Santa Rosa Subregional Long-Term Wastewater Project

RUSSIAN RIVER WATER QUALITY MODEL

SANTA ROSA SUBREGIONAL LONG-TERM WASTEWATER PROJECT

Prepared for
City of Santa Rosa
and
U.S. Army Corps of Engineers

June 1996

Prepared by
Donald J. Smith, P.E.
Resource Management Associates
4171 Suisun Valley Rd. Suisun, CA 94585 (707) 865-2950

For
HARLAND BARTHOLOMEW & ASSOCIATES, INC.

RUSSIAN RIVER WATER QUALITY MODEL

SANTA ROSA SUBREGIONAL LONG-TERM WASTEWATER PROJECT

Prepared for

City of Santa Rosa
and
U.S. Army Corps of Engineers

June 1996

Prepared by
Donald J. Smith, P.E.
Resource Management Associates
4171 Suisun Valley Rd. Suisun, CA 94585 (707) 865-2950

for
HARLAND BARTHOLOMEW & ASSOCIATES, INC.

TABLE OF CONTENTS

1.0 BACKGROUND

1.1 OBJECTIVES

The general objective of this modeling study is to provide a tool suitable for evaluating the relative impact on water quality in the Laguna de Santa Rosa and lower Russian River of alternative management strategies for the City of Santa Rosa's reclaimed water. The principal requirements of the modeling tool are

1. to compute the time history of reclaimed water concentrations throughout the system, and
2. to determine the impact of reclaimed water discharges on biological activity in the system.

This report describes the application of USEPA's QUAL2E river water quality model to the Laguna de Santa Rosa and Russian River System. Model estimates of water quality impacts are summarized by Merritt Smith Consulting (1996a, b).

1.2 PREVIOUS MODELING EFFORTS

The current modeling activity brings together and extends the previous modeling efforts in the Russian River and Laguna de Santa Rosa.

- In 1990 the City of Santa Rosa contracted with Don Smith of RMA to construct a water quality model of the Laguna de Santa Rosa. The USEPA river water quality model QUAL2E was used to simulate steady state summer flow conditions in the Laguna.
- In 1991, the California Water Resources Control Board contracted with the University of California at Davis to construct a water quality model for the Russian River. QUAL2E was used to simulate steady state water quality in the Russian River for summer and winter low flow conditions.
- The QUAL2E Laguna Model previously developed for the City of Santa Rosa was again used in the evaluation of dairy wastes and other nutrient loads on the system during summer and winter low flow conditions. Dynamic quality simulations were run using RMA2 and RMA4q dynamic flow and water quality models.

2.0 METHODOLOGY

The US EPA river water quality model QUAL2E was used for simulating flow and water quality in the Laguna de Santa Rosa and Lower Russian River system. The standard version of the QUAL2E model was modified to accommodate fully dynamic, long term simulations required by this study. QUAL2E was configured for the Laguna and lower Russian River based on previous modeling studies noted above with additional information collected from field reconnaissance and was calibrated using field data collected between 1993 and 1995.

2.1 MODEL DESCRIPTION

Building from previous modeling efforts in the Russian River and Laguna de Santa Rosa system, the U.S. EPA river water quality model QUAL2E was selected as the appropriate modeling tool for this study. The geometric description of the Laguna de Santa Rosa was adapted from the 1990 study for the City of Santa Rosa (Smith 1991). The geometric description of the Russian River was adapted from the UC Davis model (UCD 1992). These two systems were combined to form a single model. Because the two models used different methods for describing channel geometry, QUAL2E was modified to permit different types of geometric descriptions within one system. These changes are discussed in Section 2.2.

The QUAL2E model represents a river system as a series of reaches which are regions of the river with similar hydraulic and water quality characteristics (see Figure 2.1). Reaches are subdivided into two or more computational elements. The concentration of all water quality state variables included in the model are calculated at the end of each computational element. Water enters the simulated river system through headwater flows, point inflows, and incremental inflows. Each inflow must be assigned concentrations for all water quality constituents to determine the mass loading of the system. Water exits the river system through the downstream boundary, point withdrawals and incremental outflows. The QUAL2E model configuration developed for the Laguna and lower Russian River is described in detail in Section 2.4.

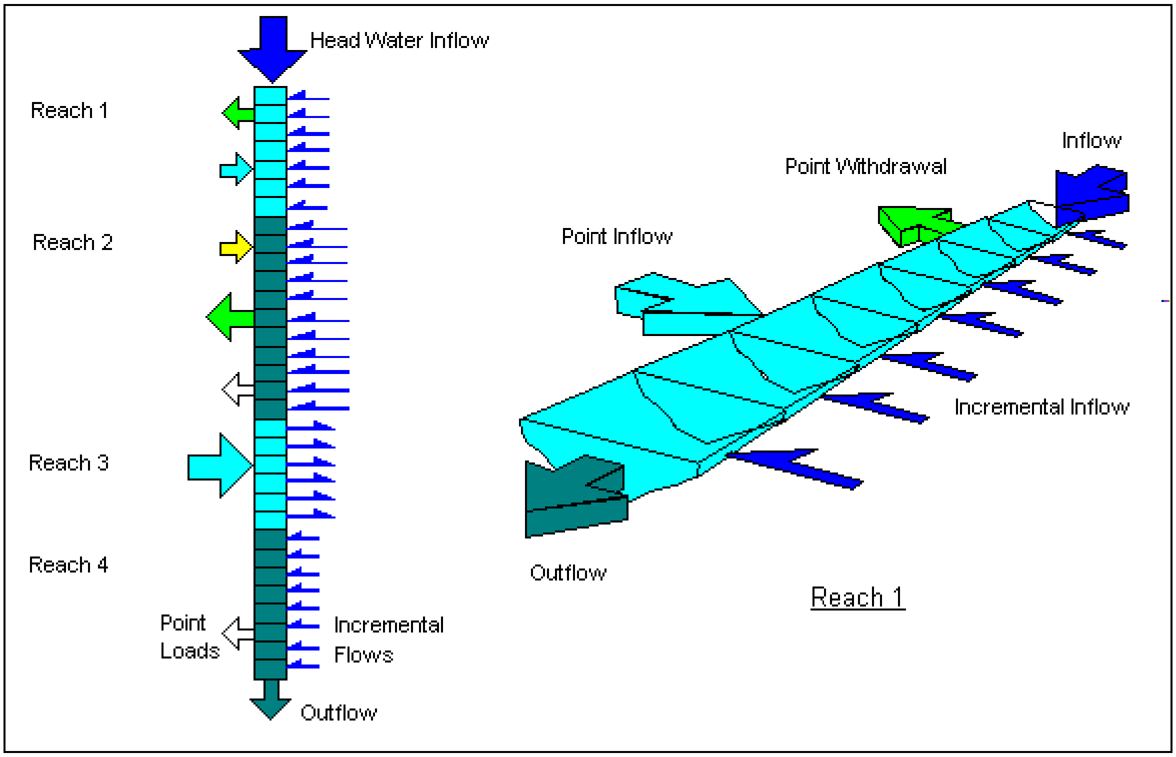
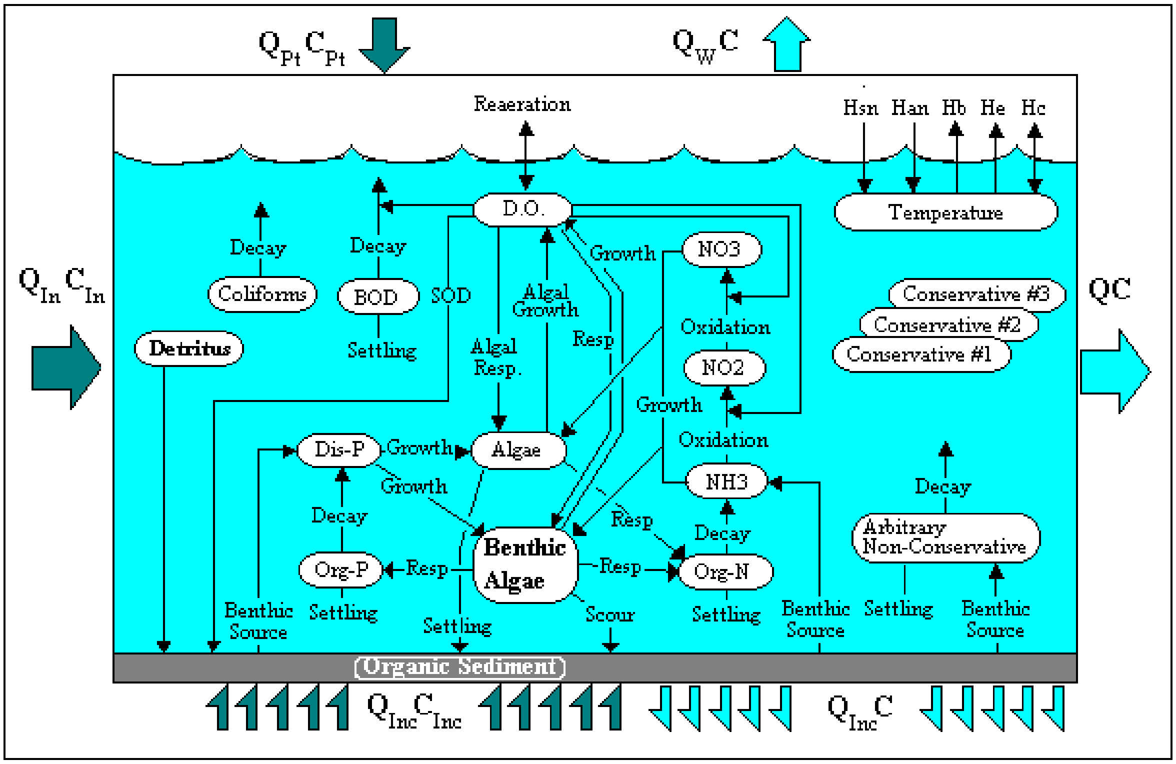


Figure 2.1. Hydraulic description used in QUAL2E.

QUAL2E was originally designed for USEPA to simulate only steady state flow and water quality boundary conditions (Brown 1988). This limitation of the original model was identified as an important shortcoming in the previous Russian River modeling studies. Because the principal objective of this study is to evaluate impacts of reclaimed water discharges both during and following the period of discharge, QUAL2E was extended to permit fully dynamic simulation of both flow and water quality. These modifications are discussed in Section 2.2.

The standard version of QUAL2E simulates up to 15 suspended or dissolved water quality constituents including water temperature, nitrogen species, phosphorus species, phytoplankton, BOD, dissolved oxygen, coliform bacteria, and arbitrary conservative and non-conservative constituents. Attached benthic algae and floating plants were identified as important contributors to primary production in the Laguna and were added to the standard QUAL2E model for the 1990 Laguna study. The current study involves the evaluation of the long term impacts of organic loading, which has required the addition of constituent relations representing organic sediments and suspended detritus. The standard constituent relations included in the QUAL2E model are fully described in the user's manual published by the USEPA (Brown 1988). New constituent relations added to QUAL2E for modeling the Laguna and lower Russian River are discussed in Section 2.3. A schematic representation of the set of water quality variables and the associated physical, chemical and biological processes simulated by the modified version of QUAL2E is shown in Figure 2.2.



State Variables

Water Temperature
Dissolved Oxygen (D.O.)
Planktonic Algae
Benthic Algae
Organic Nitrogen (Org-N)
Ammonia (NH3)
Nitrite (NO2)
Nitrate (NO3)
Organic Phosphorous (Org-P)
Ortho-Phosphate (PO4)
Detritus - suspended organic particulates
Organic Sediment
Coliform Bacteria
3 Arbitrary Conservative Constituents
Arbitrary Non-Conservative Constituent

Physical, Chemical, Biological Processes

(arrows in schematic represent direction of mass flux)

Growth
Respiration (Resp.)
Decay
Oxidation
Settling
Scour
Benthic Source
Heat Exchange (Hsn,Han,Hb,He,Hc)
Reaeration

Mass Transport from boundary flows

(Q = flow, C = concentration of each dissolved or suspended constituent):

$Q_{in}C_{in}$ - mass loading from inflow
$Q_{pt}C_{pt}$ - mass loading from point inflows
$Q_{inc}C_{in}$ - mass loading from incremental inflow
$Q_{out}C$ - mass loss though downstream boundary
Q_wC - mass loss from withdrawals
$Q_{inc}C$ - mass loss through incremental outflow

Figure 2.2. Primary Water Quality Constituent Relationships used in Laguna - Russian River QUAL2E model.

2.2 MODIFICATIONS TO GEOMETRIC REPRESENTATION AND FLOW COMPUTATIONS

A description of the system's geometry is an important requirement for any hydraulic or water quality model. In the standard version of QUAL2E, this is accomplished by several mutually exclusive approaches. One approach is the use of rating curves between flow, and velocity and depth. Another is by solving Manning's equation for cross-sectional area under a given flow and bed friction coefficient. For this, the depth and velocity are computed from a trapezoidal cross-section of a river reach. Both of these methods define the hydraulic character of a river reach. A reach can be defined as a length of river or stream with similar uniform geometric, biological or chemical characteristics. Hydraulic and biological characteristics generally coincide, since the aquatic habitat is governed by the system's hydraulics.

Two other methods were added to the Laguna/Russian River QUAL2E application to describe system geometry. One method fits two cubic polynomials to data for flow and cross-sectional area and flow and top width. The other uses a rating table developed from output of the hydraulic model HEC-2, a hydraulic model developed and maintained by the U.S. Army Corps of Engineers. These relate flow to depth, velocity, and top width. Flows between tabulated values are interpolated using a cubic polynomial.

The standard version of QUAL2E assumes steady state flows. At steady state, the flow at any stream location is the sum of all inflows upstream of that location. The steady state assumption is implicit in the computation of steady state water quality and is appropriate for the dynamic simulation of water quality for periods with relative constant hydrology (e.g., low and unchanging flow summer period). The steady state assumption is inappropriate for dynamic hydrologic periods such as the highly variable winter time flows of the Russian River.

Since the Santa Rosa disposal alternatives involve discharge during periods of highly variable river flows, the steady state flow assumption was deemed unacceptable. A dynamic flow routing capability was needed to allow a realistic simulation of flow and water quality throughout the appropriate simulation period.

A hydrologic routing procedure was implemented to route headwater flows and point and non-point inflows through the river system. The routing procedure assumes that the flow at any location is a function of the water surface elevation and the water surface elevation is a function of the volume of a section of the stream immediately upstream. The volume of the stream section is a function of the inflow less the outflow.

The flow routing was accomplished on a reach basis at one-hour time increments from upstream to downstream. For each reach, the inflow from upstream element (or headwater) and point and non-point flows was summed. Then an iterative process was employed to determine the downstream flow rate, that satisfied the relationships between flow and water surface elevation and flow and storage volume. The resulting change in volume over time was assumed uniformly distributed over the stream reach.

2.3 ADDITIONAL CONSTITUENT RELATIONSHIPS

Three new constituents were added to the standard version of QUAL2E to fit the water quality model to the problem at hand, i.e., benthic algae, detritus, and organic sediment. Detritus is handled similarly to other constituents subject to advective transport. Benthic algae and organic sediment are more or less fixed to the bed and are not modeled by advective transport. However, they can be detached or eroded[1] respectively, with the scoured mass entrained into the water column and transported downstream. From the modeling standpoint, these scoured components are handled as separate constituents. For QUAL2E, the scoured material is transported as detritus.

2.3.1 Benthic Algae

Since benthic algae are fixed to the bed with no advective transport, the equation describing benthic algae growth is an ordinary differential equation (ODE) and takes the following form:

$$\frac{dB}{dt} = \left(\mu_{ba} - \rho\theta_{14}^{(T-20)} - d\right)B$$

where B = benthic algae biomass density (gm m^{-2}), μ_{ba} = growth rate (day^{-1}), ρ = respiration rate (day^{-1}), d = detachment rate (day^{-1}), θ_{14} = temperature correction factor for respiration referenced to 20°C, T = water column temperature (°C), and t = time. The growth rate is described as the product of μ_{max}, the maximum specific growth rate, F_L, a light limitation factor, the minimum of either the nitrogen or phosphorus limitation factor (F_N or F_P, respectively), and a habitat factor F_H, and θ_{13}= temperature correction factor for growth i.e.,

$$\mu_{ba} = \mu_{max} F_L \min\left(F_N, F_P\right) F_H \theta_{13}.$$

The limitation factors are computed by the following Monod relation

$$F = \frac{I}{K_I + I}$$

with I = the value of some intensive property such as concentration or light intensity, K_I = the half-saturation constant for the property, i.e., the value of I that results in half the maximum growth rate if all other limiting properties are available in excess. Benthic algae growth is assumed to be limited by a maximum biomass density (B_{max}) for the available bed area and the portion of bed that is available for growth (S_a). S_a is determined by the proportion of bed covered by cobble, gravel, sand, and/or silt. So, the habitat factor can be described by the following.

[1] Detachment is the breaking of benthic algae filaments that are attached to the bed. Erosion is the removal of particles that have settled on the bed. Both processes result from the hydraulic drag, which is a function of the river velocity. Henceforth, the terms detachment and erosion will be lumped into the term scour.

$$F_H = 1 - \left[\frac{B}{B_{max} S_a} \right]^2$$

The squared ratio indicates the habitat factor is not large until the ratio of computed biomass density to maximum density approaches unity.

The detachment rate is a matter of continuing investigation. Mathematical relations have been presented in the literature (Grenney and Kraszewski 1981 and Smith 1978) and are presumably based on physical theory such as hydraulic drag, but have not been verified as to their validity. Field observations have been made of detachment, but were only poorly correlated with observed conditions (Canale and Auer 1982). However, laboratory data on detachment rates are available for the benthic algae found in the Russian River (*Cladophora*), and the model uses the relation found for these (Breithaupt 1996). The laboratory study used *Cladophora* collected in the upper Russian, that were in moderately good health, as indicated by the filaments dark green color. The relation found from four separate runs at different velocities is

$$d = 0.00249u^{5.45}$$

with u = velocity (fps) and d = detachment rate (1/day).

Two benthic algae classes were simulated to provide a succession of dominant species from spring through late summer. Each benthic algae class was distinguished by its temperature dependent rate coefficient and detachment characteristics.

2.3.2 Detritus

Residual organic matter from benthic algae mortality and senescence is called detritus. For a riverine system there can be both internal and external sources of detritus, which is largely composed of easily transportable particles. For this modeling exercise, the important internal sources and losses of detritus include

- phytoplankton mortality,

- detached benthic algae,
- erosion of organic sediment,
- decay, and
- settling.

The rate term at a point along the river system is described by

$$\frac{dD}{dt} = mP\theta_{14}^{(T-20)} + \frac{d}{z}B - k_{osd}D\theta_{1}^{(T-20)} + s_e$$

$$s_e = \begin{cases} \dfrac{E}{z} & \text{if} \quad \tau > \tau_{crit} \\ -\dfrac{s_D}{z}D & \text{if} \quad \tau \le \tau_{crit} \end{cases}$$

with D = detritus concentration (mg L^{-1}), m = mortality rate of phytoplankton (day^{-1}), P = phytoplankton biomass concentration (mg dry weight L^{-1}), k_{osd} = detritus decay rate (day^{-1}), θ_1 = temperature correction factor for organic decay referenced to 20°C, s_D = detritus settling rate (ft day^{-1}), and z = depth at the point (ft). The relation between shear stress (τ) and the critical shear stress (τ_{crit}) determines if erosion from or settling to the bed occurs, but both do not occur simultaneously in any particular computational element. The erosion rate (E, gm m^{-2} day^{-1}) is given by

$$E = c_1\left(\tau - \tau_{crit}\right)^{c_2},$$

where c_1 and c_2 are the scour coefficient and exponent, and τ_{crit} = minimum shear stress for scour to occur (Newtons m^{-2}). The shear stress at the point is

$$\tau = \gamma z S_0$$

with γ = weight density of water (9800 Newtons m^{-3}) and S_o = bed slope. For reaches of river where the bed slope is not stated explicitly, the bed slope is computed from the metric form of Manning's equation

$$S_o = \left(\frac{un}{z^{2/3}}\right)^2.$$

Here u = velocity (m s^{-1}) and n = Manning's friction coefficient.

External loads are possible from

- reclaimed water,

- stormwater and dairy runoff,
- tributaries and
- transport from upstream sources.

The point rates are coupled with the transport equation, which is solved by QUAL2E. For this application, all loads were input to the model at daily intervals. Hourly inputs are determined by linear interpolation of daily input data.

Other constituents, including biochemical oxygen demand (BOD), organic nitrogen, and organic phosphorus, also exhibit settling. As for detritus, the relationship between the bed shear stress and critical shear stress determines if the material will settle or remain suspended in the water column and can be transported downstream.

2.3.3 Organic Sediment

Like benthic algae, organic sediment is fixed to the bed. Its sources include

- detritus settling and
- phytoplankton settling.

while its losses are from

- decay and
- bed erosion.

Its processes are described with an ODE that takes the following form

$$\frac{dS_{os}}{dt} = s_d D\theta_2^{(T-20)} + s_P P\theta_{15}^{(T-20)} - k_{osd} S_{os}\theta_1^{(T-20)} - E$$

with S_{os} = organic sediment density (gm m^{-2}), θ_2 = temperature correction factor for detritus settling referenced to 20°C, θ_{15} = temperature correction factor for phytoplankton settling referenced to 20°C, and s_p = phytoplankton settling rate (ft day^{-1}). Note that biochemical oxygen demand (BOD) does not contribute to organic sediment, since BOD does not directly indicate the mass concentration of some organic constituent. Rather, it is a measure of a decay process. To account for organic matter from any pollutant source, it must be transported as detritus.

2.3.4 Interactions Between Bed and Water Column Constituents

The significance of these added constituents, especially benthic algae and organic sediment, is their interaction with other constituents. The constituents most affected are dissolved oxygen and nutrient concentrations. To model these interactions, the proportion of nutrients and oxygen exchanged is specified as a ratio with the quantity of growth or decay. Oxygen and nutrients are transported along the river and come into contact with the bed by turbulent mixing, so that nutrients and oxygen may be exchanged with the bed. The following relations give the source and sink terms that describe bed interactions.

2.3.4-1 Dissolved Oxygen

$$\frac{dO_2}{dt} = -\alpha_1 k_{osd} S_{os} \theta_1^{(T-20)} + \alpha_2 g_{ba} \frac{B}{z}$$

$$g_{ba} = \begin{cases} \mu_{ba} & \text{if} \quad \mu_{ba} \le c_{max}\left(1+\frac{z}{33.8}\right) \\ c_{max}\left(1+\frac{z}{33.8}\right) & \text{if} \quad \mu_{ba} > c_{max}\left(1+\frac{z}{33.8}\right) \end{cases}$$

α_1 = proportion of oxygen consumed from decay per unit of organic sediment (gm O_2/gm Organic Sediment), α_2 = proportion of oxygen produced from benthic algal growth per unit of benthic algae (gm O_2/gm Benthic Algae), g_{ba} = oxygen assimilation rate based either on the growth rate of benthic algae (μ_{ba}) or the maximum assimilation capacity (c_{max}) for dissolved oxygen when bubbles are produced by benthic algae photosynthesis. The ratio, $1+\frac{z}{33.8}$, is a pressure factor that increases with depth, indicating more oxygen is assimilated at deeper depths. The value 33.8 is the head in feet for one atmosphere of pressure.

2.3.4-2 Ammonia

The decay of organic sediment is assumed to produce ammonia, while organic nitrogen is produced in negligible amounts. Nitrate and nitrite would not be produced, since decay of organic sediment is consuming oxygen from the water column, implying that oxygen levels within the organic sediment are nil. They both require oxygen for oxidation from ammonia. Benthic algae take up ammonia from the water column during photosynthesis. The relation includes a factor comparing ammonia to nitrate preferences. The following equation describes the interactions between organic sediment and ammonia in the water column.

$$\frac{dN_1}{dt} = -\beta_1 k_{osd} S_{os} \theta_1^{(T-20)} + \beta_2 p_{nh3} \mu_{ba} \frac{B}{z}$$

with N_1 = ammonia-nitrogen concentration in the water column (mg N L^{-1}), β_1 = proportion of nitrogen in organic sediment (gm N/gm Organic Sediment), and β_2 = (gm N/gm Benthic Algae). The preference factor for NH_3 (p_{nh3}) is defined as follows.

$$p_{nh3} = \frac{P_f N_1}{P_f N_1 + (1-P_f) N_3}$$

where P_f = preference, varying from 0 to 1, for ammonia over nitrate if concentrations of both are equal and N_3 = nitrate-nitrogen concentration (mg N L^{-1}). The value for p_{nh3} will also vary from 0 to 1. The preference for ammonia is derived from the concept that less energy is required for utilization of ammonia, than for nitrate, in cell synthesis.

2.3.4-3 Nitrate

Nitrate is also taken up by benthic algae during growth in relation to the preference for ammonia described above. Hence, the greater preference for ammonia, the less preference for nitrate. The uptake by benthic algae is given by the following relation.

$$\frac{dN_3}{dt} = \beta_2 \left(1 - p_{nh3}\right) \mu_{ba} \frac{B}{z}$$

2.3.4-4 Dissolved Phosphorus

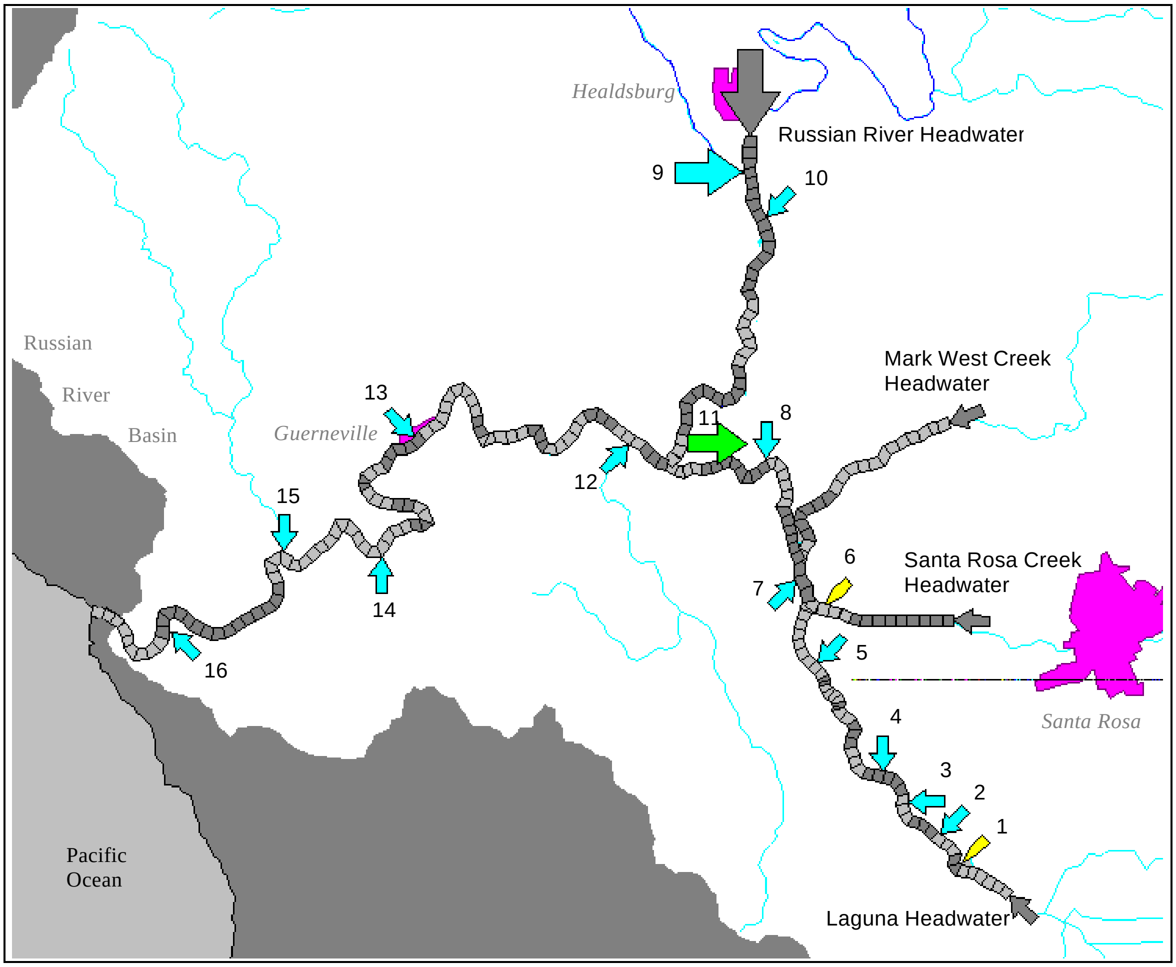
Similar to ammonia, dissolved phosphorus is produced by decay of organic sediments and taken up by benthic algae. The rate of both processes depends on the proportion of phosphorus in each constituent. The following relation describes these processes.

$$\frac{dP_1}{dt} = -\gamma_1 k_{osd} S_{os} \theta_1^{(T-20)} + \gamma_2 \mu_{ba} \frac{B}{z}$$

where P_1 = dissolved phosphorus content in the water column (mg P L^{-1}), γ_1 = proportion of phosphorus in organic sediment (gm P/gm Organic Sediment), and γ_2 = proportion of P in benthic algae (gm P/gm Benthic Algae).

2.4 MODEL CONFIGURATION

Developing the model configuration for the Laguna - lower Russian River system involves describing the channel geometry and identifying locations of point inflows and withdrawals. The geometric description for the system was based on those developed for the 1990 Laguna model (Smith 1991) and the 1991 UCD Russian River model (UCD 1991). A schematic representation of the final model is shown in Figure 2.3.



Point Loads

1. Meadowlane Pond Discharge
2. Colgan Creek
3. Roseland Creek
4. Unnamed stream
5. Unnamed stream
6. Delta Pond Discharge
7. Unnamed stream
8. Windsor Creek and Windsor WPCF
9. Dry Creek
10. Aggregate local flows between Dry Creek and the Laguna de Santa Rosa
11. SCWA withdrawal
12. Green Valley Creek
13. Fife Creek and Guerneville WPCF
14. Dutch Bill Creek
15. Austin Creek
16. Willow Creek

Figure 2.3. Laguna de Santa Rosa -Lower Russian River QUAL2E Model Configuration

2.4.1 Field Observations

Physical observations of the Russian River were made in July and August, 1994. The purpose was to characterize the geometry of the river from near the confluence with the Laguna de Santa Rosa to its mouth. Width, depth, and velocity measurements were made in sufficient detail to characterize the hydraulic properties of the river. These data were used to classify the various sections of river as riffle, run, or pool. This classification was relevant to the current problem, since the issues of concern were benthic algal growth and deposition of organic sediment/detritus. Benthic algae need sufficient light penetration to the bed in order to grow; conditions for growth are more conducive in riffle and run reaches. Organic sediment/detritus is subject to deposition and scour, exclusively; the former occurs only when a critical scour velocity is not exceeded, typically in runs and pools, while the latter occurs when that velocity is exceeded, typically in riffles. The critical scour velocity can also be exceeded in pools when the flows increase.

The locations and characteristics of recreational and water supply dams were noted, since these modify the hydraulic character of the river for some distance upstream. Secchi disk transparency was measured in several pools to estimate light extinction. Bed characteristics were noted, particularly in riffle and pool reaches. The proportion of bed that was cobble and gravel was measured to provide an estimate of the potential bed surface area that was available for benthic algal growth.

The locations of measurements and features were noted on aerial photographs of the river and indexed to field notes. The information was synthesized into a concept of the river's hydraulics, geometry, and habitat, which was used for the current modeling approach.

2.4.2 System Geometry

As stated above, river observations over the length from below Healdsburg to the mouth classified river reaches as riffle, run, or pool sections. While the reach type varied over short distances of the river, portions of the river had more of one type than another. For example, the river near the mouth is all pool, while that below the confluence with Laguna de Santa Rosa had all three types present. Since it is impractical to account for all the type variations over a river's length, sections of each type were lumped together, such that the total length of each type in a section of the river was the same as observed. Additionally, the distribution of each lumped reach type was specified to approximate the overall type distribution observed in the section.

To obtain the rating tables for the Russian River, HEC2 was run using an input file obtained from Sonoma County Water Agency (SCWA). This input file contains U.S. Army Corps cross-section data for the Russian River from the river's mouth to below the Healdsburg recreation dam. Corps cross-sections were selected which had characteristics similar to those observed during summer 1994, i.e., they had similar depth, width, and velocities. To simulate the effect of dams, cross-sections were added. These fixed the water surface elevations and weir elevations such that at low flow, the depths upstream were the same as observed. For higher flows, a weir equation was used to compute the depth over the weir. For very high flows, a flooded weir equation was used for the Guerneville dam. These depths were added to the weir elevations to give water surface elevation at the various flows. (It is recognized that the high to extreme flows used in the rating tables likely would not occur during the period when the recreation dams are in place; however, they are retained for consistency with the high runoff periods.)

2.4.3 System Hydrology and Point Loads

QUAL2E requires input of flows at all boundaries and load points. The boundaries are typically represented as headwaters for the river and any modeled tributaries. Since one of the concerns being addressed in this study effort relates to seasonal variation in effects from discharge of reclaimed water, it was necessary to develop a hydrologic data set for the entire water year.

Hydrologic data sets are required for model calibration and alternative evaluation. The model calibration was performed for the period of October 1992 through August 1995. Alternative analysis was performed for various hydrologic year types under future levels of development For the calibration period, the following data were available on a daily basis:

- Russian River flow at Hacienda Bridge. (USGS gauge)
- Russian River flow at Healdsburg. (USGS gauge)
- Releases from Warm Springs Dam to Dry Creek (Corps of Engineers)
- Withdrawals from the Russian River by Sonoma County Water Agency (SCWA)
- Reclaimed water releases to the Laguna at each discharge point. (City of Santa Rosa)

Additionally, consultants for the City of Santa Rosa (Merritt Smith) maintained gauging stations during the calibration period at the following locations:

- Laguna de Santa Rosa at Trenton-Healdsburg Road
- Mark West Creek at Slusser Road
- Santa Rosa Creek at Willowside Road

The hydrology under future development conditions has been synthesized by the SCWA using an operations model of the lower Russian River System. The synthesized data are based on historical Russian River flows and encompass the period of October, 1922 through September, 1992. The model output includes computed flows on a daily basis at the following stream locations and aggregated inflow points:

- Russian River flow at Healdsburg
- Releases from Warm Springs Dam to Dry Creek
- Russian River flow below the confluence with Dry Creek
- Withdrawals from the Russian River below Dry Creek (SCWA)
- Incremental inflow between Dry Creek and Hacienda Bridge
- Russian River flow at Healdsburg

A consistent set of assumptions was used in developing the hydrology for both the calibration and alternative analysis periods so that the calibration results would be indicative of the accuracy of the alternatives analysis. Both the observed data and the operations model output include the Russian River flow at Healdsburg, the Warm Springs Dam release, the SCWA withdrawal and the Russian River flow at Hacienda Bridge. By flow mass balance, the total incremental inflow to the Russian River system between Healdsburg and Hacienda Bridge can be computed. For the purposes of this study, the incremental inflow is defined as the total inflow to the Russian River between Healdsburg and Guerneville.

i.e., $Q_i = Q_{hb} + Q_{scwa} - Q_h - Q_{ws} - Q_{ww}$

$Q_i = Q_h + Q_{ws} - Q_{hb} - Q_{scwa} - Q_{rw}$

Where: Qi = incremental inflow

Q_h = Russian River flow at Healdsburg

Q_{ws} = Warm Springs Dam release to Dry Creek

Q_{hb} = Russian River flow at Guerneville (Hacienda Bridge)

Q_{rw} = Total reclaimed water discharge

Q_{scwa} = Sonoma County Water Agency withdrawal

For the calibration period, the recorded Laguna Plant and Delta Pond reclaimed water discharges were included in the mass balance. For the alternative analyses the reclaimed water discharge was not considered in the mass balance. A description of how the reclaimed water discharges are accounted for in the alternatives analysis is included in Section 4.3.

The total daily incremental inflow was apportioned to the individual tributaries and headwater inflow shown on Figure 2.3. The flow apportionment was based on the following:

- Stream flow measurements by MSC
- Dry Creek flow measurements for the gauge near Cloverdale
- Average annual rainfall as represented by the SCWA rainfall distribution map
- Estimates of annual infiltration based on watershed characteristics

The resulting fractions allocated to each tributary are listed in Table 2.1 and were used to allocate flow for both the calibration and alternative evaluations. The sum of the percentages for the first 12 tributaries (i.e., those above Guerneville) totals to 100 percent. The tributaries below Guerneville were not considered in the computation of the incremental inflow originating from the area between the two Russian River gauges. The inflows for the tributaries below Guerneville was determined as a function of drainage area, mean annual rainfall and infiltration assuming that unit runoff factors computed from the incremental inflow also apply to the tributaries below Guerneville.

Table 2.1

Tributary Drainage Areas, Mean Annual Rainfall and Infiltration and Flow Fraction

Tributary Name	Drainage Area Square Miles	Mean Annual Rainfall Inches	Annual Infiltration Inches	Flow Fraction Percent
Laguna de Santa Rosa	45	33	20	7.3
Santa Rosa Creek	78	39	20	18.5
Mark West Creek	52	46	22	15.6
Colgan Creek	16.3	33	23	2
Roseland Creek	9	33	23	1.1
Unnamed Stream #4	8.6	33	21	1.3
Unnamed Stream #5	8.6	33	25	0.9
Unnamed Stream #7	8	33	25	0.8
Windsor Creek	30	39	25	5.3
Dry Creek [a]	82	49	20	29.7
Misc. Below Dry Cr.	31	43	23	7.8
Green Valley Creek	43	41	23	9.7
Total Above Guerneville	411.5	41	21.6	100
Fife Creek	36	52	22	13.5
Dutch Bill Creek	16	53	20	6.6
Austin Creek	70	68	20	42
Willow Creek	24	51	20	9.3
Total Below Guerneville	146	59.6	20.5	71.4

[a] The Dry Creek values are for the drainage area below Warm Springs Dam. The total Dry Creek inflow equals the incremental inflow plus the Warm Springs Dam Release.

2.4.4 Water Quality of inflows

The model requires that the water quality for each headwater and point load be defined for the entire simulation period. Model calibration and the analysis of alternative project operation utilized a simulation period coinciding with the hydrologic year. Therefore, water quality boundary conditions were required for the entire year. Two fundamental approaches to boundary inflow water quality specification for model calibration were considered.

The first approach, which was not used in this analysis, was to adjust boundary water quality along with model parameters so that the observed ambient data were matched as closely as possible. This approach generally results in a better match between the observed data and the simulation results but may require boundary quality which is atypical of seasonal trends. Implicit in this approach is the need to tailor the boundary quality to specifics of the calibration period (e.g., hydrology, meteorology, sampling variability). An obvious shortcoming of this approach is that the calibration is specific to a set of conditions which may be not be generally applicable.

The second approach, which was adopted for calibration and alternative evaluation, is to evaluate available effluent and tributary water quality data and define the seasonal variation in each water quality parameter. During calibration, the boundary quality is not adjusted. With this approach, the calibration results reflect any variation from the actual boundary concentrations which may have occurred during the simulation period. Therefore, the calibration results are a measure of the total model response, including boundary variability and provides a measure of the accuracy and reliability of the alternative evaluation.

The water quality boundary conditions used for all headwater and point-load (tributary streams and reclaimed water discharges) are shown in the Appendix. The water quality concentrations are based on available data (Merritt Smith Consulting 1996c, d, e) and typical seasonal variations in stream temperature and water quality. The length of time that reclaimed water would have been in storage, and the effect of storage time on reclaimed water quality were considered. The Dry Creek data were derived from stream measurements and water quality profiles for Warm Springs Reservoir. Virtually all of the summertime Dry Creek flows are withdrawn from the hypolimnion of reservoir.
The tributary data of the Appendix include two generic inflow quality data types. The “rural stream” water quality category was assigned to the four lower Russian River tributaries identified as Fife, Dutch Bill, Austin and Willow Creeks on Figure 2.3. The “urban streams” category was assigned to all other tributaries which were not explicitly named in the Appendix.

The tributary water quality of the Appendix was assumed not to include the effects of runoff from dairy operations since the ambient data generally do not represent wet weather events. Therefore, the dairy loads were superimposed on the background quality. The annual BOD, organic detritus, total nitrogen and ammonia nitrogen loads estimated in CH2M Hill (1994) were used to define the dairy runoff effects on water quality. The total dairy load was distributed to the headwater and tributary streams of the Laguna based on the MSC aerial distribution. The timing of the discharge was based on the total inflow rate to the Laguna system. It was assumed that the dairy contribution would increase with increased runoff and that there would be a loading bias toward the early storm events. The daily tributary inflow concentration was computed by mass balance.

2.4.5 Climate Data

Running QUAL2E in dynamic mode requires that climatological data be input at three hour intervals over the simulation period. Climate data were obtained from the Western Regional Climate Center in Reno, Nevada for stations in Santa Rosa and Ukiah, California. These sites are the closest locations to the river for continuous daily records. Data from the Santa Rosa site were available for most dates for approximately 6 am to 8 pm, while the Ukiah site's data were collected over a 24-hour period.

Computer programs were written to sort through the data files from the Climate Center, select data closest to the three hour time intervals needed by QUAL2E, combine the data sets for Santa Rosa and Ukiah, and write the data to a file useable by QUAL2E.

The climate data contained the dry bulb and dewpoint temperatures. QUAL2E uses wet bulb and dry bulb temperatures to get vapor pressure and then computes the dewpoint temperature. The code was modified to account for this change in input data.

2.4.6 Water Quality Coefficients and Parameters

Water quality parameters were initially selected based on typical published values (Bowie 1985) then adjusted though the calibration process. Rates for most processes were set at the beginning of the simulation and fixed for all time. Transformation rates for nutrients were set within suggested ranges in the QUAL2E manual.

Water transparencies, which tend to control algal productivity, were based on flow rates. The switch to higher turbidity was triggered by a 2000 cfs flow rate at Guerneville.
Benthic algae rates were set such that the first algae class dominated in the spring and the second class dominated in the fall. The sum of biomass of both classes were used for comparison with the observed levels as determined by the chlorophyll a data. The portion of bed that is within 5 feet of the surface at low flows (as defined by the geometry data) was assumed suitable benthic habitat in both the Laguna and the Russian River. Growth, respiration, and detachment rates and the nitrogen half-saturation constant were examined. Phosphorus half-saturation was not examined, since the system is nitrogen limited, as judged from the N:P ratios indicating sufficient availability of phosphorus. Benthic algal biomass is quite sensitive to the net growth rate, since it is not advected and its solution depends on previous biomass density.

3.0 CALIBRATION

The model was calibrated for water years 1993 through 1995. Observed data were used to develop boundary conditions for the simulations and for comparison with simulation results. In the Laguna, comparisons between observed data and model results were made at Occidental Road (LOR), River Road (LRR) Trenton-Healdsburg Road (LTH), in the Russian River at Odd Fellows (OF) and Monte Rio (MR). The locations of these stations are shown in Figure 1 in Merritt Smith Consulting (1996c and 1996d).

3.1 STRATEGY

The objective of calibration is to construct the boundary condition data set that represent the calibration period and then to adjust the model parameters so that the simulation results best represent observed conditions in the prototype system. The calibration procedure began with describing the boundary conditions for the calibration period. Boundary conditions include headwater, point load, and incremental flows, the water quality constituent concentrations for all inflows, and meteorological data for the basin. With the boundary conditions established, the model was run and simulation results were compared to observed data. Then selected model parameters were adjusted and the model was run again. Model parameters include hydraulic parameters impacting the flow regime and physical, chemical and biological reaction rates and coefficients impacting water quality state variables. This process continued until the simulation results matched the observed data within an acceptable tolerance. When determining what an acceptable level of tolerance is, it is important to consider the uncertainty in the observed data.

Under ideal conditions, the geometry of the system and all boundary conditions are known precisely. Unfortunately, it is typically too expensive, if not impossible, to develop a complete description of the system geometry and boundary conditions from field measurements. Best estimates must be made from the available data. The method of developing the geometry for the Laguna - lower Russian River model was discussed in Section 2.4.2. The method of developing boundary conditions for the model is discussed in Section 2.4.4.

The emphasis of this study is on simulating long term response to waste loading on the system. When a steady state calibration is done, the model is expected to match observed data within a very small tolerance. However, when calibrating a long time series simulation it is not appropriate to force the model to match all data points. This is because boundary conditions must be estimated from field observations which are sparse in space and time relative to the data requirements of the model and because it is not possible to include the impact of unusual or random loadings on the system. Indeed, collection of hourly field data in all stream reaches to provide a data set to match model output is infeasible. For this study, it is also important to use a method of estimating boundary conditions that will be consistent with the method used to develop boundary conditions for alternative management scenarios. Thus the objective of the calibration procedure for this study is to demonstrate the capability of the model to simulate reasonable seasonal trends and reflect the appropriate response to known changes in boundary conditions. In the Laguna - Russian River system, it is of primary importance to show the correct water quality behavior both during and following the discharge season in those reaches impacted by reclaimed water discharges. Figures depicting simulated and observed parameters are in the Appendix Figures (Figures 3.1 through 3.29).

3.2 CALIBRATION RESULTS

3.2.1 Flow

Calibration of the flows in the system is critical to the modeling study because the flows affect the reclaimed water dilution estimates as well as the water quality modeling. Observed flow data from the USGS gage at Hacienda Bridge are compared with computed flow in Appendix Figure 3.1 and at an expanded scale in Appendix Figure 3.2. The magnitude of runoff varies considerably over the three calibration years. 1993 was an above-normal year where runoff occurred during many medium intensity storms. 1994 was a below-normal year with only a few small storms. 1995 was a wet year where runoff was dominated by two very large storms.

Simulated versus observed flows are plotted in Appendix Figure 3.3 for the full calibration period. The simulated flows show an excellent fit to the observed data with a slope of 0.973 and an R^2 of 0.985 (where a slope of 1.0 and an R^2 of 1.0 would indicate exact correspondence).

3.2.2 Temperature

Water temperature is a function of the temperature of the boundary inflows and heat exchange at the air-water interface. Time series of temperature are shown at stations in the Laguna and Russian River in Appendix Figures 3.4 - 3.7. There is a sinusoidal seasonal variation in temperature related to the change in altitude of the sun and the length of the day over the course of each year. Superimposed on the seasonal variations are diurnal variations caused by warming during the day and cooling at night. Diurnal variations are more pronounced during the warmer months when the days are longer and the sun is higher in the sky. Additional variability is caused by local weather. The diurnal temperature range is greatest in the Laguna where the flows are lower and the stream is shallower.

At Occidental Road the Laguna is very shallow and is subject to high summer temperatures, on the order of 85 degrees F, and large diurnal temperature fluctuations (Appendix Figure 3.4). The model tends to under-predict temperatures in the warmer months by 2 to 8 degrees F with an average error of 1.8 degrees F over the year. The diurnal range of the simulation results varies from 0.3 to 8.6 degrees F while the observed diurnal ranges vary from 0.8 to 15 degrees F. The low maximum temperatures and smaller diurnal temperature ranges of the simulated temperatures are in part due to the representation of the channel geometry near Occidental Road. At Trenton-Healdsburg

Road, the observed summer time temperatures are lower, on the order of 72 degrees F (Appendix Figure 3.5). Simulation results more closely match the peak temperatures and diurnal ranges.

The lower Russian River has higher flow and generally deeper water and thus the diurnal temperature range is smaller than in the Laguna. Simulated and observed data are shown for Odd Fellows and Monte Rio in Appendix Figures 3.6 and 3.7. At Odd Fellows the average deviation is 0.8 degrees F. The largest observed diurnal temperature range is 3.9 degrees F and the corresponding simulated range is 3.8 degrees F. At Monte Rio the average deviation is 0.7 degrees F. The largest observed diurnal temperature range is 4.4 degrees F and the corresponding simulated range is 5.1 degrees F.

3.2.3 Nitrate

Nitrate nitrogen is introduced into the system by loading from headwater, tributary, and incremental flows. It is also generated by decomposition of organic sediments and detritus to form ammonia, which oxidizes to nitrite and then to nitrate. During the discharge season, one of the most important sources of nitrate is the reclaimed water discharge. Nitrate nitrogen is removed from the water column by growth of phytoplankton and benthic algae. Time series plots of nitrate are shown in Appendix Figures 3.8 - 3.11. During the discharge season more nitrate is available in the system than can be utilized by biological growth. The variation in nitrate concentrations is due to the dilution of reclaimed water and other loadings by storm flows. When the discharge season ends, nitrate becomes a limiting constituent for biological activity and is almost completely removed from the water column.

At Occidental Road simulated nitrate nitrogen concentrations range from 1 to 11 mg/l during the discharge season with typical values on the order of 3.5 mg/l (Appendix Figure 3.8). Following the discharge season, nitrate nitrogen concentrations are near zero. These results compare favorably with the observed data which during the discharge season range from 1 to 8 mg/l with typical concentrations between 2 and 4 mg/l. Following the discharge season the observed nitrate nitrogen concentrations are near the detection limit of 0.1 mg/L.

Near Trenton-Healdsburg Road, nitrate nitrogen concentrations are generally lower than upstream locations during the discharge season due to dilution from Mark West Creek, Santa Rosa Creek, and other tributary inflows (Appendix Figure 3.9). Simulated nitrate nitrogen concentrations range from 0.5 to 7 mg/l. Concentrations in 1993 and 1995 are typically between 1 and 2 mg/l while in 1994, a dry year, the average nitrate nitrogen concentration was approximately 3 mg/l. Observed data in 1995 closely match the simulation result in both magnitude and range during and following the discharge season. Observed data collected in 1993 and 1994 (actually collected at River Road) show uncharacteristically high nitrate concentrations in the summer months relative to earlier sampling years. The quality of these data is suspect (particularly the August 1994 observation exceeding 8 mg/l) and no attempt was made to force the model to match these data.

In the lower Russian River at Odd Fellows and Monte Rio (Appendix Figures 3.10 and 3.11) the peak nitrate nitrogen concentrations are much lower than in the Laguna due to further dilution of the reclaimed water flows with the Russian River flow. Simulated nitrate concentrations during the discharge season are typically on the order of 0.5 mg/l with peaks of 1 mg/l and 1.5 mg/l in the wet and dry years respectively. Outside the discharge season, nitrate concentrations are reduced but not to the extent observed in the Laguna. Simulation results match the observed data very well for all points except one. In April 1995 the observed nitrate concentration at Odd Fellows was 1.8 and at Monte Rio was 1.6 mg/l while the simulated result was approximately 0.6 mg/l. The high value of the observed data may have been a result of an unknown boundary loading that was not reflected in the boundary conditions used for the calibration runs or it may be due to sampling error. Disregarding the possible outlier, the root-mean-squared deviation between simulated and observed nitrate concentrations is only 0.06 mg/l at both Odd Fellows and Monte Rio indicating an excellent correspondence between the model and the prototype system.

.2.4 Ammonia

Ammonia is introduced into the system by boundary flows (headwater, tributary, and incremental flows) and by degradation of organic sediments and detritus. Ammonia is removed from the water column by growth of phytoplankton and benthic algae. Unlike nitrate, Santa Rosa's reclaimed water discharges are not a major contributor of ammonia due to the nitrification process of the Laguna Plant. The principal source of ammonia during wet weather periods is non-point source boundary flows, including dairy loads. During low flow periods, there is a daily cycling of ammonia caused by uptake by phytoplankton and benthic algae during the day and release of ammonia from decomposition of organic matter. During the warmer months, the growth potential is sufficiently high that biological uptake of ammonia keeps the concentration of ammonia in the water column relatively low.

At Occidental Road the simulated and observed ammonia concentrations during the warm weather - low flow periods are typically below 0.2 mg/l (Appendix Figure 3.12 and 3.13). During the high flow periods the simulated and observed concentrations of ammonia range as high as 2 mg/l. Variation of ammonia concentrations during the high flow period reflects the sensitivity to boundary loadings. In addition to using field ammonia measurements, the boundary loadings were estimated using a procedure that attempts to provide reasonable seasonal trends (see Section 2.4.4), and therefore the simulated results should not be expected to exactly match the observed data on a point by point basis. In 1995, the simulated results show high concentrations of ammonia persisting longer into the spring than is seen in the observed data. This is most likely due to the over-estimation of ammonia concentrations in the boundary inflows during the second large storm of 1995. In the real system, the first large storm of 1995 may have flushed most of the organic loading from the watershed, and so the second large storm may have had relatively lower concentrations of ammonia (and other constituents). This unusual circumstance was not incorporated in the procedure used to estimate boundary loadings for the model, and thus the model over-estimated ammonia concentrations in the system in 1995 after the flushing event.

In the lower Russian River (Appendix Figures 3.14 and 3.15) simulated and observed concentrations of ammonia during the warm weather - low flow period are less than 0.1 mg/l. Again the over-estimate of 1995 boundary loads in the model is shown.

3.2.5 Phosphate

Like ammonia, phosphate is introduced into the system by boundary flows (headwater, tributary, and incremental flows) and by degradation of organic sediments and detritus. Phosphate is removed from the water column by growth of phytoplankton and benthic algae. The principal source of phosphate during wet weather periods is non-point source boundary flows, including dairy loads. During low flow periods, there is a daily cycling of phosphate caused by uptake by phytoplankton and benthic algae during the day and release from decomposition of organic matter. During the warmer months growth of algae causes the concentration of phosphate in the water column to be generally lower than during the high flow winter periods. However, since algae growth is limited by nitrogen, not phosphate, measurable concentrations of phosphate persist in the system during the summer months. Because phosphate is not observed to be a limiting nutrient for algae growth, it is not considered to be an important indicator of water quality in the system.

At Occidental Road observed phosphate ranges from 0.8 to 2 mg/l during all seasons (Appendix Figure 3.16). Simulated phosphate concentrations show a similar range during the high flow periods, but show lower concentrations during the low flow periods due to uptake by phytoplankton and benthic algae. At Trenton-Healdsburg Road (Appendix Figure 3.17) observed phosphate concentrations are below 0.8 mg/l over the entire calibration period, and during the low flow periods simulated concentrations are within 0.1 mg/l of the observed values.

At Odd Fellows and Monte Rio (Appendix Figures 3.18 and 3.19) simulated phosphate concentrations during the low flow period are with 0.02 mg/l of the observed values. As with ammonia, the model over-estimates phosphate concentrations during the spring of 1995 as a result of the over-estimation of the phosphate concentration of boundary flows during the second major storm event of that year.

3.2.6 Dissolved Oxygen

The concentration of dissolved oxygen (D.O.) in the water column is a function the D.O. content of boundary inflows, sources and sinks within the water column, and exchange across the air water interface. The solubility of oxygen in water is a function of water temperature and atmospheric pressure. If the concentration of D.O. in the water column is different from the oxygen saturation concentration, oxygen will transfer across the air water interface to bring the D.O. concentration in the water column to the saturation concentration. The rate at which oxygen is transferred across the air-water interface, the reaeration rate, is computed as a function of stream velocity and depth. Decay of organic matter, oxidation of nutrients, and respiration of algae remove D.O. from the water column and can lead to very low D.O. concentrations. Photosynthesis associated with algal growth increases the concentration of D.O. in the water column and can lead to super-saturation (concentrations of D.O. above the oxygen saturation concentration).

D.O. concentrations will vary over the diurnal cycle due to the changes in water temperature caused by warming during the day and cooling at night. In addition, the daily cycle of algal growth and respiration can lead to very large diurnal fluctuations in D.O. concentrations. This is particularly evident in the Laguna where reaeration is limited because of very low velocities during low flow periods. The seasonal variation in diurnal range is clearly seen in the time histories of D.O. at the four monitoring sites (Appendix Figures 3.20 - 3.23). During the high flow, winter periods there is very little diurnal temperature variation and low biological activity, thus there is virtually no diurnal variation in D.O. concentration. In the warmer, low flow period there are larger daily temperature fluctuations and significant biological activity leading to large diurnal variations in D.O.

At Occidental Road (Appendix Figure 3.20) the observed D.O. concentrations vary from nearly zero to over 17 mg/l (well above the oxygen saturation concentration). The observed diurnal range during the warmer low flow period varies from 2.7 to over 8 mg/l. Simulated D.O. concentrations show similar variation. The simulated D.O. concentrations vary from less than 1 mg/l to nearly 20 mg/l during the spring algae bloom. The diurnal range of the simulated concentrations during the warmer low flow periods is from 2 to 15 mg/l. At Trenton-Healdsburg Road, (Appendix Figure 3.21) neither the computed nor the observed D.O. concentrations vary as widely as at Occidental Road. The model over-estimates the D.O. concentration on the average of 2 mg/l, however the simulated and observed diurnal ranges are comparable, typically 2 mg/l during the warmer low flow periods.

The large variations in D.O. concentrations in the Laguna are principally a result of transient loadings that cannot be precisely described as boundary conditions for the model. It is therefore unreasonable to expect the model to precisely match observed D.O. concentrations. The calibration results presented here are considered adequate because the range of simulated D.O. concentrations in the upper Laguna are comparable to the observed range, including periods of super-saturation and critically low D.O. . And because the simulated and observed diurnal ranges are comparable, indicating that the impact of biological activity on D.O. is reasonably represented.

In the lower Russian River the seasonal and diurnal variations in D.O. are much smaller than in the Laguna due to the greater volume of water in the river. Also, the D.O. concentration is less dominated by biological activity as evidenced by the smaller diurnal range and absence of very low or very high D.O. concentrations. At Odd Fellows and Monte Rio (Appendix Figures 3.22 and 3.23) the observed D.O. concentrations vary from 7 to 10 mg/l. Simulated D.O. concentrations are within the range of the observed data. The diurnal variation of both the simulated and observed concentrations during the warmer low flow periods are on the order of 1.5 mg/l.

3.2.7 Planktonic Algae

Direct measurement of the concentration of planktonic algae (phytoplankton) is difficult since it involves filtering and drying of the sample. As an alternative, the chlorophyll a is measured to serve as an indication of the phytoplankton biomass. The ratio between chlorophyll a and phytoplankton is variable with ratios exceeding 1 to 100. Phytoplankton growth requires adequate light, nutrients and suitable temperatures. The travel time through the stream system also controls the phytoplankton concentration. When growth occurs, oxygen is produced (i.e., primary productivity). At night, the phytoplankton respire depleting the D.O. Therefore, the diurnal variation in D.O. is another indication of phytoplankton concentration and activity.

The calibration results of Appendix Figures 3.24 - 3.27 show the simulated and observed phytoplankton concentration at the four locations. The observed values correspond to a chlorophyll a to algal biomass of 1 to 100. The seasonal variations expected in a stream system is clearly seen in the model results. Cool temperatures and short residence times limit the concentrations during the winter months even though there are ample nutrients.

During the fall of 1992 and spring of 1993 at Occidental Road, the model results and observed data are nearly identical. During the spring of 1994, the shape of the observed and estimated phytoplankton concentration plot is similar, but the model over-estimates the observed levels by a factor of 3 or more. The computed peak of May 1994 is in response to the low flow conditions which provide an ideal combination of temperature, nutrients with adequate residence time. The cluster of observed values during June of 1995 average about one half of the model results. For the other locations, the computed phytoplankton are consistently higher than that suggested by the chlorophyll a data.

These calibration results illustrate the uncertainty of model output relative to observed phytoplankton conditions. Several factors suggest that the uncertainty may not be as great as indicated in Appendix Figures 3.24 - 3.27, as follows:

1. In the late 1980’s, chlorophyll a measurements in the Laguna in excess of 500 µg/L were common, indicating phytoplankton levels of 50 mg/L or more.
2. The observed diurnal variation in D.O. can only be explained if phytoplankton and/or benthic algae are present in the quantities predicted by the model.
3. Phytoplankton concentrations of 1 or 2 mg/L are virtually undetectable to the eye. Visual observations suggest that the summertime concentrations indicated by the chlorophyll a measurements are unrealistically low.

The low concentrations of phytoplankton suggested by the chlorophyll a measurements could have been attained by slight adjustments in growth, respiration and settling rates during calibration. This action make the calibration plots more presentable but would render the model insensitive to changes in nutrients associated with the proposed project alternatives. It would have also reduced the diurnal D.O. variations to below the observed

levels. The decision was made to retain the model sensitivity to nutrients and thus provide a conservative approach to evaluating the project alternatives.

The model output has greater-than-desired uncertainty associated with phytoplankton estimates of observed conditions. However, the phytoplankton output was evaluated to determine the effect of reclaimed water discharge alternatives relative to the model simulation of existing conditions. Based on the calibration, the model is considered well suited for this purpose.

3.2.8 Benthic Algae

Benthic algae are affixed to the bottom substrate and are represented as mass per area units. Direct measurement of benthic algae involves removal of the algae form the substrate and drying before weighing. As an alternative, the benthic algae can be removed from a known area by scraping or other means, placed in a known volume of water and measured for the chlorophyll a content. By applying the appropriate conversion factors, the mass per unit area can be computed. The ratio between chlorophyll a and phytoplankton is variable with ratios exceeding 1 to 125. Benthic algae biomass is more variable than water quality because of benthic algae patchiness. This variability contributes to uncertainty of field measurements.

Benthic algae growth requires adequate light, nutrients and suitable temperatures. The travel time through the stream system is not an issue since they are affixed to the bottom. As with phytoplankton, the diurnal variation in D.O. can be an indication of benthic algae activity.

The calibration results of Appendix Figures 3.28 - 3.29 show the simulated and observed benthic algae biomass at two Russian River locations. No data were available for the two Laguna sites. The observed values correspond to a chlorophyll a to algal biomass of 1 to 100. The seasonal variations expected in a stream system are clearly seen in the model results. Cool temperatures and short residence times limit the concentrations during the winter months even though there are ample nutrients. During the winter months of 1993 and 1995, the benthic algae approaches minimum model constraint due to the high flow velocities which remove the algae by scour. In 1994, flows were considerable lower, which allowed the benthic algae to prosper during the spring of that year. The measurements at Monte Rio tend to support the differences in benthic algae production seen in the model results between 1994 and 1995. The results for Odd Fellows show that the model overpredicts the observed values.

The rationale for allowing the model to predict benthic algae levels greater than those suggested by the data is similar to the reasons discussed in the phytoplankton calibration section. The likely reason for the low macrophyte biomass is that the macrophyte sampling program began after the peak growth season in the first year, and growth in the second year of the sampling was reduced from the flooding in the previous winter. Because of the flooding, the River in spring was deep and turbid, preventing growth during a time when peak growth occurs. In addition, increased scouring from the flooding and deposition of new sediment without macrophyte inocula probably occurred, which would delay growth. The Russian River measurements appear low relative to typical levels reported in the literature. Briggs (1987), Jacoby (1987) and Feminella, et al. (1989) reported levels ranging from 2.2 to 16.7 g/m2 in four New Zealand streams, Raging River (Western WA) and Big Sulfur Creek and the Rice Fork of the Eel, respectively. which correspond to 200 to 1,550 mg/ft^2.

As in the case of phytoplankton, allowing the model to predict higher level of benthic algae provides a level of sensitivity adequate for detecting changes due to proposed project operation and thus provide a more conservative analysis.

4.0 ALTERNATIVE ANALYSIS

4.1 OBJECTIVE FOR ALTERNATIVE ANALYSIS

The goal of the alternatives analysis was to evaluate the potential water quality effects of each project alternative on the lower Russian River system including Santa Rosa Creek and the Laguna de Santa Rosa. Dry, average and wet hydrologic years were analyzed to determine the range of water quality responses which could be anticipated.

Two analytical approaches were undertaken to evaluate water quality impacts. The first approach was to simulate a reclaimed water tracer to determine the hourly concentration of reclaimed water in the Laguna and Russian River at selected locations for each year type. The reclaimed water concentration was then used to evaluate the impacts on the many water quality parameters not explicitly simulated by QUAL2E. The results of this analysis are presented in Merritt Smith Consulting (1996a).

The second analytical approach was to simulate the concentrations of dissolved oxygen, plant nutrients, phytoplankton and benthic algae represented by the model for the three hydrologic year types.

4.2 HYDROLOGY

Each of the project alternatives was simulated for dry, average and wet hydrologic year classes. The 70-year operation model was used to rank each year from the driest to wettest based on Russian River flow at Guerneville (i.e., Hacienda Bridge). The allocation of inflows to the various headwater and tributary inflow points is described in Section 2.4.3. The incremental inflow, Russian River flow at Healdsburg, Warm Springs Dam release, and the SCWA withdrawals are specified by the SCWA operations model. These flows represent future conditions as defined by the cumulative impacts scenario of the SCWA EIR (SCWA 1996 Appendix).

The driest year during this period was the 1977 hydrologic year. The 1977 water year is considered the extreme low flow event of this century. During this period, the Russian River flow under operation study conditions was approximately 50,000 acre feet for the entire year. The preceding year (1976) is the third driest of the 70 year period with an annual Russian River flow volume of approximate 209,000 acre feet, which is more than four times larger than that of 1977.

In an extreme event such as 1977, the design discharge criteria would likely be violated (i.e., contingency discharges). Therefore, the 1977 year was reserved for the contingency analysis. The 1976 year was selected for detailed water quality analysis to quantify the impacts of project operation during very dry events.
The median year identified using this process was 1961. This year was selected to evaluate project effects under normal hydrology. For the wet year analysis, 1982 was selected. This year is the fifth wettest year within the 70 year period. The total annual Russian River flow under operation model assumptions was 1,047,000 and 2,985,00 acre-feet for the 1961 and 1982 hydrologic years respectively. Computation of the incremental tributary inflow is described in Section 2.4.3. A summary of the monthly and annual river flow, incremental tributary inflow and reclaimed water production for the three years is shown in Table 4.1

Table 4.1

Flow Volumes for the Dry, Average and Wet Hydrologic Years

1976 - Dry Hydrologic Year - Flow Volumes in Million Gallons

Month	Russian River at Healdsburg	Incremental Inflow	Russian River at Guerneville	Reclaimed Water Production
Oct	3,613	1,333	3,655	659
Nov	4,709	2,113	6,439	652
Dec	8,713	3,474	11,436	698
Jan	3,978	1,442	4,633	654
Feb	8,293	3,668	9,108	618
Mar	14,422	4,777	18,884	738
Apr	9,487	5,042	12,520	707
May	2,674	1,079	2,608	655
Jun	2,270	480	2,343	630
Jul	1,870	366	2,125	651
Aug	1,762	514	1,934	651
Sep	1,621	548	1,866	630
Total for the Discharge Period	54,605	22,461	68,121	5,045
Total for the Water Year	63,412	24,836	77,551	7,943

Table 4.1 Cont.

Flow Volumes for the Dry, Average and Wet Hydrologic Years

1961 - Normal Hydrologic Year - Flow Volumes in Million Gallons

Month	Russian River at Healdsburg	Incremental Inflow	Russian River at Guerneville	Reclaimed water Production
Oct	3,083	650	2,814	651
Nov	6,081	8,553	8,065	664
Dec	46,669	22,536	69,072	914
Jan	27,563	21,251	43,833	783
Feb	72,631	25,029	108,029	900
Mar	54,658	20,189	79,155	904
Apr	17,352	6,164	22,739	762
May	11,124	2,793	11,867	706
Jun	3,971	951	3,246	630
Jul	3,849	471	3,041	651
Aug	3,825	536	2,844	651
Sep	3,038	577	2,663	630
Total for the Discharge Period	234,897	106,138	341,287	5,934
Total for the Water Year	253,844	109,700	357,368	8,846

Table 4.1 Cont.

Flow Volumes for the Dry, Average and Wet Hydrologic Years

1982 - Wet Hydrologic Year - Flow Volumes in Million Gallons				
Month	**Russian River at Healdsburg**	**Incremental Inflow**	**Russian River at Guerneville**	**Reclaimed water Production**
Oct	5,707	3,100	7,429	684
Nov	68,957	54,160	115,067	976
Dec	129,532	74,631	213,327	1,162
Jan	82,169	39,572	132,302	1,038
Feb	90,344	57,361	156,276	972
Mar	61,249	43,070	105,528	990
Apr	118,643	70,893	223,388	1,144
May	17,539	11,546	30,239	855
Jun	6,014	3,313	6,829	707
Jul	4,258	1,406	3,416	659
Aug	3,972	927	2,853	651
Sep	3,448	1,044	2,823	630
Total for the Discharge Period	567,144	349,952	972,737	7,395
Total for the Water Year	591,832	361,023	999,477	10,468

4.3 DAILY FLOW OPERATIONS MODEL

The methodology for specifying the daily variation in headwater inflow, tributary inflow and withdrawals is described in Section 2.4.3. This procedure computed all flow rates based on synthesized flow data provided by the SCWA operations model for the cumulative impacts conditions as defined by SCWA (1996). The only flow not defined by this methodology is the Santa Rosa reclaimed water discharge.

To provide the required reclaimed water discharge rate for each hydrologic year of interest and each reclaimed water disposal alternative, a separate flow balance model of the reclaimed water storage facility was developed. The model was designed to simulate the daily operation of the reclaimed water facilities considering daily reclaimed water production and the characteristics and objectives of each storage option. The model simulation period extended from October 1 through May 14. Zero discharge was assumed for the remainder of the year.

4.3.1 Reclaimed Water Production

The daily reclaimed water production is a function of the average dry weather flow (ADWF) plus an increment due to infiltration into the collection system. This increment is generally associated with wet weather. The incremental inflow used in the tributary inflow model is obviously related to rainfall.

Therefore, a correlation between the recorded daily reclaimed water production and the daily incremental inflow was developed. The correlation was developed from plant operation data for the period between January 1, 1985 and September 30, 1992 and the corresponding SCWA estimates of incremental inflow.

The first step was to normalize the reclaimed water production data to a constant ADWF. The top half of Appendix Figure 4.1 shows the historical daily reclaimed water production and trend in ADWF. For the purpose of this analysis, the ADWF line was defined as 13.1 MGD on January 1, 1985 and a yearly increase of 0.427 MGD. The seasonal variation in reclaimed water production and the trend in ADWF is apparent in Appendix Figure 4.1.

The bottom half of Appendix Figure 4.1 shows the adjusted historical reclaimed water production and the model reclaimed water production. The adjusted historical reclaimed water production was calculated by scaling the actual production by the ratio of buildout ADWF to the ADWF (e.g., 21 / 13.1 on January 1, 1985) seen in the top half of Appendix Figure 4.1. This approach assumes that the relationship between wet weather flow (WWF) and ADWF will remain the same at buildout. The relationship between the model reclaimed water production and the incremental watershed inflow was developed using a regression fit between the adjusted historical reclaimed water production and incremental inflow. The following expression results in a root mean square error of 2.8 MGD.

For $Q_I > 100$ cfs

$$Q_{ww} = 21 + 0.2973\,(Q_I - 100)^{1/2}$$

For $Q_I < 100$ cfs

$$Q_{ww} = 21$$

Where: Q_{ww} = Reclaimed water production in MGD

Q_I = Incremental watershed inflow in cfs

The annual reclaimed water production for the model is within +/- 3% of the adjusted historical records of production for all years.

4.3.2 Operation Assumptions

In the model, each reclaimed water disposal alternative is defined by a maximum discharge rate, available storage volume, discharge location, contingency operation options and irrigation acreage.

The maximum discharge rate was defined as a fraction of the total flow in the Russian River at Hacienda Bridge. This maximum rate was constrained by the capacity of the discharge and conveyance facilities. The hydraulic capacity of the Delta Pond and Laguna Plant discharges across the nonflooding range of Laguna flow conditions were 120 MGD and 80 MGD, respectively. The actual hydraulic capacity of the discharge facilities decreases as water level increases toward flood stage in the Laguna. Zero discharge was assumed when the flow at Hacienda Bridge exceeded 40,000 cfs (flood stage). This constraint was imposed to eliminate the possible adverse impacts of increased flow during flood events.

The end of month storage objectives that were developed in Parsons ES (1995) were used as the basis for simulated operations, and these values are shown in Table 4.2. The available storage volume at any date was defined as a time variable fraction of the total storage capacity. For some alternatives, a contingency storage volume was assigned to store excess reclaimed water to avoid violations of the discharge objective. The contingency storage was defined as a percentage of the total available storage. The storage facilities were assumed empty on October first.

The storage objective shown in Table 4.2 for the No Project alternative was derived from the existing condition storage objectives. The 1,000 cfs discharge restriction that constrains existing discharge was assumed to not constrain the No Project operation (consistent with the Basin Plan), and the addition of irrigation lands during the interim period dictated a revised storage curve for the No Project alternative.

Discharge locations included the existing Delta Pond and Laguna Plant locations. The Laguna Plant location was only used for those periods when the total discharge exceeded the discharge capacity of the Delta Pond discharge. For the Russian River alternative the discharge location was approximate 2.5 miles above the confluence with the Laguna. The capacity of the Russian River discharge and Geysers diversion was 27 MGD and 23 MGD respectively. During periods when the total discharge exceeded the Russian River (or Geysers) pipeline capacity, the excess reclaimed water was discharged at the Delta Pond location.

Contingency operation options included winter irrigation and water conservation. The maximum available winter irrigation rate was defined as a irrigation application rate (i.e., inches/month) over the entire area encompassed by the reclaimed water irrigation program. The winter irrigation period extended from December 15 through the end of April. Water conservation assumed a reduction in reclaimed water production associated with domestic water use reduction. Such a reduction would likely occur during the extended low river flow periods when this contingency would be utilized in the model.

The operation of each alternative was based on the acreage available for irrigation. The summer irrigation periods was assumed to extend from May 1 through October 5 and 4.2 percent of the total summer irrigation was assumed for May and October periods respectively. Unlike the contingency winter irrigation application, the summer irrigation demand was always imposed.

Table 4.2

Reclaimed Water Storage Objectives

End of Period Storage

Volume in MG

Project Condition	Contingency Storage (%)[a]	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May 15
Existing Cond.	0	210	520	910	1015	850	771	520	700
No Project	5	353	503	625	720	870	1101	1292	1360
Geysers	0	92	98	191	498	679	1045	1203	1184
1% Project	0	1352	1924	2392	2755	3328	4212	4940	5200
5% Project	5	1066	1517	1886	2173	2624	3321	3895	4100
10% Project	5	806	1147	1426	1642	1984	2511	2945	3100
20% Project	5	312	444	552	635	768	972	1140	1200
Russian R. (20%)	5	312	444	552	635	768	972	1140	1200

[a] contingency storage is expressed as a percentage of the monthly storage objective. For example, 5 percent contingency storage assumed for the 20 percent discharge means that in the month of October, storage would allowed to be 5 percent more than 312 MG.

4.3.3 Reclaimed Water Discharge

The goal of the operations model was to simulate operation of the various project alternatives to determine the location and rate of discharge of reclaimed water. The following computation sequence was used to compute the fate of the reclaimed water on a daily basis.

The first step was to compute the optimal reclaimed water discharge rate. This rate was defined as the reclaimed water production (computed as a function of incremental inflow) less the summer irrigation demands, incremental storage volume requirement and other demands, if any (e.g., export to the Geysers). Then the maximum allowable discharge rate was determined as a function of the previous day's Russian River flow.

If the maximum allowable discharge exceeded the optimal reclaimed water discharge rate, the optimal discharge rate was assumed and the model proceeded to the next day. If the maximum allowable discharge rate was less than optimal reclaimed water discharge rate, the following steps were taken to reduce the discharge rate to the maximum allowed under the project specifications.

1. Allow the storage volume to exceed the target storage up to the contingency storage limit.
2. Deduct the flow increment up to the maximum winter irrigation rate
3. Deduct the flow increment up to the maximum conservation rate.

For purposes of this analysis only, winter irrigation rates were set at a time dependent application rate over the entire area included in the summer irrigation program. The winter irrigation period extended from December 15 through the end of April when the summer irrigation program commences. Consistent with Parsons ES (1995), the irrigation application rate was assumed to be a function of the potential evapotranspiration rate and to vary from one inch/month during December, January and February up to 2.5 inches/month by the end of April. The winter irrigation rate varied between 163 and 300 MG/month depending on the irrigation acreage. During extended dry periods, water conservation measures designed to reduce demand on water supplies would also reduce reclaimed water production. Water conservation was represented by a constant rate ranging from 26 to 31 MG/month.

If these measures did not result in a required discharge rate lower than the optimal discharge rate, the required discharge was made and the contingency discharge was noted in the model output. According to this daily simulation, contingency discharge was a very rare occurrence with most of the estimated contingency discharge occurring in the 1977 water year.

4.4 MITIGATION OPERATION

The end-of-month reclaimed water storage objective constraints for the Russian River discharge operations were determined as the product of the total storage capacity and the end of month storage utilization fraction defined in Parsons ES (1995). The storage utilization fraction was assumed constant for all discharge options.

The uniform fraction has a dramatic effect on the timing of the onset of discharge period. As an example, the end of October 312-MG storage capacity limit for the 20 percent project results in a storage capacity increment of 10 MGD which is less than half the ADWF. The operation rules dictate that the excess reclaimed water be discharged up to the river percentage constraint. The storage target results in a discharge on October 1 for the 20 percent discharge case. The end of October 1352 MG storage capacity limit for the 1 percent Project results in a storage capacity increment of 45 MGD which is twice the 21 MGD ADWF. This means that discharge to the stream system would not unless without appreciable wet weather inflow.

Increased nutrient loadings during October have the potential of stimulating primary production since there is ample daylight and temperatures are conducive to plant growth. The QUAL2E model evaluation for project alternatives predicted a marked increase in phytoplankton and benthic algae levels when discharges were made during October. The model also predicted elevated levels during the months of April and May related to reclaimed water discharge. Very small changes were computed during the winter months when light is at a minimum and the water is cold.
A mitigation operation approach was devised which provided additional storage volumes during the fall and spring months. The end of month storage volume targets were set such that a storage volume increment of 25 MGD was maintained through the end of November up to a total storage of 90 percent of the total storage. The end of month storage targets for March, April and May(14) were set such that the rate of 25 MGD could also be maintained during April and May. The end of March storage was constrained to 10 percent of the design storage volume. For the months of December through February, the end of month storage targets were set by interpolation between the November 30 and March 31 volume targets. The rate of 25 MGD rate was selected so that discharge would only occur during the months of October, November, April and May if there was appreciable wet weather inflow and elevated stream flow rates.

The mitigation operation for the Geysers alternative assumed a revised end of month storage objective and a contingency storage up to 2/3 of the remaining design capacity. These operation rules ensure that the May 14 storage volume can be met while maximizing the export to the Geysers. The end of month storage volumes for the mitigation operation for all project options are shown in Table 4.3. The table includes both the maximum and target storage volumes for the Geysers alternative.

The revised storage utilization criteria result in a dramatic change in end of month storage targets for the 20 percent Project while the 1 percent Project is virtually unaffected. For the 1 percent project, the uniform storage utilization fraction assumption of the design projects require disproportionately larger storage volumes since no discharges occur early in the discharge season. Had the design 1 percent Project been specified such that the end of month storage volumes resulted in discharge to the Russian River during the months of October and November (i.e., non-uniform storage utilization fraction), the mitigation operation approach would have resulted in larger changes in the end of month targets.

The mitigation operation increases the potential contingency discharge for the 5, 10 and 20 percent projects during the December through March period since storage volume increments are reduced. Contingency discharges, however, remain rare and the model simulations indicate that early and later reclaimed water discharges have much greater water quality ramifications than an occasional contingency discharge during the winter.

Table 4.3

Reclaimed Water Storage Objectives for Mitigation Operation

End of Period Storage Volume in MG

Project	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May 15
Geysers (min)	92	98	200	350	500	800	1150	1184
Geysers (max)	820	830	870	920	970	1100	1190	1200
Russian R. 20%	775	1080	840	600	360	120	825	1200
1% Project	775	1525	2162	2800	3437	4075	4825	5200
5% Project	775	1525	1887	2250	2612	2975	3725	4100
10% Project	775	1525	1637	1749	1862	1975	2725	3100
20% Project	775	1080	840	600	360	120	825	1200

4.5 CUMULATIVE IMPACTS ANALYSIS

The cumulative impacts analysis is intended to depict future load and flow conditions in the Russian River and Laguna system addressed in this analysis. Increased reclaimed water discharges in the Russian River drainage and control of nitrogen sources in the Laguna de Santa Rosa have been identified by the Regional Board as future activities affecting tributary stream water quality.

4.5.1 Increased Discharge to the Russian River and Tributaries

The Regional Board (Robert Klamt 1994) has compiled estimates of future (2005 to 2010) reclaimed water discharge rates for the Cities of Ukiah, Cloverdale and Healdsburg. The Regional Board's flow estimates are based on the general plan growth as of the time of the Regional Board's assessment (1994). Since then, Ukiah and Windsor have proposed general plan amendments that would further increase wastewater flows from existing conditions. Estimated future flows are summarized in Table 4.4.

Table 4.4

Estimated Future Wastewater Discharges to the Russian River Basin

Average Dry Weather Flow (mgd)

Community	Regional Board Flow Estimate[a]	Additional Flow Due to Growth[b]	Total Future Flow[c]	Existing Flow[d]	Incremental Flow[e]
Ukiah	3.4	0.14	3.54	2.4	1.14
Cloverdale	2.00	0	2	0.5	1.5
Healdsburg	1.80	0	1.8	1.0	0.8
Windsor	2.7	2.1	4.8	1.1	3.7
Forestville	0.12	0	0.12	0.05	0.07
Graton	0.14	0	0.14	0.08	0.06
Guerneville	0.71	0	0.71	0.35	0.36
Occidental	0.05	0	0.05	0.02	0.03

[a] General Plan projections reported in RWQCB (1994)
[b] Based on proposed general plan changes since 1994
[c] Sum of two column to the left
[d] Based on reports submitted by dischargers to RWQCB, also summarized in Table 4.6-9 in the EIR/S
[e] Flow used for cumulative impacts analysis

Based on these discharge rate increases, assumed reclaimed water quality and dry period Russian River flows, the incremental change in nitrate nitrogen and phosphate phosphorus were computed (by the Regional Board) by mass balance. This analysis ignored biological uptake and other transformations within the river.

Table 4.4 includes reclaimed water discharge rates for the communities of Cloverdale and Healdsburg, which discharge to percolation ponds. DWR (1983) indicates that, during the dry season when algae might grow in response to percolate from these communities, the net flow is from the River to groundwater in the vicinity of both percolation ponds and that no reclaimed water reaches the river. The cumulative impacts analysis assumed that future groundwater demands will continue to draw reclaimed water away from the river. Therefore these two discharges were ignored in our analysis.

The QUAL2E model can account for increased nutrient loadings by specifying the incremental flow rate and reclaimed water quality at the discharge location or by adjusting the concentration of other inflows in the vicinity of the discharge point. For the cumulative impacts analysis, the concentrations of the Russian River at Healdsburg and at Fife and Windsor Creeks were adjusted to include the seasonal variation in the inflowing nitrate and phosphate concentrations related to future reclaimed water flow rates. The discharge season for all dischargers extends from October 1 through May 14.

The effects of increased reclaimed water from Ukiah were incorporated into the Russian River quality. The reclaimed water increment and River flow rate were used to compute the change in water quality on a daily basis by mass balance. Nitrate nitrogen and phosphate phosphorus concentrations of 20 and 5 mg/L, respectively, were assumed for the reclaimed water and the seasonal variations in Russian River quality listed in the Appendix were assumed. Biological uptake of nutrients within the river above Healdsburg was accounted for by reducing the concentration increment during the fall and spring months of the discharge periods.

Direct discharge to the Russian River system below the Laguna confluence include Occidental (Dutch Bill Creek), Grayton (Atascadero Creek), Forestville (Green Valley Creek) and Guerneville (Russian River). The effects of increased reclaimed water from these sources were combined and input to the river at the Fife Creek location. The reclaimed water increment and Fife Creek flow rate were used to compute the daily variation in concentration required to input the incremental mass associated with the increased reclaimed water discharge. The discharge limits, which are currently 1 percent of the receiving water flow rate, were not considered. Nitrate nitrogen and phosphate phosphorus concentrations of 20 and 5 mg/L, respectively, were assumed for the reclaimed water and the seasonal variations in the non-urban stream quality listed in the Appendix were assumed for Fife Creek. Biological uptake of nutrients within Dutch Bill, Atascadero and Green Valley Creek was accounted for by reducing the concentration increment during the fall and spring months of the discharge periods.

The City of Windsor discharges to the Laguna at Trenton-Healdsburg Road. For the cumulative impacts analysis, it was assumed that the Windsor treatment facility would operate in a fashion similar to that of the Laguna reclaimed water treatment facility. The following procedure was used to adjust the “existing condition” Santa Rosa reclaimed water discharge rates to reflect an incremental flow of 3.7 MGD projected for the Windsor Plant.

1. Compute “existing condition” daily flows and scale by the ratio of 3.7/16.4.
2. Limit the discharge to 1% of the Laguna flow below Windsor Creek.
3. Accumulate flow in excess of the 1% limit and discharge later subject to the 1% limit.
4. Compute the equivalent Windsor Creek concentration to reflect the reclaimed water increment by mass balance.

The Windsor reclaimed water quality was assumed equal to the Delta Pond discharge quality listed in the Appendix. Windsor Creek water quality, which includes the present Windsor plant loadings, is also listed in the Appendix. The total reclaimed water discharge computed in step 1 cannot be accommodated within the 1 percent constraint.
The computed excess reclaimed water volume was 320, 540 and 21 MG for the 1961, 1976 and 1982 simulation years respectively. It was assumed that this excess would be accommodated by increased storage.

4.5.2 Long Term Reductions in Nitrogen Loading within the Laguna de Santa Rosa Watershed

Biological productivity is controlled in part by the concentrations of plant nutrients. In the Laguna, nitrogen is considered the limiting nutrient. The Regional Board (1995) has set nitrogen (ammonia and total nitrogen) loading reduction goals for the Laguna watershed with the intent of improving Laguna water quality. These reductions goals are defined by nutrient source, season, stream sub-reach and the target load reduction in pounds.

The nitrogen sources identified as candidates for reduction are reclaimed water, dairy agriculture, and dairy and urban runoff. The reduction due to reclaimed water management is not assumed since the reclaimed water discharge is the subject of the EIR.

The target reductions in dairy agriculture and dairy ponds contribution include large reductions during the summer months. The model effort has assumed that loadings associated with dairy operations are a wet weather phenomena and that the timing and magnitude of the discharge is a function of the total incremental local inflow (see Section 2.4.4.) In order to maintain consistency with the approach to modeling dairy loadings, the Board's total annual target mass load reduction was implemented for the cumulative impacts analysis but not the seasonal distribution.

The target reductions for total nitrogen and ammonia nitrogen are approximately 134,600 and 22,500 pounds/year respectively. The total annual dairy loadings assumed in the model for organic nitrogen and ammonia nitrogen are approximately 149,200 and 29,500 pounds/year respectively. In addition, the model assumes an annual organic sediment contribution of 6,067,000 pounds/year. The organic sediment contributes an additional 482,000 pounds/year of nitrogen with the chemical composition assumed in the model. The target dairy nitrogen load reductions were achieved by reducing the ammonia nitrogen dairy contribution to 22.8 percent of the present level and the organic nitrogen and organic sediments inputs to 77.2 percent of present levels.

The remaining source identified for reduction is urban runoff. The target reductions for total nitrogen and ammonia nitrogen from urban runoff are approximately 13,000 and 2,300 pounds/year respectively. No reduction was targeted to the winter season. The load reduction was implemented by revising the inflow water quality for the "urban streams" as follows.

1. The average monthly flow for each of these point loads (#2,3,4,5 & 7 of Figure 2.3) was computed over the 70 operations year
2. The total nutrient mass was computed based on average flow and the non-cumulative impacts concentration.
3. The concentration of ammonia nitrogen was adjusted until the reduction in computed mass matched the magnitude on timing of the target ammonia reduction
4. The concentrations of organic, ammonia, nitrite and nitrate nitrogen were adjusted until the reduction in computed mass matched the magnitude on timing of the target total nitrogen reduction.

The urban runoff nitrogen reduction targets required a reduction in mid-summer concentration of approximately 50 percent for each parameter. The concentrations of nitrogen parameters are listed in the Appendix.

4.6 Methodology for Comparing Alternatives

The water quality model computes the concentration of each water quality parameter at spatial intervals of one quarter mile or less at hourly intervals for the entire simulation period. These results were processed to provide the average, minimum and maximum computed values for each month at discrete points and stream reaches. The following points and reaches were selected for the purposes of evaluating each project alternative.

4.6.1 Discrete Points

1. Laguna at Occidental Road
2. Santa Rosa Creek below the Delta Pond discharge Point
3. Laguna at River Road
4. Russian River at the SCWA intake
5. Russian River at Oddfellows

4.6.2 Stream Reaches

1. Laguna below Santa Rosa Creek (average of 13 points spaced at 1/2 mile)

2. Russian River between the Laguna and the proposed Russian River discharge point (average of 13 points spaced at 1/2 mile)
3. A 6 1/2 mile reach of the Russian River below the Laguna (average of 12 points spaced at 1/2 mile)
4. An additional 6 1/2 mile reach of the Russian River immediately downstream of the #3 reach

The monthly output for each project alternative was compared with the “existing condition” and “zero discharge” conditions to quantify the magnitude and percentage change. The output is shown graphically in Merritt Smith Consulting (1996a).

5.0 REFERENCES

Bowie, George L. et al. 1985. "Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition)", U.S. Environmental Protection Agency, EPA/600/3-85/040.

Breithaupt, Stephen A. 1996. Doctoral Dissertation, Department of Civil and Environmental Engineering, UC Davis, (in preparation).

Brown, Linfield C., and T. O. Barnwell, Jr. 1987. "The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User's Manual", U.S. Environmental Protection Agency, EPA/600/3-87/007.

Briggs, Barry 1987. Effects of Sample Storage and Mechanical Blending on the Quantitative Analysis of River Periphyton. Freshwater Biology, vol. 18 pg. 197-203.

California Regional Water Quality Control Board, North Coast Region 1995. *Waste Reduction Strategy for the Laguna de Santa Rosa*, March 1, 1995.

Canale, R. P. and M. I. Auer 1982. "Ecological Studies and Mathematical Modeling of Cladophora in Lake Huron: 5. Model Development and Calibration," Journal of Great Lakes Research, vol. 8(1), pg. 112-125.

CH2M Hill and Merritt Smith Consulting 1994. "Laguna de Santa Rosa Water Quality Objective Attainment Plan", Final Report prepared for the City of Santa Rosa.

Department of Water Resources 1983. Evaluation of Groundwater Resources of Sonoma County, Volume 5. Alexander Valley/Healdsburg Area. DWR Bulletin 118-4.

Feminella, Jack W., M. E. Power, and V. H. Resh 1989. Periphyton Responses to Invertebrate Grazing and Riparian Canopy in Three Northern California Coastal Streams. Freshwater Biology, vol. 22(3), pg. 445-457.

Grenney, W. J., and A. K. Kraszewski 1981. "Description and Application of the Stream Simulation and Assessment Model, version IV (SSAM IV)," cooperating agencies USFWS, USEPA, USSCS, USGS, Report #FWF/OBS-81/46.

Jacoby, Jean M. 1987. Alterations in Periphyton Characteristics Due to Grazing in a Cascade Foothill Stream. Freshwater Biology, vol. 18(3), pg. 495-508.

Klamt, Robert 1994. California Regional Water Quality Control Board, North Coast Region, *Mass Emission Calculations for Russian River Dischargers*, Interoffice Memo., February, 28.

Merritt Smith Consulting 1996a. *Water Quality Impacts Analysis*. Technical Report, Santa Rosa Subregional Long-Term Wastewater Project.

Merritt Smith Consulting 1996b. *Aquatic Biological Resource Impacts Analysis*. Technical Report. Santa Rosa Subregional Long-Term Wastewater Project.

Merritt Smith Consulting 1996c. *Laguna de Santa Rosa Water Quality Monitoring*. Technical Report. Santa Rosa Subregional Long-Term Wastewater Project.

Merritt Smith Consulting 1996d. *Russian River Water Quality Monitoring*. Technical Report. Santa Rosa Subregional Long-Term Wastewater Project.

Merritt Smith Consulting 1996e. *Reclaimed Water Quality* Technical Report. Santa Rosa Subregional Long-Term Wastewater Project.

Parsons E-S 1995. *Water Balance Model Summary and Results* Technical Report. Santa Rosa Subregional Long-Term Wastewater Project.

Smith, Donald J. 1978. "Water Quality for River-Reservoir Systems: User's Manual", U.S. Army Corps of Engineers, Hydrologic Engineering Center.

Smith, Donald J. "1991. "Water Quality Analysis of the Laguna de Santa Rosa System including Santa Rosa Creek and Mark West Creek", Resource Manage Associates, Inc.

Sonoma County Water Agency 1996. *Russian River System Model, A Water Balance Computer Model of the Russian River System*. October 1988, Revised November 1994, Revised March 1996.

UCD December 1992. "Water Quality Modeling for the Russian River: Final Project Report", Center for Environmental and Water Resources Engineering, Department of Civil and Environmental Engineering, UC Davis, Report No. 92-3.

6.0 APPENDIX

Water quality for Headwater Streams, Reclaimed Water and Tributary Streams

Laguna de Santa Rosa

	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	56	44	42	44	48	56	66	74	80	80	66
Dissolved Oxygen	7.5	7.5	7.5	7.5	7.5	7.3	7	7.5	7.2	6.5	6.5	7.5
Carb. BOD	4	4	4	4	4	4	4	4	4	4	4	4
TDS	400	400	400	400	400	400	400	400	400	400	400	400
Chlorophyll a	10	2	1	1	1	2	5	8	10	10	10	5
Organic N	1.02	1.02	1.06	1.06	1.03	1.03	0.83	0.83	1.03	1.23	1.23	1.02
NH3 Nitrogen	0.15	0.3	0.6	0.6	0.6	0.6	0.3	0.15	0.13	0.13	0.13	0.15
NO2 Nitrogen	0.005	0.01	0.015	0.015	0.015	0.015	0.01	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.25	0.5	1.24	1.24	1.12	1.12	0.52	0.22	0.12	0.08	0.08	0.25
Organic P	0.2	0.15	0.12	0.12	0.11	0.11	0.15	0.21	0.31	0.31	0.31	0.2
PO4 Phosphorus	0.3	0.4	0.5	0.5	0.5	0.5	0.4	0.3	0.2	0.2	0.2	0.3
Detritus	1	3	5	5	5	5	3	1	0.1	0.1	0.1	1

Santa Rosa Creek

	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	55	42	42	44	48	56	65	72	76	76	66
Dissolved Oxygen	9	8	8	8	8	8	8.5	9	9	9	9	9
Carb. BOD	3	3	3	3	3	3	3	3	3	3	3	3
TDS	300	280	250	250	250	250	280	300	320	320	320	300
Chlorophyll a	5	2	1	1	1	2	5	8	10	10	10	5
Organic N	0.15	0.2	0.33	0.33	0.33	0.3	0.23	0.15	0.13	0.13	0.13	0.15
NH3 Nitrogen	0.08	0.12	0.15	0.15	0.15	0.15	0.12	0.1	0.05	0.05	0.05	0.08
NO2 Nitrogen	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.15	0.25	0.5	0.7	0.7	0.7	0.52	0.22	0.15	0.12	0.12	0.15
Organic P	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
PO4 Phosphorus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Detritus	1	1	2	3	3	3	2	1	0.1	0.1	0.1	1

Water quality for Headwater Streams, Reclaimed Water and Tributary Streams

Mark West Creek

	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	55	42	42	44	48	56	65	72	76	76	66
Dissolved Oxygen	9	8	8	8	8	8	8.5	9	9	9	9	9
Carb. BOD	3	3	3	3	3	3	3	3	3	3	3	3
TDS	250	200	180	180	180	180	200	250	275	275	275	250
Chlorophyll a	5	2	1	1	1	2	5	8	10	10	10	5
Organic N	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
NH3 Nitrogen	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
NO2 Nitrogen	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.12	0.12	0.32	0.32	0.32	0.32	0.22	0.16	0.12	0.1	0.1	0.12
Organic P	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PO4 Phosphorus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Detritus	1	1	2	3	3	3	2	1	0.1	0.1	0.1	1

Russian River at Healdsburg

	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	68	54	44	42	42	50	56	66	74	76	76	68
Dissolved Oxygen	10	10.5	11	11	11	11	10.5	10	9.3	9	9	10
Carb. BOD	2	2	2	2	2	2	2	2	2	2	2	2
TDS	150	150	150	150	150	150	150	150	150	150	150	150
Chlorophyll a	2	1	0.5	0.5	0.5	0.5	1	2	3	4	4	2
Organic N	0.15	0.15	0.3	0.3	0.3	0.25	0.2	0.15	0.15	0.15	0.15	0.15
NH3 Nitrogen	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.03
NO2 Nitrogen	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.03	0.05	0.18	0.35	0.42	0.42	0.42	0.37	0.09	0.02	0.02	0.03
Organic P	0.05	0.04	0.04	0.03	0.03	0.03	0.04	0.05	0.06	0.06	0.05	0.05
PO4 Phosphorus	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.04
Detritus	1	1	2	3	3	3	2	1	0.1	0.1	0.1	1

Water quality for Headwater Streams, Reclaimed Water and Tributary Streams

<u>Pond D</u>

	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	56	44	42	44	48	56	66	74	80	80	66
Dissolved Oxygen	8.5	8	8	8	8	8	8	8.5	7.2	6.5	6.5	8.5
Carb. BOD	6	5.3	5	4.9	4.5	4.5	5.6	6.3	8.3	8.9	7	6
TDS	455	451	357	414	444	444	435	438	428	439	441	441
recl.water tracer	100	100	100	100	100	100	100	100	100	100	100	100
Chlorophyll a	5	1	1	1	1	2	5	10	25	40	50	25
Organic N	2.6	2.7	2.8	2.8	2.8	2.6	2.4	2.2	2.9	2.3	2.3	2.6
NH3 Nitrogen	1.4	1.9	1.9	2.1	1.9	1.9	1.5	1.3	1.4	1.5	1.4	1.4
NO2 Nitrogen	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO3 Nitrogen	12.2	12.2	14.9	14.4	14.4	13.4	12.6	10.8	9.9	9.6	9.9	9.2
Organic P	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.3
PO4 Phosphorus	3.3	4.8	4.7	4.7	4.8	3.8	2.9	2.9	2.7	2.7	2.9	3.3
Detritus	10	4	2	1	1	1	5	10	15	20	25	10

<u>Delta Pond</u>	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	56	44	42	44	48	56	66	74	80	80	66
Dissolved Oxygen	8.5	8	8	8	8	8	8	8.5	7.2	6.5	6.5	8.5
Carb. BOD	6	5.3	5	4.9	4.5	4.5	5.6	6.3	8.3	8.9	7	6
TDS	455	451	357	414	444	444	435	438	428	439	441	441
recl.water tracer	100	100	100	100	100	100	100	100	100	100	100	100
Chlorophyll a	5	1	1	1	1	2	5	10	25	40	50	25
Organic N	2.6	2.7	2.8	2.8	2.8	2.6	2.4	2.2	2.9	2.3	2.3	2.6
NH3 Nitrogen	1.4	1.9	1.9	2.1	1.9	1.9	1.5	1.3	1.4	1.5	1.4	1.4
NO2 Nitrogen	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO3 Nitrogen	12.2	12.2	14.9	14.4	14.4	13.4	12.6	10.8	9.9	9.6	9.9	9.2
Organic P	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.3
PO4 Phosphorus	3.3	4.8	4.7	4.7	4.8	3.8	2.9	2.9	2.7	2.7	2.9	3.3
Detritus	10	4	2	1	1	1	5	10	15	20	25	10

Water quality for Headwater Streams, Reclaimed Water and Tributary Streams

Windsor Creek	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	55	42	42	44	48	56	65	72	76	76	66
Dissolved Oxygen	10	10.5	11	11	11	11	10.5	10	9.3	9	9	10
Carb. BOD	3	3	3	3	3	3	3	3	3	3	3	3
TDS	250	200	180	180	180	180	200	250	275	275	275	250
Chlorophyll a	5	2	1	1	1	2	5	8	10	10	10	5
Organic N	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
NH3 Nitrogen	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
NO2 Nitrogen	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.12	0.12	0.32	0.32	0.32	0.32	0.22	0.16	0.12	0.1	0.1	0.12
Organic P	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PO4 Phosphorus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Detritus	1	1	2	3	3	3	2	1	0.1	0.1	0.1	1

Dry Creek	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	61	59	52	50	52	52	61	68	68	68	68	68
Dissolved Oxygen	10	10	11	11	11	11	10	10	10	10	10	10
Carb. BOD	1	1	1	1	1	1	1	1	2	1	1	1
TDS	100	100	100	100	100	100	100	100	100	100	100	100
Chlorophyll a	1	1	1	1	1	1	1	1	1	1	1	1
Organic N	0.15	0.15	0.3	0.3	0.3	0.25	0.2	0.15	0.15	0.15	0.15	0.15
NH3 Nitrogen	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.03
NO2 Nitrogen	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.23	0.25	0.28	0.35	0.42	0.42	0.42	0.37	0.29	0.22	0.22	0.23
Organic P	0.05	0.04	0.04	0.03	0.03	0.03	0.04	0.05	0.06	0.06	0.05	0.05
PO4 Phosphorus	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04
Detritus	1	1	2	3	3	3	2	1	0.1	0.1	0.1	1

Water quality for Headwater Streams, Reclaimed Water and Tributary Streams

Urban Tributaries[a]	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	56	44	42	44	48	56	66	74	80	80	66
Dissolved Oxygen	8.5	8	8	8	8	8	8	8.5	7.2	6.5	6.5	8.5

Carb. BOD	5	5	5	5	5	5	5	5	5	5	5	5
TDS	400	400	400	400	400	400	400	400	400	400	400	400
Chlorophyll a	10	2	1	1	1	2	10	15	20	20	20	10
Organic N	1.02	1.02	1.06	1.06	1.03	1.03	0.83	0.83	1.03	1.23	1.23	1.02
NH3 Nitrogen	0.15	0.3	0.6	0.6	0.6	0.6	0.3	0.15	0.13	0.13	0.13	0.15
NO2 Nitrogen	0.005	0.01	0.015	0.015	0.015	0.015	0.01	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.25	0.5	1.24	1.24	1.12	1.12	0.52	0.22	0.12	0.08	0.08	0.25
Organic P	0.2	0.15	0.12	0.12	0.11	0.11	0.15	0.21	0.31	0.31	0.31	0.2
PO4 Phosphorus	0.3	0.4	0.5	0.5	0.5	0.5	0.4	0.3	0.2	0.2	0.2	0.3
Detritus	1	3	5	5	5	5	3	1	0.1	0.1	0.1	1
Urban Tributaries[b]												
Cumulative Impacts												
Organic N	0.51	0.51	0.76	1.06	1.03	0.74	0.42	0.42	0.52	0.62	0.62	0.51
NH3 Nitrogen	0.08	0.18	0.55	0.6	0.6	0.55	0.18	0.08	0.06	0.06	0.06	0.08
NO2 Nitrogen	0.002	0.006	0.014	0.015	0.015	0.014	0.006	0.002	0.002	0.002	0.002	0.002
NO3 Nitrogen	0.13	0.25	0.93	1.24	1.12	0.84	0.26	0.11	0.06	0.04	0.04	0.13

Water quality for Headwater Streams, Reclaimed Water and Tributary Streams

Rural tributaries[c]	Oct 1	Nov 15	Dec 15	Jan 15	Feb 14	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 30
Temperature	66	55	42	42	44	48	56	65	72	76	76	66
Dissolved Oxygen	10	10.5	11	11	11	11	10.5	10	9.3	9	9	10
Carb. BOD	3	3	3	3	3	3	3	3	3	3	3	3
TDS	250	200	180	180	180	180	200	250	275	275	275	250
Chlorophyll a	5	2	1	1	1	2	5	8	10	10	10	5
Organic N	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
NH3 Nitrogen	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
NO2 Nitrogen	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
NO3 Nitrogen	0.12	0.12	0.32	0.32	0.32	0.32	0.22	0.16	0.12	0.1	0.1	0.12
Organic P	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PO4 Phosphorus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Detritus	1	1	2	3	3	3	2	1	0.1	0.1	0.1	1

[a] Urban tributaries include point loads #2, 3, 4, 5, 7, 10 & 12 shown on Figure 2.3

[b] Nitrate nitrogen adjusted for urban runoff nitrogen reduction target (cumulative impacts analysis)

[c] Rural tributaries include point loads # 13, 14, 15 & 16 shown on Figure 2.3

7.0 APPENDIX FIGURES

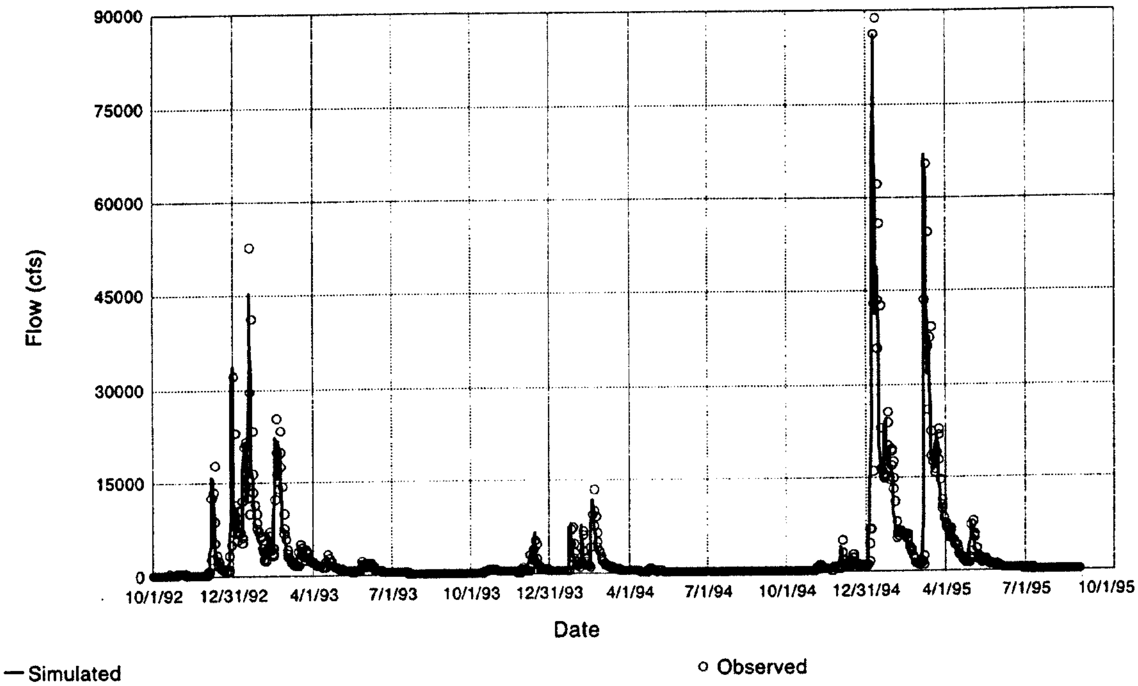


Figure 3.1 Time History of Flow in the Russian River at Guerneville

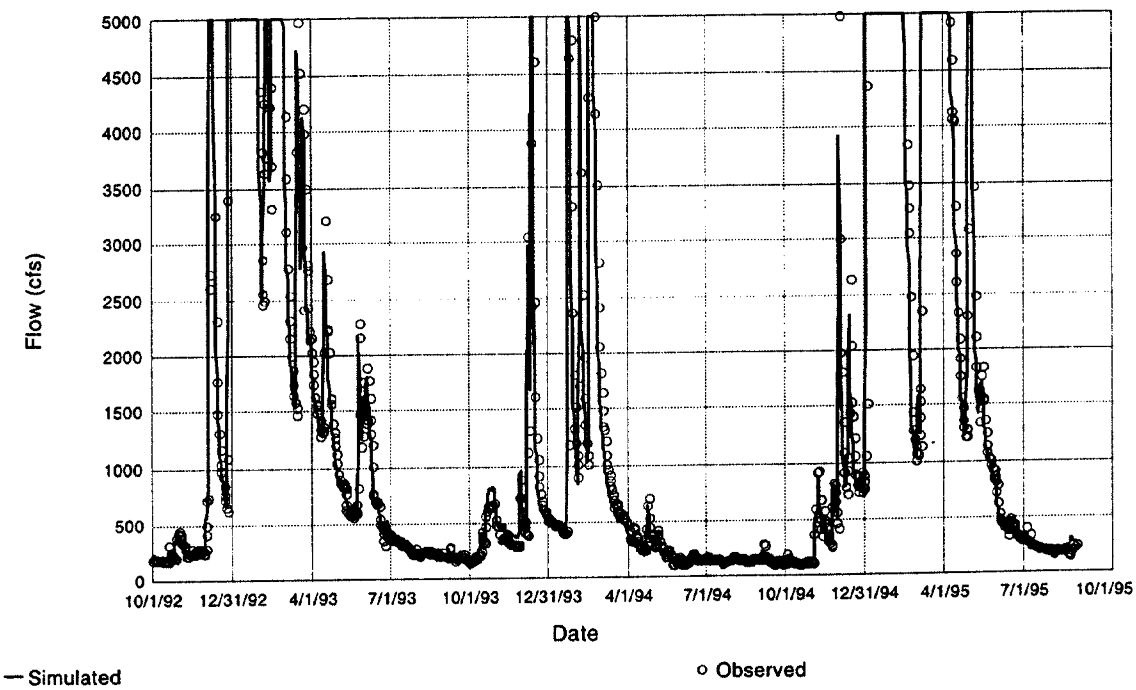


Figure 3.2 Time History of Flow in the Russian River at Guerneville (expanded scale)

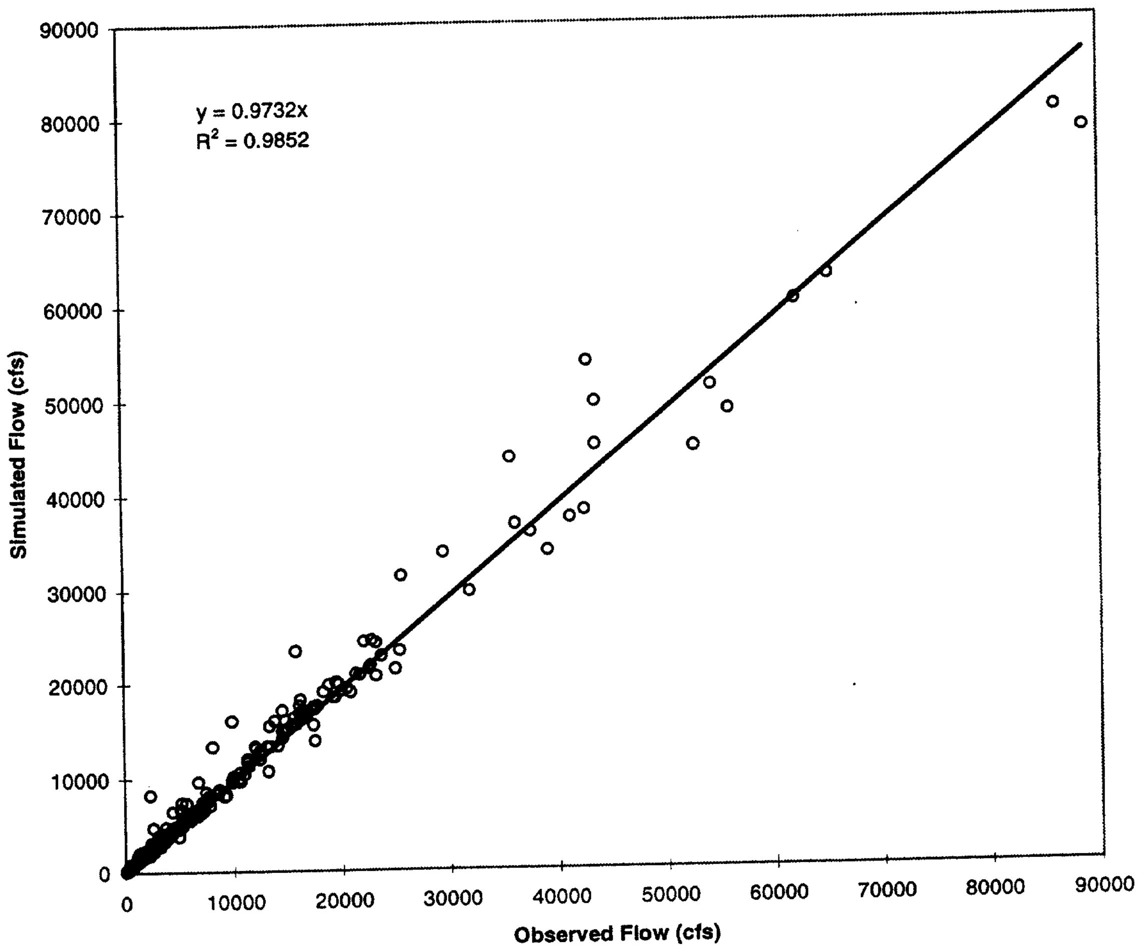


Figure 3.3 Simulated vs. Observed Flow at the Russian River at Guerneville, 1993-1995

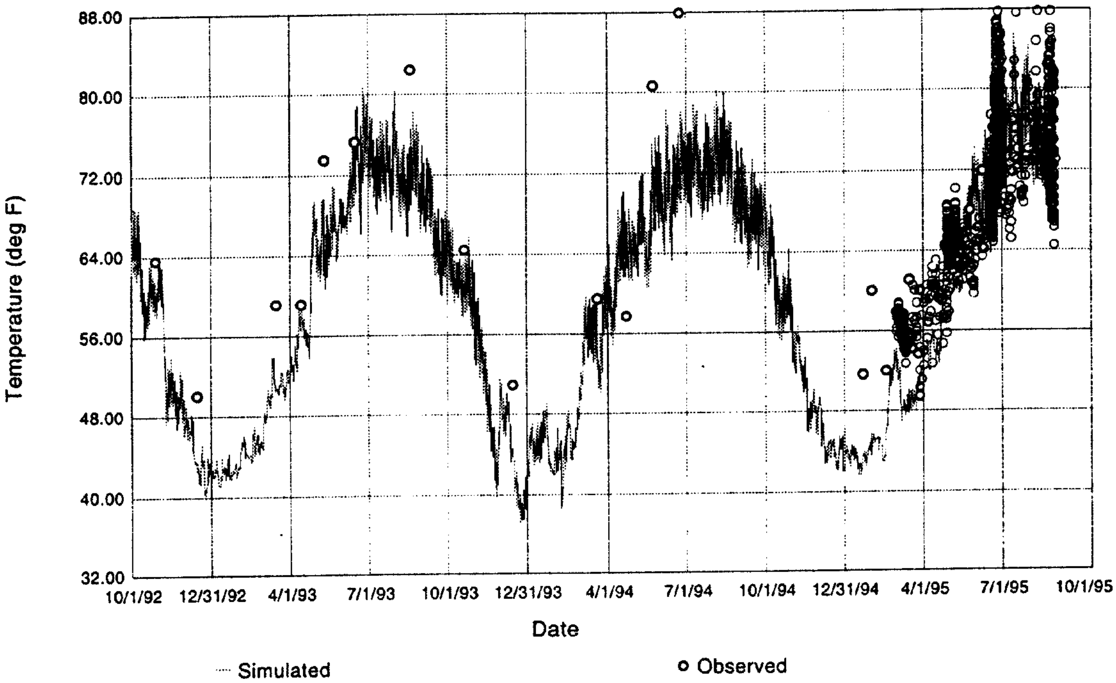


Figure 3.4 Time History of Temperature (Deg F) in the Laguna de Santa Rosa at Occidental Road

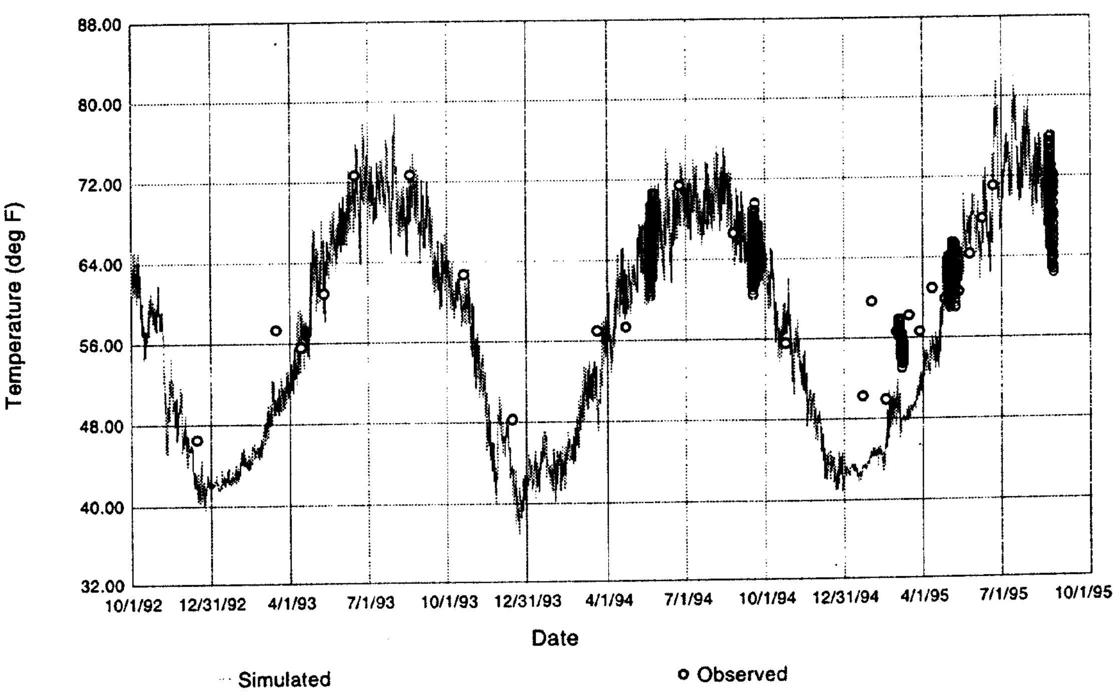


Figure 3.5 Time History of Temperature (Deg F) in the Laguna de Santa Rosa at Trenton-Healdsburg Road

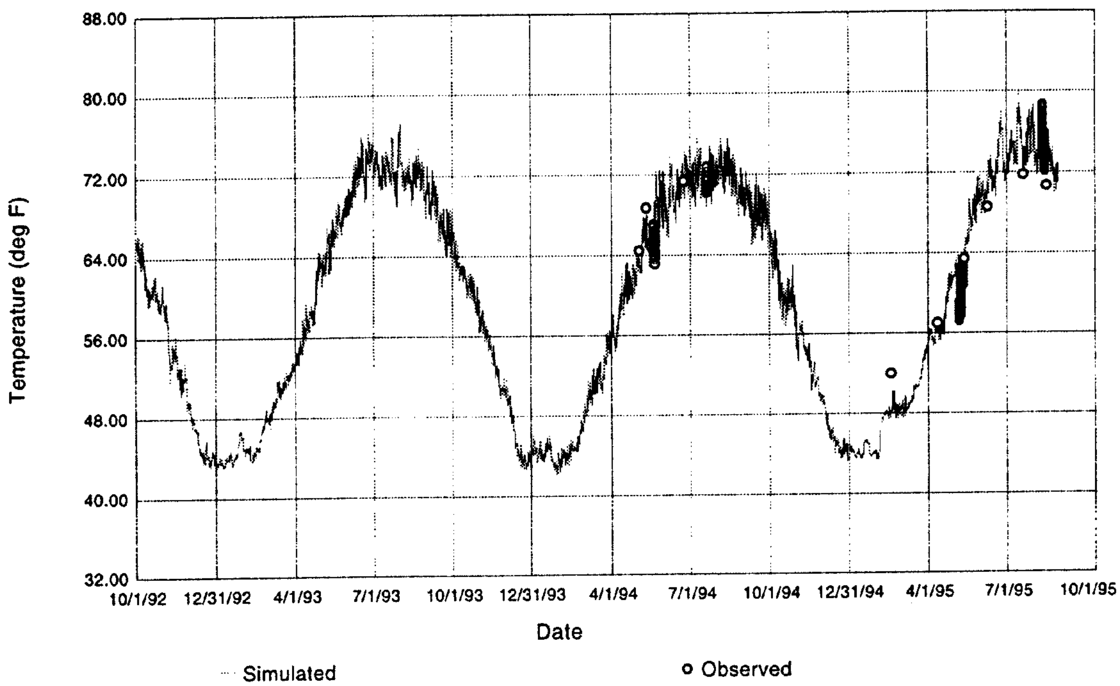


Figure 3.6 Time History of Temperature (Deg F) in the Russian River at Odd Fellows

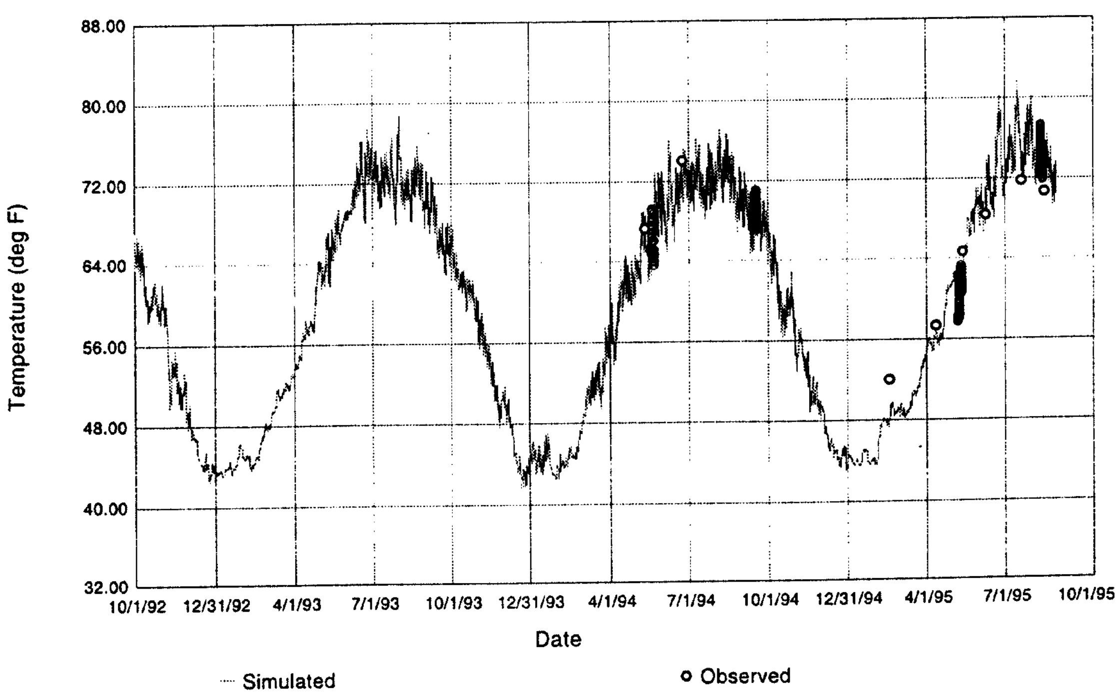


Figure 3.7 Time History of Temperature (Deg F) in the Russian River at Monte Rio

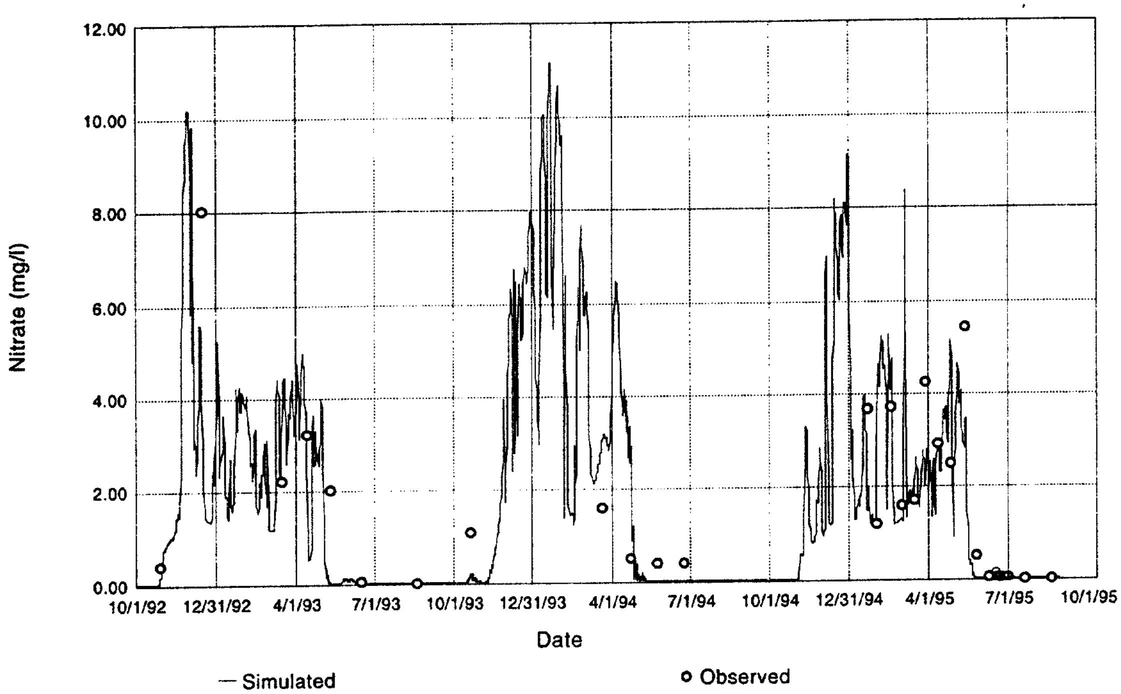


Figure 3.8 Time History of Nitrate (NO3) in the Laguna de Santa Rosa at Occidental Road

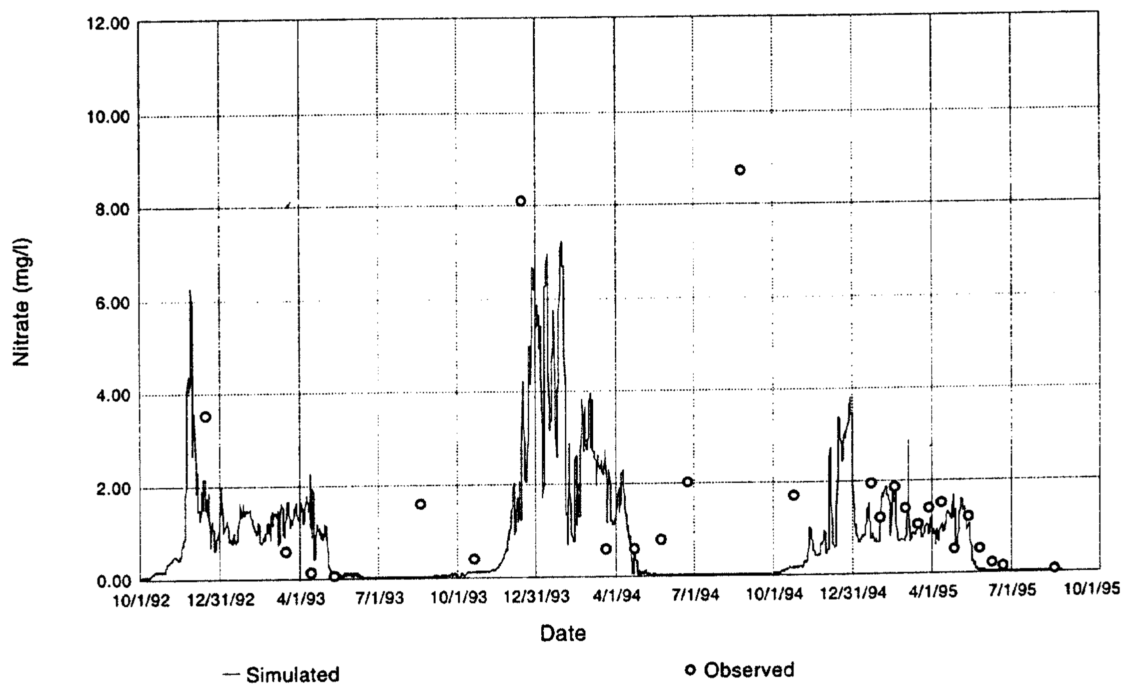


Figure 3.9 Time History of Nitrate (NO3) in the Laguna de Santa Rosa at Trenton-Healdsburg Road

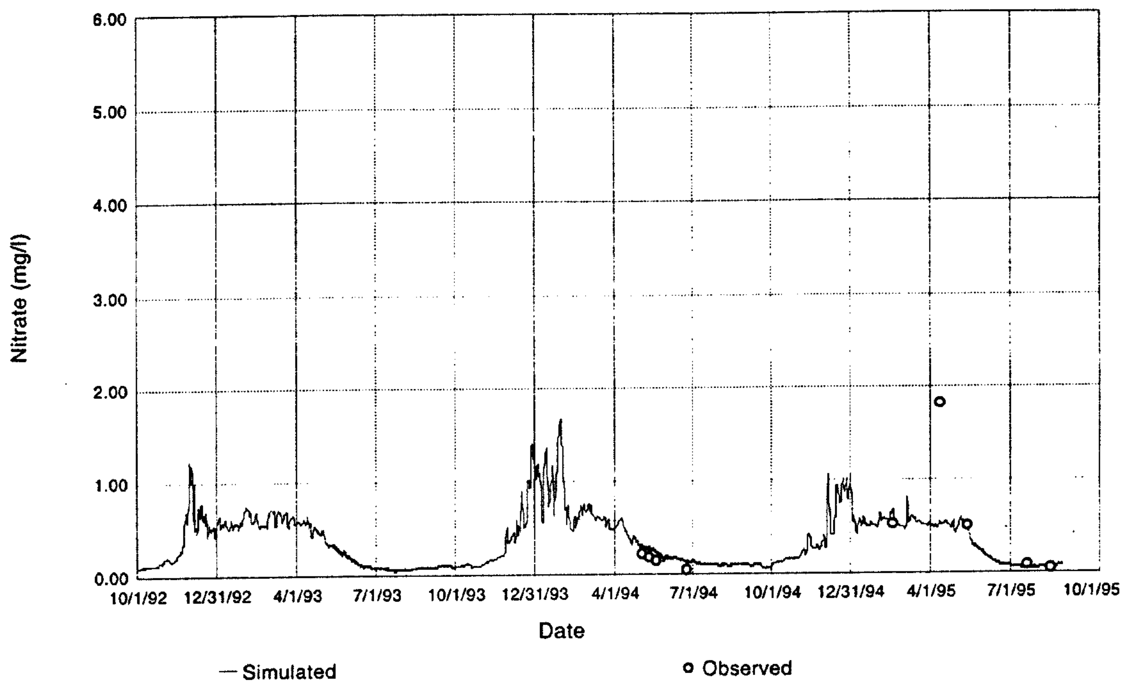


Figure 3.10 Time History of Nitrate (NO3) in the Russian River at Odd Fellows

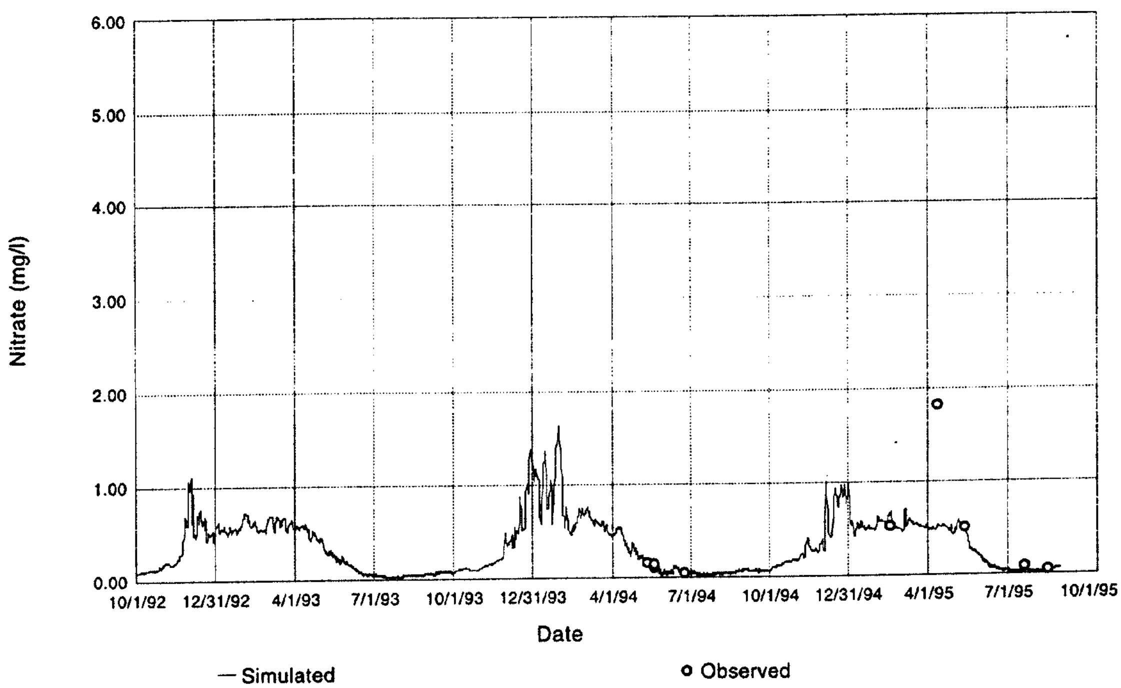


Figure 3.11 Time History of Nitrate (NO3) in the Russian River at Monte Rio

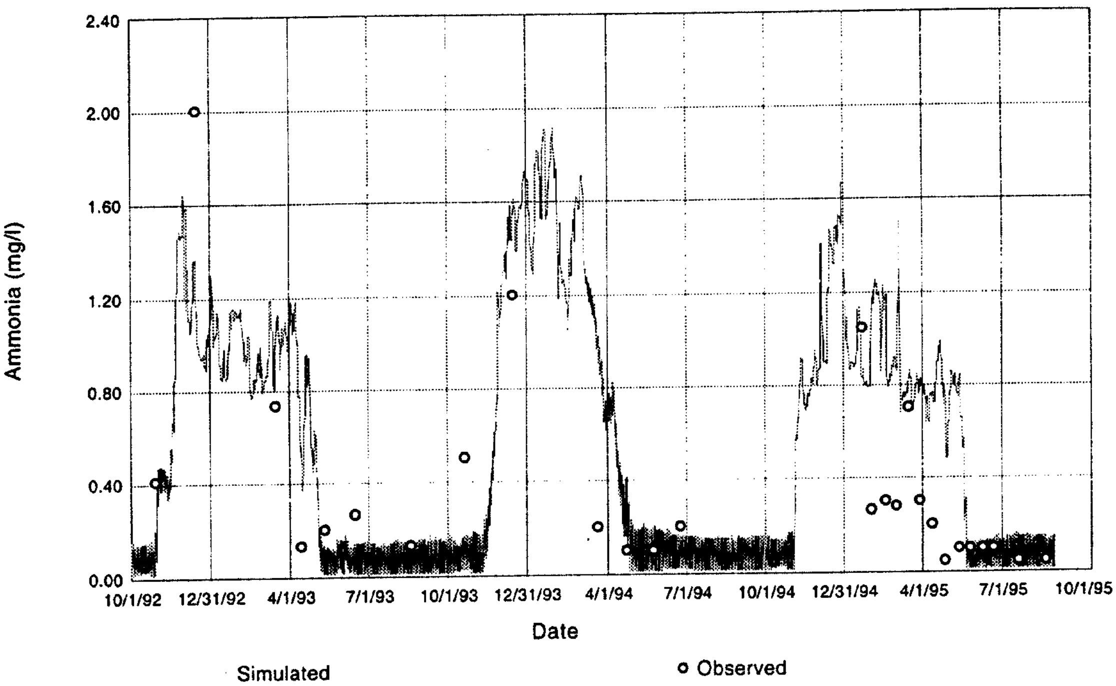


Figure 3.12 Time History of Ammonia (NH3) in the Laguna de Santa Rosa at Occidental Road

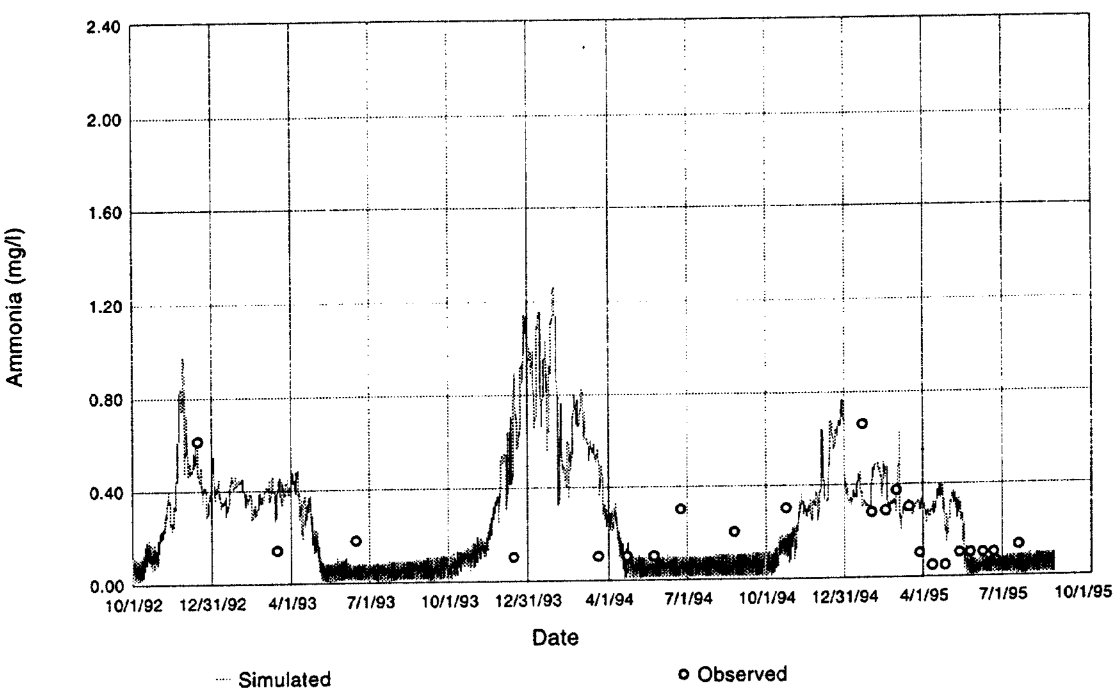


Figure 3.13 Time History of Ammonia (NH3) in the Laguna de Santa Rosa at Trenton-Healdsburg Road

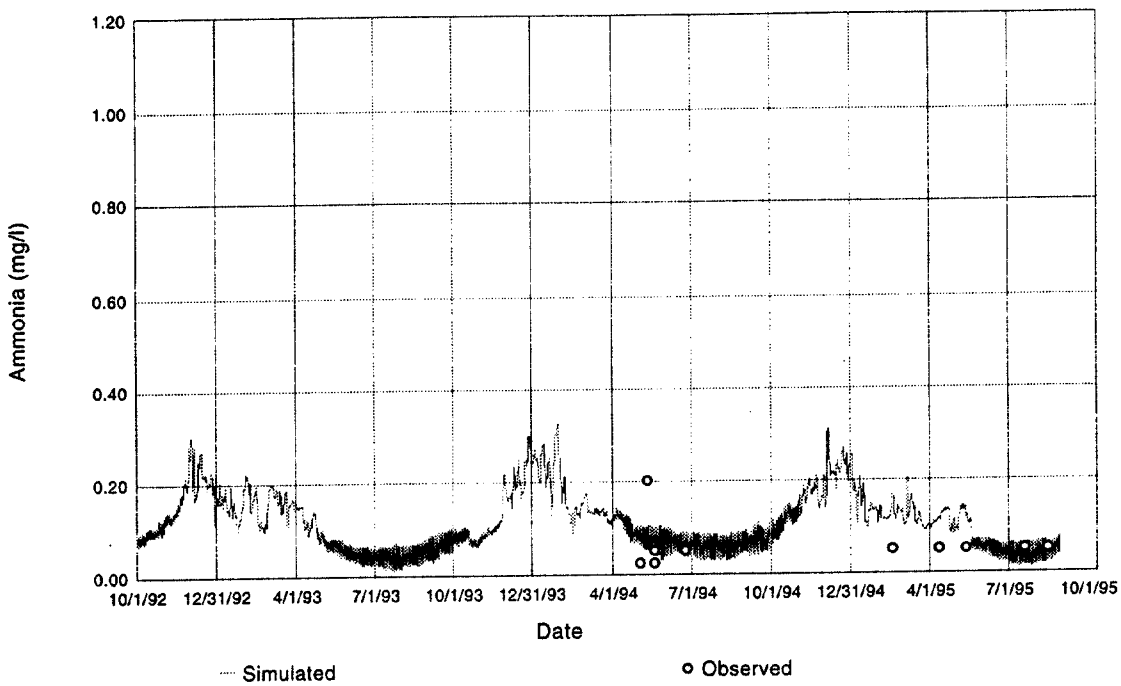


Figure 3.14 Time History of Ammonia (NH3) in the Russian River at Odd Fellows

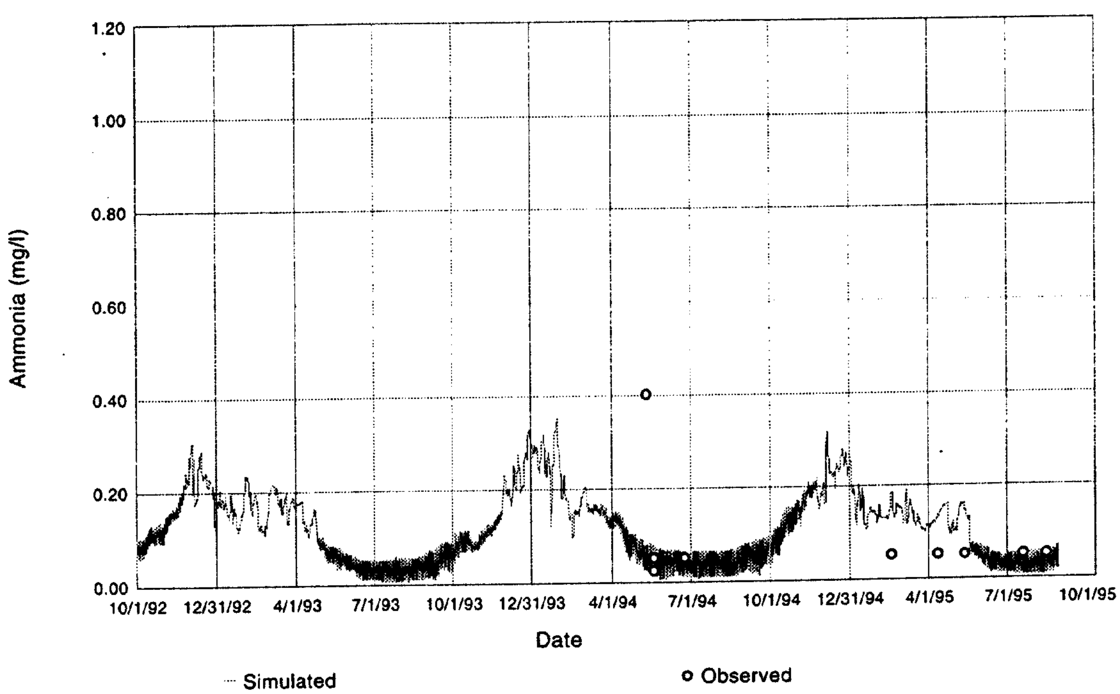


Figure 3.15 Time History of Ammonia (NH3) in the Russian River at Monte Rio

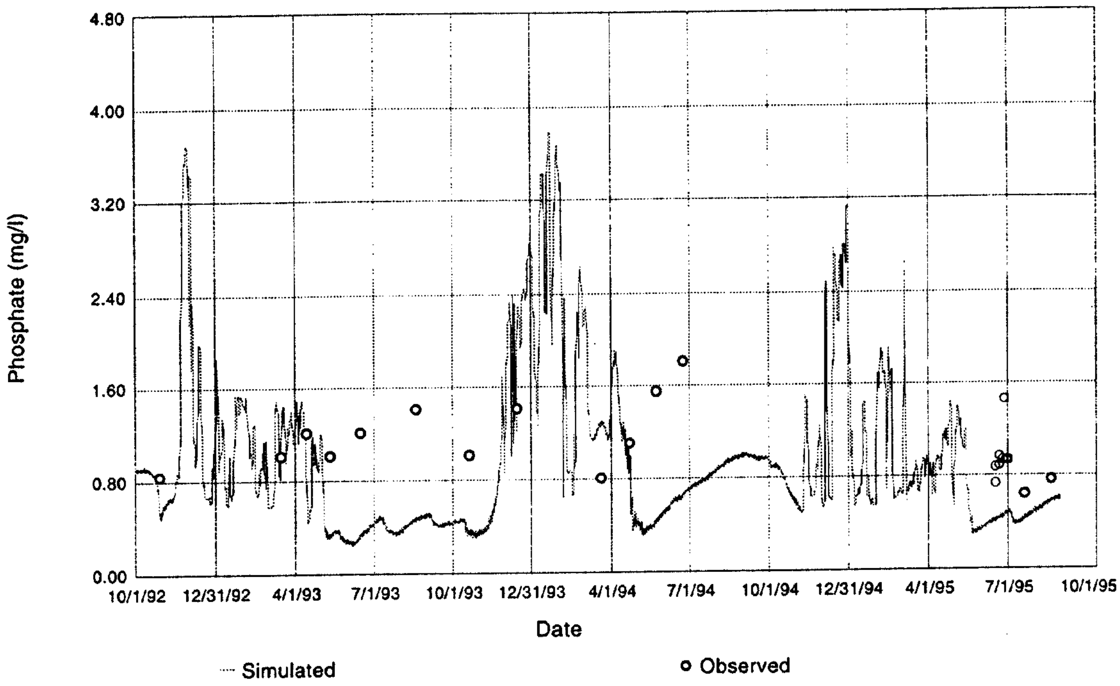


Figure 3.16 Time History of Dissolved Phosphate (PO4) in the Laguna de Santa Rosa at Occidental Road

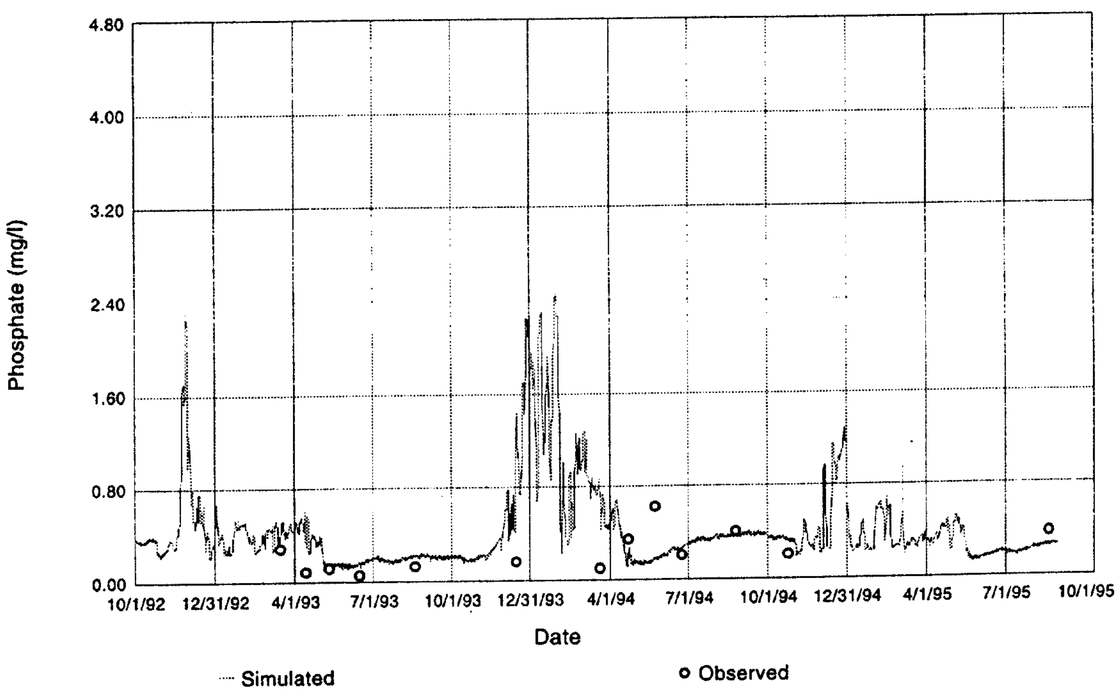


Figure 3.17 Time History of Dissolved Phosphate (PO4) in the Laguna de Santa Rosa at Trenton-Healdsburg Road

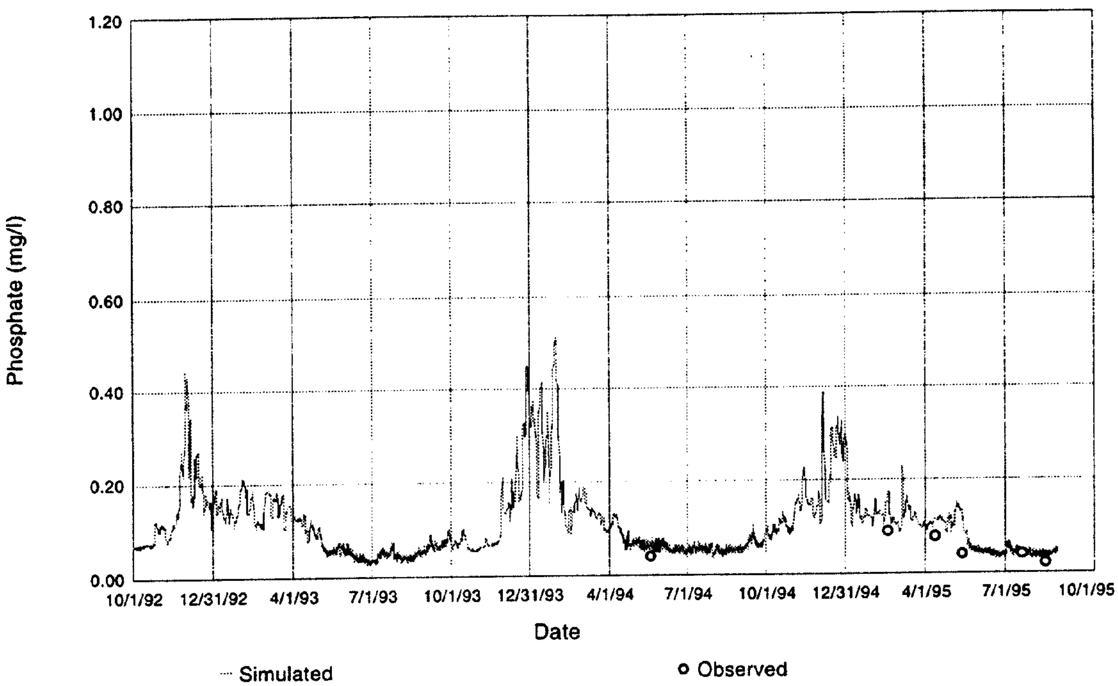


Figure 3.18 Time History of Dissolved Phosphate (PO4) in the Russian River at Odd Fellows

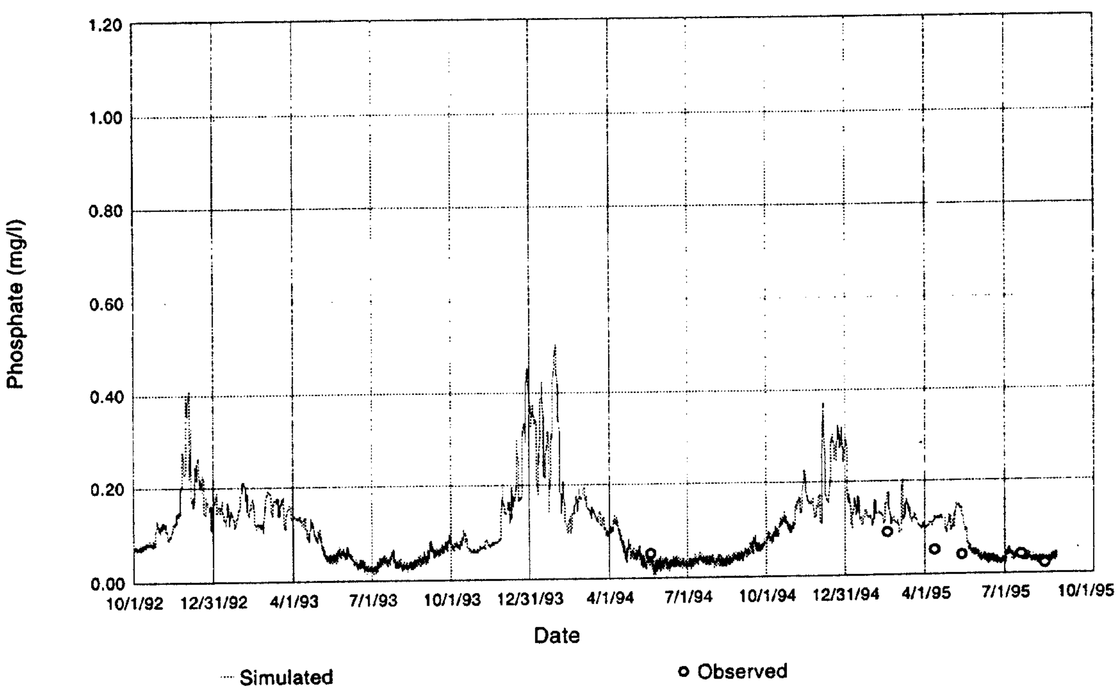


Figure 3.19 Time History of Dissolved Phosphate (PO4) in the Russian River at Monte Rio

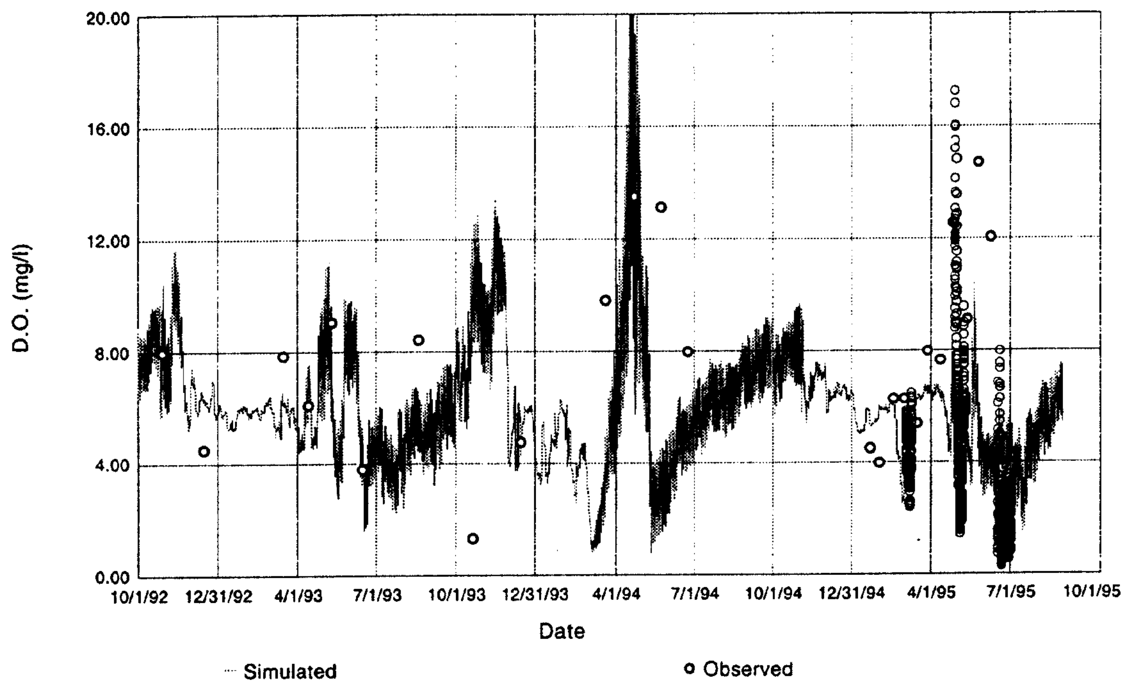


Figure 3.20 Time History of Dissolved Oxygen (DO) in the Laguna de Santa Rosa at Occidental Road

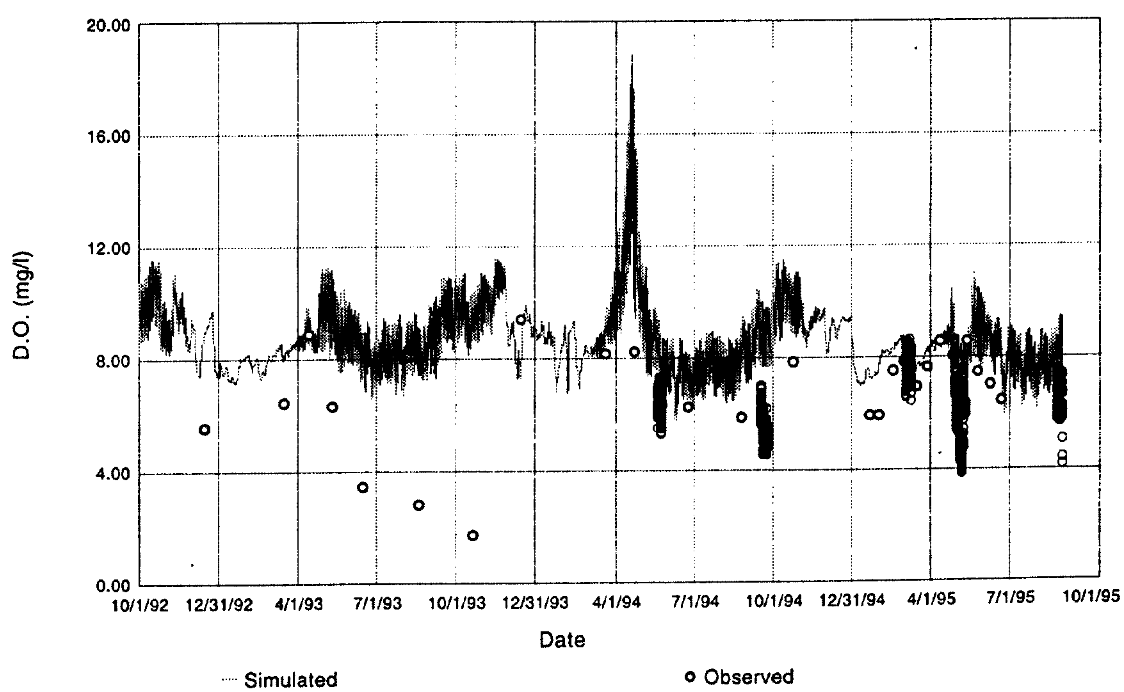


Figure 3.21 Time History of Dissolved Oxygen (DO) in the Laguna de Santa Rosa at Trenton-Healdsburg Road

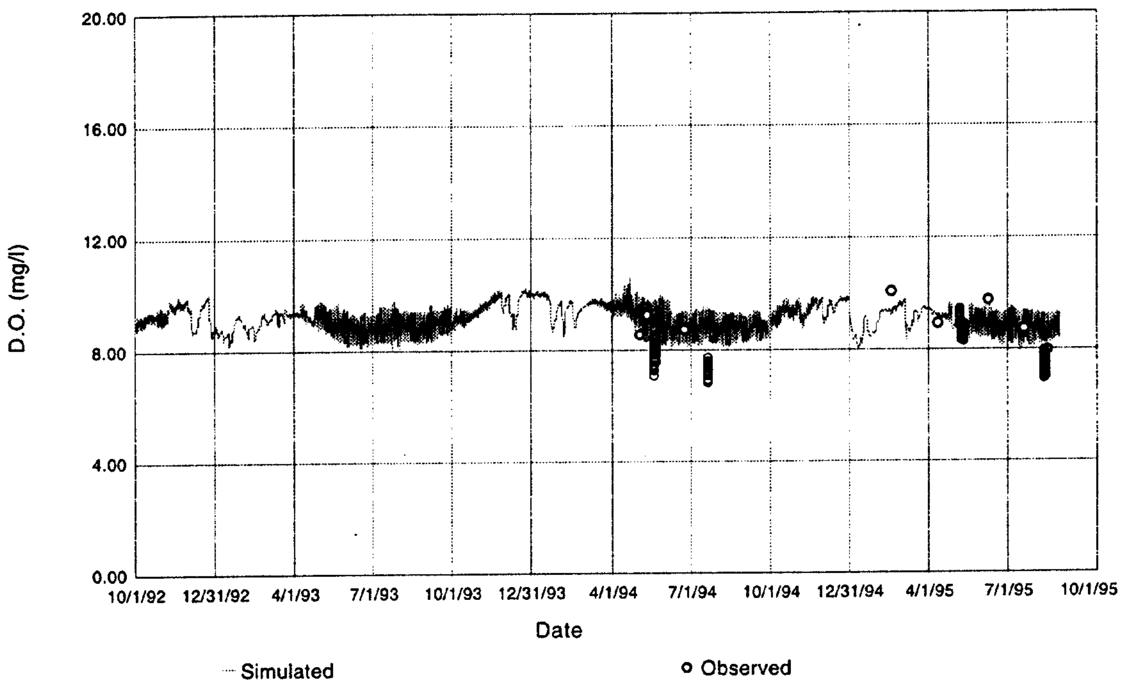


Figure 3.22 Time History of Dissolved Oxygen (DO) in the Russian River at Odd Fellows

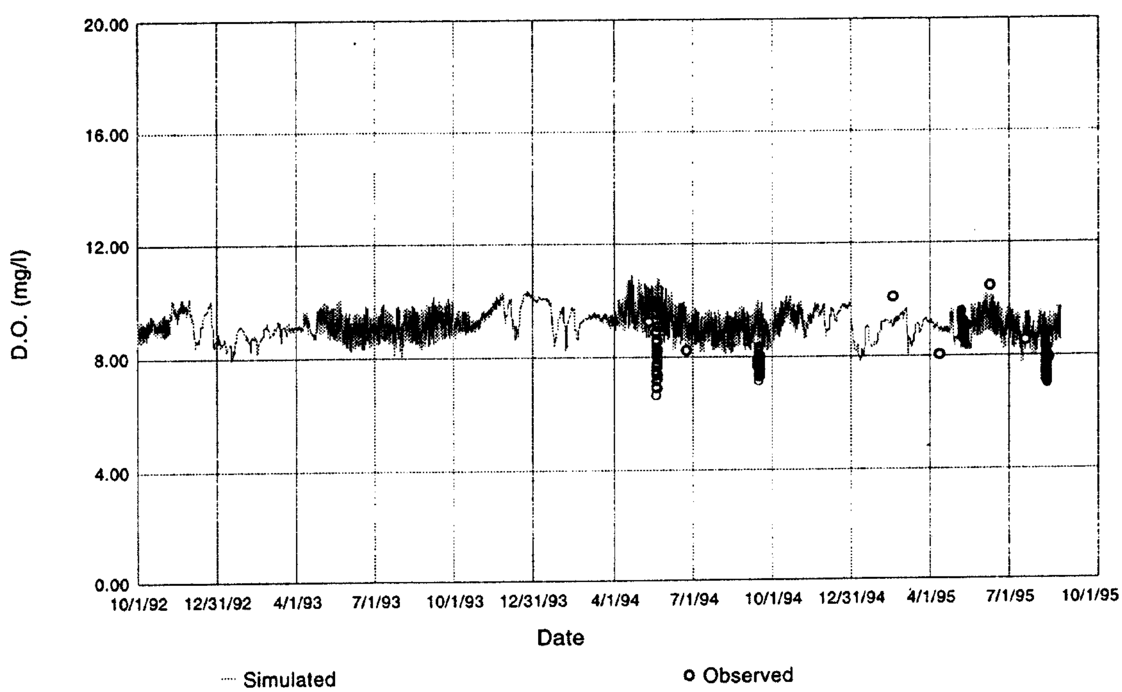


Figure 3.23 Time History of Dissolved Oxygen (DO) in the Russian River at Monte Rio

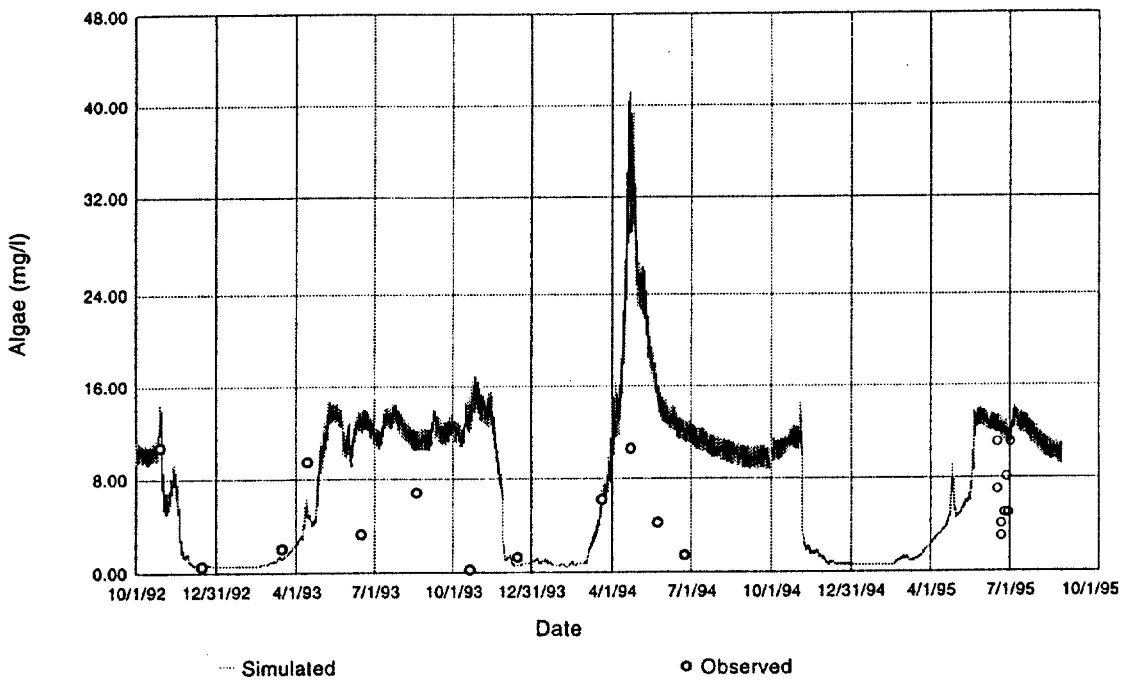


Figure 3.24 Time History of Algae in the Laguna de Santa Rosa at Occidental Road

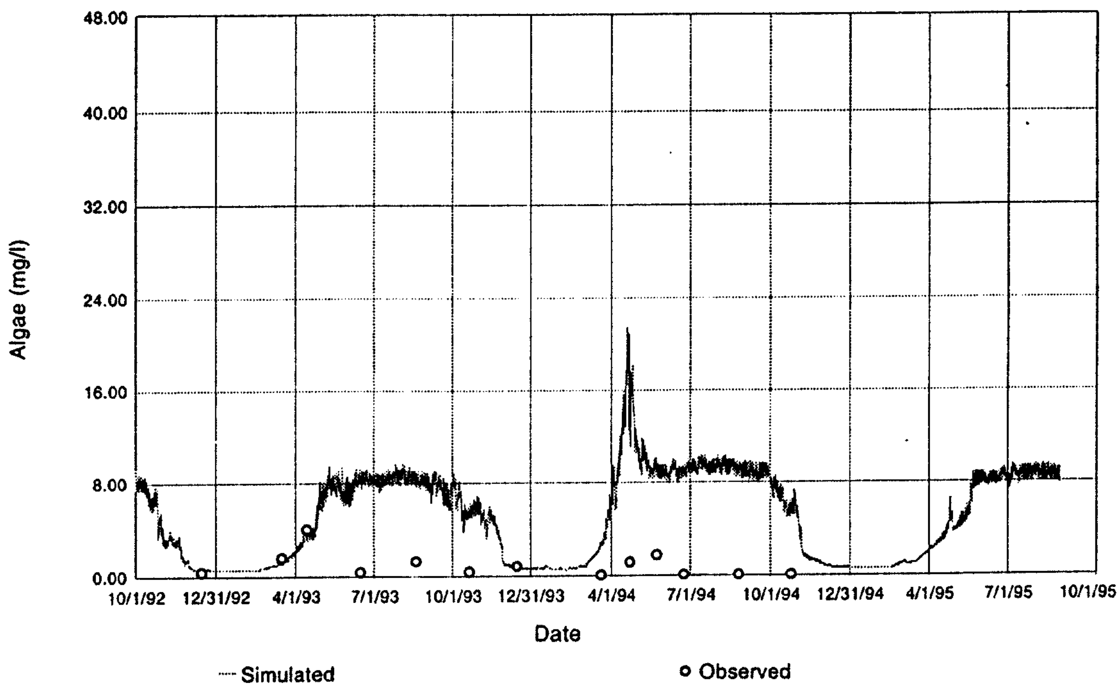


Figure 3.25 Time History of Algae in the Laguna de Santa Rosa at Trenton-Healdsburg Road

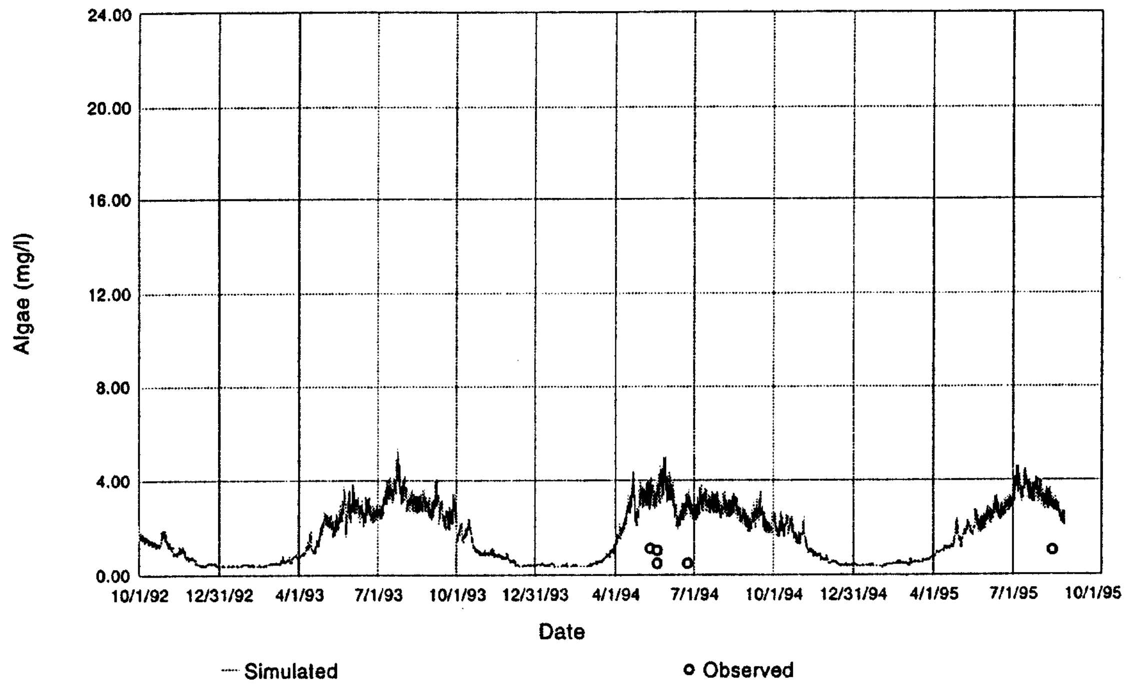


Figure 3.26 Time History of Algae in the Russian River at Odd Fellows

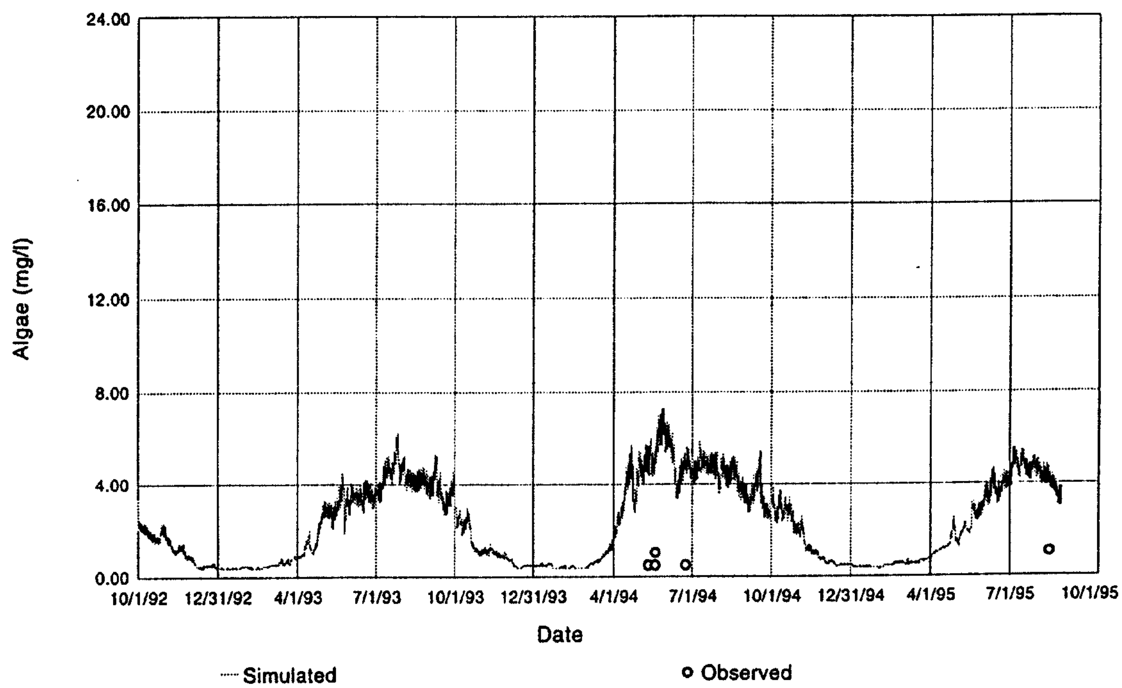


Figure 3.27 Time History of Algae in the Russian River at Monte Rio

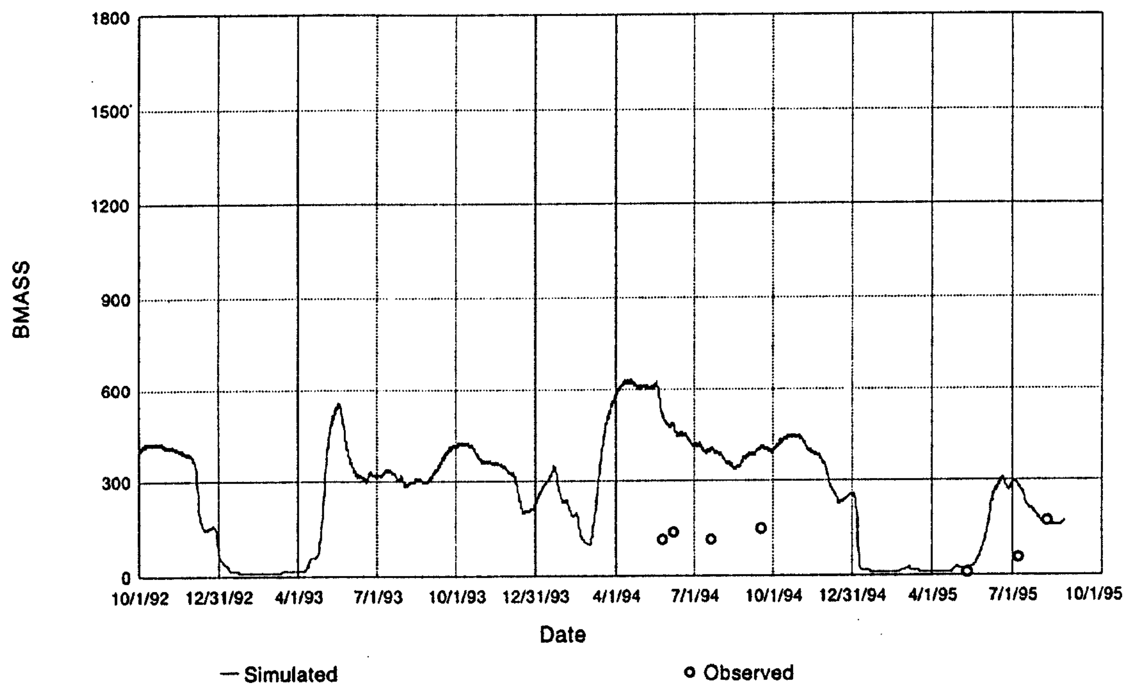


Figure 3.28 Time History of Benthic Algae in the Russian River at Odd Fellows

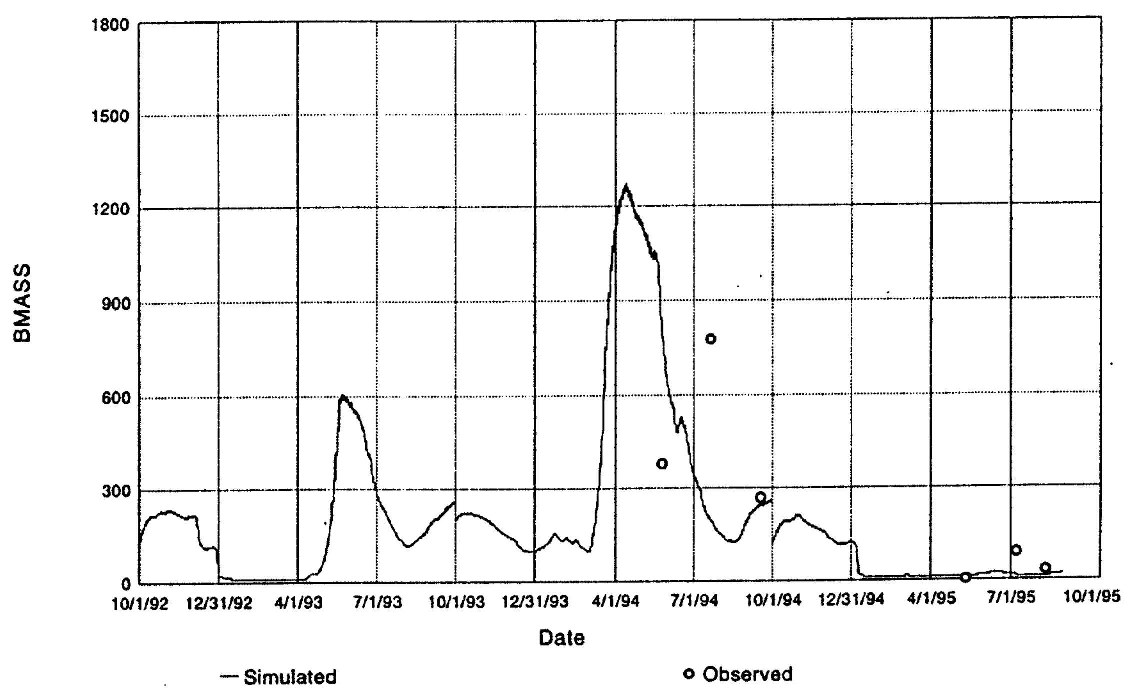
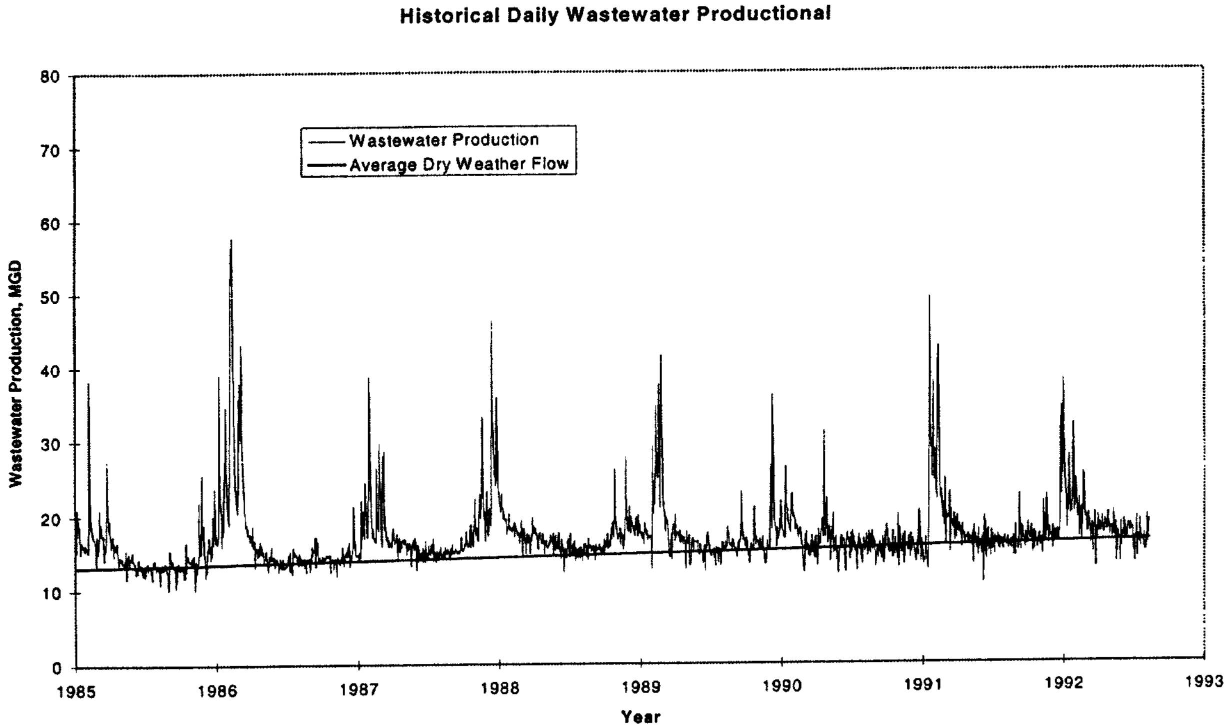


Figure 3.29 Time History of Benthic Algae in the Russian River at Monte Rio



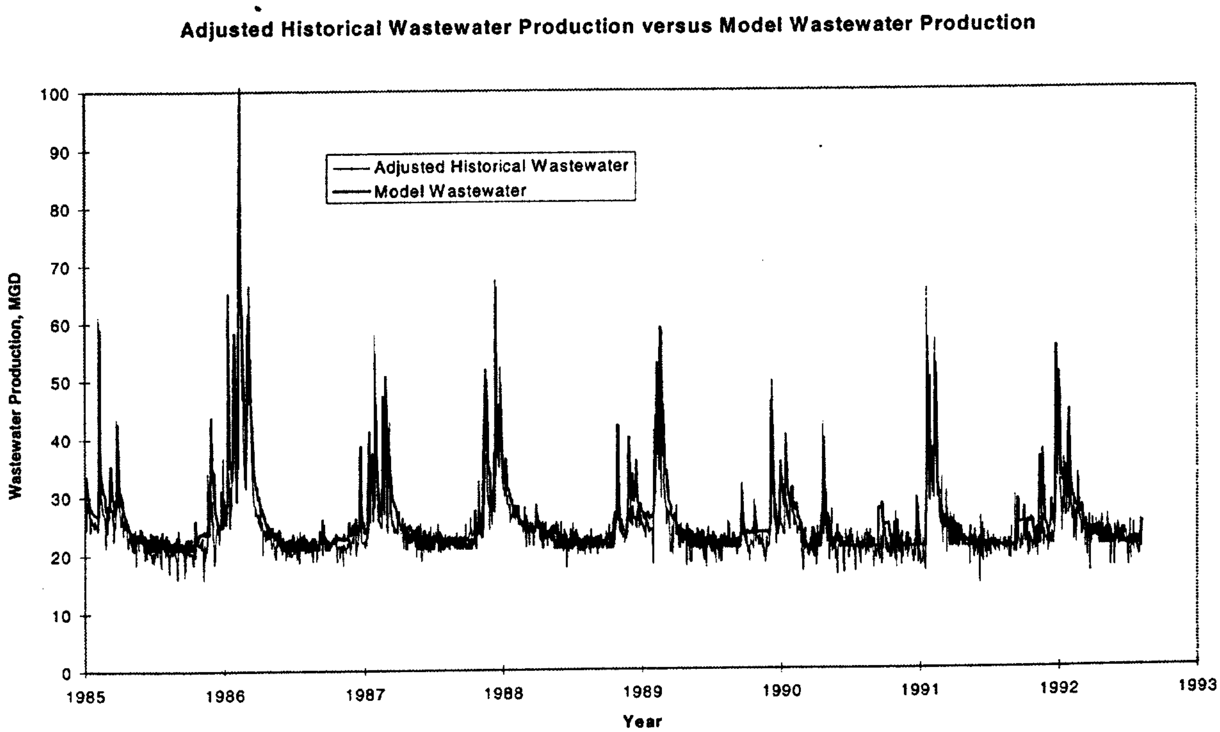


Figure 4.1 Historical Wastewater Production and Model Wastewater Production for the Period of January, 1985 through September, 1993