Appendix F

Water Quality Modeling Documentation

This appendix contains the documentation for the modeling and analyses performed to evaluate the potential effects on water quality constituents of concern. Three different models were used to evaluate different water quality parameters and each is described in this appendix. The salinity module of the CRSS RiverWare™ model was used to evaluate changes in salinity concentrations for all alternatives. The CRSS RiverWare™ model is described in Appendix A. The CE-QUAL-W2 model and the GEMSS model were used to evaluate potential changes in temperature and water quality corresponding with reservoir draw down and respective reservoir releases. The results of the modeling and evaluation of these water quality parameters are described in Section 4.5.

Table of Contents

List of Figures

List of Tables

F.1 Salinity Modeling Using the Salinity Module of the CRSS RiverWare^{TM} Model - Model and Approach Description

F.1.1 Model Description (Salinity Module of the CRSS RiverWare^{TM} Model)

Salinity is the only water quality parameter modeled in CRSS. It is modeled as a conservative substance; therefore, dissolution and precipitation are not modeled. As with the hydrology component, salinity is modeled at a monthly time step and both reservoir and reach objects are assumed fully mixed over the month; thereby, requiring no lagging algorithms to route salt.

Seven of the twelve reservoirs (Flaming Gorge, Starvation, Navajo, Powell, Mead, Mohave, Havasu) are represented in CRSS model salinity. The reservoirs Flaming Gorge, Navajo, Powell, Mead, and Mohave use a Huen or Predictor-Corrector numerical method to route salinity through the reservoirs. The reservoirs Starvation and Havasu use a weighting method developed by Reclamation that facilities routing salinity in a reservoir that has a small storage to inflow ratio. Under this scenario standard numeric methods, such as the Huen method, can become numerically unstable. Both methods assume the reservoirs are fully mixed at a monthly time step. Flaming Gorge, Powell, and Mead include salinity in their bank storage computation. Water flows into the bank at the current time step concentration and fully mixes with the “bank” water. Water flows out of the “bank” at the current time step “bank” concentration.

Salt can enter the river system from either a natural source, salt loading resulting from irrigated agriculture return flows, or from flows imported into the system. Salt can leave the system from flows exported out of the system. Additionally, water quality improvement projects represent salt prevented from entering the system as the result of salinity control measures.

F.1.2 Input data

The CRSS salinity component requires several salinity specific data inputs. These include natural salinity at 24 nodes throughout the Colorado River System, future levels of salt loading resulting from agriculture, the concentration of exported and imported flows, future levels of salinity control, and initial reservoir salinity concentrations.

Salinity associated with the available natural flow data (described in Section 3.3) is computed with a single site salinity model presented in Prairie et al. (2005). This model uses a nonparametric regression method based on local polynomial estimation, which describes the variability of salt mass as a function of flow. The model is defined as: natural salt mass = f(natural streamflow) The main feature is that the function f is estimated locally (Loader 1999). The implementation steps are as follows.

1) At any value of the streamflow, say x*, K-nearest neighbors (K-NN) are identified from the observations.

2) To the K-NN a polynomial of order p is fit.

3) The fitted polynomial is then used to estimate the salt mass corresponding to the streamflow x*.

The number of nearest neighbors (K) and the order of polynomial p are estimated for the observed data using objective criteria, Generalized Cross Validation (GCV). The local estimation of the function f provides the capability to capture any arbitrary features (linear or nonlinear) that might be present in the data; besides, this obviates making any assumptions as to the underlying form of the function f (linear in the case of traditional linear regression approach). Prairie et al. (2005) provides details on the methodology and its development for salinity modeling.

Natural salt mass, required in compute the flow-salt regressions, is computed by removing anthropogenic influences (upstream reservoir regulation, salt loading from agriculture return flows, and salt removed with exports) affecting salt from observed historic data. Natural salt mass data from 1971-1995 were used for the 15 Upper Basin gauges, matching the time period used in the 2005 Triennial Review. The 9 Lower Basin gauges were modeled based on 1971-2004 natural salt mass data. Once the monthly regression relationships were determined for each gauge the associated natural salt for the natural flows from 1906-2004 are computed.

Salt loading resulting from agriculture is available at an annual time step and disaggregated to monthly values for modeling purposes. The concentrations of exported and imported flows are developed from available historic data at each export location and held constant through time. Future levels of salinity control are estimated from hydro-salinity studies performed for each salinity control project. Initial reservoir salinity concentrations were set based on the latest historic values available. These are the December 2005 values reported by the USGS with the exception of Davis and Parker Dam, which were assumed to be equivalent to Mead concentration since a December 2005 value is not available.

F.1.3 Calibration

To ensure the regressions properly capture the flow-salt relationship the regressions used to determine natural salt based on the 1971-1995 natural flows is input in a CRSS based model. The model is run with historic data representing salt loading from agriculture, concentration of exported flows, levels of salinity control, and initial reservoir salinity concentrations for the time period 1971-1995. If the simulated historic salinity concentrations below Powell and above Imperial Dam compare well with the actual historic salinity at these locations the model is properly calibrated. An example of this is shown in Prairie and Callejo (2005).

F.1.4 Limitations

Since the regression relationship between flow and salt is based a post-1971 values future projections are limited to simulating the post-1971 flow and salt relationship. A changing relationship cannot be modeled.

Limited data is available describing the monthly salt loading resulting from agriculture. Annual estimates are disaggregated for modeling purposes and monthly salinity results are typically aggregated to an annual time step before analysis of results. The variability of annual salt loading resulting from agriculture is not well understood; therefore, the annual estimate is held constant over all years. This assumption forces the variability in agricultural salt loading to be back computed into the natural salt mass. Therefore, it is important to recognize that the natural salt mass, as well as the natural flow, is NOT only what would naturally have occurred throughout the basin without anthropogenic effects. It also incorporates the error in any assumptions or in the accuracy of our estimates of the anthropogenic effects that we removed from the historic gauge records.

Lastly, the CRSS salinity component is generally intended for long-term modeling (15-20 years) and reservoir salinity is highly sensitive to initial reservoir conditions for the first 10-12 years. More accurately determining initial reservoir conditions will greatly improve the accuracy of the first 10-12 years of results. After these first 10-12 years the initial conditions have minimal impact on model results.

F.2 Reservoir Modeling Using CE-QUAL-W2 Water Quality Model - Model and Approach Description

F.2.1 Model Description (CE-QUAL-W2 Model)

CE-QUAL-W2 is a two dimensional, longitudinal/vertical, hydrodynamic, and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients (Cole 2003). Development and evolution of CE-QUAL-W2 has spanned three decades. The U.S. Army Corp of Engineers (USACE), J.E. Edinger and Associates (Edinger), and Dr. Scott Wells at Portland State University working with Mr. Tom Cole (USACE) have been the major developers in recent years. J.E. Edinger and Associates were contracted by the Upper and Lower Regions of the U.S. Bureau of Reclamation to test the earliest version of this model (LARM) in 1980 on Lake Powell and Lake Mead. All of the above have been helpful and provided some insight on the development of this application.

F.2.2 Model Capabilities & Limitations

The CE-QUAL-W2 model is capable of predicting water surface elevations, velocities, temperatures, and a number of water quality constituents. Water is routed through cells in a computational grid where each cell acts as a completely mixed reactor for each time step. Geometrically complex waterbodies can be represented through multiple branches and cells. Multiple inflows and outflows to the waterbody are represented through point/nonpoint sources, branches, precipitation, and other methods. Tools for modeling hydraulic structures such as spillways and pipes are available. Output from the model provides options for detailed and convenient analyses.

The model uses several assumptions and approximations to simulate hydrodynamics, transport, and water quality processes. The model solves for gradients in the longitudinal and vertical directions and assumes lateral gradients are negligible. This assumption may be inappropriate for waterbodies with significant lateral variations. Turbulence is modeled through eddy coefficients of which the user must decide which scheme is most appropriate for an application. An algorithm for vertical momentum is not included and results may be inaccurate in waterbodies with significant vertical acceleration. Water quality processes are extremely complex and the model uses simplified approaches to reach solutions. Several water quality processes are not simulated including zooplankton, macrophytes, and a dynamic sediment oxygen demand.

F.2.3 Input Data

The model is limited by the quality and availability of input data. This includes meteorological, inflow and outflow, water temperature, water quality, and calibration data. These data most often determine the accuracy and usefulness of the application.

F.2.4 Bathymetry

The bathymetry file of a CE-QUAL-W2 model is the two-dimensional numeric representation of a waterbody and is also referred to as the computational grid. The two dimensions represented are the longitudinal and vertical dimensions, or the length and depth of a waterbody which are divided into longitudinal segments and vertical layers. The lateral dimension, or width, is not represented in the grid but an average width is computed and used to determine volume. Since the model grid is two-dimensional all modeled parameters such as temperature, velocity, and water quality constituents can only vary in the longitudinal and vertical directions. This assumes that modeled parameters do not vary significantly in the lateral direction. This assumption has been found appropriate in relatively long and narrow waterbodies.

The components of the grid are, from smallest to largest, cells, segments, branches, and waterbodies. The cell is a single vertical layer within a single segment. Segments consist of one or more cells, branches are one or more longitudinal segments, and a waterbody is one or more branches. Bathymetry files are dimensions from a single waterbody.

The volume of the grid is computed by multiplying a cell’s length, thickness, and width. The sum of all cells within the grid is then the total storage for the waterbody. The computational grid storage is compared to actual storage-capacity charts to verify the model bathymetry accuracy.

F.2.5 Model Calibration

Model calibration involves comparing observed data to modeled, or predicted, results. The observed values are typically vertical profile and reservoir discharge observations for temperature and other water quality parameters. Calibration statistics are generated by computing the absolute mean error (AME). This computation is the sum of the absolute value of the predicted value minus the observed value, which is then divided by the total number of observations. This describes, on average, the difference between predicted and observed values.

F.2.6 Code Modifications

The unique chemical fingerprinting in Lake Powell with the build up of saline water, reservoir turn over and routing of the salt presents a unique data base to test the mixing algorithms of various models. The original WRE one-dimensional model, LARM, and earlier versions of CE-QUAL-W2 all completely mixed the reservoir each year, and thus multi-year runs were not possible. These models all fairly represented temperatures of the releases from the dam to test selective withdrawal alternatives. The version of CE-QUAL-W2 being utilized for this analysis is 3.2; however, Reclamation has contracted Environmental Resources Management (ERM) to assist in peer review and in code modification specific to this system. Since hydrodynamic mixing is critical to maintaining long term salinity profiles in this reservoir, a modification in the code was made for this modeling to improve seasonal mixing. Evaporation is one of the primary variables affecting vertical mixing in the reservoir. The code has been modified to allow the evaporation coefficients to be changed to a fixed value at any frequency. For the Lake Powell application monthly coefficients are used. By setting monthly evaporation coefficients the model calibration has been significantly improved for the test period in both heat and salinity budgets. Evaporation totals were compared with Reclamation computed monthly evaporation values as a calibration check.

F.2.7 Lake Powell Model

F.2.7.1 General Description

The Lake Powell model simulates hydrodynamics, temperature, salinity, dissolved oxygen, phytoplankton and organic matter decay. The model uses a geometric, computational grid and various input data to simulate these processes. The grid is discussed below. Input data describe meteorological conditions, inflows, outflows, and water quality parameters. Meteorological data are collected from Page, Arizona and Hanksville, Utah. Inflow records are used for the Colorado River (combination of the Colorado, Green, and San Rafael Rivers), San Juan River, and the Dirty Devil River. For inflows where little or no data is available estimates are made. These include:

- North Wash
- Trachyte Creek
- Hansen Creek
- Bullfrog Creek
- Halls Creek
- Escalante River
- Cha Creek
- Rock Creek
- Last Chance Creek
- Warm Creek

- Navajo Canyon
- Wahweap Creek

Outflow is for all releases made through Glen Canyon dam. Data for water quality parameters are from major tributaries where available. These datasets have been collected from the Bureau of Reclamation, United States Geological Survey, National Climatic Data Center, and Utah and Arizona state and local agency records.

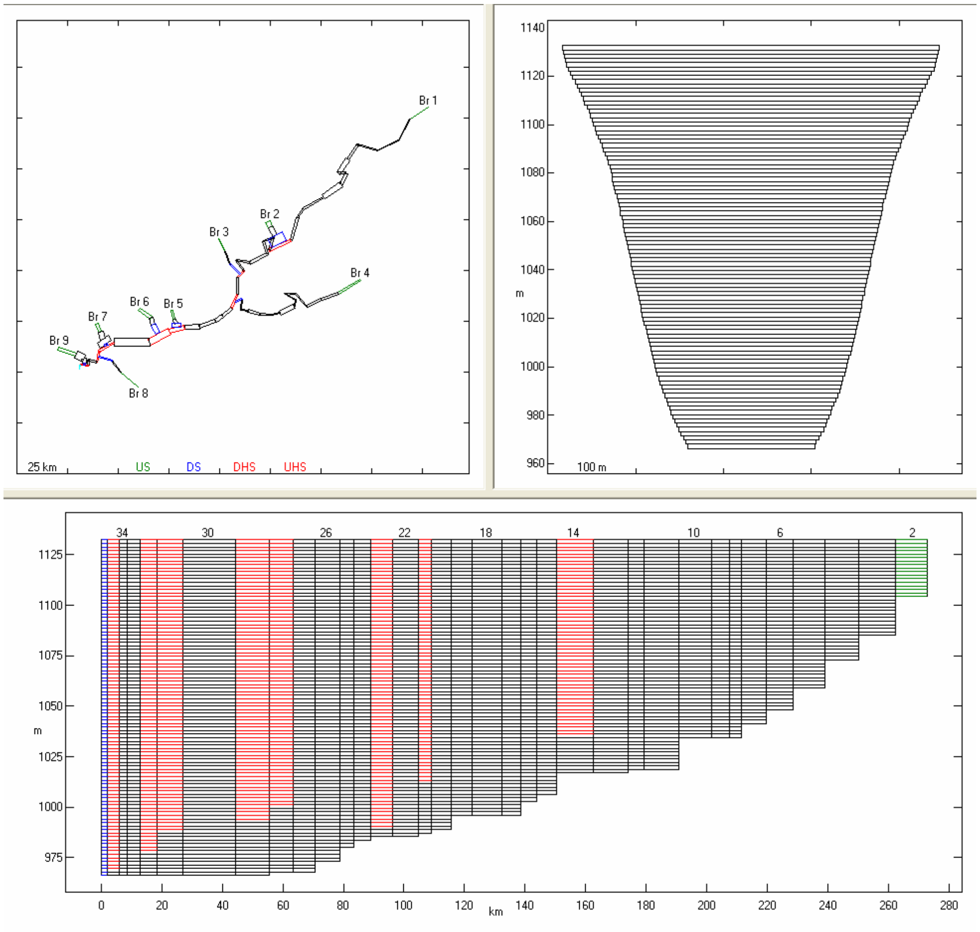
F.2.7.2 Lake Powell Bathymetry

The Lake Powell CE-QUAL-W2 bathymetry consists of 9 branches, 90 segments, and 97 layers. All layers are 1.75 meters thick. The branches represent the following channels and/or bays:

- Main (Colorado River) channel
- Bullfrog Bay
- Escalante River channel
- San Juan River channel
- Rock Creek Bay
- Last Chance Bay
- Warm Creek Bay
- Navajo Canyon
- Wahweap Bay

Figure F-1 is a diagram of the Lake Powell model bathymetry with top, front, and side views of the grid.

Figure F-1
Lake Powell Bathymetry



F.2.7.3 Lake Powell Model Assumptions

The input data used in the model are the best available and are assumed to be accurate representations of meteorology, flow, and water quality parameters. Additional assumptions, described below, may also affect model accuracy and reliability.

F.2.7.4 Meteorological Conditions

Meteorological conditions are represented in the model by one dataset. Data from the Page, Arizona airport is used to represent meteorological conditions on Lake Powell, mainly because it is the most complete dataset in the region. Page is located at the southernmost end of the reservoir and conditions there are not always representative of conditions on the rest of the lake, especially near the major inflows and northern end. The errors that result, however, are considered acceptable.

F.2.7.5 Water Balance

The model is calibrated to reproduce observed water surface elevations. An additional input referred to as the distributed tributary is created. This input includes flows that are required to balance the water budget, positive or negative. This represents precipitation, ungaged flow, bank storage, and other source/sinks. CE-QUAL-W2 distributes this flow evenly over the water surface in a simulation. Large flows can have water quality impacts. Reasonable assumptions are made for assigning water quality constituent concentrations to these flows.

F.2.7.6 Sediment Delta Interactions

Sediment deltas have built up near the mouth of major and minor inflows. Deposition and scour of these deltas creates interactions that impact several water quality parameters. The CE-QUAL-W2 model does not simulate sediment delta scouring, sediment digenesis of dissolved phosphorus, or chemical and biological oxygen demand release. This is on the edge of modeling and data gathering technology at this time. These processes are either not represented or an alternate approach is used to model them. The impact of these processes is not insignificant and until the approaches used are studied further the dissolved oxygen and nutrient calibrations are largely qualitative.

F.2.7.7 Lake Powell Model Calibration

The Lake Powell CE-QUAL-W2 model is considered calibrated for temperature and total dissolved solids for the period 1990-2005. Predicted results are compared to observed data from 13 locations including the tailwater. Calibration efforts for other water quality parameters such as dissolved oxygen, nutrients, and algae are ongoing and considered qualitative at this stage.

F.2.7.8 Temperature Calibration

Calibrations statistics for temperature are shown for each station in Table F-1. The number of profiles at each station is also given in the table. The AME of the temperature profiles is 0.8°C. The AME of the dam release temperatures is 0.45°C.

There are hundreds of individual profiles over the 15 year run period within the model. Three select vertical profiles with AME statistics are shown below for Wahweap (Figure F-2), Bullfrog (Figure F-3), and Cha (Figure F-4). A graph of the observed and predicted reservoir discharge temperatures is also shown (Figure F-5).

Table F-1
Lake Powell Temperature Calibration Statistics

Station	Years	AME	# of Profiles
Hite	91-05	1.39	52
Good Hope	92-05	1.11	52
Bullfrog	91-05	0.84	53
Escalante Confluence	91-05	0.69	54
San Juan Confluence	95-05	0.59	38
Oak Canyon	91-05	0.62	58
Crossing of the Fathers	91-05	0.58	60
Lower Zahn	91-03	1.21	38
Upper Piute	91-05	0.97	49
Lower Piute	91-05	0.80	44
Cha Canyon	91-05	0.69	51
Wahweap	91-05	0.65	179
Release Temperature	90-05	0.45	
Average		0.80	

Figure F-2
Temperature Profile at Wahweap Station, 2.4 kilometers from Glen Canyon Dam (AME = 0.39°C)

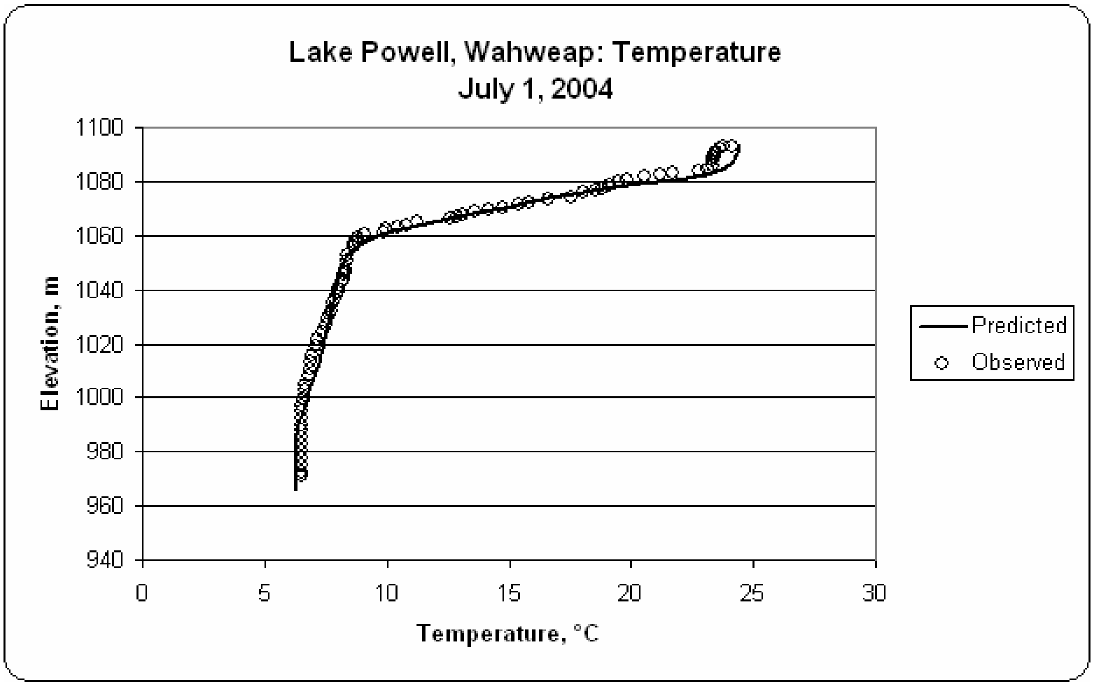


Figure F-3
Temperature Profile at Bullfrog Station, 169.2 kilometers from Glen Canyon Dam

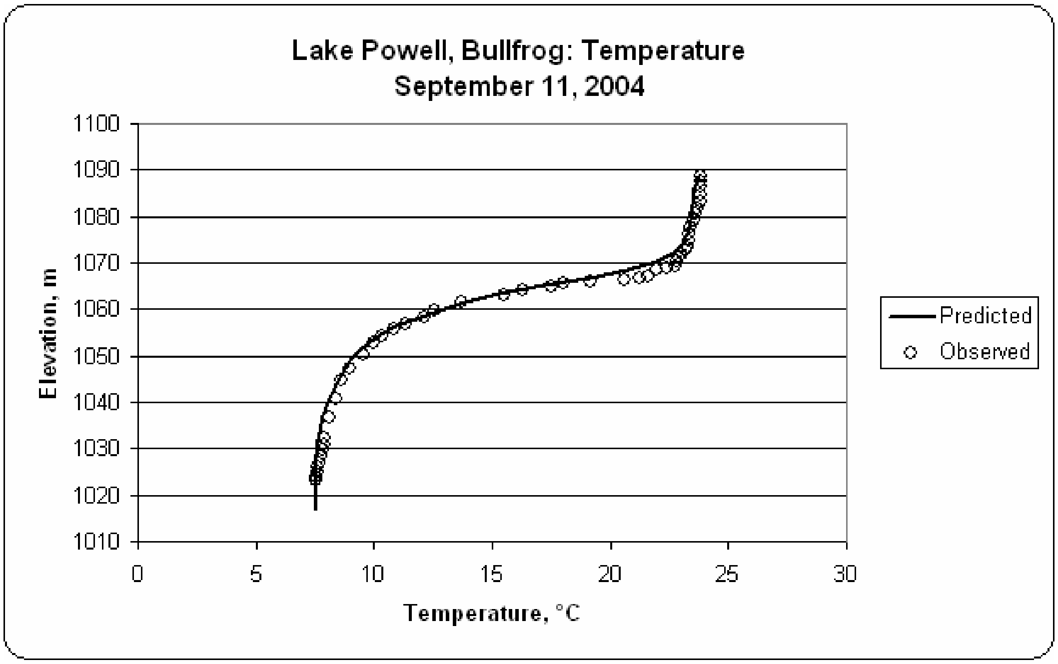


Figure F-4
Temperature Profile at Cha Station, 19.3 kilometers from the Confluence of the San Juan River and Colorado River Channels (AME = 0.32°C)

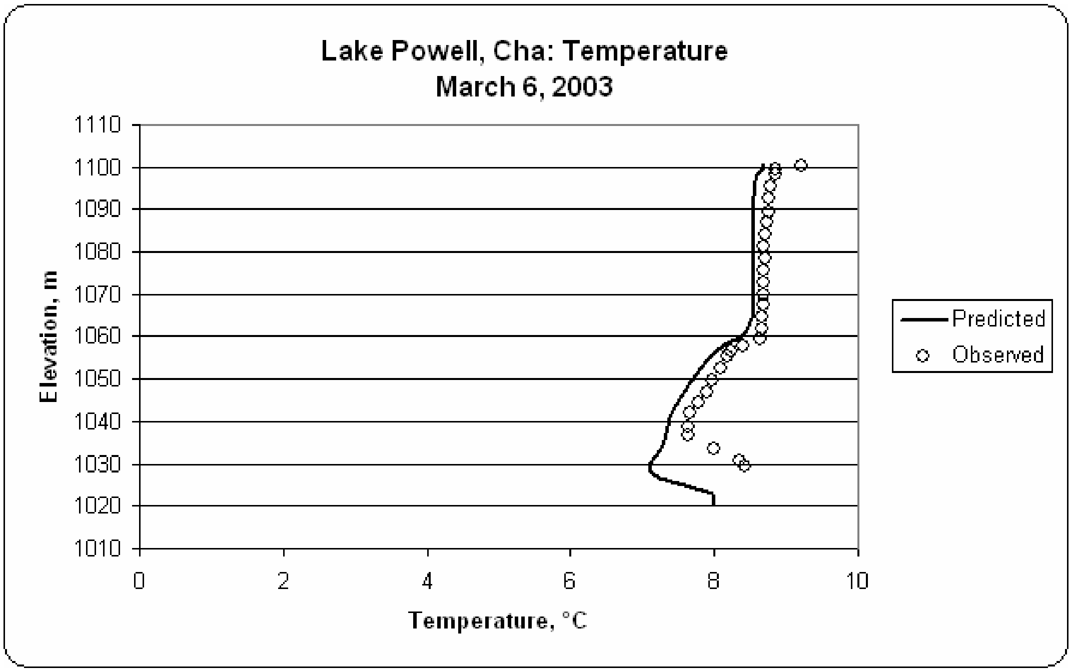
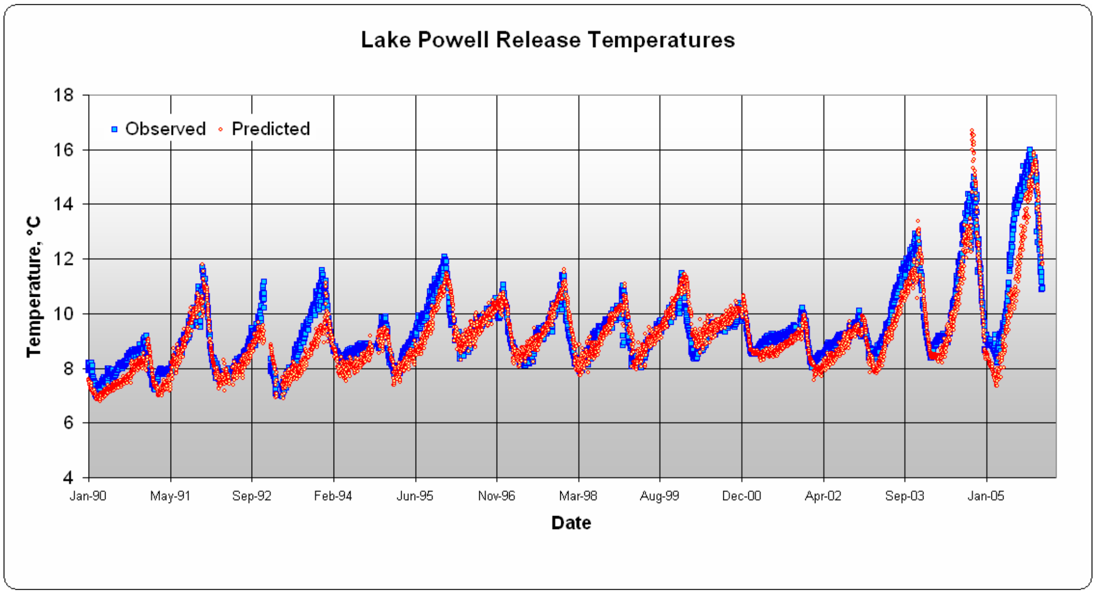


Figure F-5
Glen Canyon Dam Discharge Temperature Calibration



F.2.7.9 Total Dissolved Solids Calibration

Total dissolved solids, or TDS, are assumed to be a conservative parameter and, therefore, act as a tracer and help verify the hydrodynamic calibration. Calibration statistics and the number of profiles for TDS at each station are shown in Table F-2. The AME of the TDS profiles is 32.6 mg/L. The AME of the tailwater TDS is 14.1 mg/L.

Table F-2
Lake Powell TDS Calibration Statistics

Station	Years	AME	# of Profiles
Hite	91-05	54.98	52
Good Hope	92-05	41.61	42
Bullfrog	91-05	31.04	53
Escalante Confluence	91-05	27.88	54
San Juan Confluence	95-05	26.65	38
Oak Canyon	91-05	25.99	58
Crossing of the Fathers	91-05	25.42	60
Lower Zahn	91-03	40.43	38
Upper Piute	91-05	29.22	49
Lower Piute	91-05	24.25	44
Cha Canyon	91-05	27.01	51
Wahweap	91-94	34.71	179
Release TDS	90-05	14.1	
Average		32.63	

Three TDS vertical profiles with AME statistics, for the same stations and dates as the temperature profiles, are shown in Figure F-6, Figure F-7, Figure F-8, and Figure F-9.

Figure F-6
TDS Profile at Wahweap Station, 2.4 kilometers from Glen Canyon Dam (AME = 19.5 mg/L)

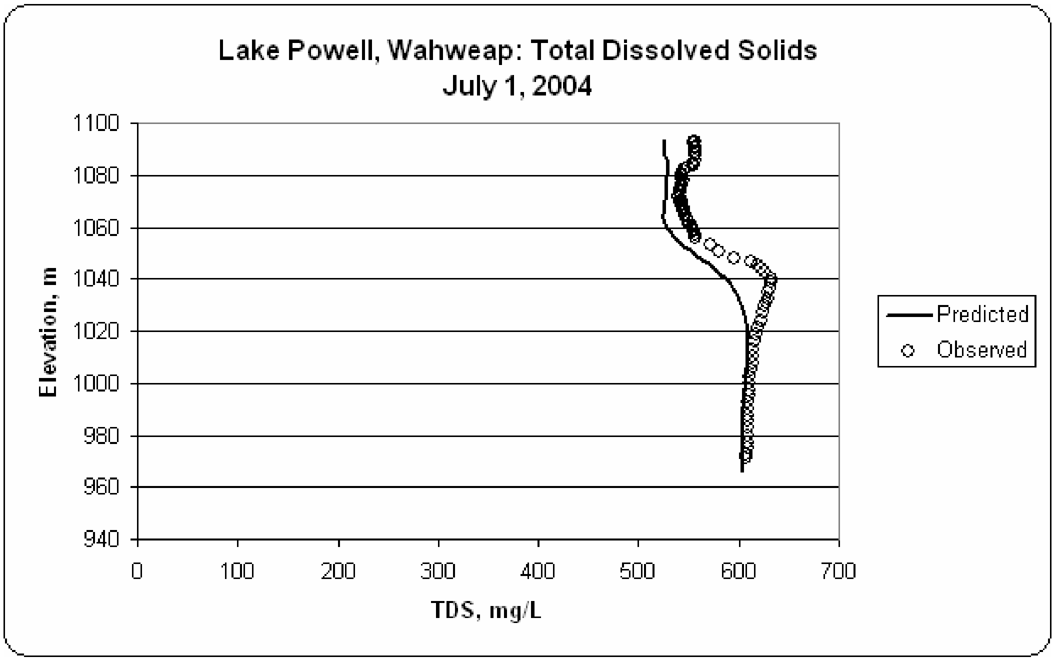


Figure F-7
TDS Profile at Bullfrog Station, 169.2 kilometers from Glen Canyon Dam (AME = 30.2 mg/L)

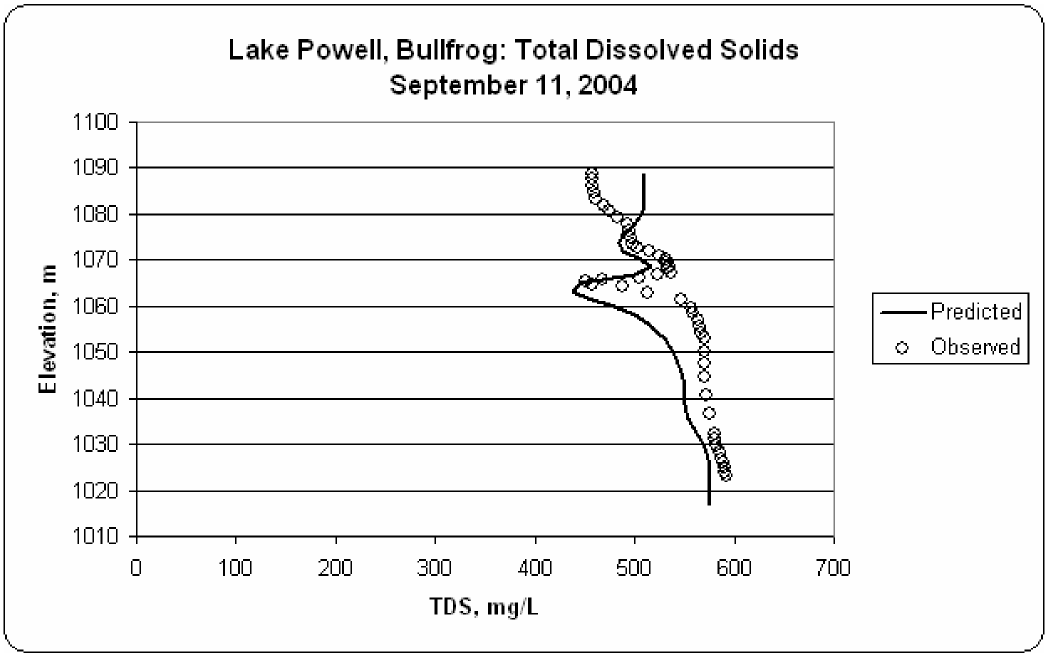


Figure F-8
TDS Profile at Cha Station, 19.3 kilometers from the Confluence of the San Juan River and Colorado River Channels (AME = 30.8 mg/L)

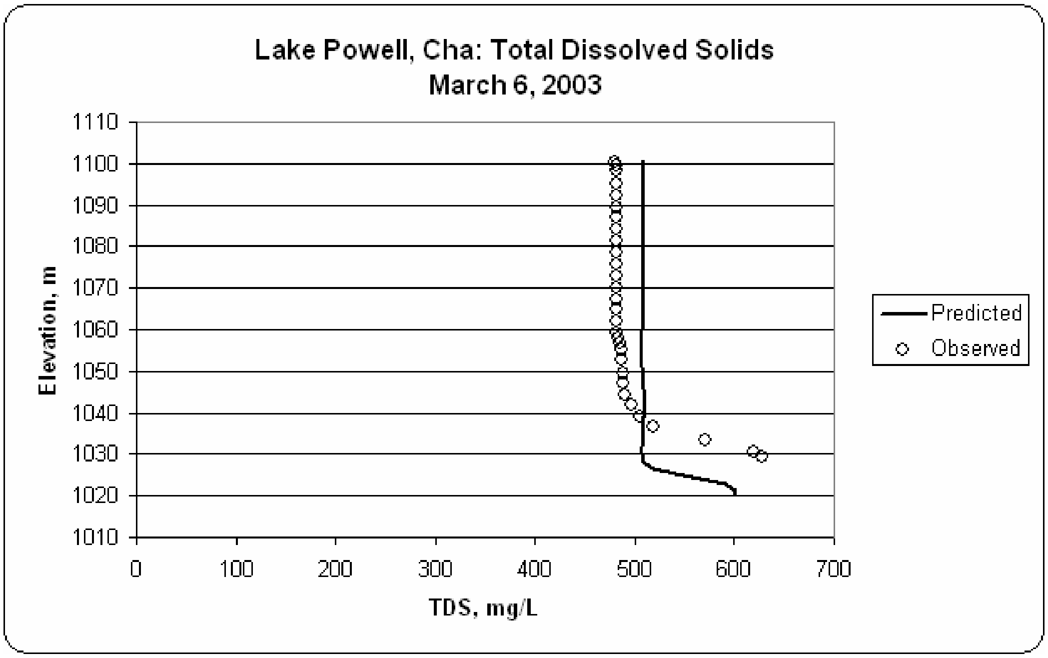
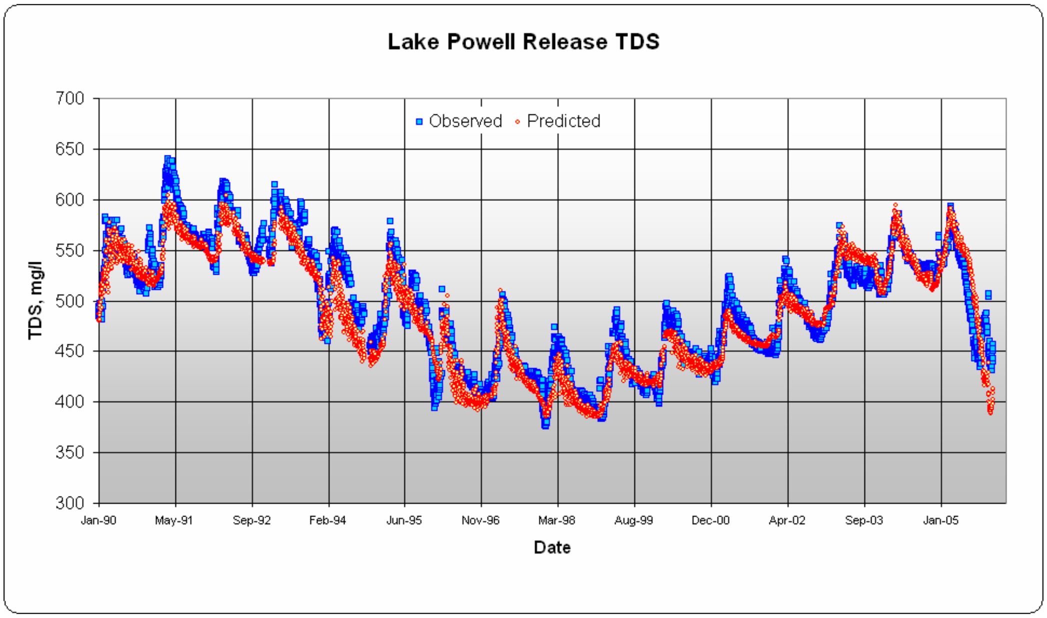


Figure F-9
Glen Canyon Dam Discharge TDS Calibration



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F.2.7.10 Dissolved Oxygen Calibration

The dissolved oxygen calibration is still in its initial stages of development. It is affected by temperature, wind and wave mixing, plankton production and respiration, organic matter decay, and other chemical and biological oxygen demands. Many of these are complex and not extensively monitored. A qualitative/semi-quantitative analysis using an empirical method is being developed, a summary of which is given below.

Dissolved oxygen trends and cycles appear to be related to hydrology and reservoir drawdown. Based on these two parameters two CBOD compartments in the CE-QUAL-W2 model are being utilized to represent the sum total oxygen demand. They are loaded as part of the parameters in the inflow constituent file. The loading values in these two inflow CBOD boxes are being calculated by a set of rules and relationships based on changes in reservoir elevation, inflow volume, and water temperature. One box is used to represent chemical oxygen demand processes predominating cold water inflow conditions, while the other is used more to represent summer time carbonate biological oxygen demand processes associated with bacteriological decay of organic matter. Calibration is accomplished by iterative runs (trial and error) and comparison with downstream segment oxygen, phosphorus, carbon, and phytoplankton profile numbers. The overall DO calibration has an AME of 1.2 mg/L for vertical profiles and 0.9 mg/L for reservoir discharge DO (see Table F-3). Vertical profiles of the dissolved oxygen calibration at Wahweap (Figure F-10 and Figure F-11), Bullfrog (Figure F-12), and Cha (Figure F-13) are shown below as well as the discharge concentrations (Figure F-14). Calibration is expected to be further improved with additional iterative runs and refinement to the method.

Table F-3
Lake Powell DO Calibration Statistics

Station	Years	AME	# of Profiles
Hite	91-05	1.11	52
Good Hope	92-05	0.96	51
Bullfrog	91-05	1.00	54
Escalante Confluence	91-05	1.04	54
San Juan Confluence	95-05	1.13	38
Oak Canyon	91-05	1.00	58
Crossing of the Fathers	91-05	1.21	60
Lower Zahn	91-03	1.45	38
Upper Piute	91-05	1.23	49
Lower Piute	91-05	1.11	44
Cha Canyon	91-05	1.19	51
Wahweap	91-94	1.40	182
Release DO	90-05	0.86	
Average		1.19	

Figure F-10
DO Profile at Wahweap Station, 2.4 kilometers from Glen Canyon Dam (AME = 1.3 mg/L)

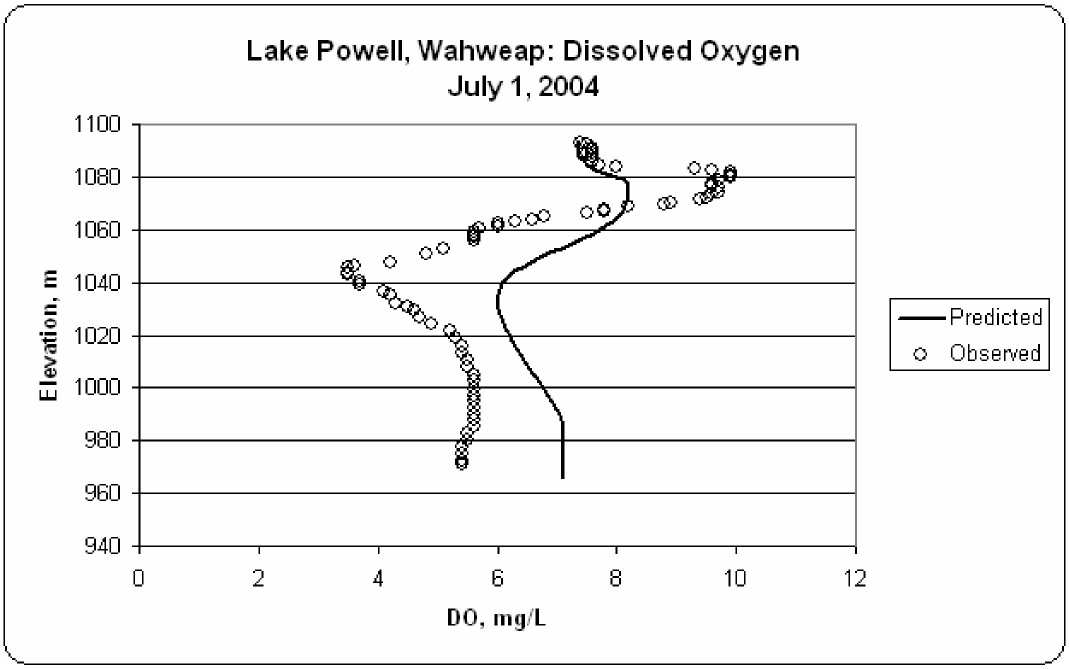

Figure F-11
DO Profile at Wahweap Station, 2.4 kilometers from Glen Canyon Dam (AME = 0.6 mg/L)

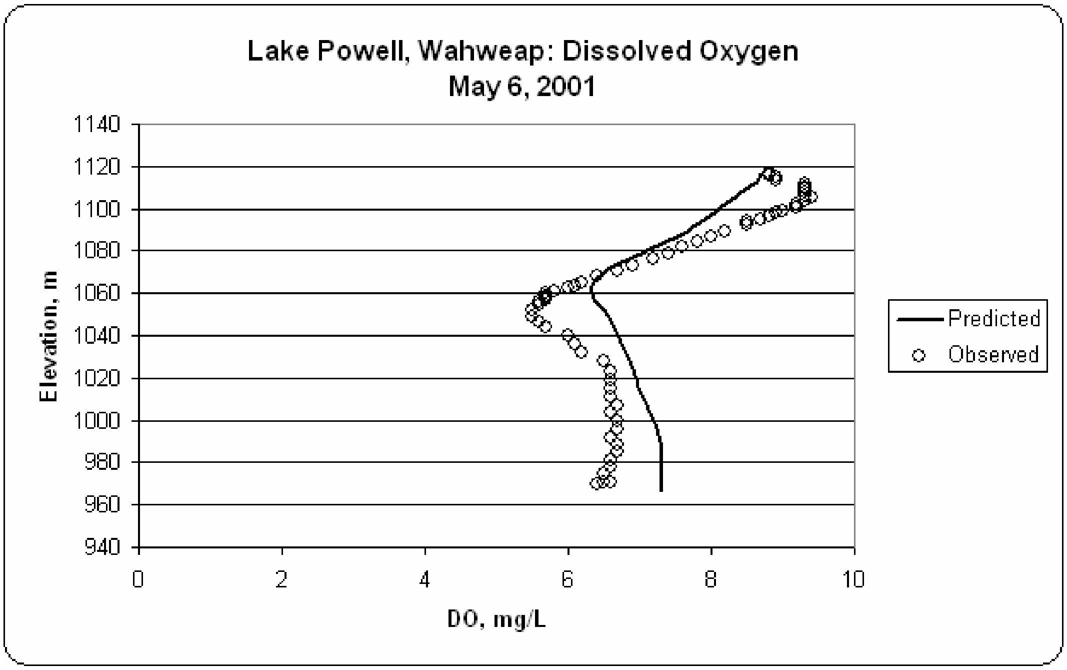

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Figure F-12
DO Profile at Bullfrog Station, 169.2 kilometers from Glen Canyon Dam (AME = 0.9 mg/L)

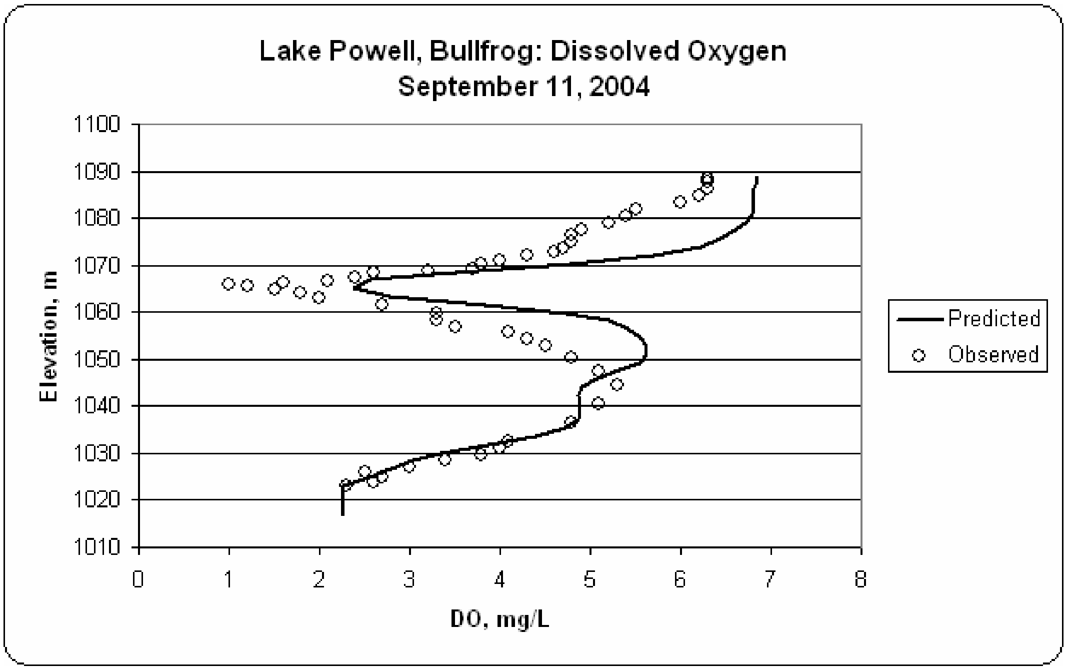

Figure F-13
DO Profile at Cha Station, 19.3 kilometers from the Confluence of the
San Juan River and Colorado River Channels (AME = 0.8 mg/L)

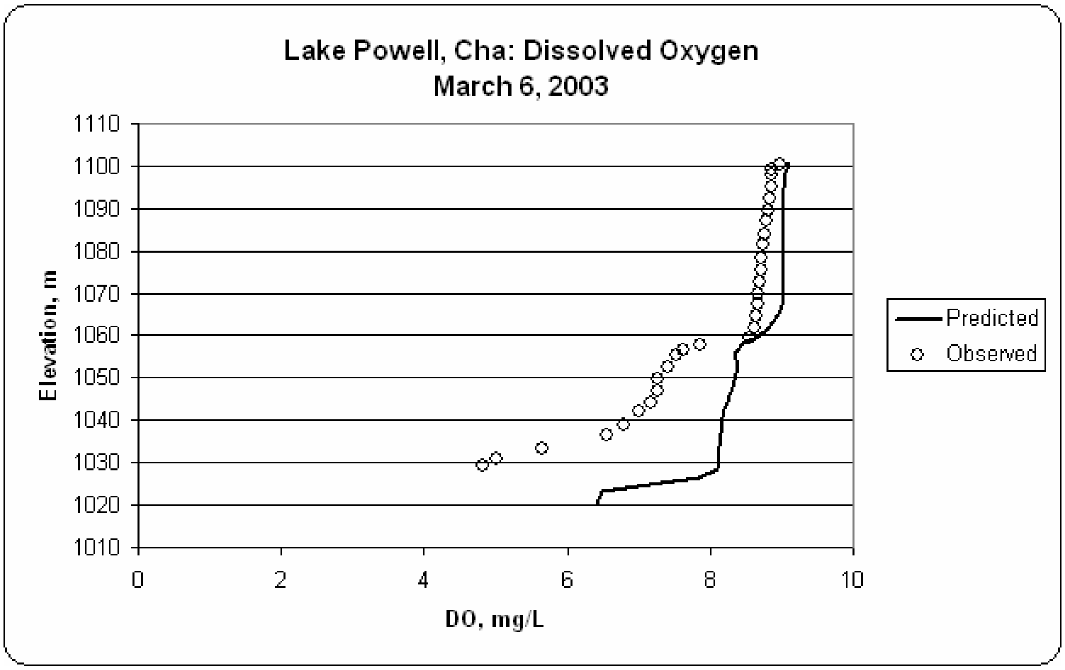

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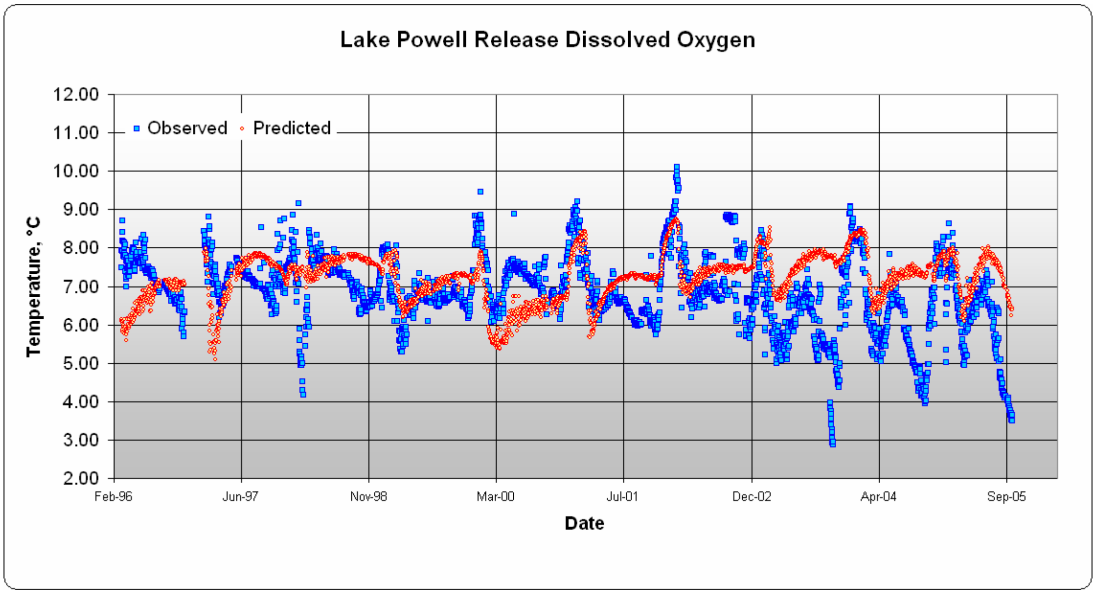
Figure F-14
Glen Canyon Dam Discharge DO Calibration



F.3 Temperature Modeling of Colorado River Flows Between Glen Canyon Dam and Lake Mead Using the GEMSS Water Quality Model - Model and Approach Description

F.3.1 Model Description (GEMSS Model)

The 1-D hydrodynamic and water quality model GEMSS was developed by J. E. Edinger Associates, Inc. (Wayne, PA). The transport equations for this model were similar to W2 which was based on the Generalized Longitudinal Hydrodynamic and Transport (GLHT) computation derived from the three-dimensional equations of fluid motion and continuity (Edinger and Buchak 1980). This model was selected because of its successful applications of the 1-D water quality/hydrodynamic module in TMDL studies. Like the CE-QUAL-W2 model it can model numerous water quality parameters; however, only water temperature was modeled for this study.

F.3.2 Model Geometry

The model’s geometry data below Glen Canyon Dam to the Inflow of Lake Mead was based upon GIS spatial information and river cross sections available from USGS Grand Canyon Monitoring and Research Center (GCMRC). This information was used to generate a simplified geometry grid covering 280 miles of the Colorado River using 102 segments with averaged length of 7,000 m (23,000 ft) each and 234 slope points.

F.3.3 Model Time-varying Data

The model's time-varying data sets included flow rates, water temperatures, downstream water surface elevation, and meteorological data which were used to compute surface heat exchange. The boundary hydrology included daily average release data from Lake Powell and daily inflows of an average year (1947-2004) from the Little Colorado River. These data came from USGS gauging stations and Reclamation database. The water temperature boundary conditions included daily measured temperatures at Lees Ferry and daily temperature of an average year from the Little Colorado River. Meteorological data from Page, AZ was required to compute surface wind shear and heat exchange and consisted of hourly air and dew point temperature, wind speed, wind direction, cloud cover, solar radiation, and atmospheric pressure.

F.3.4 Temperature Calibrations

The GEMSS model was calibrated to observed Diamond Creek hydrology and observed water temperature at three locations (Lees Ferry, Little Colorado River confluence, and Diamond Creek) that were provided by GCMRC. The calibration period was based on the same period used in CE-QUAL-W2 (1990 to 2005); however observed data for these three locations were sporadic for this time period.

To verify the mass balance calculation of the model, the modeled flows were compared with actual flows at Diamond Creek. The modeled flows at Diamond Creek were consistently lower than observed flows by about 6% due to limited tributary inflows and constant average daily flows of a year from the Little Colorado River. The average errors for comparison between modeled and observed water temperatures were -0.08 °C at Lees Ferry, 0.09 °C below the Little Colorado River, and -1.1 °C at Diamond Creek (Figures F-15, F-16, and F-17 respectively). The modeled water temperatures at the Diamond Creek station were consistently lower than the observed data. This was likely caused by the difference in meteorological data between Diamond Creek and Page.

Figure F-15
GEMSS Modeled and Observed Temperatures at Lees Ferry (a sample period of 1995 to 2002)

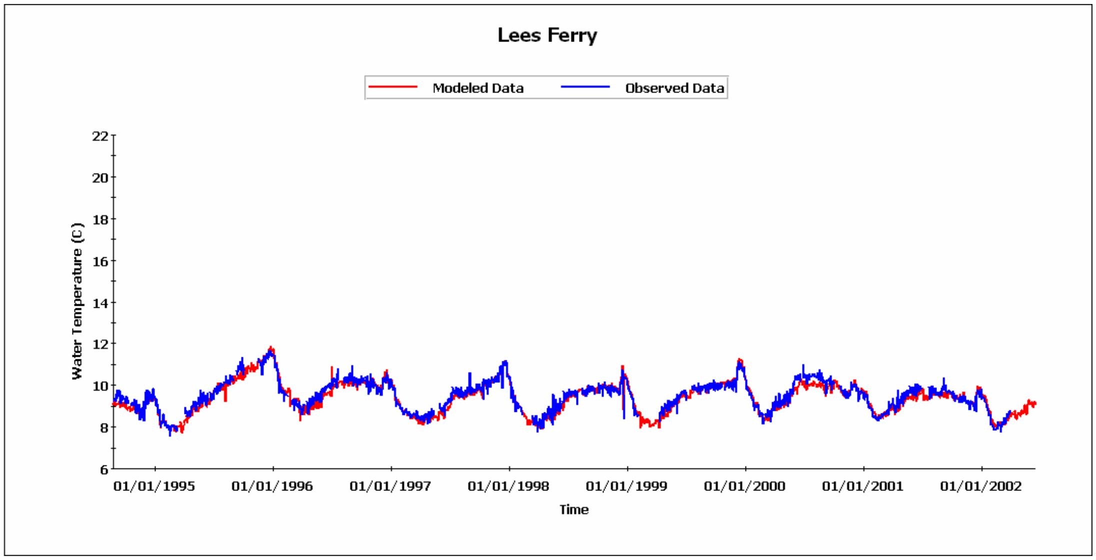


Figure F-16
GEMSS Modeled and Observed Temperatures at Diamond Creek (a sample period of 1999 to 2002)

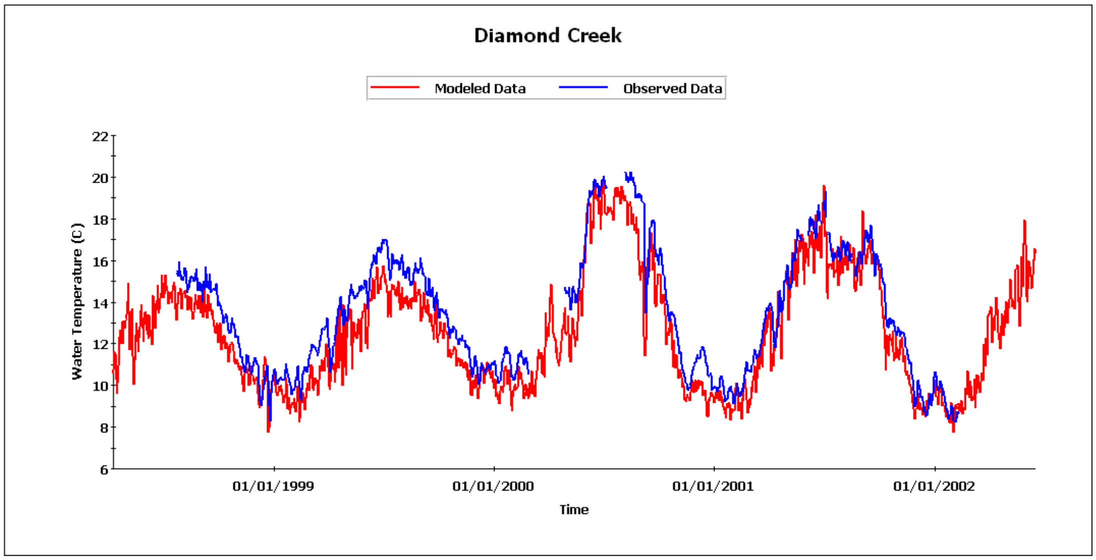
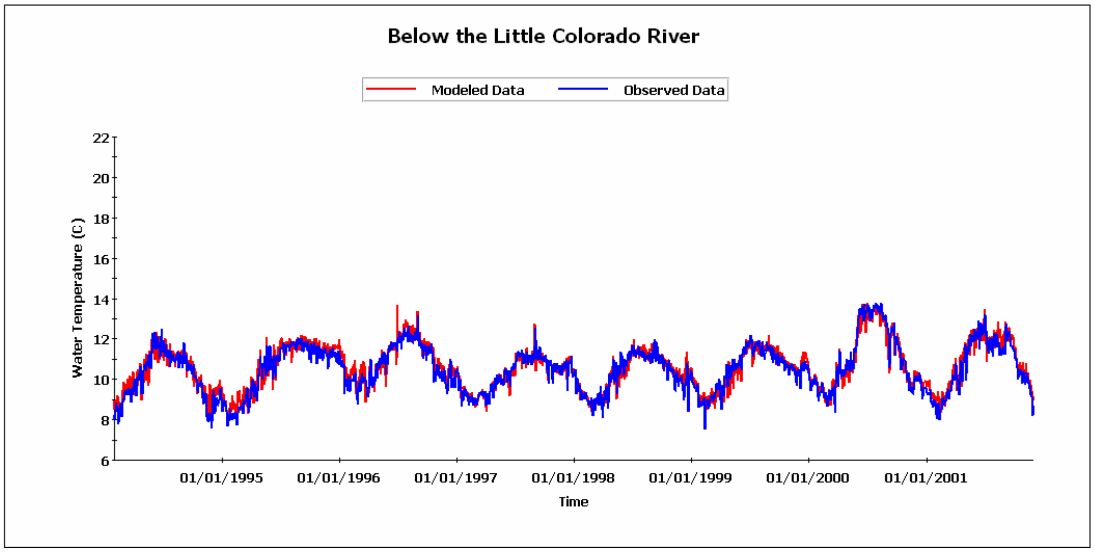


Figure F-17
GEMSS Modeled and Observed Temperatures for Below the Little Colorado River (a sample period of 1994 to 2002)



F.3.5 Analysis of Alternatives

The calibrated GEMSS model was used to analyze downstream temperature regimes for the Shortage alternatives. Release water temperatures from the CE-QUAL-W2 model and the flows from the CRSS model were used as inputs to the GEMSS model. The following assumptions were made in analyzing water temperatures downstream of Glen Canyon Dam:

- Monthly average reservoir release volumes were used for each of the CRSS 90th, 50th, and 10th percentile Powell elevations.
- Minimum and maximum release volumes based on each of the alternatives (including No Action) were used for each of the CRSS percentiles as mentioned in number one.
- Minimum and maximum release temperatures from CE-QUAL-W2 for all Shortage alternatives were used for each of the CRSS percentiles.
- A warm and a cool meteorological year (i.e. warmer or cooler air and dew point temperatures) were applied across alternatives and CRSS percentiles.
- The Basin States Alternative and Conservation Before Shortage Alternative were analysis as one alternative.

The outcome from combination of variable release volume, temperature, and meteorological conditions resulted in a range of temperatures at any given location and time of year.

F.4 References

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