SOUTH CAROLINA ELECTRIC & GAS COMPANY

COLUMBIA, SOUTH CAROLINA

SALUDA DO STANDARD PROJECT

LOWER SALUDA RIVER DO TECHNICAL STUDY REPORT

JULY 2003

Prepared by:

Kleinschmidt Associates
Energy and Water Resources Consultants

Loginetics, Inc.

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1.0 EXECUTIVE SUMMARY

South Carolina Electric & Gas (SCE&G) is proposing a site-specific standard for dissolved oxygen for the Lower Saluda River (LSR) downstream from Saluda Hydro. This report documents results of scientific investigations necessary to formulate that proposed site-specific standard. These investigations included a trout growth study conducted during 2002-2003 and extensive modeling related to tailwater water quality, fish growth, and turbine venting effectiveness.

The fish growth study on the LSR indicated that an excellent trout fishery exists on the river. This fishery exists even though dissolved oxygen concentrations currently fall below 2 mg/L. Fish modeling showed that the successful fishery is due in part to the relatively high average dissolved oxygen concentrations that have occurred in the river due to the aeration system (implemented by SCE&G in 1999), in conjunction with the reduced incidence of high flows due to recent drought years, and a favorable temperature regime. It is estimated that the fishery would do nearly as well during normal hydrologic years using the current aeration system; however, in wet years or in years when the pool level of Lake Murray is drawn down for special purposes in September or October, the difference in fish growth might be measurable (i.e., a difference greater than 1/2 ounce or 1/16 inch was considered measurable for fish weighing over 2 pounds and having a length of about 18 inches).

To estimate the range of DO conditions the fishery might be exposed to in the future a turbine aeration model was developed to predict the effects of using various aeration alternatives. This model was then used to predict DO conditions in the river for the years 1990 (wet), 1992 (normal), 1996 (normal with a special drawdown of Lake Murray), and 1999 (dry). The results of the turbine aeration model were summarized as DO metrics (e.g., minimum daily DO, average daily DO, 30-day average DO, etc) that represented potential measures of DO that could be considered for setting DO standards.

A tailwater hydrodynamic water quality model was calibrated using actual onsite water quality data. A fish bioenergetics model was calibrated using tailwater quality model results and results of the growth study. The fish bioenergetics model was then used to estimate trout growth for various aeration scenarios for each of the four years. The results showed that growth was best correlated to the moving 30-day average DO. This finding is consistent with the recommendations in the EPA criteria document for DO.

A central concern was found to be the minimum DO level that occurs with the current aeration system. A minimum DO of 3 mg/L is considered to be protective for trout survival, and this same level likely would be sufficient for other aquatic life that serve as food supply for the fishery. However, a minimum of 4 mg/L has been set by SCDHEC for application to all waters of the State, so SCE&G has little choice but to consider 4 mg/L as the minimum DO to propose for the site-specific standard.

The results of the scientific studies showed that following site-specific standard should be considered for the lower Saluda River:

- daily DO: 4 mg/L minimum
- 30 day average DO 5.5 mg/L minimum

These levels of DO were shown to be protective of the fishery and would achieve trout growth objectives equivalent to those that would result from application of the DO standard previously proposed by SCDHEC.

2.0 INTRODUCTION

The South Carolina Department of Health and Environmental Control (SCDHEC) has proposed changes to the existing dissolved oxygen (DO) site-specific standard for the Lower Saluda River (LSR) downstream of the Saluda Dam/Lake Murray. On August 13, 2002, SCE&G met with SCDHEC and the South Carolina Department of Natural Resources (SCDNR) to discuss these proposed changes. As part of that meeting, SCE&G proposed to develop a study plan that would:

1. Describe the methodology to be used to identify a scientifically-based alternate DO standard for the LSR, and;
2. Develop and present a proposed numerical site-specific standard to the SCDHEC and SCDNR.

SCE&G prepared a detailed study plan and on September 30, 2002 submitted the proposed study work scope and schedule to the SCDHEC, SCDNR and Environmental Protection Agency (EPA) for review and comment (Appendix A). The scope of work in the draft study plan included a combination of accepted multi-dimensional models using historic scientific data supplemented with site-specific data from the LSR. The study plan proposed distinct elements that are all integrated and critical in determining a site specific DO standard for the LSR. The studies in the plan address the designated use which is trout put, grow, and take. Those elements include:

1. In-situ trout growth study
2. Turbine venting modeling
3. Tailwater modeling
4. Bio-energetics modeling
5. Lake Murray water quality model

This approach of site-specific application of latest science allows the 1986 EPA DO criteria document to serve as a basis for determining the site-specific DO standard.

SCE&G received valuable input and comments from the regulatory agencies and incorporated those comments into the study plan. A condition of acceptance was that SCE&G propose no standard with less than a 4 mg/L minimum DO. On November 5, 2002, SCE&G received a letter of acceptance from the SCDHEC to pursue and conduct the proposed studies necessary to develop a site-specific DO standard for the LSR.

This report provides a summary of the outputs of work elements outlined in the approved Study plan. All supporting documentation will be supplied in appended reports and CD-ROMs to this summary report. These reports/CDs will present input data, modeling assumptions and sensitivity analyses, and calibration results used to develop the model simulations for scenario runs.

With any use of models it should be recognized that modeling results provide a general indicator of what is likely to occur under a given sets of conditions. As is the case in all aquatic environments, natural conditions are more complex than models, so the models tend to reproduce the major patterns that are observed in the field, but may lack resolution, inputs or formulations to reproduce all the minor patterns that are observed. Models are internally consistent and based on rigorous governing equations, so they can often help explain apparent discrepancies in field observations. The model results contained in this report are scientifically sound and can be used for regulatory decision-making purposes for determining a site-specific DO standard for the LSR.

These studies and modeling efforts are based upon state of the art approaches that are logical, sound extensions of well-founded research and studies conducted over the past half century.

3.0 SUMMARY OF EPA DO CRITERIA

The 1986 EPA DO criteria document represents the latest and most scientifically peer-reviewed regulatory guidance on the effects of DO on freshwater aquatic life. Prior to the 1986 EPA DO criteria document, the EPA criterion was a simple 5 mg/L minimum. The 5 mg/L criteria was overprotective against acute mortality if rigorously applied. It was also potentially underprotective against chronic effects. In addition, States often used 5 mg/L as a daily mean value, allowing unacceptably lower true daily minima. The revised EPA criteria for DO for the protection of trout contain limits to protect both survival and growth. A criterion of 3 mg/L daily minimum is recommended for survival of trout, but trout mortality does not occur even if they are exposed continuously to 3 mg/L for 30 days. Exposures to lower minima produce mortality of trout when DO levels fall below 2 mg/L. For protection of trout growth, the EPA criterion recommended a 30-day average DO of 6.5 mg/L. The EPA document recommends the average be considered a moving average rather than a calendar monthly average.

Any pattern of DO concentration that meets these limits would be acceptable and would be protective of a put, grow, and take trout fishery such as that in the LSR. However, a more restrictive minimum of 4 mg/L is recommended by EPA in order to protect sensitive aquatic insects such as are present in some mountain, cold-water trout habitats. A more detailed description of the EPA DO criteria is provided in Appendix B.

The EPA DO criteria for growth are based almost entirely on studies of exposure to constant DO levels. In order to apply these criteria to streams where DO concentrations can fluctuate greatly, EPA initiated the development of a model that predicts growth of trout and other fish exposed to day-to-day and hour-to-hour fluctuations of DO. With the cooperation of EPA and TVA engineers, modelers, and biologists, a joint EPA-TVA fish bioenergetic model (FISH) was developed that uses the data from the studies in the EPA DO criteria document. These DO-growth effect data are inserted into the fish growth model, and the model predicts the trout growth resulting from any combination of DO exposure patterns.

4.0 FISH GROWTH MODEL

The FISH model was used to compare annual trout growth under a range of DO patterns in the LSR. Among other comparisons, the growth predictions can be compared with growth achievable at the EPA criteria concentration of 6.5 mg/L. Model predictions also allow comparison of trout growth under any other patterns of DO dynamics. Making such comparisons was the goal of the EPA-TVA model development.

All fish growth models used in fishery management and research have an almost identical structure using information from studies on fish diet, food consumption, digestion, excretion and respiration, as well as how these are affected by water temperature. The EPA-TVA model also included the effects of DO on food consumption and growth from the studies included in the EPA DO criteria document. For use in this study, the 1993 EPA-TVA growth model was updated to include rainbow trout bioenergetic data of better precision than available during earlier model development.

Trout growth can be limited by temperature, DO, or food availability (Figure 1). Given an essentially unlimited food supply and adequate DO, temperature will control fish food consumption (appetite), respiration, and growth. At any temperature, some low level of DO will restrict appetite and, if food availability exceeds appetite, growth will be affected by DO. Whenever food availability is less than the fish's appetite, as determined by temperature and DO, the availability of food will limit growth.

In order to predict trout growth in the LSR, the model requires information on the effects of both temperature and DO on appetite and an estimation of the amount of food available to trout in their natural environment. The effects of temperature on appetite are well documented for use in growth models, and the data from the EPA criteria document were used for determining the effects of DO on appetite. Food availability in the LSR can be estimated by measuring the growth of trout in the river and knowing the temperature and DO during the period that growth is measured. Site-specific data on trout growth were gathered through a study of trout planted into the LSR in 2002-2003. A summary of the growth study is contained below, and Appendix B provides more detailed information regarding the trout growth study conducted on the LSR.

5.0 GROWTH STUDY

Approximately 11,000 rainbow trout *Oncorhynchus mykiss* were released into the lower Saluda River between December 2002 and March 2003. The tagging efforts were a joint venture between Clemson University Cooperative Unit, SCE&G, Kleinschmidt Associates and the SCDNR. Typical stocking sizes of rainbow trout in the LSR are around 8-10 inches (per communication, Hal Beard, SCDNR), and this size class was utilized in the study. Each trout was individually tagged using large format visible implant alphanumeric (Vialpha) tags. Tagged fish were grouped in lots of 1000 at the fish hatchery and were planted at four times (December, January, February, and March) with each release date denoted by a different color tag. Each set of color-coded tags contained a unique alphanumeric combination allowing identification of individual fish. Fish were tagged, then, approximately 21 days after tagging each tagged fish in that release batch was weighed and measured and the data recorded by tag code. Planting numbers and locations generally corresponded to normal SCDNR trout release stocking locations. An additional release site was added below the Saluda Hydro powerhouse.

During April, May, and June, fish were recovered from the river by electroshocking, at which time the fish were again weighed and measured and their tag identifications were recorded. Angler caught fish were also weighed and measured in some instances. Limited creel surveying was conducted, but those fishermen surveyed typically had 4 to 10 trout in their possession. Weight and length data are not reliable except for freshly caught trout. Those fish that were kept in livewells after being caught were in good condition and were weighed and measured and included in the database. About one percent of the planted fish were recovered (111) by the combined collection methods, and growth rates of these fish were calculated. Factors that likely affected recapture of the tagged specimens included fishing pressure and predation by striped bass. With respect to predation by striped bass, sampling efforts yielded significantly fewer brown trout in the 200-300 mm size range as the year progressed, suggesting that predation may impact trout survival in the LSR. No stomach content analyses were conducted on striped bass to confirm this supposition, but discussions with SCDNR indicate this may be occurring.

The growth data collected, along with temperature and DO data from the USGS gages and the tailwater model for the LSR, were used to calculate the amount of food available to the fish. As is common to such studies, the results indicated that the amount of food available was less than the appetite of the fish. In this case, about 68% of maximum appetite was available, based on model calibration. After determining food availability, the model was used to predict trout growth under a range of temperature and DO conditions for various hydropower, meteorological, and regulatory conditions.

The measured average trout growth rate (0.7 percent weight gain per day, 0.67 inches per month) is higher than that found in most other tailwater trout growth studies. Analysis of the growth data (Appendix B) indicated that data from all 111 fish could be pooled and used in the model, as there was no significant difference in growth as a result of fish size or condition at release, site of release, date of release, date of capture, direction and distance of movement in the stream, or site of capture.

Additional information collected during the growth study revealed significant numbers of rainbow and brown trout that appear to be carryovers from previous stockings. A total of 441 tagged and untagged trout were collected from the LSR, with 253 rainbow and 188 brown trout comprising the total catch.

Of the 441 rainbow and brown trout collected, 74 exceeded 16 inches in length. The largest rainbow and brown trout collected during these surveys were 22 and 24 inches, respectively, with all fish appearing robust and healthy. This may be attributable to higher DO levels since the inception of SCE&G's turbine venting program than those DO levels historically observed in the LSR.

6.0 PREDICTION OF DO CONDITIONS FOR DISCHARGES FROM SALUDA HYDRO

Exposure of the trout to DO concentrations in the river is an important consideration for developing a site-specific water quality standard. Accordingly, the frequency and duration of various levels of DO that occur under various conditions for the discharges from Saluda Hydro must be quantified.

River flows and DO conditions in tailwaters like that below Saluda Hydro are highly variable compared to natural rivers for which DO standards are normally applied. For example, in natural systems, low flow conditions usually occur for long periods of time, like several weeks or even months, and low DO conditions (when they occur) usually occur during these low flow periods. In contrast, the river downstream from Saluda Hydro experiences low DO conditions when flows are high, and these high flows usually occur for brief periods on the order of hours. In fact, it is estimated that lower DO levels like 4 mg/L would occur with new aerating turbines only when flow levels are greater than about 10,000 cfs, which occur about one percent of the time, and these high flow periods are usually less than 24 hours. This percentage of time is greater in wet years and less in dry years.

To determine the exposure of trout to DO under aerated conditions for the Saluda Hydro discharges, a turbine aeration model was developed to predict release DO under the following aeration cases:

1. Current aeration practices
2. Current aeration practices plus the addition of hub baffles
3. Installation of new aerating turbine wheels (auto-venting turbines, AVT)
4. AVT plus use some additional aeration method that could provide a minimum DO of 4 mg/L
5. AVT plus use some additional aeration method that could provide a minimum DO of 6 mg/L

These cases were simulated using hydrologic conditions for the years 1990 (wet with a special drawdown in September and October for maintenance of intake towers), 1992 (normal), 1996 (normal but with high flows during September associated with a lake draw down for aquatic plant control), and 1999 (dry). A range of hydrologic years was considered since this significantly affects hydropower operations that in turn affect the DO conditions in the tailwater—e.g., in wet years, there is more generation resulting in the tailwater being exposed to more frequent low DO conditions.

6.1 Model Development and Calibration

The model was developed using the discrete bubble model described in technical Appendix C. The model predicts DO using the following inputs:

1. 15-minute flow data from the USGS gage located below the dam
2. temperature of the water entering the turbines
3. DO concentration of the water entering the turbines
4. 15-minute tailwater elevation data

The model was calibrated using the draft tube geometry for Units 1- 4 and Unit 5 and test data collected in 1997 and 1998 to measure DO uptake through the individual units over a range of turbine operating conditions. Figures 2 and 3 show results of the model calibrations for DO versus flow for each unit. These figures show that Units 1, 2, and 4 produce greater DO increases than Units 3 and 5. Units 1, 2, and 4 have the advantage of sitting higher over the tailwater elevation than Unit 5, and they aspirate relatively greater amounts of air into the units over the whole range of tailwater elevations. The reason that Unit 3 draws less air has not been determined (Unit 3 also sits high over the tailwater like Units 1, 2, and 4, but it does not draw as much air as these units.)

After the models for each unit were calibrated using 1997- 98 test data, the individual unit models were then programmed using FORTRAN to integrate the effects of all the units so that DO could be predicted for the total plant discharge. The output from the program was then validated against actual operating conditions for the year 2000 when the current aeration system was operational. Figure 4 shows how the model matched the data at the USGS monitor located below Saluda dam. This figure shows that the model closely simulates the DO when flows exceed approximately 6000 cfs and when DO is less than about 5 mg/L. The DO at the USGS gage is occasionally higher than the model prediction due to photosynthetic activity by aquatic macrophytes in the tailrace. Also, occasionally, the measured DO is less than the model prediction for brief periods. This is attributed to the Saluda turbines not being operated in an “optimized manner” for aeration at all times, i.e., the operator may not have used more than one unit to operate the plant and increase DO by using less flow through each unit. Optimized operations for aeration would require modification of the current automatic control system, which is currently being considered by SCE&G for implementation sometime in the future.

6.2 Prediction Of DO Conditions in the Tailrace

The calibrated model was then programmed to simulate DO conditions if hub baffles were placed on the current turbine wheels to increase air uptake in the units at gate settings that produce flows exceeding approximately 1500 cfs. Next, the model was programmed to simulate DO conditions if new turbine wheels (AVT) were installed with “auto-venting” capabilities, which could increase DO even more than the addition of hub baffles while also improving efficiency of the units. Figures 5 and 6 show how much DO improvement was predicted using hub baffles and AVT.

The model was then ready for predicting DO conditions in the tailwater for the range of operating scenarios that are listed above. Since fish grow all year, model runs were made for the entire year. Model results were summarized in plots like Figure 7. The results of all model runs are included on the enclosed CD. These results summarized DO conditions using the following DO metrics:

1. Minimum daily DO
2. The moving 7-day average of the minimum daily DO
3. Daily average DO
4. The moving 7-day average of the DO
5. The moving 30-day average of the DO

The results of the various turbine aeration model runs were used as inputs for the bioenergetic model runs. All references to "7-day" and "30-day" averages hereafter in this report denote moving averages.

7.0 TAILWATER FISH GROWTH MODEL CALIBRATION

7.1 Tailwater Model and Calibration

A one-dimensional (longitudinal) hydrodynamic and water quality model was calibrated and applied to predict dynamic temperature and DO throughout the Saluda tailwater in response to various hydro plant operations and release quality. These results were then used to calibrate the bioenergetics model described in the next section.

The tailwater model consisted of two modules, ADYN and RQUAL. ADYN is based on governing equations for conservation of water mass and momentum. RQUAL is based on governing equations for conservation and kinetics of constituent mass transported in the water. ADYN simulates discharge, water surface elevation, depth, velocity, wetted area, and other hydraulic variables over time at numerous model nodes throughout the simulated river system, based on a series of irregular channel cross-sections and user-specified channel roughness, boundary conditions, and initial conditions. RQUAL simulates temperature, DO, and carbonaceous and nitrogenous forms of BOD over time at numerous model nodes throughout the simulated river system, based on user-specified temperature and water quality for dam releases and tributary inflows. The model includes atmospheric heat exchange, reaeration, aquatic plant effects, sediment oxygen demand, waste loads, and other important in-stream kinetic processes. Such models are widely applied to transient flow and water quality issues in rivers downstream from hydropower stations. The reader is referred to Appendix C for more details on the tailwater model.

ADYN and RQUAL were calibrated using October 1998 release flows, temperature, and DO measured at the USGS monitor downstream from Saluda Dam as upstream boundary conditions. Model calibration is shown by comparing model results to field data at downstream monitors as shown in Figure 8. The model successfully reproduced the major discharge, temperature, and DO patterns evident in the data. Minor mismatches were attributed to uncertainty in local inflows, local inflow quality, and meteorology data that was at times unrepresentative of actual local meteorology. More details on calibration inputs and the calibration can be found in Appendix C.

7.2 Bioenergetics Model and Calibration

The bioenergetics model, FISH, was used to explore different trout growth responses due to various aeration alternatives at Saluda Dam. FISH simulates fish biomass over time at modeled river locations resulting from bioenergetic exchanges during food consumption and respiration processes. A team of TVA and EPA-Corvallis researchers developed this model in the early 1990s for use in hydropower tailwaters. In FISH, fish growth responds to fluctuations in temperature, DO, and food availability. Temperature and DO are provided by the RQUAL water quality model or by direct user input if continuous data are available at necessary locations. Food availability is not simulated in FISH; rather, it is back-calculated by calibrating the model to fish growth data from tagged cohorts that are stocked and retrieved over time to measure growth. Growth rates at each modeled timestep are simulated as the net of food consumption (corrected for assimilation ratio) less respiration. In the model, food consumption (appetite) is related to temperature and DO, and respiration is related to temperature, based on relationships derived from laboratory experiments for rainbow trout. Appendix D contains more details on the bioenergetics model.

Calibration of FISH was accomplished by adjusting food availability until modeled growth reproduced the data from the 2002-2003 growth study. Food availability was expressed as a percentage of maximum appetite. Individual fish from the growth study exhibited a wide range of growth rates over the period from stocking to recapture, so the model was calibrated to reproduce the central tendency of data represented by an exponential fit to the growth data. Calibration indicated that food availability of 68% of maximum appetite produced the best calibration results across the four stockings. Modeled growth using 68% food availability is shown versus growth data for the four stockings in Figure 9. The model reproduced growth of the first and third cohorts well, but it somewhat underpredicted growth in the second cohort and it somewhat overpredicted growth in the fourth cohort. Appendix C contains more discussion on the model calibration.

8.0 TURBINE VENTING AND BIOENERGETICS MODEL RESULTS

Rainbow trout growth was simulated for a range of aeration scenarios using the calibrated bioenergetics model. Release DO patterns for the following aeration scenarios were quantified for four different hydrologic years (wet, average with special drawdown, average, dry):

- no aeration
- current aeration
- hub baffles
- AVT
- AVT with minimum DO of 4 mg/L
- AVT with minimum DO of 6 mg/L

Release DO patterns for all but the "no aeration" scenario were developed using outputs from the turbine venting model. For the "no aeration" scenario, the inflow DO to the turbine venting model was used as an estimate of release DO.

Fish growth in the bioenergetics model is the result of the combined effects of temperature, DO, and food availability. Temperature in each scenario was based on the observed temperature at the USGS tailrace monitor, so the temperature pattern varied with hydrologic year but not with aeration scenario within a year.

Model simulations and growth study data indicated that little difference in growth rates could be attributed to location in the tailwater. Accordingly, growth simulations for turbine venting options were based directly on release DO patterns from the turbine venting model. As such, modeled growth represents growth of a fish anchored in the immediate tailrace of the dam which is exposed to release DO levels.

Certain processes such as avoidance, predation, and competition are not included in the model. Also, mortality is not included in the model, so the growth results require qualification in those cases where the release DO suggests acute toxicity. Where release DO fell to values less than 2 mg/L, it is possible that a certain percentage of the trout would experience mortality if short-term avoidance of low DO were not possible, as is assumed in the model. In reality however, such exposure might be avoided by fish moving temporarily to the surface or to tributary inflow locations, or to bank locations where DO would be higher. Thus, modeled growth during periods of low DO exposure carries the above qualifications.

Food availability for all growth simulations was set at 68% of maximum appetite, in accordance with model calibration to 2002-2003 growth study data. Thus, the 68% food availability level reflects “current” conditions. It is recognized that food availability may not be constant, and may itself be affected by DO over the wide range of DO patterns simulated in the aeration scenarios, and this deserves some discussion. After long-term operations at the “no aeration” level, it is possible that food availability could be significantly lower than current conditions. This may have been suggested by the fact that food availability required to reproduce the 1988-1989 (pre-aeration) growth study data supplied by SCDNR was 45%. This apparent change in food availability between the late 1980s and the early 2000s could be due to a number of factors in addition to DO, including flow patterns and aquatic plants, food levels present in hydro releases, seasonal and annual differences in available food types and feeding preferences, etc. After long-term operation at aeration levels beyond “current aeration”, food availability could be slightly higher than the current condition. There is no good way to quantify the expected changes in food availability due to future aeration, nor is there strong basis for using the 45% food availability for the “no aeration” case because it is uncertain that the difference was due exclusively to DO changes between 1988-89 and 2002-03. Accordingly, all growth simulations were based on the same food availability of 68%, which reflects the growth differences one might expect in the short term relative to current aeration prior to any long-term change in food availability that might be associated with additional aeration.

Simulated release DO and rainbow trout growth, based on results of the turbine venting and bioenergetics models, are shown in Figures 10 through 13 for a wet year (1990), a moderately wet year (1996), an average year (1992), and a dry year (1990). “Wet” here implies a higher frequency of high flows in the September-October period, coincident with low DO. 1990 and 1996 are the “wettest” and “next wettest” years in recent history by this definition, respectively. It is significant to note that these were special drawdown years. In 1990, there was a special drawdown for maintenance on the intake towers, and in 1996 there was a special drawdown during the low DO period to reduce aquatic plants in Lake Murray. So a year can be “wet” due to special operations as well as hydrology. For example, 1990 was a wet year hydrologically in addition to being a special drawdown year and the higher flows throughout 1990 are part of the reason release temperatures were warmer that year.

Simulations ran from day 1 (January 1) to day 365 (December 31), with initial fish size of 200g on day 1. For reference, Figures 10 through 13 also shows the time-series of fish weights that would be associated with 1 inch per month and 0.5 inch per month growth, based on a condition factor of 1.1 to convert between length and weight. Table 1 shows modeled final fish weight on day 365 for each simulation.

Inspection of the growth patterns produced by the various aeration scenarios shows that the biggest improvement in growth occurs between the “no aeration” case and the “current aeration” case, with diminishing returns in growth for aeration levels above “current aeration”. This pattern occurs because of the diminishing effect of DO on fish appetite for incremental DO increases at higher DO levels. Also, wet years exhibit greater effect of aeration on growth than dry years, because wet years produce more frequent and prolonged episodes of low DO than dry years. That said, it is significant to note that, even with lower DO, overall growth in the wet year (1990) exceeded that in the normal year with a special drawdown (1996), due to the more prolonged periods of favorable temperatures (17-20 ºC) in the wet year.

9.0 RESULTS OF FISH GROWTH AND CORRESPONDING DO METRICS

This section presents the results from the previous sections and compares the results of the fish modeling to the DO metrics that summarize the DO conditions to which the fish were exposed in the fish model. The DO metrics presented here focus on those that might be considered for setting a site-specific standard. In considering regulatory DO standards it is important to set DO thresholds that are intended to be met or exceeded under defined conditions. Hence most of the discussion in the section regarding DO metrics will focus on the minimum values of each of the metrics.

Table 2 presents results of the fish modeling as well as the various minimum DO metrics that might be considered. The DO metrics were taken from plots like that shown in Figure 7 and the fish modeling results were taken from Table 1. Figures 14 through 17 graphically depict the information in Table 2 for each year, respectively. Figures 18 and 19 summarize selected information from Table 2 for the minimum daily DO and the minimum 30-day average DO for all four years.

It is readily apparent from these figures (and to some extent by examination of the table) that year-end fish weight is not affected directly by minimum daily DO values. Annual fish growth (i.e., year-end weight) is strongly correlated with average values of DO, especially and most consistently with 30-day average values when the results for all years are considered. For the year 1990, which experienced the "worst-case" minimum daily DO conditions, fish growth was poorly correlated with minimum average daily DO and 7-day average DO. It is more important to consider the results for the years 1990 and 1996 because these were the only years where simulated year-end fish weight showed any measurable difference between the aeration alternatives.

Regression correlation coefficients were determined for the relationships between year-end fish weight and the DO metrics, and the R^2 values were significantly higher for the 30-day average than for the daily average, i.e., for the year 1990, the R^2 value was near 1 for the 30-day average DO while the R^2 value was 0.8 for the minimum average daily DO.

Figure 20 presents the frequency of exposure for fish to DO conditions below Saluda Hydro for actual conditions over the years 1989 through 2000 (note: results for 2001 and 2002 would be similar to conditions for 1999 and 2000) as well as for the years 1990, 1992, and 1999 with predicted conditions for new aerating turbines as well as with the DO minimum set to 4 mg/L. The frequency plot includes only the period when DO is generally lowest during the year. This figure shows how dramatically DO improved during the years 1999-2000 as well as how well DO would be improved using the aeration alternatives plotted.

It is important to note that the median DO exceeds 7 mg/L for all plotted aeration alternatives in Figure 20, and these plots include only July through mid-November. This means that during the period of the year when DO is lowest, the median DO is greater than the EPA criteria of 6.5 mg/L for the 30-day average. Hence, the annual median DO would be even greater since DO is near saturation for much of the rest of the year. This figure also shows that the DO would be less than the EPA 30-day mean criterion of 6.5 mg/L for only about 30 days in the wettest year (1990).

10.0 CONSIDERATIONS FOR SETTING THE SITE-SPECIFIC DO STANDARD

10.1 Current Conditions

The current fishery and invertebrate food supply in the LSR are excellent by comparison to other southeastern hydropower tailwaters, even though DO concentrations have periodically dropped to about 1 mg/L during high flows. This high quality fishery can be attributed in large part to SCE&G aeration practices over the past 4 years, in conjunction with drought conditions that have occurred over this same period of time.

Fish growth modeling shows that current aeration practices provide near-maximum growth (i.e., no measurable difference compared to additional aeration) for low- and normal-flow years. Minimum DO levels near 1 mg/L would occur, however, and potentially cause some avoidance or mortality (although no such mortality has been observed in the past).

The most critical DO conditions in the LSR occur during high flows. When special drawdowns of Lake Murray occur, especially in wet years, more water has been released during the time of year when DO in the discharges was at its lowest levels. Under these conditions (2 of the last 14 years), low DO occurred more frequently and for longer durations. Fish modeling indicates that the current aeration practice would result in good growth, i.e., 0.67 inches/month and year-end fish lengths of about 18 inches and weights of over 2 pounds. However, with additional aeration, small increases in growth may occur, and DO levels low enough to cause mortality or avoidance would be less likely to occur.

10.2 Potential DO Metrics

The following DO metrics are commonly used or considered for reporting DO conditions in waterways for regulatory purposes:

1. Minimum daily DO
2. The 7-day average of the minimum daily DO
3. Daily average DO
4. The 7-day average DO
5. The 30-day average DO

The minimum daily DO and the average daily DO are commonly used in South Carolina water quality regulations. The 30-day average DO in combination with a daily minimum DO is recommended in the EPA criteria document. A daily average criterion is typically set lower than a 30-day criterion. Because a lower one-day average could occur continuously over extended periods of time, a higher long term average is more protective of fish growth.

10.3 Needed DO Metrics for Acute Toxicity and Growth

At least two DO metrics are needed: one to protect against acute toxicity, and one to ensure suitable fish growth. These metrics should be selected to protect designated water uses, as well as allow Saluda Hydro to operate as cost-efficiently as possible. To protect against acute toxicity, a minimum DO based on hourly DO measurements is considered most effective.

To protect fish growth, a longer-term average DO is considered most effective. DO levels greater than about 5.5 mg/L, as determined for the minimum 30-day average, did not yield higher measurable growth levels (see Figure 19 and Table 2.) Hence, this DO metric should reflect a reasonable expectation of fish growth but not be overly restrictive for Saluda Hydro.

10.4 DO Metric for Acute Toxicity

Data used to prepare the EPA criteria document as well as subsequent research by EPA and others showed that trout can survive short periods down to 1.5 to 2 mg/L before significant mortality occurs. A minimum of 3 mg/L is considered sufficient for protection against acute toxicity to trout.

SCDHEC has specified that the proposed standard minimum be no less than 4 mg/L and this value is the EPA minimum criteria for trout waters. This EPA minimum criterion for trout waters was set in order to protect insect species that may be more sensitive than trout. Trout are killed in the 1-2 mg/L range; and EPA recommended a minimum value of 3 mg/L to avoid trout mortality. Considering that SCDHEC has set 4 mg/L as the minimum DO level to be allowed anywhere in the State unless extensive research is conducted on all potentially sensitive organisms, SCE&G has no practical, current alternative but to consider proposing 4 mg/L as the minimum DO level for the site-specific standard.

10.5 DO Metric for Growth

The 30-day average DO metric clearly correlates to fish growth better than any other metric based on a comparison using various DO metrics (daily average, 7-day average, and 30-day average) and fish growth results for all 1990 aeration scenarios. Regression coefficients (R^2) were determined for the relationships between year-end fish weight and the DO metrics, and the R^2 values were significantly higher for the 30-day average than for the daily average (Appendix E). Average DO metrics for shorter periods like daily and 7-day average fell below 5 mg/L intermittently for brief periods in 1990 and 1996 (see Table 2). In combination with a minimum DO standard of 4 mg/L, it would be unreasonable to consider the daily and 7-day average DO for a growth standard because their use is less protective of trout growth than the 30 day average, and their use would limit hydropower flexibility resulting in undue extra costs for aerating the releases from Saluda Hydro.

An approach using the 30-day average, which protects fish growth (as well as being best for hydropower dischargers), is the approach recommended in the EPA criteria document, which is EPA's scientifically peer-reviewed regulatory guidance on the effects of DO on freshwater aquatic life. Although a 30-day average differs from the daily average DO currently used by South Carolina for most waters of the state, it is more protective as a growth metric when proposed along with a minimum daily DO standard. The 30-day average is more protective because it is a higher level of DO over a longer period of time, which is more important to growth.

Therefore a 30-day average 5.5 mg/L (with a 4 mg/L daily minimum as specified by SCDHEC) is suggested as a site-specific standard for the LSR. A 30-day average of 5.5 mg/L can be used with only minor, immeasurable differences in weight or length relative to that attainable with a minimum DO of 6 mg/L.

"Immeasurable" is defined to be 14 grams, 0.5 ounces, or 1/16 inches less than conditions achieved using a minimum DO of 6 mg/L. The mean difference in year-end fish size with a 30-day average DO of 5.5 mg/L versus a minimum DO of 6 mg/L from all four years that were modeled was 6 grams, 0.22 ounces, and 1/32 inches. Difference in growth in 1990 was also determined to be immeasurable: 12 grams, 0.45 ounces, and 1/16 inches. These results are indicative of a higher level of protection than the "high level of protection" delineated in the EPA DO criteria document.

10.6 <u>Rationale for 5.5 mg/L 30-Day Mean as Growth Metric</u>

A 5.5 mg/L, 30-day mean is best overall for these reasons:

- It accomplishes essentially the same growth as achieved using a minimum DO of 6 mg/L;
- Model results show that for a minimum DO of 4 mg/L, the lowest 30-day average was 5.9 mg/L, so the minimum 30-day average would likely be close to 6 mg/L or above in actual practice;

- This last consideration indicates that SCE&G could reasonably achieve compliance with the 5.5 mg/L level of 30-day average while primarily focusing on the minimum daily requirement of 4 mg/L;
- Fish growth correlated better with the 30-day average than any other DO metric, especially the average daily DO;
- Due to the nature of operations at Saluda Hydro (i.e., DO is low when flows are high, and DO is high when flows are low), assimilative capacity of the LSR for wastewater discharges is not likely to be an issue, especially for current wastewater dischargers;
- The 30-day average is consistent with averaging allowed for point source discharge permits. It allows some flexibility to deal with difficult events without causing environmental damage since the minimum DO would be 4 mg/L;
- More than any other metric, the 5.5 mg/L 30-day average satisfies both SCDHEC/EPA/DNR environmental objectives and SCE&G's objectives for cost-effective compliance, both in capital costs, operational costs, and "operator difficulty" for complying with the target DO.

10.7 Why not use the minimum daily average or 7-day average instead of 30-day?

Short period average DO drives neither acute toxicity nor fish growth. Short period averages set high enough to protect growth over the long term would prohibit DO excursions that have no impact on long term growth. Table 2 shows that in model runs exhibiting immeasurable growth impacts relative to 6 mg/L minimum (i.e., those runs with 30-day average exceeding 5.5 mg/L), the 7-day average could fall to as low as 4 mg/L. On the other hand, applying a 4 mg/L 7-day average standard could allow chronic exposure to 4 mg/L and not protect fish growth as well as a 5.5 mg/L 30 day average.

10.8 Since the EPA national criteria is a 6.5 mg/L, 30-day average, how could 5.5 mg/L be acceptable?

The EPA criteria were established based on available scientifically sound data, but available studies were largely limited to exposure to stable, continuous DO levels. Real world DO exposure is more dynamic, especially in nutrient rich habitats and tailwaters. This "issue" with the EPA criteria has long been recognized, and this concern is what led Dr. Chapman to recommend the development of a bioenergetic model to Ruane and Hauser in 1990. The bottom line: when the model is run for an entire year, the average DO is well over 6.5 mg/L (see discussion regarding Figure 20) so the fish grow very well. The suggested 30-day average DO of 5.5 mg/L only occurs for a brief period of the year, so the growth is not affected to a measurable level, especially in the LSR.

10.9 What about proposing 6 mg/L, 30-day average?

This level for the standard would produce no improvement in growth from the baseline case of minimum DO ≥ 6 mg/L. It would cost more to comply with this standard, but the additional cost would be mainly for operational expenses during years like 1990 and 1996. The main concern about proposing a 6 mg/L, 30-day average would be regulatory compliance with a DO level that would be more difficult to achieve than the 5.5 mg/L, 30-day average. The main problem here would be that while the 5.5 mg/L, 30-day average might be achieved almost automatically while maintaining the 4 mg/L minimum DO, a 30-day 6 mg/L average might require special, additional enhancement measures (more than just operational measures) and there would be no measurable benefit for the fishery.

10.10 Site-Specific Nature of Saluda DO Standard

These considerations for a site-specific standard are specific to the Saluda Hydro tailwater. The primary reason that a 5.5 mg/L, 30-day average DO was found to be sufficient to protect growth is that for Saluda, low DO values would occur only a relatively small amount of the time…on average about 1 % of the time, and in difficult years like 1990 and 1996, 18-26 % of the time.

Another site-specific characteristic of Saluda tailwater is that DO is low when flow is high (about 10,000 cfs or more). Fishing experience is not as likely to be impacted during low DO conditions since fishing is not as prevalent under these high flow conditions.

The 30-day average is probably more difficult to measure and maintain for point source dischargers on unregulated streams; however, it is relatively easy to measure for hydropower discharges since continuous monitors are used for these discharges and software can easily present the results in terms of 30-day average values. Another advantage of using the 30-day average is that it provides important flexibility needed for operations of a large hydropower project where the entire river passes through the project, i.e., the hydropower project is essentially challenged to "treat" a whole river that discharges as much as 18,400 cfs, or almost 12,000 MGD or about 200 times the size of the wastewater discharge from the City of Columbia.

Site-specific standards can be either higher or lower than state-wide or national criteria which are "one-size-fits-all." The pursuit of site-specific standards is encouraged by regulatory agencies because this activity usually results in dischargers developing critical data targeted to the site in question. Whether the data result in higher or lower standards, the product of the effort is more scientifically defensible.

TABLES

Table 1: Modeled End-of-Year Fish Mass For Aeration Scenarios

WET YEAR (1990)	M (g)	W (lb)	W (oz)	L (in)
no aeration	832.34	1.83	29.33	16.65
current aeration	1119.37	2.47	39.45	18.37
hub baffles	1167.41	2.57	41.14	18.63
AVT	1190.51	2.62	41.96	18.75
AVT with min 4 mg/L	1199.87	2.64	42.29	18.80
AVT with min 6 mg/L	1199.88	2.64	42.29	18.80

MODERATELY WET YEAR (1996)	M (g)	W (lb)	W (oz)	L (in)
no aeration	701.07	1.54	24.71	15.67
current aeration	991.53	2.18	34.94	17.59
hub baffles	1015.84	2.24	35.80	17.73
AVT	1026.85	2.26	36.19	17.79
AVT min 4 mg/L	1030.59	2.27	36.32	17.81
AVT min 6 mg/L	1030.62	2.27	36.32	17.81

AVERAGE YEAR (1992)	M (g)	W (lb)	W (oz)	L (in)
no aeration	734.40	1.62	25.88	15.97
current aeration	1123.83	2.48	39.61	18.40
hub baffles	1132.35	2.49	39.91	18.44
AVT	1134.77	2.50	39.99	18.46
AVT min 4 mg/L	1136.22	2.50	40.04	18.47
AVT min 6 mg/L	1136.22	2.50	40.04	18.47

DRY YEAR (1999)	M (g)	W (lb)	W (oz)	L (in)
no aeration	844.20	1.86	29.75	16.72
current aeration	1188.58	2.62	41.89	18.74
hub baffles	1190.30	2.62	41.95	18.75
AVT	1190.64	2.62	41.96	18.76
AVT min 4 mg/L	1190.67	2.62	41.96	18.76
AVT min 6 mg/L	1190.66	2.62	41.96	18.76

Table 2: Summary of Bioenergetic Model Results for Year-End Fish Conditions and Their Corresponding Minimum and Average DO Metrics

1990--wet year with special drawdown	**Weight at end of the year**			**Length**	**Minimum DO Metrics**		**Average DO Metrics**		
	Grams	Pounds	Ounces	Length at end of year, in.	Minimum Daily DO	Minimum 7-Day Moving Average of daily minimum DO	Minimum Daily average, mg/L	Minimum 7-Day Average of Hourly DO, mg/l	Minimum 30-Day Average of Hourly DO
No Aeration	832.3	1.83	29.3	16.65	0.0	0.0	0.0	0.0	0.0
Current	1119.4	2.47	39.4	18.37	0.5	0.8	0.7	2.0	4.4
Hub Baffles	1167.4	2.57	41.1	18.63	1.5	1.7	1.9	3.0	5.0
New Aerating Wheels	1190.5	2.62	42.0	18.75	2.1	2.4	2.6	4.0	5.7
AVT with min. DO = 4 mg/L	1199.9	2.64	42.3	18.80	4.0	4.0	4.1	4.8	5.9
AVT with min. DO = 6 mg/L	1199.9	2.64	42.3	18.80	6.0	6.0	6.0	6.1	6.5
AVT with min. DO = 6 mg/L	1030.6	2.27	36.3	17.8	6.0	6.0	6.2	6.4	6.6
AVT with min. DO = 6 mg/L	1136.2	2.50	40.0	18.5	6.0	6.1	6.5	6.9	7.0

Table 2: Summary of Bioenergetic Model Results for Year-End Fish Conditions and Their Corresponding Minimum and Average DO Metrics (continued)

1996--normal year with special drawdown	**Weight at end of the year**			**Length**	**Minimum DO Metrics**		**Average DO Metrics**		
	Weight at end of the year, gm	W (lb)	W (oz)	Length at end of year, in.	Minimum Daily DO	Minimum 7-Day Moving Average of daily minimum DO	Minimum Daily average, mg/L	Minimum 7-Day Moving Average of Hourly DO, mg/l	Minimum 30-Day Moving Average of Hourly DO
No Aeration	701.1	1.54	24.6	15.7	0.0	0.0	0.0	0.0	0.0
Current	991.5	2.18	34.9	17.6	0.7	1.0	2.0	3.0	3.7
Hub Baffles	1015.8	2.24	35.8	17.7	2.0	2.2	3.0	3.9	4.5
New Aerating Wheels	1026.9	2.26	36.2	17.8	2.8	3.0	4.0	5.0	5.6
AVT with min. DO = 4 mg/L	1030.6	2.27	36.3	17.8	4.0	4.0	4.6	5.4	5.9
AVT with min. DO = 6 mg/L	1030.6	2.27	36.3	17.8	6.0	6.0	6.2	6.4	6.6

Table 2: Summary of Bioenergetic Model Results for Year-End Fish Conditions and Their Corresponding Minimum and Average DO Metrics (continued)

1992--normal year	Weight at end of the year			Length	Minimum DO Metrics		Average DO Metrics		
	Weight at end of the year,gm	W (lb)	W (oz)	Length at end of year, in.	Minimum Daily DO	Minimum 7-Day Moving Average of daily minimum DO	Minimum Daily average, mg/L	Minimum 7-Day Moving Average of Hourly DO, mg/l	Minimum 30-Day Moving Average of Hourly DO
No Aeration	734.4	1.620	25.9	16	0.0	0.0	0.0	0.0	0.0
Current	1123.8	2.48	39.6	18.4	0.5	1.6	3.6	4.3	5.1
Hub Baffles	1132.4	2.49	39.9	18.4	1.9	2.8	4.2	5.0	5.7
New Aerating Wheels	1134.8	2.50	40.0	18.5	2.6	3.7	5.2	6.1	6.8
AVT with min. DO = 4 mg/L	1136.2	2.50	40.0	18.5	4.0	4.7	5.7	6.3	6.9
AVT with min. DO = 6 mg/L	1136.2	2.50	40.0	18.5	6.0	6.1	6.5	6.9	7.0

Table 2: Summary of Bioenergetic Model Results for Year-End Fish Conditions and Their Corresponding Minimum and Average DO Metrics (continued)

1999--Dry year	Weight at end of the year			Length	Minimum DO Metrics		Average DO Metrics		
	Weight at end of the year,gm	W (lb)	W (oz)	Length at end of year, in.	Minimum Daily DO	Minimum 7-Day Moving Average of daily minimum DO	Minimum Daily average, mg/L	Minimum 7-Day Moving Average of Hourly DO, mg/l	Minimum 30-Day Moving Average of Hourly DO
No Aeration	844.2	1.86	29.8	16.7	0.0	0.0	0.0	0.0	0.0
Current	1188.6	2.62	41.9	18.7	1.4	3.3	4.5	5.7	6.6
Hub Baffles	1190.3	2.62	41.9	18.8	2.5	4.2	5.0	6.0	6.7
New Aerating Wheels	1190.6	2.62	42.0	18.8	3.5	5.0	6.0	6.1	7.0
AVT with min. DO = 4 mg/L	1190.7	2.62	42.0	18.8	4.0	5.1	6.0	6.1	7.0
AVT with min. DO = 6 mg/L	1190.7	2.62	42.0	18.8	6.0	6.1	6.0	6.1	7.0

FIGURES

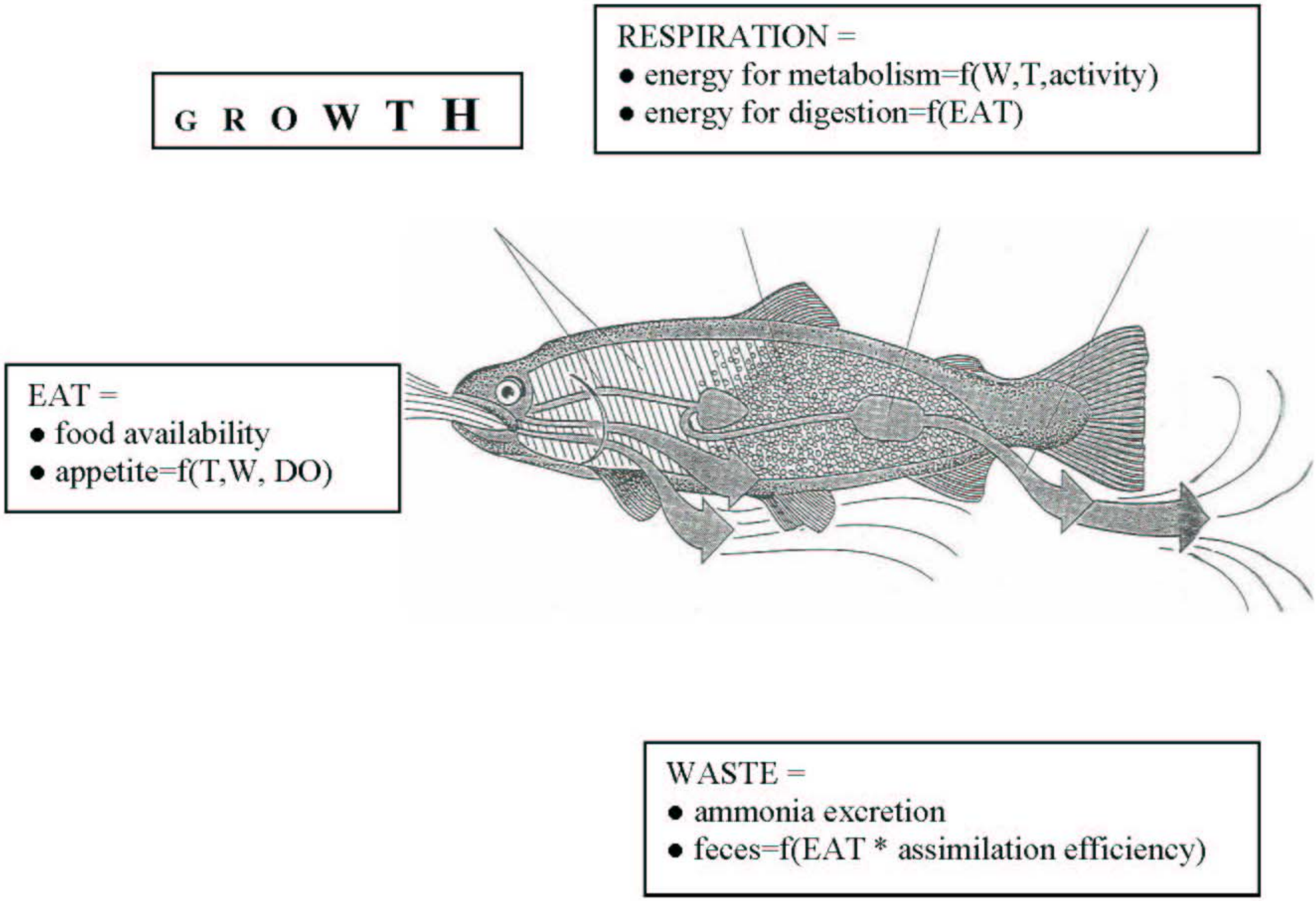


Figure 1: **General Illustration of Terms Used to Describe Energy Partitioning in the Fish Bioenergetic Model**
Details of the model are described in Appendix 2. EAT = Food consumption, T = Temperature, W = Weight, DO = Dissolved Oxygen

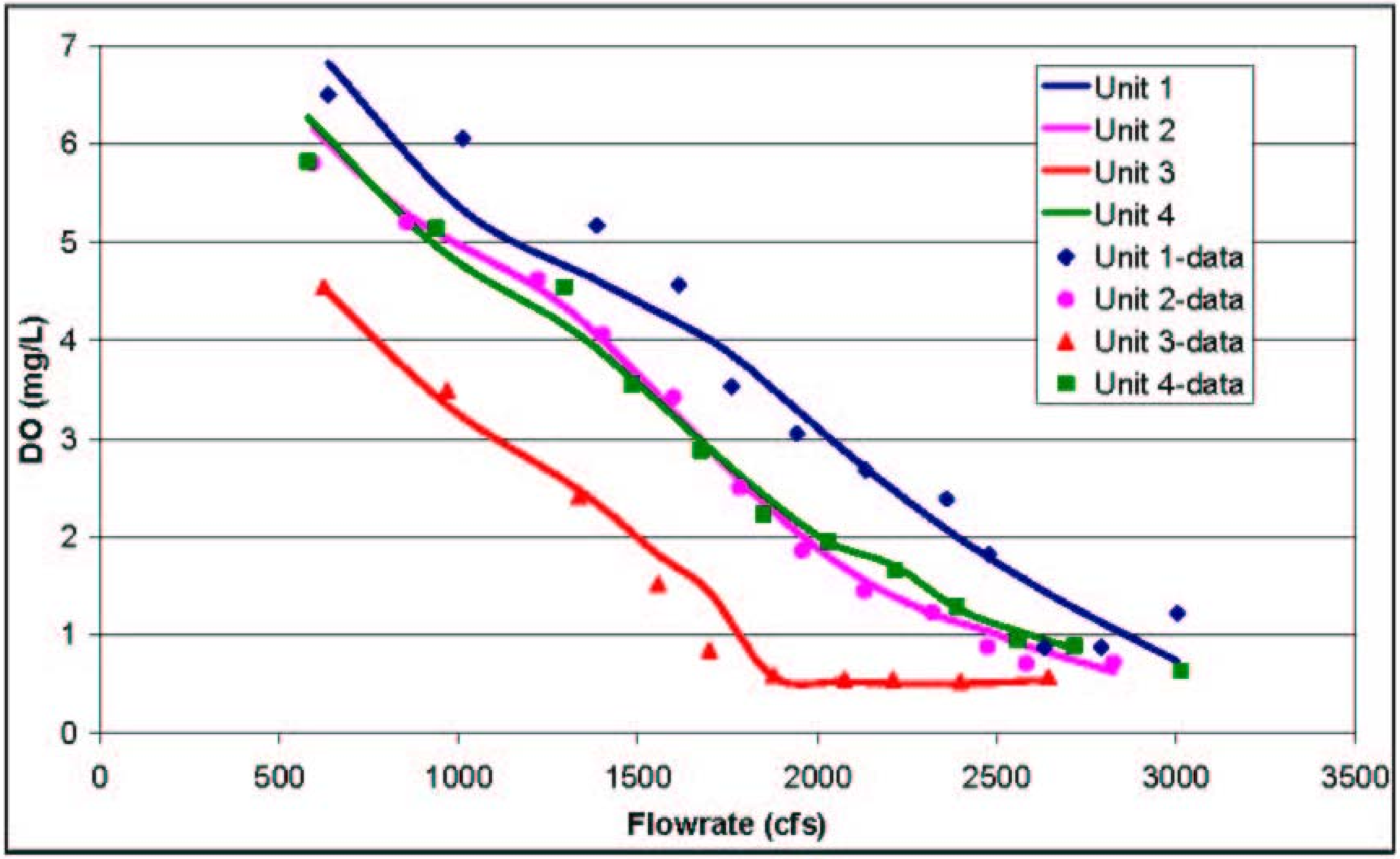


Figure 2: Model Predictions Compared to Data Collected on DO at Various Unit Flows for Units 1-4

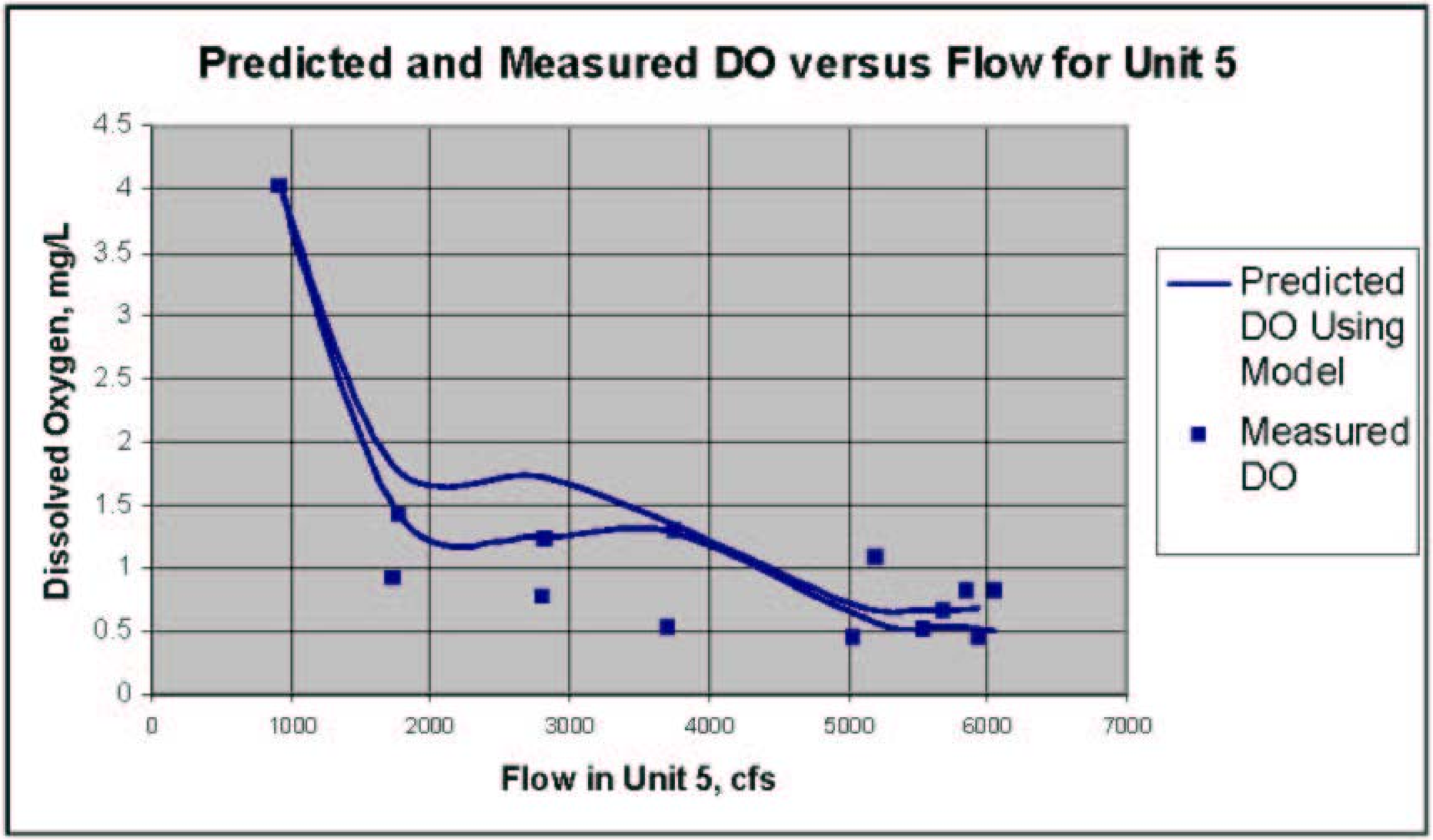


Figure 3: **Model Predictions Compared to Data Collected on DO at Various Unit Flows for Unit 5**

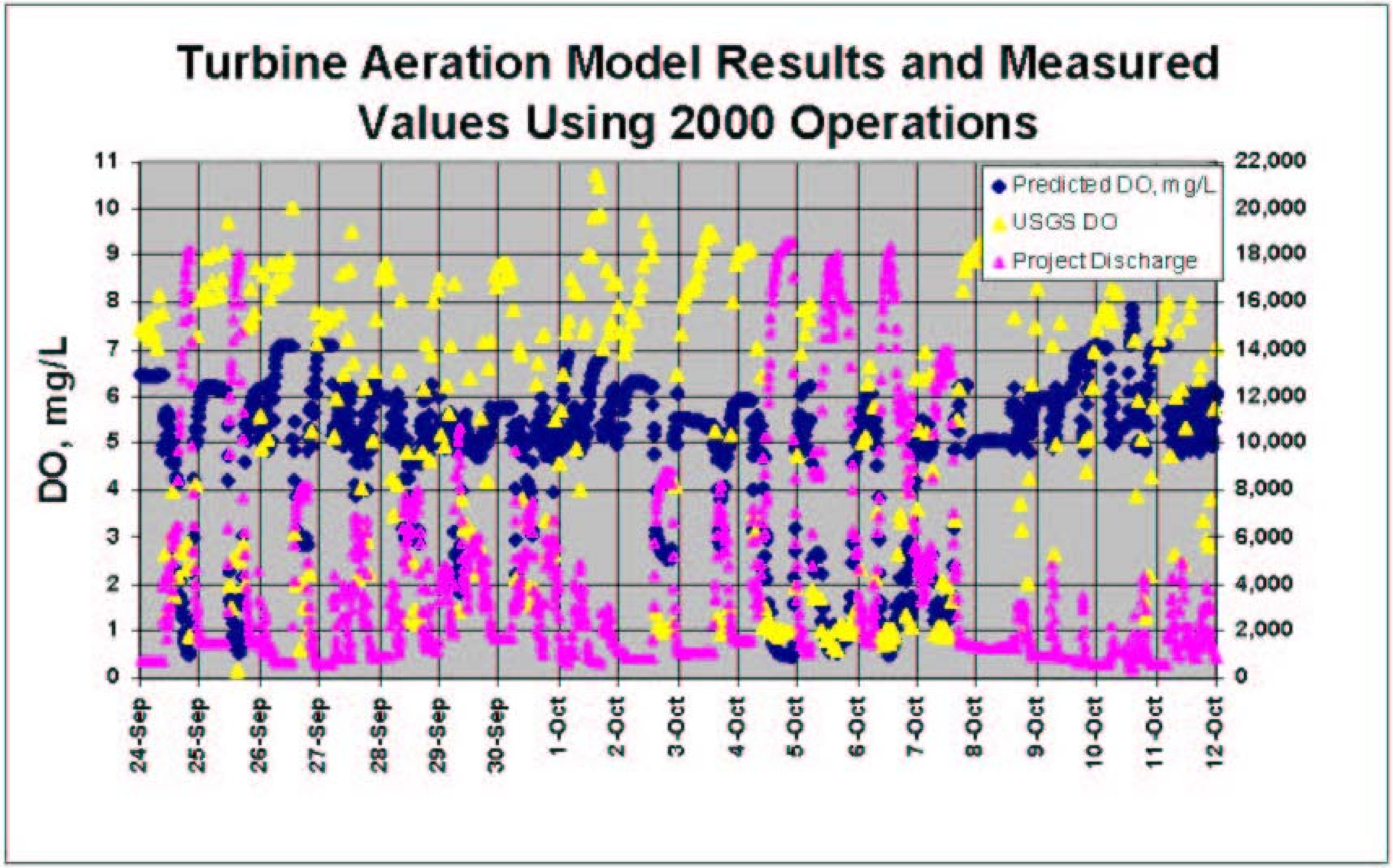


Figure 4: **Turbine Aeration Model Predictions for Discharges from Saluda Hydro Compared to Data from the USGS Monitor 1,000 Feet Downstream from the Dam**

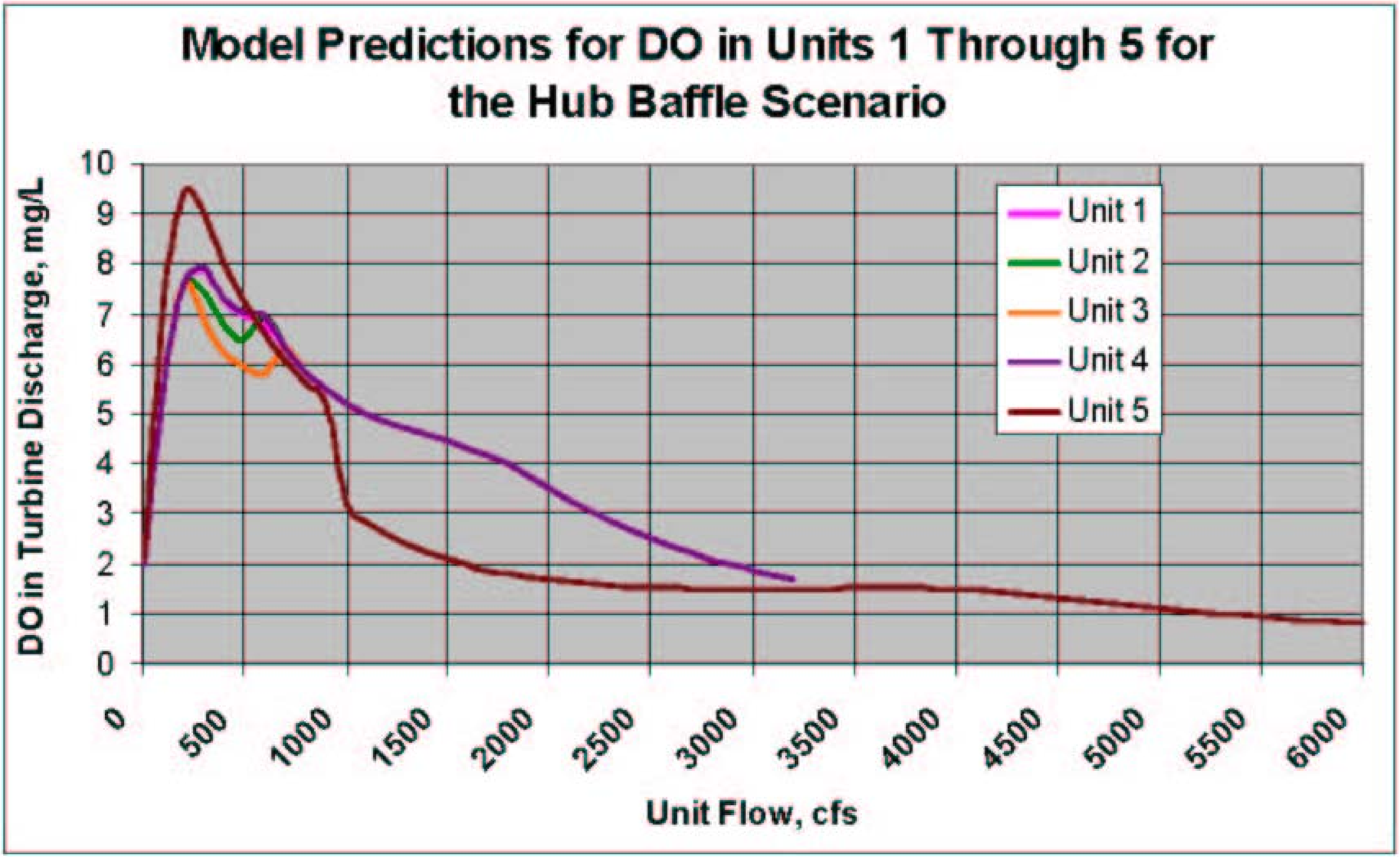


Figure 5: **Predicted DO at Various Flow Levels for Each Unit Assuming Hub Baffles Have Been Installed on Units 1-5**

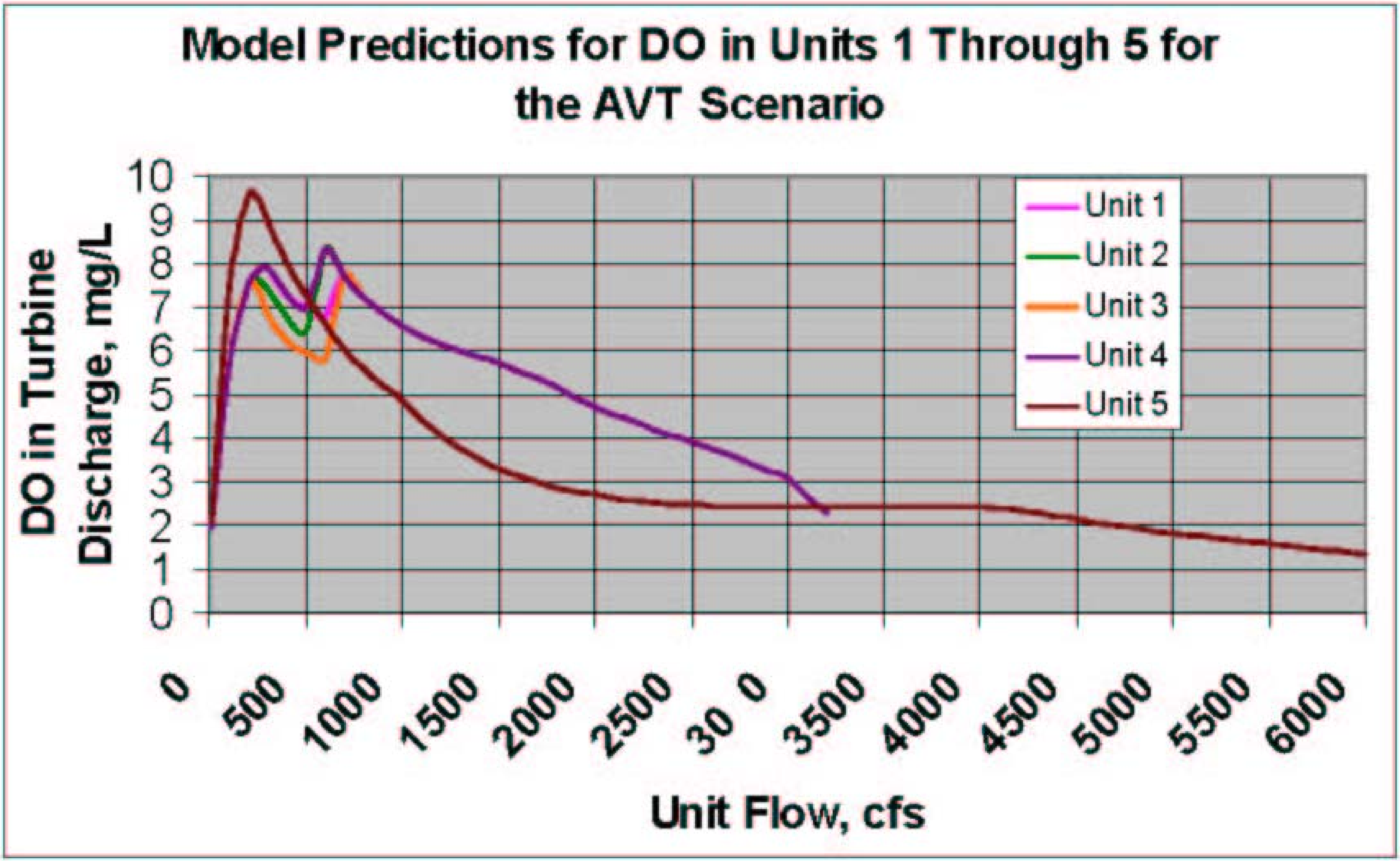


Figure 6: **Predicted DO at Various Flow Levels for Each Unit Assuming New Aerating Turbine Wheels Have Been Installed on Units 1-5**

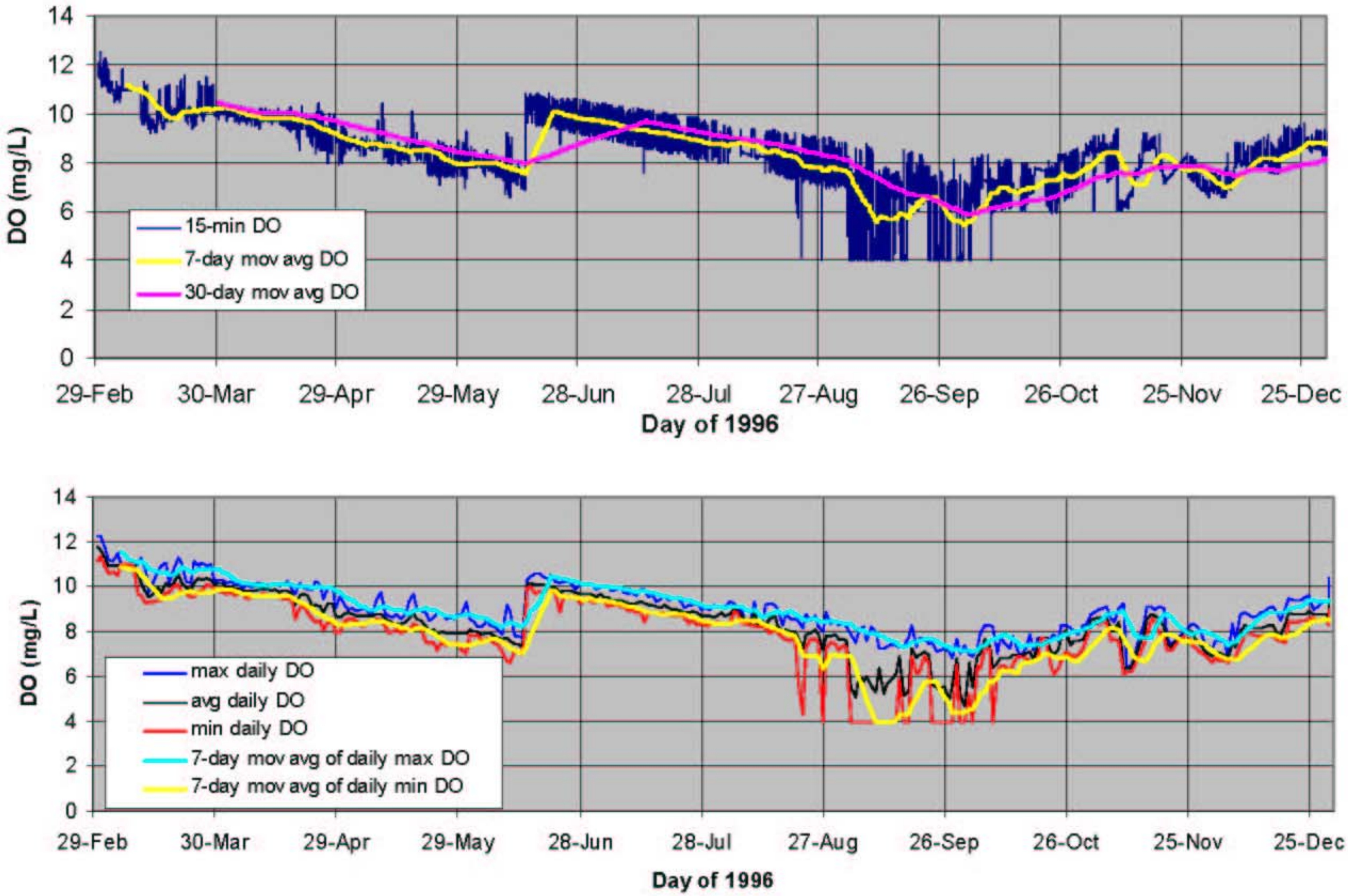


Figure 7: **Summary of DO Metrics from a Model Run for the Year 1996 Assuming that New Aerating Turbines were Installed and Some Supplemental Aeration System was Used to Maintain a Minimum DO of 4 mg/L**

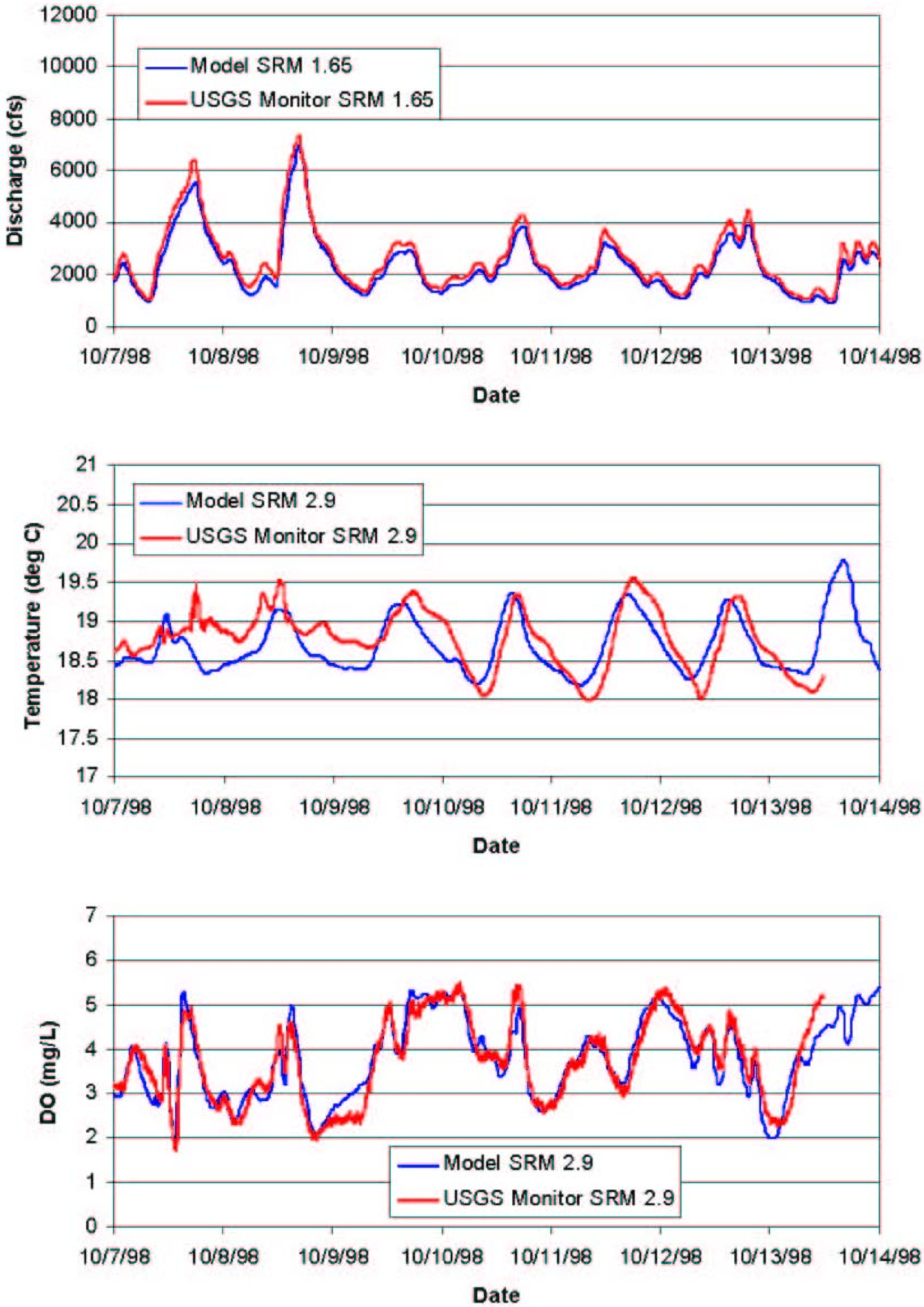


Figure 8: Model vs. Measured Flow at SRM 1.65 and Temperature and DO at SRM 2.9

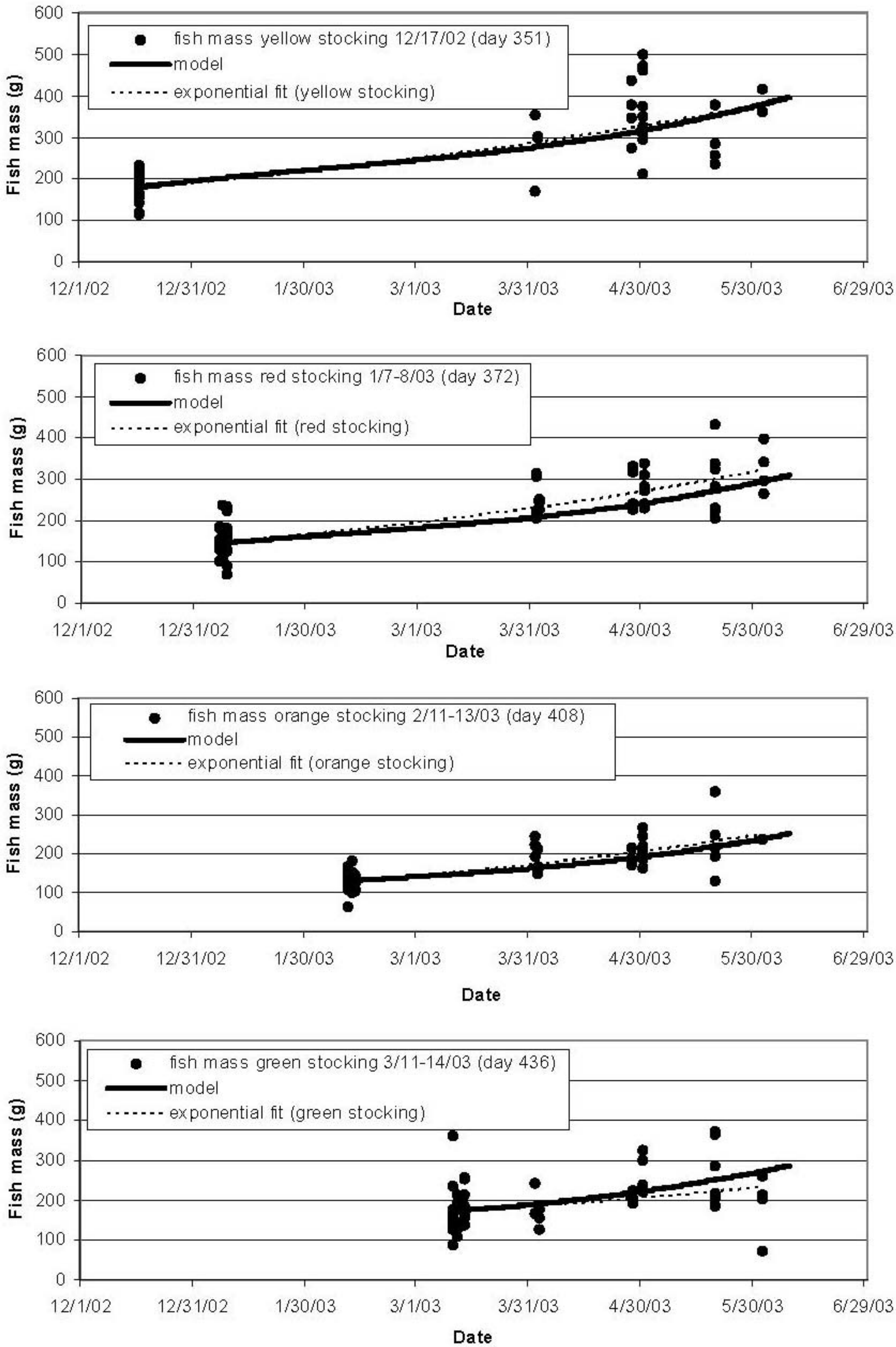


Figure 9: Bioenergetics Model vs. 2002-2003 Growth Study Data

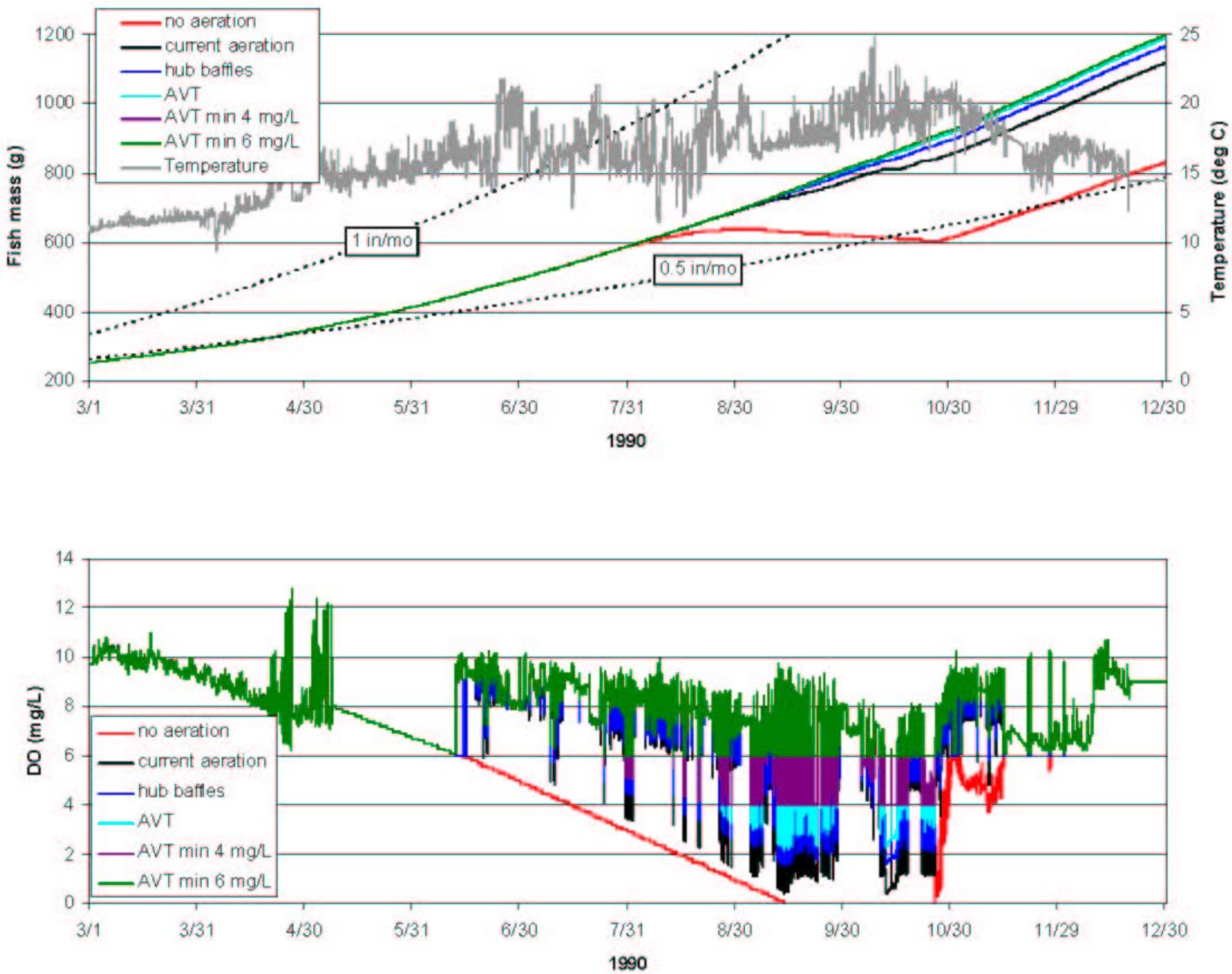


Figure 10: Modeled Release DO and Fish Growth for Aeration Scenario – Wet Year (1990)

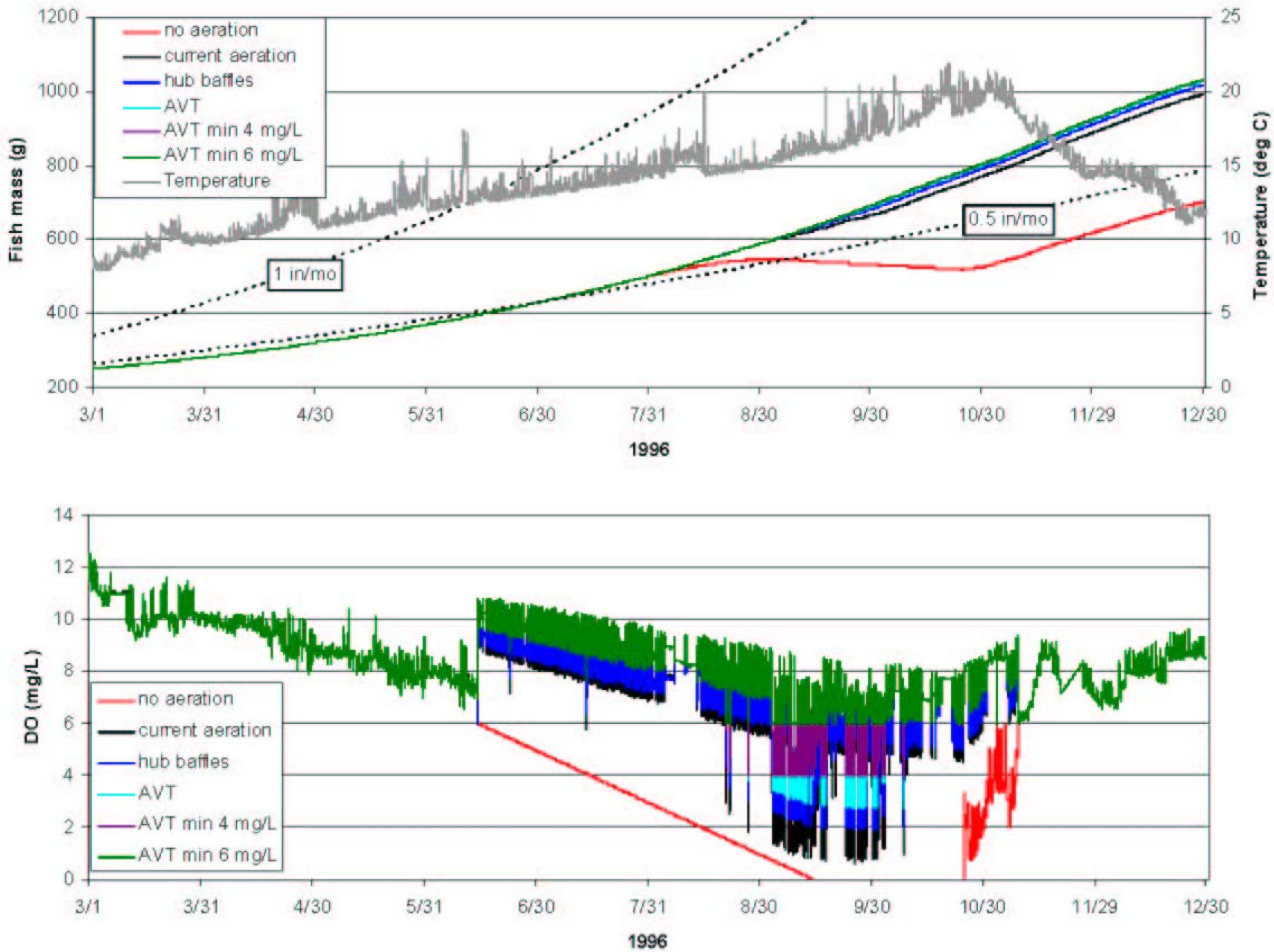


Figure 11: Modeled Release DO and Fish Growth for Aeration Scenario – Moderately Wet Year (1996)

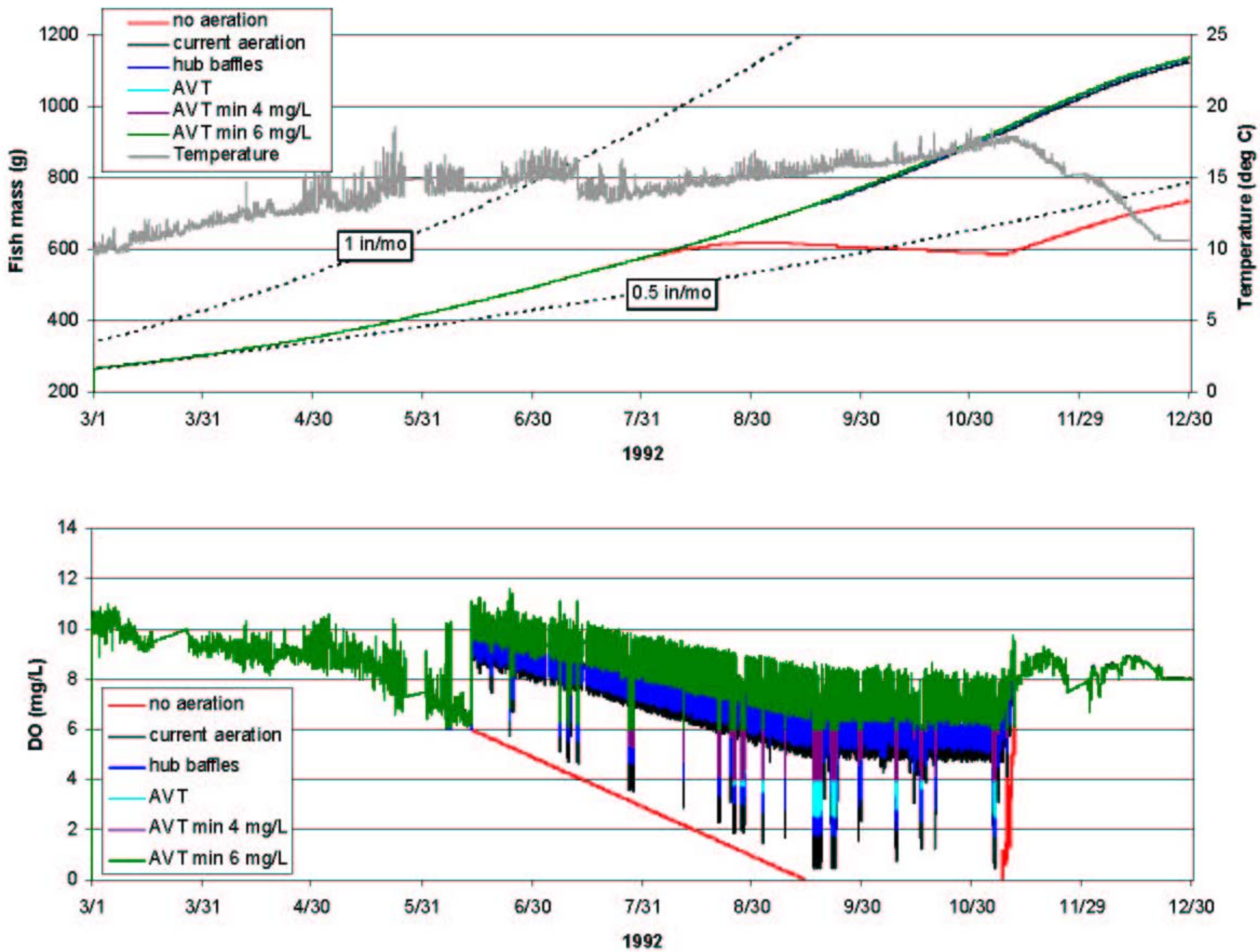
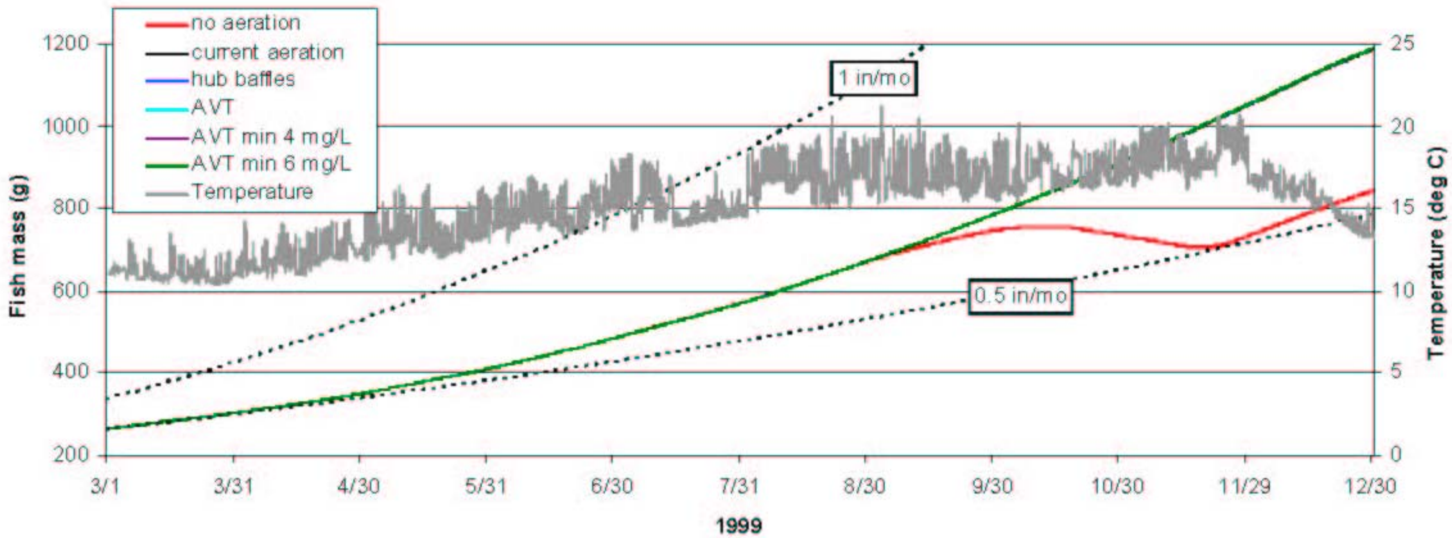


Figure 12: Modeled Release DO and Fish Growth for Aeration Scenario – Average Year (1992)



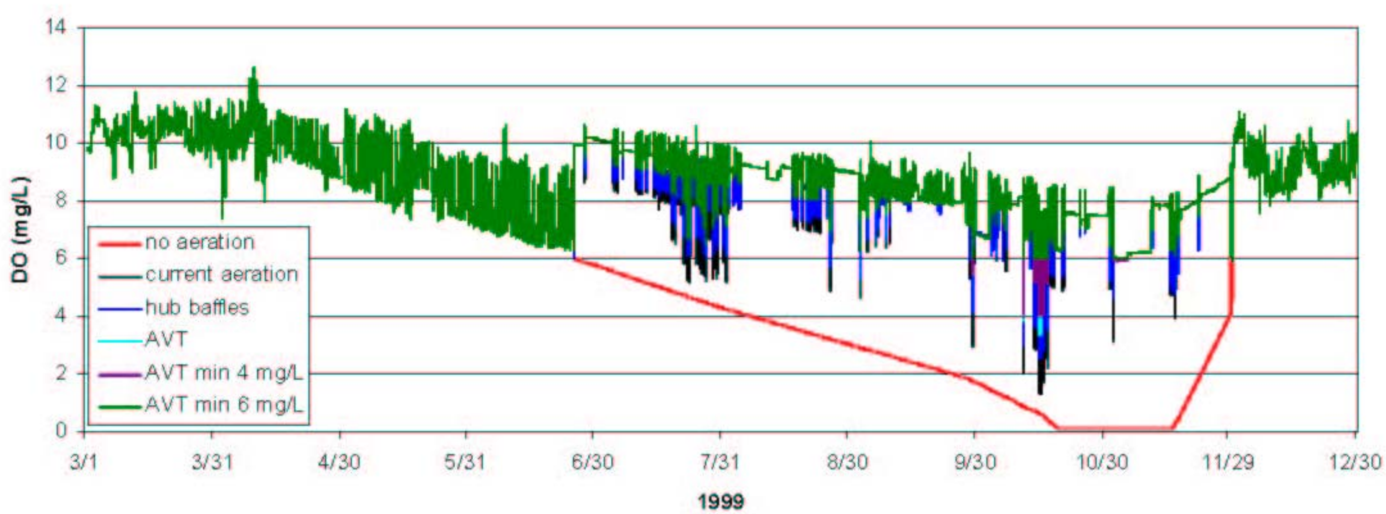


Figure 13: Modeled Release DO and Fish Growth for Aeration Scenarios – Dry Year (1999)

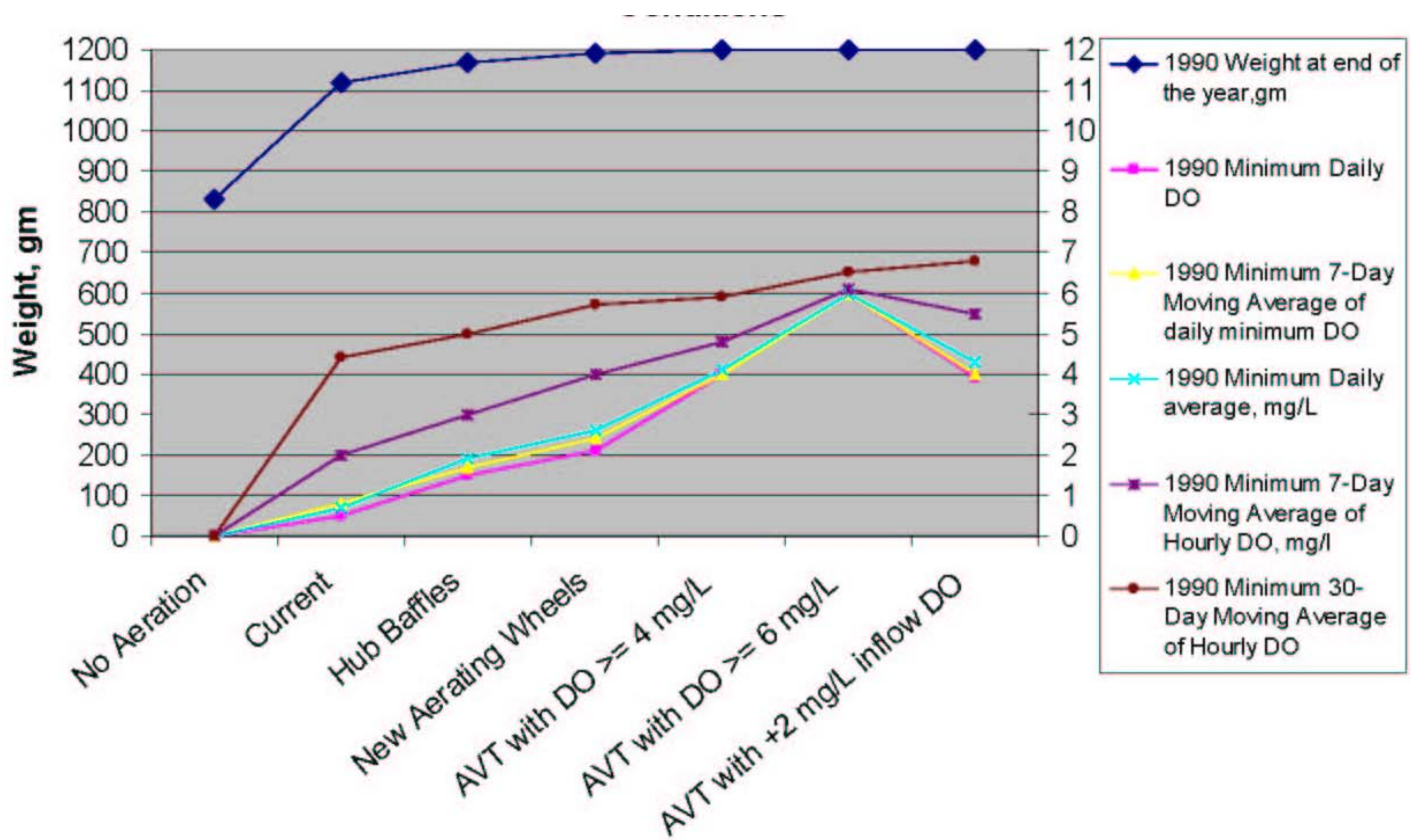


Figure 14: 1990 – Weight at End of the Year for Various Aeration Scenarios and DO Conditions

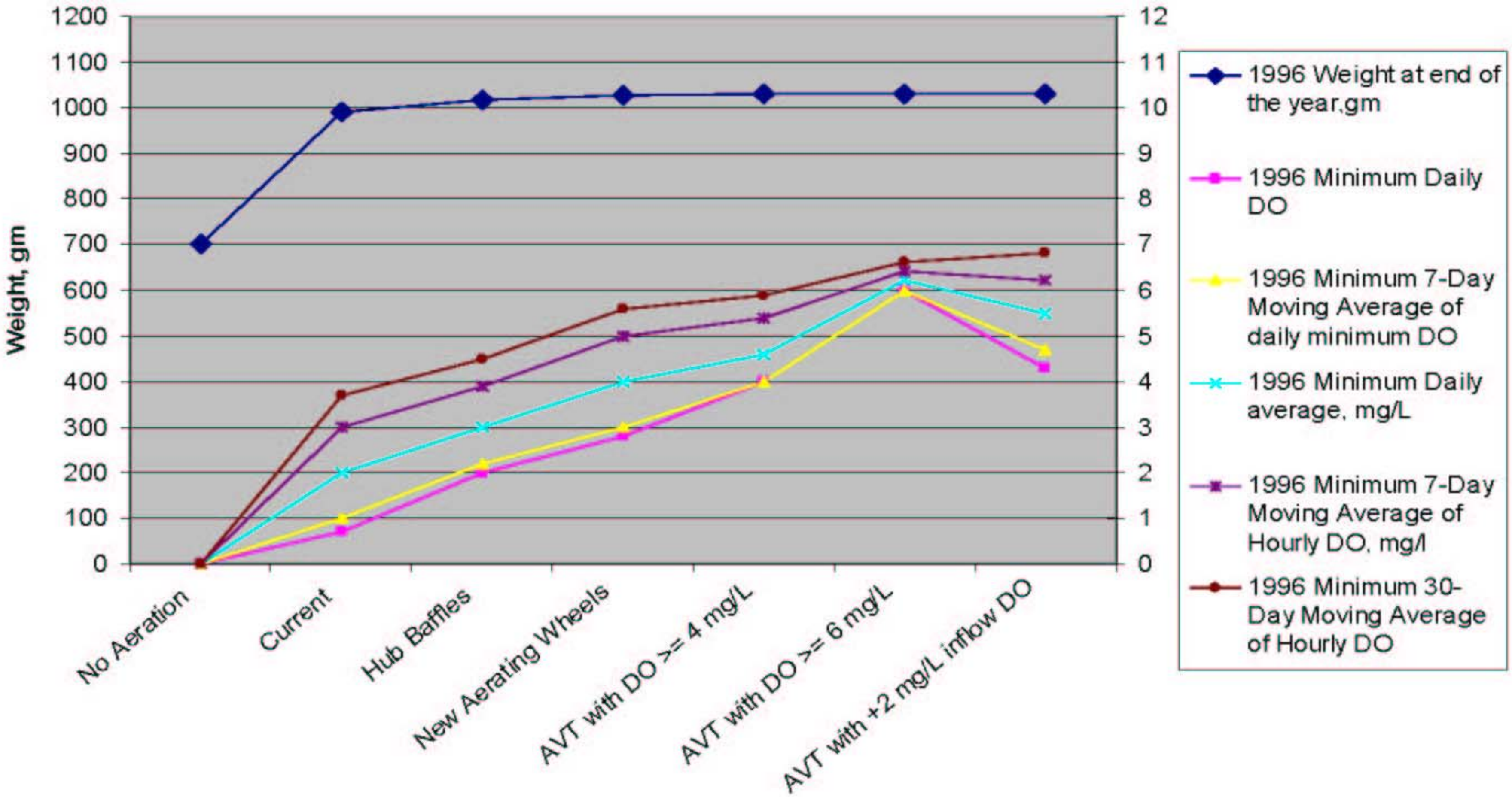


Figure 15: 1996 – Weight at End of the Year for Various Aeration Scenarios and DO Conditions

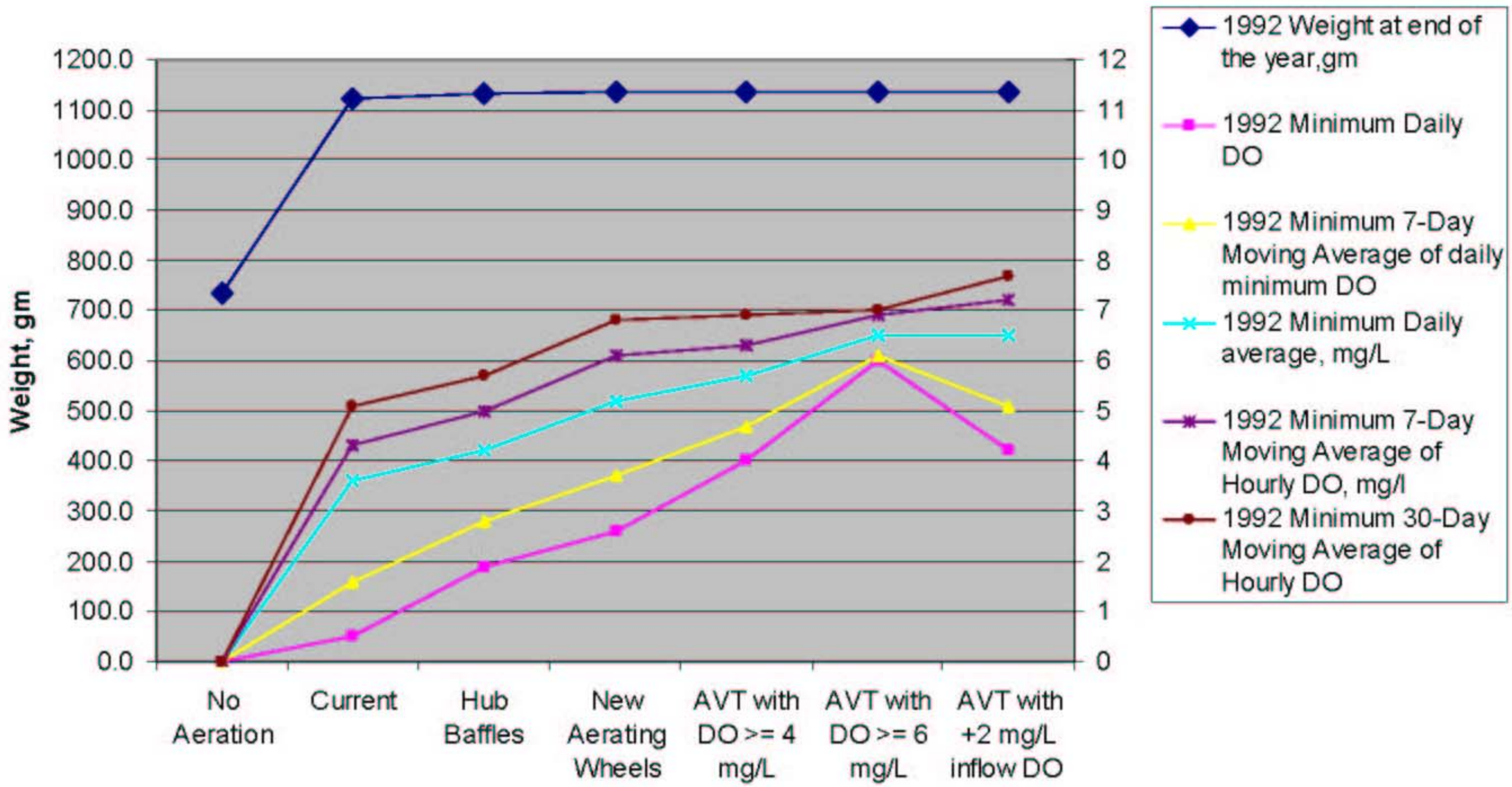


Figure 16: 1992 – Weight at End of the Year for Various Aeration Scenarios and DO Conditions

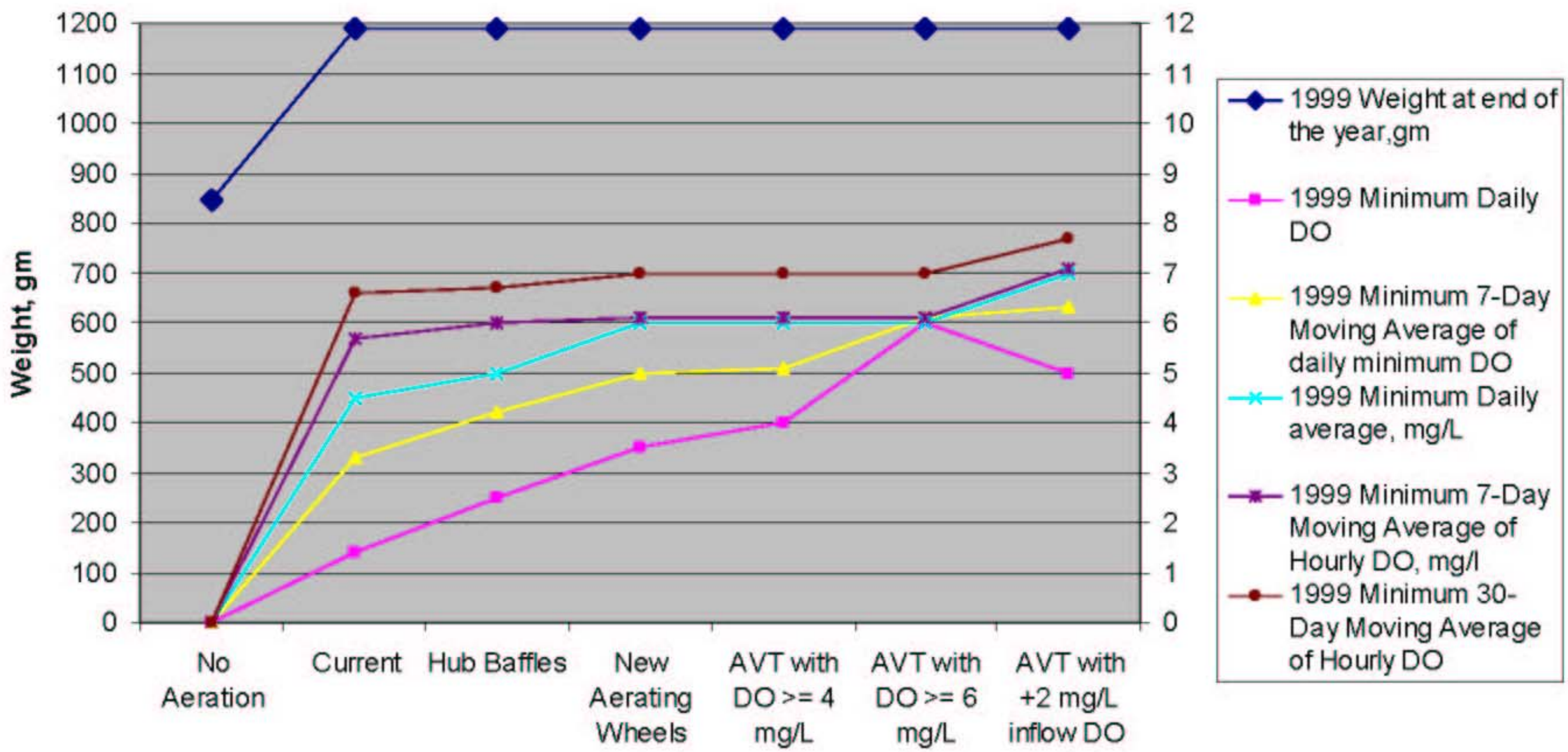


Figure 17: 1999 – Weight at End of the Year for Various Aeration Scenarios and DO Conditions

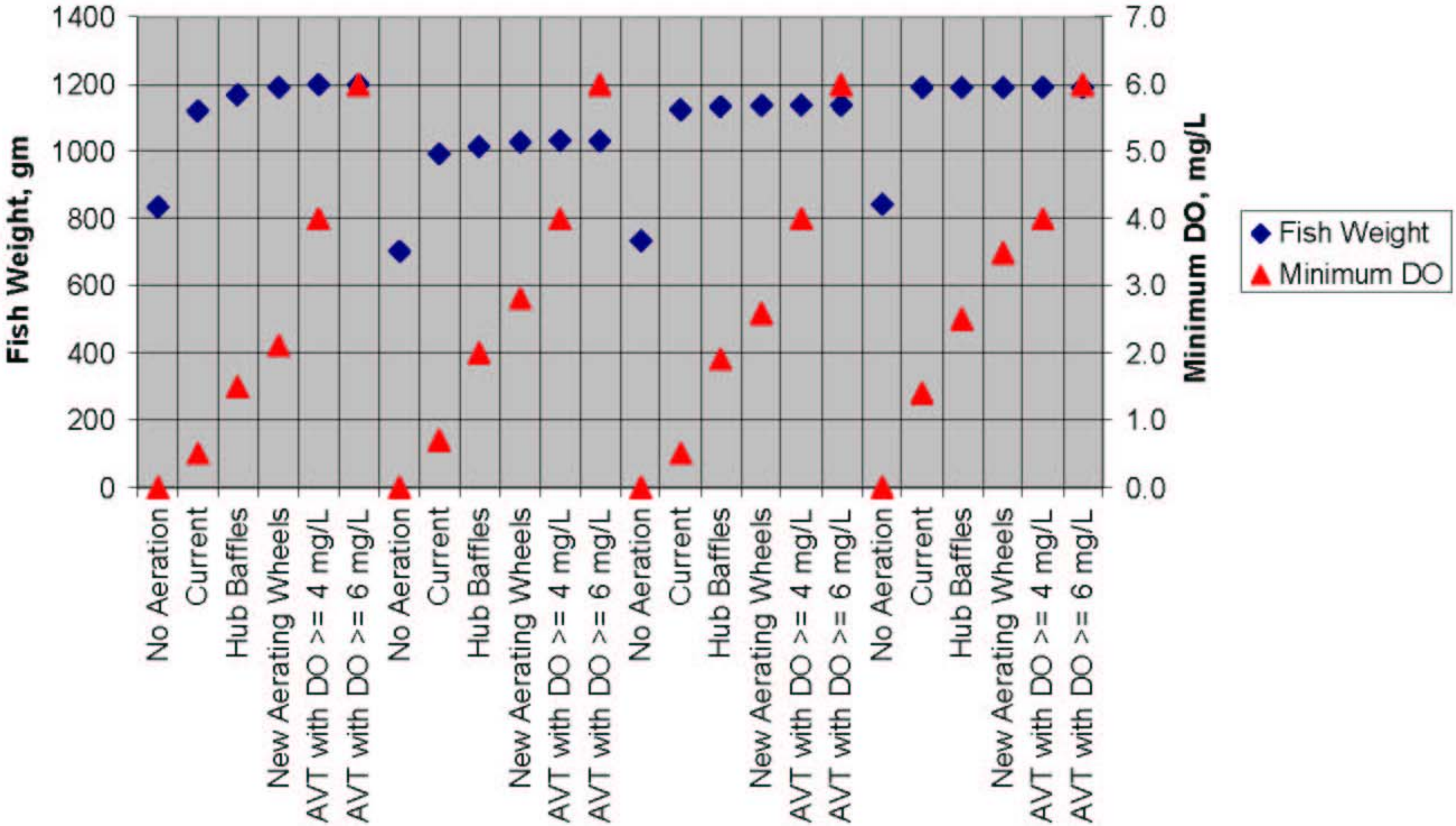


Figure 18: Year-End Fish Weight and Minimum Daily DO Levels Observed for Each Year for the Aeration Scenario Considered

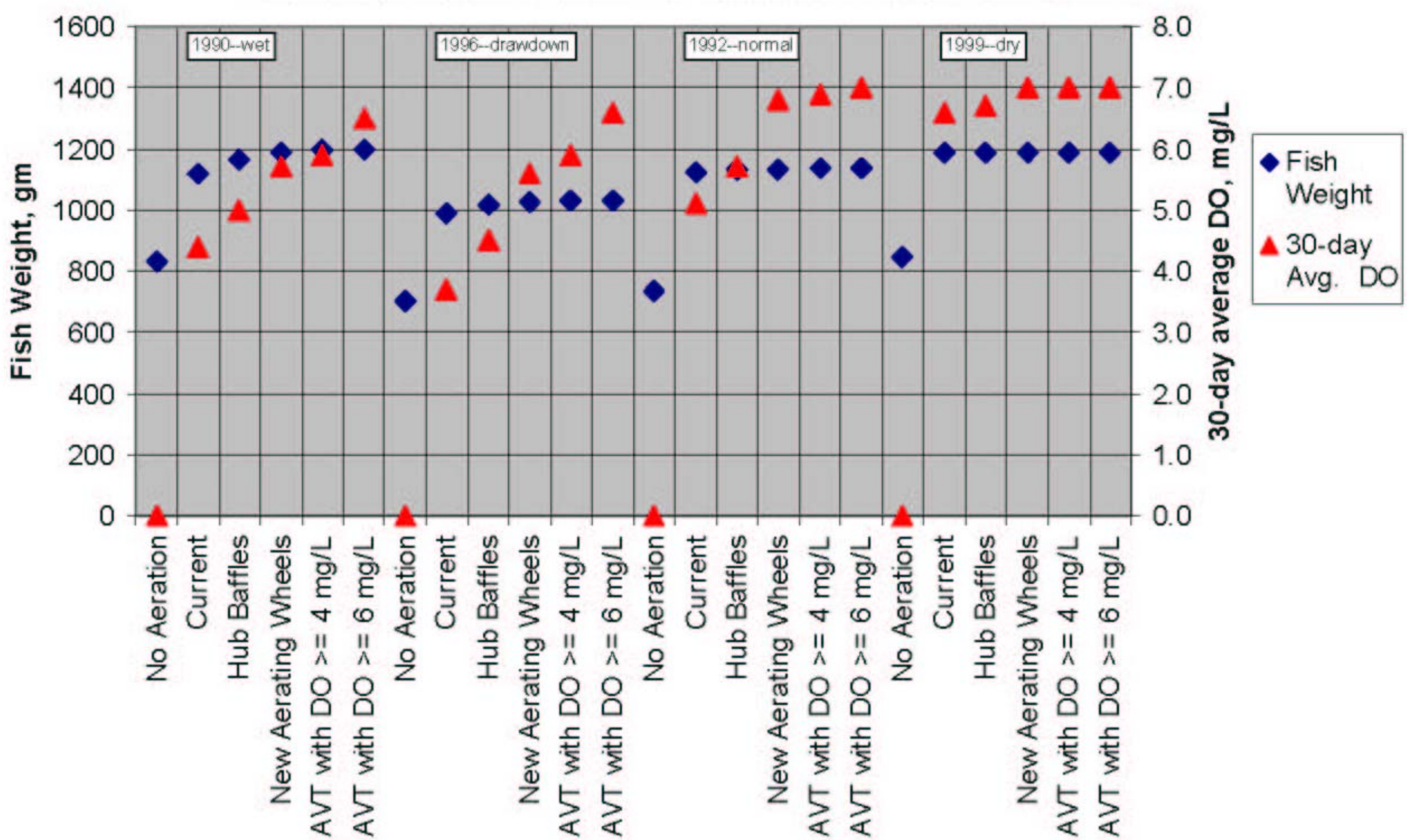


Figure 19: **Year-End Fish Weight and Minimum 30-Day Average DO Levels Observed for Each Year for Various Aeration Scenarios**

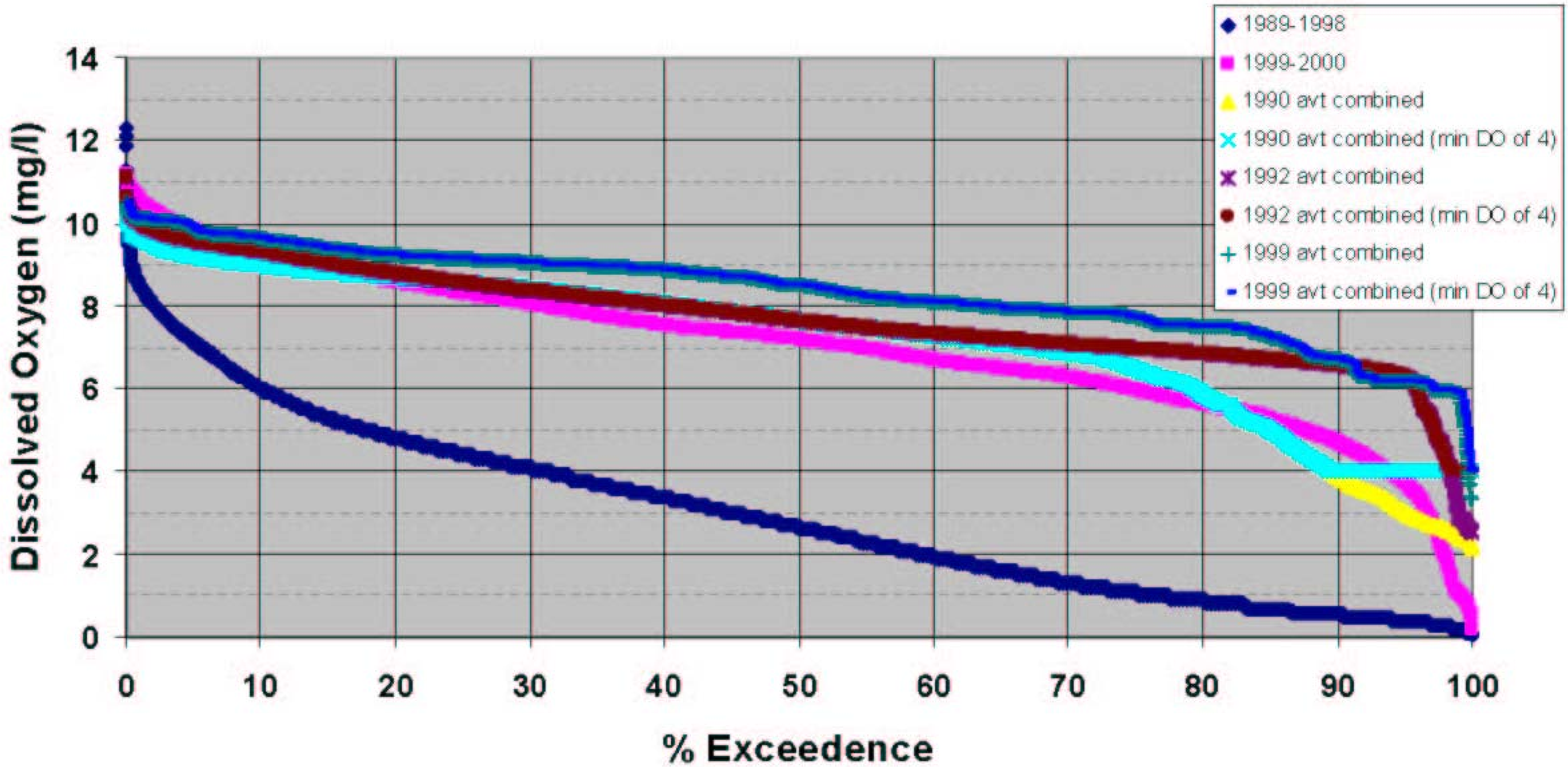


Figure 20: Percent of Time That Various Dissolved Oxygen Concentrations Would be Exceeded in Saluda Hydro Tailwater – for the Low DO Period (~7/1 – 11/15)