United States Environmental Protection Agency
EPA Region 10
OEA-095
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April 2004

Water Quality Assessment of American Falls Reservoir

April 2004

Office of Environmental Assessment
EPA Region 10
1200 Sixth Avenue
Seattle, Washington 98101

EPA has developed this report as part of a multi-agency effort to improve our understanding of nutrient pollution in American Falls Reservoir. For more information about this report, contact:

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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February 1, 2008

Reply To
Attn Of: OEA-095

TECHNICAL MEMORANDUM

Subject: Errors in Loading Information in "Water Quality Assessment of American Falls Reservoir" (EPA, 2004)

From: Ben Cope, Environmental Engineer
Office of Environmental Assessment

To: File

I recently re-visited the 2004 report on American Falls Reservoir and discovered an error the figures and the text related to the contribution of phosphorus loading from the Portneuf River to the American Falls Reservoir. The error originates in the flow estimates for the Portneuf River. The error is evident in the phosphorus loading estimates on graphs and in the text of the report.

The error was the use of flows from the station "Portneuf River at Pocatello" rather than "Portneuf River at Tyhee". Tyhee is lower on the river and therefore closer to the inflow to American Falls Reservoir. Due to groundwater inflow between Pocatello and Tyhee locations, the flows are approximately 215 cfs higher at Tyhee than at Pocatello. This is a significant increase relative to the base flow (and associated phosphorus loadings), particularly in the summer.

See attached to the two corrected plots of estimated inflow loadings to American Falls Reservoir (replace Figures 9 and 10) in the report.

The same flow error carries into the text on Page 17 of the report. The following is a correction of the loading numbers in the text:

> A comparison of the estimated daily phosphorus loadings from the Snake, Portneuf, and ungauged inflows for 2001 is shown below. Cumulatively, these loads result in an estimated annual loading of approximately ~~450,000~~ **900,000** lbs of total

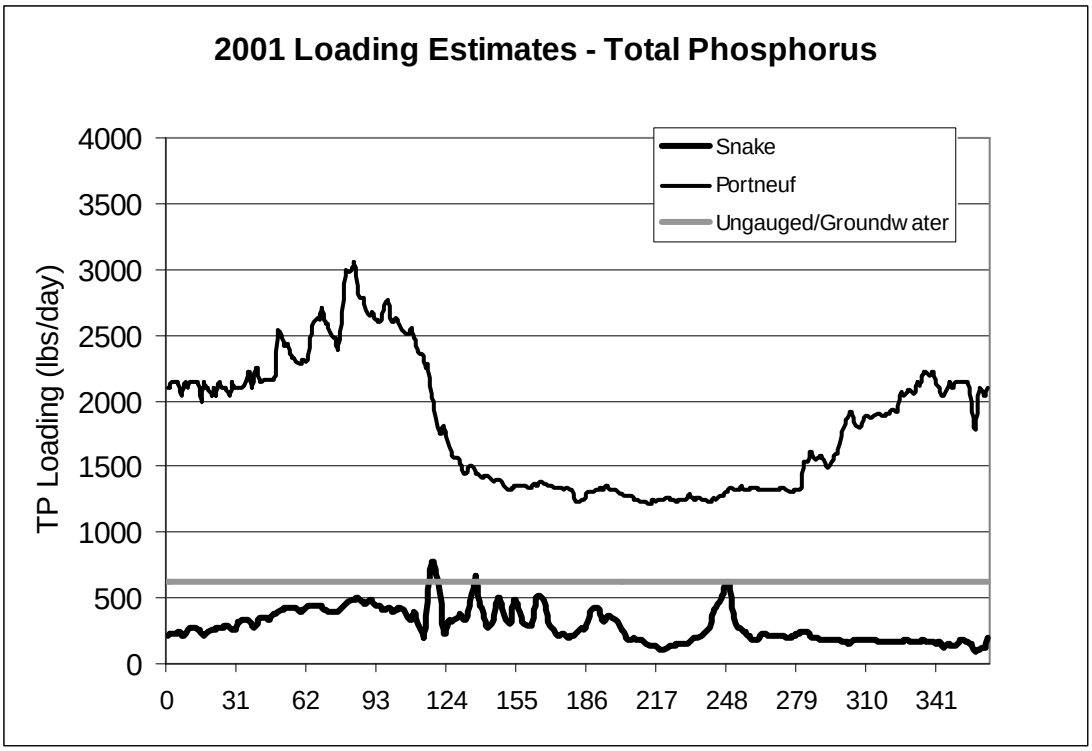
phosphorus, an average of ~~1,200~~ **2,500** lbs/day. The second figure is the estimated loadings for 1968, with an estimated annual loading of approximately ~~2,000,000~~ **3,500,000** lbs of total phosphorus. For reference, note that the same ungauged tributary/groundwater loads were assumed for both simulations and the y-scale is markedly different. As a result of significantly higher flows and phosphorus concentrations in 1968, the loads carried by the Snake and Portneuf Rivers were much higher that year than in 2001.

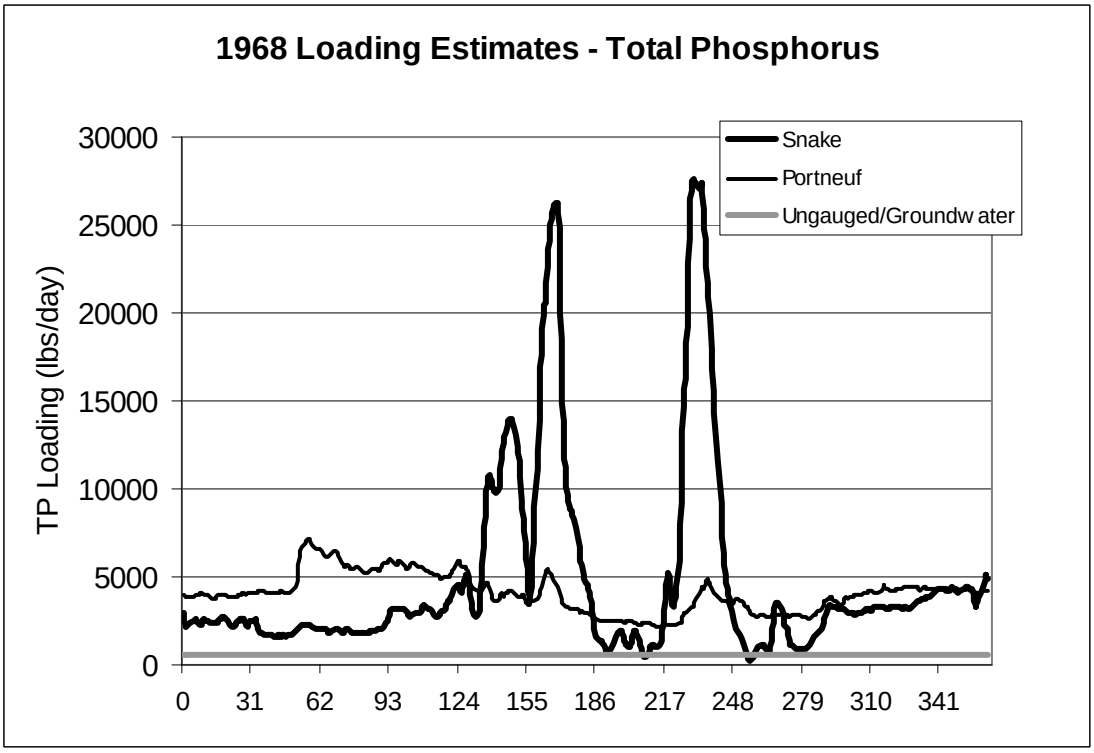
Finally, the corrected loadings indicate that the Portneuf River carries a higher proportion of the total load to the reservoir (estimated at approximately 70% of the total loading). The text in the conclusions should be revised accordingly:

- The Portneuf River and a number of ungauged tributaries carry relatively high loadings of orthophosphate and total phosphorus to the reservoir, ~~at times~~ exceeding the loading from the Snake River in a low water year (2001). **Based on 2001 data and load estimation, the Portneuf River contributes over two thirds of the total loading to the reservoir.**

Finally, the loading error also affects the water quality simulations. The corrected simulation for 1968 showed small changes in the phytoplankton concentrations in the surface layer because of the diminished influence of the Portneuf River in that year. However, the simulation for 2001 showed more notable differences in the predictions, compared to the original simulations, with an increase of approximately 11% in the peak chlorophyll concentration. While re-calibration of the model could be considered, the data and model limitations are unchanged, and a re-calibration is unlikely to significantly reduce the uncertainty of the model.

Aside from the edited conclusion above, the remaining conclusions in the report remain valid.


2001 Loading Estimates - Total Phosphorus
TP Loading (lbs/day)
4000
3500
3000
2500
2000
1500
1000
500
0
0
31
62
93
124
155
186
217
248
279
310
341
Snake
Portneuf
Ungauged/Groundw ater


1968 Loading Estimates - Total Phosphorus
TP Loading (lbs/day)
30000
25000
20000
15000
10000
5000
0
0
31
62
93
124
155
186
217
248
279
310
341
Snake
Portneuf
Ungauged/Groundw ater

Introduction

The Clean Water Act calls for states to identify waterbodies under their jurisdiction that do not meet water quality standards and develop restoration plans called Total Maximum Daily Loads (TMDLs) to reduce pollution of those waterbodies. States submit their TMDLs to EPA for review and approval. In addition to conducting this oversight function, EPA provides funding and technical assistance to states in support of their TMDL programs.

The state of Idaho is developing a TMDL for American Falls Reservoir on the Snake River near Pocatello, Idaho. During the planning phase, the state determined that an analytical tool was needed to assess the potential effects of a range of phosphorus loadings on phytoplankton growth and dissolved oxygen levels in the reservoir. In the fall of 2003, the state requested technical assistance from EPA to develop a water quality model for the reservoir. This assessment and model report is a product of information sharing and discussions between the Idaho Department of Environmental Qualitiy, EPA, and the Shoshone-Bannock tribe.

This report describes a mathematical model developed for the reservoir and the available water quality data used to estimate boundary conditions and evaluate the model. This assessment relies on available data that was collected prior to model development and testing. Based on this assessment, recommendations for future monitoring are identified at the end of the report.

I. Management Objectives

Scope of problem

American Falls Reservoir is listed as an impaired waterbody by the state of Idaho (1998 303(d) list). The listed parameters for the reservoir include dissolved oxygen, flow alteration, nutrients, and sediment. This report contains an analysis of nutrient and dissolved oxygen levels in the reservoir in support of a TMDL.

Elevated nutrients can cause excessive growth of phytoplankton, which can diminish the recreational value of the waterbody and impact fish habitat by depleting dissolved oxygen in deeper waters. Nitrogen or phosphorus can be the limiting nutrient controlling phytoplankton growth. Phosphorus is most commonly the limiting nutrient in fresh water systems. Recent studies by Idaho Power of the Brownlee Reservoir on the Snake River concluded that phosphorus was the limiting nutrient for the reservoir (Harrison, et al, 1999). Generally, the water quality data for American Falls Reservoir are consistent with a phosphorus-limited system. In addition, the blue-green algae that are dominant in the summer months are capable of fixing nitrogen. For these reasons, the model and assessment described in this report are focused on phosphorus as the nutrient of concern.

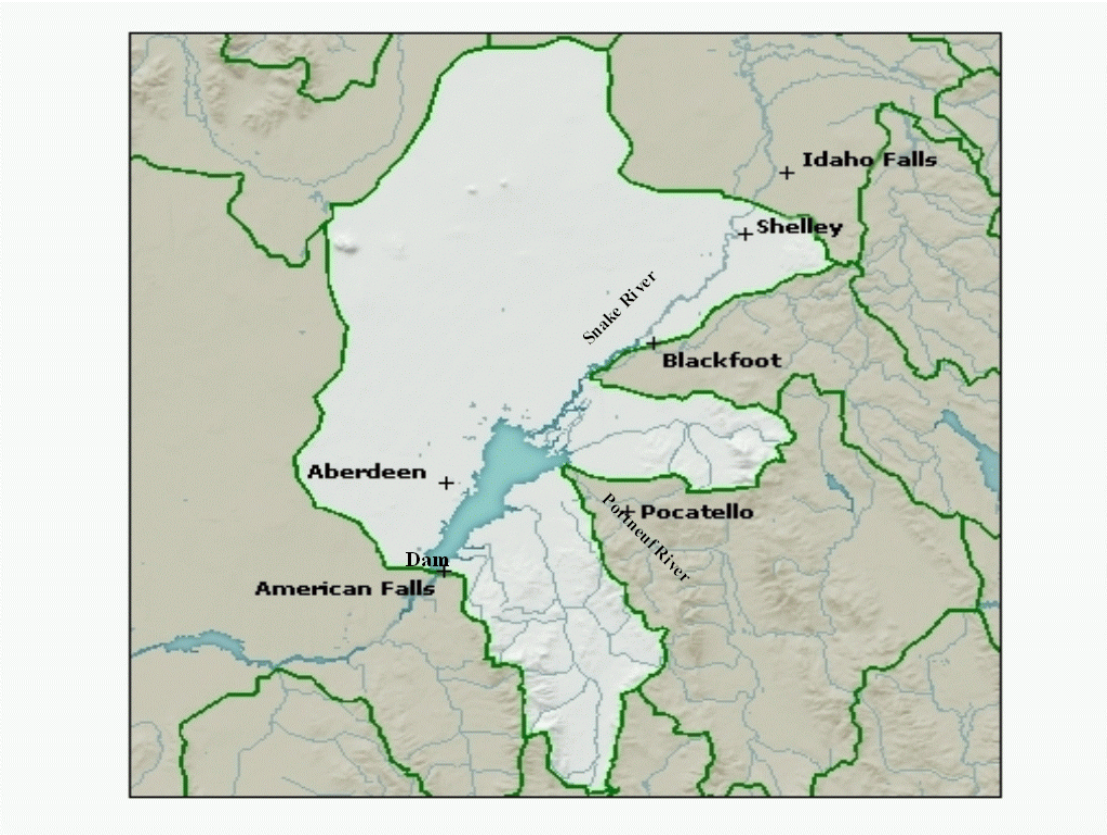


Figure 1: Study Area

Technical analysis objectives

The objective of this analysis is to develop a mathematical model of the chemical, physical, and biological characteristics of the reservoir for use in development of a Total Maximum Daily Load (TMDL). Specifically, the analysis focuses on those characteristics that pertain to phosphorus uptake by phytoplankton and the effects of the phytoplankton activity on dissolved oxygen levels in the water column. The model includes a water balance, boundary inputs (energy, nutrients), reservoir heat budget, phosphorus transformations, and factors that affect phytoplankton growth, mortality, and settling.

II. Conceptual Model

A model framework similar to that used for the Winchester Lake nutrients TMDL (March 1999) was adapted to American Falls reservoir. This framework is developed using the STELLA software environment, which is specifically designed for mathematical modeling applications. The model is a one-dimensional (two cells in the vertical) dynamic model framework that includes modules for heat budgets, phosphorus cycling, phytoplankton kinetics, and dissolved oxygen. Simulated variables include phosphorus (total, organic, inorganic, particulate), dissolved oxygen (impacts from background detritus and primary productivity/respiration), water temperature, and organic matter (phytoplankton, detritus).

The diagrams below depict the model system and processes included in the model for phosphorus, phytoplankton, and dissolved oxygen.

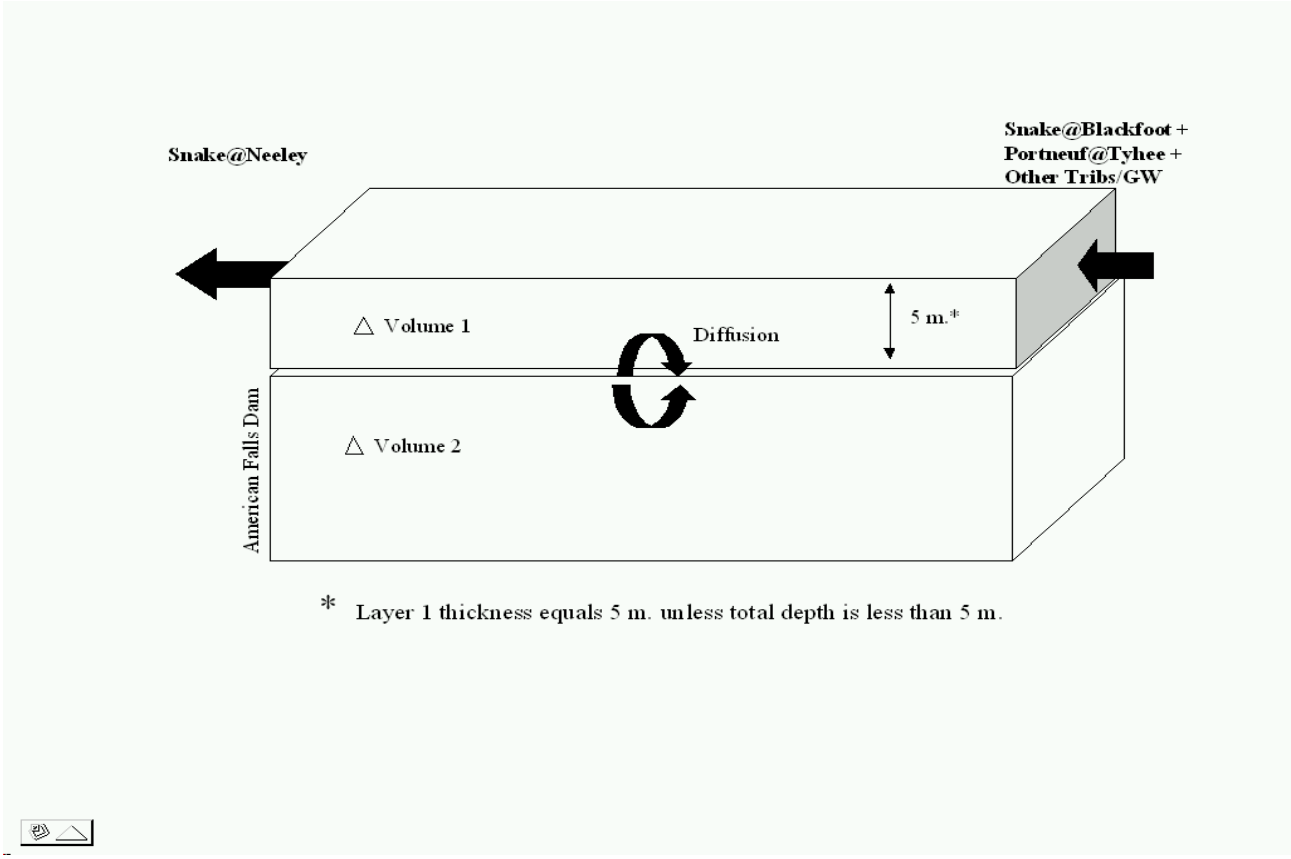


Figure 2 : Conceptual Model

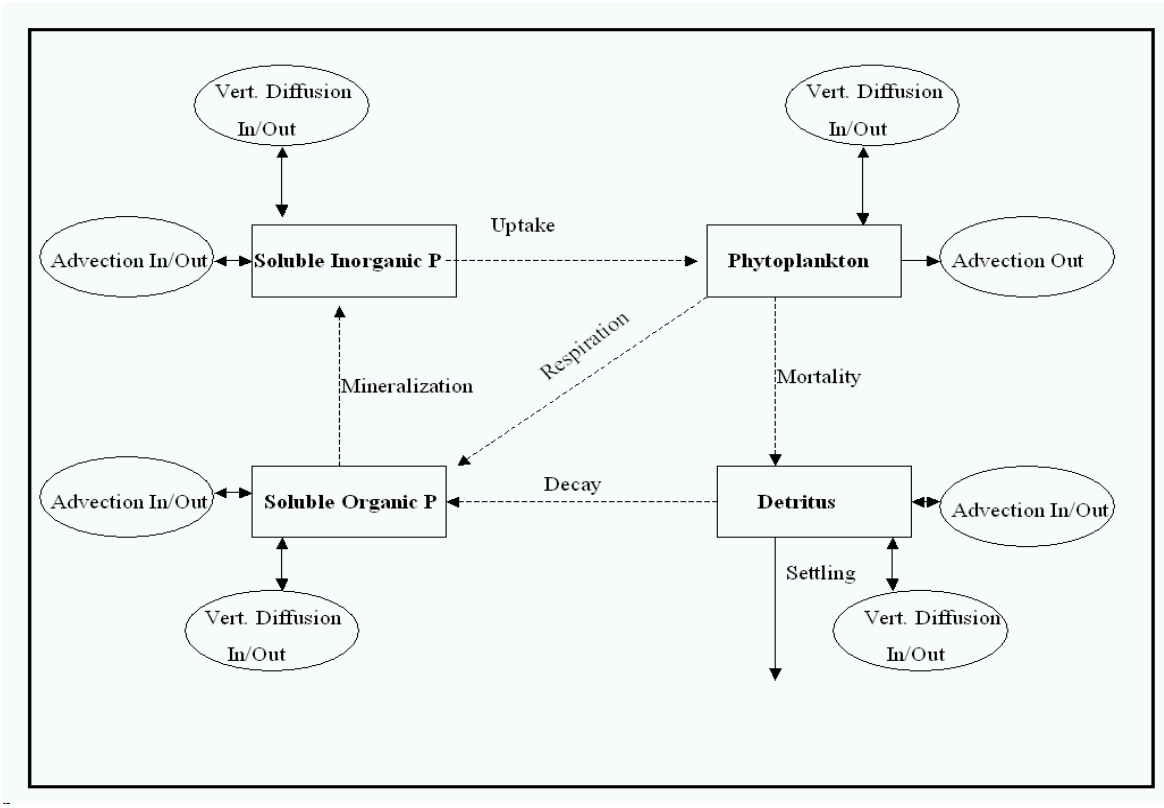


Figure 3: Phosphorus and Phytoplankton Processes in the Model

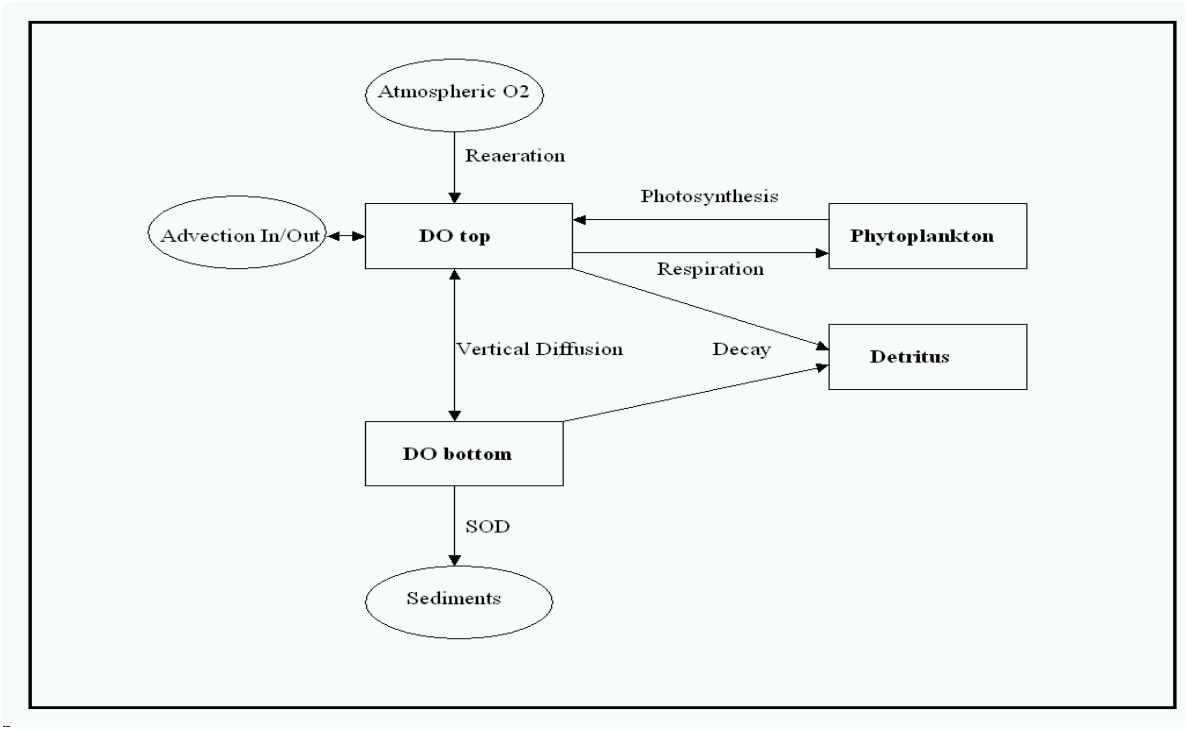


Figure 4: Dissolved Oxygen Processes in the Model

The following changes have been made to the Winchester Lake model to adapt it to American Falls reservoir:

Variable Elevation and Volume - the water surface elevation and total volume varies based on management of the reservoir.

Variable Layer Thickness - the thickness of the top layer (epilimnion) is assumed to be 5 meters unless the average depth of the reservoir falls below 5 meters, in which case the top layer thickness is essentially equal to the reservoir depth (and the bottom layer thickness less than one meter).

Uniform Inflows - a feature that placed the inflow into either the top or bottom layer based on its density was removed based on the shallow depths of this reservoir. The inflows and outflows occur in the top layer.

Zero Sediment Phosphorus Flux- the Winchester Lake model included a constant flux from the sediments. Based on observed aerobic conditions in the bottom of American Falls reservoir, which is generally shallow and weakly stratified, it was assumed that there is zero influx of inorganic phosphorus from sediments. Further analysis (see below) indicates that there are episodes of diminished oxygen in the hypolimnion and orthophosphate flux from sediments.

Sediment Oxygen Demand - this process was added to the American Falls model to achieve better agreement between observed and simulated dissolved oxygen.

System boundaries

The model domain is the American Falls Reservoir, bounded by the dam and the entry point of the Snake River and other tributary inputs to the reservoir. Because it is a storage system, with significant changes in surface water elevation, the reservoir boundaries change over the year. These changes are incorporated into the model by dynamically adjusting the reservoir volume based on the water budget and volume/elevation relationships for the reservoir.

Important time and length scales

Residence Time

The reservoir has a full pool volume of approximately 1.6 million acre-ft at an elevation of 4355 feet, but this volume is highly variable due to large agricultural withdrawals during periods of low inflow in the summer, subsequent re-filling in the fall and winter, and flood control management in the spring. At full pool and average June flow in the Snake River (11 kcfs), the residence time is approximately 76 days. During a typical October condition, with a pool elevation of 4335 feet, the residence time assuming average October Snake River flows is approximately 140 days.

Vertical, Longitudinal, and Lateral Mixing

The model incorporates both advective and vertical mixing components of constituent transport. The reservoir can be generally characterized as weakly stratified. Using the physical dimensions of the system and velocity estimates, time scales for vertical, horizontal, and lateral mixing can be estimated and compared. The characteristic time scale for vertical diffusion is estimated using the value of the coefficient of eddy diffusivity used in the model (5.0×10^{-5} m^2/day) and the length over which the diffusion is assumed to occur (assumed to be 6 m from top layer midpoint to bottom layer midpoint). This results in time scale of approximately 8 days. Based on typical flows in the Snake River, the time scale for longitudinal advection at a similar scale (6 m mixing length) is on the order of 0.02 days. Based on a typical Portneuf River flow, the time scale for lateral mixing at this scale is on the order of 1 day. These comparisons are indicative of a system where the dominant mixing process is longitudinal advection.

Model Resolution

The reservoir is approximately 21 miles long with a maximum width of approximately 9 miles. Because the reservoir is represented by a single cell in the model, lateral and longitudinal variability seen in the water quality data are not resolved in the model. Based on the importance of advective transport and the significant length and width of the reservoir, one would expect longitudinal and lateral variation in the system. Longitudinal variation is evident in the water quality data. For example, the chlorophyll-a data indicate that peak chlorophyll-a growth does not occur simultaneously at the four monitoring sites. In the completely mixed model representation, a single growth pattern is simulated, representative of an idealized average condition for the reservoir as a whole.

Important Processes

Water quality and the resulting beneficial uses of American Falls Reservoir are impacted by nuisance phytoplankton growth. There are numerous types of phytoplankton, and each has specific ideal conditions for propagation. This model includes a single phytoplankton community type and the main processes limiting growth, including light limitation, temperature limitation, and nutrient limitation. Blue-green algae are the focus for this analysis based on the high concentrations of the species *Aphanizomenon* observed in the reservoir in the summer.

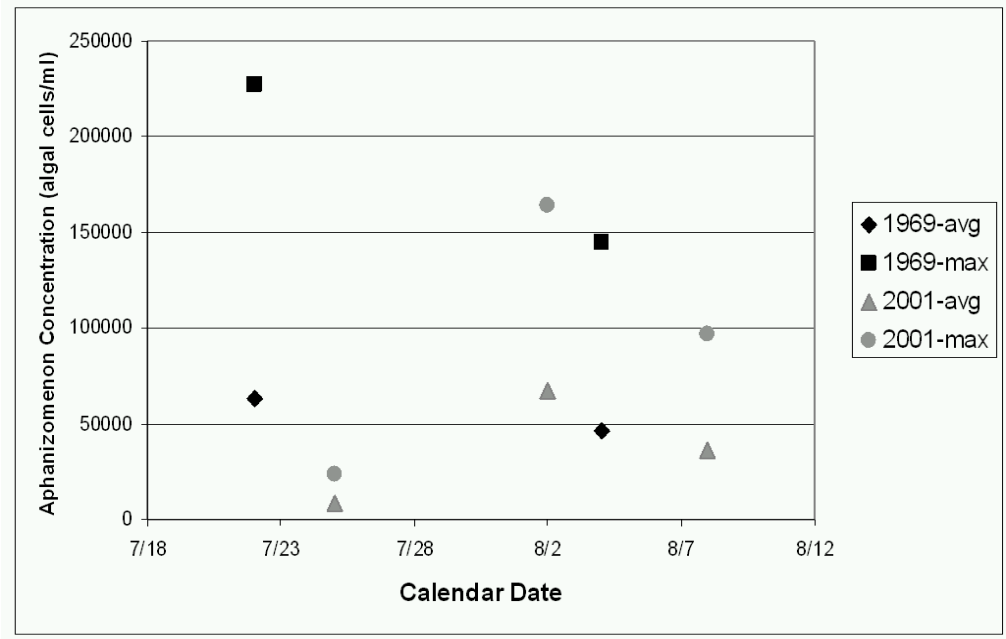


Figure 5: Algal cell concentrations of Aphanizomenon in American Falls in 1969 (seven sites) and 2001 (four sites).

In the model formulation (see Figures 3 and 4), the phytoplankton biomass growing in the upper water column is reduced by mortality, respiration, sinking, and advection through the dam outlet. The hypolimnion receives phytoplankton and detritus from the epilimnion due to the processes of settling and diffusion, and further settling removes the biomass from the hypolimnion. Based on studies of the physiology of *Aphanizomenon* and its ability to adjust its buoyancy and location within the water column (Welch, 1992), a low settling rate would be expected.

Dissolved oxygen in the water column results from the processes of advection, vertical diffusion, reaeration (top layer only), photosynthesis (top layer only), detrital decomposition, and respiration. The detritus and material that has settled to the bottom from the water column exert oxygen demand on the waters of the lower layer.

Phosphorus in the form of orthophosphate is advected into the system from tributaries and groundwater. Like other substances, it is transferred between the top and bottom layer through vertical mixing estimated as a diffusion process. Orthophosphate is converted to phytoplankton biomass (organic phosphorus) and subsequently transformed back into orthophosphate by mineralization. Since the bottom waters are not anaerobic (based on 2001-2003 conditions), it is assumed that there is zero loading of orthophosphate from the sediments. However, a review of the data does indicate that internal loading of phosphorus from the sediments may be occurring during calm summer periods. This potential phosphorus source is described in the “Discussion” section.

Phosphorus source characteristics

The model does not currently include specific pollutant sources that deliver phosphorus to the American Falls Reservoir. Rather, phosphorus loads are introduced to the reservoir at the mouths of the tributaries and through groundwater flows. Potential sources of phosphorus to the reservoir include municipal treatment works such as the City of Pocatello and cities upstream of the reservoir that discharge to the Snake River, industrial facilities such as FMC, agricultural activities in the watershed, and natural background contributions.

Available data sources (quality and quantity)

The model relies on monitoring information for both estimation of boundary conditions and comparison of simulations and observations within the reservoir. Past studies, particularly a study by the Bureau of Reclamation (Bushnell, 1968), USGS (Kjelstrom, 1995), and Battelle (Baca, et al, 1974), provide insights into historic conditions in the reservoir. Monitoring of reservoir conditions by Idaho DEQ began in 2001 and continues to the present (Van Every, 2003). The locations of the DEQ sampling are depicted in Figure 6. This information, combined with boundary condition estimates using data from USGS (flow, tributary quality) and the National Weather Service (heat budget parameters), was used in the modeling analysis. Table 1 shows the types of monitoring information used in this analysis.

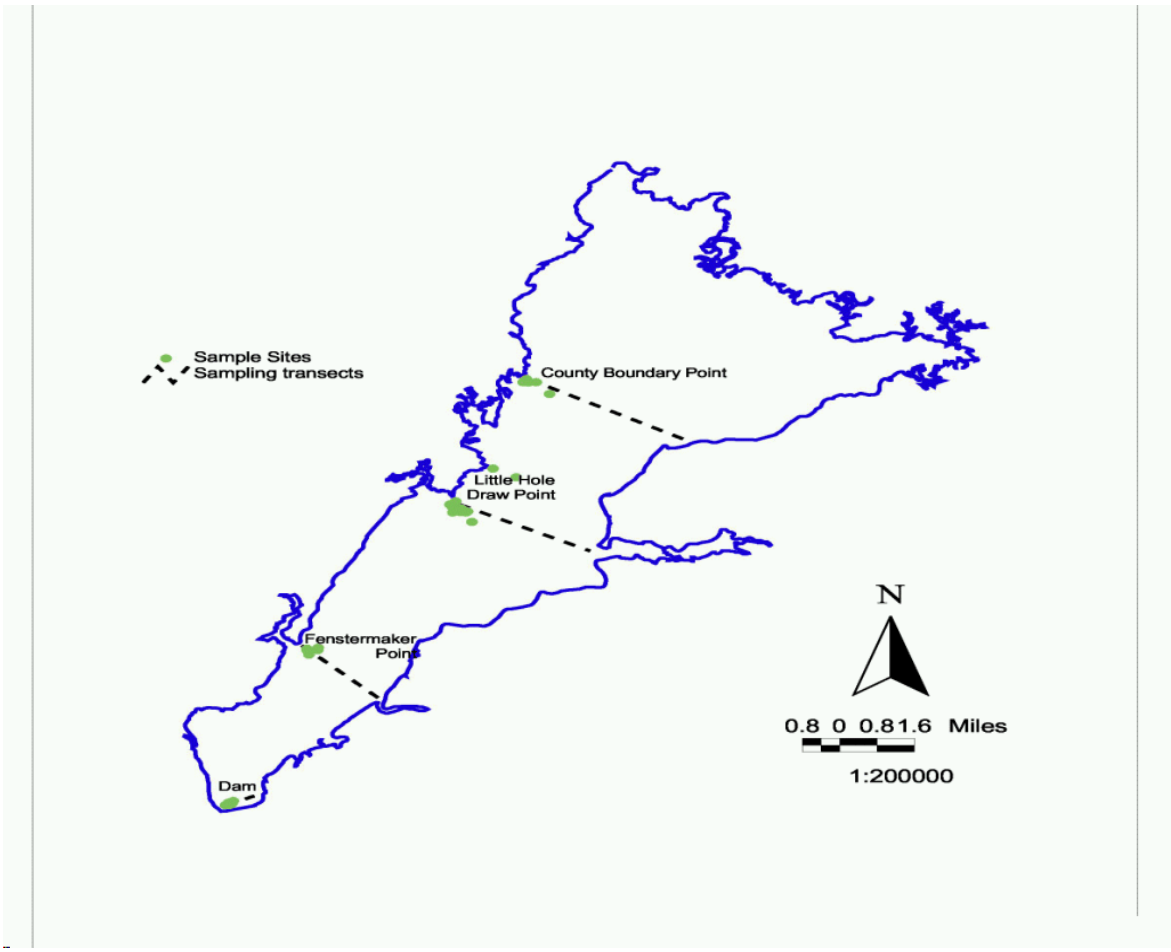


Figure 6 : DEQ 2001-2003 Sampling Sites in American Falls Reservior

Table 1: Summary of Available Data

Parameters	Frequency	Location	Period of Record	Agency
total phosphorus orthophosphate chlorophyll-a dissolved oxygen temperature nitrogen parameters	approx. 2/month between May and early August	vertical profiles at 4 locations in the reservoir	2001-2003	Idaho DEQ
total phosphorus orthophosphate dissolved oxygen temperature nitrogen parameters	8 samples between May and October	vertical sampling at 3-4 locations in the reservoir	1968	BOR
flow	daily	Snake River near Blackfoot (#13069500) Snake River at Neeley (#13077000) Portneuf River at: Pocatello (#13075500) Tyhee (#13075910)	1910-2002 1907-2002 1897-2002 1985-1994 2001-2002	USGS
total phosphorus orthophosphate	118 samples over period 27 samples over period 46 samples over period approx. 20 samples	Snake River near Blackfoot Portneuf River at Tyhee Portneuf River at Tyhee American Falls drains and tributaries	1972-2002 1970-1994 1999-2003 2001-2003	USGS USGS City of Pocatello BOR
temperature	daily	Snake River near Blackfoot	2000-2001	USGS
weather, including: dry bulb air temp dew point temp wind speed barometric pressure cloud cover	daily	Surface Airways Station in Pocatello	1968 to present	NWS
weather, including: dry bulb air temp dew point temp wind speed barometric pressure solar radiation	daily	Agrimet station at Aberdeen	1983 to present	BOR

Data gaps

Like many TMDL modeling analyses, this analysis relies on existing, available data. There are a number of gaps in the data that require filling to accomplish a reasonable dynamic simulation. The following table highlights the most significant data gaps and the manner in which they are handled in the model.

Table 2: Data Gaps

Parameter(s)	Problem	Model Assumptions or Estimation	Comments
water quality profiles in reservoir	no information prior to May or after early August	none	cannot evaluate simulations of spring or late summer conditions
Snake inflows of phosphorus	2001 sampling focused on summer months	interpolation used in winter/spring; constant values assumed in fall	simulated orthophosphate in reservoir suggest that inputs are reasonable
Portneuf inflows of phosphorus	no sampling in 2001; grab sampling over long term	long term average used	does not account for long term changes in average phosphorus
groundwater & ungauged tributary phosphorus	very limited or no sampling	assumed equal to Snake River levels	higher levels known to exist in Portneuf - this is addressed by data at Tyhee gauge
ungauged flows	no routine sampling	constant value assumed and water balance checked for 1999 and 2001	constant value (2285 cfs) resulted in good water balance
Portneuf flows at mouth	Tyhee gauge not operated in 1997 and 1999	constant value added to Pocatello flows; checked years when both gauges operated	constant value (215 cfs) resulted in reasonable agreement at Tyhee

III. Choice of Technical Approach

Rationale for approach in context of management objectives and conceptual model

The management objective for this work is to provide technical information for the establishment of a TMDL. Because of resource constraints and lack of bathymetry data for the reservoir, the option of developing a more complex, 2-D model using a framework such as CE-QUAL-W2 was not pursued. At the same time, it was desirable to use a mathematical process model rather than a more simple empirical model (e.g., Vollenweider loading plots) to enable some exploration of the effects of the large seasonal variations in reservoir volume on water quality. In addition, the need

for a dissolved oxygen analysis for the TMDL required a linkage between eutrophication and dissolved oxygen conditions in the reservoir.

The selected model framework includes many of the processes in CE-QUAL-W2 (e.g., water balance, reservoir heat budget, phosphorus transformations, and phytoplankton kinetics). It also includes the effects of the phytoplankton activity on dissolved oxygen levels in the water column. However, it does not provide the longitudinal spatial resolution that can be obtained using a model like CE-QUAL-W2.

Important assumptions

The model developed for American Falls includes the following simplifying assumptions:

- The top and bottom layers are completely mixed.
- There is a single phytoplankton community (blue-green algae).
- Phosphorus is the limiting nutrient
- There is no wind mixing (general mixing is captured in the diffusion coefficient).
- The temperature/density gradient occurs at 5 meter depth.
- There is no phosphorus loading from sediments.

The model rests primarily on mathematical formulations and literature values for parameters cited in EPA guidance on surface water quality modeling (Bowie, et al, 1985).

IV. Parameter Estimation

Data used for parameter estimation

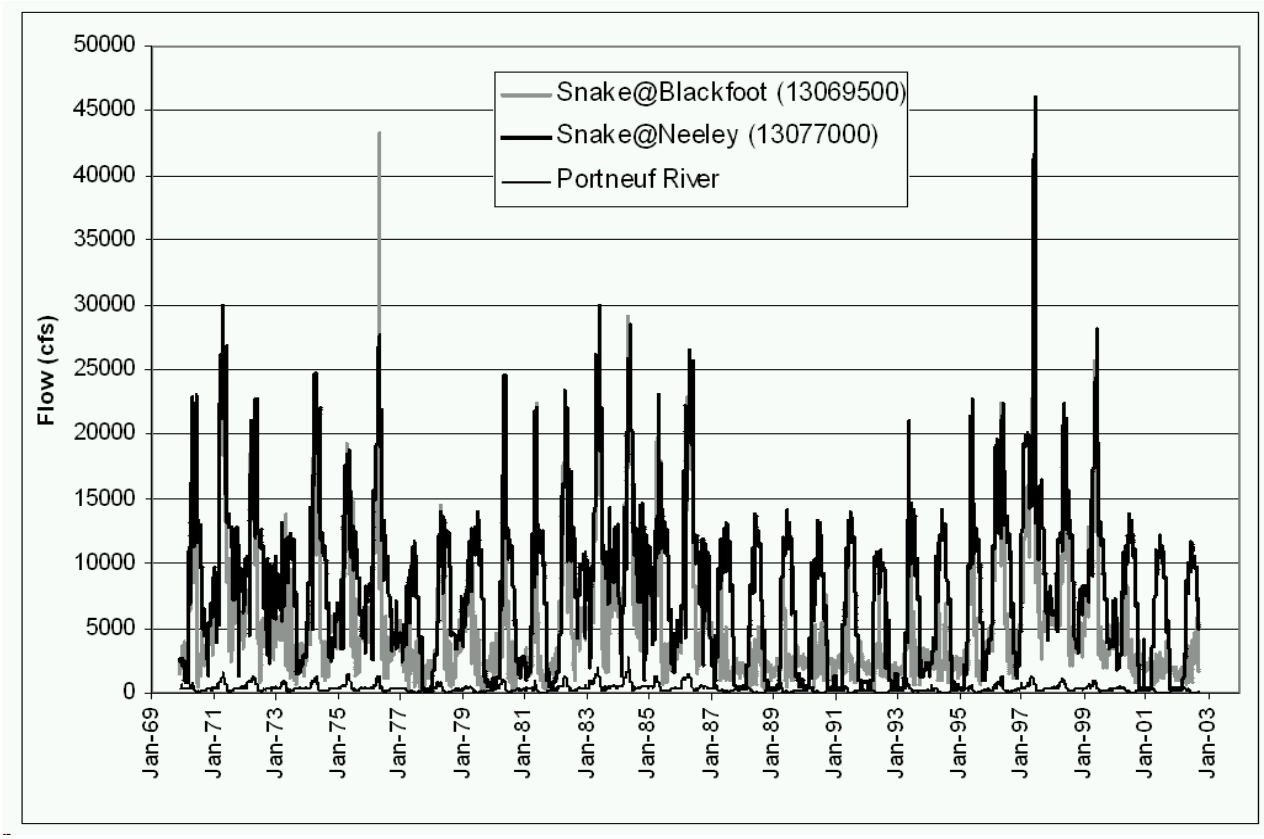
The model was developed using 2001 observations of the system. Model parameters related to phytoplankton stoichiometry, growth, respiration, mortality, and settling were set in the range of literature values (Bowie, et al, 1985) for blue-green forms such as genus *Aphanizomenon*.

<u>Boundary Conditions</u>

Hydrology, Inflow Temperatures, and Weather

Inflows to American Falls are estimated as the sum of the flows measured in the Snake River below the Blackfoot River confluence, Portneuf River near Tyhee, and ungauged tributaries/groundwater. This last inflow is a combination of numerous small creeks and groundwater inflows to the reservoir, and the estimated magnitude of this inflow (2,300 cfs) is significant with respect to the Snake and Portneuf River inflows in low flows years. The estimate calculated for this analysis was found to be consistent with previous estimates for ungauged flows to the reservoir by USGS (Kjelstrom, 1995). Also, review of long term flow records indicates that this average net inflow to the reservoir does not vary significantly from year to year (Vaga, personal communication). Based on BOR sampling of 10 creeks, the surface water contribution to this inflow is estimated at approximately 750 cfs.

Figure 7: Snake and Portneuf River Flows (1970-2002)



Outflows are estimated as the flow measured in the Snake River at Neeley (see figure below for upstream/downstream flow comparisons). The estimated annual water balances for the reservoir were checked by calculating a predicted daily surface water elevation using volume/elevation relationships for the reservoir (BOR, 1971) and measured/estimated inflows and outflows, and comparing this predicted water surface elevation to the elevation observed at the dam. The comparison for 2001 is shown below.

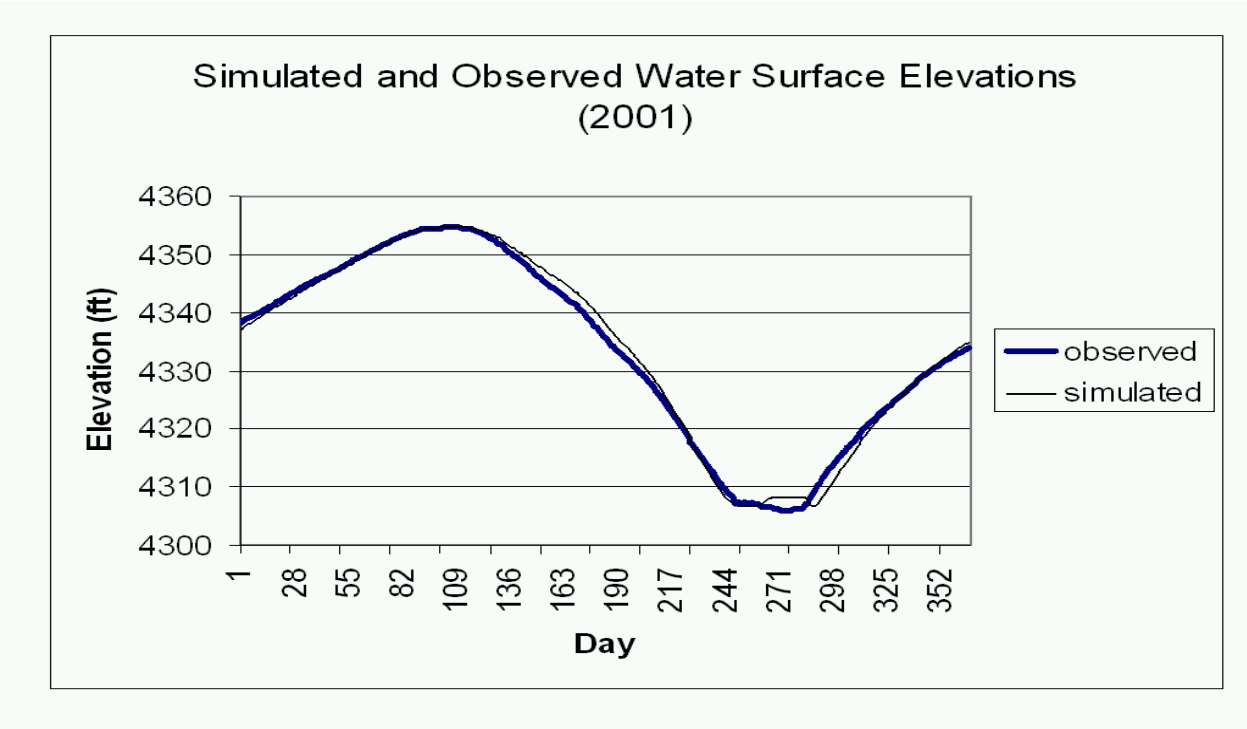


Figure 8: Comparison of Simulated and Observed Reservoir Elevation (2001)

The USGS monitored the temperature of the Snake River continuously between April and September of 2000 and 2001, and the daily average temperatures were used as input temperatures for the model. For the period prior to April and after September, a trigonometric function was used to fill the data gap. The same temperatures were assumed for the Portneuf River and ungauged tributaries.

For weather data, the Pocatello station provides daily observations of air temperature, dew point, wind speed, and pressure for the heat budget calculations. The Agrimet station at Aberdeen, in the vicinity of the reservoir, records solar radiation. These data were used in the model and also used in conjunction with clear sky radiation to estimate the cloud cover. Each component of the heat budget has estimation uncertainty, but the evaporation estimates are typically the most uncertain of the heat budget components. The evaporation rate coefficient was adjusted based on observed temperatures.

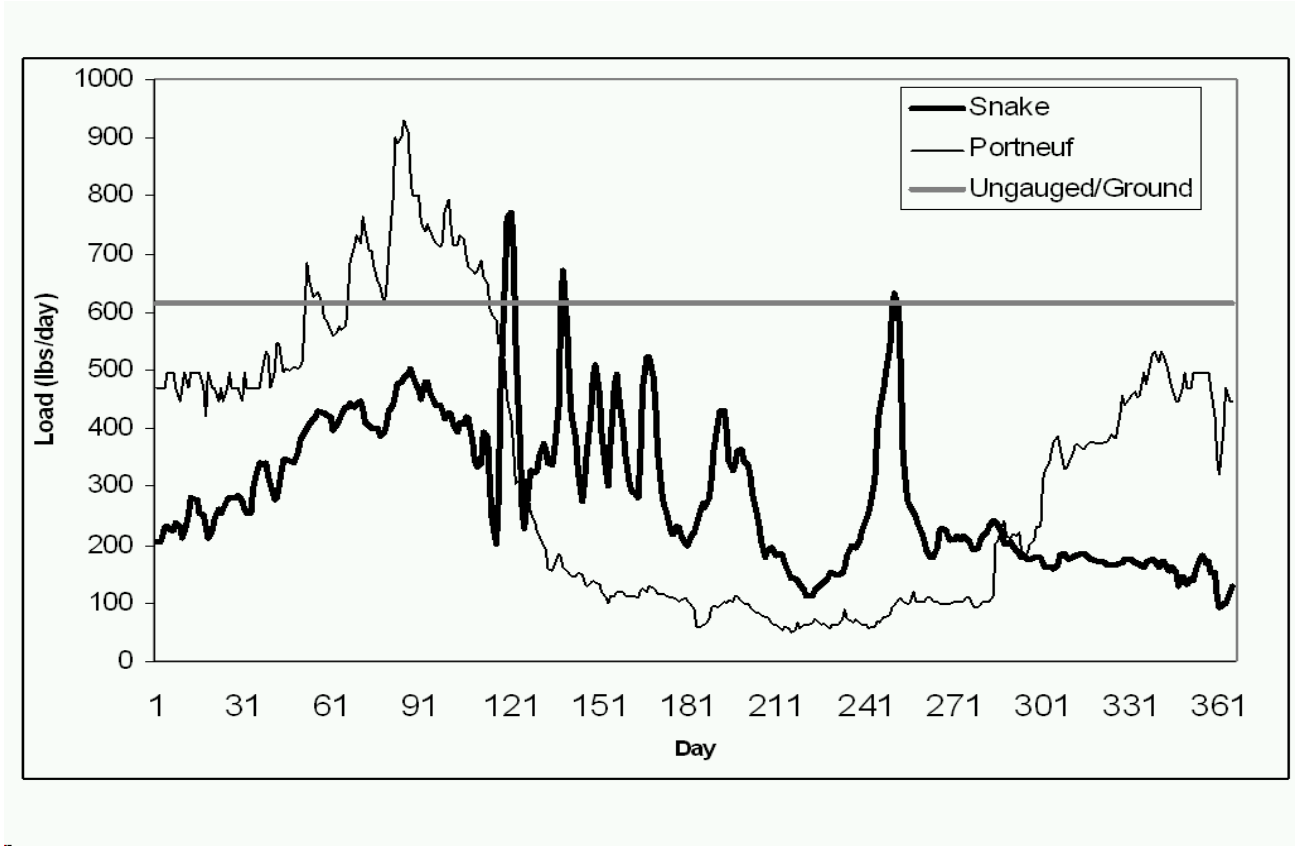
Phosphorus Loadings

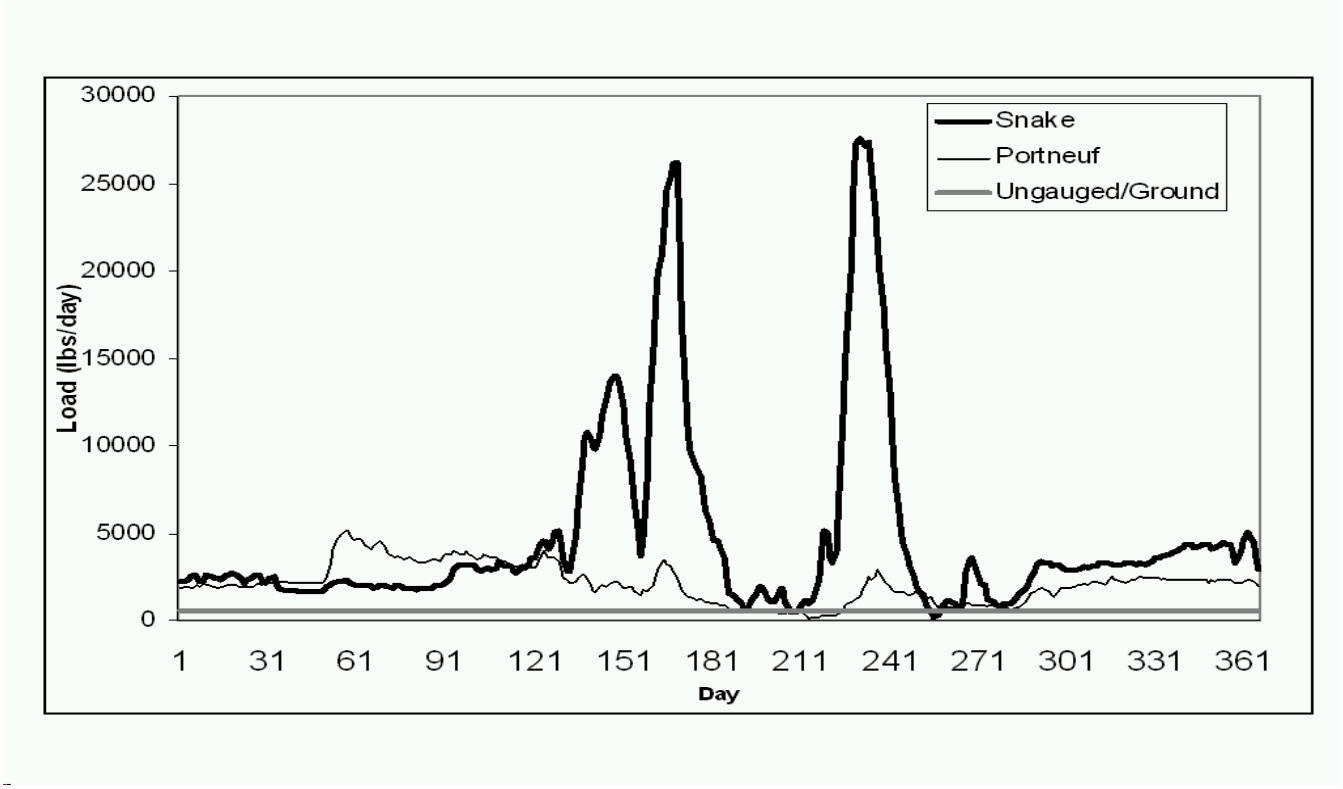
Orthophosphate inputs are estimated using observed total phosphorus samples from the Snake and Portneuf rivers and an estimate of the ratio between total phosphorus and orthophosphate. USGS collected 12 samples for phosphorus and orthophosphate in the Snake River below the confluence of the Blackfoot River in the spring/summer of 2001. The total phosphorus concentration ranged from 17-51 ug/l. The average ratio of total phosphorus and orthophosphate was approximately 5:1 (the actual ratio may be higher, because many of the orthophosphate samples were below detection levels).

For the Portneuf River, there are two datasets available. USGS collected approximately 20 samples from 1989 to 1994 at Tyhee. The total phosphorus concentrations ranged from 290-770 ug/l. The City of Pocatello has collected over 40 samples in the Portneuf River just upstream of the Tyhee gauge from 1999-2003. The total phosphorus concentrations ranged from 200-1590 ug/l, with a mean of 960 ug/l. For both datasets, the average ratio of total phosphorus and orthophosphate was approximately 1:1 (meaning virtually all of the phosphorus is in the orthophosphate form).

As noted above, in addition to the Snake and Portneuf rivers, there is a significant flow from smaller tributaries and groundwater into the reservoir. BOR has sampled a number of smaller tributaries to the reservoir, such as Bannock Creek, Spring Creek, and McTucker Creek. For the model, the flow-weighted average of all the samples collected from all tributaries (approximately 50 ug/l total phosphorus) was used as a constant inflow concentration. The average ratio of total phosphorus and orthophosphate for these tributaries was approximately 2:1

A comparison of the estimated daily phosphorus loadings from the Snake, Portneuf, and ungauged inflows for 2001 is shown below. Cumulatively, these loads result in an estimated annual loading of approximately 450,000 lbs of total phosphorus, an average of 1,200 lbs/day. The second figure is the estimated loadings for 1968, with an estimated annual loading of approximately 2,000,000 lbs of total phosphorus. For reference, note that the same ungauged tributary/groundwater loads were assumed for both simulations and the y-scale is markedly different. As a result of significantly higher flows and phosphorus concentrations in 1968, the loads carried by the Snake and Portneuf Rivers were much higher that year than in 2001.





Figures 9 and 10: Estimated Total Phosphorus Loadings for 2001 and 1968

Estimated Model Parameters

Model simulation results were compared to available DEQ observations of phosphorus, chlorophyll-a, temperature, and dissolved oxygen in the reservoir. The following parameters, aside from the phytoplankton parameters, were adjusted to the following values to achieve a qualitative fit to the observations:

Table 3: Parameters adjusted during model development

Parameter	**Value**	**Units**
Evaporation Rate	1.0E-09	/mb
Vertical Diffusion Coefficient	5.0E-5	m^2/s
Sediment Oxygen Demand	0.10	gm O2/m^2-day
Detrital Decay Rate	0.15	/day

It was noted that the vertical diffusion coefficient was comparable to the estimated value (1.0E-5 m^2/s) for American Falls Reservoir referenced in Bowie, et al (EPA, 1985). A table with all of the parameter values used in the model is included in the Results section of this report.

Reliability of parameter estimates

It is important to note that it is not possible to determine a single set of parameter values that uniquely and correctly represents the system. Parameters are estimated through a process of literature review, sensitivity tests, and comparisons of simulated and observed conditions. The reliability of parameter estimates can be examined by simulating a variety of waterbody conditions with the same parameter sets and comparing model estimates and observations. The recent monitoring of the reservoir by DEQ provides a set of observations for parameter estimation. Unfortunately, this period of sampling has been characterized by a persistent drought. Water quality information for the reservoir during wetter years is limited.

To evaluate reliability of the parameter estimates, the model parameters estimated for 2001 were used in a simulation of 1968 conditions using reservoir and boundary observations from Bushnell's report. The reservoir elevation, inflows, and water quality were significantly different in 1968 than in 2001, so the observations from this year provide a useful test of the model.

V. Uncertainty/Error

Error/uncertainty in boundary conditions

There are a number of sources of uncertainty and error in the assumed boundary conditions, including data gaps (described earlier), measurement error, and simplified representations of the boundaries. The model includes three advective inflows (Snake River, Portneuf River, and ungauged tributaries/groundwater). This last inflow is significant in magnitude with respect to the other two inflows, but it is an aggregation of numerous small creeks and groundwater inflows

to the reservoir. BOR has sampled 10 creeks with an average collective inflow to the reservoir of approximately 750 cfs, out of an estimated aggregate inflow of 2300 cfs. Estimates of the quantity and quality of aggregate groundwater inflows were not available for this analysis.

There are no measurements of sediment oxygen demand, and the model assumption is that this demand is moderate and constant over the year. There may be significant variability in the demand, particularly during and after spring and summer phytoplankton blooms, when organic detritus settles to the bottom. The 2001 simulation, which does not include a spring diatom bloom, predicts higher dissolved oxygen in the bottom than was observed in the June 2001 samples.

Structural assumptions in methodology (e.g., effects of aggregation or simplification)

Like any model, this model presents a simplified representation of the waterbody. The two-layer approach assumes American Falls reservoir consists of two well-mixed layers with uniform total depths across the reservoir, whereas the actual reservoir depths vary substantially (e.g., from 8 m at County Boundary to 19 m depth at the dam in May 2001). The depth of the epilimion is assumed to be a constant 5 m, whereas the available temperature data indicates substantial variability in vertical gradients over the summer period.

Horizontal gradients also appear in some of the water quality observations that would not be captured in the model. For example, the peaks in chlorophyll-a concentrations do not occur simultaneously in the observed data. The peak at the County Line site is generally earlier than at the other sites. One possible explanation for these observations would be earlier productivity due to earlier peaks in temperature at this location.

The model accounts for a single phytoplankton community, and a blue-green algae community was selected for analysis based on the prevalence of *Aphanizomenon* in the summer algal samplings by DEQ. Low concentrations of orthophosphate and dissolved oxygen measured in May 2001 suggest significant diatom productivity in the reservoir prior to the first chlorophyll-a samples collected in June. Comments in the Bushnell report also suggest a significant diatom bloom prior to the onset of the blue-green bloom, and Idaho Power observes spring diatom blooms in Brownlee Reservoir. The model does not capture this spring productivity or its effect on the initial conditions prior to the summer bloom.

VI. Results

Parameter values used for analysis

In addition to the parameters adjusting in the parameter estimation process (see discussion and table above), the following parameter values to characterize phytoplankton activity were selected based on ranges reported in EPA guidance (Bowie, et al, 1985).

Table 4: Phytoplankton parameters in the model

Parameter	Value	Units
Detrital Sinking Velocity	0.20	m/day
Phytoplankton Mortality Rate	0.20	/day
DO/Detrital Carbon ratio	2.0	gm DO/gm C
DO/Phyto Carbon ratio	2.0	gm DO/gm C
Mineralization rate - Org P to dissolved PO4-P	0.10	/day
Max Phytoplankton Growth Rate	2.0	/day
Max Phytoplankton Respiration Rate	0.10	/day
Half-saturation constant - light limitation	.004	kcal/meter^2-sec
Half-saturation constant - PO4-P	.02	gm P/m^3
Phytoplankton sinking speed	0.10	m/day
Ratio - C to chlorophyll in phytoplankton	.025	gm Chla/gm C
Ratio- phosphorus to C in phytoplankton	.025	gm TP/gm C

Comparison of model simulations and measurements - 2001 and 1968

As discussed above, the model parameters were estimated based on comparisons of simulated and observed water quality in the summer of 2001. Graphical comparisons of simulations and depth-averaged observations were generated for temperature, chlorophyll-a, phosphorus, and dissolved oxygen. In order to provide some perspective on the spatial/temporal variability in the observations, observations from the individual sample collection sites are included on the graphs.

Discussion

2001 Simulation

General

In general, the model predicts the observed patterns of water quality in the reservoir in the June through early August time frame. The temperature simulations generally follow the warming and cooling patterns and range of vertical stratification seen in the observations. Figure 11 depicts a comparison of simulated and observed temperatures at the dam, as well as observations in the surface at the county line station (at the shallower, upstream end of the reservoir). The plot shows the vertical and longitudinal variability observed in reservoir temperatures. Waters at the shallow, county line site are more responsive to weather changes, heating faster in the spring and cooling faster in the fall.

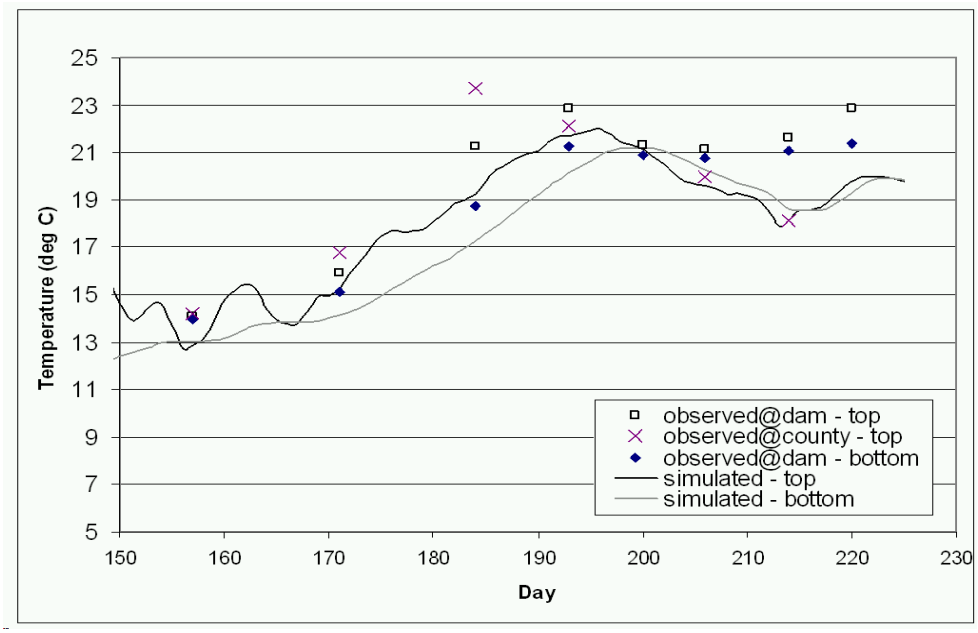


Figure 11: Simulated and Observed 2001 Temperatures

For chlorophyll-a, a spike in the concentration was observed between mid-July and mid-August 2001 at the sampling sites, and the model generates a spike of similar magnitude in this general time frame (see Figure 12). Note that the observed chlorophyll peak occurs at different times across the reservoir, with later peaks at the Dam and Little Hole sites compared to the more upstream County Line site).

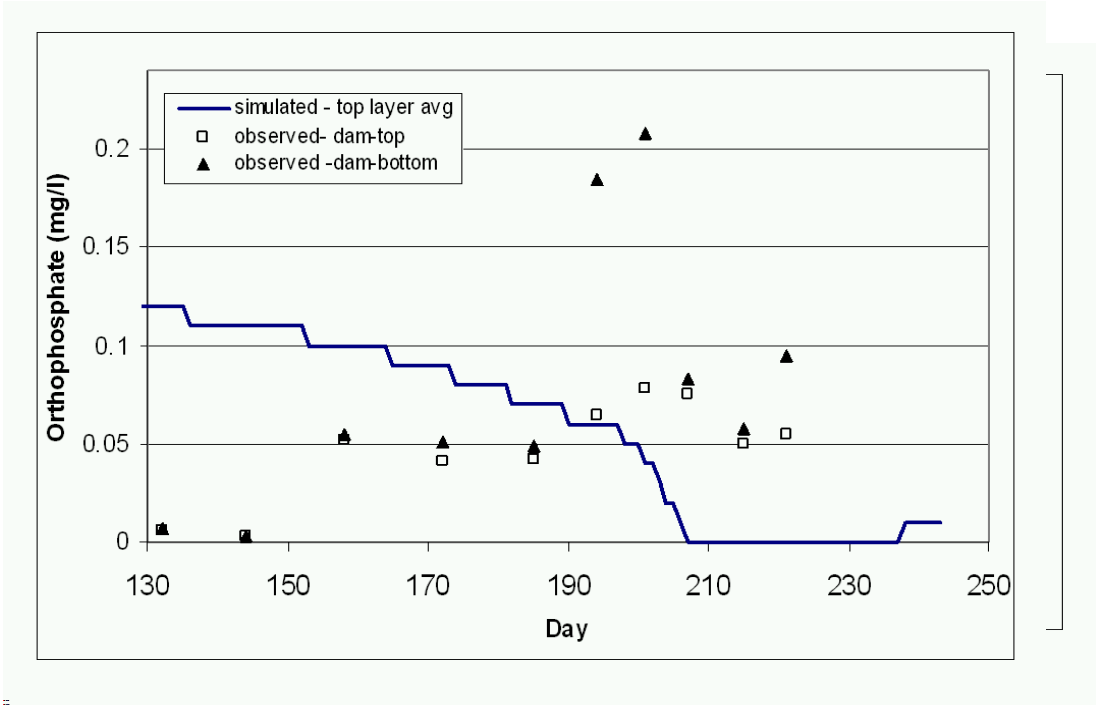


Figure 12: Comparison of Simulated and Observed Chlorophyll for 2001

In both model simulations and observations, phosphorus concentrations are increasing in the late spring and early summer. While temporal patterns in water quality vary between sites, top and bottom layer dissolved oxygen levels are generally comparable to the observations. The observations do not continue past early August, and the model predicts a recurrence of significant biomass growth in the late summer and fall.

2001 Spring Conditions

As note earlier, the model includes a single phytoplankton community with growth requirements of blue-green species. There is evidence that the reservoir experiences spring productivity in addition to the blue-green productivity in July/August. The orthophosphate and dissolved oxygen levels are significantly lower in the earliest samples available (May) than simulated levels (Figure 13). Unfortunately, there are no chlorophyll samples for May in the 2001-03 data.

2001 Residual Orthophosphate Concentrations

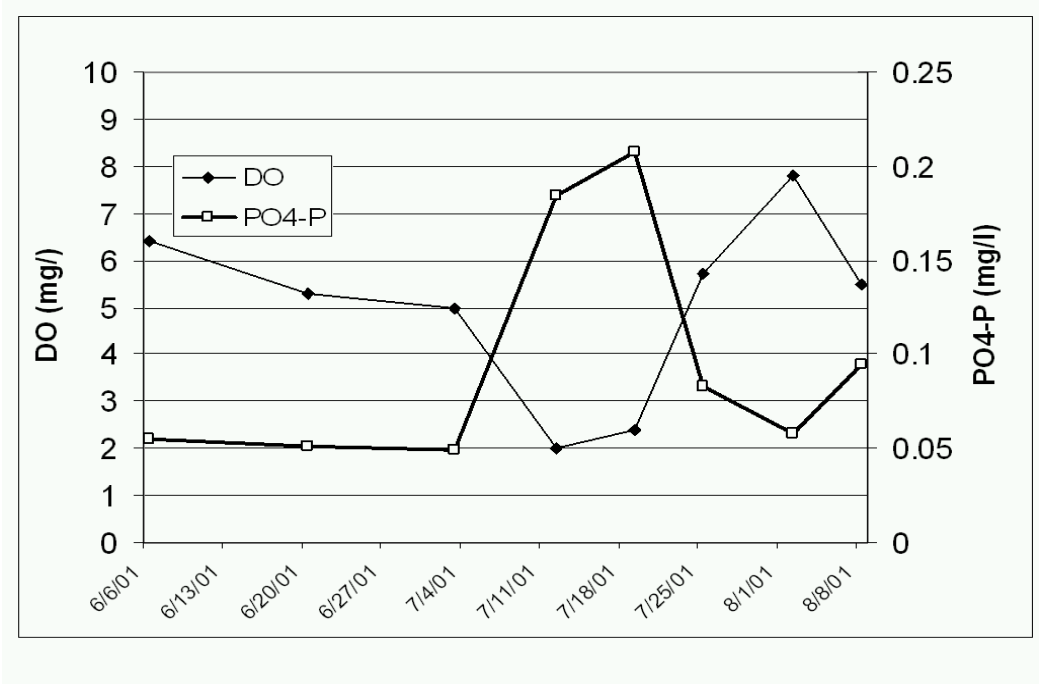
The model predicts that the July/August 2001 phytoplankton bloom is limited first by temperature, then by light limitation, and finally by low phosphorus concentrations. This last phase in the simulation is not consistent with the 2001 observations, which generally show fairly high orthophosphate concentrations even after the bloom/crash in 2001. Tests with a variety of parameter adjustments failed to produce both the observed chlorophyll-a pattern and a significant post-bloom orthophosphate concentration.

Figure 13: Simulated and Observed Orthophosphate for 2001

It should also be noted that data from different locations and different years indicates some variability in the chlorophyll-a/orthophosphate pattern. For example, the last sample from 2003 at the Little Hole site indicates a combination of a chlorophyll-a spike and severe depletion of orthophosphate concentrations similar to the pattern in the 2001 simulations (but not the 2001 observations).

Phosphorus Loading from Sediments

Because of the complexities of phytoplankton growth and reservoir dynamics, there are numerous possible explanations for the observed relationship between phytoplankton biomass and orthophosphate, and its departure from the mechanisms incorporated into the model. One compelling hypothesis is that significant orthophosphate loads are released from the sediments in the summer due to low dissolved oxygen at the bottom of the reservoir. The observations of dissolved oxygen and orthophosphate near the dam for 2001-2003 show a consistent pattern that supports this hypothesis. In July of each year, dissolved oxygen is depleted in the bottom during periods of stratification, and there is a corresponding spike in orthophosphate concentrations at depth (Figure 14). This spike occurs when dissolved oxygen levels reach about 2 mg/l. This threshold concentration is identical to a threshold concentration for sediment phosphorus release cited in the literature (Marsden, 1989).



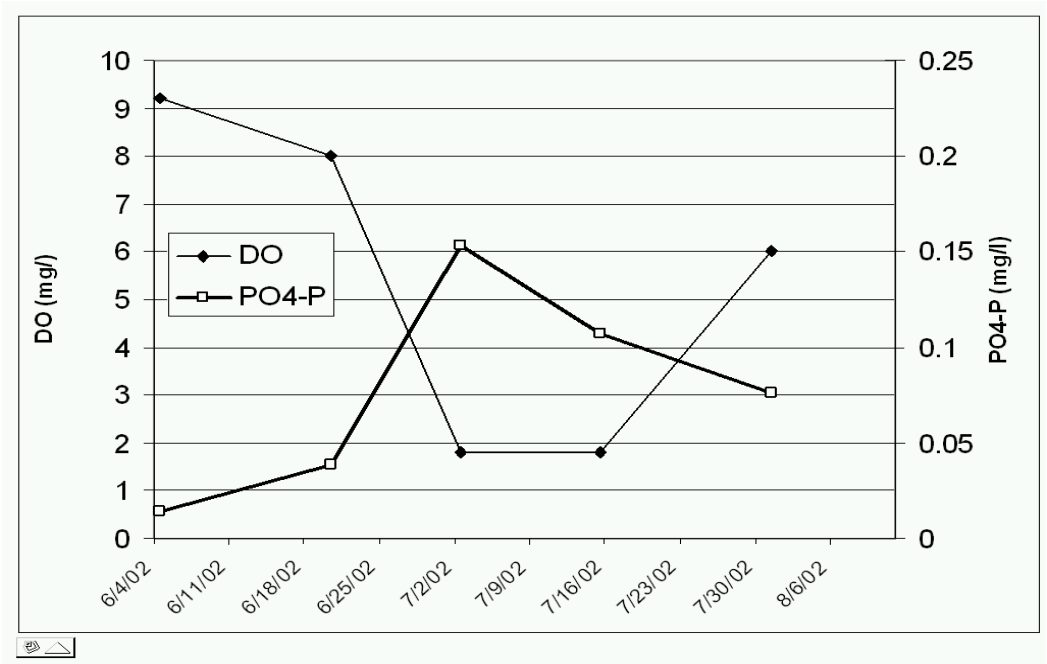


Figure 14: Dissolved Oxygen and Orthophosphate in Bottom Samples in 2001 and 2002

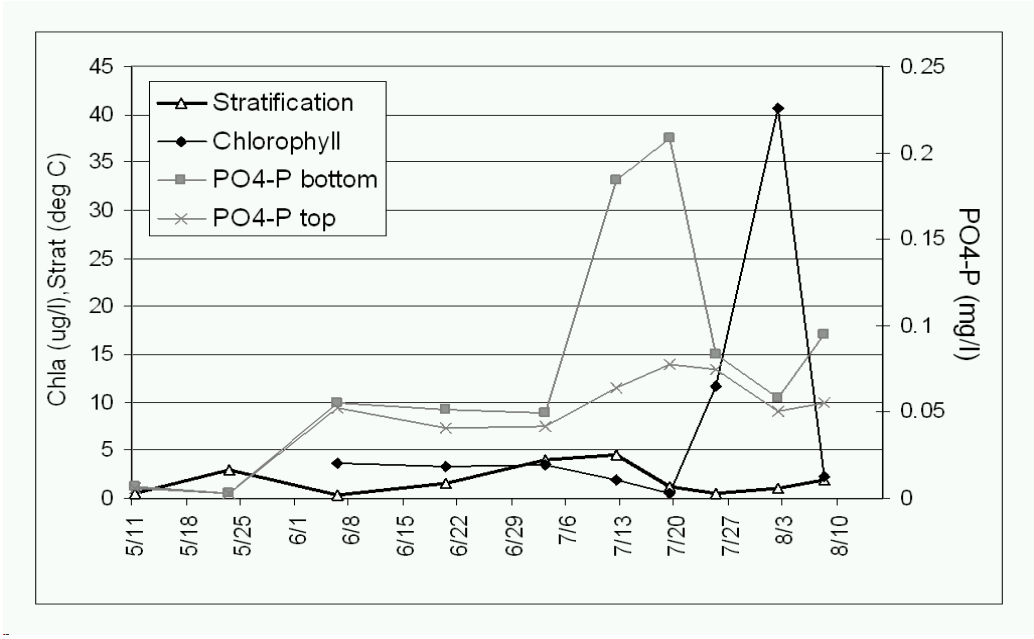


Figure 15: Water Quality Observations for 2001. Note that "stratification" is the difference between the surface and bottom temperatures

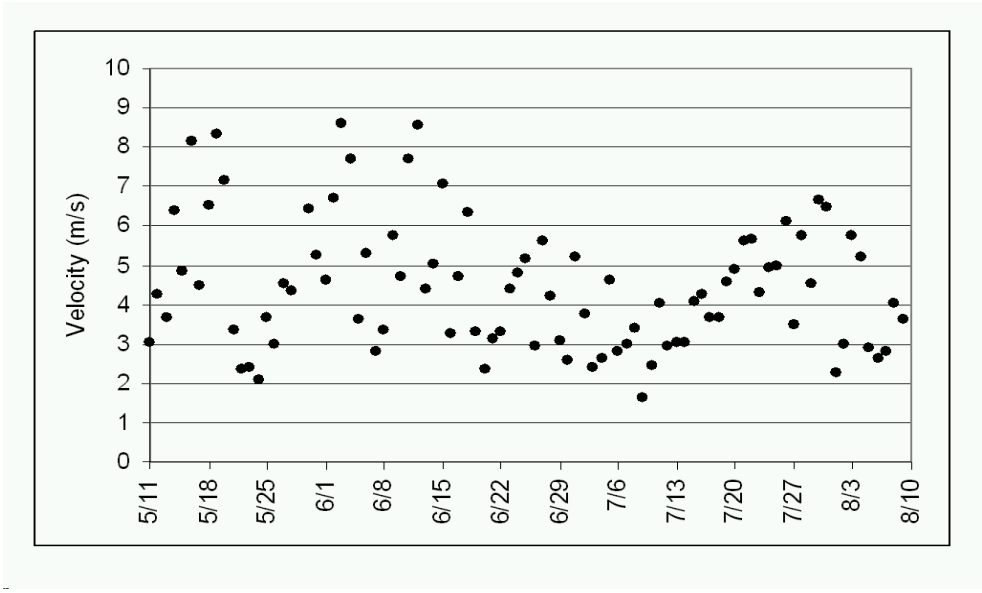


Figure 16: Wind Speed Recorded in 2001 at Pocatello, Idaho

Once the episode of thermal stratification ends (see Figure 15 for measure of stratification), dissolved oxygen concentrations in the bottom rebound and there is a corresponding drop in orthophosphate concentrations. A relationship is apparent between the onset and breakdown of stratification and wind speed recorded in the vicinity (Figure 16).

The reduction in orthophosphate concentrations after the breakdown in stratification is likely the result of a combination of factors, including cessation of the sediment flux, vertical mixing with less concentrated surface waters, and phytoplankton uptake (which occurs in July as well). As noted above, *Aphanizomenon* has a buoyancy regulation mechanism and may extract orthophosphate directly from deeper waters.

There are no data available for later dates in the summer to evaluate whether these patterns of stratification, dissolved oxygen concentrations, and phosphorus concentrations were repeated during calm periods over the remainder of the summer and early fall. The occurrence of this pattern in 2001, when the reservoir was relatively shallow, also raises questions about water quality conditions during years of average or above-average flow and reservoir depth. A model sensitivity test comparing the effects of 2001 and 1999 hydrology on water quality indicates that dissolved oxygen concentrations are lower when the reservoir is deeper (see discussion below).

Because of the amount of phosphorus commonly present in the eutrophic lake bed sediments, sediment phosphorus release can hamper attempts to improve water quality by reducing external phosphorus loads to the system. Marsden (1989) found that the persistence of sediment loading is influenced by lake morphometry, flushing rate, sediment type, trophic state, and history of enrichment. He offers examples of highly enriched, shallow lakes that were slow to respond to significant reductions in external phosphorus loadings because of persistent sediment phosphorus releases. In an extreme case, Lake Trummen in Sweden did not show water quality improvements until enriched sediments were mechanically removed from the lake. Marsden generally found that "in lakes with annual mean TP (total phosphorus) concentrations greater than 100 mg/m^3, few improvements have been noted unless the reduction in loading were greater than 60%. Even where the reductions in loading have been greater a proportion of lakes still failed to respond." For comparison, the mean total phosphorus concentration at the DEQ sampling site near the American Falls dam from 2001 to 2003 was 90 mg/m^3.

The efforts to identify and reduce external loadings to the reservoir are underway. The State of Idaho developed a TMDL for nutrients in the Portneuf River in April 1999 (Idaho DEQ, 1999) and EPA approved the plan in April 2001). This plan calls for a reduction of 81% in the major sources of total phosphorus to the river upstream of the Tyhee gauge. The TMDL identified springs and Pocatello municipal discharges as the largest sources of nutrients in this area.

2001 Dissolved Oxygen

A comparison of simulated and observed dissolved oxygen is shown in Figure 17. The model predicts a consistent difference between the top and bottom layers of approximately 1-3 mg/l until the period of maximum reservoir drawdown in the late summer. A significant spike in the top layer oxygen (and a smaller increase in the lower layer) corresponds to the period of peak phytoplankton activity.

In the observations, there is virtually no difference in the top and bottom in the spring, which suggests that the model is under-predicting vertical mixing during this period. Beginning in July, however, observed differences are similar to predicted differences. Consistent with the timing of the phytoplankton activity at the dam and in the simulation, the spike in surface oxygen occurs later at the dam than in the simulation.

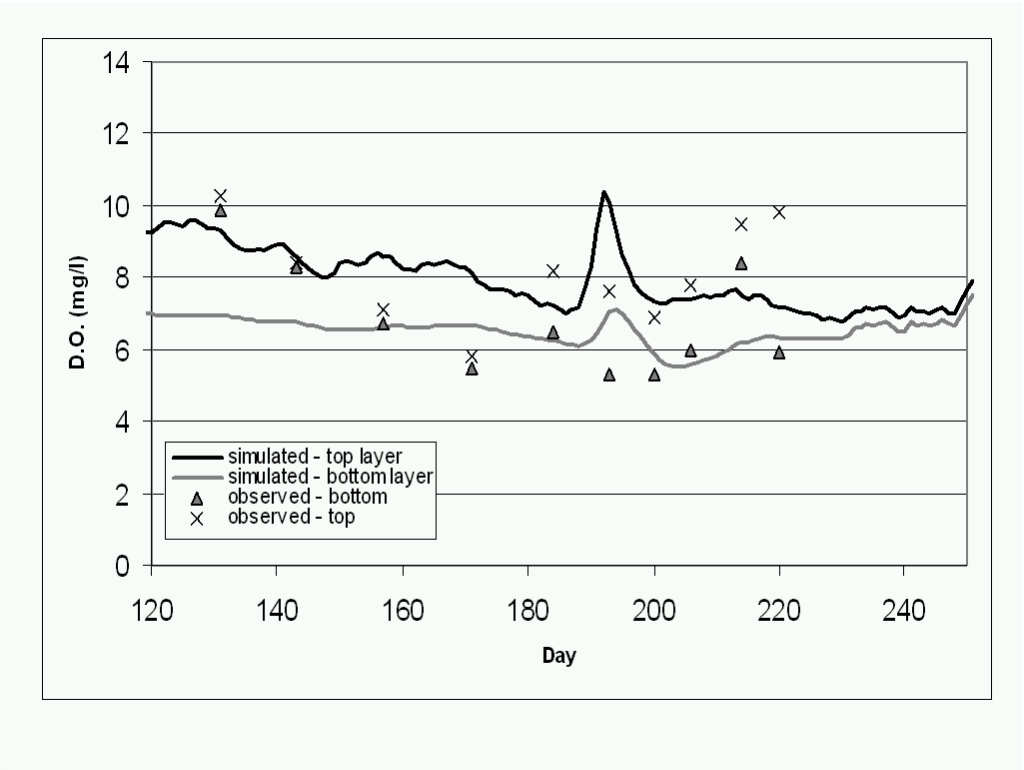


Figure 17: Simulated and Observed Dissolved Oxygen - 2001

A comparison of simulations for 2001 (drought) and 1999 (average flow) under identical 2001 weather inputs indicates that predicted hypolimnetic dissolved oxygen is consistently lower in 1999. In theory, shallow conditions of 2001 would be conducive to more effective oxygen transfer from the surface to the small hypolimnion volume. In the 1999 test, the effects on dissolved oxygen of higher inflows are counteracted by the greater hypolimnetic volume and depth of the reservoir. This larger, deeper pool of sequestered water is less efficiently

oxygenated. While the model theory for these predictions is sound, we have no data from 1999 to compare to the predictions.

1968 Simulation

General

Phosphorus concentrations in the Snake and Portneuf rivers were notably higher in 1968 than in 2001. The average total phosphorus in the Snake River samples was 0.260 mg/l compared to 0.030 mg/l in 2001, and the Portneuf averaged 0.46 mg/l in the early 1990s versus 1.7 mg/l in 1968 samples.

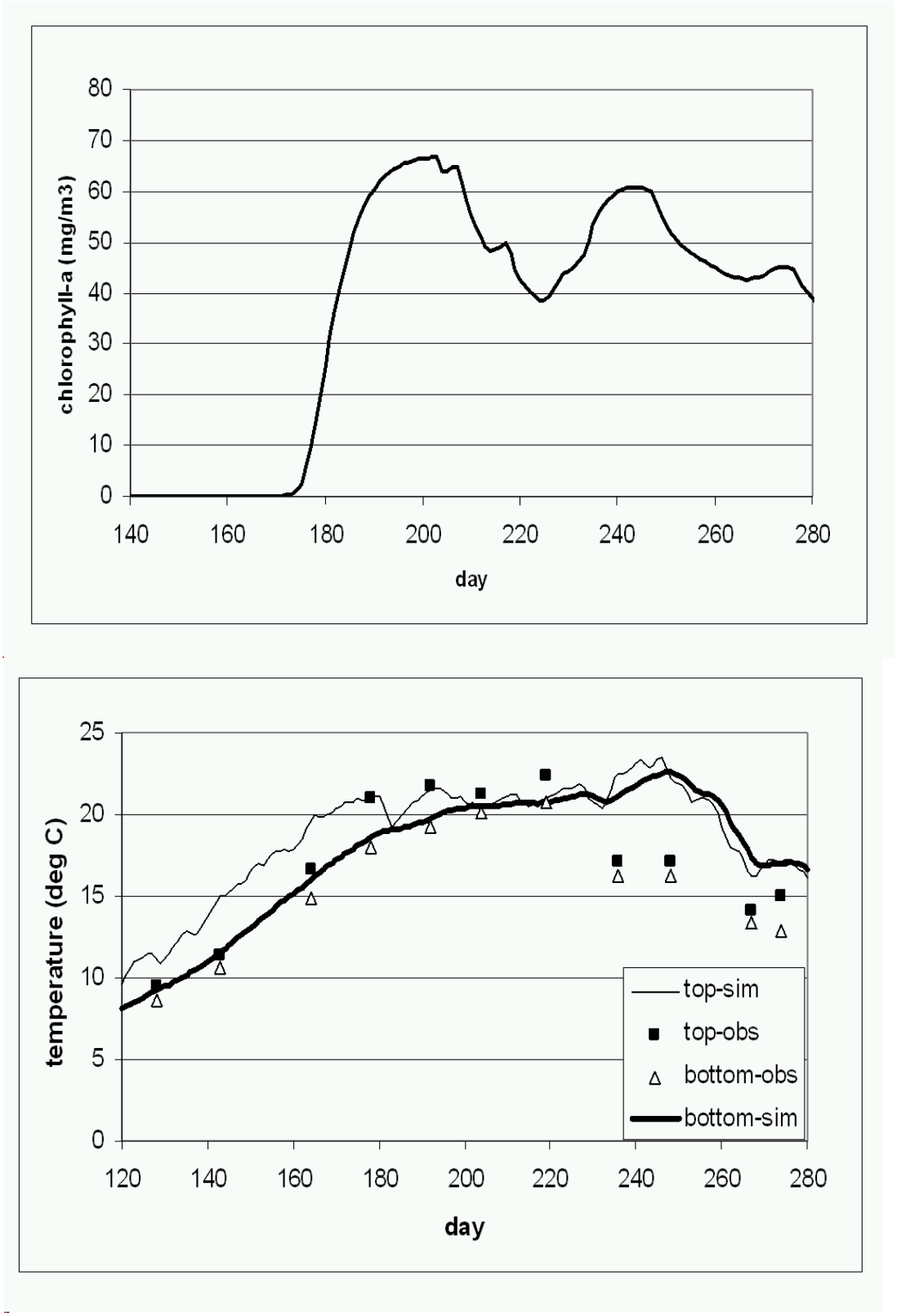
In addition to differences in phosphorus concentrations, the seasonal inflows were higher in 1968 than in 2001. The higher concentrations and flows in 1968 resulted in substantially higher estimates of phosphorus loading to the reservoir compared to 2001 levels (see Figures 9 and 10 earlier). The higher flows also resulted in higher reservoir elevations in the summer.

Unfortunately, chlorophyll was not monitored in 1968. There are phytoplankton samples from several locations on July 22 and August 4 of 1969 showing high *Aphanizomenon* counts; one sample near the dam was higher than any individual sample in 2001.

The model simulation, with phosphorus limitation governing the ultimate peak concentration, predicts a higher peak chlorophyll-a concentration in 1968 compared to 2001 (66 ug/l compared to 42 ug/l for 2001). Unlike the 2001 simulation, where phytoplankton levels drop precipitously after the initial peak, the 1968 simulations show sustained high phytoplankton concentrations after the initial peak. This occurs even though simulated orthophosphate levels in the reservoir remain low after the peak. This model prediction suggests that external phosphorus loadings in 1968 would have been sufficient to sustain phytoplankton activity in the absence of internal loading.

1968 Temperature

The simulated and observed temperatures are quite similar except for two samples in the late summer. The observations at different locations were highly variable during this sampling period. The primary source of these discrepancies (e.g., local variation, sampling error, boundary condition uncertainty) is unclear. It was noted that observed Snake River temperatures were lower than the assumed temperatures used as boundary conditions in the model (2001 conditions); however, simple tests with lower Snake River temperatures did not close the gap significantly.



Figures 18 and 19 : Simulated 1968 Chlorophyll and Temperature

1968 Dissolved Oxygen

Given the paucity of chlorophyll data for 1968, the dissolved oxygen data provides an important dataset for comparison to the simulations, because oxygen concentrations are influenced by multiple processes included in the model, including phytoplankton growth/mortality, vertical mixing, and heat budgets. While the model tends to over-predict the difference in dissolved oxygen in the top and bottom layers, the model predicts concentrations (approximately 8 mg/l and 4 mg/l in the top and bottom, respectively) and differences (approximately 4 mg/l between top and bottom) that are similar to the observations in the critical August time period.

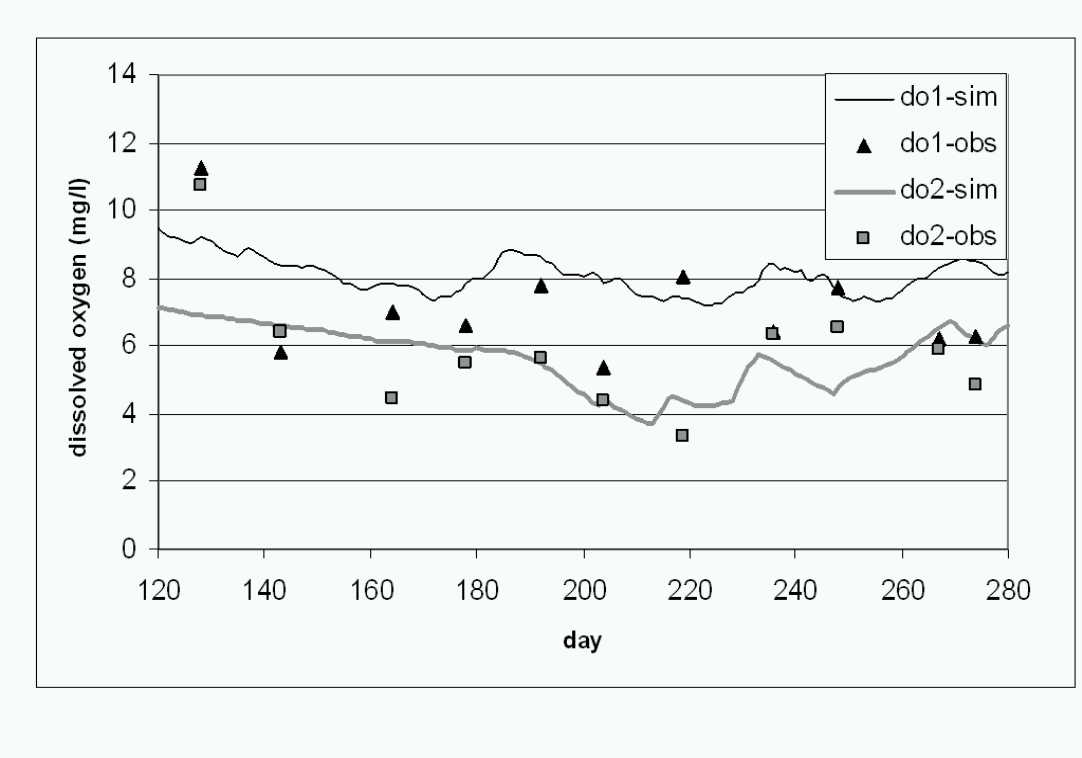


Figure 20 : Simulated and Observed Dissolved Oxygen - 1968

1968 Residual Orthophosphate Concentrations

Similar to the 2001 simulations, the orthophosphate predictions reach peak concentrations similar to the observations, but the overall simulated pattern is significantly different than the observed pattern. First, the model predicts higher levels in the spring than observed, potentially due to a diatom bloom. Second, the simulated orthophosphate plunges to near-zero, while the observed phosphorus level remains high. As noted earlier, this may be the result of internal loading, which is not included in the model. Conditions in 1968 were more conducive to anoxia at the sediment surface than in 2001, with average oxygen bottom layer concentrations about 2 mg/l lower in

1968 and individual samples near the bottom below 1 mg/l on August 6, 1968 (Julian day 218).

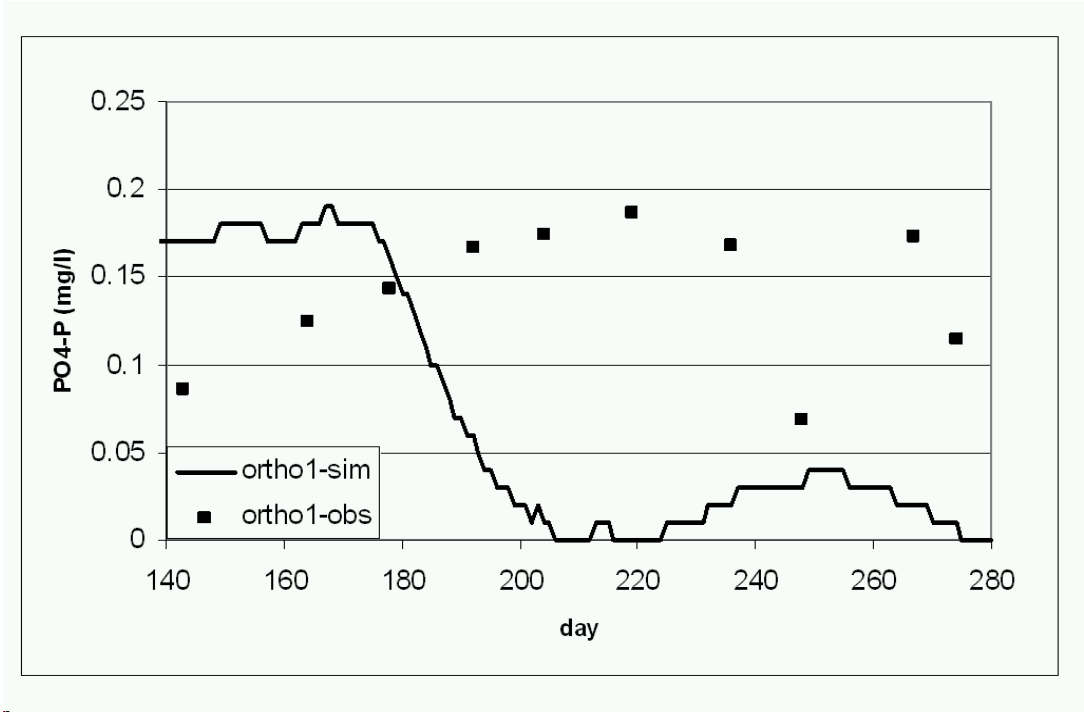


Figure 21: Simulated and Observed Orthophosphate (top layer)

Hydrology Sensitivity Test - 2001 and 1999

As noted earlier, the recent sampling has occurred over a period of very low flows in the basin. In order to provide insights into the effect of inflows and reservoir elevations on water quality, a simulation was constructed using all of the 2001 boundary conditions except daily tributary inflows, dam outflows, and reservoir elevations. Flows and elevations for 1999, a more typical hydrologic year, were substituted for the 2001 inputs. The results indicate that despite the higher inflows, predicted chlorophyll and lower layer dissolved oxygen concentrations are worse under the 1999 conditions. This could be the result of greater reservoir depth and/or differences in loading due to changes in relative flow of the Snake, Portneuf, and ungauged tributaries/groundwater.

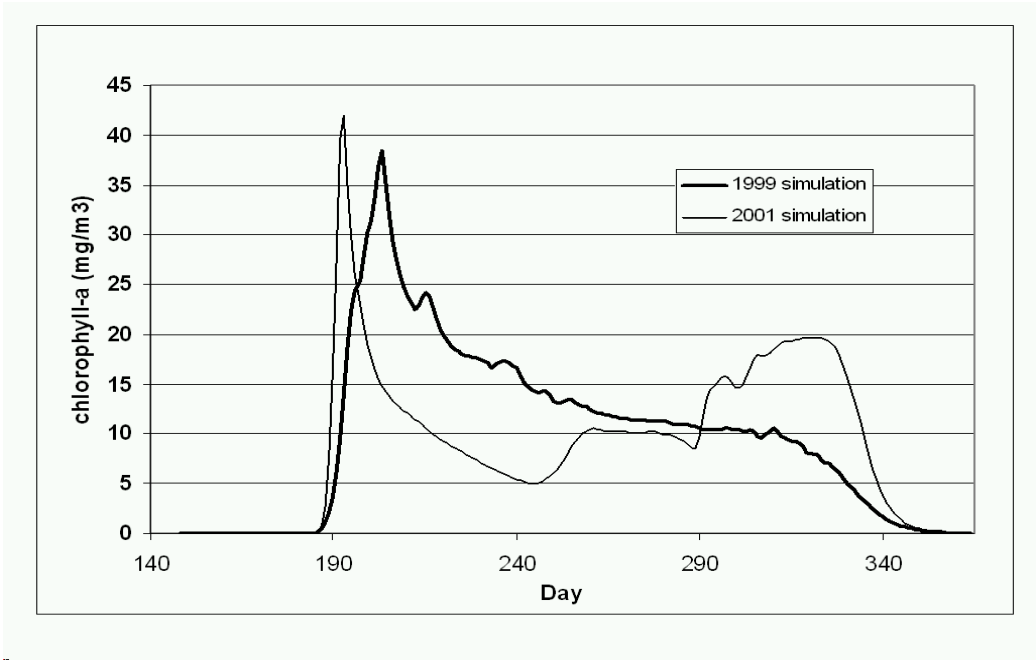


Figure 22: Comparisons of Predicted Chlorophyll - 1999 and 2001

Figure 23: Comparisons of Predicted Lower Layer Oxygen - 1999 and 2001

Conclusions of analysis in relationship to management objectives

As noted earlier, the state of Idaho determined that an analytical tool was needed for assessment of the potential effects of a range of phosphorus loadings on phytoplankton growth and dissolved oxygen levels in the reservoir. Based on the available data and model simulations, the following conclusions are offered:

- The American Falls water quality model provides useful information for the assessment of water quality dynamics in the reservoir as a whole, despite the observed heterogeneity in water quality across sampling locations. The model parameters estimated for 2001 resulted in reasonable estimates for chlorophyll, temperature and dissolved oxygen in 2001 and 1968 during the July/August period of interest.

- Observations and simulations suggest that release of phosphorus from the sediments is a significant source of phosphorus to the system during periods of stratification in July and August.

- Spring diatom activity and subsequent settling may be contributing to diminished oxygen levels at depth during periods of stratification, thus contributing to release of orthophosphate from sediments.

- The Portneuf River and a number of ungauged tributaries carry relatively high loadings of orthophosphate and total phosphorus to the reservoir, at times exceeding the loading from the Snake River in a low water year (2001).

- Simulations suggest that, with zero phosphorus release from sediments and consumption of surplus orthophosphate in late July, phosphorus loadings from the tributaries would be sufficient to drive measurable productivity for the remainder of the summer and fall.

- Model simulations indicate that periods of low flow and reservoir elevation (e.g., 2001) may not represent the worst-case conditions for water quality in the reservoir.

Recommendations for additional monitoring and analysis

This assessment has identified a number of information gaps that warrant additional sampling and analysis. The following recommendations are offered:

Improvements to Sampling Plan

– extend the time frame for lake and river sampling to April through October, with a particular focus on potential spring diatom blooms

– add routine sampling of the Snake River, Portneuf River near the mouth (at Tyhee), and high load, ungauged tributaries

– conduct groundwater phosphorus sampling and reservoir sediment sampling

- conduct sampling closer to centerline of reservoir if possible

- subject to agency resources, collect bathymetry information to support a two-dimensional, laterally-averaged model

Additional Analysis

- using existing and new data, refine the flow estimates and loading analysis of ungauged tributaries/groundwater

- subject to agency resources, examine potential improvements to the model, including variation of the dispersion coefficient based on wind speed, addition of sediment phosphorus flux tied to bottom water dissolved oxygen levels, and addition of a second phytoplankton community (spring diatoms)

VI. References

Baca, R.G., Lorenzen, M.W., Mudd, R.D., Kimmel, L.V. "A Generalized Water Quality Model for Eutrophic Lakes and Reservoirs". Battelle Pacific Northwest Laboratories. 1974.

Bowie, G., Mills, W., Porcella, D., Campbell, C., Pagenkopf, J., Rupp, G., Johnson, K., Chan, P., and Gherini, S. "Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling" (Second Edition). EPA. Environmental Research Laboratory. EPA/600/3-85/040. June 1985.

Bureau of Reclamation. Letter from Regional Supervisor to John Yearsley (EPA) with Attachments (area-elevation-volume relationships for American Falls Reservoir). Oct. 15, 1971.

Bushnell, V. "Eutrophication Investigation of American Falls Reservoir". Bureau of Reclamation, Pacific Northwest Region. 1968-69.

California Dept. of Fish and Game. "Prediction of Thermal Energy Distribution in Streams and Reservoirs". Water Resources Engineers, Inc. June 1967.

Harrison, J., Wells, S., Myers, R., Parkinson, S., and Kasch, M. "1999 Status Report on Brownlee Reservoir Water Quality and Model Development". Draft Technical Report and Appendices. Idaho Power. Boise, ID. November 1999.

Idaho Department of Environmental Quality. "Portneuf River TMDL: Waterbody Assessment and Total Maximum Daily Load." Pocatello Regional Office. March 1999.

Kjelstrom, L.C. "Streamflow Gains and Losses in the Snake River and Ground-water Budgets for the Snake River Plain, Idaho and Eastern Oregon" U.S. Geological Survey. Paper 1408-C. 1995.

Marsden, M. "Lake Restoration by Reducing External Phosphorus Loading: The Influence of Sediment Phosphorus Release". Freshwater Biology. Vol. 21, 139-162. 1989.

Vaga, R. Environmental Protection Agency. Personal Communication. 2004.

Van Every, L. "Water Quality Monitoring Workplan: American Falls Reservoir". Idaho Department of Environmental Quality. Pocatello Regional Office. April 2003.

Welch, E. "Ecological Effects of Wastewater: Applied Limnology and Pollution Effects". E and FN Spon. 1992.