PORTLAND GENERAL ELECTRIC
PORTLAND, OREGON

PELTON ROUND BUTTE HYDROELECTRIC PROJECT
FISH PASSAGE PROGRAM

WATER QUALITY MODEL OF THE LOWER DESCHUTES RIVER

FINAL REPORT

Prepared By:

FOSTER WHEELER
FOSTER WHEELER ENVIRONMENTAL CORPORATION

under contract to
ENSR CONSULTING AND ENGINEERING

for
Portland General Electric

June 2001

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Prepared by

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ACRONYMS AND ABBREVIATIONS

CO_2	carbon dioxide
DO	dissolved oxygen
DOM	dissolved organic matter
EPA	U.S. Environmental Protection Agency
JD	Julian day
LBC	Lake Billy Chinook
m^3/s	cubic meters per second
mg/L	milligrams per liter
O_2	oxygen
PDOS	percent dissolved oxygen saturation
RK	river kilometer
RM	river mile
TC	Trout Creek
TIC	total inorganic carbon

1. INTRODUCTION

1.1 BACKGROUND

Portland General Electric (PGE) owns and operates the Pelton Round Butte Hydroelectric Project on the Deschutes River, near Madras, Oregon. The project consists of three hydropower generating dams that impound three reservoirs over a total distance of approximately 25 miles (Figure 1-1). The Round Butte Dam is the upstream-most dam and is located at river mile (RM) 110.4, near the confluence of the Metolius, Deschutes, and Crooked branches. Construction of Round Butte Dam created the Lake Billy Chinook (LBC) the first reservoir of the system. Pelton Dam, located at RM 102.5, created Lake Simtustus (LS), the second reservoir of the system. The third dam, located 2.4 miles below the Pelton Dam, at RM 100.1, is called Reregulating Dam and was designed for regulating the peaking flows from Pelton Dam. The third reservoir is the waterbody created by this dam and is called Reregulating Reservoir. The Deschutes River below the Reregulating Dam runs over a distance of 100 miles before its confluence with the Columbia River. This stretch of river is called the Lower Deschutes River.

Construction of these dams 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. As a part of the current re-licensing process, PGE has developed an adaptive management plan for re-establishing natural anadromous fish runs above Round Butte Dam. 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. These include (a) fish collection structures, (b) structures for selective withdrawal of surface or deep water at LBC, and (c) fish screens for power plant intakes (ENSR and Duke Engineering, September 2000).

As part of these efforts, hydrodynamic, temperature, and water quality models were first developed for Lake Billy Chinook, and applied to provide a preliminary evaluation of various fish passage enhancement alternatives (Foster Wheeler, March 2000). The study results showed that selective withdrawal operation provided major benefits. The surface withdrawal phase of operation would enhance surface currents, which would improve fish motion towards the collectors. Also, the blending of surface and bottom waters would allow

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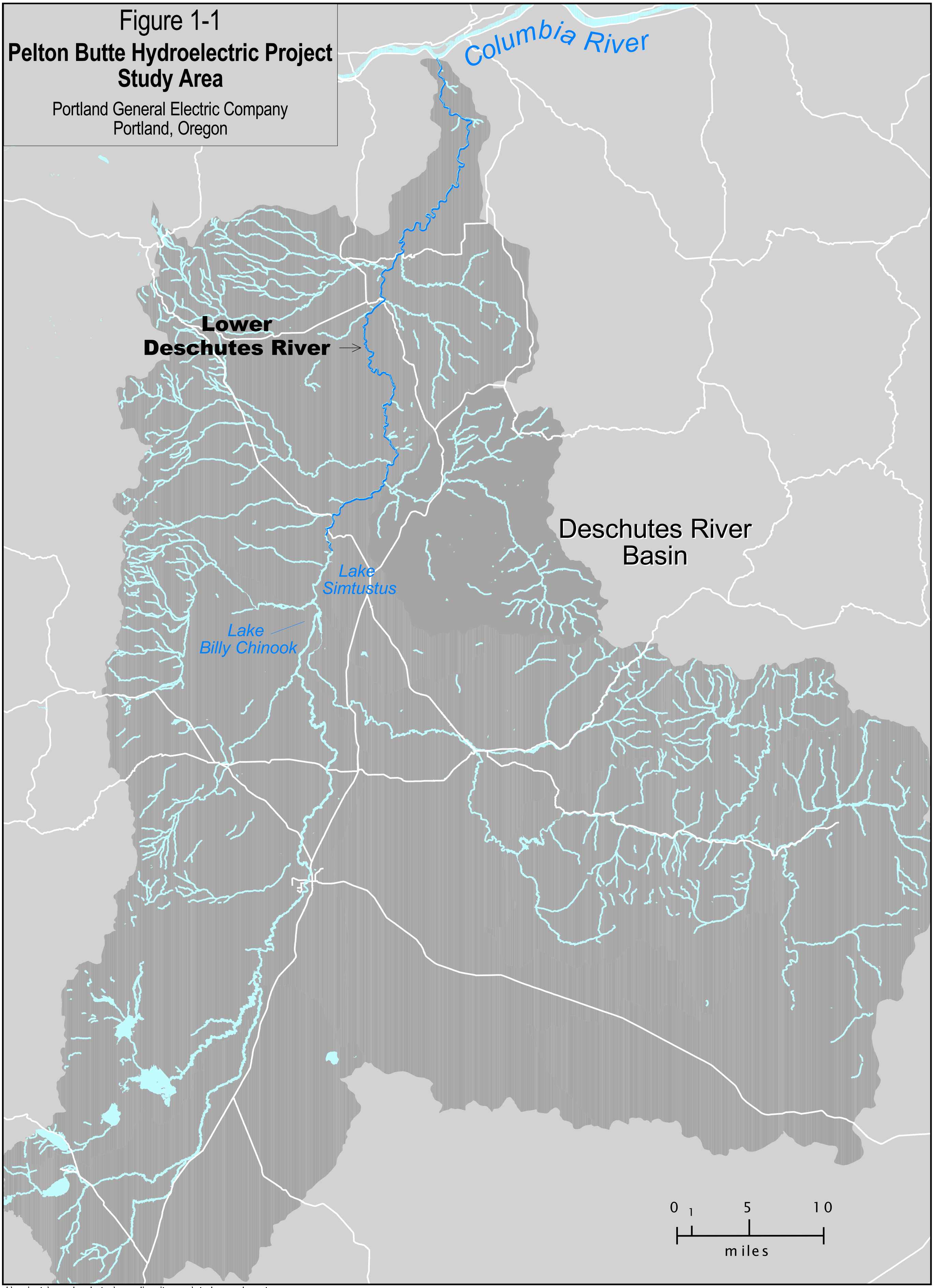

Figure 1-1
Pelton Butte Hydroelectric Project Study Area
Portland General Electric Company
Portland, Oregon

d:\projects\pge-deschutes\samplingsites.apr\study area layout

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alteration of outlet temperatures such that a temperature management plan could be developed and implemented. However, the impact of the proposed modifications on water quality parameters such as dissolved oxygen, pH, and algal biomass in the waterbodies downstream was not clear.

The current re-licensing process also involves an evaluation of impacts of the existing dam operation and proposed modifications in project design or operation on the water quality downstream of LBC. In addition to improving the conditions for downstream migration, there is considerable interest in ensuring that the selected design will also enable PGE to maintain compliance with applicable water quality standards in the Lower Deschutes River. Water bodies affected by the Pelton Round Butte project include Lake Billy Chinook, Lake Simtustus, Reregulating Reservoir, and the Lower Deschutes River downstream of the Reregulating Dam.

PGE therefore initiated this effort to develop a comprehensive and compatible set of water quality modeling tools for the system. The goal was to develop the water quality models to a level of sophistication so that model predictions may be used for evaluation of compliance with water quality criteria and support the development of a water quality management plan. For this purpose, the models should be capable of predicting water quality parameters at any location in the system at any specified time, as a function of external influences such as inflows, meteorological conditions, and operation of the reservoirs.

This report describes the development of a water quality model of Lower Deschutes River including the setup, calibration, verification, and application for evaluation of proposed modifications at LBC.

1.2 STUDY OBJECTIVES AND APPROACH

The overall objective of this study is to develop a predictive water quality model of the Lower Deschutes River. This was accomplished using the finite element models RMA2 and RMA4q and the available data collected by PGE in 1997 and 1999. RMA4q was derived from RMA4 by including entrophication processes. Periphyton simulation was added by Breithaupt (1997). The calibrated model could then be used to evaluate the effect of various reservoir modifications on downstream water quality, and to provide additional information as follows:

- to support the experimental phase of PGE's fish passage program for the Pelton Round Butte Project;

- to provide data required for the project water quality certification application;
- to support conceptual engineering of fish passage facilities; and
- to support the development of a water quality management plan.

Specific objectives of this study are as follows:

- Review and process existing water quality data and develop model input and boundary conditions.
- Set up the hydraulic (RMA2) and water quality (RMA4q) models of the Lower Deschutes River.
- Evaluate and refine the model grid based on the RMA2 hydraulic model performance for average flow conditions.
- Calibrate the RMA4q water quality model to match observed temperatures and dissolved oxygen concentrations and pH using 1999 data. This is accomplished via a periphyton sub-model that modifies dissolved oxygen and pH.
- Verify the model using an independent data set from 1997.
- Apply the model and simulate conditions from 1995 corresponding to the Selective Withdrawal Alternative at LBC, and evaluate water quality impacts on the Lower Deschutes River from this proposed modification.

1.3 MODEL AND DATA LIMITATIONS

As described above, the approach to the development of the water quality model was to conduct a calibration and verification using the existing data. PGE is conducting supplemental data collection in the year 2000-2001 on LBC, Lake Simtustus, and the Lower River simultaneously (Foster Wheeler April 7, 2000)[1]. The model developed in this study will be further improved following completion of that monitoring activity. The existing data are from 24 stations in the Lower Deschutes River. It is important to note that the objective is to evaluate the sensitivity and response of Lower Deschutes River to the various alternative inflow conditions. The model results, as such, must be interpreted with caution. The following model and data limitations are noted:

- Calibration and verification of dynamic models is best accomplished using synoptic time-series data. These data were available for 1999, but 1997 data were limited to

[1] Foster Wheeler. April 7, 2000. *Proposed Supplemental Data Collection Plan*. Technical Memorandum from Curtis DeGasperi and Tarang Khangaonkar of Foster Wheeler to Scott Lewis of Portland General Electric.

spot-survey measurements. Model calibration was done using 1999 data and verified against the available 1997 data.

- Although the periphyton model used for the Lower Deschutes River includes grazing by benthic invertebrates, this information was not explicitly included because no data were available to support implementation. The periphyton model does handle scour, but uses a function based on cohesive material transport.
- The model calibration and verification focused on the dates when data were available. These data show diurnal variations. When these data are from different seasons, they reflect seasonal variations occurring upstream in the reservoirs and within the Lower Deschutes River itself.
- There is a gap in the cross-section data between RK 36 and RK 64 (RM 22 and RM 40). Since the model is sensitive to river geometry, model results in and below this river section must be used with caution.
- The model results best fit the observed data in the upstream reaches. The discrepancy between data and model predictions at the downstream end of the river is likely due to the fact that the meteorologic data were available from only one site that is at an elevation higher than the study area. These data may not reflect the meteorologic conditions present along the river channel, especially in the canyons through which the Lower Deschute River flows. The model results may be improved by incorporation of site specific meteorological input.

1.4 REPORT ORGANIZATION

This report is logically organized to provide optimal access to information, as follows:

- Section 1 provides an introduction to the project background and a description of the objectives of this study.
- Section 2 provides a summary and review of available data that are suitable for the development and calibration of the water quality model.
- Section 3 describes setup and validation of the hydraulic model for 1999 and 1997 conditions.
- Section 4 describes the setup and calibration of the water quality model to 1999 conditions.
- Section 5 describes verification of the water quality model to 1997 data.
- Section 6 describes an application of the model to evaluate the effect of a proposed selective withdrawal operation on in-river water quality.

- Section 7 provides a summary of the calibration and verification results and contains conclusions and recommendations for further development of a water quality model of the Lower Deschutes River.

2. REVIEW OF AVAILABLE DATA

2.1 INTRODUCTION

Models that describe hydraulic and water quality processes based on physical, chemical, and biological principals require considerable data input. The hydraulic model RMA2 requires physical characteristics of the system including inflows and channel characteristics. The water quality model RMA4q requires meteorological inputs that characterize the various river reaches and water quality constituent concentrations at entry points to the system. These entry points are at the same locations as inflow points for the hydraulic model.

The following sections describe the available data that can be used as input for the RMA2 and RMA4q models. The study area is presented in Figure 2-1, showing the river mile locations for the Lower Deschutes River.

2.2 GEOMETRY DATA

The Lower Deschutes River study area is located in the lower 100 miles of the Deschutes River, Oregon, extending from RM 100.1 at the Reregulating Dam to the river mouth at RM 0, the confluence with the Columbia River. The overall bed slope for the river is about 0.0023, with several steep sections and cascading falls. Figure 2-2 presents the river profile and shows the locations of measured cross-sections. Figure 2-3 shows the river cross sections locations in plan view. Note that no data exist for the section of river from RM 24 to RM 40 (RK 40 to RK 65). Appendix A Figures A-1 through A-10 illustrate the measured cross-section data available, including those measured by PGE in 2000.

2.3 HYDROLOGIC DATA

Hydrologic inputs to the Lower Deschutes River include discharge from the main stem Reregulating Reservoir, Shitike Creek, Trout Creek, Warm Springs River, and White River (see Figure 2-7 for locations). The majority of flow comes from the Reregulating Reservoir, with Warm Springs River being the second largest inflow (see annual average flows below).

Madras gage flows cover the entire period of study, from January 1, 1995, through the present (Figure 2-4). Moody gage flows also cover the entire period of study, from January 1, 1995, through the present (Figure 2-4). Shitike Creek flow records begin late 1996 and continue through the present (Figure 2-5). Trout Creek flows are only available since late 1999 (Figure 2-5). Records for the Warm Springs River also cover the entire period of study, January 1, 1995, through the present (Figure 2-6). There are no records for the White River during the study period. Figure 2-6 presents the most recent three years of record. Mean flows for the plotted periods are as follows:

- Lower Deschutes River—Madras Gage 5065 cfs (143.5 m^3/s)
- Lower Deschutes River—Moody Gage 6885 cfs (195.0 m^3/s)
- Shitike Creek 146 cfs (4.14 m^3/s)
- Trout Creek 53.4 cfs (1.51 m^3/s)
- Warm Springs River 614 cfs (17.4 m^3/s)
- White River 326 cfs (9.23 m^3/s)

2.4 LOWER DESCHUTES RIVER WATER QUALITY DATA

Water quality data collection has been performed using two different approaches (E&S, April 2000). One approach was a river survey that collected samples along the river during a multi-day sampling event. This provided a longitudinal data set with sample collection times that varied throughout the daylight period depending on when the grab sample was collected. The second was a synoptic data collection approach, with samples from several specified locations. The samples were collected at regular and frequent intervals during the sampling event simultaneously at all locations. This sampling event lasted from 36 to 48 hours, providing a set of time series data. The sampling locations used for both approaches are presented in Figure 2-7.

Figures 2-8 through 2-12 present the 1999 time series water quality data collected during the synoptic survey at the Regulating Dam discharge location (RM 100.1), RM 88, RM 57, RM 24, and RM 01. No other data set of this nature is available for the Lower Deschutes River. These data, consisting of temperature, dissolved oxygen, and pH, were collected using a Hydrolab field instrument (E&S, April 2000). It is apparent on some sampling days that the meters failed. Dissolved oxygen at RM 88 for Julian Day (JD) 117–119 and pH at RM 57 for JD 117–119 are two such instances. The dissolved oxygen and pH data at RM 24 on JD 278–281 may need additional evaluation. Dissolved oxygen concentrations at RM 01 on JD 278–281 are extremely high and could be indicative of sensor error, especially since the concentrations remain high even at night, when they are expected to decrease rapidly towards saturation values.

Temperature time series are available at most sites, through PGE's temperature monitoring program conducted on the Lower Deschutes River. The data cover periods from 1997

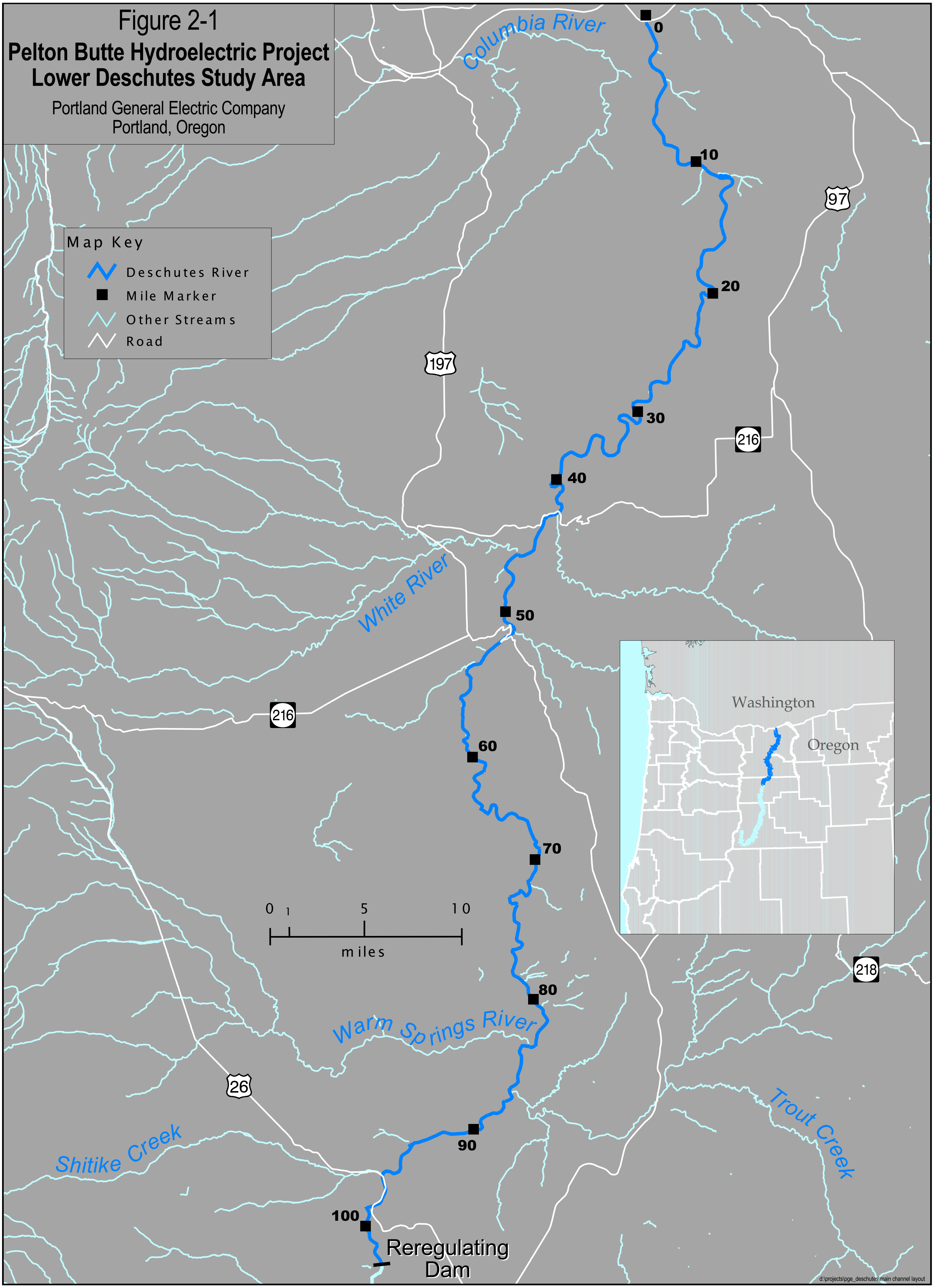
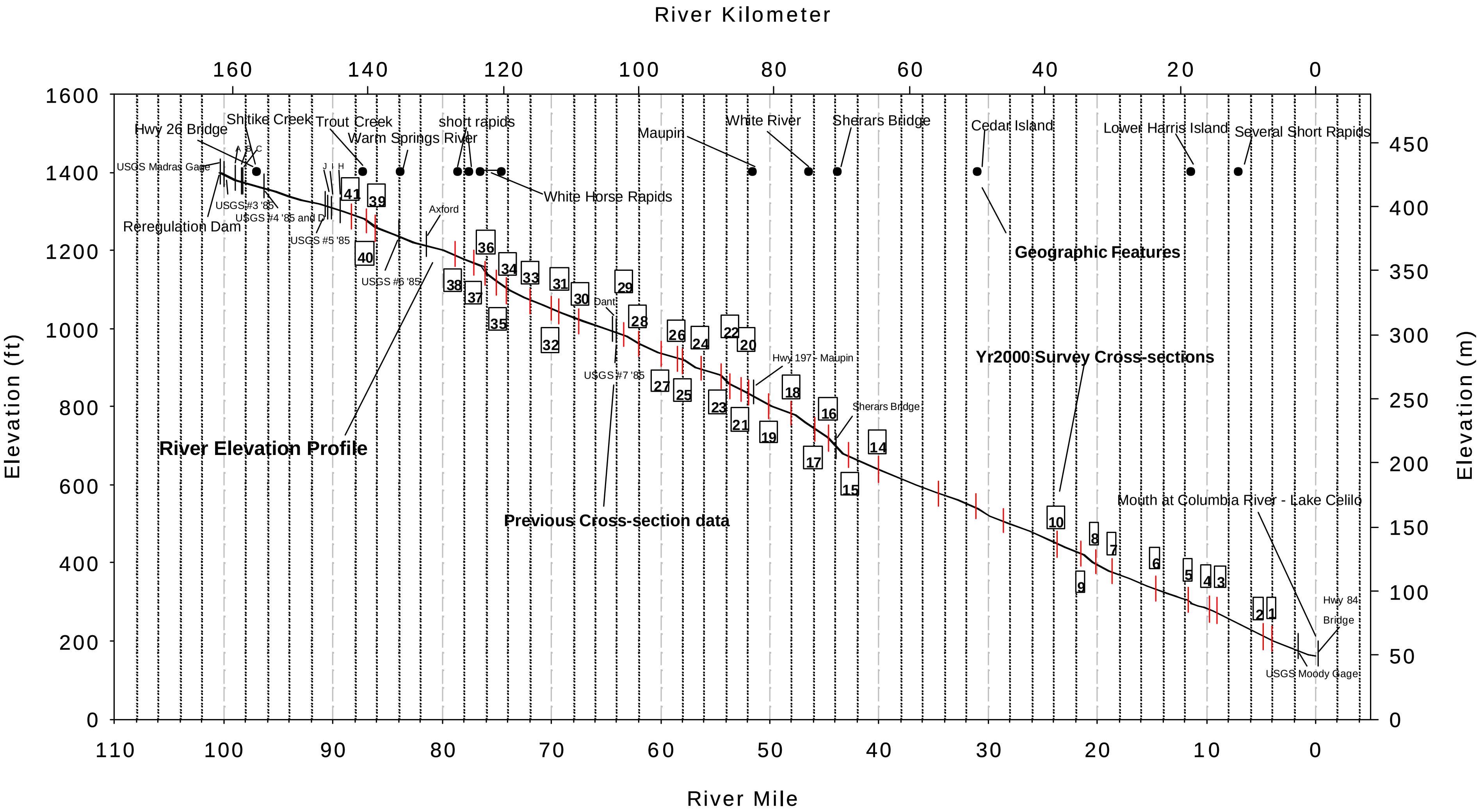


Figure 2-1
Pelton Butte Hydroelectric Project
Lower Deschutes Study Area
Portland General Electric Company
Portland, Oregon



Note: Vertical datum is NGVD of 1929. Elevation at mouth at Columbia River controlled by Lake Celilo elevation (The Dalles Dam).

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FILENAME: LDRprofiles.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE 2-2
LOWER DESCHUTES RIVER
ELEVATION PROFILE
AND CROSS-SECTION LOCATIONS
Portland General Electric Company
Portland, Oregon

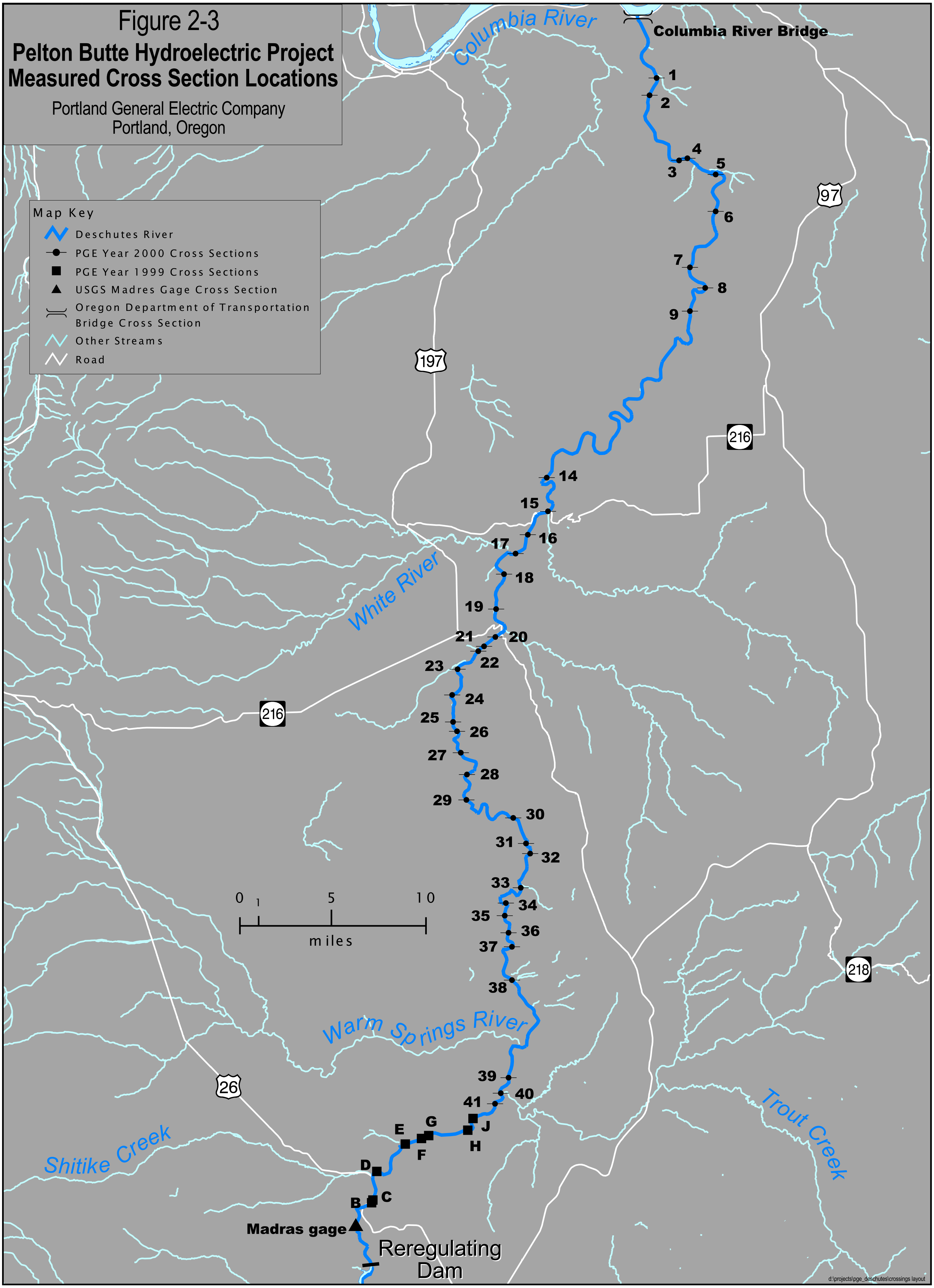

Figure 2-3
Pelton Butte Hydroelectric Project Measured Cross Section Locations
Portland General Electric Company
Portland, Oregon

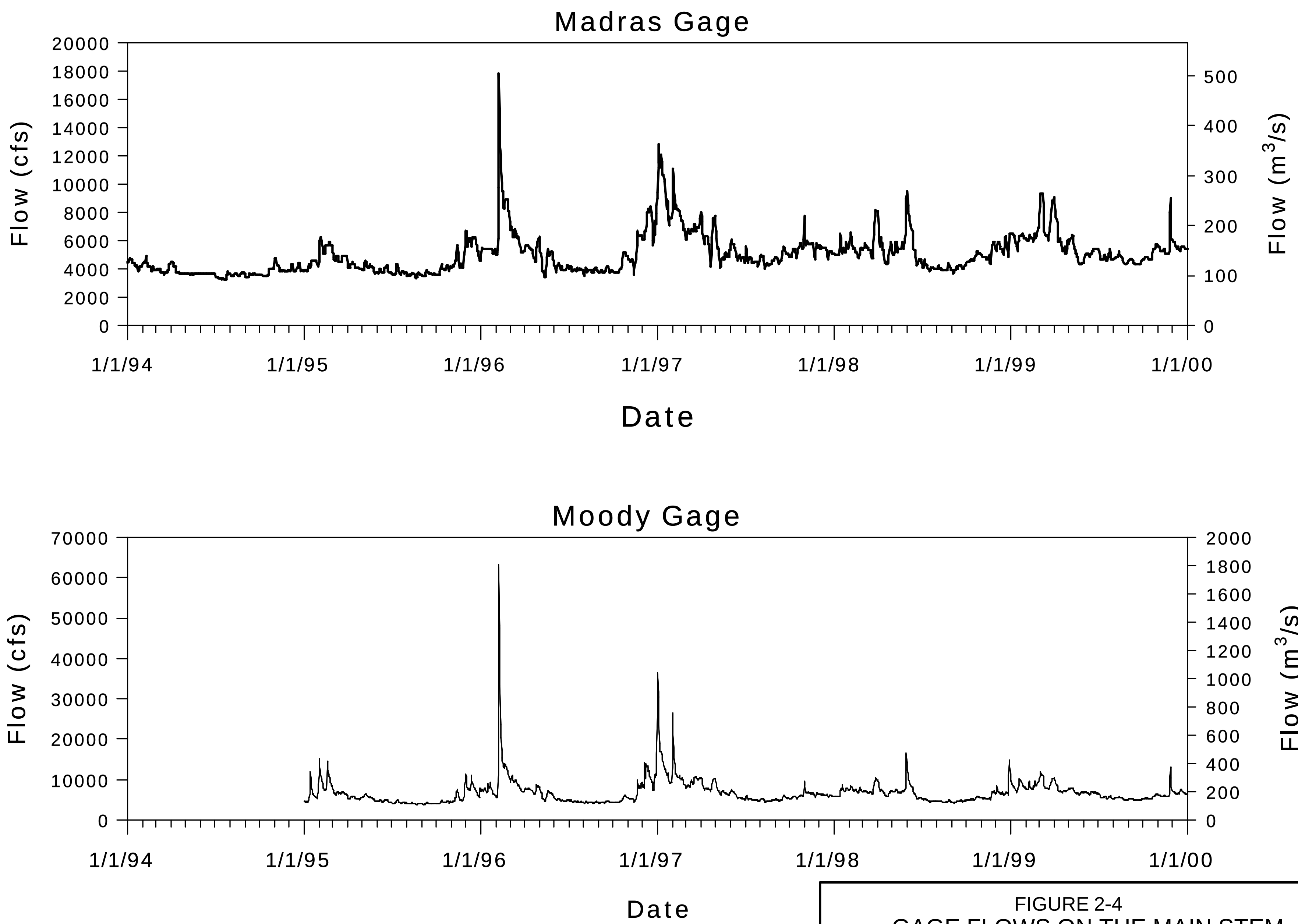

FIGURE 2-4
GAGE FLOWS ON THE MAIN STEM
LOWER DESCHUTES RIVER
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
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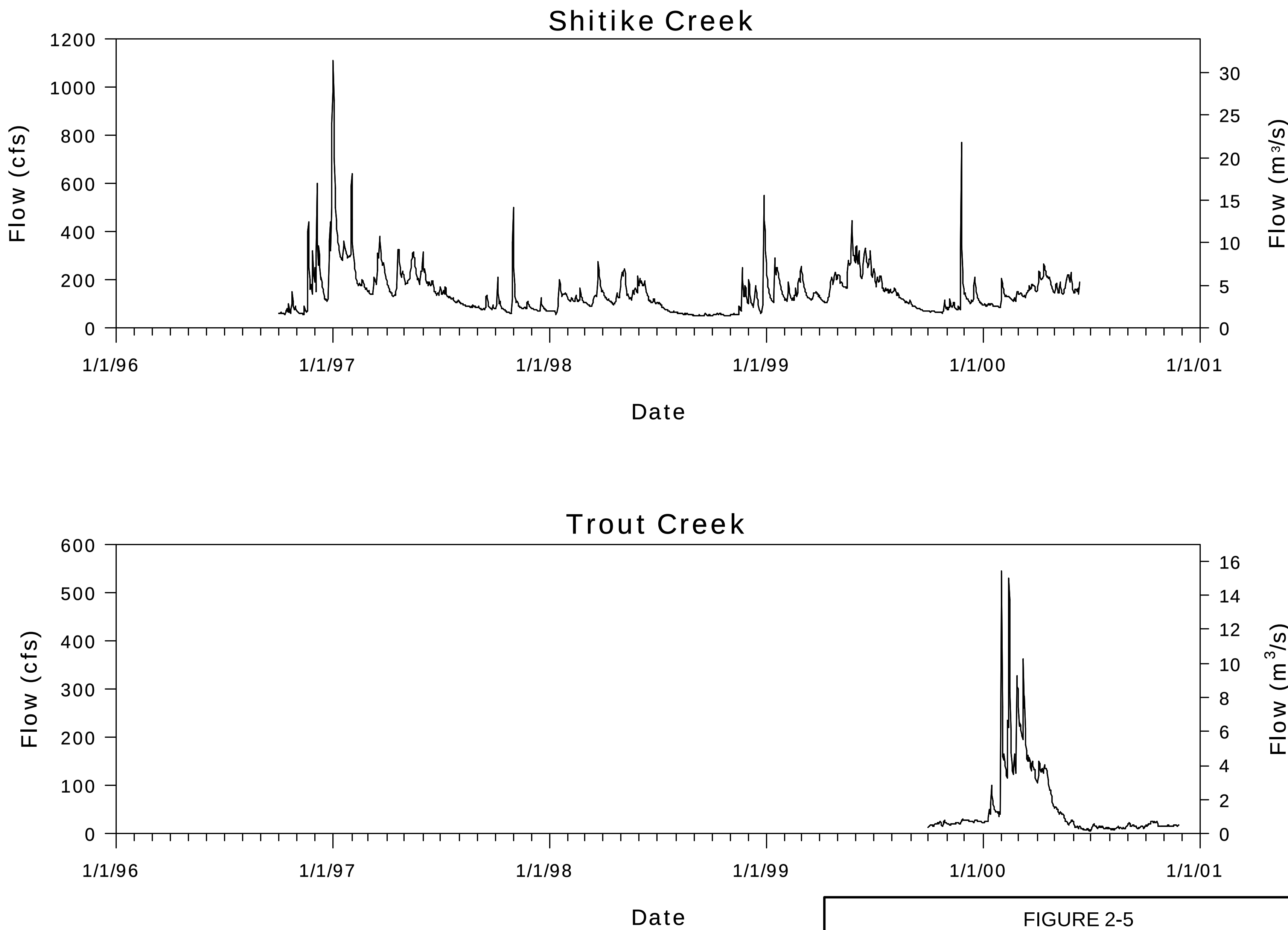

FIGURE 2-5
SHITIKE AND TROUT CREEK FLOWS

Portland General Electric Company
Portland, Oregon

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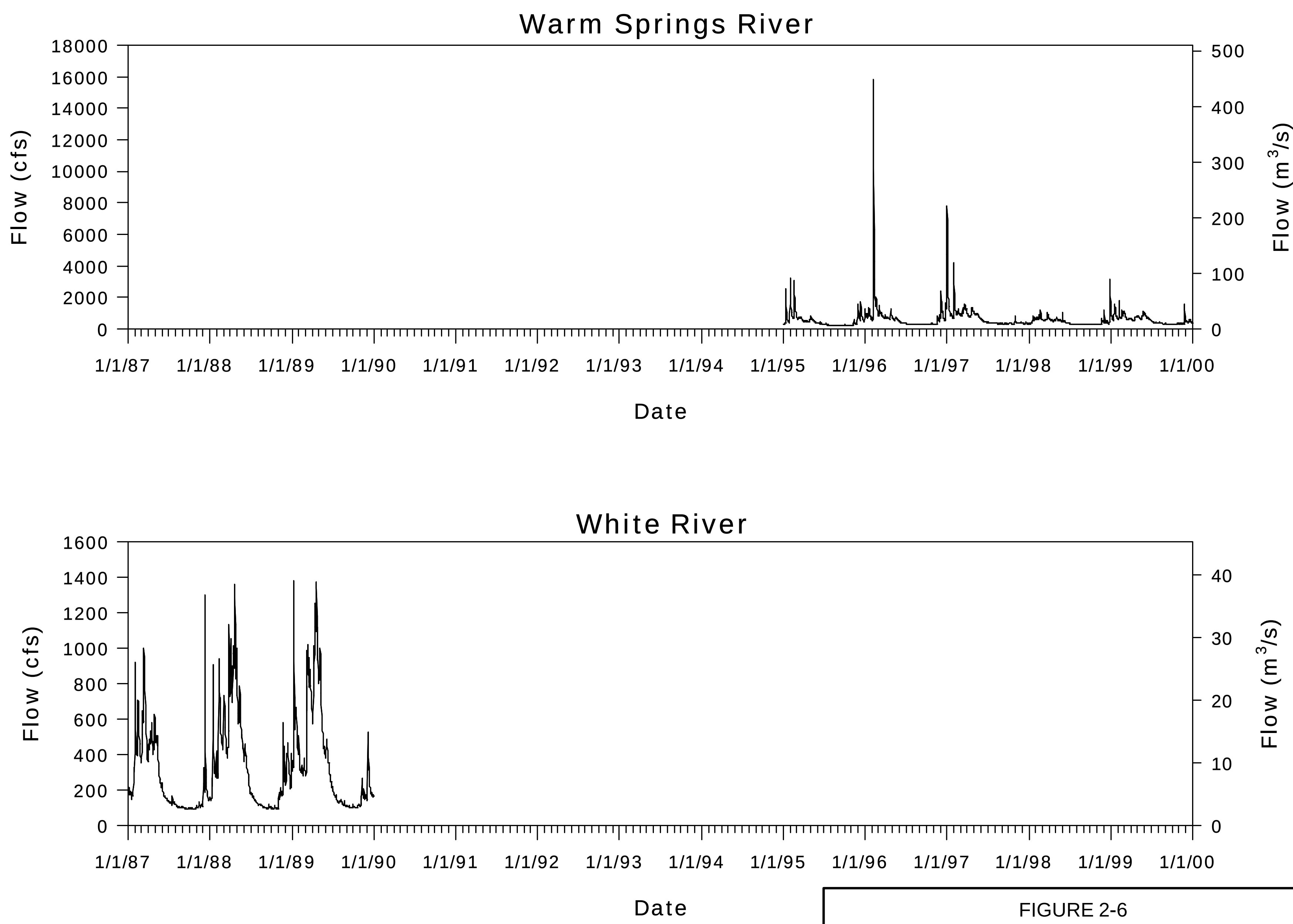

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:	FIGURE 2-6 WARM SPRINGS AND WHITE RIVER FLOWS Portland General Electric Company Portland, Oregon
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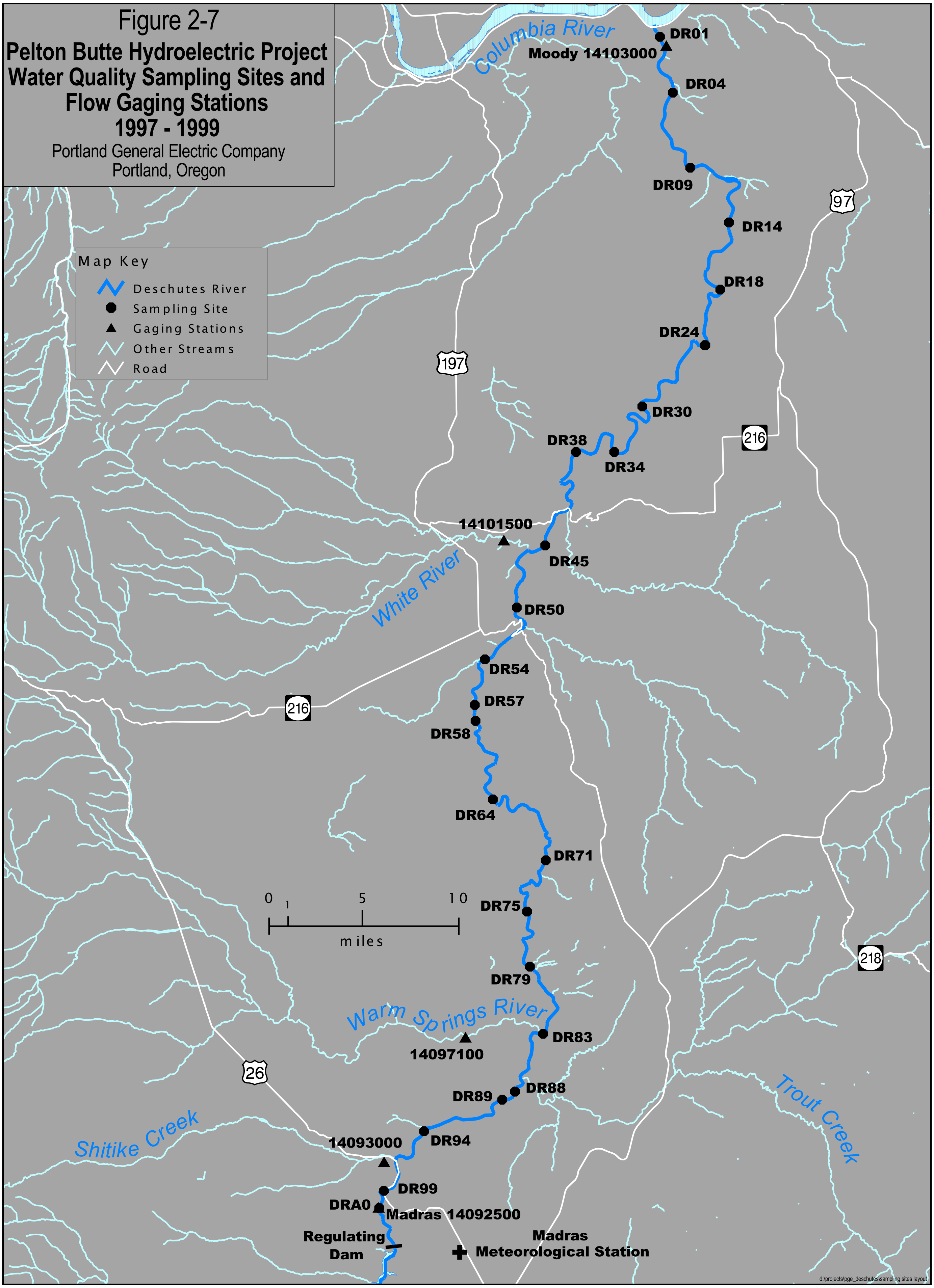

Figure 2-7
Pelton Butte Hydroelectric Project Water Quality Sampling Sites and Flow Gaging Stations 1997 - 1999
Portland General Electric Company
Portland, Oregon

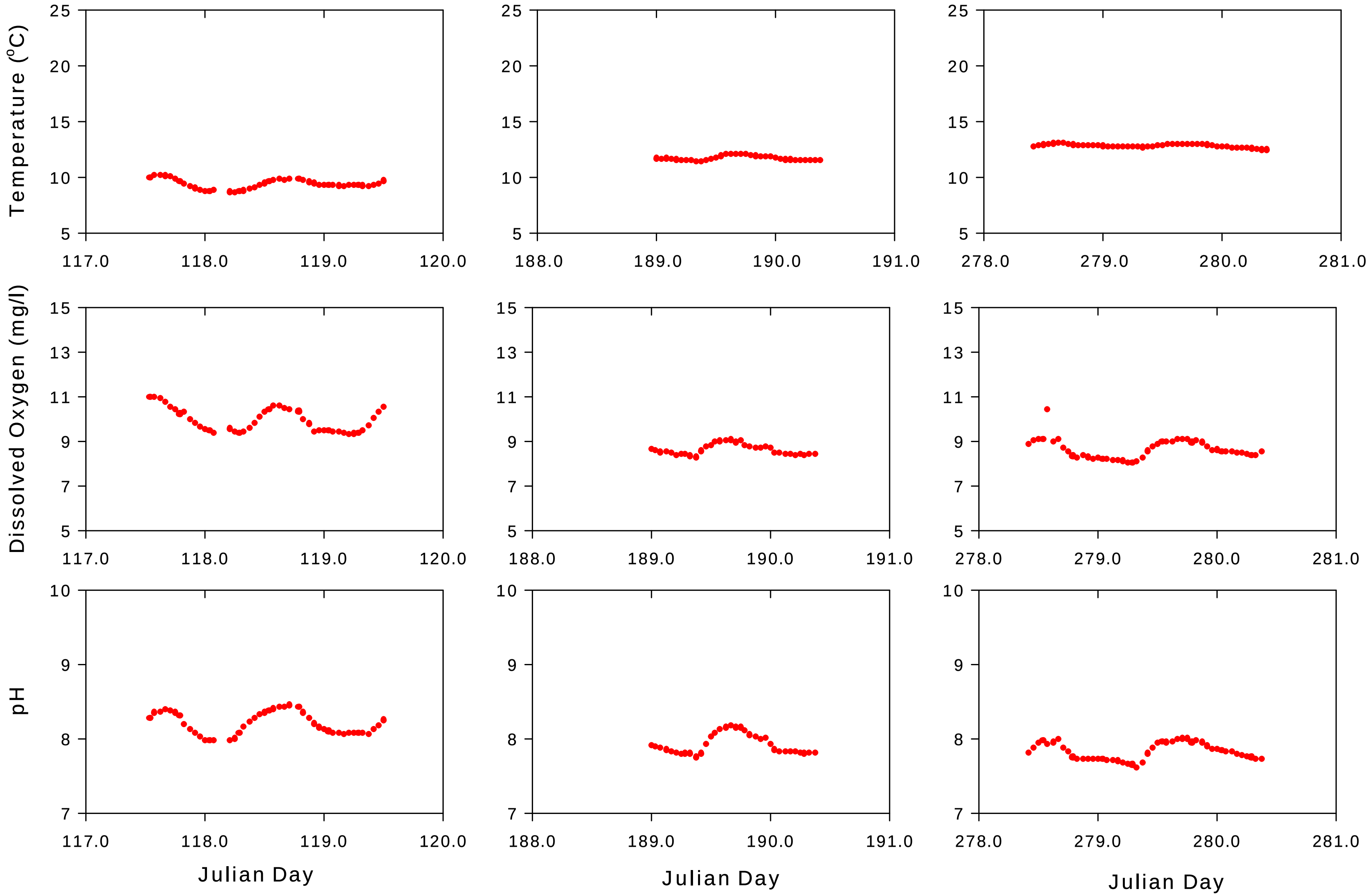

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FIGURE 2-8
SYNOPTIC SURVEY SAMPLING RESULTS
AT RM 100.1 FOR 1999
Portland General Electric Company
Portland, Oregon

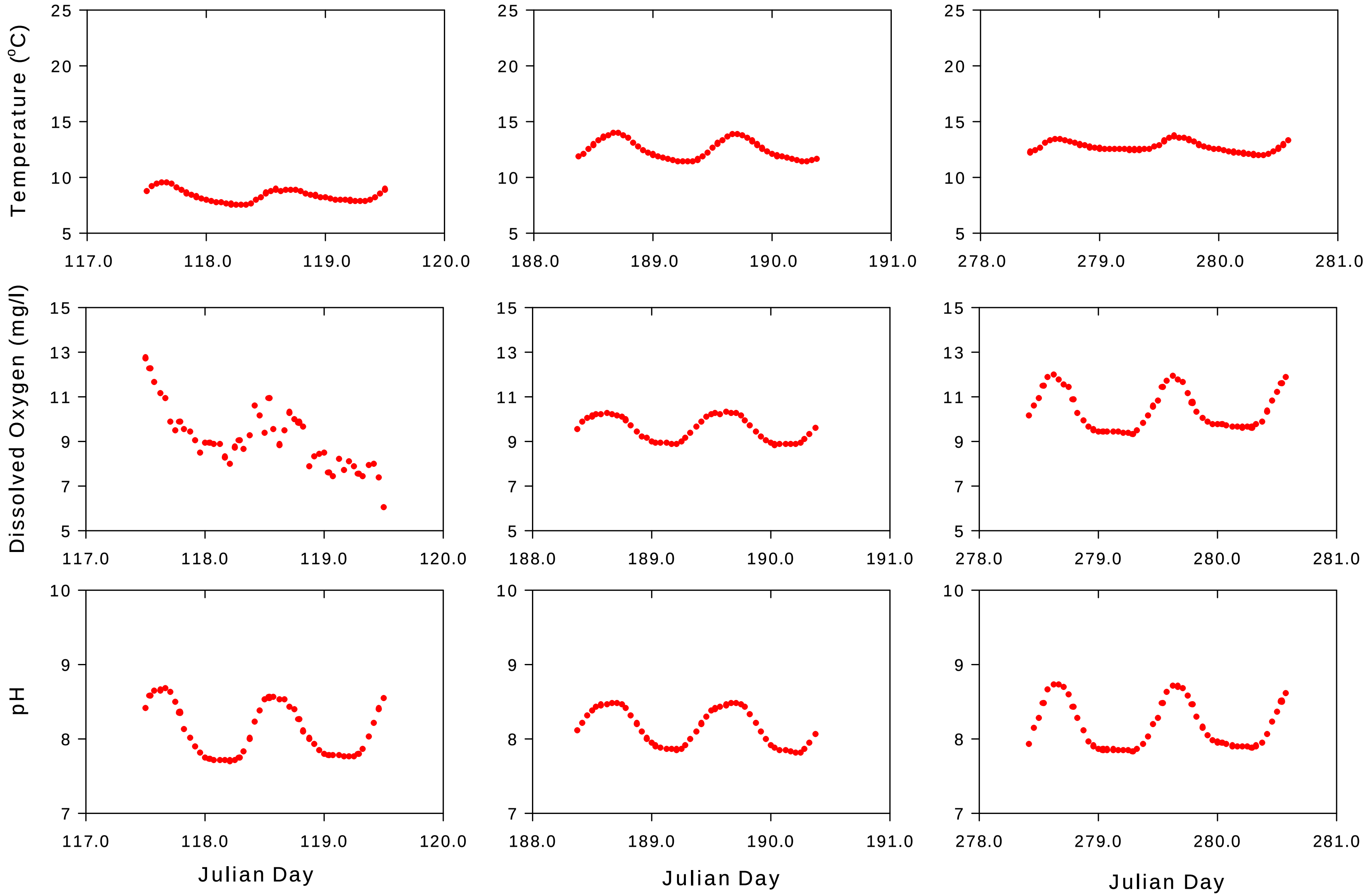

FIGURE 2-9
SYNOPTIC SURVEY SAMPLING RESULTS
AT RM 88 FOR 1999
Portland General Electric Company
Portland, Oregon

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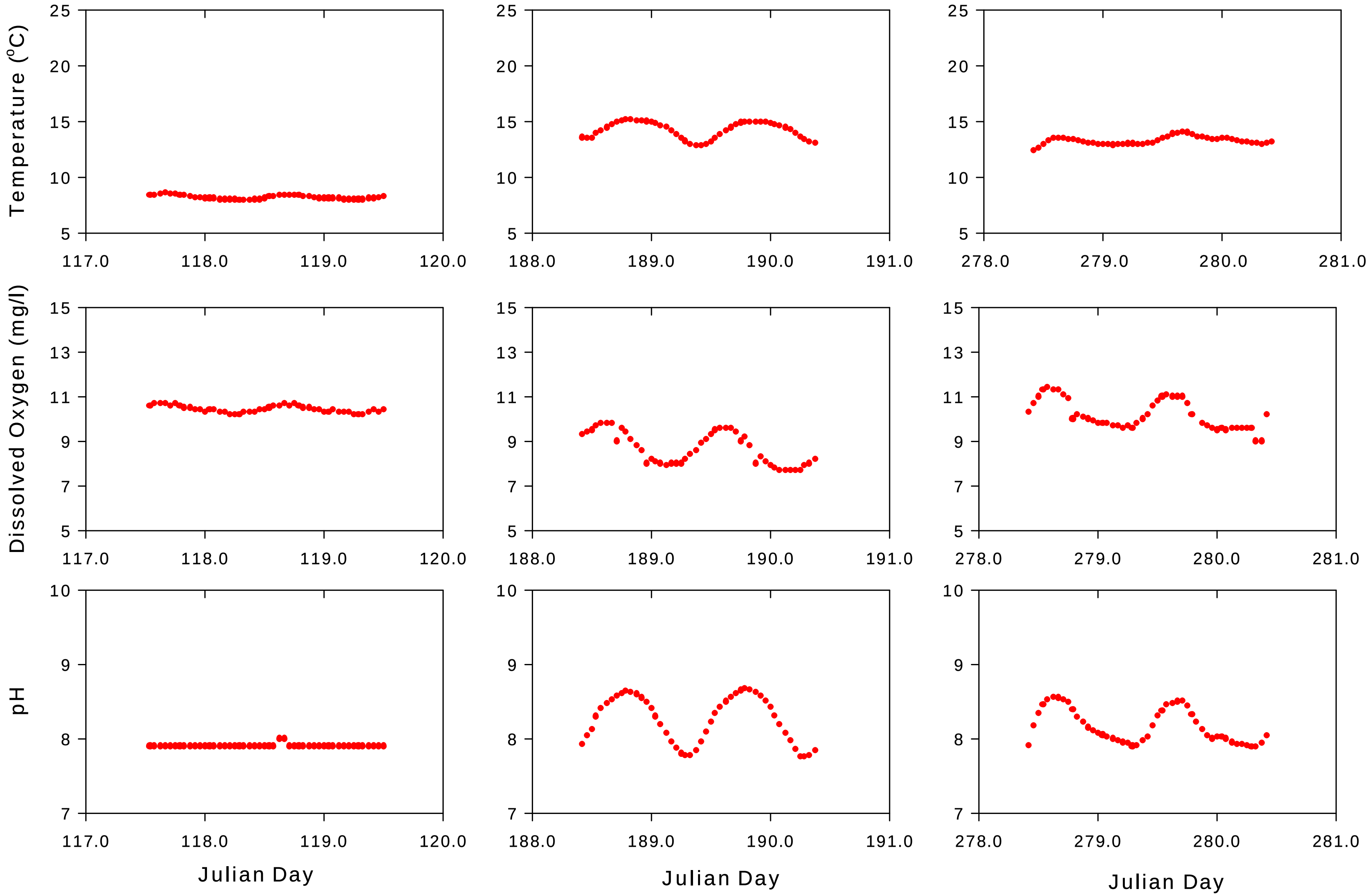

FIGURE 2-10
SYNOPTIC SURVEY SAMPLING RESULTS
AT RM 57 FOR 1999
Portland General Electric Company
Portland, Oregon

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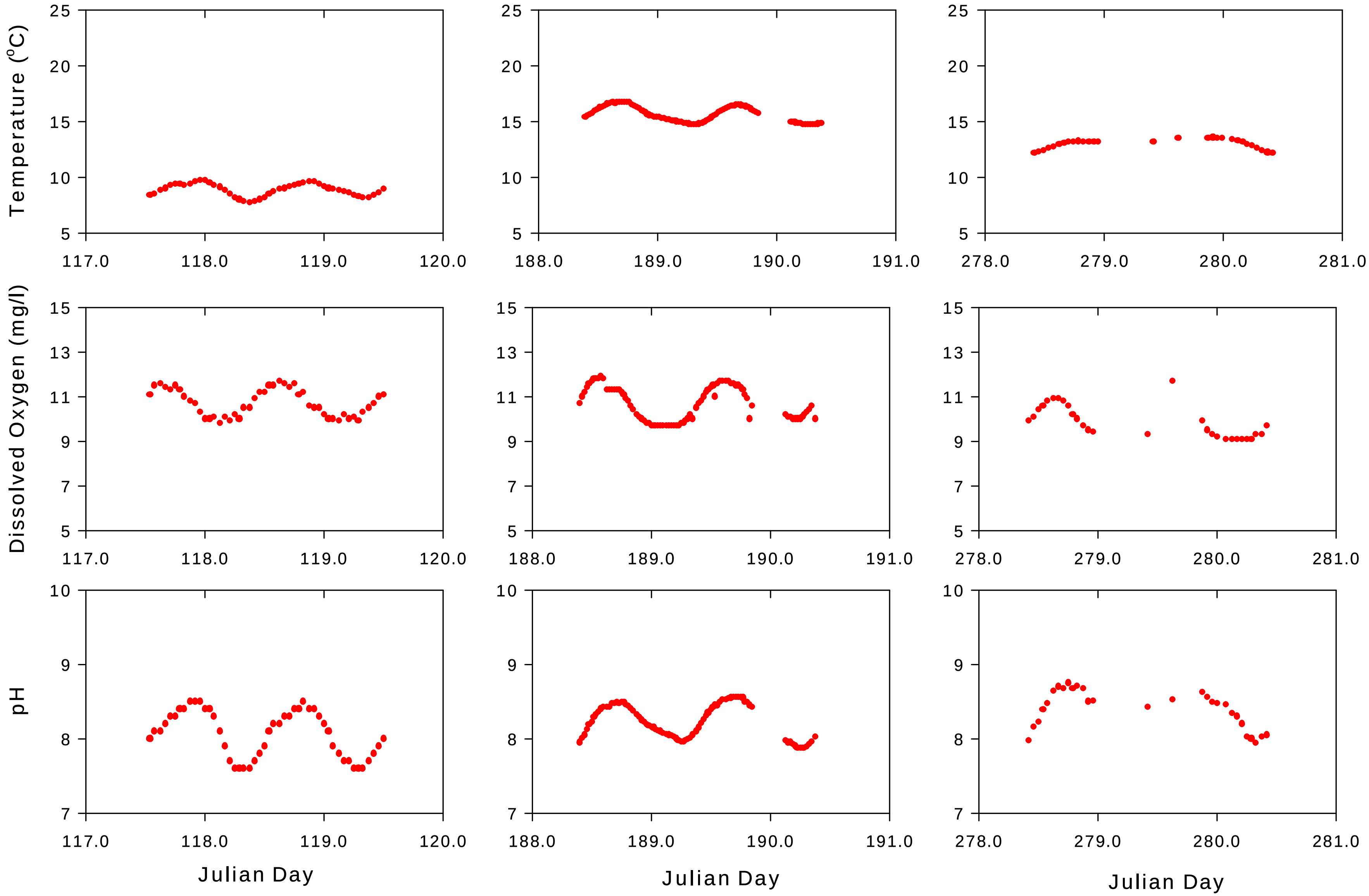

FIGURE 2-11
SYNOPTIC SURVEY SAMPLING RESULTS
AT RM 24 FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang/S.Breithaupt	DATE: March 22, 2001	PROJECT NO:
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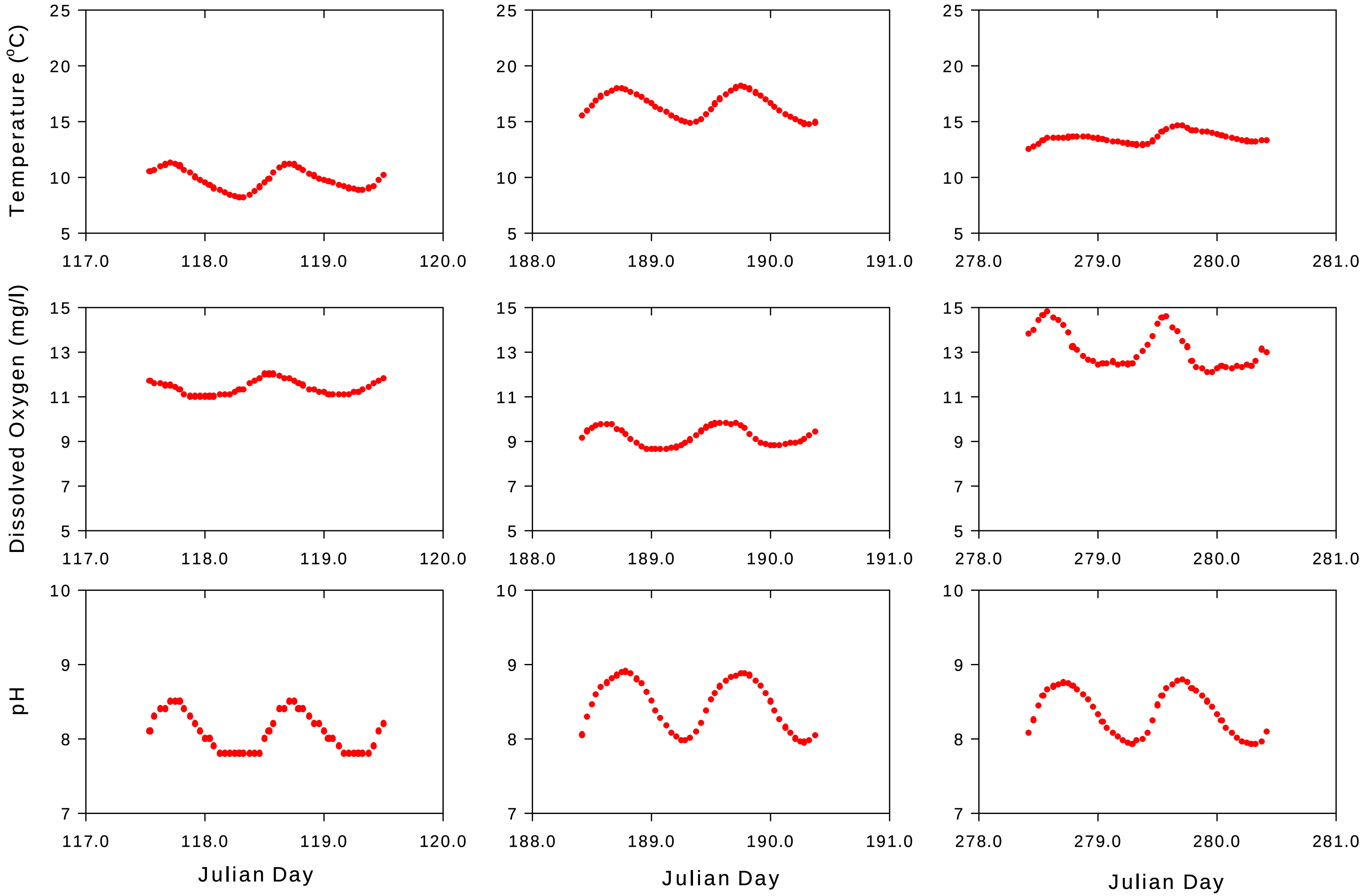

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FIGURE 2-12
SYNOPTIC SURVEY SAMPLING RESULTS
AT RM 01 FOR 1999
Portland General Electric Company
Portland, Oregon

through 1999 and were collected at approximately hourly intervals. The data are shown in Figures 2-13a through 2-13c. Note the increase in summer-time maximum temperatures from upstream (RM 100.1) to downstream (RM 01) stations.

Data collected from river surveys conducted in 1997 are presented in the form of longitudinal plots in Figures 2-14 through 2-19. Three sampling events occurred in 1997: in May, in July, and in September. Some of the data clearly show the effect of sampling at different times over several days, particularly temperature, dissolved oxygen, and pH. No alkalinity data were available for September 1997. In 1999, only one river survey sampling event occurred. The data collected from it are presented in Figure 2-20. The temperature, dissolved oxygen, and pH each show the effect of sampling at different times over several days.

Water quality tributary data are presented in Figures 2-21 through2-23 including temperature, dissolved oxygen, pH, and nitrate. Regulating Dam discharge data are presented along with tributary data in Figures 2-24 through 2-26, including nitrate, ortho-phosphate, and ammonium. Chlorophyll *a* data from the Reregulating Dam discharge are presented in Figure 2-27. Relative to the main stem of the Lower Deschutes River, tributary data are quite sparse, with only a few points over the 1997 to 1999 period. Nitrate data are available at a slightly higher frequency than other nutrient data.

2.5 METEOROLOGICAL DATA

Meteorological data were taken from the Oregon Solar Radiation Monitoring Laboratory station in Madras, Oregon, at latitude 44.69, longitude 121.16, and altitude 997 meters). The data required for modeling water quality using RMA4q are air temperature, dew point temperature, and wind speed. The data for 1995, 1997, and 1999 are shown in Figures 2-28 through 2-30.

2.6 DATA ADEQUACY FOR MODELING

Data are needed as boundary condition values to be used by the model during simulation. For the water quality model, the constituents being simulated include the following: temperature, alkalinity, total inorganic carbon, dissolved oxygen, ammonia, nitrite, nitrate, ortho-phosphate, labile dissolved organic matter, and suspended (planktonic) algae. Each constituent requires data to be specified at the boundary. Because the model is dynamic and is expected to simulate year-long periods, time series of each constituent is required at the model boundaries for the entire year of simulation. For constituents that have minimal impact on results, representative constant values may be specified for the whole simulation.

Constituents having relatively small impact with respect to diurnal variation include alkalinity, ammonia, nitrite, ortho-phosphate, and labile dissolved organic matter. Other constituents that exhibit diurnal cycles require a better boundary condition definition. Preferably these data would be collected at near hourly time intervals to adequately describe the daily variation. Diurnal cycle constituents include temperature, dissolved oxygen, and pH.

Data are also needed for comparison with model results for calibration and verification. The same requirements apply here as for the boundary condition. That is, for constituents that exhibit diurnal cycles, data are needed in the form of time series that adequately describe those variations.

Examination of the available data shows that temperature data largely satisfy the requirements for a dynamic, year-long simulation, at least for the main stem locations. Tributary temperature data are lacking, however. This could affect model results when estimates are made to fill in the gaps. Considering the fact that tributary inflows are small relative to the river flow, negative effects of the lack of time-series data will be limited to a short distance near the confluences only.

Dissolved oxygen time series are available for 1999 from three separate sampling events. These are adequate, though more data would be helpful in defining the boundary values at the Reregulating Dam boundary and thereby refining the model setup. The same can be said for total inorganic carbon, which is computed from pH and alkalinity measurements.

Data adequacy for 1997 is limited by the fact that no time-series data for water quality constituents are available. Only temperature data were collected at sufficient frequency to define boundary conditions and to use for calibration. Boundary data variation for other constituents will be estimated using data from other years.

Nitrate data are available at sufficient frequency for seasonal trends; however, only a few samples were collected each year.

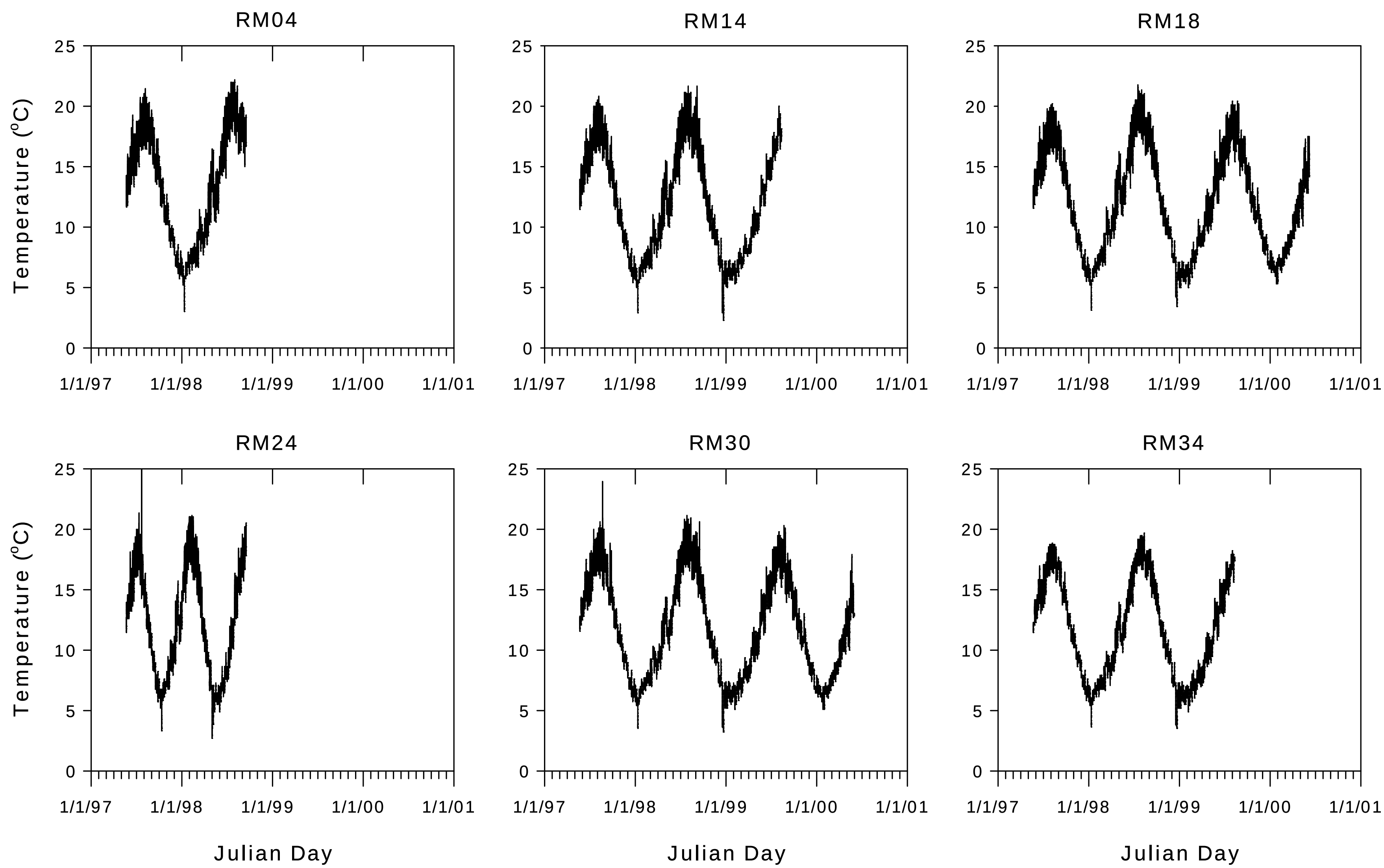

FIGURE 2-13a
CONTINUOUS TEMPERATURE MONITORING DATA FOR 1997 THROUGH 1999 AT RM 04 TO RM 34
Portland General Electric Company
Portland, Oregon

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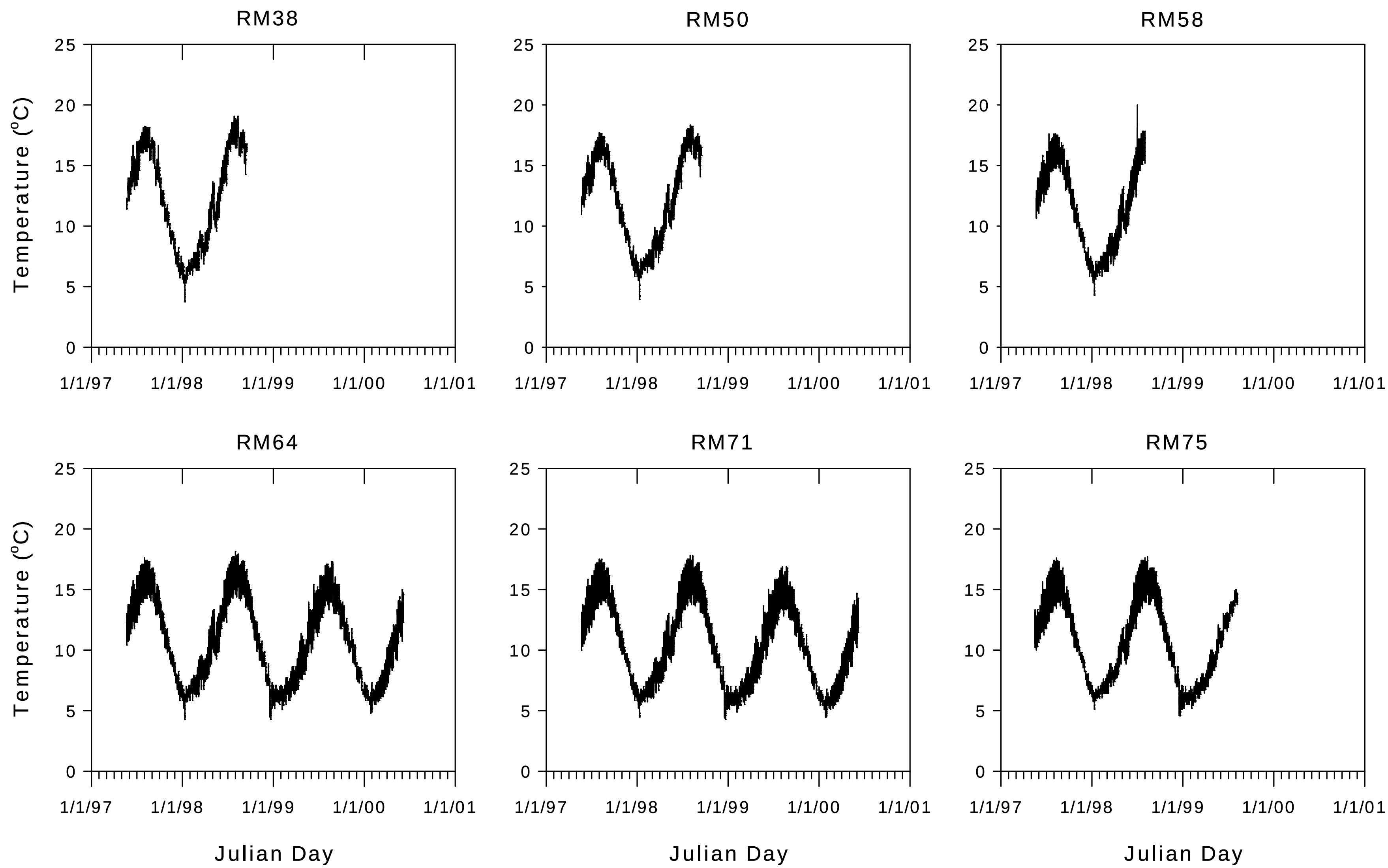

FIGURE 2-13b
CONTINUOUS TEMPERATURE MONITORING DATA FOR 1997 THROUGH 1999 AT RM 38 TO RM 75

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
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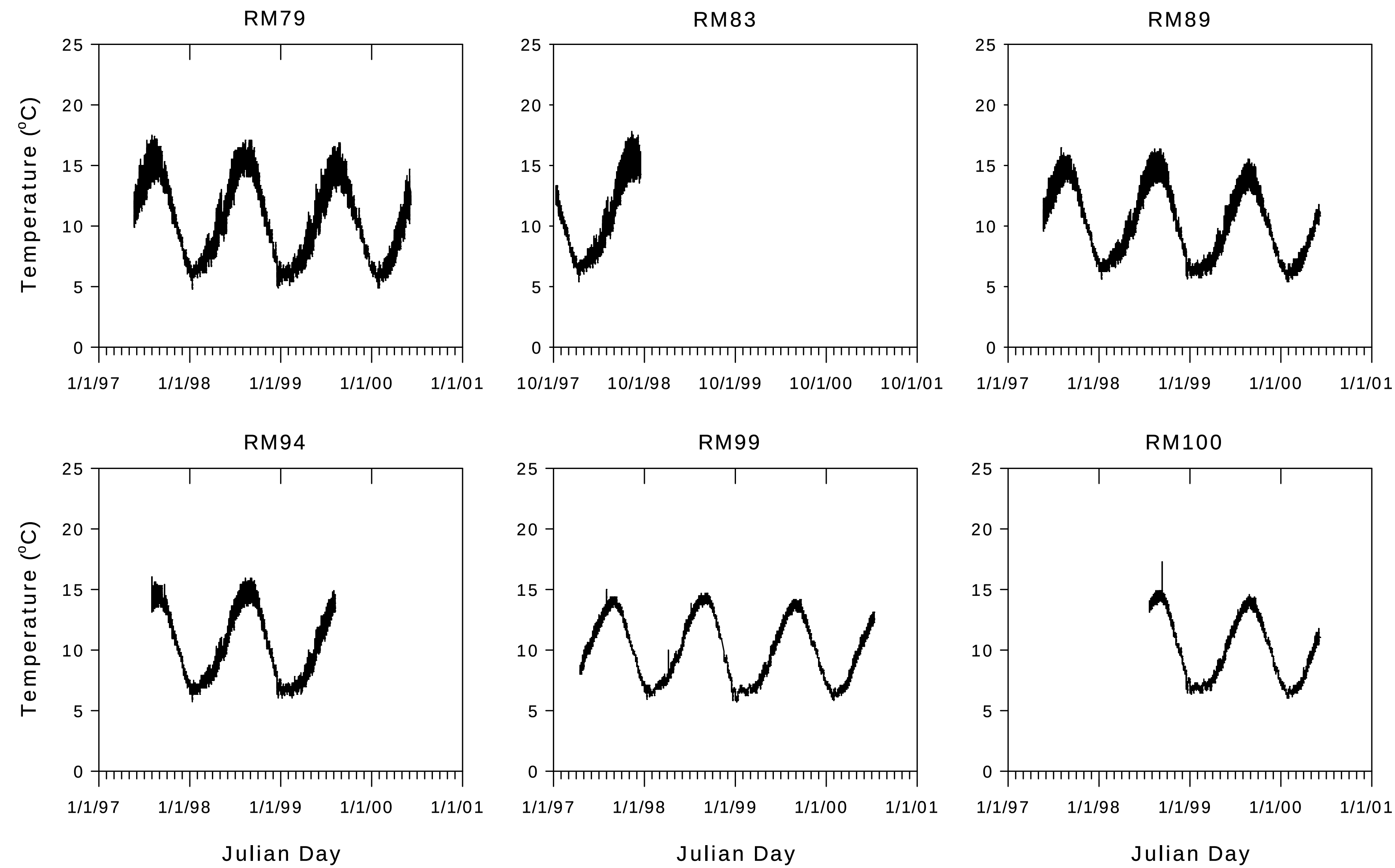

FIGURE 2-13c

CONTINUOUS TEMPERATURE MONITORING DATA FOR 1997 THROUGH 1999 AT RM 79 TO RM 100

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
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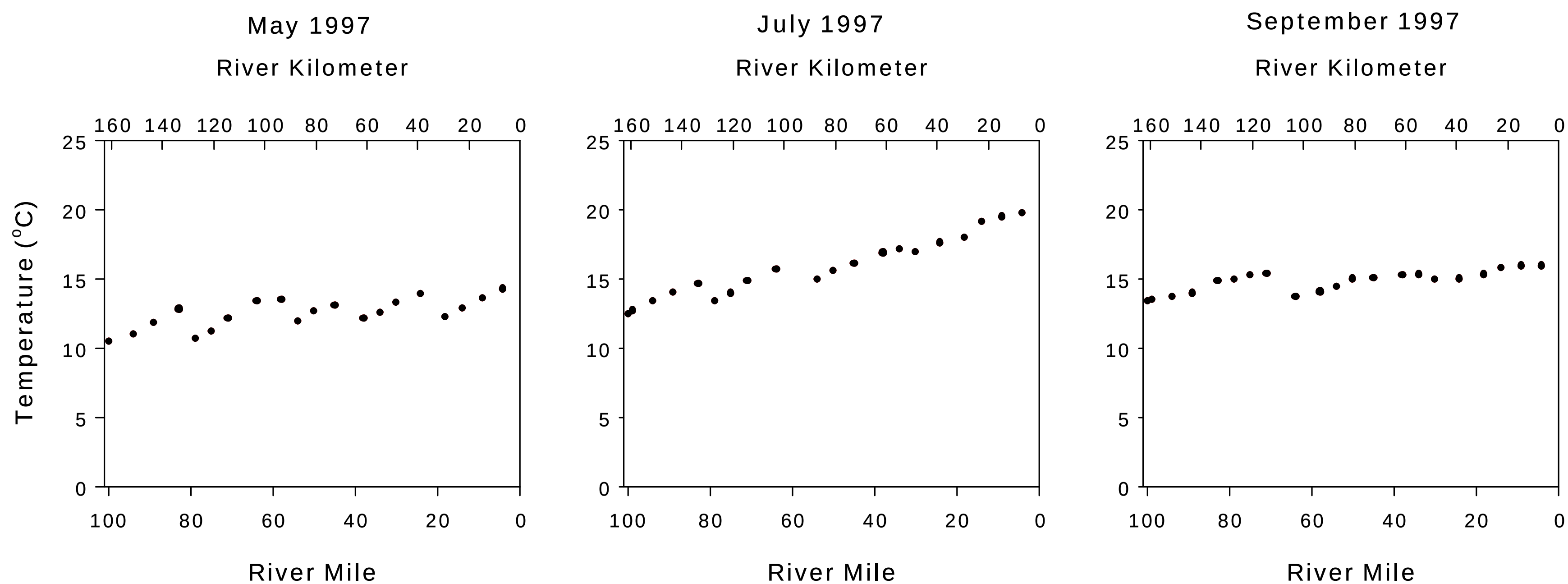

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:	FIGURE 2-14 RIVER SURVEY TEMPERATURE DATA FOR 1997 Portland General Electric Company Portland, Oregon
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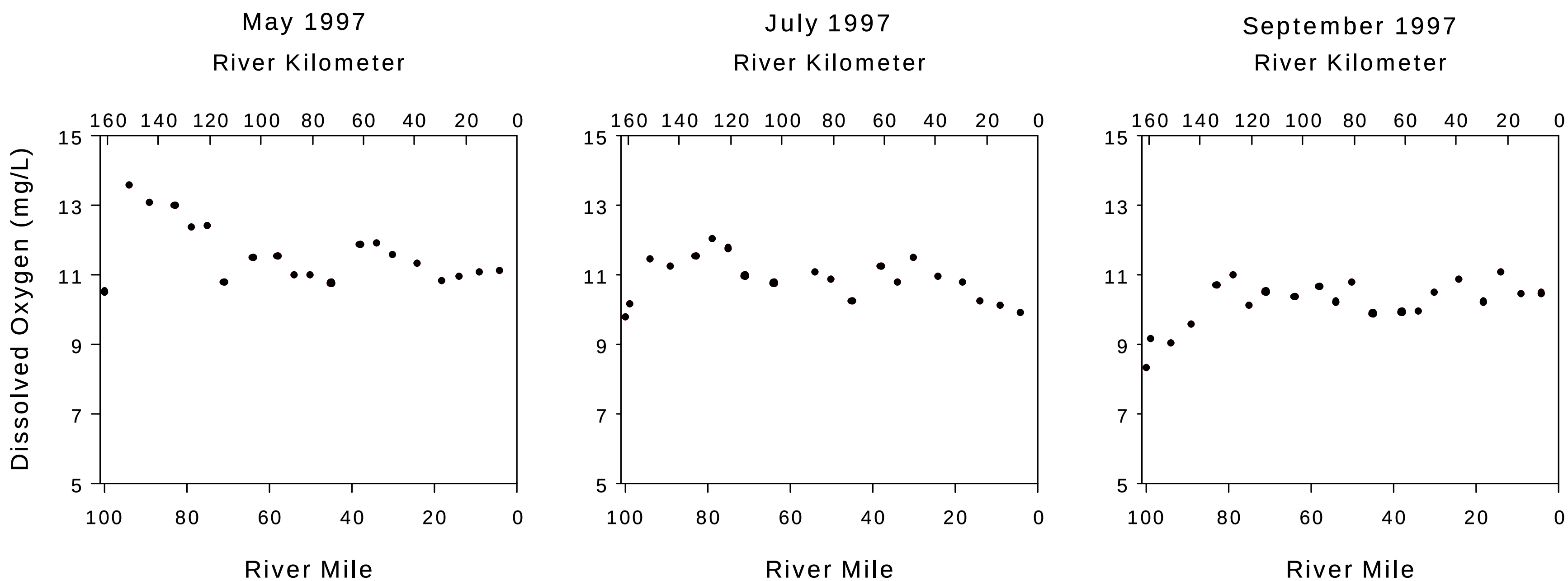
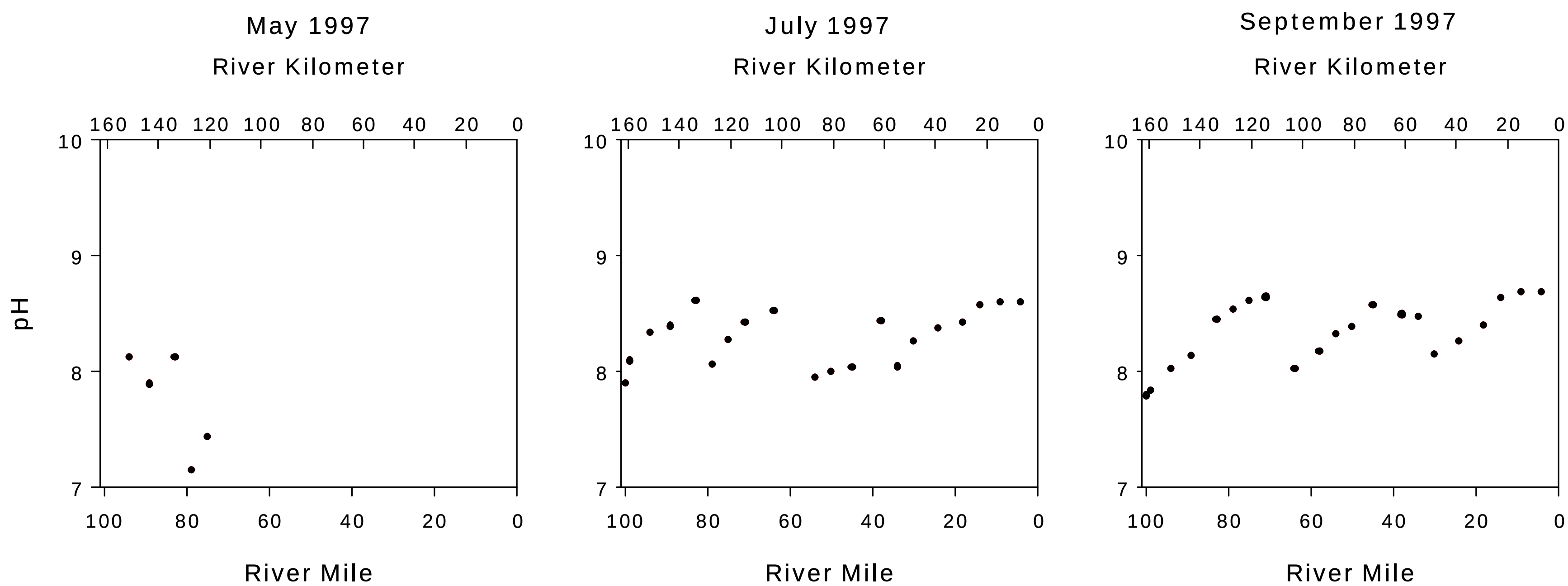
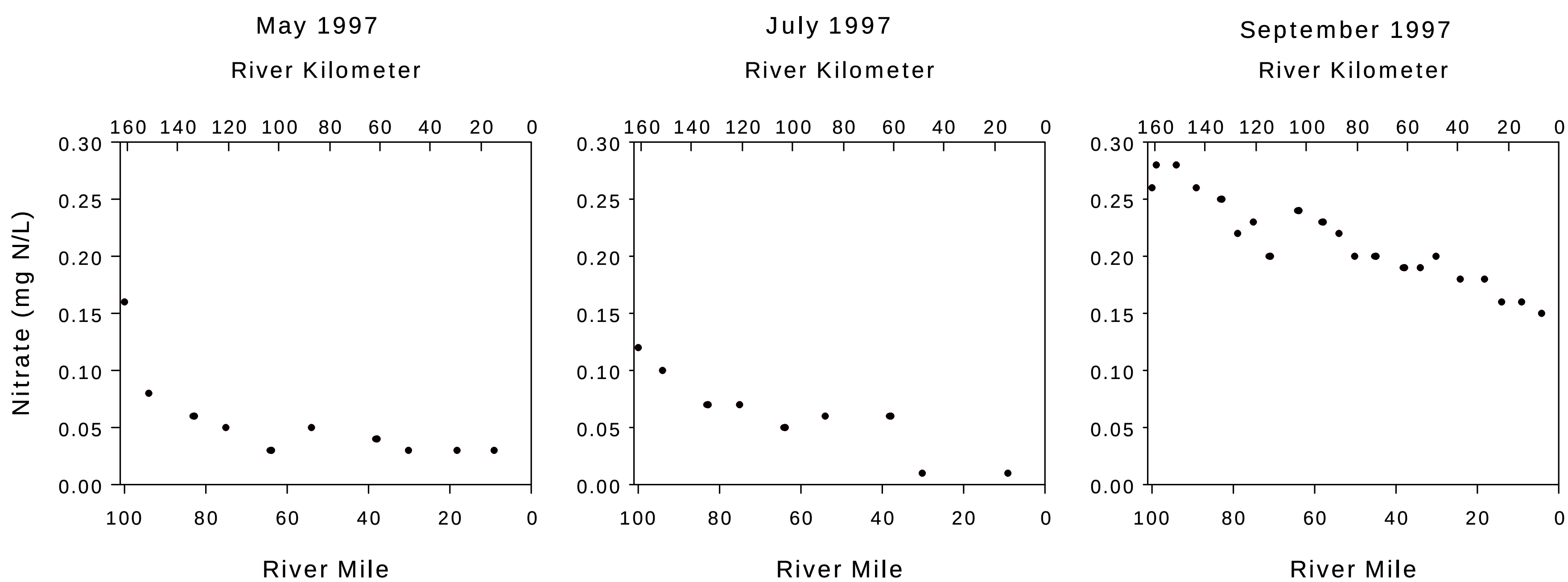


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:	FIGURE 2-15 RIVER SURVEY DISSOLVED OXYGEN DATA FOR 1997 Portland General Electric Company Portland, Oregon
	FILENAME: LDR97data.jnb	CHECKED: T. Khangaonkar	2200.0001.0005	



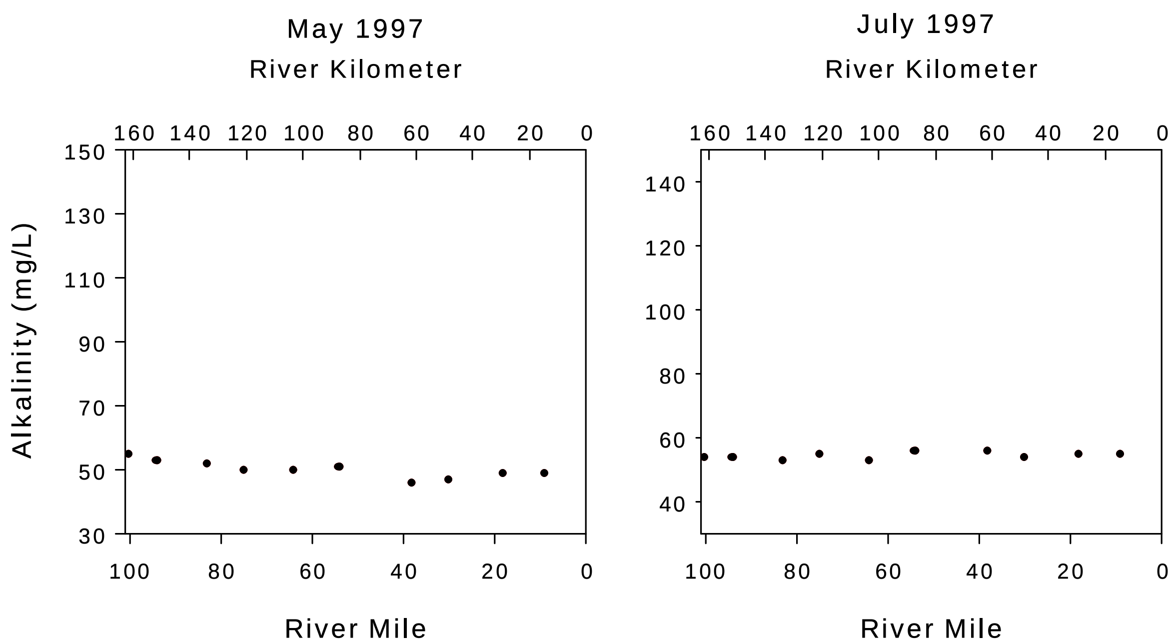
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME: LDR97data.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-16
RIVER SURVEY pH DATA
FOR 1997
Portland General Electric Company
Portland, Oregon



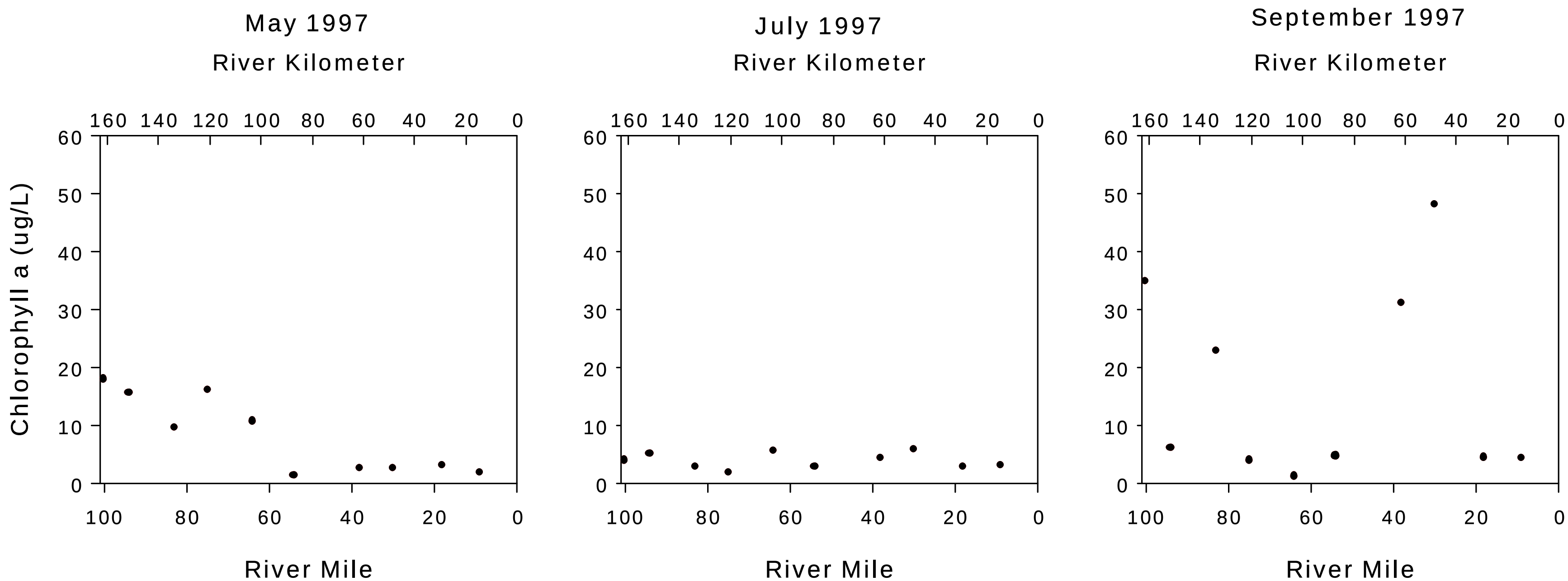
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME: LDR97data.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-17
RIVER SURVEY NITRATE DATA FOR 1997
Portland General Electric Company
Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME: LDR97data.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-18
RIVER SURVEY ALKALINITY DATA FOR 1997
Portland General Electric Company
Portland, Oregon



FOSTER ENVIRONMENTAL WHEELER CORPORATION

DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
FILENAME: LDR97data.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-19
RIVER SURVEY CHLOROPHYLL *a*
FOR 1997
Portland General Electric Company
Portland, Oregon

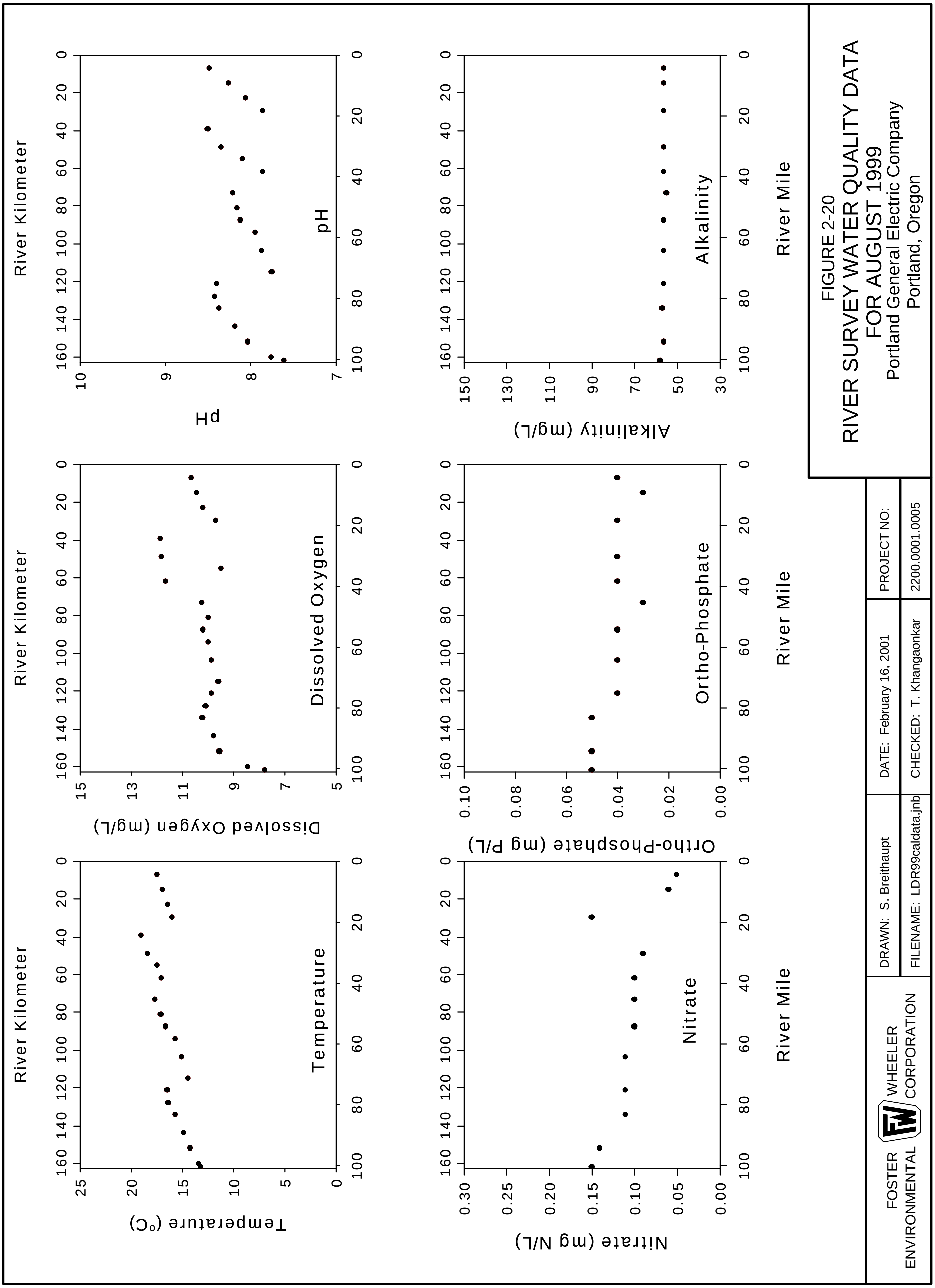
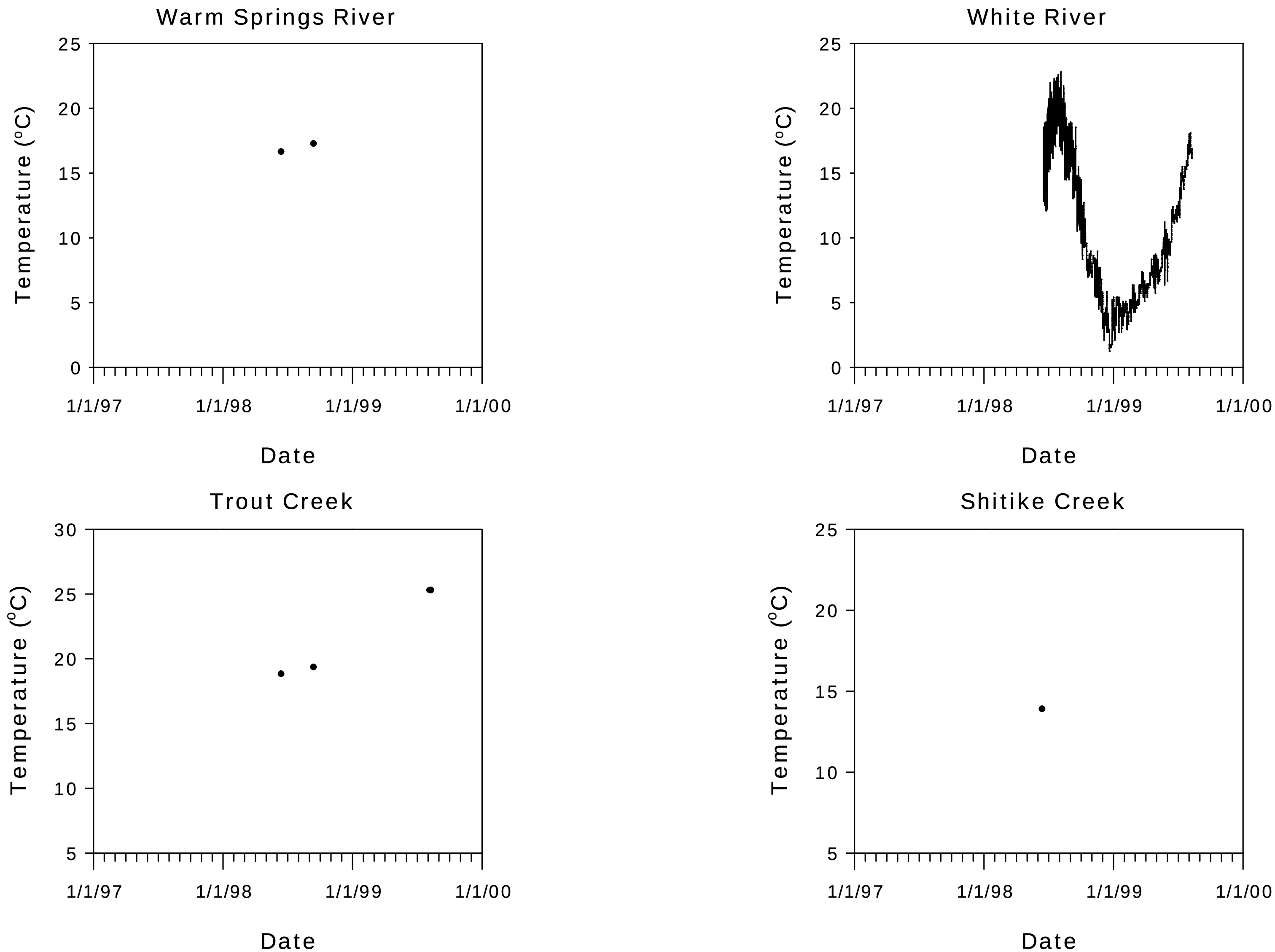
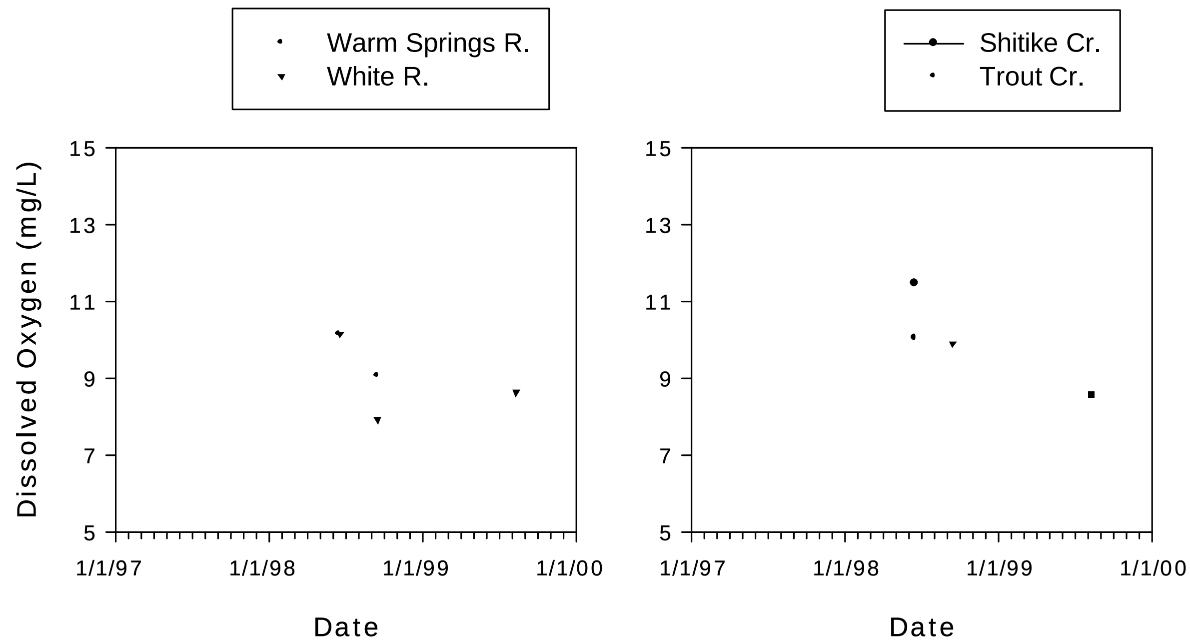


FIGURE 2-20
RIVER SURVEY WATER QUALITY DATA FOR AUGUST 1999
Portland General Electric Company
Portland, Oregon

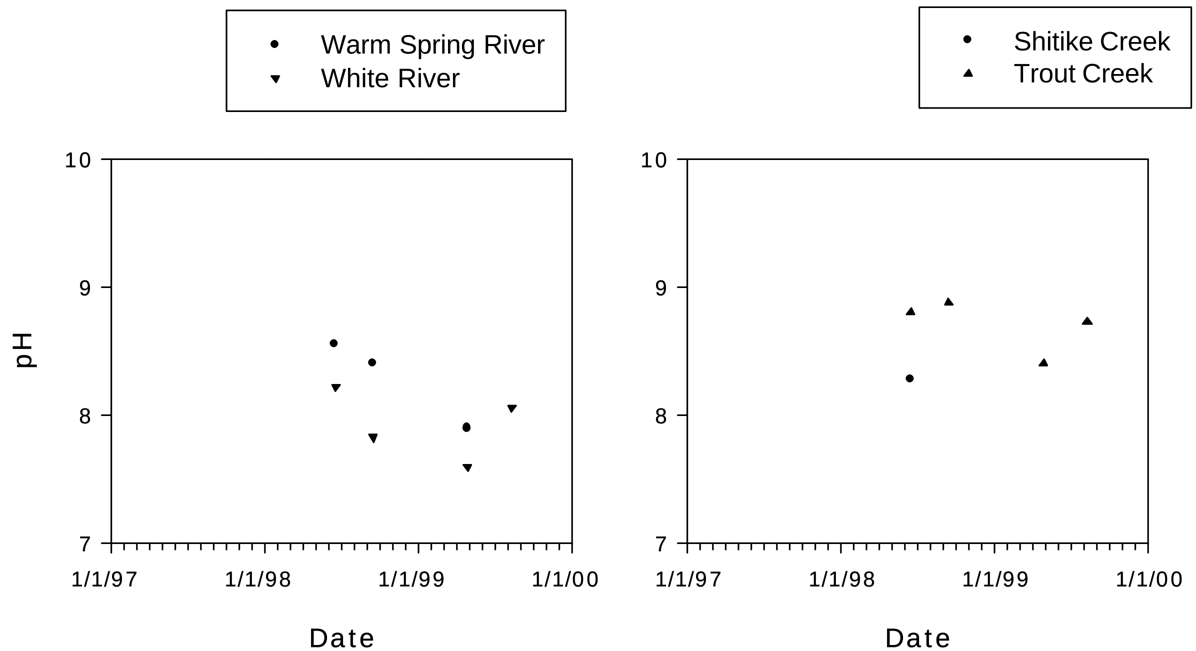


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 26, 2001	PROJECT NO:	FIGURE 2-21
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005	TRIBUTARY TEMPERATURE DATA Portland General Electric Company Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 26, 2001	PROJECT NO:
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-22
TRIBUTARY
DISSOLVED OXYGEN DATA
Portland General Electric Company
Portland, Oregon

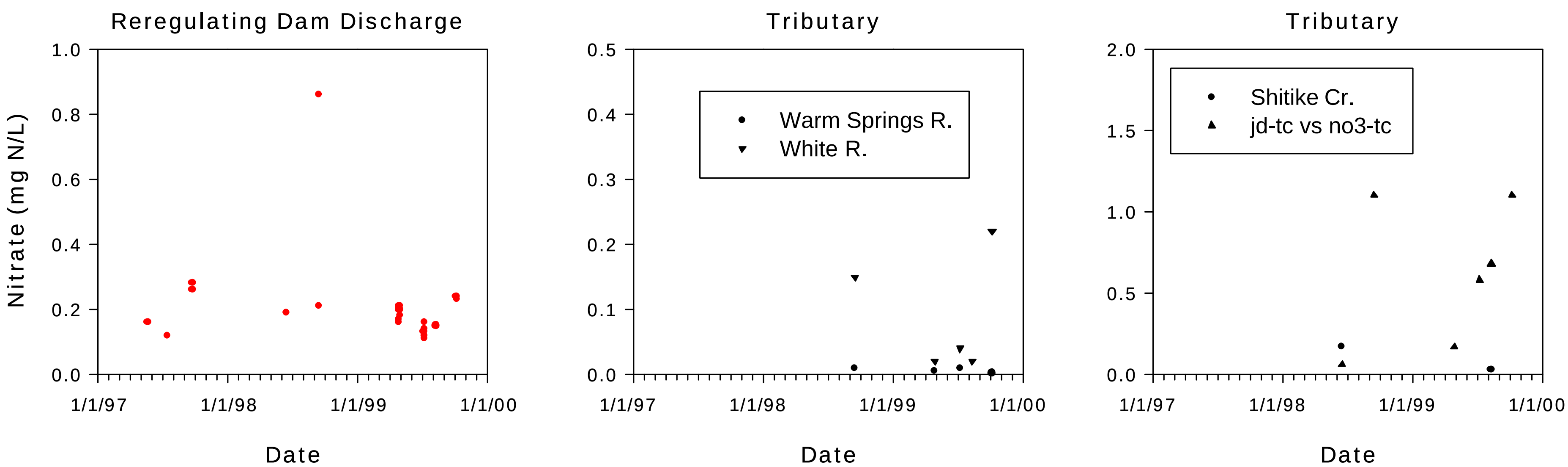


FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 26, 2001	PROJECT NO:
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-23

TRIBUTARY pH DATA

Portland General Electric Company
Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 26, 2001	PROJECT NO:
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 2-24
REREGULATING DAM DISCHARGE AND TRIBUTARY DATA FOR NITRATE
Portland General Electric Company
Portland, Oregon

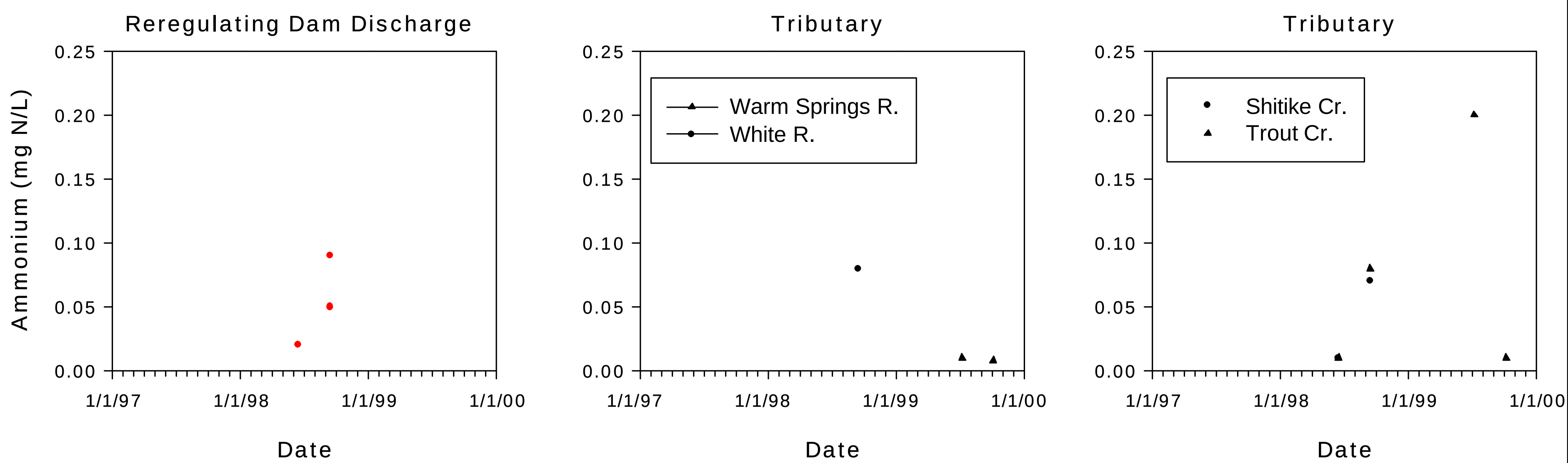


FIGURE 2-25
REREGULATING DAM DISHCARGE
AND TRIBUTARY DATA FOR AMMONIUM
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 26, 2001	PROJECT NO:
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

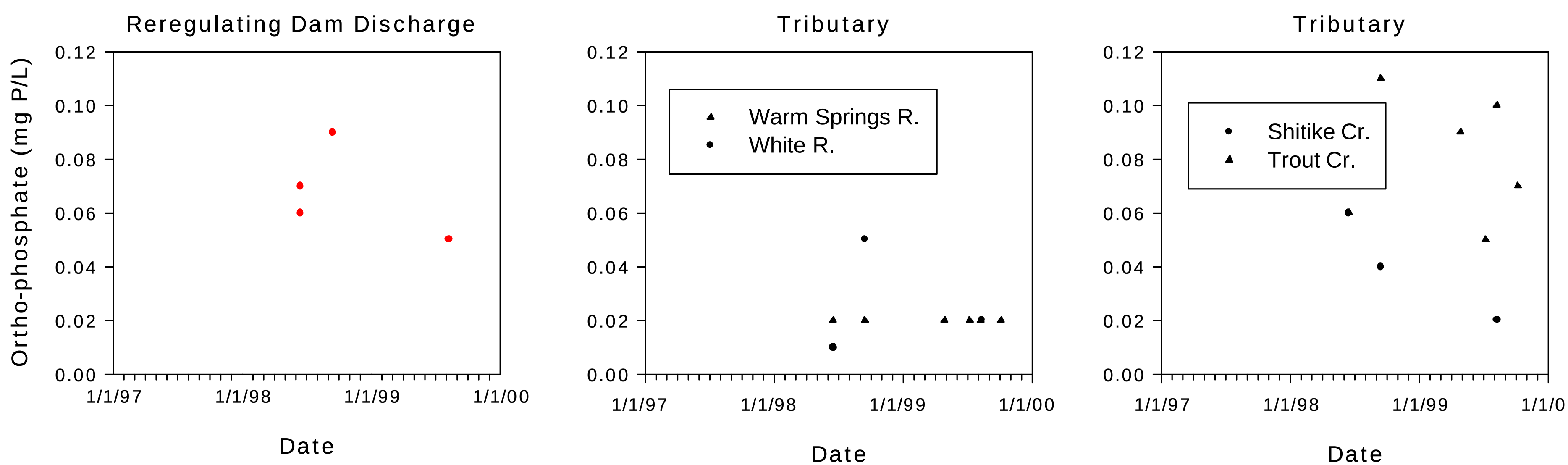


FIGURE 2-26
REREGULATING DAM DISCHARGE AND TRIBUTARY DATA FOR ORTHO-PHOSPHATE
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL / WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: March 26, 2001	PROJECT NO:
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

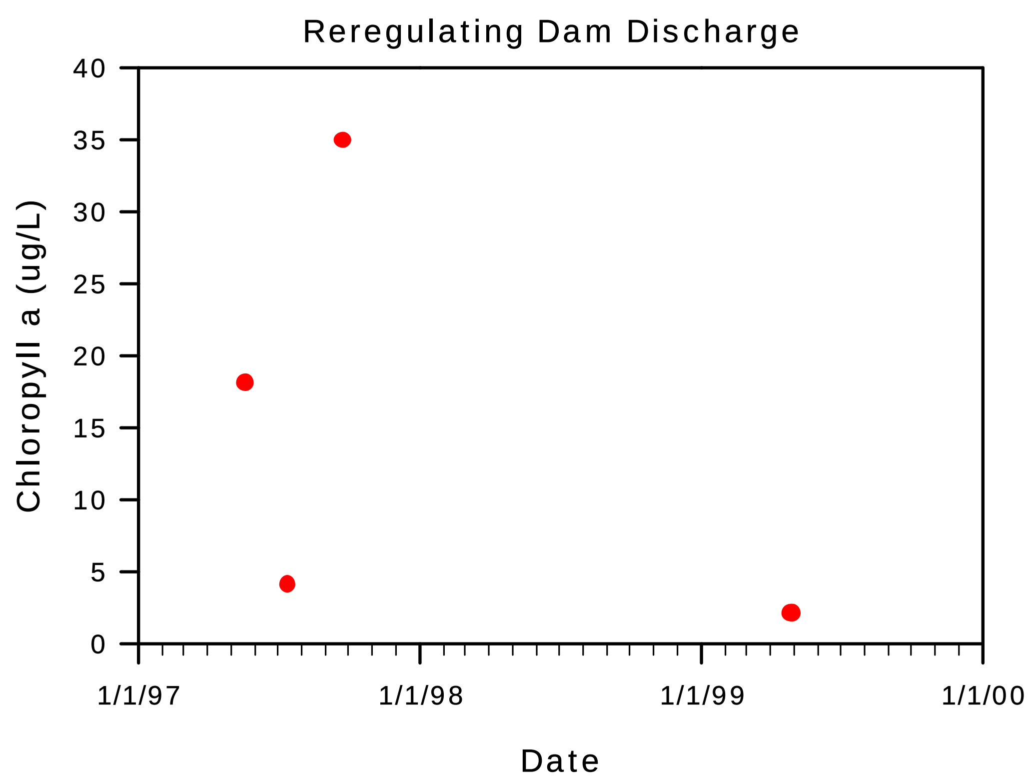
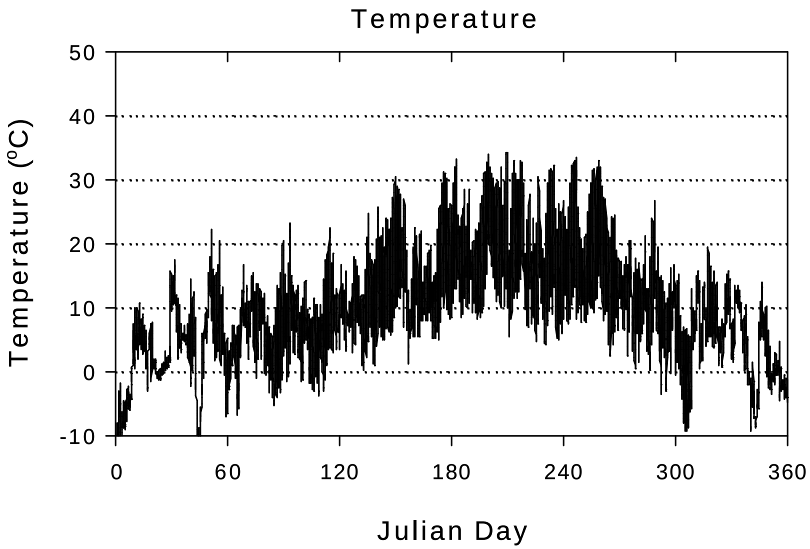
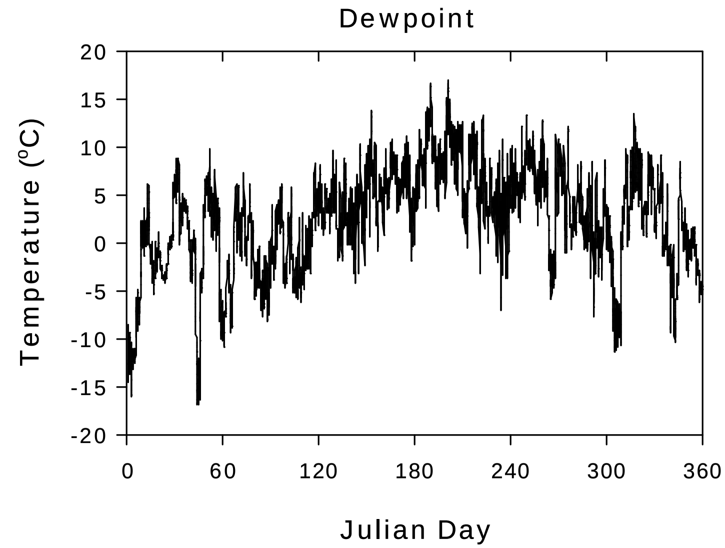


FIGURE 2-27
REREGULATING DAM DISCHARGE DATA
FOR CHLOROPHYLL *a*
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: Tribs.jnb	CHECKED: T. Khangaonkar	2200.0001.0005





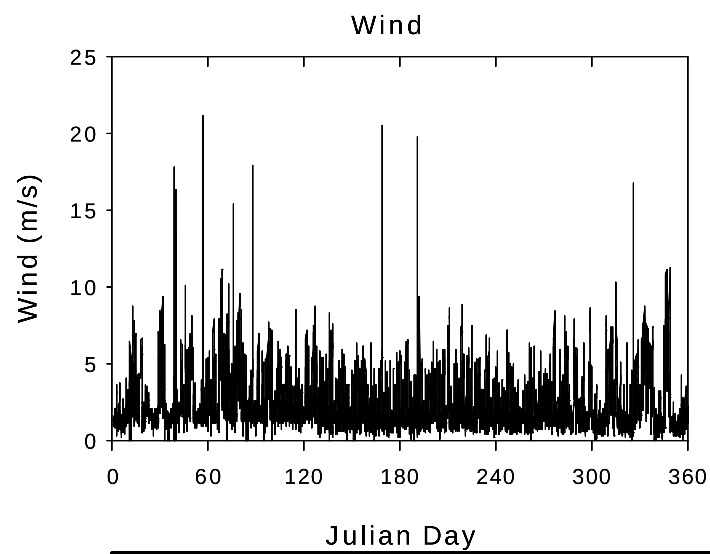


FIGURE 2-28
METEOROLOGICAL DATA FROM THE MADRAS STATION OF THE OREGON SOLAR RADIATION MONITORING LABORATORY FOR 1995
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: metdata.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

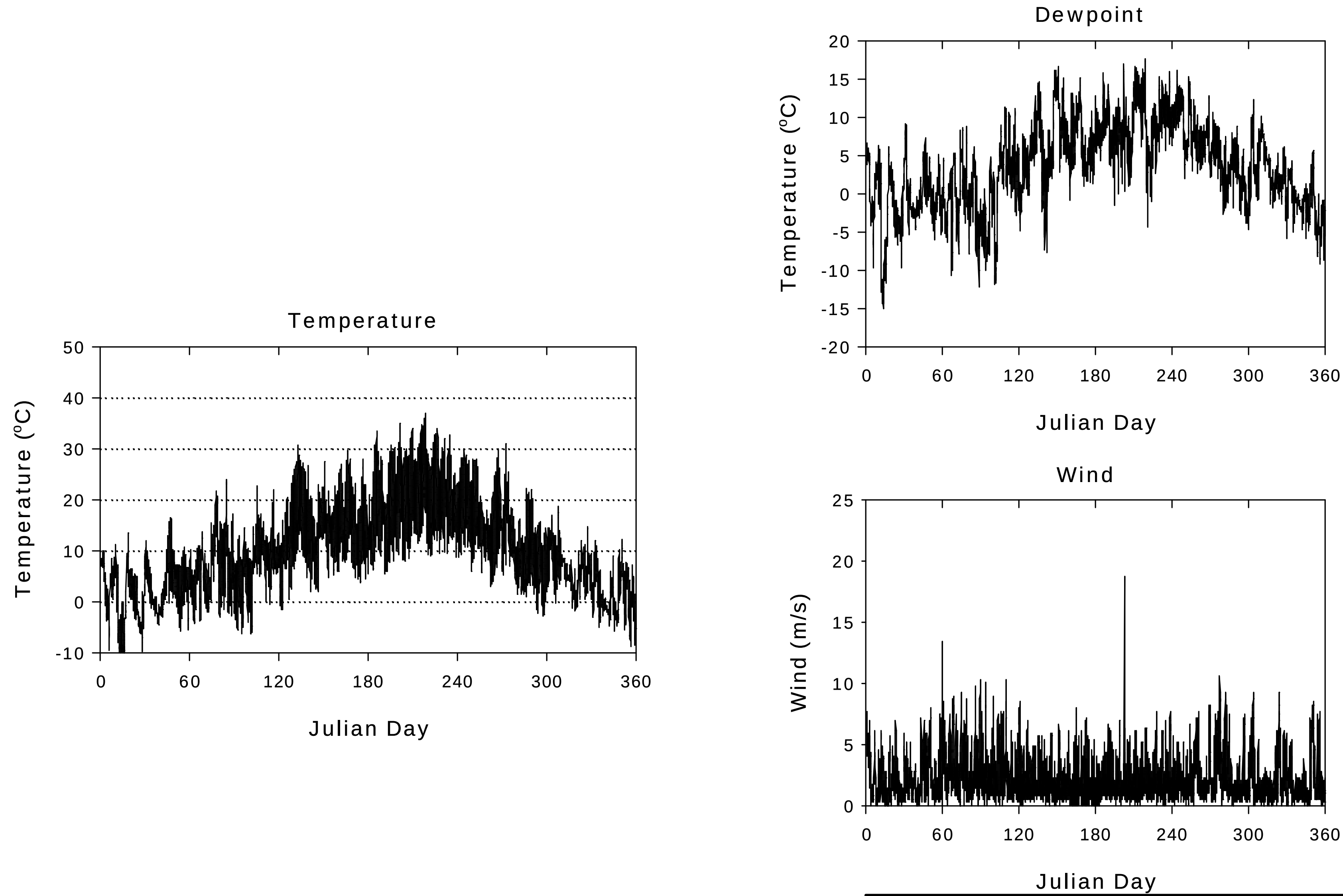


FIGURE 2-29
METEOROLOGICAL DATA FROM THE MADRAS STATION OF THE OREGON SOLAR RADIATION MONITORING LABORATORY FOR 1997
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL FW WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: metdata.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

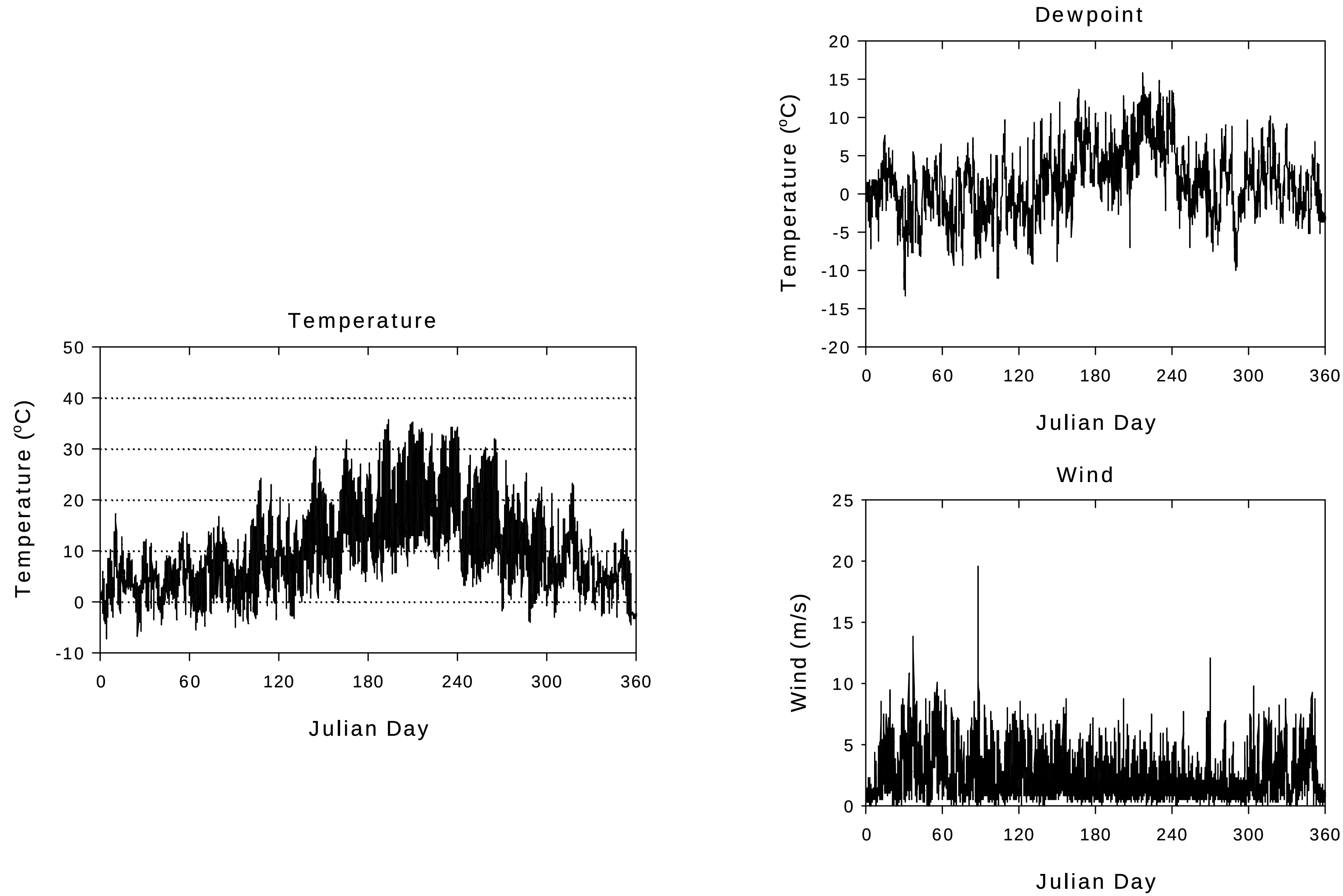


FIGURE 2-30
METEOROLOGICAL DATA FROM THE MADRAS STATION OF THE OREGON SOLAR RADIATION MONITORING LABORATORY FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL FW WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: metdata.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

3. HYDRAULIC MODEL SETUP AND VALIDATION

3.1 INTRODUCTION

The hydraulic model RMA2 provides the velocity and depth data to drive the water quality model RMA4q. The hydraulic model uses the river geometry and hydrologic inputs (boundary conditions) to compute the velocities and depths at each model grid point. RMA2 can be set up in 1-D and/or 2-D mode; for application to the Lower Deschutes River, the 1-D mode is appropriate. This assumes the river is completely mixed, both vertically and laterally, which is a reasonable assumption considering the fast flowing, turbulent nature of the Lower Deschutes River.

3.2 MODEL SETUP

The first step in RMA2 model setup involves specifying the river geometry. For 1-D simulations, this is provided through a cross-section description at each node (xy coordinate location, bed elevation, bed width, and side slope angles). The model assumes the river is described by trapezoidal cross-sections; thus, measured cross-section data are converted into equivalent trapezoidal cross sections. The grid was created by combining the processed cross-section data and the geometry data describing the plan view Lower Deschutes River.

The second step involves defining the hydrologic data input that is specified as model boundary conditions. For calibration, the 1999 calendar year data were used. A flow balance was necessary to account for unmeasured tributary inflows, so that inflows equaled the outflows.

The model was run at an hourly time step. This provided sufficient temporal resolution to accurately represent diurnal variations, and also provided a large enough time step to keep computational costs low.

3.2.1 Lower Deschutes River Cross-sections

Cross-section data were available from the U.S. Geological Services (Miller, 2000) and the Oregon Department of Transportation (ODOT, 2000), but these are only for a small number of locations (see Figure 2-3). PGE measured 41 additional cross-sections in 2000 specifically for this project. Of these 41 cross-sections, data were lost from four stations. This gave a total of 54 cross-sections for analysis and grid interpolation.

The cross-section data were processed in a Microsoft Windows program (VisualRMA) written for the creation of 1-D networks for the RMA models. VisualRMA reads the data as xyz coordinate locations, with a horizontal datum of NAD1927, and a vertical datum of NGVD1929. A trapezoidal cross-section was then fitted for each measured cross-section.

3.2.2 Model Grid

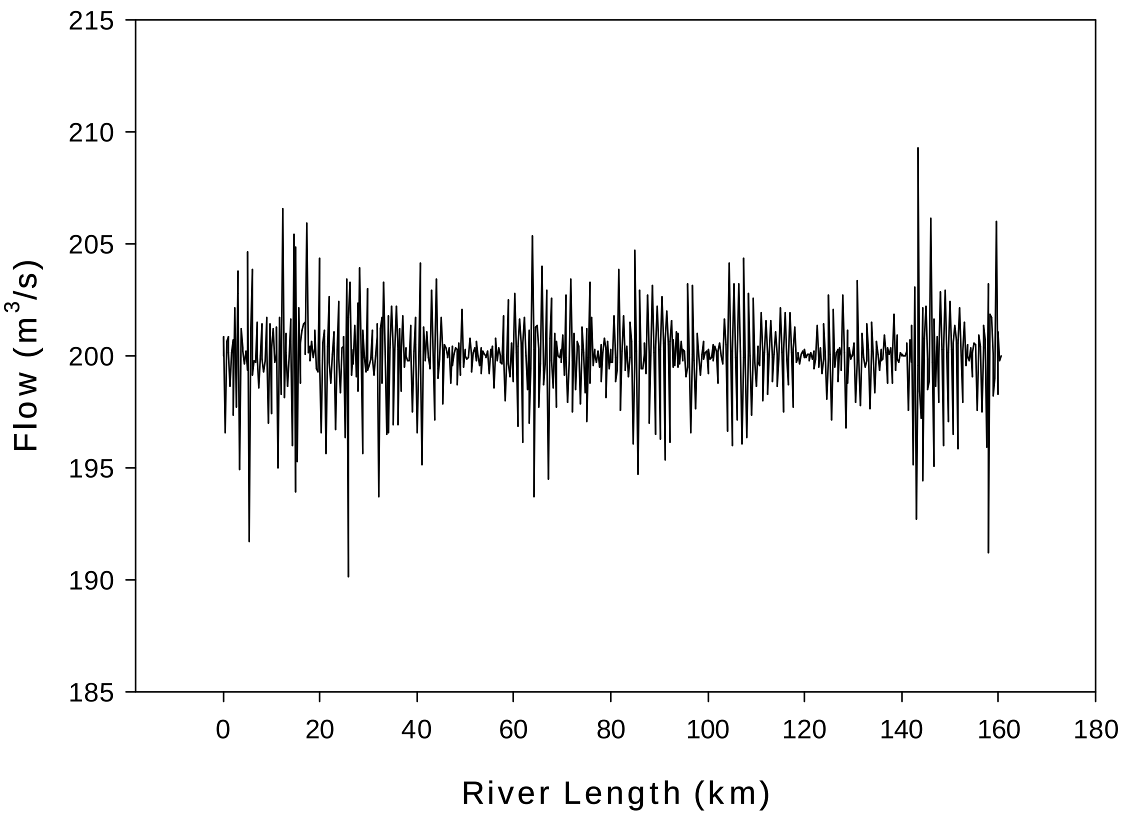
The horizontal geometry of the Lower Deschutes River was digitized from plan view GIS maps using VisualRMA. This created a set of horizontal locations that define the Lower Deschutes River channel, on which the 1-D model grid was built. Waterfalls were implicitly included as defined by the cross sections described above.

Cross-section data were entered as xyz coordinate locations (NAD1927 and NGVD1929) and were plotted with the digitized channel. Each cross-section was plotted as lateral distance across the channel versus elevation.

The grid was created by determining the distance of each cross-section along the length of the channel. Intermediate cross-sections were interpolated from the existing cross-section data. The nominal distance between nodes was specified as 250 meters. The actual length varies so as to provide a whole number of nodes between measured cross-sections. The interpolations were made using a cubic spline method; this provided smoother geometry to minimize the occurrence of instabilities in the numerical solution of the hydrodynamic and water quality transport equations. Note that for the reach between RM 22 and 40 (RK 36 and 64), where cross-section data were not available, grid data were also interpolated from measured cross-sections at either end.

The grid resolution was tested by setting the flow boundary condition to 7062 cfs (200 m^3/s). This was run to steady-state, and computed flows were examined to evaluate flow mass balance. If it was seen that in a particular location the flow deviated from 200 m^3/s by more than 5%, the grid resolution was doubled in the location. This was done iteratively, until all regions met the flow mass balance criteria (Figure 3-1).

Tributary channels for Shitike and Trout Creeks and Warm Springs and White Rivers were also added to the system in a manner similar to that described above. Junction elements



Note: grid resolution adjustments were made to get the flow mass balance to fall within +-5%.

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FIGURE 3-1
FLOW MASS BALANCE CHECK OF GRID RESOLUTION
Portland General Electric Company
Portland, Oregon

were required that maintained flow continuity. These were created when the main stem and tributary grids were merged.

3.2.3 Input Data

There is a total of 739 nodes in the grid, with 40 of those nodes in the tributaries, and the remaining 699 in the Lower Deschutes River. Because the models are finite element models, there are nodes associated with the elements, with three nodes per element for 1-D grid sections. The elements can be defined as different types, which gives spatially varying element characteristics. In the case of the RMA2, the characteristics are eddy diffusivity and bed roughness.

For the Lower Deschutes River, two element types were specified for hydraulic characteristics – one for the main stem and the other for tributary stubs. Eddy diffusivity was set as a function of the nominal element length. The bed friction (Manning's "n") in the main stem was set to 0.03 for the bed and banks, while in the tributary stubs, Manning's "n" was set to 0.08 for the bed and 0.05 for the banks. Higher values were used in the tributaries to ensure stability with low flows and the use of nominal cross-section data.

3.2.4 Flow Balance and Model Boundary Conditions

Hydrologic data for the whole of calendar year 1999 were available for the Lower Deschutes River from the Madras gage, the Moody gage, and for the tributaries Shitike Creek and Warm Springs River. A partial set of data were available from Trout Creek covering October through December, 1999. No data were available in 1999 for the White River, a major tributary to the Lower Deschutes River.

Because the White River and Trout Creek were missing hydrologic data, it was necessary to estimate the flows of each tributary for 1999. For Trout Creek, data have been collected for most of 2000. These data were spliced with the 1999 data, and monthly averages computed. Because the flow was much smaller than the main stem flows, the monthly averages were used as the Trout Creek hydrograph. For the White River, flow data were available for 1987, 1988, and 1989. An initial estimate of White River flow was made by determining a monthly scale factor to the Moody gage flow. The monthly scale factor was accomplished by (1) computing daily ratios for each year of measured flows in the White River to corresponding flows in the Lower Deschutes River at the Moody gage; (2) then computing the daily average of ratios of all three years; (3) and finally averaging the daily average ratios monthly. The monthly ratios between the White River and the Moody gage were used to estimate an initial 1999 hydrograph.

The difference between all known and estimated inflows (Regulating Dam discharge, Shitike Creek, Trout Creek, Warm Springs River, and White River) and the flow at the Moody gage provided an initial estimate of groundwater inflow. However, the groundwater estimate was thought to be too great, being as large as the White River. It also had a large daily variation, which was also thought to be excessive. A re-evaluation of the system was made wherein it was assumed that most of the difference between measured/estimated inflows and outflow from the system at the Moody gage would be assigned to the White River only, and groundwater was assumed to be small.

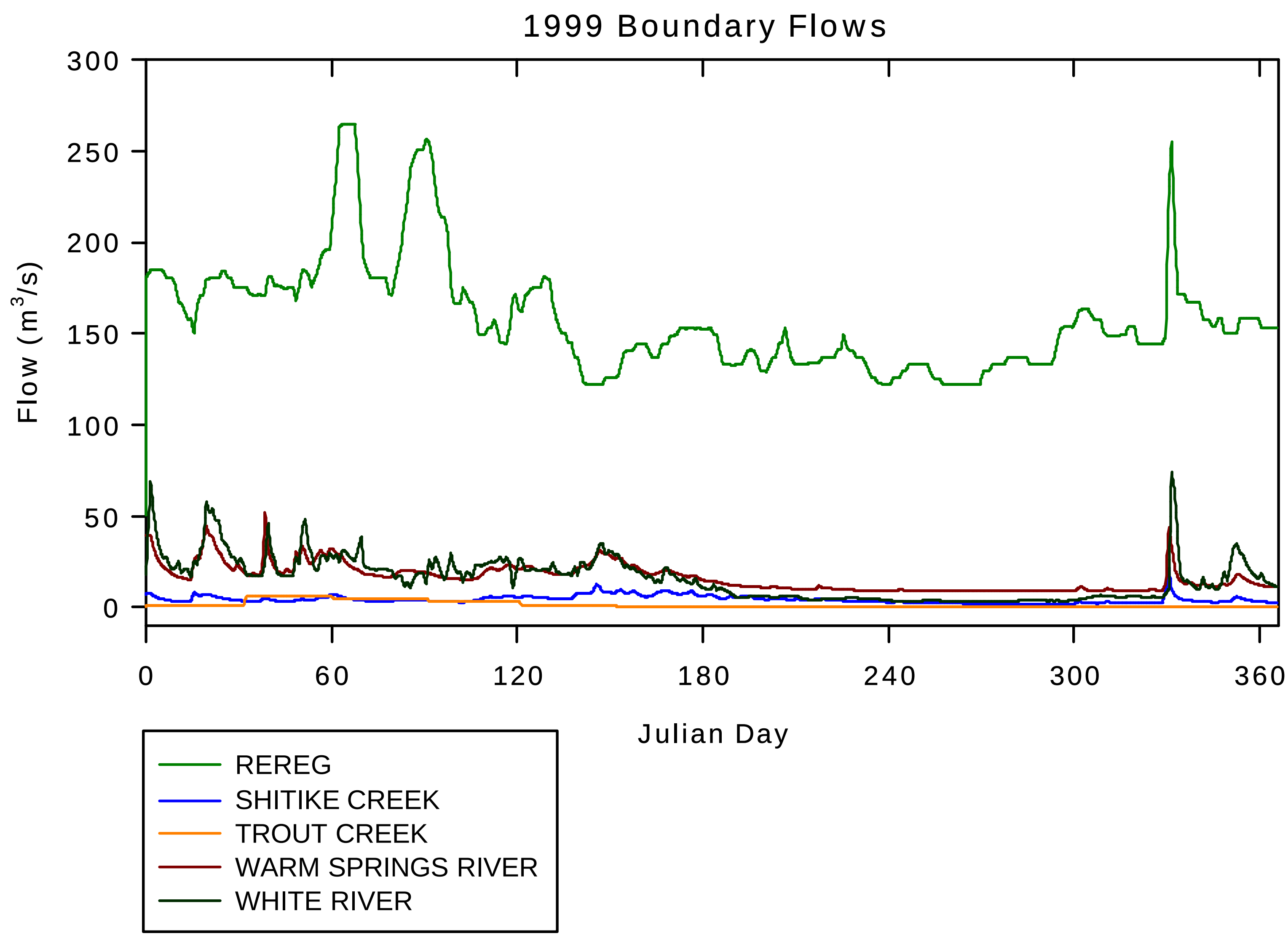
For 1997 verification year flows, the Madras gage, the Moody gage, the Shitike Creek gage, and the Warm Springs River gage hydrologic data were available for the whole year. Trout Creek data for 1997 were assumed to be the same as for 1999. The White River flow was estimated in the same manner as for 1999. For 1995 application year flows, the Madras gage, the Moody gage, and the Warm Springs River gage hydrologic data were available for the whole year. Shitike and Trout Creeks were estimated from 1997 and 1999 data, and White River flow was estimated as was done for 1999.

The results of the flow balance for the years 1999, 1997, and 1995 are shown in Figures 3-2, 3-3, and 3-4, respectively.

3.3 MODEL EVALUATION

The model was evaluated by applying the measured and estimated inflows for 1999 and 1997 and comparing with measured flow at the Moody gage near the mouth of the Lower Deschutes River. Comparisons of results are seen in Figures 3-5 and 3-6. The figures show the mean daily measured flow from the Moody gage and hourly flow computed by the hydraulic model at the system's outflow. The results agree very closely. This shows (1) the flow balance is reasonable, at least in terms of system-wide results, and (2) the model accurately routes the flows through the system. It would be desirable to make comparisons at locations within the Lower Deschutes River channel, other than at the mouth. However, such data are not available.

It was observed that the model flood peak of JD 332.5 (254.6 m^3/s) reached the mouth at JD 332.88 (368.47 m^3/s), which is an elapsed time of 9.12 hours. This indicates travel time through the Lower Deschutes River is very short.



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	FILENAME: flows.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE 3-2
LOWER DESCHUTES RIVER MODEL
BOUNDARY FLOWS FOR 1999
Portland General Electric Company
Portland, Oregon

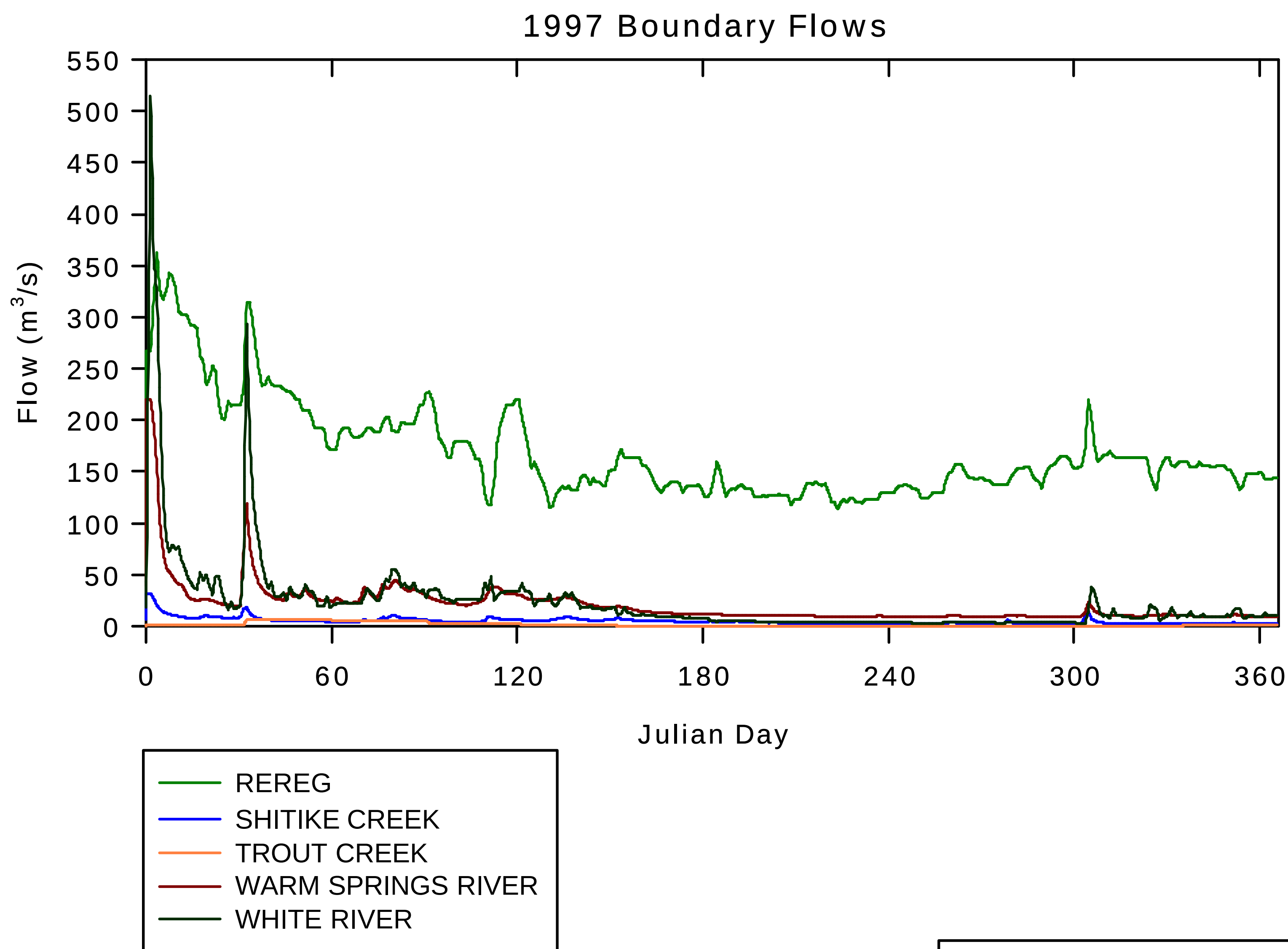

FIGURE 3-3
LOWER DESCHUTES RIVER MODEL
BOUNDARY FLOWS FOR 1997
Portland General Electric Company
Portland, Oregon

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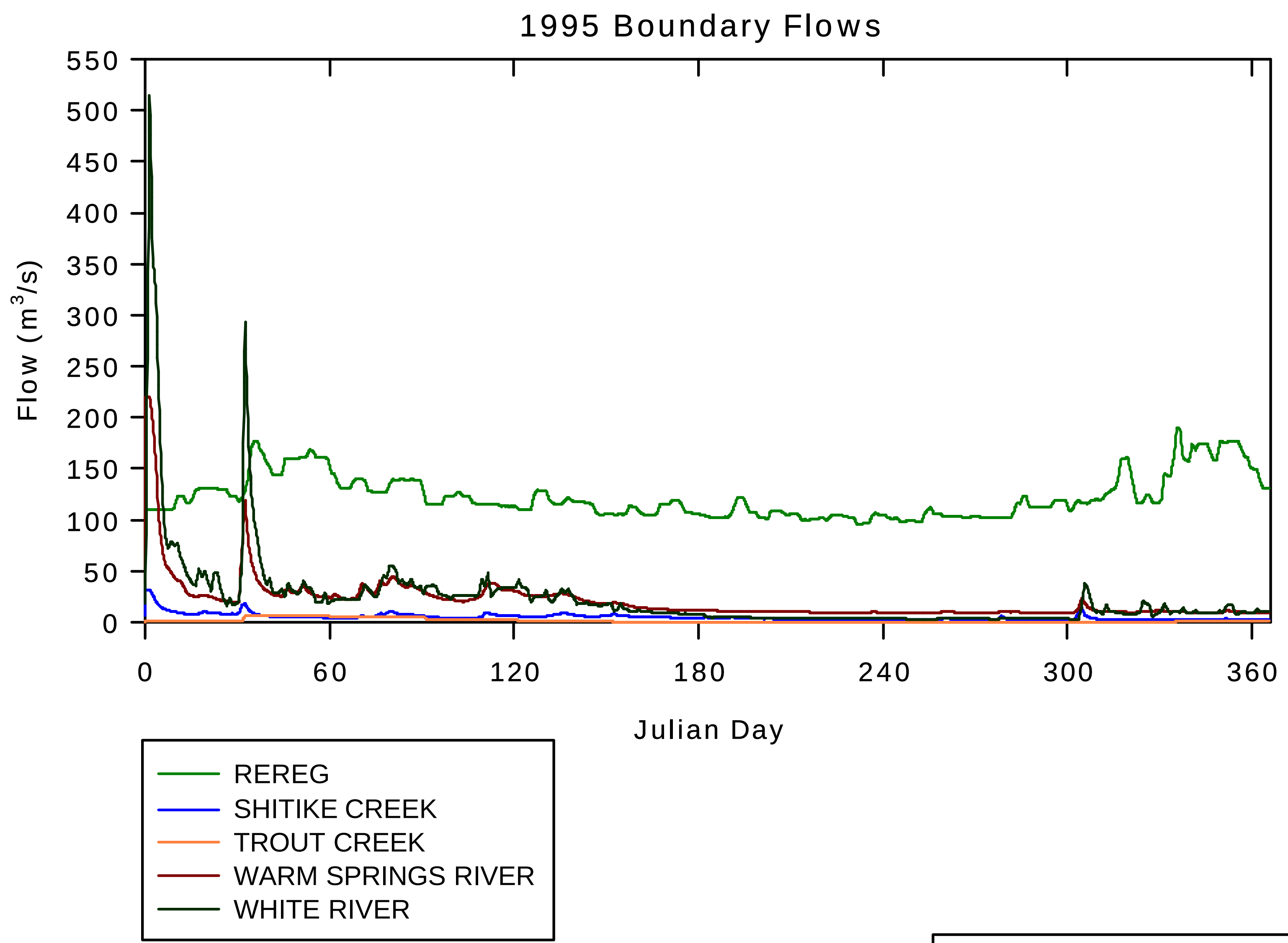
	FILENAME: flows.jnb	CHECKED: T. Khangaonkar	2200.0005.0003



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 22, 2001	PROJECT NO:
	FILENAME: flows.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE 3-4
LOWER DESCHUTES RIVER MODEL
BOUNDARY FLOWS FOR 1995
Portland General Electric Company
Portland, Oregon

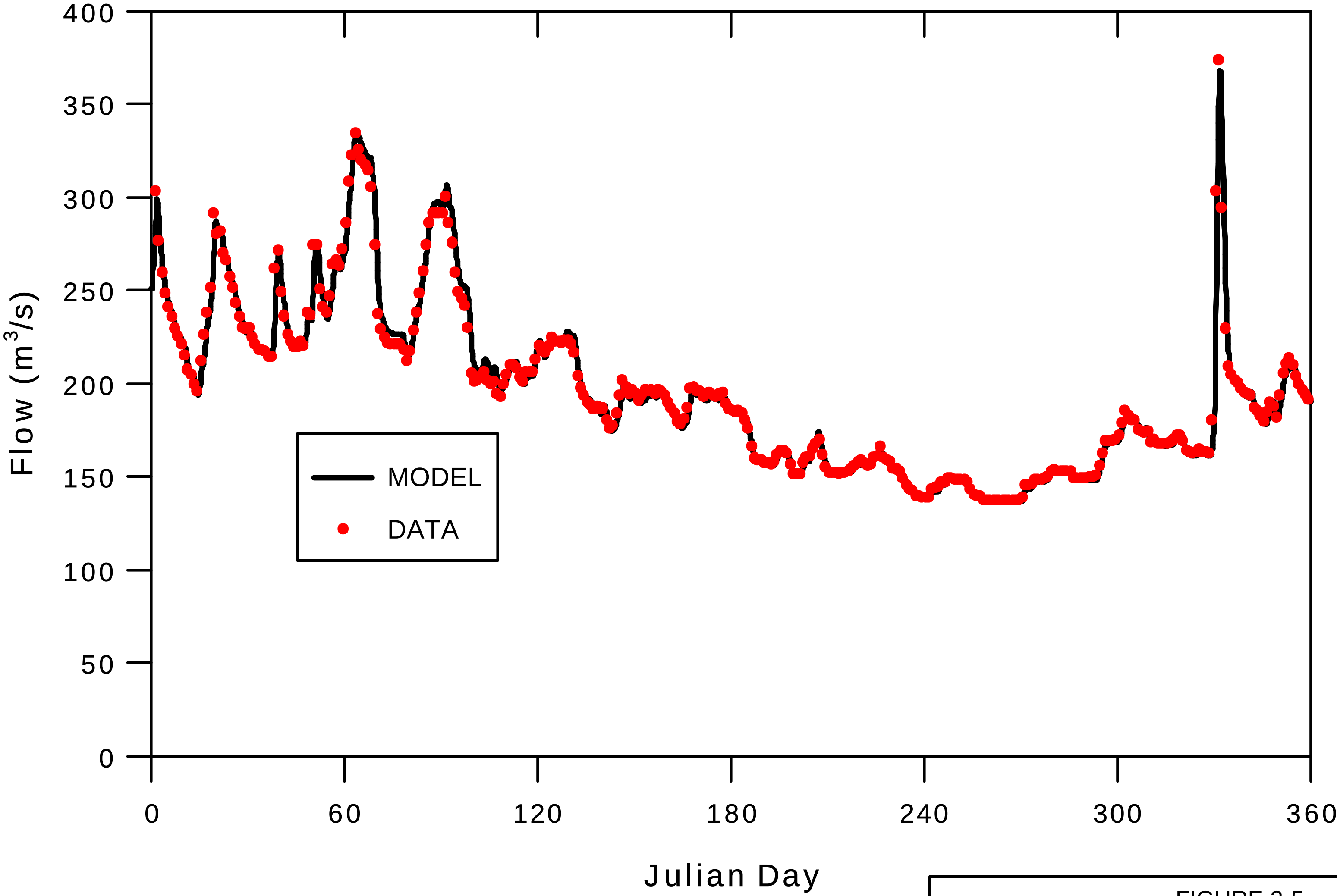


FIGURE 3-5
LOWER DESCHUTES RIVER MODEL
CALIBRATION FLOWS AT MOODY GAGE
FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 22, 2001	PROJECT NO:
	FILENAME: flows.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

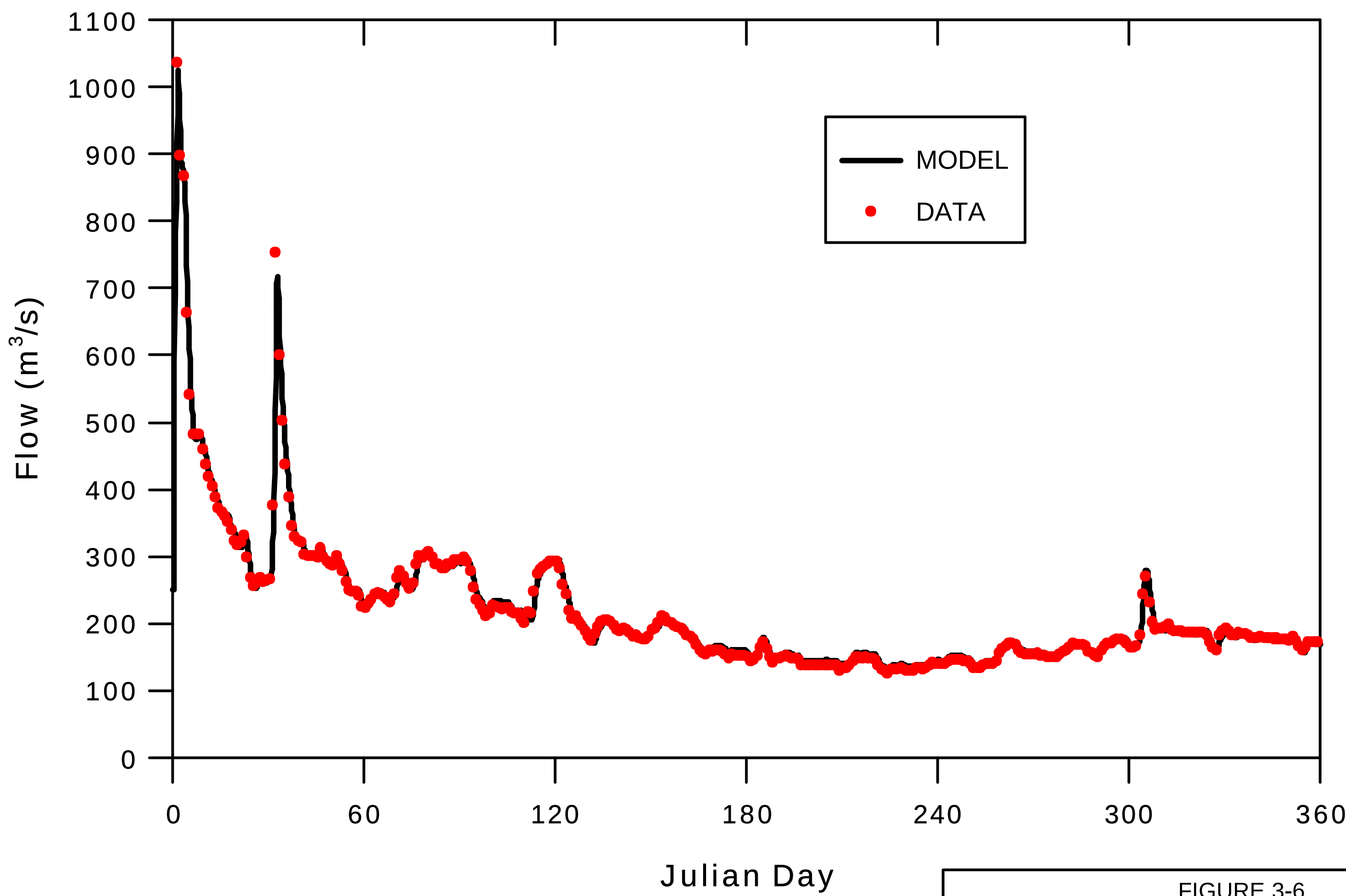


FIGURE 3-6

LOWER DESCHUTES RIVER MODEL
CALIBRATION FLOWS AT MOODY GAGE
FOR 1997

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 22, 2001	PROJECT NO:
	FILENAME: flows.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

4. WATER QUALITY MODEL SETUP AND CALIBRATION

4.1 INTRODUCTION

The water quality model RMA4q is a companion to the hydraulic model RMA2. It also uses finite element method for solution of the transport equations. RMA4q accounts for the advective transport and kinetic relations for several water quality constituents. The version used for the Lower Deschutes River solves for temperature, alkalinity, total inorganic carbon, ammonia, nitrite, nitrate, ortho-phosphate, dissolved oxygen, and suspended algae, with pH computed from the alkalinity, total inorganic carbon, and temperature data. Additionally, and importantly for riverine systems, the model has benthic processes sub-models, including periphyton. The periphyton model is based on Breithaupt (1997). RMA4q was also modified for this project to provide pH and organic matter handling.

Its ability to handle periphyton was a primary reason for choosing the RMA2 and RMA4q model set. Periphyton are particularly important in the lower river, since the residence time of the water column is very short; transit times through the length of the river from the Regulating Dam discharge to the mouth are less than 24 hours for the 162-km (100-mile)-long river. This short residence does not allow the conventional phytoplankton water column process enough time to produce the variations seen in dissolved oxygen and pH; only growth of periphyton can account for these variations. The velocity and depth results generated by RMA2 are read by RMA4q during water quality simulation, and the values are then input to the transport equations. Velocity affects transit times through the system. Depth affects light penetration and influences the constituent flux with the benthic community. Both velocity and depth influence reaeration rates of dissolved oxygen and carbon dioxide.

4.2 MODEL SETUP AND MODEL GRID

The water quality model RMA4q utilizes the grid developed for the RMA2 hydraulic model, as well as the velocity and depth results generated by RMA2. The biological component and its affect on water column constituents is assumed to be dominated by periphyton, as stated in E&S (2000). Constituent reactions in the water column were assumed relatively insignificant because of the short residence time. These include suspended algal growth and organic matter decay.

For water quality transport, many input parameters and coefficients were varied by element type; that is, they varied spatially (see Table 4-1). Meteorological data were also varied by element type. While the hydraulic model had one element type for the main stem and one for the tributaries, the water quality model used four element types encompassing three sections of the main stem to account for climatic variability within the canyon occupied by the Lower Deschutes River: an upper section (RM 100 to 73; RK 161 to RK 118), a mid-section (RM 73 to 38; RK 118 to RK 64), and a lower section (RM 38 to 0; RK 62 to RK 0.0).

Table 4-1. Model Element Types and Location

Element Type	River Kilometer	River Mile
1	161 – 127	100.1 – 78.6
2	tributaries	tributaries
3	118 – 62	73.1 – 38.3
4	62 – 0.0	38.3 – 0.0
5*	127 – 118	78.5 – 73

Note: *This type was added to accommodate the falls along the Lower Deschutes River, but subsequent analysis showed insignificant differences to model calibration when accommodation was not made.

Input data for the periphyton model were also defined spatially (see Table 4-2). The node type locations largely correspond to the locations where calibration data were collected.

Table 4-2. Periphyton Nodal Types and Location

Node Type	River Mile
1	100.1 – 73.3
2	tributaries
3	73-3 – 40
4	21.9 – 40.0
5	21.9 – 0.0

4.3 MODEL CALIBRATION

4.3.1 Meteorological Inputs – 1999

RMA4q simulates temperature using meteorological data input to the model. The input time interval for the Lower Deschutes River modeling is one hour, the same as the model transport time step. The data required include the following parameters: atmospheric dust attenuation factor, cloud cover, dry bulb temperature, dew point (or wet bulb) temperature, atmospheric pressure, and wind speed. Also included with the time series of meteorological data are two heat exchange coefficients and a shading factor for direct solar (short wave) radiation. RMA4q computes solar radiation impinging on outer layers of the earth's atmosphere based on the Julian day and hour. Atmospheric dust, cloud cover, and reflection from the water surface attenuate this solar radiation.

Meteorological data were obtained from the Madras AgriMet Station at latitude 44.69, longitude 121.16, and altitude 997 meters (3270 ft). The station included solar radiation (not used), air temperature, relative humidity, wind speed, and wind direction (not used). Barometric pressure was not available; it was assumed constant at 30.00 in-Hg. The relative humidity data were converted to dew point temperature using equation 2-7 from Linsley, et al. (1982).

A lapse rate of air temperature was applied to account for temperature variation with elevation. For the purposes of lapse rate computations, element types 1 and 2 were assigned an elevation of 422 meters (1,380 ft), element type 3 was assigned an elevation of 274 meters (900 ft), and element type 4 was assigned an elevation of 121 meters (396 ft). The lapse rate for element types 1 to 3 and 5 was 1°C/100m, while that for element type 4 was 1.5°C/100m. The processed meteorological data used as model inputs are presented in Figure 4-1.

4.3.2 Model Boundary Conditions for Calibration

The model boundary conditions required water quality data at the main stem, Shitike Creek, Trout Creek, Warm Springs River, and White River. Data required include temperature, alkalinity, total inorganic carbon, dissolved oxygen, ortho-phosphate, nitrate, nitrite, ammonia, and suspended algae. Ideally, the data would be time series with time intervals corresponding to the model time step, or at least a time interval to adequately define diurnal variations. This is particularly important for those constituents that vary diurnally, such as

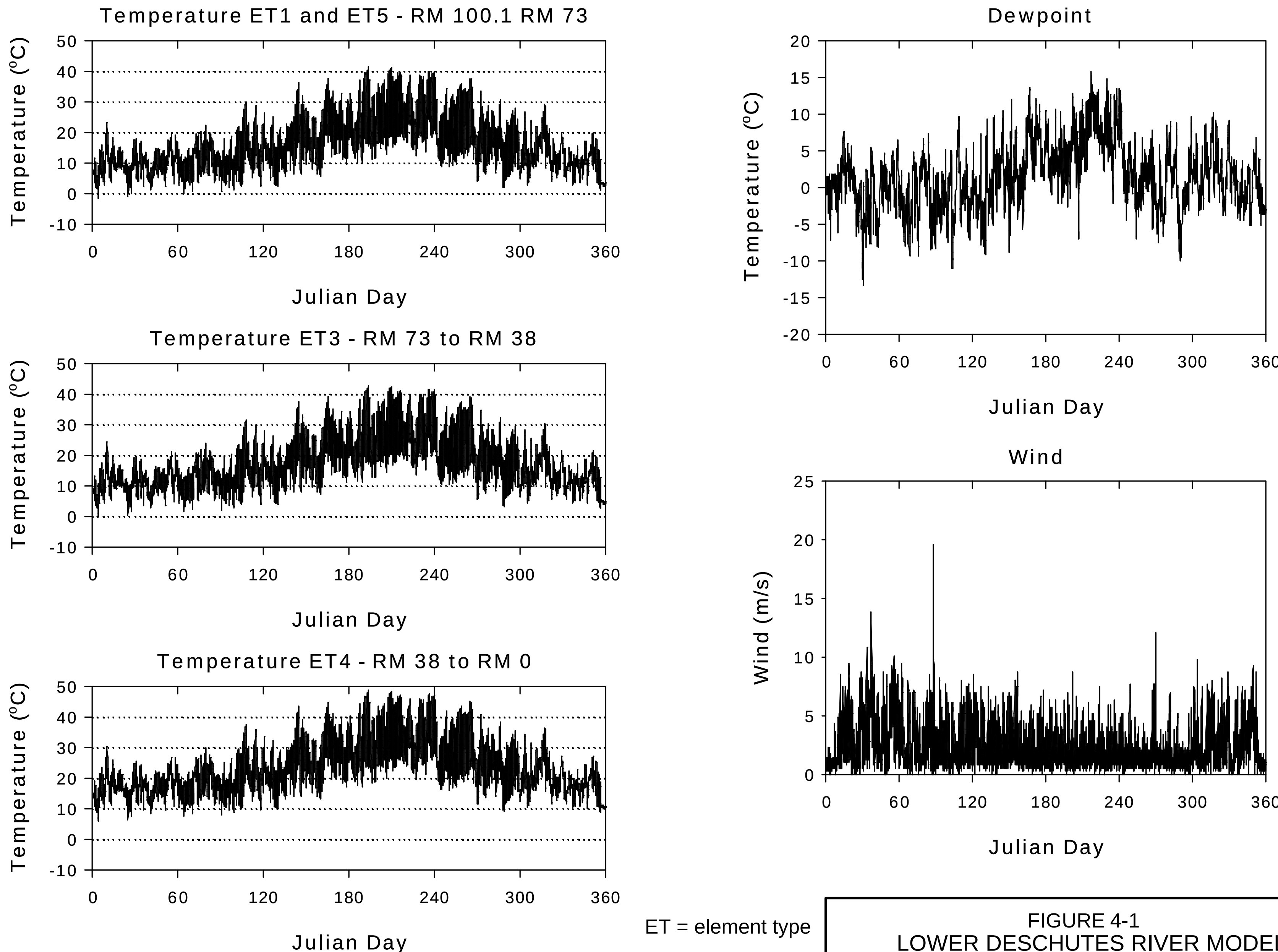


FIGURE 4-1
LOWER DESCHUTES RIVER MODEL
INPUT METEOROLOGICAL DATA FOR 1999
Portland General Electric Company
Portland, Oregon

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	FILENAME: LDR99met.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

temperature, dissolved oxygen, and pH (computed from total inorganic carbon). The temperature data at the Regulating Dam discharge (Figure 2-7; RM 100.1 and RM 99; RK 162 and RK 160) achieve this ideal, since continuous monitoring was made throughout 1999. Monitoring of dissolved oxygen and pH (as well as temperature) were made over three diurnal periods (April, July, and October, 1999) at the station RM 100.1, but the monitoring periods were limited to a period of less than two days. It was necessary to interpolate between the diurnally sampled values of dissolved oxygen percent saturation using percent saturation values computed from the measured temperatures. Total inorganic carbon (necessary for pH computations, along with alkalinity) was computed in a similar manner as for dissolved oxygen.

Alkalinity, nitrate, ammonia, and ortho-phosphate were collected as grab samples during the diurnal sampling periods. Data were also collected as grab samples during the river survey in August 1999. Chlorophyll *a* data were collected only twice during 1999. Figure 4-2 presents the boundary conditions input to the modal at the Regulating Dam discharge location (RM 100.1; RK 162). Few data were available for tributary boundary conditions; samples had been collected during diurnal sampling events. Where data were missing it was necessary to synthesize boundary conditions from existing data (by including other years 1997 and 1998) using best professional judgement. In each case where data were sparse it was necessary to interpolate intermediate values for 1-hour model time steps.

4.3.2.1 Temperature

Reregulating Dam Discharge

Station RM 99 (RK 160) data were used to obtain the boundary condition data for the main stem/Regulating Dam discharge inputs. Station RM 100.1 (RK 162) data exhibited some phase shifting that was not present in RM 99 and was not used for the temperature boundary condition. The data were taken at approximately hourly intervals and provide an adequate input data set defining the daily variation in temperature. These data are presented in Figure 4-2.

Tributaries

Temperature data time series were available only from June, 1998 to August, 1999 for the White River (WR00) and Trout Creek (TC00), but temperature time series were not

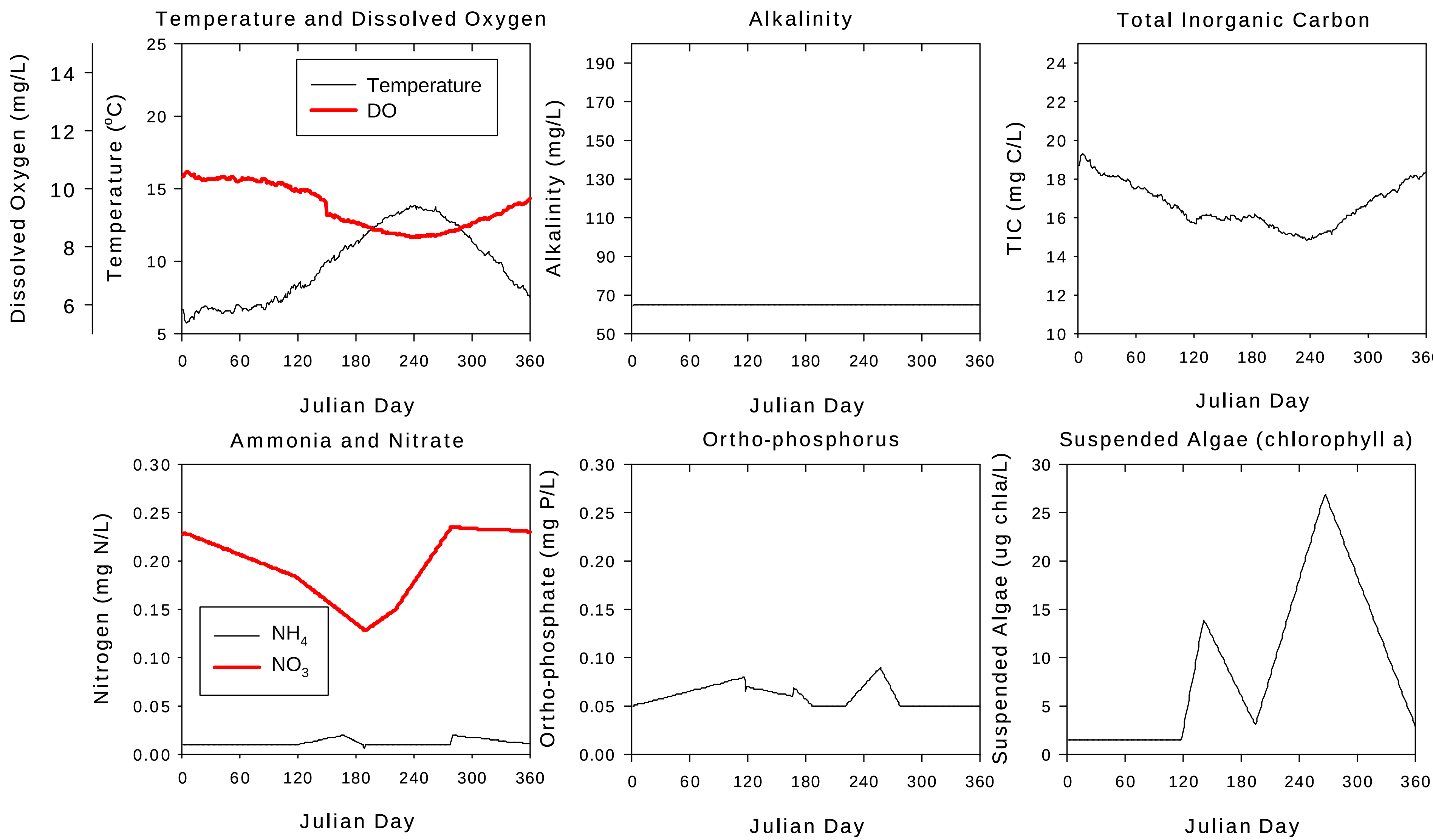


FIGURE 4-2
LOWER DESCHUTES RIVER MODEL CALIBRATION BOUNDARY CONDITIONS FROM THE REREGULATING DAM DISCHARGE FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

available for either the Warm Springs River or from Shitike Creek. Hence it was necessary to synthesize data to provide time series required for boundary condition specification.

For the both the White River and Trout Creek, the 1999 data from January to August were merged with the 1998 data from August to December to provide a continuous time series. These hourly data were then averaged using a 14-day running average to track the trends in temperature. The averaged data were used to specify the respective boundary conditions. For Shitike Creek, in the absence of any time series data, the Trout Creek data were used with a 28-day average. For the Warm Springs River, the White River data were used as an approximation, also with a 28-day average. These are shown in Figure 4-3.

4.3.2.2 Alkalinity and Total Inorganic Carbon

Reregulating Dam Discharge

Few alkalinity data were available for 1999. Since the model considers alkalinity to be conservative, it was set to a constant value of 64.75 mg $CaCO_3$/L (Figure 4-2). This value is the average of 1998 and 1999 data (4 samples) at station RM 100.1 and RM 99.

Total inorganic carbon (TIC) concentrations were computed from pH data collected during synoptic surveys 1999 in April 27-29, July 7-9, and October 4-7. The pH for these dates ranged from 7.41 to 8.45, while the computed TIC ranged from 15.56 to 16.56 mg C/L. Note that with the relatively low alkalinity, a small change in TIC causes a large change in pH (hydrogen ion concentration). To generate TIC data for most of the year, the relationship between computed TIC for the observation periods and temperature was examined. Significant and well-correlated relationships were found for the April, July, and October data. The coefficients of the linear regression equations varied between the sampling periods, so the data were interpolated between the sampling dates using a linear time weighting for the slope and the intercept. The TIC was generated using the interpolated regression equations and measured temperature at the boundary and are shown in Figure 4-2. The range of TIC concentrations generated was 14.39 to 19.00 mg C/L.

Tributaries

There were also few alkalinity and pH data for the tributaries. Data for 1998 and 1999 were used for both the alkalinity and computed TIC values. The ranges of data used are given in Table 4-3.

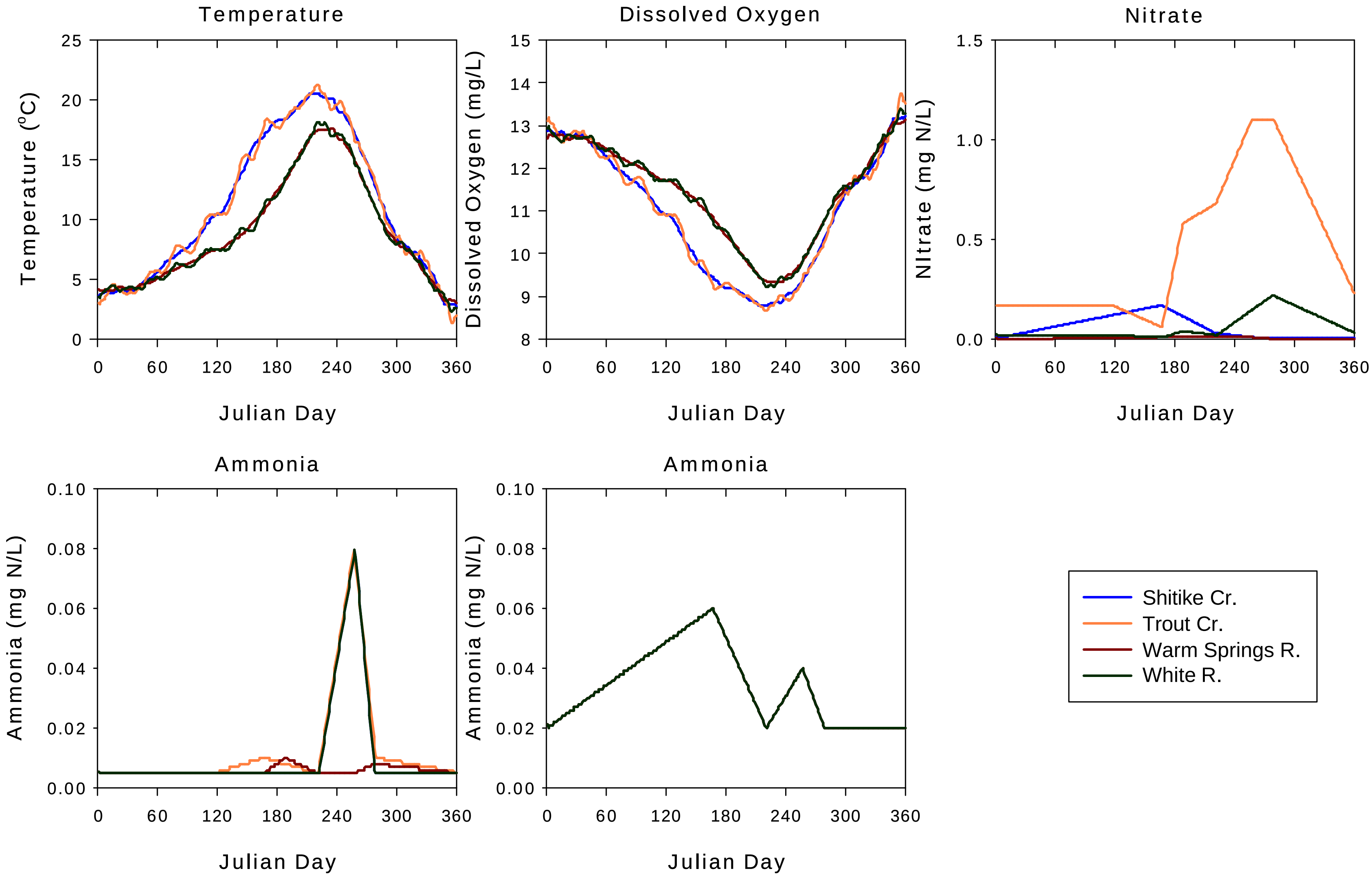


FIGURE 4-3
LOWER DESCHUTES RIVER MODEL
CALIBRATION BOUNDARY CONDITIONS
FOR THE TRIBUTARIES FOR 1999

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

Table 4-3. Alkalinity and Total Inorganic Carbon Boundary Conditions

Tributary	Alkalinity mg $CaCO_3$/L	Total Inorganic Carbon mg C/L
Shitike Creek	30 to 63	15.227
Trout Creek	91 to 170	33.619
Warm Springs River	31 to 41	10.647
White River	23 to 49	9.479

4.3.2.3 Dissolved Oxygen

Reregulating Dam Discharge

Dissolved oxygen time series were collected at RM 100.1 (RK 162) during April, July, and October, 1999 for diurnal sampling events. The data synthesis procedure started with the complete annual time series for temperature. For each temperature datum, a saturation dissolved oxygen value was computed. Next, a 24-hour time series of percent dissolved oxygen saturation (PDOS) was generated for each diurnal sampling period (April, July, and October). These generated PDOS values were then applied to the computed saturation dissolved oxygen values for the periods between the diurnal sampling times. This generated the estimated dissolved oxygen boundary conditions. Additionally, the actual dissolved oxygen values were used for boundary conditions for the actual diurnal sampling times. The generated values are illustrated in Figure 4-2.

Tributaries

No dissolved oxygen time series data for the tributaries have been collected for use as model boundary conditions. A few grab sample data were available, but these are too few in number to use for deriving time series data for a whole year. So, the approach taken was to compute saturation values from the synthesized temperature data. This approximation provides the diurnal variation that would be expected from actual tributary data. Figure 4-3 shows the dissolved oxygen time series generated and used for model boundary conditions.

4.3.2.4 Nutrients and Chlorophyll *a*

Reregulating Dam Discharge

For the calibration period, nutrient grab samples were collected during the three diurnal sampling events in April, July, and October, 1999. A sample was also collected in August 1999. Chlorophyll *a* data were only collected in April 1999. Figure 4-2 shows the time series generated for ammonia, nitrate, ortho-phosphate, and chlorophyll *a* and used for model boundary conditions.

In the case of chlorophyll *a*, it was necessary to use data from 1997. The same was true for ammonia and ortho-phosphate. This was done using best professional judgement, especially in the case where data were not highly variable (ortho-phosphate) or when most of the data were non-detects (ammonia). For nitrate, 1999 data alone were used, since the 1997 showed higher values in late fall.

Tributaries

For the tributaries, the only nutrient and chlorophyll *a* data were from grab samples in 1998 and 1999; there were three sampling events during this period. Hence, it was necessary to use all the data to develop an annual time series for model boundary conditions. The data are plotted in Figure 4-3. Ortho-phosphate values were set at the same for each tributary. Chlorophyll *a* was set to a constant value of 5-µg chlorophyll *a*/L in each tributary.

4.3.3 Model Calibration Data

Data collected during calendar year 1999 were used for comparison with model results during the calibration process to adjust model parameters for reaching the best reproduction of observed data. The available data were presented in Section 3. These data include time series for temperature, dissolved oxygen, and pH. Temperature data were available from two different sampling activities. Long-term temperature data were collected using "hobo" and "tidbit" sensors. The diurnal data were collected using Hydrolab instruments.

4.3.4 Calibration Procedures

Calibration of the Lower Deschutes River model was accomplished iteratively through several sweeps. The first sweep was for temperature, and the second sweep was for the water quality constituents dissolved oxygen, pH, and nitrate. The water quality model calibration was achieved using periphyton growth and respiration as the primary mechanisms. There were data in 1997 for periphyton chlorophyll *a*, but the dry weight biomass to chlorophyll *a* ratio is not well documented, making the data highly variable. Periphyton is also composed of other organisms besides algae: bacteria, microinvertebrates, and organic and inorganic detritus. These additional components will affect the production/utilization of oxygen and carbon dioxide; however, these are not included in the RMA4q periphyton model. As such, it was necessary to adjust some parameters (particularly the stoichiometry for oxygen production or respiration) in certain instances to account for other organisms and achieve a match to dissolved oxygen data.

Temperature calibration required using a lapse rate adjustment of air temperature in the meteorological input file, as discussed in Meteorological Inputs Section 4.3.10. In addition, it was necessary to include an additional heating term to account for the large temperature increases downstream observed in the "hobo" and "tidbit" data. This factor was equivalent to the amount of heat received from solar radiation and was applied from JD 100 through 264.

4.3.5 Calibration Results

4.3.5.1 Calibration Parameters and Coefficients

Water Column

Calibration proceeded with the assumption that the short residence time provided little opportunity for algae and organic matter to directly affect dissolved oxygen, pH, and nutrients. Periphyton were assumed to be the primary agent affecting dissolved oxygen and pH. They are fixed to the bed and accumulate over the growth season. Although not a dominant mechanism, phytoplankton kinetics in the water column were included because suspended algae play an indirect role by reducing light penetration. Ammonia concentrations were so low that any oxidation to nitrite and nitrate has a minimal affect on nitrate concentrations. Nitrate concentrations are the limiting factor in periphyton growth, so water column transport is important. Thus, the primary water column process considered was reaeration of both oxygen and carbon dioxide.

Many of the rates specified for the water column were taken from calibration results of the model CE-QUAL-W2 implemented for Lake Simtustus (Foster Wheeler, April 2001). Other coefficients were based on various references (Brown and Barnwell, 1987; Jorgenson, 1979). The tables in Appendix B (Table C-1, C-2, and C-3) present the values used for the RMA4q model of the Lower Deschutes River. The capabilities of the model had been extended for this project to include computation of pH and the transport of total inorganic carbon, alkalinity, and labile dissolved organic matter.

Periphyton

With periphyton assumed as the primary agent for changes in dissolved oxygen, pH, and nutrients, most of the calibration effort involved adjustments of periphyton parameters and rates. The calibration values derived turned out to be site specific. This is not unexpected, since periphyton are fixed to the substrate and accumulate over periods of weeks and months. Other components besides periphyton can also have an impact on CO_2 production and O_2 uptake, namely bacteria, microinvertebrates, and settled detritus. At present, these components are not in the periphyton model; hence, some parameters, particularly oxygen production and uptake, were adjusted to reflect overall conditions of periphyton.

Periphyton modeling introduces complexities different from those found in modeling water column processes only. Because periphyton accumulate, the attainment of significant biomass was found to be heavily dependent on the respiration rate. If periphyton biomass were allowed to grow indefinitely, it would attain a large density at the point of nutrient loading, causing the removal of all nutrients, which would prevent any growth from occurring downstream. This is not a realistic solution. To prevent this, an assumption is made that there is a habitat limitation on density. Even with a habitat limitation, large densities can still occur, so it was also necessary to include a density dependent term for erosion, which was seen to be quite important for the Lower Deschutes River with its high shear stress. The effect of biomass density was included via a power function of the biomass; a value of 1.0 gives the standard erosion equation, while values greater than 1.0 increase the rate of erosion as a function of biomass.

It was necessary to simulate four different types of periphyton that reflects different temperature ranges for algae growth. The calibrated parameters and coefficients are presented in Appendix B (Tables C-4 through C-8).

The following sections present the calibrated model results. Most of the calibration effort was centered on time series data collected in April, July, and October 1999 for temperature, dissolved oxygen, and pH. These data were collected for approximately two days in each month (see Section 2, Review of Available Data). For temperature, there were also data collected over the entire year (also presented in Section 2). Ortho-phosphate is not limiting to periphyton growth and so was not the focus of the current analysis. Ammonia concentrations are an order of magnitude smaller than the nitrate concentrations and were considered insignificant to the current analysis. Chlorophyll *a* was similarly considered to be relatively ineffective in causing response of the primary water quality constituents, because the residence time of the river is on the order of one day. This is too short a time to produce significant water quality changes.

4.3.5.2 Temperature

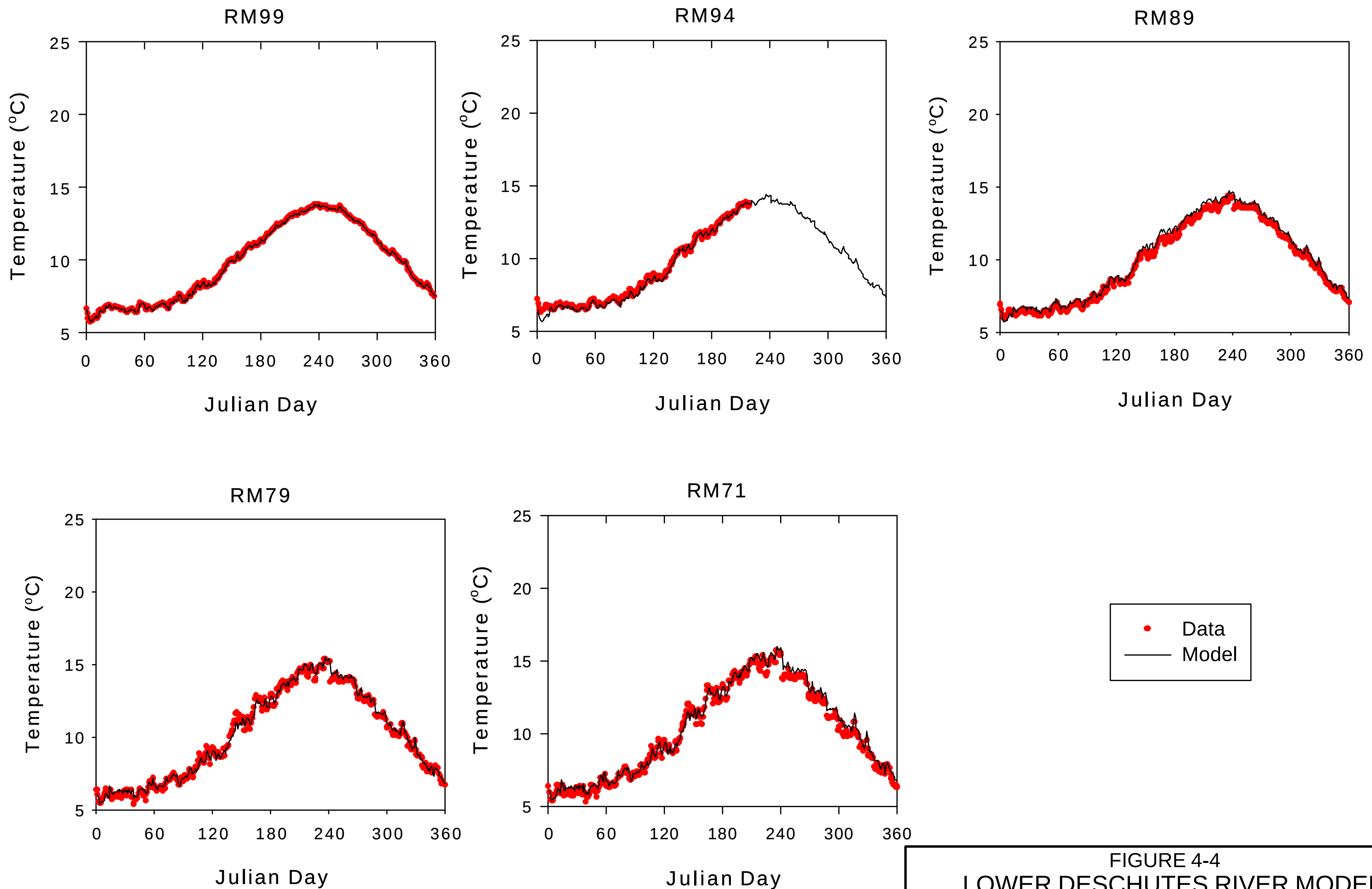
The temperature calibration was mostly made using the annual data collected at several stations in the Lower Deschutes River. As discussed in Calibration Procedures (Section 4.3.4) and Meteorological Data (Section 4.3.1), the use of a lapse rate to adjust dry bulb temperatures was required, especially with the difference in elevation between the various river reaches and the meteorological station. Additionally, a heat source was required for element type 4 to approximate canyon conditions during summertime.

For the annual data comparisons, daily average values were used. Figures 4-4 and 4-5 present the model results and averaged data. At RM 99 (RK 160), the fit is excellent, as expected because the boundary is located just upstream. This shows that the boundary values are correct. At downstream locations the model results and data match very well.

Comparing model calibration results with temperature collected by Hydrolab equipment during diurnal sampling events shows quite good fits at each of the synoptic stations (RM 100.1, RM 88, RM 57, RM 24, and RM 01; RK 162, RK 142, RK 92; RK 39, and RK 02) (Figures 4-7, 4-9, 4-11, 4-13, and 4-15, respectively). The fact that the Hydrolab diurnal data fit the RM 01 (RK 02) model results relatively well supports the procedure used for adjusting meteorological observations.

4.3.5.3 Periphyton

Figures 4-6, 4-8, 4-10, 4-12, and 4-14 show periphyton biomass time series plotted at each station. There are no data to calibrate periphyton biomass. As stated previously, the use of periphyton was a means to affect the water quality constituents of concern; that is, dissolved oxygen, pH, and nitrate. The four periphyton types are differentiated largely by their growth-temperature curves (see Appendix B, Table C-4). It was necessary to have at least this many types of periphyton in order to have growth under the varying temperature regimes present



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	FILENAME: LDR99ca;.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-4
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF DAILY AVERAGE TEMPERATURE AT RM 99 - RM 71 FOR 1999
Portland General Electric Company
Portland, Oregon

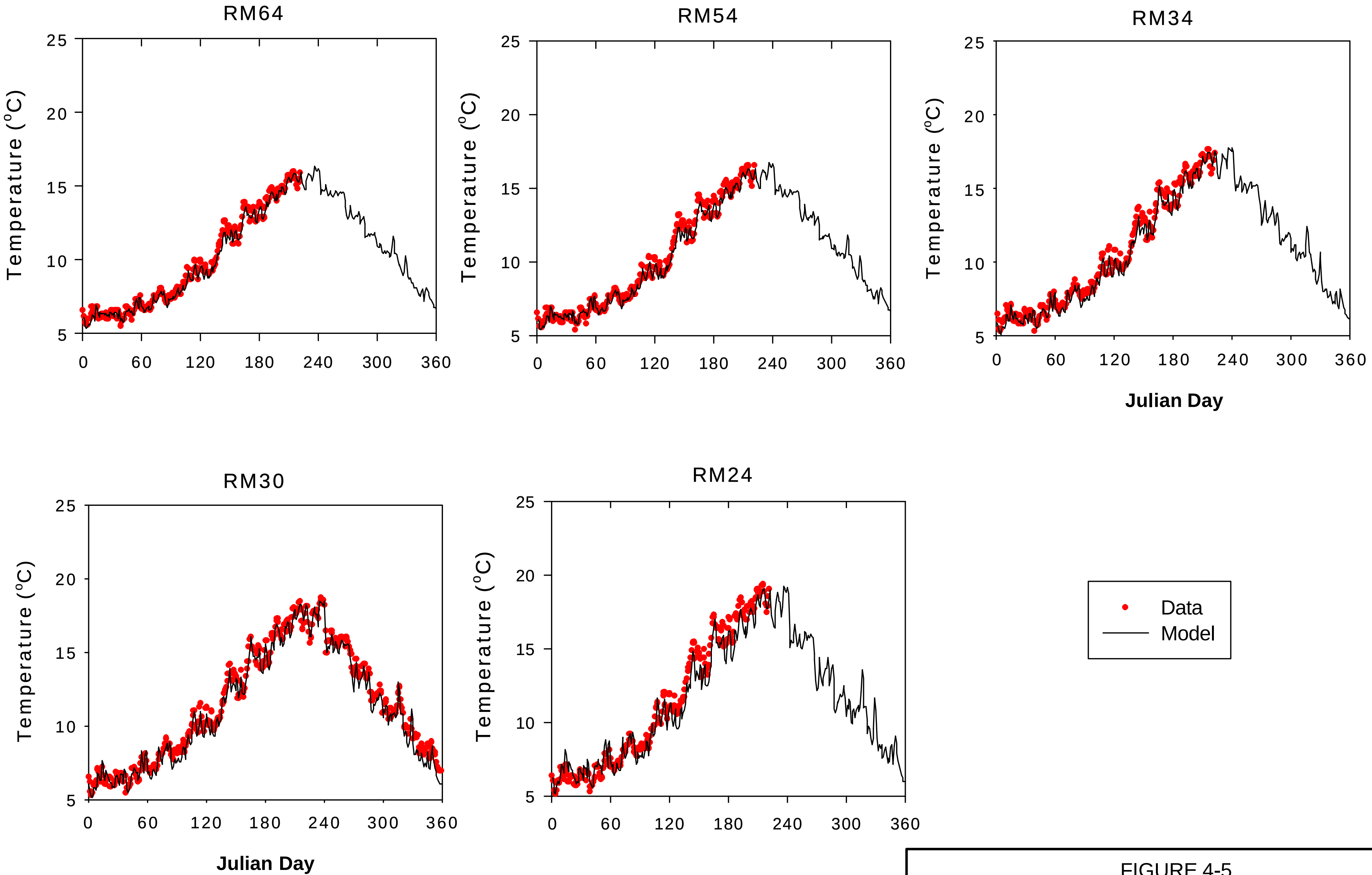

FIGURE 4-5
LOWER DESCHUTES RIVER MODEL
CALIBRATION RESULTS OF
DAILY AVERAGE TEMPERATURE
AT RM 64 - 24 FOR 1999
Portland General Electric Company
Portland, Oregon

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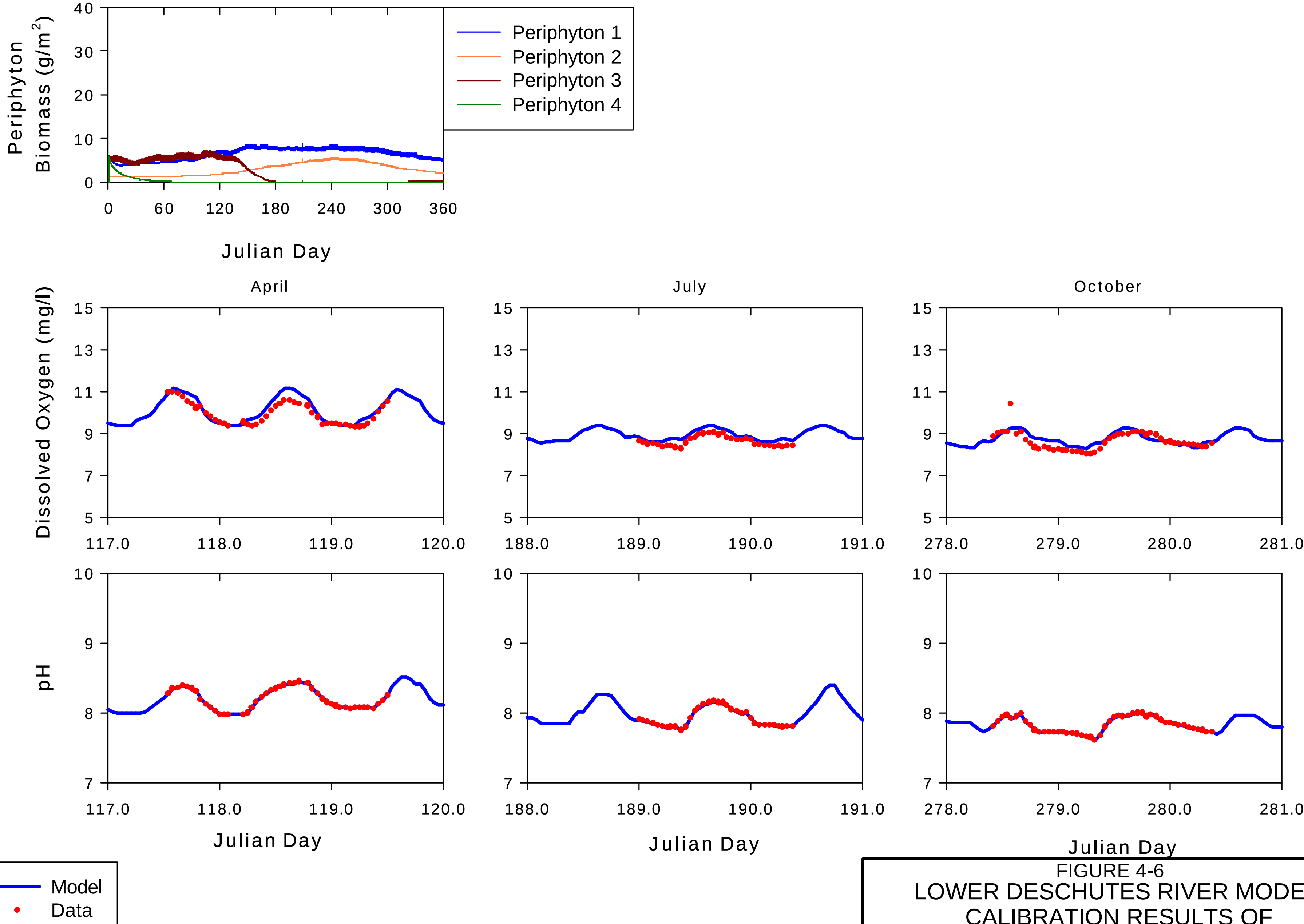

FIGURE 4-6
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF PERIPHYTON, DO AND pH AT RM99 FOR 1999
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Portland, Oregon

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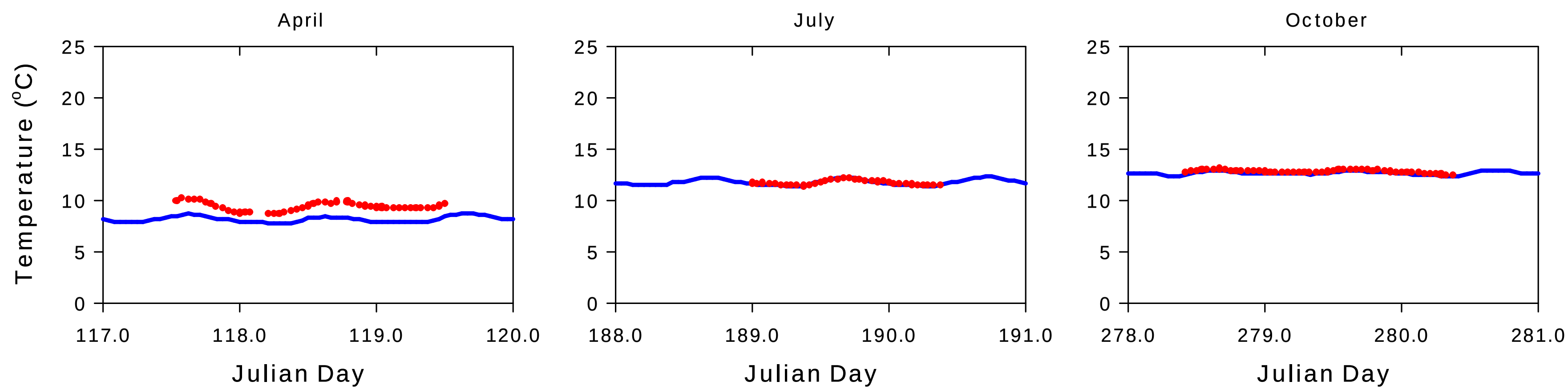
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



Model
Data

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-7
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF TEMPERATURE AT RM99 FOR 1999
Portland General Electric Company
Portland, Oregon

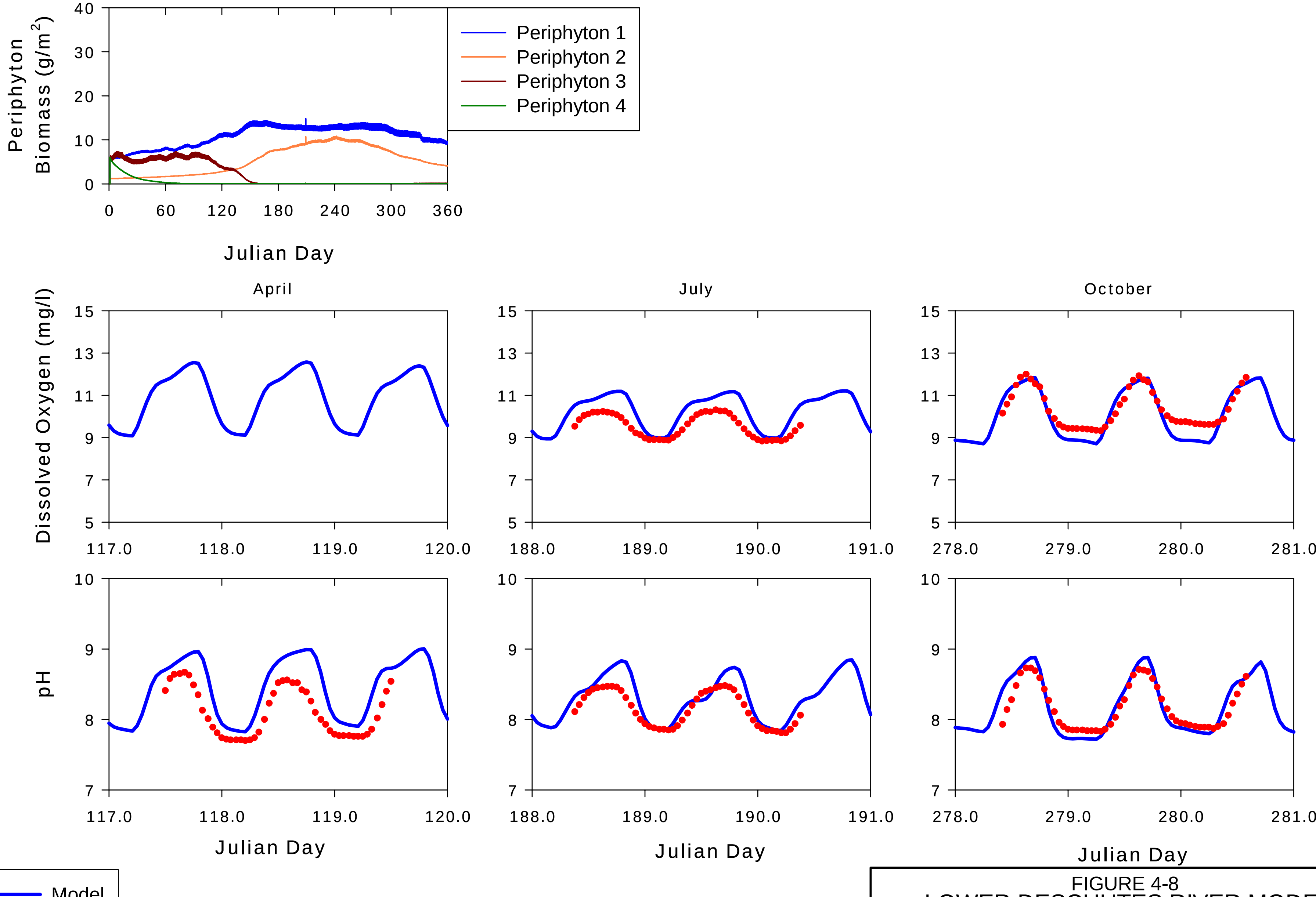
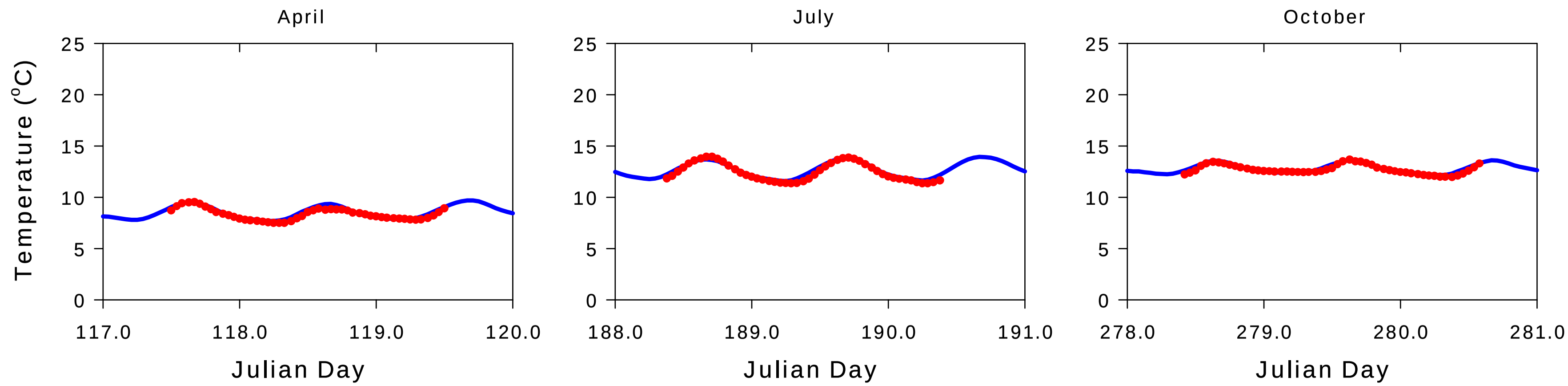


FIGURE 4-8
LOWER DESCHUTES RIVER MODEL
CALIBRATION RESULTS OF
PERIPHYTON, DO AND pH AT RM88 FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-9
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF TEMPERATURE AT RM88 FOR 1999
Portland General Electric Company
Portland, Oregon

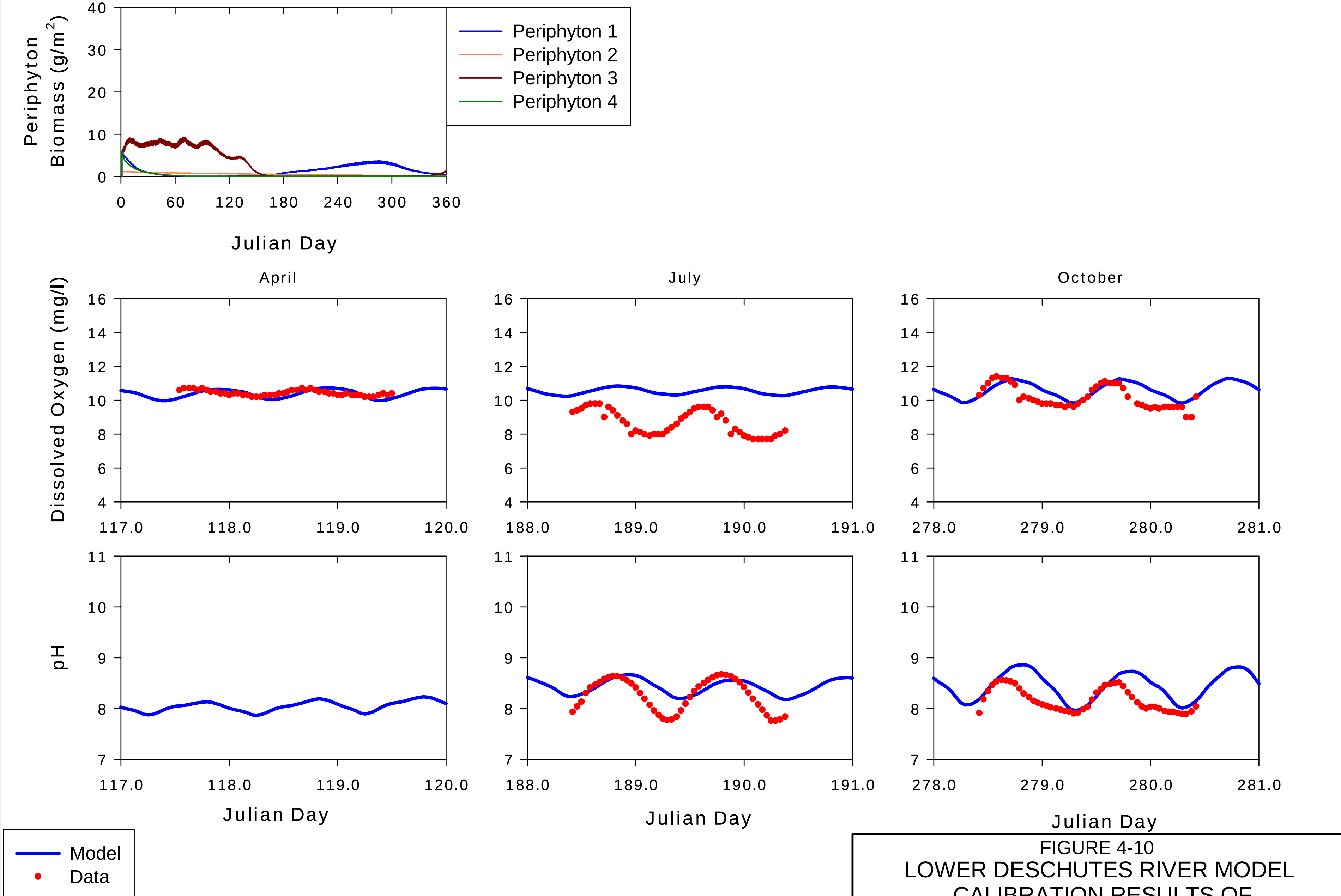
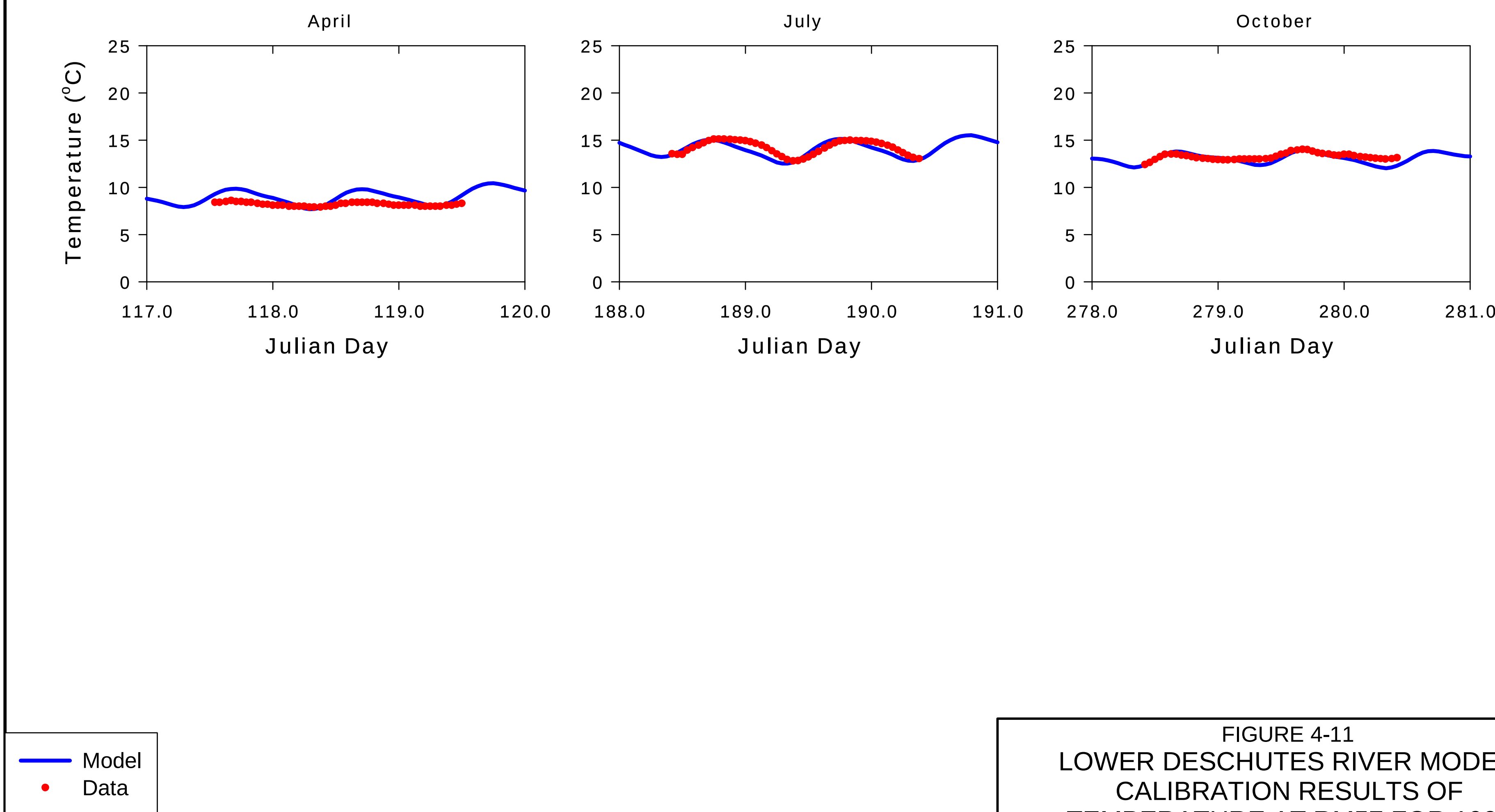


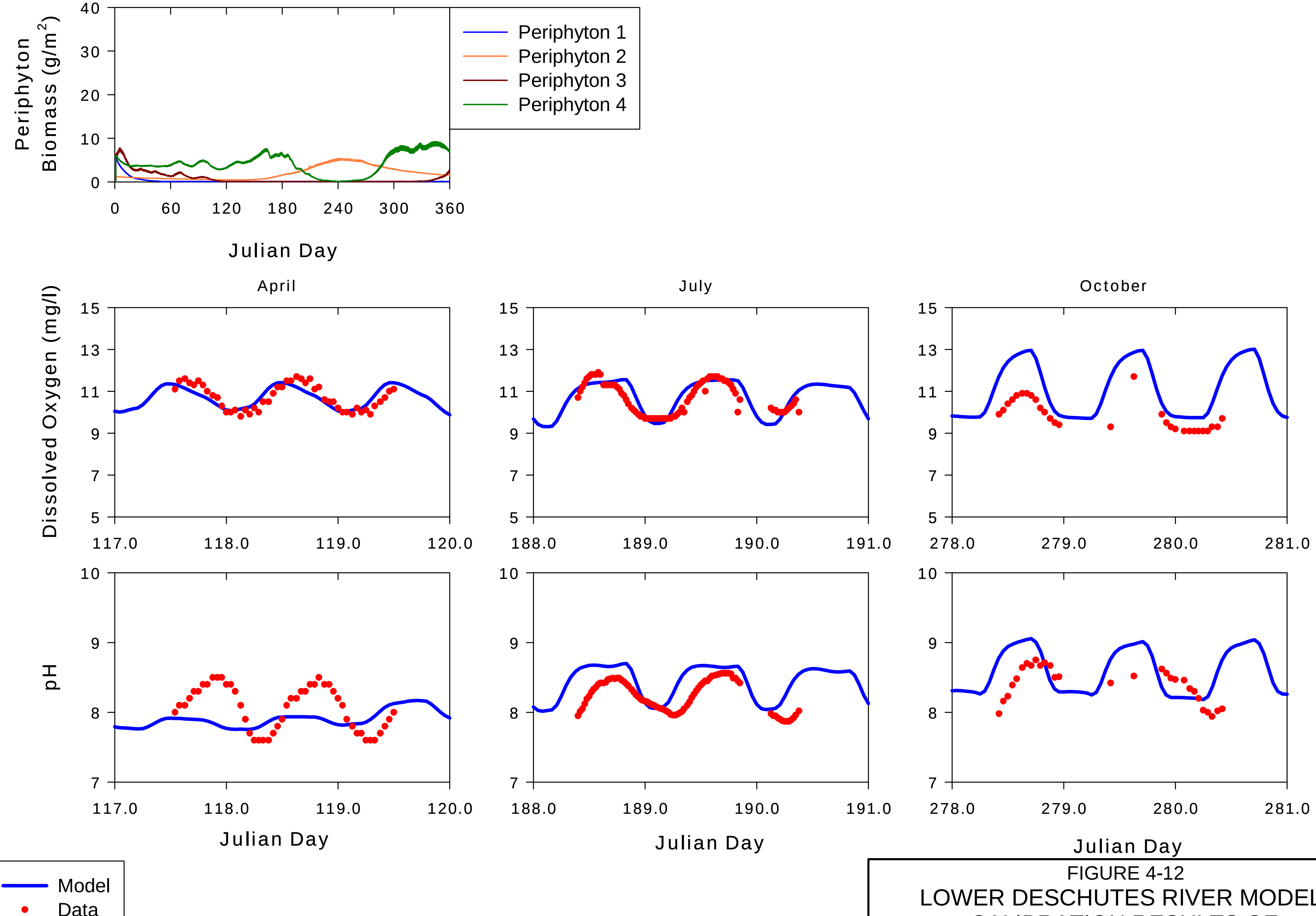
FIGURE 4-10
LOWER DESCHUTES RIVER MODEL
CALIBRATION RESULTS OF
PERIPHYTON, DO AND pH AT RM57 FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE 4-11
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF TEMPERATURE AT RM57 FOR 1999
Portland General Electric Company
Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION

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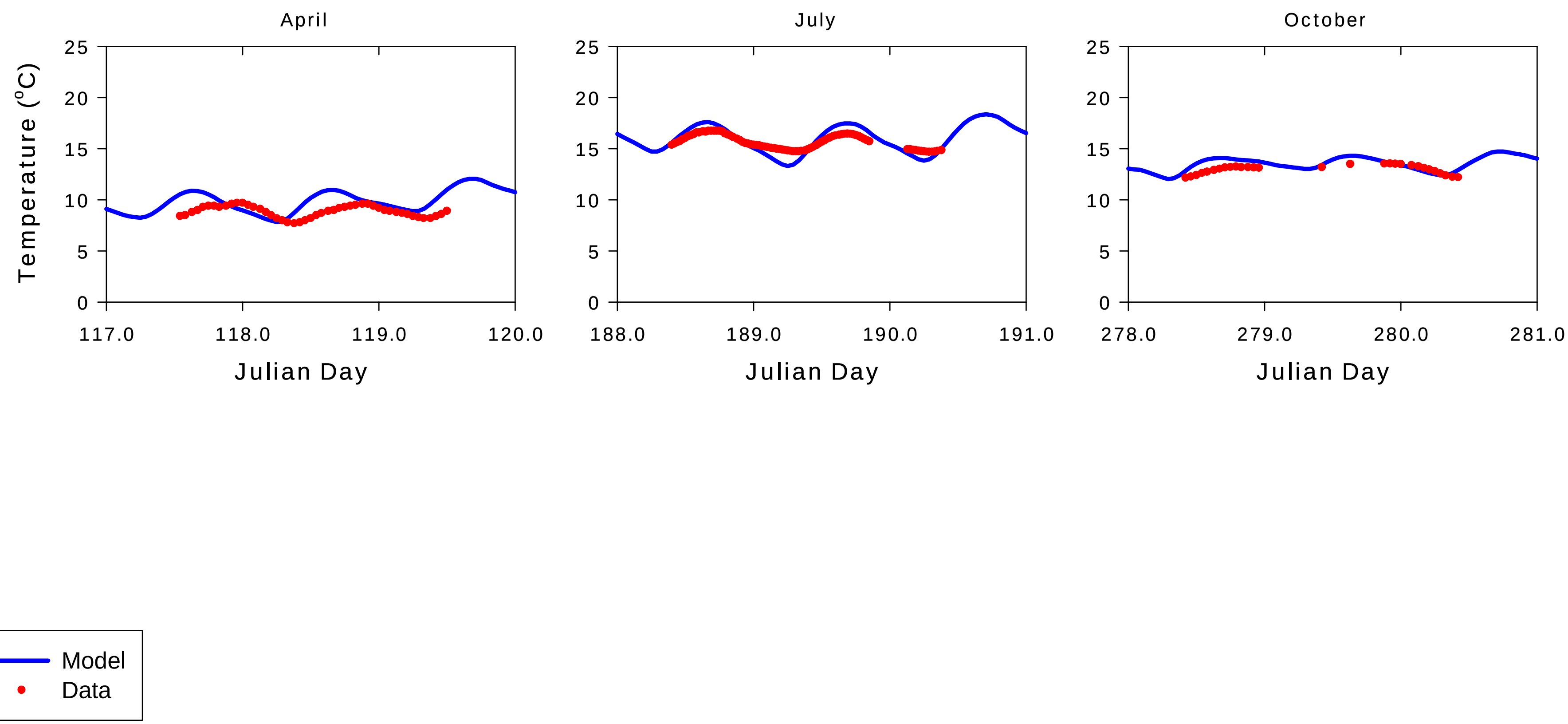
FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-12

LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF PERIPHYTON, DO AND pH AT RM24 FOR 1999

Portland General Electric Company
Portland, Oregon



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-13
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF TEMPERATURE AT RM24 FOR 1999
Portland General Electric Company
Portland, Oregon

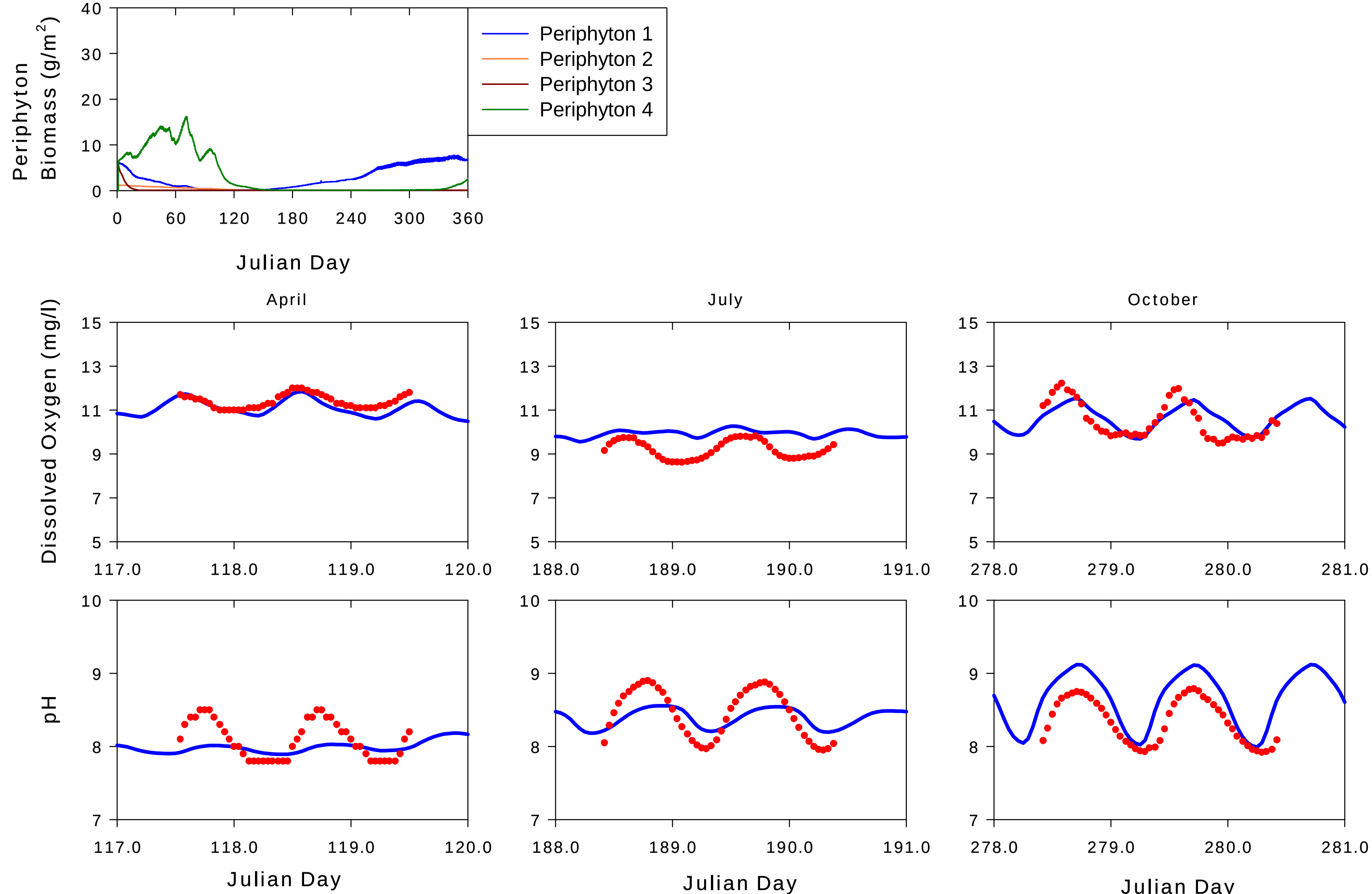
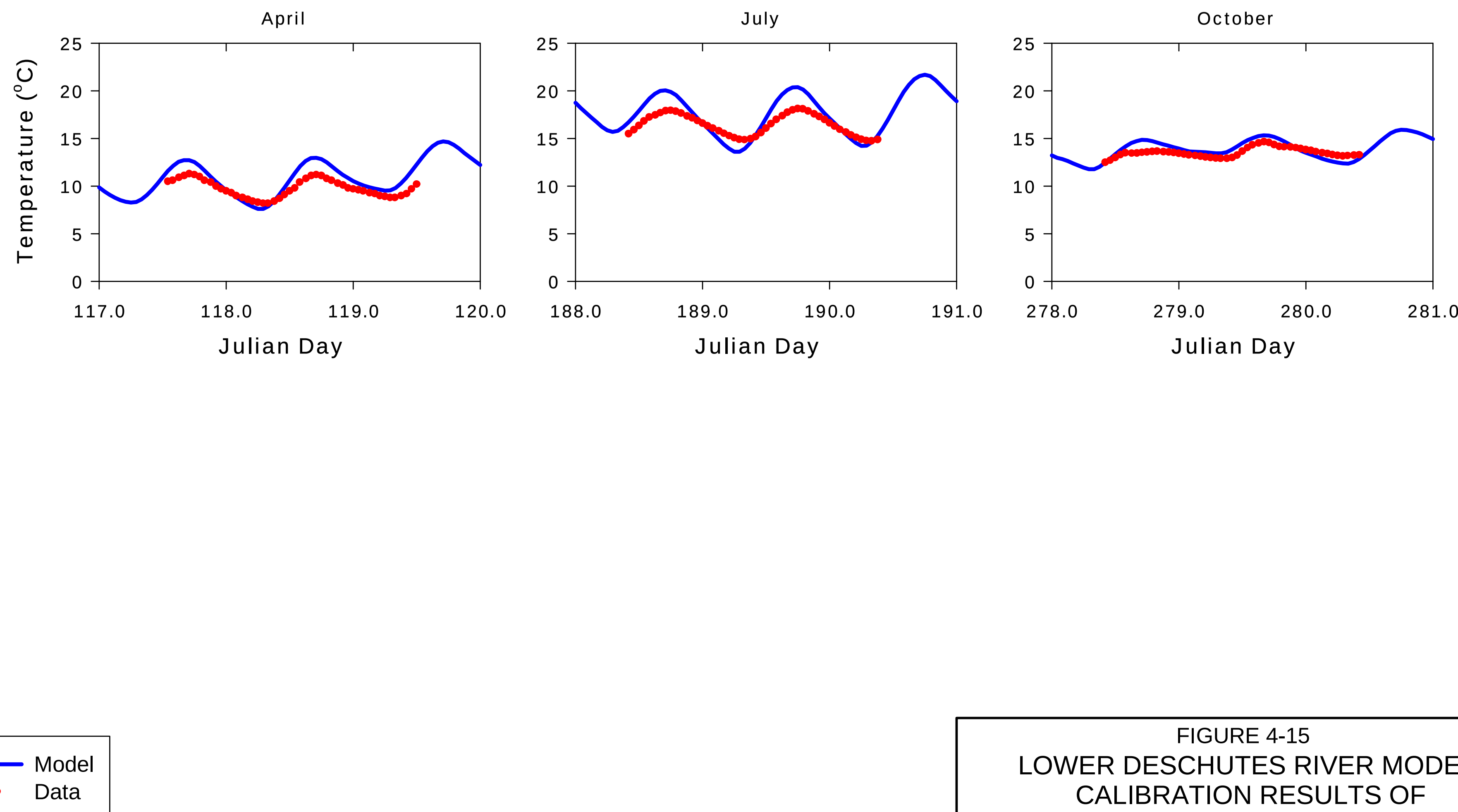


FIGURE 4-14
LOWER DESCHUTES RIVER MODEL
CALIBRATION RESULTS OF
PERIPHYTON, DO AND pH AT RM01 FOR 1999
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL / WHEELER CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: Z. Yang	DATE: March 22, 2001	PROJECT NO:
	FILENAME: LDR99cal.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-15
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS OF TEMPERATURE AT RM01 FOR 1999
Portland General Electric Company
Portland, Oregon

in the river and simulated by RMA4q. The growth-temperature curves are set globally. Locally defined curves would likely provide better control of model response; however, this effort was not included in this study.

As can be seen in the upstream stations (RM 99 and RM 88; RK 160 and RK 142; Figures 4-6 and 4-8), periphyton growth was predicted throughout the year, with different types growing at different temperature regimes, as defined by their growth-temperature curves. At these locations, nitrate is in abundant supply. To prevent excessive growth, high half-saturation constants for nitrogen were necessary (see Appendix B, Table C-5). Additionally, high scour exponents and somewhat low maximum biomass densities were required to prevent excessive growth. Further downstream (RM 57, RM 24, and RM 01; RK 92; RK 39, and RK 02), because nitrate was utilized, it was necessary to lower the nitrogen half-saturation coefficients and scour exponent, else little growth occurred (see Appendix B Tables C-4 through C-8; Figures 4-10, 4-12, and 4-14). At RM 57 and RM 01 (RK 92 and RK 02), with the global growth-temperature settings that provided calibration at RM 99, RM 88, and RM 24 (RK 160, RK 142, and RK 39), it can be seen that mid-year periphyton concentrations declined to near zero (Figures 4-10 and 4-14).

4.3.5.4 Dissolved Oxygen

The variation in dissolved oxygen is driven by periphyton growth, this supported by the observation that peak concentrations in data occur after midday, which is opposite the direction being forced by temperature variations. Higher midday temperatures lower the dissolved oxygen saturation concentrations.

At RM 99 (RK 160), the model results closely reflect the boundary conditions (Figure 4-6). At RM 88 (RK 142), the April data set are considered erroneous and are not plotted. The July and October comparisons show the model is simulating the diurnal oxygen curves well (Figure 4-8). At RM 57 (RK 92), the April and October model results fit the observations reasonably well (Figure 4-10). The July predicted values are too high in comparison with the data and do not show the proper diurnal variation. Note, however, that the observed data are less than saturation values, indicating that either an oxygen sink is present in this region of the river at this time or there is an error in the data. A sink (such as sediment oxygen demand) would need to be around 5 gm O_2/m^2 per day, which is substantial. Such a sink would have to derive from organic matter either deposited or generated in place from periphyton. Deposition of organic material from an external source is unlikely even if there was a source, because the high river velocity and high corresponding bed shear stress would make deposition unlikely. However, high sediment oxygen can occur because of settling and decay of dead algal biomass. The dissolved oxygen comparisons at RM 24 (RK 38) are generally good (Figure 4-12). The October data are spotty and may be suspect. At RM 01 (RK 02), the April and October values fit the dissolved oxygen data well, but the simulated results for April do not show the proper diurnal variation as well. This could be owing to proximity to the Columbia River boundary.

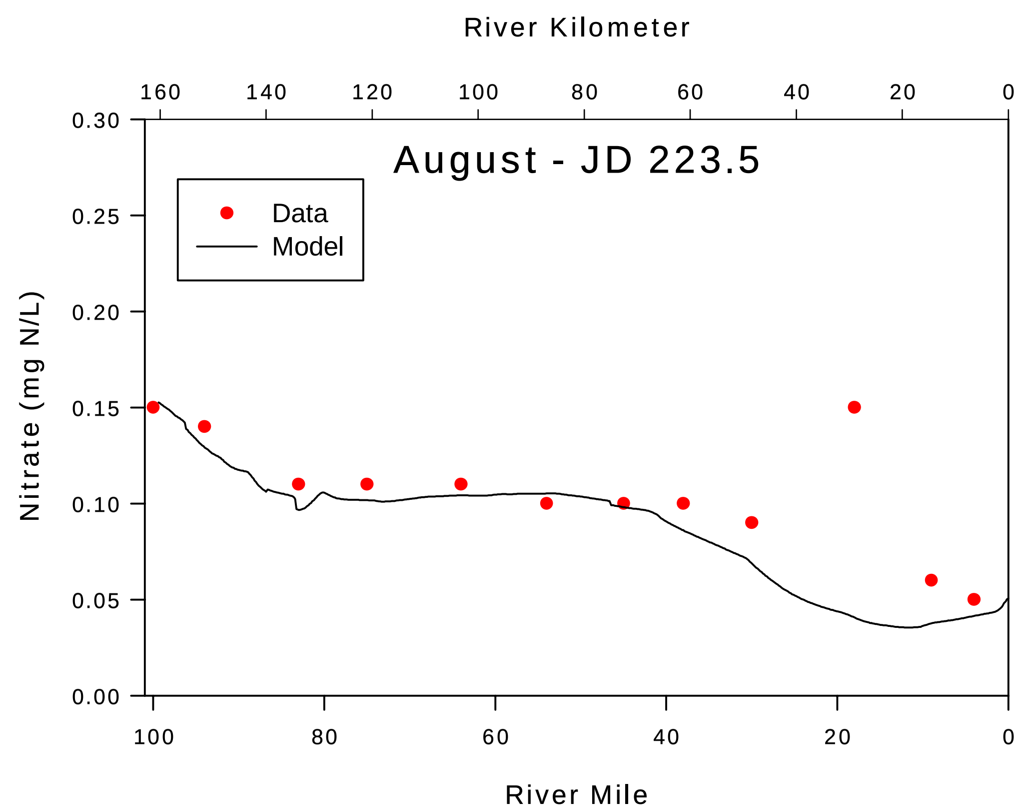
4.3.5.5 pH

The growth of periphyton not only produces dissolved oxygen but also utilizes carbon dioxide. The uptake of carbon dioxide causes the carbonate system to shift to higher pH. Carbon dioxide is added by periphyton respiration. Atmospheric reaeration also adds or removes carbon dioxide depending on the water column's degree of saturation.

At the upper most station (RM 99; RK 160), model results track the observed pH time series in April, July, and October (Figure 4-6). This shows that the model boundary conditions are correctly set. At RM 88 (RK 142), the model results follow the diurnal variations quite well (Figure 4-8). In April and July, predicted values of pH are slightly higher than observed data. At RM 57 (RK 92), the April pH data are considered suspect and are not presented. The July model diurnal variation is somewhat dampened, likely due to little periphyton growth at this time (Figure 4-10). By October, the diurnal variation is larger than April, even though periphyton biomass is only slightly greater at this location. At RM 24 (RK 39), the July and October pH results from the model show significant diurnal variation, while April does not (even though dissolved oxygen does) (Figure 4-12). The July data fit the observations fairly well. The model response at RM 01 (RK 02) are similar to that seen at RM 24 (Figure 4-14), with larger diurnal ranges occurring during October than at previous times. That is, the July model results are somewhat dampened in comparison with observations, though they fall within the observed range.

4.3.5.6 Nitrate

The range of data available of calibration for nutrients was not as large as for temperature, dissolved oxygen, and pH. The only data for the 1999 calibration year were from August, collected over a four-day period (JD 221 through 224; August 9 though 12, 1999). For calibration purposes, the model results used were at noon on an intermediate day (JD 223) (Figure 4-16). The plot shows a good fit to observations. The trend of declining concentrations as water flows downstream is well captured. It is this trend that necessitated the use of nitrogen half-saturation coefficients that declined downstream. Otherwise, little periphyton growth would occur at downstream locations.



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: February 16, 2001	PROJECT NO:
	FILENAME: LDR99caldata.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 4-16
LOWER DESCHUTES RIVER MODEL CALIBRATION RESULTS FOR NITRATE ON JD 233.5 FOR 1999
Portland General Electric Company
Portland, Oregon

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5. MODEL VERIFICATION

Model verification was done for calendar year 1997. The calibrated model derived from 1999 data was applied without modification of the coefficient. The purpose of this exercise is to ensure that model development is not limited to the calibration data set only but can in fact reliably predict water quality with an independent data set.

Three sets of sample data are available in May, July, and September 1997. These data are grab samples taken along the length of the Lower Deschutes River over three to four day periods. These samples were not taken synoptically, but were collected at various times during daylight hours as part of the river surveys. Therefore, no time series data for dissolved oxygen or pH for 1997 is presented.

5.1 METEOROLOGICAL INPUTS – 1997

Meteorological data were obtained from the Madras AgriMet Station at latitude 44.69, longitude 121.16, and altitude 997 meters (3270 ft). The procedures used for construction of these meteorological data were the same as those used for calibration for 1999. The input meteorological data for 1997 conditions are presented in Figure 5-1.

5.2 MODEL BOUNDARY CONDITIONS FOR VERIFICATION

Temperature data time series were available for the period April 18, 1997 through the end of the year and were applied at the Reregulating Dam boundary location. To complete the annual data set for the Reregulating Dam boundary condition, the 1998 data for the period of January 1 through April 17 was used as an approximation. The 1998 data were selected after comparison of data from 1998 through 2000 and were selected as being the most similar to 1997 data. The resulting composite model input is presented in Figure 5-2.

Nitrate boundary condition data for the Regulating Dam discharge location were assembled from 1997 grab sample data, as was done for the 1999 input data. These input data are also presented in Figure 5-2.

Dissolved oxygen boundary condition data were computed using (1) the 1997 temperature data at the Reregulating Dam location to get saturation dissolved oxygen concentration and (2) the 1999 percent oxygen saturation values.

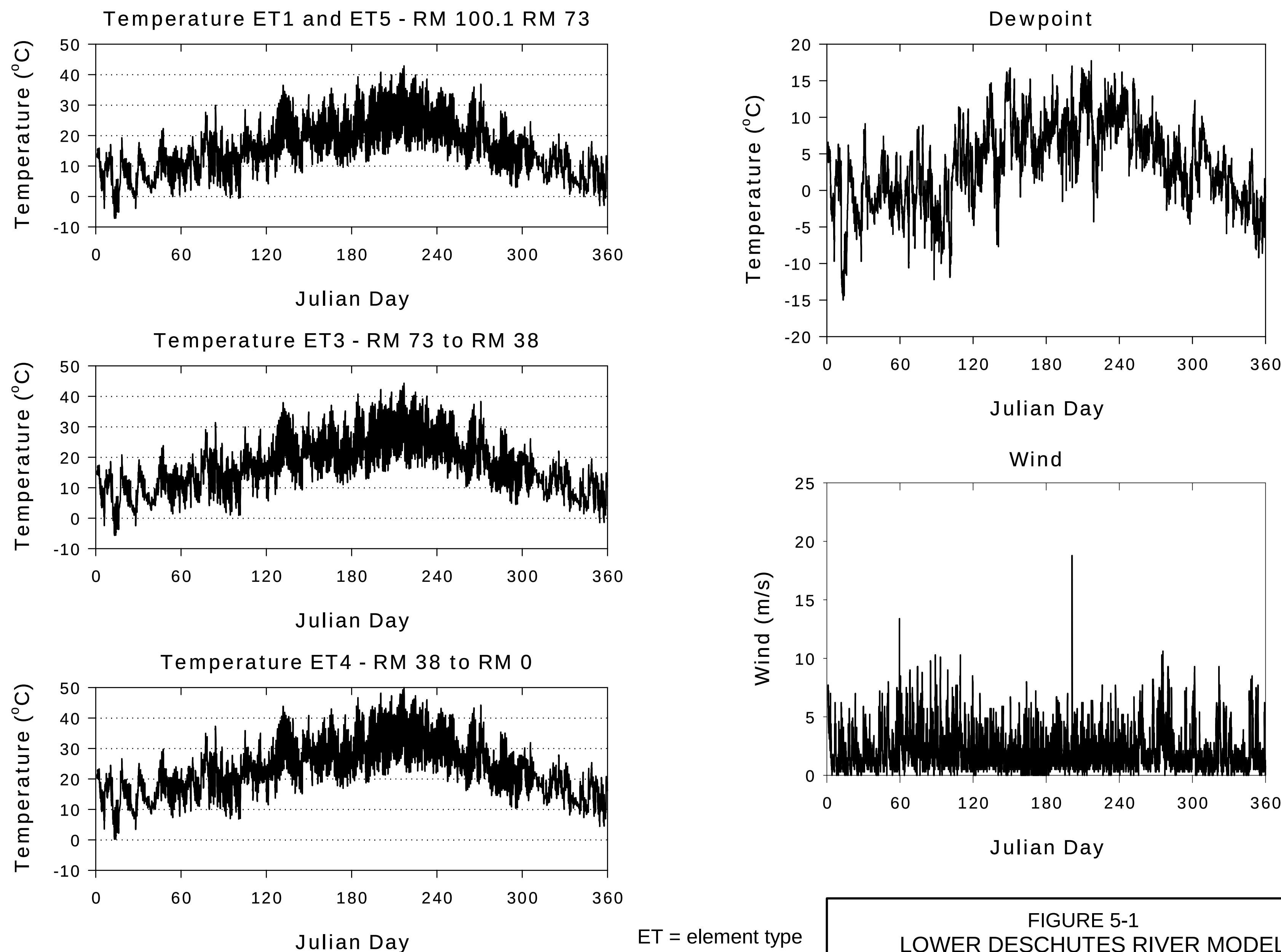


FIGURE 5-1
LOWER DESCHUTES RIVER MODEL
INPUT METEOROLOGICAL DATA FOR 1997
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: LDR97met.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

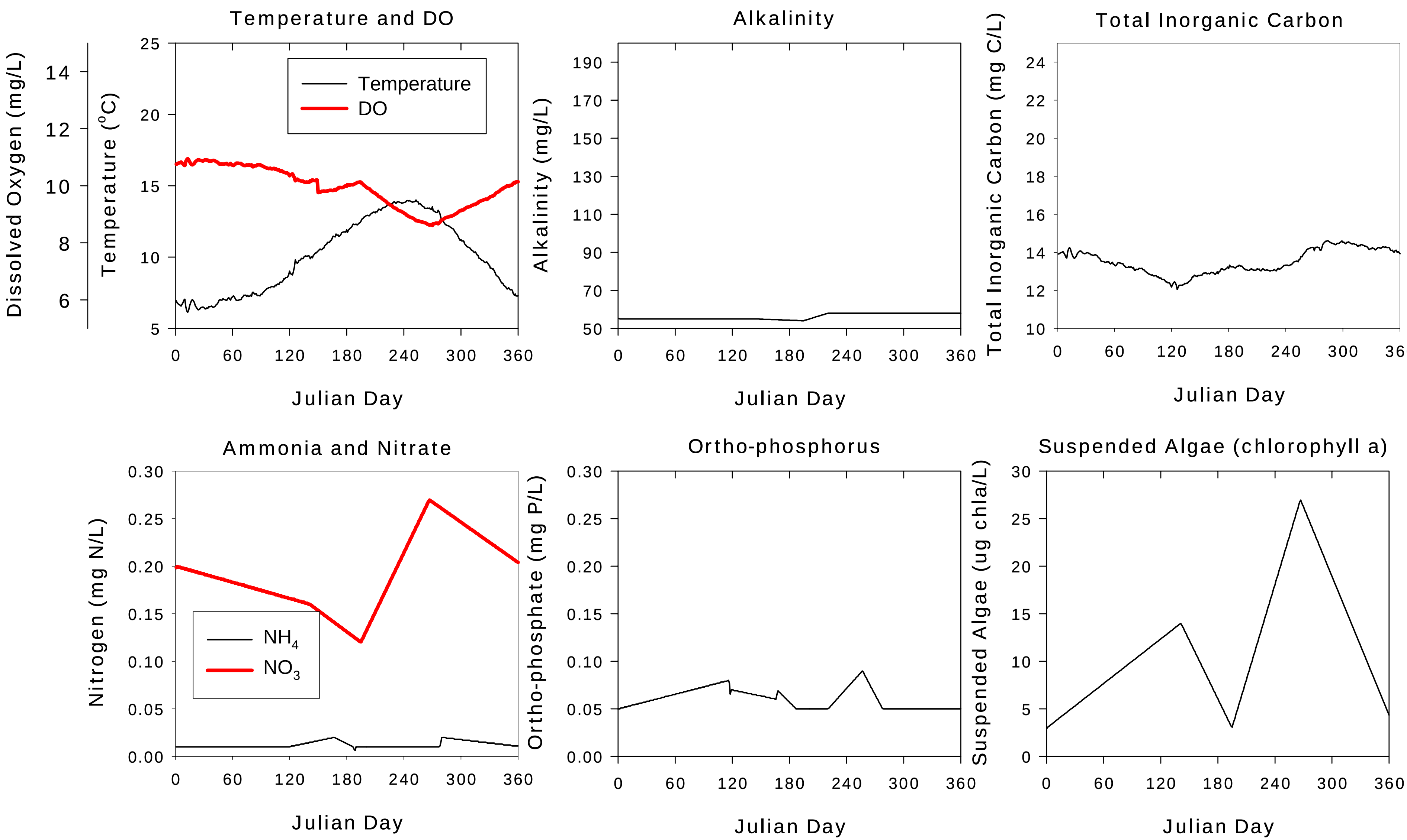


FIGURE 5-2
LOWER DESCHUTES RIVER MODEL
VERIFICATION BOUNDARY CONDITIONS FROM
THE REREGULATING DAM DISCHARGE FOR 1997

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

The total organic carbon concentrations were based on the 1999 Reregulating Dam boundary values, adjusted so the model matched the observed pH at the Reregulating Dam boundary location (Figure 5-2).

Data for the tributary boundary conditions were set at the 1999 values, as an approximation. This assumes year-to-year variation is relatively small and that the influence of the tributary loads on the main stem Lower Deschutes water quality is also relatively small.

5.3 VERIFICATION RESULTS

5.3.1 Temperature

Comparisons of model results to observed data were made on the basis on daily averaged values. Figures 5-3 through 5-6 present the results from temperature verification. Note that at most stations, data begin in April 1997.

Model results show excellent fit to daily averaged temperatures data. Below RM 30 (RK 48), the model results exceed observed temperatures slightly during summer. Fine tuning of the temperature model using local meteorological data likely eliminate this difference and improve the performance of the model.

Longitudinal comparisons of temperature model results with observations were also made for the data collected during river surveys (Figure 5-7). Because the observation times were scattered over several days during each sampling event, the observations show the effect of sampling time on data (morning vs. afternoon). Therefore, model results were extracted corresponding to each sampling time and at each location, and plotted longitudinally. As show in the figure for temperature, the comparison between predicted temperature and observed data is quite good for all three sampling periods.

5.3.2 Dissolved Oxygen and pH

The dissolved oxygen data from river surveys was not synoptic. The comparison to model results was conducted for each sampling time and at each location, and plotted longitudinally (Figure 5-8). Considering the variability in data because of sampling times, the match is quite good, especially in regard to the trends in dissolved oxygen.

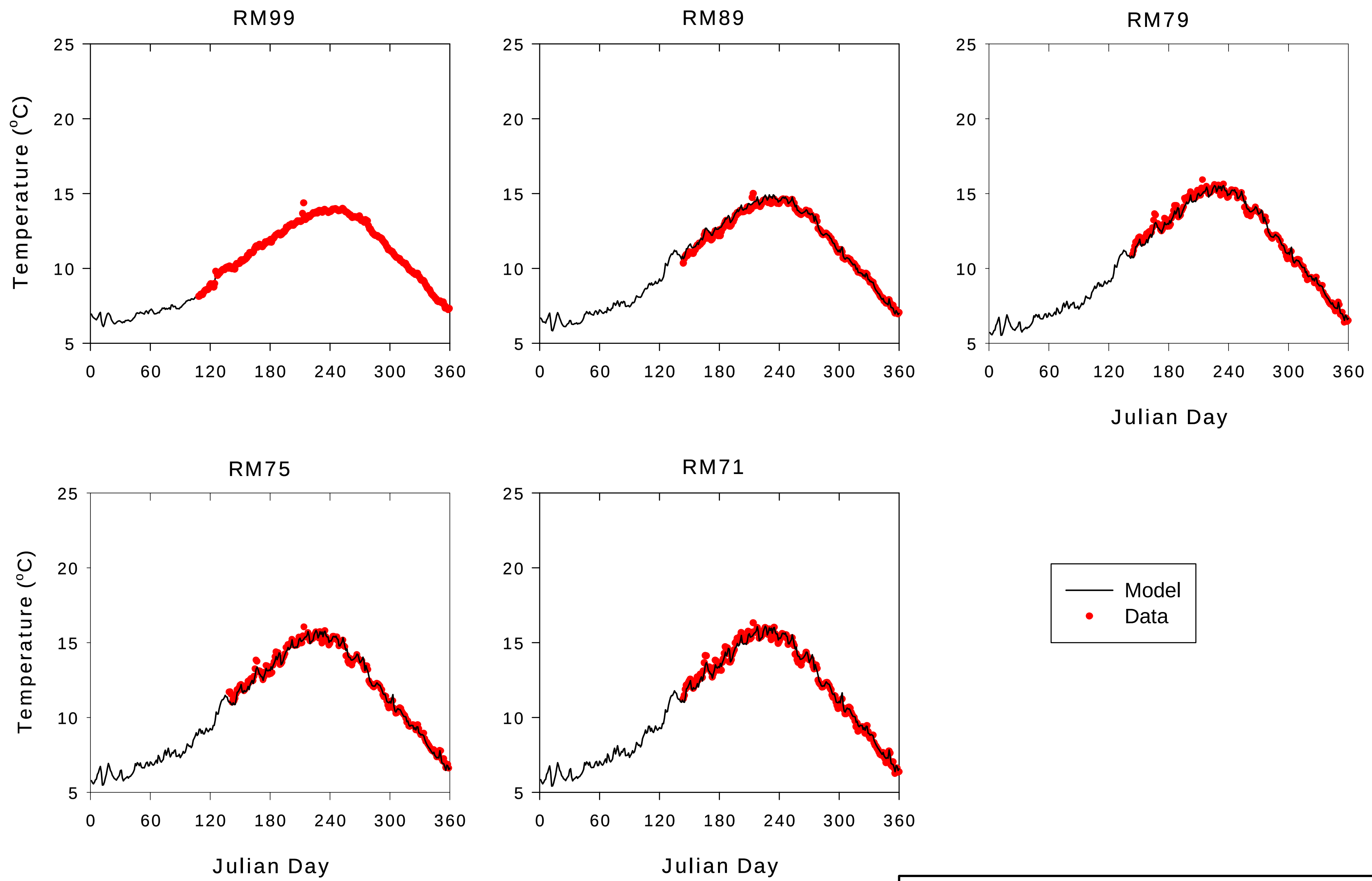


FIGURE 5-3
LOWER DESCHUTES RIVER MODEL
VERIFICATION RESULTS OF
DAILY AVERAGE TEMPERATURE
AT RM 99 - RM 71 FOR 1997
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

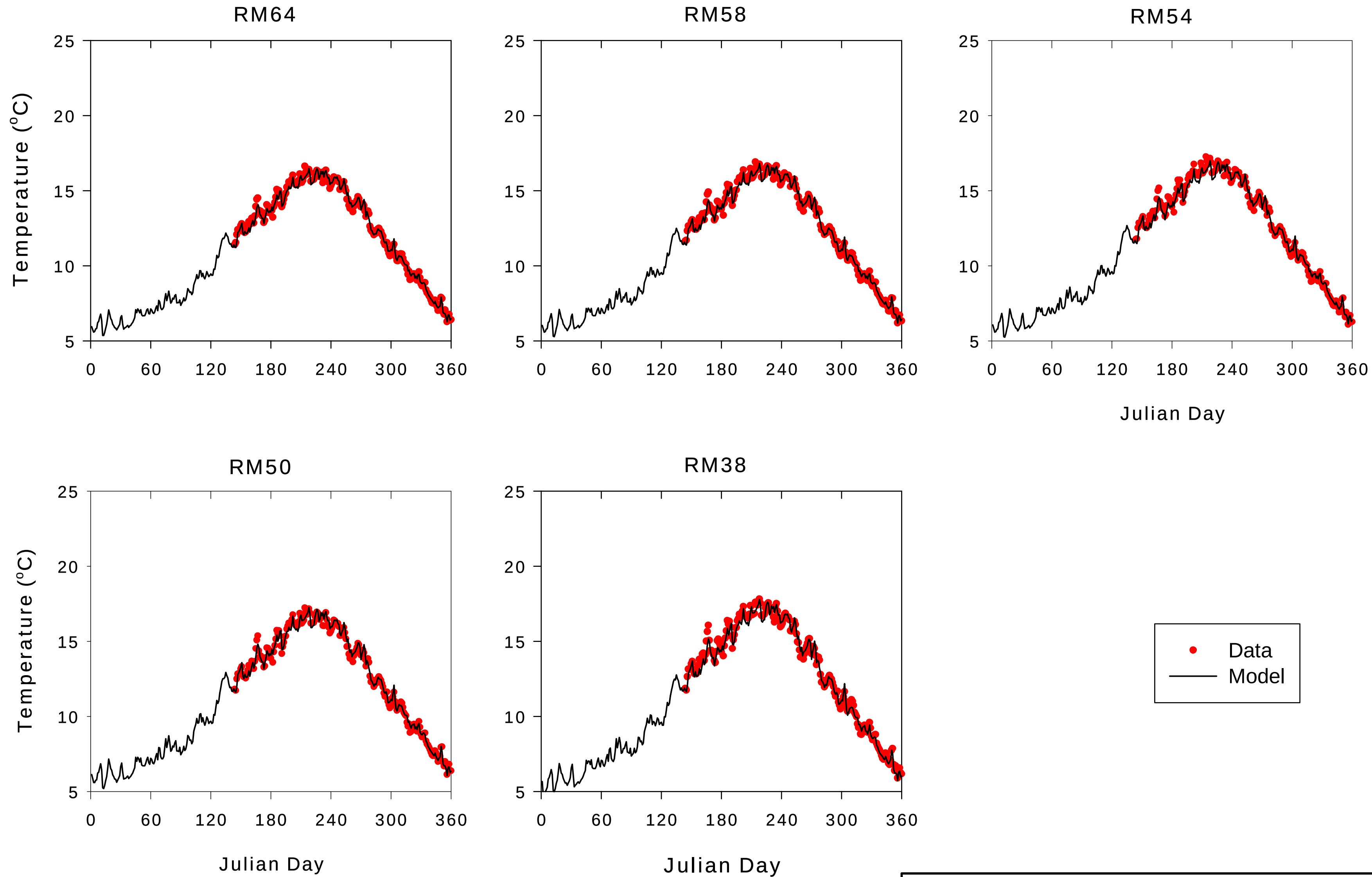
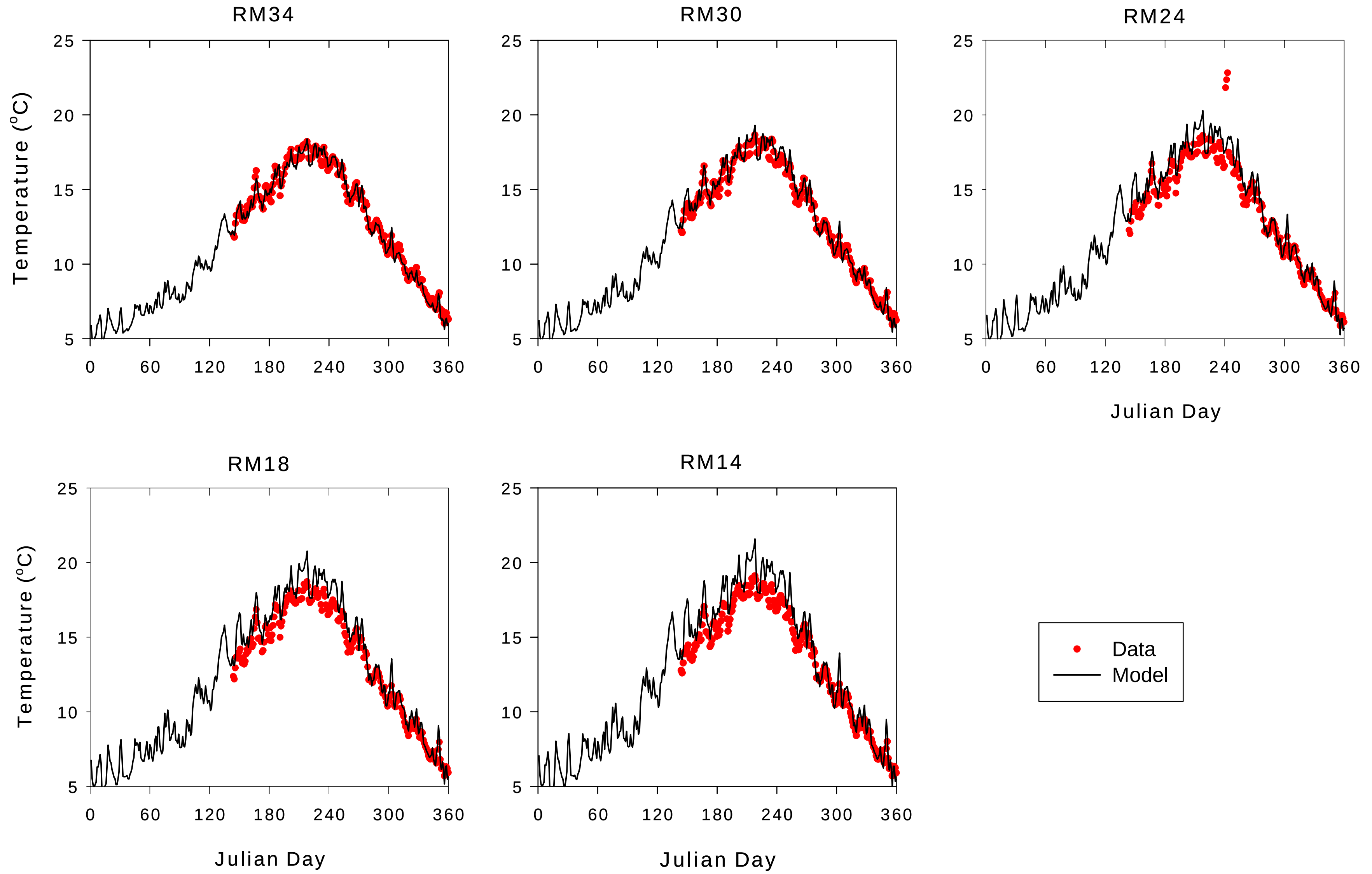


FIGURE 5-4
LOWER DESCHUTES RIVER MODEL
VERIFICATION RESULTS OF
DAILY AVERAGE TEMPERATURE
AT RM 64 - RM 38 FOR 1997
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 5-5
LOWER DESCHUTES RIVER MODEL
VERIFICATION RESULTS OF
DAILY AVERAGE TEMPERATURE
AT RM 34 - RM 14 FOR 1997
Portland General Electric Company
Portland, Oregon

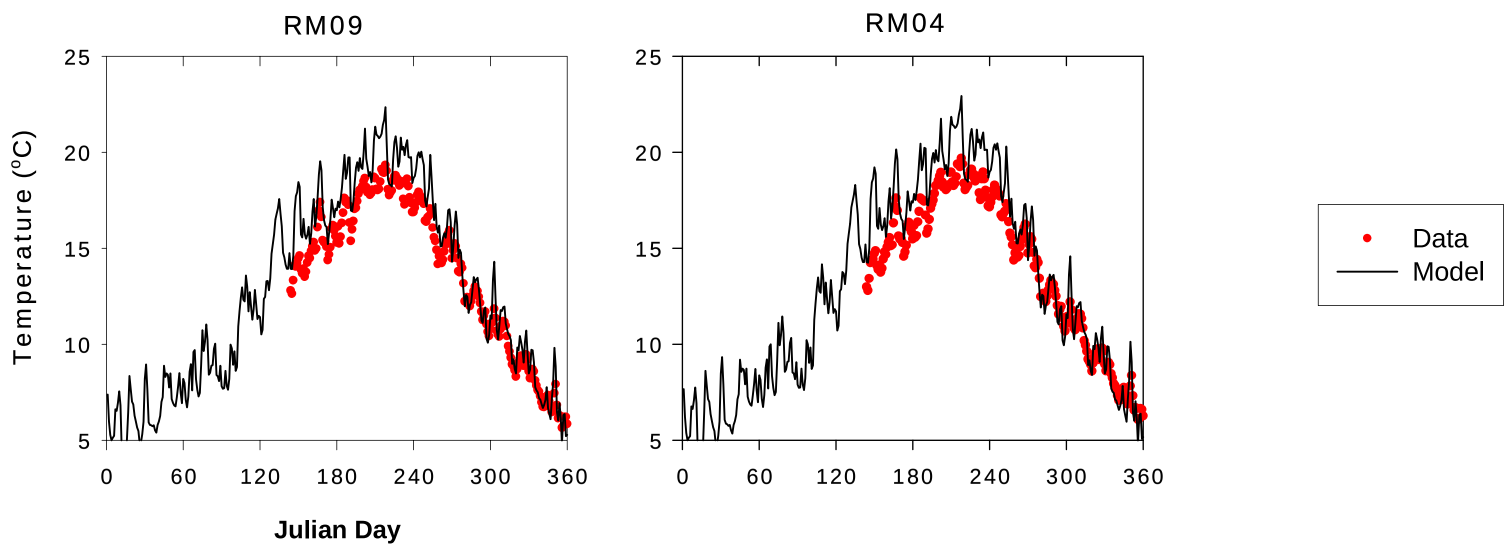
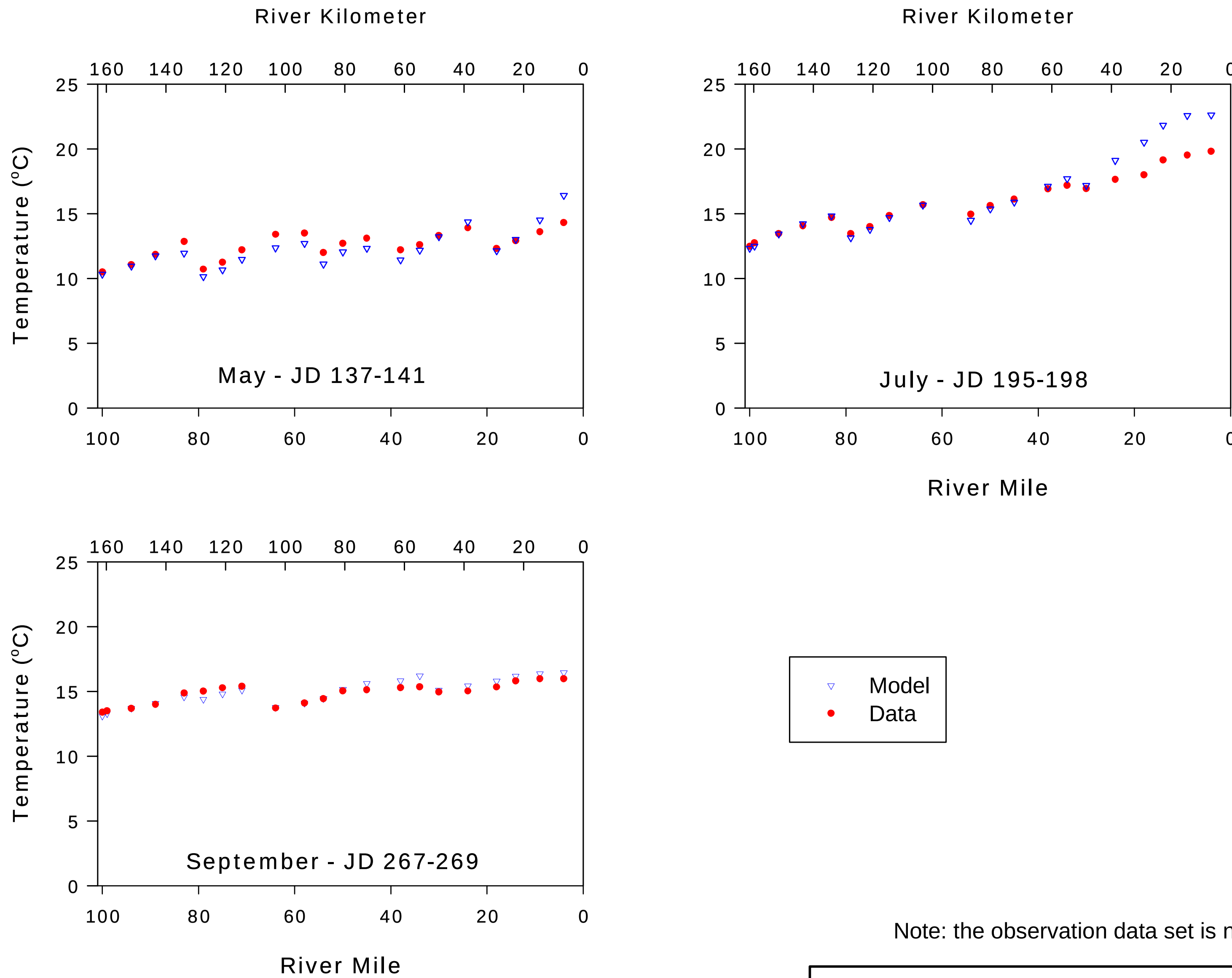


FIGURE 5-6

LOWER DESCHUTES RIVER MODEL
VERIFICATION RESULTS OF
DAILY AVERAGE TEMPERATURE
AT RM 09 - RM 04 FOR 1997

Portland General Electric Company
Portland, Oregon

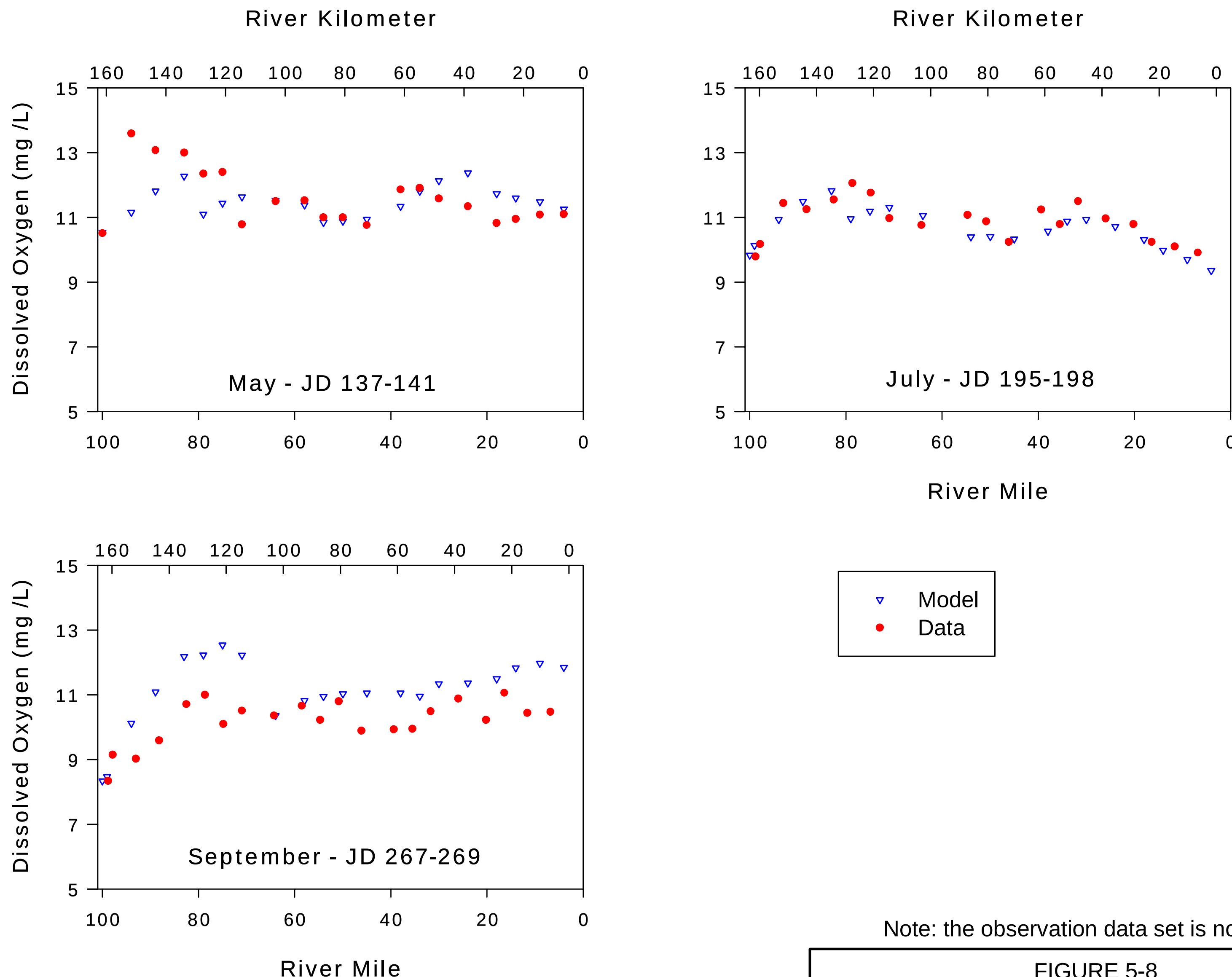
FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



Note: the observation data set is not synoptic.

FIGURE 5-7
LOWER DESCHUTES RIVER MODEL VERIFICATION RESULTS COMPARISON TO RIVER SURVEY TEMPERATURES FOR 1997
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



Note: the observation data set is not synoptic.

FIGURE 5-8

LOWER DESCHUTES RIVER MODEL VERIFICATION RESULTS COMPARISON TO RIVER SURVEY DISSOLVED OXYGEN FOR 1997

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

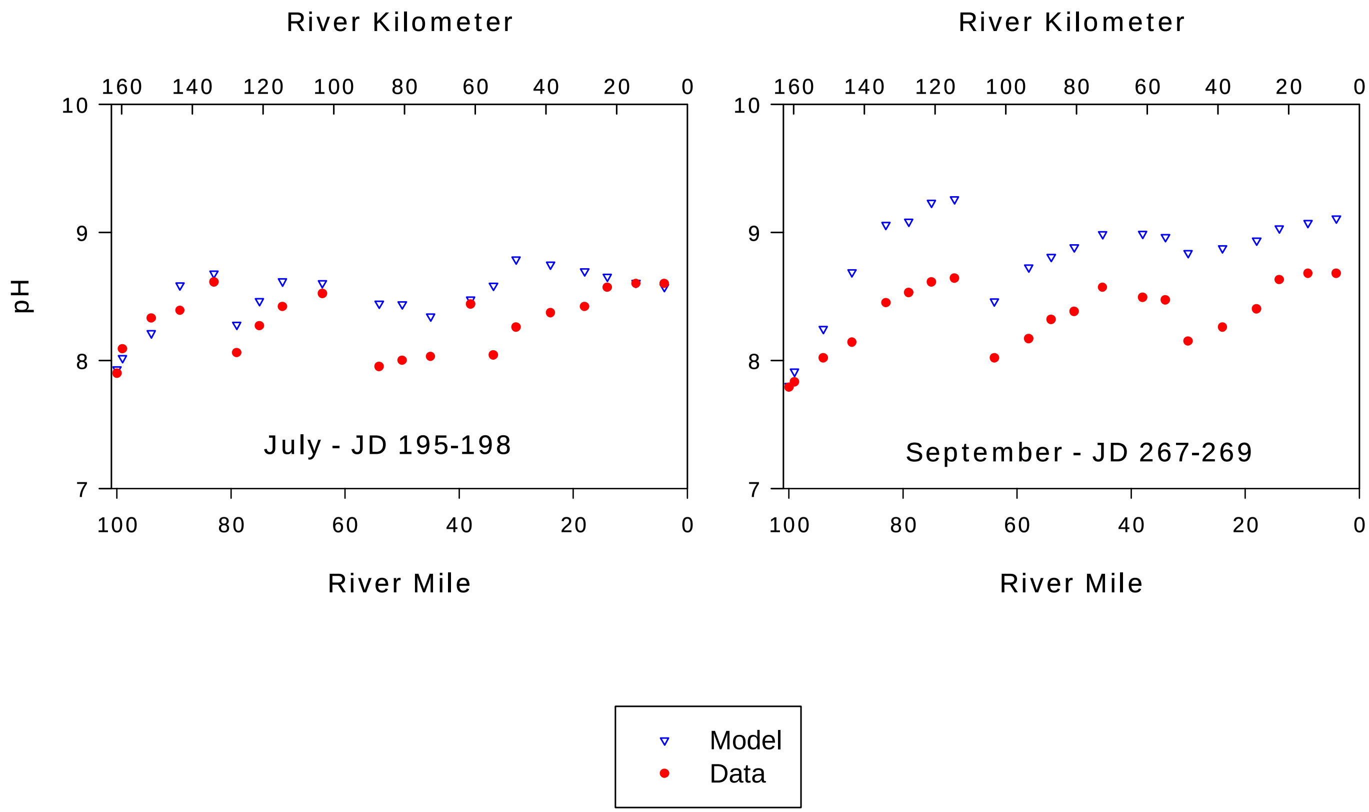
5.3.3 pH

The same type of data comparison was also made for pH (Figure 5-9). Note that the May data are inadequate and are not presented. Model results for July are good for the upper river, but as shown in the figure, the model-predicted pH values in September are higher than observed data by approximately 1/2 unit.

As stated previously, the amount of data for constructing boundary conditions for pH kinetics was inadequate for 1997, and some approximations were required. This is most likely the cause for this observed discrepancy between the model prediction for 1997 and data. However, in general, the model simulated dissolved oxygen and pH with reasonable accuracy.

5.3.4 Nitrate

The model results best match the observations during the summer (Figure 5-10). Considering the declining nitrate concentrations from upstream to downstream, the model provided good performance in showing nitrate consumption by periphyton along the river. Overall, the model simulations match the data reasonably well.



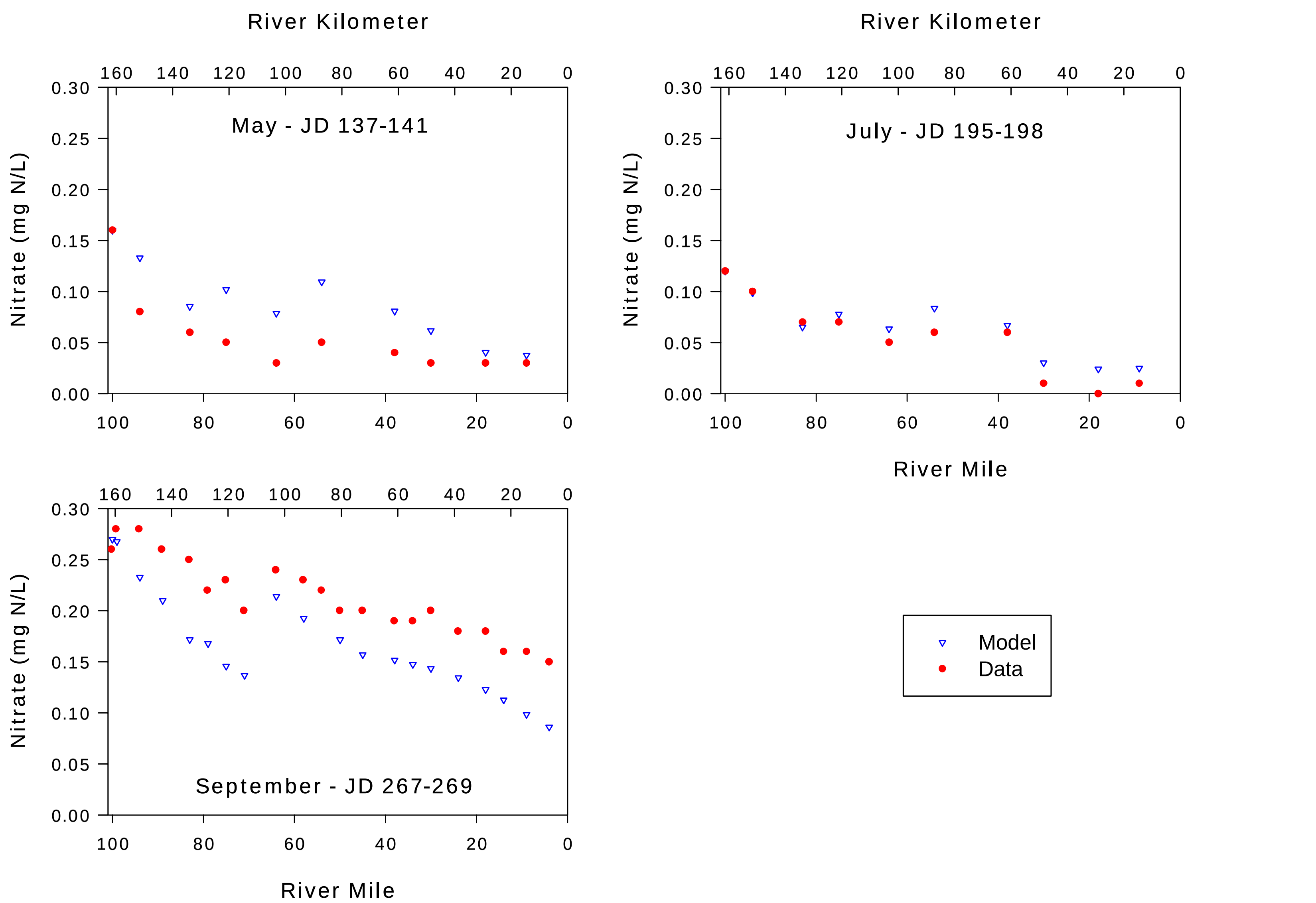
Note: the observation data set is not synoptic.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 5-9

LOWER DESCHUTES RIVER MODEL VERIFICATION RESULTS COMPARISON TO RIVER SURVEY pH FOR 1997

Portland General Electric Company
Portland, Oregon



Note: the observation data set is not synoptic.

FIGURE 5-10
LOWER DESCHUTES RIVER MODEL VERIFICATION RESULTS COMPARISON TO RIVER SURVEY NITRATE FOR 1997
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 30, 2001	PROJECT NO:
	FILENAME: LDR97veri.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

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6. MODEL APPLICATION

6.1 INTRODUCTION

As described in the Introduction Section 1.0, PGE is evaluating the “Selective Withdrawal” alternative at Round Butte Dam to enhance downstream passage of salmonids and to improve compliance with temperature standards. The selective withdrawal alternative was primarily designed to achieve compliance with temperature by altering the regime of discharged water to one that closely matches the conditions prior to the construction of the dams. However, there were concerns that the selective withdrawal alternative, which would require structural and operational modifications at the Round Butte Dam, would modify the water quality properties of water discharged into Lake Simtustus. Lake Simtustus would consequently discharge water that is different from the existing conditions into Reregulating Reservoir and on to the Lower Deschutes River. Therefore, the primary purpose for development of the Lower Deschutes River model was to evaluate the effect of proposed modifications on the water quality downstream of Reregulating Dam.

6.2 APPROACH

The selective withdrawal operation was developed through an iterative process which looked at a number of possible combinations of blending of surface and bottom waters to meet target temperature conditions immediately below the Reregulating Dam discharge location. A previous study (Foster Wheeler August 23, 1999) showed that it would be feasible to meet the temperature criteria at Regulating Dam using an optimum Blending sequence titled “Blend-13” selective withdrawal scenario (Blend-13).

In order to examine the effect of Blend-13 on the Lower Deschutes River, it is necessary to evaluate the effect of Blend-13 on Lake Simtustus, compute the modified discharge from Lake Simtustus through Pelton Dam, and estimate the water quality of discharge at Reregulating Dam. The effect on the Lower Deschutes River could then be evaluated using the Lower Deschutes River Model developed in this study. In this study, the evaluation was conducted through the following steps.

1. <u>Selection of Baseline Conditions</u>: Based on availability of data and completeness of available information, the year 1995 was selected as the baseline conditions for all comparisons.

2. Application of Water Quality Model of Lake Billy Chinook (BETTER): The BETTER model of Lake Billy Chinook was applied for the 1995 existing scenario and for the Blend-13 scenario (Foster Wheeler March 2000; Foster Wheeler February 22, 2001).

3. Application of Water Quality Model of Lake Simtustus (CE-QUAL-W2): The resulting discharge from Lake Billy Chinook, for the existing 1995 and the Blend-13 conditions, was routed through Lake Simtustus using the CE-QUAL-W2 model developed as part of this overall project (Foster Wheeler April 2001)

4. Estimate of Water Quality of Reregulating Dam Discharge: The water quality of Pelton Dam discharge into the Reregulating Reservoir was correlated to Reregulating Dam Discharge water quality, using regression analysis. Correlation between Pelton Forebay (discharge) water quality, and Reregulating Dam Tailrace (discharge) water quality was developed based on available data (Foster Wheeler May 24, 2000). The regression equations were used to develop water quality time histories at the Reregulating Dam boundary for the 1995 existing and Blend 13 conditions.

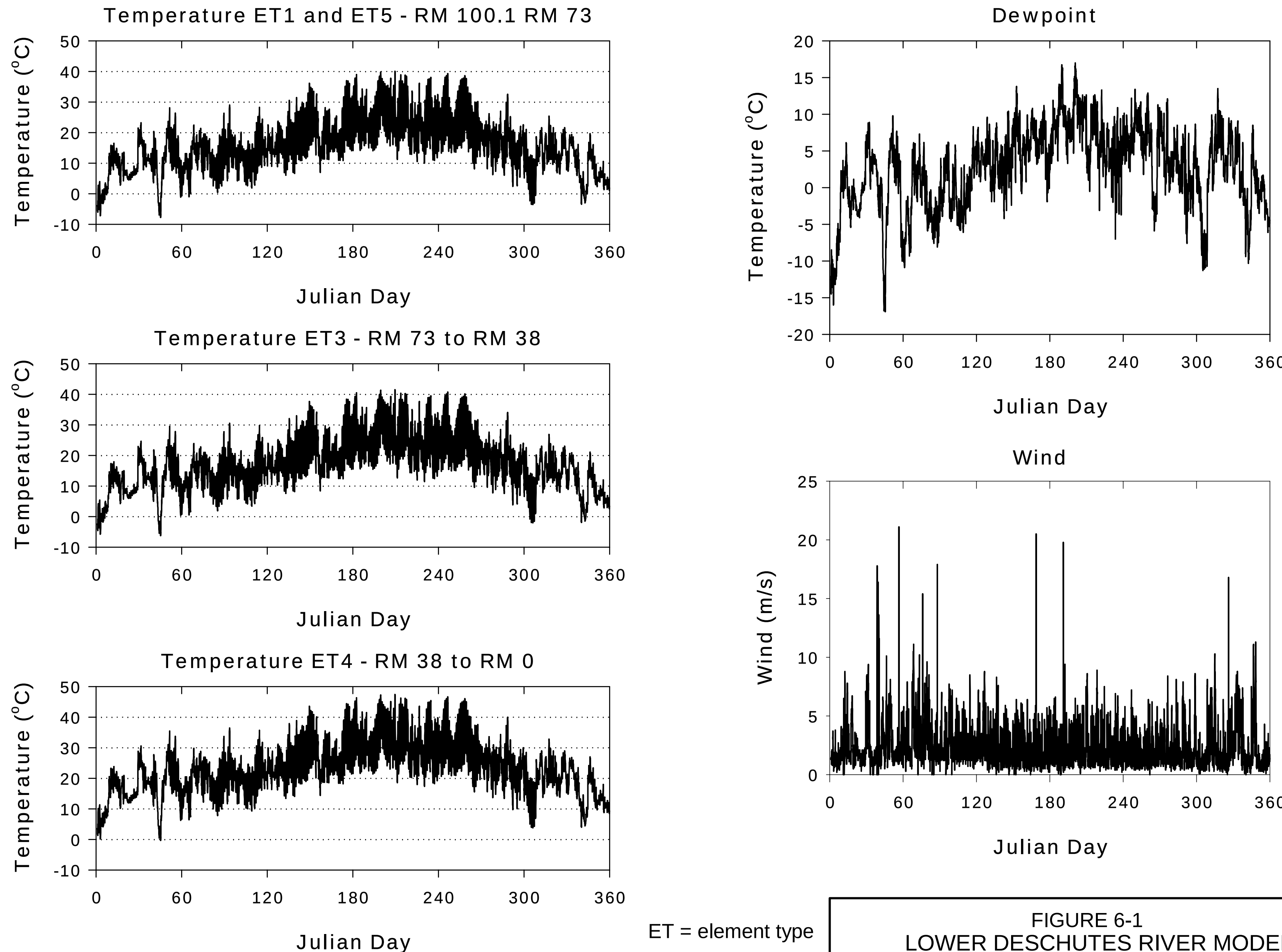
5. Setup and Application of the Lower Deschutes River for 1995 and Blend-13 Conditions: The Lower Deschutes River Model (calibrated for the 1999 conditions, verified for 1997) was set up to simulate 1995 existing conditions, and applied for the Blend-13 scenario.

The Lower Deschutes River is listed in the Oregon Department of Environmental Quality 303d list as having water quality impairment with respect to temperature, dissolved oxygen, and pH. These constituents are therefore the focus of this evaluation.

6.3 SETUP OF LOWER DESCHUTES WATER QUALITY MODEL FOR 1995 CONDITIONS, AND THE BLEND-13 SCENARIO

Meteorological data for the year 1995 were obtained from the Madras AgriMet Station. The same procedures were used for construction of these meteorological data as was done for the calibration for 1999. The input data are presented in Figure 6-1. Peak air temperatures, with lapse rate applied, are lower for calendar year 1995 than for the calibration and verification years 1999 and 1997, respectively.

Model boundary conditions at the Reregulating Dam discharge location were developed using model output from the Lake Simtustus model. The minor adjustments in water quality



ET = element type

FIGURE 6-1
LOWER DESCHUTES RIVER MODEL
INPUT METEOROLOGICAL DATA FOR 1995
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 4, 2001	PROJECT NO:
	FILENAME: LDR95met.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

during transit through the Reregulating Reservoir were made using regression equations developed previously (Foster Wheeler May 24, 2000).

Water quality boundary condition data for the tributaries were taken from the 1999 data, since no 1995 water quality data were available for these locations.

Once the Lower Deschutes River was set up for the 1995 exiting condition, its application for the Blend-13 scenario simply required replacing the existing boundary of Reregulating Dam discharge to the one corresponding to Blend-13 boundary condition. Note that the boundary condition data for each constituent is presented in the time series plots as Reregulating Dam tailrace at RM 100.1.

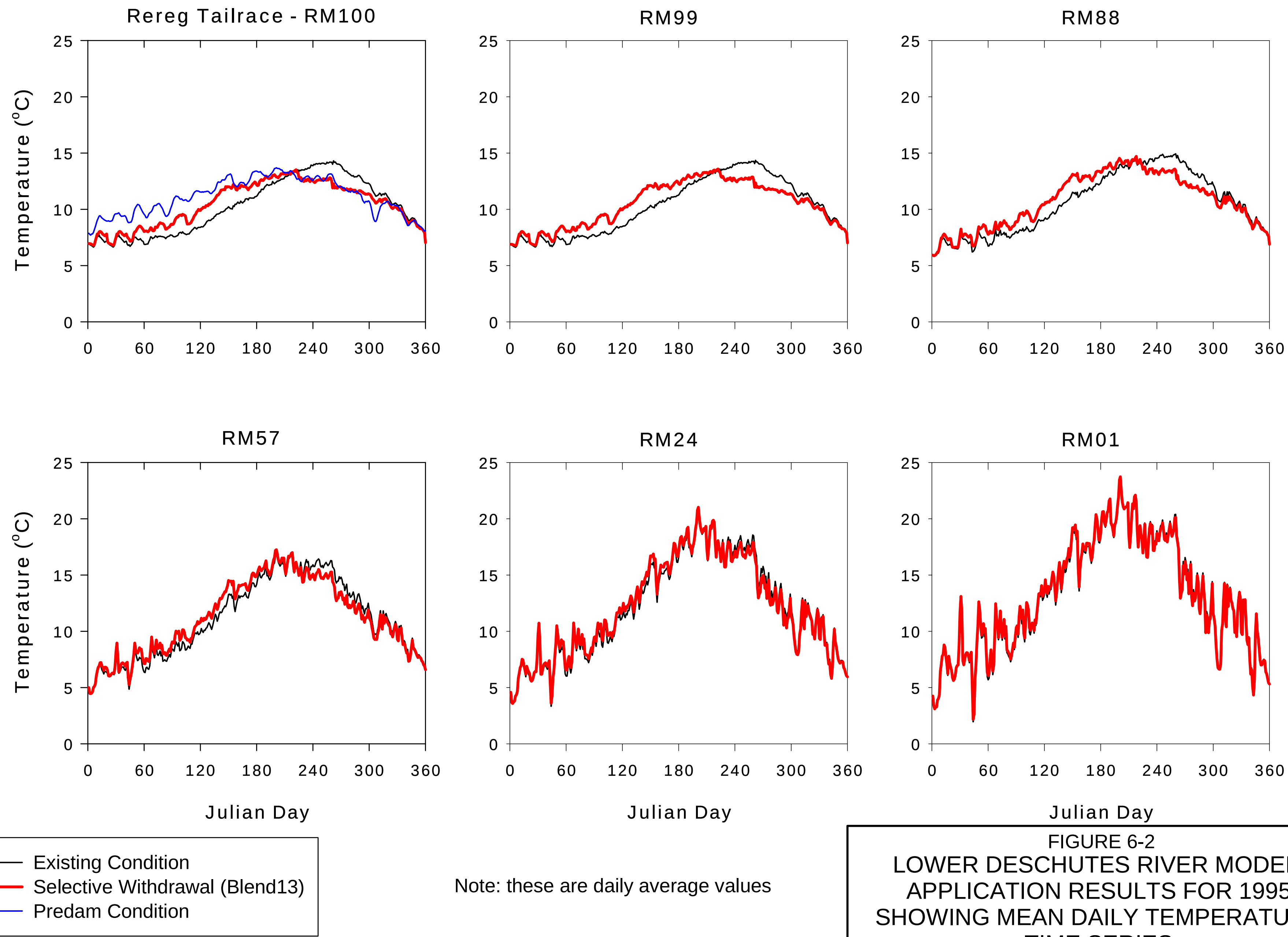
6.4 WATER QUALITY MODELING RESULTS FOR 1995, EXISTING CONDITION AND BLEND-13 SCENARIO

Model results are presented in two fashions: as mean daily time-series plots of each constituent at representative locations and as longitudinal plots during three different days of the year. The longitudinal plots are at four-hour intervals to illustrate the daily variation in constituent values.

Temperature, dissolved oxygen, pH, nutrients, and suspended algae (chlorophyll *a*) are presented in the time-series plots. Only temperature, dissolved oxygen, and pH are shown in the longitudinal plots, because they are primary constituents of concern.

6.4.1 Temperature

The Reregulating Dam (RM 100.1) discharge temperature time series for the existing and Blend-13 conditions are presented in Figure 6-2. Also included in the figure is a plot showing the estimate of temperature corresponding to the condition before the construction of dams (pre-dam condition) (Huntington et al. 1999). The results show that the Lower Deschutes River’s response to the blended discharge generally follows the pattern observed in the previous results observed in Lake Billy Chinook (Foster Wheeler March 2000), where the spring temperature lies between the existing and pre-dam conditions. By late August, the existing temperature exceeds the Blended-13 and pre-dam temperatures. The extent of blending warm surface and cooler bottom waters in Lake Billy Chinook was based on maintaining the resulting discharge temperature just below the pre-dam temperature as long as possible so that compliance with temperature criterion is achieved. The applicable temperature criterion appropriate to the Lower Deschutes River is [10°C (50°F)] based on



Note: these are daily average values

FIGURE 6-2
LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY TEMPERATURE TIME SERIES
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: Aoril 3, 2001	PROJECT NO:
	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

viability of native Oregon bull trout. When the temperatures exceed 10°C, the criterion is T+0.25 °F, where T is the pre-dam temperature.

Figure 6-2 shows that the beneficial effect of blended water (that is, reduction in summer-time temperatures, maintaining temperatures below the pre-dam temperatures) are noticeable in the Lower Deschutes River for several miles. As expected, the temperature for both existing and Blend 13 conditions increases with distance from the Reregulating Dam because of warming from direct solar heating of the water and due to possible trapping of heat in the canyons. At the river's mouth, the data from the two runs (existing conditions and Blend-13 conditions) are nearly identical, showing the equilibrating effect of heat-exchange processes.

Figure 6-3 shows a sequence of longitudinal temperature plots for the existing condition and Blend-13 conditions during April 1995. The plot begins at midnight (JD 118.000, April 27, 1995) and ends at 8 p.m., April 27, 1995 (JD 118.833). At the Reregulating Dam boundary (RM 100.1), the temperature of Blend-13 discharge is higher than for the existing condition, because in April 100 percent of the discharge is composed of warmer surface waters. Note that diurnal variation in the temperatures of the boundary flow at Reregulating Dam is small in comparison to the increase in downstream temperatures during the day (as shown during JD 118.333 through JD 118.667). Even more heating is indicated in the July 1999 plots (Figure 6-4), though the trends are the same as noted for the April data. Note that the difference in boundary data is smaller for the July data than in April. By October, there is much less heating (Figure 6-5). Also, the boundary temperature for the Blend-13 condition is lower than the existing condition run, since by this time 100 percent of water discharged from Lake Billy Chinook is cooler bottom water.

6.4.2 Dissolved Oxygen

The time series plot of daily average dissolved oxygen values is shown in Figure 6-6, starting from the upstream boundary at the Reregulating Dam (RM 100.1), through various locations downstream to the river mouth. The figures clearly show the beneficial effect of Blend-13 conditions in terms of improving dissolved oxygen concentrations in the Lower Deschutes River. This beneficial effect is seen to last a considerable distance downstream of the boundary at Reregulating Dam. By the time the river flows reach the river mouth, the difference between existing and Blend-13 dissolved oxygen time series is minimal as the river tends towards equilibrium. This may be explained in terms of the internal production and consumption of oxygen by periphyton, and the reaeration with the atmosphere driven

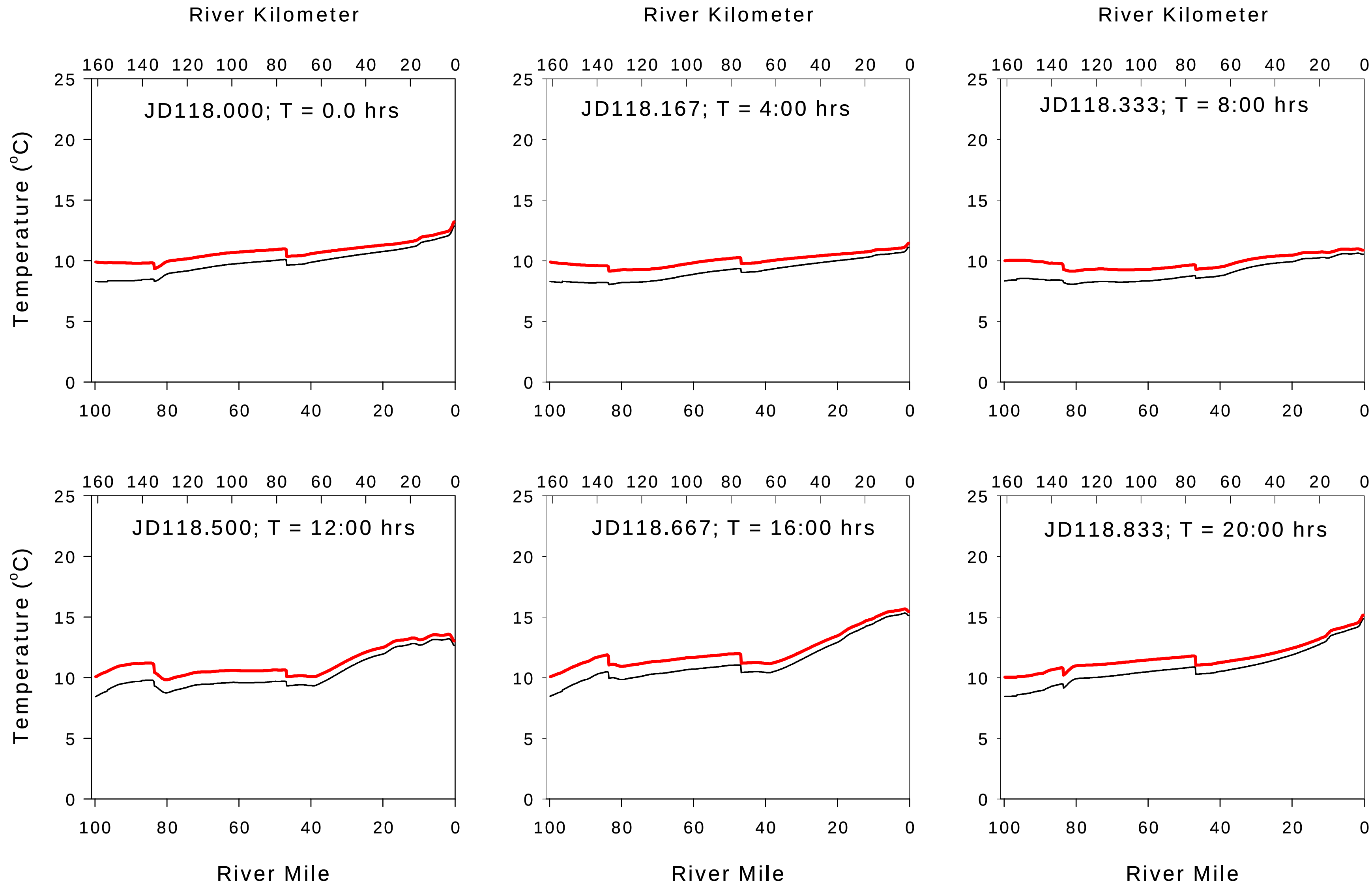


FIGURE 6-3
LOWER DESCHUTES RIVER MODEL APPLICATION TEMPERATURE RESULTS FOR APRIL 1995 SHOWING THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

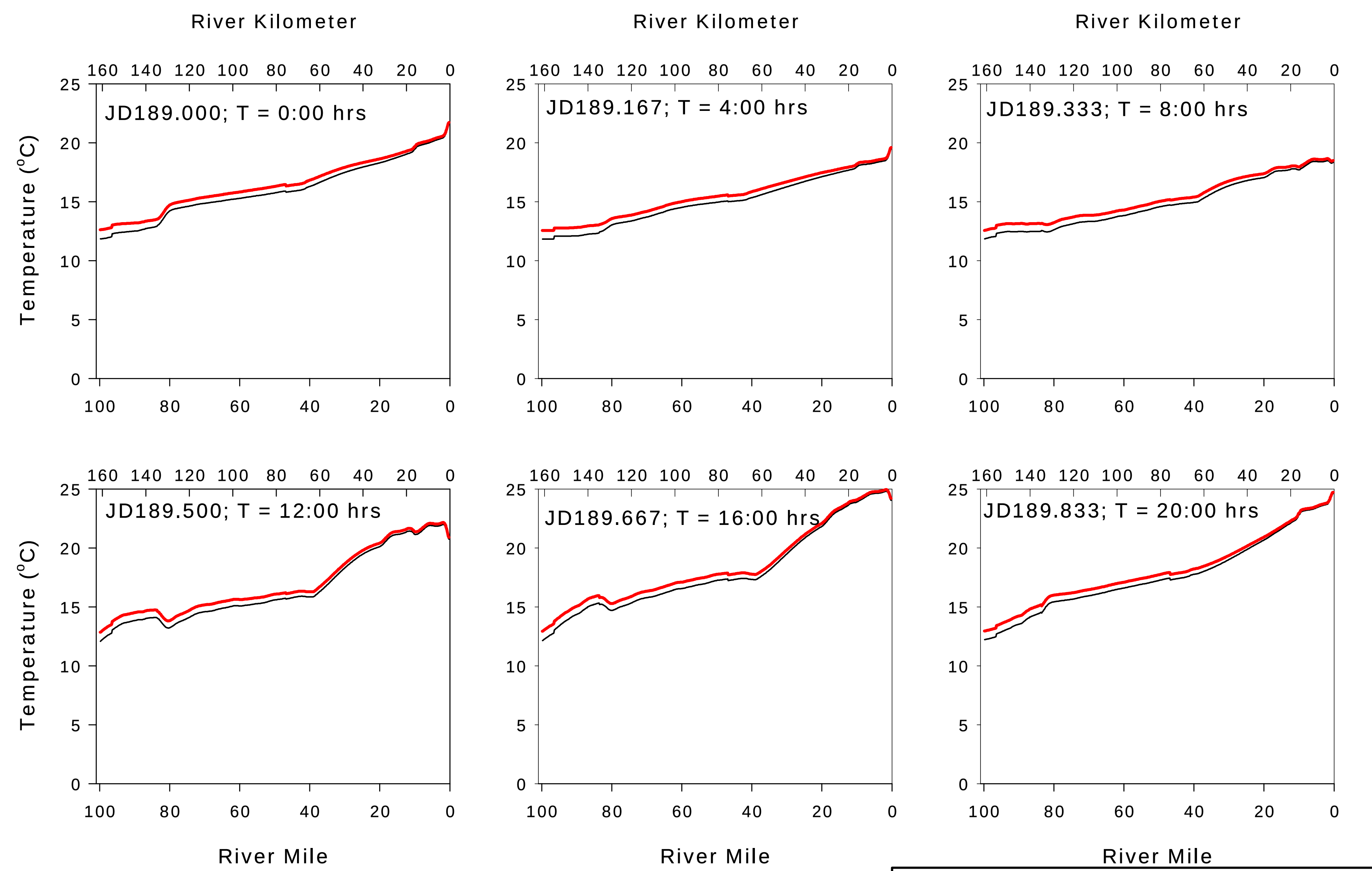


FIGURE 6-4
LOWER DESCHUTES RIVER MODEL APPLICATION TEMPERATURE RESULTS FOR JULY 1995 SHOWING THE DIRUNAL VARIATION
Portland General Electric Company
Portland, Oregon

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

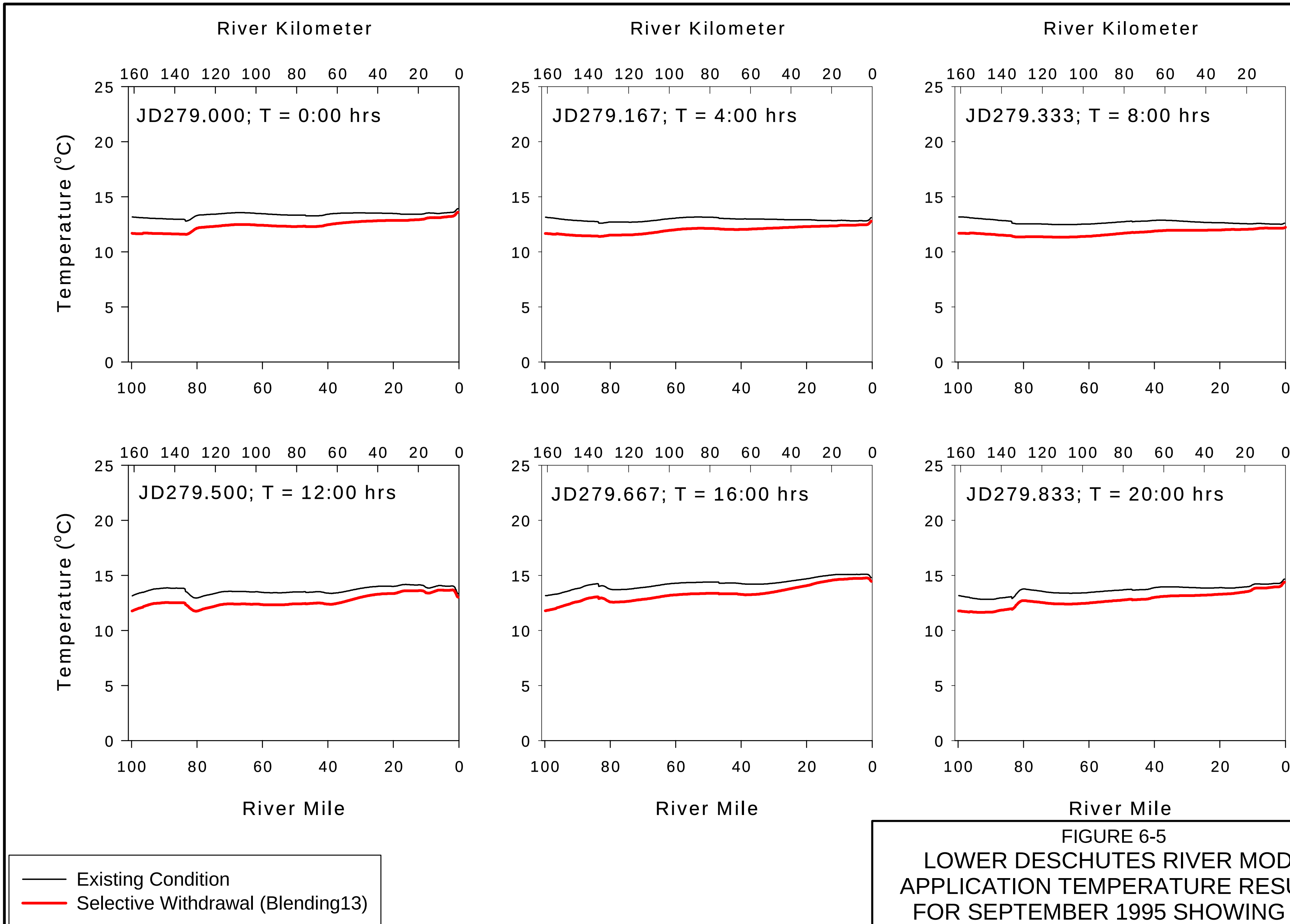
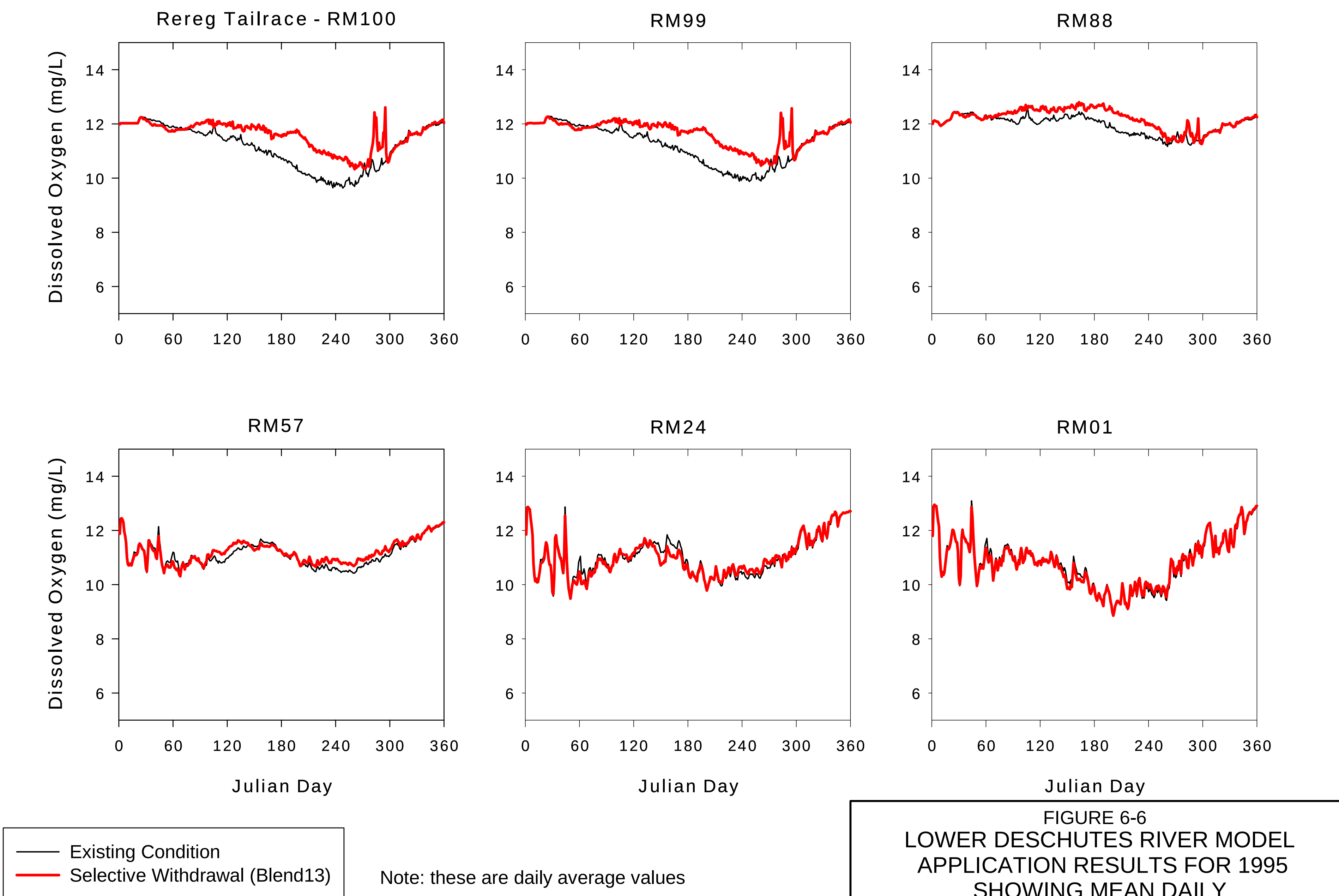


FIGURE 6-5
LOWER DESCHUTES RIVER MODEL APPLICATION TEMPERATURE RESULTS FOR SEPTEMBER 1995 SHOWING THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: Aoril 3, 2001	PROJECT NO:
	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-6
LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY DISSOLVED OXYGEN TIME SERIES
Portland General Electric Company
Portland, Oregon

by the tendency towards oxygen saturation in the water column. The fall spike resulting from overturn of Lake Simtustus is evident at the Reregulating Dam boundary (RM 100.1) and RM 99 but much less so at RM 88. By RM 57, internal processes have removed this effect. At RM 01, the daily average dissolved oxygen is seen to have a minimum in mid-summer for both the existing and Blend-13 conditions.

The April 1999 longitudinal plot (Figure 6-7) shows that the boundary values of dissolved oxygen for Blend-13 conditions are greater than those for the existing condition. They also show little diurnal variation. However, in the upper reaches of the modeled river domain (RM 99 to about RM 70), nighttime oxygen lows and daytime oxygen highs are evident. These result from the nighttime respiration by periphyton and daytime growth of periphyton, with growth resulting in oxygen production. The Blend-13 condition carries higher dissolved oxygen through most of the year and follows the diurnal variation observed in the existing condition. The improvement in dissolved oxygen concentrations is highest at the boundary, which reduces asymptotically to match the existing condition at the river mouth.

6.4.3 pH

Time series plots of pH for the existing condition and Blend-13 conditions are presented as daily average values in Figure 6-10. The plot at the boundary location RM 100.1 shows that the pH in the Blend-13 condition is slightly higher than the existing condition by 0 to 0.5 units. However, as water proceeds downstream, the difference in pH values declines relatively quickly. The difference is small by RM 88 and is negligible below RM 57. This movement toward equilibrium is expected, because pH is governed by carbon dioxide concentrations that in turn are produced by periphyton respiration and consumed by periphyton growth. Additionally, carbon dioxide is subject to reaeration similarly to dissolved oxygen, and its saturation values vary with water temperature.

The longitudinal plots of pH also show (Figures 6-11 through 6-13) that the pH values are slightly higher for the Blend-13 conditions relative to existing conditions, with the difference varying from 0 to 0.5 units. For the April 28th diurnal plots (Figure 6-11), the onset of daylight and periphyton growth can be seen to increase pH as carbon dioxide is consumed. This is particularly evident in the upper reaches of the river (RM 99 - RM 70). The effect of tributary inflows produces pronounced decreases in pH at this time. By July 8th (JD 189), periphyton growth has a major effect on pH (via carbon dioxide uptake during

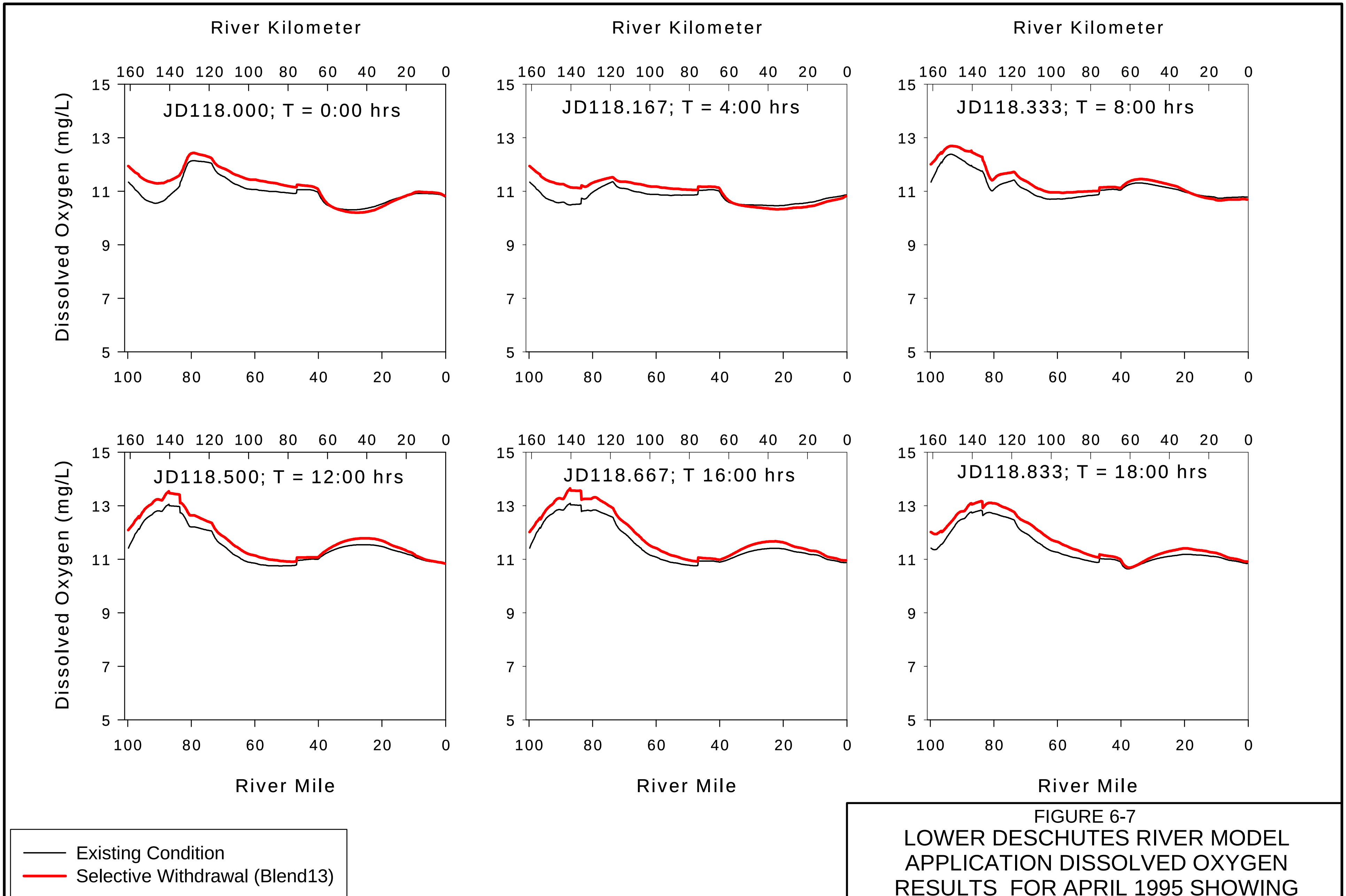


FIGURE 6-7
LOWER DESCHUTES RIVER MODEL APPLICATION DISSOLVED OXYGEN RESULTS FOR APRIL 1995 SHOWING THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

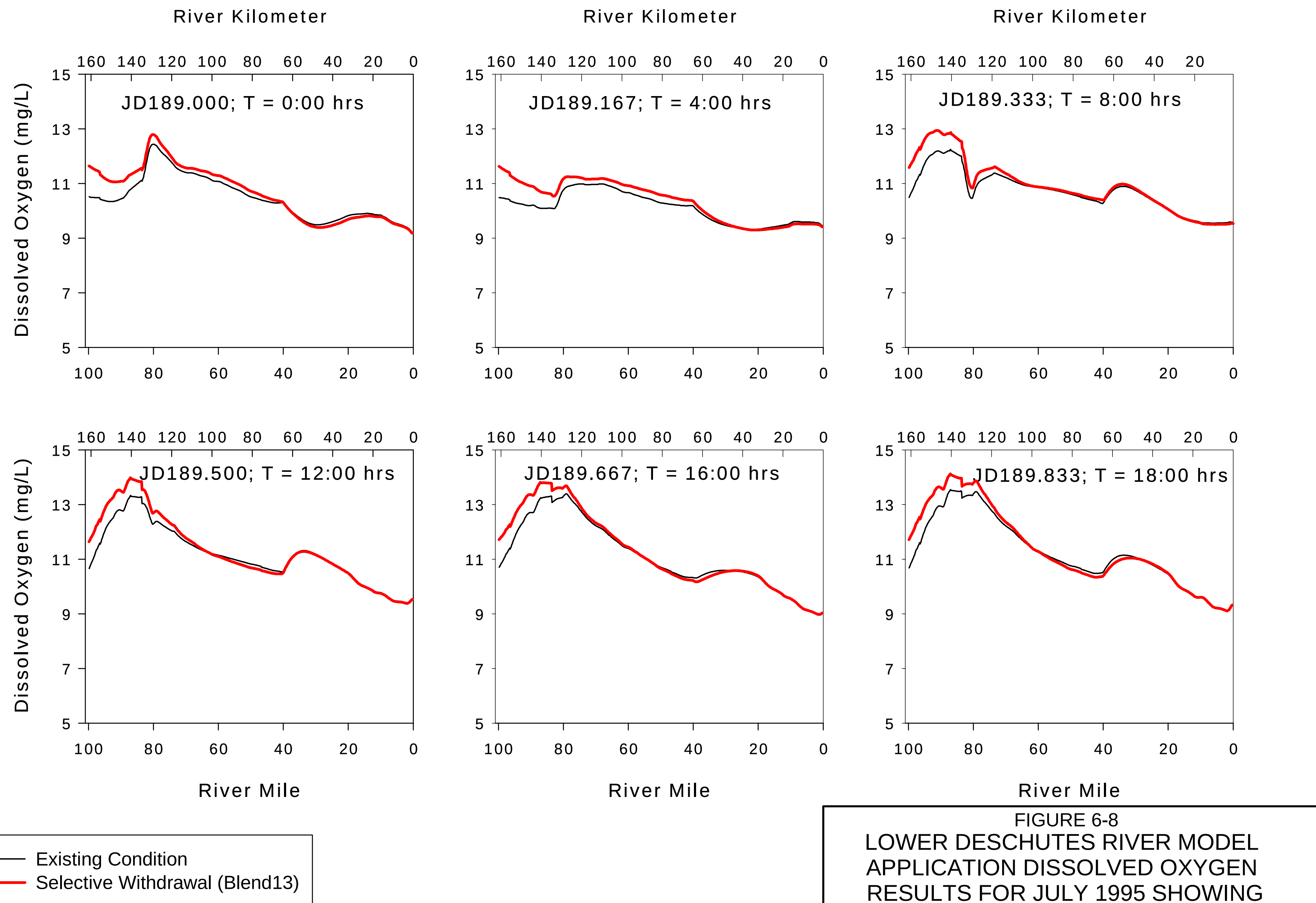
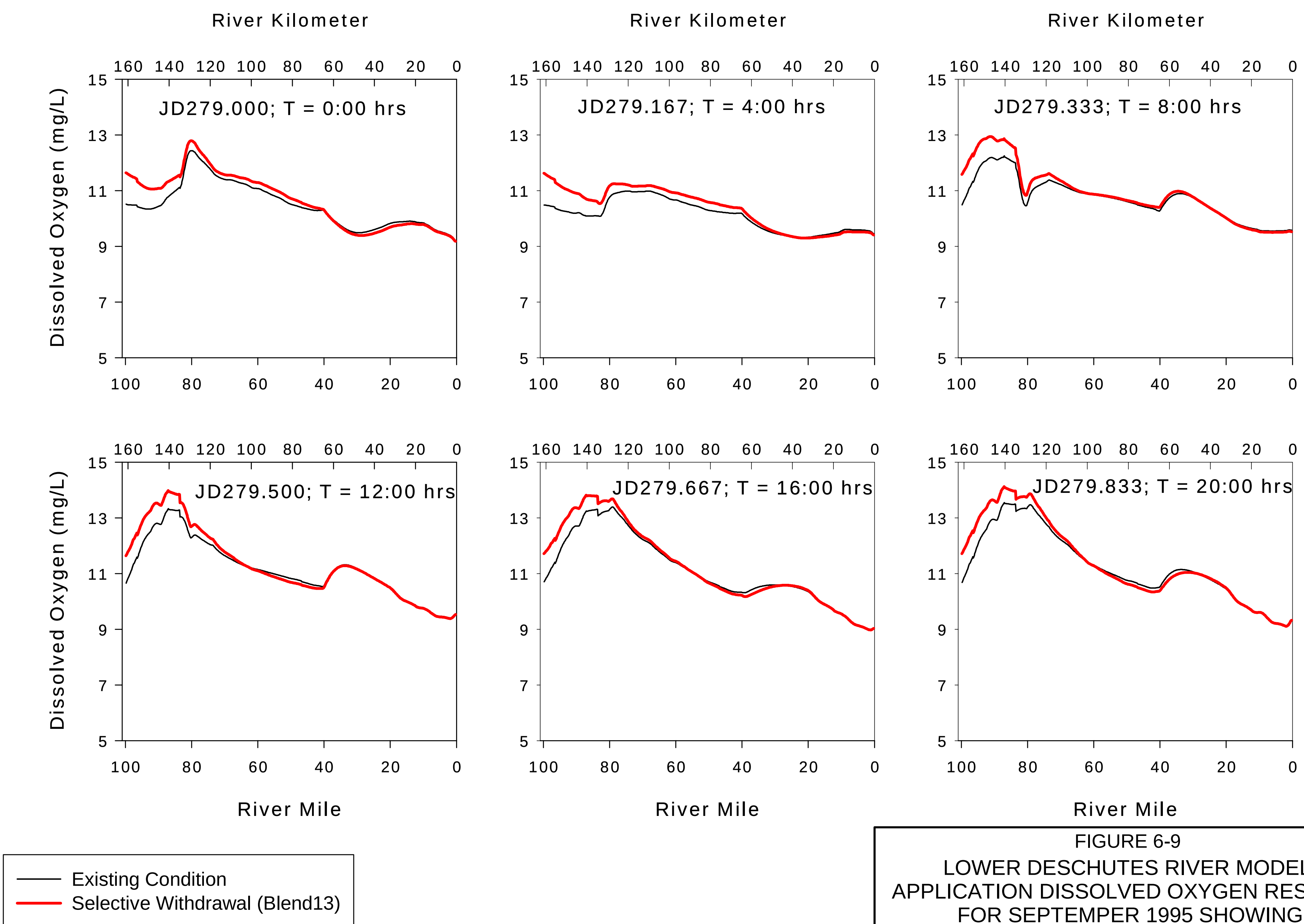


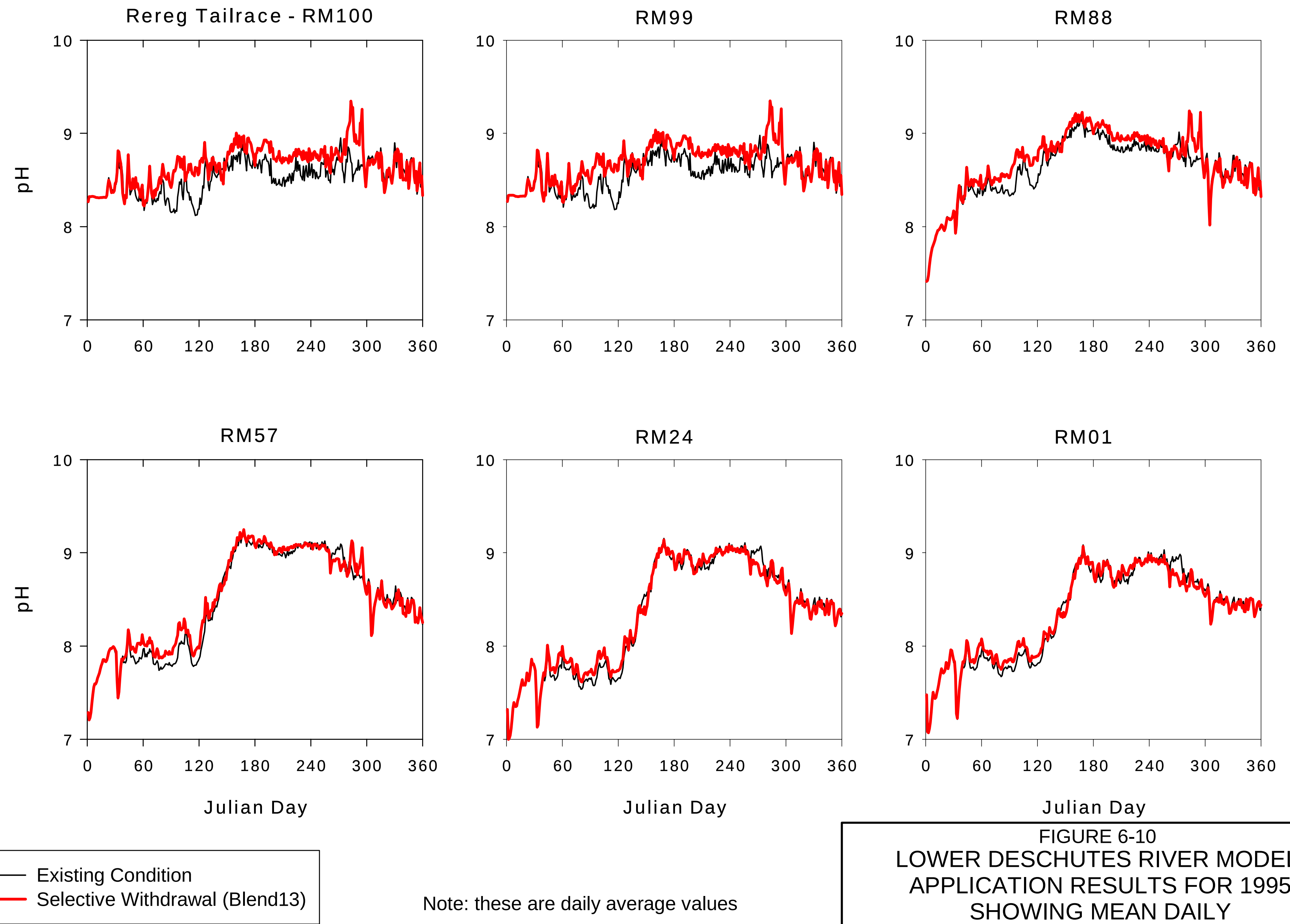
FIGURE 6-8
LOWER DESCHUTES RIVER MODEL APPLICATION DISSOLVED OXYGEN RESULTS FOR JULY 1995 SHOWING THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-9
LOWER DESCHUTES RIVER MODEL
APPLICATION DISSOLVED OXYGEN RESULTS
FOR SEPTEMPER 1995 SHOWING
THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon



Note: these are daily average values

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	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-10
LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY pH TIME SERIES
Portland General Electric Company
Portland, Oregon

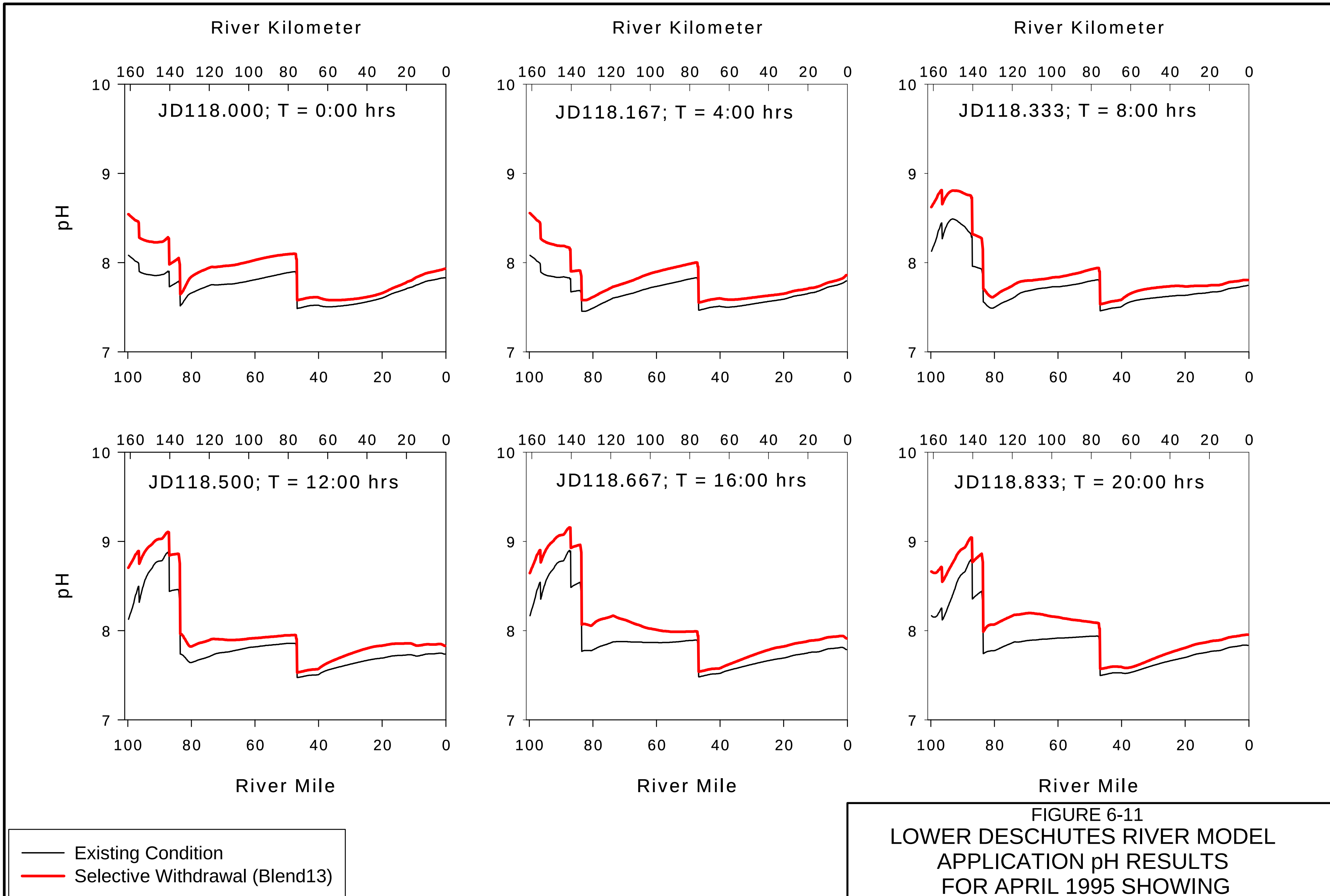
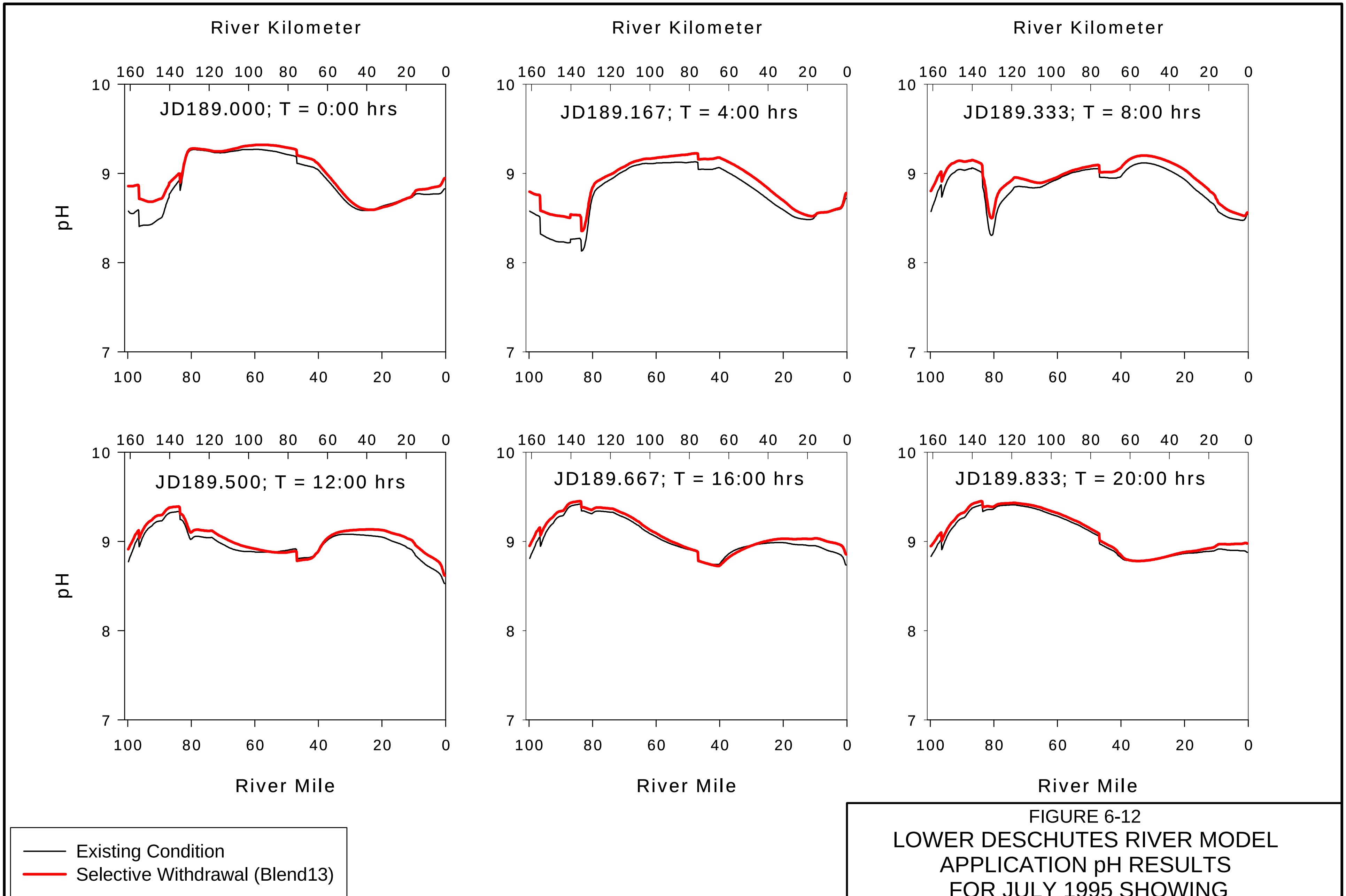


FIGURE 6-11
LOWER DESCHUTES RIVER MODEL APPLICATION pH RESULTS FOR APRIL 1995 SHOWING THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
	FILENAME:LDR95-LDR29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-12
LOWER DESCHUTES RIVER MODEL APPLICATION pH RESULTS FOR JULY 1995 SHOWING THE DIURNAL VARIATION
Portland General Electric Company
Portland, Oregon

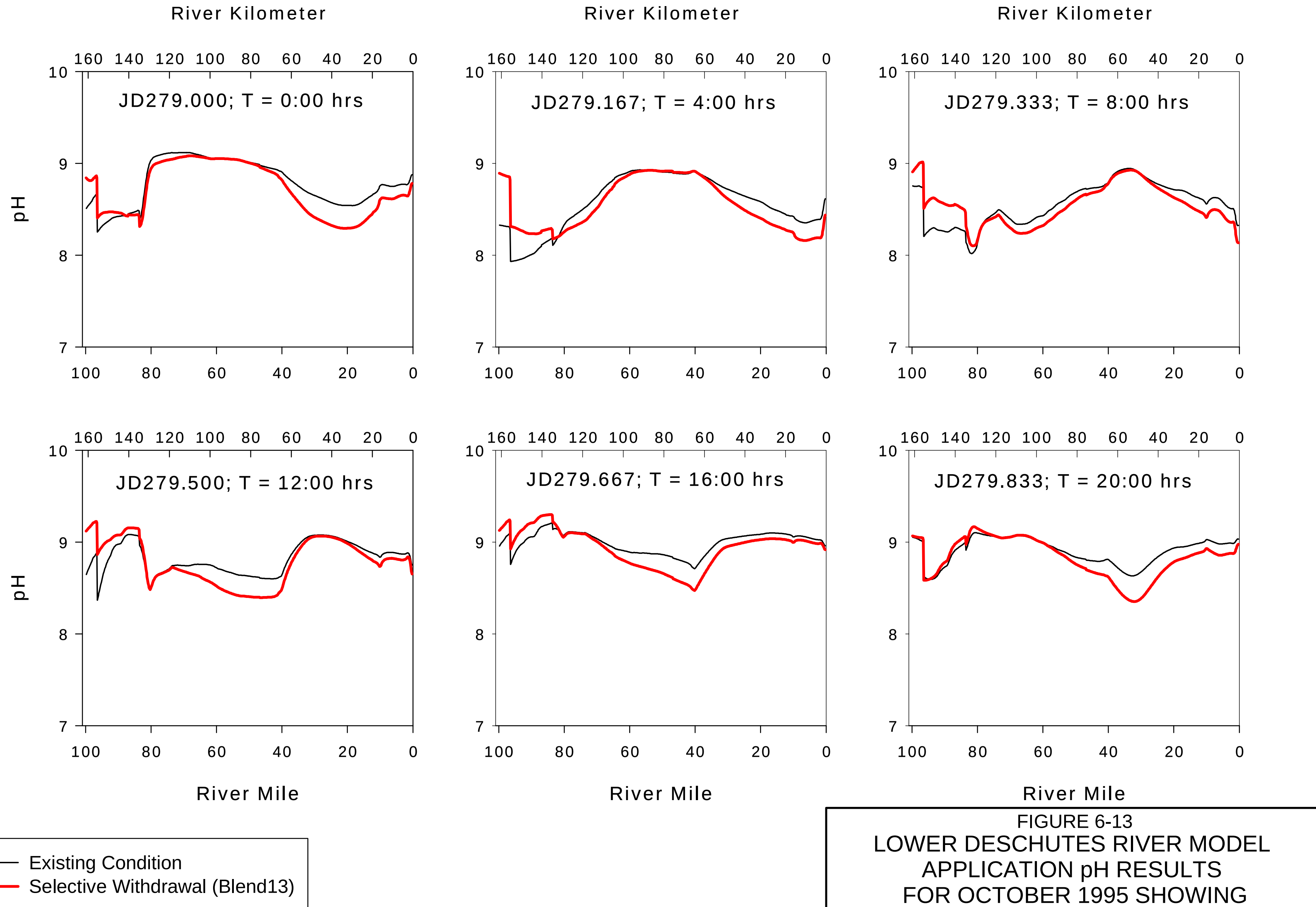


FIGURE 6-13
LOWER DESCHUTES RIVER MODEL APPLICATION pH RESULTS FOR OCTOBER 1995 SHOWING THE DIURNAL VARIATION

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: March 23, 2001	PROJECT NO:
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growth) (Figure 6-12). The differences between the existing condition and the Blend-13 condition are small throughout most of the system, with the largest differences generated by the boundary values from the Regulating Dam discharge.

6.4.4 Nutrients and Chlorophyll *a*

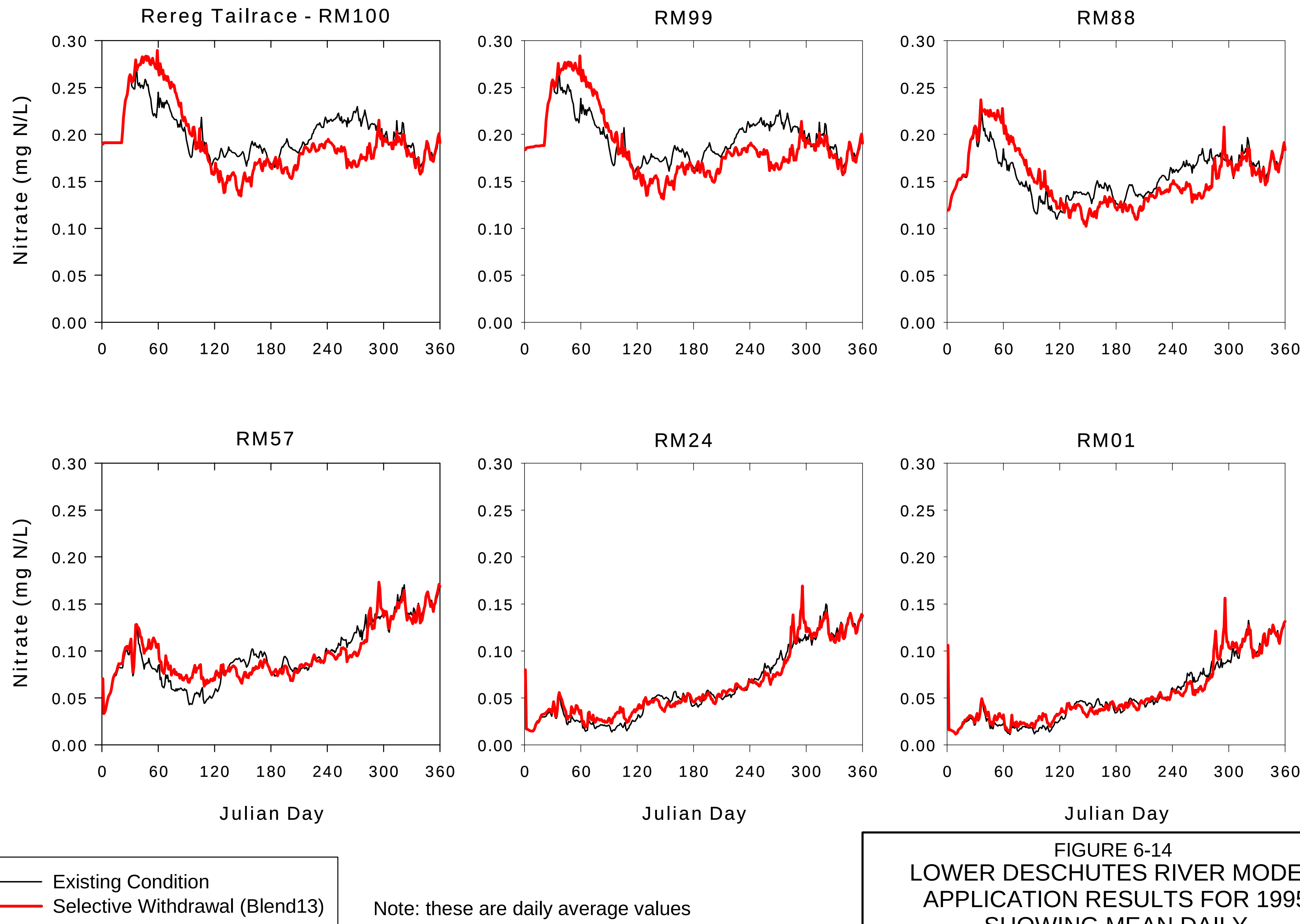
The primary nutrient affecting water quality changes is nitrate. Ammonia concentrations are an order of magnitude lower than nitrate values and consequently do not have as much of an affect on periphyton growth as nitrate. Ortho-phosphate is in abundant supply, as indicated by the boundary condition N:P molar ratio of 6.3. These nutrients are presented here for a qualitative comparison between the existing and Blend-13 conditions, as are chlorophyll *a* concentrations. Chlorophyll *a is* not likely to be to an important factor because its mass changes little over the river length and is transported out. This is expected with a residence time of about 24 hours.

Figure 6-14 clearly shows the decline in nitrate concentrations as the river flows downstream. Nitrate is used by periphyton for growth. The plot at the boundary location (RM 100.1) also shows nitrate values early in the year are higher for the Blend-13 condition than for the existing condition. However, after March, nitrate concentrations in the Blend-13 condition discharged by the Reregulating Dam are lower than the existing condition values.

Ammonia values are plotted (Figure 6-15) at the same scale to show the low values of ammonia relative to nitrate concentrations. Even at the small values, ammonia is used by periphyton, and concentrations decline as water flows downstream.

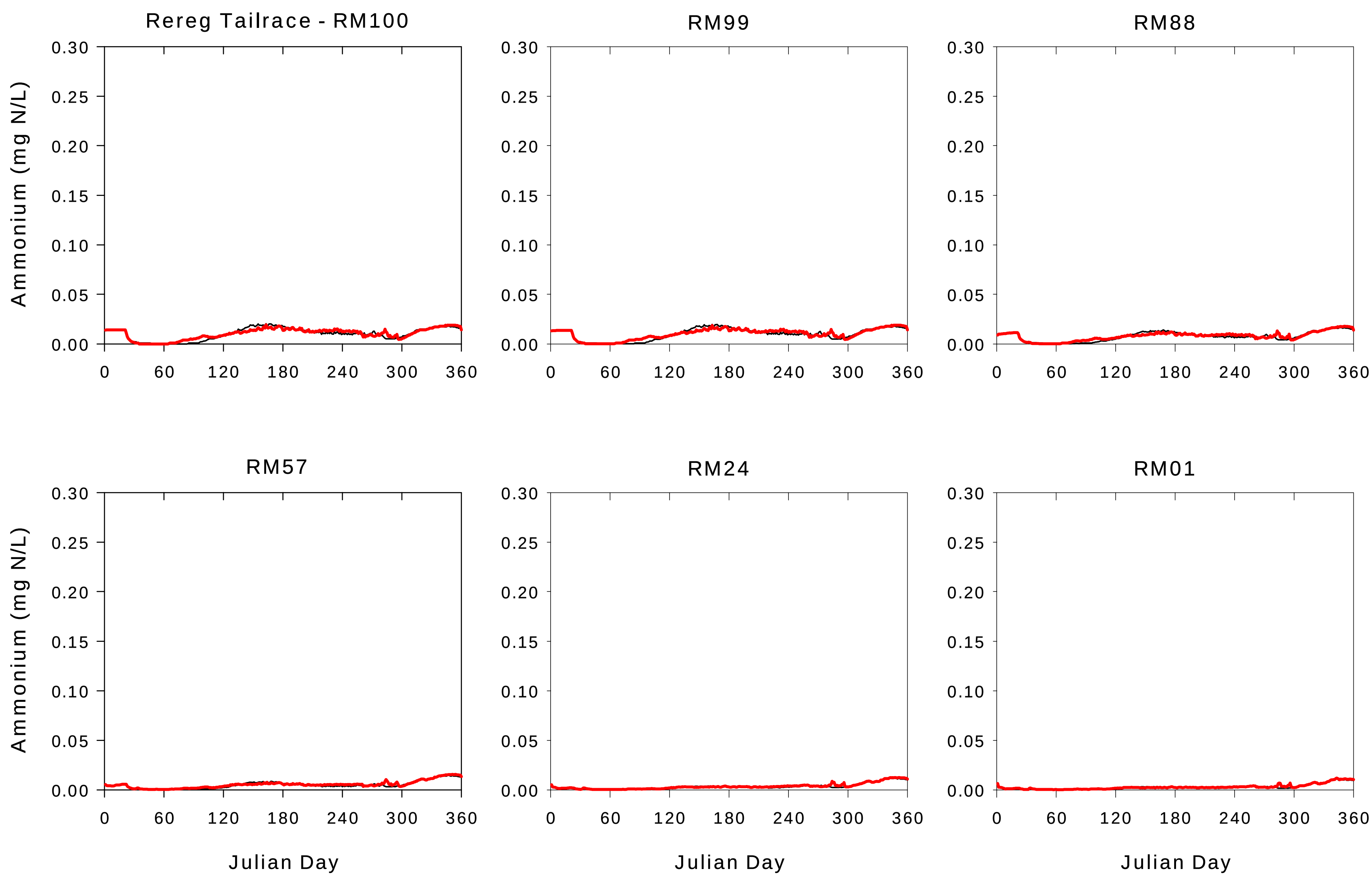
Ortho-phosphate remains relatively constant over the year (Figure 6-16). Blend-13 conditions result in values that are slightly lower than existing values at the boundary. Uptake by periphyton is evident as concentrations decline as water flows downstream.

Chlorophyll *a* remains nearly unchanged as river water travels downstream from the Regulating Dam discharge to the mouth (Figure 6-17). The fall spike in chlorophyll *a* travels downstream undiminished. The travel time through the system is not long enough for suspended algae to have time to grow and so has little impact on water quality. It is be noted that the periphyton model does not include the addition of periphytic algae by scour into the water column, nor does the model include filtering of suspended algae by aquatic invertebrates. Both these processes affect the dynamics of water column chlorophyll *a*, but examination of the small amount of data available suggest that these effects are relatively small and the concentrations predicted by the present model are reasonable.



FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: Aoril 3, 2001	PROJECT NO:
	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-14
LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY NITRATE TIME SERIES
Portland General Electric Company
Portland, Oregon

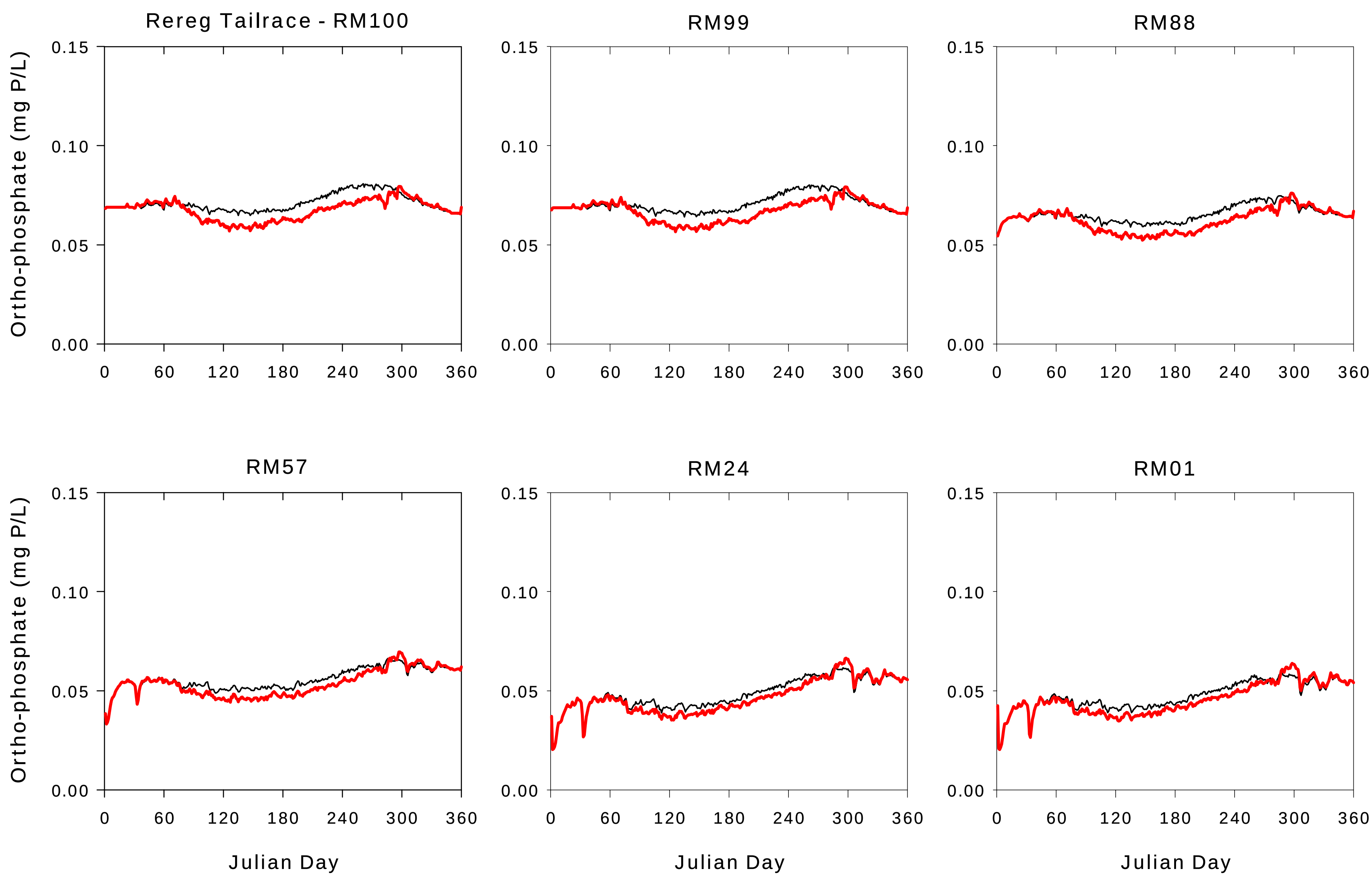


Existing Condition
Selective Withdrawal (Blend13)

Note: these are daily average values

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: Aoril 3, 2001	PROJECT NO:
	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-15
LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY AMMONIUM TIME SERIES
Portland General Electric Company
Portland, Oregon

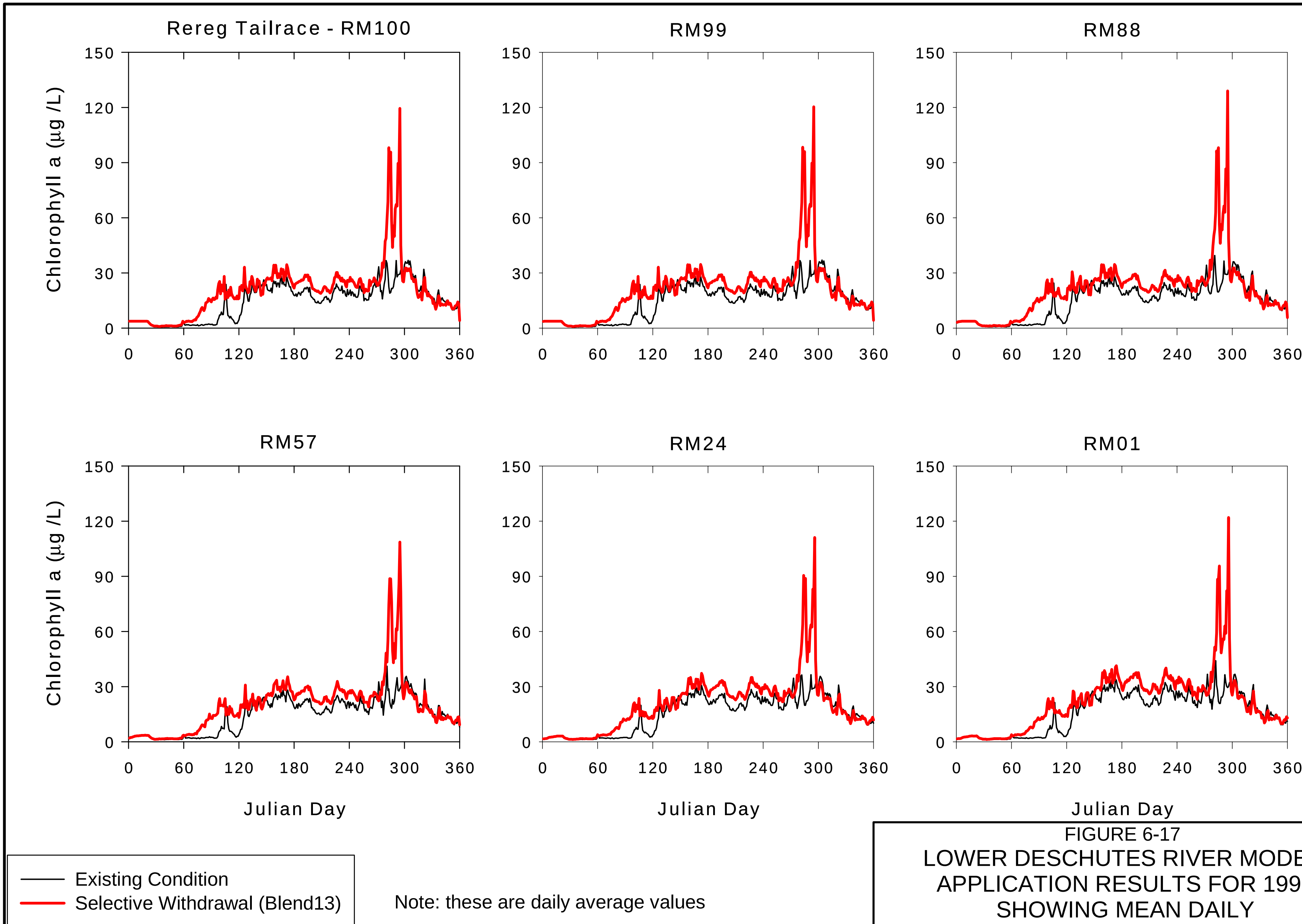


Existing Condition
Selective Withdrawal (Blend13)

Note: these are daily average values

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: Aoril 3, 2001	PROJECT NO:
	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-16
LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY ORTHO-PHOSPHATE TIME SERIES
Portland General Electric Company
Portland, Oregon



Note: these are daily average values

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: Aoril 3, 2001	PROJECT NO:
	FILENAME:LDR95-ldr29exbl.jnb	CHECKED: T. Khangaonkar	2200.0001.0005

FIGURE 6-17

LOWER DESCHUTES RIVER MODEL APPLICATION RESULTS FOR 1995 SHOWING MEAN DAILY CHLOROPHYLL *a* TIME SERIES

Portland General Electric Company
Portland, Oregon

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7. CONCLUSIONS AND RECOMMENDATIONS

A water quality model of the Lower Deschutes River has been implemented using the models RMA2 and RMA4q. The Lower Deschutes River was simulated in the 1D dynamic mode and focused on temperature, dissolved oxygen, and pH as the constituents of interest. Other simulated constituents included nitrate, ammonia, ortho-phosphate, alkalinity, total inorganic carbon, labile dissolved organic matter, and chlorophyll *a*. They were simulated as part of the complete eutrophication cycle. Model calibration was performed using synoptic data collected in the year 1999. This year had the best set of data for defining boundary conditions and for comparing with model results. The calibration process revealed that conventional water column phytoplankton kinetics could not describe the observed behavior, and that periphyton kinetics were likely the dominant mechanism controlling water quality in the Lower Deschutes River. Suspended algae added to the river from the Regulating Dam discharge had little effect on water quality, because the residence time of the river is very short (on the order of 1 day). Nitrogen was found to be the primary limiting nutrient, as expected from low N:P molar ratios (around a value of 6) so that nitrate and ammonia were used by periphyton and declined downstream. Ortho-phosphate passed through the system with little change, similar to chlorophyll *a* in the water column.

In general, very good calibration was achieved. Temperature results from the model match the observations throughout most of the system. The model results in the lower reaches could be further improved with local meteorological information. Dissolved oxygen and pH also generally match the diurnal time series observations well, considering the large diurnal variations observed in this fast-flowing shallow river.

Data available for model verification were river survey data (unlike synoptic data for calibration) and, therefore, the verification objective was to ensure that observed data fell within the diurnal variation predicted at each location. In the absence of data, boundary values for many constituents were assumed the same as for calibration. Even with these limitations the model results generally gave good matches and the same trends as seen in observations. These results indicate the robustness of the model.

The model was then applied to simulate 1995 conditions and the “selective withdrawal” Blend-13 conditions. The boundary conditions were taken from Lake Simtustus withdrawal data computed by the model CE-QUAL-W2. These withdrawal data were then used to compute water quality at Reregulating Dam using regressions previously developed to account for the effect of the Reregulating Reservoir. This formed the baseline condition for comparison with modified discharges. The model was then applied for the Blend-13 scenario. Lake Billy Chinook discharge for the Blend-13 condition, simulated by the BETTER model, was routed through Lake Simtustus using the CE-QUAL-W2 model. The Lower Deschutes River model was then applied for the Blend-13 boundary conditions. The results can be summarized as follows:

- Selective withdrawal results in modifying the temperatures in the Lower Deschutes River so that the river is cooler during the peak summer months. The study showed that it is feasible to alter the temperatures in the Lower Deschutes River through modifications at Lake Billy Chinook.

- The effect of selective withdrawal (Blend-13 condition) on temperature persists several miles downstream, evident at least to RM 57; but by the mouth, the difference in daily average temperature between existing and modified Blend-13 conditions is not readily apparent.

- Selective withdrawal (Blend-13 conditions) results in dissolved oxygen concentrations that are generally higher than under existing conditions. This improvement is also apparent through about RM 57, with differences approaching zero near the mouth.

- pH levels are slightly elevated the Blend-13 scenario, in comparison with existing conditions. As in the case of pH and dissolved oxygen, the difference between the two scenarios becomes very small by RM 88 and is negligible by RM 55 and below.

- Nitrate concentrations, which drive periphyton growth, start higher in selective withdrawal because of the discharge of surface waters in the spring. However, by early summer nitrate concentrations are less for the Blend-13 selective withdrawal scenario than for the existing condition.

Model calibration and verification of the Lower Deschutes River was completed successfully. A predictive tool which may be used to evaluate various alternatives of operational and structural modification for fish passage or for meeting 401 water quality certification requirements is now available. The model calibrations will likely be improved as PGE completes the Year 2000 system-wide water quality sampling program that will provide a consistent set of data for all waterbodies.

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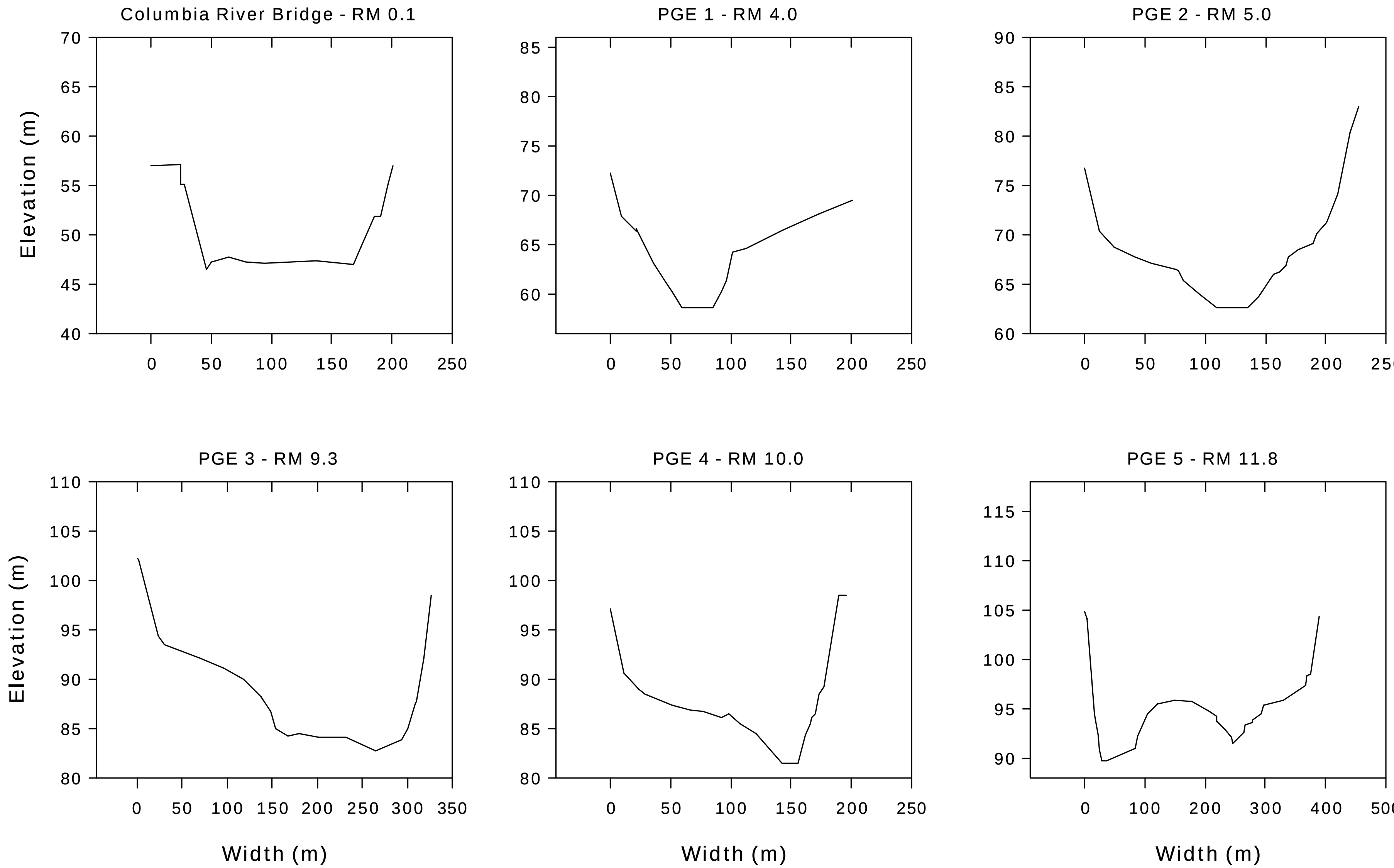
APPENDIX A

MEASURED CROSS SECTION FIGURES



Note: the vertical range of 30-m is used for all plots.

FIGURE A-1

MEASURED CROSS SECTIONS FROM RM 0 TO RM 11.8

Portland General Electric Company
Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
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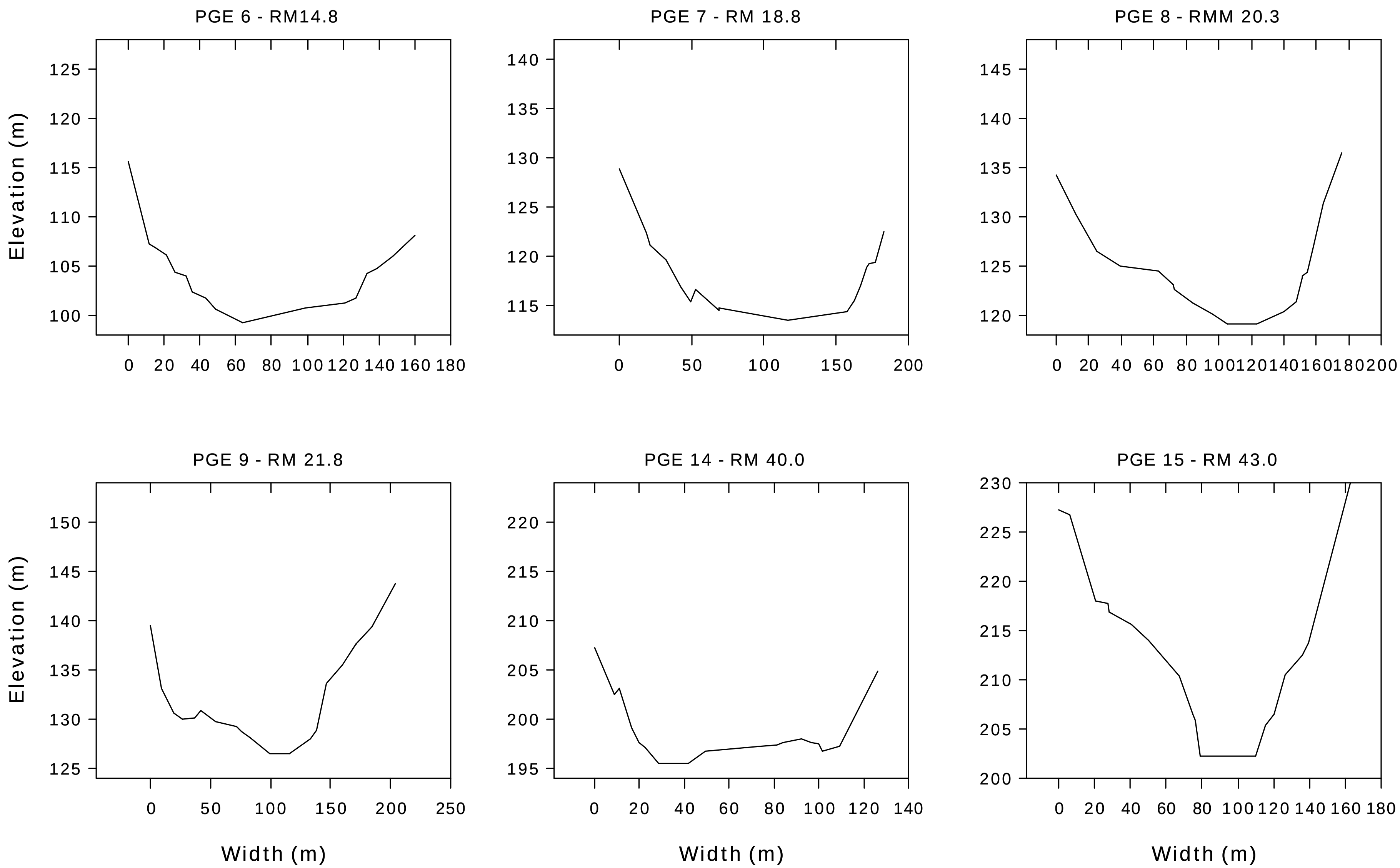
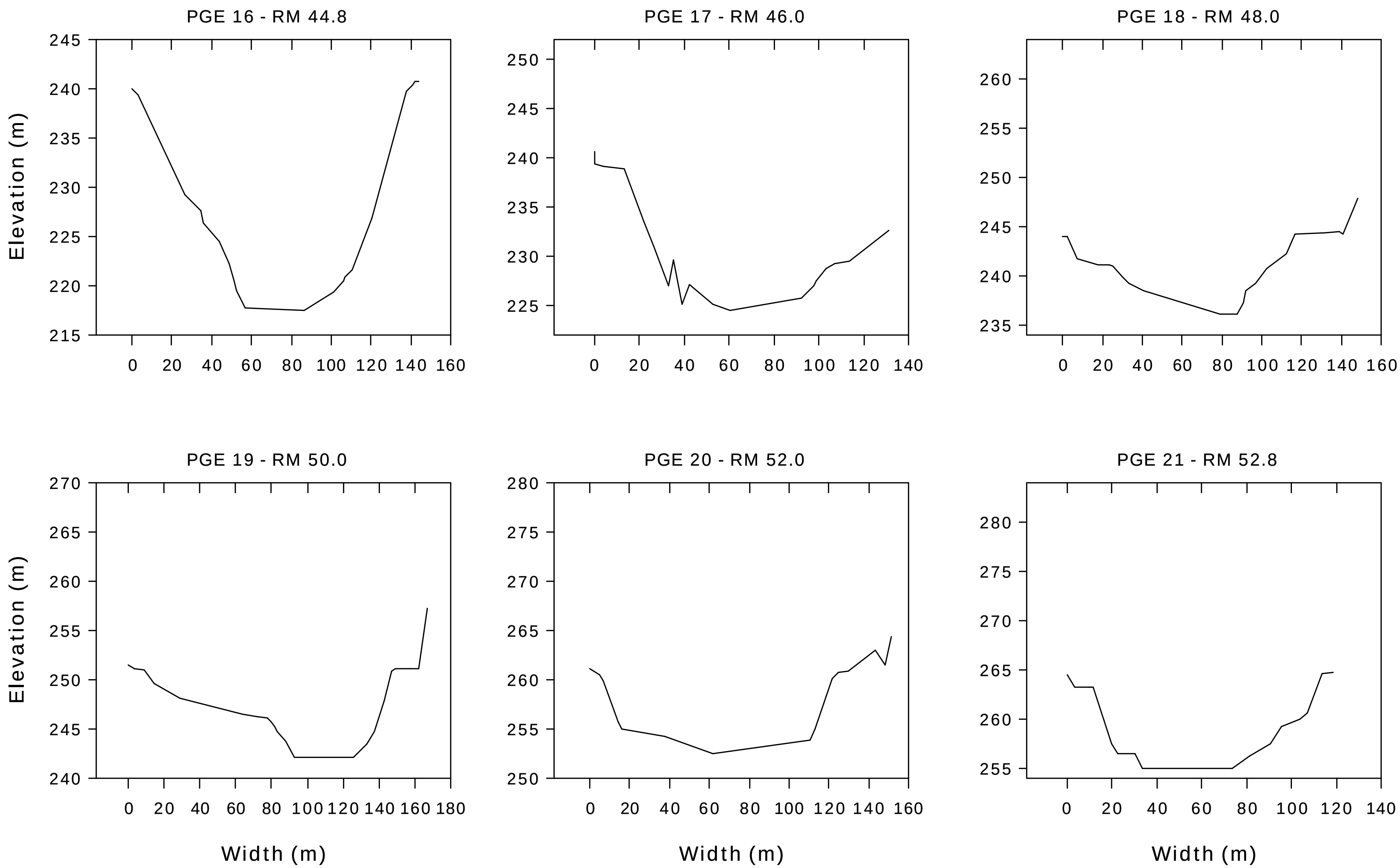


Note: (1) no data for locations PGE 10-13
(2) the vertical range of 30-m is used for all plots.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

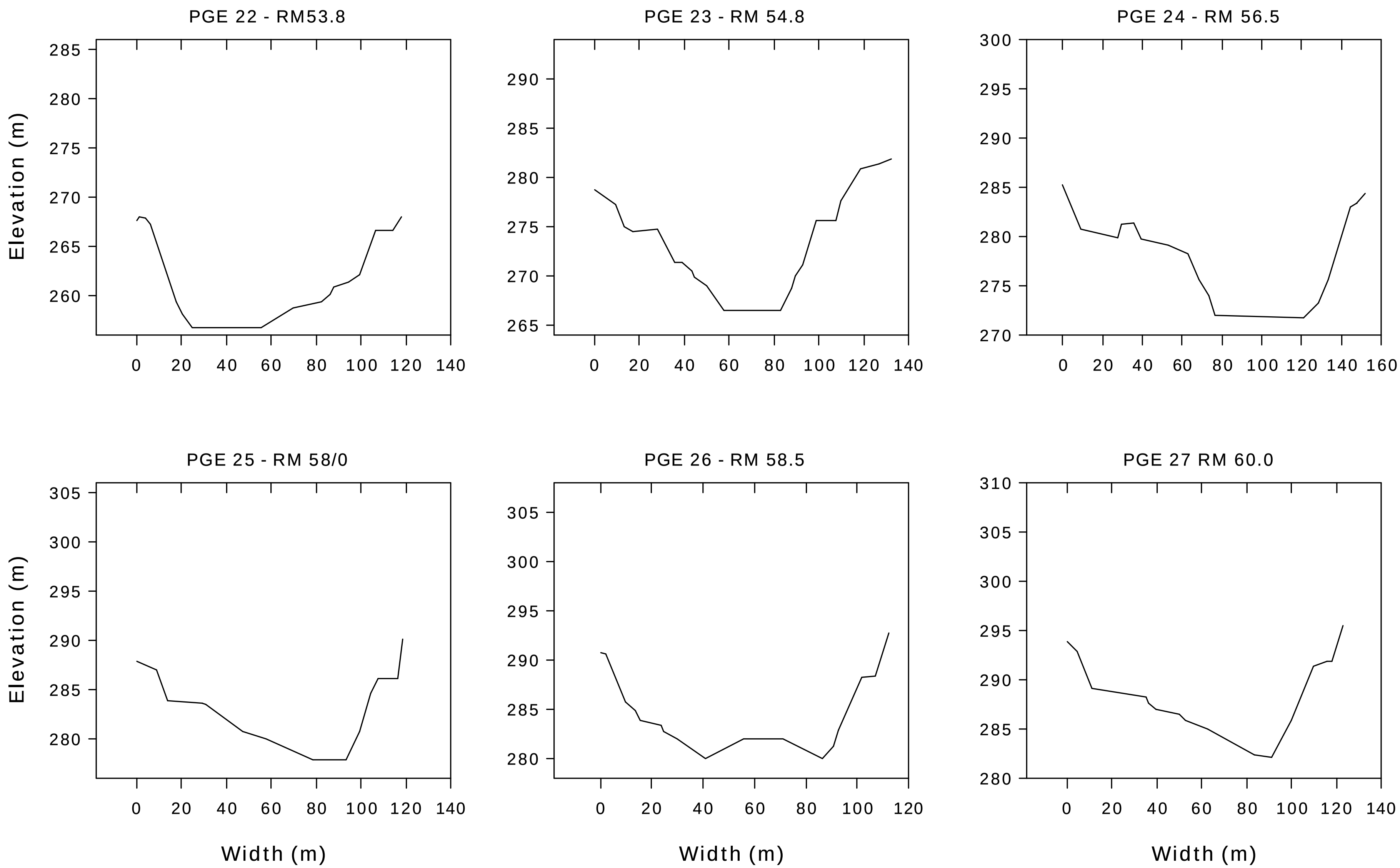
FIGURE A-2
MEASURED CROSS SECTIONS
FROM RM 14.8 TO RM 43
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

FOSTER ENVIRONMENTAL WHEELER CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

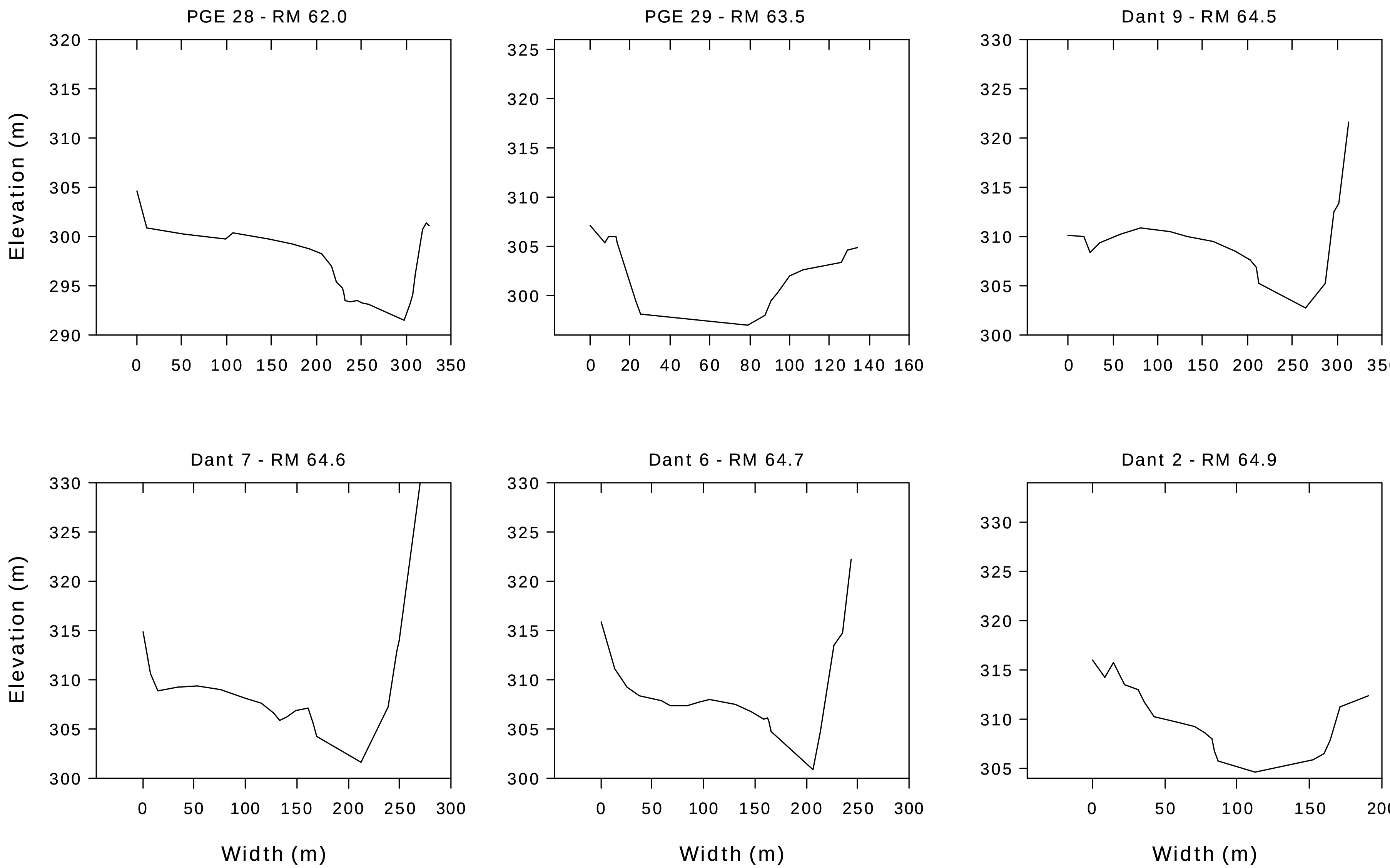
FIGURE A-3
MEASURED CROSS SECTIONS
RM RM 44.8 TO RM 52.8
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

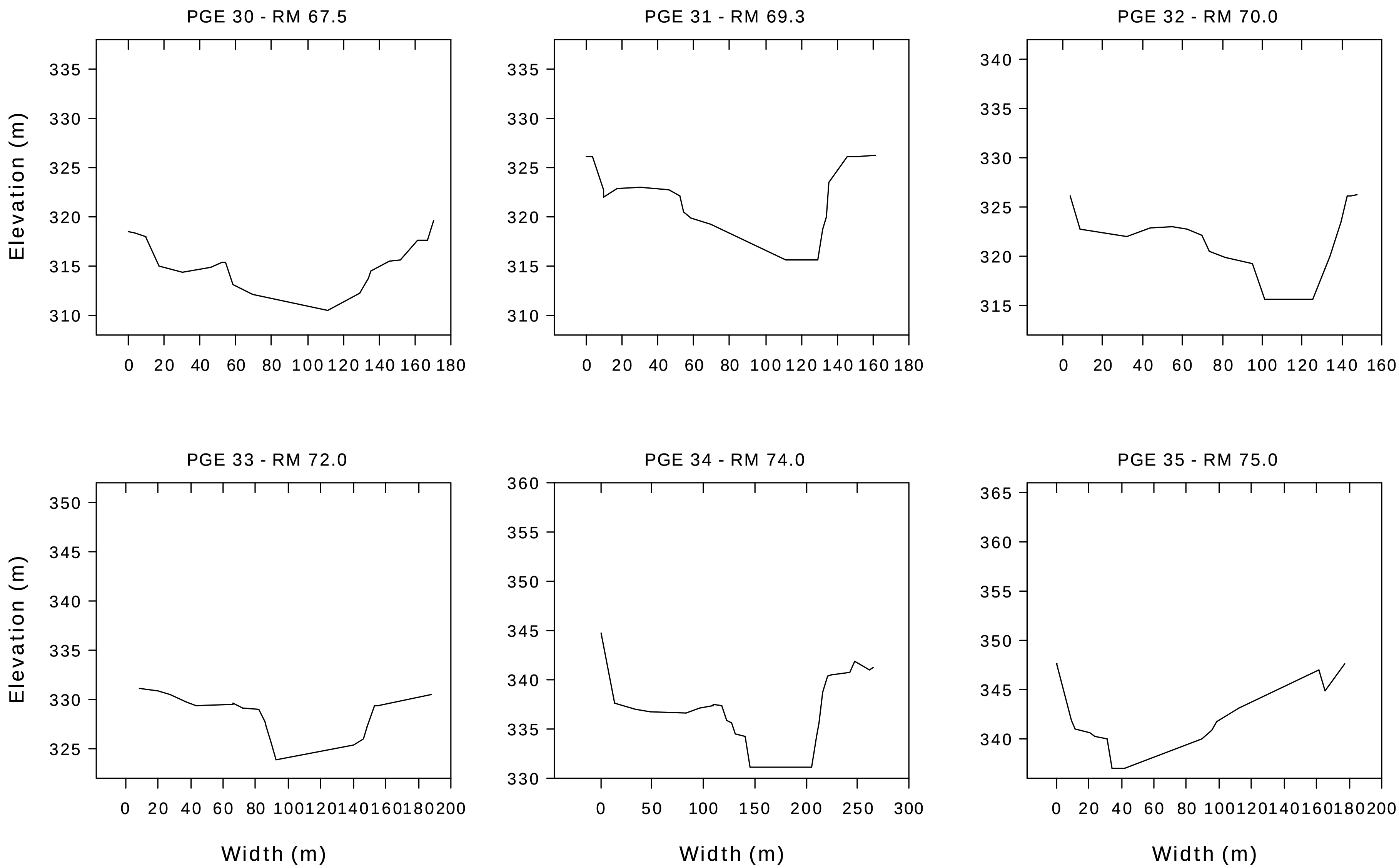
FIGURE A-4
MEASURED CROSS SECTIONS
FROM RM 53.8 TO 60.0
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

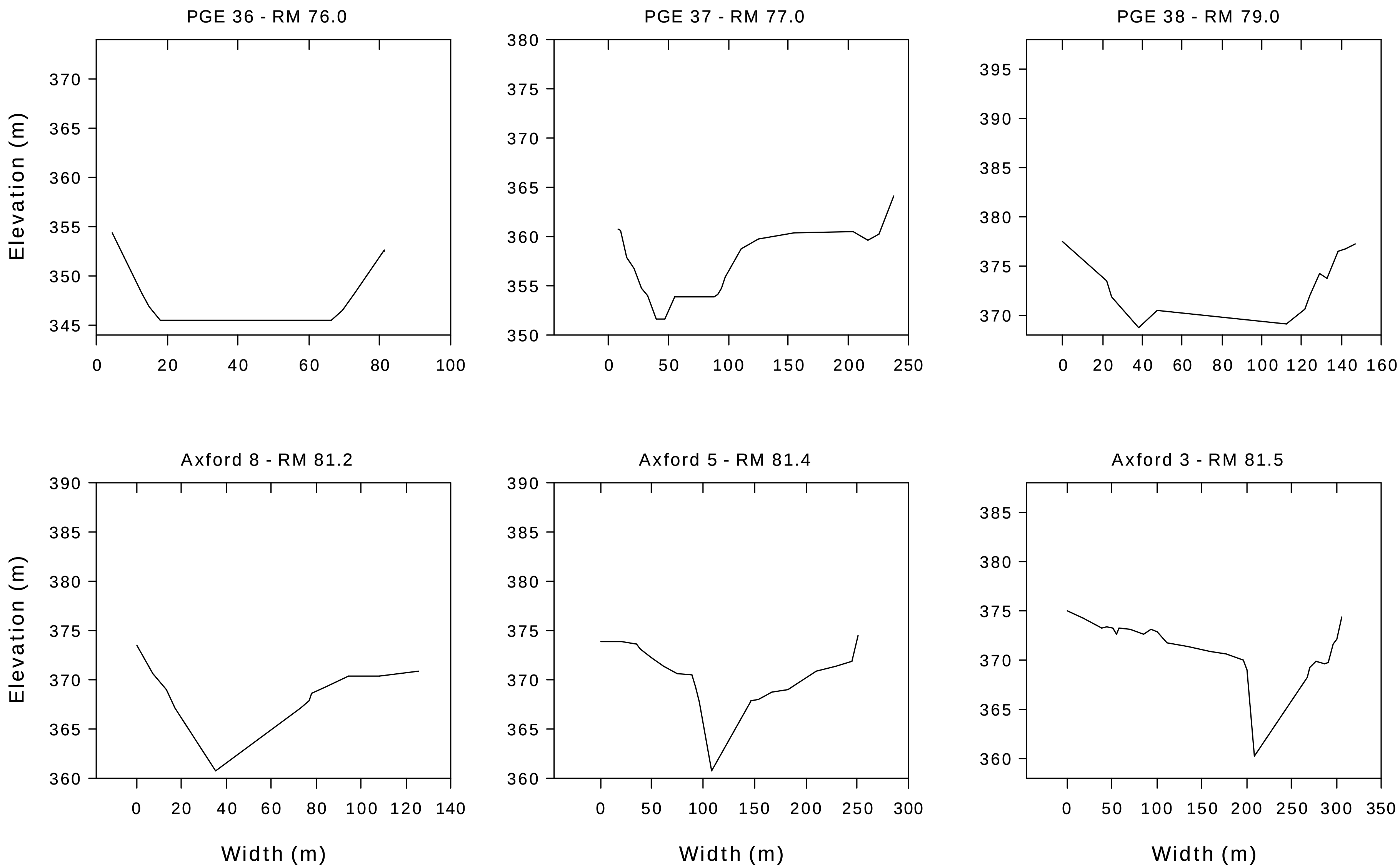
FIGURE A-5
MEASURED CROSS SECTIONS
FROM RM 62.0 TO RM 64.9
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE A-6
MEASURED CROSS SECTIONS
FROM RM 67.5 TO RM 75.0
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

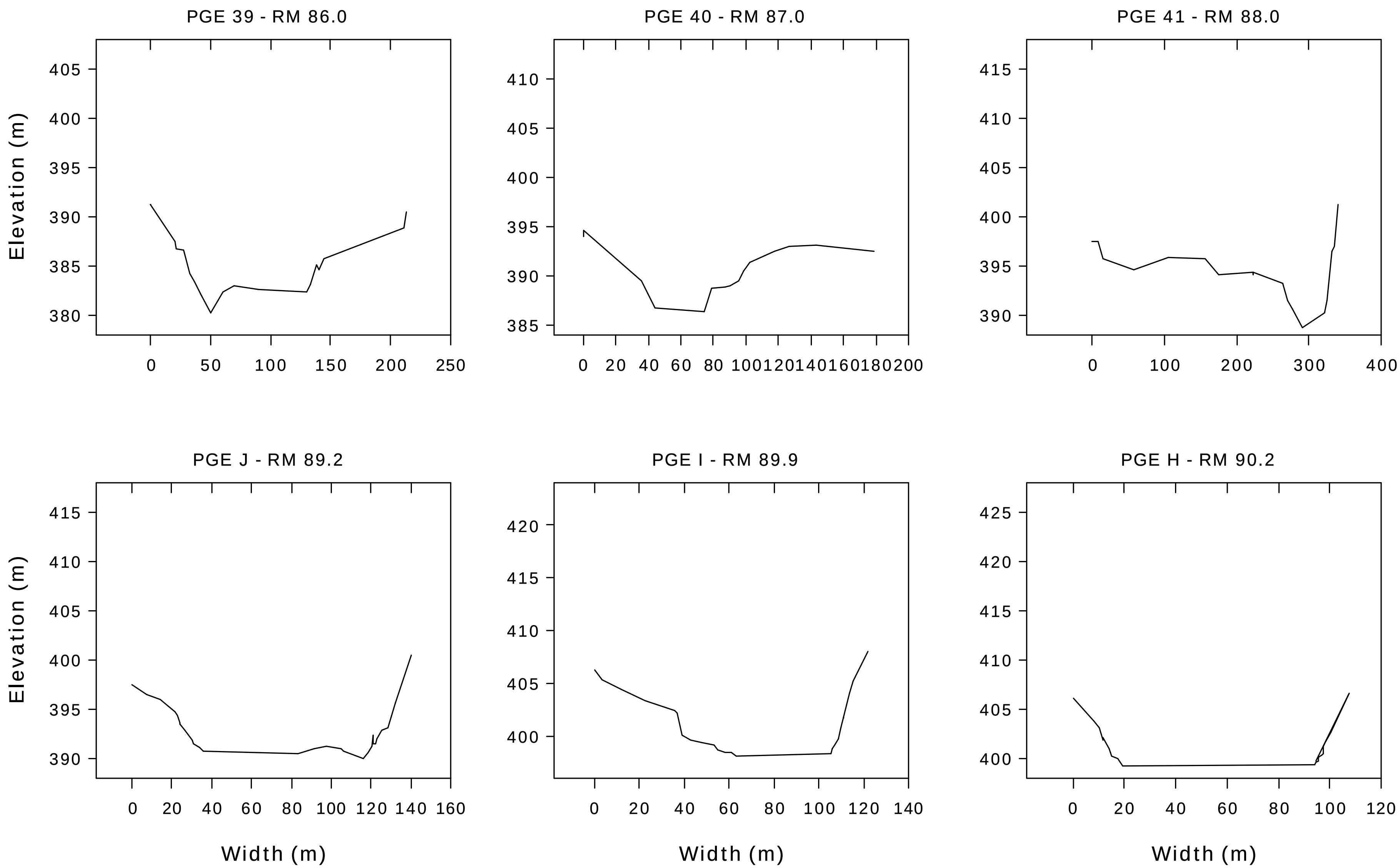
FIGURE A-7

MEASURED CROSS SECTIONS FROM RM 76.0 TO RM 81.5

Portland General Electric Company

Portland, Oregon

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003



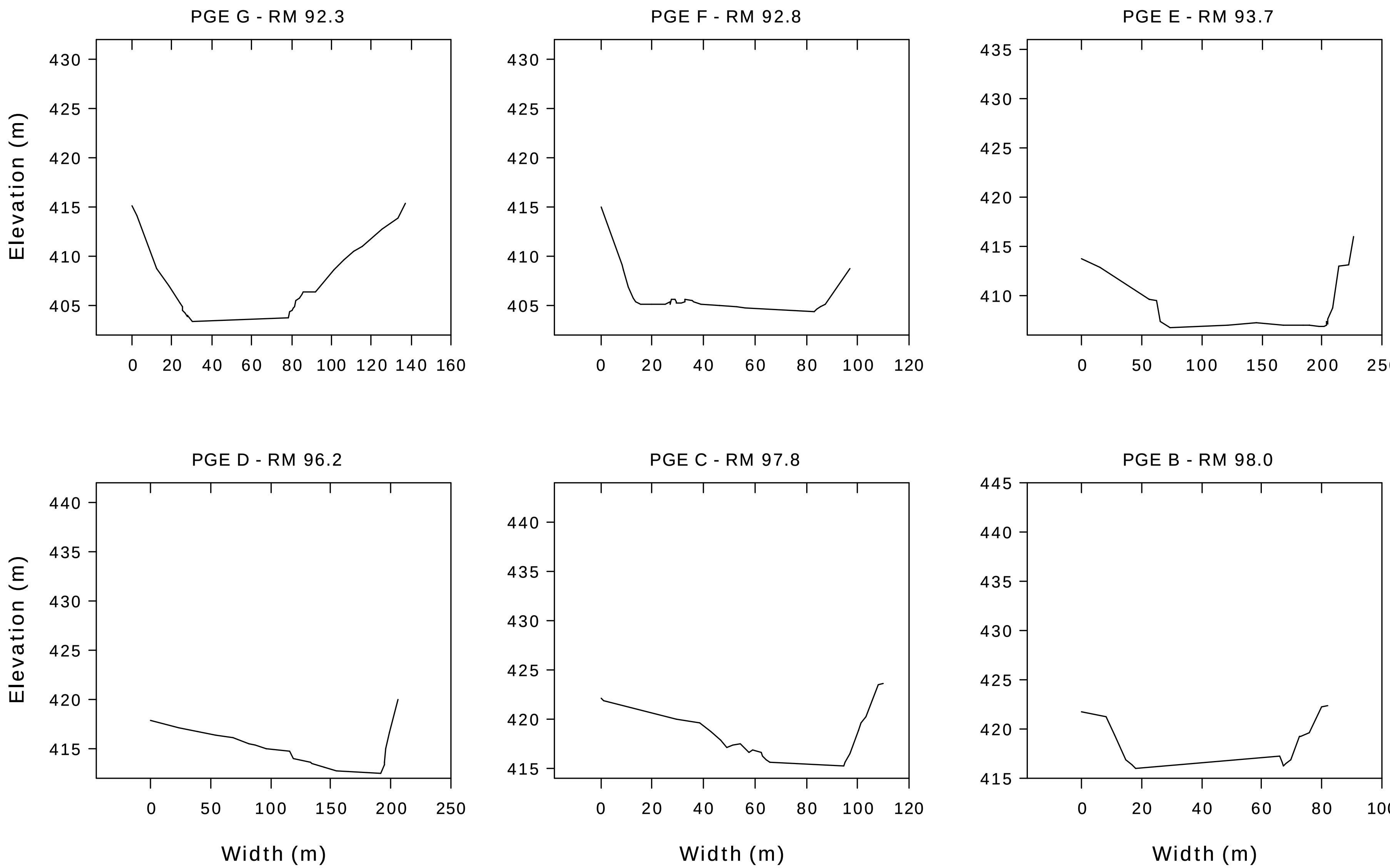
Note: the vertical range of 30-m is used for all plots.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE A-8

MEASURED CROSS SECTIONS FROM RM 86.0 TO RM 90.2

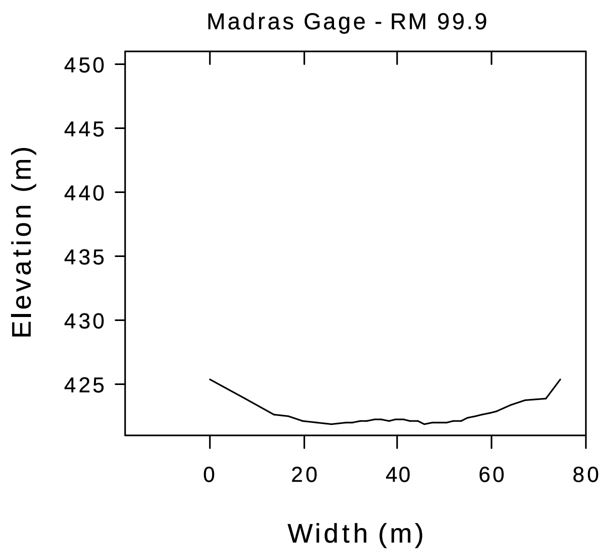
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE A-9
MEASURED CROSS SECTIONS
FROM RM 92.3 TO RM 98.0
Portland General Electric Company
Portland, Oregon



Note: the vertical range of 30-m is used for all plots.

FOSTER WHEELER ENVIRONMENTAL CORPORATION	DRAWN: S. Breithaupt	DATE: April 9, 2001	PROJECT NO:
	FILENAME: LDRxs.jnb	CHECKED: T. Khangaonkar	2200.0005.0003

FIGURE A-10
MEASURED CROSS SECTIONS
AT RM 99.9
Portland General Electric Company
Portland, Oregon

APPENDIX B

CALIBRATED MODEL PARAMETERS AND COEFFICIENTS

APPENDIX B - CALIBRATED MODEL PARAMETERS AND COEFFICIENTS

Table B-1. Suspended Algae Input Values for the Coefficients and Parameters of RMA4q

Global Suspended Algae Parameters and Coefficients	Value	Comment
Ratio of chlorophyll *a* to algal biomass	50.0	From CE-QUAL-W2 model of Lake Simtustus
Fraction of algal biomass that is carbon	0.45	From CE-QUAL-W2 model of Lake Simtustus
Fraction of algal biomass that is nitrogen	0.08	From CE-QUAL-W2 model of Lake Simtustus
Fraction of algal biomass that is phosphate	0.005	From CE-QUAL-W2 model of Lake Simtustus
Oxygen production per unit of algal growth	1.4	From CE-QUAL-W2 model of Lake Simtustus
Oxygen uptake per unit of algal respiration	1.1	From CE-QUAL-W2 model of Lake Simtustus
Temperature correction for algal growth	1.047	Default value
Temperature correction for algal respiration	1.047	Default value
Temperature correction for algal settling	1.047	Default value
Preference for ammonia-N over nitrate-N	0.6	Default value
Monod half-saturation coefficient for light (Ly/sec)	0.01	From CE-QUAL-W2 model of Lake Simtustus
Monod half-saturation coefficient for nitrogen (mg N/L)	0.014	From CE-QUAL-W2 model of Lake Simtustus
Monod half-saturation coefficient for phosphate (mg P/L)	0.003	From CE-QUAL-W2 model of Lake Simtustus
Non-algal light extinction coefficient (1/m)	0.25	Default value
Linear algal self-shading light coefficient (1/m-ug chla)	0.02	Default value
Non-Linear algal self-shading light coefficient (1/m-ug chla$^{2/3}$)	0.0	

Note: These data are for water column transport processes.

Table B-2. Nutrient, Dissolved Oxygen, and pH Constituent Input Values for the Coefficients and Parameters of RMA4q

Global Nutrient, Dissolved Oxygen, and pH Parameters and Coefficients	Value	Comment
Oxygen uptake per unit of ammonia oxidation (nitrification)	2.28	Default value
Oxygen uptake per unit of nitrite oxidation	1.14	Default value
Temperature correction for ammonia oxidation	1.047	Default value
Temperature correction for nitrite oxidation	1.047	Default value
1st order nitrification inhibition coefficient	0.01	Default value
Temperature correction for reaeration rate	1.047	Default value
Oxygen stoichiometry for SOD	1.0	Default value
Temperature correction coefficient for CO_2 reaeration	1.047	Default value
Temperature correction coefficient for LDOM decay	1.047	Default value
Oxygen uptake per unit of LDOM decay (gmO2/gmLDOM)	0.53	From CE-QUAL-W2 model of Lake Simtustus

Note: These data are for water column transport processes.

Table B-3. Nutrient, Dissolved Oxygen, and pH Constituent Input Values for the Coefficients and Parameters of RMA4q

Nutrient, Dissolved Oxygen, and pH Parameters and Coefficients Applied to each Element Type	Value	Comment
Method for computing CO_2 reaeration	4	4= Langbien & Durum (1967)
Method for computing oxygen reaeration	4	4= Langbien & Durum (1967)
Rate of biological oxidation ammonia to nitrite	0.01	Units = 1/day
Rate of biological oxidation of nitrite to nitrate	0.01	Units = 1/day
Suspended algae maximum specific growth rate	2.0	Units = 1/day. From CE-QUAL-W2 model of Lake Simtustus
Suspended algae respiration rate	0.01	Units = 1/day. From CE-QUAL-W2 model of Lake Simtustus
Suspended algae settling rate	0.04	Units = 1/day. From CE-QUAL-W2 model of Lake Simtustus
Labile DOM (LDOM) decay rate	1.0	Units = 1/day. From CE-QUAL-W2 model of Lake Simtustus. Note that LDOM uses the same stoichiometry as specified for algae to compute mineralization rates for N and P.

Note: These data are for water column transport processes.

Source: Langbien, W.B. and W.H. Durum. 1967. The Aeration Capacity of Streams. Circ. 542. U.S. Geological Survey. Washington, D.C.

Table B-4. Global Periphyton Input Parameters Used to Achieve Model Calibration

Global Periphyton Parameters and Coefficients	Periphyton 1	2	3	4	Comment
Fraction of benthic algal biomass that is carbon	0.450	0.450	0.450	0.450	
Fraction of benthic algal biomass that is nitrogen	0.030	0.030	0.072	0.030	
Fraction of benthic algal biomass that is phosphate	0.004	0.004	0.004	0.004	
Fraction of mortality that produces refractory DOM	0.1	0.1	0.1	0.1	The remainder of mortality produces labile DOM
Preference for ammonia-N over nitrate-N by benthic algae	0.6	0.6	0.6	0.6	range 0.0-1.0
Temperature function coefficient - 1	0.10	0.10	0.10	0.10	Used to scale growth, respiration, and mortality by temperature
Temperature function coefficient - 2	0.99	0.99	0.99	0.99	
Temperature function coefficient - 3	0.99	0.99	0.99	0.99	
Temperature function coefficient - 4	0.01	0.01	0.01	0.01	
Temperature function breakpoint -1	4.0	10.0	2.0	4.0	
Temperature function breakpoint -2	13.0	30.0	4.0	10.0	
Temperature function breakpoint -3	14.0	35.0	5.0	15.0	
Temperature function breakpoint -4	20.0	40.0	15.0	20.0	
Temperature scaling factor for respiration and mortality	1.0	1.0	2.0	1.5	Adjusts respiration and mortality curves.

Table B-5. Periphyton Input Parameters for Node Type 1 Used to Achieve Model Calibration

Nodal Periphyton Parameters and Coefficients	Nodal Type 1 Periphyton 1	2	3	4	Comment
Effective surface area	1.2	1.2	1.2	1.2	
Maximum specific growth	1.20	1.50	2.00	0.0	Unit = 1/day
Respiration rate	0.05	0.05	0.30	–	Unit = 1/day
Mortality rate	0.01	0.01	0.01	–	Unit = 1/day
Light half saturation constant	0.00011	0 .00011	0.00011	–	Unit = Ly/sec
Nitrogen half saturation constant	0.18	0.14	0.18	–	Units = mg N/L
Phosphorus half saturation constant	0.005	0.005	0.005	–	Units = mg P/L
Maximum density allowed by the habitat	30.0	30.0	30.	–	Units = gm/m^2
Scour coefficient	5.0e-4	5.0e-4	5.0e-4	–	Units = 1/day
Critical shear stress for erosion	0.8	0.8	0.8	–	Units = N/m^2
Erosion exponent for biomass density	3.0	3.0	3.0	–	
Oxygen production per unit of benthic algae growth	1.5	1.5	1.5	–	
Oxygen uptake per unit of benthic algae respiration	2.0	2.0	2.0	–	

Table B-6. Periphyton Input Parameters for Node Type 3 Used to Achieve Model Calibration

Nodal Periphyton Parameters and Coefficients	Nodal Type 3 Periphyton 1	2	3	4	Comment
Effective surface area	1.2	1.2	1.2	1.2	
Maximum specific growth	1.20	–	1.50	–	Unit = 1/day
Respiration rate	0.30	–	0.20	–	Unit = 1/day
Mortality rate	0.01	–	0.01	–	Unit = 1/day
Light half saturation constant	0.00011	–	0.00011	–	Unit = Ly/sec
Nitrogen half saturation constant	0.10	–	0.10	–	Units = mg N/L
Phosphorus half saturation constant	0.005	–	0.005	–	Units = mg P/L
Maximum density allowed by the habitat	30.0	–	30.0	–	Units = gm/m^2
Scour coefficient	5.0e-4	–	5.0e-4	–	Units = 1/day
Critical shear stress for erosion	0.8	–	0.8	–	Units = N/m^2
Erosion exponent for biomass density	2.0	–	2.0	–	
Oxygen production per unit of benthic algae growth	1.5	–	0.5	–	
Oxygen uptake per unit of benthic algae respiration	2.0	–	4.0	–	

Table B-7. Periphyton Input Parameters for Node Type 4 Used to Achieve Model Calibration

Nodal Periphyton Parameters and Coefficients	Nodal Type 4 Periphyton 1	2	3	4	Comment
Effective surface area	1.2	1.2	1.2	1.2	
Maximum specific growth	–	1.00	1.50	0.90	Unit = 1/day
Respiration rate	–	0.20	0.20	0.15	Unit = 1/day
Mortality rate	–	0.01	0.01	0.01	Unit = 1/day
Light half saturation constant	–	0.00011	0.00011	0.00011	Unit = Ly/sec
Nitrogen half saturation constant	–	0.05	0.05	0.05	Units = mg N/L
Phosphorus half saturation constant	–	0.005	0.005	0.005	Units = mg P/L
Maximum density allowed by the habitat	–	30.0	30.0	30.0	Units = gm/m^2
Scour coefficient	–	5.0e–4	5.0e–4	5.0e–4	Units = 1/day
Critical shear stress for erosion	–	0.8	0.8	0.8	Units = N/m^2
Erosion exponent for biomass density	–	2.5	1.5	2.5	
Oxygen production per unit of benthic algae growth	–	2.5	1.5	2.0	
Oxygen uptake per unit of benthic algae respiration	–	2.0	4.0	2.0	

Table B-8. Periphyton Input Parameters for Node Type 5 Used to Achieve Model Calibration

Nodal Periphyton Parameters and Coefficients	Nodal Type 5 Periphyton				Comment
	1	2	3	4	
Effective surface area	1.2	1.2	1.2	1.2	
Maximum specific growth	1.00	–	–	1.50	Unit = 1/day
Respiration rate	0.20	–	–	0.20	Unit = 1/day
Mortality rate	0.01	–	–	0.01	Unit = 1/day
Light half saturation constant	0.00011	–	–	0.00011	Unit = Ly/sec
Nitrogen half saturation constant	0.05	–	–	0.18	Units = mg N/L
Phosphorus half saturation constant	0.005	–	–	0.005	Units = mg P/L
Maximum density allowed by the habitat	30.0	–	–	30.0	Units = gm/m^2
Scour coefficient	5.0e-4	–	–	5.0e–4	Units = 1/day
Critical shear stress for erosion	0.8	–	–	0.8	Units = N/m^2
Erosion exponent for biomass density	2.0	–	–	2.0	
Oxygen production per unit of benthic algae growth	2.0	–	–	2.0	
Oxygen uptake per unit of benthic algae respiration	1.5	–	–	2.0	

PERIPHYTON NODAL TYPE INPUT TRENDS

Examination of the periphyton nodal type inputs (Tables C-4 through C-8) reveals a few trends in periphyton model inputs. In general, the half-saturation values for nitrogen decreased from upstream to downstream. The biomass erosion exponent also exhibited a downstream decrease. Maximum specific growth rate also showed some decreases from upstream to downstream. Nitrate-nitrogen, which made up the bulk of inorganic nitrogen content, decreases from upstream to downstream, because it is being used for periphytic algae growth. With lower concentrations downstream, it was necessary to lower half-saturation values for nitrogen to attain adequate periphyton growth. Diminished nitrate-nitrogen concentrations also necessitated lower growth rates and lower biomass erosion exponents to prevent too much growth with the lower half-saturation values.