High Rock Lake

Technical Advisory Committee

Draft Lake Response Models

Review Comments and Responses

Prepared for

United States Environmental Protection Agency, Region 4
61 Forsyth Street, SW
Atlanta, GA 30303
Contract Number: EP-C-08-004

Task Order: 036

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Completed by Tetra Tech March 28, 2013

Final remarks included by NC Division of Water Resources March 26, 2015

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1.0 Introduction

The High Rock Lake Technical Advisory Committee (TAC) reviewed the High Rock Lake draft response models (hydrodynamic and water quality), developed by Tetra Tech, Inc, under EPA Contract. The TAC received the models on September 27, 2012. Due to the complexity of the models, DWQ extended the comment period from 45 days to 60 days. As a result, final review comments were due by November 28, 2012.

Several TAC members provided comments: Yadkin Riverkeeper, Alcoa Power Generating, Inc. (APGI), Piedmont Triad Regional Council (PTRC), and the Yadkin-Pee Dee River Basin Association (YPDRBA) and the North Carolina Department of Transportation (NC DOT) submitted joint comments that were developed under contract by LimnoTech (LTI).

This document contains the relevant comments submitted by reviewers and the responses to those comments. Comments developed by LTI for YPDRBA and NCDOT are designated as YPDRBA/NCDOT/LTI.

March 2015 Division of Water Resources (DWR) Note: Note additions to this document by DWR to document final changes to the model are included below.

2.0 Review Comments on Draft Hydrodynamic Model (EFDC)

2.1 Turbine Intake

Comment (APGI): At High Rock dam, the reservoir is modeled as five (5) vertical layers and the thickness of these vertical layers varies depending on the depth of water in the reservoir. As the depth increases, each layer gets thicker to account for the additional water. In the model, withdrawal from the reservoir to account for the flow through the turbines is removed from the second layer down from the surface of the water (indicated in the EFDC input file QSER.inp). In the model, the top and bottom of the inlet to the turbine vary due to the sigma stretch component of the model. As represented in the model, the average intake bottom elevation and top elevation are 602.8 ft USGS and 612.2 ft USGS, respectively.

In actuality, the High Rock turbine intake structure has the following elevations:
Top of Intake: 605.9 ft USGS
Bottom of Intake: 568.9 ft USGS
Turbine Centerline: 575.9 ft USGS

Comparison of these elevations to those used in the model clearly shows that the modeled intake elevations and the actual intake elevations do not align. Thus, as currently configured the model is drawing water from higher in the water column than actually occurs.
APGI believes the discrepancy between the physical layout of the dam and that assumed in the model is a critical issue that must be addressed. We recommend the model be adjusted to incorporate the turbine withdrawal in layers 2 and 3 of the model, such that the intake elevations modeled more closely align with the actual intake elevations.

Response: *The turbine representation in the hydrodynamic model will be modified. Potential impacts on the hydrodynamic simulation will be evaluated and the model adjusted as needed.*

2.2 Mass Balance and Turbine Efficiency

Comment 1 (APGI): APGI is also concerned about the water balance and flow correction used in the model and discussed in the Model Report. Specifically, Section 3.2.1 discusses how during preliminary runs of the High Rock Lake EFDC model estimated inflows exceeded reported outflows. The Model Report further indicated that this discrepancy was likely due to seepage losses from the reservoir and uncertainty in the estimated releases through the turbines due to gradual declines in turbine efficiency.

Overall, the Model Report indicated that a correction factor of about 15% was utilized to account for this difference. APGI believes that the discrepancy between the estimated inflows and the USGS inflows is due to the estimated turbine outflows and is on the order of 5-6% as opposed to the 15% reported in the Model Report.

APGI measures and records kilowatt hours (kWh) and headwater elevation hourly. Turbine discharge is estimated by converting measured energy in kWh to flow volume in cfs-hr using hydro unit efficiencies as determined when the units were commissioned. Spillway gate discharge is estimated as a function of headwater elevation and gate opening. Inflow to High Rock is then calculated as a function of reservoir storage change and discharge.

As a part of the hydropower project operations modeling that was conducted during the recent FERC relicensing process, APGI conducted a review of the High Rock Reservoir mass balance by comparing the inflows to High Rock (estimated as described above) to the inflows constructed from USGS gauging station data (see Yadkin Project FERC License Application Exhibit B) for the period from calendar year 1980 to 2002. APGI found that the average monthly inflow based on USGS data was on average 6% higher than flow estimates, based on new unit efficiency.

Seepage is currently monitored by APGI at 19 monitoring locations at the High Rock dam and powerhouse area. The historical maximum seepage ranges from 0 to 60 gpm with a maximum of 171 gpm. Based on the monitoring and on-site observation, the seepage around the dam is insignificant in comparison with the quantity of inflow and outflow. Losses from the reservoir to groundwater and potential underflow are also likely insignificant; otherwise, the large losses would be detected during the long history of High Rock dam and powerhouse operations and inspections. Because the method of calculating inflows described above accounts for evaporation, no formal estimate of evaporative losses was conducted.

Given the information available regarding seepage and turbine efficiency, APGI believes that correcting the mass balance in the model with the LOESS approach is not the best approach. As an alternative, APGI suggests that Tetra Tech consider using the water level at the dam as a boundary condition in the model. This modification would also require model recalibration, which could be undertaken in conjunction with changes made to correct the problem with the intake elevations, described previously.

If, however, the suggested alternative boundary conditions are not used to recalibrate the model and the LOESS approach is kept, the modeling effort must include an investigation of whether there is any statistical significance to the apparent creep in calibration (there appears to be worse agreement between the predicted water levels and observed water levels later in time specifically beginning in mid-2009), and a discussion of this behavior must be included/extended in the Model Report.

Comment 2 (PTRC): On pages 3-3 through 3-5, Section 3.2.1 ("Water Balance and Flow Correction"), the flow inputs to High Rock Lake are modeled and calibrated with validation data collected from the lake. Tetra Tech uses a LOESS curve to smooth outlying data that deviates from the statistically normal flow data for High Rock Lake. The resulting curve is then applied to the lake model as representative of flow dynamics in the lake.

This approach appears to ignore the seasonal periodicity of High Rock Lake's flow dynamics, with higher disparities between high and low flows being observed in the late fall and winter of every year, likely due to higher precipitation and lower lake levels. The PTRC requests that NC DWQ and Tetra Tech explore non-linear flow models that will better represent this periodicity and the more challenging dynamism of flow in the Lake during the late fall and winter months. We would at least like a report on why the LOESS model delivers a curve that is most representative of flow dynamics in High Rock Lake compared to other options.

Response: *The flow correction on outflow is equivalent to about 15 percent of the reported dam outflow. APGI suggests that the discrepancy due to estimated turbine outflows is on the order of 5-6 percent based on comparison of estimated outflow to USGS gaging of inflows.*

We agree that the flow balance discrepancy is not entirely due to the turbine outflow efficiency curves, and the report lists this as only one among several causes. However, the APGI estimate of the turbine effect is also uncertain because portions of the watershed are ungaged (see Table 2-3). How flow from these ungaged areas is estimated will clearly have an effect on the overall water balance.

APGI also notes that monitored seepage rates through the dam are small. However, losses to ground water that may re-emerge downstream of the dam are unknown.

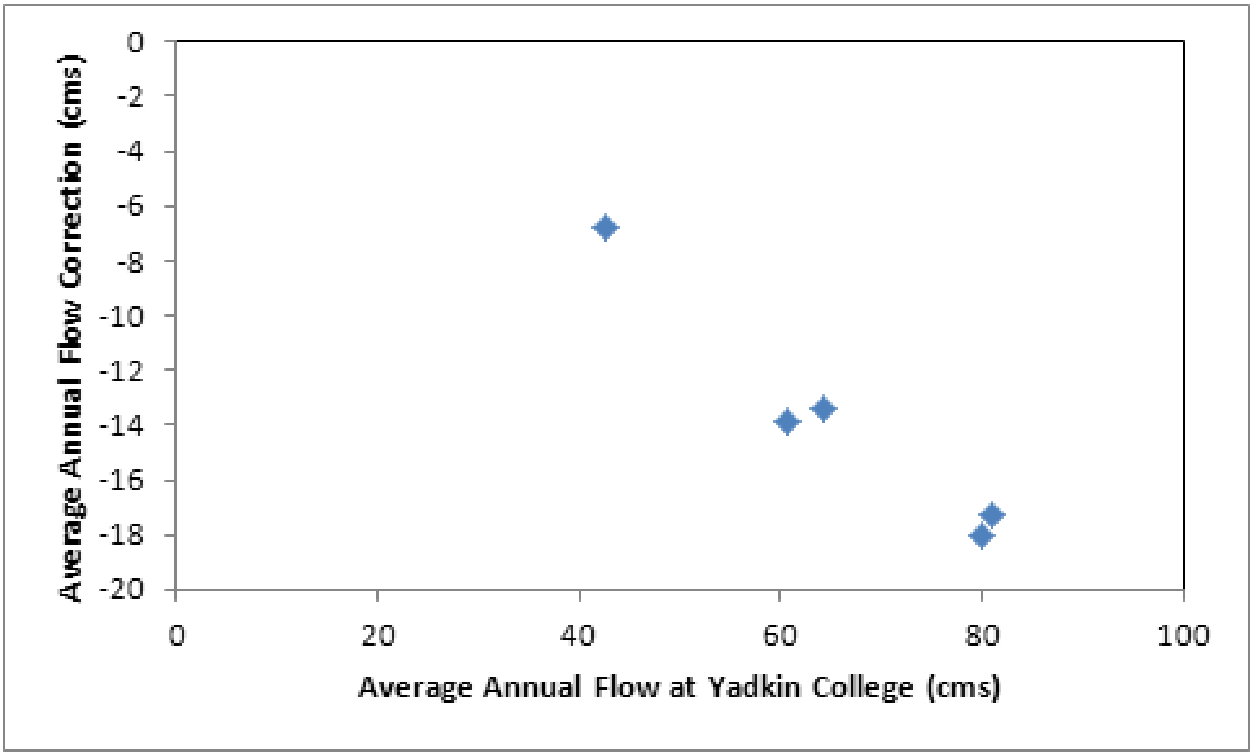
In sum, the flow correction accounts for a number of sources of uncertainty, including the following:

- *Estimation of turbine outflows based on unit efficiencies "as determined when the units were commissioned."*
- *Estimation of spillway discharge based on head and gate opening.*
- *Uncertainty in USGS gage records.*
- *The extrapolation of USGS gage records to ungaged areas.*
- *Net groundwater exchanges, including dam seepage (likely small) and losses to deeper groundwater pathways (magnitude unknown).*
- *The fact that the model representation of stage versus storage is specified on a relatively coarse grid, which necessarily introduces some discrepancies relative to the true stage-storage curve.*

Given these various sources of uncertainty, the magnitude of the proposed flow correction is believed to be reasonable.

A suggestion was made that the flow correction approach be abandoned in favor of "using the water level at the dam as a boundary condition in the model." Use of an elevation boundary condition is not feasible for several reasons. First, as APGI points out, releases from both the turbines and the spillway are from subsurface layers. Simulation with an elevation boundary condition would incorrectly constrain *all releases to occur from the surface. Second, an elevation boundary condition is only appropriate when the elevation profile above the dam is not influenced by momentum and approach velocity considerations. It could be used when outflow occurred over a very wide and constant elevation weir; however, the outflow for the actual dam configuration would be over-estimated.*

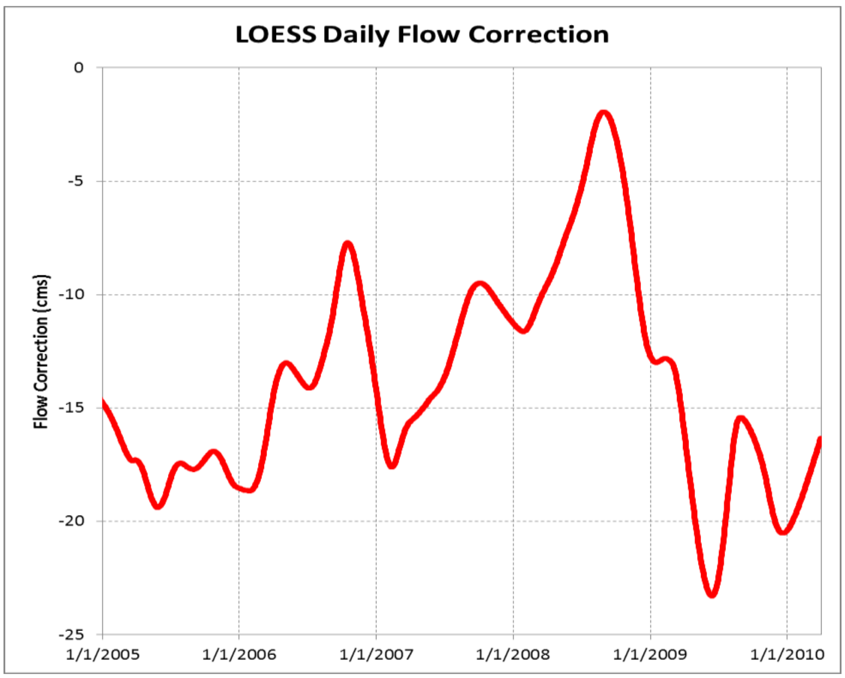
Contrary to the comments, there is not a consistent "creep" in the WSE calibration over time. The points in Figure 3-2 in the report show the daily discrepancies in terms of the difference in flow needed to match the reported WSE. The magnitude of these daily discrepancies average 17.25 cms in 2005 and 17.99 cms in 2009 and the average for some of the intervening years is smaller. Instead, what is seen is that the magnitude of the flow correction, averaged by year, is correlated to the magnitude of average annual flow in the Yadkin River at Yadkin College, with the smallest average flow correction in the driest year (2008) and the largest magnitude flow correction in the wet years of 2005 and 2009.



This correlation suggests that a significant part of the flow correction may be related to the uncertainty in extrapolating flows to ungaged areas and/or the estimation of flow from the gated spillway, which accounts for a greater proportion of the outflow during high flow years. A note to this effect has been added to Section 3.2.1.

For related reasons, the fit between observed and simulated WSE appears worse in 2009 and the beginning of 2010 than in earlier years. In addition, 2009-2010 include significant periods in which the WSE was above normal full pool. As noted in Section 3.2.2, the model grid does not represent lateral expansion of the lake surface into low-lying nearshore areas when the water surface elevation exceeds the normal pool elevation, leading to spurious discrepancies in the WSE fit. This is a standard approach in grid-based models. As discussed in Section 2.2.1, EFDC can be configured to include grid cells that wet and dry, allowing lateral expansion of the surface area during high-flow conditions. However, use of this option greatly increases run times in the hydrodynamic model. Further, the WASP water quality model *does not allow drying segments and detaching the EFDC wet-dry segments from the WASP simulation would not preserve mass. Therefore, standard practice for linking EFDC and WASP is to use a fixed lateral grid. The resulting impacts on the water quality simulation are small as the volumes are correct. The discrepancies in layer thickness and surface area have a minor impact on reaeration and light penetration calculations, but only during those periods when the WSE is above normal full pool.*

The relationship of flow correction to flow magnitude also accounts for the fact that the daily discrepancies are "noisier" (have greater variance) in the winter period when inflows are typically higher. Note (see Figure 3-2) that daily disparities tend to be larger in the later fall and winter (in both the positive and negative directions), but cumulative differences stay within a relatively small range. PTRC requested exploration of "non-linear flow models that will better represent this periodicity." The LOESS approach is inherently non-linear as it fits local trends that shift over time. Specifically, it allows for somewhat larger (more negative) flow corrections in the fall and winter period without overfitting the daily discrepancies. A plot of the LOESS flow correction series (Figure 3-2 with the individual daily data points removed for clarity) shows that the series does indeed incorporate seasonal patterns along with patterns associated with the magnitude of flow.



Tetra Tech did investigate use of a daily unsmoothed flow correction series. With such an approach a perfect fit to observed WSE can be forced; however, this requires use of large daily flow corrections in both the positive and negative directions. This approach was rejected because it appeared physically unrealistic and amounted to overfitting of the data. The LOESS-smoothed approach is believed to provide a reasonable approximation that is consistent with the likely sources of error in the flow balance.

2.3 Gated Spillway

Comment (APGI): In addition to our concerns about modeled withdrawal for the turbine intake, APGI believes that Section 2.2.7 of the Model Report suggests that Tetra Tech may misunderstand how the gate-controlled spillway at High Rock dam is operated. We recommend that the discussion in Section 2.2.7 be modified to provide a more accurate description of how the hydropower project is operated. For your convenience, we have developed a modified version of Section of 2.2.7. Specifically:

> APGI (2002) describes High Rock Dam as 936 feet long, with a maximum height of 101feet. The dam has a gate-controlled spillway with an integral powerhouse intake. The dam is currently operated in a store and release mode according to an operational rule curve established in 1968. The rule curve is written in terms of power generation as a function of~~, rather than~~ elevation, and ~~but~~ generally maintains higher lake levels from mid-May to mid-September. The pool is drawn down in the fall, and then refilled during winter rains. The annual maximum drawdown averages 12 feet in winter and 5 feet in summer. The normal daily fluctuation in water level is 1 foot, with a maximum daily fluctuation of 2 to 4 feet.
>
> Water is discharged from the lake via the hydropower turbines and the gated ~~overflow~~ spillway. Turbine flow is controlled by wicket gates on the units. Spillway discharge occurs through a 550 foot long gated spillway. The spillway gates are vertical lift or underflow gates with an invert at ~~above an~~ elevation 593.9 ft. ~~MSL~~ NGVD 29. APGI operates High Rock Lake for hydropower generation through the year. The primary outflow of the lake is through the turbines to generate power. The intake for the turbines is subsurface. As needed during infrequent high flow events, excess water is released over the dam ~~through the~~ spillway gates in accordance with a gate operating procedure. The procedure specifies that gates are opened on increasing inflow to maintain headwater at or near full pond until gates are full open at approximately 290,000 cfs. ~~The spillway is 550 feet long.~~ Hourly estimates of flow through the turbines and ~~over the~~ spillway gates were provided by APGI as well as the description of when the spillways gates were used. These data were aggregated to daily values for use in the model and assigned as time series to the subsurface model layer representing the turbines and the surface model layer representing the spillway. There were two lateral model grid cells representing the forebay at High Rock Dam. One was used with the surface layer cell to represent the spillway flow and the other lateral location was used at the cell layer just below the surface to represent discharge through the turbines.

Given that the gated spillway is operated specifically to maintain full pond elevation during high inflows, but not beyond that water level, the model should not predict water levels well above full pond elevations. Where this occurs in the model results, we believe that these spikes are an indication of model instability as opposed to actual high water level events. The gated spillway is incorporated into the model in layer 5 which is constantly at the surface and never overlaps with the turbine intake, which is different from how the dam is actually operated. Because of the design of the spillway gates, APGI believes that the gated spillway should be incorporated into model layer 3. The suggested changes in incorporation of the dam into the model will result in a more accurate prediction of how dam operation influences water levels in High Rock Reservoir and consequently a better water quality model of the reservoir.

Response: *We thank APGI for providing corrected details on the representation of the turbine and spillway discharges. The suggested modifications to the text provided by APGI have been used to revise Section 2.2.7 of the report. The hydrodynamic model is being rerun using the corrected vertical layer assignments. Preliminary runs suggest that this has only a small impact on the simulated temperature profile in the lake forebay.*

2.4 Flow Boundary Conditions

Comment 1 (APGI): Section 2.2.4 of the Model Report states that "Gaged flow, rather than simulated flow, was used to drive the lake model during calibration and validation to minimize errors propagated from the watershed model". APGI believes that the use of gaged flow for model calibration calls into question the legitimacy of any future application of the model.

APGI agrees that the use of gaged flows will limit propagation of the errors from the watershed model during calibration and validation; however, we question how the watershed model and the Lake Model will be coupled together during model application. It is likely that the hydrology of the watershed will be much different under any future scenario that includes more intense development in the watershed. Likewise, the probable future utilization of best management practices (BMPs) to control suspended solids and phosphorus will likely include many infiltration BMPs. By design, such BMPs will change the hydrology of the watershed. If the predicted watershed model flows will be used in actual model application, they should be used in calibration and validation. If this is not done, the propagation of errors from the watershed model will be present in the Lake Model and the impact of this propagation will not have been quantified. This would call into question the validity of model application.

Further, Section 2.3.2 of the Model Report indicates that while gaged flows were used to drive the hydrodynamics, "watershed model simulated pollutants are used to drive the lake water quality model." Tetra Tech acknowledges that this has the potential to introduce timing discrepancies. To account for this Tetra Tech applied water quality constituents as concentration boundary conditions. APGI believes that this is a questionable approach because it assumes a linear relationship between all water quality constituents and flow. This may be appropriate for some parameters (for example DO), but may not be appropriate for other parameters (for example TSS).

Given these limitations and concerns, APGI suggests that the decision to use gaged flows for model calibration be carefully re-evaluated. If the final Lake Model calibration continues to utilize gaged flows, then at the very least the Model Report must discuss the limitations this approach imparts on future linkage between the watershed and lake models, and should provide a detailed explanation of guidelines for simulation of flows during model application.

Section 2.2.4 of the Model Report indicates that Tetra Tech scaled flows from ungaged watersheds off of gaged watersheds. APGI believes this is an appropriate approach, but recommends that a discussion of the uncertainty (i.e. percent error) that this approach generates would be a valuable addition to the Model Report.

Comment 2 (Yadkin Riverkeeper): It also appears that the observed streamflows are problematic in that not all tributaries are gauged and, for gauged streams, the flows are reported as daily averages whereas sub-daily flow dynamics can be significant during rainfall events. There is no discussion of how these issues affect the accuracy of the model, and in particular, how it can affect assessment of stormflow loading estimates. It is important to evaluate and explain how the uncertainty of the overall water mass balance and resulting flow corrections impact the accuracy of the boundary condition.

Response: *More analysis will be conducted and discussion will be added to the report regarding the assignment of boundary conditions.*

Gaged, rather than watershed model simulated flow, was used to drive the hydrodynamics as a means of separating the uncertainty in the watershed model simulation from uncertainty in the lake response model. The watershed model fits the hydrology of the watershed well; however, there are clear instances in which, due to limitations in the meteorological data, the watershed model produces errors in timing or fails to simulate the magnitude of individual storm events. To reduce propagation of these errors into the lake hydrodynamics the decision was made to represent the model calibration boundary conditions with gaged flows.

Use of gaged flows for calibration does not preclude full linkage of the watershed and lake models for simulation. The watershed model has been shown to be, on average, unbiased. Thus, representation of the expected range of lake responses under current or future management scenarios can be addressed through direct linkage of the watershed and lake models. The un-linked version is preferable for calibration because it enforces better time agreement between inflow events and in-lake measurements; however, a fully linked set of models will provide similar predictions and can be used in an apples-to-apples comparison of relative changes associated with different watershed management options.

An important caveat to this approach is that not all areas draining to the lake are covered by flow gages, although the majority of the drainage area is gaged. Ungaged tributaries are represented by drainage area-based scaling to gaged flows. Additional columns showing drainage area and percent of total drainage area have been added to Table 2-3 (USGS Area-Weighted Flow Forcing Assignments for EFDC).

The true flow from ungaged tributaries is unknown. However, it is relevant to compare the HSPF-simulated flow from these tributaries to the flow estimated by area-weighting gaged flows from nearby stations (Table 2-3 in the report). An explanation of the differences between HSPF-simulated and USGS area-weighting will be added to the report. Overall, the watershed model output and the lake model input based on area-weighted gage flows agree within 4 percent, which is within the error of the watershed model fit over the 2005-2010 lake model simulation period. For comparison, the calibrated and gaged flows for Yadkin River at Yadkin College differ by 8 percent. For all three of the partially gaged inputs (Yadkin River, South Yadkin River, and Abbotts Creek) the difference is less than 8 percent.

For the smaller ungaged tributaries, the true amount of flow is unknown. The watershed model output and estimates extrapolated from other gages are within 15 percent for Grants, Swearing, and Flat Swamp Creek, and within 25 percent for South and North Potts Creek. Larger discrepancies are seen for Town/Crane (48 percent) and Dutch Second Creek (45 percent), for both of which extrapolation from the Second Creek gage leads to consistently higher flows than are predicted by the watershed model. These represent a small portion of the total drainage area (3.4 percent), and so have little impact on the overall flow balance. Both Town/Crane and Dutch Second Creek are simulated in the watershed model on the basis of precipitation records from Salisbury (317615), but the adequacy of the simulation of runoff responses in this part of the watershed model is not known because there are no flow gages. The series extrapolated from the gage records use the Second Creek flow gage, which will differ to some unknown extent from the actual flow response in Town/Crane and Dutch Second. Thus, actual error associated with flow estimates for these locations cannot be calculated.

Consistent with remarks made above, Tetra Tech believes it is preferable to use the flow series extrapolated from the gages for lake model calibration - because this ensures greater consistency with the observed timing of inflows. However, the watershed model (which incorporates differences between drainage areas in land uses and soils) is likely to provide a more accurate representation of cumulative *flow volume and pollutant mass – at the expense of some accuracy in timing of inflows. Therefore, Tetra Tech continues to recommend use of linked watershed and lake models for scenario comparisons.*

March 2015 Division of Water Resources (DWR) Note:
The lake model is calibrated against in-lake measured chlorophyll a concentrations using the gaged flow method. Therefore, running scenarios with different flow from the calibrated model is not a recommended approach.

Nutrient reduction scenarios will use the same flow regime as currently modeled, only nutrient concentrations will be altered to determine the reductions needed to meet chlorophyll a water quality standards in the lake. The scenarios will not involve evaluation of future flow patterns.

2.5 Static Reservoir Surface

Comment (APGI): The EFDC hydrodynamic model and the WASP water quality model have a constant relationship between stage and surface area. In reality this is not the case and the assumption directly impacts both the total solar radiation and atmospheric deposition of nutrients. APGI suggests including a graph illustrating the stage – surface area relationship in the Model Report and if realistic variations in stage result in significant differences in surface area, then we would suggest some sensitivity analysis of how the surface area impacts model results. Regardless of what additional information is included in the Model Report, this issue, combined with the issues previously raised regarding dam operation, strongly suggest that this model is not appropriate for assessing potential changes in water quality associated with the operation of High Rock dam.

Response: *The High Rock Lake model is set up with a curvilinear orthogonal grid that attempts to simultaneously approximate the lake's stage-storage and volume-area relationships. APGI provided a stage-area relationship that was used to help guide model setup; however, this was marked "Confidential" and so is not directly cited in the report.*

As is typical for these types of grid-based model applications, lake surface area is considered as approximately constant at the normal pool area. In fact, the surface area does change with storage and water surface elevation.

The changing surface area does have an effect on direct inputs to the lake, including atmospheric deposition and solar radiation; however, the effect is not large. For the 2008-2010 period, the atmospheric deposition of atmospheric N is equal to about 1.73 mg/m^2/d. Based on the model surface area of 13,568 acres this amounts to a load of 34.7 metric tonnes per year. In comparison, the estimated watershed loading of N is 6,066 tonnes/yr, so the atmospheric load is only 0.6 percent of the total. Thus, small changes in lake surface area are unlikely to have a significant impact on the nutrient balance. Expansion of the lake area during high stage will increase the net solar radiation input and warm shallow nearshore areas. However, there is little or no temperature monitoring in these areas and the effect on the main body of the lake, where temperatures are available, will be small.

It should also be noted that the fixed-area assumption establishes a clear boundary between the lake model and the watershed model. Those areas that may be temporarily inundated during high lake stage are simulated within the HSPF watershed model. Thus, both nutrient and heat inputs for these areas are addressed in the watershed model. Conversely, when stage and area decline, the HSPF model area is not *expanded and the atmospheric deposition that falls on the newly exposed land area is accounted for within the lake model and not the watershed model.*

The lake is not particularly sensitive to direct inputs to the lake surface, and small discrepancies in the lake area over time do not invalidate model results.

2.6 Weather Station Assignments

Comment (APGI): Weather data for the model comes from Winston-Salem which is over 40 miles from High Rock Reservoir. APGI recommends that the Model Report include a discussion of the applicability of Winston-Salem weather to the High Rock Reservoir area.

Response: *The weather time series used by the lake models are air pressure, relative humidity, rainfall, air temperature, cloud cover, solar radiation, wind direction, and wind speed. Winston-Salem Airport is the nearest location that reports these time series on an hourly scale. There is no significant topographic change between the lake and Winston-Salem. For typical weather (not extreme events), the observations at Winston-Salem should be generally representative of conditions at High Rock Lake. It is expected, however, that there will be some differences, and, in particular, relative humidity is likely to be higher and wind speed somewhat less than at the Airport. Wind observations would be preferred at multiple locations on the lake, but are not available. Because these meteorological time series are not available for the lake itself it is expected that some calibration adjustments will be needed to match the observed temperature profiles in the lake.*

2.7 Temperature Calibration

Comment (APGI): APGI observed that 20 out of a total of 32 thermal profiles (Section 3.2.3, Figures 3-7 through 3-10) in which the model simulated temperature is higher than the actual measured temperature. This overprediction appears particularly prevalent for profiles during the summer stratification period. Tetra Tech concludes that the difference between the two data sets is small. APGI generally agrees with that conclusion, but given the model's consistent over-prediction, believes that a discussion of cumulative model bias should be summarized and included in the text of the Model Report.

For parts of the reservoir near the dam, the thermal regime is dictated, in part, by the depth of the turbine intakes and gate discharge. When water levels are high, the intakes draw water from cooler deeper portions of the reservoir. Depletion of this layer of deep cool water can result in warmer water being drawn deeper into the reservoir. Section 2.3.2 should be revised to reflect this phenomenon.

Response: *The turbine and spillway representation in the hydrodynamic model will be modified; water temperature calibration and validation results will be evaluated and updated accordingly.*

3.0 Review Comments on Draft Water Quality Model (WASP)

The original intention of the project was to apply WASP to simulate three algal groups. Unfortunately, the executable code for the multiple algal group simulation was not working properly when water quality model calibration was undertaken. Therefore, EPA directed Tetra Tech to use the existing single algal group model.

Various commenters have requested recalibration using multiple algal groups. EPA has agreed to undertake this recalibration. This will likely result in a better fit to observed chlorophyll *a* during the winter season when diatoms dominate the algal community. Because the water quality model is being recalibrated, comments on specific details of the existing calibration are addressed only briefly herein.

3.1 2008-2010 Intensive Monitoring Data Summary Tables

Comment (YPDRBA/NCDOT/LTI): The HRL LRM report provides a summary of the scoping monitoring program conducted in 2005-06 in Tables 1-4 and 1-5; however, a similar summary is not provided for the 2008-10 intensive monitoring effort funded by the Section 319 grant.

As noted, Tables 1-4 and 1-5 provide a useful summary of the scoping monitoring that was conducted during the 2005-06 period, including number of observations per station and per water quality parameter and a statistical summary of results. In order to provide a more comprehensive summary of the available data to support the lake response models, we recommend incorporating tables analogous to Tables 1-4 and 1-5 that summarize observations for the 2008-10 monitoring program.

Response: *The intensive monitoring summary tables were in the draft version of the report reviewed by DWQ. DWQ suggested removing them because the reference was already provided in the lake model report for the intensive monitoring final report (http://portal.ncdenr.org/c/document_library/get_file?uuid=901501d5-6df3-4815-8747-a24401782703&groupId=38364), prepared by LimnoTech, which is a valuable reference containing much more information than the number of samples included in the original tables. No such report exists for the scoping study data, so DWQ recommended keeping the scoping study summary.*

3.2 Boundary Conditions: Tributary Loadings of Sediment and Nutrients

Comment 1 (YPDRBA/NCDOT/LTI): Load inputs to the HRL model for the calibration period were calculated from a combination of U.S. Geological Survey (USGS) gaged flows and concentrations simulated by the HRL WSM (HSPF model). While this approach may have utility in running model simulations for periods where no load data were collected, it makes no direct use of the extensive data collected during the 2008-2010 intensive monitoring period. The HRL LRM report does not provide any comparisons of the tributary input loadings used in the HRL LRM, nor does it provide justification for neglecting the 2008-2010 data when defining the loads.

This loading approach in the model appears to be driven by an acknowledgment that the flows predicted by the watershed model do not match gaged flows well enough to enable an adequate calibration of the hydrodynamic portion of the lake model. This approach also necessitated development of daily flow-weighted average concentrations from the watershed model output, to avoid potential problems associated with differences in timing between flows and modeled wet weather events. For locations where there is good agreement between the watershed model and gaged flows on a daily total basis, this approach can be expected to reproduce the modeled daily load reasonably closely. Where the watershed model flows depart from the USGS data, however, the resulting loads to the lake model will depart from the watershed model predictions. In any case, however, there is no general assurance that this approach will represent the monitoring data itself.

Total annual loads were derived previously from the data using the Beale Ratio Estimator approach (LimnoTech 2010). This approach has been widely used and provides estimates with minimal bias (Dolan et al., 1981). The calculated loads were compared with the loads used in the model calibration via the combination of USGS gaged flows and flow-weighted daily average concentrations from the HSPF model output.

The comparisons show that, for the Yadkin River, the approach taken for the HRL model under-represents the loads of both nutrients and solids throughout the calibration period. This has significant implications for model calibration because the Yadkin River accounts for approximately 80% of the total system nutrient and sediment loads. For the South Yadkin River, the differences vary among constituents and between years, and variability is also seen in the smaller tributaries. The effects of these discrepancies on model calibration are not clear, but they do underscore the overall inconsistency of the method.

It is further noted that the loads used in the HRL model calibration are expected to become the baseline from which future load reduction scenarios are derived, in which case the disconnect between model and monitoring data poses additional difficulties. Load reduction targets derived from under-estimated annual loads may have smaller effects than they are expected to (i.e., based on model application results), whereas those derived from over-estimated loads may be unnecessarily large and possibly unachievable. These issues compound those related to the model's ability to represent the effects of load reductions on water quality. A potential alternative approach that would overcome this issue would involve representing watershed sediment and nutrient loadings based on the available monitoring data for 2005-2010 (e.g., based on the USGS LOADEST software), and then using the results of the HSPF model to determine the relative reductions in loadings that should be applied in the HRL LRM.

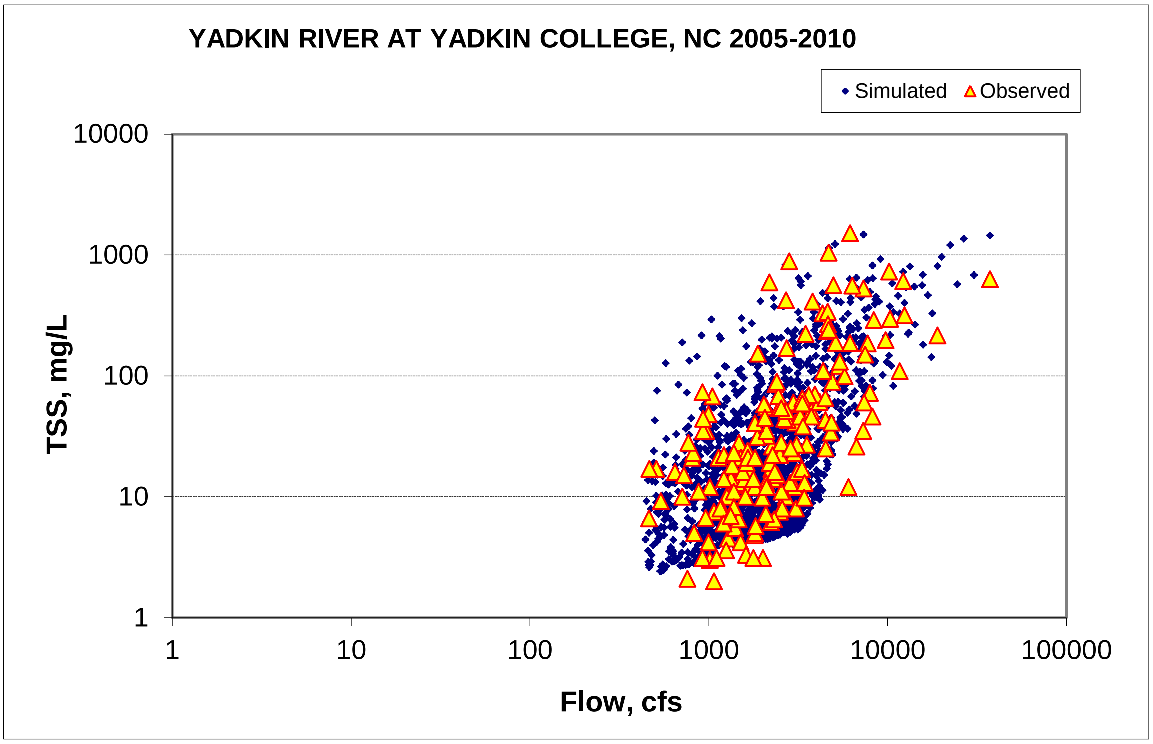
Response: *The commenters are aware that the 2008-2010 data were used for watershed model calibration and as such, the data were not "neglected" as asserted in the comments. Furthermore, the watershed model was calibrated against observed nutrient concentrations and daily loads, rather than estimates of cumulative load. The load calculated by using the watershed model-simulated concentrations and the observed flow may depart from the watershed model-simulated load, but may be considered as a more accurate (than directly using the model-simulated load) representation of the real tributary loading.*

We acknowledge that uncertainties are associated with tributary loading estimates. This would be the case with any method used to determine boundary conditions. Daily data are not available to calculate daily loads.

The implication in this comment that the model has problems in its "ability to represent the effects of load reductions on water quality" is totally unfounded and based on an incorrectly specified sensitivity analysis undertaken by the commenter's consultant, as is further explained in Section 3.10.

Watershed model calibrations for the Yadkin River and other monitored tributaries endeavored to fit both concentrations and loads. We agree that the Beale Ratio Estimator is a useful technique for estimating long-term pollutant loads from sparse data. However, like all load estimators, it is subject to considerable uncertainty and it is also not the best approach for model fitting. With a ratio estimator, loads are calculated as the product of the total annual flow volume and the ratio of mean daily load to mean daily discharge on days with samples, plus a statistical bias correction term. Application is typically done after stratifying flow into two or more groups. In essence, the approach then assigns a constant concentration (the ratio of mean daily load to mean daily discharge) to all observations within a flow stratum – in contrast to regression-based approaches which take into account the correlation between flow and concentration. Ratio estimators can be shown to be generally unbiased, but are often less precise than other estimation methods. A comparative study by Preston et al.[1] found that no one load estimation approach can be shown to be a priori superior in all situations, but regression estimators performed better when there was a strong correlation between concentration and flow, while stratified ratio estimators were preferable when strong correlation did not exist.

For the Yadkin River, there is a very strong relationship between TSS concentration and flow, as shown below, suggesting that ratio estimators would be suboptimal. Total P and flow are also correlated, although less strongly, while the correlation for N is weaker.



Examination of the monitoring results at Yadkin College also shows why the total load estimates from the data are subject to high levels of uncertainty. Of the days with samples, a full 20 percent of the total load sum for TSS is represented by a single sample of Jan. 26, 2010 in which a TSS concentration of 626 mg/L was reported with a very high flow (the point on the upper right on the chart above). If this

[1] Preston, S.D., V.J. Bierman, Jr., and S.E. Silliman. 1989. An evaluation of methods for the estimation of tributary mass loads. *Water Resources Research*, 25(6): 1379-1389.

observation was omitted, or if it was simply not representative of the integrated load on this day, significantly different load estimates would result.

Given the uncertainty in estimating total loads from sparse data, the approach taken of pursuing simultaneous fit to observed concentrations, individual daily load estimates, and the relationship of both concentrations and loads to flow and season was the correct choice for model calibration.

A later suggestion in the comment is to represent watershed loads based on the USGS LOADEST software (note that this flow regression based approach is contradictory to a Beale Ratio estimator) is not useful because, for unmonitored days, this would result in load estimates that are purely a function of flow. This would also provide no information on pollutant sources.

Comment 2 (Yadkin Riverkeeper): According to WASP model documentation and training material, "[b]oundary concentrations (BCs) must be specified with reasonable accuracy [and] [u]nknown BC is OK only if insensitive (i.e., changes in BC do not significantly change model prediction in Area of Interest)." The boundary defines the mass loading (flow * concentration) entering the network. The Lake Model report at page 3-1 states that:

> High Rock Lake presents an inherently difficult case for calibration because residence time is relatively short, ranging from 4 to 50 days (APGI, 2006b). As a result, conditions within the lake are strongly affected by boundary conditions (loads from the watershed), which are imprecisely known, and less determined by in-lake reaction parameters that are typically adjusted during calibration.

Accordingly, the conditions in High Rock Lake are highly sensitive to nutrient loading from the watershed and those loadings do not appear to be known to be reasonably accurate. This appears to be partially due to the fact that the lake model uses gauged flows and simulated pollutant loads from the watershed model. While there is some discussion of how this issue was handled in the model at pages 2-12 through 2-13, there is no documentation of or scientific support provided for the approach taken. It would be helpful to understand exactly how deviating from a loading time series approach and using water quality constituents on inflows for concentration boundary conditions affects the model, and whether there is any precedent or research to support the validity of specifying daily flow-weighed concentrations, calculated as the total simulated load from a watershed model divided by the total simulated flow for each day. Additional clarification about the impact of the differences in constituent state variables in the HSPF and WASP models and support for the approach taken to these issues should also be provided. It also appears that the observed streamflows are problematic in that not all tributaries are gauged and, for gauged streams, the flows are reported as daily averages whereas sub-daily flow dynamics can be can be significant during rainfall events. There is no discussion of how these issues affect the accuracy of the model, and in particular, how it can affect assessment of stormflow loading estimates. It is important to evaluate and explain how the uncertainty of the overall water mass balance and resulting flow corrections impact the accuracy of the boundary condition.

As noted on page 4-1 of the Lake Model Report, the inputs that primarily affect chlorophyll-a response in the lake include flow, nutrient load and light availability. If the loading estimates (flow * concentration) are not reasonably accurate, the adequacy of the model for assessing nutrient reduction scenarios is severely limited. As noted on page 4-3 of the Lake Model Report, High Rock Lake is very sensitive to variations in the boundary conditions. Accordingly, it is essential to the usefulness of the model that the boundary conditions be specified with reasonable accuracy. It also appears that the approach to specifying the boundary conditions adversely affected the predictive accuracy of the model. The calibration and validation for phosphorus, nitrogen and chlorophyll *a* do not meet the correlation coefficient target and simulated concentrations of nitrate-nitrogen do not meet the RE and CV targets. As noted on page 4-3 of the Lake Model Report, correlation coefficients between observed and daily simulated concentrations of nutrients and chlorophyll *a* are generally low - suggesting the model has a limited ability to predict individual algal blooms in High Rock Lake.

Response: *We agree with the comment that High Rock Lake is highly sensitive to nutrient loading from the watershed; however, we disagree with the characterization that these loads "do not appear to be known to be reasonably accurate." In fact, the model does an acceptable job of representing loads inferred from observations in the major tributaries to High Rock Lake, as was documented in the watershed model report.*

The approach taken to link the watershed and lake models preserves the loading time series generated by the watershed model. The only modification is that the loads are converted to flow-weighted concentrations applied to gaged flows. This does not reflect any deficiencies in the watershed flow simulation (which is quite good with small bias), but rather is used to minimize large errors that would result when the timing of load pulses is not precisely simulated.

We agree that there are uncertainties in representing flows and loads from ungaged tributaries. This is addressed in more detail in the responses to comments on the hydrodynamic model.

We also agree that the model, as currently configured, has a limited ability to predict individual algal blooms in High Rock Lake – although the distribution of summer algal concentrations appears to be simulated well. This finding may be modified as a result of model revisions being undertaken in response to comments. It is precisely because High Rock Lake is sensitive to boundary conditions that it will likely never be possible to predict individual algal blooms. Recall, however, that the usefulness of the model for decision making purposes depends on the ability to predict the risk or probability of such blooms, not their exact timing.

3.3 Model Representation of Sediment Dissolved Inorganic Nutrient Release

Comment (YPDRBA/NCDOT/LTI): The HRL LRM specifies constant release rates from the sediment bed for dissolved inorganic nutrients between April 1st and October 31st of each simulation year. The constant release rates during the April-October period are specified as 55 mg/m^2/d for ammonia and 9 mg/m^2/d for orthophosphate (based on Table 2-7 in the HRL LRM report and a review of WASP7 model inputs). These releases were estimated by calculating an arithmetic average of in-situ flux measurements made at stations YAD152C and YAD169A during spring 2005. There are two significant concerns with the use of these static release rates in the HRL LRM:

1. The use of static release rates does not account for variation in bottom DO concentrations, which are the primary driver for enhanced nutrient release from the sediment bed. The current model design assumes that the same release rate occurs through the April-October period. Based on the substantial bottom DO data collected during 2008-10, hypoxic conditions (e.g., DO concentrations < 2 mg/l) are unlikely in April, early May, and October. Therefore, the current approach overestimates nutrient releases during these time periods, likely resulting in an overabundance of PO4 in the water column where it is available for algal uptake.

2. The static release rates are applied to every horizontal grid location represented in the model domain. As discussed above, hypoxic/anoxic conditions are unlikely to occur in relatively shallow areas of the lake where physical disruption due to currents and wind stress prevent stratification from occurring. Therefore, the current approach very likely over-predicts the amount of nutrient flux into the water column in the shallower areas of the lake.

The use of spatially-constant release rates for ammonia and PO4 during the April-October time period has important implications for algal growth dynamics in HRL. In the case of the current model, fluxes of ammonia and PO4 are likely over-predicted in the spring and fall months, and for shallow areas during the entire April-October period.

Looking ahead to future applications of the HRL LRM, if watershed and/or direct point source loadings of phosphorus are reduced to HRL (i.e., for evaluating watershed management scenarios), the relative importance of "internal" dissolved P loadings from the sediment bed in terms of algal production will only increase. A more robust representation of dissolved nutrient releases from the sediment bed is needed to properly represent: 1) the spatial and temporal variations in enhanced nutrient releases, and 2) the long-term impact of reduced (future) nutrient loadings from the watershed on nutrient releases. It is common practice to use a sediment diagenesis model to dynamically simulate the impact of bottom DO concentrations on nutrient releases from the bed. In fact, the "Advanced Eutrophication" module in WASP7 includes the DiToro sediment diagenesis model, which is the framework that is typically used for this purpose (DiToro et al. 2001).

Response: *Sediment nutrient releases are a known data limitation in the model, because very few measurements are available. Lack of better sediment oxygen demand and nutrient flux data limits our ability to set rates on a spatially and temporally varying basis. Instead, SOD/nutrient fluxes are specified in the model based on the best observational data available.*

We agree that nutrient release rates are affected by redox conditions and likely vary throughout the year. However, the redox conditions on which releases depend are those in the sediment, not those in the water column. Measurements of DO in the surface sediment or at the sediment-water interface are generally lacking. Further, the available SOD/nutrient flux rates appear to have been obtained at times that would likely exhibit less than maximum rates, i.e., they were not obtained during periods in which stratification and the late summer temperature maximum coincide. The current approach probably underestimates nutrient releases during these time periods.

Given the paucity of data it appeared best to specify constant rates for bottom segments. While the comment raises a valid issue, the commenters did not provide any additional data or literature information to support model information. SOD and sediment nutrient flux may be adjusted during the upcoming model revision as appropriate as part of the recalibration of the model.

March 2015 Division of Water Resources (DWR) Note*: The only change to sediment nutrient flux rates was in regards to the ammonia flux rate. The average measured ammonia flux was applied from April 1 through October 31 and then reduced to 60 percent during other days.*

3.4 Nutrient Calibration

3.4.1 Documentation

Comment (APGI): In the Model Report discussion of nutrient calibration, the depth at which phosphorus and nitrogen samples used for the calibration and validation is not specified. In High Rock Reservoir, nutrient concentrations can be quite variable with depth. In particular, the time series plots presented in Section 3 should specify whether the observations are whole water column averages or concentrations at a specific depth.

Response: *The primary calibration data for nutrients are depth-averaged composites from the epilimnion. These samples were composited over twice the Secchi depth, per standard DWQ protocol. The samples approximate the upper (surface) layer in the WASP model.*

Notes have been added to the report to clarify this issue.

3.4.2 Orthophosphate Calibration

Comment (YPDRBA/NCDOT/LTI): Graphical and statistical model-data comparisons for orthophosphate (PO4) are excluded from the report. Because PO4 is one of the primary drivers for algal productivity in systems like HRL, it is essential that the model's ability to represent PO4 concentrations be assessed and reported upon as part of the calibration and validation.

Despite the importance of orthophosphate (PO4) to algal production, no graphical or statistical model-data comparisons are provided for this variable in the HRL LRM report. Section 3.3.2 states the following:

"The WASP model simulates the full range of nutrient species. Inorganic nutrients are most important for algal growth, but, in the case of inorganic phosphorus in High Rock Lake concentrations are often near practical quantitation limits. Therefore, the calibration focuses on total phosphorus and total nitrogen along with nitrate and ammonium nitrogen, the two major inorganic species of nitrogen." (p. 3-18)

In many lake systems similar to HRL, PO4 is the primary nutrient limiting algal growth. Although the nutrient limitation status depends on the relative availability of PO4 and inorganic nitrogen (including ammonium (NH4) and nitrate (NO3) nitrogen), it is essential that PO4 (as well as NO3 and NH4) concentrations be accurately simulated by the model so that realistic algal growth behavior is represented. Therefore, calibration of the model to PO4 and reporting upon the model-data comparisons is standard practice and, more importantly, necessary to demonstrating that the model appropriately represents observed conditions in the HRL system.

Despite the assertion made in the HRL LRM report regarding the adequacy of the PO4 data, we feel that the PO4 data are more than adequate to support model calibration for this important variable. The following summarizes the PO4 monitoring results for the 2008-10 intensive monitoring period for HRL, including the total number of samples and the number of PO4 results below the practical quantitation limit (PQL) of 0.10 mg/l (see Table 27 in LimnoTech 2010):

- <u>Composited samples</u> – of 449 samples, 216 results (48%) for PO4 were below the PQL; and

- Discrete hypolimnion samples – of 42 samples, 14 results (33%) for PO4 were below the PQL.

Based on this summary, less than half of all PO4 analyses conducted resulted in concentrations that were below the PQL of 0.010 mg/l. Even if the results that fell below the PQL were not considered at all in the calibration, 261 (unqualified) PO4 concentrations are available to support model calibration. Furthermore, PO4 results that fall below the PQL threshold still provide valuable information (i.e., that a concentration is below 0.010 mg/l) that can be used in a qualitative/visual manner during the model calibration process.

In summary, we strongly contend that available PO4 data are adequate to permit an assessment of the WASP7 model performance with respect to PO4 based on the same graphical and statistical approaches used for other water quality parameters.

Response: *The comment acknowledges that nearly half of the PO_4 samples were below the PQL. Most of the remainder of the samples were within one or two times the PQL. As the PQL also establishes the increment for reporting, these samples are numerically imprecise, with many of them being reported as either 0.01 or 0.02 mg/L. As such, they are not appropriate for rigorous quantitative statistical tests. However, a visual comparison of model and observed data would be of some use. This will be provided when the model recalibration for multiple algal groups is completed.*

3.5 TSS Calibration

Comment 1 (APGI): The end of Section 3.3.1 of the Model Report indicates that "uncertainty in the TSS simulation will have only a minor effect on the simulation of nutrients and algae." APGI does not agree, and believes that the Model Report should include a more substantive discussion of why this is asserted to be the case. Since the report states that algae are light limited in the upper reaches of the reservoir, and that this is likely attributable to suspended solids, it is apparent that suspended solids are quite important to algal growth in the upper reaches of High Rock. Since chlorophyll *a* is one of the parameters of most concern to the TMDL process, underestimating suspended solids during quiescent periods when algae would be expected to grow is potentially a critical shortcoming of the model that should be acknowledged. Tetra Tech should also include a discussion of TSS sampling techniques and how they may be under representing the presence of TSS in High Rock Reservoir, particularly during high flow events.

Turbidity in the reservoir has been the focus of many studies in High Rock Reservoir and has been shown to be a significant and complicated influence on the reservoir. Turbidity in the upper reaches of High Rock Reservoir is often very high and suspended solids at depth are often elevated through either settling or underflow phenomena. These conditions are not well captured in the calibration data set. Turbidity is a known concern (six of the ten assessment units in High Rock Reservoir are listed as impaired with respect to turbidity). In addition, turbidity has a direct influence on other water quality parameters such as chlorophyll *a*. The TSS data do not match the model in either the calibration or validation runs. Because turbidity is such a critical parameter, either the model should be revisited to better represent the data or additional data should be collected to confirm the high predicted TSS concentrations.

Response: *Please also refer to the response to Section 3.7 Comment 1 below for a discussion of the selection of eutrophication model in WASP. Due to the excessive memory demand caused by the large number of High Rock Lake model grid cells (>1500 grid cells), Tetra Tech, at the time of model development, was forced to move in the direction of using the eutrophication model which represents only one sediment group. However, as EPA has worked to solve the memory issue with large grid cells with the newer version of WASP (version 8), the High Rock Lake model will be modified to represent 3 sediment groups using the newer version of WASP. Sediment simulation will be re-calibrated during the model revision.*

March 2015 Division of Water Resources (DWR) Note*: As EPA has worked to solve the memory issue with large grid cells with the newer version of WASP, DWR requested that the High Rock Lake model be modified to represent 3 sediment groups using the newer version of WASP. However, resource limitations prevented EPA from including 3 sediment groups in the final model. The result is that DWR will not be able to use the model to address turbidity impairment.*

The influence of light limitation on algae production has been addressed through an alternative method as discussed in Section 2.3.8 in the final report. Because the WASP simulation of suspended sediment (which addresses only a single particle size class) does not provide an accurate representation of the spatial gradient in light extinction due to suspended inorganic solids under variable hydrologic conditions, the background light extinction function was used to represent the typical light extinction within different areas of the lake, with incremental contributions from simulated inorganic solids and chlorophyll a concentrations. Specifically, the background light extinction rate was set equal to the observed light extinction after backing out contributions from algae and suspended inorganic sediment as simulated by the model. The model output was checked to ensure that simulated light extinction time series were consistent with the range obtained from observed Secchi depth and PAR measurements.

Comment 2 (YPDRBA/NCDOT/LTI): The HRL LRM calibration to total suspended solids (TSS) data is poor, with model results biased high relative to data during high flow events in the HRL watershed and biased low relative to data during other time periods.

Based on review and comparison of HRL LRM output to available data, observed TSS concentrations in High Rock Lake are poorly predicted by the HRL LRM. Specifically, the LRM tends to over-predict TSS data during watershed high-flow events and under-predict TSS during periods of low inflow from the watershed.

The significant discrepancies between the model and observed data are due to a combination of factors, including poor prediction by the watershed model (WSM) during high-flow events. The model results and data in Figure 3 (included in original comment), which reflect simulated and actual upstream loading from the Yadkin and South Yadkin rivers, suggest that loadings estimated based on USGS gaged flows and the WSM-predicted TSS concentrations do not resemble the data-based loads. Model-simulated TSS concentrations at HRL-051 exceed 150 mg/l for roughly 10 events and exceed 300 mg/l for 5 events during the 2008-10 time period. Data were collected during limited events (e.g., June 2009), but measured concentrations never exceeded 40 mg/l. The significant peaks in sediment are transported downstream, and significant over-prediction of TSS concentrations occurs even at High Rock Lake Dam. Although linkage of the watershed and lake models is ultimately necessary to supporting the evaluation of loading metrics, it appears that the calibration would have been better served by specifying loads based on monitoring data rather than predictions from the watershed model.

The other factor contributing to the poor TSS calibration is the use of a single sediment class in WASP7. The HRL LRM report acknowledges the challenges in calibrating TSS as follows:

"Total suspended solids (TSS) calibration proved difficult due in part to the WASP model representing only a single sediment variable. Inflows to the lake typically carry coarser particles during high flow events and the influent load becomes progressively finer through deposition as flow slows within the lake. Large amounts of sediment deposition are known to occur between the confluence of the Yadkin and South Yadkin Rivers and the I-85 bridge (Normandeau, 2004; Copeland, 2007), within the domain of the lake model. This effect was approximated by assigning high rates of solids deposition in this part of the model grid; however, WASP is not able to represent the different, lower deposition velocity of fine sediment. In addition, TSS measurements are inherently subject to a degree of sampling uncertainty, while point-in-time grab samples can be unrepresentative of spatial and temporal averages simulated by the model." (pg. 3-13, HRL LRM report)

Solids entering HRL consist of a mixture of clay, silt, and sand, and these three different particle types exhibit a wide range of settling rates. The use of a single sediment class requires the selection of a single settling rate, which cannot be expected to adequately represent the range of settling conditions present in HRL. (In the HRL LRM, a settling rate of 1 m/day is specified for most of HRL, with a higher rate used upstream near the Yadkin River inflow.) Therefore, we agree that use of a single sediment class in WASP7 is problematic for calibrating TSS concentrations for the HRL system. However, we note that the above excerpt from the HRL LRM report neglects to mention that WASP7 does provide the capability to simulate up to three sediment classes if the "Advanced Eutrophication" option is selected (i.e., during model setup and development). The limitations of using a single sediment class (and associated settling rate) could have been avoided by using the "Advanced Eutrophication", and, as noted in additional comments included below, use of this advanced option is also warranted to represent multiple algal groups.

In addition to the large collection of TSS data available for the 2008-10 monitoring period, particle size distribution data were measured every three months at stations HRL-051 and HRL-052. Along with TSS concentration and turbidity data, the particle size distribution data were collected specifically to assist in calibrating multiple sediment classes to realistically represent TSS/turbidity conditions in High Rock Lake.

Based on the significant concerns and limitations with the current TSS calibration, the TSS portion of the HRL LRM should not be used in any future evaluations to support a turbidity TMDL unless further refinement and recalibration of the model occurs. We believe that this should be stated explicitly in the discussion of the suspended solids calibration in Section 3.3.1 of the HRL LRM report.

The issues identified above with HRL LRM simulation of TSS generally have only a small impact on light extinction calculation, as noted in the HRL LRM simulation (see Section 2.3.8). However, the WASP7 model simulates the effective adsorption of orthophosphate to TSS and subsequent settling. The representation of this process in the model is important because it directly affects the overall mass balance of total and inorganic phosphorus in the HRL system, and specifically the availability of inorganic P for algal uptake. Therefore, the simulation of TSS transport and settling in HRL affects inorganic P dynamics in HRL and as a result, the poor TSS calibration could negatively impact the orthophosphate (PO4) calibration (see comment 4.4 below) and potentially force an artificial parameterization of algal growth dependency on PO4 in order to effect a chlorophyll *a* calibration. The HRL LRM report seemingly acknowledges this, and describes the workaround that was developed using dissolved fractions of P specified in the model:

"The WASP model distinguishes between sorbed and dissolved forms of nutrients. This is an important distinction as it is the dissolved fractions that are bioavailable, while the sorbed fractions are subject to settling and deposition. Standard practice in WASP is to assign a fixed dissolved fraction for nutrients, although a simulation based on equilibrium partitioning to solids is also possible in version 7.5. This application uses specified dissolved fractions, primarily because the WASP model does not represent progressive fining of sediments as inflows proceed into the lake. Instead, sorption of nutrients (ammonium, orthophosphate, and organic nutrients) was represented by assigning progressively smaller dissolved fractions away from inflow points during model calibration. Values were set to be generally consistent with the ratio of dissolved to total nutrient concentrations observed in lake monitoring." (p. 2-15 in HRL LRM report)

The workaround described is designed to reduce the dissolved fraction of inorganic P (i.e., orthophosphate) moving downstream through the lake, which generally would result in higher particulate inorganic P concentrations and settling to the sediment bed. However, Figures 4 and 5 (included in original comment) suggest that the TSS concentration in HRL is significantly under-predicted during non-event time periods, and the ability of the model to reasonably represent inorganic P adsorption and settling is questionable. In order to accurately represent the adsorption of inorganic P and removal from the system via settling, the use of multiple sediment classes would likely be required.

Response: *The commenters provided incorrect figures. Specifically, Figure 3 (included in the original comment), which is labeled as High Rock Lake at HRL051 and is discussed as representative of the inflow from the Yadkin River, is actually a plot of model and results for High Rock Lake at the Dam (YAD169F).*

Nonetheless, it is true that the model tends to under-predict observed TSS during quiescent periods and over-predict TSS during events. As discussed in the comment, this is largely due to the difficulties of representing inorganic solids via a single size class, whereas the flow entering the lake deposits solids via progressive fining.

The assertion that the watershed model does a poor job of simulating TSS is not supported. The watershed model does a credible job of predicting TSS in the Yadkin River at Yadkin College and other monitored tributaries during both high and low flow events (see the Watershed Model Report). Apparent problems arise during transport between Yadkin College and HRL051, the uppermost station in the lake, which is located a considerable distance downstream. For this reason, the suggestion of "specifying loads based on monitoring data" would not be helpful.

Phosphorus settling may also be revisited with the recalibration of the model. However, it should be noted that solids present in the epilimnion during non-event periods are likely to be dominated by non-settling fine clay particles, flocs, and neutrally buoyant organic materials that are not a major route of removal of phosphorus from the system.

3.6 Dissolved Oxygen Calibration

Comment (YPDRBA/NCDOT/LTI): Because dissolved oxygen is an important variable in the context of algal dynamics and enhanced inorganic nutrient release from bottom sediment, it is important to assess and report on the calibration and validation results for this variable.

Although dissolved oxygen (DO) is included in the calibration guidelines presented in Table 3-1, there are no graphical or statistical model-data comparisons or related text provided for DO in the report. Because DO dynamics in lake systems are tightly coupled to nutrient and algal growth, respiration, and death processes, it is important that the model be capable of adequately simulating observed DO conditions if adequate data exist to support calibration/confirmation. In the case of HRL, a comprehensive dataset is available for DO from the 2008-10 intensive monitoring period, including frequent surface and bottom water samples at 8 locations (yielding approximately 900 concentration results). There is no question that this robust dataset is adequate to support a calibration of the DO processes simulated in the WASP7 model.

In the HRL system DO has relevance to the following physical, chemical, and biological processes:

- DO concentrations in the bottom waters of HRL are partially driven by the amount of mixing and (potential) stratification that occurs between surface and bottom waters. Within the context of a three-dimensional lake model, model-data comparisons for bottom DO can be used to confirm that the vertical mixing rates in the EFDC model and the water quality processes in the WASP7 model are adequately represented and constrained.
- Production of algae results in production of DO, while respiration consumes DO. In addition, algal death generates detrital material, which promotes DO consumption as the detritus undergoes decay processes as it settles through the water column and deposits in the sediment bed.
- Low DO concentrations in the lower water column are typically strongly driven by sediment oxygen demand (SOD), which results from diagenesis processes occurring in the adjacent sediment bed. SOD is ultimately driven by the flux of detrital carbon and nutrients (e.g., generated by algal death) from the water column to the bed. Therefore, DO concentrations in the lower water column are strongly influenced by long-term fluxes of detrital material to the bed, and SOD can be expected to change as a result of a shift in external nutrient loads (i.e., watershed conditions).
- Depressed DO concentrations (e.g., < 2-4 mg/l) in the lower water column typically result in significantly enhanced fluxes of inorganic nitrogen (NO3, NH4) and orthophosphate (PO4) from bottom sediments to the water column (i.e., internal nutrient loads) in systems like HRL. The enhanced release of inorganic nutrients provides additional nutrients in the water column that results in an increase in algal productivity (provided that production is otherwise nutrient-limited). Data available for HRL from the 2008-10 monitoring period indicate that DO concentrations in bottom waters are frequently below 2 mg/l (and even near zero) during the summer months at many of the lake stations (LimnoTech 2010).

Because external loading to the water column, SOD production, bottom DO concentrations, and enhanced nutrient release are tightly coupled processes that can significantly affect algal productivity in the HRL, it is essential that these processes be represented in the model. Therefore, we strongly recommend that a discussion of the DO calibration be included in the HRL LRM report, including supporting graphical and statistical model-data comparisons.

Response: *The scope of work for this project did not specify DO as a priority parameter for calibration; thus, calibration statistics were not presented and DO should not have been included in Table 3-1. However, DWQ recognizes the coupling between oxygen levels and various other eutrophication related processes and endeavored to ensure that the DO simulation was qualitatively reasonable. Dissolved oxygen will be further evaluated during the model revision and results will be included in the resulting model report.*

3.7 Chlorophyll-a Calibration

Comment 1 (APGI): Algal Community Groups – The Model Report discusses that WASP only models bluegreen algal growth and multiple algal communities are present in High Rock Reservoir. Tetra Tech acknowledges this limitation. While APGI understands that this is a limitation of the WASP model, we nonetheless believe that this limits the applicability of the model only to seasons where blue-green algae are dominant. The Model Report provides some discussion of the season which blue-green algae is dominant, but does not provide a recommendation on the limits of applicability of the model. We recommend that the Model Report's discussion of the limitation of the model to simulate algal growth during times when blue-green algae are not dominant, be expanded.

Response: *The original stated goal for this effort was to use WASP to represent multiple algal groups. However, the large number of grid cells (over 1500 cells) in the High Rock Lake model prevented the use of the multi-algae model due to the way that versions 7 and lower of WASP allocates memory. The multi-algae model has 10 more state variables, thus a larger footprint. In other words, this was a memory issue with the model framework itself and forced Tetra Tech to move in the direction of representing only one algal group. Blue greens were appropriately chosen as they are the most dominant group during the most active algal season, the summer months.*

EPA has been working to revamp WASP to be able to represent multiple algal groups in systems with a high number of grid cells. EPA has converted WASP to use dynamic dimensioning which overcomes the memory issue. This is the basis for WASP version 8.

The model will be revised to represent three algal groups with the newer version of WASP 8.

March 2015 Division of Water Resources (DWR) Note*: The final version of the model contains two algal groups as a third group was not needed. Algal groups are defined to represent warm-water algae and cold-water algae. Results are described in the final report.*

Comment 2 (Yadkin Riverkeeper): WASP 7.x documentation and training materials state that "[t]hat the growth rate of a population of phytoplankton in a natural environment is a complicated function of the species of phytoplankton present [and] involves differing reactions to solar radiation, temperature, and the balance between nutrient availability and phytoplankton requirements. Due to the lack of information to specify growth kinetics for individual algal species in a natural environment, this model characterizes the population as a whole by the total biomass of the phytoplankton present." However, this lake model does not characterize the population as a whole by the total biomass of the phytoplankton present. Instead, the model focuses on only one algal class, blue green algae and calibrates to observed chlorophyll-a during the season of June through October. The Lake Model Report further states that in comparing model results to observed data it was assumed that biomass (carbon) and chlorophyll *a* concentrations are related to one another in a fixed ratio despite the fact that the ratios are well-documented to be variable among different algal groups and individual species.

The water quality standard for chlorophyll *a* is exceed in all months except December and the Lake Model Report acknowledges that focusing on blue green algae from June through October is likely to, and actually does, result in under-prediction of chlorophyll *a* during the winter and spring. The Lake Model Report also acknowledges that the approach utilized does not do a reasonable job of predicting the timing of individual algal bloom events and the correlation coefficients for simulated and observed data do not meet the desired target indicating uncertainty in the reliability of individual event predictions. The Lake Model Report acknowledges that WASP and other eutrophication models predicts algal growth and density on the basis of biomass expressed as organic carbon. The reason given for not following this approach is that the "relevant" monitoring is conducted through measurements of chlorophyll *a*. However, extensive TOC data is available for the Lake in addition to chlorophyll *a* data. Additionally, the Lake Model Report states that the algal calibration focused on blue green algae because "the available tested and verified public releases of the WASP address only a single algal group." However, Tetratech recently completed a WASP model for the EPA on Floyd's Fork in Kentucky which acknowledges that current versions of the WASP model can simulate four classes of algae. That report, issued on August 31, 2012, states that "WASP is a dynamic compartment-modeling program for aquatic systems, simulating one-dimensional, two-dimensional, and three-dimensional systems, and a variety of pollutants. It is capable of simulating four classes of algae (three free floating and one benthic algae class), sediment-water oxygen, pH/alkalinity and nutrient exchanges."

The Lake Model Report does not adequately explain the reason for focusing on blue green algae only and does not sufficiently support the scientific validity of the approach. Further, the information presented in Section 2.3.7 of the report does not support the conclusion that blue green algae is actually the dominant species during the months of July through October. This is especially concerning given the fact that model simulations did not achieve a "good fit" with observed data in either calibration or validation as reflected in Tables 3-14 and 3-15 of the Lake Model Report. The Lake Model Report at page 4-1 concludes that:

> As currently developed, the eutrophication model provides valuable insights into the dynamics of nutrient and algal response in High Rock Lake and can provide a good estimate of the expected responses of chlorophyll *a* concentrations to nutrient loads during the period of blue-green algal dominance from June through October. This version of WASP is not able to simulate multiple algal groups, so occasional winter-spring excursions of the chlorophyll *a* criterion are not predicted – most likely because a lower carbon to chlorophyll *a* ratio applies during this period. Reductions in nutrient load that achieve the chlorophyll *a* criterion in summer are also likely to result in reducing the less frequent excursions of the criterion during winter and spring conditions to acceptable levels.

In other words, the model does not provide a good estimate of expected responses to chlorophyll *a* concentrations to nutrient load from November through May, and chlorophyll *a* excursions during those periods are not predicted. The report does not conclude that that nutrient load reductions will prevent violations of the chlorophyll *a* criterion from November through May (7 months) and the statement that nutrient reductions would "likely" reduce the current criterion violations is wholly unsupported by any analysis or the model itself. Even for the months of July through October, the calibration statistics do not support the conclusion that the model can provide a good estimate of expected responses of chlorophyll *a* concentrations to nutrient loading. This is reflected in Tables 3-14 and 3-15, as well as in the text at page 3-45. These issues need to be addressed in the Lake Model Report and in the model itself.

Response: *See response to Section 3.7, comment 1 above.*

Comment 3 (YPDRBA/NCDOT/LTI): The calibration of a single algal functional group in the model is inconsistent with available phytoplankton group data and inadequate to sufficiently reproduce the chlorophyll *a* monitoring data for the calibration time period (2008-10).

As part of the intensive monitoring program conducted during 2008-10 period, phytoplankton species count and biovolume data were measured monthly at four locations in HRL. Samples collected were analyzed to estimate the relative biovolume (as a proxy for biomass) for three algal functional groups: blue-green algae, green algae, and diatoms. The analysis also quantified the fraction of other major phytoplankton groups, including dinoflagellates and cryptomonads. The results of these analyses are summarized graphically in Figure 16 (included in original comment) for four time periods: winter (December – February), spring (March – May), summer (June-August), and fall (September – November). In this summary, algal species that do not fit into one of the three main groups (e.g., cryptomonads) are classified as "Others". Note that in Figure 16 (included in original comment) and the following discussion, biovolume is used as a surrogate for phytoplankton biomass. The following observations can be made concerning algal dynamics in HRL based on this summary:

- Diatoms and green algae generally dominate the phytoplankton composition during the winter and spring months, with blue-green species representing less than 5% of the total biovolume.
- Blue-greens are the most dominant phytoplankton group during the summer and fall months; however, even during these periods blue-greens comprise only ~60% of the biovolume. "Others", green algae, and diatoms comprise the other ~40% of the biovolume during these months.

Similar observations concerning phytoplankton seasonal trends are described in the HRL LRM report:

"The algal community in High Rock Lake is dominated by different algal groups at different times of the year. Winter populations tend to be dominated by diatoms (bacillariophytes), late fall and spring populations contain high proportions of green algae (chlorophytes), and summer – early fall populations are typically dominated by blue-green algae (cyanobacteria), as described in Section 2.3.7." (p. 3-45 of HRL LRM report)

These statements are followed by a summary of the approach used to represent phytoplankton in the HRL system within the HRL LRM:

"These different algal groups tend to have somewhat different temperature, light, and nutrient requirements. However, the available tested and verified public releases of the WASP code address only a single algal group. Accordingly, the algal calibration for High Rock Lake used a single algal group representation to focus on summer growing season chlorophyll a, and is thus tuned to summer blue-green algal characteristics." (p. 3-45 of HRL LRM report)

Based on the available data, it is evident that using a single algal group within the LRM cannot account for the trends and seasonal succession that occur in the HRL algal community. The above excerpt also indicates that the single algal group was "tuned to summer blue-green algal characteristics". This statement is problematic for the following reasons:

1. Based on available data, blue-green algae comprise only 60% of the phytoplankton biovolume during the summer months; therefore, nearly half of the biomass represents green algae, "other" algae, and diatoms during the summer. During the winter months, blue-green algae are only a very small fraction of the overall algal biomass.

2. The final parameterization for key model coefficients that drive algal growth are outside the range of the coefficients typically employed to simulate blue-green algal growth behavior. These coefficients include the maximum growth rate and the half-saturation constants for nitrogen and phosphorus.

The maximum growth rate of 2.8 day^{-1} (i.e., at 20 degrees Celsius) specified in the model is high relative to typical ranges of maximum growth rates used for blue-green algae. For example, Bowie et al. (1985) document typical blue-green growth rates in the 1 day^{-1} to 2 day^{-1} range at water temperatures of 20 degrees Celsius (see Figure 6-3, from Canale and Vogel 1974). The half-saturation constants for uptake specified in the model are 1 µg/l for orthophosphate and 10 µg/l for dissolved inorganic species of nitrogen (nitrate and ammonia). The half-saturation constants effectively dictate the concentrations at which dissolved nutrient availability becomes limiting for algal growth. For both dissolved P and N, the specified half-saturation constants are at the extreme low end of typical ranges (Bowie et al. 1985). As a result, algal growth limitations are only realized at extremely low dissolved nutrient concentrations, especially for orthophosphate. The selection of these coefficients has important implications for simulating the response of the HRL system to watershed nutrient loading reductions. This is because the effectiveness of potential loading reductions will be assessed based on the LRM's prediction of whether the nutrient concentrations simulated in the lake are sufficiently low to limit/reduce algal biomass and chlorophyll *a* production.

The model-data comparisons for chlorophyll *a* demonstrate the significant limitations of using a single algal class to represent phytoplankton dynamics in the HRL system. Figures 17-21 (included in original comment) compare the 2008-10 time series for observed and simulated chlorophyll *a* at the following HRL locations: HRL-052 (Figure 17), YAD152 (Figure 18), YAD169A (Figure 19), YAD169B (Figure 20), and YAD169F (Figure 21). The chlorophyll *a* data included in these figures are consistent with the expected behavior of the system based on the seasonal dynamics summarized in Figure 16 (included in original comment). Observed chlorophyll *a* concentrations are generally highest during the warm summer months and lower during non-summer periods. However, significant levels of chlorophyll *a* are consistently measured during the non-summer months. A collective review of Figures 17-21 suggests that the single algal approach is unable to capture the seasonal dynamics represented by the chlorophyll *a* data. Throughout the winter and early spring time period simulated chlorophyll *a* concentrations are close to zero until water temperatures warm sufficiently in May for algal growth to occur. This failure would not happen if a diatom group were represented in the model, because diatom optimum temperature for growth is typically 10-15^{o} C. Then, during late April and May, the model simulates significant growth (based on an elevated growth rate of 2.8 day^{-1}) to compensate for the lack of algal biomass present in the system, so that model-predicted concentrations are roughly consistent with observed concentrations by mid-May or late June. As documented in comment 4.4 above, the lack of algal production represented by the model also significantly impacts predicted orthophosphate in HRL during non-summer periods.

As summarized in Section 1.1.1 of the HRL LRM report, High Rock Lake is impaired for chlorophyll *a*, with a prescribed water quality standard of 40 µg/l. This standard applies for the entire calendar year and not just the summer months. Section 2.3.7 of the report makes the following statement concerning observed excursions of chlorophyll *a* above the 40 µg/l standard:

"Excursions of the water quality standard of 40 µg/L chlorophyll a have been reported in High Rock Lake during the 2005 – 2010 monitoring in all months except December. However, the majority of such excursions occur during the period in which blue-green algae (cyanobacteria) dominate the biovolume

(Figure 2-10). Therefore, it is a reasonable approximation to apply WASP version 7.5, which is limited to the representation of one algal class, and is calibrated to observed chlorophyll a during the blue-green algae-dominated season of June through October." (p. 2-20 of the HRL LRM report)

Although it is accurate that the *majority* of chlorophyll *a* excursions above the 40 µg/l criterion occur during the summer months, a notable number of excursions also occur in the non-summer months. This is especially true in the tributary arms of HRL (e.g., Abbotts Creek arm, as shown in Figure 17). Even at locations where excursions of chlorophyll *a* above the standard do not typically occur (i.e., for non-summer periods), concentrations are often very close to the standard (i.e., above 30 µg/l). This is notable because future "build-out" activities in the watershed could potentially increase non-summer nutrient loadings and result in increases in chlorophyll *a* levels during these time periods. The current model would be unable to represent the potential impacts of such loading increases on exceedances of the existing chlorophyll *a* standard.

The algal model approach description provided on p. 3-45 of the HRL LRM report suggests that no alternative to using a single algal group was available within WASP7. However, the "Advanced Eutrophication" option provided in WASP7 (version 7.5) includes representation of up to three algal groups and appears to provide an appropriate alternative to the single group approach (Wool et al., n.d.). As discussed in previous comments, the "Advanced Eutrophication" available option in WASP7 also provides more flexible and appropriate algorithms for representing suspended sediment transport and settling (i.e., via multiple sediment classes) as well as representing dynamic release of dissolved inorganic nutrients from the sediment bed (i.e., via simulation of sediment diagenesis processes, including bottom DO feedback). The "Advanced Eutrophication" approach is not only an available option in the public domain WASP7 (version 7.5) software, but documentation is available to support the multi-algal approach that it supports (Wool et al., n.d.). If for some reason the "Advanced Eutrophication" approach in WASP7 is not viable, then an alternative water quality response model should have been selected to represent the algal and sediment dynamics and nutrients responses in the HRL LRM in a more realistic manner. As illustrated above, the current model calibration based on a single algal group performs very poorly relative to observations outside of the June-August time period, and the current model parameterization does not realistically represent algal dynamics in the system.

Response: *See response to Section 3.7, comment 1 above.*

3.8 Calibration/Validation Performance Targets

3.8.1 Descriptions of Methods Used to Quantify Performance Targets

Comment(YPDRBA/NCDOT/LTI): Several comparative statistical metrics were selected to quantify the "goodness of fit" to the model relative to the available monitoring data for the calibration (2008-10) and validation (2005-06) time periods. These metrics include:

- Relative error (RE);
- Relative absolute error (RAE);
- Coefficient of variation (CV);
- Correlation coefficient (r); and
- Relative mean square error (RMSE).

Model-data comparative results based on these metrics are provided in the HRL LRM report for the calibration and validation periods for the following water quality variables:

- Water temperature (Tables 3-3, 3-4);
- Total suspended solids (Tables 3-5, 3-6);
- Total phosphorus (Tables 3-8, 3-9);
- Total nitrogen (Tables 3-10, 3-11);
- Nitrate nitrogen (Tables 3-12, 3-13); and
- Chlorophyll *a* (Tables 3-14, 3-15).

It was not possible to reproduce the results in these tables with confidence (i.e., using output from the EFDC and WASP7 models and the monitoring data provided in the WRDB) because the details of the approach are not documented in the report. Although the equations for some of the metrics, such as “relative error”, are well-known, others (e.g., coefficient of variation) could be developed using more than one approach. In addition, the pairing of model results and data values to support the metric calculations is a subjective process and requires decisions regarding 1) which grid cell(s) and/or layer(s) to compare against a particular data point, and 2) how to match up model results and data points through time (e.g., use of daily average or sub-daily results). Because the model-data comparative statistics presented in the HRL LRM report quantify the “goodness of fit”, it is important that the methods used for all statistical metrics be precisely described in either the main body of the HRL LRM report or an appendix to the report.

Response: *The revised version of the model report will contain a full description of the methods for calculating goodness of fit statistics at the end of Section 3.1. The specific model grid cells at which comparisons are made are already shown in the report on the relevant figures. For example Figure 3-17 has a legend that shows that the total phosphorus comparison at station HRL051 is made to WASP segment #472, corresponding to EFDC cell 56-46-5.*

March 2015 Division of Water Resources (DWR) Note*: The cell numbers associated with each monitoring station for EFDC and WASP have been added in Appendix A in the final report.*

3.8.2 Water Quality Validation Data

Comment (PTRC): On pages 3-13 through 3-17, Section 3.1.1 (“Suspended Solids Calibration and Validation”), the datasets used for validation of the total suspended solids are out of proportion and perhaps comparison with the much larger calibration datasets, failing to have good correlation coefficients. The PTRC cannot support the use of these validation data due to their statistical insignificance and irrelevance to the calibration dataset.

These small datasets are prone to unusual and acute circumstances that may affect their records, including weather, human errors including spills or illegal activity, human error in data sampling and analysis, and uncharacteristic infrastructure failures, and are therefore less statistically significant and of questionable use as applied in the document. Unfortunately, the only solution for this problem is the use of a more robust data set, which may require more data collection. Until a statistically significant and more robust data set is collected and used for model validation purposes, the PTRC cannot support the use of the High Rock Lake model as representative of actual water quality conditions.

[PTRC submitted similar comments for nutrients and chlorophyll *a* validation data sets.]

Response: *The data for the validation period are acknowledged to be limited, but are believed to be adequate for the purposes of model evaluation. We would always wish for more data, but this cannot be rectified in retrospect. In general, DWQ believes that there was adequate data for model calibration. The validation data sets are smaller, but generally confirm the strengths and weaknesses of the model observed during calibration.*

The statistical guidelines discussed in Section 3.1 of the lake model report are primarily intended to guide the calibration effort. The main goal of validation is to check for significant declines in model performance when applied to conditions other than those used for calibration. While more data is better, there is no requirement that the validation data set contain a comparable number of samples to the calibration data. With small sample sizes, statistics for the validation are themselves subject to considerable uncertainty. However, for High Rock Lake, the validation statistics are generally similar to those observed during calibration.

It is the case the correlation coefficients between observations and data are often lower than desired despite a good match between observed and simulated seasonal and annual averages. This reflects the fact that High Rock Lake is a highly dynamic, run-of-river system in which day-to-day changes in conditions are inherently difficult to predict. As is stated in Section 3.1, the results of the calibration and validation inform the appropriate uses of the model. In the case of the current version of the High Rock Lake model, general spatial and temporal trends are represented well, but individual events are not always well fit.

The plan for model calibration and validation was laid out prior to the start of modeling efforts in the Quality Assurance Project Plan (QAPP). The model calibration process consists of fine-tuning the parameters within the model that are not known a priori to provide an optimal match to observed data. Validation consists of a second, independent test of the calibrated model's ability to fit observations on a different set of data.

As described in the QAPP, the calibration endeavors to use "the best available data." In the case of High Rock Lake, the best available data are the data collected during the intensive monitoring effort conducted by YPDRBA from April 2008 through March 2010. Data for multiple stations at multiple times are available for this period, yielding a fairly robust calibration data set. In addition, the calibration period contains a range of hydrologic conditions, including a very dry year in 2008 and wetter conditions in 2009-2010.

Validation is undertaken to address the concern that a set of calibrated parameters may not represent the system under a different set of boundary conditions or hydrologic stresses and is used to evaluate confidence in the calibration and the predictive capabilities of the model. Typically, validation is performed on a separate time period than that used to calibrate the model. When the validation period is prior to the calibration period the validation data is independent of the calibration data.

For High Rock Lake, the available validation period is provided by TMDL scoping sampling conducted by NCDWQ from 2005 through 2006. The validation period also covers wet conditions (2005) and moderately dry conditions (2006). The validation sampling provides good spatial coverage (12 stations within the lake); however, data sizes are somewhat small. For water quality, the validation data set had

7 to 18 observations per station versus 44 to 59 observations for the calibration data set. For chlorophyll a, there are 24 to 28 observations per station for the calibration period, but only 3 to 4 observations during the validation period – largely due to loss of data due to laboratory errors. The small sample size at individual stations is mitigated by the number of stations. Predictions at any one station are strongly correlated with conditions at other stations; thus, obtaining a reasonable fit to all stations simultaneously is a good indicator of model adequacy despite small sample sizes at individual stations.

Given that the water quality model is being recalibrated the conclusions regarding the degree of model fit may change.

3.9 Model Application Guidelines

Comment (APGI): The end of Section 3.1 states that in order for a model to be deemed as acceptable it should achieve a "good" level of fit. This section concludes by stating that if a model does not achieve appropriate levels of fit, the model can still be useful, but, "… a detailed description of the model's potential range of applicability should be provided." The conclusion of the Model Report (Section 4.2) briefly summarizes the quality of fit for various water quality parameters and indicates that inorganic nitrogen calibration is not strong. Likewise, the Model Report states that the model has limited ability to predict individual algal blooms. APGI believes that this Model Report is the most appropriate place for a discussion of the potential range of applicability of the model. This section should be extensively expanded to make it clear in what cases this model is applicable and in what cases the model is not applicable.

Response: *This comment will be addressed following model revision. DWQ had instructed Tetra Tech not to include recommendations on model applicability until after the TAC had the opportunity to review the draft models and provide comments on how to improve model performance.*

March 2015 Division of Water Resources (DWR) Note*: Model Application Guidelines will be developed outside of the model development report during the stakeholder group process.*

3.10 75% Phosphorus Reduction Scenario

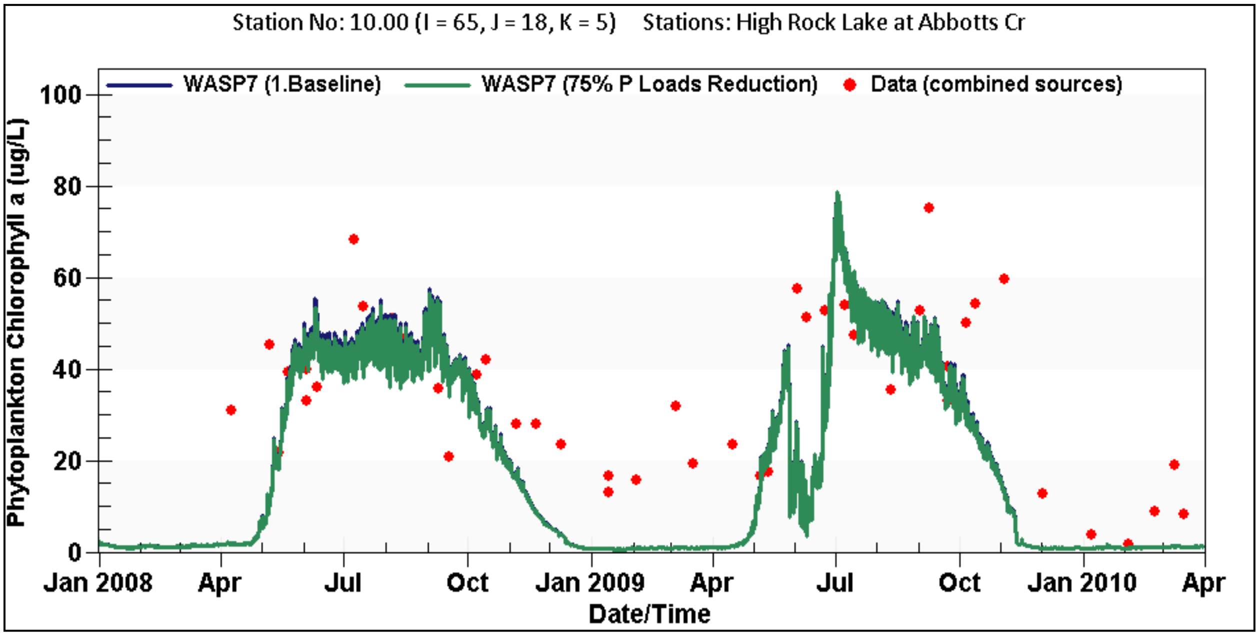
Comment (YPDRBA/NCDOT/LTI): To illustrate the importance of the concerns related to algal growth and chlorophyll a production, we conducted an example management scenario where the watershed loadings for phosphorus were uniformly reduced by 75%. A complete model simulation was run using this load reduction assumption for the 2005-10 baseline time period, and the results were compared against the baseline model results. Figures 25 and 26 (*note: provided below in response*) provide time series comparisons of the chlorophyll a predicted by the HRL LRM for the 75% reduction scenario relative to the baseline run for 2005-10. Monitoring data are also included in these figures for reference. The model results for the 75% reduction scenario are virtually identical to the chlorophyll *a* concentrations predicted by the baseline model simulation. These results illustrate that the current model is configured and parameterized such that even severe reductions in phosphorus loading will demonstrate no impact on (simulated) chlorophyll a levels in HRL. Based on our extensive experience in evaluating data, and developing, calibrating, and applying eutrophication models, this result is likely not reasonable and has the potential to misguide the selection of management actions in the HRL watershed.

Response: *This comment reflects errors in the commenters' model set-up for the scenario. In fact, reductions in phosphorus input yield a marked reduction in simulated chlorophyll a concentrations.*

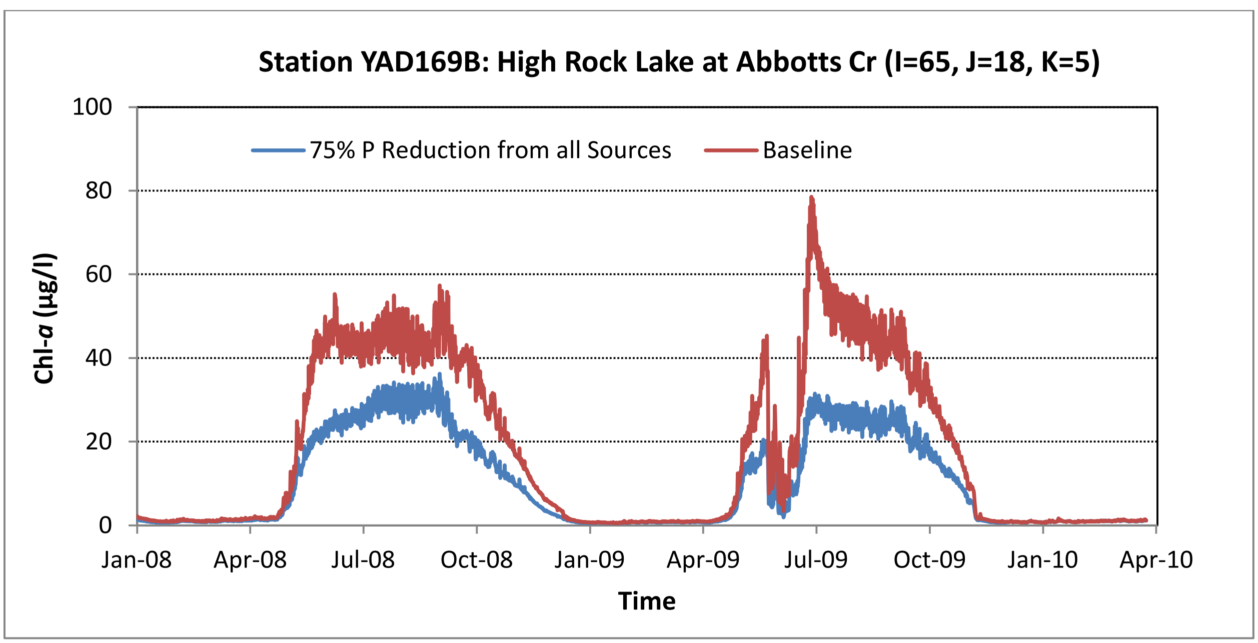
Tetra Tech and DWQ independently tested the 75% reduction scenario described in the comment above. Tetra Tech and DWQ produced the same results, which are very different from the figures represented in the comment and conclusively demonstrate that the model does respond appropriately to reductions in phosphorus load. Reduction of watershed phosphorus load by 75% results in an approximately 50% reduction in summer predicted chlorophyll a concentrations at Abbotts Creek (YAD 169B) and at the dam (YAD169F) for 2005-2010. The correct results are provided below.

DWQ requested the input file that LimnoTech used to run the scenario to determine the source of the discrepancy. LimnoTech responded with an email acknowledging that the plots submitted in their original comment (shown below) were incorrect and provided figures that were more in line with those produced by DWQ and Tetra Tech.

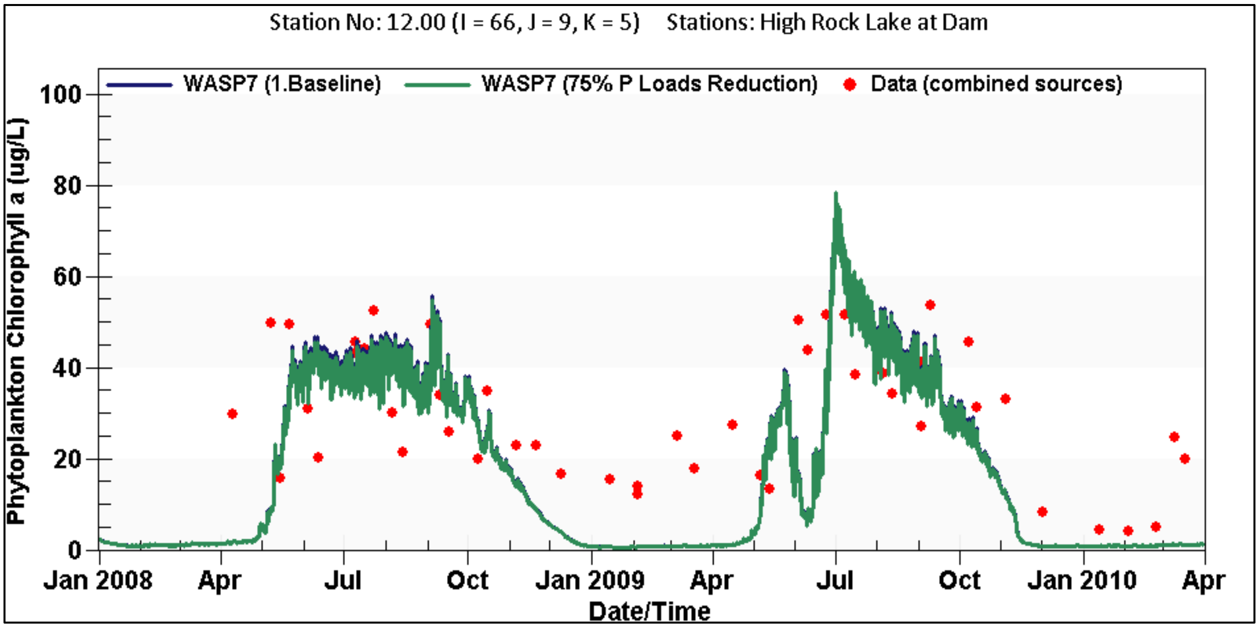
Results of 75% Phosphorus Reduction Scenario



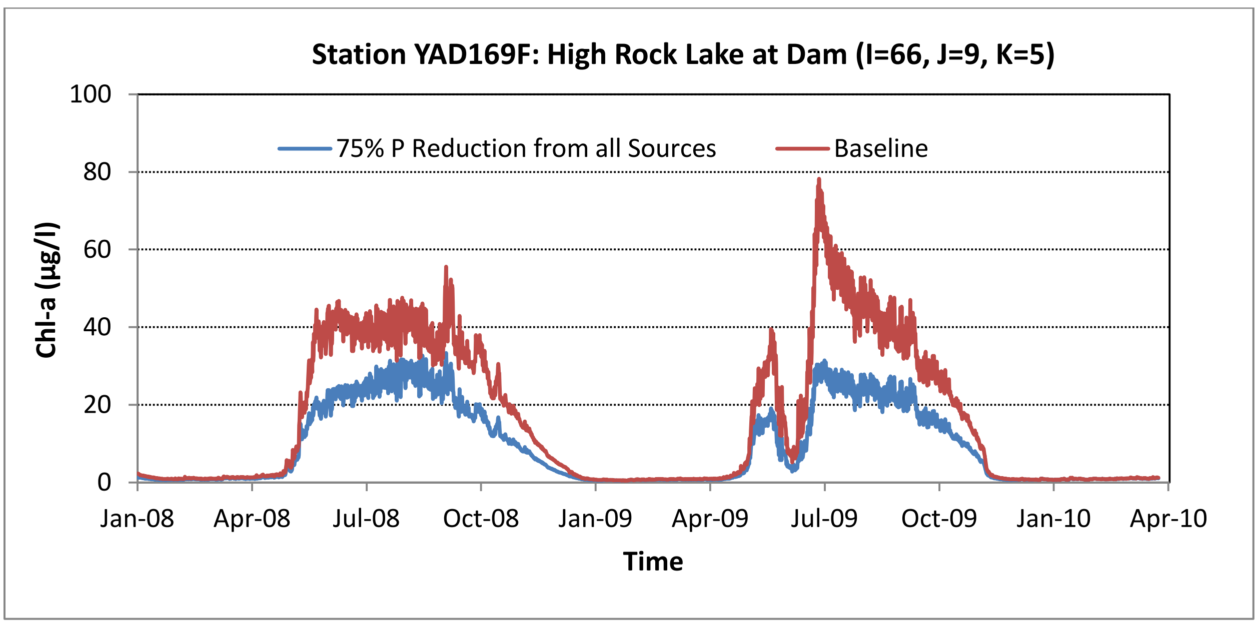
Incorrect figure originally submitted by YPDRBA/NCDOT/LTI.



Correct figure developed by DWQ and independently verified by Tetra Tech.



Incorrect figure originally submitted by YPDRBA/NCDOT/LTI.



Correct figure developed by DWQ and independently verified by Tetra Tech.