PORTLAND GENERAL ELECTRIC
Portland, Oregon

Pelton Round Butte Hydroelectric Project

Calibration and Verification of Hydrodynamic and Temperature Models of Lake Billy Chinook

FINAL REPORT

Prepared by:

Foster Wheeler Environmental Corporation
Zhaoqing Yang, Ph.D.
Tarang Khangaonkar, PE, Ph.D.
Curtis DeGasperi

and

ENSR Consulting & Engineering
Walter Bowles
Liaqat Khan, Ph.D.
Charles Sweeney, PE

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EXECUTIVE SUMMARY

The development, calibration and validation of two numerical models, a 2D temperature model and a 3D hydrodynamic model, of Lake Billy Chinook, Oregon are presented in this report. This modeling effort was performed in support of PGE's adaptive management plan to re-establish anadormous fish runs above the lake. One of the study tracks identified by PGE is the evaluation of conceptual designs of facilities that will aid successful collection and downstream migration of salmonids at the Round Butte Dam. The calibrated and verified numerical models developed in this study are capable of describing the temperature and velocity distributions in the lake. Therefore, these models can be used for analyzing design options to favorably alter flow fields in the forebay of Round Butte Dam to enhance collection and downstream migration of fish.

Preliminary setup and application of the temperature and the hydrodynamic models were performed by ENSR previously (1999). Long term temperature distributions were computed using the BETTER model developed by Tennessee Valley Authority (TVA). Three-dimensional hydrodynamic simulations were performed using EFDC, a 3D model developed by the Virginia Institute of Marine Sciences. These models were configured and calibrated using historical data available for 1995. Due to the lack of current data, the hydrodynamic model calibration was based on best professional judgement and limited drogue data. The temperature model was calibrated, but it was not verified. Consequently, to enhance the credibility of the models, data were collected in 1999 to verify the temperature model. Data were also collected for calibration and verification of the hydrodynamic model. The study described in this report presents refinements and enhancements to the models of Lake Billy Chinook reported on in 1999.

An extensive effort was made to obtain data from different organizations and collect additional data for the calibration and verification of the models. Available historical data have been reviewed by ENSR (1999). Tributary inflow data for the Deschutes, Crooked, and Metolius Rivers were obtained from the United States Geological Survey (USGS). Temperature and water quality data for 1995 were available from limnological studies conducted by E & S Environmental Chemistry (E&S) (Raymond et al., 1997). These data were collected at eight stations within the reservoir and three tributary stations. In 1999, temperature and water quality data were collected by PGE and additional tributary temperature and water quality data were available from EPA STORET. Three meteorological stations near the lake, maintained by PGE, were the main source of meteorological data. This data set was supplemented by data from Redmond Airport, Desert Research Institute, and University of Oregon. In 1999, ENSR conducted a field program to collect current and temperature data at four key locations in the lake. These data are presented in this report. Bottom-mounted acoustic Doppler current profiles (ADCPs) were used to record current profiles in the water column, while near-surface currents were measured by electronic magnetic current meters. Arrays of Hobo data loggers were used to obtain temperature data throughout the water column.

Comparisons of monthly mean inflows from the Deschutes, Crooked, and Metolius Rivers indicate that hydrologic conditions in 1995 were similar to the historical average, while river inflows in 1999 were relatively high, representing a wet year. In July 1995, temperature stratification in the reservoir was greatly enhanced by strong surface warming. Though temperature stratifications in 1999 were similar, stations in the Deschutes and Crooked Rivers showed pronounced horizontal temperature gradients. Thus, these modeling periods represent two significantly different hydraulic regimes suitable for model calibration and verification.

Meteorological data needed for the numerical models are solar radiation, air and dew point temperatures, wind speed and direction, rain fall, and pan evaporation. Time series of data were plotted and analyzed. Most of these data, especially the wind data, contained many gaps due to instrument failures. However, wind data from PGE's meteorological station showed strong temporal and spatial variations, resulting in significantly different dominant wind directions at these stations. Therefore, adequate parameterization of the spatial variability in wind speed and direction over the whole model domain was not possible. However, this lack of data did not affect the model calibration identification process. The technique of averaging was adopted to eliminate the effect of local and temporal variability of wind and currents in the surface layer.

Analyses of current data from the ADCPs and current meters indicated that currents were small, on the order of 3 cm/s, but there were strong temporal trends. Residual circulation patterns in the lake were analyzed by plotting 1-day and 7-day mean velocity profiles. The velocity profiles in the forebay clearly showed that the net transport was toward the power intakes. Two- and sometimes three-layer circulation patterns were observed at many stations. Near-surface currents were strongly correlated with surface wind speed recorded at PGE's meteorological stations.

For the application of the BETTER model, Lake Billy Chinook was divided into 35 segments in the horizontal and 30 layers in the vertical. The bathymetry data used for grid development are presently being reviewed and updated by PGE. Minor adjustments may be made to the model grid in 2000 on the basis of this update. These adjustments are not expected to affect model results. The computational time step used in the simulations was 12 hours. Boundary information necessary for the application of the model consisted of meteorological conditions and reservoir inflows and outflows and their temperatures and water quality parameters. The model was calibrated by using available 1995 historical data, while data collected in 1999 were used for model verification. The temperature profiles computed by the model are consistent with observations, particularly in the forebay and in the Deschutes arm. However, the model under predicts bottom temperature in the Metolius arm.

The lake was divided into 493 cells in the horizontal plane, and 10 vertical layers for simulating the 3D flow field using the EFDC model. As with the BETTER model, the EFDC grid will be adjusted in 2000 on the basis of the updated bathymetry data; no change in performance is anticipated.

The average grid size in the forebay was about 300 feet by 300 feet. The hydrodynamic model was calibrated to observed current and temperature for spring conditions (May 1999). The model was then verified using data from July 1999, representing summer conditions. Because of the high computational demands of 3D models, the hydrodynamic model was only run for 6-day periods. Initial conditions for temperature were obtained from the temperature model. The calibrated model successfully reproduced the main features of flow patterns due to outflow discharge at the power intake, and the downstream movement of the Metolius water. However, there are some discrepancies in the subsurface layer in the Metolius and Deschutes arms. These discrepancies are mainly due to insufficient wind data to define the spatial variability of wind in the model domain. Sensitivity calculations with artificial wind forcing functions support this conclusion.

The calibrated and validated 2D temperature model and the 3D hydrodynamic models have reproduced the flow patterns and temperature stratifications in Lake Billy Chinook reasonably well. Therefore, these models can be used for analyzing different flow patterns resulting from structural features to aid the collection and downstream migration of juvenile anadromous fish. Preliminary analyses of four design options for modifying the forebay flow fields have been conducted by ENSR (1999). With the availability of the calibrated and validated models, these features can be further analyzed to refine the design concepts.

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1.0 INTRODUCTION

1.1 Background

Lake Billy Chinook reservoir was created by the completion of 440-foot high Round Butte Dam in 1964. Inflows to the reservoir come from three independent sources: the Crooked, Deschutes, and Metolius Rivers. These tributary rivers discharge to distinct arms of the reservoir and each tributary has distinct water quality and temperature characteristics. There is also significant groundwater inflow to the reservoir. Construction of the dam created a major obstacle to migratory fish passage. Much of the passage problem was associated with ineffective collection of downstream migrating salmon and steelhead smolts. Studies of in-reservoir flow patterns, and smolt distribution and behavior, found that tributary inflow, thermal stratification, and reservoir withdrawal patterns resulted in surface flow reversals that directed smolts away from fish collection facilities.

In conjunction with the current re-licensing process, Portland General Electric (PGE) has developed an adaptive management plan for re-establishing natural anadromous fish runs above Round Butte Dam (PGE 1996). Numerous biological, chemical, and physical studies have been initiated to support this effort. One of the study tracks identified by PGE as part of this plan is the development and evaluation of conceptual designs of facilities that will successfully collect and pass downstream migrating salmonids at Round Butte Dam. In order to design effective fish collection facilities and to achieve success in fish collection, flow guidance of fish in the reservoir and thus flow patterns in the reservoir must be understood. The flow patterns in the reservoir are complex and dependent upon a number of parameters. Ability to simulate the temperature stratification and velocity distribution in the reservoir as a function of external influences is also required. Therefore, development of comprehensive reservoir temperature and hydrodynamic models was recommended.

In 1997, a modeling/monitoring study plan was developed for the Pelton Round Butte Project; the *Pelton Round Butte Project Hydrodynamic Modeling Action Plan* (ENSR 1997). The action plan recommended a preliminary development of hydrodynamic and thermal mass balance models calibrated using the existing data only. The action plan also recommended a synoptic data collection program to be conducted following the setup of the preliminary models. The approach adopted was to use preliminary models to evaluate the responsiveness of the reservoir to modifications in the outlet structure. If the results were positive and showed that it would indeed be possible to alter the reservoir flow pattern through changes in the project operation and structural modifications, a detailed synoptic data collection program would be initiated.

In January of 1999, *Preliminary Temperature and Hydrodynamic Modeling of Lake Billy Chinook – Pelton Round Butte Project* (ENSR January, 1999) was completed. The study results clearly indicated that the Lake Billy Chinook Reservoir would be responsive to attempts to change the stratification and hydrodynamics through structural modifications near Round Butte Dam. Consequently, a detailed monitoring program and a synoptic data collection program were initiated. The purpose of these field studies was specifically to provide data for calibration and verification since the preliminary models were based only on existing data and best professional judgement. Once the models are properly calibrated and verified, they may be used to evaluate various design alternatives and to assist the design refinement process.

1.2 Study Objectives

The overall objective of this study is to improve the existing preliminary temperature and hydrodynamic models of Lake Billy Chinook (ENSR January 1999) by completing the model calibration and verification using the data recently collected from the site. Considerable effort was spent in collecting field data specifically suited for model calibration and verification. The result of this study will be the development of predictive numerical tools capable of describing the varying temperature and velocity distributions in Lake Billy Chinook as a function of inflow and outflow characteristics, meteorological conditions, and reservoir geometry.

The specific objectives of this study were as follows.

- <u>Field Data Processing.</u> Process the temperature, velocity, and meteorological data collected in 1999 into a format suitable for temperature and hydrodynamic model calibration and verification.

- <u>Temperature Model Calibration.</u> Re-calibrate the existing preliminary temperature model using the 1995 data to account for new groundwater inflow information.

- <u>Temperature Model Verification</u>. Verify the temperature model using an independent data set from 1999.

- <u>Hydrodynamic Model Calibration.</u> Calibrate the hydrodynamic model using the spring 1999 velocity information

- <u>Hydrodynamic Model Verification.</u> Verify the hydrodynamic model using velocity data from summer of 1999.

1.3 Report Organization

This report includes an introduction to the background and objectives of the study (Section 1). Section 2 provides a summary and review of the available data that are suitable for the setup, calibration, and verification of the temperature and hydrodynamic models. This includes existing information that was already collected by PGE or that was available through research and government agencies. It also includes data collected by PGE and ENSR specifically to provide monitoring data and synoptic hydrodynamic information required by the models. Section 3 describes the two-dimensional (2D) temperature model, its setup, calibration, and verification. Section 4 describes the three-dimensional (3D) hydrodynamic model, its setup, calibration, and verification. Section 5 provides results and conclusions. The final section (Section 6) contains a list of references.

2.0 SUMMARY OF AVAILABLE DATA FOR MODEL CALIBRATION AND VERIFICATION

2.1 Introduction

The data available for model calibration and verification are a combination of limnological data compiled by PGE previously and the synoptic current and temperature data collected as part of this study.

Available historical data were reviewed previously as part of the preliminary temperature and hydrodynamic modeling of Lake Billy Chinook (ENSR January 1999). An extensive limnological study of Lake Billy Chinook was conducted between 1994 and 1996 which provided sufficient data for preliminary calibration of the models. PGE has also extensively studied and documented the ecological aspects of the project area, and a number of reports were available for review. The previous studies provided valuable information on the physical characteristics of Lake Billy Chinook that was useful in developing an understanding of the dominant hydrodynamic processes occurring in the study area. New data reviewed included those from an ongoing data collection program of water quality and local meteorological conditions. These data were collected primarily in 1999. They also include the synoptic currents and temperature profiles measurements. The periods chosen for temperature and hydrodynamic model calibration and verification were 1995 and January through mid-July 1999 for the focus of this review.

This section summarizes the existing data on bathymetry, discharge flow rate, water quality, and meteorology. Although a number of studies have been conducted in the past, each study had a different focus and therefore did not address all the physical parameters relevant to describing the hydrodynamic and thermodynamic characteristics of the reservoir. The data presented or summarized in this section were used either as direct model input, or to specify model boundary conditions. This section also includes data that were used to calibrate and verify the model predictions of temperature profiles and velocity distributions.

2.2 Geometry Data

Geometry data refer to the study area morphology including water depths (bathymetry), land elevations (topography), and land-water boundaries. This information is required for the construction of the numerical model grid boundaries, and was obtained from available topographic and bathymetric maps of Lake Billy Chinook and Round Butte Dam.

2.2.1 General Study Area

Round Butte Dam is located on the Deschutes River near the town of Madras in north-central Oregon. The dam is located at approximately River Mile 110 and impounds Lake Billy Chinook. Lake Billy Chinook is approximately 3,800 acres (1,544 ha) in surface area and extends 6 to 13 miles into the canyons of the Deschutes, Metolius, and Crooked Rivers. The Crooked and Deschutes River arms run parallel north and south with lengths of 6.0 and 8.5 miles, respectively. The Metolius River arm extends 12.5 miles west. The study area is shown in Figure 2-1.

2.2.2 Bathymetric Data

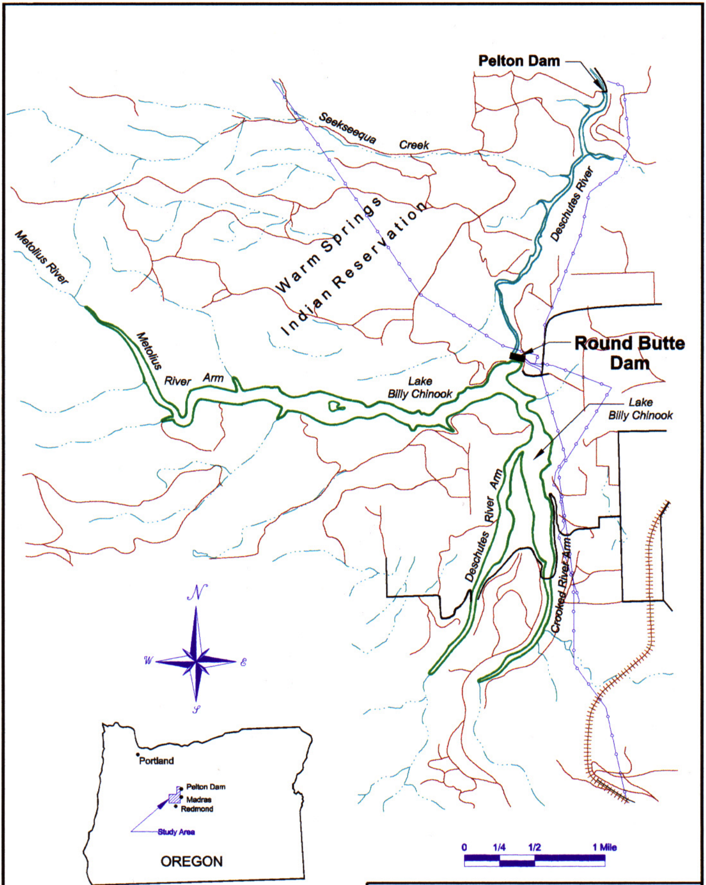
The project area is a gently sloping, high plateau at about 2,500 feet above mean sea level with deep, river-cut canyons. Bathymetry maps of the study area were received from C&G White Cartography based on a 1960 USGS survey conducted before Round Butte Dam was constructed. The 10-foot contours were of high quality, however, they did not extend below the historical river water surface. In August 1994, E&S Environmental Chemistry (E&S) conducted a complete bathymetric survey of Lake Billy Chinook. The 1994 bathymetry was selected for use in this study because it includes bathymetry below the historical river surface as well as the dam face, and would account for changes resulting from deposition of material behind the dam. The lake bathymetry is shown in Figure 2-2 with 50-foot contour intervals. The average depth of the lake is 119 feet, while the maximum water depth is 394 feet. The bathymetry are presently being reviewed and updated by PGE. Minor adjustments will be incorporated in the data set applied in the models in 2000.

2.2.3 Round Butte Dam

Round Butte Dam construction was completed in 1964, with a fish hatchery added in 1972. The 440-foot-high rock-filled earthen dam is PGE's largest hydroelectric plant in terms of peak capacity and annual production. The spillway intake crest elevation is at 1,915 feet, while the power intake invert elevation is at 1,699 feet (intake centerline is at 1,712.5 feet). PGE's normal minimum operating pool is elevation 1,925 feet and the minimum water surface elevation is 1,860 feet. The maximum normal pool elevation is 1,945 feet.

2.3 Hydrologic Data

The available hydrologic and hydrodynamic data from the inflow rivers, Round Butte Dam, and Lake Billy Chinook are described in the following sections.



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PROJECT NO:	5499-002
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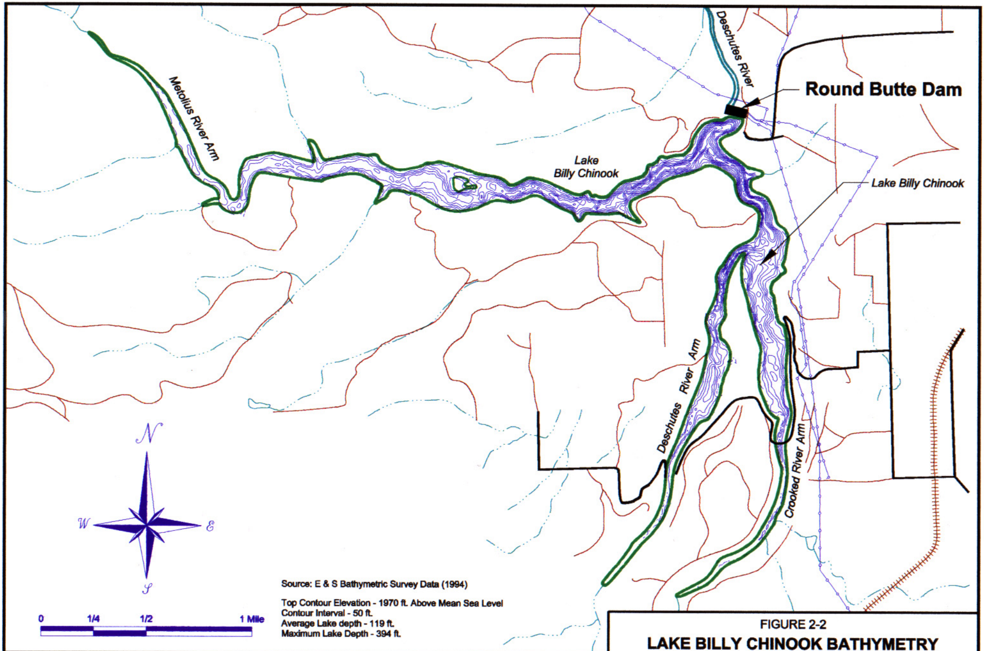
DATE:	March 15, 2000
FILENAME:	S-Area

FIGURE 2-1

STUDY AREA

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon



Source: E & S Bathymetric Survey Data (1994)

Top Contour Elevation - 1970 ft. Above Mean Sea Level
Contour Interval - 50 ft.
Average Lake depth - 119 ft.
Maximum Lake Depth - 394 ft.

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	FILENAME: Bathy-NC	CHECKED: L. Khan	5499-002

FIGURE 2-2

LAKE BILLY CHINOOK BATHYMETRY

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

2.3.1 Tributary Inflow

The United States Geological Survey (USGS) maintains hydrologic gauges on the tributary rivers. Complete daily average discharge data were available for the three tributaries in 1995. Provisional data were available for January through mid-July in 1999. Provisional data have not been reviewed and edited and are subject to change before final publication by the USGS. Final data were not available for the modeling conducted for this report. Descriptions of the gauges are presented in Table 2-1.

Table 2-1
USGS Hydrologic Gauging Stations

USGS Station	River Mile	Discharge Summary Statistics [1]		
		Average	Minimum	Maximum
Deschutes River Near Culver, OR [2]	120.6	915	425	4,790
Crooked River below Opal Springs, Near Culver, OR [3]	6.7	1,560	920	8,260
Metolius River near Grandview, OR [4]	13.6	1,490	1,080	7,100

1 Source: Moffatt et al. (1990) and http://www.usgs.gov (on-line access to USGS historical stream gauging data).

2 Gauge number 14076500. Period of record July 1952 to October 1998. Minimum measured on July 7 and 8, 1964. Maximum measured on December 24, 1964.

3 Gauge number 14087400. Period of record October 1917 to October 1998. Minimum measured on October 14, 1945. Maximum measured on March 30, 1943.

4 Gauge number 14091500. Period of record October 1921 to October 1998. Minimum observed on February 17, 1932, October 2-31, November 6, 7, 10-14, 1942.

Generally, the Crooked and Metolius Rivers each contribute about 40 percent of the inflow to Lake Billy Chinook, while the Deschutes River contributes about 20 percent. The peak daily average discharges during the periods of interest (1995 and January through mid-July 1999) were 2,670 cfs in the Metolius (February 1, 1995), 4,490 in the Crooked (March 30, 1999), and 2,320 cfs in the Deschutes (February 28, 1999). River regulation for irrigation withdrawals has damped peak flows in the Deschutes River. The Crooked River is also regulated by upstream irrigation reservoirs and receives significant hydrologic inputs from several springs within 17 miles of the station. The Metolius River is relatively unregulated and likely receives groundwater contributions from springs.

Time series plots of the daily average discharge in the three rivers and local (Pelton Dam) rainfall during 1995 and 1999 are shown in Figure 2-3. Relatively high tributary flows were observed in the spring of 1999 due to heavy rainfall in the basin and upstream dam releases. A comparison of the monthly average discharge of the Deschutes River just below the project for 1995, 1999, and the long-term average recorded at this gauging station, is shown in Figure 2-4. This comparison indicates that 1995 was very similar to historical monthly average discharge while discharge during the first half of 1999 was relatively high, especially during summer when the 1999 monthly average equaled or exceeded the long-term average discharge.

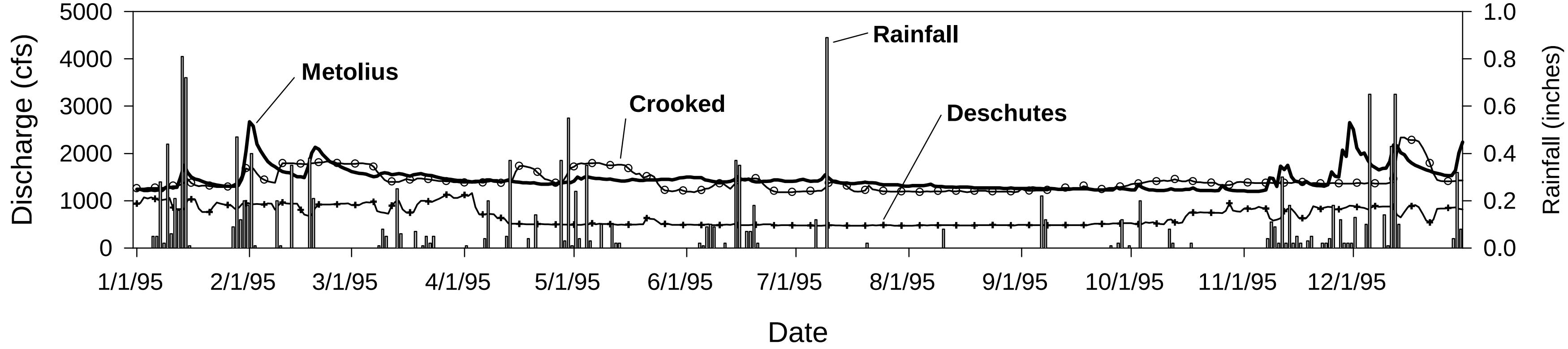
2.3.2 Round Butte Dam Discharge

Hourly power generation withdrawals and spill data from 1994 through July 1999 were provided by Duke Engineering and Services (Carson, P. August 11,1998 and August 13, 1999). The hourly plant flow ranged from 0 during off peak hours to a maximum of 12,099 cfs on January 2, 1997, with an average of 4,595 cfs. Two spills were reported at the dam during high river flows. A 114-hour-long spill in February 1996 averaged 3,223 cfs. A shorter spill in May 1997 for the purpose of drogue tracking studies averaged 4,727 cfs. No spill occurred in 1995 or between January and mid-July 1999. Daily and hourly water surface elevation for 1994 through July 1999 were also included. The average water elevation was 1,943 feet above mean sea level, with extremes of 1,933.9 to 1,945.3 feet above mean sea level. Time series plots of the hourly power discharge and reservoir water surface elevation during 1995 and 1999 are shown in Figure 2-5. In general, peaking reservoir flows were higher and water surface elevations were lower in 1999.

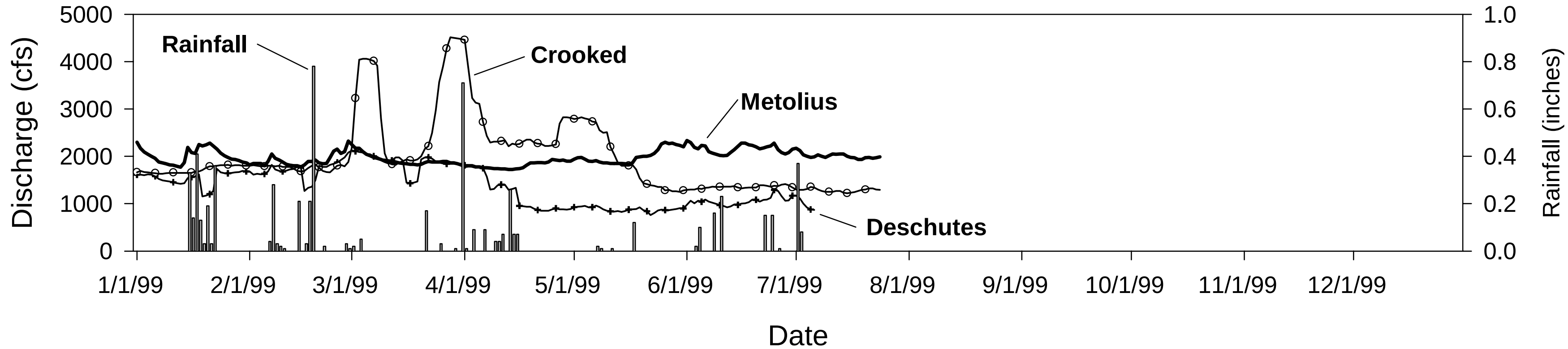
2.4 Lake Billy Chinook Water Quality Data

Water quality monitoring of the reservoir and its tributaries has been conducted at a number of locations since 1994 (Figure 2-6). Water quality data from July 1994 through 1996 were available for Lake Billy Chinook and its tributaries from a limnological study conducted by E&S (Raymond et al. 1997). Additional water quality data (temperature, conductivity, pH, and dissolved oxygen) were collected by PGE during 1999. Supplemental tributary water quality data were obtained from the EPA STORET database. The tributary and in-lake temperature data are the focus of review below. A brief description of the sources of additional water quality data used in the temperature model is also provided.

1995 Rainfall and Tributary Discharge



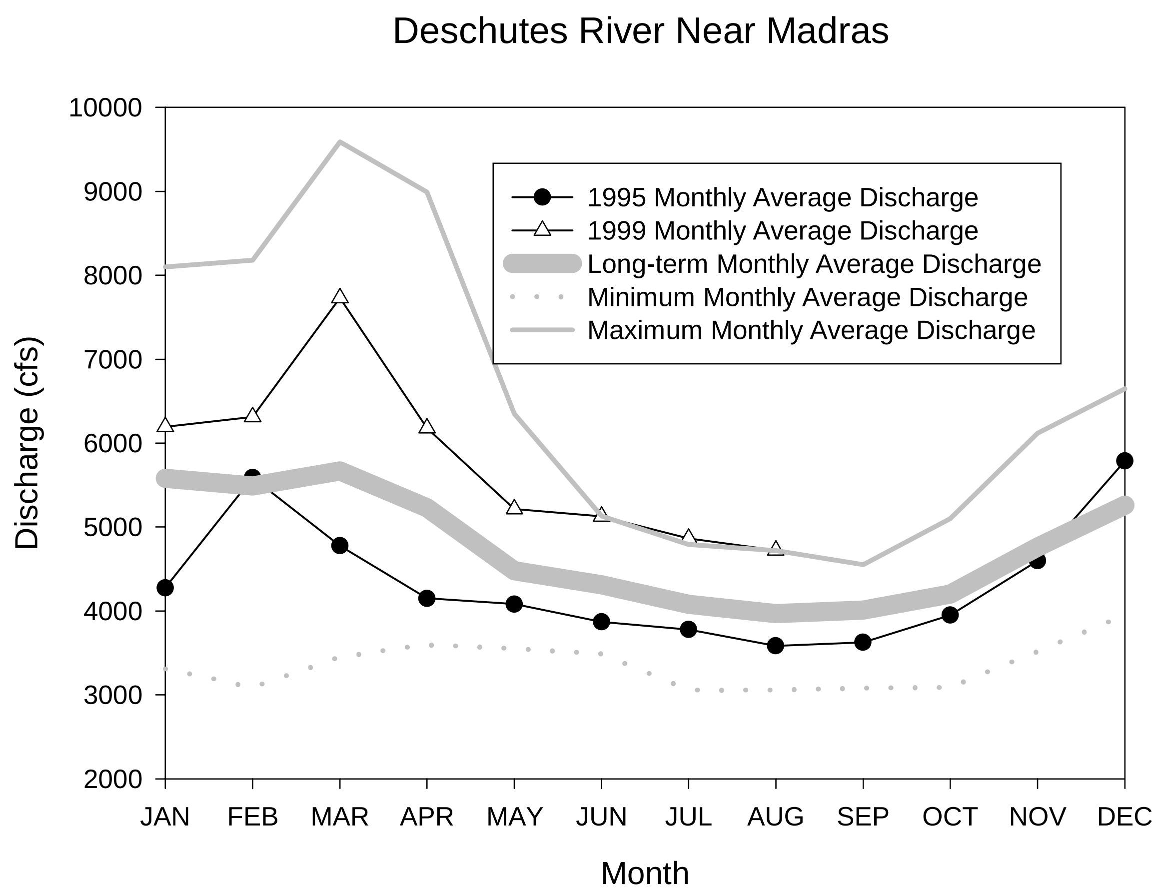
1999 Rainfall and Tributary Discharge



Note: USGS Gauge Numbers:
Deschutes River near Culver (14076500)
Crooked River below Opal Springs near Culver (14087400)
Metolius River near Grandview (14091500)
Rainfall data from gauge at Pelton Dam.

FIGURE 2-3
HYDROGRAPHIC DATA
1995 AND 1999
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 3, 1999	PROJECT NO:
	FILENAME: Disch95-99.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



Note: Historical monthly average discharge based on summary statistics for Deschutes River near Madras, 1964-1987 (after completion of Round Butte Dam) (Moffatt et al. 1990). All data from USGS gauge 14092500.

FIGURE 2-4
1995 AND 1999 DISCHARGE COMPARED TO THE HISTORICAL AVERAGE
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 3, 1999	PROJECT NO:
	FILENAME: Disch95-99.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

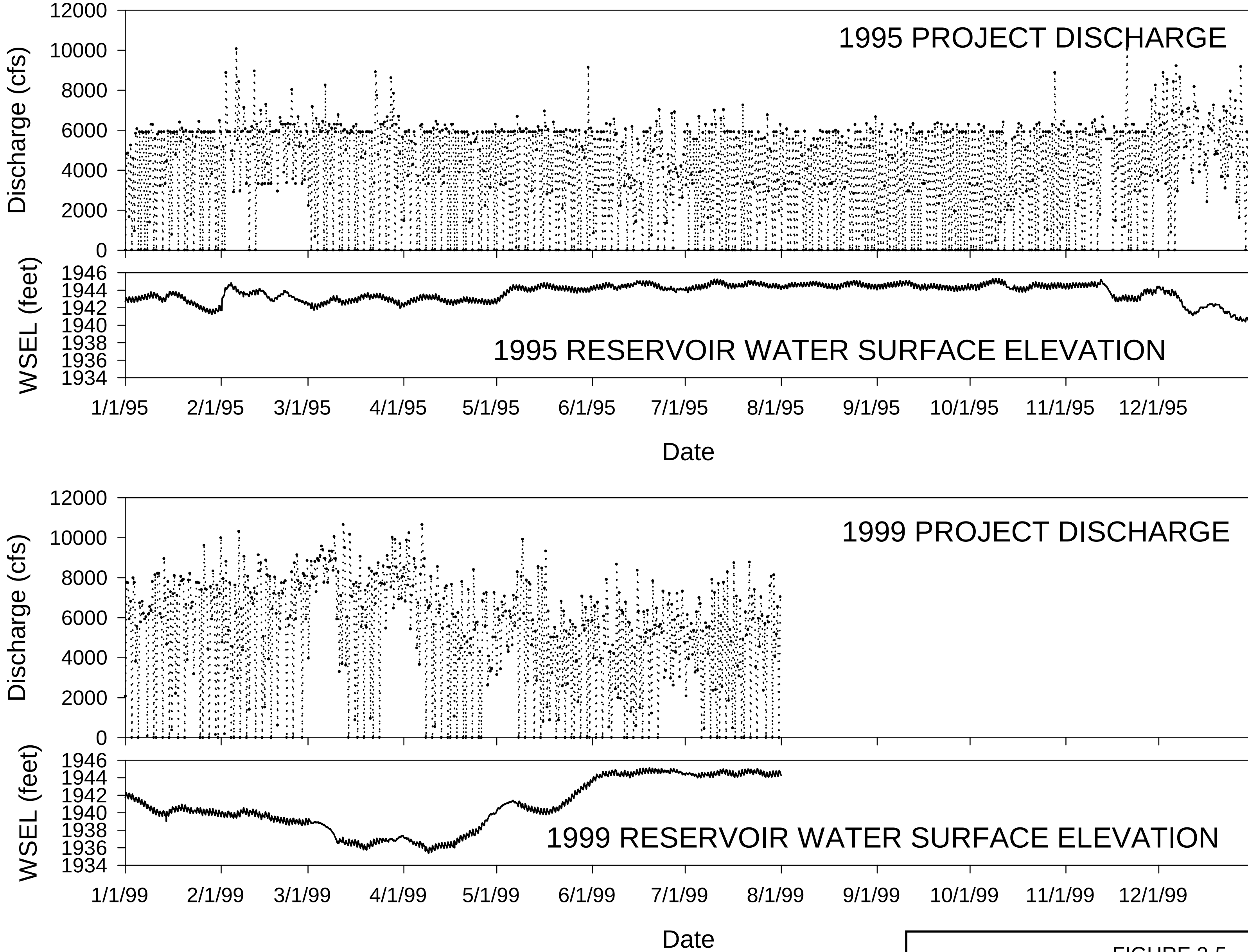
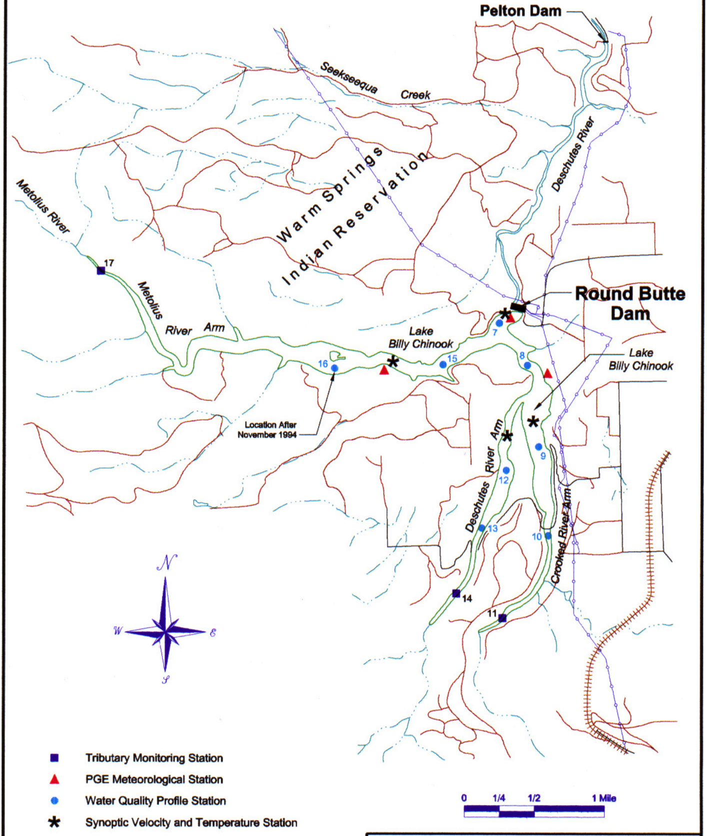


FIGURE 2-5
1995 AND 1999 DISCHARGE AND WATER SURFACE ELEVATIONS
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 3, 1999	PROJECT NO:
	FILENAME: Disch95-99.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



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PROJECT NO:	5499-002
DRAWN:	km/dn/km
CHECKED:	L. Khan
DATE:	March 15, 2000
FILENAME:	FDS-Loc

FIGURE 2-6

FIELD DATA STATION LOCATIONS

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

2.4.1 Tributary Water Temperatures

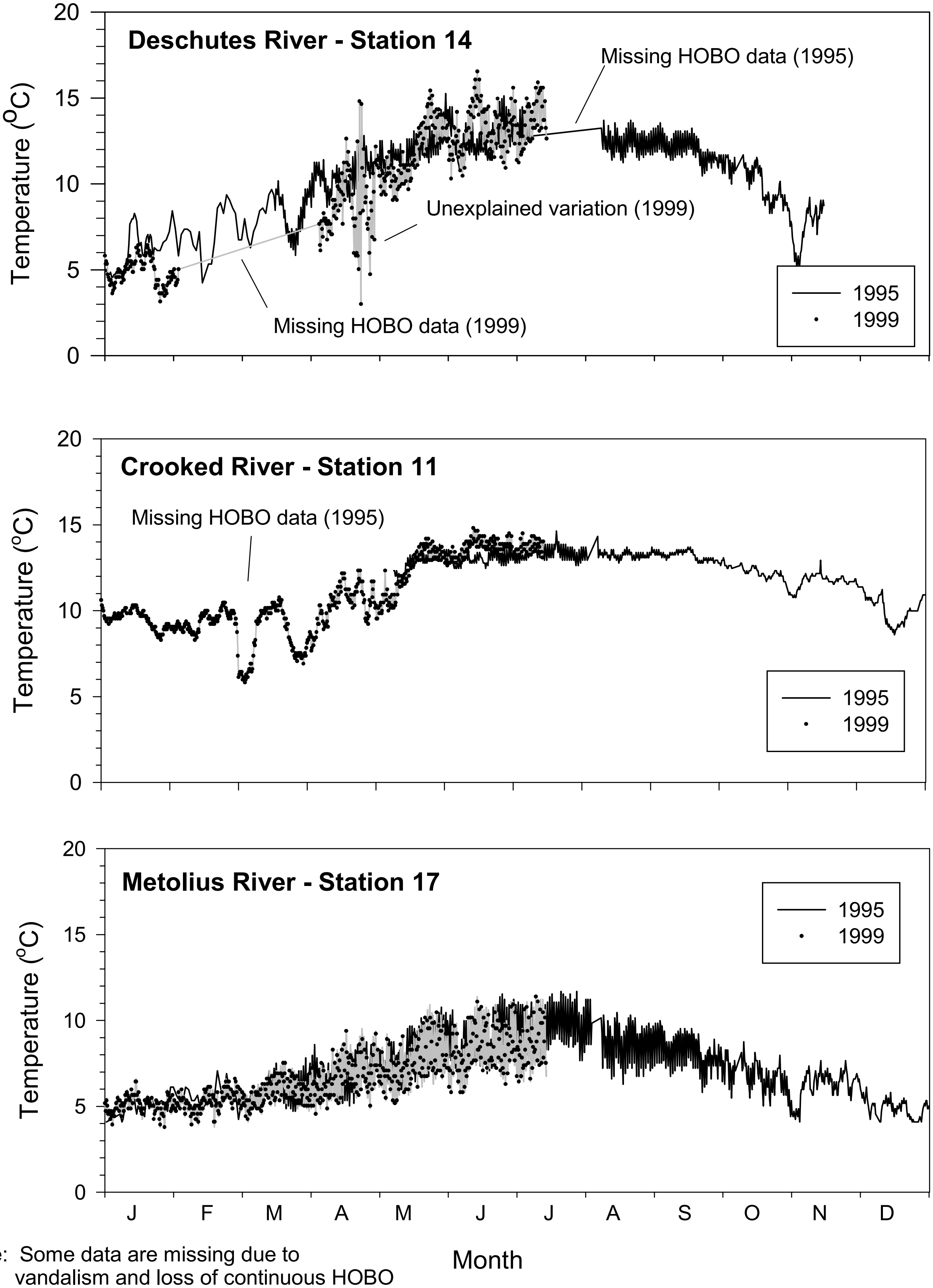
Tributary water temperatures were measured relatively continuously (hourly 1994 through 1997 and every 3 hours 1998 through 1999) using HOBO temperature monitors. Single grab measurements were also made approximately once a month during the periods of continuous tributary temperature monitoring. Some gaps in the continuous data record occurred due to loss of monitors and data during the study period. The Crooked River water temperatures are consistently higher due to warm springs in the drainage basin. The Deschutes River temperatures are slightly cooler and the Metolius River has the coldest water due to its cold spring water source. The tributary water temperatures measured in 1995 and 1999 are compared in Figure 2-7. The cause of the large diel variation observed at Station 14 on the Deschutes River during April 1999 can not be easily explained. It is possible that the sensor was moved to a nearshore location (resulting in greater solar warming and cooling over the course of the day) and then moved back to its original position before it was retrieved.

2.4.2 In-lake Temperature Profiles

Lake Billy Chinook water column profile data have been collected at eight stations within the reservoir (see Figure 2-6):

- Stations 15 and 16 located in the Metolius arm
- Station 7 located in the Round Butte Dam forebay near the intake tower
- Stations 9 and 10 located in the Crooked arm
- Stations 12 and 13 located in the upper Deschutes arm
- Station 8 located in the lower Deschutes arm

Water temperature profiles in Lake Billy Chinook were recorded at 3-hour time intervals using vertical arrays of HOBO temperature sensors at Stations 7, 10, and 13 from 1994 to 1997 and at Station 7 during 1999. Temperature profiles were monitored at all reservoir stations approximately ten times per year during 1994 to 1997 and every 2 weeks at stations 7, 8, 9, 12, and 15 during 1999. The lake is thermally stratified in the summer with a 10- to 20-meter thermocline. The data suggest that warmer water from the Crooked River may be traveling west in the surface layer of the Metolius arm while the Metolius River water dives below the thermocline and travels in the hypolimnion to the forebay and up the Deschutes arm of the reservoir.



Note: Some data are missing due to vandalism and loss of continuous HOBO sensors. Data supplemented with available grab data collected approximately monthly.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	FIGURE 2-7 1995 AND 1999 INFLOW TEMPERATURE Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
	CHECKED: T. Khangaonkar	
	DATE: December 6, 1999	
PROJECT NO: 2200.0001.0002	FILENAME: 95-99intemp.jnb	

Figure 2-8 shows the comparisons of the river inflow temperatures and the reservoir temperatures at all observed stations in April and July 1995, respectively. In April 1995, the Metolius River water is slightly colder than the reservoir bottom water and the Crooked River water is slightly warmer than the reservoir surface water. The Deschutes River temperature is about the same as the subsurface temperature in the reservoir. In July 1995, the temperature stratification in the reservoir was greatly enhanced due to surface warming. The surface temperature in the reservoir was much warmer than the warmest tributary (Crooked River). The horizontal temperature distributions at all water levels in the reservoir were almost uniform. The Metolius River temperature was colder than the bottom temperature in the reservoir and the Crooked and Deschutes River temperatures were much colder than the surface temperature in the reservoir.

Figure 2-9 shows the comparisons of the river inflow temperatures and the reservoir temperatures at all observed stations in April and July 1999, respectively. In April and July 1999 the general stratification pattern seen in 1995 is observed, although some stations, particularly Stations 8 and 9 in the lower Deschutes and Crooked arms, respectively, showed more pronounced horizontal reservoir stratification in April 1999. It is also apparent that the reservoir surface was generally cooler in April 1999 compared to April 1995. This was a result of relatively larger tributary inputs of cooler water, particularly from the Crooked, which appeared to be much cooler in April 1999 than in April 1995. By July 1999, the reservoir temperature was very similar to that observed in 1995. These observations are more apparent in the comparison of Forebay temperature profiles based on the continuous HOBO data collected in 1995 and 1999 (Figure 2-10).

2.4.3 Additional Water Quality Data

Water quality input data are required for the temperature model, and are described in more detail as part of the water quality model calibration report (ENSR and Foster Wheeler Environmental 2000). Tributary water quality data were obtained from a database produced as part of the E&S limnological study. Stations on the Deschutes (Station 14), Metolius (Station 17), and Crooked (Station 11) were sampled approximately once per month from July 1994 through October 1996. The station locations are presented in Figure 2-6. The parameters of interest extracted from the database include: chlorophyll *a*, ammonia nitrogen, dissolved oxygen, pH, nitrate+nitrite nitrogen, orthophosphate (as phosphorus), alkalinity, water temperature, and chloride.

The E&S database was supplemented with EPA STORET data to characterize the tributary water quality. The Oregon Department of Environmental Quality (DEQ) as part of their Ambient Monitoring Program collected these data. The sampling locations are summarized in Table 2-2. Parameters of interest include: chlorophyll *a*, ammonia nitrogen, dissolved oxygen, pH, nitrate+nitrite nitrogen, orthophosphate (as phosphorus), total suspended solids, alkalinity, total organic carbon, and water temperature.

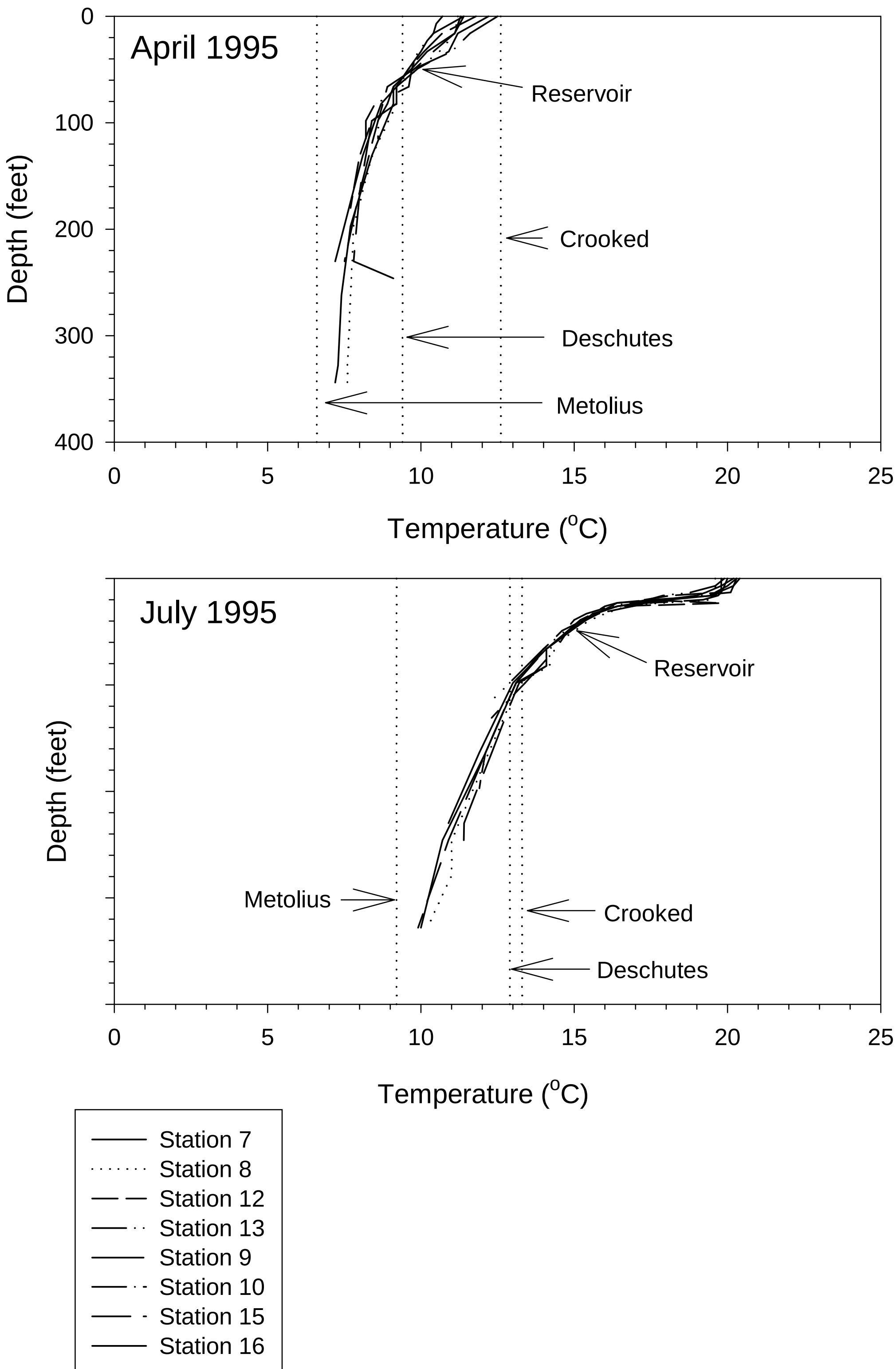
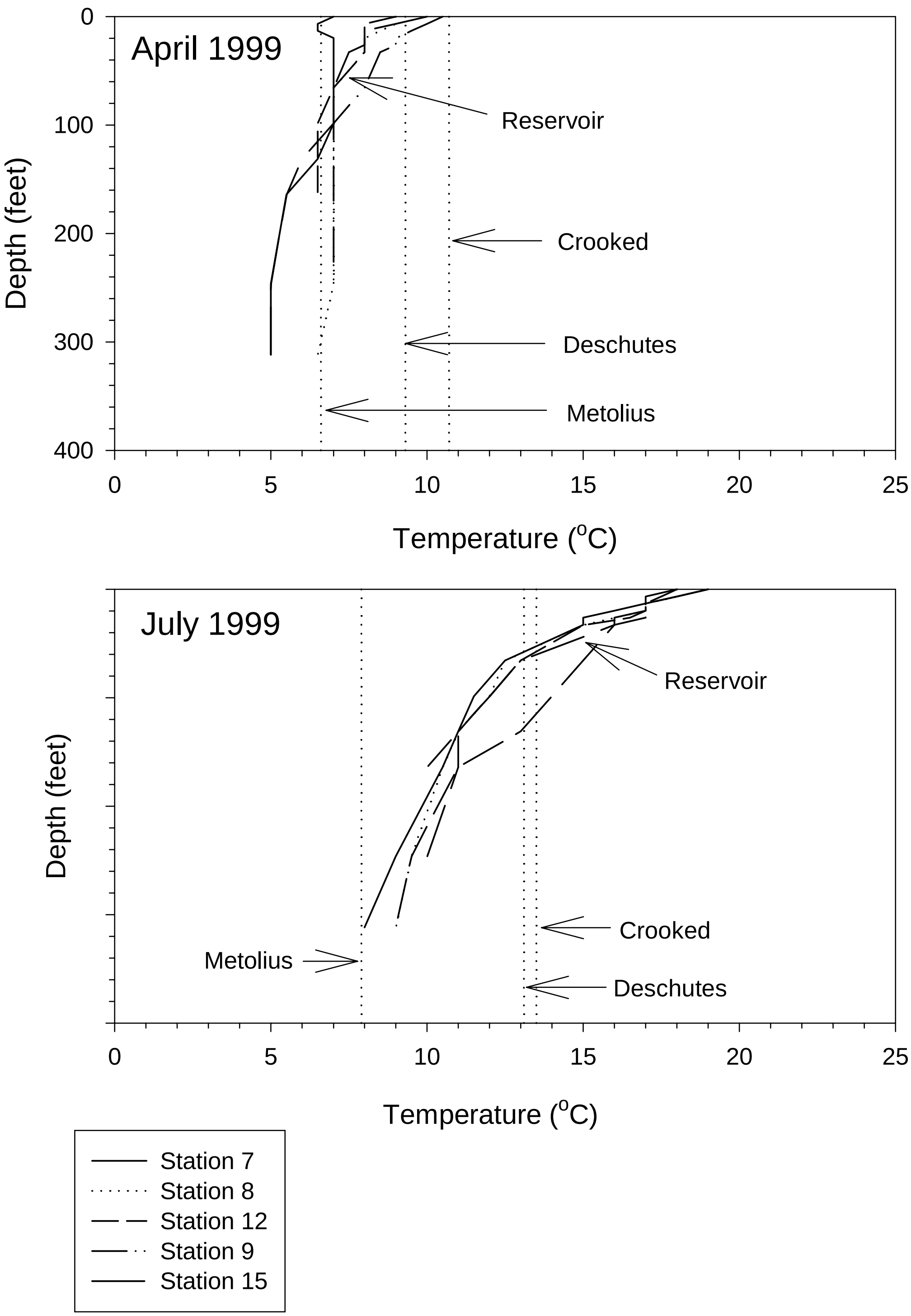


FIGURE 2-8

1995 PGE TEMPERATURE PROFILES
APRIL AND JULY 1995

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi
	CHECKED: T. Khangaonkar
	DATE: December 8, 1999
PROJECT NO: 2200.0001.0002	FILENAME: PGEprofiles.jnb



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: C. DeGasperi

CHECKED: T. Khangaonkar

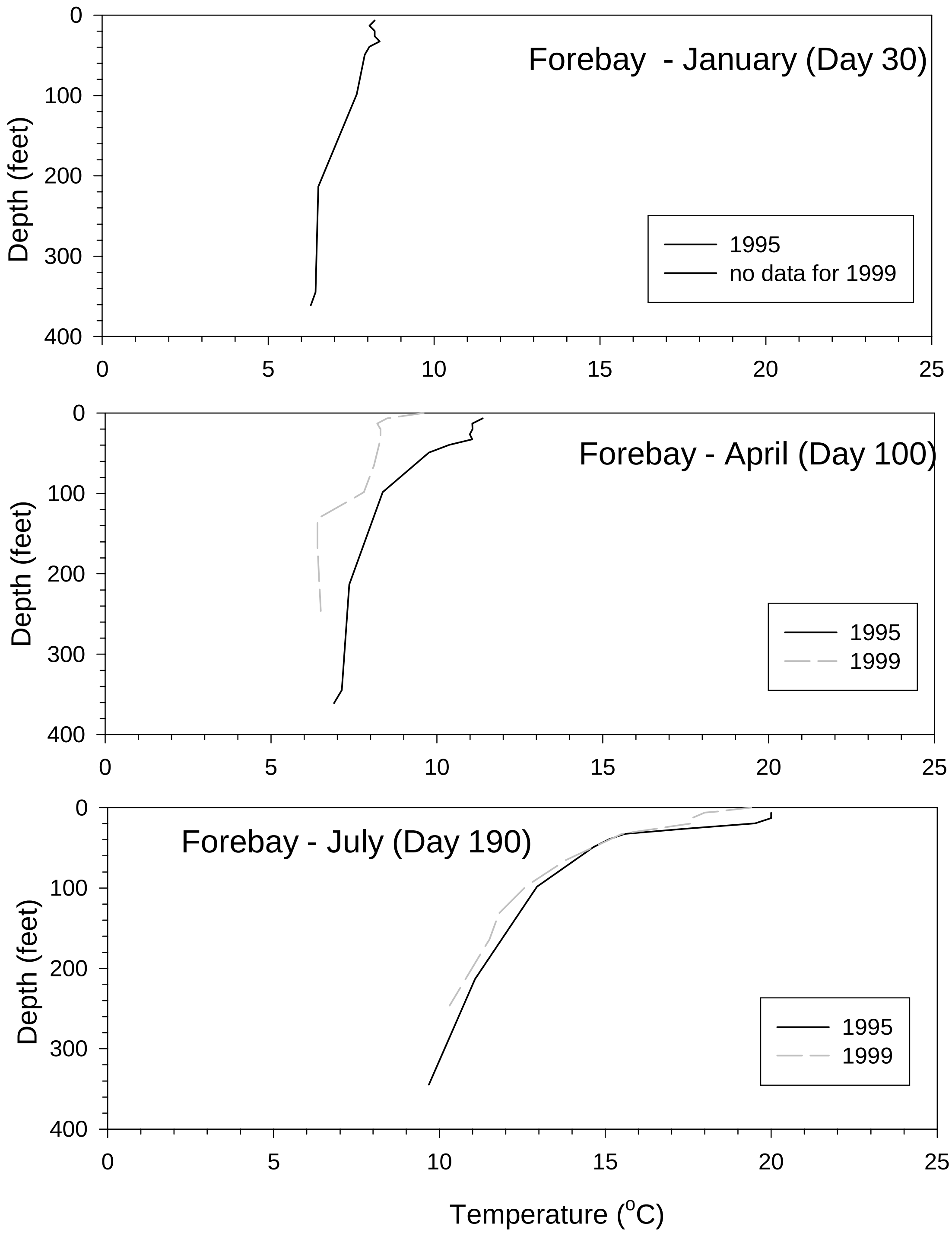
DATE: December 8, 1999

PROJECT NO: 2200.0001.0002

FILENAME: PGEprofiles.jnb

FIGURE 2-9
1999 PGE TEMPERATURE PROFILES
APRIL AND JULY 1999

Portland General Electric Company
Portland, Oregon



Note: Temperature profiles are based on the daytime average (6 AM-6PM) of continuous observations made using the HOBO temperature sensors.

FOSTER WHEELER ENVIRONMENTAL CORPORATION

PROJECT NO: 2200.0001.0002

DRAWN: C. DeGasperi

CHECKED: T. Khangaonkar

DATE: December 8, 1999

FILENAME: PGEprofiles.jnb

FIGURE 2-10

PGE TEMPERATURE PROFILES
STATION 7 1995 AND 1999

Portland General Electric Company
Portland, Oregon

The temperature model was re-calibrated to 1995 water quality conditions using the available tributary and in-lake water quality data described above (ENSR and Foster Wheeler Environmental 2000). No additional water quality data were collected in 1999. Therefore, the 1995 water quality data were used as default inputs for 1999 temperature model verification.

Table 2-2
EPA STORET Sample Station Location

Sample Station	ID Number	River Mile
Deschutes River at Lower Bridge	402178	135
Crooked River at Lone Pine Road (Terrebonne)	402187	31
Metolius River North of Camp Sherman (Bridge 99)	402637	29
Note: Data retrieved from U.S. EPA's STORET database.		

2.5 Meteorological Data

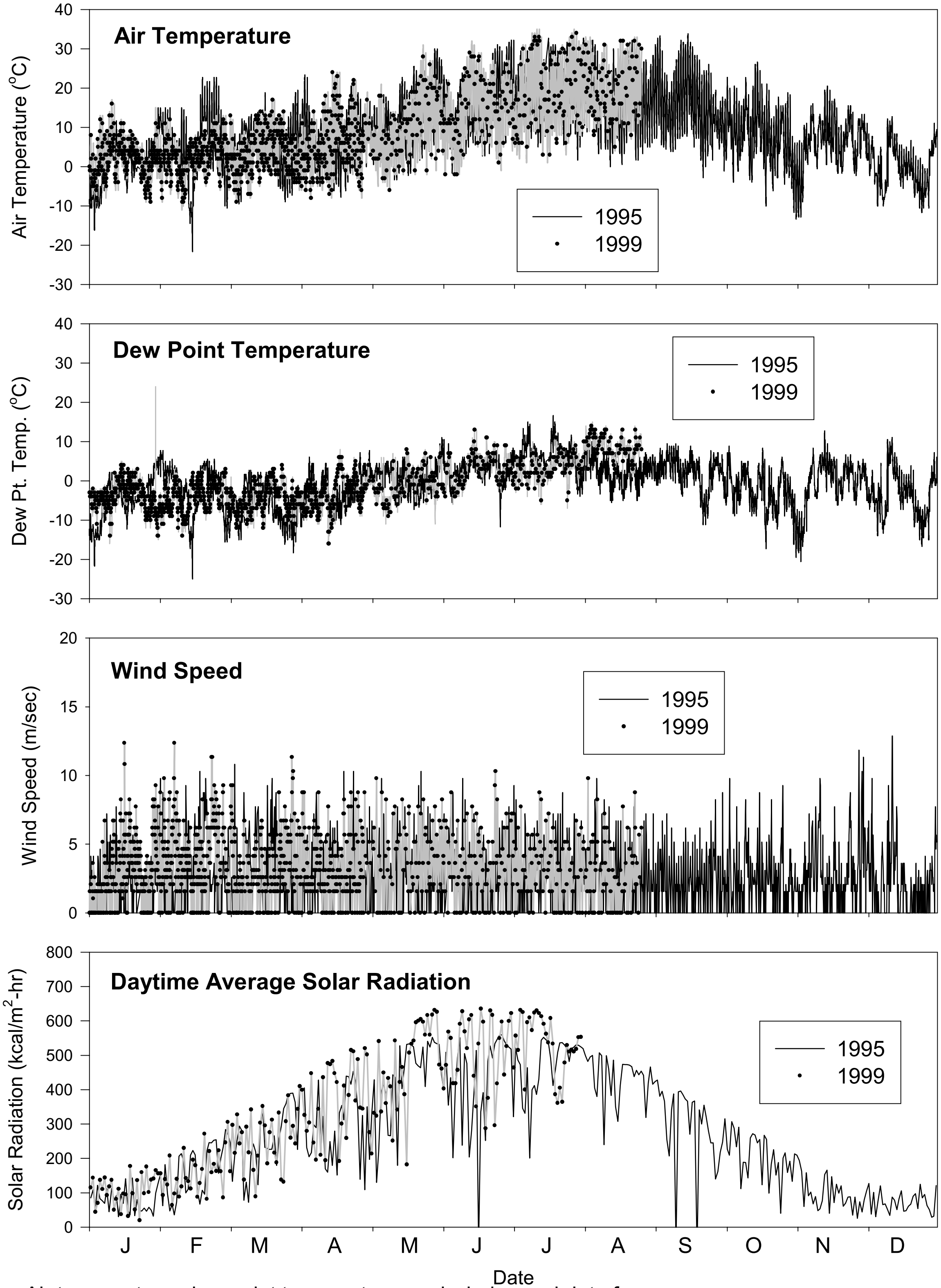
Meteorological data for use in temperature and hydrodynamic modeling have been compiled from a number of data sources and locations in the vicinity of the project, including three on-site meteorological stations set up by PGE (Figure 2-6). The available meteorological data and their sources are summarized below.

2.5.1 WRCC and Solar Radiation Monitoring Lab

Meteorological data from stations in the vicinity of Round Butte Dam were obtained from the Desert Research Institute's Western Regional Climate Center (WRCC) and the University of Oregon's Solar Radiation Monitoring Lab.

2.5.1.1 Air Temperature, Dew Point Temperature, Wind Speed

Meteorological data from Redmond Airport, approximately 15.5 miles south of the project were obtained from the WRCC. The reported air temperature, dew point temperature, and wind speed reported at Redmond Airport in 1995 and 1999 are compared in Figure 2-11. These comparisons indicate very similar temperature and wind conditions during these years.



Note: Air temperature, dew point temperature, and wind speed data from Redmond Airport, Redmond, OR. Solar radiation data from Madras, OR.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	FIGURE 2-11
	CHECKED: T. Khangaonkar	1995 AND 1999 CLIMATE DATA
	DATE: December 6, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: 95-99climdata.jnb	

2.5.1.2 Solar Radiation

Solar radiation data for 1995 and 1999 were obtained from one of the University of Oregon Solar Radiation Monitoring Lab's AgriMet stations. The station, equipped with a LiCor Pyranometer, is located in Madras, Oregon, approximately 7 miles northeast of the project. Daily average solar radiation measured at Madras in 1995 and 1999 is also compared in Figure 2-11. The pattern and intensity of solar radiation is similar during these 2 years.

2.5.1.3 Rainfall and Pan Evaporation

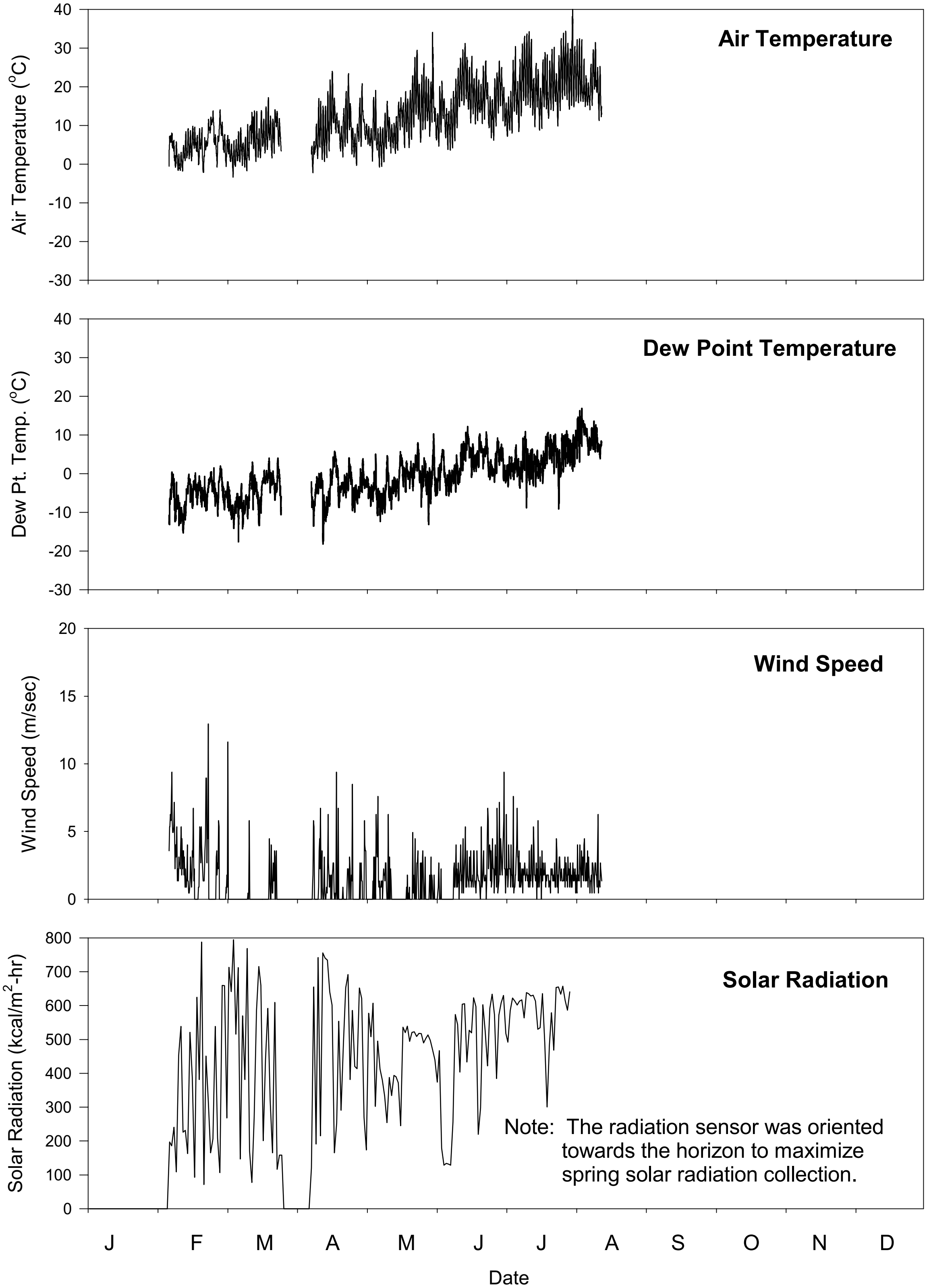
Rainfall and pan evaporation data are required by the temperature model for the development of a reservoir water budget. This budget allows for the estimation of ungauged inflows needed to balance the water budget and provide an estimate of this flow for input to the model. Rainfall data were obtained from the WRCC from a station located at Pelton Dam, approximately 7 miles north of the project. Data for 1995 and 1999 are presented in Figure 2-3. Pan evaporation data were obtained from the WRCC from a station located in Madras.

2.5.2 PGE Meteorological Stations

PGE has collected wind speed and direction data from three locations around the reservoir since 1995. One station is located at the intake tower in the forebay, another station is located on the Metolius arm, and a third station is located at the confluence of the Deschutes and Crooked arms of the reservoir (Figure 2-6). In 1999, monitoring of air temperature, dew point, and solar radiation was added to the forebay tower station and air temperature was added to the other two stations.

Figure 2-12 shows the recorded air temperature, dew point temperature, wind speed, and solar radiation at the Intake Tower station in 1999. Some data gaps in the continuous monitoring record occurred due to equipment failure. The anomalous pattern in solar radiation (highest radiation in spring) is due to the optimization of the pyranometer for spring radiation collection.

FOREBAY INTAKE TOWER - PGE 1999 METEOROLOGICAL DATA



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	FIGURE 2-12
	CHECKED: T. Khangaonkar	1999 PGE METEOROLOGICAL DATA FOREBAY INTAKE TOWER
	DATE: December 6, 1999	Portland General Electric Company
PROJECT NO: 2200.0001.0002	FILENAME: 99PGEclimdata.jnb	Portland, Oregon

Wind data from late April to mid July 1999 in Intake Tower, Deschutes and Metolius meteorological stations are presented in Figures 2-13, 2-14 and 2-15, respectively. Wind data were recorded in 30-minute intervals. Wind data were provided by PGE as text compass directions, i.e., N (0 degrees), NNE (22.5 degrees), NE (45 degrees), etc. The resolution of wind directions is 22.5 degrees. There are some large data gaps in the Intake Tower and Deschutes wind data. Significant diurnal signals in both wind speed and direction are observed in all three stations. Wind directions in daytime appear to be opposite to the wind directions in nighttime of the same day. The diurnal wind pattern is probably caused by the opposite temperature gradients at the air-ground interface during the day and at night. Wind speeds were in the range of 0-10 m/s in the Intake Tower and Deschutes stations, and 0-15 m/s in the Metolius station. Figure 2-16 shows the wind roses for the same wind data sets in the Intake Tower, Deschutes, and Metolius stations. The dominant wind directions are northeast-north and southwest-south in the Intake Tower station. In Deschutes station, dominant wind directions are southeast-east and northwest-west, which are not orientated along the Deschutes and Crooked River channels. In the Metolius station, the dominant wind direction is downstream toward the east along the river channel.

2.6 Synoptic Velocity and Temperature Profile Data Collection Program

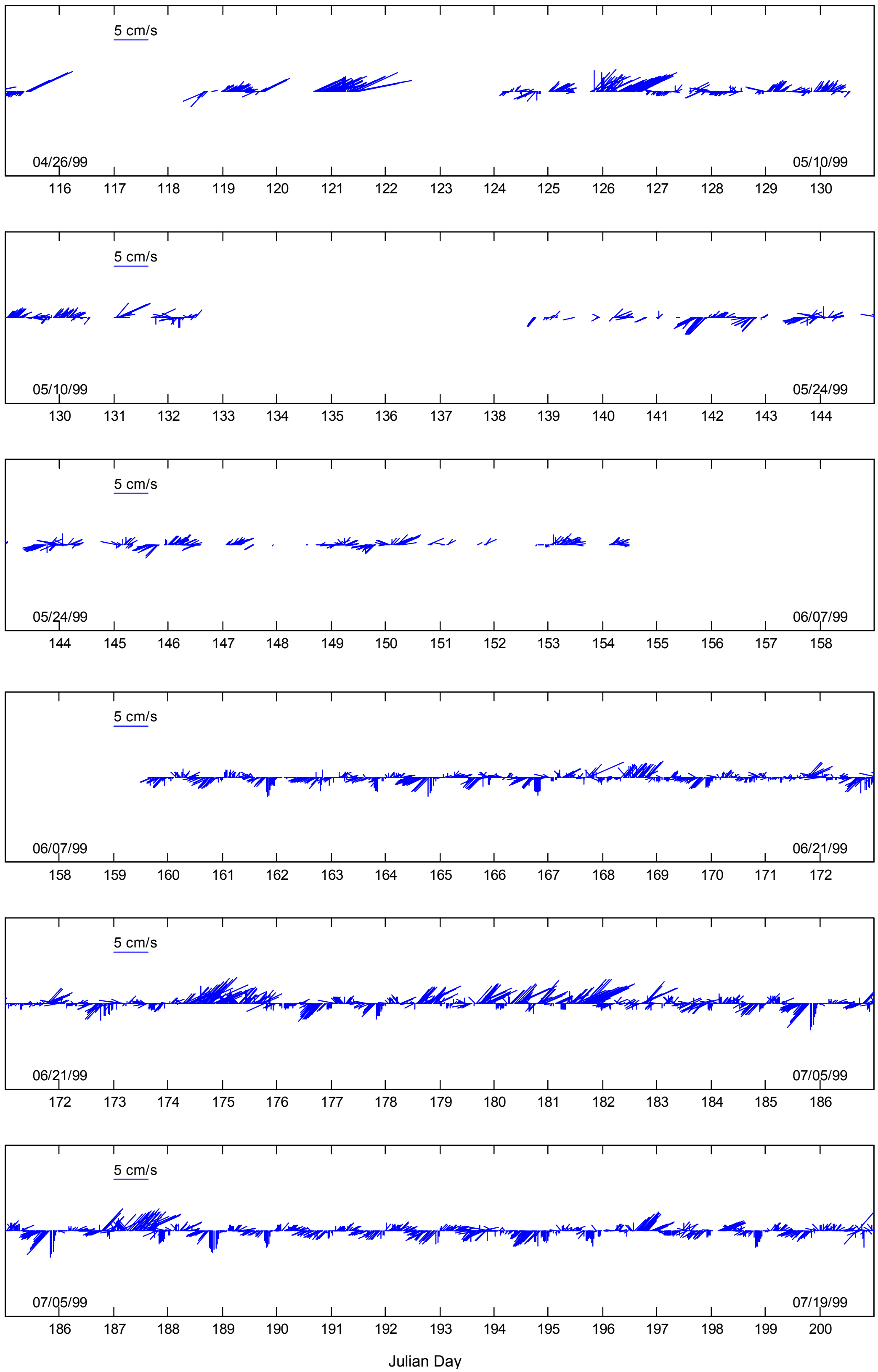
2.6.1 Data Collection

Data relating to current velocity and temperature were collected at stations on the Metolius, Crooked, and Deschutes Rivers and in the forebay in the vicinity of the Pelton-Round Butte Dam. The locations and depths of the sample stations are listed in Table 2-3 and shown in Figure 2-6.

Table 2-3
Lake Billy Chinook Array Coordinates

Location	Northing (m)	Easting (m)	Depth (ft)
Metolius	4,938,097	632,668	307
Crooked	4,935,184	637,454	262
Deschutes(1)	4,935,518	636,283	262
Deschutes(2)	4,935,520	636,283	262
Forebay(1)	4,940,088	636,360	365
Forebay(2)	4,940,086	636,361	365

(1) Initial deployment location
(2) Location after mid-deployment data recovery
Coordinates are NAD 83 UTM Zone 10
Depths based on a reservoir pool surface elevation of 1945 feet



Note: The orientation of the sticks indicates the wind flow direction ("to").

FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: January 18, 2000

PROJECT NO: 2200.0001.0002

FILENAME: pgeplots-P.doc

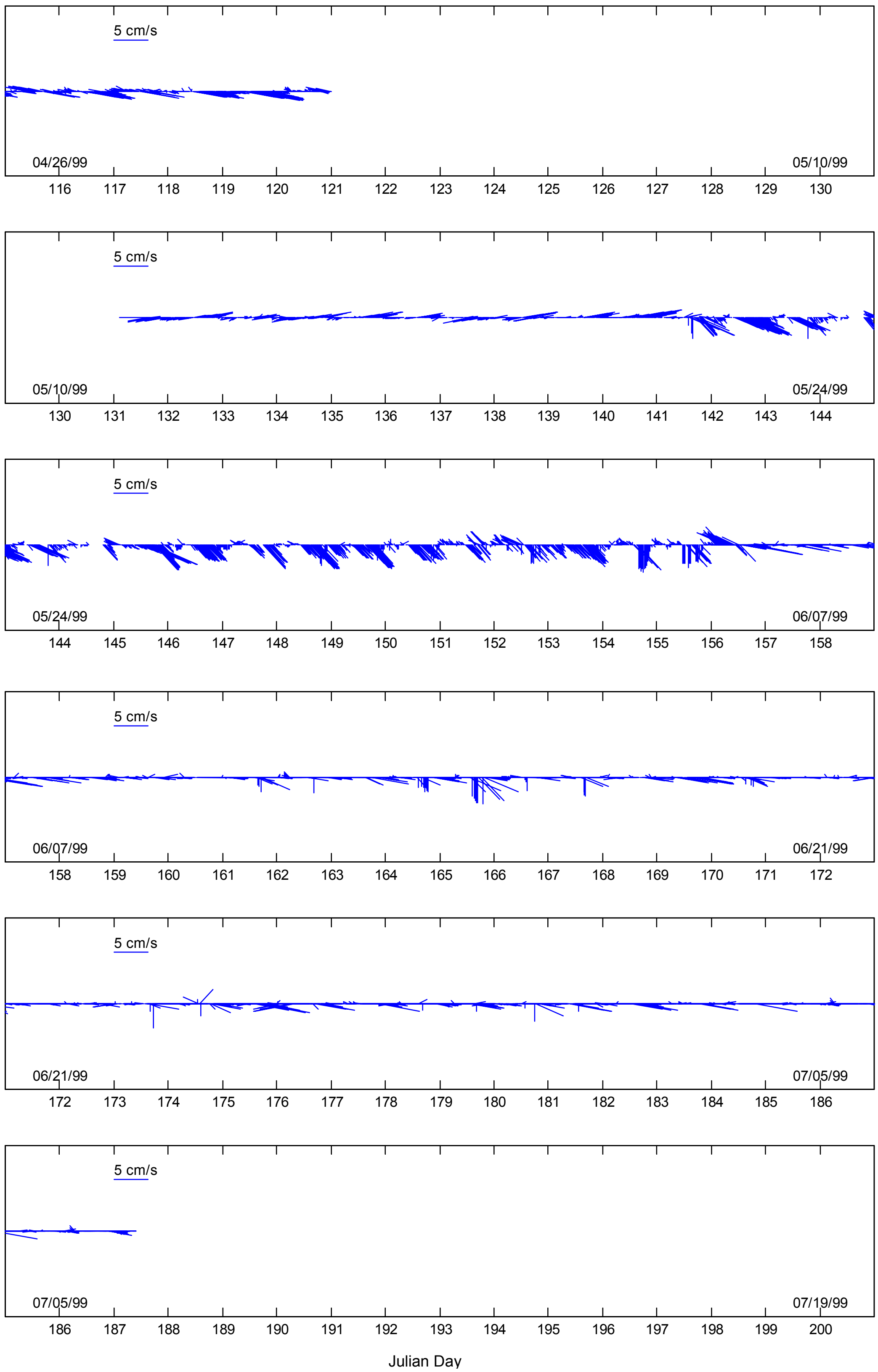
FIGURE 2-13

PGE 1999 FOREBAY WIND DATA

Pelton Round Butte Hydroelectric Project No. 2030

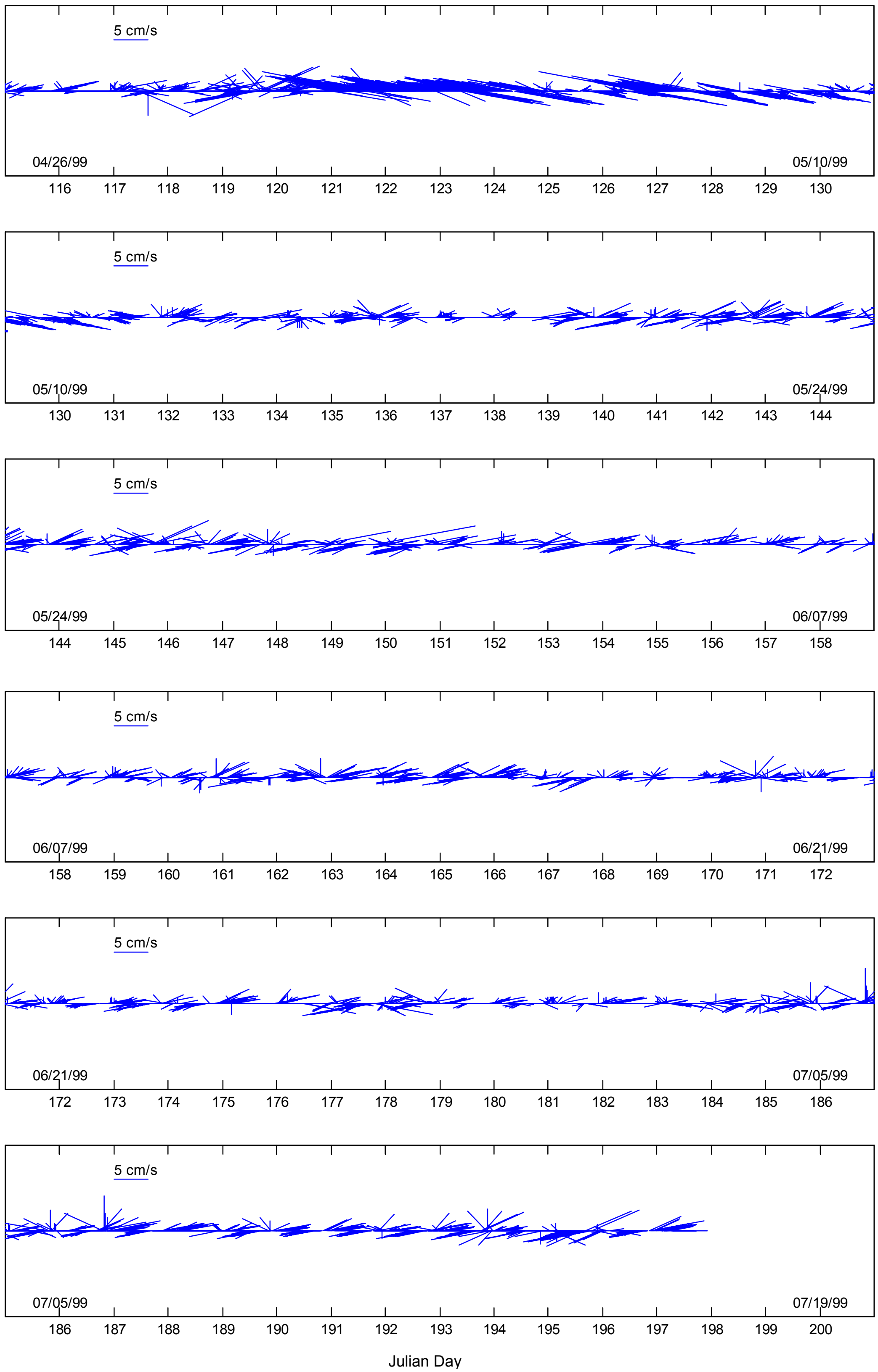
Portland General Electric Company

Portland, Oregon



Note: The orientation of the sticks indicates the wind flow direction ("to").

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: January 18, 2000	**FIGURE 2-14** PGE 1999 DESCHUTES WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	



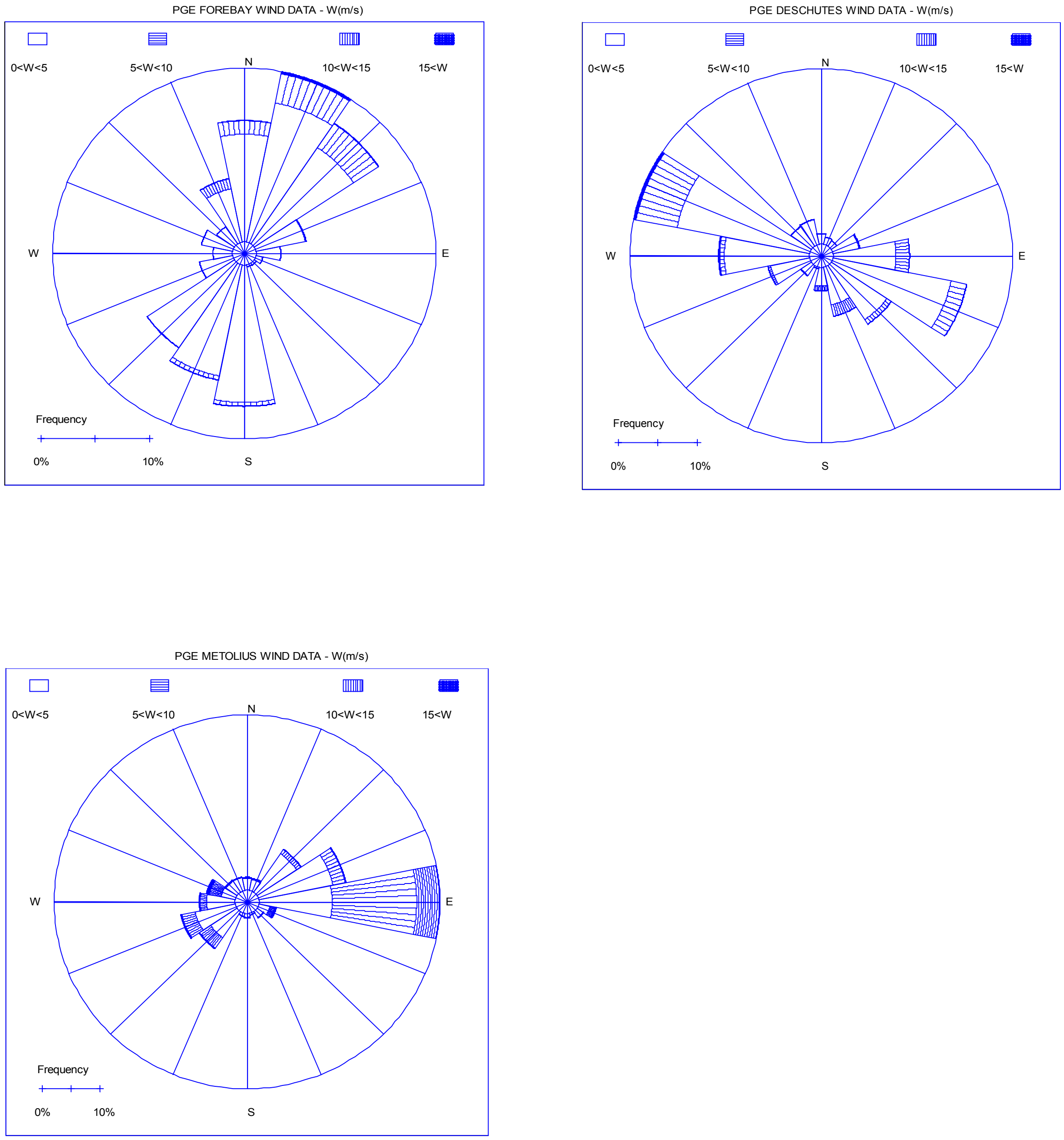
Note: The orientation of the sticks indicates the wind flow direction ("to").

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: January 18, 2000
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc

FIGURE 2-15

PGE 1999 METOLIUS WIND DATA

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon



Note: Wind orientation angle is the wind flow direction ("to").

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: January 18, 2000	**FIGURE 2-16** WIND ROSES, 1999 Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	

Prior to the actual deployment of instruments and the collection of data, a reconnaissance trip was made to Lake Billy Chinook to examine the proposed sites. At the river sites, each location was examined by underwater video to determine if any hazards to successful deployment and recovery were present. At each location, trees were present but enough clear bottom was available to deploy a bottom-mounted current meter array.

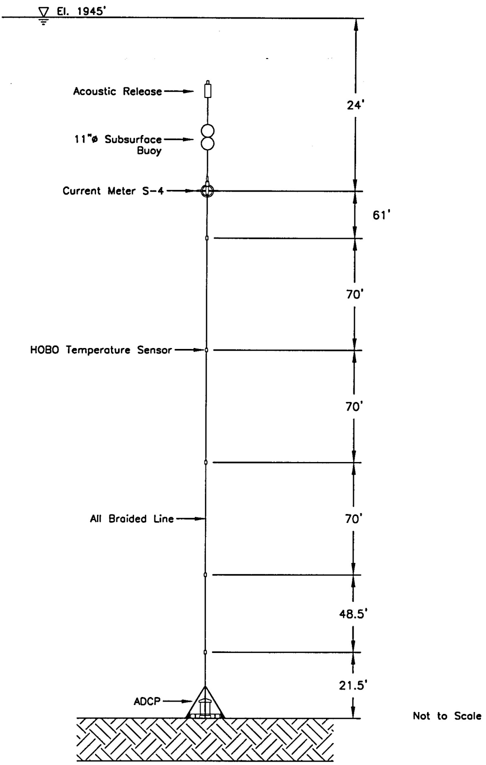
2.6.2 Instruments

Two types of current meters were used to measure currents in the reservoir. Bottom mounted upward-looking RD Instruments ADCPs were used to measure current throughout most of the water column at each station. Electromagnetic 2D current meters (InterOcean S4s or a Coastal Leasing Miniflow) were deployed in the top 10 meters of the water column at each station to measure current speed and direction. These were required because ADCP readings become unreliable near boundaries, in this case, the air-water interface. The surface current meters were serviced and calibrated by the manufacturer prior to deployment. The ADCPs required no calibration for velocity, but the internal fluxgate compass of each was calibrated at the site just prior to deployment. The surface current meters measured currents with an accuracy of ±1 cm/s over a range of 350 cm/s, and directions with an accuracy of 0.5 degrees. The ADCPs measured currents with an accuracy of ±0.5 cm/s over a range of 500 cm/s.

The temperature sensors used for this study were Onset Corporation HOBO data loggers deployed in waterproof housings. These sensors measured temperature with an accuracy of ±0.2 degrees centigrade with a resolution of 0.35 degrees.

The current meter arrays consisted of an ADCP attached to a stainless steel frame weighted with 200 pounds of lead. A deployment line extended from the frame to an acoustic release approximately 10 to 15 feet below the water surface. Six temperature sensors were deployed at approximately uniform intervals along the mooring line. The exceptions to this spacing were the upper and lower sensors. The lower sensor was attached to the mooring line as close as possible to the ADCP without interfering with the ADCP operation. The upper sensor was attached to the acoustic release to measure temperature as high in the water column as possible. A schematic of a typical array is shown in Figure 2-17a.

Once the location for an ADCP array had been chosen, the depth was determined and the array constructed on the boat. During deployment, the reservoir water surface elevation was approximately 7 feet below the normal pool elevation of 1,945 feet. This made it difficult to construct the arrays so that when the pool was at a normal level the S4 current meters were within



ENSR Consulting • Engineering • Remediation	DRAWN: W. Bowles	FIGURE 2-17a
	CHECKED: C. Sweeney	FOREBAY CURRENT METER ARRAY
	DATE: Jan. 21, 2000	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 5499-003-900	FILENAME: PGEarray	

30 feet of the surface. As originally deployed, the S4 current meters were within 15 to 20 feet of the surface. As the water level rose to 1,945 feet, the depth of the S4s increased to between 22 and 27 feet below the surface. The S4s could not be placed at the top of the arrays because the flotation buoys and acoustic releases needed to be above them and there needed to be sufficient space between the S4 and the buoys so the buoys would not interfere with S4 current measurements.

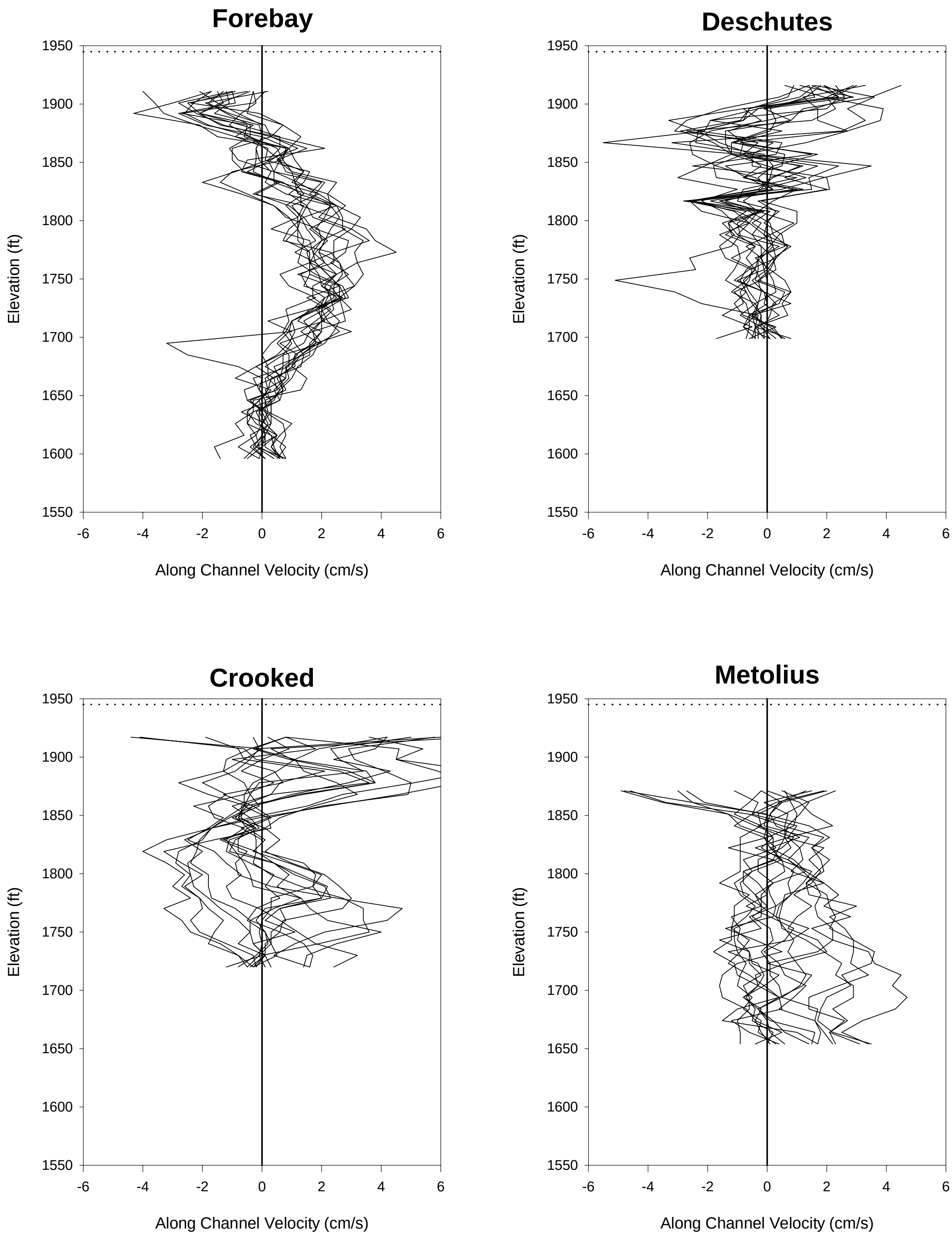
The current meter arrays were deployed from April 23 to April 26, 1999. The actual deployment site for each station was chosen using both underwater video and a precision depth recorder. Upon arrival at each site, a bathymetric cross-section was measured using a Ross precision depth recorder. The analog record from the recorder, in conjunction with position data recorded by the boat's navigation system allowed areas suitable for deployment near the station's nominal coordinates to be identified. When a flat area large enough for deployment was identified, it was examined by underwater video for debris which would not show up in the analog bathymetry record. If the site was free of debris, the current meter array was deployed. After deployment, the array was examined again to make sure that it was sitting correctly on the bottom. The arrays were deployed in the thalweg of each river and in the deepest part of the dam forebay near the proposed measurement location. The position of each array was determined using differential GPS with an accuracy of ± 1 meter.

The ADCPs were programmed to record velocities in 3-meter-high bins throughout the water column. The ADCP measured velocity once each second for a 250-second period every 1 ½ hours. The S4s measured currents twice a second for 2 minutes every ½ hour and the Miniflow measured currents for 1 minute every ½ hour. Temperature was recorded every 2 hours.

The arrays were recovered and serviced during the week of June 21, 1999. The data from each instrument were downloaded, the instrument reprogrammed, and redeployed. Final recovery of the instruments occurred during August 9 and 10, 1999. Complete data sets were recovered from each instrument except for the Miniflow current meter in the Deschutes River. Data from this instrument indicated that battery power ceased July 12. Data collected by this instrument prior to battery failure were successfully downloaded.

2.6.3 ADCP Velocity Profile Data

ADCP data were first processed and analyzed at 1 ½ hour intervals for all the stations for a 7-day period in late April and mid-July, respectively, for calibration and verification purposes. However, it was found that velocity magnitudes were very small (on the order of about 3 cm/s in general) and there were strong temporal variations in all the ADCP velocity profiles. Figure 2-17b shows the ADCP velocity profiles at intervals of 1 ½ hour at all four mooring stations on April 30, 1999. Positive value (right side of the dashed line) represents downstream flow. Except for the Forebay



Note: All ADCP profiles are at one and half hours intervals.
Positive values represent downstream flow.

FIGURE 2-17b

ADCP PROFILES, APRIL 30, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

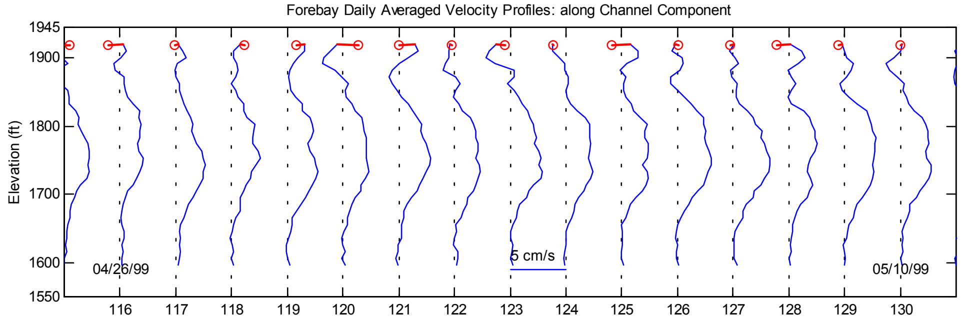
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	
	CHECKED: T. Khangaonkar	
	DATE: January 18, 2000	
PROJECT NO: 2200.0001.0002	FILENAME: adcphourly.jnb	

station, no clear velocity distribution patterns can be identified directly from the instantaneous velocity profiles at the Deschutes, Crooked and Metolius stations. The velocity magnitudes were on the order of 2 to 3 cm/s, however, the ranges of velocity magnitude variations were as large as 6 cm/s. Therefore, it is difficult to utilize the instantaneous ADCP velocity profiles for the hydrodynamic model calibration and verification. Further data analysis efforts were necessary to extract useful information from the direct observed ADCP data.

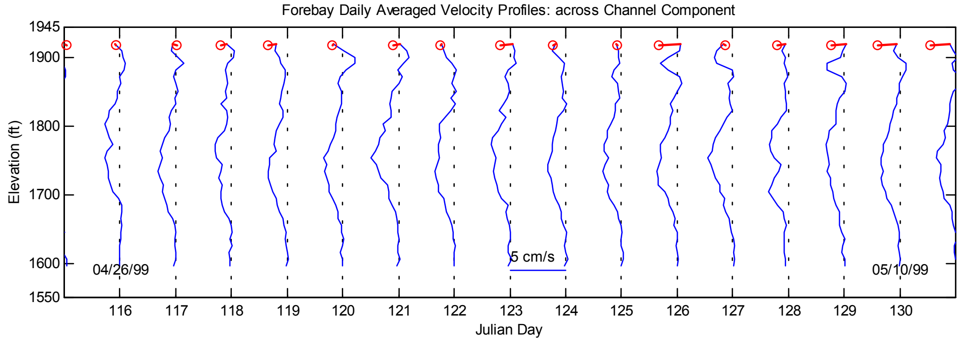
ADCP velocity profile data were resolved into the along-channel and across-channel components. Then daily and 7-day moving averages over time were applied to the entire data set to reduce the temporal variations. Figures 2-18 through 2-21 show the moving averaged results of ADCP velocity profiles at all four stations from April 26, 1999 to May 10, 1999. Daily and 7-day averaged ADCP velocity profiles for the entire data set are presented in Figures A-1 through A-8 in Appendix A. Velocity profiles at all stations show much more consistent distribution patterns when 7-day moving averages were applied. The surface velocities from S4 current meters are also plotted in the same figures for comparisons with the ADCP velocity profiles. However, there is no strong consistency between the S4 current meter results and the top ADCP bin results for the entire record. At the Forebay station, water movement toward the Forebay at about elevation 1,750 feet is evident due to the outflow discharge at the power intake (Figures A-1 and A-2). Velocities in the Deschutes arm were very small in most of the water column. There was a downstream flow at the subsurface layer near 1,900 feet, which may have been caused by the Deschutes River inflow, and an upstream flow at the surface, which may be caused by the wind effect or Crooked surface currents (Figures A-3 and A-4). Velocities in the Crooked arm were very small; below 1,900 feet during most of the observation period. Above 1,900 feet, ADCP profiles always showed a tendency of downstream flow, while S4 current meter data showed upstream and downstream flows at different times, which may have been due to temporal wind patterns. During the period of April 27 to May 12, 1999, a relatively strong downstream flow was observed in the ADCP data (Figures A-5 and A-6). The reason for such a strong flow at the mid-layer of the water column is unknown. In the Metolius arm, ADCP velocity profiles show downstream flow in mid- and lower-water column and upstream flow in the upper-water column (Figures A-7 and A-8).

Daily Averaged

Forebay Daily Averaged Velocity Profiles: along Channel Component

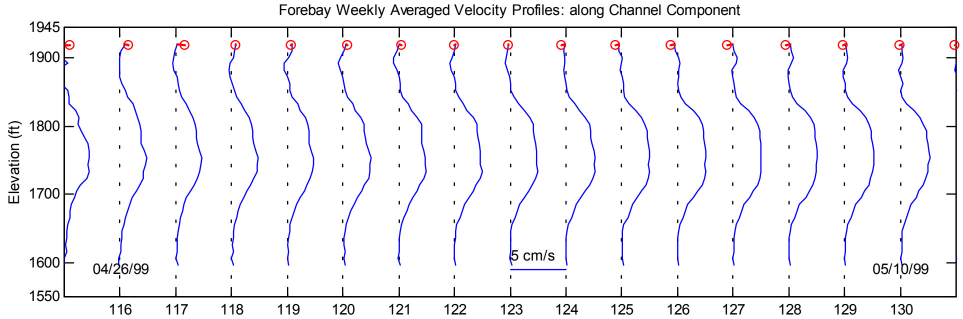


Forebay Daily Averaged Velocity Profiles: across Channel Component

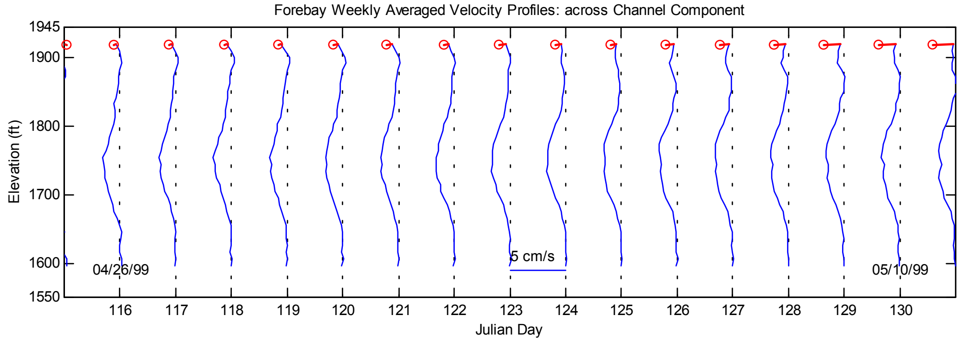


7-day Averaged

Forebay Weekly Averaged Velocity Profiles: along Channel Component



Forebay Weekly Averaged Velocity Profiles: across Channel Component



Note: circle represents S4 surface velocity data

FOSTER WHEELER
ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

PROJECT NO: 2200.0001.0002

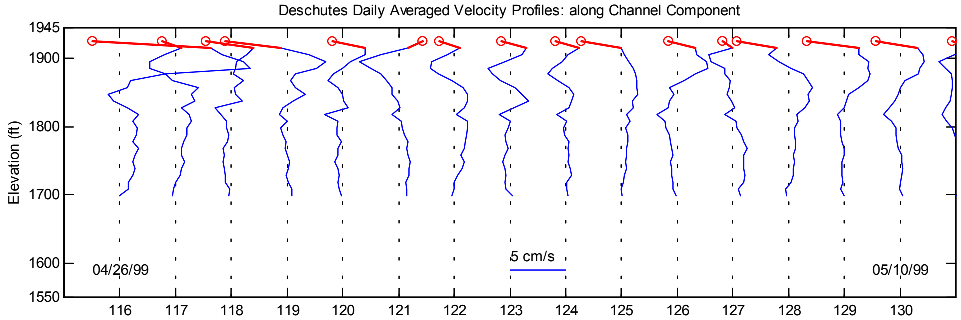
FILENAME: pgeplots-P.doc

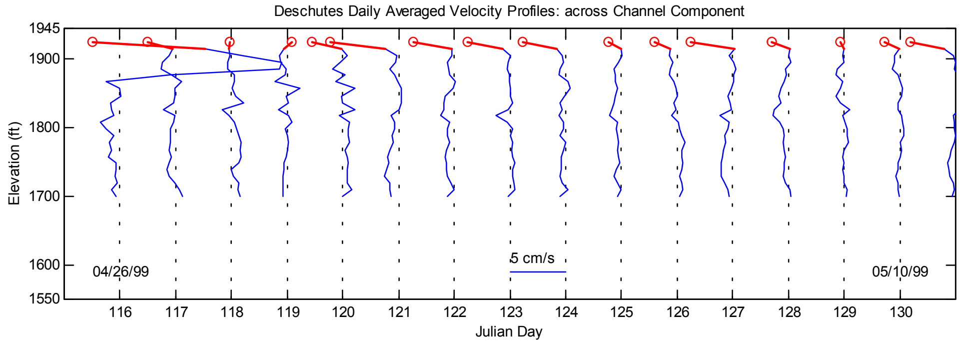
FIGURE 2-18

FOREBAY ADCP PROFILES

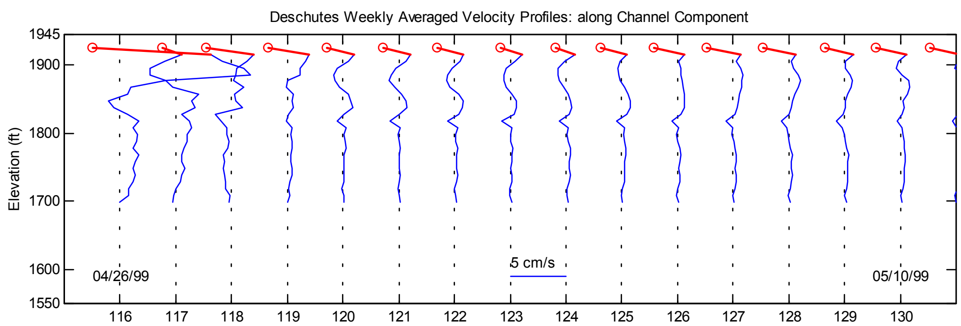
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

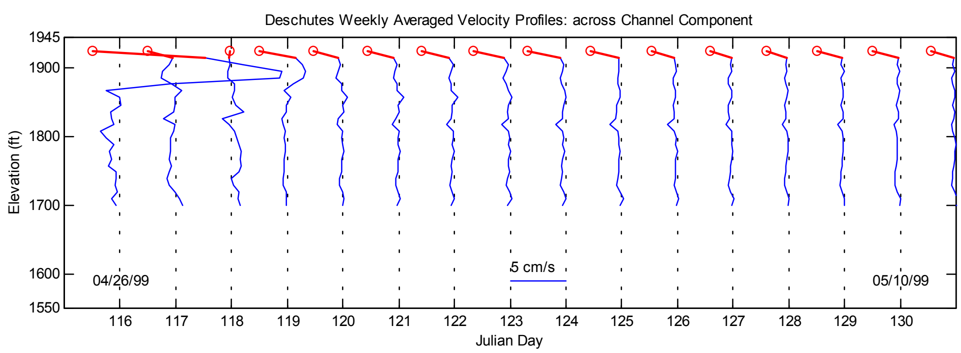
Daily Averaged





7-day Averaged

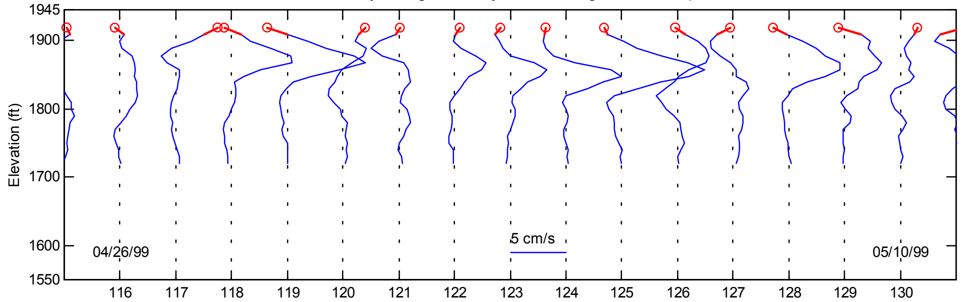


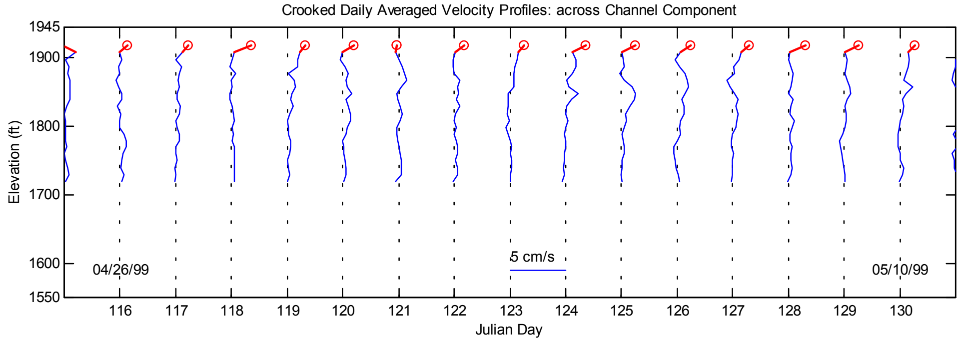


Note: circle represents S4 surface velocity data

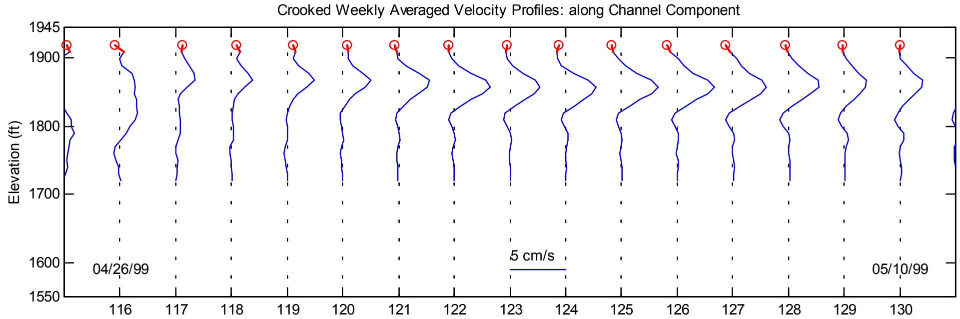
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE 2-19**
	CHECKED: T. Khangaonkar	DESCHUTES ADCP PROFILES
	DATE: December 22, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	

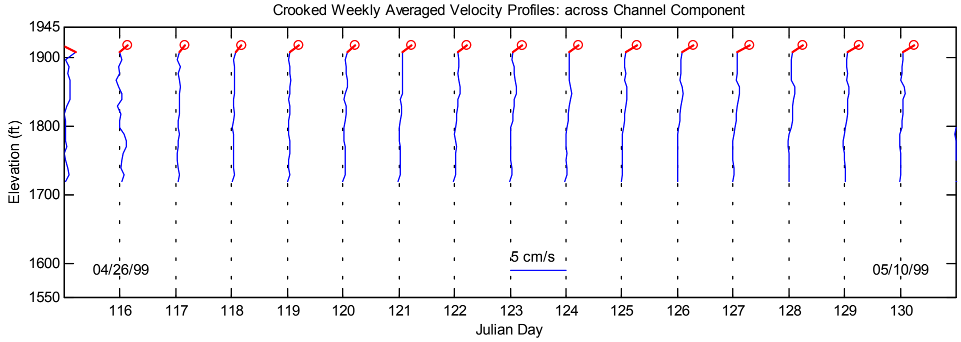
Daily Averaged





7-day Averaged

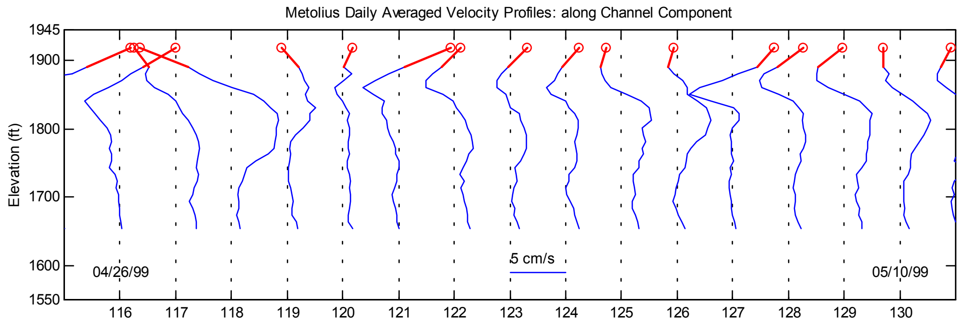


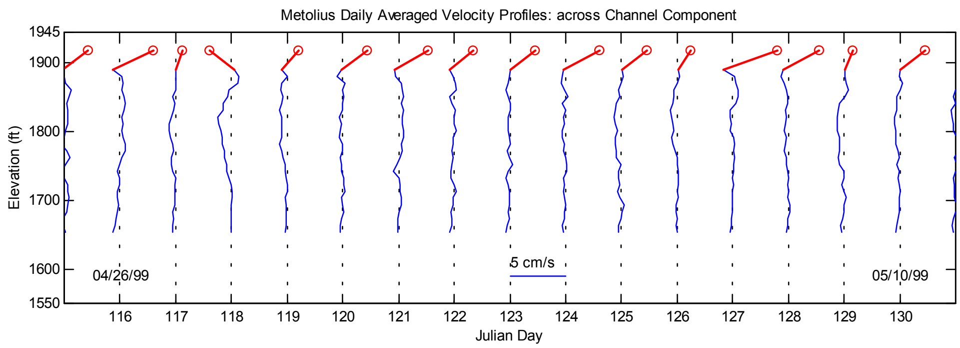


Note: circle represents S4 surface velocity data

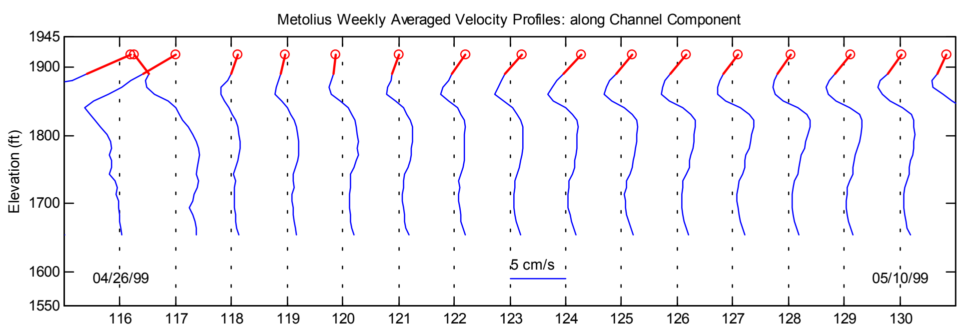
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE 2-20** CROOKED ADCP PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	

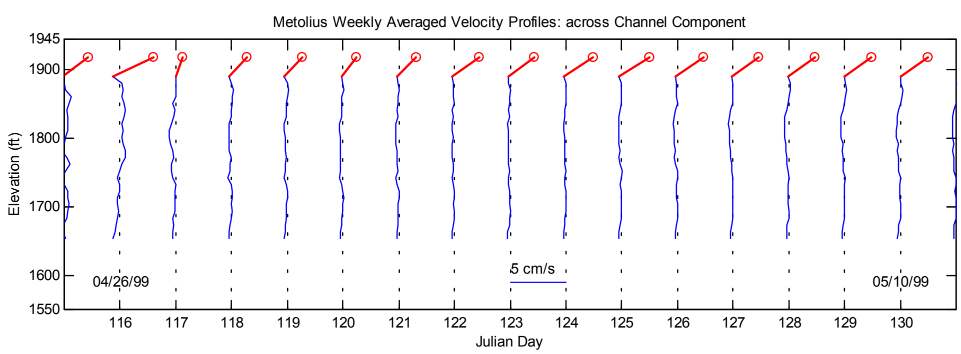
Daily Averaged





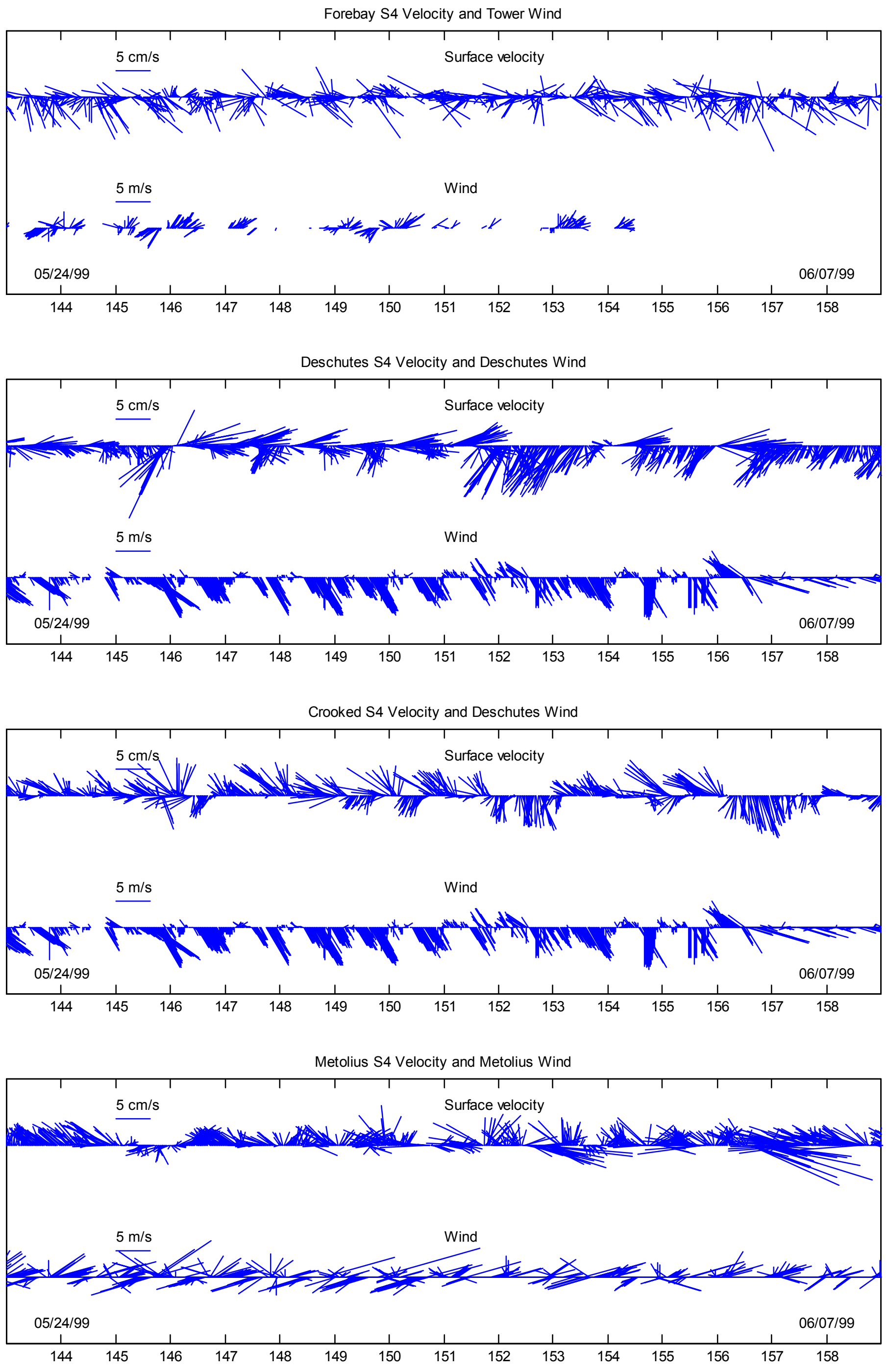
7-day Averaged





Note: circle represents S4 surface velocity data

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE 2-21** METOLIUS ADCP PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
	CHECKED: T. Khangaonkar	
	DATE: December 22, 1999	
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	



Note: The orientation of the sticks indicates the wind flow direction ("to").

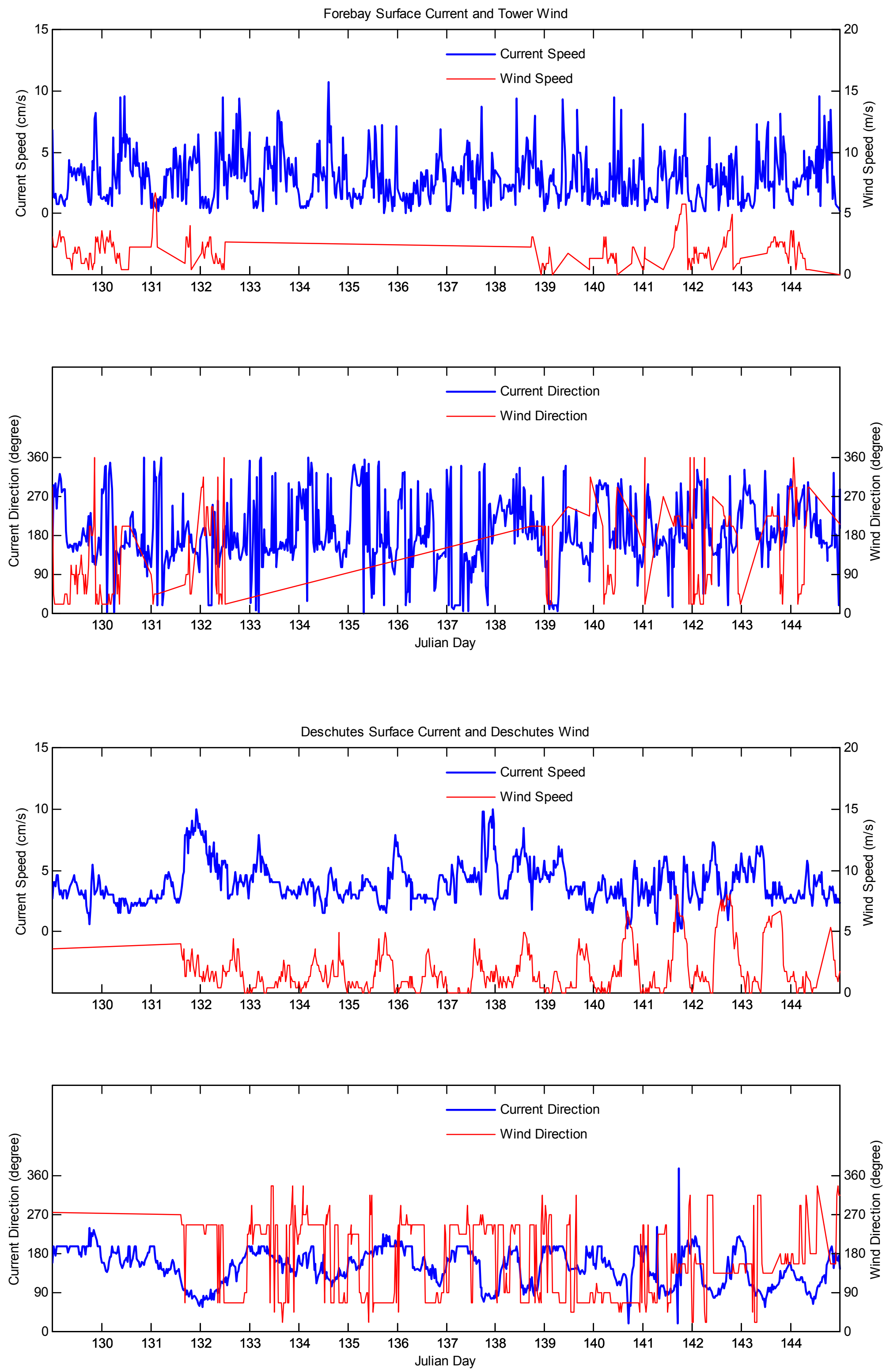
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE 2-22**
	CHECKED: T. Khangaonkar	S4 AND WIND STICKS
	DATE: January 18, 2000	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	

2.6.4 Surface Velocity Data (S4 Current Meter)

Instantaneous surface velocities obtained from S4 current meters for the period of May 24 to June 7, 1999 at all four mooring stations are plotted in Figure 2-22. S4 velocity vector plots for the entire data set at four stations are shown in Figures A-9 through A-12 in Appendix A. In order to correlate the surface velocities to the wind data, wind vectors are also plotted in the same figures for the same period. S4 velocity magnitudes were much greater than those of ADCP velocity profiles. There were strong diurnal variations in both the S4 current data and wind data. Figures 2-23a and 2-23b show the comparison of S4 current speeds and directions with the wind speeds and directions for the period of May 24 to June 7, 1999. Plots for similar comparisons for the entire data set are given in Figures A-13 through A-16 in Appendix A. The current speeds and wind speeds are strongly correlated in a diurnal variation pattern. The correlation between current and wind directions is not as clear as that between current and wind speeds. Further analysis using better methods, such as Fourier Transform, may be necessary in order to identify the correlation between S4 surface velocities and wind data. Figure 2-24 shows the S4 surface current roses based on the entire data record for all the stations. Apparently, current directions are dominant in the east in the Forebay. In the Deschutes arm, dominant currents are in a southerly direction, but with some portion of the data showing an easterly flow, which is in the across-channel direction. In the Crooked arm, southern and northwestern flows are observed. In the Metolius arm, current directions seem to be very scattered. However, for velocities greater than 5 cm/s, velocity directions are mainly in the westerly direction, which indicates upstream surface flow in the Metolius arm.

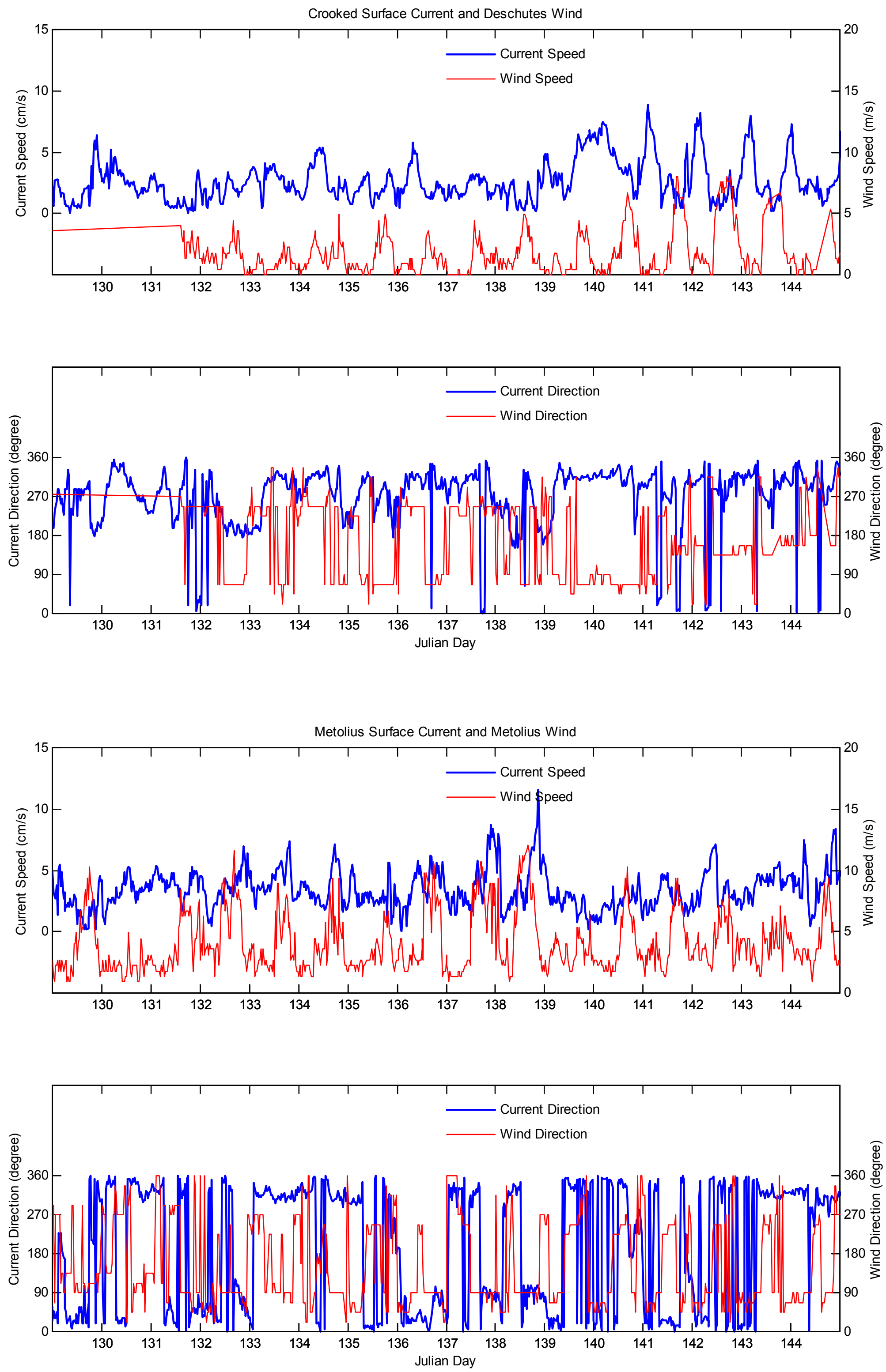
2.6.5 Temperature Profiles

Figure 2-25 shows the daily averaged temperature profiles observed by ENSR for the period of May 10 to May 24, 1999 at all four stations. Temperature profiles for the entire data record are plotted in Appendix A in Figures A-17 through A-20. A slow surface warming from May 10 to May 24, 1999 in all the stations is observed in Figure 2-25. However, the changes in bottom temperatures in all stations are very small. This indicates the development of temperature stratification in the water column as the atmospheric temperature increases.



Note: circle represents S4 surface velocity data

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: January 18, 2000	**FIGURE 2-23a** S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	

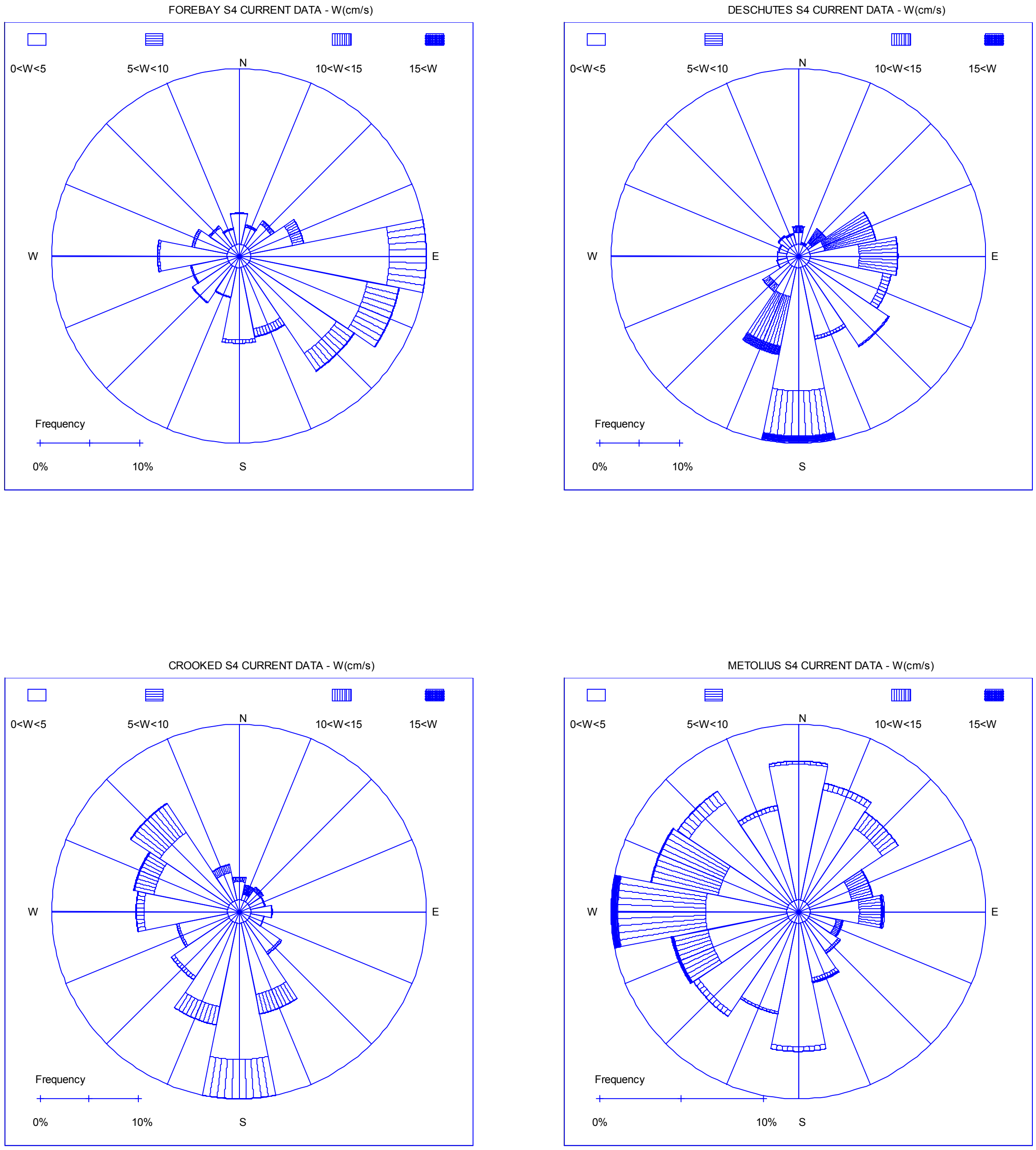


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: January 18, 2000
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc

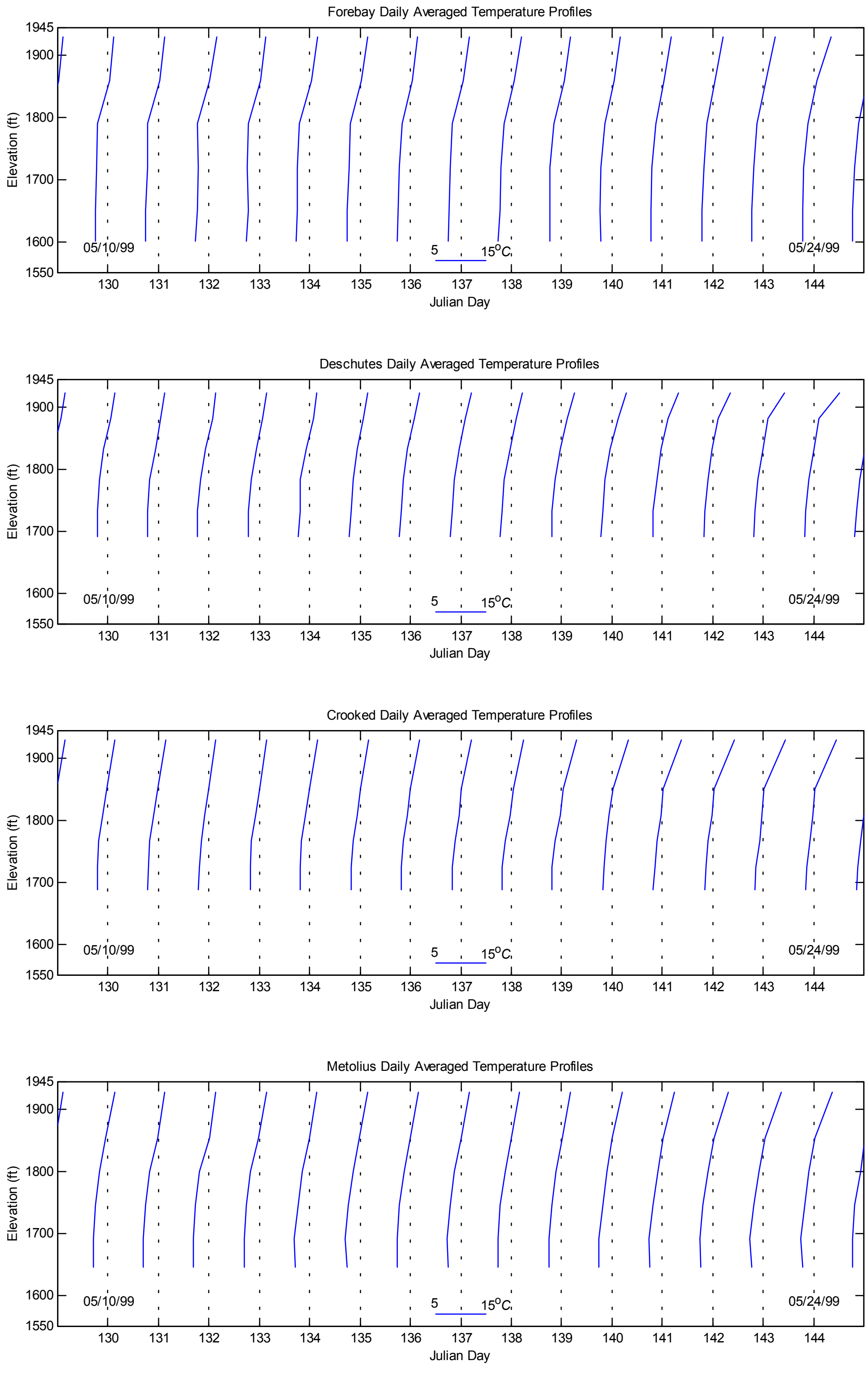
FIGURE 2-23b

S4 AND WIND DATA

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: January 18, 2000	**FIGURE 2-24**
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	S4 SURFACE VELOCITY ROSES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE 2-25** TEMPERATURE PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
	CHECKED: T. Khangaonkar	
	DATE: January 18, 2000	
PROJECT NO: 2200.0001.0002	FILENAME: pgeplots-P.doc	

3.0 TEMPERATURE MODEL CALIBRATION AND VERIFICATION

The 2D water quality model known as the Box-Exchange, Transport, Temperature, and Ecology of a Reservoir (BETTER) model was previously set up for Lake Billy Chinook using available 1995 historical data (preliminary calibration). The calibrated model was used as a predictive tool as part of an evaluation of downstream fish passage enhancement alternatives (ENSR January 1999). The BETTER model was selected due to its relative ease of use, reasonable computer run times for long (annual) simulations, and the availability of a post-processor to facilitate evaluation and interpretation of model output. The calibrated model simulated the general pattern of water exchange among the three arms of the reservoir and the development of summer temperature stratification due to solar radiation and inflow water temperatures and volumes. This section describes the re-calibration of the temperature model using revised input conditions for 1995 and verification of the model using data collected in 1999. The temperature model output of the 1999 model verification run also provided the initial condition for the calibration and verification of the 3D hydrodynamic model discussed in Section 4.

3.1 Introduction

The BETTER model was developed by the Tennessee Valley Authority (TVA) and has been successfully applied to several mainstem and tributary reservoirs (Bender et al. 1990). The model is designed to reproduce observed seasonal patterns of temperature stratification, dissolved oxygen, nutrients, suspended solids, pH, and algal biomass. The model can also be used to simulate the transport of a conservative substance such as dye to track the movement of water through the reservoir.

The initial step in the setup of the model is to divide the reservoir into an array of layered volume elements or boxes. Each box has a specified volume, surface area, and downstream conveyance area. A floating layer scheme is used in the model to allow the water surface to move in relation to the specified model geometry. This allows the model to maintain the integrity of strong gradients that develop in the surface layers.

The movement of water in the reservoir is modeled as longitudinal and vertical exchanges between the arrays of volume elements. The pattern of water movement is influenced by the temperature of the inflow, the pattern of thermal stratification arising from heat exchanges with the atmosphere, and water mixing. Vertical mixing occurs in the model as a result of wind, surface cooling, and turbulent flow. Following the calculation of the water and temperature exchanges within a model time step, water quality constituents are modeled in each volume element, and the resulting masses are transferred using the previously determined water exchanges.

3.2 Temperature Model (BETTER) Setup

Model setup involves the development of the model grid (i.e., model arms, segments, and layers) and establishment of model boundary conditions. Boundary conditions include tributary inflows, inflow water quality, meteorological forcing, and reservoir discharge data. The setup of the BETTER model of Lake Billy Chinook is described in detail below.

3.2.1 Model Grid

The model segmentation and geometry were developed using the bathymetry data provided in electronic format by E&S. SURFER (version 6.04) was used to identify model segment boundaries and calculate element volumes, surface areas, and downstream conveyance areas. Lake Billy Chinook was divided into three arms containing a total of 35 segments, including 3 upstream mixing boxes for tributary inflows (Figure 3-1). The Deschutes River was specified as the mainstem model branch with the Crooked and Metolius arms identified as secondary branches. This provides for adequate model resolution of horizontal mixing and temperature patterns observed at monitoring stations sampled from 1994 through 1996.

The lake was also separated into 30 vertical layers beginning 10 feet above the normal maximum pool level of 1,945 feet and extending to the lake bottom at 1,545 feet (Figures 3-2 through 3-4). BETTER simulates the variation of water surface level within the grid, so no adjustment in the grid itself is necessary to vary the water level. Layer volumes are equivalent to the depth-to-volume relationship derived from the most recent bathymetry study of the lake. The first 16 layers of the model are 5 feet thick down to the 1,875-foot elevation, which is below the maximum-recorded depth of the thermocline in Lake Billy Chinook (Raymond et al. 1997). Below the 1,875-foot elevation there are two 10-foot thick layers followed by 25-foot thick layers down to the bottom. This model geometry provides for sufficient model resolution of the vertical temperature stratification that develops in the reservoir.

Minor changes in the grid may be made in 2000 on the basis of a review and update in bathymetry data presently being performed by PGE. These are not expected to affect model performance.

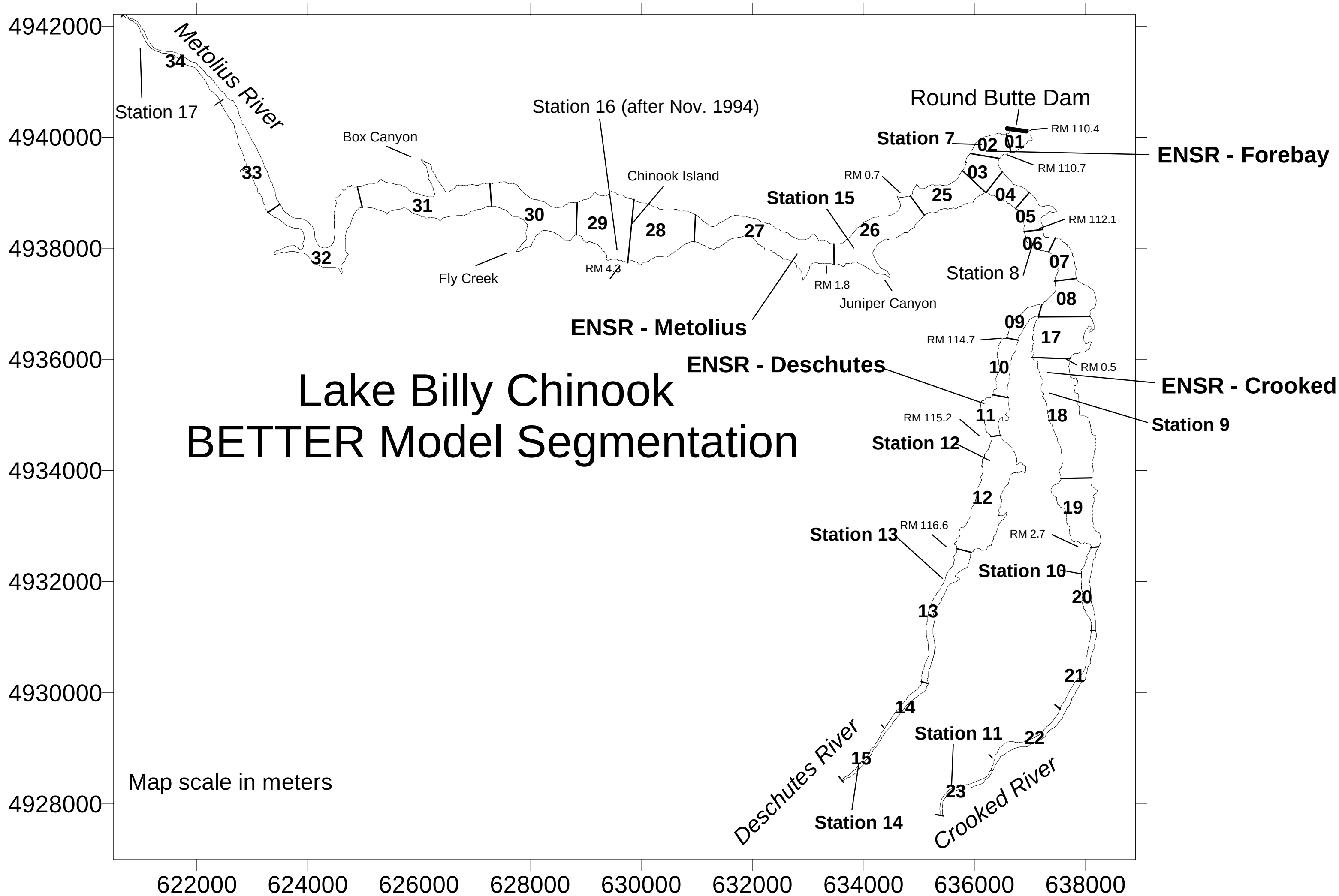
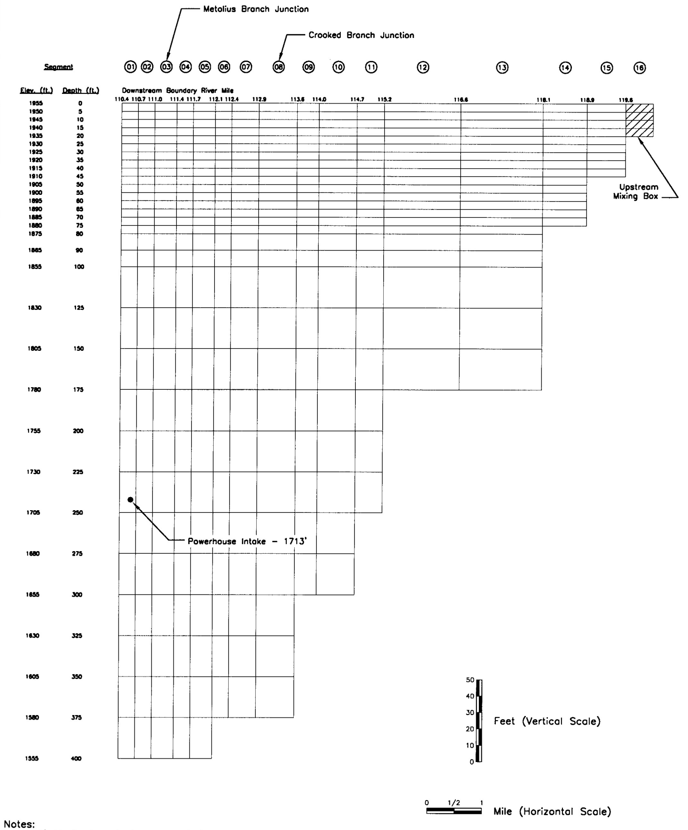


FIGURE 3-1
BETTER MODEL SEGMENTATION
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 30, 1999	PROJECT NO:
	FILENAME: modgrid.jnb	CHECKED: T. Khangaonkar	5499-002-500



Notes:

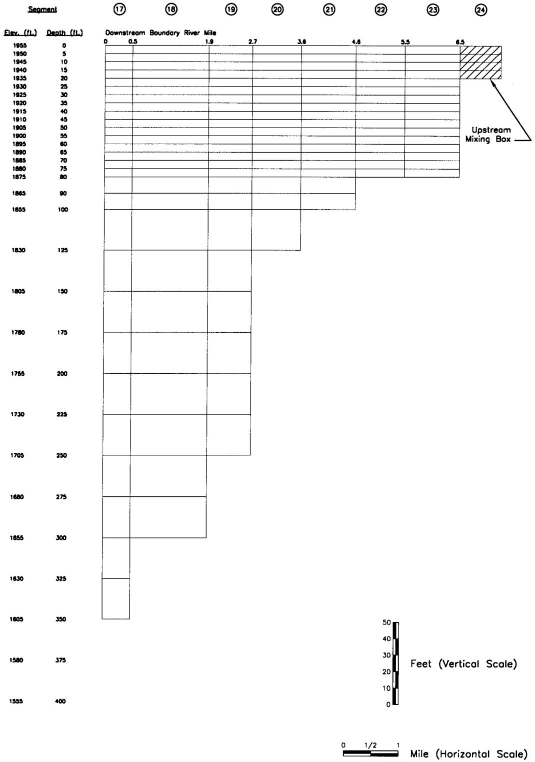
1) Vertical scale is exagerated
2) Top of grid is at elevation 1995'
3) Water surface elevation varies as required within the grid

ENSR Consulting • Engineering • Remediation	DRAWN: km/dn/km
	CHECKED: L. Khan
	DATE: March 15, 2000
PROJECT NO: 5499-002-500	FILENAME: Des-Rivr

FIGURE 3-2

DESCHUTES RIVER BRANCH GEOMETRY

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon



Notes:

1) Vertical scale is exagerated
2) Top of grid is at elevation 1995'
3) Water surface elevation varies as required within the grid

ENSR

Consulting • Engineering • Remediation

PROJECT NO: 5499-002-500

DRAWN: km/dn/km

CHECKED: L. Khan

DATE: March 15, 2000

FILENAME: Cr-Rivr

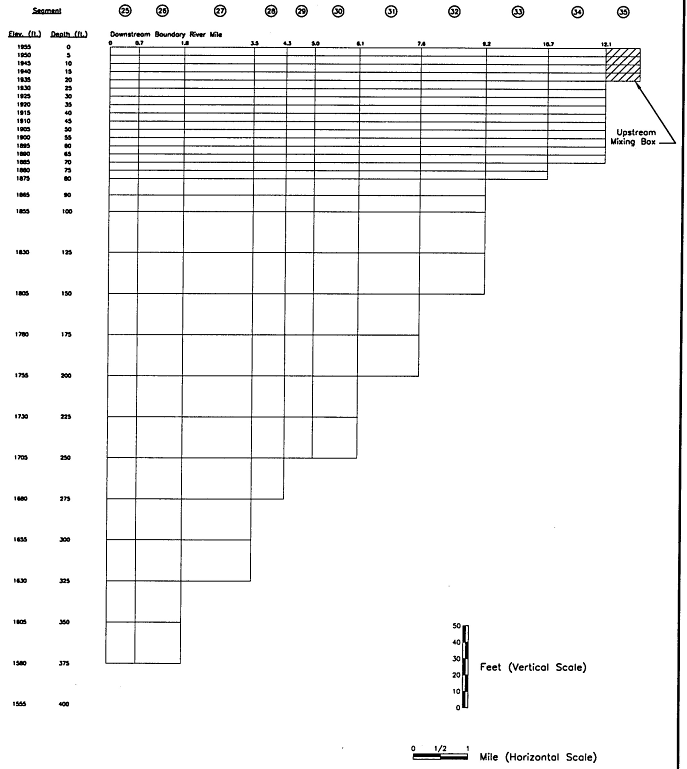
FIGURE 3-3

CROOKED RIVER BRANCH GEOMETRY

Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

Portland, Oregon



Note: Vertical scale is exagerated.

ENSR Consulting • Engineering • Remediation	DRAWN: D. Norwood
	CHECKED: L. Khan
	DATE: February 2, 2000
PROJECT NO: 5499-002-500	FILENAME: Met-Rivr

FIGURE 3-4

METOLIUS RIVER BRANCH GEOMETRY

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

3.2.2 Model Boundary Conditions

Model boundary conditions consist of meteorological conditions (i.e., air and dew point temperatures, wind speed, and solar radiation), reservoir inflow and outflow rates, and inflow temperatures and water quality parameters. Inflow water quality parameters include suspended solids, algae, detritus, dissolved organic matter, and nutrients. The temperature model includes the effect of suspended solids and algae on the depth of solar energy penetration below the water surface. These parameters affect the vertical temperature gradients in the reservoir. With the exception of inflow water quality, much of these data are available on a daily to hourly basis.

To provide adequate resolution of day-to-day temperature dynamics in the reservoir, a model time step of 12 hours was selected. This allows for reasonable model run times while still providing a reasonable simulation of the effect of peaking discharges from the reservoir on the temperature structure in the forebay. The use of a 12-hour time step required averaging of hourly data over the 12-hour day and night period for input to the model (e.g., air temperature). Data that were available on a daily basis were repeated for each day's 12-hour time step (e.g., hydrographic data); data that were available less frequently (e.g., monthly) required interpolation for input to the model (e.g., tributary water quality data).

Previous evaluation of the available hydrographic and temperature data indicated that 1995 would be the most appropriate period for temperature model calibration (ENSR January 1999). Data for 1994 were incomplete and extreme discharge events in the winter of 1996 could introduce uncertainties that would complicate the model calibration effort. Year 1995 has a relatively complete set of monitoring data for the selection of model boundary conditions and for model calibration purposes. River inflow records also indicated that 1995 was a relatively normal hydrologic year, and as such, was more suitable for model calibration (see Section 2.3.1).

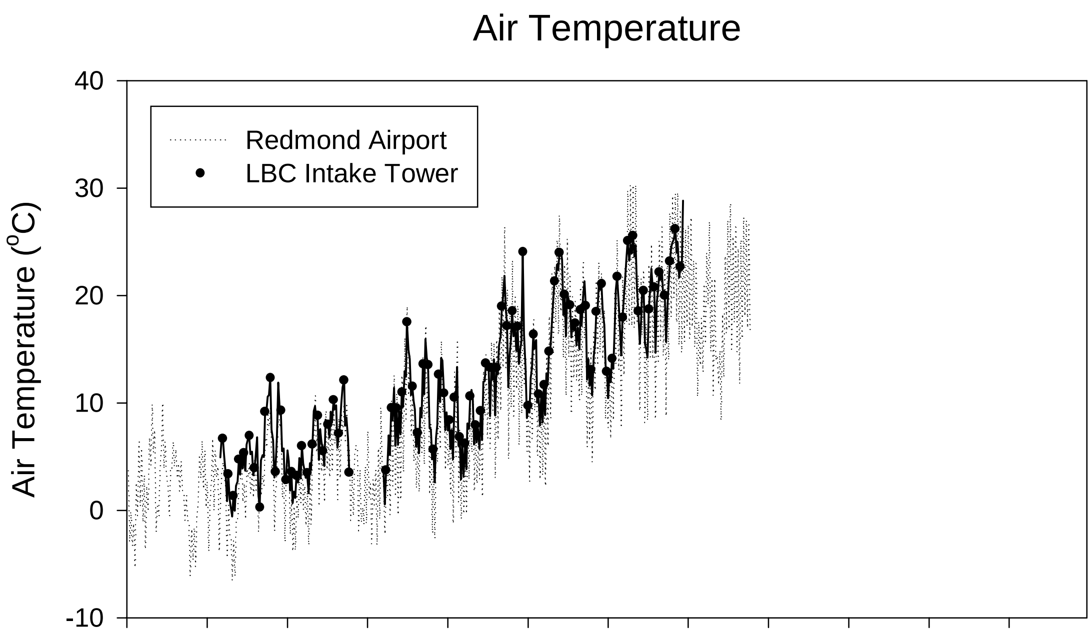
3.2.2.1 Meteorological Inputs

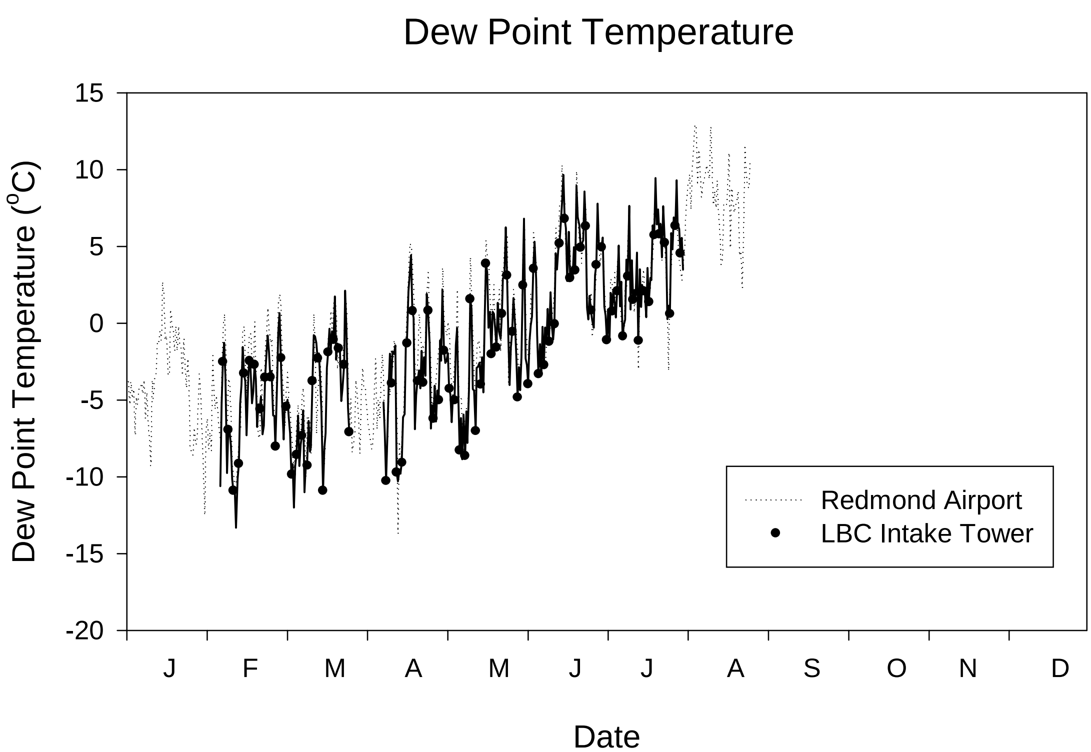
Annual meteorological data were not available for locations at the reservoir surface or dam for use in preliminary model calibration. However, meteorological stations established by PGE at the project site in 1999 provided data on air and dew point temperatures, wind speed, and solar radiation. Because of the technical difficulties associated with maintaining local monitoring stations (some data were lost or missing due to equipment failures), comparisons were made between the locally collected data and data available from nearby stations to determine the suitability of off-site data for use in the model.

Air and Dew Point Temperature: Hourly air and dew point temperature measurements from Redmond Airport and PGE's Intake Tower station were averaged over 12-hour day and night intervals and compared graphically (Figure 3-5). Visual comparison of the two data sets suggests that daytime air temperatures between the two locations are similar but nighttime temperatures at the reservoir are higher than those at Redmond. This is likely due to the effective heat capacity of the lake, which would tend to cool the local surroundings during the day and provide warmer nighttime temperatures. Dew point temperatures at the two locations appear very similar.

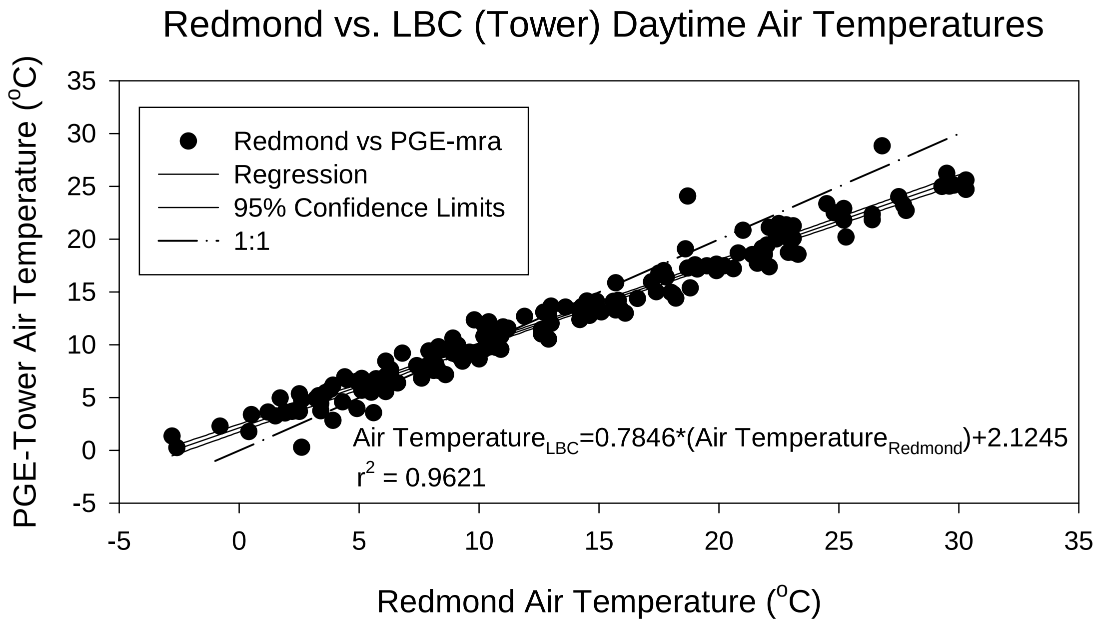
The elevation of the Redmond station is 938 meters (3,077 feet) which is considerably higher than the normal lake surface (593 m; 1,945 feet) near the Intake Tower station. Previously, the Redmond Airport air temperature data were scaled upward by 3.5 degrees assuming a lapse rate of 1.0-Celsius degree per 100 m (5.4 Fahrenheit degrees per 1,000 feet) decrease in height (Linsley et al. 1982) to account for warmer temperatures that would occur at the lower elevation of the lake (ENSR January, 1999). Since comparison of day and night temperatures between the two stations indicated a distinctly different pattern between the stations during the day and at night, linear regression analysis was conducted to identify statistical relationships between the two stations. Statistically significant linear relationships were identified for day and night air temperature (Figure 3-6). Night temperatures at the reservoir are elevated approximately $4^{o}C$ relative to Redmond temperatures over the entire range of temperatures analyzed (-5 to $20^{o}C$). Day temperatures at the reservoir are generally higher during cold weather and lower during warm weather. The regression equations shown in Figure 3-6 were used to adjust the 1995 and 1999 Redmond air temperature data for use in model calibration and verification. The relationship between Redmond and Intake Tower dew point temperature was also statistically significant (Figure 3-7). This relationship indicated the need to decrease the Redmond dew point temperature by approximately $0.75^{o}C$. The regression equation shown in Figure 3-7 was used to adjust the 1995 and 1999 Redmond dew point data for use as model input.

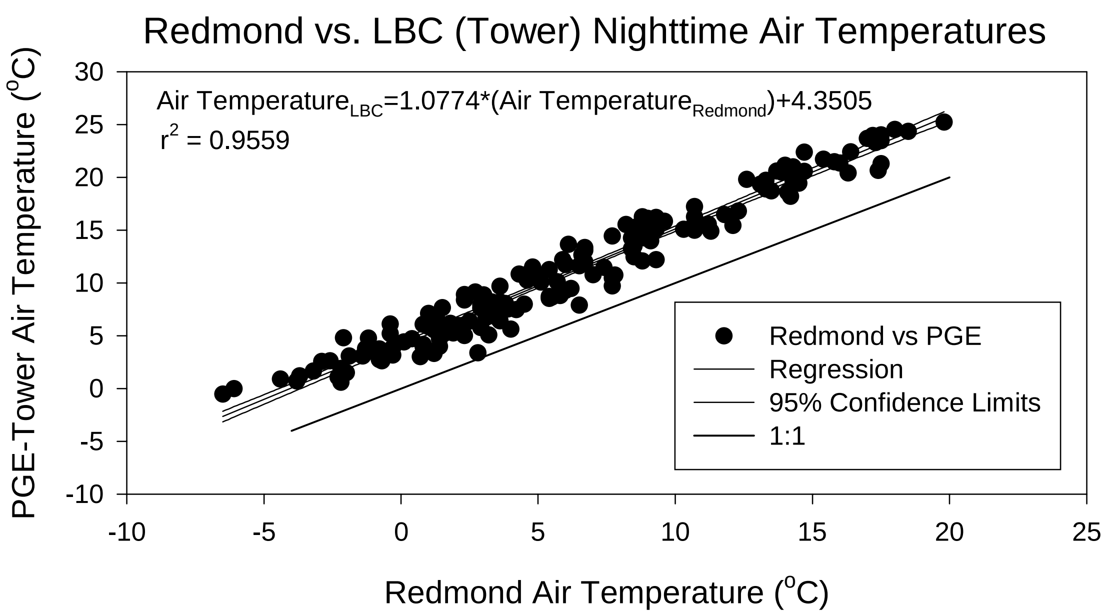
Wind Speed: Hourly wind speed data for 1995 and 1999 were available from the Redmond Airport station. Wind speed data were also available from PGE's local monitoring stations in 1999. Although comparison of the Redmond and PGE 1999 data indicate somewhat lower wind speeds recorded at the reservoir stations, no significant linear relationship was identified between Redmond and any of the PGE station data (Figure 3-8). The model requires continuous data input for wind speed, and the model provides coefficients to adjust the effect of wind speed input on reservoir mixing and cooling. The data from the Redmond Airport station were used in the model without adjustment, since no data were available for the reservoir in 1995.





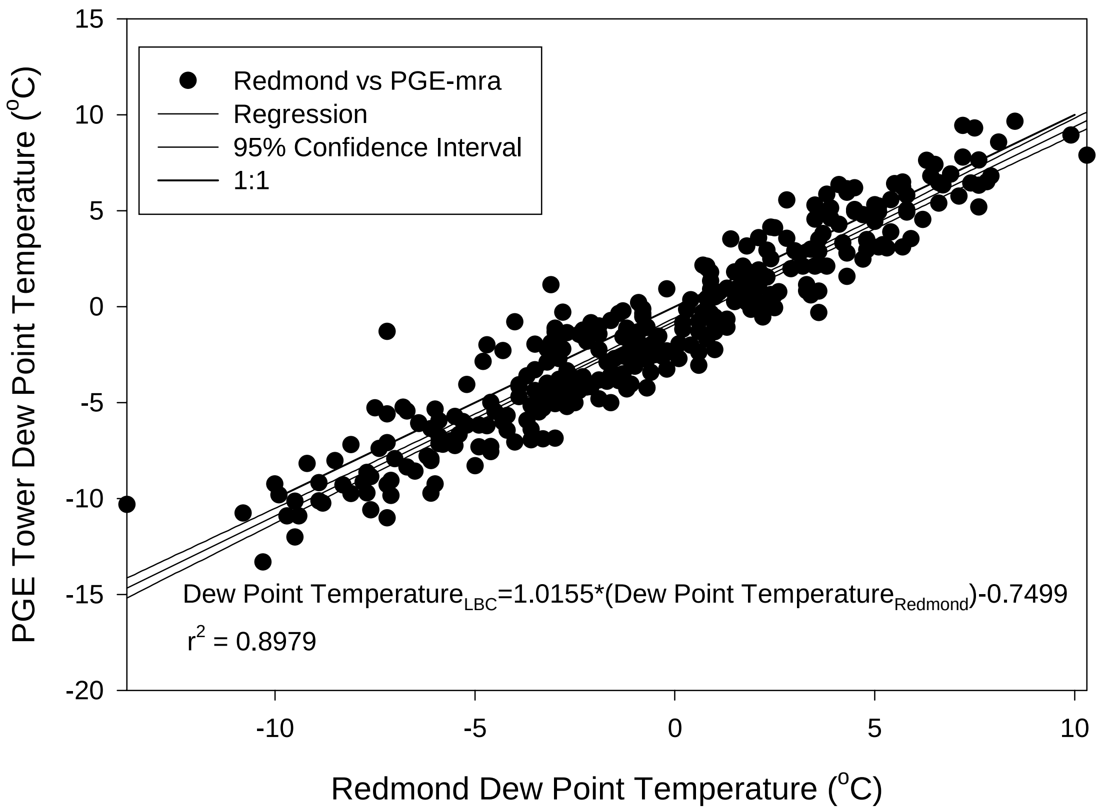
FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	FIGURE 3-5
	CHECKED: T. Khangaonkar	1999 DEWPOINT TEMPERATURES
	DATE: October 28, 1998	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: AirTemp99.jnb	



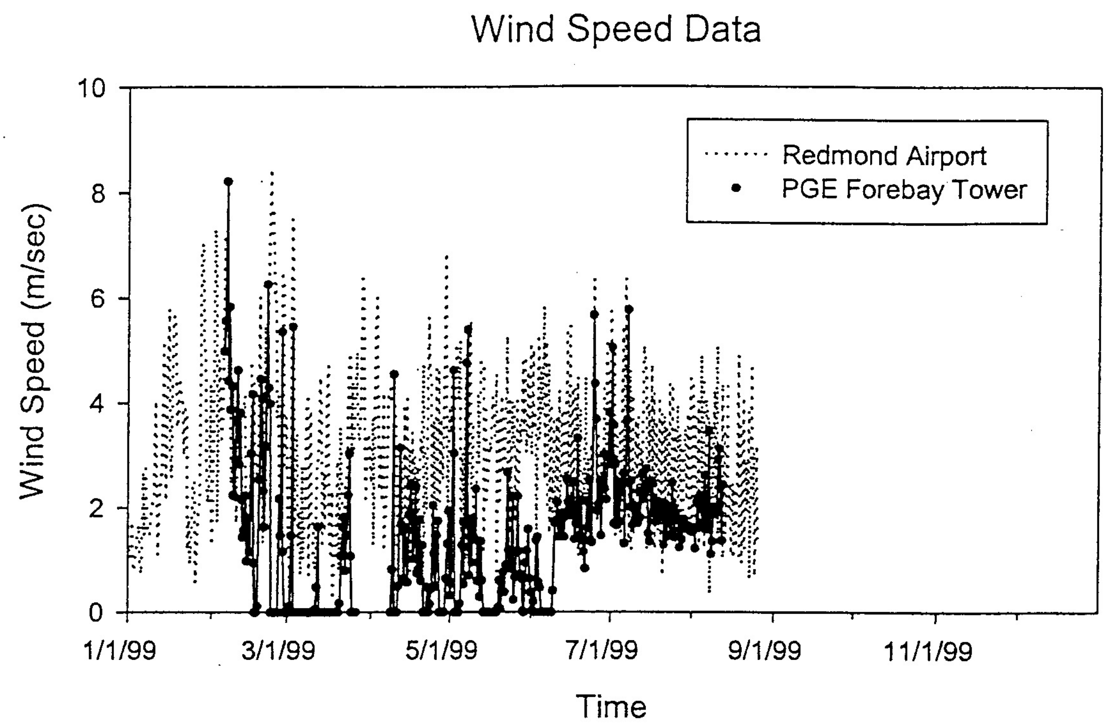


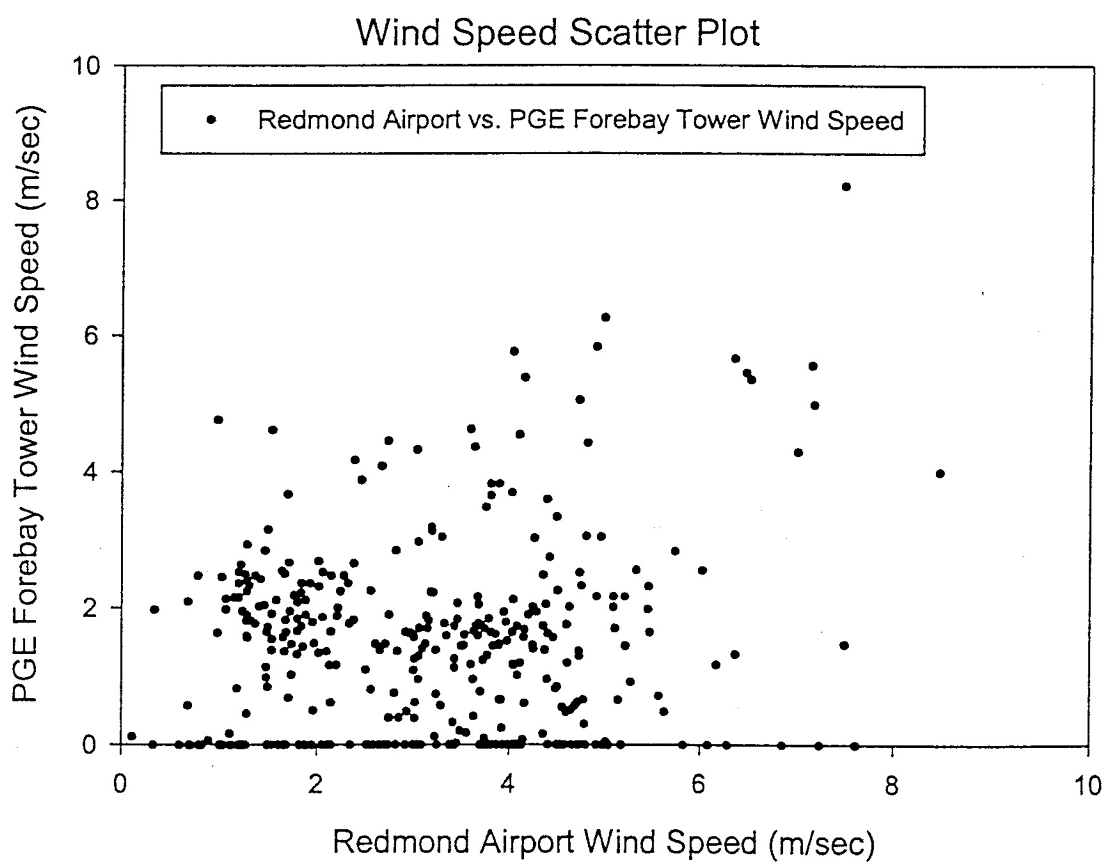
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi CHECKED: T. Khangaonkar DATE: December 17, 1999	FIGURE 3-6 1999 AIR TEMPERATURE RELATIONSHIPS Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: AirTemp99.jnb	

Redmond vs. PGE Dew Point Temperature - 1999



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi CHECKED: T. Khangaonkar DATE: October 28, 1998	FIGURE 3-7 1999 DEWPOINT TEMPERATURES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: AirTemp99.jnb	





FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi CHECKED: T. Khangaonkar DATE: December 30, 1999	FIGURE 3-8 1999 WIND SPEED DATA COMPARISONS Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: WindSpd99.jnb	

Solar Radiation: Daily solar radiation for 1995 and 1999 was available from a station located in Madras. Solar radiation data were also collected at PGE's Intake Tower station in 1999. However, the orientation of PGE's radiation sensor was optimized for collection of spring solar radiation. The model requires an estimate of radiation from a horizontal collector. Therefore, the solar radiation data from the Madras station were converted to kcal/hr and scaled to a 12-hour day for input to the model.

3.2.2.2 Hydrographic Inputs and Reservoir Discharge

Hydrographic inputs to the model include surface inflows from the three tributaries and the net ungauged inflow required to balance reservoir storage and discharge (Figures 3-9 and 3-10). Ungauged inflow is the water input required to balance the water losses from the reservoir, including groundwater, powerhouse discharge, spill, and evaporation. Because there are currently no direct or indirect measurements of groundwater inflow or outflow, the ungauged inflow is essentially the net amount of water required to balance the reservoir water budget. Therefore, the ungauged inflow includes ungauged nearshore runoff, ungauged tributary inputs, and the net influence of groundwater movement into and out of the reservoir. The equation describing for the ungauged inflow is:

Ungauged Inflow = Daily Outflow (Powerhouse and spill discharge)
+ Direct Lake Precipitation – Evaporation – Storage

Daily precipitation data were available at Pelton Dam, approximately 7 miles north of Lake Billy Chinook. Limited pan evaporation data from a station located near Madras, Oregon were converted to estimates of reservoir evaporation using a pan evaporation coefficient of 0.7 (Linsley et al. 1982) and a lake surface area of 3,800 acres. Daily water surface elevations recorded by PGE as well as the lake surface area were used to calculate daily storage. Finally, incorporation of daily powerhouse discharge estimated by PGE (no spills were recorded in 1995 or 1999) allowed for estimation of the ungauged inflow.

Although there is some uncertainty associated with estimates of powerhouse discharge (powerhouse discharge is estimated as a function of power production); the amount of ungauged inflow for 1995 was consistently positive and averaged approximately 10 percent of the estimated powerhouse discharge in 1995 (Figure 3-9). In this relatively arid region, ungauged inputs of this magnitude over the course of the year may primarily reflect net groundwater inputs to the reservoir. Peaks in ungauged inflow that occur during winter runoff events may reflect inputs from local surface water runoff. In 1999, the amount of calculated ungauged flow was occasionally negative, and the average ungauged flow was considerably lower; approximately 3 percent of the estimated outflow. Negative flow could indicate a number of things. If the water balance is correct then it suggests short-term net losses of groundwater from the reservoir. It is also possible

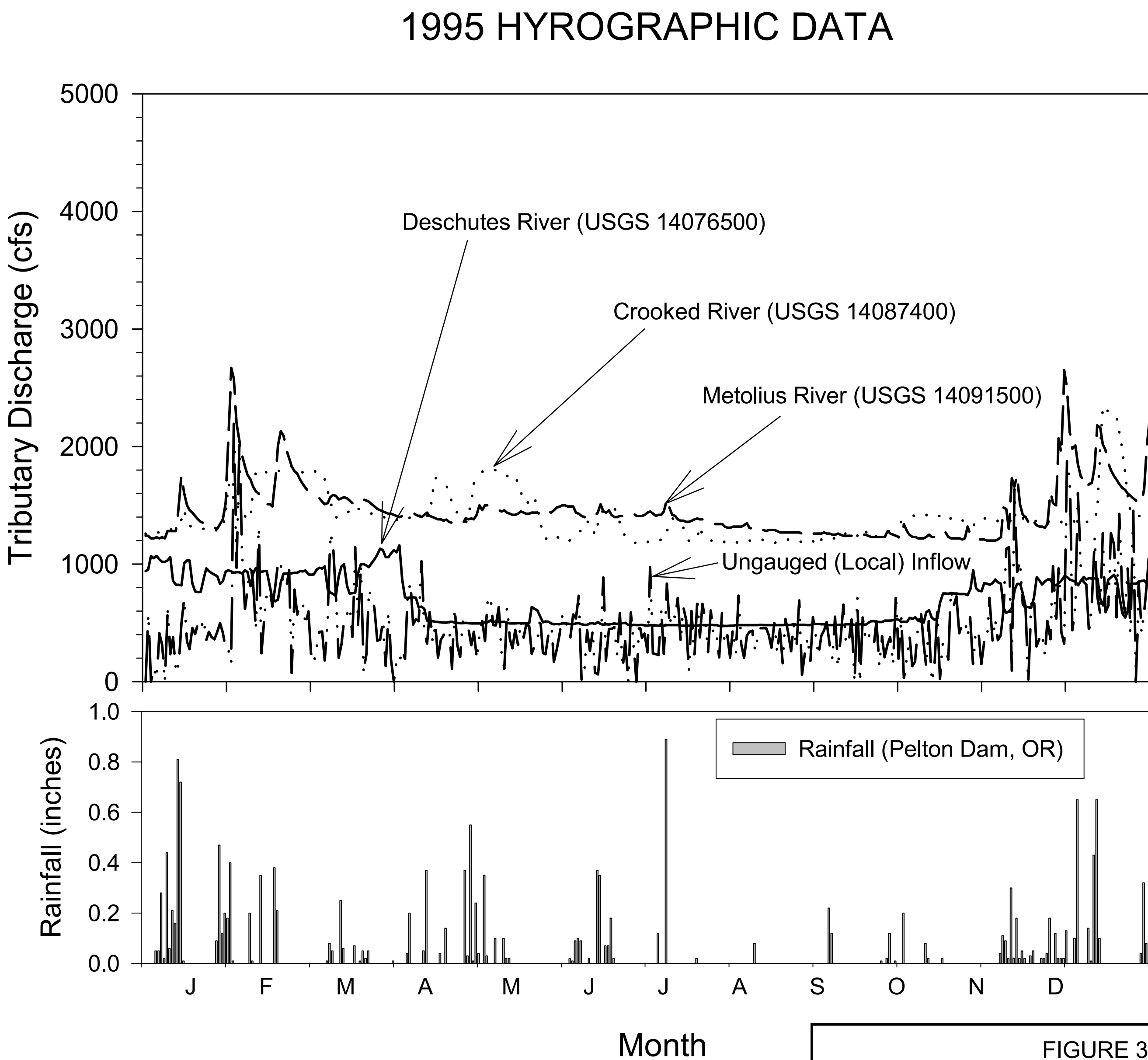
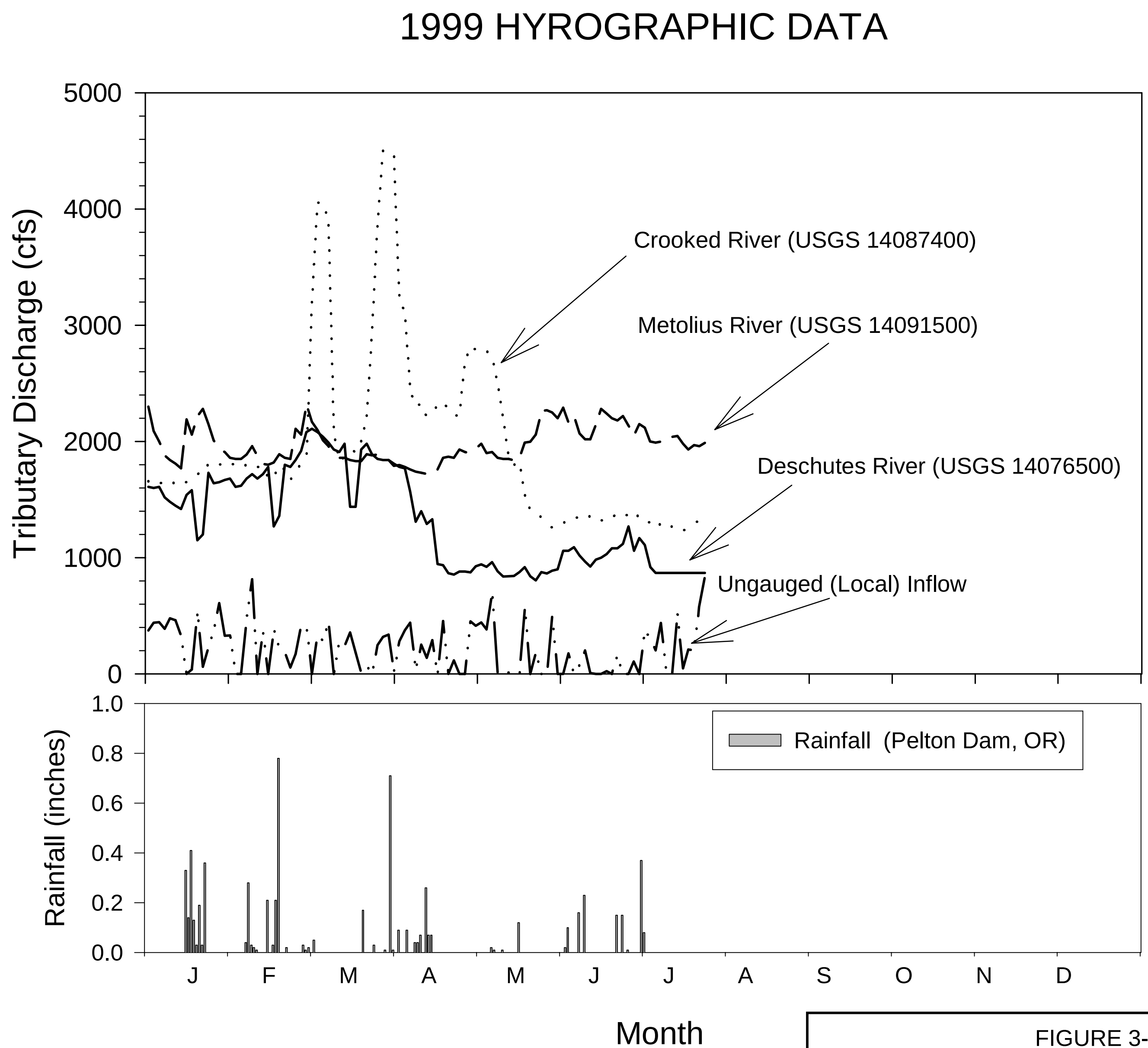


FIGURE 3-9
1995 TRIBUTARY AND RAINFALL HYDROGRAPHIC DATA
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 16, 1999	PROJECT NO:
	FILENAME: flowbalance.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: C. DeGasperi	DATE: December 16, 1999	PROJECT NO:
FILENAME: flowbalance.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-10
1999 TRIBUTARY AND RAINFALL HYDROGRAPHIC DATA
Portland General Electric Company
Portland, Oregon

that these negative fluctuations indicate uncertainties in the water budget. These uncertainties might include an over-estimate of the tributary inputs, an under-estimate of the powerhouse discharge, or an over-estimate of storage loss due to errors in recording the reservoir water surface elevation. Errors in the water surface elevation could have an appreciable impact on inflow estimates. Because the model only allows for positive inflow values, the water balance required some minor adjustments (negative flows were removed and positive flow estimates were adjusted accordingly) to provide a final estimate of the lake water balance for 1999 (Figure 3-10).

Due to the uncertainties regarding the source of the ungauged inflow, it was distributed among the model segments in proportion to segment reach length. Conceptually, this distribution acknowledges that a portion of the ungauged flow may be derived from ground and local surface water inputs.

Hourly powerhouse discharge data were averaged to provide model input for each daytime and nighttime 12-hour time step in 1995 and 1999 (Figures 3-11 and 3-12). Also shown in these figures is the fit of the model-predicted lake surface elevation to daily observations recorded in 1995 and 1999 based on the estimate of ungauged inflow described above. In general, there was good agreement between model-predicted and observed water surface elevations.

3.2.2.3 Inflow Temperature Data

Continuous inflow temperature data recorded in 1995 and 1999 were averaged to provide 12-hour average day and night values for input to the model (Figures 3-13 and 3-14). Data gaps were filled by interpolation of grab sample data collected from the same monitoring stations.

In the preliminary model calibration effort, the water temperature of the ungauged inflow was set to that of the Deschutes River, which was typically intermediate between the Crooked and Metolius Rivers. However, since that effort, two reports have been identified (Caldwell and Truini 1997, Caldwell 1998) that provide measurements of groundwater temperatures in the vicinity of Lake Billy Chinook. Based on these data a constant temperature of 12.1 ^{o}C (54 ^{o}C) was used for the ungauged inflow in the model.

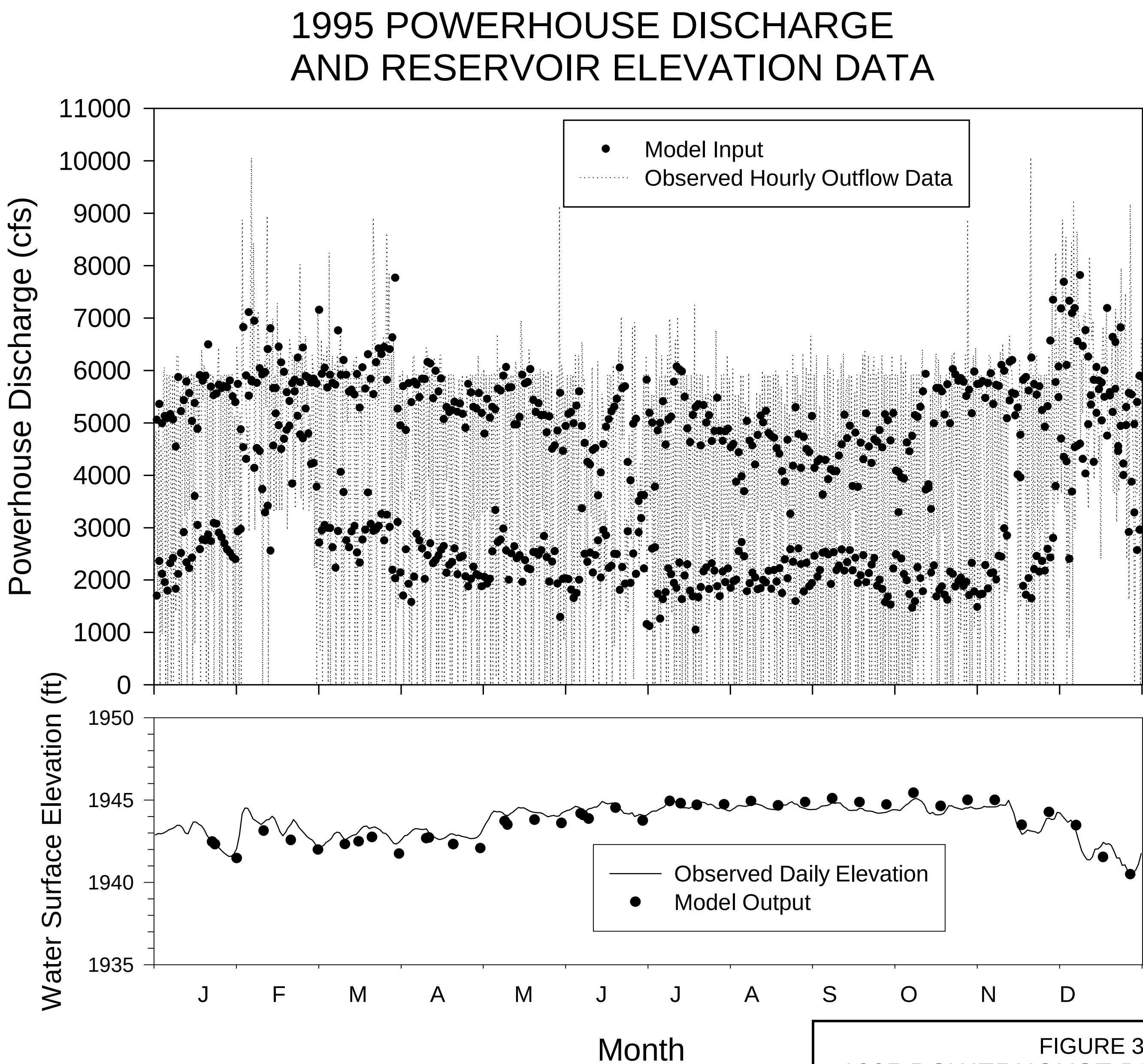


FIGURE 3-11
1995 POWERHOUSE DISCHARGE AND RESERVOIR ELEVATION DATA
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 16, 1999	PROJECT NO:
	FILENAME: flowbalance.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

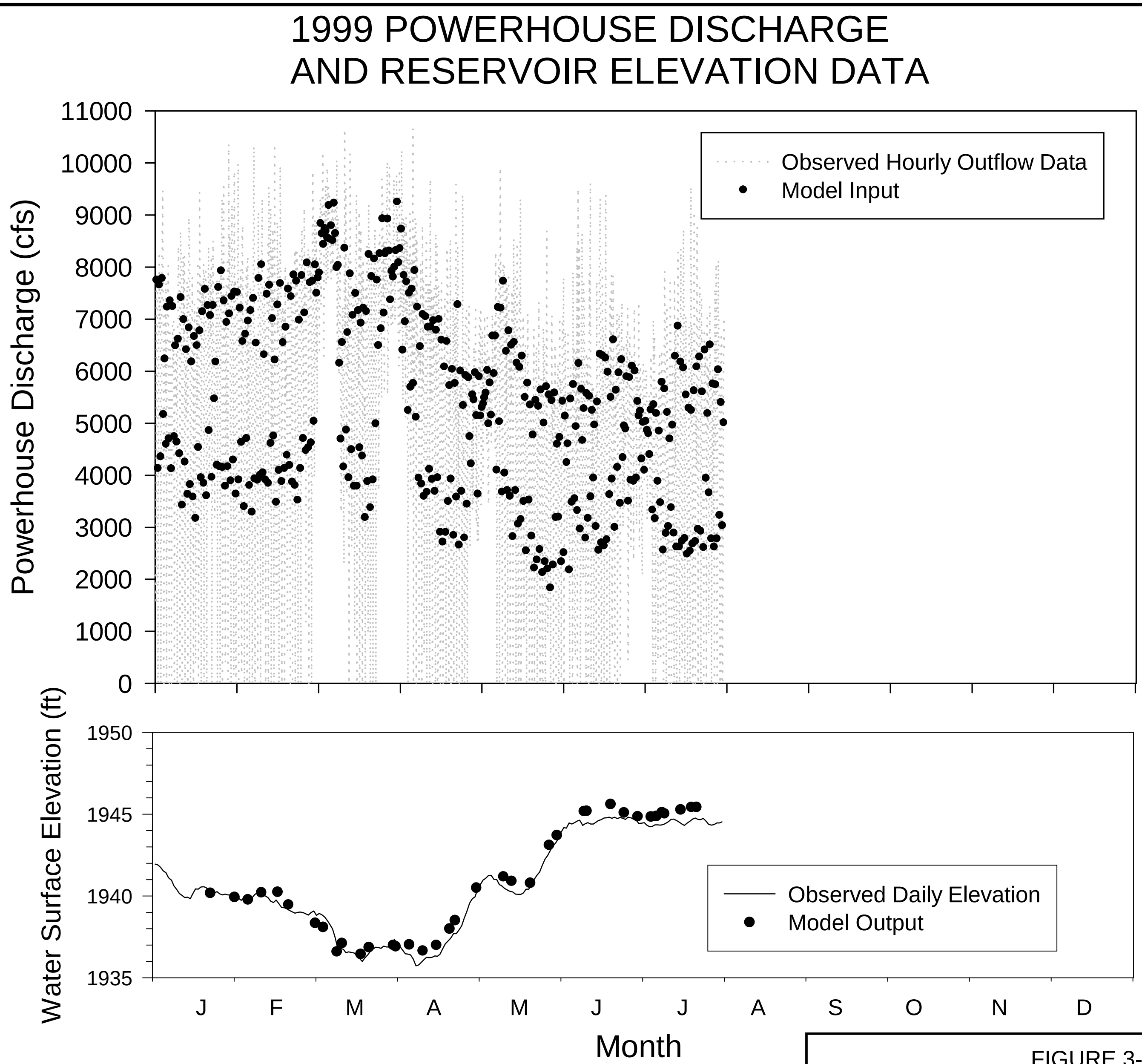
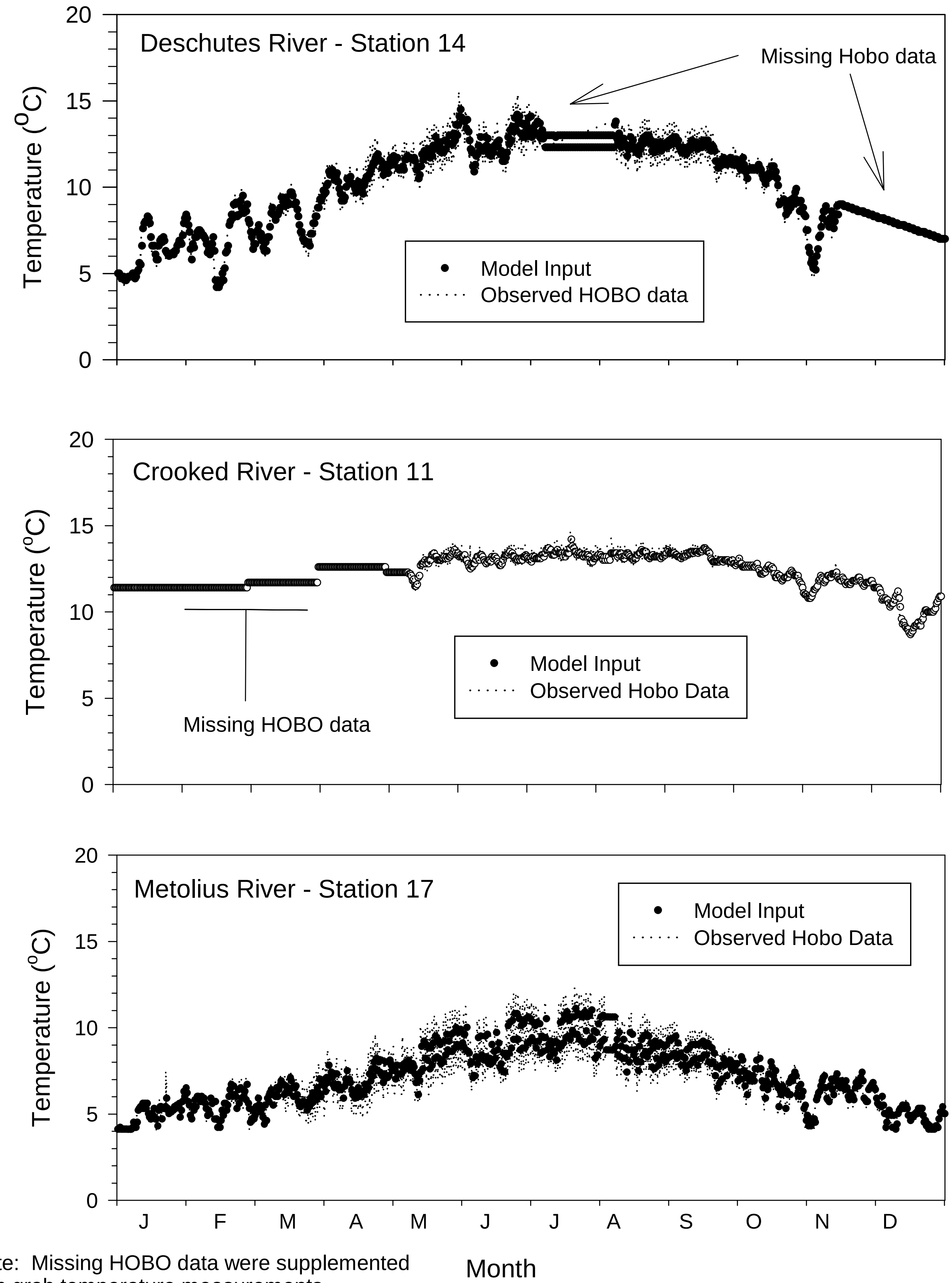


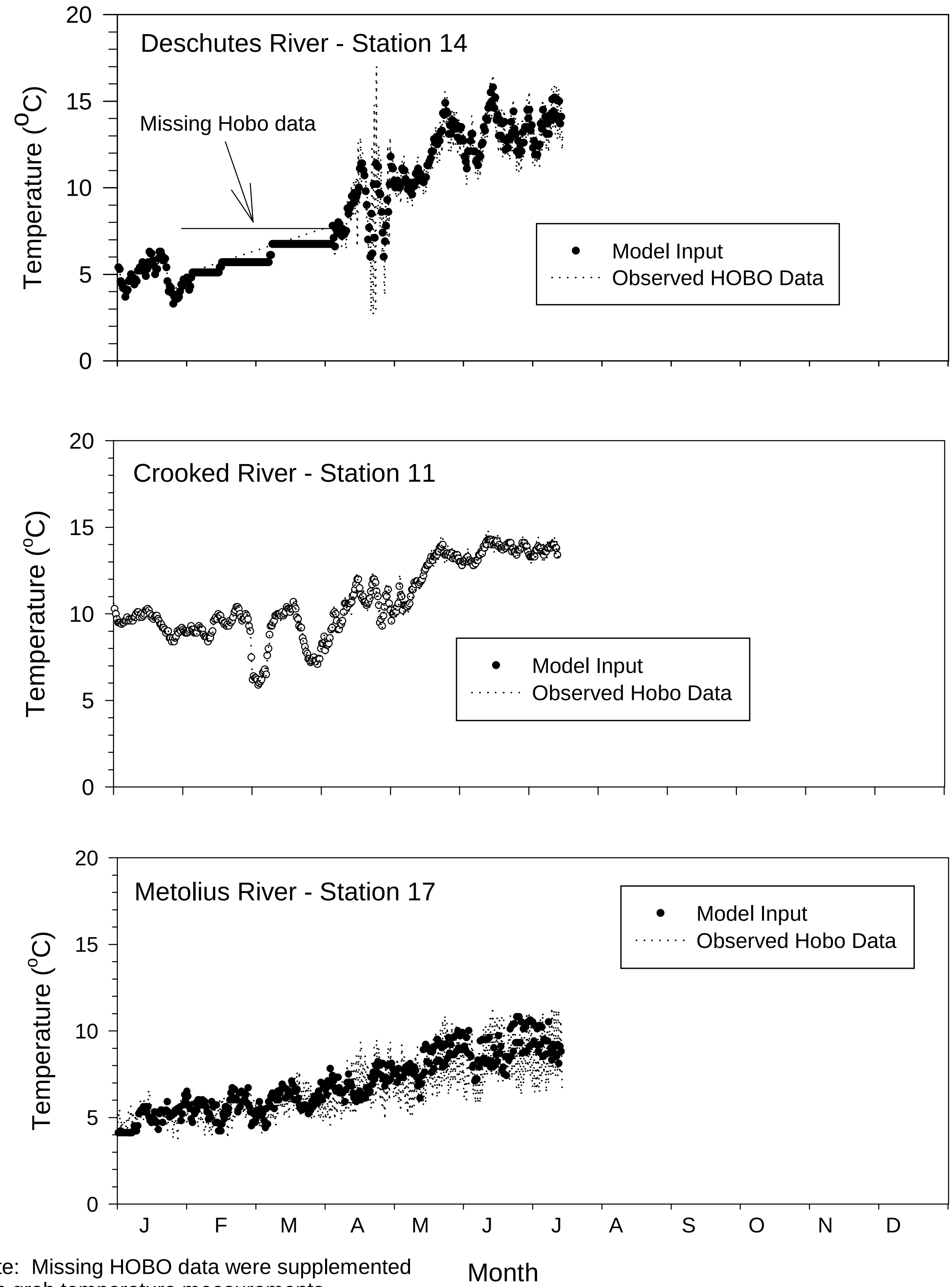
FIGURE 3-12
1999 POWERHOUSE DISCHARGE AND RESERVOIR ELEVATION DATA
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 16, 1999	PROJECT NO:
	FILENAME: flowbalance.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



Note: Missing HOBO data were supplemented with grab temperature measurements. Daily inflow temperature was interpolated from these data.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi CHECKED: T. Khangaonkar DATE: October 28, 1998	FIGURE 3-13 1995 INFLOW TEMPERATURE DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: LBCintemp.jnb	



Note: Missing HOBO data were supplemented with grab temperature measurements. Daily inflow temperature was interpolated from these data.

FOSTER ENVIRONMENTAL FW WHEELER CORPORATION	DRAWN: C. DeGasperi CHECKED: T. Khangaonkar DATE: October 28, 1998	FIGURE 3-14 1999 INFLOW TEMPERATURE DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: LBCintemp.jnb	

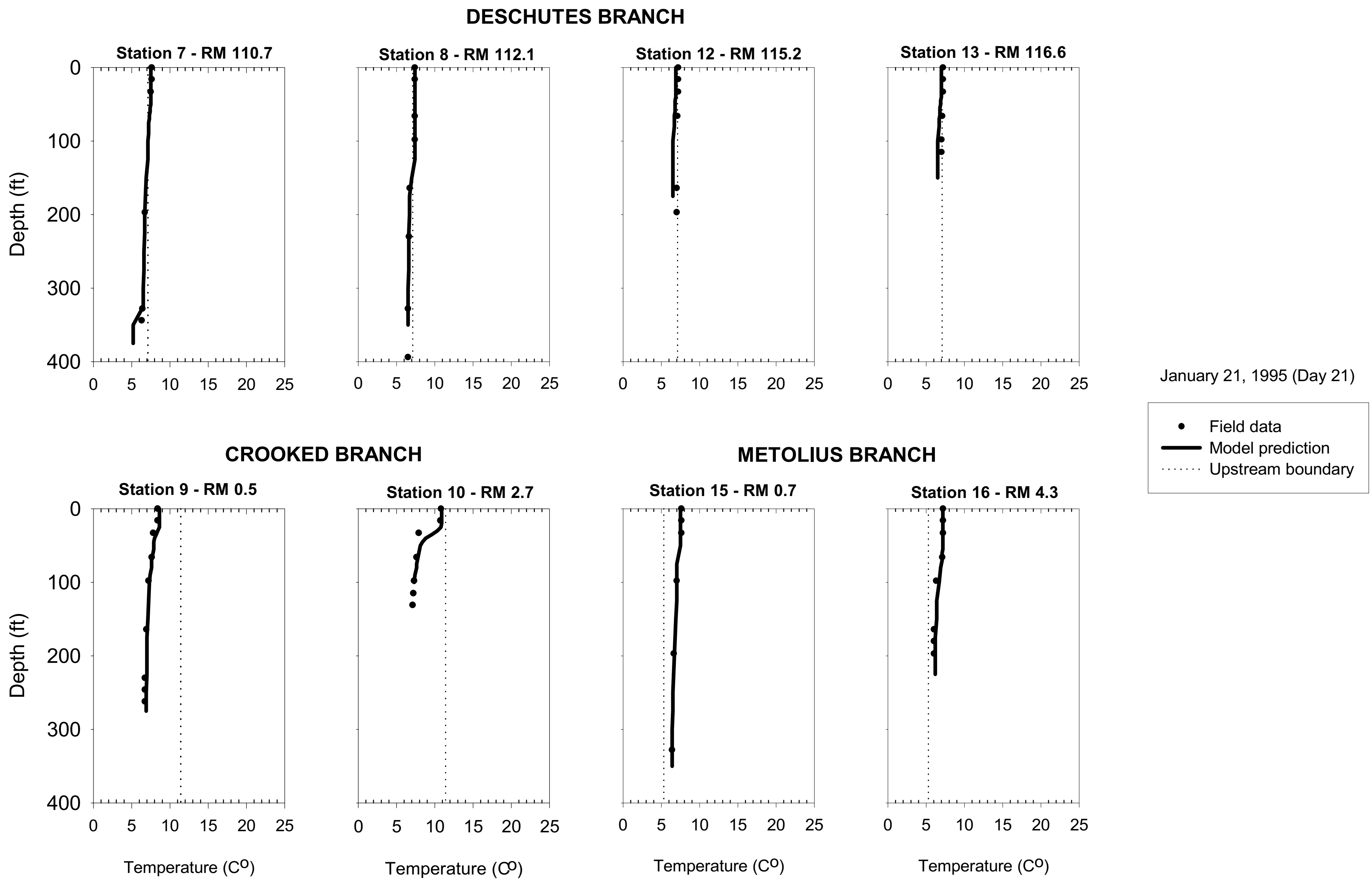
3.2.2.4 Inflow Water Quality Data

Inflow water quality data were derived from the limnological study of Lake Billy Chinook and routine monitoring data collected by the Oregon Department of Environmental Quality (DEQ) available in STORET. These data were collected no more frequently than once a month during 1995 and therefore required interpolation to provide daily input values for the model. Chlorophyll *a* data were converted to algal biomass for input to the model by multiplying these data by the algal biomass:chlorophyll *a* ratio of 50. Because no additional water quality data for model input (other than temperature) were collected in 1999, the 1995 water quality input data were used as default inputs for the 1999 model verification run.

3.3 Model Calibration

Model calibration consisted of adjusting various model coefficients and factors that control vertical and horizontal mixing, withdrawal zone thickness, and evaporative cooling. These variables include the fraction of wind energy available for mixing (WCOEF), the density deflection factor (FDFAC), the vertical mixing coefficient (DC), wind speed adjustment factor (WDFAC), evaporation adjustment factor (EVFAC), and the withdrawal zone thickness factor (QTH). With the exception of the vertical mixing coefficient, these are global model variables (i.e., a single value is applied to the entire reservoir). Different vertical mixing coefficients may be specified for each reservoir branch.

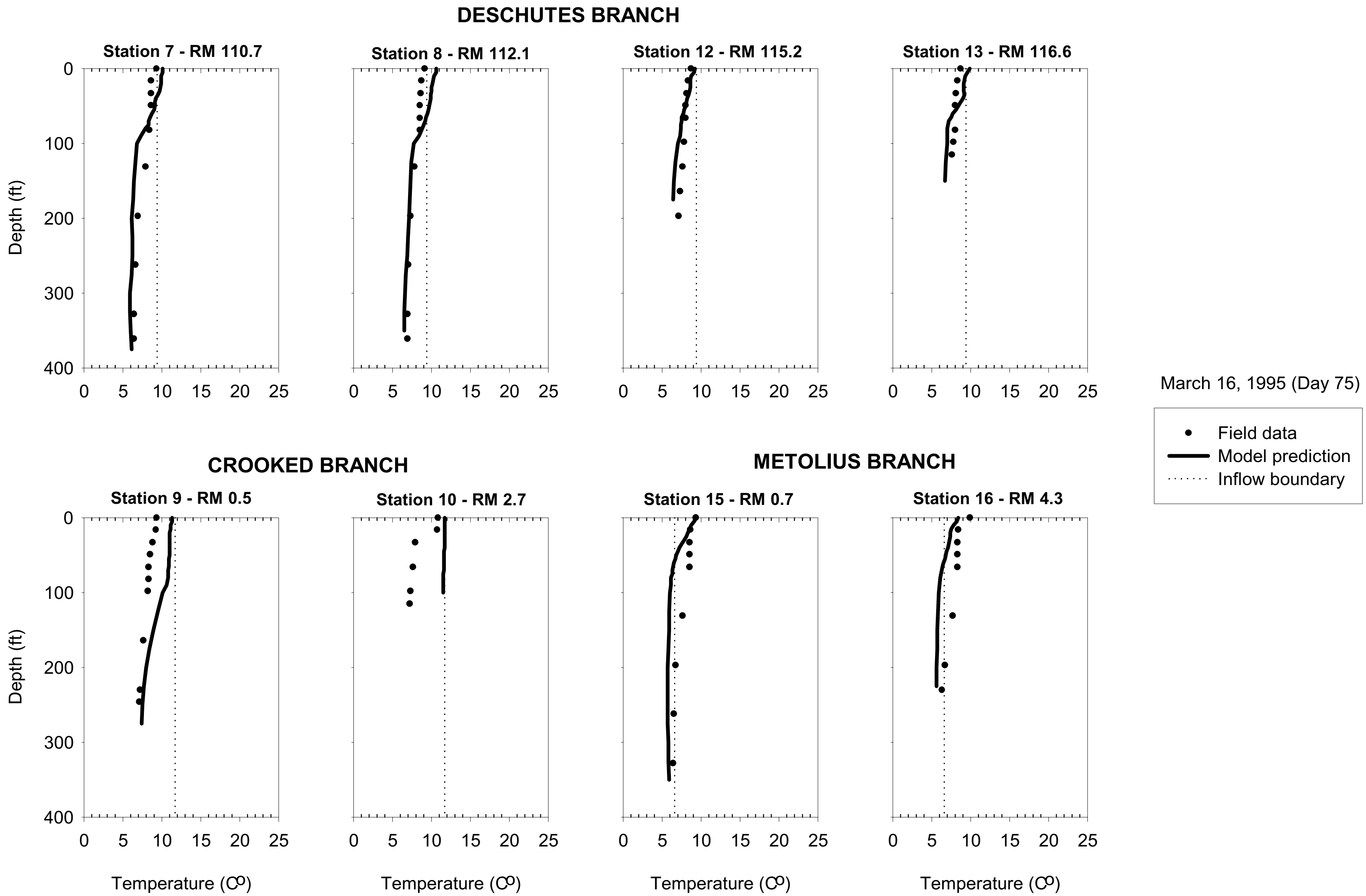
The calibration of the model to observed water quality conditions is described in a companion report (ENSR and Foster Wheeler Environmental January 2000). During the water quality model calibration, the sensitivity of model-predicted bottom dissolved oxygen (DO) concentrations to the density deflection factor (FDFAC) was identified. Adjustment of FDFAC had a significant effect on late summer mixing patterns in the lower Deschutes arm. The FDFAC was adjusted to optimize the fit of the model-predicted DO and temperature to the observed data. The model coefficients were systematically adjusted until the best model fit-by-eye to the profiles measured in 1995 was obtained (Figures 3-15 through 3-25).



Note: Station locations are shown in Figure 3-1.

FIGURE 3-15
BETTER MODEL CALIBRATION RESULTS
JANUARY 21, 1995
Portland General Electric Company
Portland, Oregon

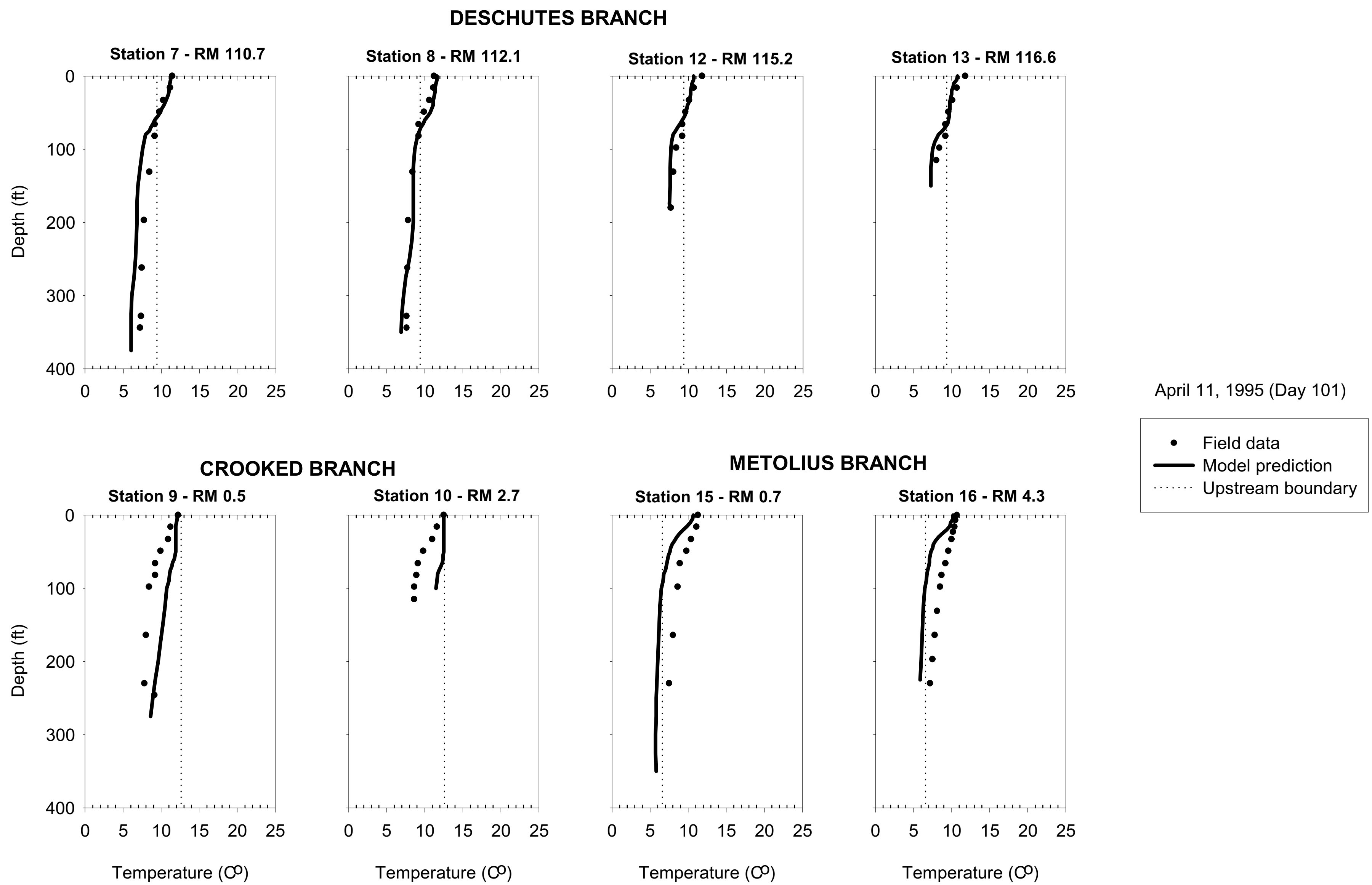
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



Note: Station locations are shown in Figure 3-1.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

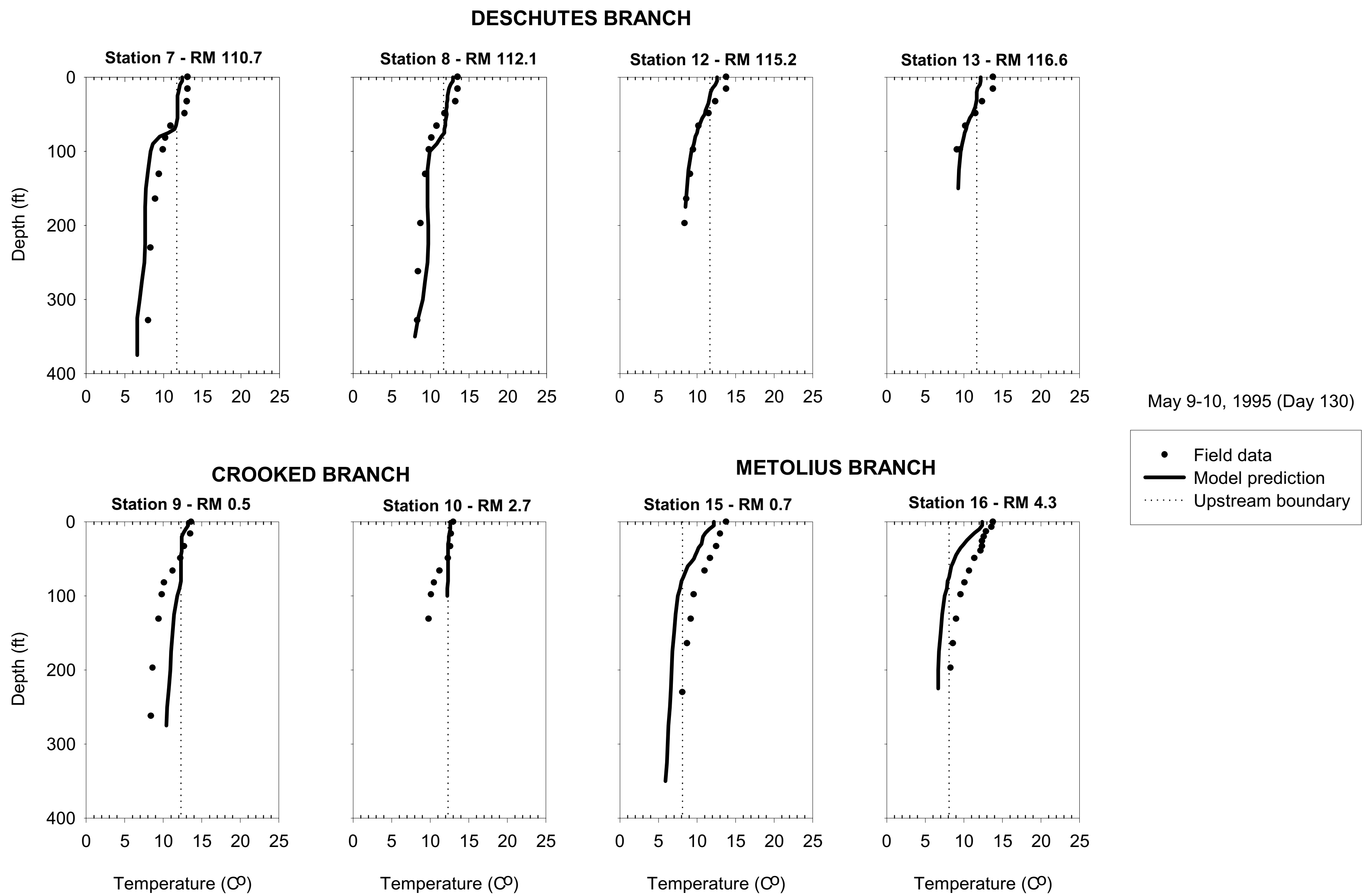
FIGURE 3-16
BETTER MODEL CALIBRATION RESULTS
MARCH 16, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

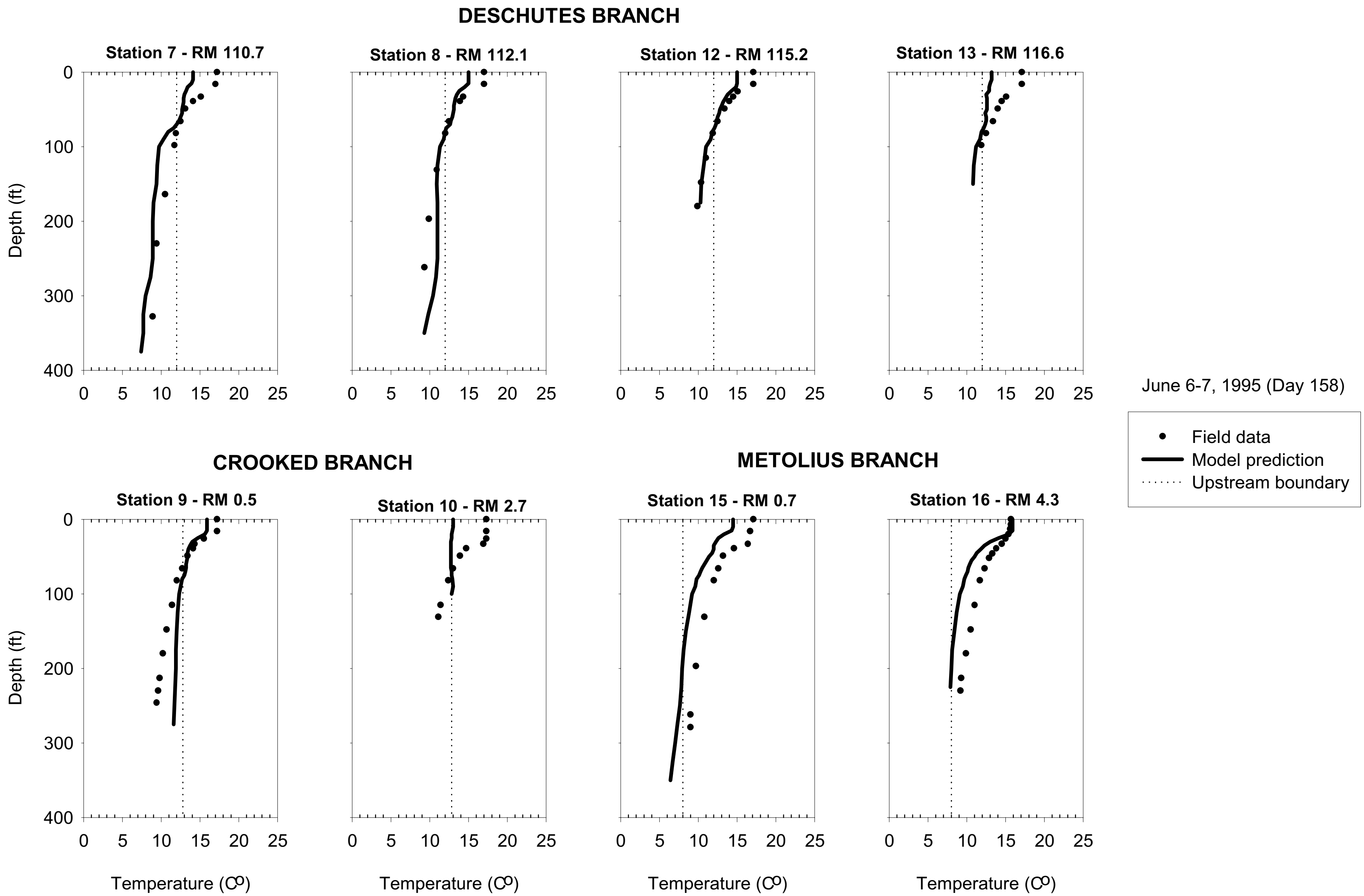
FIGURE 3-17
BETTER MODEL CALIBRATION RESULTS
APRIL 11, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL FW WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

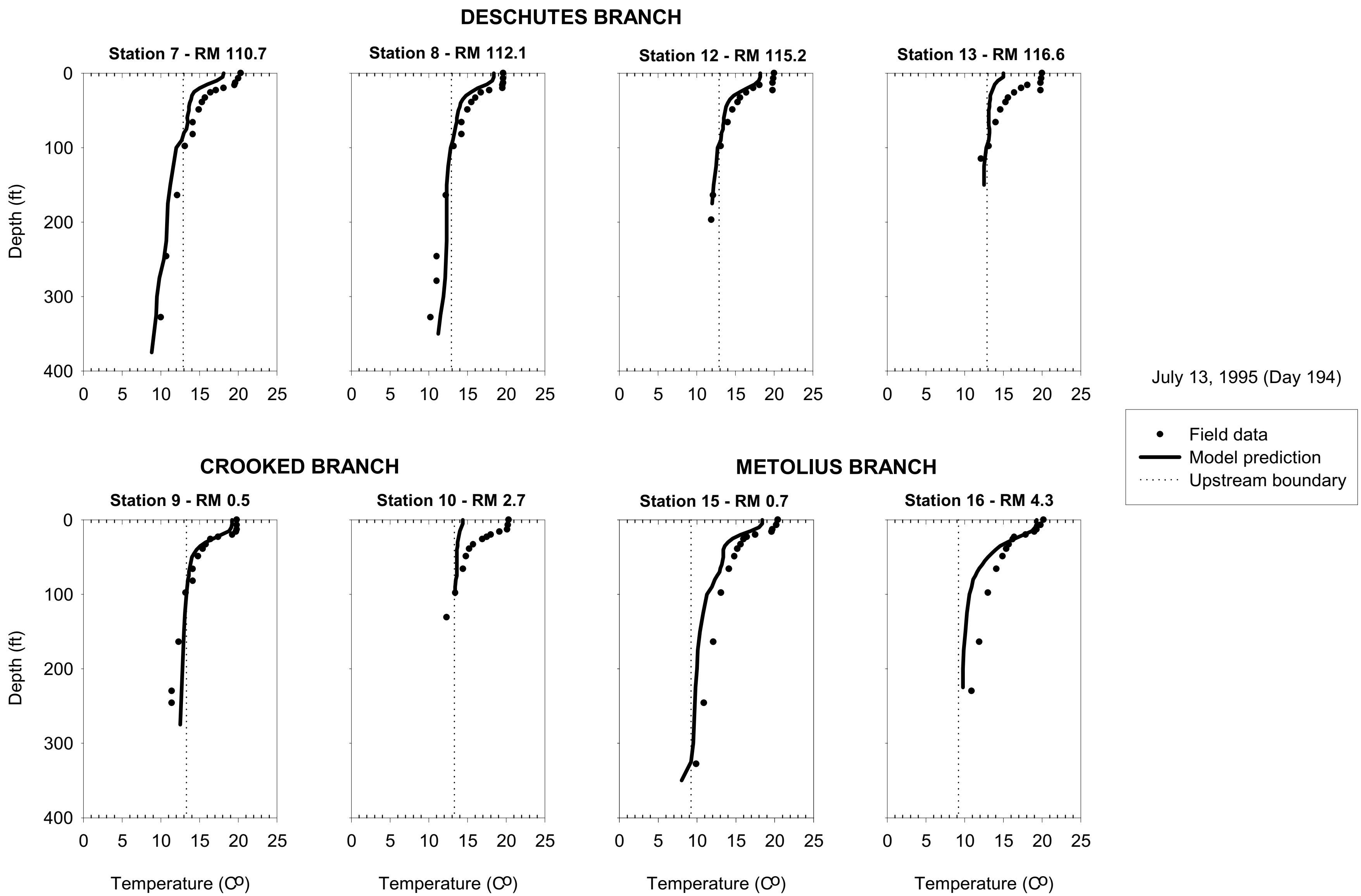
FIGURE 3-18
BETTER MODEL CALIBRATION RESULTS
MAY 9-10, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

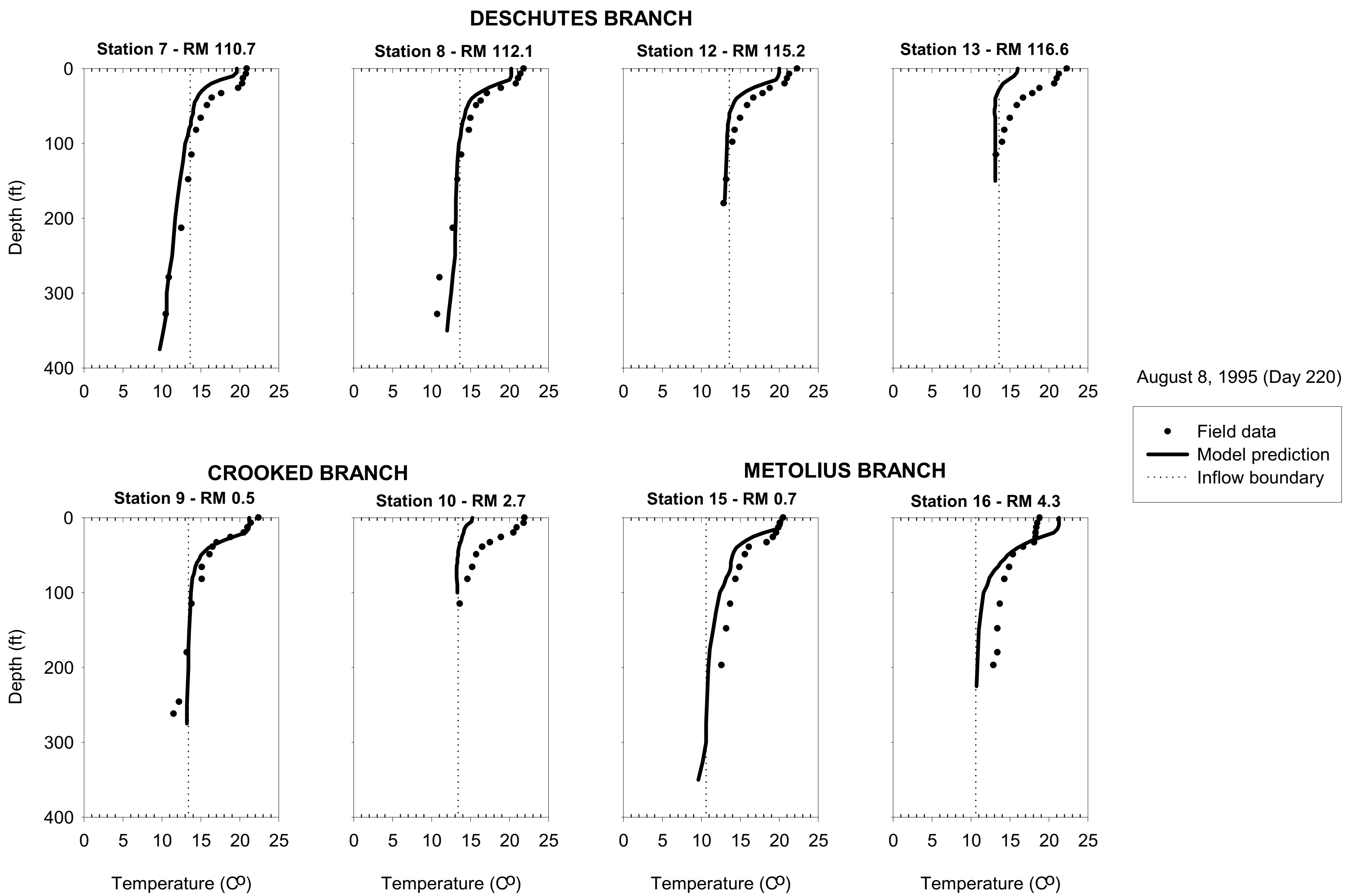
FIGURE 3-19
BETTER MODEL CALIBRATION RESULTS
JUNE 6-7, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

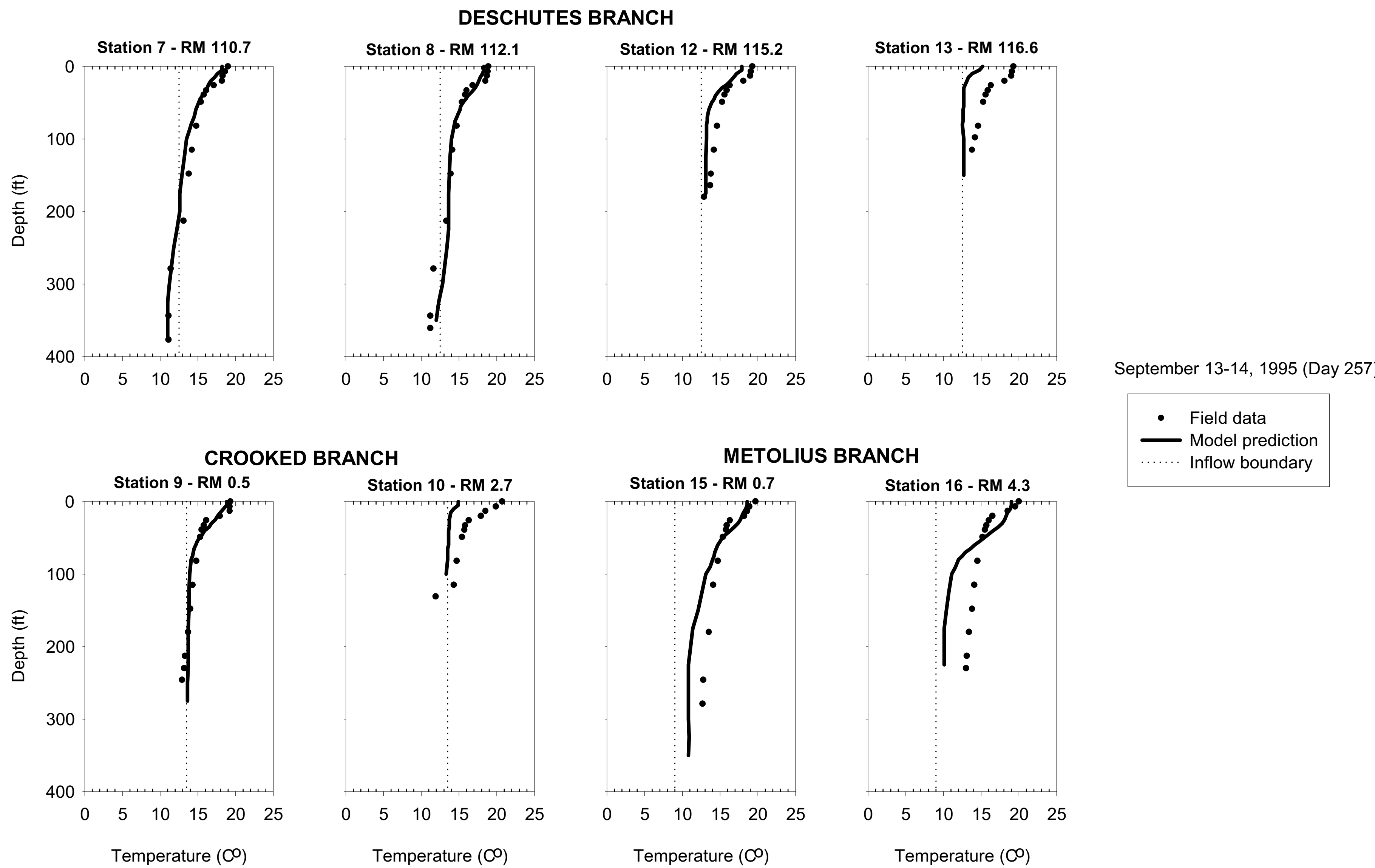
FIGURE 3-20
BETTER MODEL CALIBRATION RESULTS
JULY 13, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	5499-002-500

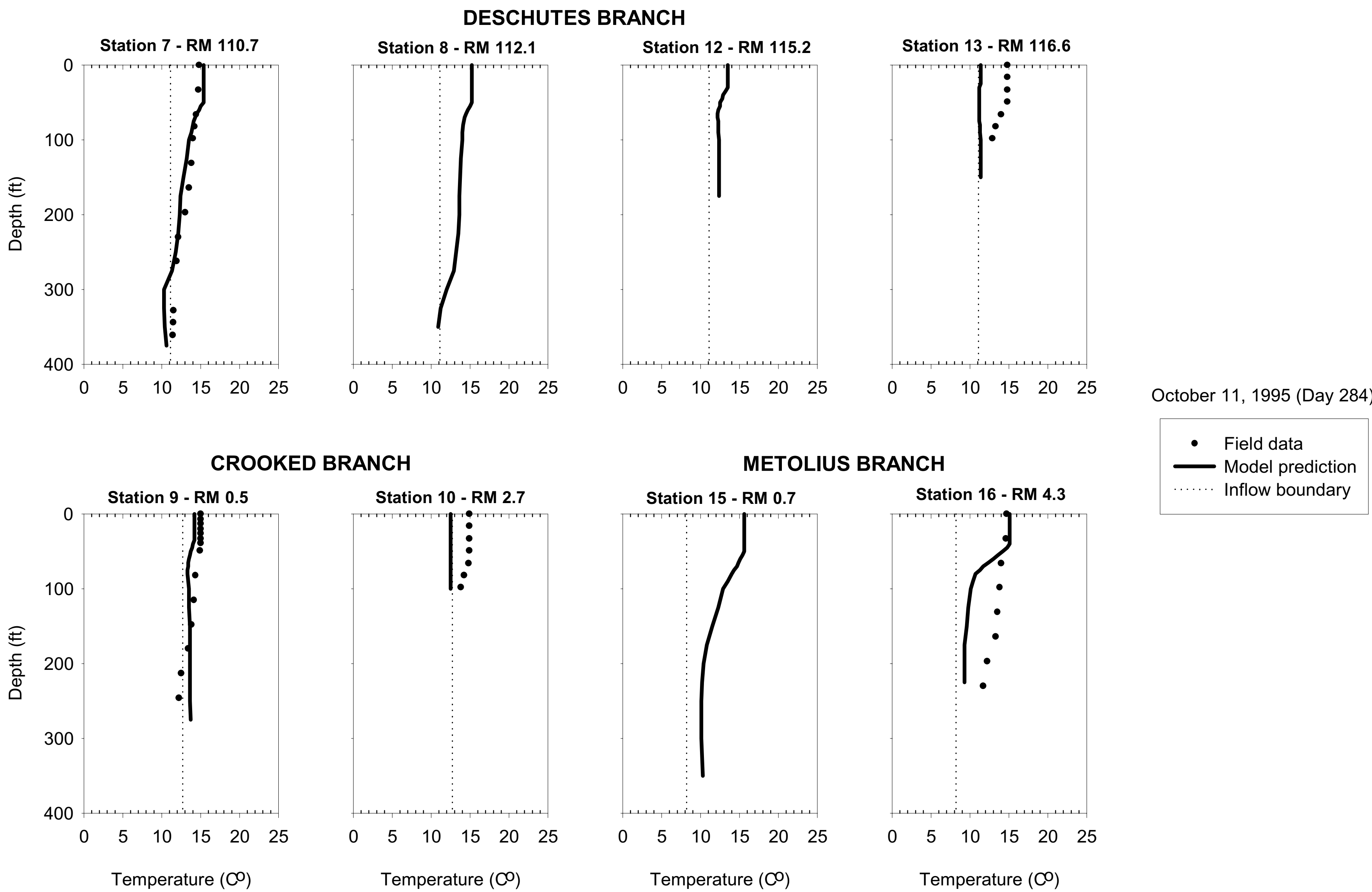
FIGURE 3-21
BETTER MODEL CALIBRATION RESULTS
AUGUST 8, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

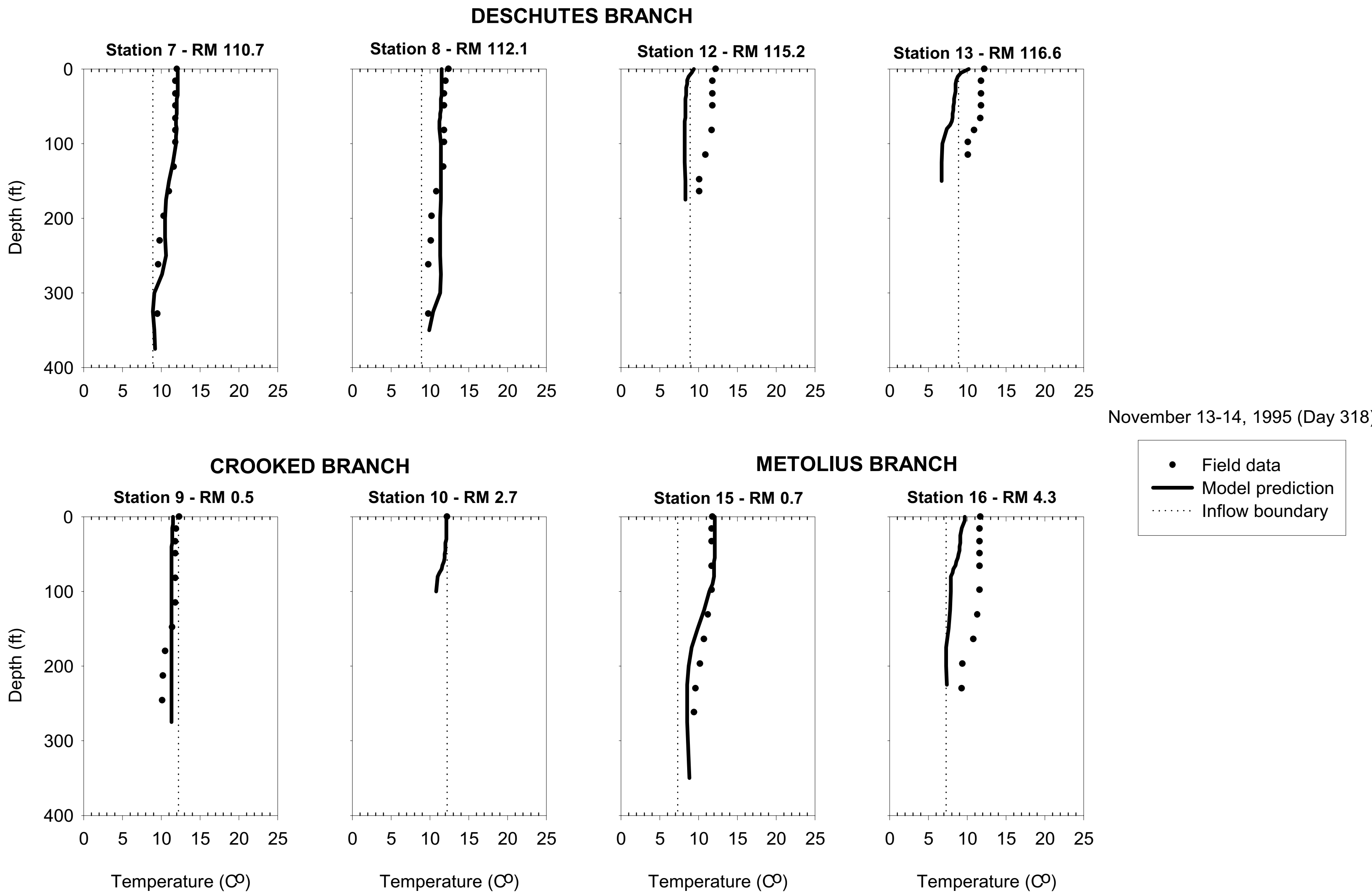
FIGURE 3-22
BETTER MODEL CALIBRATION RESULTS
SEPTEMBER 13-14, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-23
BETTER MODEL CALIBRATION RESULTS
OCTOBER 11, 1995
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: November 12, 1998	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-24
BETTER MODEL CALIBRATION RESULTS
NOVEMBER 13-14, 1995
Portland General Electric Company
Portland, Oregon

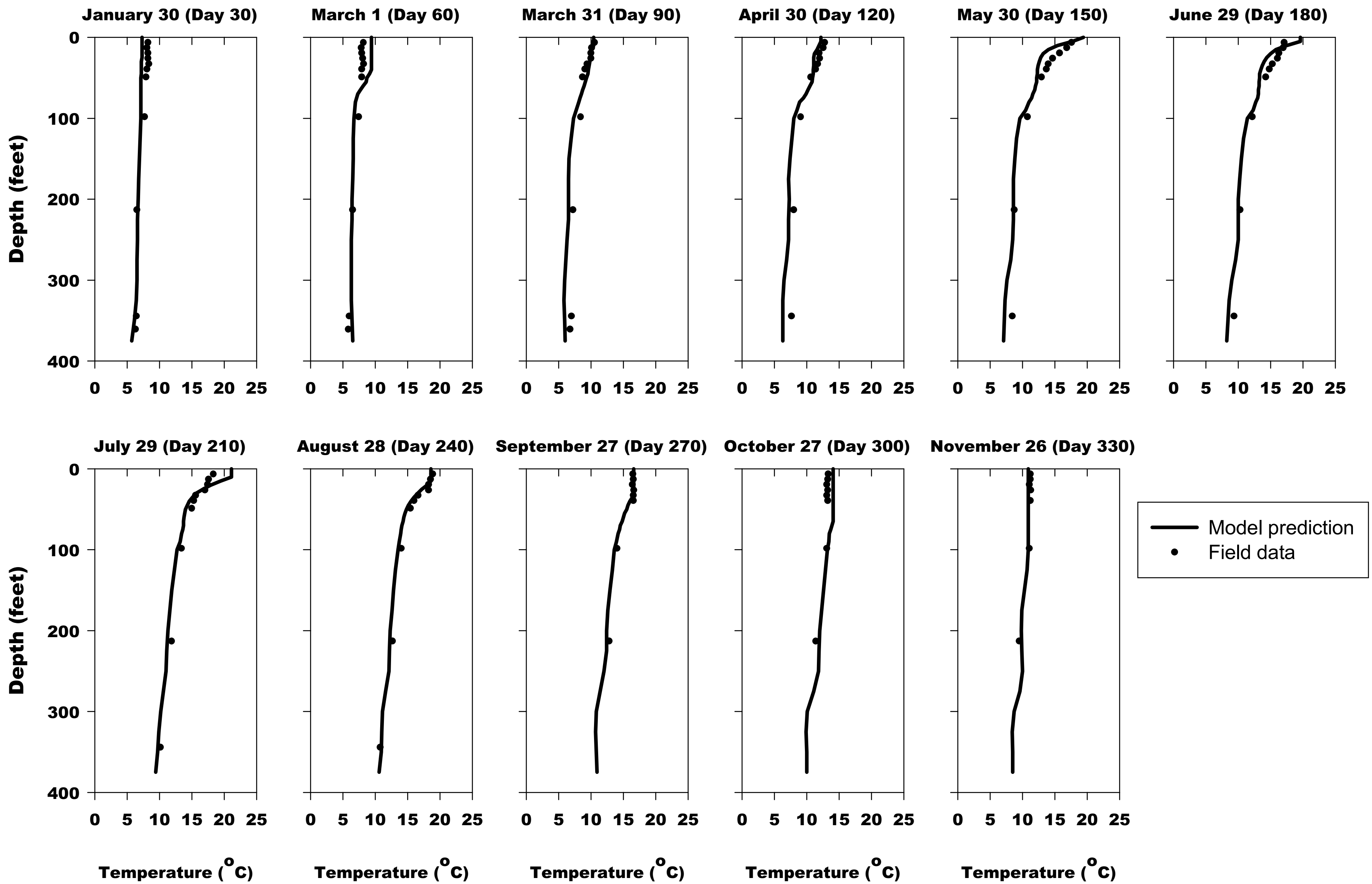


FIGURE 3-25

BETTER MODEL CALIBRATION RESULTS

STATION 7 (FOREBAY) - 1995

Portland General Electric Company

Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 95calfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

The calibrated model temperature output is consistent with the observed vertical stratification patterns within the reservoir, particularly at the forebay Station 7 (see Figure 3-25) and upstream stations on the Deschutes arm of the reservoir. The model typically under-predicts the bottom temperature of the Metolius arm and over-predicts the temperature of the Crooked arm.

The final calibrated model coefficients and factors are provided in Table 3-1.

Table 3-1
Calibrated Model Coefficients and Factors

Model Variable	Deschutes Branch	Crooke d Branch	Metolius Branch
Mixing Coefficient (DC) [Range 0.1-10]	1	1	1
	Calibration Value	Typical Range	
Wind mixing factor (WCOEF)	0.02	0 - 0.1	
Density deflection factor (FDFAC)	0.7	0.1 – 10	
Wind speed adjustment factor (WDFAC)	1	0.5 – 2	
Evaporation adjustment factor (EVFAC)	0.8 – 1.2	0.8 – 1.2	
Withdrawal zone thickness factor (QTH)	20	10 – 50	

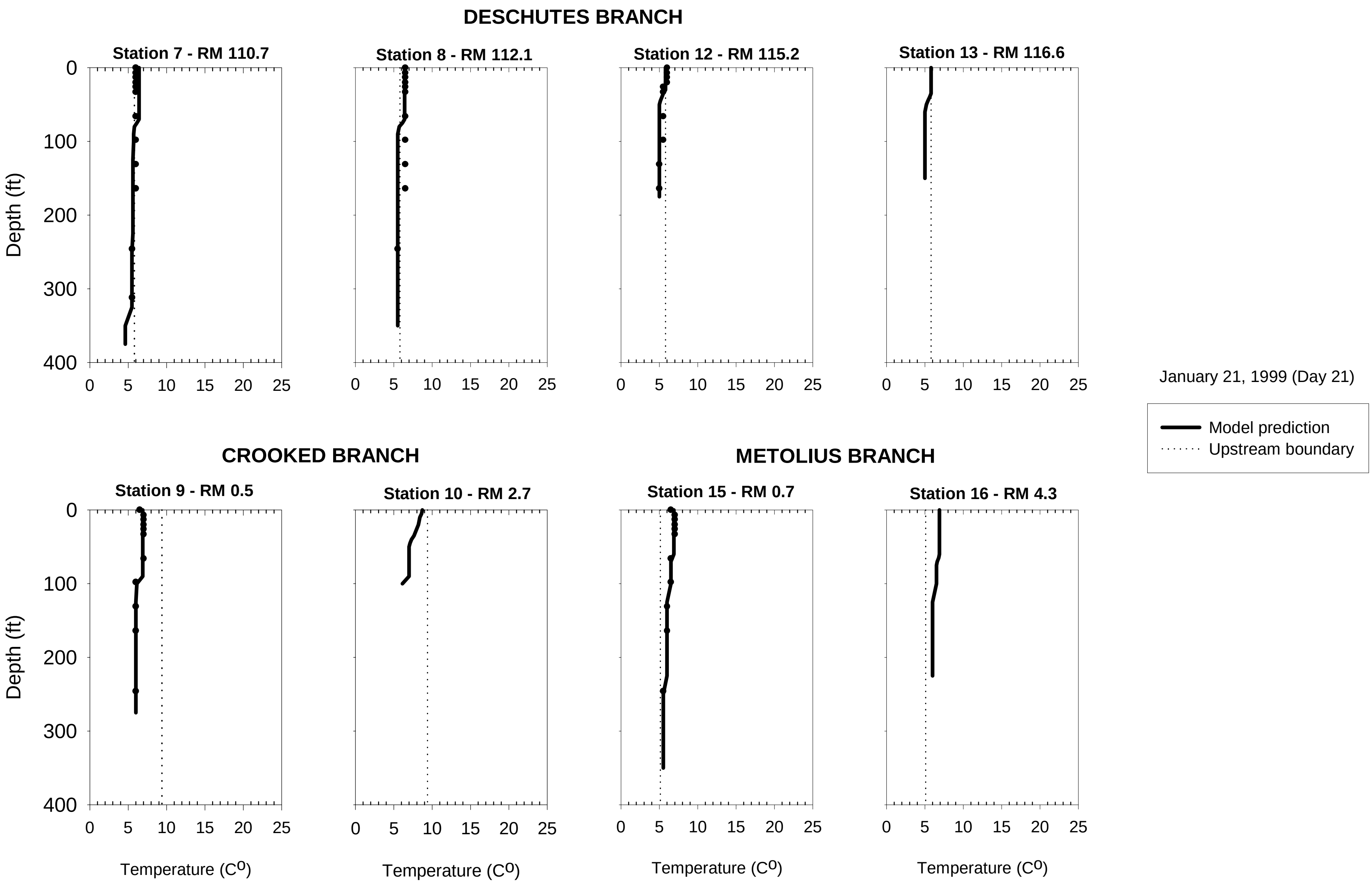
3.4 Model Verification

Model verification consisted of using the existing model geometry, calibrated coefficients, and 1999 input data to generate model output for comparison to the observed 1999 reservoir temperature data.

Figures 3-26 through 3-33 show the fit of model-predicted temperatures to the stations monitored every 2 weeks by PGE from January through mid-July 1999. Figures 3-34 through 3-37 show the fit of model-predicted temperatures to the stations monitored using HOBO sensors (Forebay-Station 7 monitored by PGE and ENSR and the Deschutes, Crooked, and Metolius stations monitored by ENSR). These continuously monitored stations allow averaging of the observation data at the same 12-hour output interval provided in the model output.

3.5 Conclusions

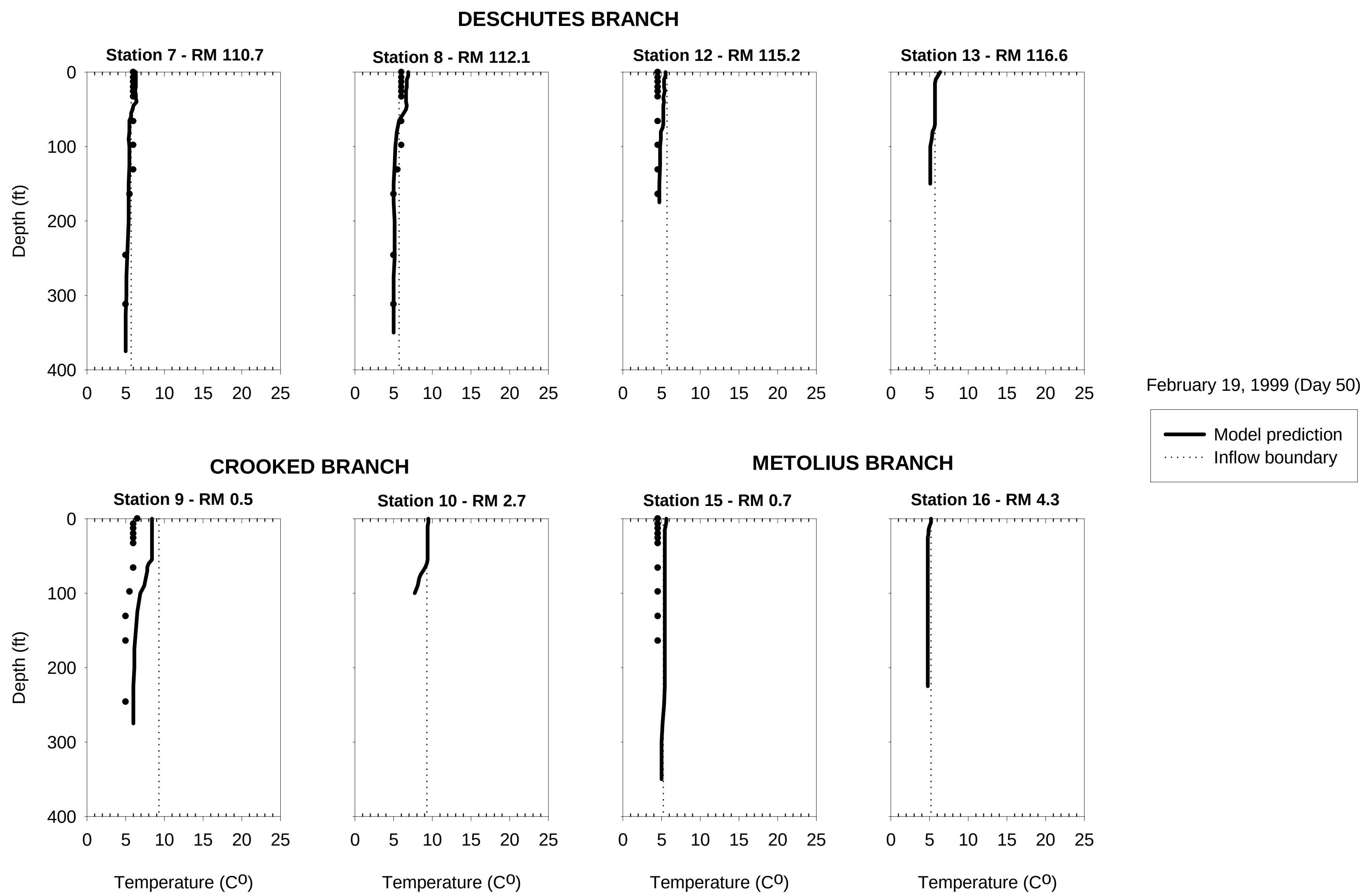
The model fit to the observed temperature profile data was reasonably good and demonstrated that the model could be used reliably as a predictive tool under reservoir conditions similar to 1995 and 1999 (Figures 3-26 through 3-37). The comparisons to the daytime average HOBO data provide the best evidence that the model is well calibrated and provides reliable tool for the evaluation of reservoir response to proposed modifications. The results of the model verification demonstrate that the model can successfully characterize reservoir behavior for the typical environmental conditions characteristic of the project location.



Note: Station locations are shown in Figure 3-1.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-26
BETTER MODEL VERIFICATION RESULTS
JANUARY 21, 1999
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FIGURE 3-27

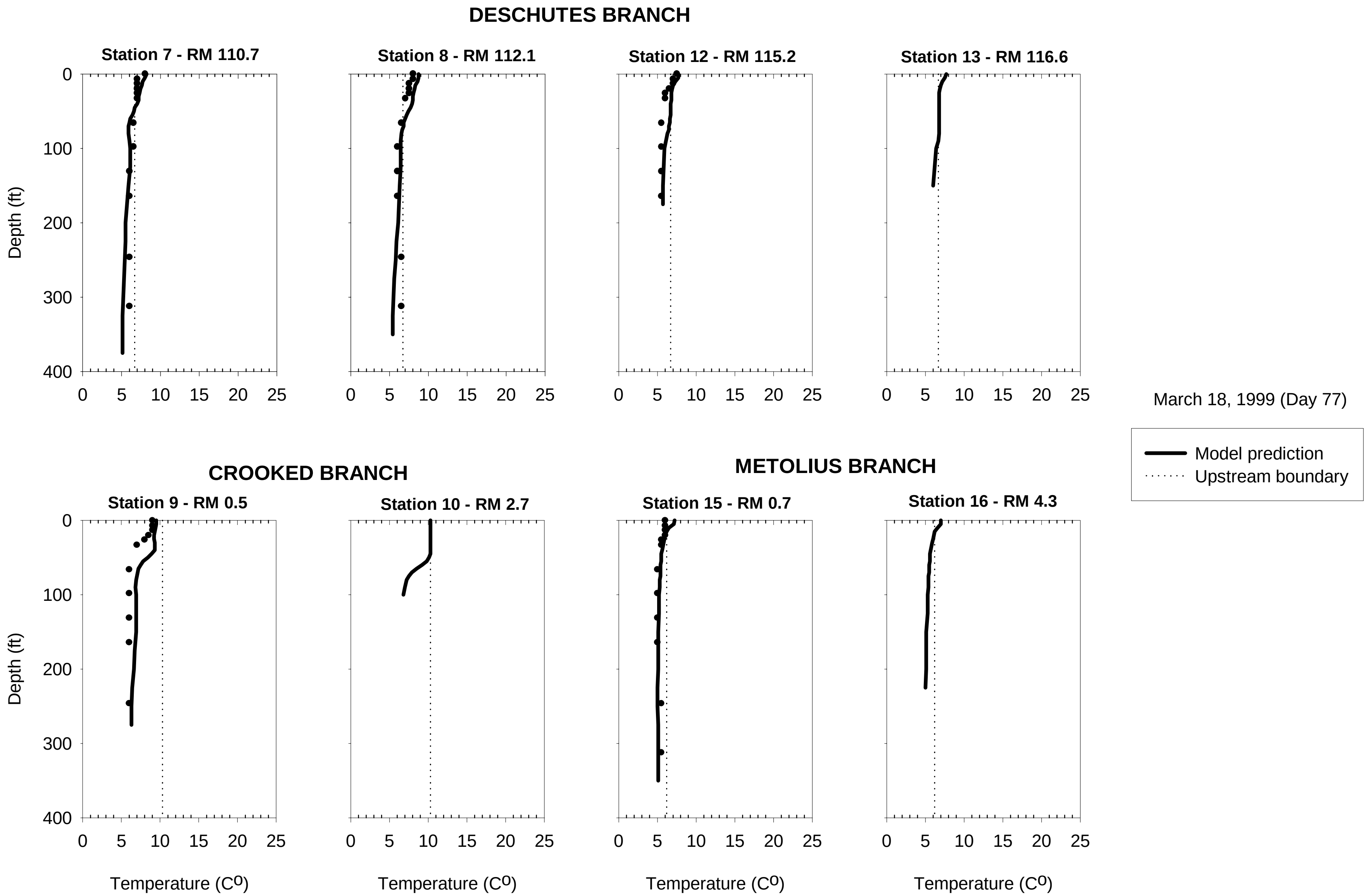
BETTER MODEL VERIFICATION RESULTS

FEBRUARY 19, 1999

Portland General Electric Company

Portland, Oregon

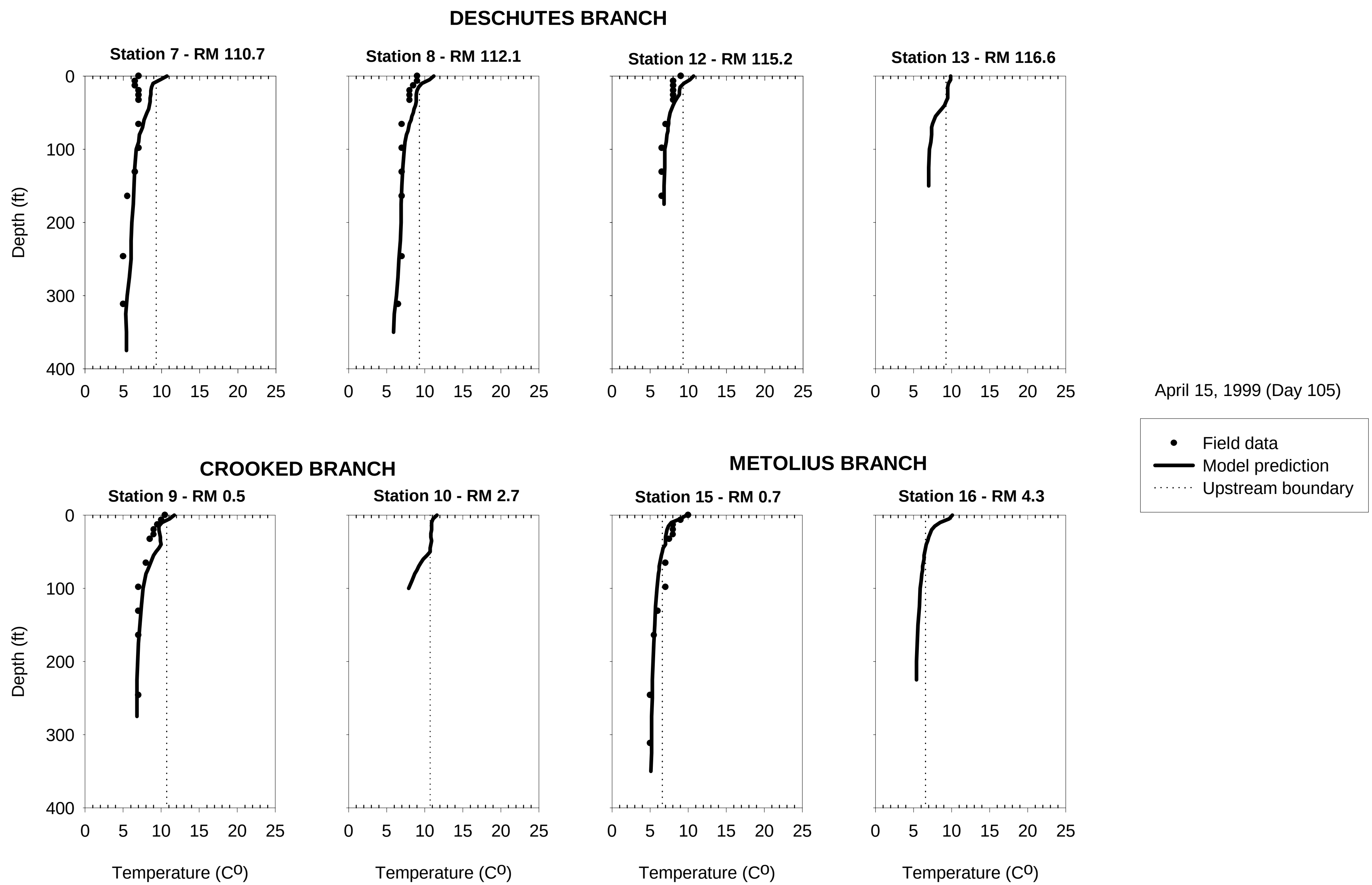
FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

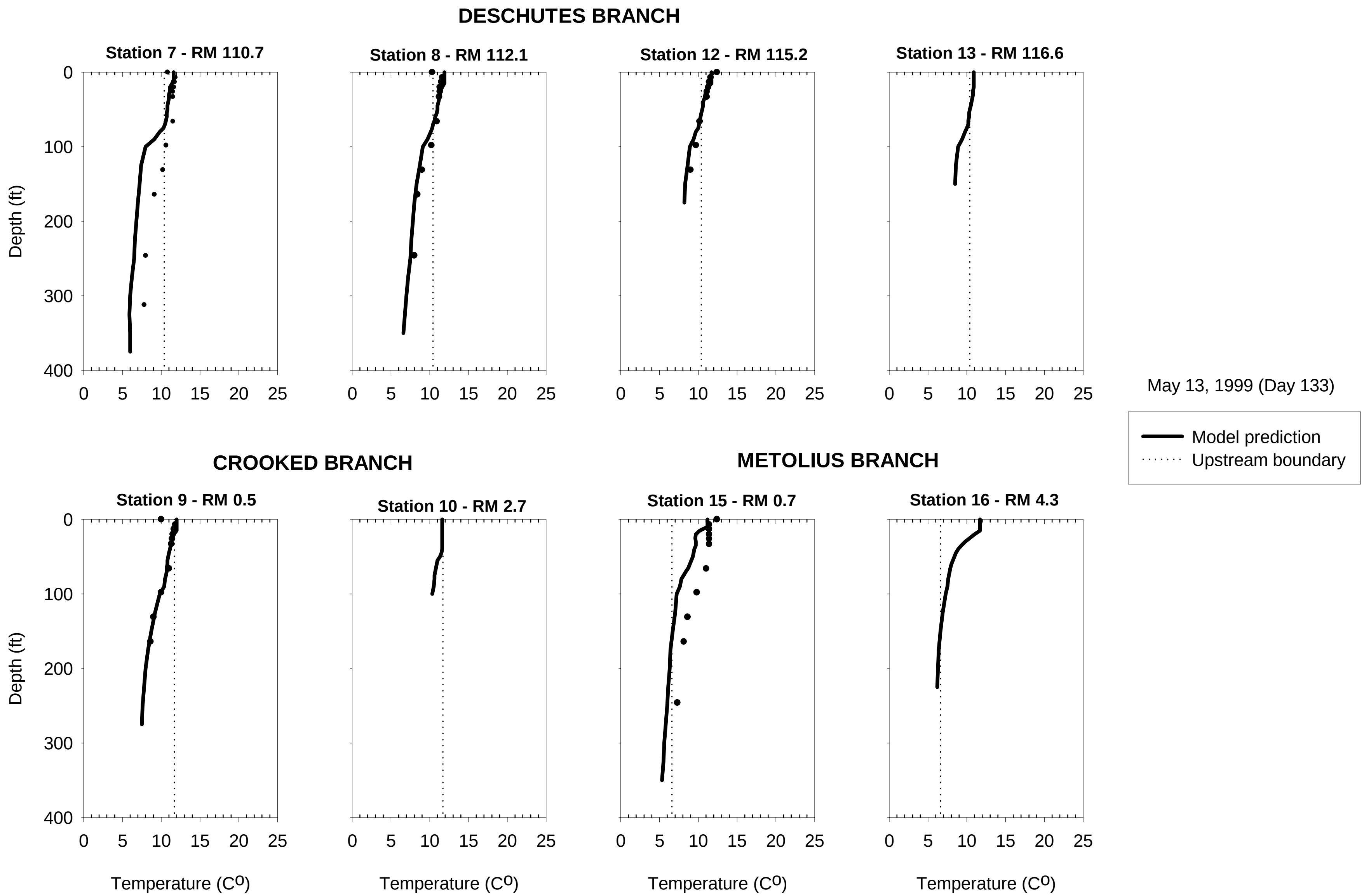
FIGURE 3-28
BETTER MODEL VERIFICATION RESULTS
MARCH 18, 1999
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

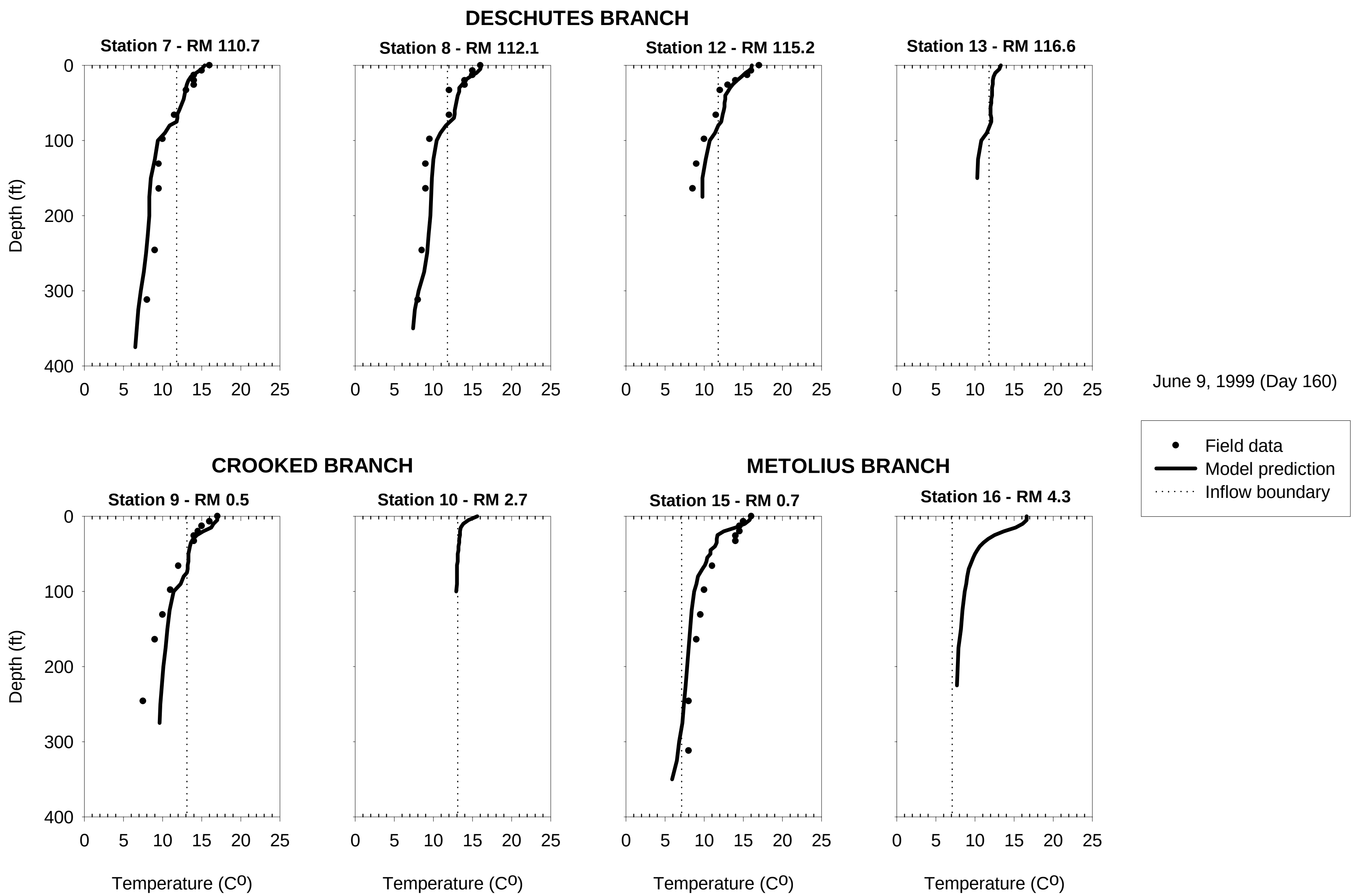
FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-29
BETTER MODEL VERIFICATION RESULTS
APRIL 15, 1999
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:	FIGURE 3-30 BETTER MODEL VERIFICATION RESULTS MAY 13, 1999 Portland General Electric Company Portland, Oregon
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002	



Note: Station locations are shown in Figure 3-1.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: November 12, 1998	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

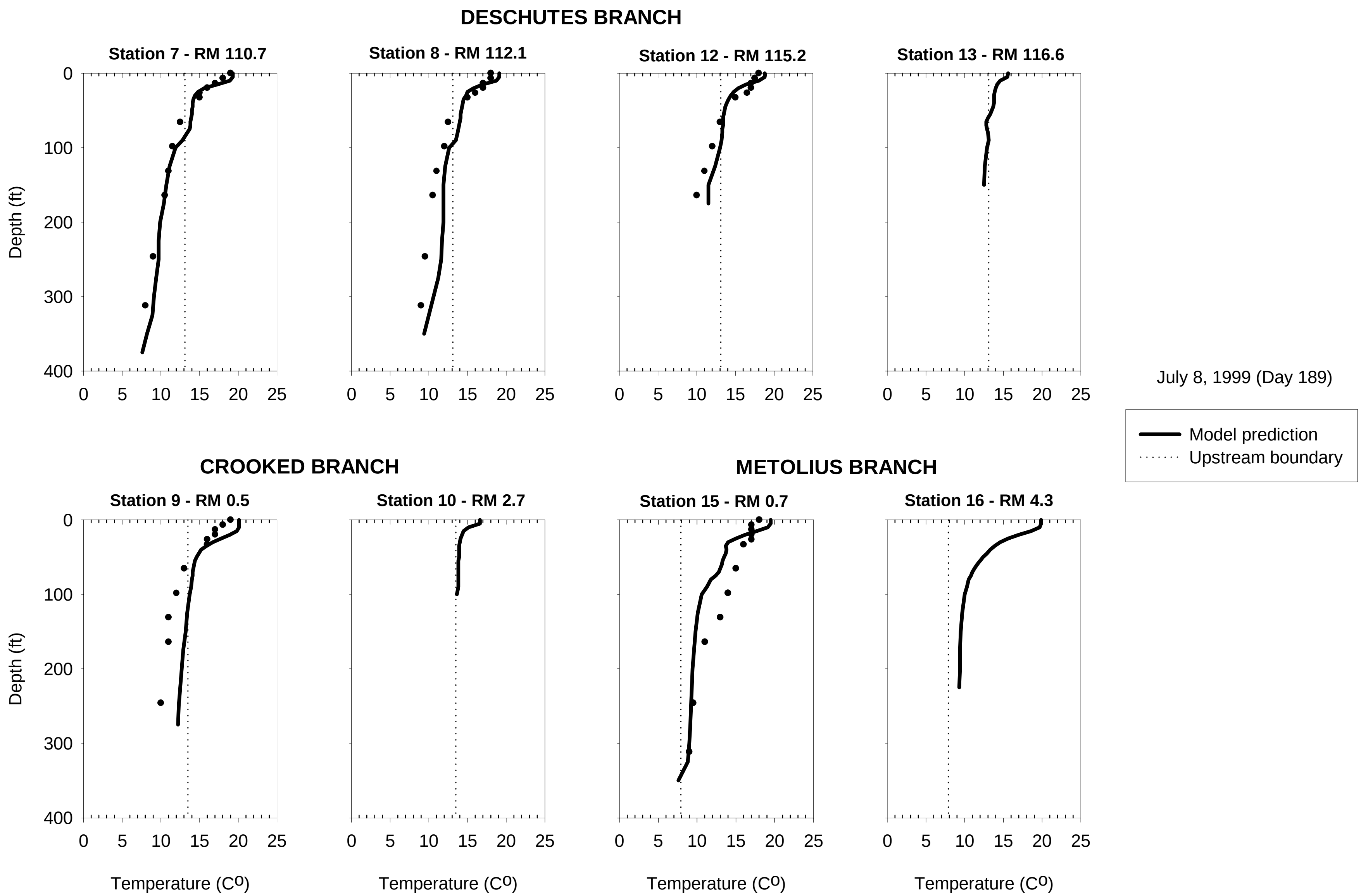
FIGURE 3-31

BETTER MODEL VERIFICATION RESULTS

JUNE 9, 1999

Portland General Electric Company

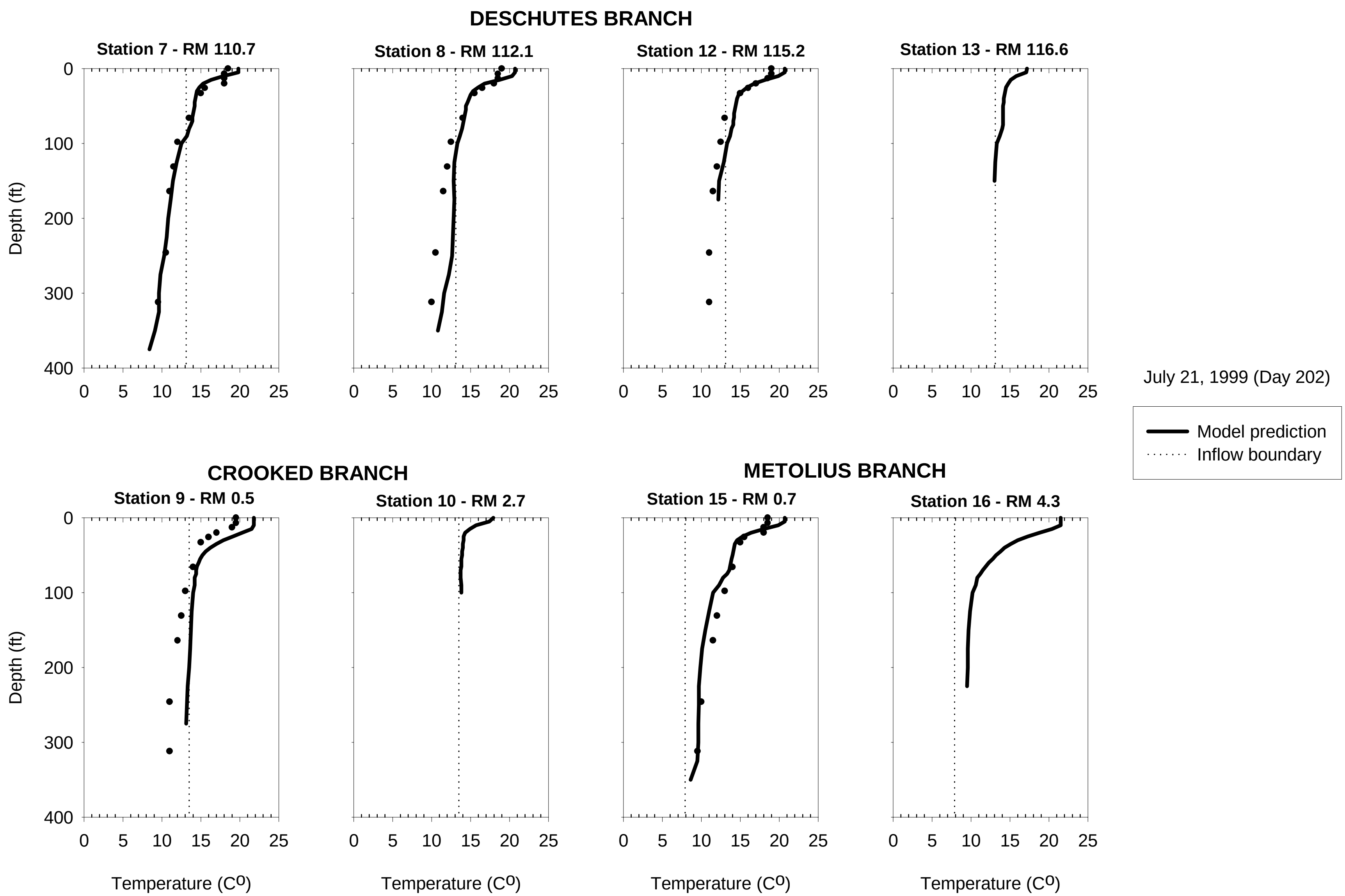
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER ENVIRONMENTAL FW WHEELER CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:
	FILENAME: 95verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-32
BETTER MODEL VERIFICATION RESULTS
JULY 8, 1999
Portland General Electric Company
Portland, Oregon



Note: Station locations are shown in Figure 3-1.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 1, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-33

BETTER MODEL CALIBRATION RESULTS

JULY 21, 1999

Portland General Electric Company

Portland, Oregon

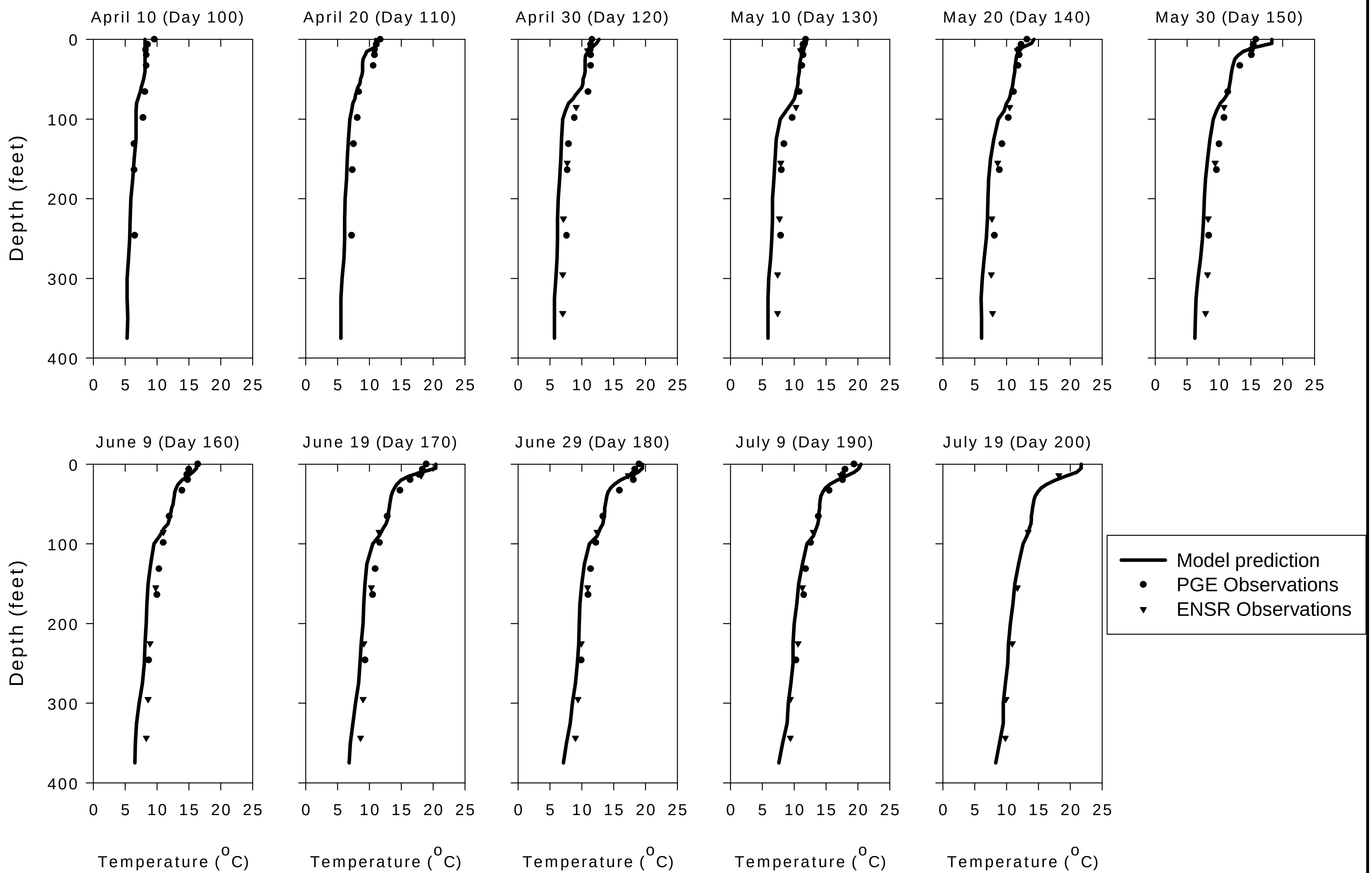


FIGURE 3-34
BETTER MODEL VERIFICATION RESULTS
FOREBAY STATION - 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

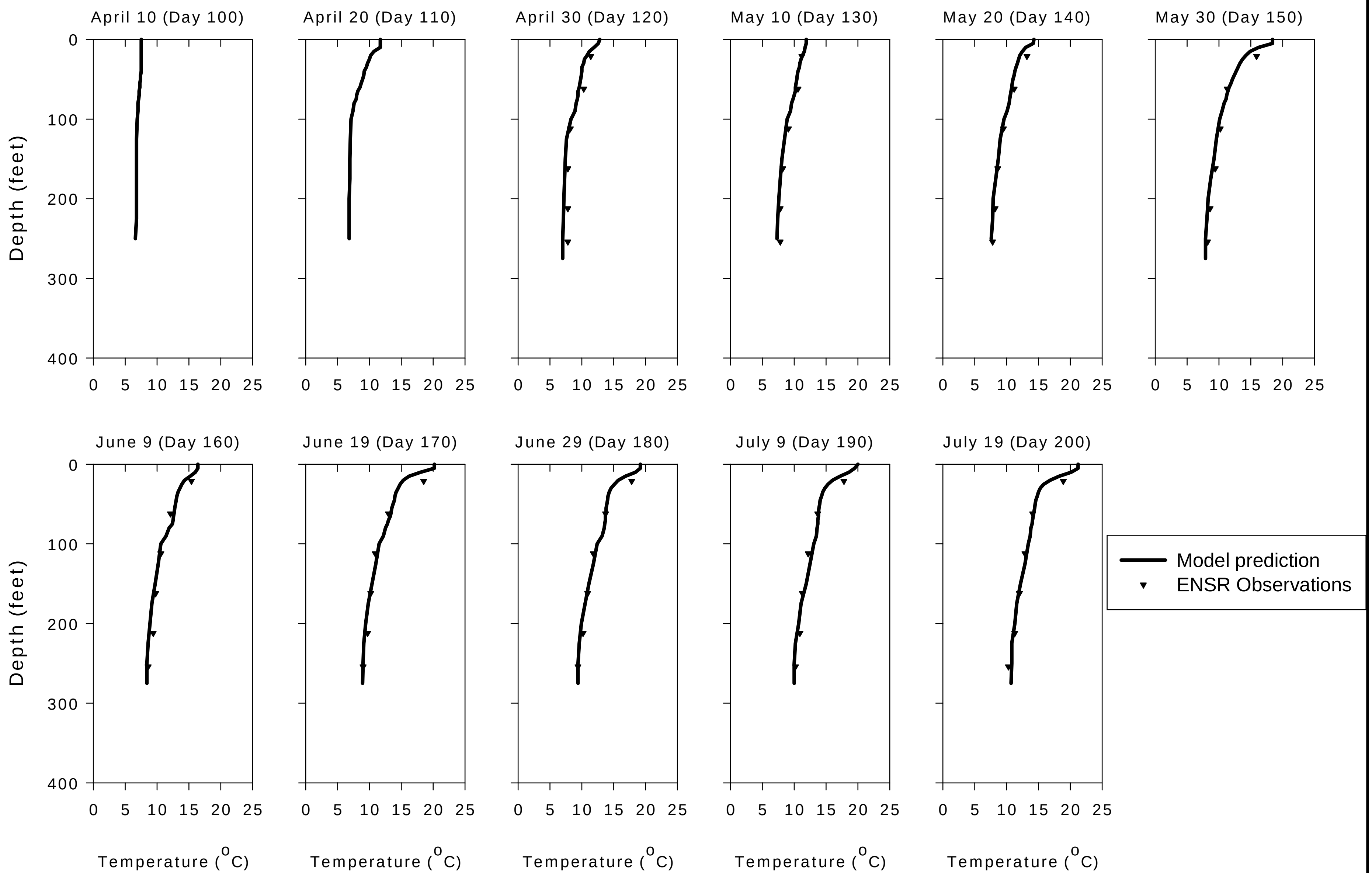


FIGURE 3-35
BETTER MODEL VERIFICATION RESULTS
DESCHUTES ARM STATION - 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

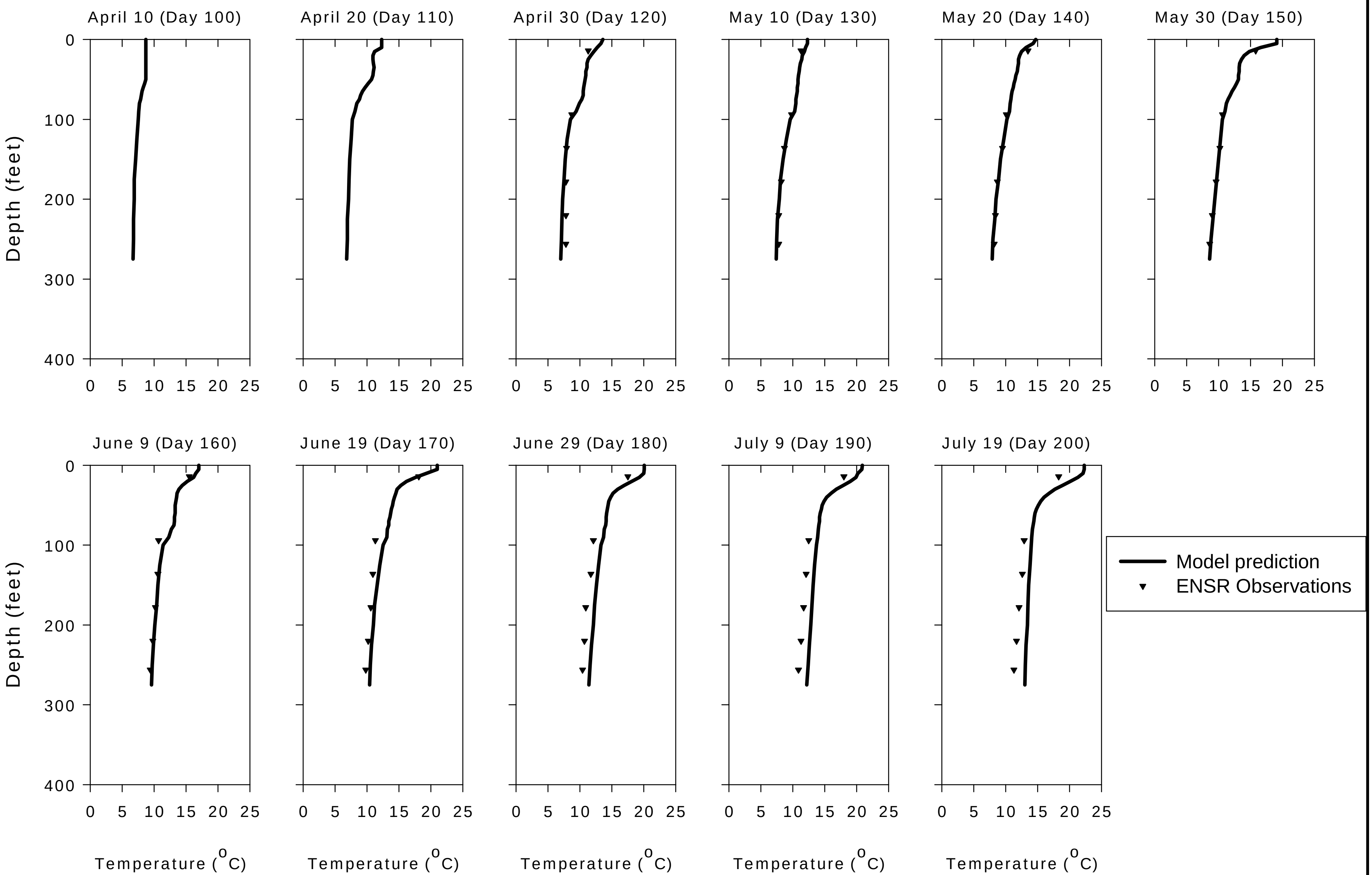
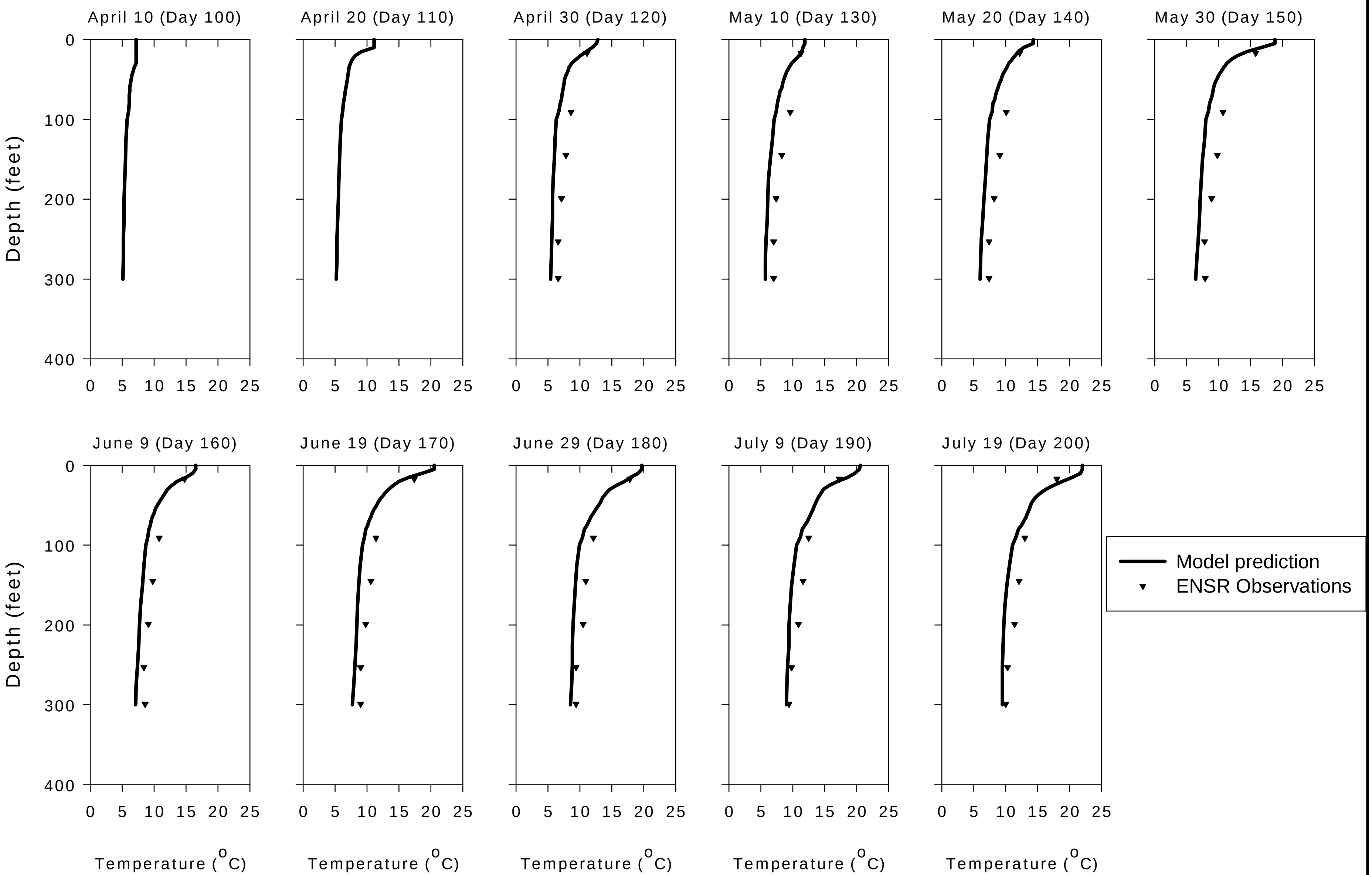


FIGURE 3-36
BETTER MODEL VERIFICATION RESULTS
CROOKED ARM STATION - 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
	FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: C. DeGasperi	DATE: December 2, 1999	PROJECT NO:
FILENAME: 99verfinal.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 3-37
BETTER MODEL VERIFICATION RESULTS
METOLIUS ARM STATION - 1999
Portland General Electric Company
Portland, Oregon

4.0 HYDRODYNAMIC MODEL CALIBRATION AND VERIFICATION

4.1 Introduction

The circulation in Lake Billy Chinook is affected by its complex geometry, the effect of wind, and the baroclinic motion induced by the distinct temperature characteristics of the reservoir tributaries (i.e., Crooked, Deschutes, and Metolius Rivers). To study the hydrodynamics in Lake Billy Chinook, a state-of-the-art 3D hydrodynamic numerical model was developed and used to predict the flow field in Lake Billy Chinook (*Preliminary Temperature and Hydrodynamic Modeling of Lake Billy Chinook – Pelton Round Butte Project* (ENSR January, 1999). That modeling effort was labeled preliminary because hydrodynamic data in Lake Billy Chinook was not available for model calibration and verification. The model was thus set up using best professional judgement. In this study, the preliminary hydrodynamic model of Lake Billy Chinook was modified, and then calibrated and verified using the field temperature and velocity data collected through the synoptic data collection program described in Section 2.

The hydrodynamic modeling effort of Lake Billy Chinook provides useful information for two major purposes: 1) assessing our level of understanding of the observed reservoir flow patterns; and 2) providing assistance in the evaluation and design of downstream fish collection and passage facilities. The numerical model is used to simulate the 3D velocity field with the effects due to temperature stratification included in the predictions (baroclinic mode). The model was first calibrated to the observed temperature and velocity data in the spring condition (May 1999). The model was then verified using data from summer condition (July 1999). The wind effect on the circulation in the reservoir was also investigated. The initial temperature distribution required for operating the hydrodynamic model was obtained from the results produced by the BETTER model discussed in Section 3.0.

The numerical model used in this study is the Environmental Fluid Dynamic Code (EFDC), initially developed at the Virginia Institute of Marine Science (Hamrick 1992). The model is designed for the simulation of flows and transport processes in estuaries and coastal oceans, as well as reservoirs, lakes, and rivers. The model is a time domain finite difference model that solves the 3D primitive variable vertically hydrostatic equations of motion for turbulent flow in a coordinate system that is curvilinear and orthogonal in the horizontal plane and sigma-stretched in the vertical direction. A second moment turbulence closure scheme (Mellor and Yamada, 1982) is used to relate turbulent viscosity and diffusivity to the turbulent intensity and length scale. Horizontal diffusion is calculated using the Smogarinsky formula (Smogarinsky 1963). An equation of state relates the water density to pressure, salinity, temperature, and suspended sediment concentration. Transport equations for the turbulent intensity and length scale as well as temperature, salinity, tracer, and suspended sediment can be also solved simultaneously in

EFDC. For the details of the theoretical aspects and numerical methods of the model, the reader is referred to Hamrick (1992) and Hamrick and Wu (1996).

4.2 Hydrodynamic Model (EFDC) setup

The hydrodynamic model setup consists of two components: 1) construction of the 3D computational grid for Lake Billy Chinook; and 2) specification of boundary and initial conditions. The initial model grid that was generated for the preliminary modeling of hydrodynamics in Lake Billy Chinook and evaluating the four alternatives for improving downstream fish passage (ENSR January1999) was modified during this study. In order to simulate the flow induced by the power intake withdrawal in the Forebay, the grid resolution in the vertical direction was refined. The horizontal grid resolution remained the same. Further minor adjustments may be made to the grid in 2000 as better bathymetry data become available from PGE's ongoing review and updating of these data. The boundary conditions specified were also similar to those in the previous study.

4.2.1 Model Grid

The model grid was constructed in a horizontal curvilinear-orthogonal and vertical sigma-stretched coordinate system. A curvilinear-orthogonal grid for Lake Billy Chinook was generated using the EFDC boundary-fitted grid generation package GEFDC. The horizontal computational grid used in this study is shown in Figure 4-1. There are 493 grid cells in the horizontal plane. Because the region of interest is the downstream confluence of the reservoir arms and the forebay of Round Butte Dam, the numerical grid is designed in such a way that the grid resolution gradually increases from the three river upstream boundaries to the forebay. The average grid cell size in the forebay region is about 300 feet by 300 feet.

A total of 10 grid layers were specified in the vertical direction. Because the epiliminion is mainly confined within the upper 100 feet, finer vertical layers were specified in the upper 100 feet of the water column to capture the sharp temperature gradient in the thermocline. In order to simulate the flow structure near the power intake correctly, finer vertical layers were also specified near the bottom. The vertical grids along three river arms are plotted in Figure 4-2. The fraction of each layer in the water column is given in Table 4-1 (Layer 1 corresponds to the bottom layer). The initial water surface level is at elevation 1,945 feet above mean sea level.

Table 4-1
Vertical Layer Thickness Distribution for the Lake Billy Chinook Hydrodynamic Model

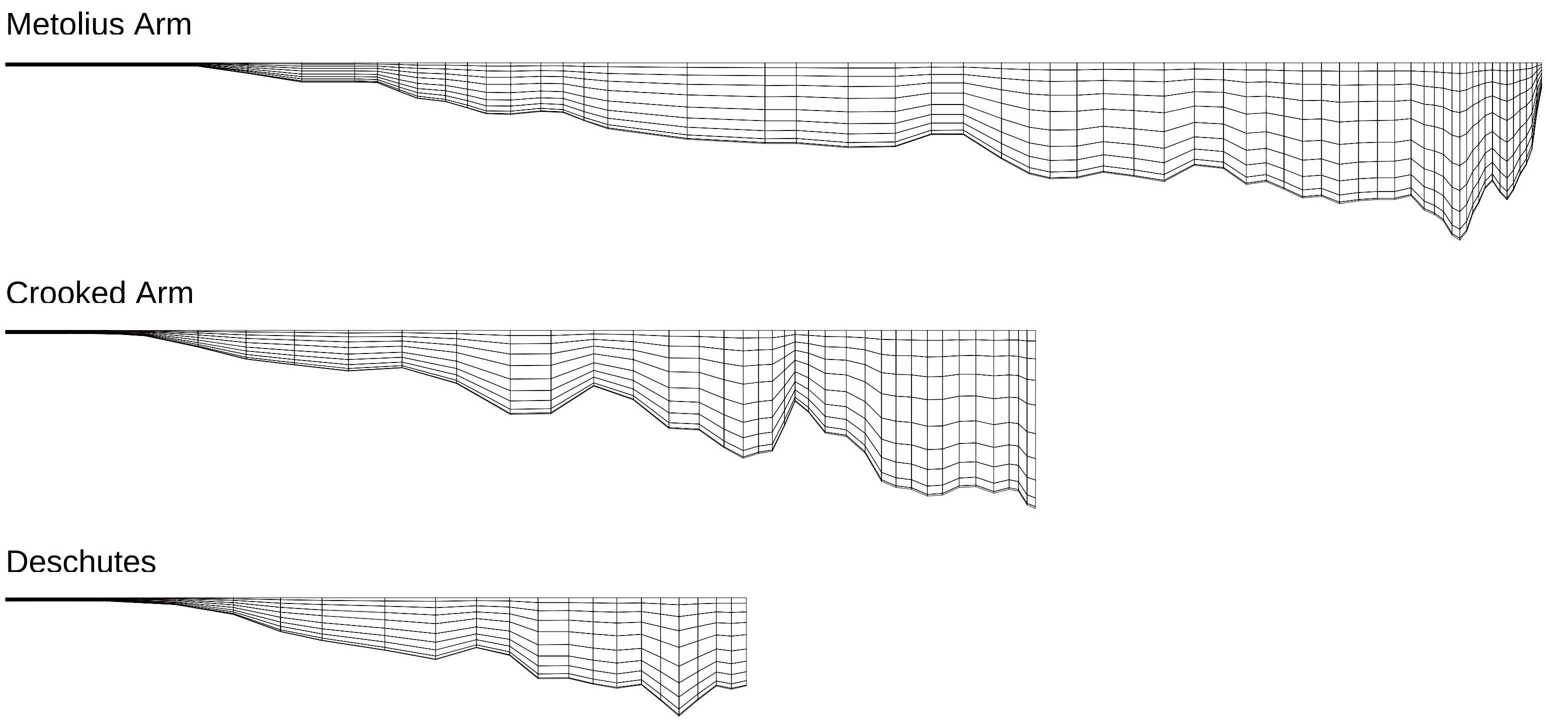
Layer Number	1	2	3	4	5	6	7	8	9	10
Relative Thickness	0.01	0.05	0.1	0.12	0.14	0.16	0.14	0.12	0.1	0.06

FIGURE 4-1

EFDC MODEL HORIZONTAL GRID

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 18, 2000	PROJECT NO:
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 18, 2000	PROJECT NO:
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 4-2

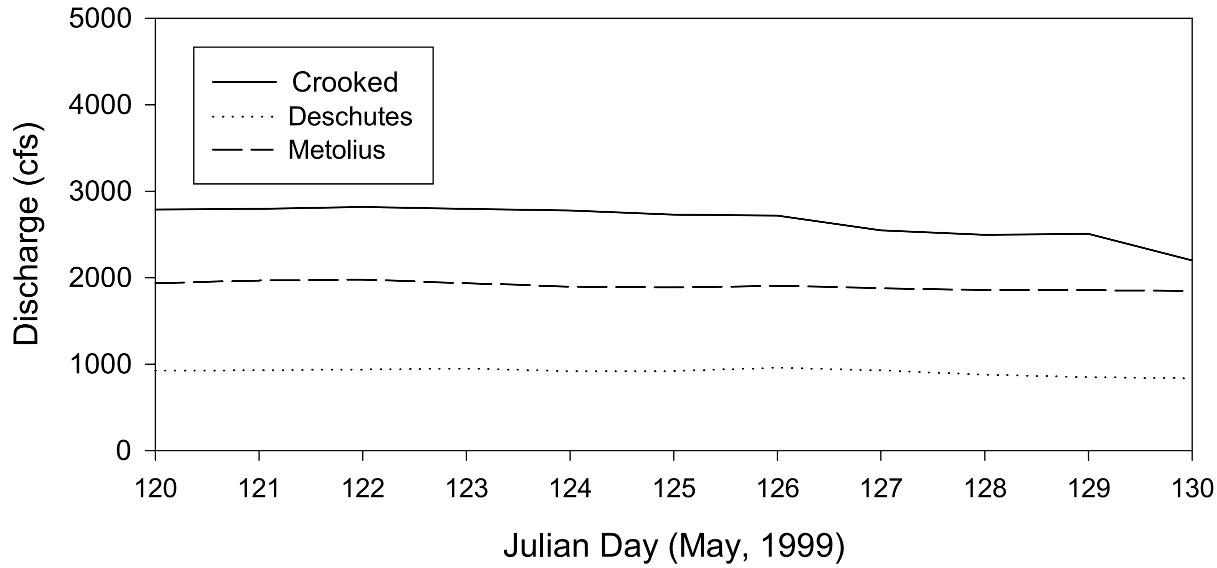
EFDC MODEL VERTICAL GRID

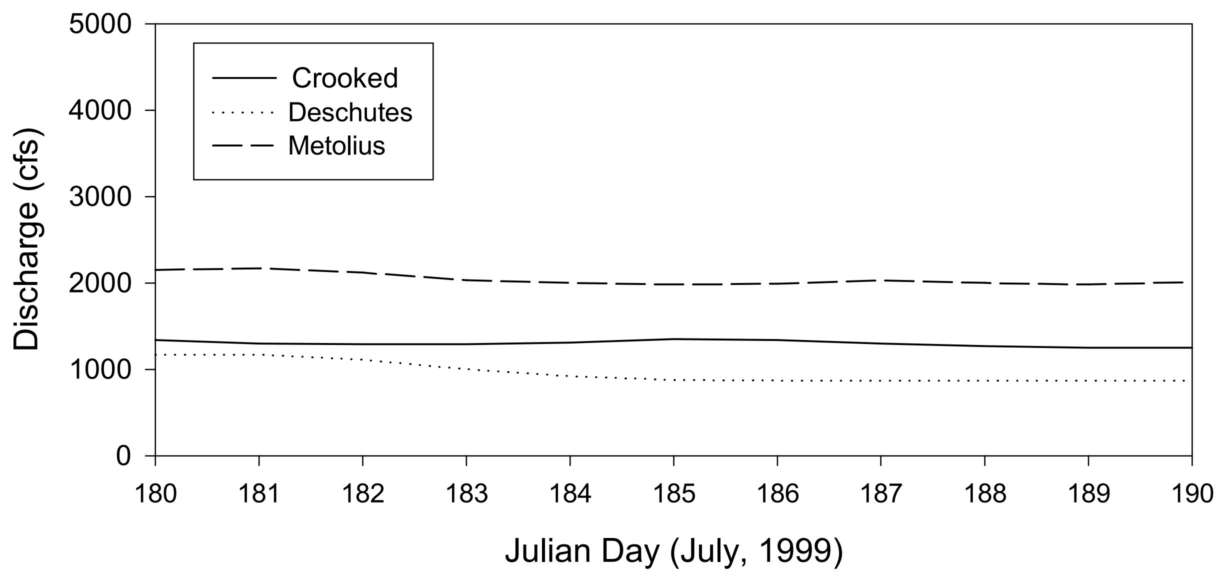
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

4.2.2 Model Boundary Conditions

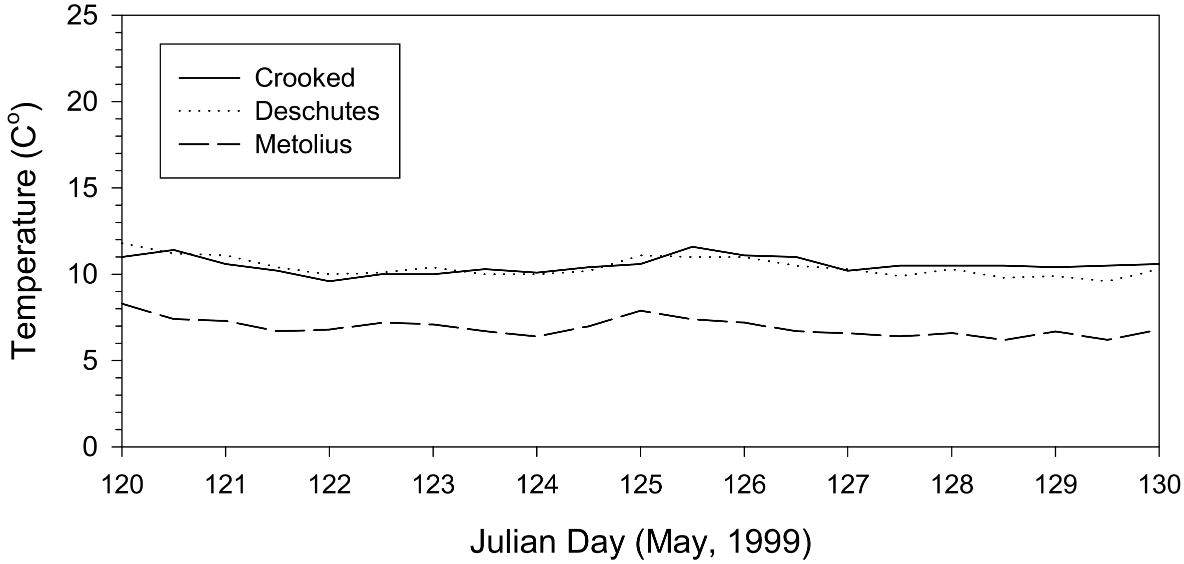
The hydrodynamic solution in the model is calculated based on the specified boundary condition. The circulation in Lake Billy Chinook is driven by three types of forcing mechanisms: 1) tributary inflow and powerhouse discharge; 2) temperature (density) stratification, and 3) wind stresses. Because the model is set up to simulate the hydrodynamics coupled with heat transport, the following types of boundary conditions are required: 1) tributary inflow and powerhouse discharge; 2) the vertical temperature distribution associated with each tributary inflow; 3) and wind stresses at the water surface. The river inflows and powerhouse discharge are simulated as sources and sinks in the model system. Because the river heads are far from the forebay area and the water depths at the river heads are very small (< 2m), the river inflow rates and temperatures are uniformly distributed in the water column at each of the three upstream boundaries. The powerhouse intake is located at the bottom in the reservoir, therefore, the powerhouse discharge is specified in the bottom layer of the forebay grid cell only. Due to the relatively large grid size, the velocity in the nearfield of the intake withdrawal cell may not match the exact velocity through the outlet. However, total outflow water mass is conserved. A much finer grid would be required in order to simulate the flow field closes to the power intake accurately.

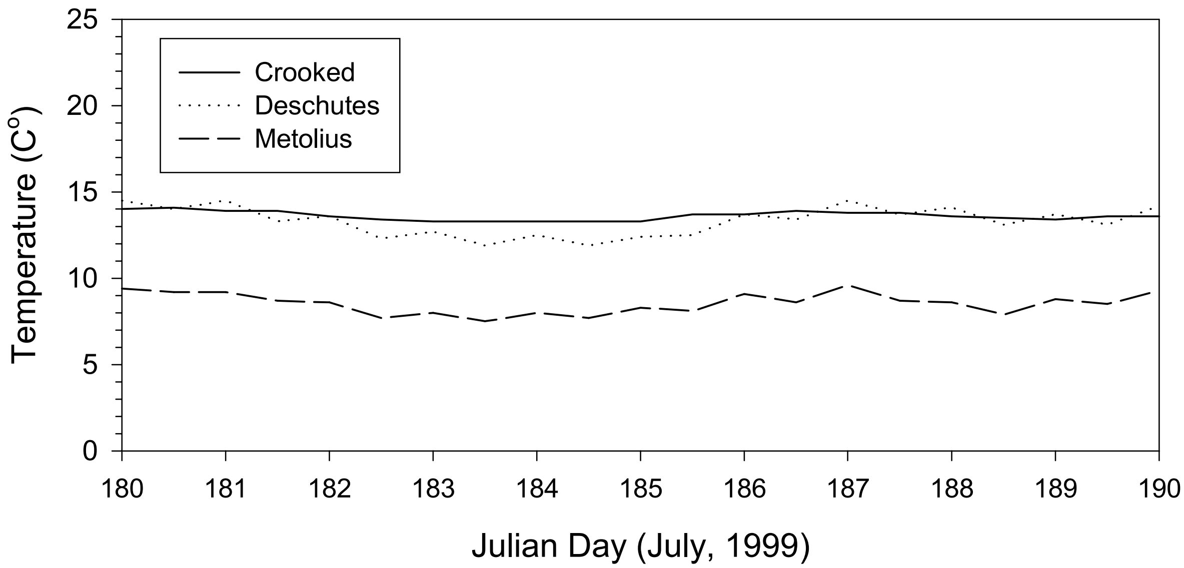
In general, the data used for the boundary conditions are the same as those used in the Lake Billy Chinook BETTER temperature model verification described in the previous section, except that the data are interpolated at a much finer time step for input to the hydrodynamic model. Unlike the temperature model, which was run for a period of 7 months for model verification in 1999, the hydrodynamic model was applied for 6 days for each simulation due to considerations of computational time. The river inflows for a 10-day period in May and July of 1999 are shown in Figure 4-3. Figure 4-3 shows that the Crooked River inflow is the highest in spring and reduces to half in the summer. Metolius inflow is the highest in the summer and Deschutes inflow is always the lowest. Inflows from the Deschutes and Metolius Rivers remain about the same in the spring and summer seasons. The river inflow temperatures for the same period are given in Figure 4-4. The Deschutes and Crooked River temperatures are about the same and the Metolius River temperature is about 3 to 5 degrees lower than the Deschutes and Crooked River temperatures. The powerhouse discharges for the same periods are plotted in Figure 4-5. Unlike 1995, the daily peaking pattern of the power intake is not always evident in 1999. Discharge outflow in general is greater than that in 1995 and sometimes the low outflow discharge never drops down to zero within a day.





FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE 4-3**
	CHECKED: T. Khangaonkar	1999 RIVER INFLOW
	DATE: December 20, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: 99inftem.jnb	





FOSTER WHEELER ENVIRONMENTAL CORPORATION

PROJECT NO: 2200.0001.0002

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DATE: December 20, 1999

FILENAME: 99inftem.jnb

FIGURE 4-4

1999 RIVER INFLOW TEMPERATURE

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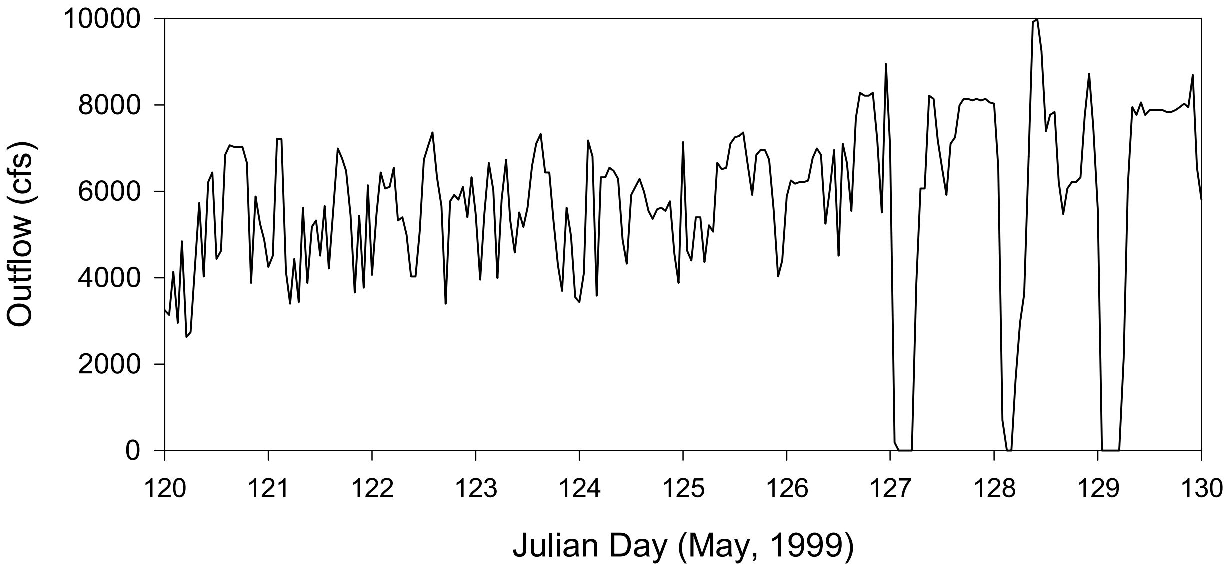
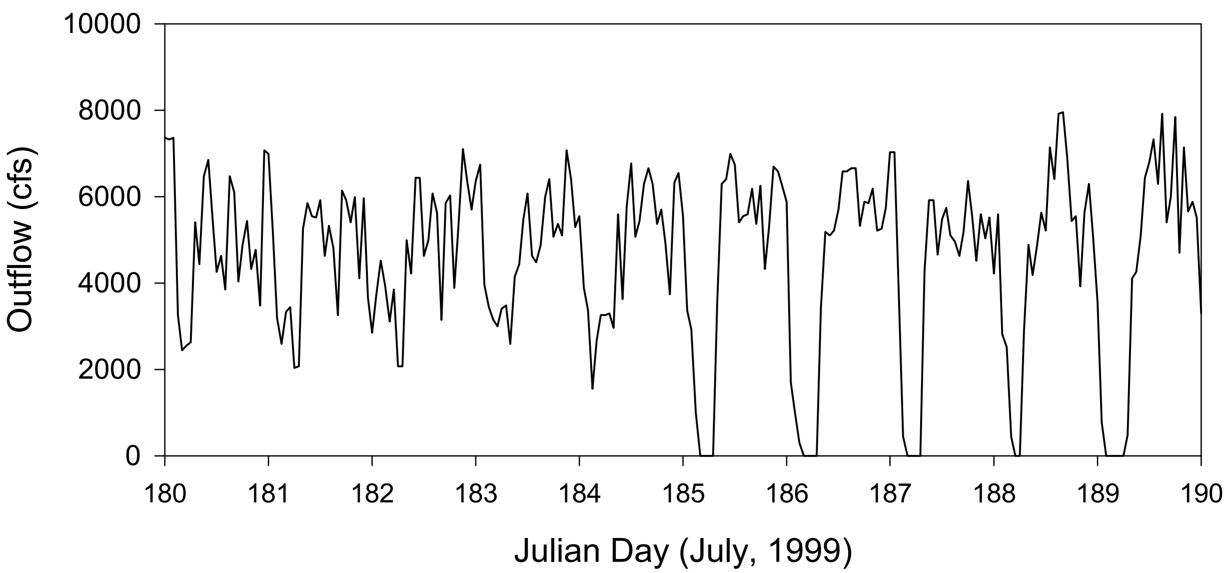
Portland, Oregon





FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE 4-5** 1999 POWERHOUSE DISCHARGE Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
	CHECKED: T. Khangaonkar	
	DATE: December 20, 1999	
PROJECT NO: 2200.0001.0002	FILENAME: 99inftem.jnb	

At the free surface, a time-invariant equilibrium temperature surface heat exchange formulation is used in the hydrodynamic model to account for the heat exchange at the air-water interface. The atmospheric forcing (wind stress) is a very important factor to the circulation in the lake. Even though the dominant wind directions are along the tributary channels, significant cross-channel winds were also observed (see Section 2). Due to the complex tributary geometry, wind stress distribution would be highly spatially and temporally dependent. During the period of ENSR's field survey program, wind data were recorded at three PGE meteorological stations (see Section 2). However, data from these three wind stations are not sufficient to provide realistic wind stress input for the model simulations for entire model domain. Because of the limitation of wind data, a simplified approach is used in this study. Wind stresses are assumed spatially uniform in each individual tributary and the Forebay. Wind stresses in the entire Forebay region and the Metolius arm are specified using the Forebay and Metolius wind data, respectively. In the Deschutes and Crooked arms, wind stresses are assumed the same and specified using the Deschutes wind data only. Such an assumption might generate model prediction results that may not match the observed velocity data exactly. To better understand the density-driven circulation, separate model sensitivity runs were conducted with and without considering wind effect. Also, in order to reproduce the observed velocity profiles in the lake, "artificial wind data" were generated to demonstrate that observed velocity profiles can be well reproduced by the hydrodynamic model if detailed realistic wind data with higher temporal and spatial resolution were available.

Because the initial conditions for the 3D velocities and relative water surface elevation are unknown, the default zero value was used at the beginning of each simulation. The initial temperature conditions for the hydrodynamic model were obtained from the calibrated seasonal temperature model (BETTER) described in the previous section. Because the BETTER model is a vertical 2D model, the initial temperature distribution in the transverse direction is assumed to be uniform. The BETTER model was set up to provide a season wide variation of reservoir temperatures at a time step of 12-hours. Depending on the specific period that was selected for hydrodynamic application (6-day period in a specific month), the initial temperature condition was extracted from BETTER model results. The hydrodynamic model was then applied at a finer time step (20 seconds).

4.3 Model Calibration

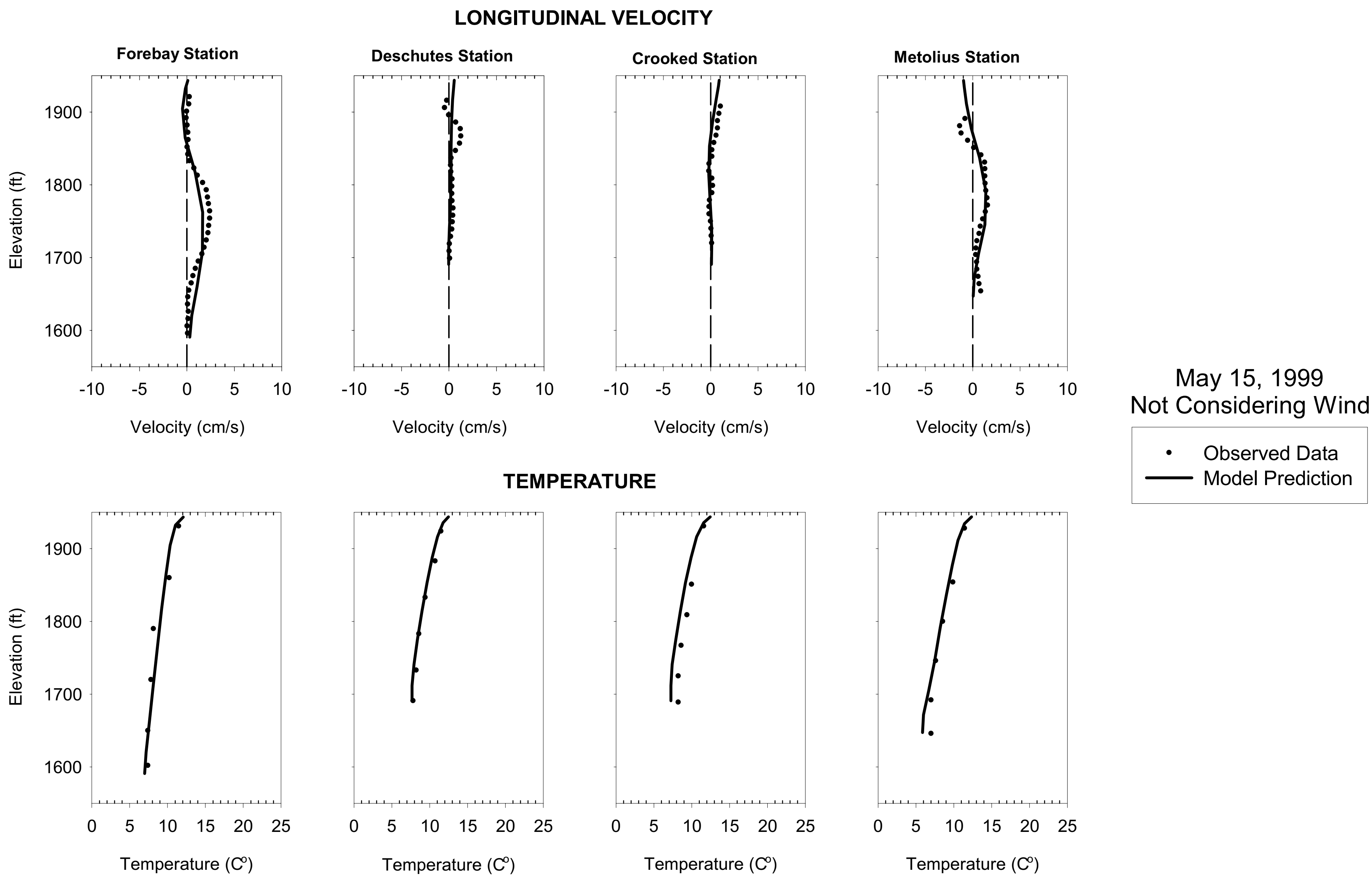
Because the spring season is of the most interest in terms of downstream fish passage issues, simulation for the existing conditions in spring of 1999 was selected for model calibration. However, in the early period of observation (April 26 to May 12, 1999), high velocities were observed in the mid-water column in the Crooked arm. The forcing function corresponding to such a high velocity event was unclear. Therefore, the period from May 10 to May 16, 1999 was chosen for the hydrodynamic model calibration. The calibration process mainly consisted of adjusting the bottom roughness and background horizontal diffusion and background vertical diffusion coefficients, as well as the equilibrium temperature transfer coefficient between the air and water, such that velocity profiles predicted by the model in each river arm and the forebay match the observed data. The model was run for 6 days for each simulation and the model simulation time step was 20 seconds.

A 6-day model run for the period of May 10 through May 16, 1999 (Julian days 130 through 136) was conducted to simulate the spring hydrodynamic conditions in the reservoir without considering wind effect. The bottom roughness height, background horizontal diffusion, background vertical diffusion and equilibrium heat exchange coefficients were adjusted within the typical range reported in the literature such that model predictions matched the observed data in the reservoir. The final adjusted model parameters are presented in Table 4-2.

Table 4-2
Calibrated Hydrodynamic Model Parameters

Model Parameters	Bottom Roughness	Horizontal Diffusion	Vertical Diffusion	Temperature Transfer Coefficient
Calibrated Values	10 cm	1 m^2/s	10^{-4} m^2/s	5×10^{-5} m/s

Comparisons of model predictions and observed data on Julian Day 135 (May 15, 1999) are plotted in Figure 4-6. Both observed ADCP velocity data and model predicted velocities used for comparison are from 7-day moving averaged results. Figure 4-6 shows that model predicted velocity profiles match the data quite well in all the stations. In particular, the model successfully reproduced the flow pattern due to the outflow discharge at the power intake in the Forebay station and the downstream movement of Metolius water in the middle and lower water column in the Metolius arm. In the Crooked and Deschutes arms, small velocities in the bottom layers were also well reproduced by the model. There are some discrepancies in the subsurface layer in the Metolius and Deschutes arms, which might be because the local wind effect was not considered in this model run. Unlike the non-calibrated model predictions in spring of 1995, the calibrated model results in spring of 1999 showed that Metolius cold water travels downstream in the middle and lower portion of the water column, instead of plunging to the deep bottom layer and moving downstream. Both model results and observed data showed upstream flow in the surface layer in the Metolius arm, but the velocity magnitudes are not as large as that predicted in the previous model run in spring of 1995. Model predictions and observed data also showed downstream currents in the upper part of the water column in both the Deschutes and Crooked arms, which are induced by the density stratification because of the warm inflow from the Deschutes and Crooked Rivers and cold inflow from the Metolius River.



Velocity data/model predictions - 1-day average
Temperature data/model predictions - 7-day average

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FIGURE 4-6
MODEL AND DATA COMPARISIONS WITHOUT WIND, MAY 15, 1999
Portland General Electric Company
Portland, Oregon

Temperature comparisons at Forebay and the Crooked, Deschutes, and Metolius arms are also presented in Figure 4-6. The observed temperature data are from the ENSR field survey and temperature observation locations are the same as the location of the ADCP velocity profiles. Both model predictions and field observed data are daily averaged values. Model predicted temperatures show good agreement to the observed data in general. In the Crooked station, the hydrodynamic model slightly under-predicted the temperatures in the entire water column.

Model results are presented as 2D velocity vectors along the vertical longitudinal sections, shown in Figure 4-7, in the Metolius (Section A), Crooked (Section B), and Deschutes (Section C) arms of the reservoir and in a plan view in the surface layer. The surface layer vectors are shown in Figure 4-8 and the longitudinal section velocities in Figure 4-9. These figures show the horizontal and vertical velocity distributions on Julian Day 135 (May 15, 1999). From the surface velocity distribution (Figure 4-8) one can see that the surface water from the Crooked River moves downstream to the forebay and upstream to the Metolius River. Surface water in the Deschutes arm also moves downstream joining the surface water from the Crooked River. Without considering wind effect, surface velocity magnitudes in general are very small. The maximum predicted surface velocity magnitude in the entire reservoir in about 0.1 ft/s (3 cm/s). In the forebay near Round Butte Dam, a clockwise eddy develops, as a result of geometry effect, the location of the power intake and the movement of the Crooked surface flow past the forebay and up to the Metolius arm. This flow pattern agrees with the drogue studies conducted by PGE in the Forebay in the spring of 1996 (McCollister and Ratiff 1996, ENSR 1999). From the vertical longitudinal section velocity profiles (Figure 4-9), a two-layer circulation is evident in the Metolius arm. The cold Metolius River water mainly moves downstream in the middle and bottom layers in the column and the surface upstream flow in the Metolius arm is quite small compared to the downstream bottom flow. In the Deschutes and Crooked arms, downstream surface flows are predicted in the model. Velocities below the surface layer in the Deschutes and Crooked arms are very small. Unlike in 1995 where the Deschutes inflow temperature was colder than the Crooked inflow temperature, in 1999, the Deschutes and Crooked inflow temperatures were about the same (Figure 4-4). Therefore, upstream flow from the Crooked arm to the Deschutes arm does not occur in the 1999 simulation. Due to the outflow at the powerhouse outlet, large bottom velocities at the location of the powerhouse outlet are observed in Section A (Figure 4-9).

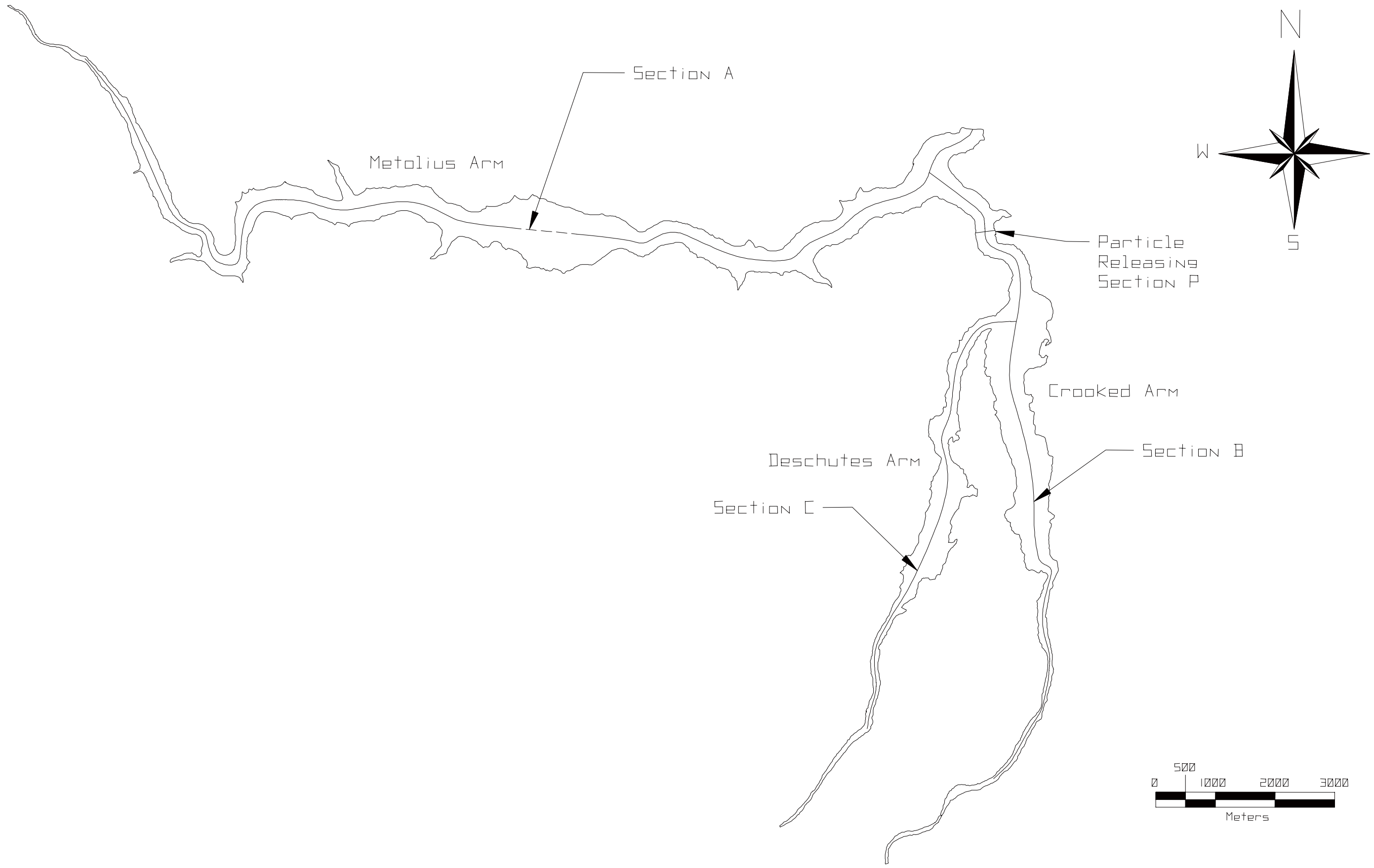

FIGURE 4-7
VELOCITY VISUALIZATION SECTIONS
Pelton Round Butte Hydroelectric Project No. 2030
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Portland, Oregon

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FIGURE 4-8

SURFACE VELOCITY DISTRIBUTION
WITHOUT WIND, MAY 15, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 18, 2000	PROJECT NO:
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002

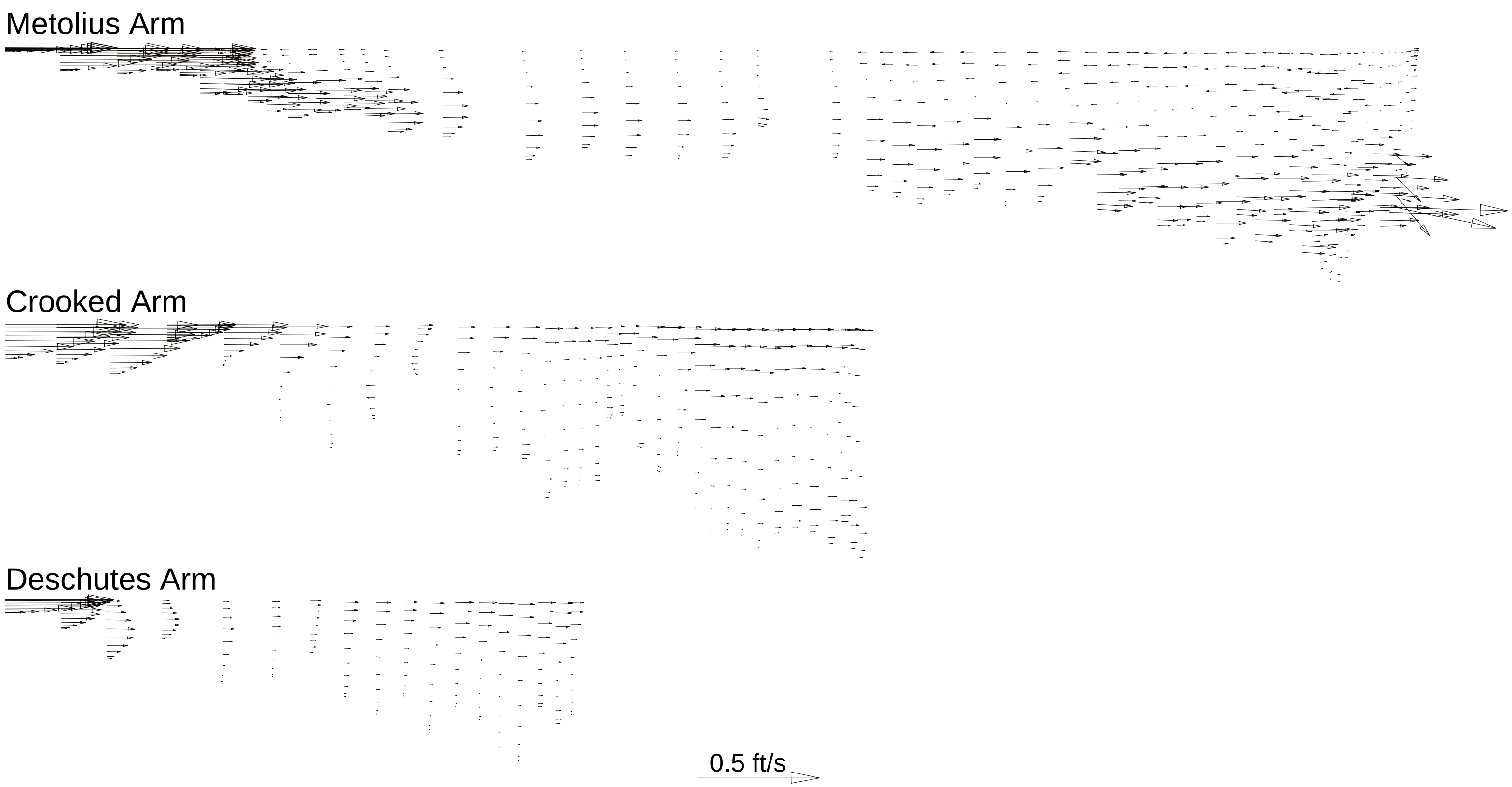

FIGURE 4-9

LONGITUDINAL VELOCITY DISTRIBUTION
WITHOUT WIND, MAY 15, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

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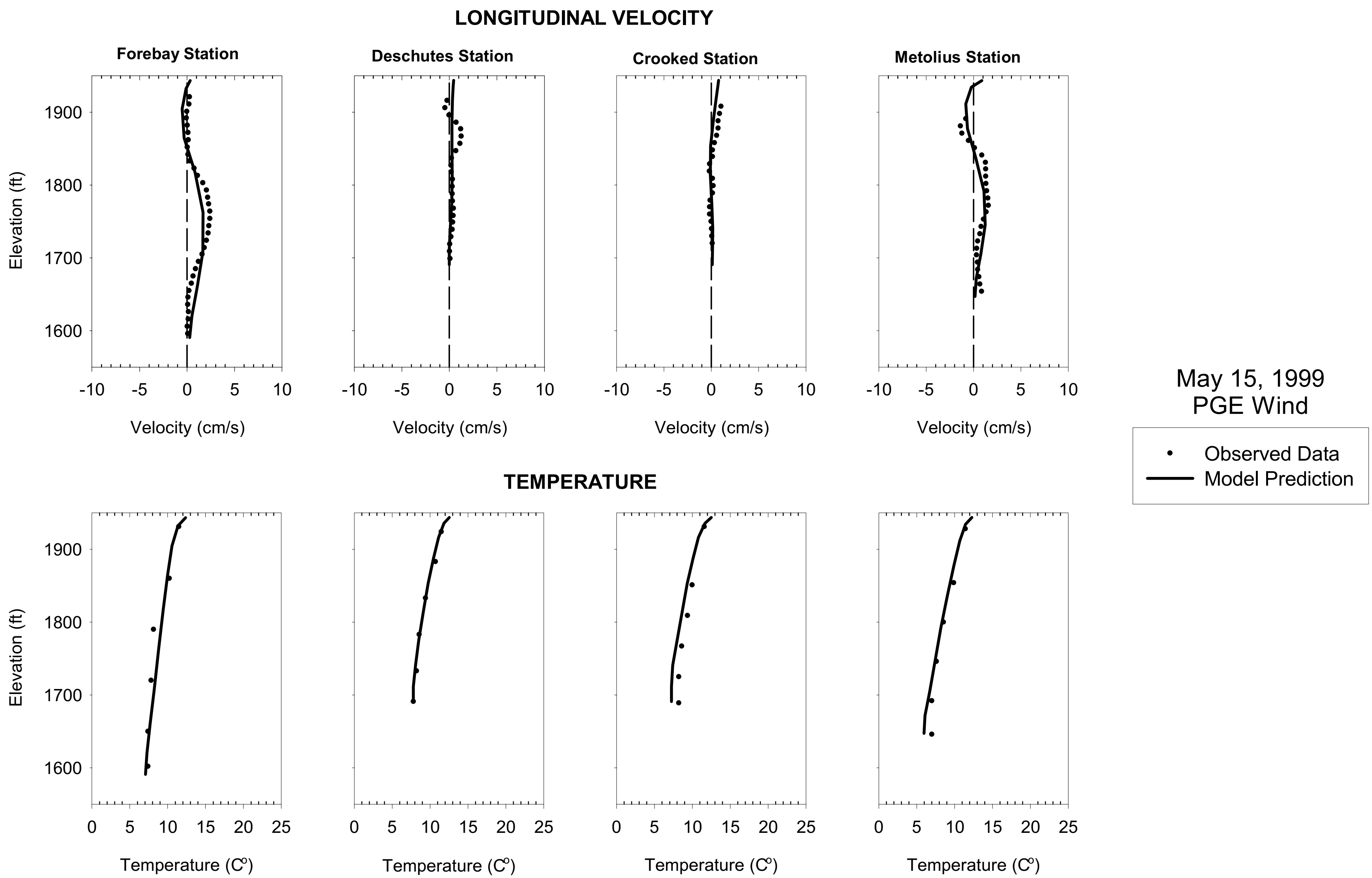
The model run discussed above did not consider wind effect. To include the wind effect, wind data from three PGE meteorological stations are used in a separate model run. Figure 4-10 shows the velocity and temperature comparisons between model predictions and observed data in May 15, 1999. Compared to Figure 4-6 for the case without considering wind, the wind effect on the temperature profiles is very small. The wind effect on the surface velocities is also small except in the Metolius arm. Due to the wind effect, surface flow in the Metolius arm changes direction from upstream to downstream. The reason that the model showed small wind effect on the surface velocities in the Forebay and the Deschutes and Crooked arms is that wind speeds in the simulation period (Julian day 130 through 136) are relatively small and the dominant wind directions are not orientated along the river channels (Figures A-13, A-14 and 2-16). Wind data are actually missing from Julian day 132 to 139 in the Forebay station. In this model simulation period, wind speeds in the Deschutes station are generally below 5 m/s during high wind period (about 12 hours) and less than 1 m/s during low wind period (about 12 hours). However, in the Metolius wind station, wind speeds are almost 10 m/s at peaking period and about 2.5 m/s during low wind period (Figure A-16). Figure 4-11 and 4-12 show the model-predicted horizontal and vertical velocity distributions on Julian day 135 (May 15, 1999) with wind effect. Strong surface downstream flow is observed in the Metolius arm in Figure 4-11 due to the downstream wind effect. Surface flows in the upstream Deschutes and Crooked arms are similar to the model results without wind effect. Figure 4-12 shows that the upstream flow in the Metolius arm predicted previously is depressed down to the subsurface layer due to surface wind effect. The surface layer now flows in the downstream direction in the Metolius arm.

Beside the effects of density stratification and wind, the flow pattern in the reservoir is also affected by tributary river inflows. However, due to the relatively small river inflows and large river cross-section areas, the currents driven by the river inflows are generally very small. For example, in the lower Deschutes arm, the cross-sectional area is about 208,600 feet^2 and the combined inflow rate from the Crooked and Deschutes Rivers is about 2,400 cfs. So the mean velocity across the river due to river inflows is about 0.012 ft/s (or 3 mm/s), which is an order-of-magnitude smaller than the velocity induced by the effect of density stratification.



Velocity data/model predictions - 1-day average
Temperature data/model predictions - 7-day average

FIGURE 4-10
MODEL AND DATA COMPARISIONS
WITH PGE WIND, MAY 15, 1999
Portland General Electric Company
Portland, Oregon

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FIGURE 4-11

SURFACE VELOCITY DISTRIBUTION
WITH PGE WIND, MAY 15, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

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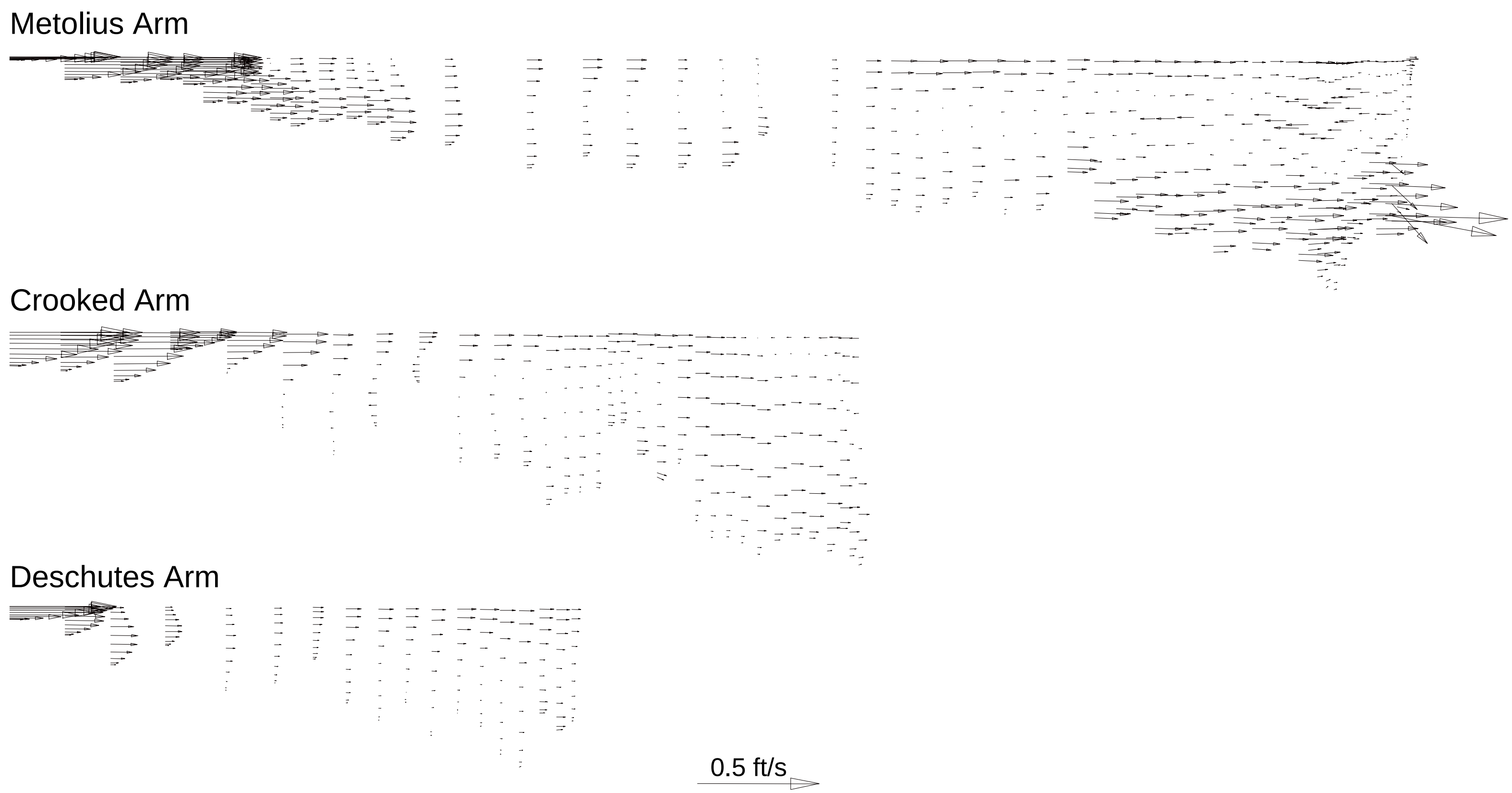
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 18, 2000	PROJECT NO:
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 4-12

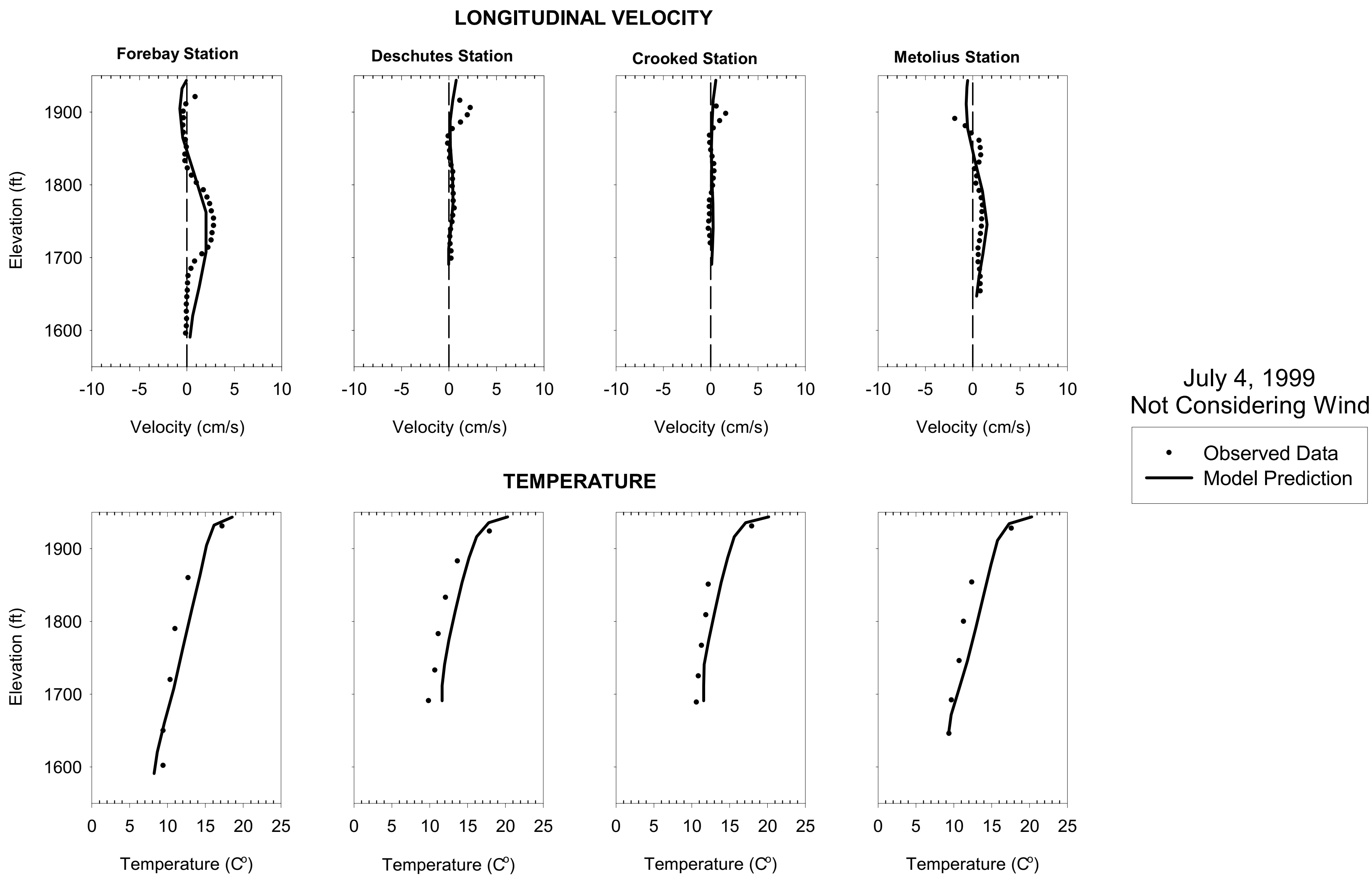
LONGITUDINAL VELOCITY DISTRIBUTION WITH PGE WIND, MAY 15, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

4.4 Model Verification

Once the hydrodynamic model was calibrated for spring 1999, the model was verified using data from a different time period. Model parameters were unchanged. A 6-day model simulation was conducted for the summer condition from June 29 to July 5, 1999 (Julian day 180 to 186). Due to the strong surface heating in the summer, the surface water in the reservoir becomes much warmer. Stratification in the reservoir is strongly enhanced. The initial temperature condition for the hydrodynamic model was obtained from the calibrated BETTER temperature model. In the first verification model run, wind effect was not considered. Comparisons between model predictions and observed data for velocity and temperature profiles are presented in Figure 4-13. Model-predicted velocity profiles match the ADCP observations in general. However, the model still failed to predict some flow features in the subsurface layer, which may be induced by the wind effect. In the forebay station, the model also predicted the high velocities in the middle of the water column. However, the vertical range of the high speed predicted is broader than that observed, which is probably caused by the relatively low vertical grid resolution in the middle of the water column and the effect of numerical diffusion. Temperature predictions reproduced the stratification pattern in the summer, but the model under-predicted temperatures in all the stations, especially in the Deschutes station. One of the possible causes of the model under-predicting is that the initial conditions provided by the BETTER model in July are warmer than the observed data in general (see Figures 3-32 and 3-36). The other possibility is the simple equilibrium temperature surface heat exchange formulation, which transfers too much heat from the atmosphere to the water when the air temperature is much higher in the summer. A more sophisticated formulation accounting for time-variant air temperature, wind, rainfall, evaporation and solar radiation effects may be necessary to improve the temperature predictions in the hydrodynamic model.

The surface velocity distribution and vertical longitudinal section velocity profiles for the summer condition are given in Figures 4-14 and 4-15. Figure 4-14 shows that the surface currents in the reservoir are generally smallerr in the river arms compared to the spring condition. This is because river temperatures are all cooler than the reservoir surface temperatures in July (Figure 2-9), which results in the water discharged from the Deschutes and Crooked Rivers no longer forming a thin, warm layer on the reservoir surface. Instead, the Crooked and Deschutes inflows enter the reservoir below the surface layer in the upstream of the river arms (Figure 4-15).



Velocity data/model predictions - 1-day average
Temperature data/model predictions - 7-day average

FIGURE 4-13
MODEL AND DATA COMPARISIONS
WITHOUT WIND, JULY 4, 1999
Portland General Electric Company
Portland, Oregon

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FIGURE 4-14

SURFACE VELOCITY DISTRIBUTION WITHOUT WIND, JULY 4, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

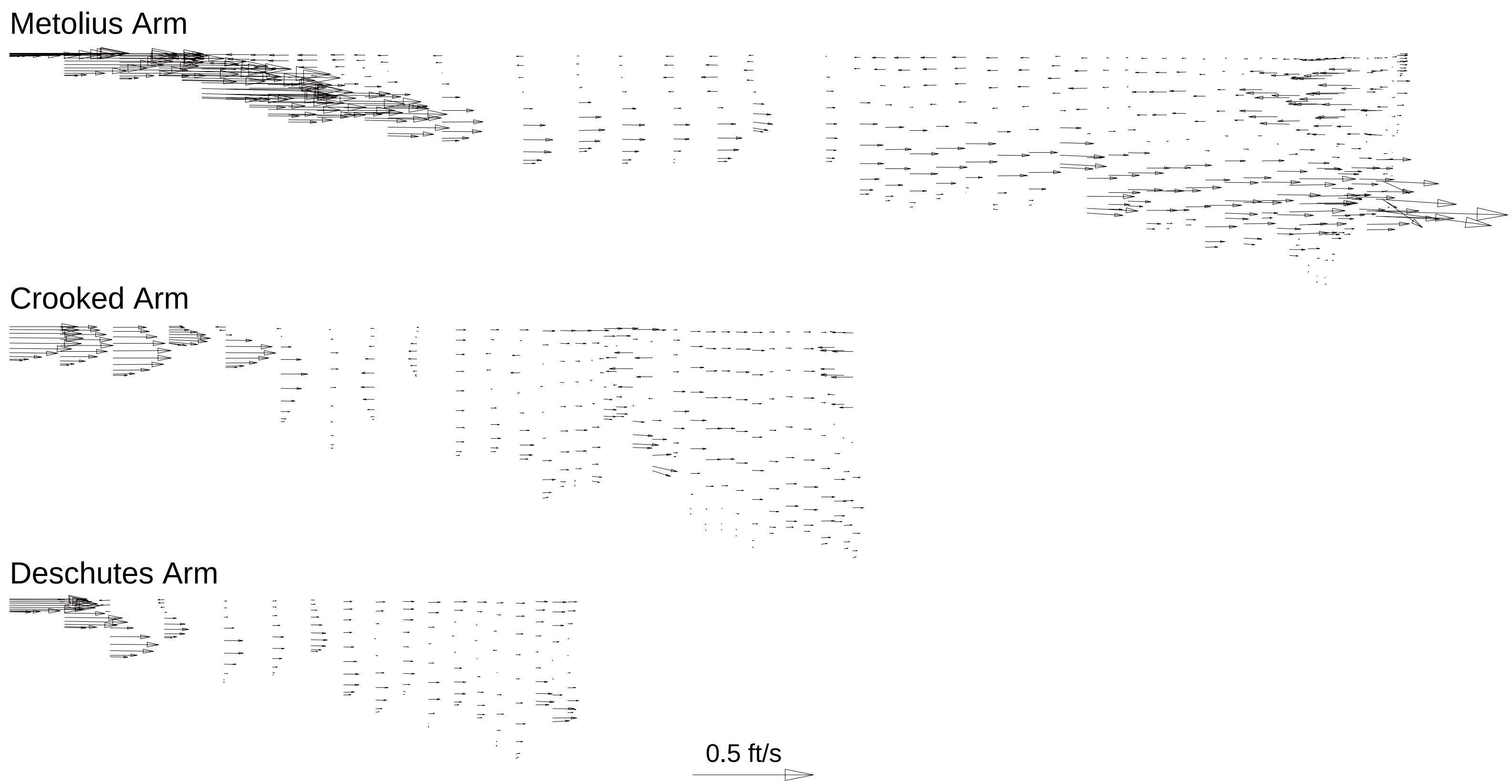

FIGURE 4-15

LONGITUDINAL VELOCITY DISTRIBUTION WITHOUT WIND, JULY 4, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

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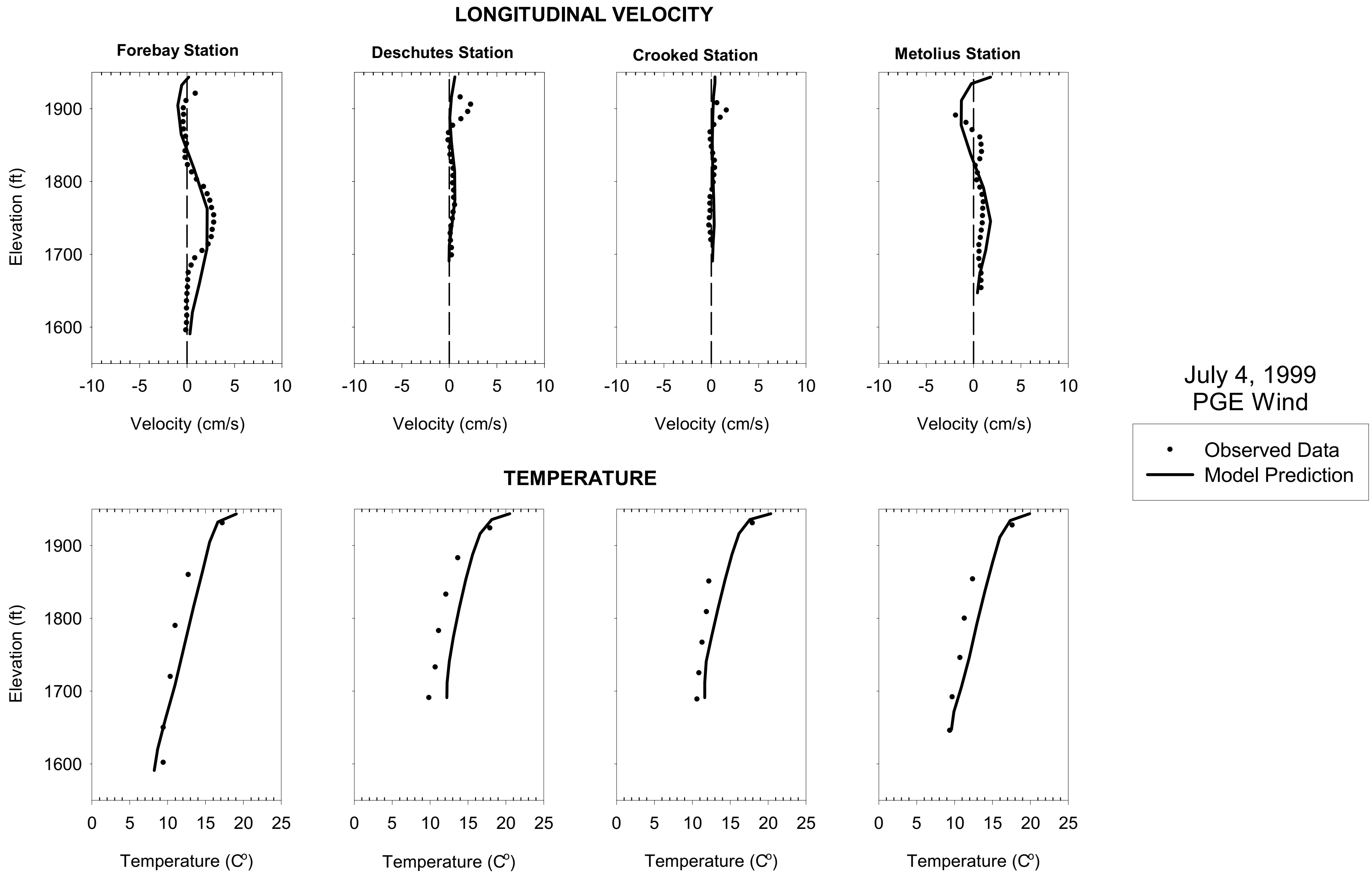
A model run including wind effect was also conducted for the same verification period. Figure 4-16 shows the model prediction and observed data comparisons for velocity and temperature profiles. Similar to the calibration case, no significant changes are observed in all the temperature profiles and velocity profiles in the Forebay, Deschutes, and Crooked stations. Upstream surface flow in the Metolius arm is significantly enhanced by the wind effects. The surface velocity distribution and vertical longitudinal section velocity profiles with wind effect for the verification period are given in Figures 4-17 and 4-18. Surface velocities increase in most regions of the reservoir because of wind effect.

4.5 Sensitivity Analysis of Wind Effects

Wind stress is an important factor influencing the circulation patterns in Lake Billy Chinook, especially the surface currents. Even though wind effect was considered in the calibration and verification model runs, model results still failed to predict some velocity features in the surface layer. The wind data from three PGE meteorological stations may not correctly represent the local wind effect and the spatial variations in the reservoir. Therefore, a sensitivity model run was conducted to demonstrate that the high velocity distribution in the subsurface layer may be reproduced if correct wind data are available for the model input. Artificial wind data were generated to represent the local wind at the locations of ADCP profiles. Figure 4-19 shows the artificial wind generated for the sensitivity simulation in the Forebay, Deschutes, and Metolius arms. Wind speeds having sinusoidal distribution and variation in magnitudes are assumed the same in all river arms. The wind directions are mainly orientated along the river arms. Figure 4-20 shows the velocity and temperature comparisons between model predictions with artificial wind data and that observed data on July 4, 1999. Apparently, the simulated winds improve the velocity prediction in the surface layer of the water column. The strong upstream winds in the Deschutes and Crooked arms result in upstream surface flows and push down the downstream flow to the subsurface layer, which is consistent with the observed data. This model simulation demonstrates that the hydrodynamic model could reproduce the velocity structures in the reservoir if wind data are sufficient to provide detailed realistic forcing and to specify boundary and initial conditions.

4.6 Summary

Despite the difficulty in verifying the velocity response of the model in the immediate surface layer to wind shear stress, the overall match of the model to the verification data set throughout the water column is considered good. The EFDC model is considered a satisfactory tool for predicting the response of reservoir currents to changes in project structures and operations.



Velocity data/model predictions - 1-day average
Temperature data/model predictions - 7-day average

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 7,2000	PROJECT NO:
	FILENAME: cal-ver.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

FIGURE 4-16
MODEL AND DATA COMPARISIONS
WITH PGE WIND, JULY4, 1999
Portland General Electric Company
Portland, Oregon

FIGURE 4-17

SURFACE VELOCITY DISTRIBUTION
WITH PGE WIND, JULY 4, 1999

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 18, 2000	PROJECT NO:
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002

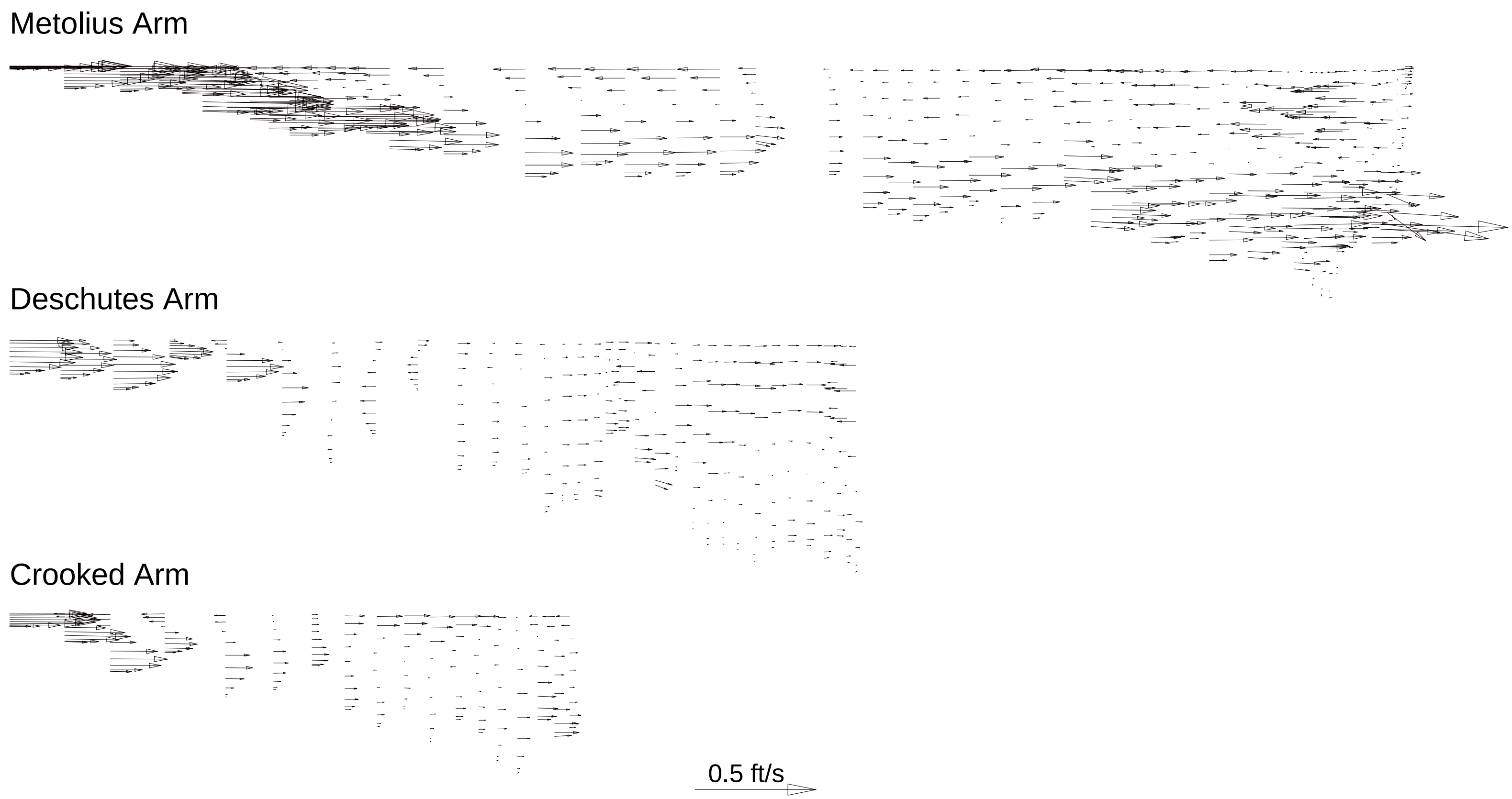
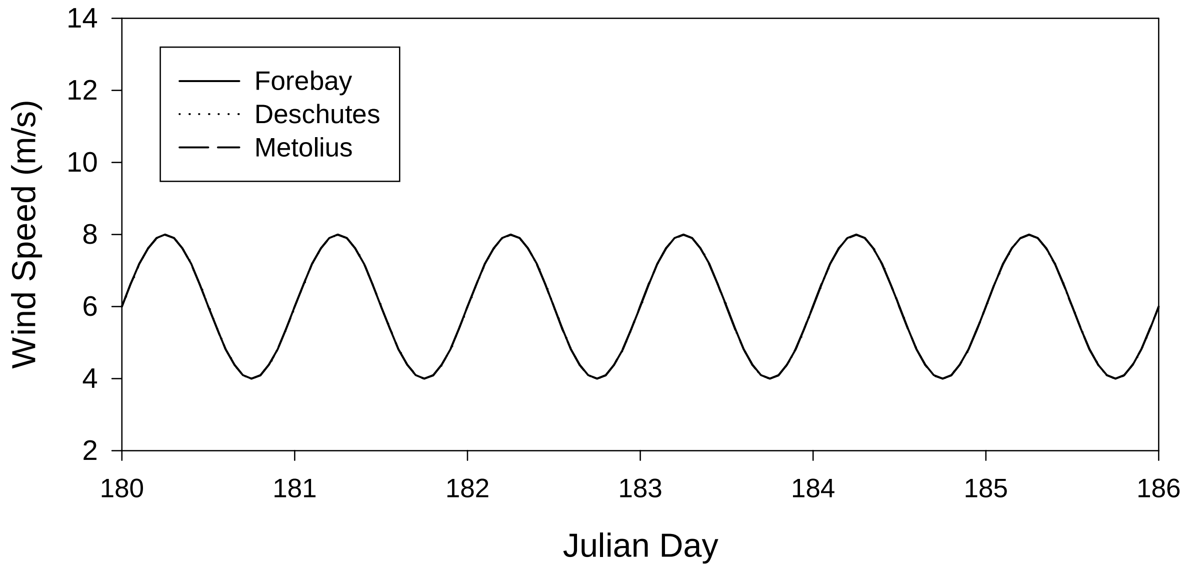


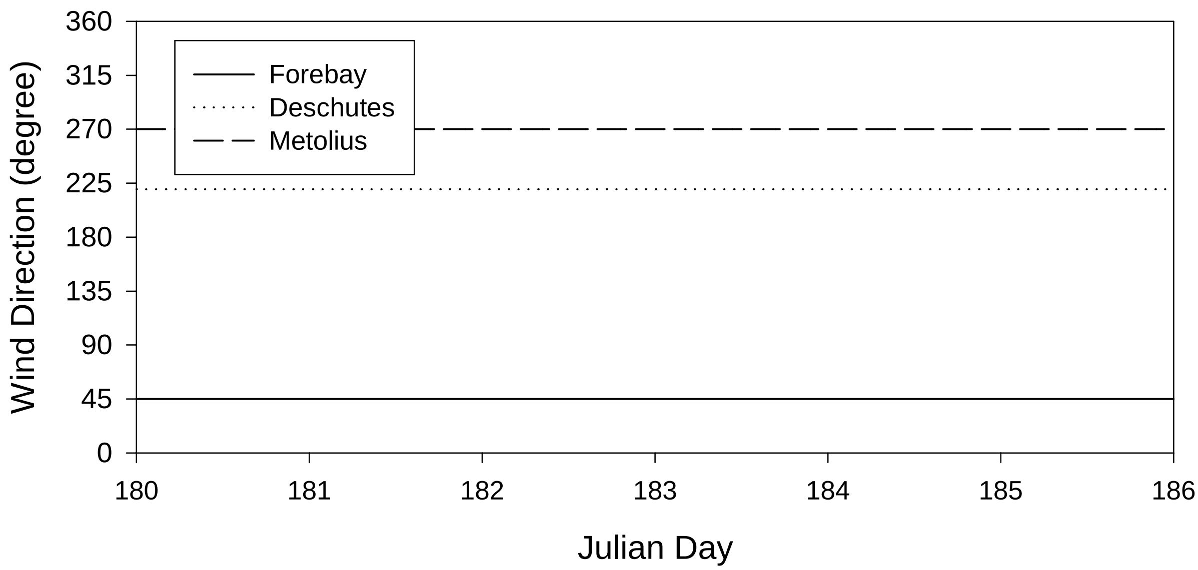
FIGURE 4-18

LONGITUDINAL VELOCITY DISTRIBUTION
WITH PGE WIND, JULY 4, 1999

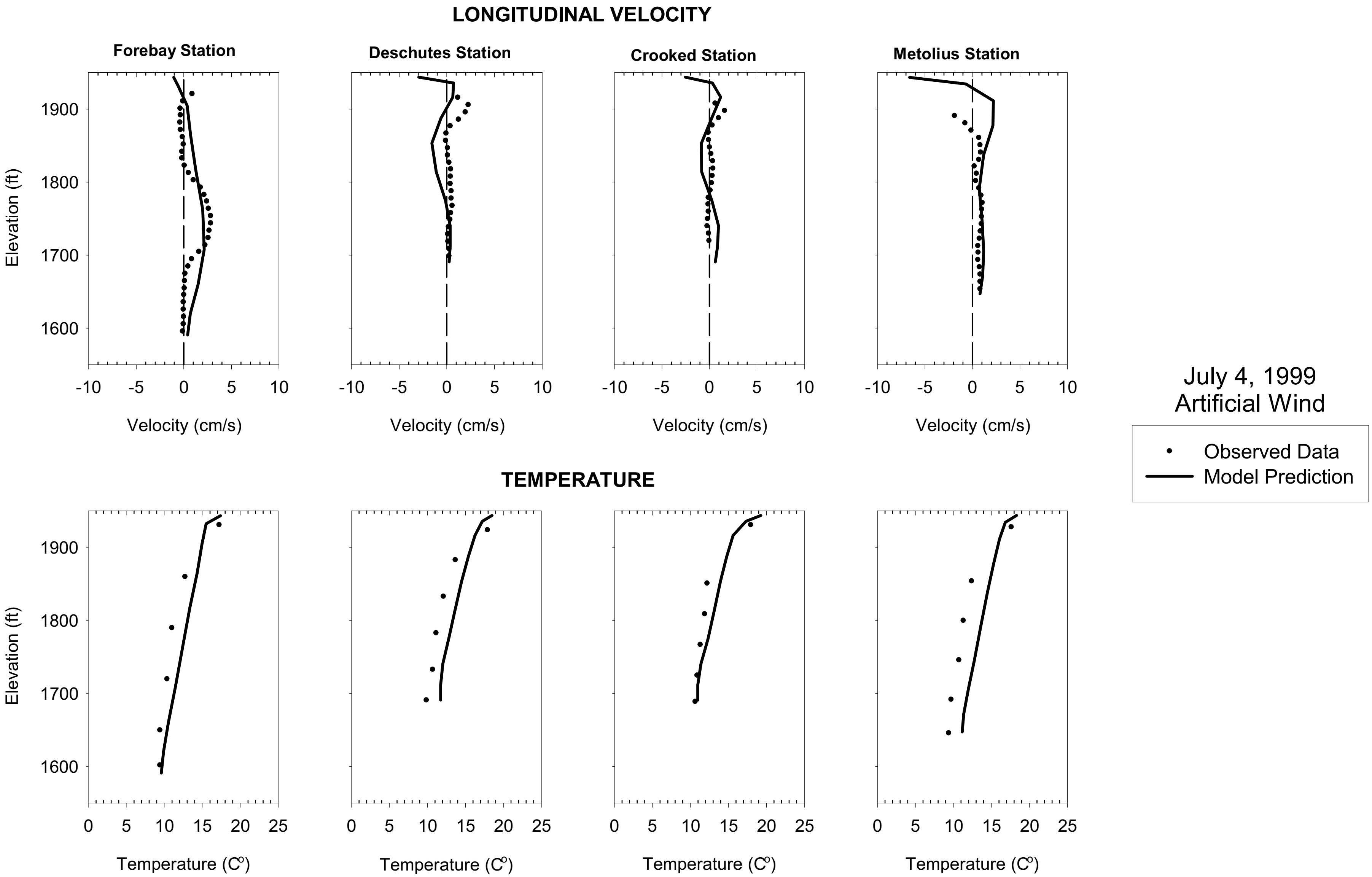
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 18, 2000	PROJECT NO:
	FILENAME: pgeplots-L.doc	CHECKED: T. Khangaonkar	2200.0001.0002





FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 20, 1999	**FIGURE 4-19** ARTIFICIAL WIND Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: 99inftem.jnb	



Velocity data/model predictions - 1-day average
Temperature data/model predictions - 7-day average

FIGURE 4-20
MODEL AND DATA COMPARISIONS
WITH ARTIFICIAL WIND, JULY 4, 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: January 7,2000	PROJECT NO:
	FILENAME: cal-ver.jnb	CHECKED: T. Khangaonkar	2200.0001.0002

5.0 RESULTS AND CONCLUSIONS

The results of observed data collected by ENSR from April 1999 to July 1999 and the temperature and hydrodynamic model calibrations and verifications for the existing reservoir condition are summarized below.

Synoptic measurements of velocity and temperature were conducted by ENSR at four mooring stations in the Deschutes, Crooked, and Metolius Rivers and in the Forebay from April 1999 to July 1999 for temperature model verification and hydrodynamic model calibration and verification purposes. Instantaneous velocity data show high temporal variations at all stations for the entire record. Useful information can be extracted when daily and 7-day moving averages are applied to the data. In general, velocity profiles at the forebay station show strong flow at around elevation 1,750 due to the powerhouse discharge at the power intake. Velocity data in the Metolius arm indicate that surface currents move upstream and cold Metolius water travels downstream in the middle and bottom of the water column. In the Deschutes and Crooked arms, velocities are very small in the lower part of the water column. At the surface, downstream flows are observed due to the warm water discharge from Deschutes and Crooked Rivers. Temperature profile data over the entire observation period demonstrate that temperature stratification gradually develops in the lake system as a function of surface heating due to solar radiation.

The 2D temperature and 3D hydrodynamic model results for the existing condition were consistent. Both models reproduced the temperature gradients and flow patterns that have been observed in the lake reasonably well. Specifically, the models reproduced the surface flow of warm Crooked River water up the Metolius arm of the reservoir and the flow of colder Metolius River water along the bottom of the Metolius arm to the deep powerhouse intake located in the forebay. Two-layer circulation in the Metolius arm results because Metolius River water is always colder than the surface water in the reservoir. In the Deschutes and Crooked Rivers, the pattern and strength of the vertical circulation varies due to the seasonal variation in tributary and reservoir temperatures in these two arms of the reservoir.

The existing flow patterns in the reservoir are the result of three different types of forcing: 1) temperature/density stratification; 2) wind stresses; and 3) river inflows. The effect of temperature-related density stratification is the dominant forcing mechanism. The pattern and strength of the reservoir circulation strongly depends on the relationship between the river inflow temperatures and reservoir water temperatures. Overall, temperature stratification is a function of reservoir surface heating and cooling and the different river inflow temperatures. Wind forcing is also important and can enhance, weaken, or reverse surface layer current velocities. The river inflow rates have a relatively small effect on reservoir circulation due to the relatively small river inflow rates compared to the large reservoir volume and large reservoir arm cross-sectional areas. Powerhouse operations strongly affect circulation patterns and velocity profiles near the forebay.

The BETTER temperature model was calibrated to 1995 data and verified against data collected in January through mid-July 1999. In general, the model predicted the seasonal development of stratification in the reservoir and the overall vertical and horizontal temperature patterns that were observed in 1995 and 1999. The model is considered verified for use in predictive evaluations for conditions similar to those under which the model was developed.

The hydrodynamic model was calibrated against the observed temperature and velocity data in May 1999 and verified against data collected in July 1999. Model results show good agreement with the field observations. There are some discrepancies between model-predicted velocities and observed data in the subsurface layer of the water column. These discrepancies are possible due to the limitations of the wind data. The hydrodynamic model over-predicted temperatures in the verification period (July 1999), which could be a result of the simple equilibrium formulation used in the heat transfer between the atmosphere and water interface and might be improved with additional effort. Model verification indicated that the EFDC model is a satisfactory tool for simulating reservoir currents to predict response of reservoir flow patterns and currents to changes in project structures and operations.

6.0 REFERENCES

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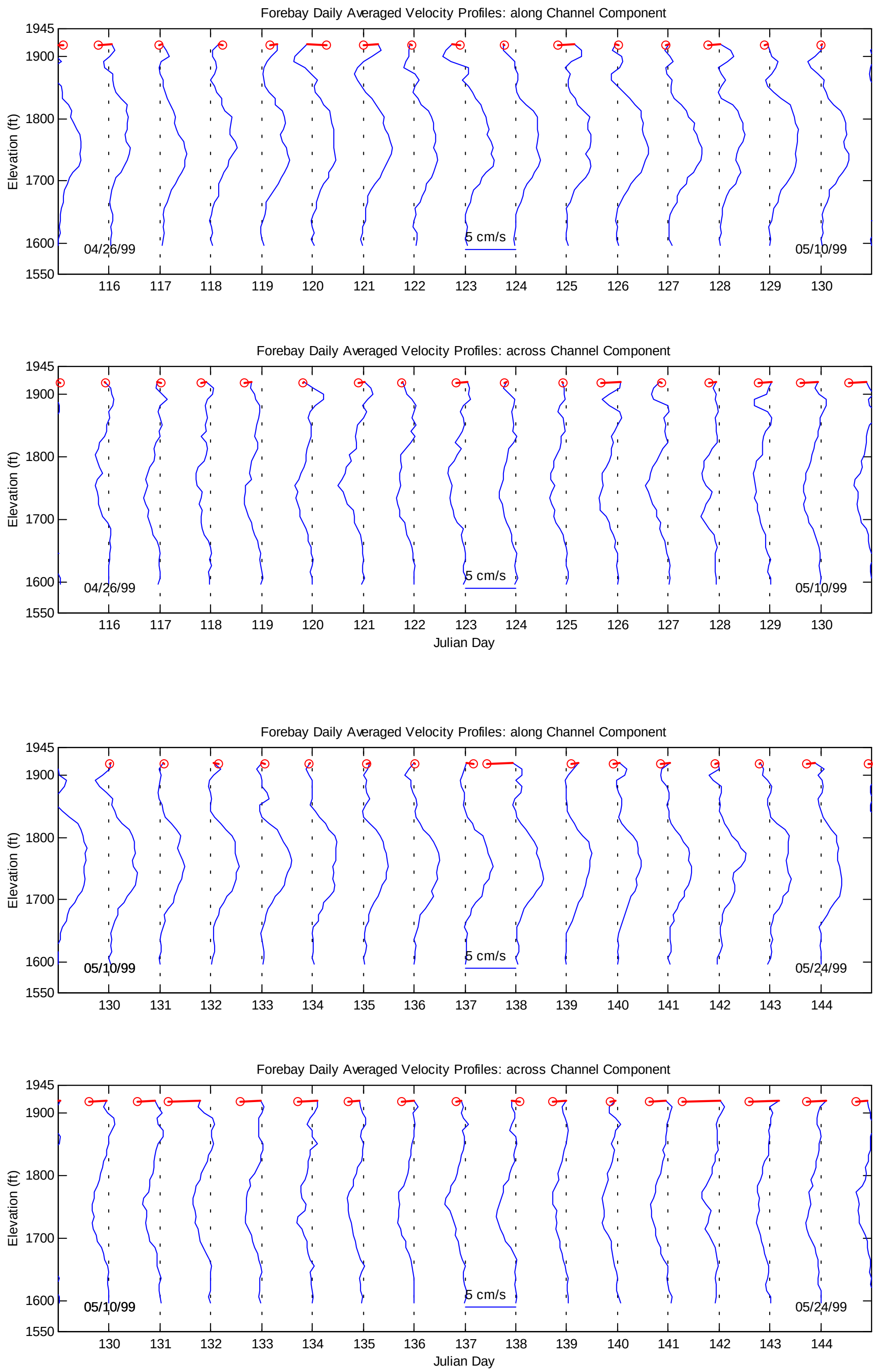
ADCP Profiles



5 cm/s

5 cm/s

FOSTER WHEELER
ENVIRONMENTAL CORPORATION

PROJECT NO: 2200.0001.0002

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

FILENAME: pgeapp-P.doc

FIGURE A-1a

FOREBAY DAILY AVERAGE ADCP

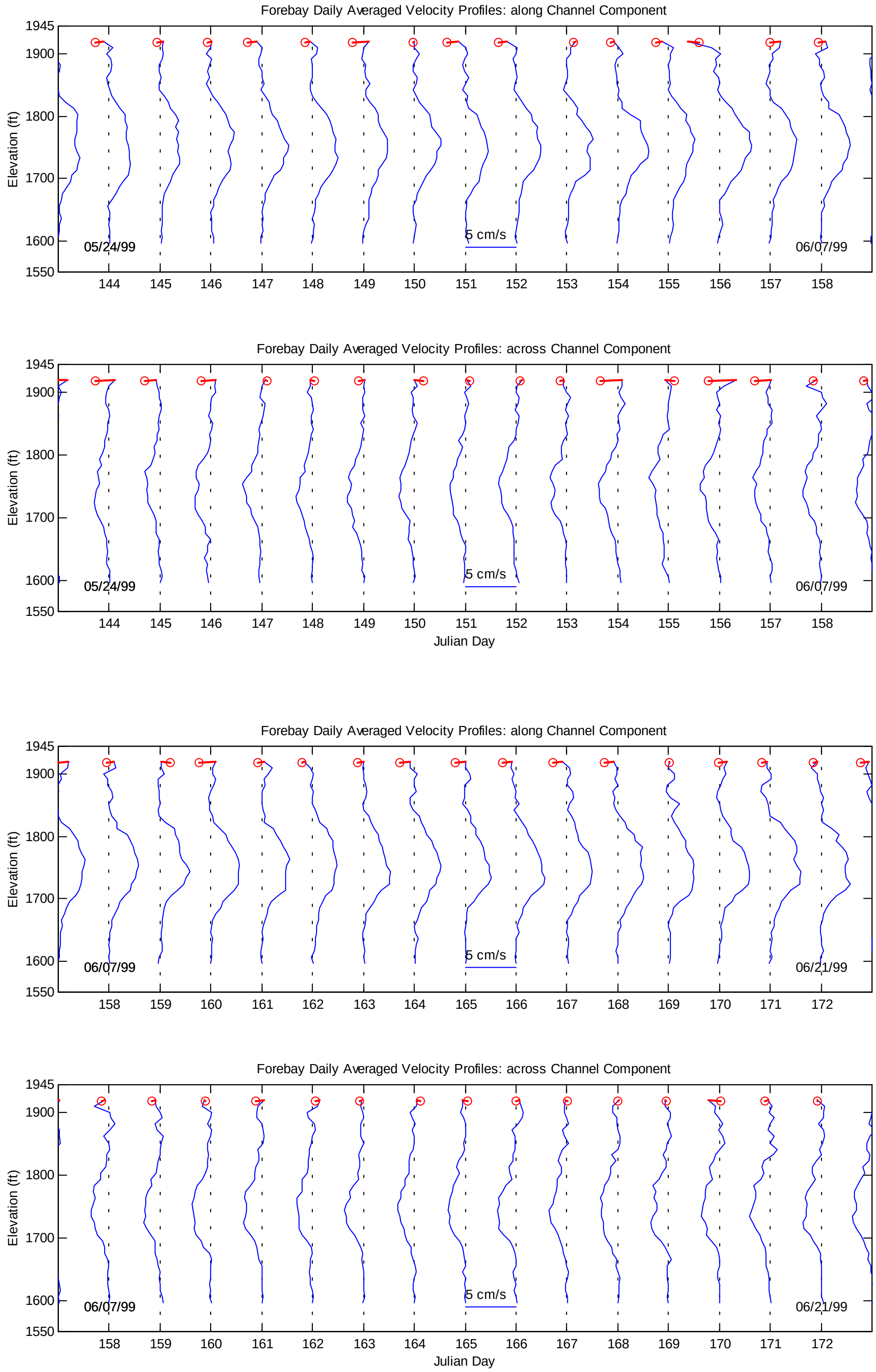
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s

5 cm/s

5 cm/s

5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-1b** FOREBAY DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

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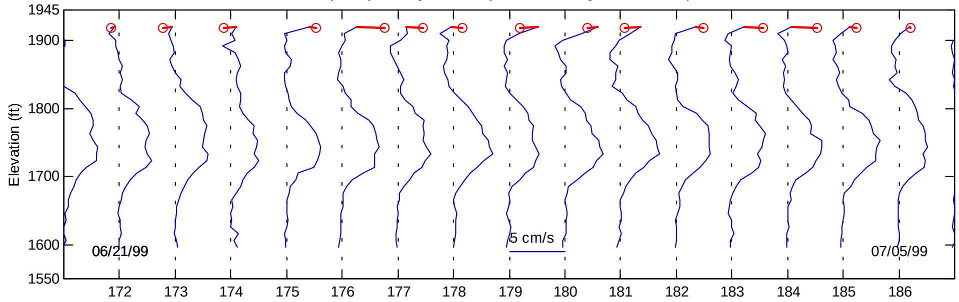
Forebay Daily Averaged Velocity Profiles: along Channel Component



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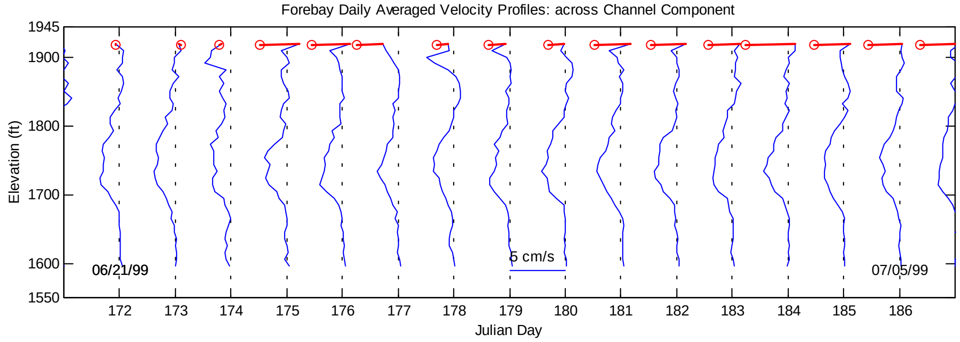

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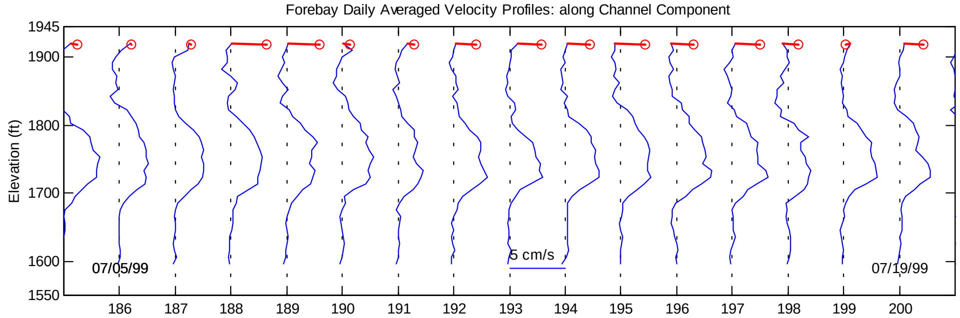

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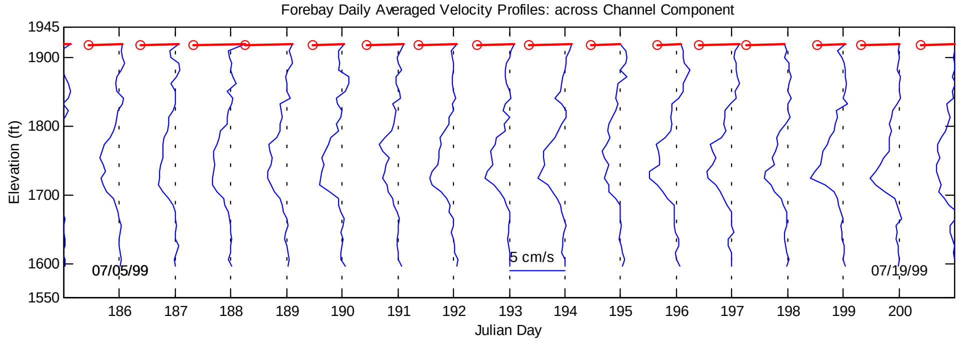
Forebay Daily Averaged Velocity Profiles: across Channel Component



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-1c** FOREBAY DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
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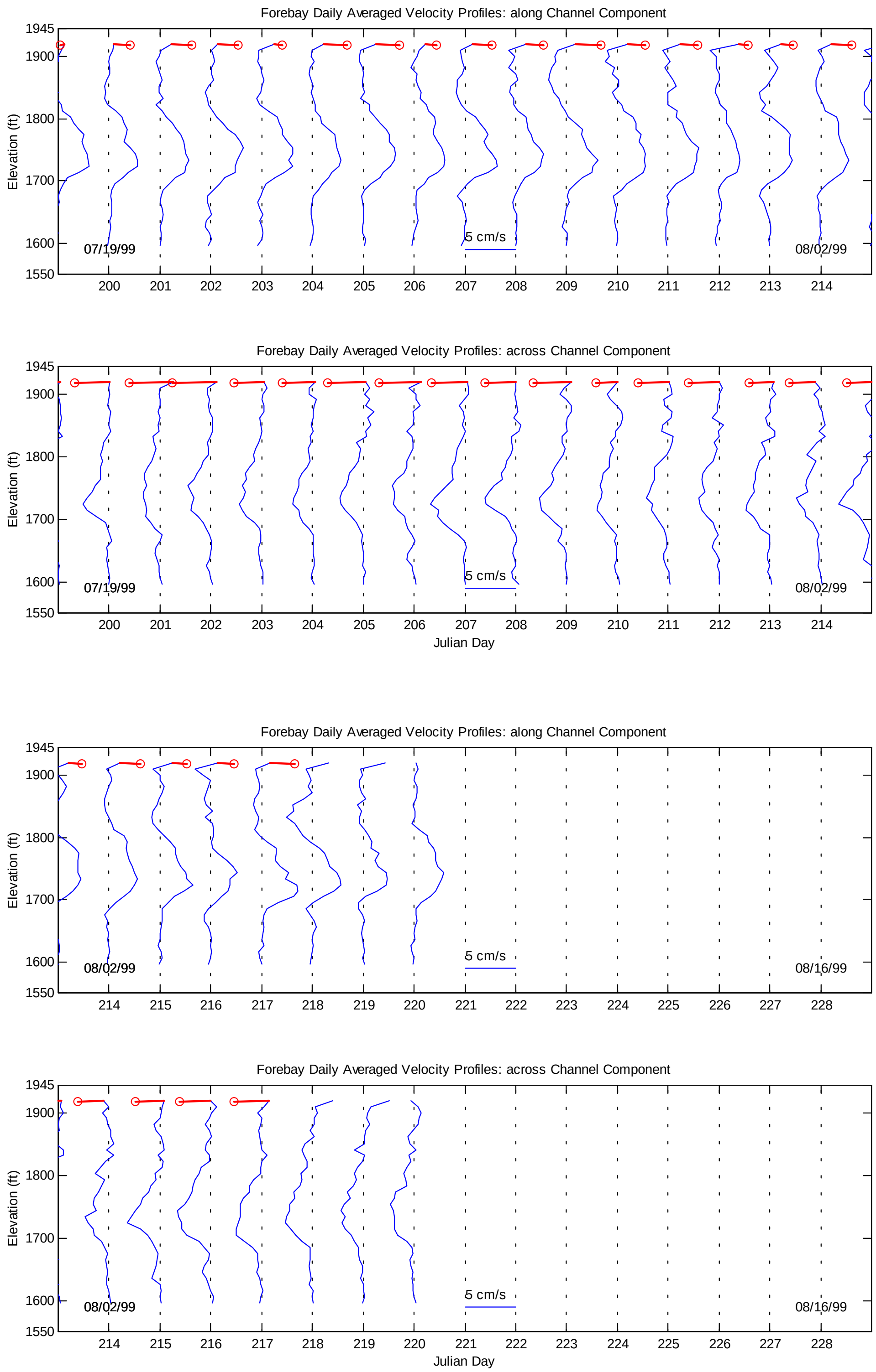

5 cm/s

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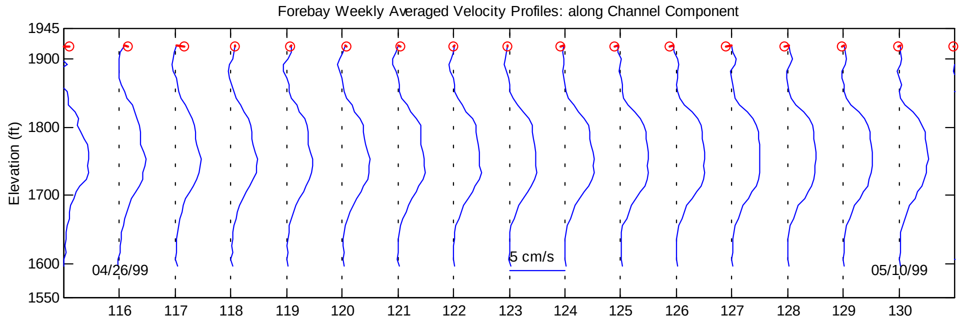
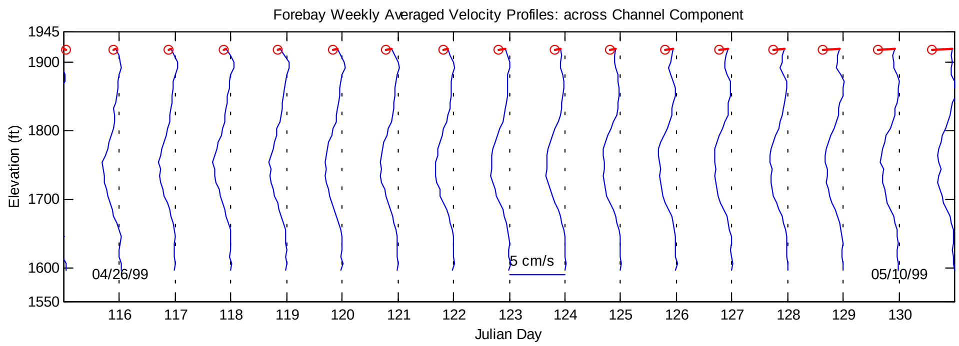
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-1d** FOREBAY DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	





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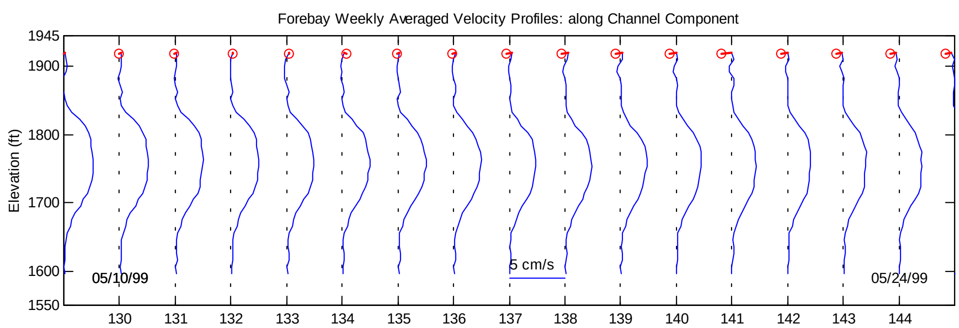

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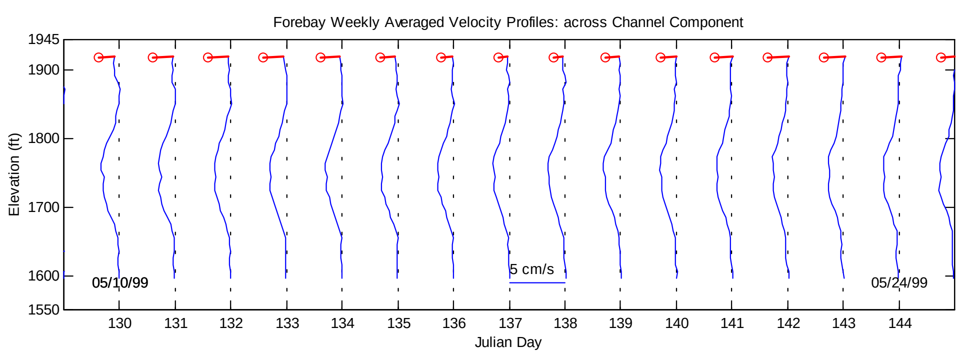

FOSTER WHEELER ENVIRONMENTAL CORPORATION

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CHECKED: T. Khangaonkar
DATE: December 22, 1999

PROJECT NO: 2200.0001.0002
FILENAME: pgeapp-P.doc

FIGURE A-2a

FOREBAY 7-DAY AVERAGE ADCP

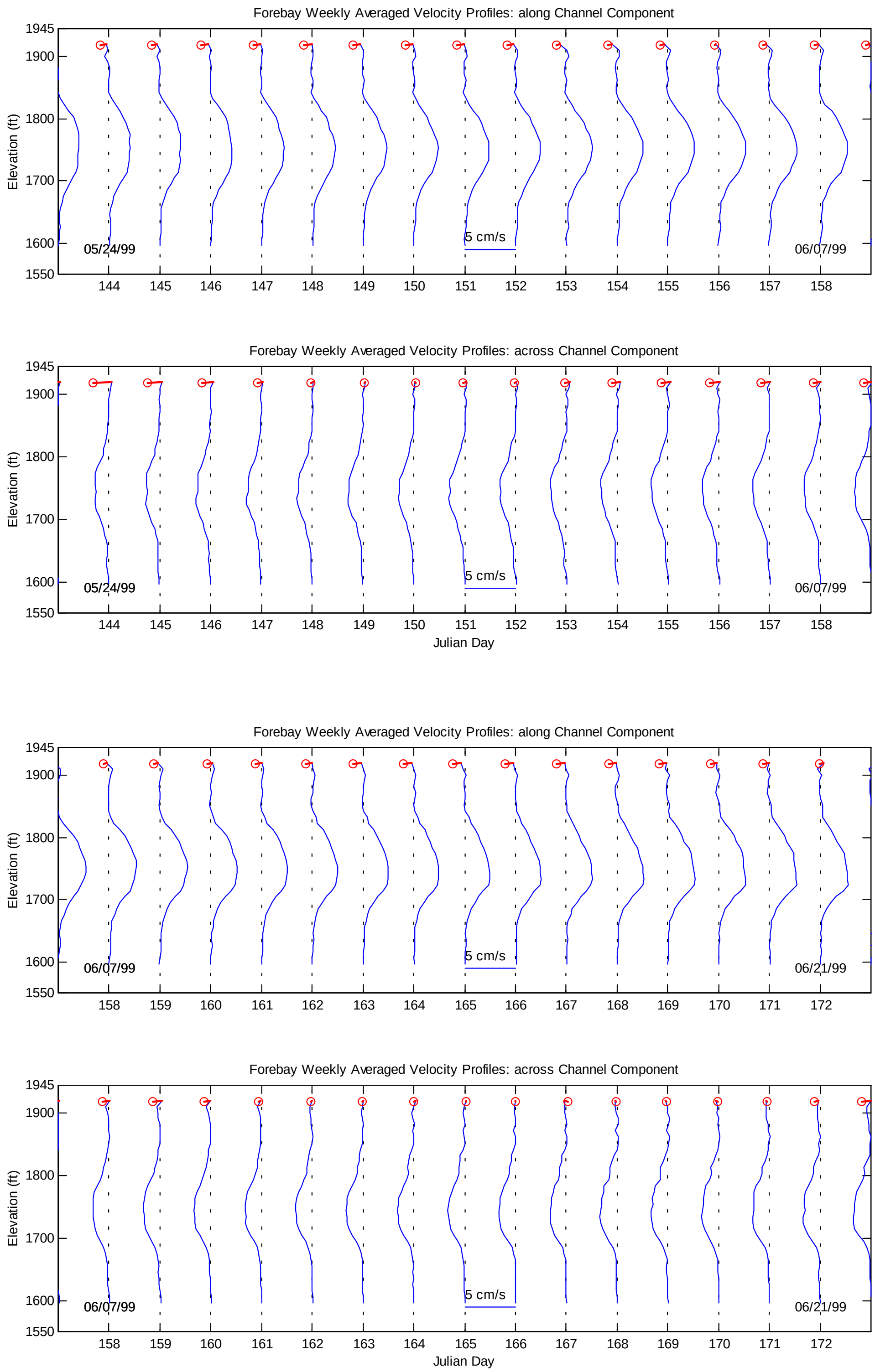
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s

5 cm/s

5 cm/s

5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-2b** FOREBAY 7-DAY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

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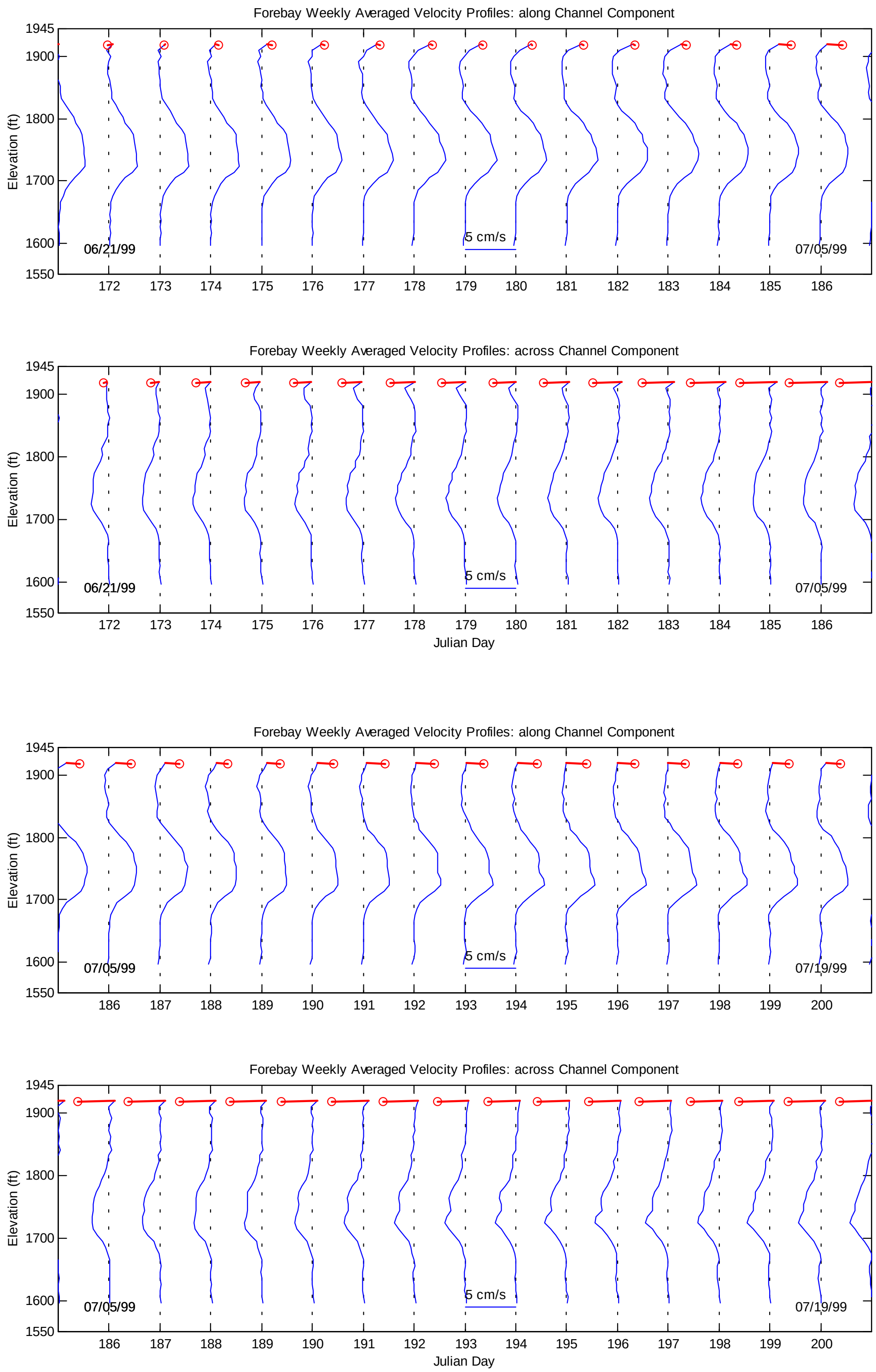

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-2c** FOREBAY 7-DAY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

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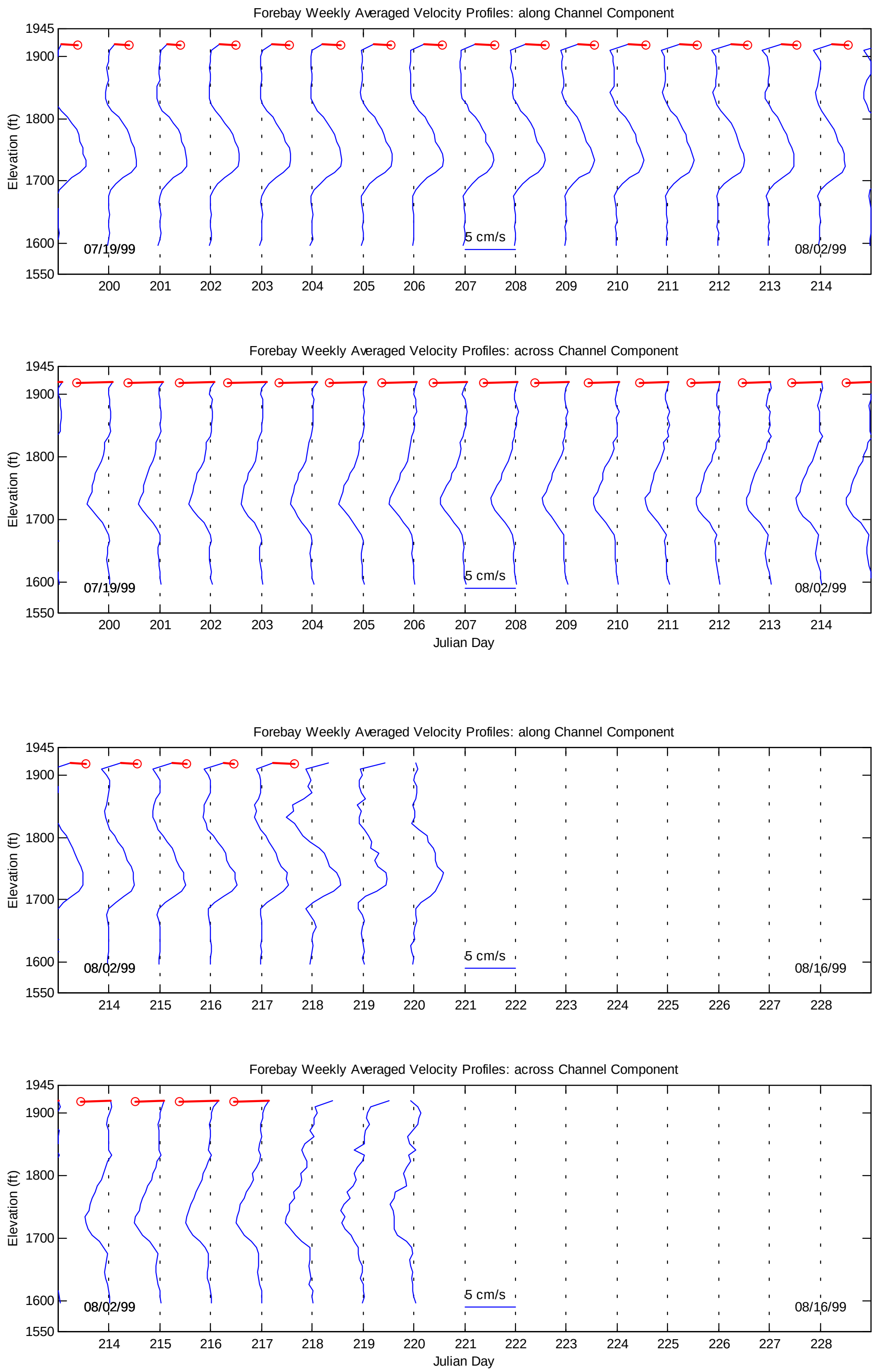
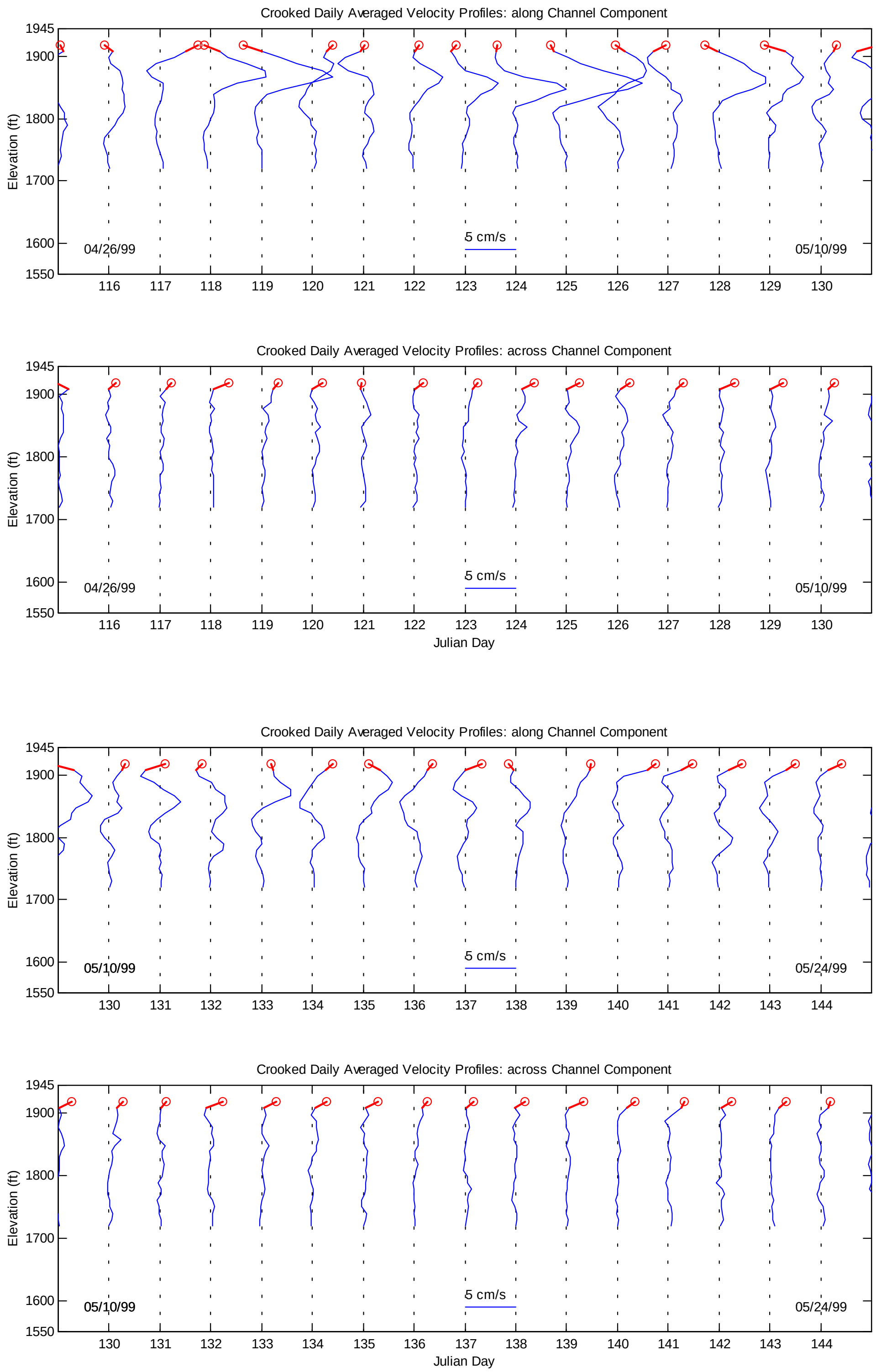


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-2d

FOREBAY 7-DAY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon



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FOSTER WHEELER
ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

FIGURE A-5a

CROOKED DAILY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

Portland, Oregon

5 cm/s

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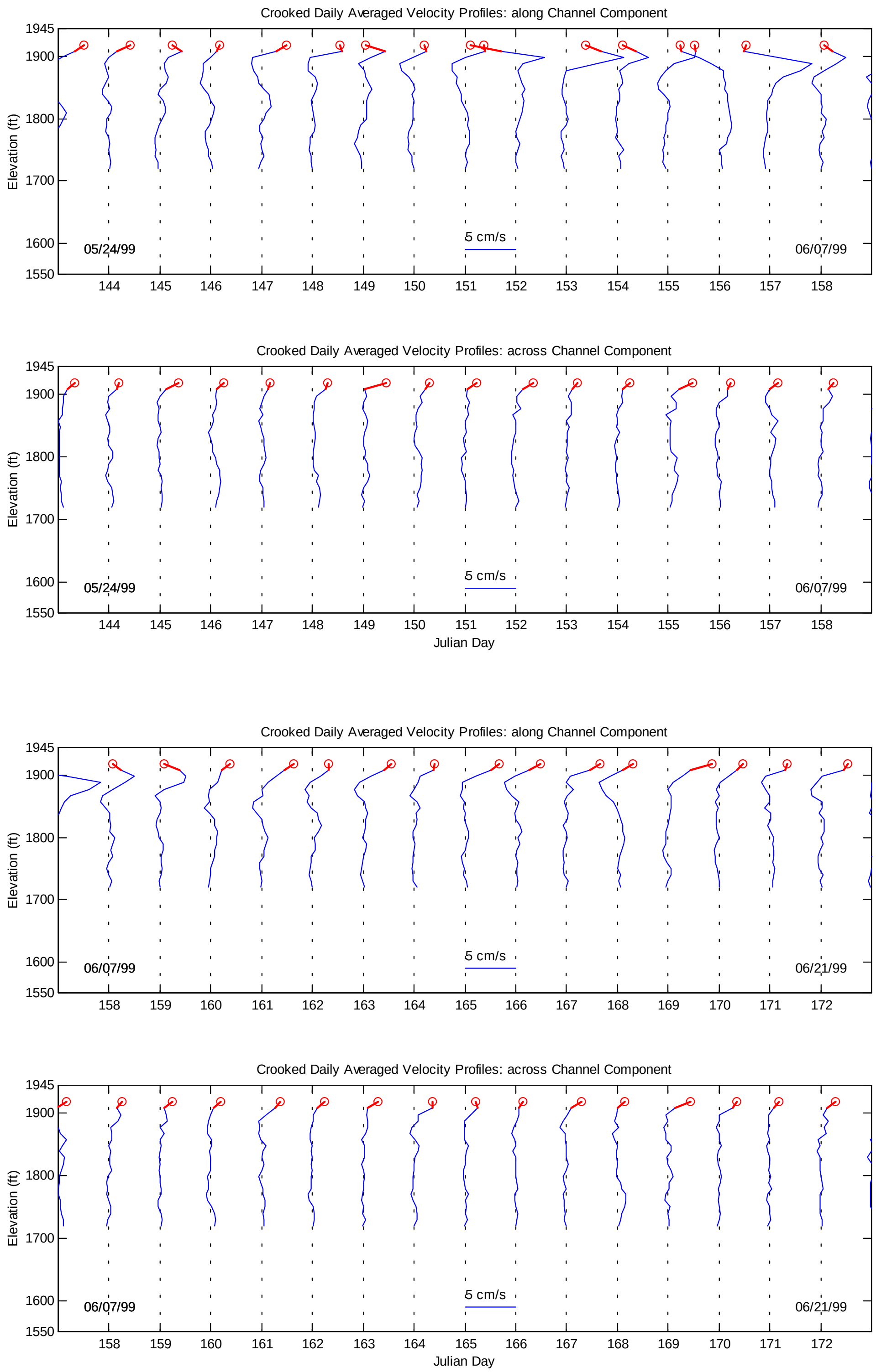
5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-5b**
	CHECKED: T. Khangaonkar	CROOKED DAILY AVERAGE ADCP
	DATE: December 22, 1999	Pelton Round Butte Hydroelectric Project No. 2030
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	Portland General Electric Company Portland, Oregon

5 cm/s

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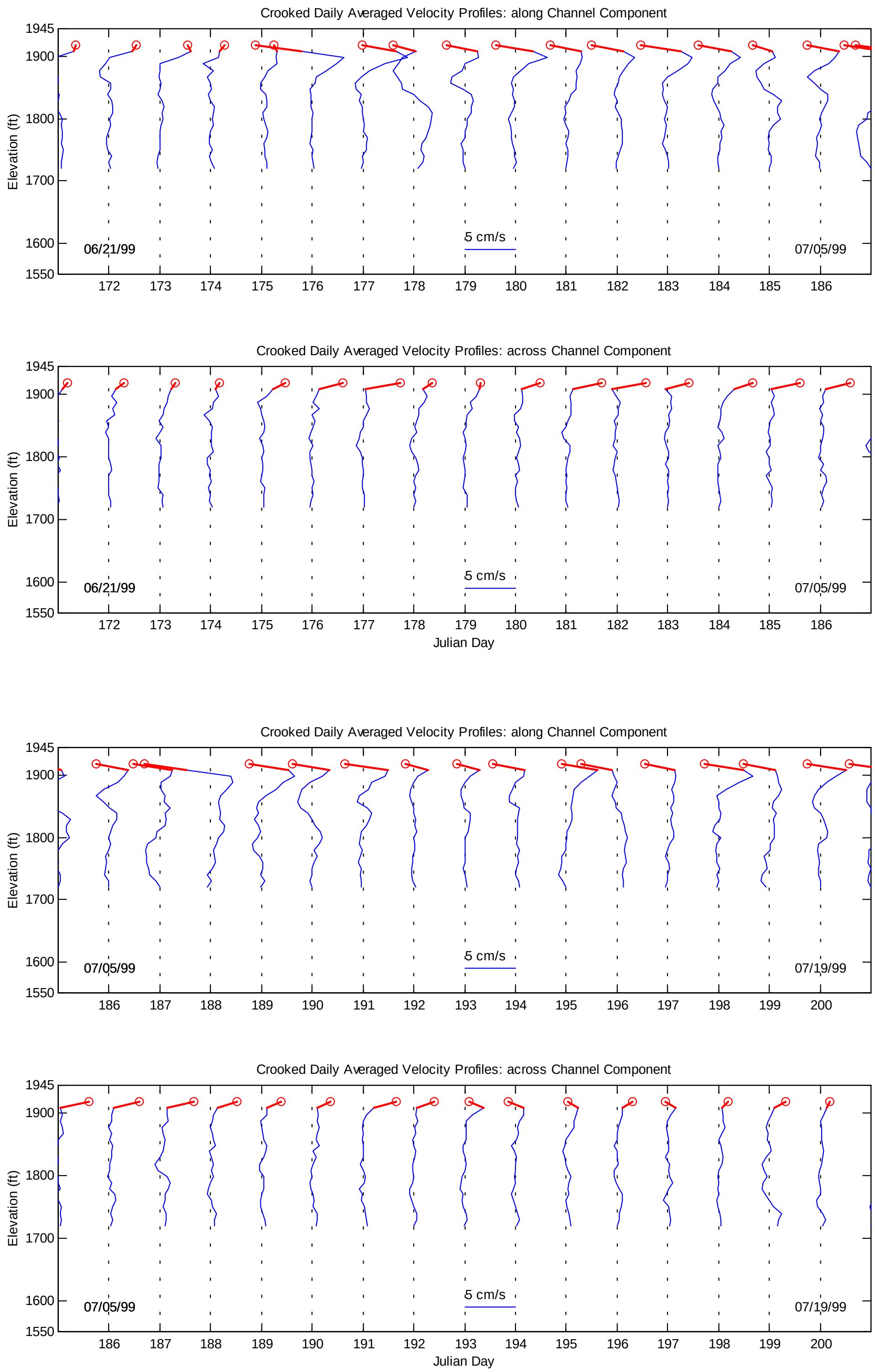

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-5c** CROOKED DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

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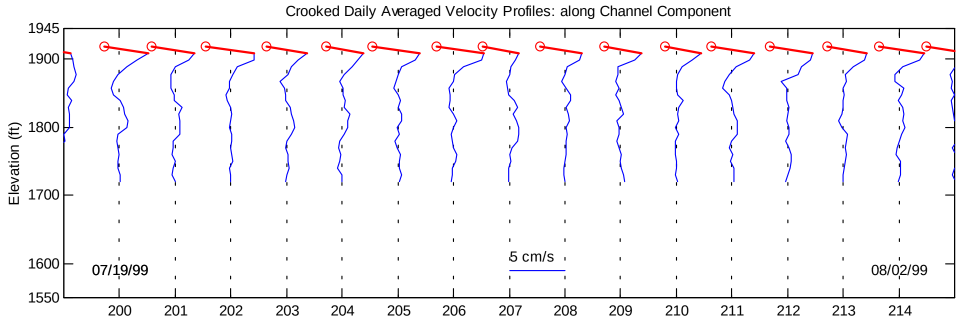

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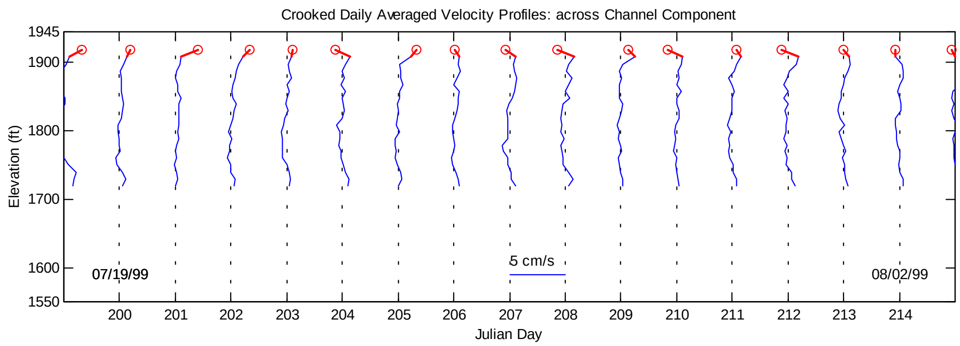

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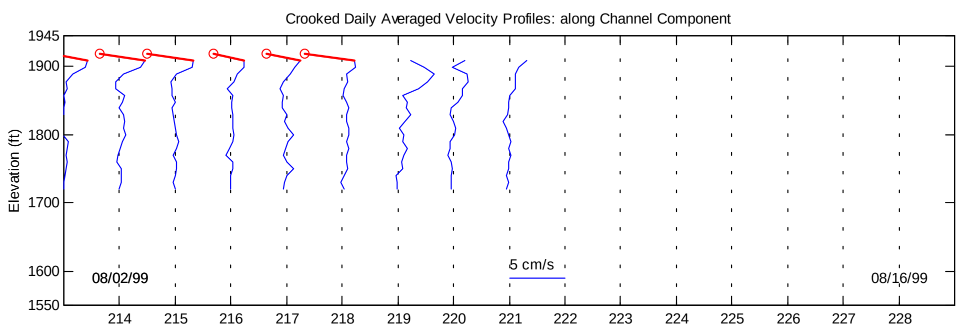

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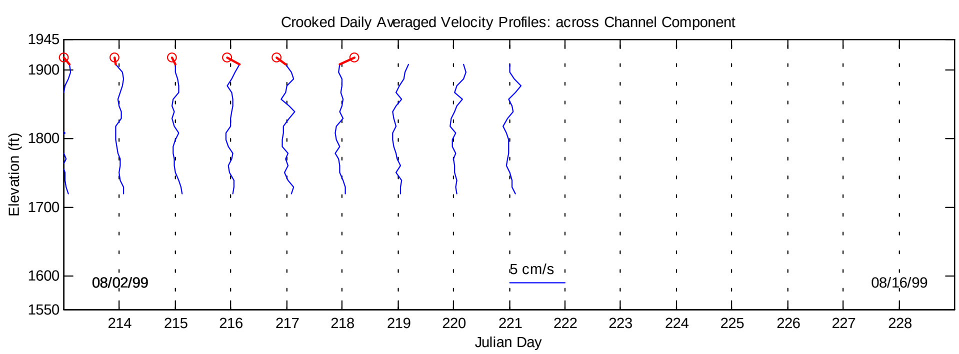

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-5d** CROOKED DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
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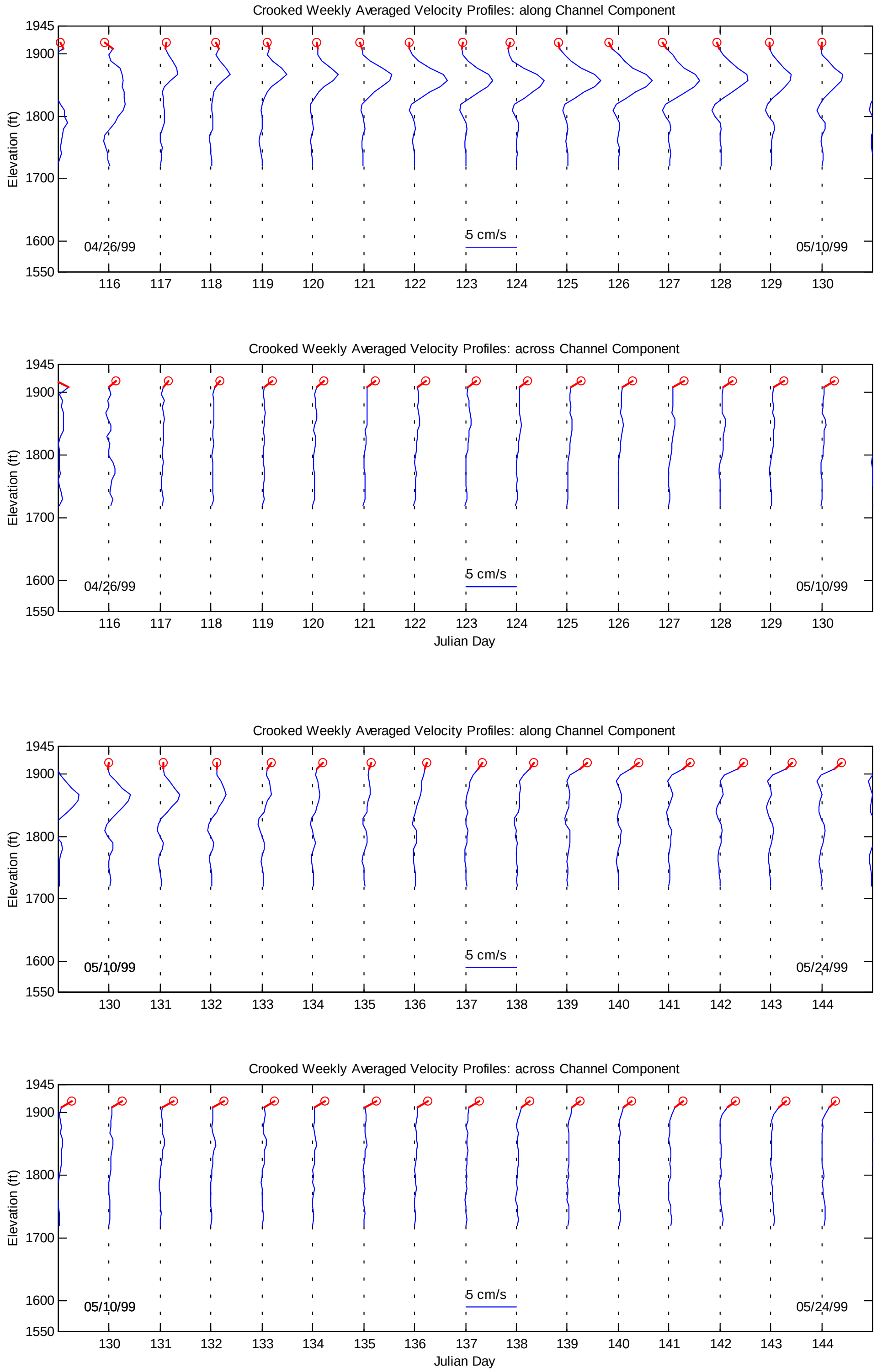

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FOSTER WHEELER
ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

FIGURE A-6a

CROOKED 7-DAY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

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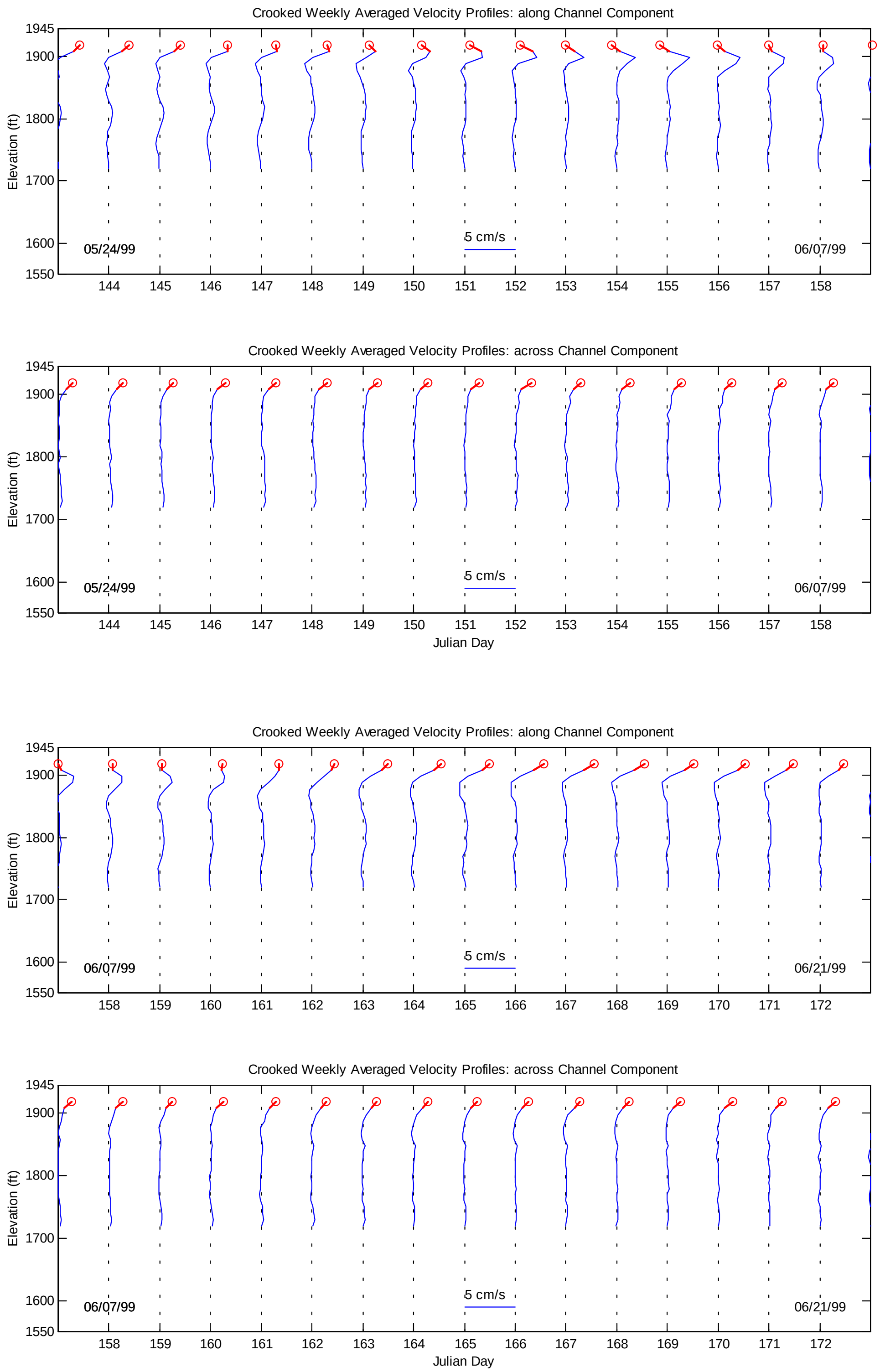
5 cm/s

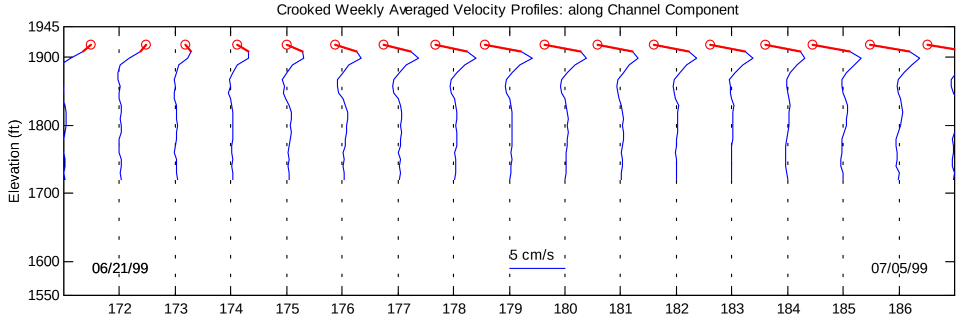
5 cm/s

5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-6b**
	CHECKED: T. Khangaonkar	CROOKED 7-DAY AVERAGE ADCP
	DATE: December 22, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

5 cm/s



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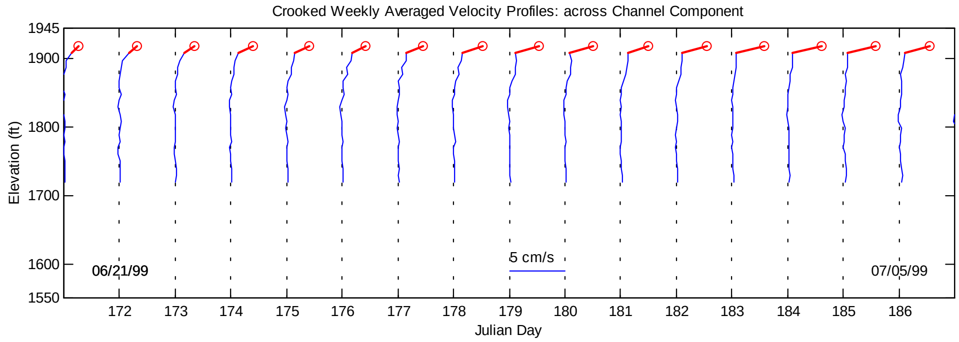

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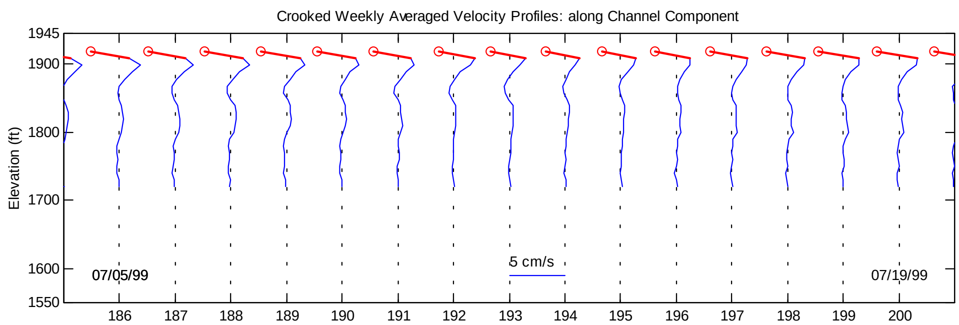

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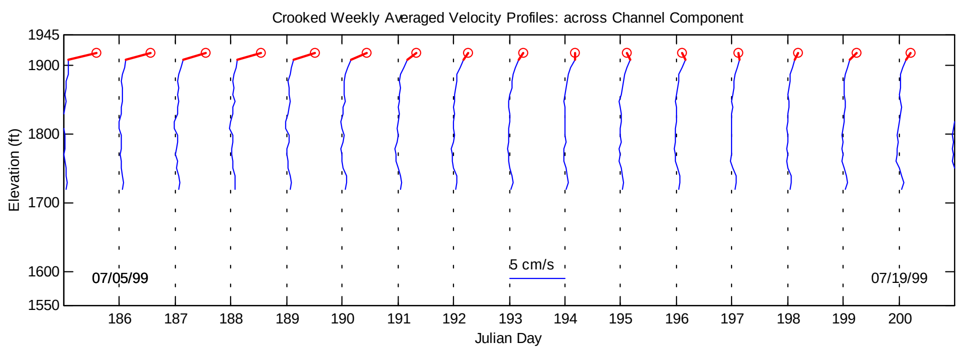


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 22, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-6c

CROOKED 7-DAY AVERAGE ADCP

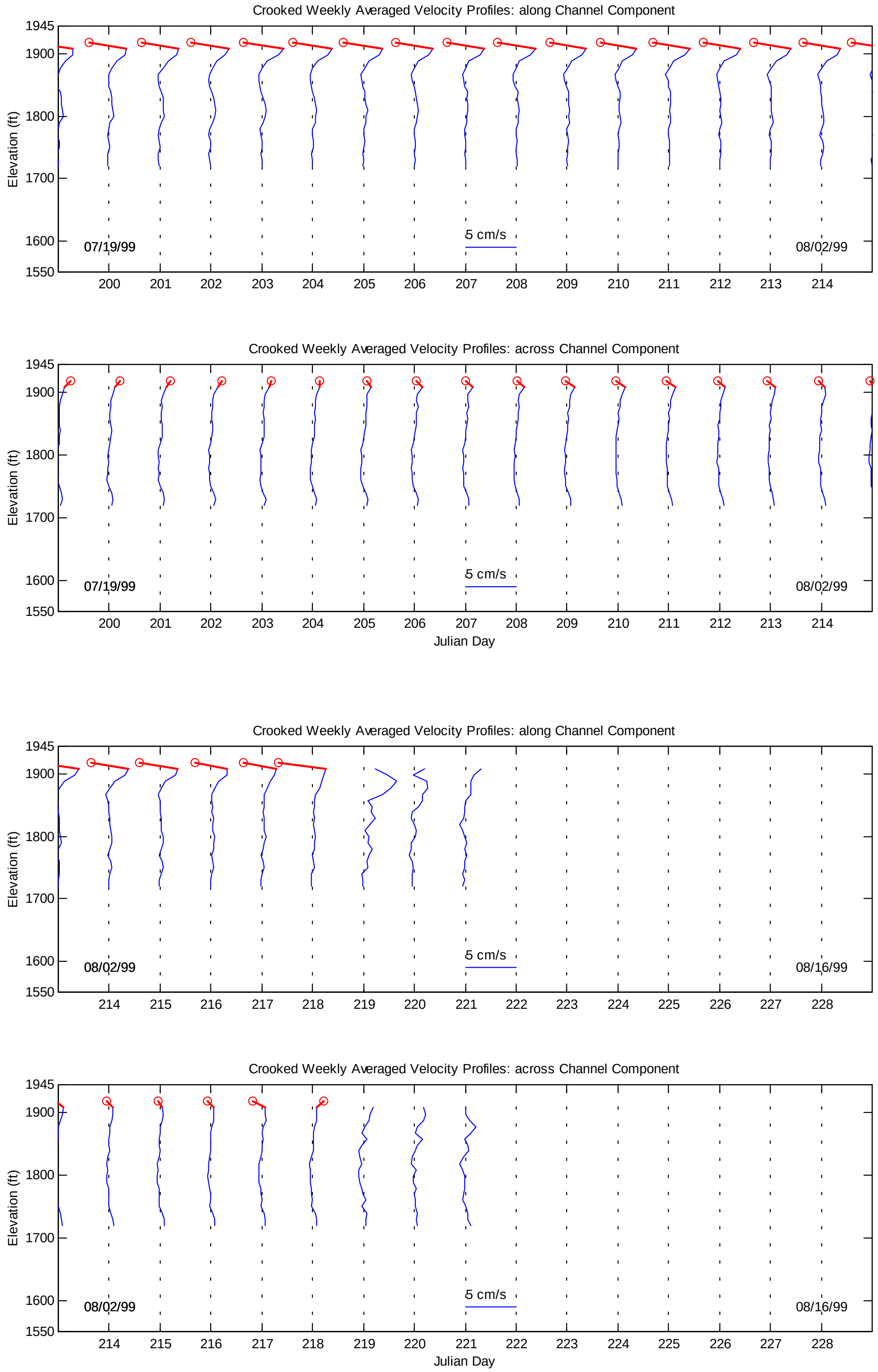
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s

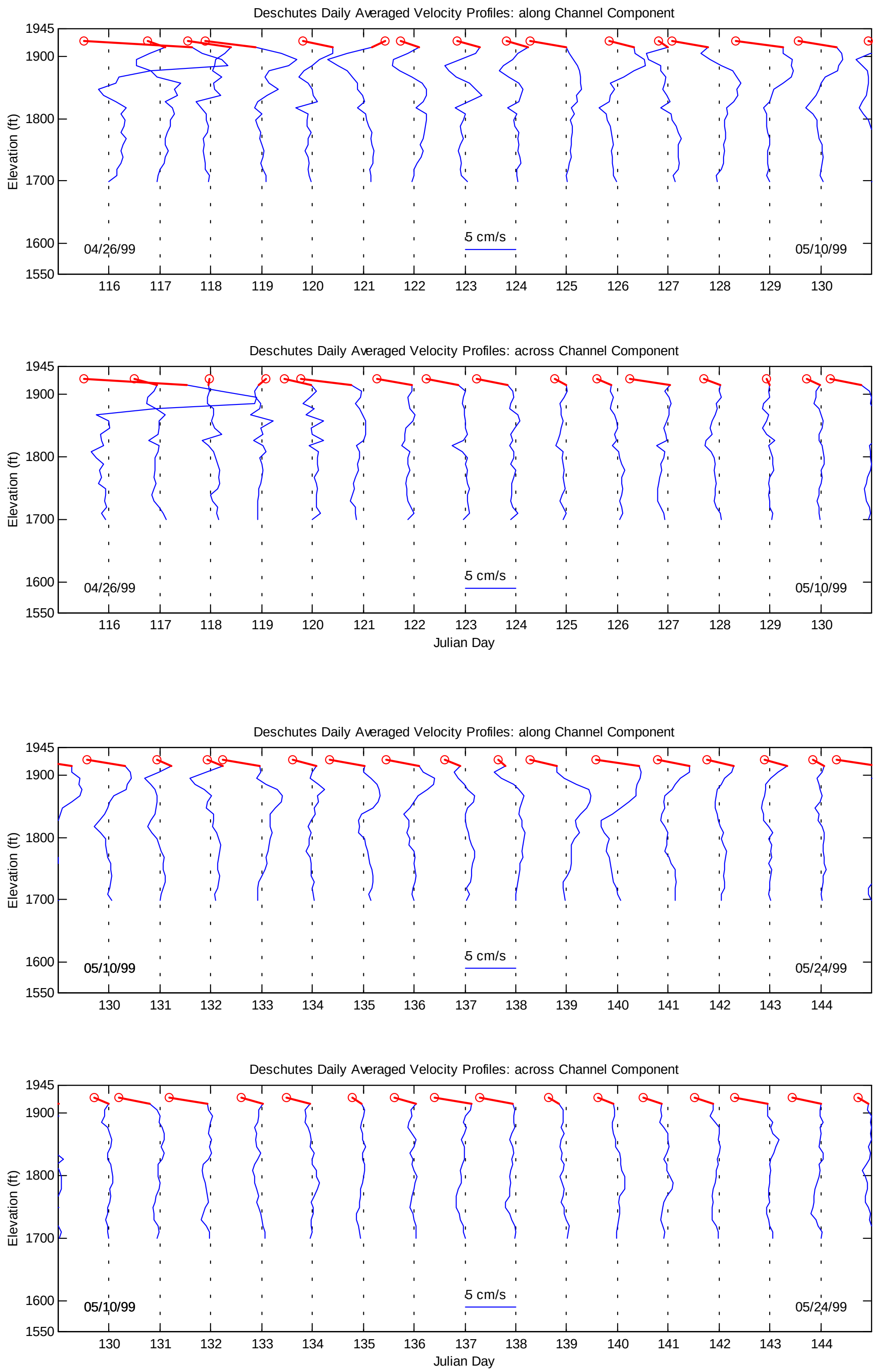
5 cm/s

5 cm/s

5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-6d** CROOKED 7-DAY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



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FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 22, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-3a

DESCHUTES DAILY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

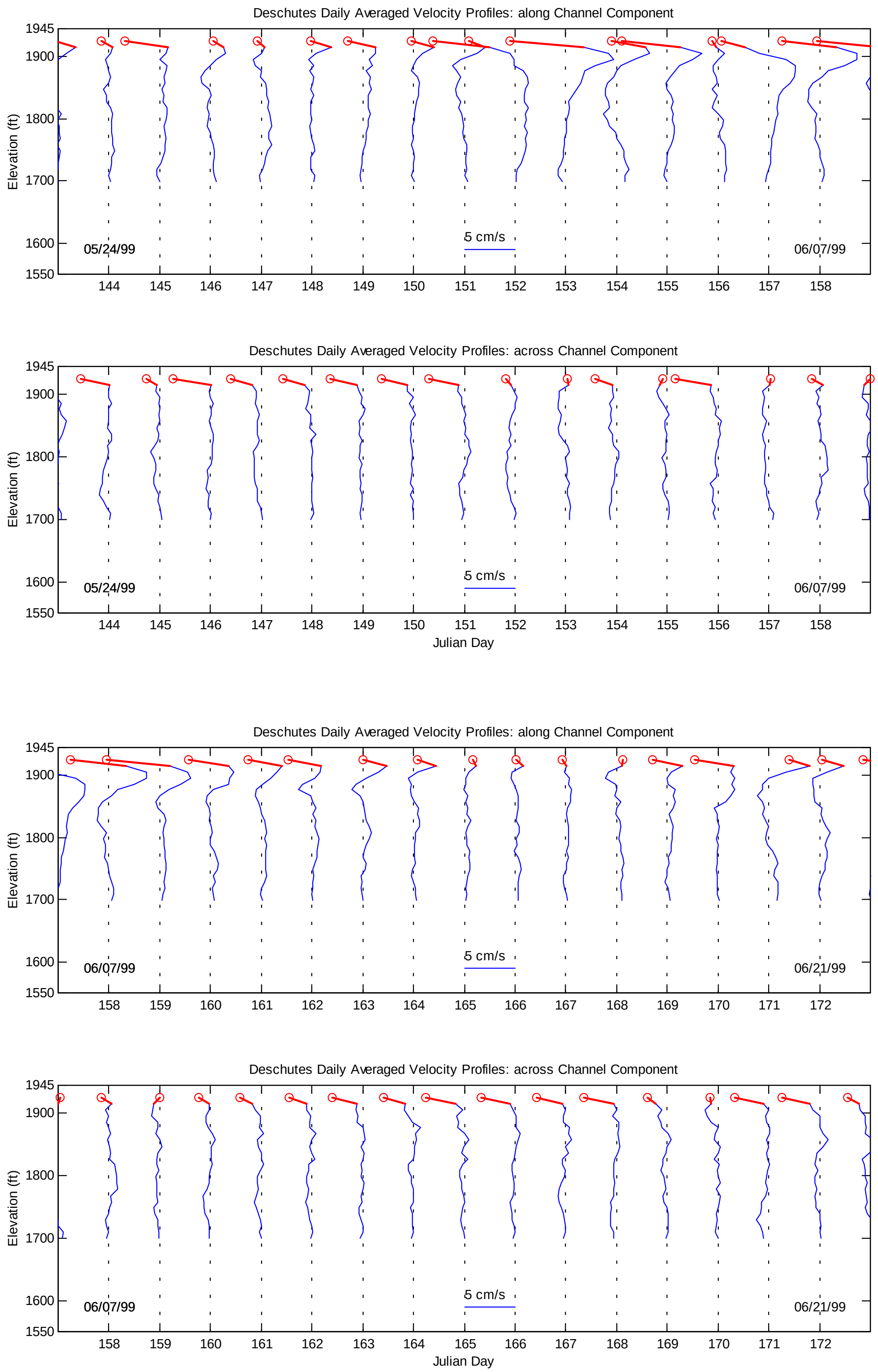
Portland, Oregon

5 cm/s

5 cm/s

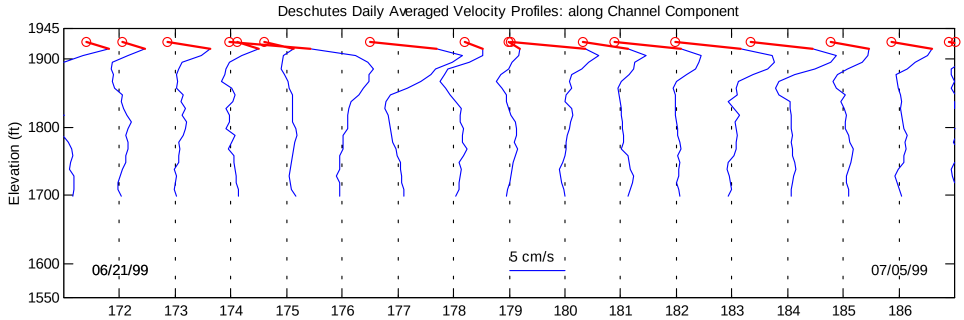
5 cm/s

5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-3b** DESCHUTES DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

5 cm/s



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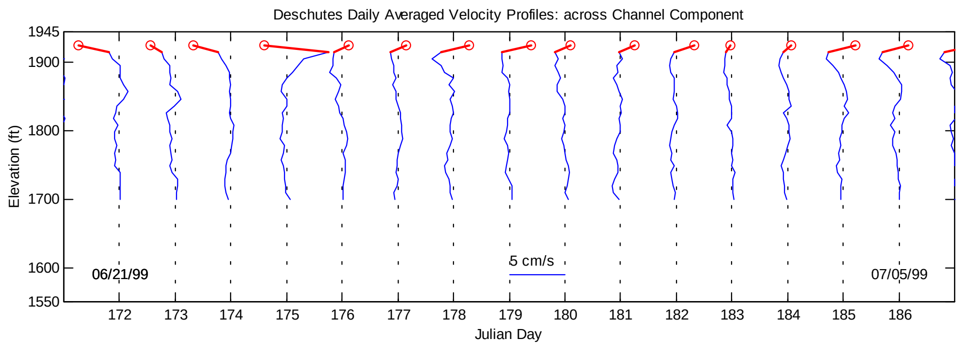

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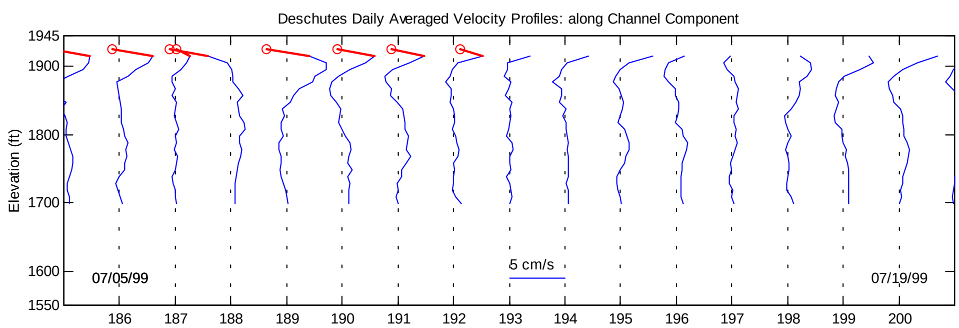

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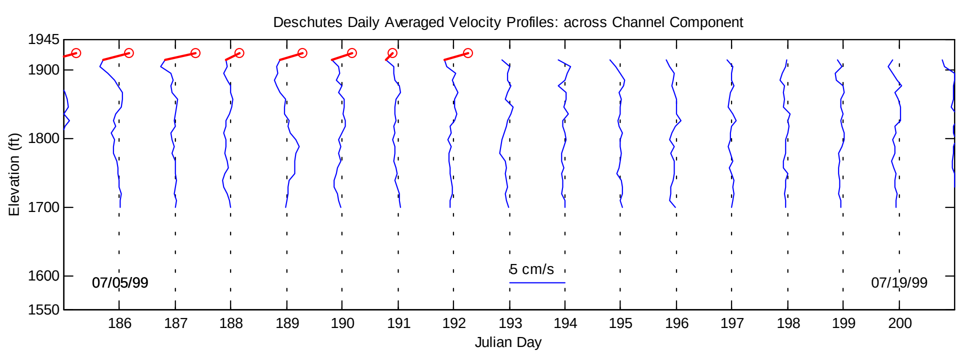


FOSTER WHEELER
ENVIRONMENTAL CORPORATION

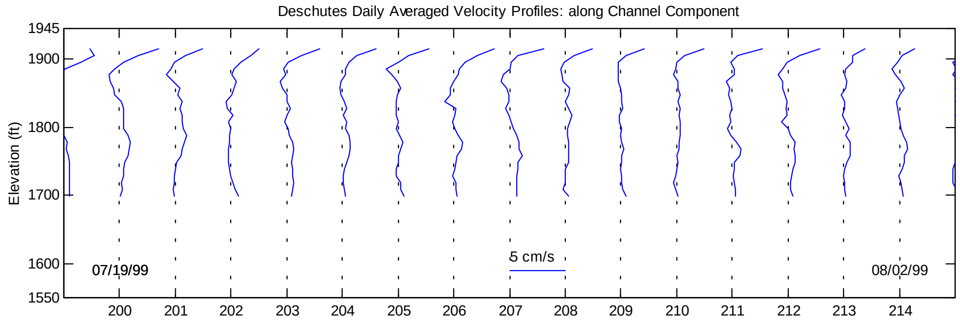
DRAWN: Z. Yang
CHECKED: T. Khangaonkar
DATE: December 22, 1999

PROJECT NO: 2200.0001.0002
FILENAME: pgeapp-P.doc

FIGURE A-3c

DESCHUTES DAILY AVERAGE ADCP
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s



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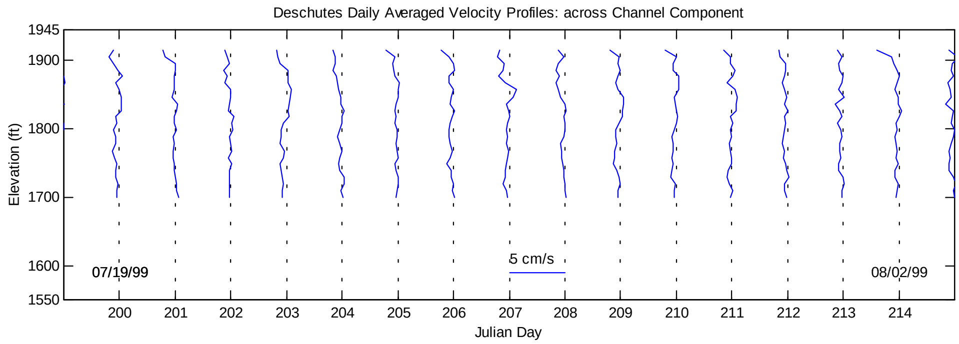

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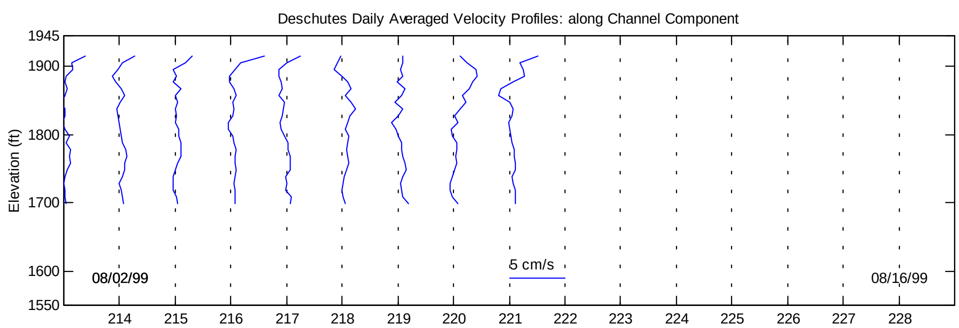
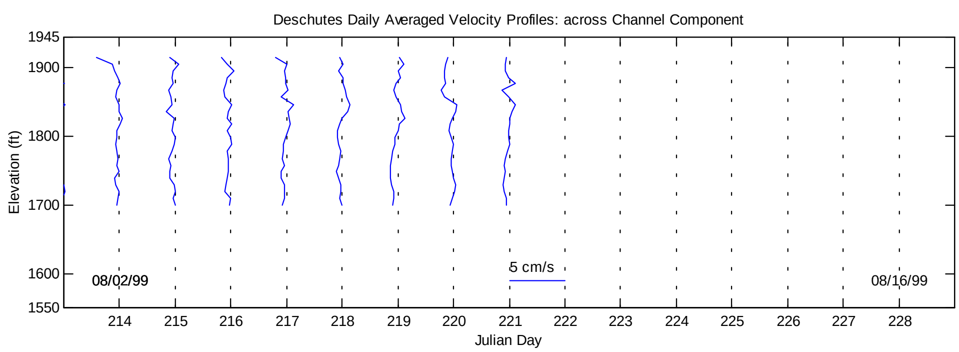


5 cm/s



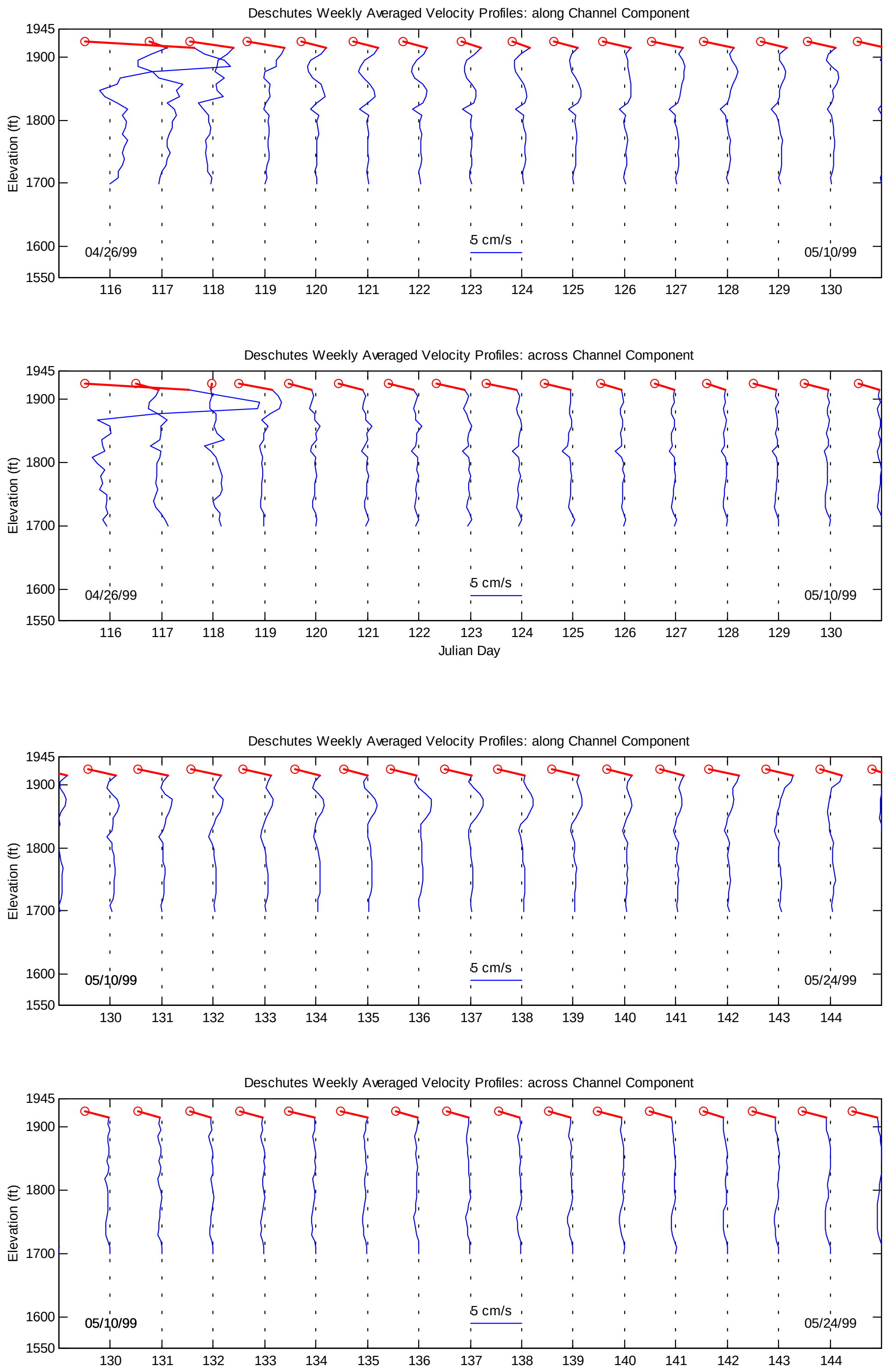
FOSTER WHEELER
ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang
CHECKED: T. Khangaonkar
DATE: December 22, 1999

PROJECT NO: 2200.0001.0002
FILENAME: pgeapp-P.doc

FIGURE A-3d

DESCHUTES DAILY AVERAGE ADCP
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon



5 cm/s

5 cm/s

FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

PROJECT NO: 2200.0001.0002

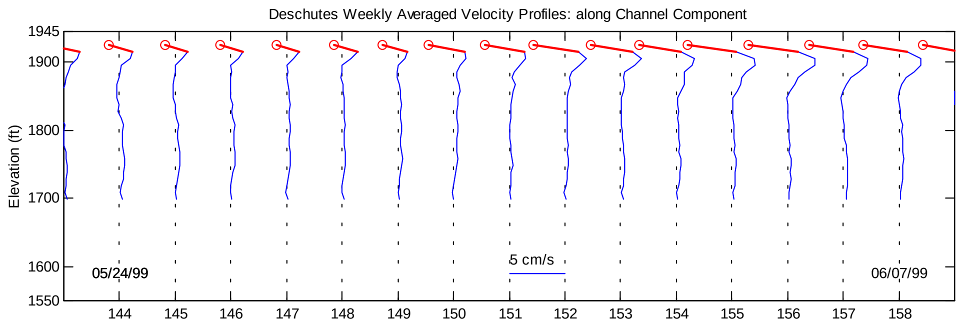
FILENAME: pgeapp-P.doc

FIGURE A-4a

DESCHUTES 7-DAY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s



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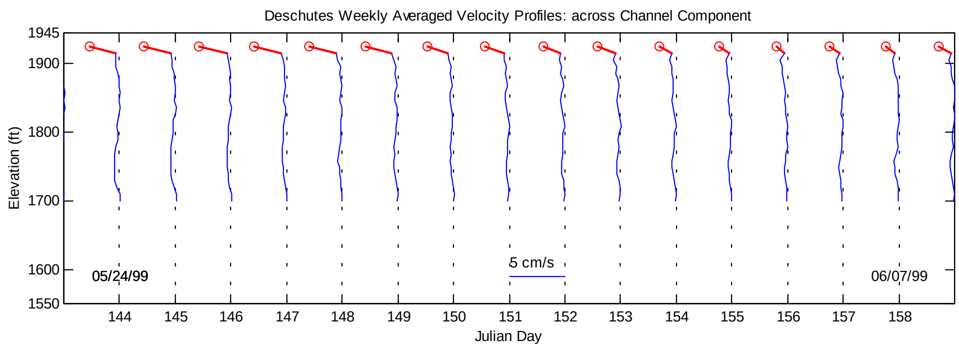
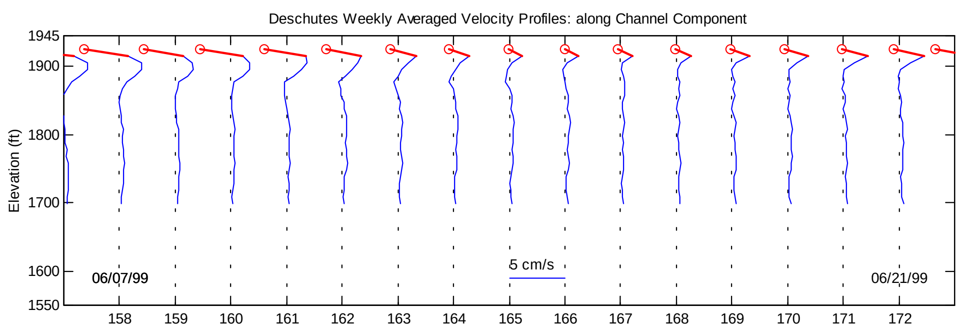


5 cm/s



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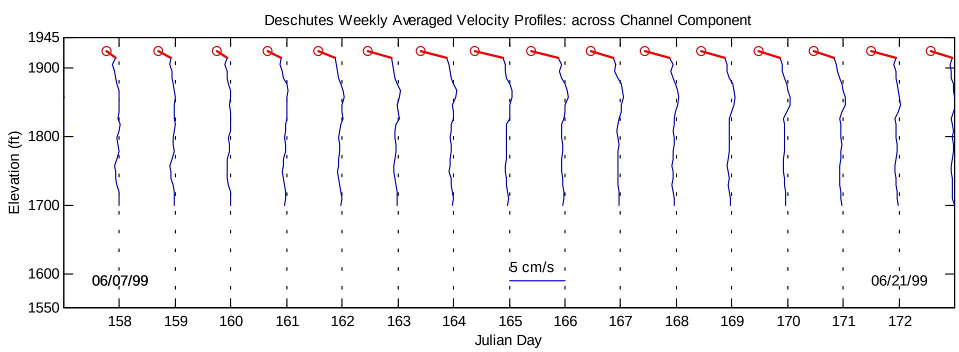


FOSTER WHEELER
ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang
CHECKED: T. Khangaonkar
DATE: December 22, 1999

PROJECT NO: 2200.0001.0002
FILENAME: pgeapp-P.doc

FIGURE A-4b

DESCHUTES 7-DAY AVERAGE ADCP

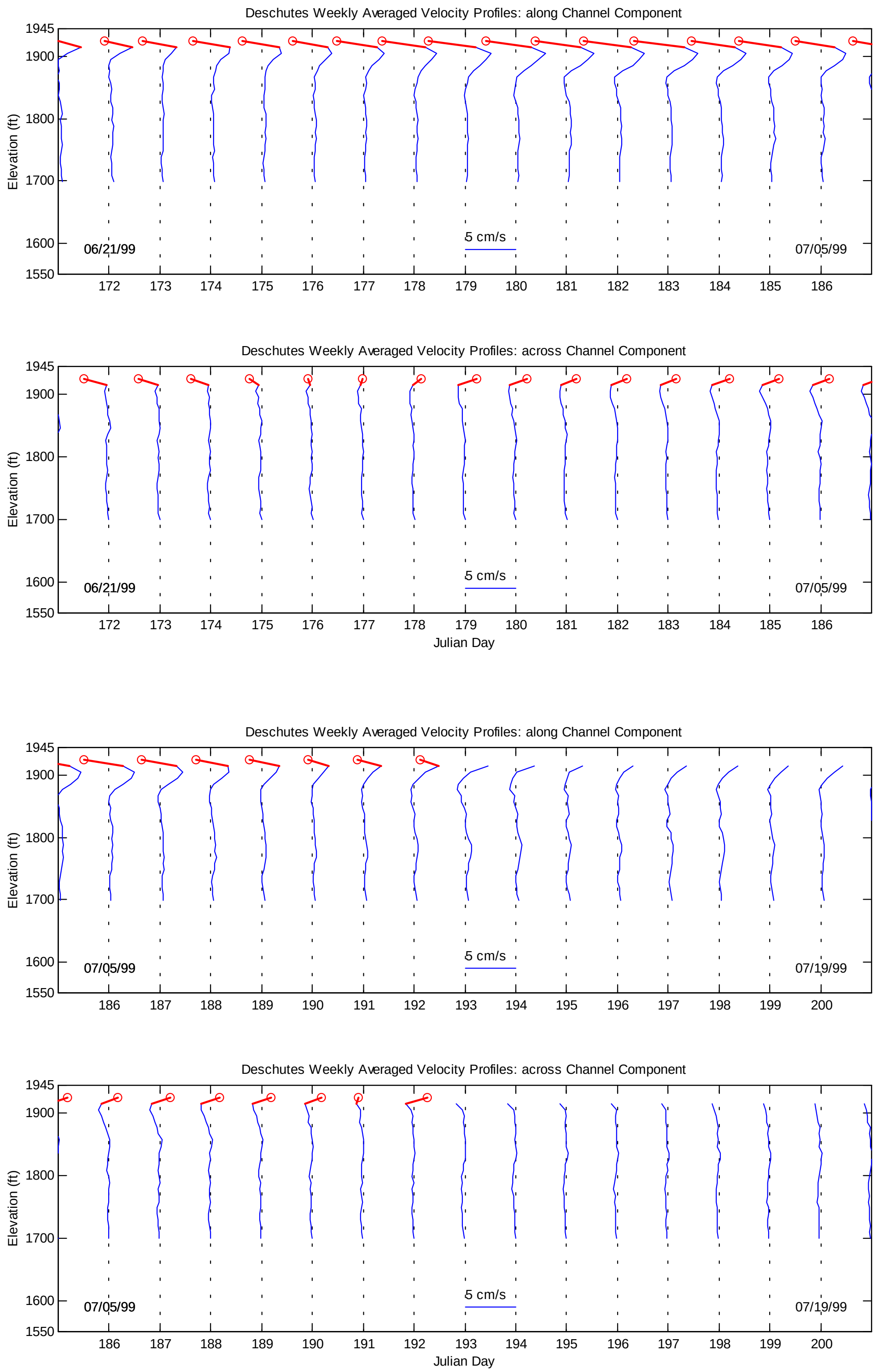
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s

5 cm/s

5 cm/s

5 cm/s



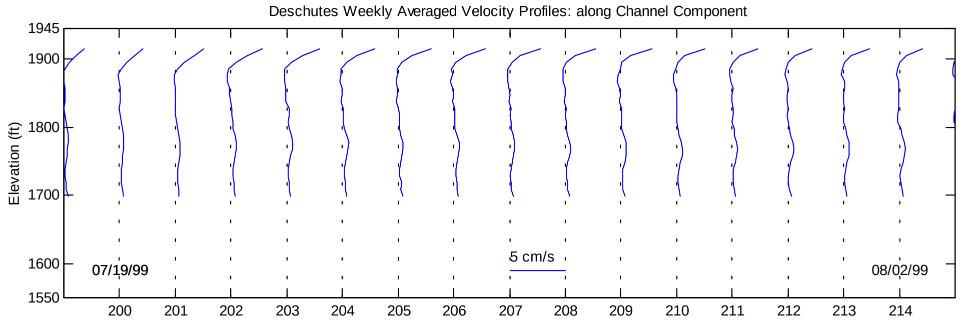
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 22, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-4c

DESCHUTES 7-DAY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

5 cm/s



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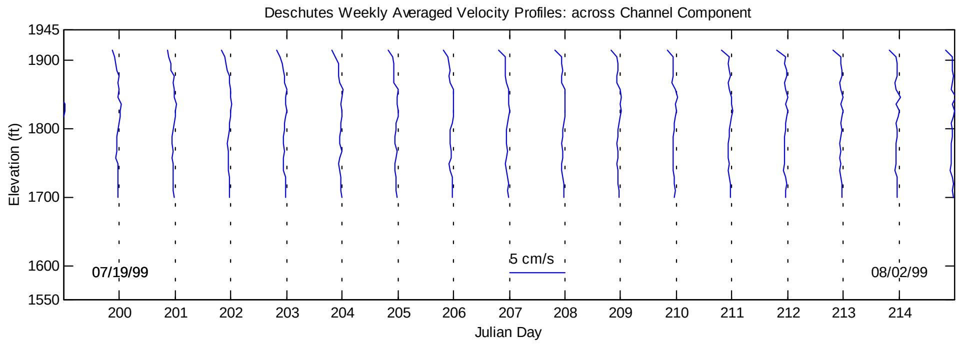

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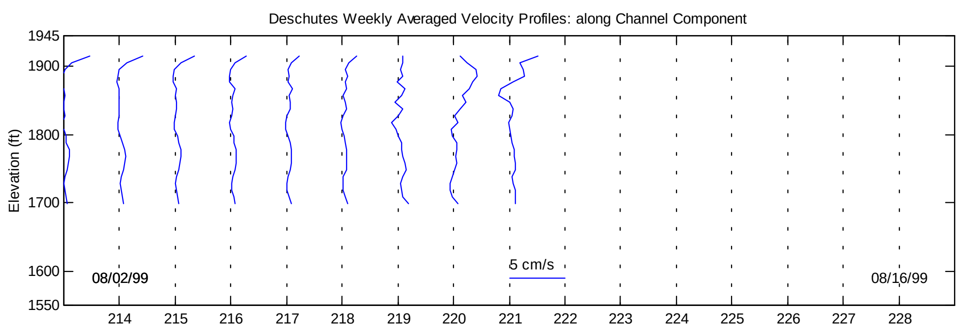
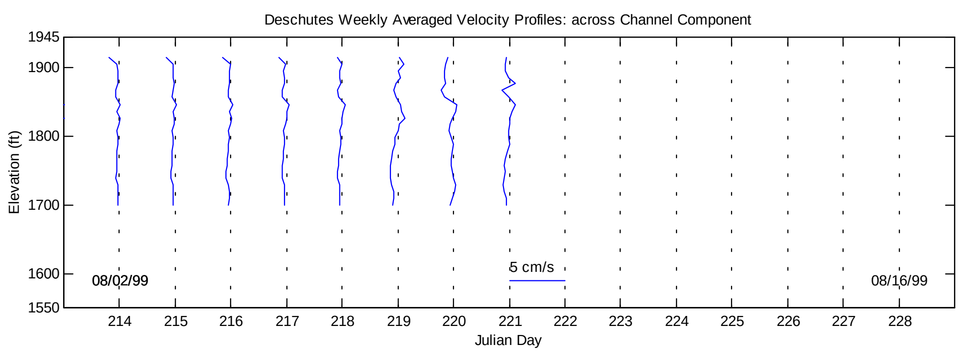
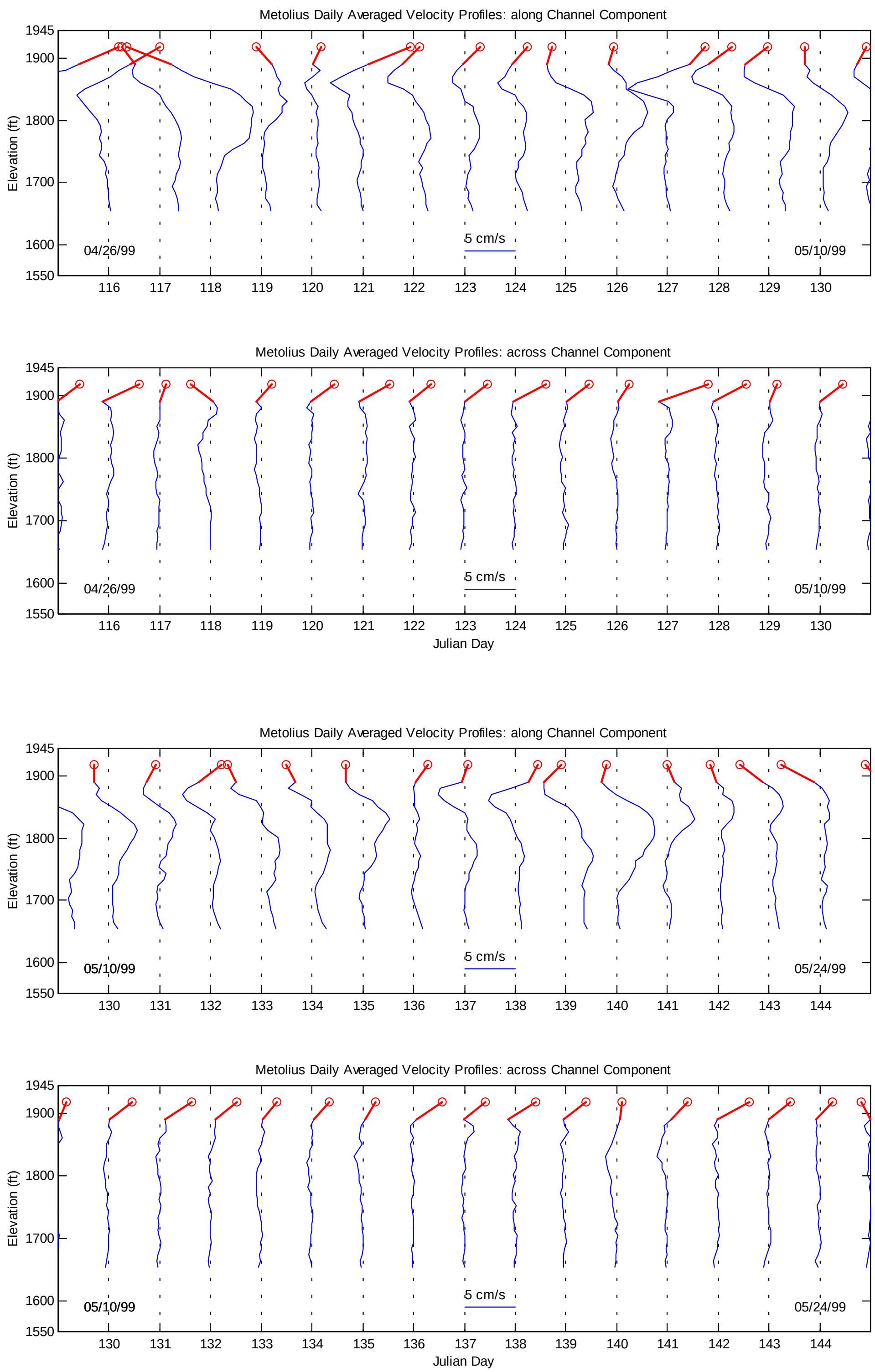


5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-4d**
	CHECKED: T. Khangaonkar	DESCHUTES 7-DAY AVERAGE ADCP
	DATE: December 22, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

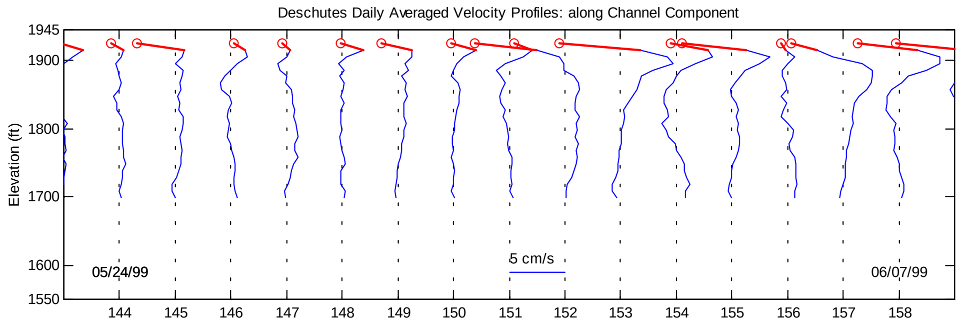


5 cm/s

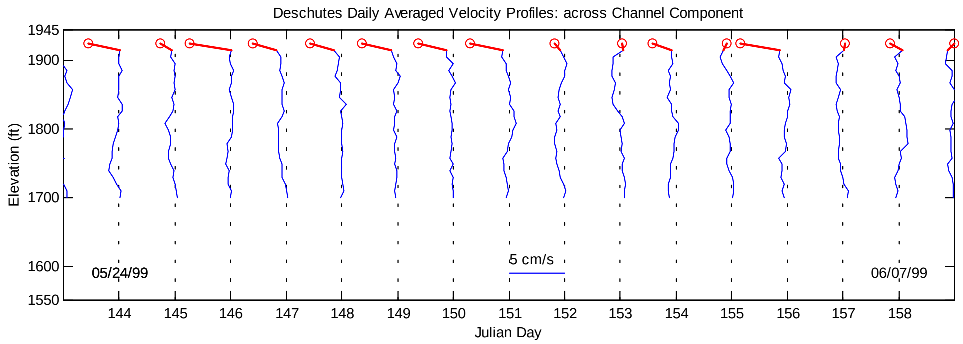
5 cm/s

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-7a** METOLIUS DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

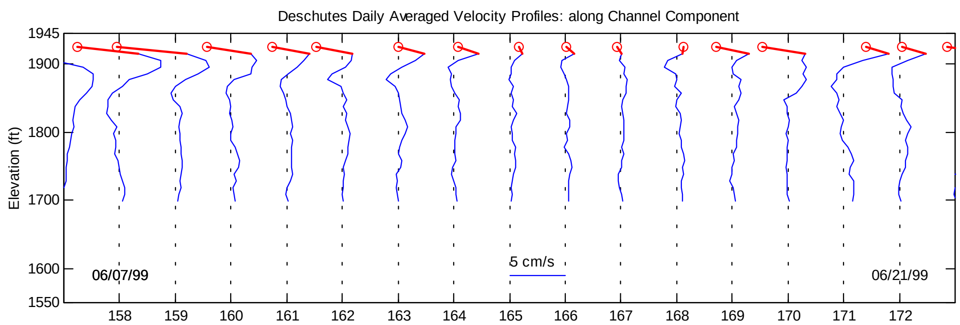
5 cm/s



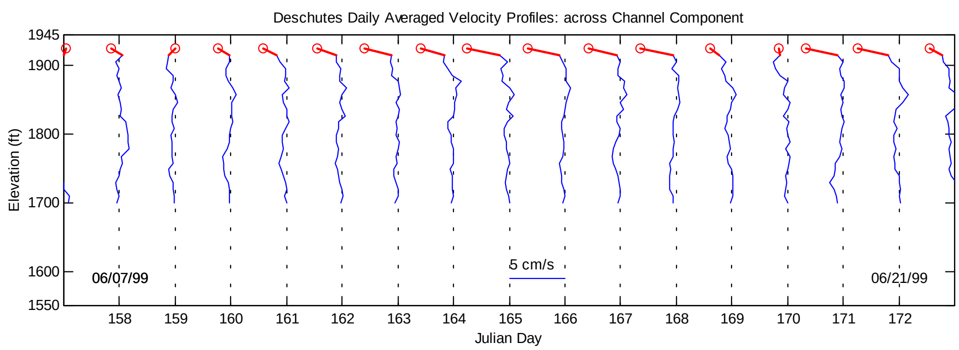
5 cm/s



5 cm/s

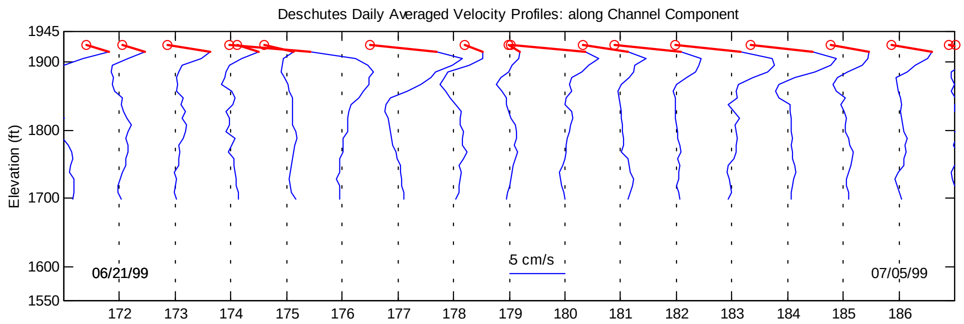


5 cm/s

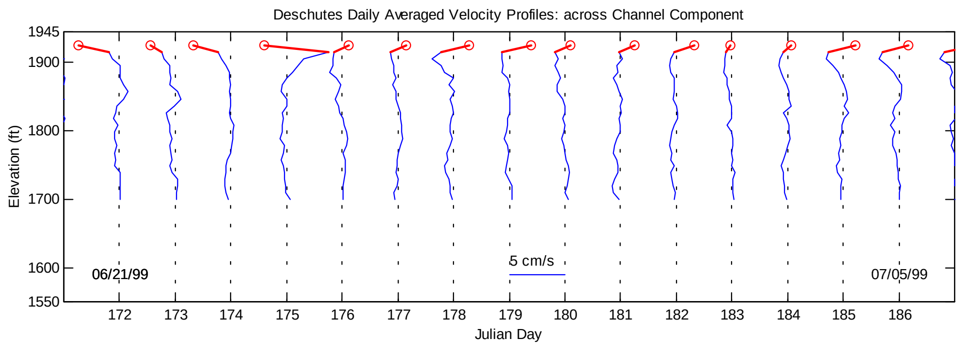


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-7b** METOLIUS DAILY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

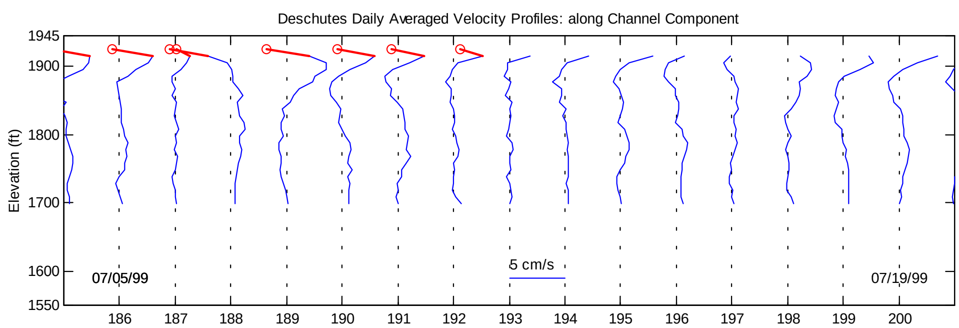
5 cm/s



5 cm/s



5 cm/s



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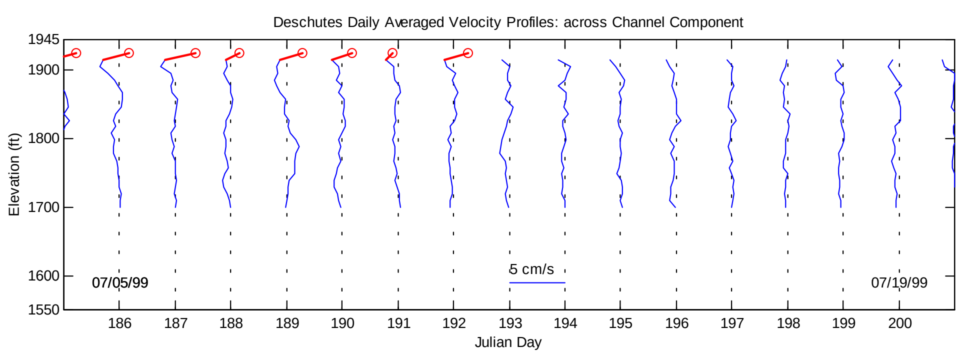


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 22, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-7c

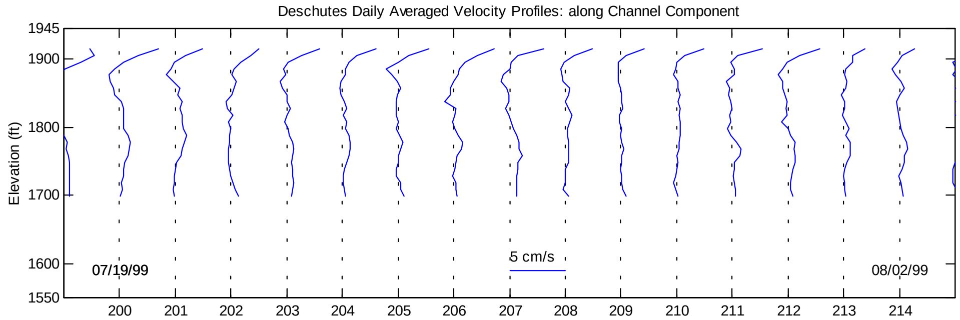
METOLIUS DAILY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

Portland, Oregon

5 cm/s



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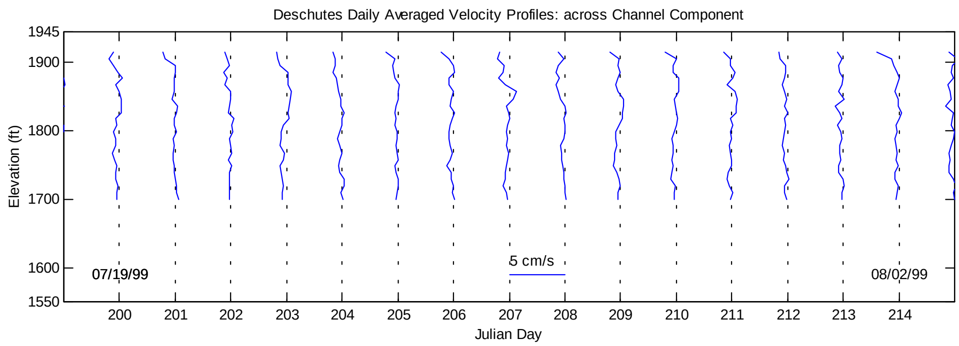
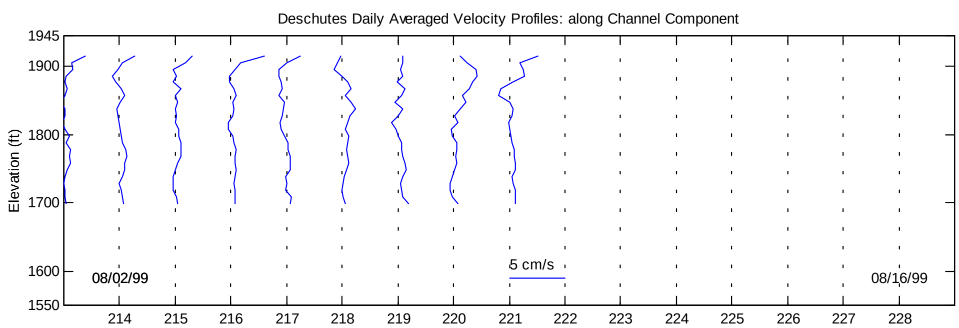
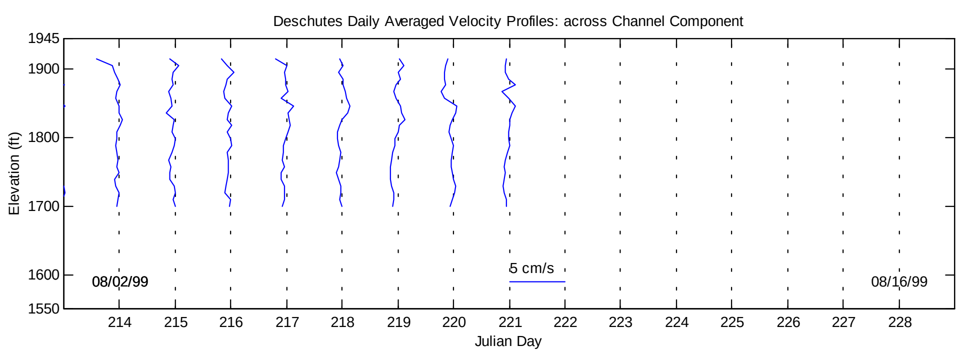


5 cm/s



5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

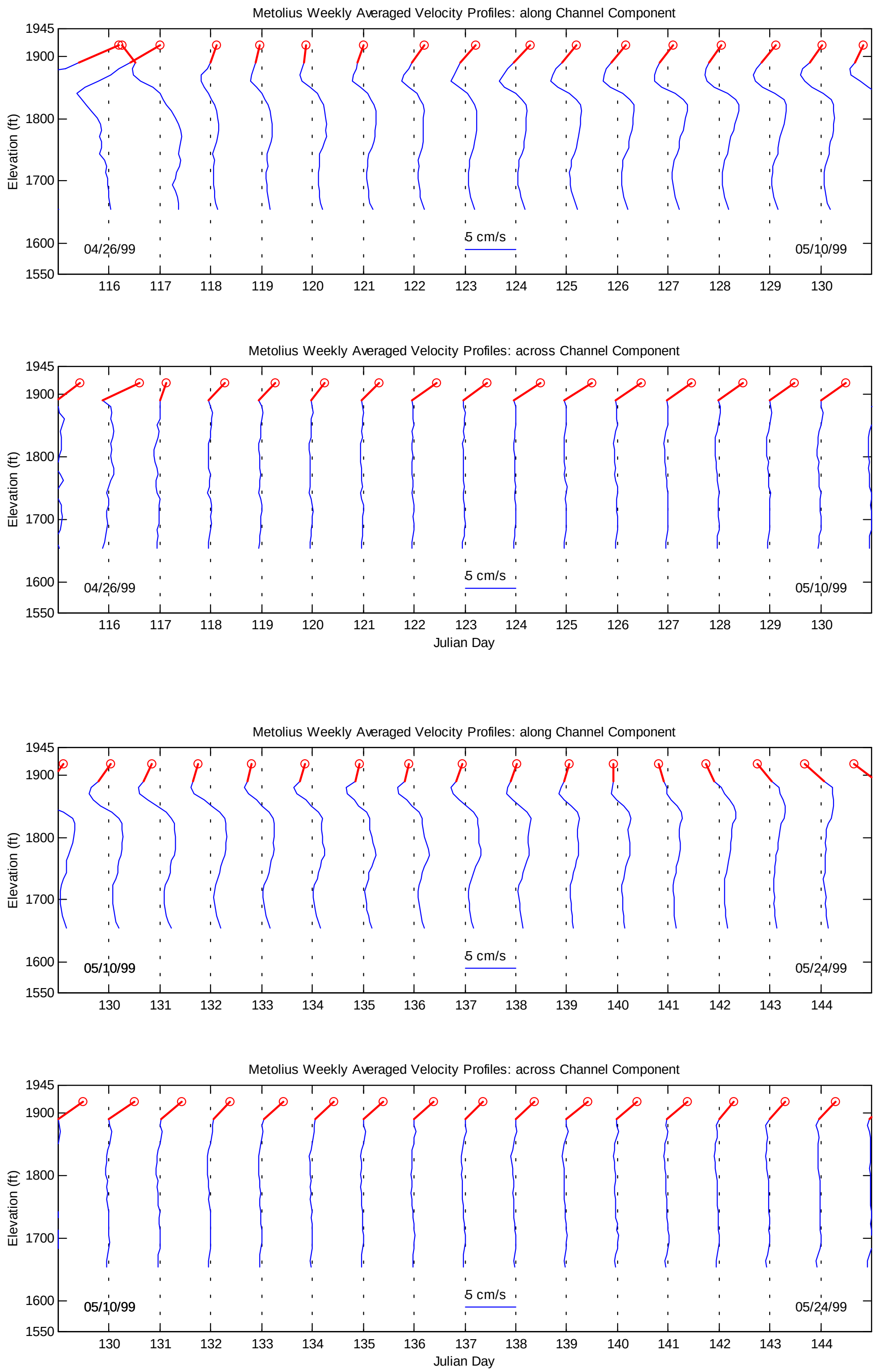
FIGURE A-7d

METOLIUS DAILY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

Portland, Oregon



5 cm/s

5 cm/s

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 22, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-8a

METOLIUS 7-DAY AVERAGE ADCP

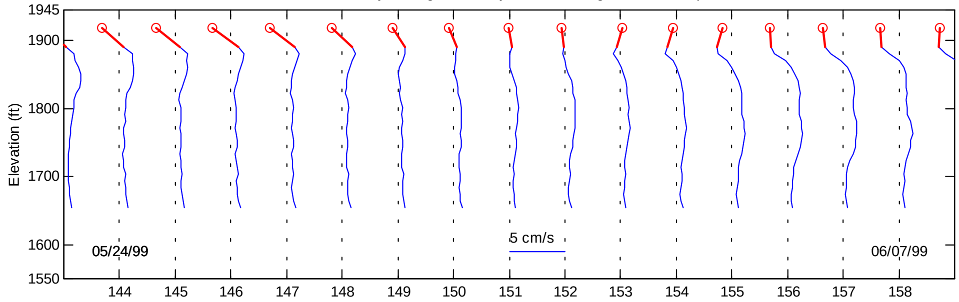
Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

Portland, Oregon

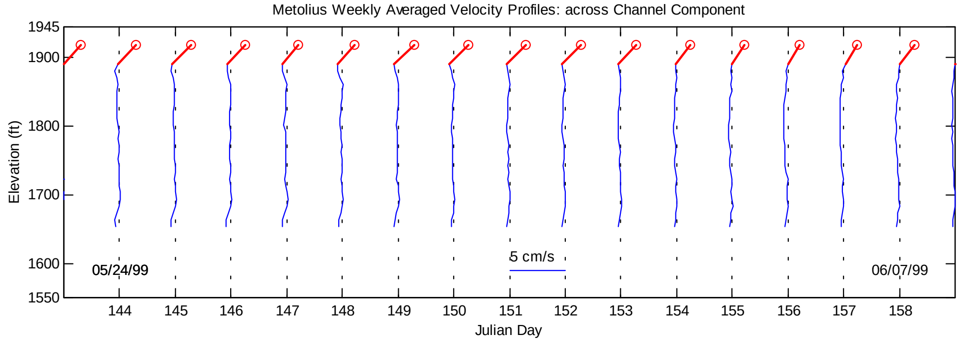
5 cm/s

Metolius Weekly Averaged Velocity Profiles: along Channel Component



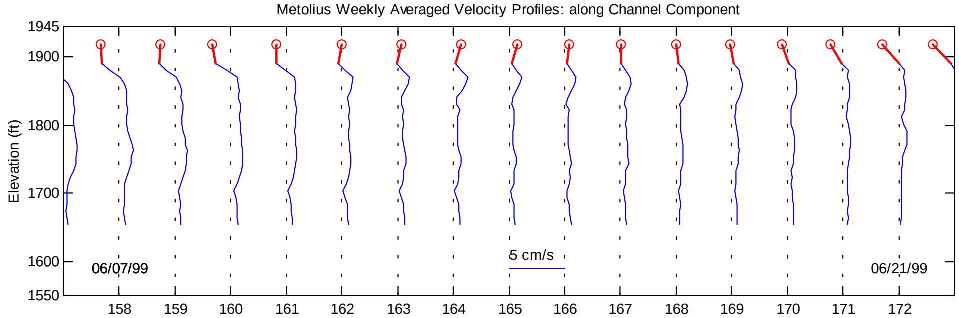
5 cm/s

Metolius Weekly Averaged Velocity Profiles: across Channel Component



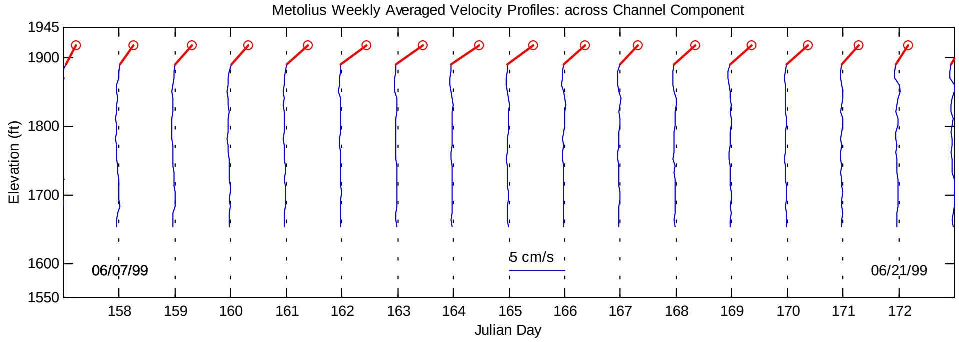
5 cm/s

Metolius Weekly Averaged Velocity Profiles: along Channel Component



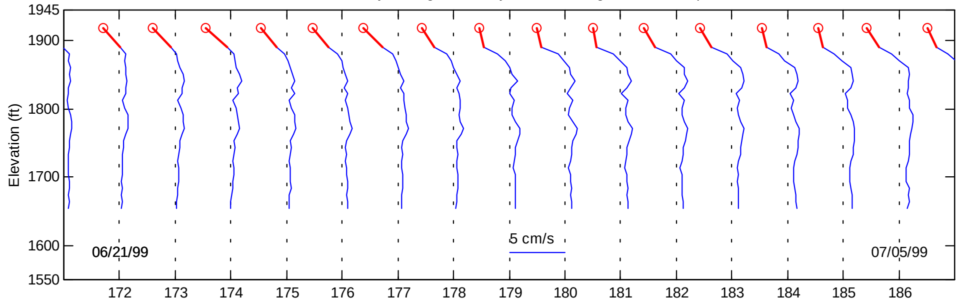
5 cm/s

Metolius Weekly Averaged Velocity Profiles: across Channel Component



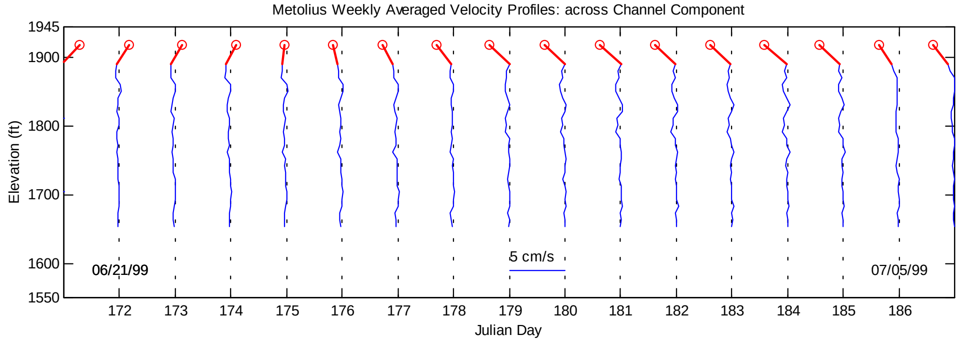
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 22, 1999	**FIGURE A-8b** METOLIUS 7-DAY AVERAGE ADCP Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

Metolius Weekly Averaged Velocity Profiles: along Channel Component



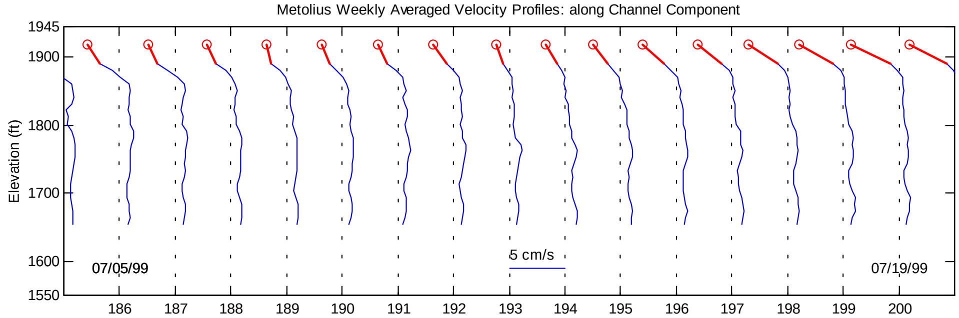
5 cm/s

Metolius Weekly Averaged Velocity Profiles: across Channel Component



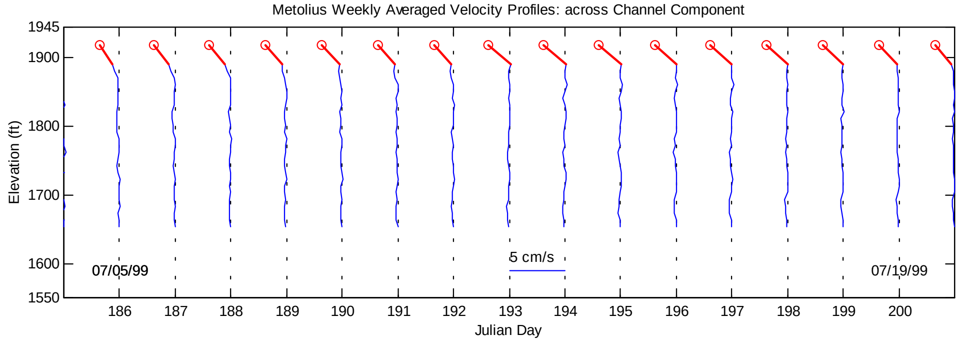
5 cm/s

Metolius Weekly Averaged Velocity Profiles: along Channel Component



5 cm/s

Metolius Weekly Averaged Velocity Profiles: across Channel Component



5 cm/s

FOSTER WHEELER ENVIRONMENTAL CORPORATION

PROJECT NO: 2200.0001.0002

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 22, 1999

FILENAME: pgeapp-P.doc

FIGURE A-8c

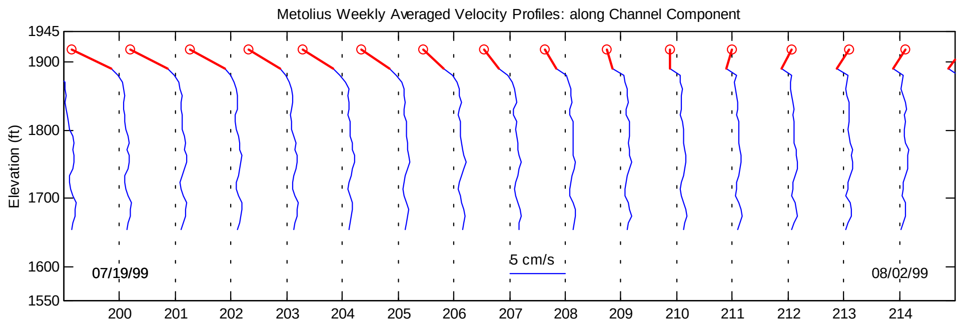
METOLIUS 7-DAY AVERAGE ADCP

Pelton Round Butte Hydroelectric Project No. 2030

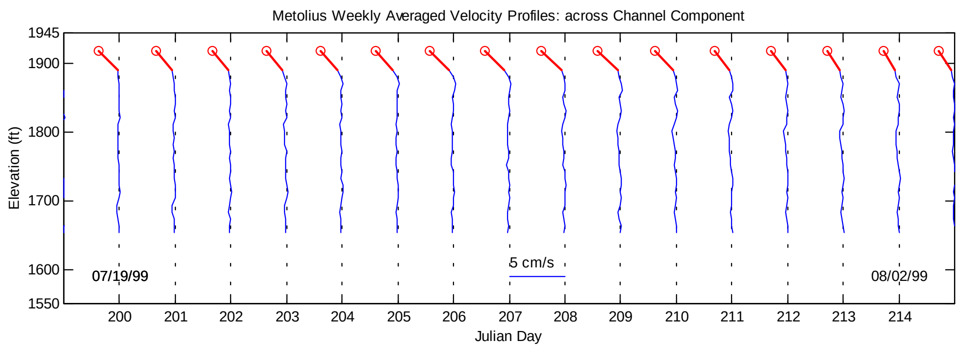
Portland General Electric Company

Portland, Oregon

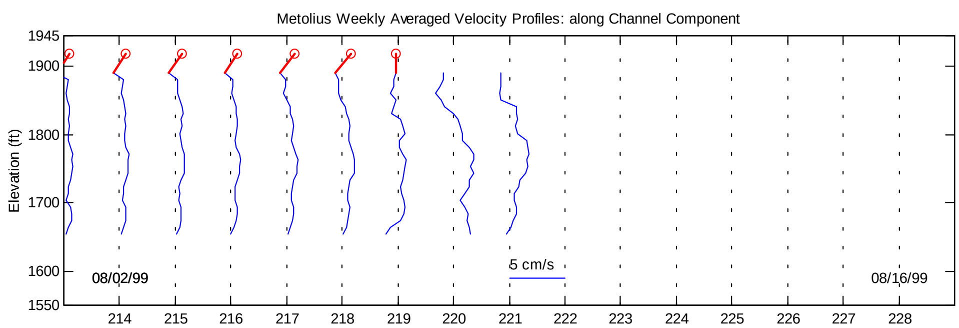
5 cm/s



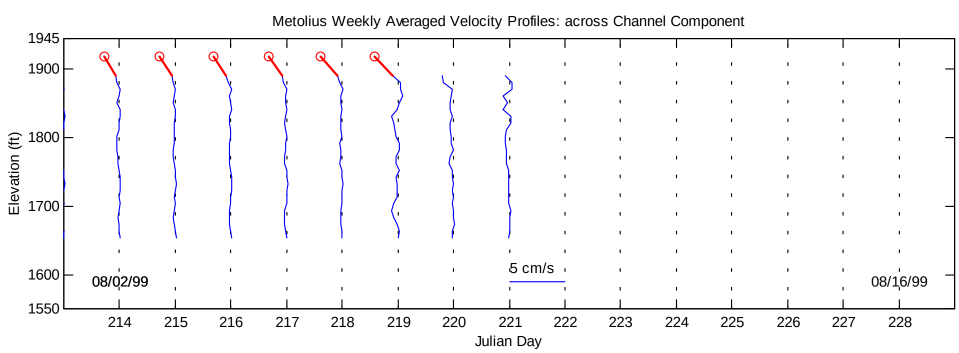
5 cm/s



5 cm/s



5 cm/s



FOSTER WHEELER ENVIRONMENTAL CORPORATION

PROJECT NO: 2200.0001.0002

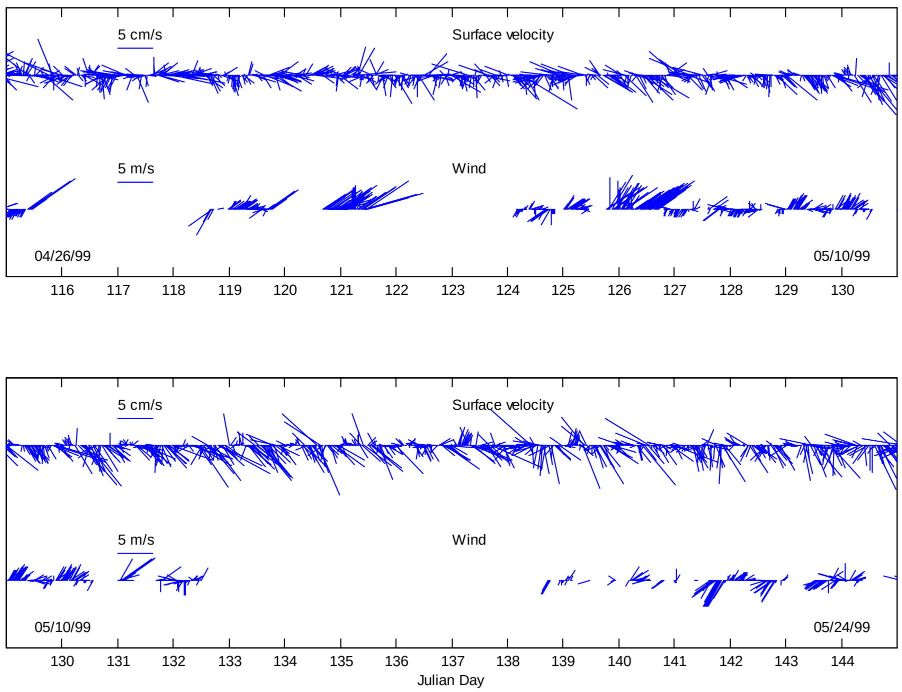
DRAWN: Z. Yang
CHECKED: T. Khangaonkar
DATE: December 22, 1999
FILENAME: pgeapp-P.doc

FIGURE A-8d

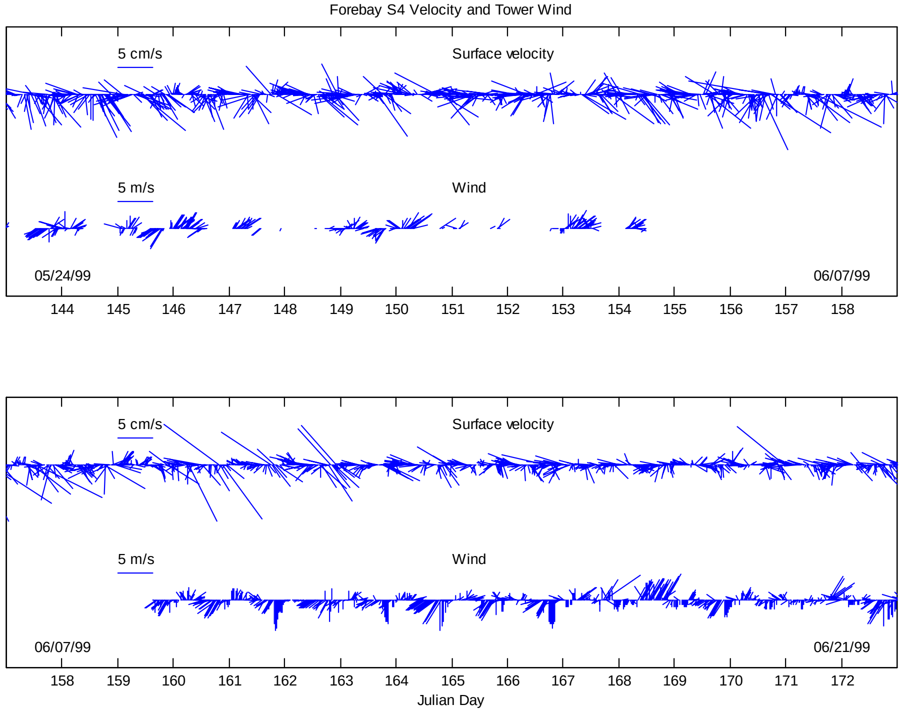
METOLIUS 7-DAY AVERAGE ADCP
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

Surface Velocities

Forebay S4 Velocity and Tower Wind



Forebay S4 Velocity and Tower Wind



Note: stick direction is towards to.

FOSTER WHEELER ENVIRONMENTAL CORPORATION

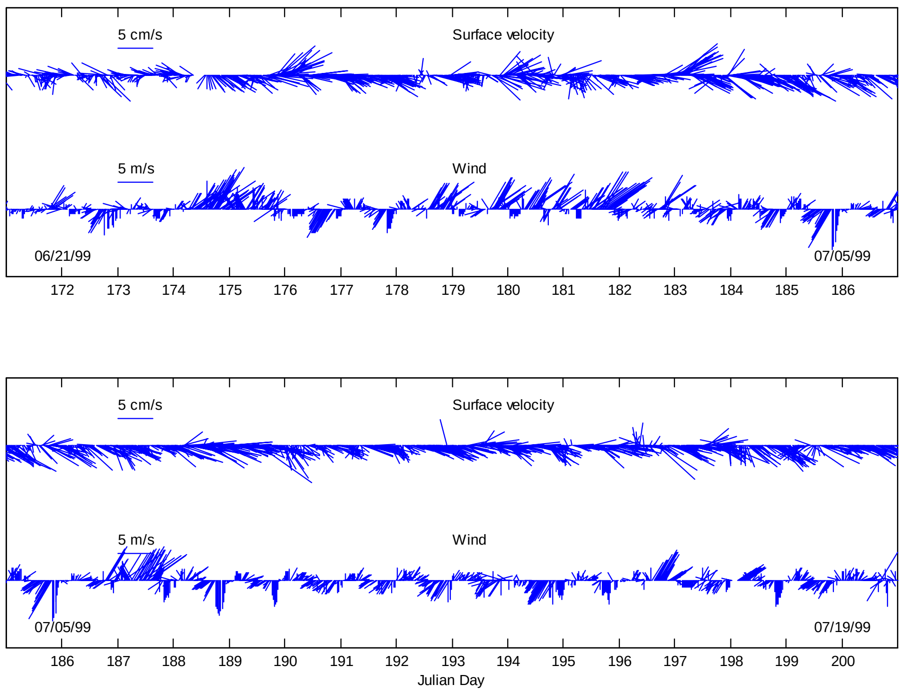
DRAWN: Z. Yang
CHECKED: T. Khangaonkar
DATE: December 15, 1999
PROJECT NO: 2200.0001.0002
FILENAME: pgeapp-P.doc

FIGURE A-9a

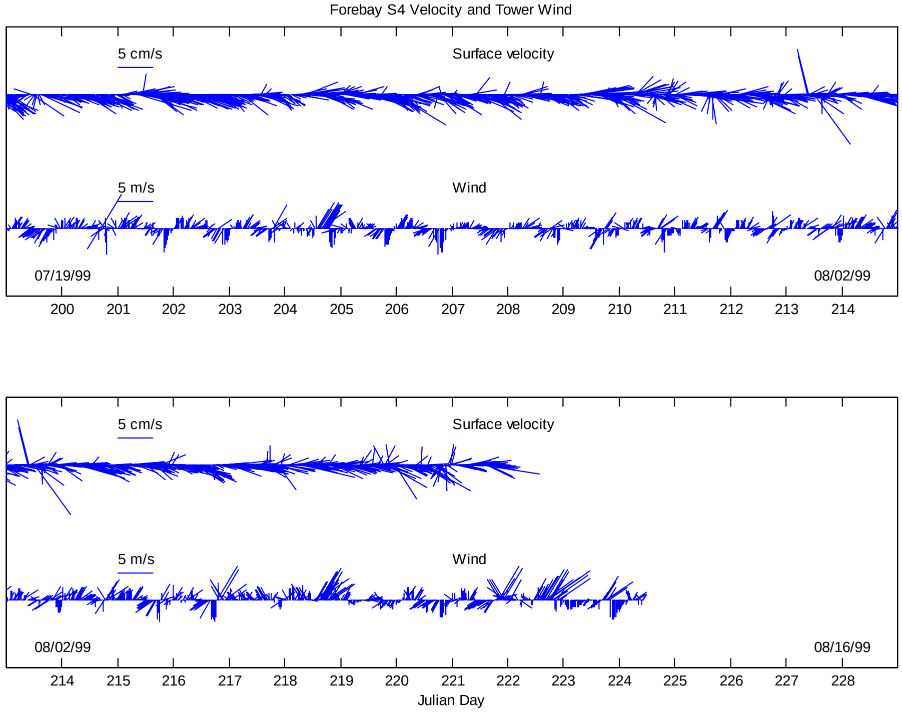
FOREBAY S4 AND WIND STICKS

Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

Forebay S4 Velocity and Tower Wind



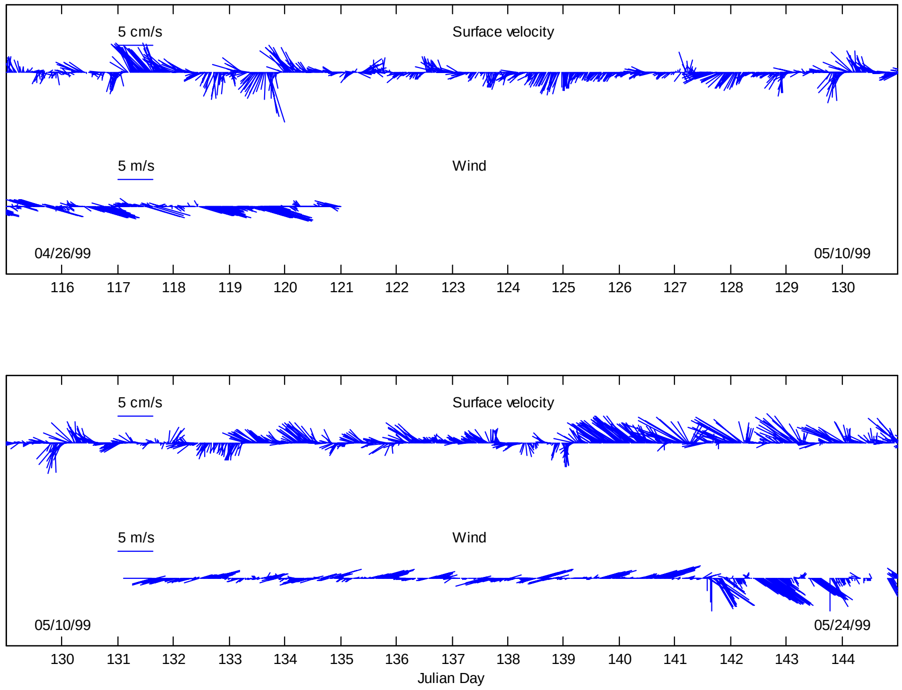
Forebay S4 Velocity and Tower Wind



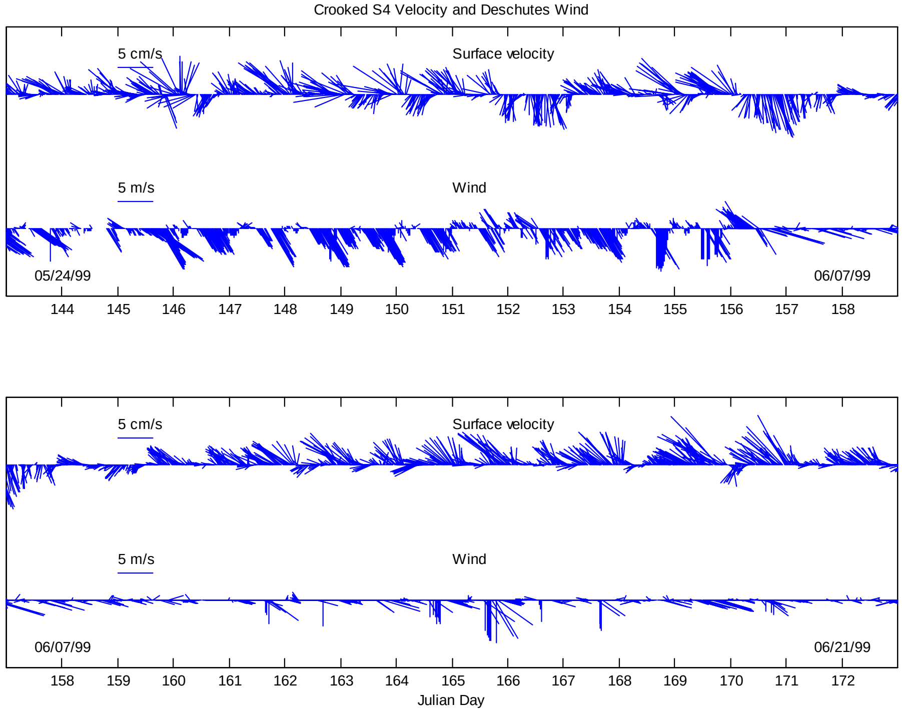
Note: stick direction is towards to.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-9b** FOREBAY S4 AND WIND STICKS Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

Crooked S4 Velocity and Deschutes Wind

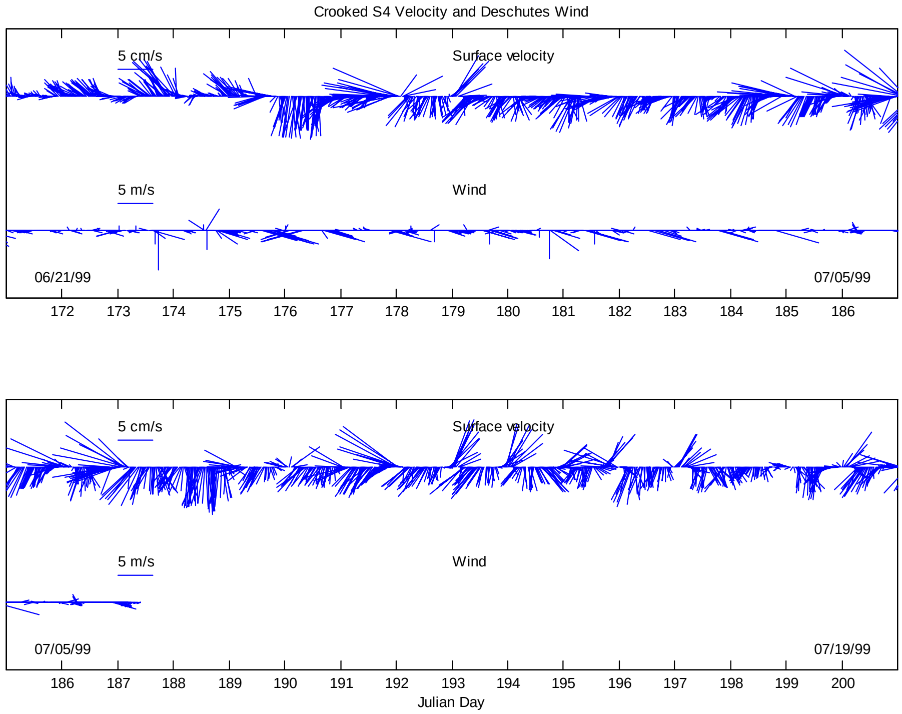


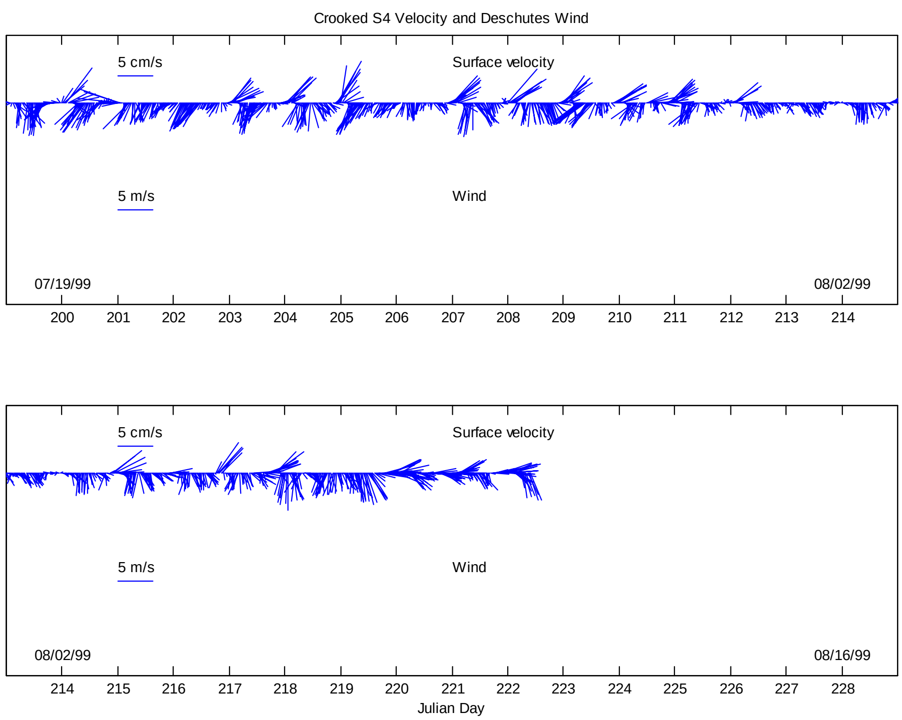
Crooked S4 Velocity and Deschutes Wind



Note: stick direction is towards to.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-11a** CROOKED S4 AND WIND STICKS Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	





Note: stick direction is towards to.

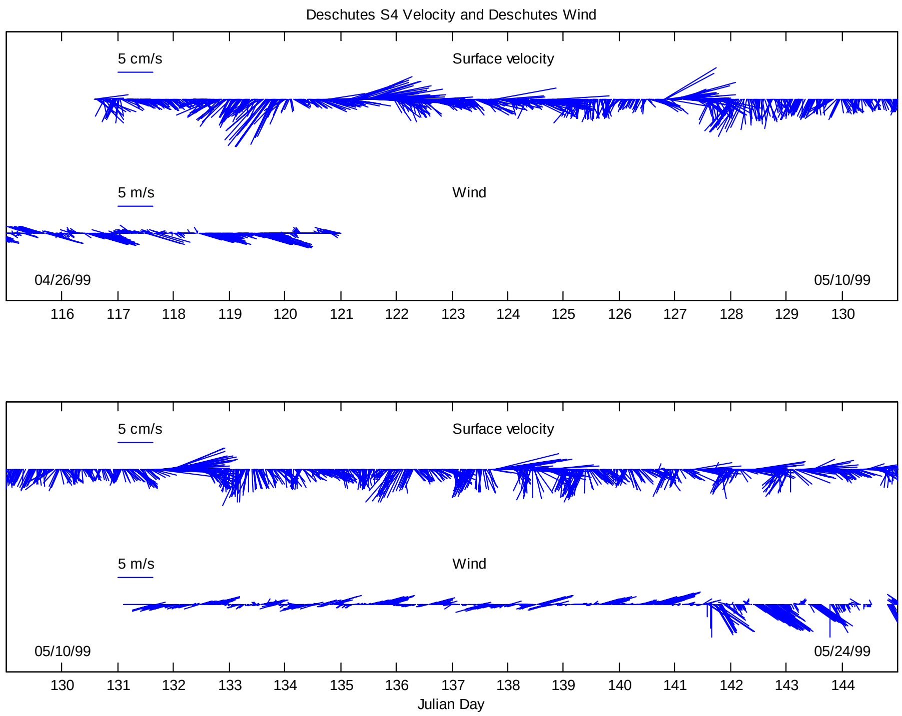
FOSTER WHEELER
ENVIRONMENTAL CORPORATION

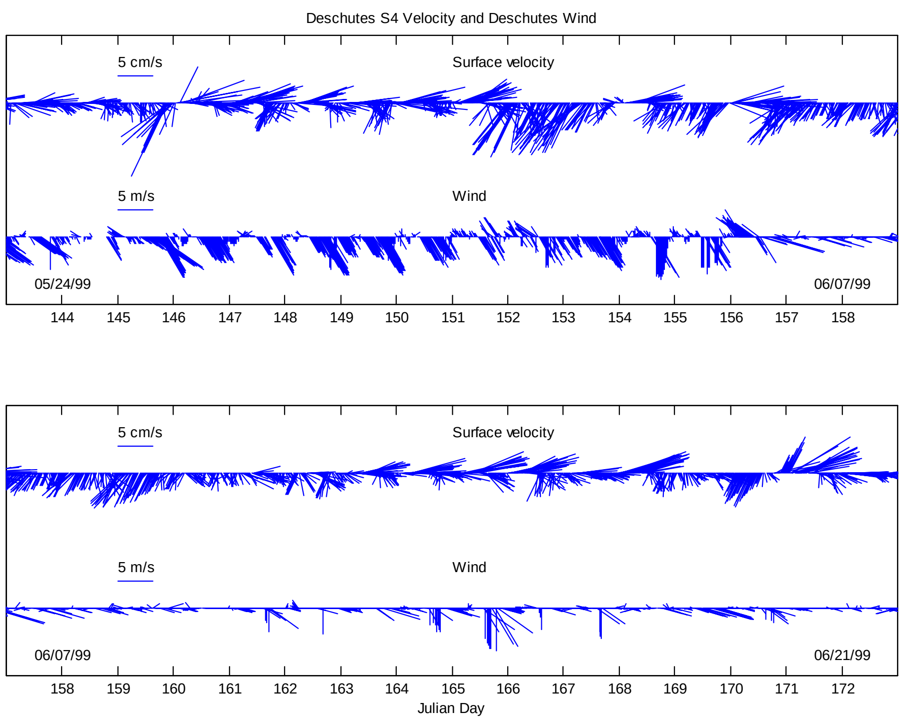
DRAWN: Z. Yang
CHECKED: T. Khangaonkar
DATE: December 15, 1999
PROJECT NO: 2200.0001.0002
FILENAME: pgeapp-P.doc

FIGURE A-11b

CROOKED S4 AND WIND STICKS

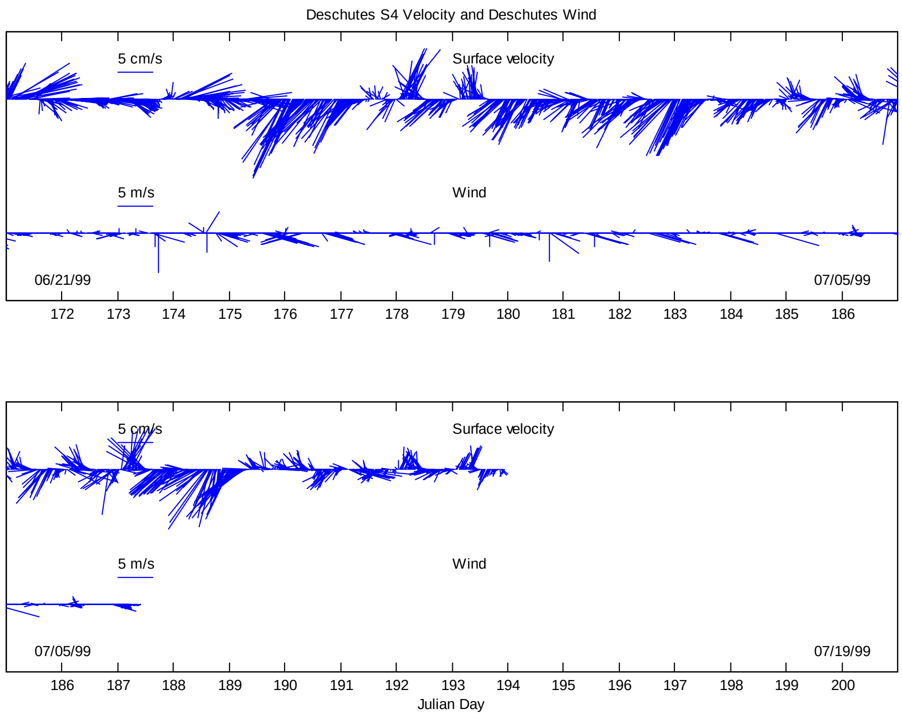
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon





Note: stick direction is towards to.

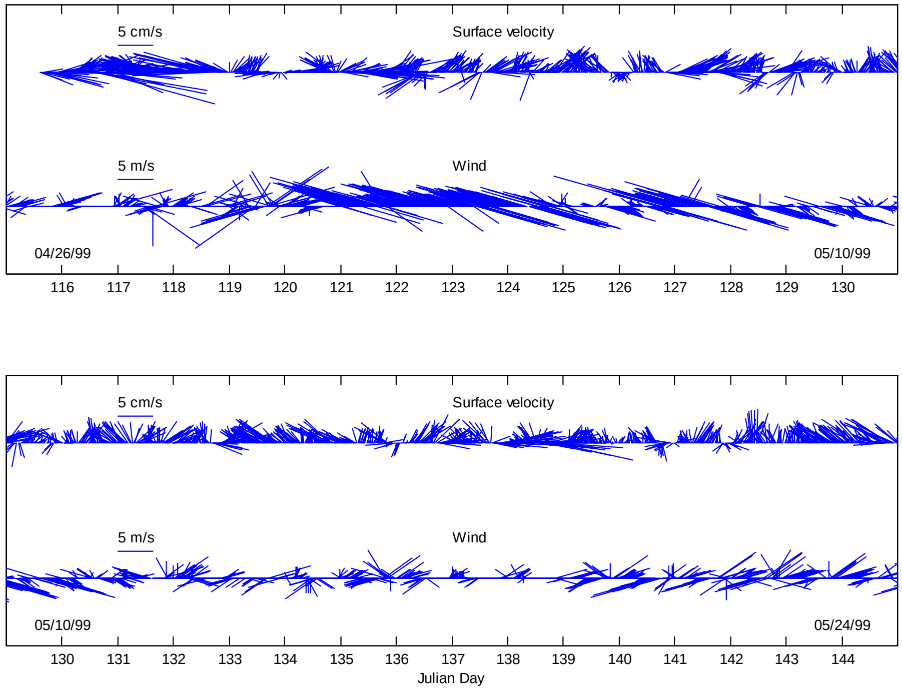
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-10a**
	CHECKED: T. Khangaonkar	DESCHUTES S4 AND WIND STICKS
	DATE: December 15, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



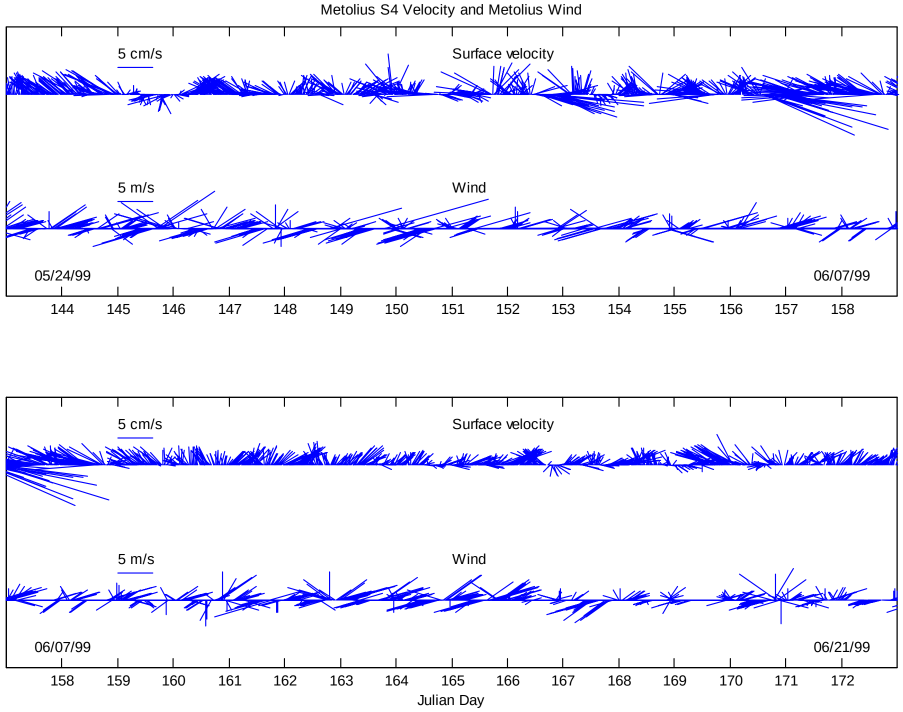
Note: stick direction is towards to.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-10b**
	CHECKED: T. Khangaonkar	DESCHUTES S4 AND WIND STICKS
	DATE: December 15, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

Metolius S4 Velocity and Metolius Wind



Metolius S4 Velocity and Metolius Wind



Note: stick direction is towards to.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 15, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

FIGURE A-12a

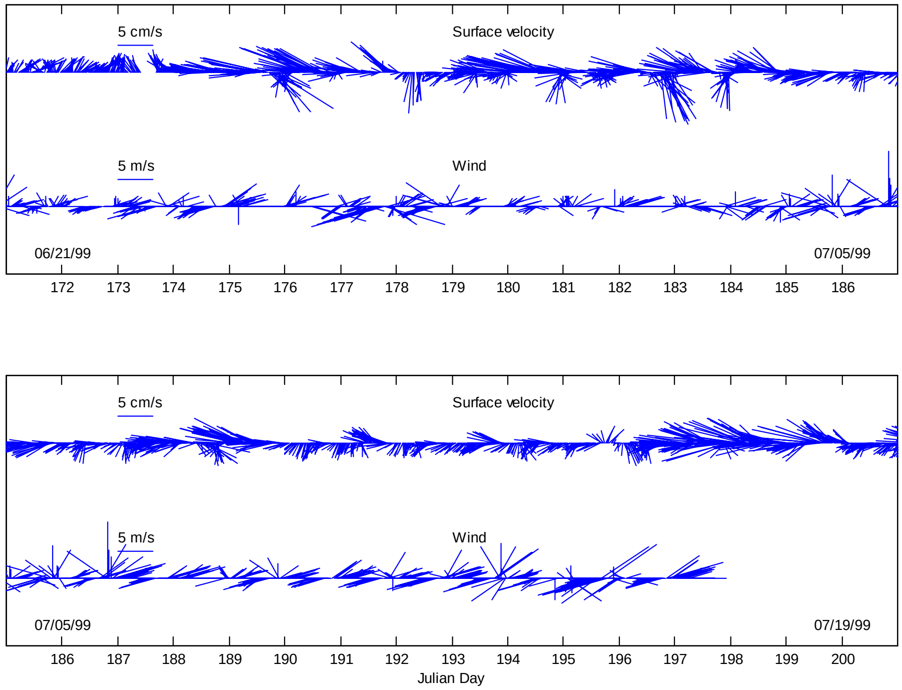
METOLIUS S4 AND WIND STICKS

Pelton Round Butte Hydroelectric Project No. 2030

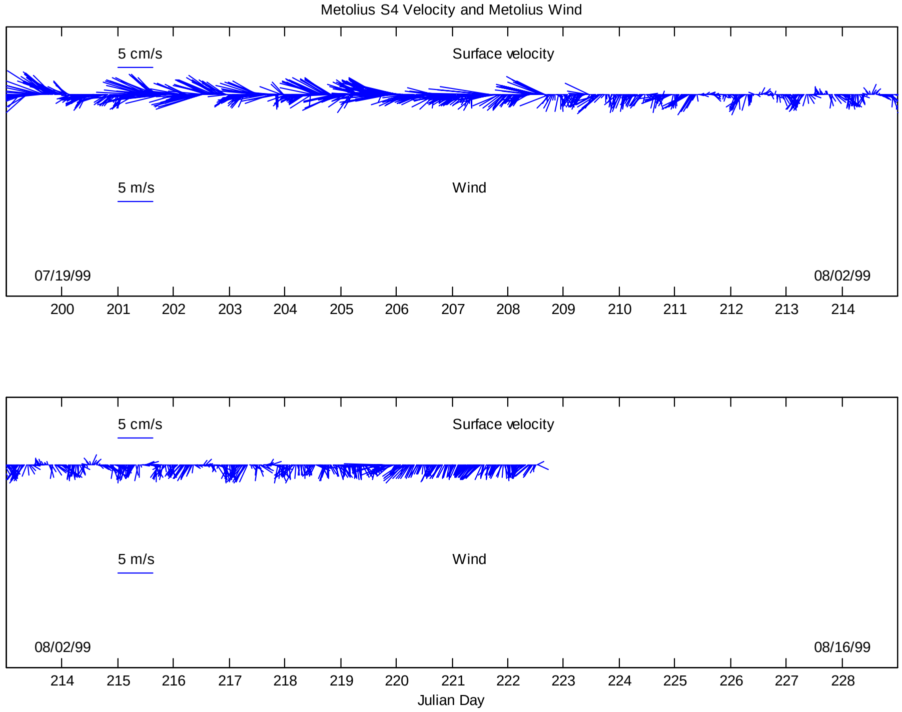
Portland General Electric Company

Portland, Oregon

Metolius S4 Velocity and Metolius Wind



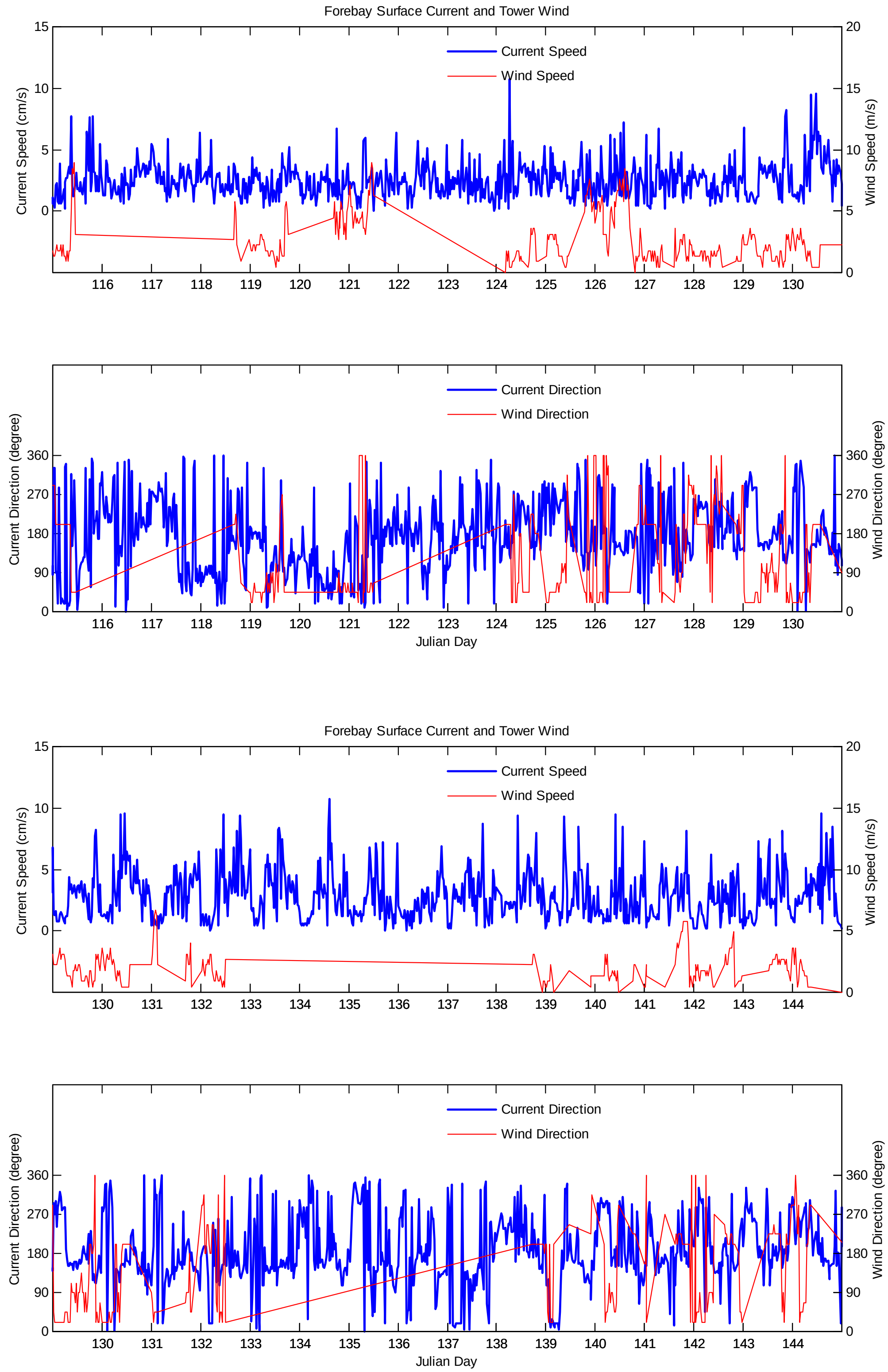
Metolius S4 Velocity and Metolius Wind



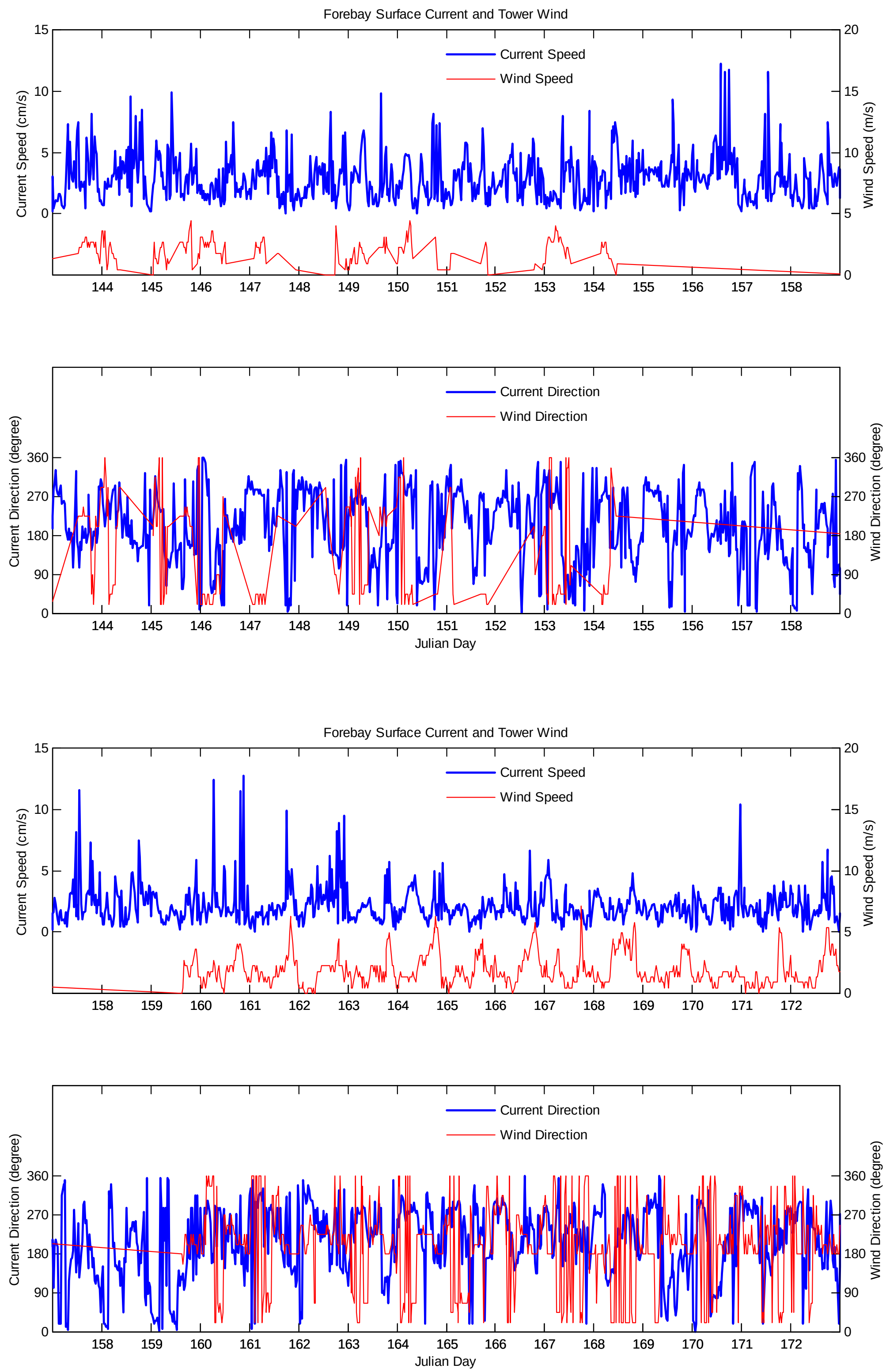
Note: stick direction is towards to.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-12b** METOLIUS S4 AND WIND STICKS Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

Velocity and Temperature Profiles



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-13a** FOREBAY S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



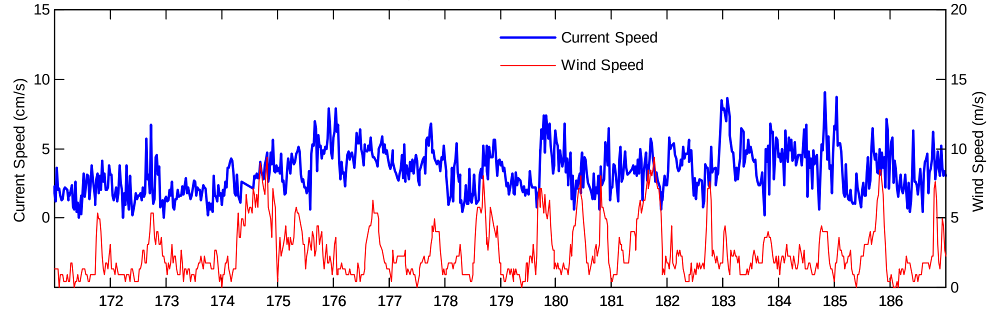
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 15, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

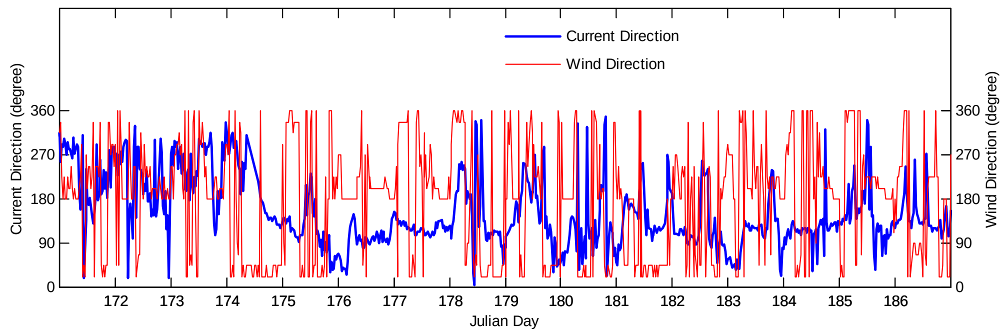
FIGURE A-13b

FOREBAY S4 AND WIND DATA

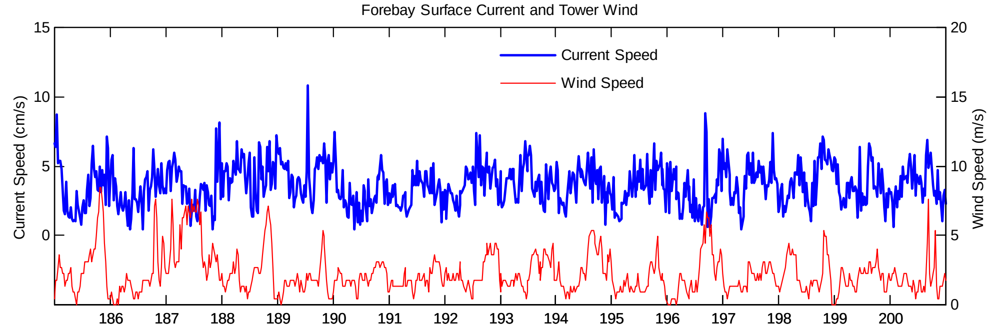
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

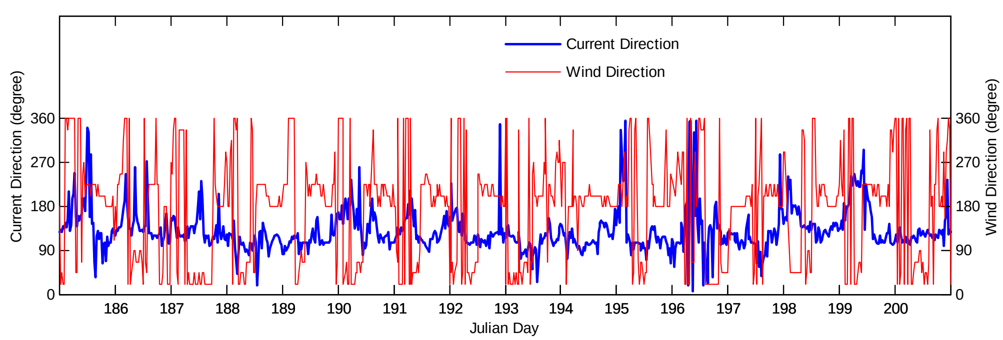
Forebay Surface Current and Tower Wind



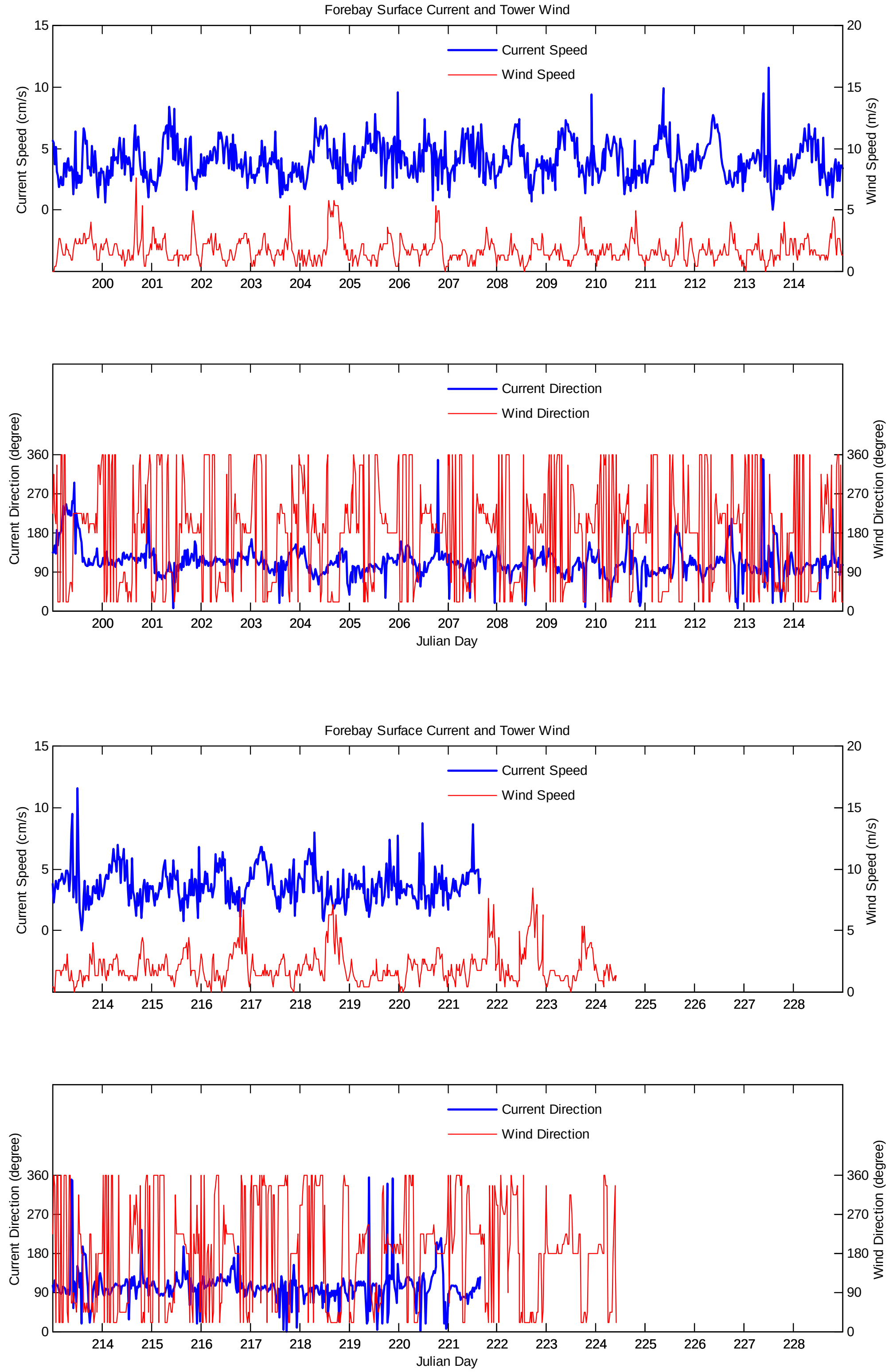


Forebay Surface Current and Tower Wind

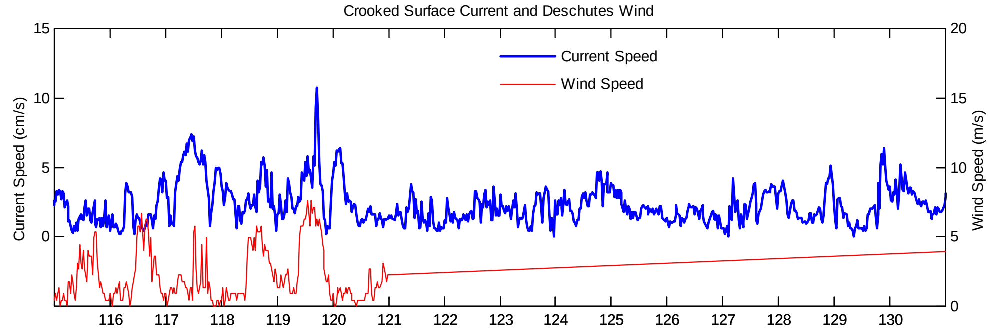


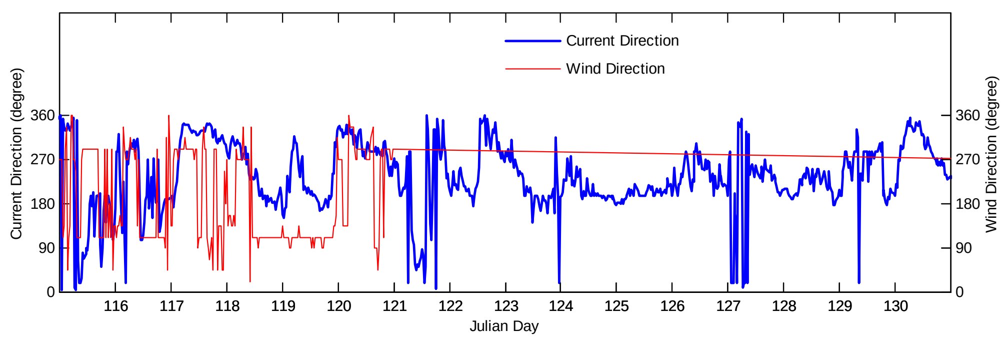


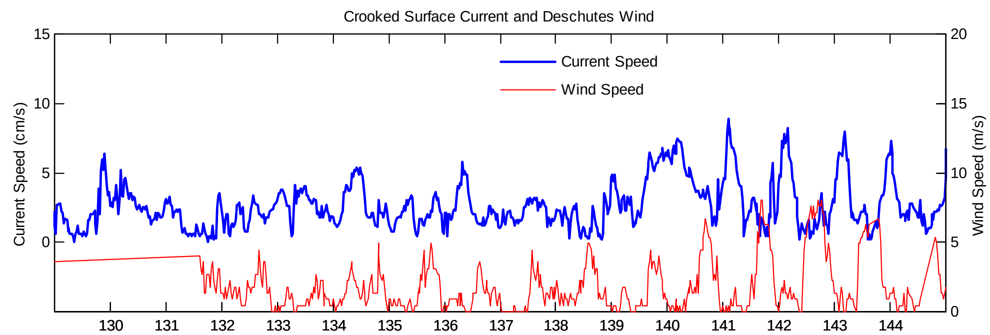
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-13c** FOREBAY S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pqeapp-P.doc	

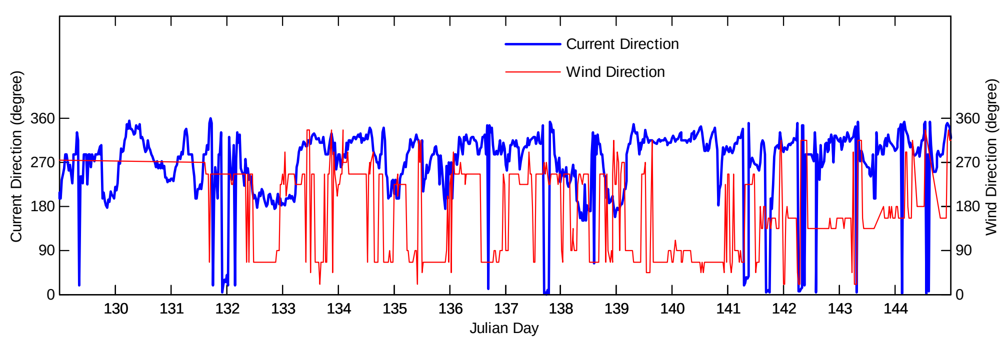


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-13d** FOREBAY S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



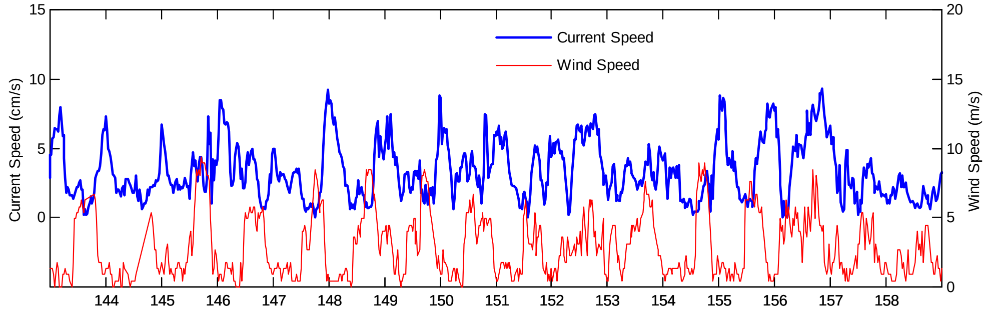


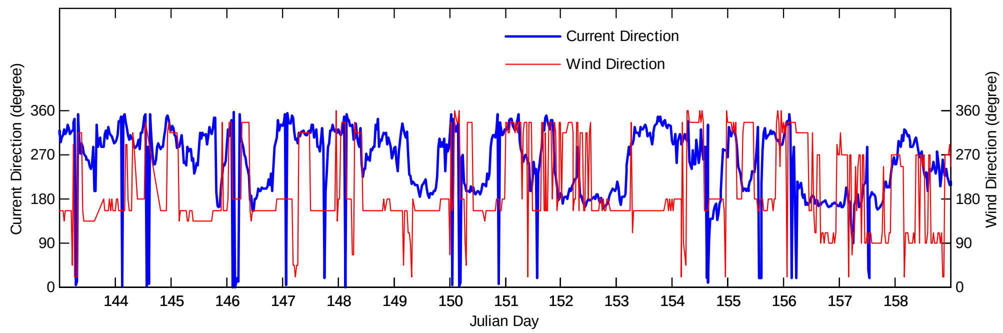




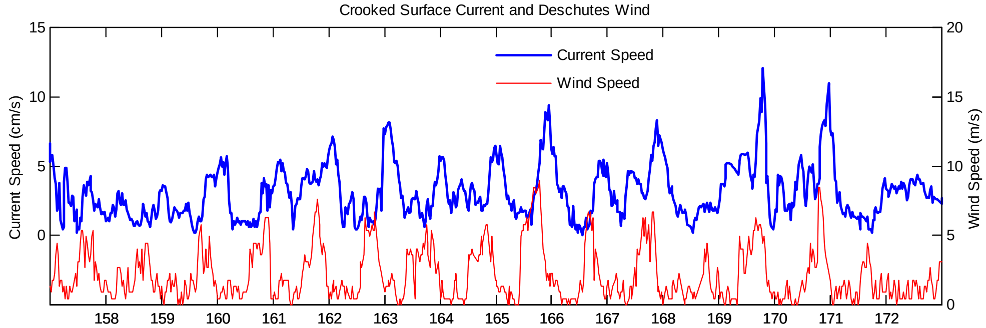
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-15a** CROOKED S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

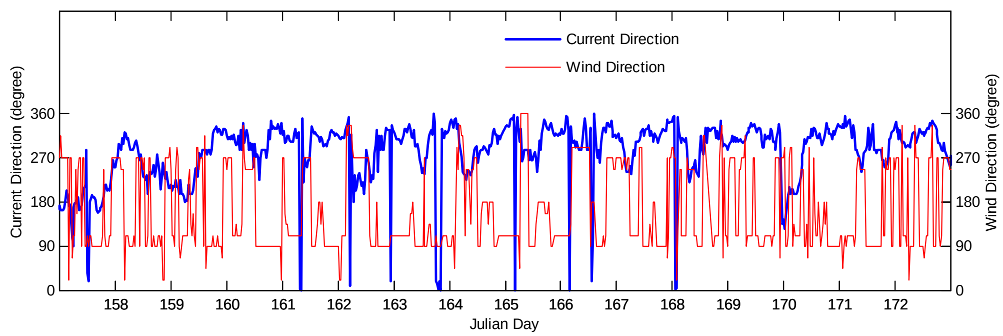
Crooked Surface Current and Deschutes Wind





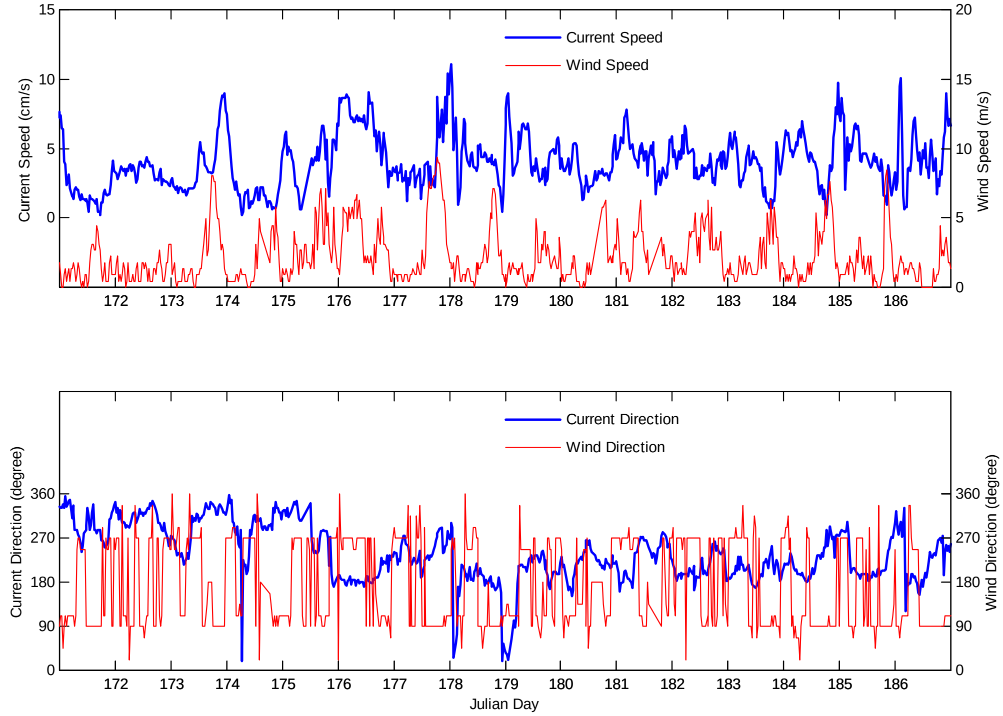
Crooked Surface Current and Deschutes Wind



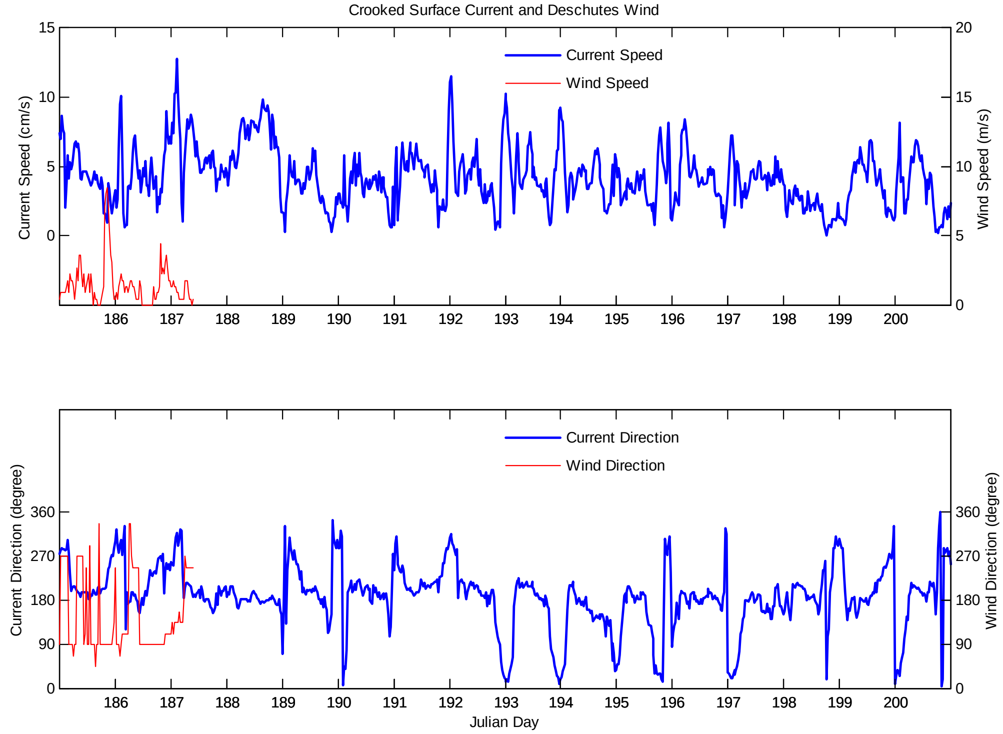


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-15b** CROOKED S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

Crooked Surface Current and Deschutes Wind



Crooked Surface Current and Deschutes Wind



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 15, 1999

PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

FIGURE A-15c

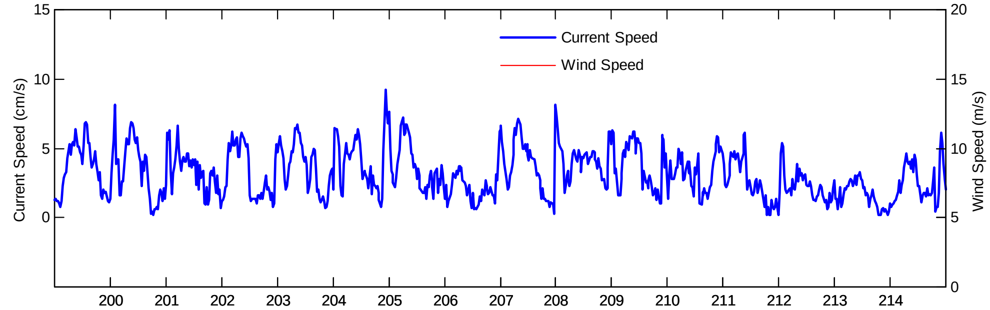
CROOKED S4 AND WIND DATA

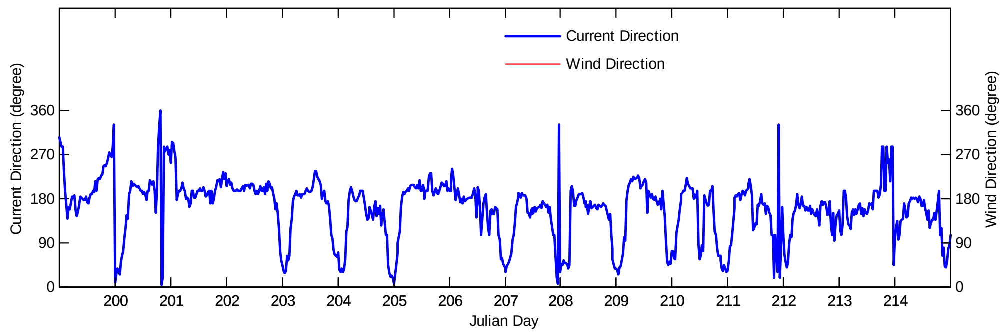
Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

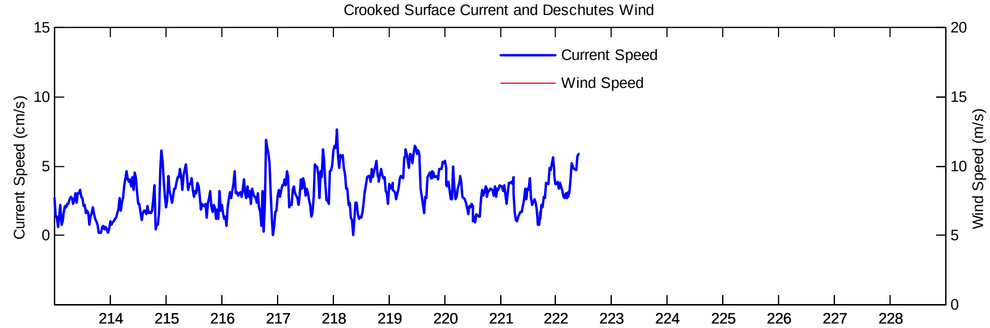
Portland, Oregon

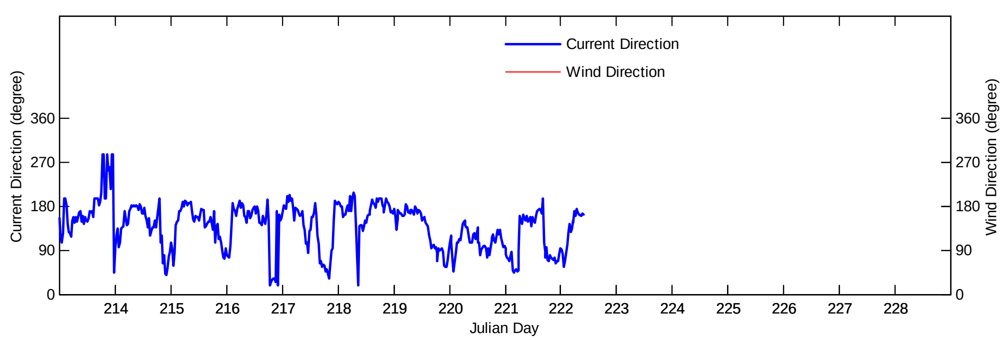
Crooked Surface Current and Deschutes Wind



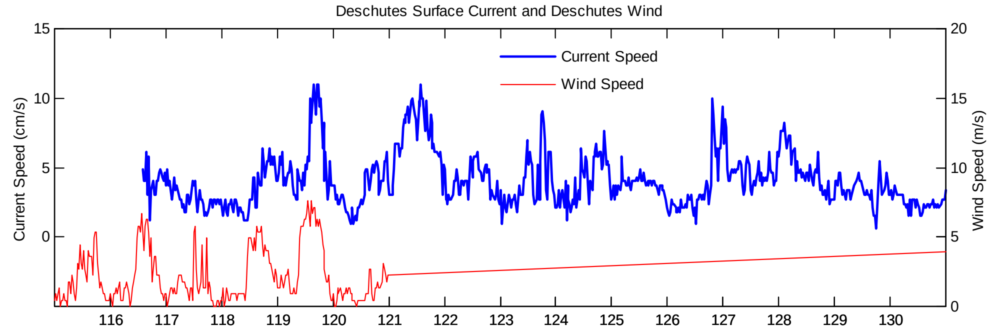


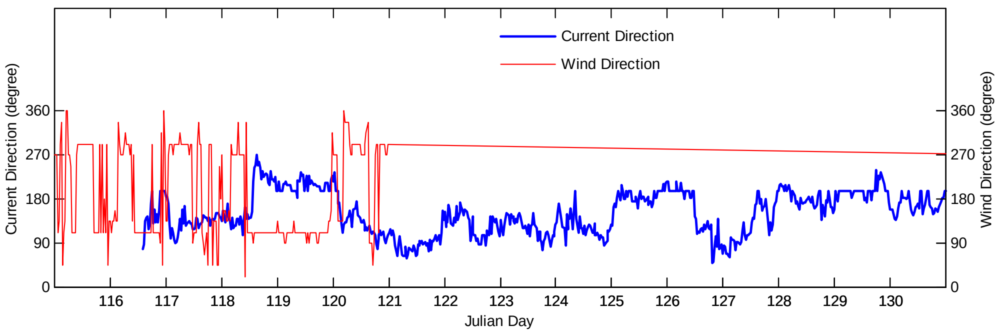
Crooked Surface Current and Deschutes Wind

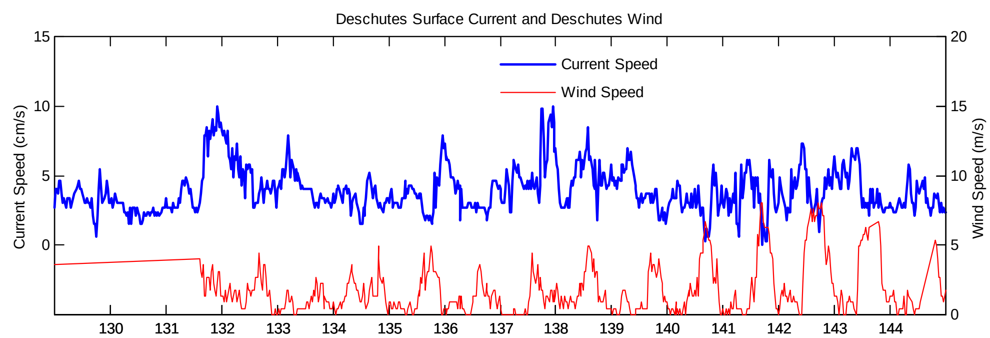


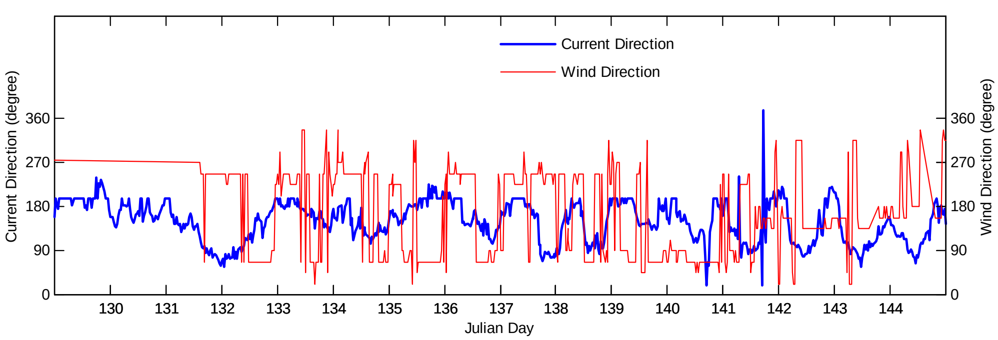


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-15d**
	CHECKED: T. Khangaonkar	CROOKED S4 AND WIND DATA
	DATE: December 15, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	









FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang
	CHECKED: T. Khangaonkar
	DATE: December 15, 1999
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc

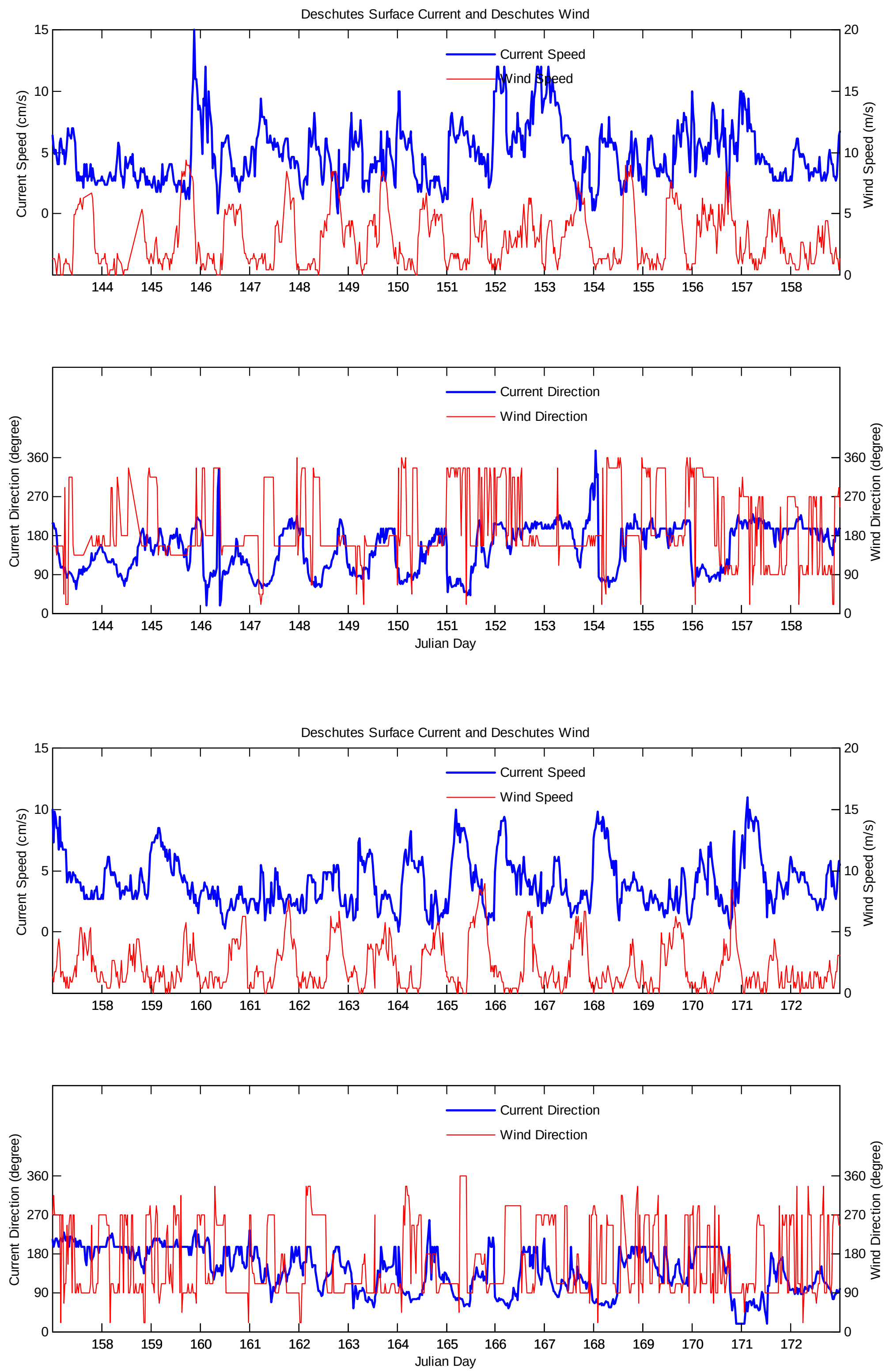
FIGURE A-14a

DESCHUTES S4 AND WIND DATA

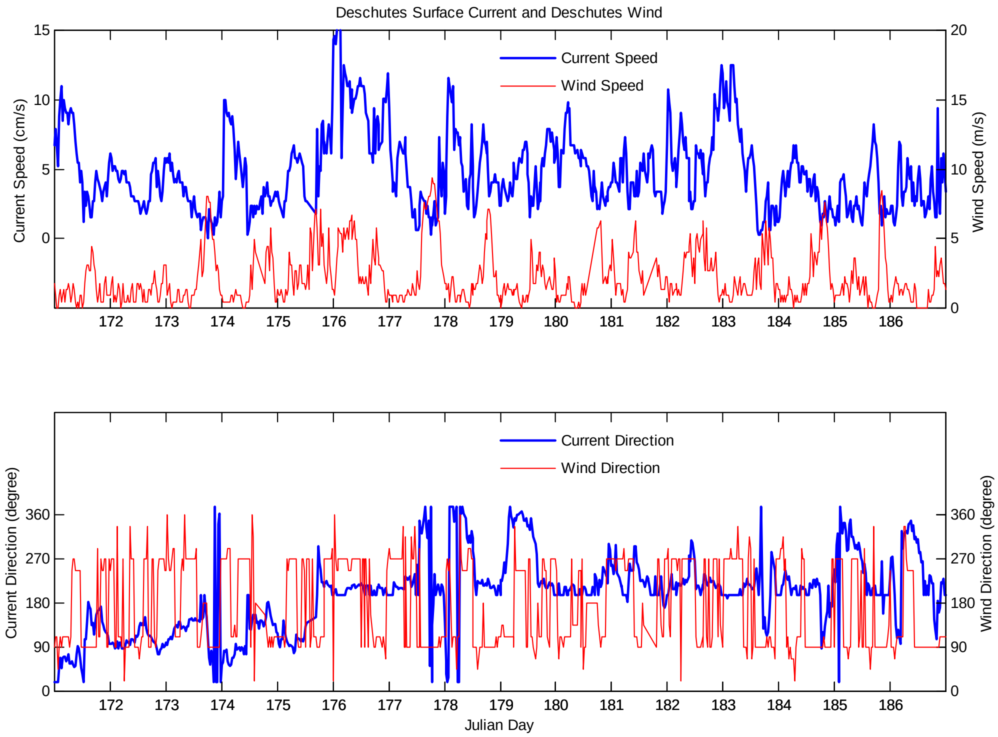
Pelton Round Butte Hydroelectric Project No. 2030

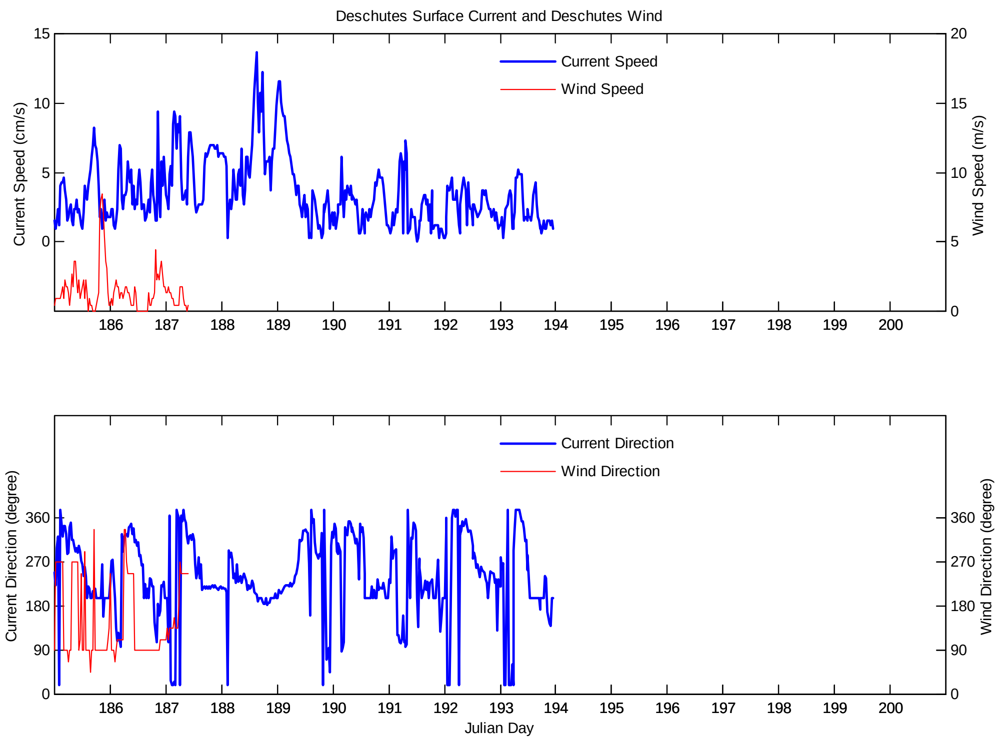
Portland General Electric Company

Portland, Oregon

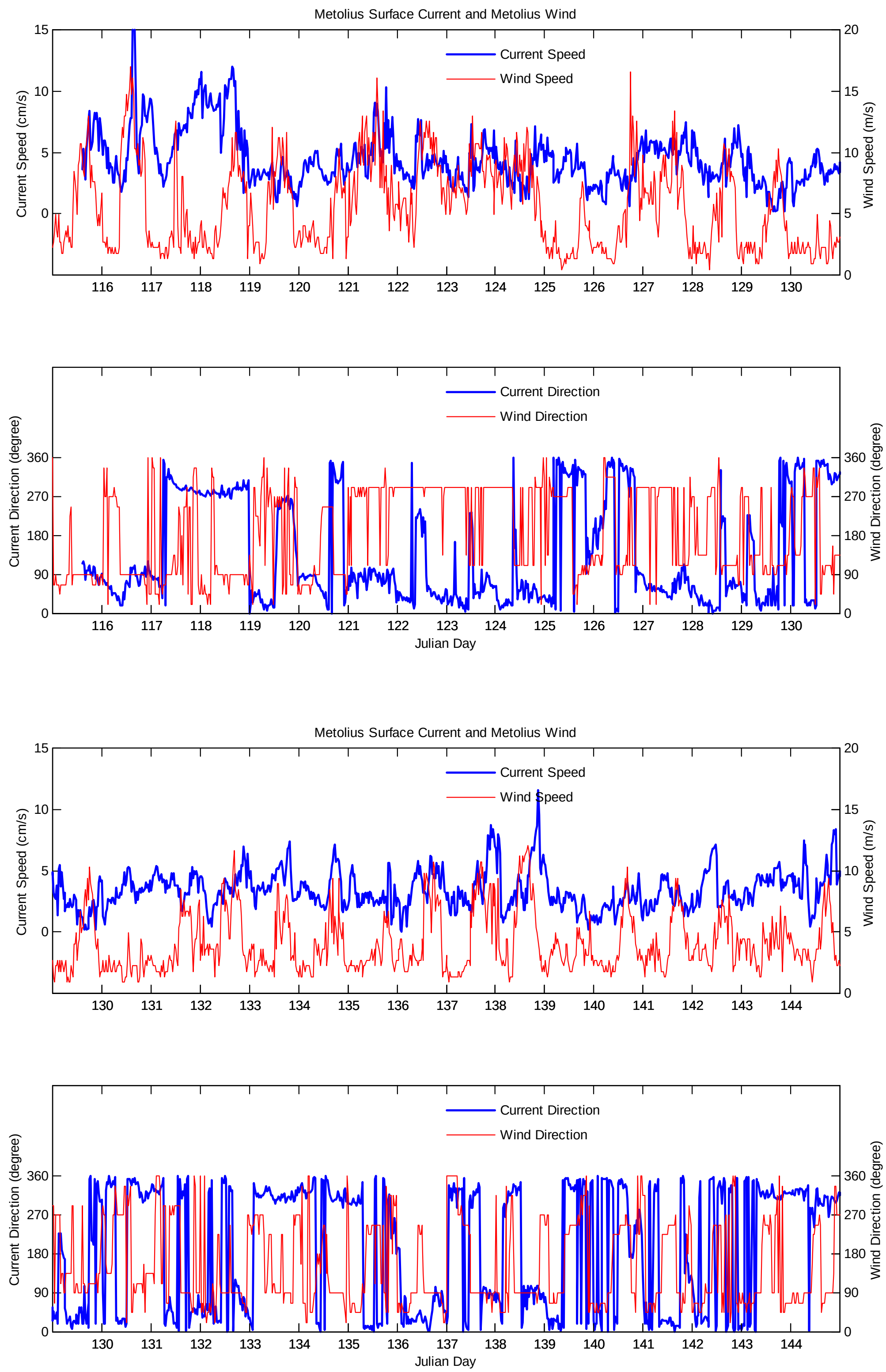


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-14b** DESCHUTES S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	





FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-14c** DESCHUTES S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 15, 1999

PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

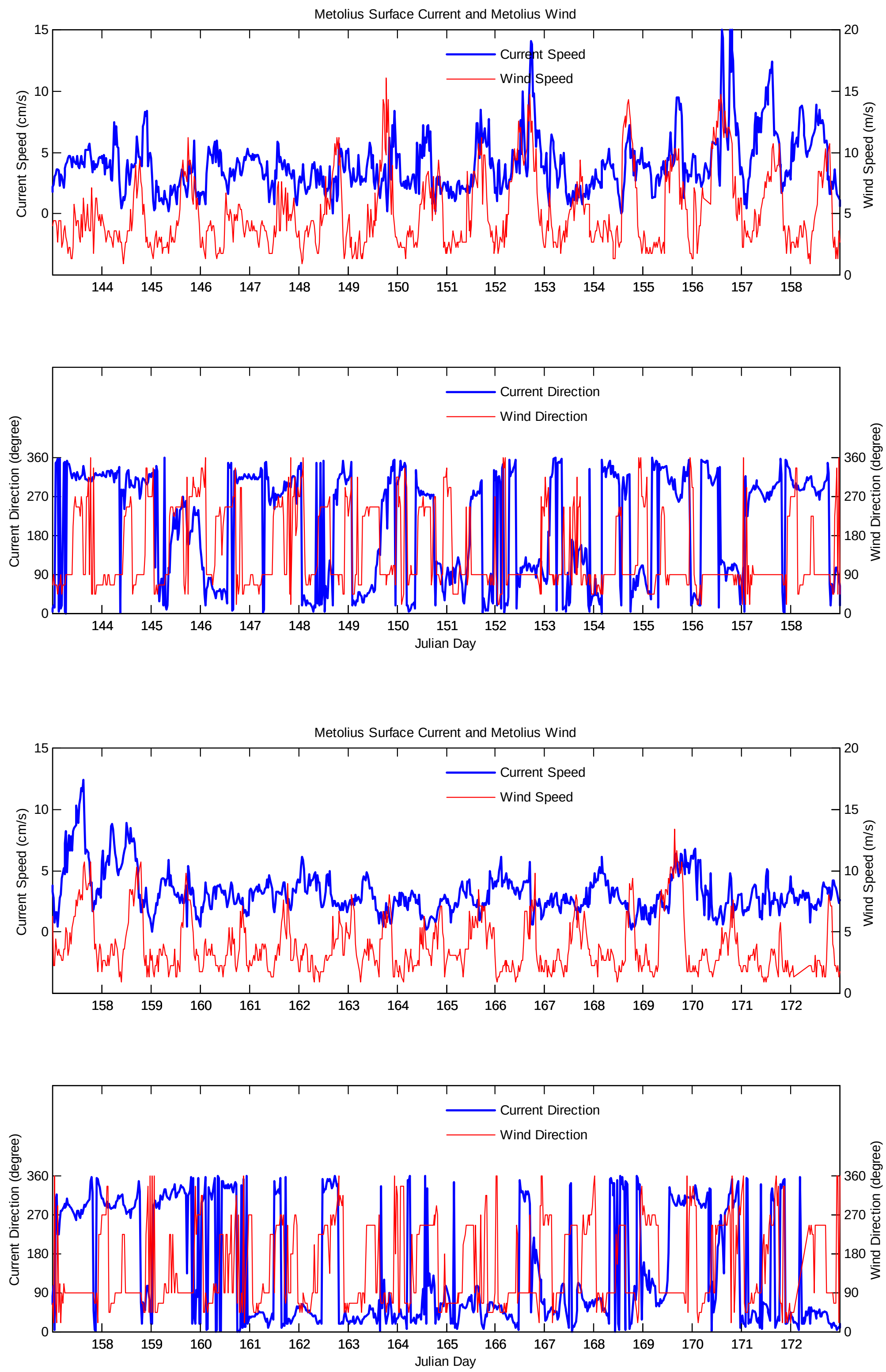
FIGURE A-16a

METOLIUS S4 AND WIND DATA

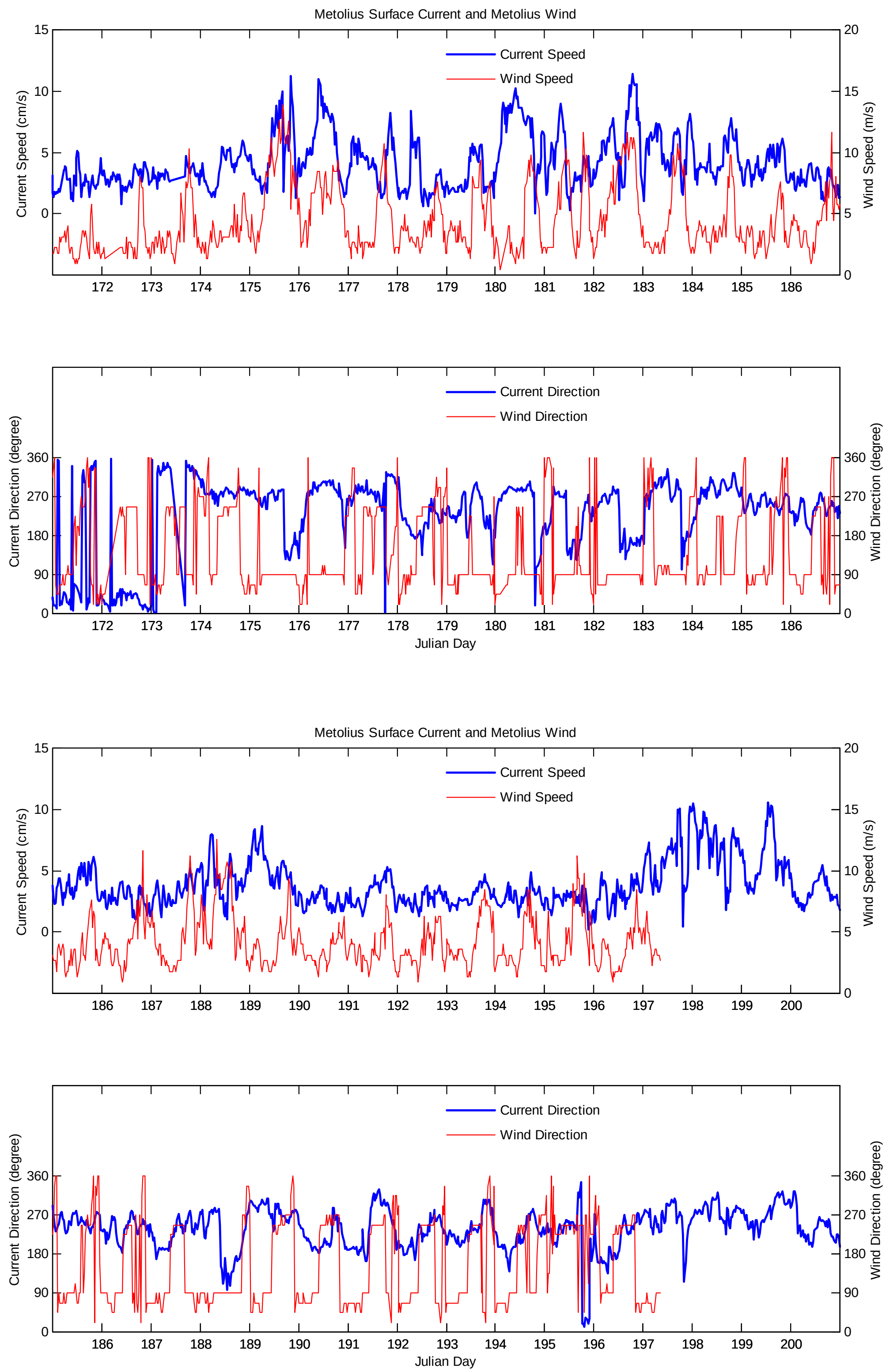
Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

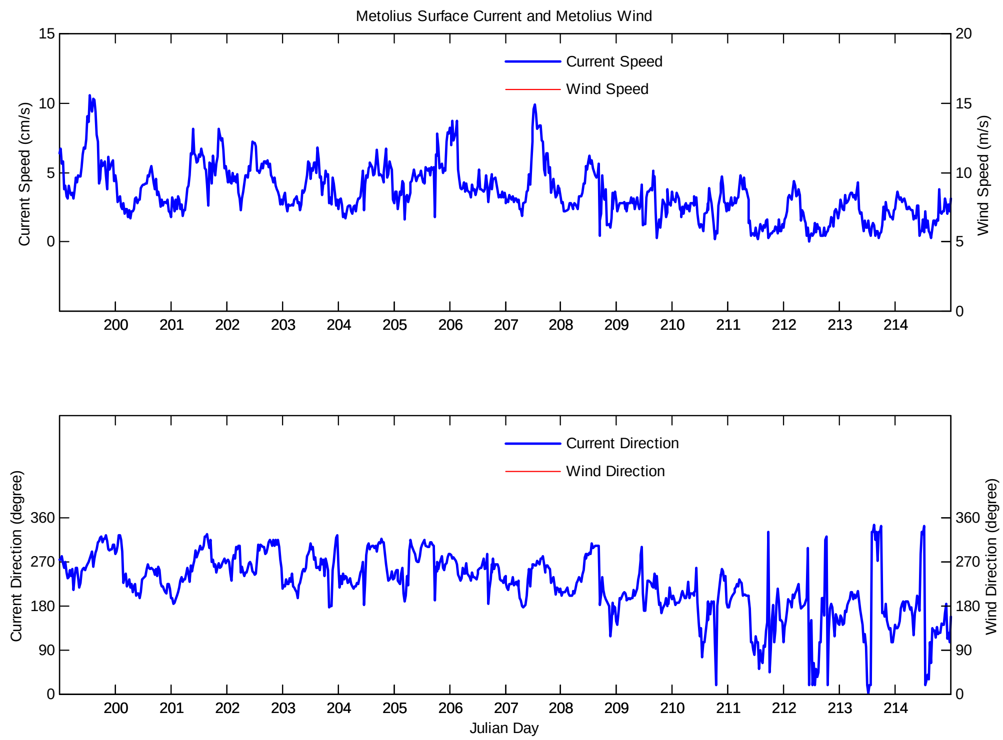
Portland, Oregon

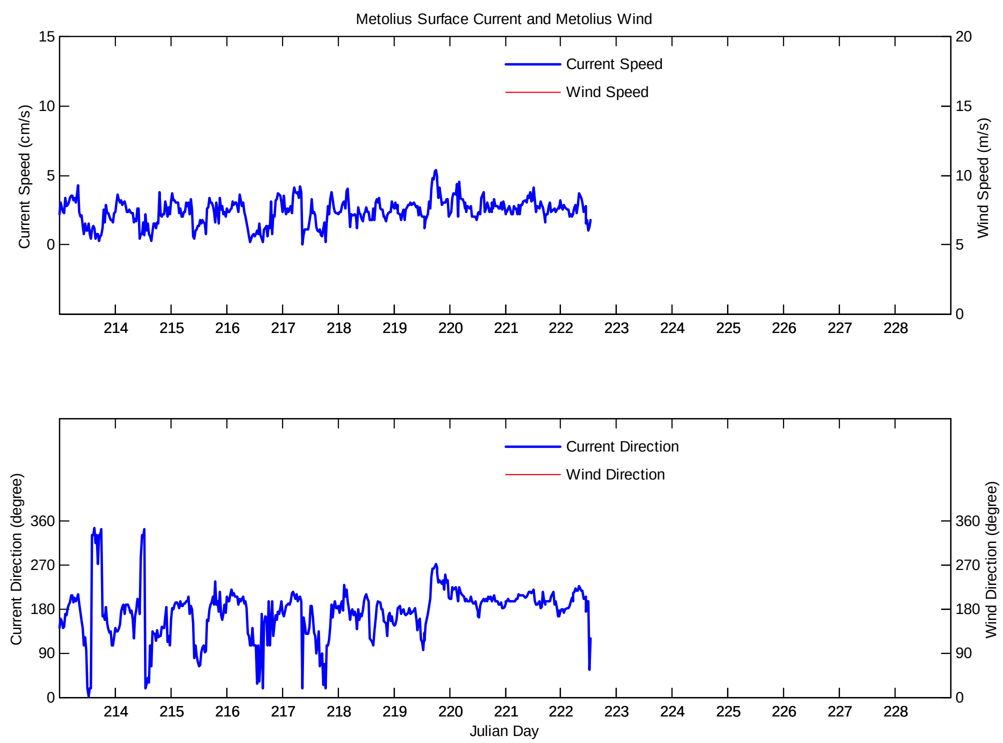


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-16b** METOLIUS S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



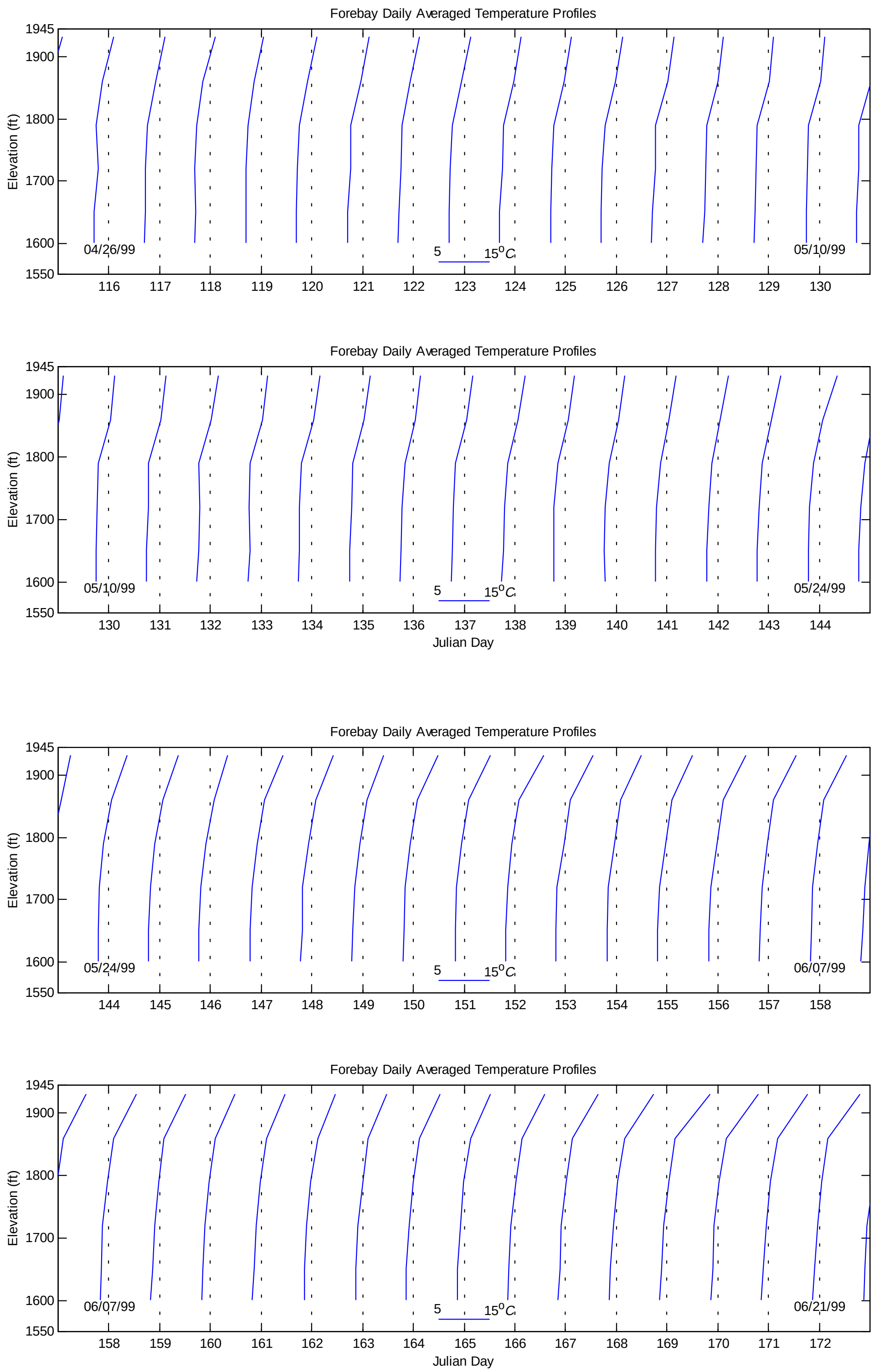
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-16c** METOLIUS S4 AND WIND DATA Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



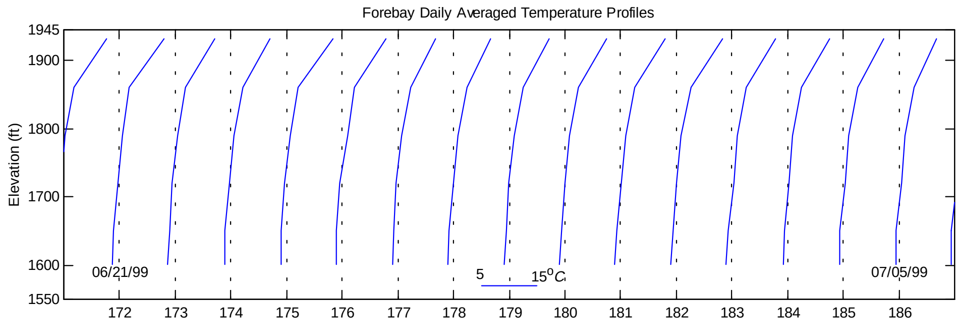


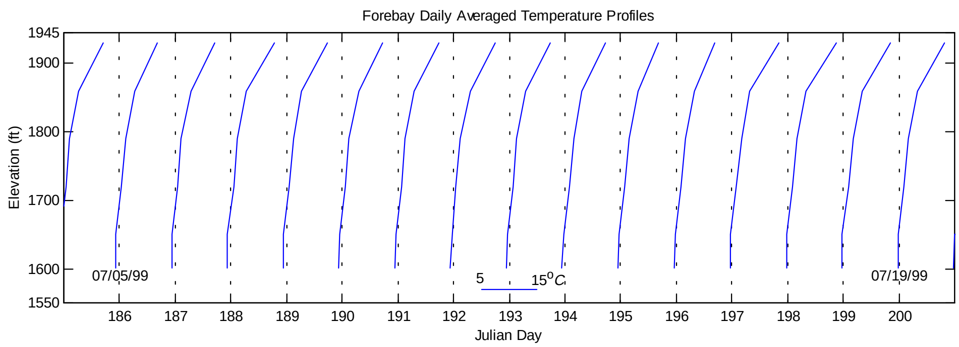
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-16d**
	CHECKED: T. Khangaonkar	METOLIUS S4 AND WIND DATA
	DATE: December 15, 1999	Pelton Round Butte Hydroelectric Project No. 2030
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	Portland General Electric Company Portland, Oregon

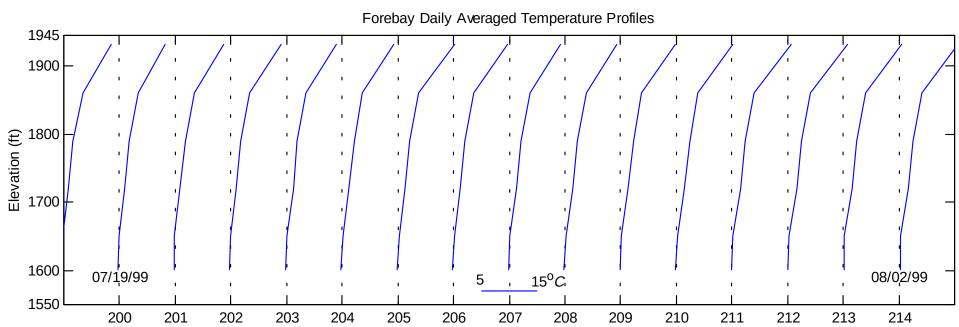
Temperature Profiles

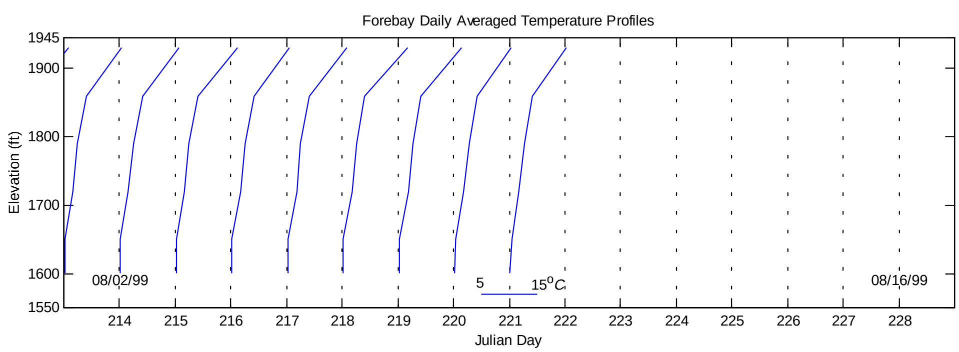


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-17a** FOREBAY TEMPERATURE PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

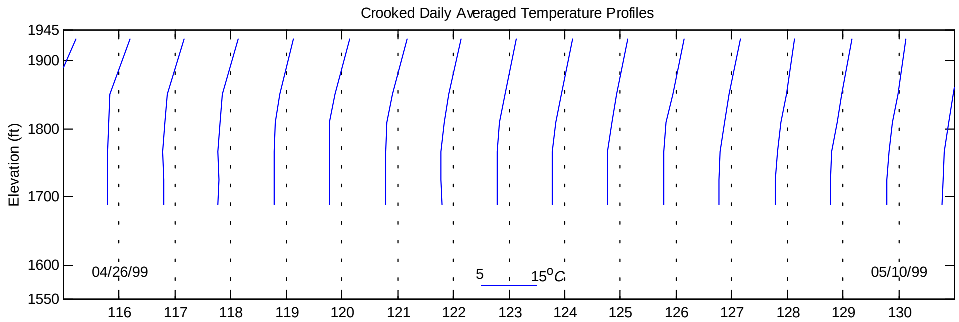


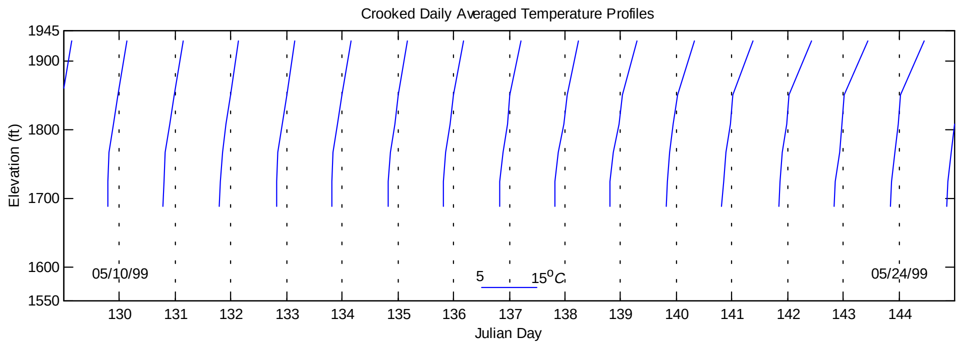


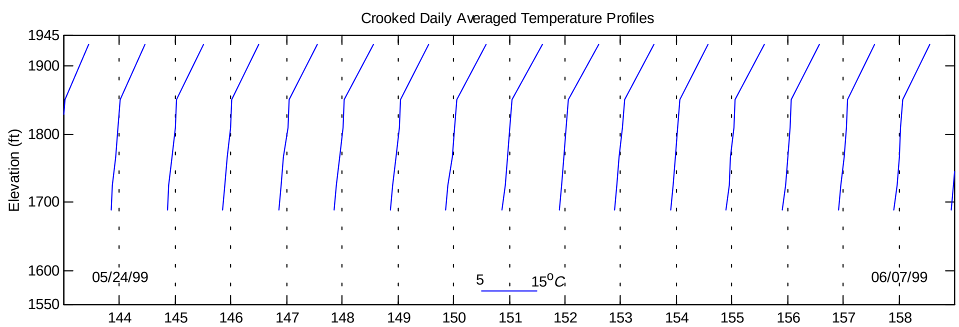


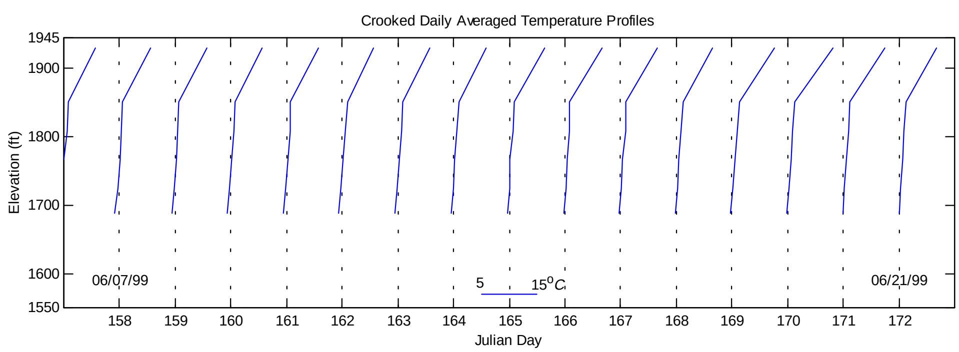


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-17b** FOREBAY TEMPERATURE PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	









FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 15, 1999

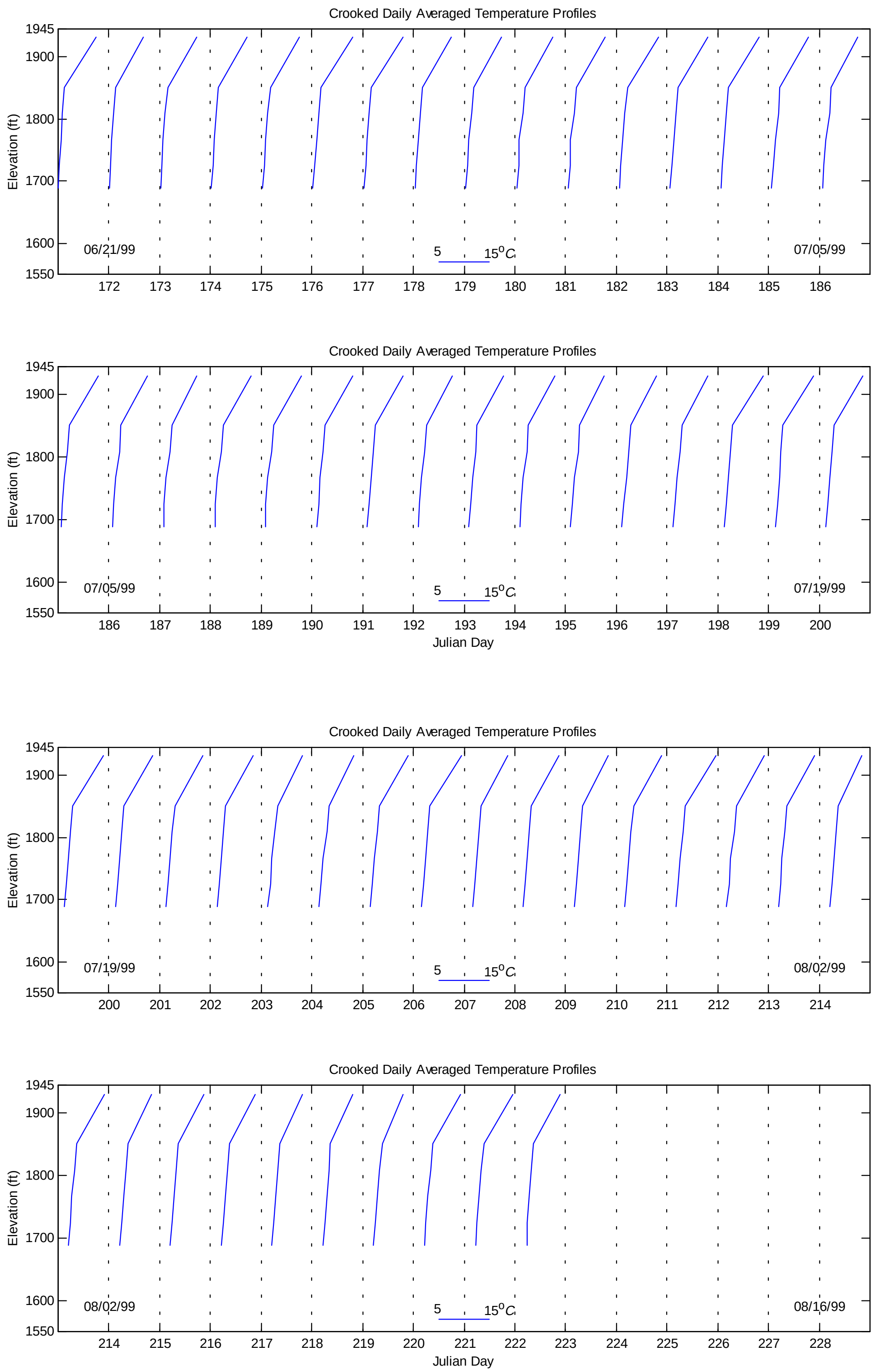
PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

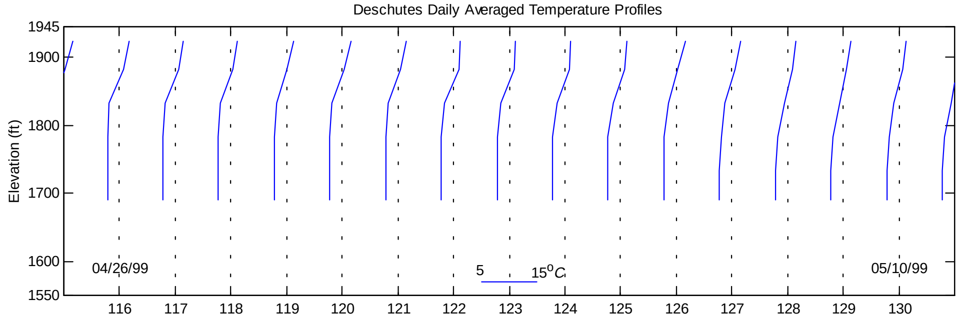
FIGURE A-19a

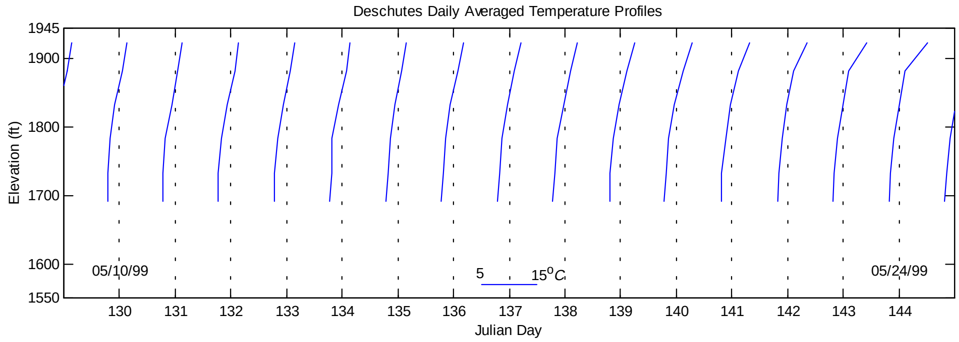
CROOKED TEMPERATURE PROFILES

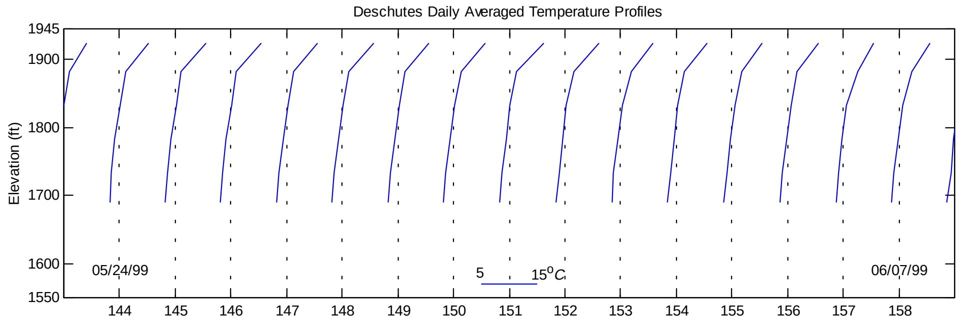
Pelton Round Butte Hydroelectric Project No. 2030
Portland General Electric Company
Portland, Oregon

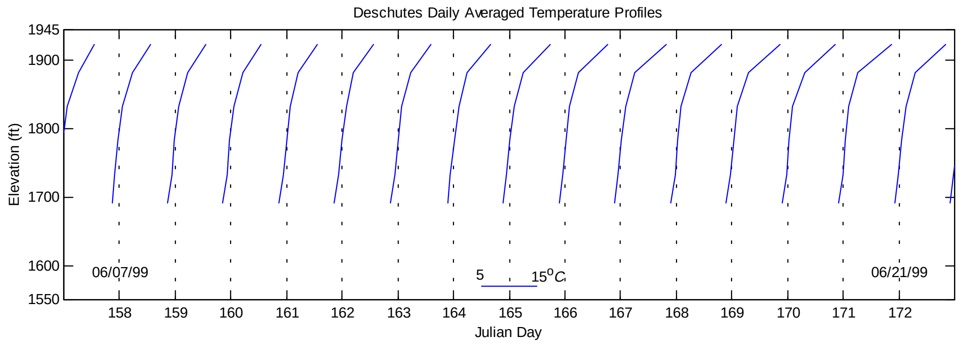


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-19b** CROOKED TEMPERATURE PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	

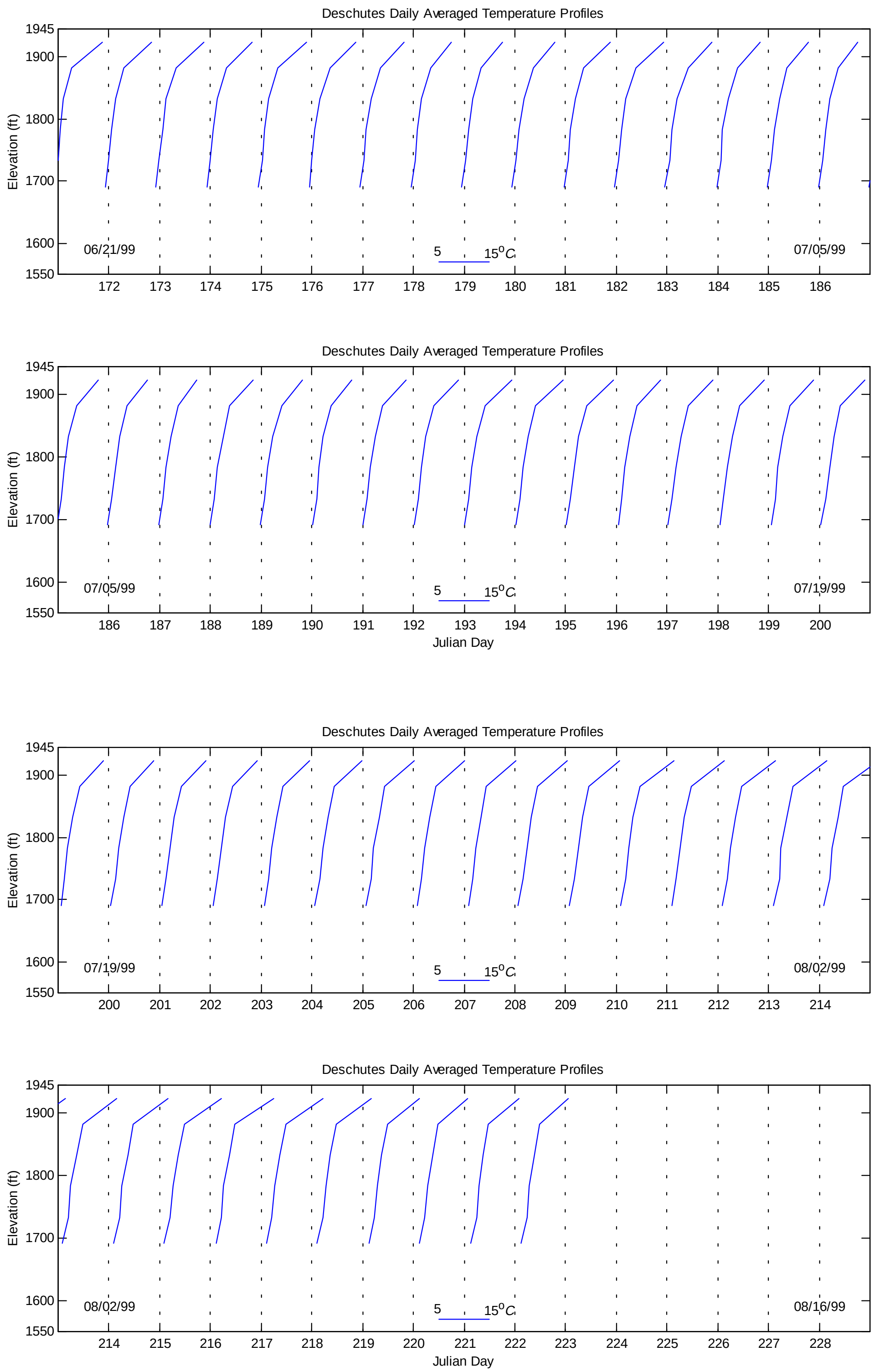




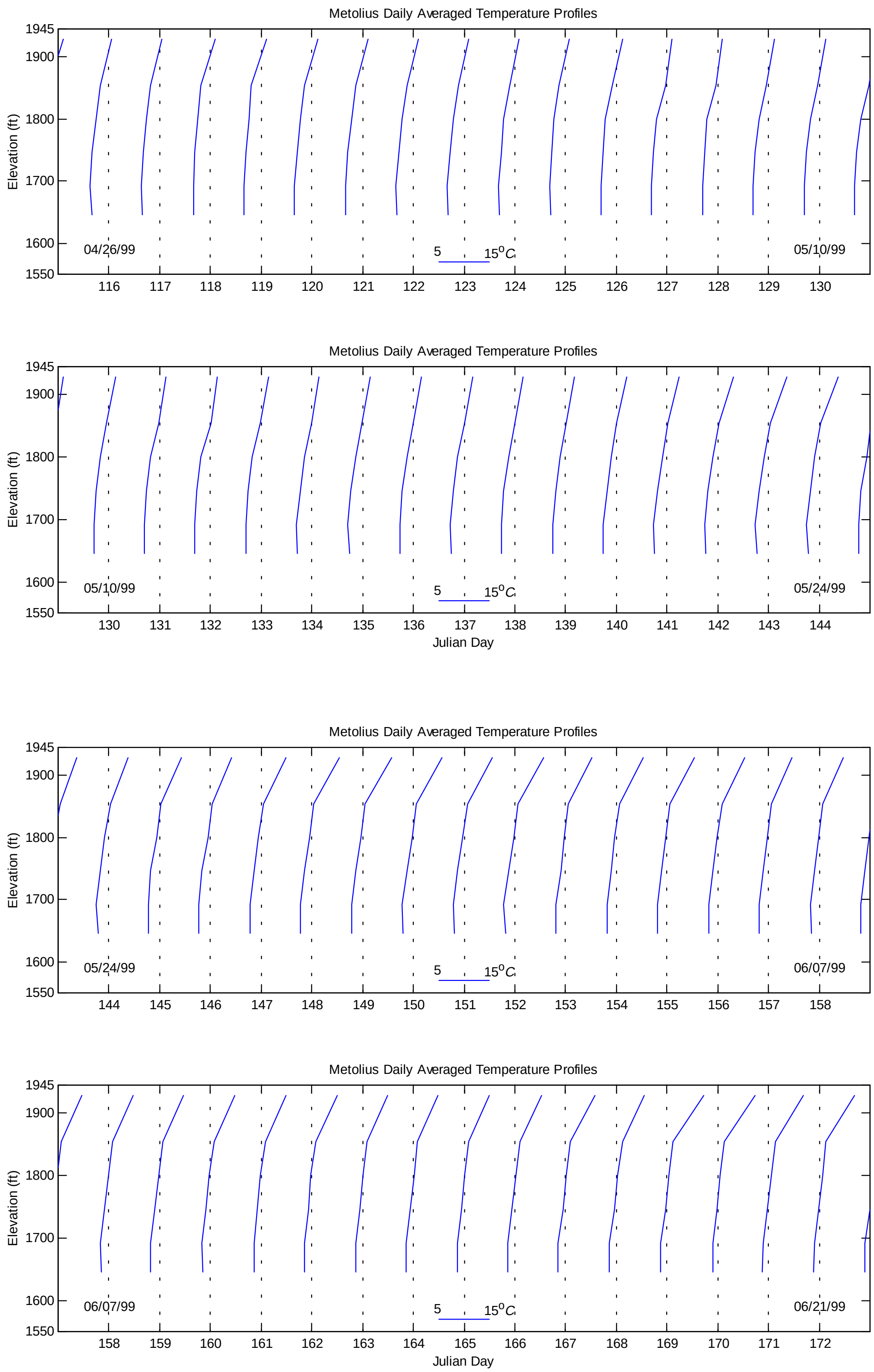




FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-18a** DESCHUTES TEMPERATURE PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang CHECKED: T. Khangaonkar DATE: December 15, 1999	**FIGURE A-18b** DESCHUTES TEMPERATURE PROFILES Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	



FOSTER WHEELER ENVIRONMENTAL CORPORATION

DRAWN: Z. Yang

CHECKED: T. Khangaonkar

DATE: December 15, 1999

PROJECT NO: 2200.0001.0002

FILENAME: pgeapp-P.doc

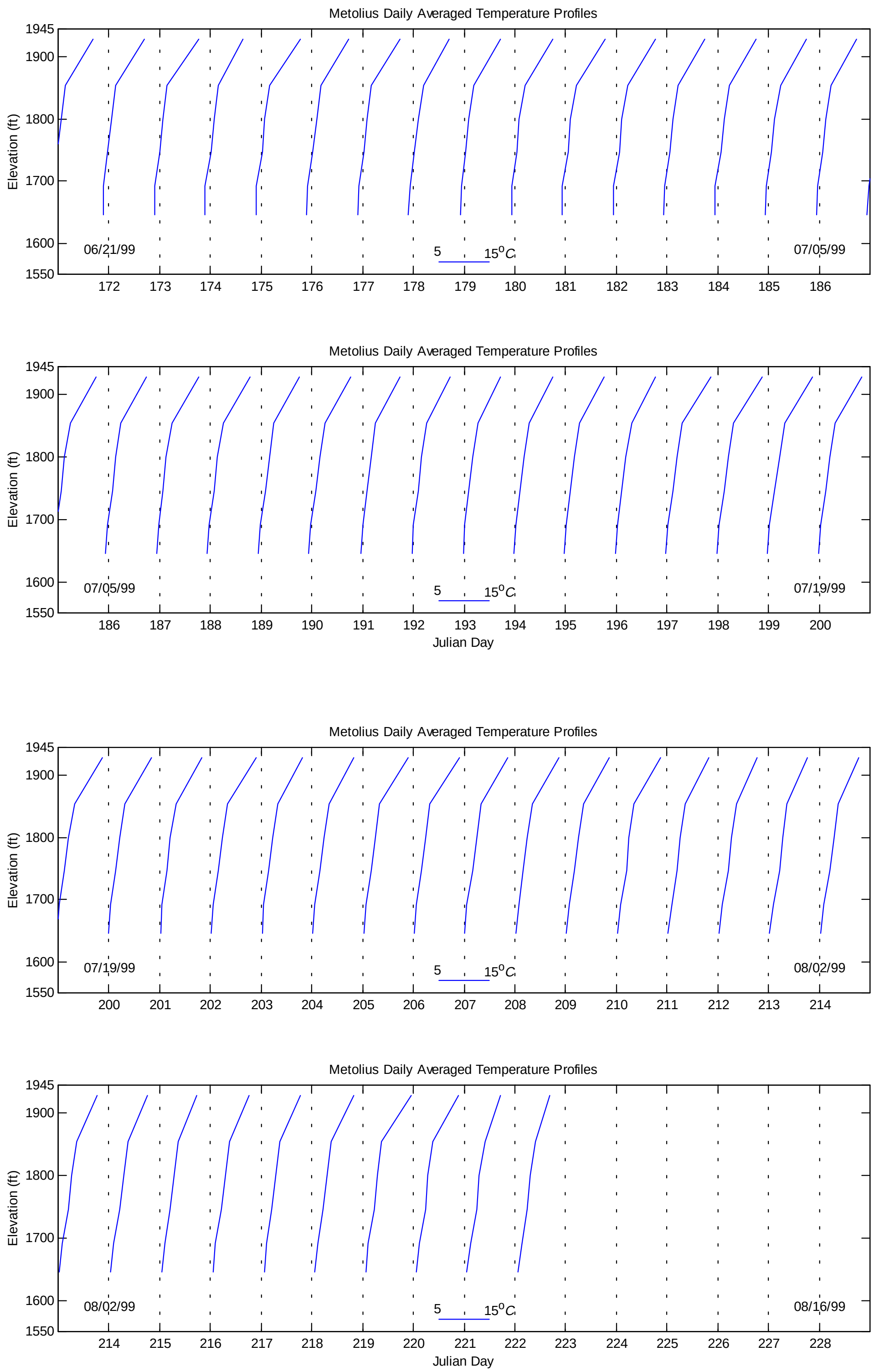
FIGURE A-20a

METOLIUS TEMPERATURE PROFILES

Pelton Round Butte Hydroelectric Project No. 2030

Portland General Electric Company

Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	**FIGURE A-20b**
	CHECKED: T. Khangaonkar	METOLIUS TEMPERATURE PROFILES
	DATE: December 15, 1999	Pelton Round Butte Hydroelectric Project No. 2030 Portland General Electric Company Portland, Oregon
PROJECT NO: 2200.0001.0002	FILENAME: pgeapp-P.doc	