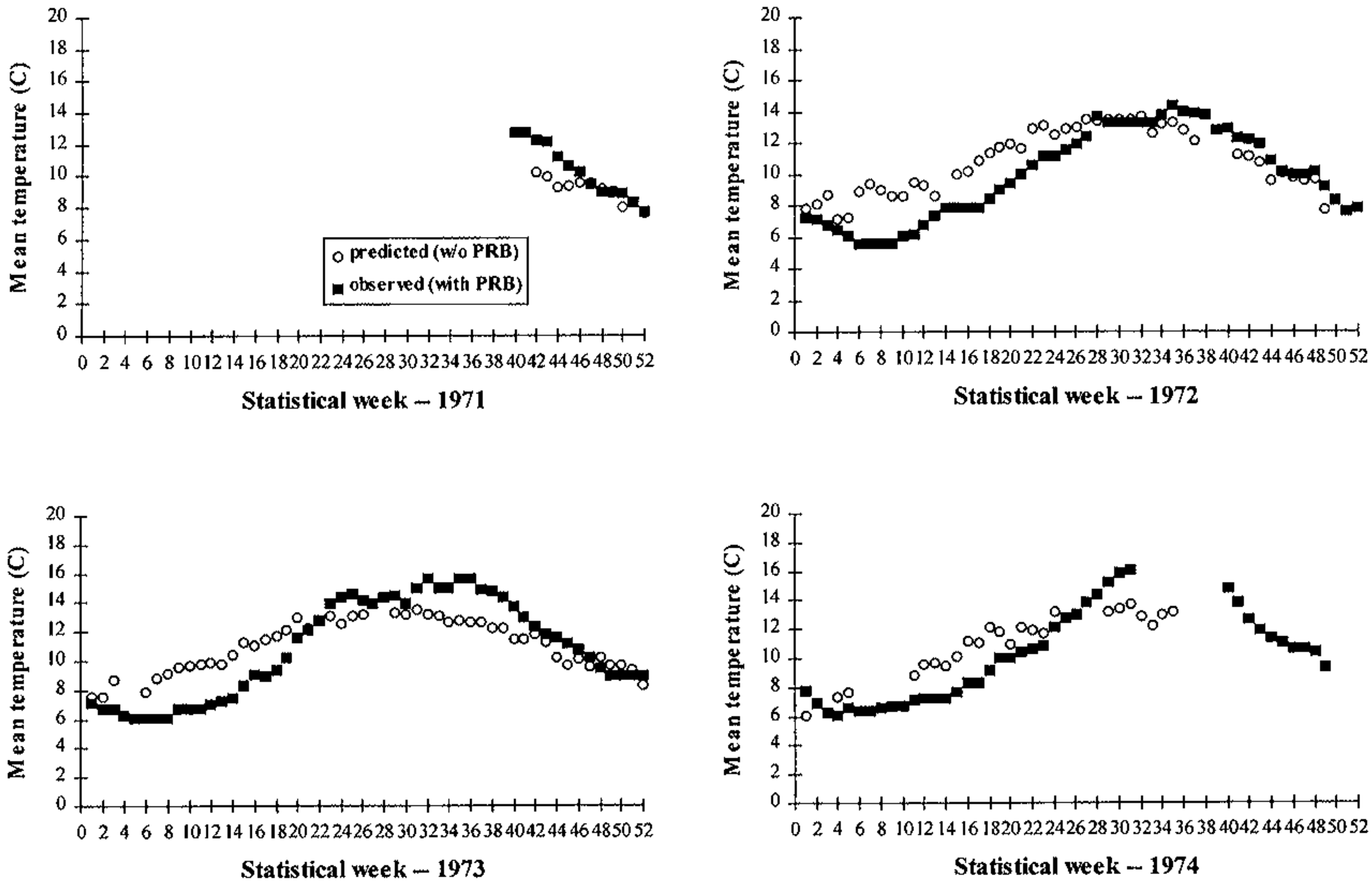


Figure 12. Predicted (without PRB) and observed (with PRB) mean water temperatures for the Deschutes River immediately below the Reregulating Dam, by statistical week, 1971–1974. Note: statistical weeks 1, 14, 27, and 40 begin on 01 January, 02 April, 02 July, and 01 October, respectively.

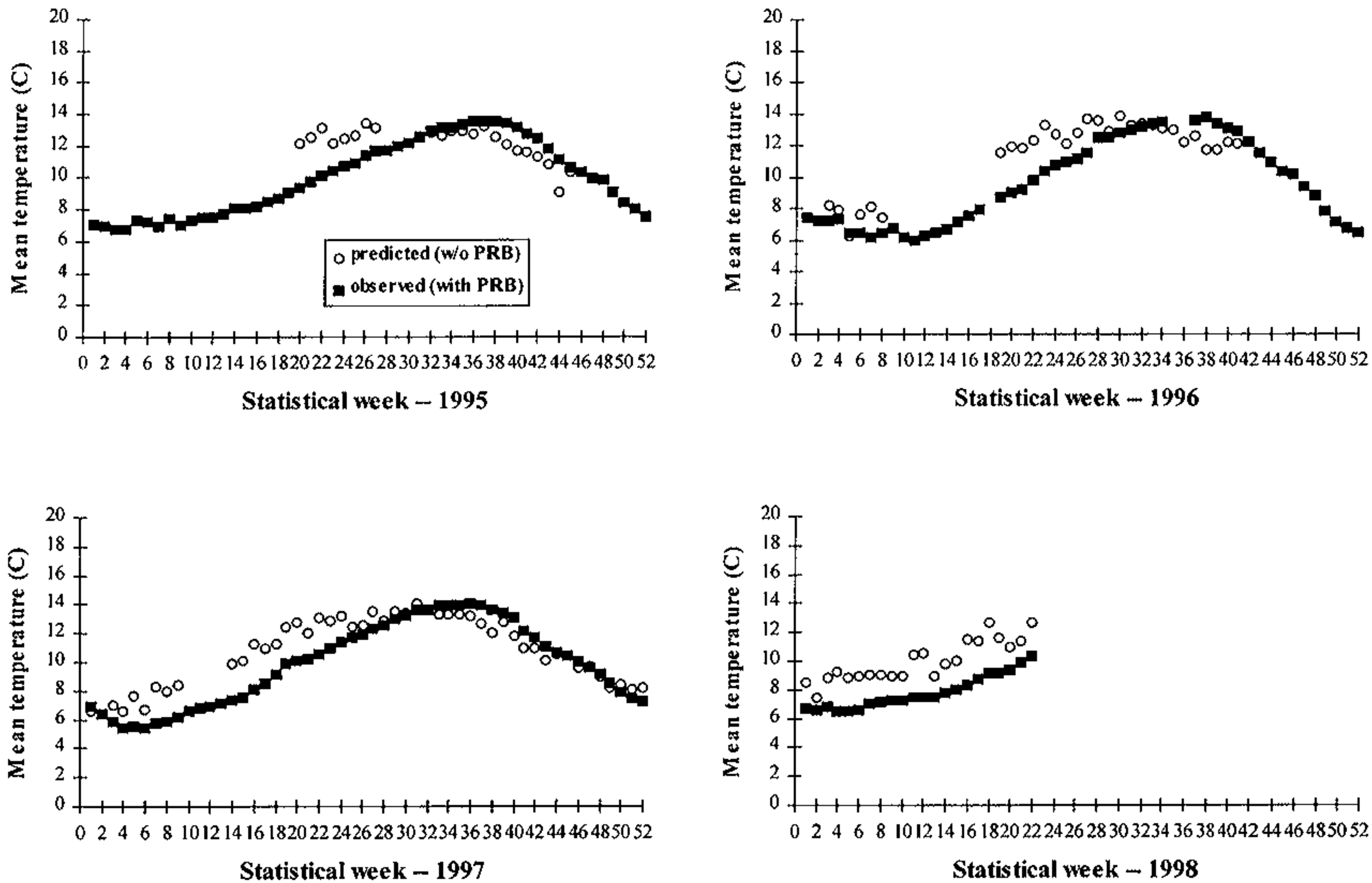


Figure 13. Predicted (without PRB) and observed (with PRB) mean water temperatures for the Deschutes River immediately below the Reregulating Dam, by statistical week, 1995–1998. Note: statistical weeks 1, 14, 27, and 40 begin on 01 January, 02 April, 02 July, and 01 October, respectively.

River decreased with increasing distance below PRB. This pattern of PRB influence is nearly identical to pre- versus post-PRB differences in river temperatures evident in historic data.

Modeling results for four specific sites along the lower Deschutes River are summarized below. Additional results of our SNTEMP-based simulations are given in appendices A through D.

5.1.3.a. Deschutes River at Pelton Gage (RM 100.1). Our simulations suggest that at Pelton Gage, PRB elevated weekly mean temperatures by an average of approximately 0.7°C (range: +0.2 to +1.5°C) from early August to mid-December and reduced them by an average of about 1.7°C (range: -0.2 to -3.5°C) during the remainder of the 1-year cycle examined (Figure 14). With PRB in place, the maximum weekly mean temperature of 13.9°C occurred during week 36 and the minimum of 6.5°C occurred in week 4. The simulations suggest that without PRB, a maximum weekly temperature of 14.0°C would have occurred in week 31 and a minimum weekly temperature of 7.4°C would have occurred during week 2.

5.1.3.b. Deschutes River at Nena (RM 59.0). Our SNTEMP-based modeling suggests that PRB elevated mean weekly temperatures in the Deschutes River at Nena by an average of about 0.6°C (range: -0.1 to +1.3°C) from early August to mid-December and reduced them by an average of approximately 1.3°C (range: -0.3 to -2.4°C) during the rest of the 1-year cycle (Figure 15). Under our "with PRB" scenario, SNTEMP estimated a maximum weekly mean temperature of 16.7°C in week 33 and a minimum of 5.5°C during week 2. The "without PRB" simulations for this site indicate a maximum weekly mean temperature of 16.9°C during week 31 and a minimum weekly mean temperature of 6.2°C in week 2.

5.1.3.c. Deschutes River at Mack's Canyon (RM 24.0). Simulations of river temperatures at Mack's Canyon suggest that the effect of PRB during our 1-year modeling period was to increase mean weekly water temperatures by an average of approximately 0.5°C (range -0.12 to +1.8°C) between early August and mid-December, and to reduce them by an average of about 1.0°C (range: -0.1 to -1.8°C) during the other weeks (Figure 16). Mean weekly temperatures SNTEMP predicted

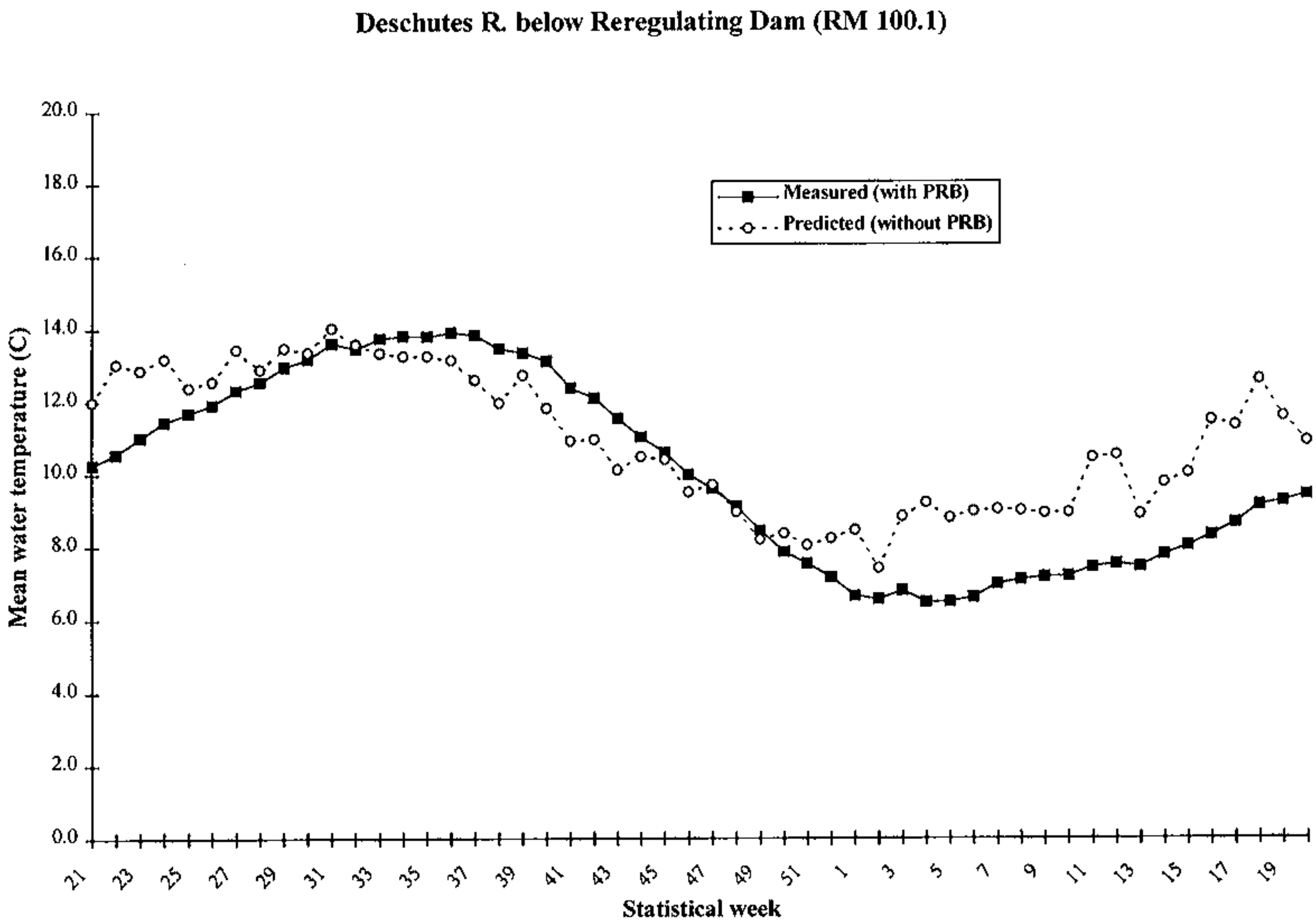


Figure 14. Predicted (without PRB) and measured (with PRB) mean water temperatures for the Deschutes River immediately below the Reregulating Dam (RM 100.01) for statistical week 21 in 1997 through statistical week 20 in 1998. Note: statistical weeks 27, 40, 1, and 14 begin on 02 July, 01 October, 01 January, and 02 April, respectively.

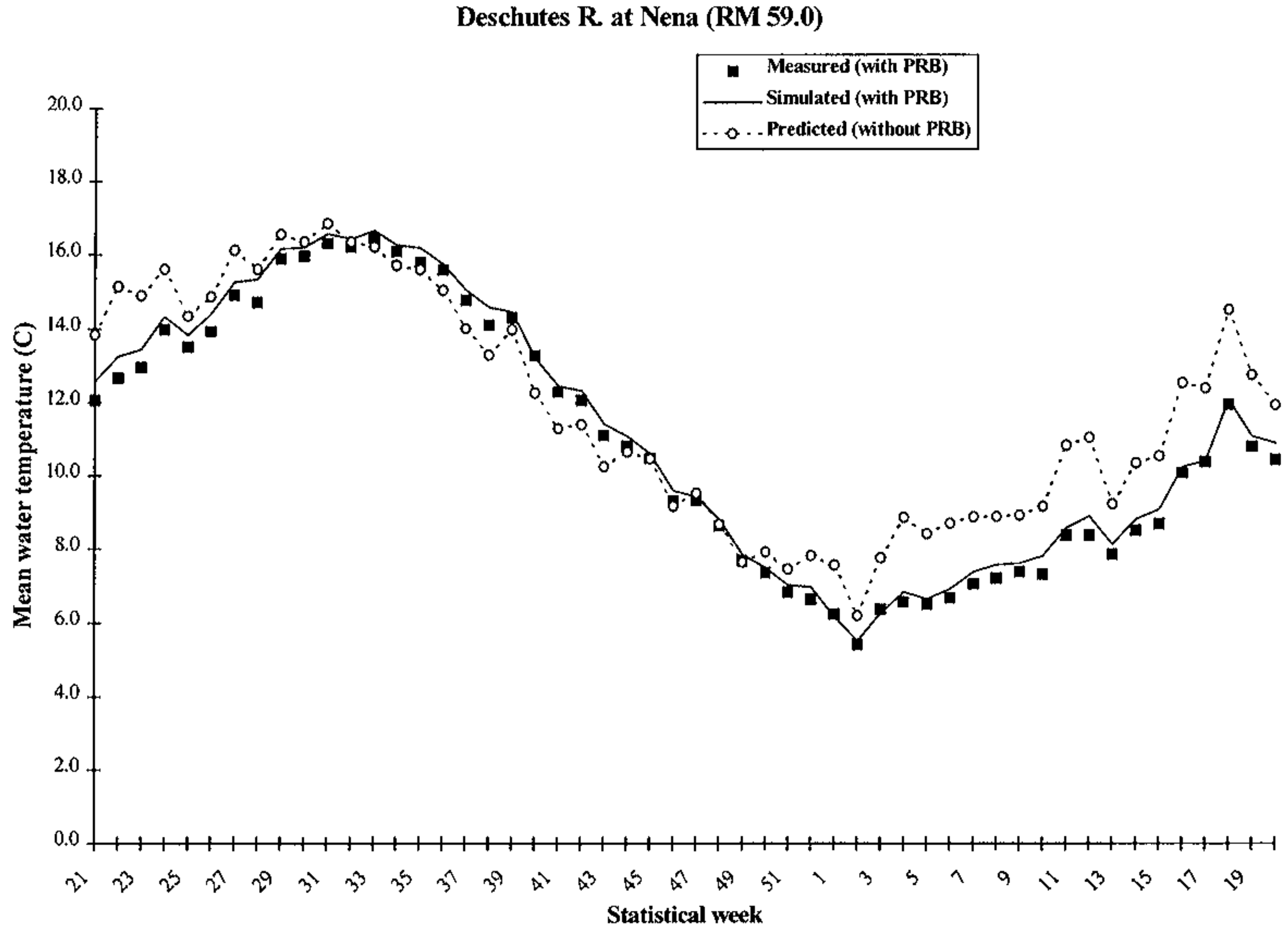


Figure 15. Measured and SNTEMP-simulated mean water temperatures for the Deschutes River at Nena (RM 59.0), for statistical week 21 in 1997 through statistical week 20 in 1998. Note: statistical weeks 27, 40, 1, and 14 begin on 02 July, 01 October, 01 January, and 02 April, respectively.

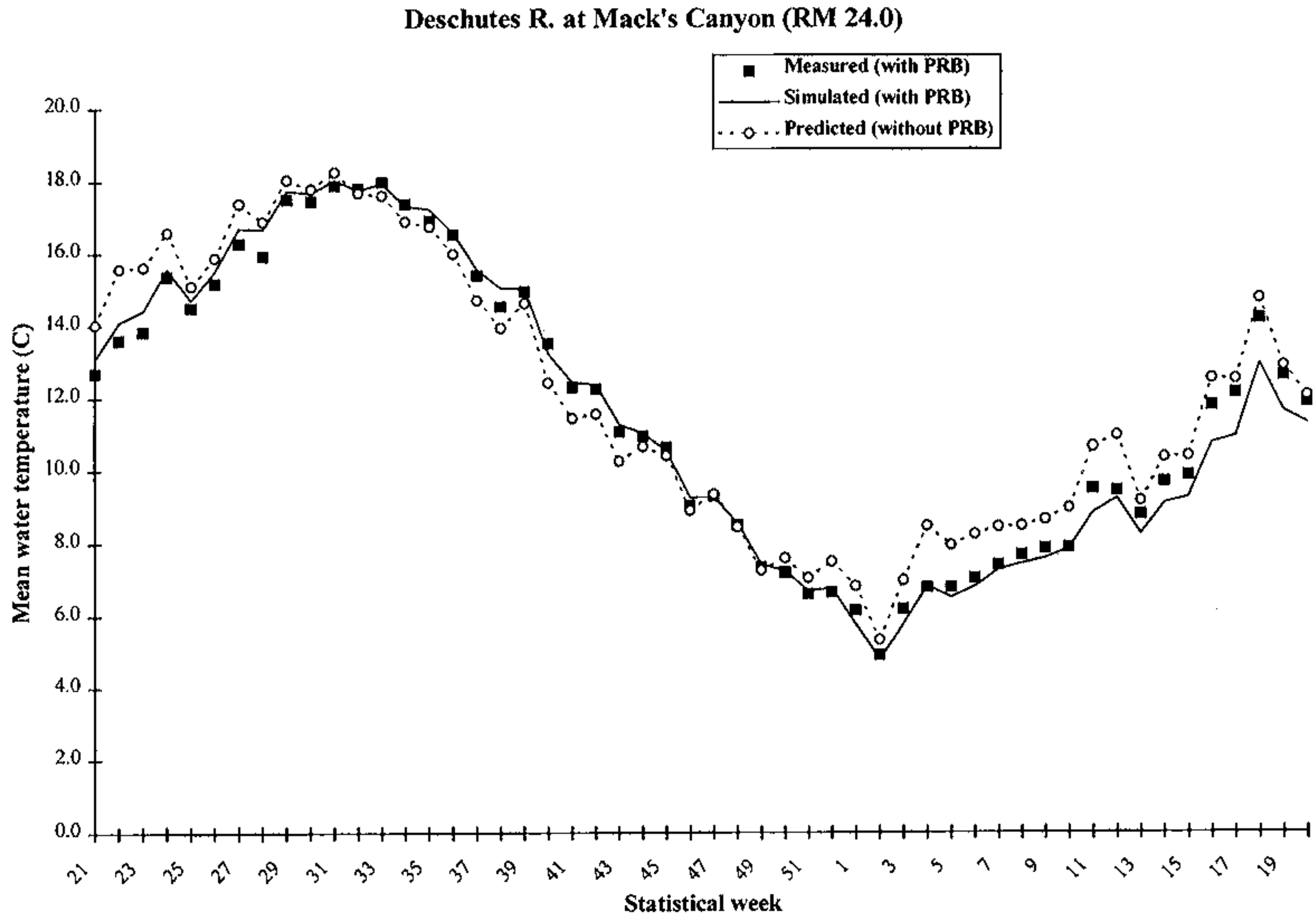


Figure 16. Measured and SNTEMP-simulated mean water temperatures for the Deschutes River at Mack's Canyon (RM 24.0), for statistical week 21 in 1997 through statistical week 20 in 1998. Note: statistical weeks 27, 40, 1, and 14 begin on 02 July, 01 October, 01 January, and 02 April, respectively.

at this site "with PRB" ranged from a high of 18.0°C during statistical week 33 to a low of 4.8°C in week 2. Mean weekly temperatures predicted "without PRB" reached a high of 18.3°C in week 31 and a low of 5.3°C during week 2.

5.1.3.d. <u>Deschutes River at Colorado Rapids (RM 4.0)</u>. Our simulations suggest that PRB may have raised weekly mean river temperatures at Colorado Rapids by an average of about 0.5°C (range: -0.1 to +1.0°C) from early August to mid-December and lowered them by an average of approximately 0.6°C (range: -0.1 to -1.7°C). during the rest of the 1-year modeling period (Figure 17). Mean weekly temperatures simulated for this location "with PRB" reached a maximum of 18.9°C in statistical week 31 and a minimum of 4.4°C during week 2. SNTEMP predictions of mean weekly temperatures at Colorado Rapids "without PRB" ranged from a high of 19.1°C during week 31 to a low of 4.9°C in week 2.

5.2. EFFECTS ON COLDWATER BIOTA

5.2.1. Changes in the Emergence Timing of Anadromous Salmonids

5.2.1.a. <u>Timing of Fall Chinook Emergence</u>. We found that the mean date of emergence for fall chinook during post-PRB years may have been later at Pelton Gage and slightly earlier at Moody than it was prior to completion of PRB. However, these changes were statistically insignificant ($p=0.378$ for Pelton and $p=0.735$ for Moody) and well within the range of natural variation at each site (Figure 18). Mean dates of emergence calculated for the Pelton site were 18 February for four pre-PRB years and 22 February for 13 post-PRB years. Mean dates of emergence calculated for the Moody site were 06 March for three pre-PRB years and 03 March for six post-PRB years.

5.2.1.b. <u>Timing of Summer Steelhead Emergence</u>. Our analysis suggests statistically significant pre- versus post-PRB differences in the timing of steelhead emergence in the Deschutes River at Pelton Gage ($p<0.001$) and nearly significant differences ($p=0.055$) at Moody (Figure 19). Dates of emergence estimated for steelhead spawning at the Pelton site on 10 April during 20 post-PRB years was 01 June, 11 days later than the average date of emergence (21 May) for fish spawning there on 10 April during four pre-PRB years. Dates of emergence calculated for summer steelhead

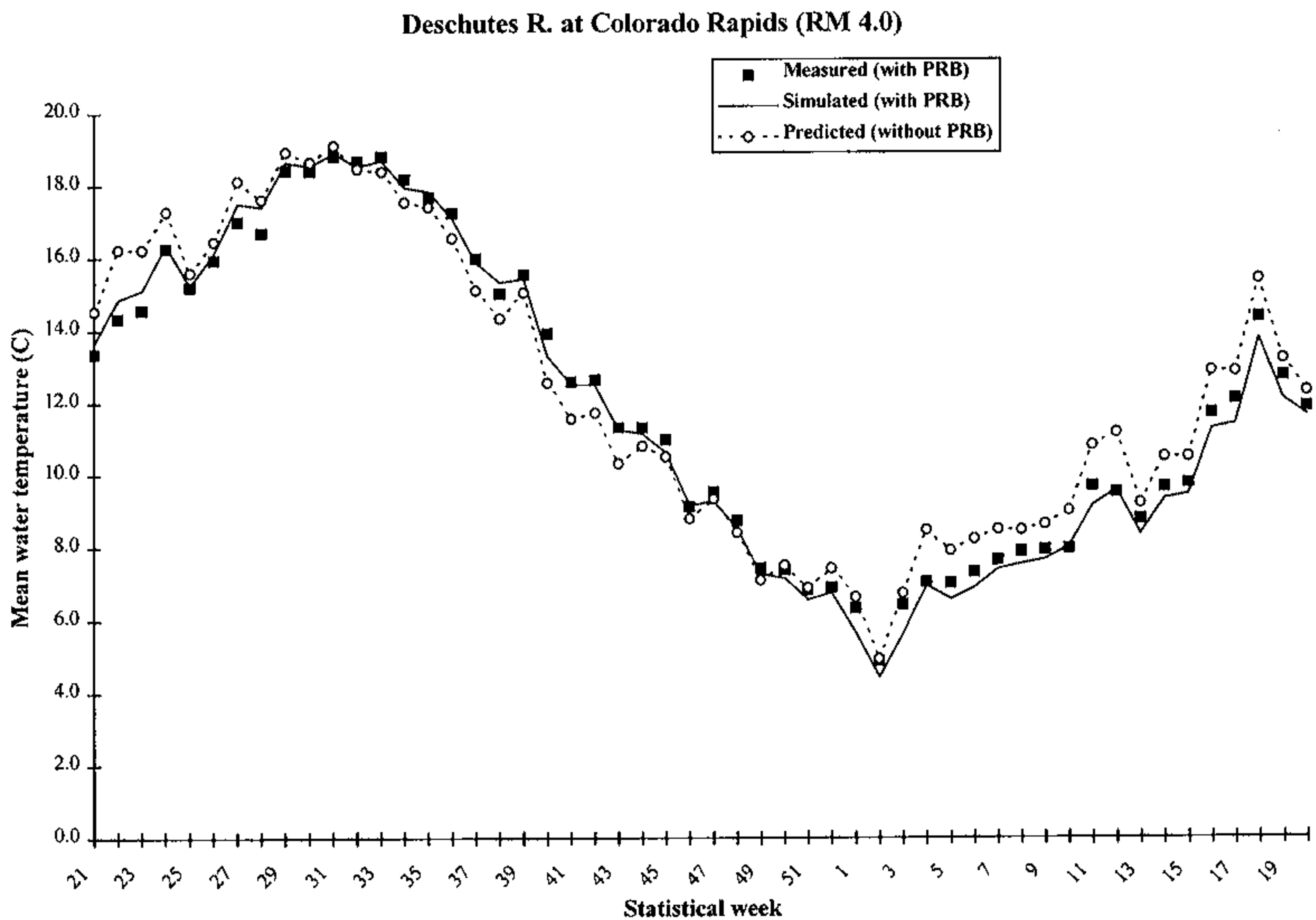


Figure 17. Measured and SNTEMP-simulated mean water temperatures for the Deschutes River at Colorado Rapids (RM 4.0), for statistical week 21 in 1997 through statistical week 20 in 1998. Note: statistical weeks 27, 40, 1, and 14 begin on 02 July, 01 October, 01 January, and 02 April, respectively.

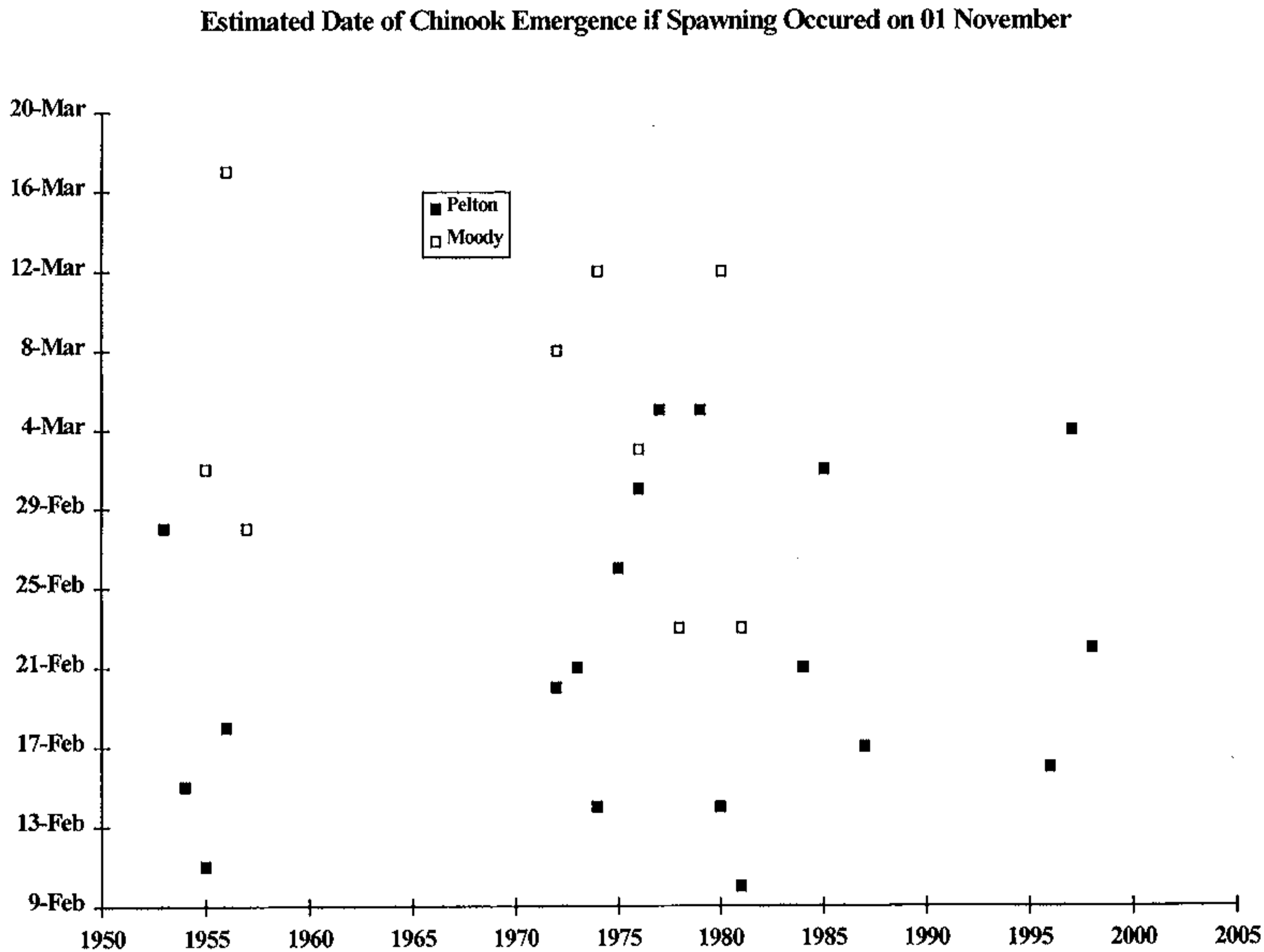


Figure 18. Estimated timing of chinook emergence in the Deschutes River near Pelton Gage and at Moody, assuming egg deposition on 01 November, 1953–1998.

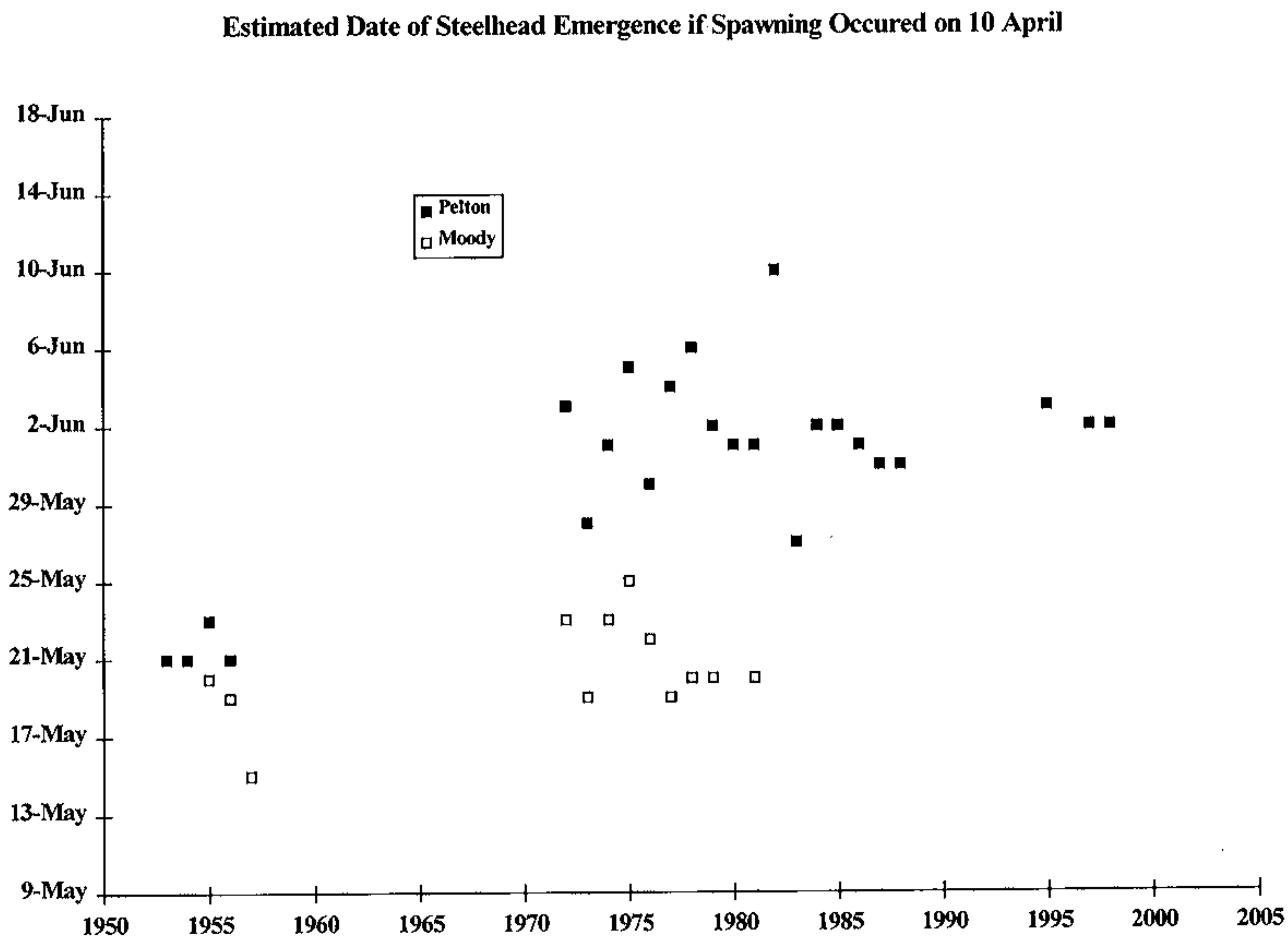


Figure 19. Estimated timing of steelhead emergence in the Deschutes River near Pelton Gage and at Moody, assuming egg deposition on 10 April, 1953–1998.

spawning on 10 April at the Moody gage site averaged 21 May for ten post-PRB years, 3 days later than the average date of emergence (18 May) calculated for three pre-PRB years.

The delay in steelhead emergence in the Deschutes River at Pelton Gage appears likely to be greatest for the offspring of early spawning fish. On average, steelhead embryos spawned on 19 March or 30 April during the post-PRB years would have emerged an estimated 14 days or 10 days later, respectively, than embryos spawned on those dates during the pre-PRB years.

5.2.2. Changes in Peak 7-Day Mean Maximum Temperatures

During summer and fall 1997, peak 7-day mean maximum temperatures measured at 21 stations in the Deschutes River below PRB increased with increasing distance downriver, and ranged from 14.3°C (ending on 06 September) immediately below the Reregulating Dam to 20.9°C (ending on 07 August) at Colorado Rapids (Figure 20). The State's temperature standard for coldwater biota like salmonids (17.8°C) was exceeded at all stations below White River (RM 46.4) but at no stations above that point.

Our SNTEMP simulations of weekly mean maximum temperatures for the river suggest that by releasing cooler than "natural" water in July and early August 1997, PRB may have caused a small reduction in the annual peak 7-day mean maximum temperatures observed along much of the river (Table 7). This would slightly reduce the length of river that fails to meet the State's temperature standard for coldwater biota. In contrast to most other patterns evident in the SNTEMP simulations, it appears that the degree of PRB-related depression of peak weekly mean maximum temperatures increased with distance below the Reregulating Dam. For example, our modeling suggests a 5-week delay but little effect on the magnitude of the highest weekly mean maximum temperatures (analogous but not identical to the peak 7-day mean maximum) at Pelton Gage but a shorter (2-week) delay and a larger (0.3°C) reduction at Colorado Rapids, the validation site nearest the mouth of the Deschutes.

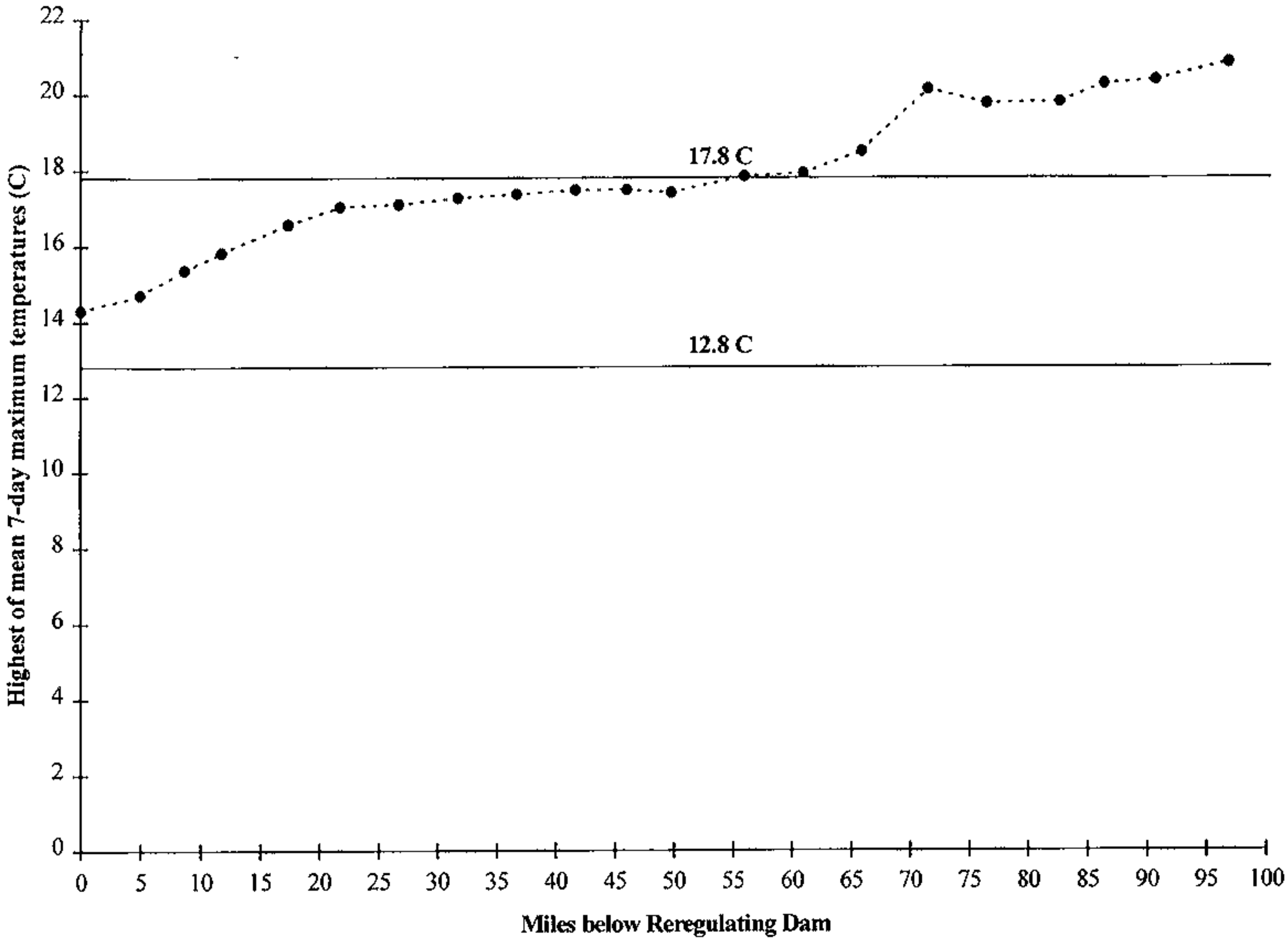


Figure 20. Highest mean 7-day maximum temperature versus distance below the PRB Reregulating Dam, Deschutes River, Summer/Fall 1997.

Table 7. Peak values predicted for weekly mean maximum temperatures along the lower Deschutes River with and without the presence of PRB, for summer/fall 1997. Statistical weeks in which peak temperature values were predicted to occur are given in parentheses.

Location on the Deschutes River	Peak values predicted for weekly mean maximum temperatures		Estimated PRB effect
	With PRB	Without PRB	
Below the Reregulating Dam (RM 100.1)	14.8°C (36)	14.8°C (31)	0.0°C
Dry Creek (RM 93.0)	15.8°C (33)	15.9°C (31)	- 0.1°C
Kaskela (RM 79.1)	17.1°C (33)	17.2°C (31)	- 0.1°C
Nena (RM 59.0)	17.8°C (33)	18.0°C (31)	- 0.2°C
Sandy Beach (RM 45.0)	18.4°C (33)	18.6°C (31)	- 0.2°C
Mack's Canyon (RM 24.0)	19.3°C (31)	19.5°C (31)	- 0.2°C
Colorado Rapids (RM 4.0)	20.1°C (31)	20.4°C (29)	- 0.3°C

Note: Actual PRB-related reductions of high temperatures may have been greater than suggested by our SNTEMP-based simulations because predictive relationships we used to estimate "without PRB" temperatures at the Reregulating Dam may have underestimated "natural" temperatures there by as much as several tenths of a degree centigrade.

6. DISCUSSION

Results of our multiple analyses indicate that PRB decreases temperatures downstream in the Deschutes River during the winter, spring, and early summer, then increases them in the late summer and fall. This pattern of PRB influence is clearly shown by period-of-record analyses of pre- versus post-PRB river temperatures and by functional changes in historic relationships between river temperatures at specific locations, streamflows, and air temperatures. As best we can tell, PRB's effect on river temperatures immediately downstream has been of the same general magnitude as pre- versus post-PRB differences evident in USGS data for the Pelton Gage. In terms of mean monthly conditions, those differences ranged from temperature decreases of a little more than 2.5°C (in April and May) to increases of about 1.5°C in October.

Output from our SNTEMP-based modeling of the river from late May 1997 through mid-May 1998 shows the same seasonal patterns of temperature change as we found in historical data, and suggests that PRB's effects on mean river temperatures are generally greatest at Pelton Gage, immediately below the Reregulating Dam, and attenuate downstream. However, our modeling also suggests that PRB affects river temperatures all the way downstream to the mouth of the Deschutes.

The relatively long distance of travel our modeling suggests for PRB's effects on downstream temperatures (>100 mi., to the mouth) may be related to the unique nature of the lower Deschutes River. Near PRB, the river is naturally influenced by springs that tend to keep water temperatures moderate and flows relatively high and stable (Figure 21). These conditions are of significance for two reasons. First, because PRB operates as a run-of-river project, flows down the lower Deschutes remain relatively high year-round. Water released from PRB always travels quickly down the Deschutes River Canyon toward the Columbia River (unpublished current velocity data from A. Laenen, USGS, suggest a total transit time of a little over 1.5 day at low flow) and has limited time to equilibrate with temperatures in the surrounding environment. Second, Deschutes River temperatures near PRB were historically (and continue to be) influenced by springs and thus may not have been well equilibrated with the surrounding environment even prior to PRB completion.

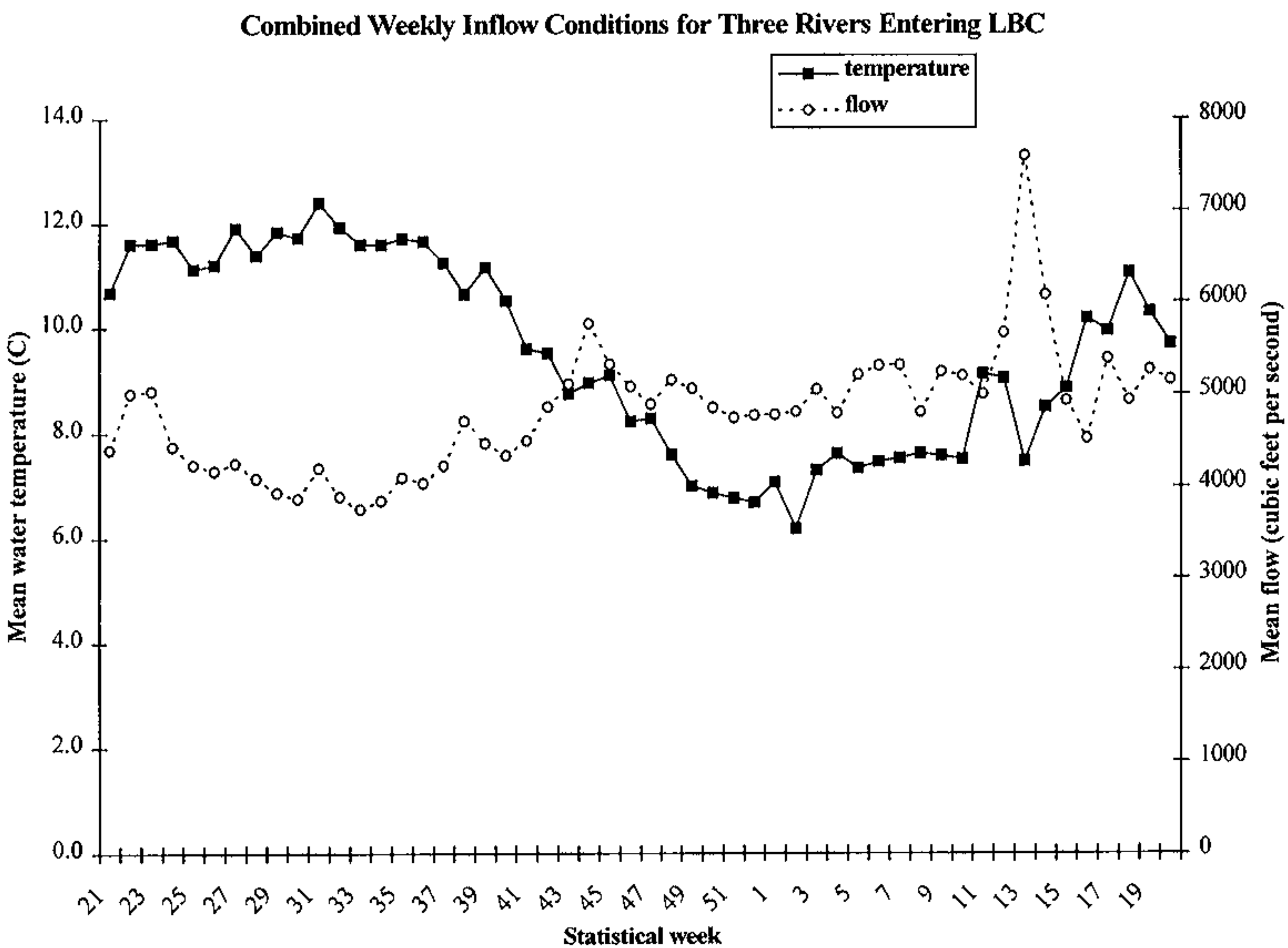


Figure 21. Mean weekly streamflows and temperatures for the combined inflows of the three rivers entering Lake Billy Chinook (LBC), statistical week 21 in 1997 through statistical week 20 in 1998. Note: statistical weeks 27, 40, 1, and 14 begin on 02 July, 01 October, 01 January, and 02 April, respectively.

Post-PRB changes in river temperatures appear likely to have had mixed effects on the river's coldwater biota (including anadromous salmonids). Observed changes in river temperatures likely delayed the emergence of incubating steelhead embryos by about 10–14 days immediately below PRB (i.e., near Pelton Gage) and have probably delayed their emergence to a lesser degree much farther downriver. This contrasts with our findings on the emergence timing of fall chinook embryos, which were inconclusive. The differential incubation responses of these two species are related to seasonal variation in PRB's effect on temperatures in the lower Deschutes River. PRB depresses river temperatures during most or all of the incubation period for steelhead embryos, but has apparently offsetting effects on fall chinook embryos as it raises then lowers river temperatures (relative to "natural") during their incubation period.

We also found that PRB may be having a very small but beneficial effect on coldwater biota by releasing slightly cooler than "natural" water at the time of year (early to mid-summer) when river temperatures would otherwise be warmest. Our SNTEMP simulations suggest that during 1997, this type of PRB release caused up to 0.3°C reductions in peak 7-day mean maximum temperatures along the lower Deschutes River, with the largest reductions near the river's mouth. These reductions would have slightly reduced the length of the lower river that exceeded Oregon's temperature standard for coldwater biota (7-day mean maximum temperature <17.8°C).

Further use of the SNTEMP model offers an opportunity to assess the likely effects of potential changes in PRB configuration or operations. This is important because PGE and others are currently discussing possible fish passage activities at PRB that will have the potential to change the temperature of water released at the Reregulating Dam. Post-PRB changes in the Deschutes River's thermal regime suggest that small future increases in late winter or spring temperatures might prove beneficial to native aquatic biota. However, completely reversing PRB-related changes in lower river temperatures will not necessarily create ideal thermal conditions downriver because conditions upstream of PRB may at times be substantially affected by water storage, irrigation diversions, and riparian degradation.

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