Evaluation of Stockton Deep Water Ship Channel

Water Quality Model Simulation of 2001 Conditions:

Loading Estimates and Model Sensitivity

Prepared for

San Joaquin River Dissolved Oxygen TMDL
Technical Advisory Committee

and

CALFED Water Quality Program

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Introduction

The San Joaquin River (SJR) Dissolved Oxygen TMDL Technical Advisory Committee (TAC) directed some of the money in CALFED Directed Action Task 01-N61-06 "Downstream Tidal Exchange" (awarded to Jones & Stokes) to be used for preliminary data analysis and simulation of 2001 water quality conditions in the DWSC. The modeling was accomplished by Systech Engineering using the improved San Joaquin River water quality model developed under the 2000 CALFED Grant. The results from the 2001 simulations are described in this short technical report. This modeling work was accomplished in February 2002 by Systech Engineering to support the preliminary analysis of 2001 data that was requested by the TAC. This written documentation will be included as part of the final "Tidal Exchange" report to CALFED.

Modeling Task Description

The improved version (CALFED 2000 Grant) of the Stockton Water Quality Model, originally developed by Systech in 1993 for the City of Stockton, was used to simulate calendar year 2001 dissolved oxygen (DO) and other water quality conditions. The results show the validation of the water quality model for 2001 flows and concentrations, using the previously calibrated model coefficients. Additional simulations demonstrate the sensitivity of the DO concentrations to slightly different coefficient values and inflow concentrations during 2001. The simulated cases were:

1. Validation results for 2001 using the best estimates of river and Stockton Regional Wastewater Control Facility (RWCF) effluent flows, river and RWCF concentrations, and calibrated coefficients. Comparisons with DO, VSS, ammonia, chlorophyll and phaeophytin will be emphasized.

2. Sensitivity of DO to river flow will be demonstrated by comparison with two runs with slightly higher (i.e., 150%) and slightly lower (50%) net river flows. The summer low-flow period will be emphasized in the flow evaluation. Simulations with a constant steady flow of 250 cfs, 500 cfs and 1,000 cfs will be shown to indicate the flow sensitivity throughout the year.

3. Sensitivity of DO to light and resulting algae growth in the DWSC will be evaluated with two runs with slightly higher (150%) and lower (50%) euphotic depths (i.e., depth with 1% surface light). The effects of higher and lower algal growth rates will also be compared.

4. Sensitivity of DO to the RWCF effluent concentrations (loads) will be simulated. The CBOD load and the ammonia load will be reduced to 50% and increased to 150% to accomplish this comparison.

5. Sensitivity of DO to the SJR loads of CBOD, VSS, and algae biomass (chlorophyll) will be evaluated with a series of comparisons that will include increasing the concentrations to 150% and reducing the concentrations to 50%.

6. The sensitivity of DO to the settling rate coefficients for particulate organic materials (i.e. VSS and chlorophyll) will be shown with increased settling rates (150%) and decreased settling rates (50%).

Review of Model Assumptions and Coefficient Values

The Stockton Water Quality model is fully documented in the final report for the 2000 CALFED grant (Chen & Tsai, 2002). The model extends about 20 miles from the Head of Old River (HOR) to the City of Stockton River station 8 (Navigation Light 17/18) near Columbia Cut. The model calculates tidal flows between segments (approximately 0.5 to 1.0 mile long) and uses mass balance equations to simulate the concentrations of several water quality variables, including DO. The model includes several tidal sloughs (Fourteen Mile, Mormon, French Camp) and side channels that join the SJR in the vicinity of Stockton.

The water quality variables that are simulated include the following: temperature, DO, CBOD, chlorophyll (i.e., live algae) and phaeophytin (i.e., dead algae), VSS (i.e., detritus), TSS, ammonia, nitrate, total phosphorus, and EC (i.e., TDS). The original purpose of the model was to simulate the effects of RWCF effluent on DO concentrations in the DWSC. Some water quality variables that are not currently included in the model are pH, organic nitrogen, and TOC. The model processes that produce or consume oxygen include: atmospheric reaeration, sediment oxygen demand, detritus decay, algae growth, algae respiration/decay, nitrification (ammonia to nitrate), and CBOD decay. The model can also simulate artificial aeration from bubble columns or waterfall devices; the model properly simulates the amount of DO added as a function of the DO deficit from saturation at the location of the aeration device.

The model has been improved and calibrated as part of the CALFED 2000 Grant (99-B16). Several years have been simulated (i.e., 1991, 1996, 1999, and 2000) and a generally reasonable match to the measured water quality concentrations (i.e., temperatures, DO, nutrients and TSS) has been obtained with the model. Several additional parameters were measured in the special field studies during the summer of 1999, 2000, and now 2001 that allow more of the model variables (i.e., BOD, chlorophyll, phaeophytin) to be calibrated and validated. The calibrated coefficients are described in the final modeling report (Chen and TSAI, 2002).

Estimating Daily River and RWCF Flows

Daily SJR flows passing the HOR and entering the DWSC are generally provided by the USGS tidal flow meter (i.e., UVM) located near the Stockton RWCF. However, the UVM tidal flow device was not operational for a large portion of the summer in 2001, and estimates of DWSC daily flow were obtained using flow regression equations developed from Vernalis flow and Delta Export pumping (Jones & Stokes, 2001).

Figure 1 shows the measured and estimated DWSC flows during 2001. The Vernalis USGS flows are shown for reference. The measured UVM data generally follows the estimated range of Stockton flows at the beginning and ending of the summer period with missing records. The June-September Stockton flows are estimated to have ranged between 750 cfs and 1,000 cfs. The combination of measured UVM flow and estimated flow on days without UVM measurements were used in the modeling. The flows are very important in the water quality modeling because they control the dilution of the RWCF discharge, the travel time between Mossdale and the DWSC, and the residence time within the DWSC.

Figure 2 shows the Stockton RWCF daily discharge flows for 2001. Although the discharge is sometimes shut off on weekends and holidays, the monthly average discharge rate during the summer and fall was between 31 cfs and 47 cfs. The RWCF flow is important because it directly controls the effluent loads (e.g., ammonia and CBOD) discharged to the river. The river or discharge load can be calculated from the concentration and flow as:

Daily load (lbs/day) = 5.4 * concentration (mg/l) * flow (cfs)

Daily River Concentrations

A large amount of field data is needed to provide daily estimates of the model inflow concentrations for the river and the RWCF discharge. The DWR Mossdale water quality monitoring station provides hourly temperature, pH, conductivity, and DO measurements. These were used for estimating daily river concentrations. Weekly water quality measurements were available from Mossdale and Vernalis during the summer and fall TMDL sampling period. Concentrations for the winter period were only roughly estimated from assumed general seasonal patterns.

Figure 3 shows the daily average EC measured at Vernalis, Mossdale, and Rough & Ready Island (R&R). The Vernalis EC was relatively constant at about 600-650 uS/cm during the summer period, as required by the SWRCB 1995 WQCP Vernalis salinity objective of less than 700 uS/cm from April through August. The EC at Mossdale is slightly higher than at Vernalis during the summer period, suggesting the influence of agricultural drainage. The EC at R&R is not very much higher than Mossdale, although the RWCF discharge EC is about 1200 uS/cm. The expected increase in river EC at R&R would be about 25 uS/cm with a dilution of 20 (i.e., river flow of 760 cfs and

RWCF discharge of 40 cfs). The water quality model should match the observed EC changes in downstream segments. For example, the delayed reduction in EC at R&R following the October pulse flow event at Vernalis should be reasonably well simulated by the model. This simulated EC pattern was not evaluated, however, because the emphasis of this study was on the 2001 DO concentrations.

Figure 4 shows the temperatures in the SJR at Vernalis, Mossdale, and R&R. Temperatures were greater than 20 C from May through September, and were greater than 25 C for portions of June, July, and August. Temperatures of less than 10 C were measured only in January, early February, and December. Nitrification is greatly reduced at temperatures of less than 10 C. The saturated DO concentration declines from about 11.5 mg/l at 10 C to about 8.5 at 25 C. All of the model decay rates are assumed to be temperature dependent, so BOD and algae decay will have a stronger effect on DO in the summer.

Figure 5 shows the Mossdale minimum and maximum DO and the daily average value used in the model. The Mossdale average DO was greater than saturation and the diurnal range was greater than 2 mg/l from June through September, indicating significant algae concentrations because algae photosynthesis is the only process that can create this diurnal variation in DO. Mossdale DO was slightly less than saturation (i.e., 1-2 mg/l) and the diurnal range was less than 1 mg/l during the remainder of the year.

Figure 6 shows the minimum and maximum pH recorded at Mossdale. Although pH is not included in the water quality model, the pH data confirms the diurnal DO measurements and indicates a substantial algae concentration in the river from June through September. The Mossdale pH is greater than 8 from late May through September. The pH is generally lower at R&R (i.e., 7.5 to 8.0) suggesting that algae growth is still present but less active. The RWCF effluent pH is usually about 6.5

Figure 7 shows the measured and estimated turbidity values for Mossdale in 2001. The assumed seasonal pattern is somewhat arbitrary. A mathematical "sine-squared" shape has been assumed for the seasonal pattern. Summer concentrations of TSS and turbidity are higher than winter values, unless a large storm produces surface runoff to the river. The model uses the turbidity values to represent inorganic suspended solids (TSS) that may settle in the DWSC. The model estimates the light extinction coefficient and depth of algae growth (i.e., euphotic depth, 1% of surface light) from the TSS, as well as algae and VSS concentrations. TSS is settling and is re-suspended in the DWSC by the tidal velocity. Because the observed downstream decrease in turbidity is moderate, there must be substantial re-suspension of the clay particles, or else the settling rate is very slow.

Figure 8 shows the measured and estimated VSS (organic particles including algae and detritus) concentrations for 2001. The strong seasonal pattern follows the Mossdale diurnal DO and pH measurements that are strongly peaked (i.e., "sine-squared" shape) during the summer. The VSS measurements at Mossdale and Vernalis are very similar, declining rapidly in September at both stations. The seasonal estimate of river VSS concentration uses a minimum of 2 mg/l and a maximum of 12 mg/l. VSS is the simplest and most basic measurement of organic material entering the DWSC. However, the model will separately track the DO decay from algae respiration and decay, so the algae contribution to the VSS must be separated from the VSS estimate. This is a little involved and requires an important assumption about the pigment content of algae.

The primary algae measurements are the pigments, chlorophyll and phaeophytin, assumed to represent the live and decaying algae. To estimate algae biomass, the fraction of algae that is pigment molecules must be assumed. The water quality model assumes a constant pigment content of 1.25% of the biomass. With this assumption, 1 mg/l of algae biomass (VSS) would be equivalent to 12.5 ug/l of pigment (chlorophyll or phaeophytin). This basic assumption can be confirmed by comparing the total pigment concentration with the VSS measurements. The VSS (ug/l) concentration should always be greater than 80 times the total pigment (ug/l) concentration. The measured algae pigment at Mossdale and Vernalis has been converted to equivalent biomass with the assumed 1.25% pigment content. Figure 8 indicates that this ratio is a reasonable guess and that the algae biomass may represent a majority of the river VSS concentrations. The detritus variable in the model represents the non-algae organic particles that decay and settle. The estimated river detritus concentrations for 2001 obtained by subtracting the algae biomass from the VSS concentrations are relatively constant at between 2 mg/l and 4 mg/l.

Figure 9 shows the measured and estimated Mossdale chlorophyll concentrations used for the model input. The chlorophyll concentrations decreased rapidly in September. The weekly measurements at Mossdale and Vernalis were used to fit an assumed seasonal curve with a very strong peak (i.e., "sine-cubed" shape). Although both temperatures and light have seasonal sinusoidal shapes, the reason for this extremely seasonal peaked shape is not obvious. The maximum chlorophyll is assumed to be 80 ug/l (equivalent to 6.4 mg/l VSS) and the winter minimum is 0 ug/l.

Figure 10 shows the measured and estimated Mossdale phaeophytin concentrations that were assumed to be 50% of chlorophyll, based on the summer TMDL measurements. The maximum of 40 ug/l corresponds to a VSS concentration of 3.2 mg/l. The total algae biomass (live and dead) is the majority of the 10-12 mg/l VSS measured in June and July.

Figure 11 shows the estimates of ultimate dissolved CBOD at Mossdale. The 5-day total BOD measurements was used to estimate the dissolved, carbonaceous BOD values. Because the model separately tracks the BOD from ammonia oxidation, algae decay, phaeophytin decay, and detritus decay, only the dissolved carbonaceous BOD fraction of total BOD is simulated with CBOD in the model. The model assumes that 1 mg/l of detritus or algae biomass will produce 1.6 mg/l of BOD during decay. The model assumes that ultimate CBOD is 2.5 times the 5-day CBOD. The 2.5 factor is derived from long-term BOD measurements that indicate the 5-day BOD is about 40% of the ultimate (30-day) BOD. This ratio suggests that the daily BOD decay rate is about 0.10 day $^{-1}$. After accounting for the BOD equivalent of the measured VSS (detritus and algae), the data suggests that only about 1 mg/l is dissolved 5-day CBOD. The model therefore assumes the ultimate CBOD is about 2.5 mg/l throughout the year.

The model requires estimates of river ammonia, nitrate, and phosphate concentrations. The ammonia at Mossdale varied from 0 to 1.0 mg/l and was simulated as a constant 0.5 mg/l. This will have an ultimate BOD equivalent of about 2.5 mg/l. The SJR nitrate concentrations are very high at Mossdale and were simulated as a constant of 2.0 mg/l. The SJR phosphorus concentrations (assumed dissolved and available for algae growth) were assumed to be a constant of 0.15 mg/l.

There may be substantial variations in the daily river concentrations that are not included in these seasonal model estimates, which are based on weekly summer and fall grab samples. The daily changes in river concentrations caused by variations in river flows or variations in algae growth conditions were not simulated by the model for 2001.

Daily Stockton RWCF Effluent Concentrations

Daily (24-hour composite) measurements of CBOD, VSS, and ammonia-N in the RWCF effluent are routinely collected. These measurements provide very accurate RWCF load estimates for the model.

Figure 12 shows the daily measurements of 5-day CBOD, and the corresponding estimates of ultimate CBOD in the RWCF effluent. The first estimate of ultimate CBOD is assumed to be 2.5 times the 5-day CBOD measurements. The second estimate of ultimate CBOD is based on the assumption that each 1 mg/l of VSS will produce 1.6 mg/l of ultimate CBOD during decay. The two estimates of ultimate CBOD are similar throughout the summer and fall. Because the oxidation ponds and tertiary dissolved air flotation and sand filters are most effective in the summer, the CBOD concentrations are actually lowest in the spring and summer period.

The data suggest that the ultimate CBOD estimated from VSS (i.e., particulate) is often slightly greater than the ultimate CBOD estimated from 5-day CBOD. Therefore, very little RWCF effluent CBOD is dissolved. The total ultimate RWCF effluent CBOD (detritus and algae and dissolved) varies from about 5 mg/l to 25 mg/l during the summer and fall months, with the estimates from VSS being about 5 mg/l higher than the estimates from 5-day CBOD. The assumed 2.5 factor for 5-day CBOD or the 1.6 factor for VSS must be adjusted slightly to produce the same estimate of ultimate CBOD.

Figure 13 shows the daily ammonia-N concentrations for the RWCF effluent. The maximum ammonia-N concentrations of 25 mg/l during the winter are similar to the inflow concentrations to the RWCF, and indicate that very little removal of ammonia occurs during the winter. The majority of the ammonia is removed by algae uptake and growth during the spring and summer months. The RWCF performance during 2001 was not as good as most years, when ammonia has consistently been less than 2 mg/l from May through August (Jones & Stokes 1998). The total kjeldahl nitrogen (TKN), that includes ammonia and organic nitrogen, were measured weekly and are shown in Figure 13. The majority of the TKN concentration was ammonia-N.

Figure 14 shows the ultimate BOD equivalent for the TKN, assuming that 4.7 mg/l of oxygen are required to oxidize (i.e., nitrify) each 1 mg/l of ammonia-N. The maximum ultimate NBOD concentrations are about 150 mg/l during the winter, when the TKN concentration is 25 mg/l. However, the nitrification rate is less during the winter and may cease altogether at temperatures of less than 10 C. The ultimate NBOD dominates the ultimate CBOD, which was generally less than 25 mg/l. These high ultimate BOD concentrations from the RWCF effluent are, however, diluted by the SJR flow before entering the DWSC.

Combined SJR River and RWCF BOD Loads to DWSC

A simple way to visualize the two sources of BOD loading (i.e., river and RWCF) is to consider the total ultimate BOD concentrations entering the DWSC each day. The river load at Mossdale will change (i.e., decay) as it flows to the DWSC. The RWCF load will be diluted by the river flow before entering the DWSC. The model simulates the decay of BOD and decline of algae biomass during the travel time from Mossdale to the DWSC. At a flow of 500 cfs the travel time is about 2.5 days, and at a flow of 1000 cfs the travel time is only 1.2 days. Field measurements of VSS and chlorophyll indicate that the R3 concentrations are generally less than 50% of the Mossdale concentrations. A considerable reduction in the Mossdale load of particulate organics (i.e., ultimate BOD) apparently occurs in the river between Mossdale and DWSC, although the travel time was generally only 1-2 days during 2001.

The ultimate BOD concentration entering the DWSC will be increased by the RWCF effluent BOD concentration after dilution by the river flow. The fraction of the effluent concentration of ultimate BOD that will enter the DWSC in the river flow can be estimated from the ratio of the combined river flow and effluent discharge to the effluent discharge:

Dilution Factor = (River flow + RWCF Discharge) / RWCF Discharge

A higher river flow will provide a greater dilution of the RWCF discharge. The river and diluted effluent water will then move through the DWSC more quickly, and exert less of the ultimate BOD within the DWSC volume, when the river flow is higher. A 5-day moving average of the river flow and discharge has been assumed to account for tidal mixing in the SJR.

Figure 15 shows the resulting dilution factor pattern for 2001. The model assumed the higher flow estimate shown in Figure 1. The dilution factor was generally greater than 20 through out the summer. During December the dilution factor declined to less than 10 for several days. The assumed ultimate BOD concentration that enters the DWSC from Mossdale was assumed to be 50% of the Mossdale ultimate BOD. The ultimate BOD concentration entering the DWSC from Mossdale follows a seasonal pattern that is a minimum of 5 mg/l in the winter and a maximum of 12 mg/l in the summer.

The ultimate BOD concentrations from the RWCF effluent were high when ammonia-N concentrations were greater than 10 mg/l (i.e., 50 mg/l ultimate NBOD). However, because the dilution of effluent by the river flow was generally greater than 20, the contribution of ultimate BOD from the RWCF discharge to the DWSC was almost always less than 5 mg/l. Only in January and December were the ultimate BOD concentrations entering the DWSC from the diluted RWCF effluent higher than 5 mg/l. The contribution of ultimate BOD from the RWCF discharge to the DWSC was therefore almost always less than the contribution of ultimate BOD from the river.

Figure 16 shows the measured daily DO deficit (i.e., saturated DO - average DO) at the Rough and Ready Island monitoring station operated by DWR. The DO deficit pattern already accounts for the change in DO saturation that depends directly on the water temperature. The DO deficit reflects the total BOD decay that was exerted in the river downstream of Mossdale or in the DWSC during the travel time of the water to the Rough & Ready station. The longer the travel time, the more of the ultimate BOD will actually decay within the DWSC and cause the DO concentrations at R&R to decline. The total ultimate BOD entering the DWSC assuming 50% of the Mossdale BOD and the diluted RWCF BOD is also shown in Figure 16. The two patterns show a strong similarity and suggest that the seasonal ultimate BOD concentration entering the DWSC accounts for the majority of the observed DO deficits at the R&R Island station.

The DO deficit indicates that the ultimate BOD loads exceeded the ability of reaeration and algae production to add DO to the DWSC. Reaeration of the DWSC increases as the DO deficit increases, and reaeration also increases as the residence time increases, but the net effects of reaeration on the effective BOD loads are difficult to evaluate without a model to perform the calculations. A model is also needed to track the net effects of algae growth in the DWSC. Algae photosynthesis is assumed to produce as much DO as algae respiration and decay will subsequently consume, but the net effects on DO in the DWSC does not appear to be balanced. These more complicated and involved calculations can only be performed with a water quality model.

Validation of Model Results for 2001 DO Conditions

The Stockton DWSC water quality model was used to simulate 2001 conditions without any changes in model coefficients. The inflow concentrations were specified as described in this report, and the field data collected at the City of Stockton river sampling stations in the DWSC were compared with the model predictions. Because the river concentration estimates do not include daily variations, only the basic seasonal patterns of river water quality can be simulated with the model. The daily changes in river flow and the daily changes in RWCF effluent concentrations and flows will produce some daily variations in simulated water quality in the DWSC. Daily fluctuations in water temperatures will also slightly change BOD decay rates in the DWSC. Figure 4 indicates that temperature between Mossdale and R&R are very similar. The model is able to reproduce the short-term temperature fluctuations caused by meteorology, but the seasonal effects of temperature on DO saturation and BOD decay processes are the dominant effects for DO simulation.

Figure 17 shows the simulation of ammonia concentrations at R3 and R5 compared with Mossdale. Mossdale ammonia was assumed to be 0.5 mg/l, although the data indicates considerable variation in ammonia. The highest summer ammonia concentration of about 1.0 mg/l was measured at R3 during August. The concentrations had decreased to about 0.75 mg/l at R5. The model concentrations were a little less than measured at R3, and the simulated decline at R5 was smaller, suggesting that the simulated decay rate may be slightly too fast. The green line represents the expected ammonia concentration entering the DWSC without any ammonia oxidation. The DWSC ammonia values would have been about 1.5 to 2.0 mg/l during the summer. The model appears to be simulating about the right amount of nitrification, although reducing the rate slightly from 0.05 day^{-1} to 0.04 day^{-1} might improve the match with field data. The model could also be modified to include organic nitrogen, which would allow the TKN measurements to be used and would allow the complete nitrogen cycle to be simulated. The TKN concentrations at Mossdale were about 1.0 to 1.5 mg/l during the summer, and this additional organic nitrogen will decay to ammonia and then nitrify, thereby increasing the oxygen demand.

Figure 18 shows the measured and simulated VSS concentrations at Mossdale, R3 and R5 for 2001. The water quality model had a re-suspension term added that is a function of the river velocity that includes a strong tidal component within the DWSC. The re-suspension term for VSS is unlimited (i.e., total VSS is not tracked) and therefore acts as a net source of VSS. The model is simulating too much re-suspension of VSS in the river and DWSC, with model R3 concentrations of 5 to 15 mg/l. The measured VSS at R3 is about 5 mg/l. The simulated decrease of about 1 mg/l VSS between R3 and R5 is properly simulated. But the simulated tidal signal (i.e., spring-neap tidal energy) in VSS is much greater than indicated by the VSS data. Field measurements suggest a more constant resuspension source of VSS within the DWSC that counteracts the settling of VSS (Litton, 2002). The VSS simulation for 2001 is not adequate because the average VSS is too high (from the simulated re-suspension source of VSS) and the tidal variation within each month is too strong.

Figure 19 shows the measured and simulated chlorophyll concentrations at Mossdale, R3 and R5 for 2001. The simulated net decline in chlorophyll (i.e., algae) between Mossdale and R3 is apparently too slow in the model because the simulated chlorophyll at R3 is about 3x higher than measured. As Figure 19 indicates, the model simulates the R3 chlorophyll to decline to about 75% of the Mossdale chlorophyll, but the data indicate that the R3 chlorophyll is only about 25% of the Mossdale value. The algae simulations at R5 are also too high compared with the data. The model does simulate a 50% decline in chlorophyll between R3 and R5, which is similar to the observed decline. The chlorophyll simulation for 2001 is not adequate because the net decline in chlorophyll between Mossdale and the DWSC is not enough to match the R3 algae data. The modeled algae growth rate may be too high, or the decay rate might be too slow.

Figure 20 shows the measured and simulated phaeophytin concentrations at Mossdale, R3 and R5 for 2001. The net decline in phaeophytin (i.e., dead algae) between Mossdale and R3 is apparently too slow in the model because the simulated phaeophytin at R3 is higher than measured in June, July, and August. The data indicate that phaeophytin at R3 and R5 was higher than at Mossdale in September and October. The model decay rates for both chlorophyll and phaeophytin may be too low. Some special algae decay rate experiments suggest that the dark decay of chlorophyll was about 0.5 day^{-1} and the dark decay of phaeophytin was about 0.25 day^{-1} (Litton, 2002). The model is currently using a chlorophyll decay rate of 0.13 day^{-1} and a phaeophytin decay rate of 0.10 day^{-1}. Increasing these coefficient values may improve the match with field data. The simulated growth rate of algae in the light conditions typical of the river below Mossdale (i.e., 10-15 feet depth) and in the DWSC (i.e., 25-35 feet depth) should also be verified with field measurements.

Figure 21 shows the simulated and measured DO concentrations at R3 and R5. The minimum daily DO concentration from the DWR R&R monitoring station are also shown. The saturation DO concentration for the R&R station temperature is shown for comparison. The seasonal decline in DO at R3 and R5 is simulated. The simulated DO at R5 is about 1 mg/l below the measured R5 data and below the R&R minimum DO concentrations during the spring and summer. The measured DO was nearly saturated during April and May when the flows were at least 3,000 cfs during the VAMP period. The simulated DO at R5 was about 2 mg/l lower than the R&R data during this event.

The general magnitude of the simulated DO deficit at R5 matches the field data quite well during the summer and fall period of June through October 2001. However, the simulated DO at R3 was considerably less than the measured DO data at R3, suggesting that the model is simulating too much BOD decline in the river between Mossdale and DWSC. The model therefore simulates too little BOD remaining at R3 to lower the DO between R3 and R5. The simulated settling and decay processes between Mossdale and R3 should be better balanced with the simulated settling and decay processes within the DWSC from R3 to R5.

Figure 22 shows the cumulative travel time between Mossdale and R3 and then to R5. The DO deficit measured at R5 appears to be generally related to this pattern. As described in Figure 16, the highest concentrations of CBOD and NBOD from the river and the RWCF effluent occurred during the June-September period. The travel time to the DWSC was about 3 days, and the cumulative travel time to R5 was about 10 days, with a corresponding dilution factor of about 20 for the RWCF effluent. The model is not able to track the short-term fluctuations in the measured DO at the R&R station that were observed during this summer period. Some of the suggested changes in the VSS, ammonia, and algae simulations will also likely improve the DO simulations.

Sensitivity Results

The model was also used to demonstrate sensitivity of simulated DO concentrations in the DWSC to changes in RWCF effluent and river concentrations, as well as to changes in river flow and some important model coefficients. These sensitivity results will increase confidence in the model if the sensitivity simulations bracket the measured data. The sensitivity results also emphasize the importance of the measured river and RWCF concentrations of the ultimate BOD components (i.e., algae, TKN, detritus, and dissolved CBOD).

Sensitivity of DO to Flow in 2001

Figure 23 shows the simulated daily average DO concentrations at R3 for the base case with actual flows in 2001 compared with a reduced (50%) flow case and an increased (150%) flow case. The base simulation used the high flow estimate shown in Figure 1. The same seasonal Mossdale river concentrations and the same RWCF effluent flows and concentrations were used in each simulation. The higher flow case gave shorter travel times (67% of base) and greater dilution of the RWCF effluent so the effective BOD concentrations entering the DWSC were less than the base. The reduced flow case gave longer travel times (2x base) and less dilution (50% of base) for the RWCF effluent. The simulated changes in DO concentrations at R3 were greater for the reduced flow case than for the increased flow case. A large difference (i.e., 2-3 mg/l) in the simulated DO concentrations at R3 was predicted during the summer period, indicating that flow is a very important variable for accurately simulating DO concentrations. The measured DO data at R3 appears to be better matched with the increased flow (150%) case.

Figure 24 shows the simulated daily average DO concentrations at R5 (Rough & Ready) for the base case with actual flows in 2001 compared with a reduced (50%) flow case and an increased (150%) flow case. The simulated changes in DO concentrations at R5 were greater for the reduced flow case than for the increased flow case. A difference of 1-2 mg/l in the simulated DO concentrations at R5 was predicted during the summer period, indicating that flow is a very important variable for accurately simulating DO concentrations. The measured DO data at the R&R monitoring station appears to be better matched with the increased flow (150%) simulation case. This does not mean that the flows should be increased, because the flows are accurately measured. Rather, the model coefficients need to be further adjusted to match the DO data with the measured base flows.

Sensitivity of DO to VSS and Algae Settling Rates in 2001

Figure 25 shows the simulated daily average DO concentrations at R3 for the base case compared with reduced settling rates (50%) for algae and VSS and with increased settling rates (150%). The same seasonal Mossdale river concentrations of algae and VSS and the same RWCF effluent flows and concentrations of VSS were used in each simulation. The reduced settling produced lower DO concentrations (i.e., 1 mg/l less during the summer period), presumably because of greater concentrations of VSS and algae remaining in the flow entering the DWSC. Figure 26 shows the simulated results at R5 (Rough & Ready). The effects of the increased settling rates (150% base) were not as great at either R3 or R5. These results suggest that VSS settling is a very important coefficient for simulating DO in the DWSC. The settling rates should not be reduced, however, because the simulated DO concentrations with the reduced settling rates were much lower than the measured DO data at R3 and R5. The increased settling rates case gave a better match with the measured DO, but the settling rates should only be adjusted if comparison with the measured VSS and algae (i.e., chlorophyll and phaeophytin) concentrations suggests a change is necessary. The model VSS settling and re-suspension formulations might need to be revised to track to total VSS and limit the mass of VSS that is available to be re-suspended from the bottom.

Sensitivity of DO to Algae Growth Rates in 2001

Figure 27 shows the simulated daily average DO concentrations at R3 for the base case compared with reduced algae growth rate (50%) and increased algae growth rate (150%) cases. The reduced algae growth rate produced slightly higher DO concentrations at R3. The reduced algae growth rate only slightly reduced the algae biomass, suggesting that the majority of the algae originated from Mossdale, rather than growing in the river between Mossdale and the DWSC. The increased algae growth rate had a dramatic effect on the simulated DO at R3, reducing the DO concentrations by 2 mg/l during the summer period. This indicates that the simulated growth rate should not be raised. Any additional algae biomass grown in the river will enter the DWSC and reduce the DO as the algae decays. Figure 28 shows the simulated results at R5 (Rough & Ready). The effects of the increased algae growth rate (150% base) on DO at R5 was very strong, causing a decrease of 2 mg/l during the summer period. Because this is the same effect as simulated at R3, the mechanism appears to be growth of algae in the river between Mossdale and the DWSC.

Conclusions

These sensitivity results suggest that the model needs additional calibration of the algae growth, decay and settling processes that occur between Mossdale and the DWSC. Similarly, the VSS settling and re-suspension processes that occur between Mossdale and the DWSC need additional calibration. Model simulations of the moderate decline in algae, VSS, and DO concentrations between R3 and R5 appear to be much closer to the measured data.

The Stockton DWCS water quality model is our most useful existing tool for integration and systematic analysis and evaluation of alternative management actions. The existing model should continue to be used to increase our understanding of the DWSC water quality processes. The model equations and coefficient values have been improved from the original model developed in 1993 for the City of Stockton. However, additional simulations and integration of results from recent experiments performed by the CALFED funded projects (e.g., Litton, 2002 and Lehman, 2002) should be made. The recent peer review panel wondered why the existing model was not being used to provide integration of field data and analysis of potential management actions. The existing water quality model should be used until a more comprehensive alternative model are available.

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Gary M. Litton (2002). Sediment Deposition Rates and Oxygen Demands in the Deep Water Ship Channel of the San Joaquin River, Stockton, California. Prepared for CALFED Bay-Delta Program 2001 Grant 01-N61-005.

Figure 1. Measured and Estimated SJR Flows entering the Stockton Deep Water Ship Channel in 2001.

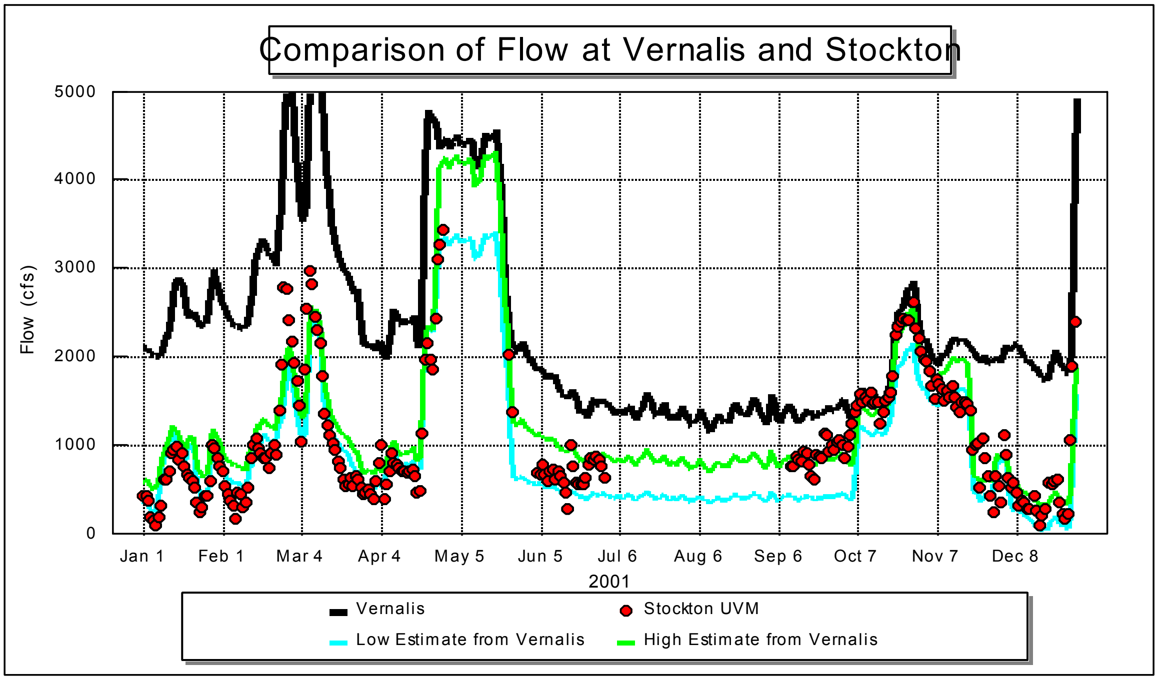

Figure 2. Stockton RWCF Daily Discharge During 2001.

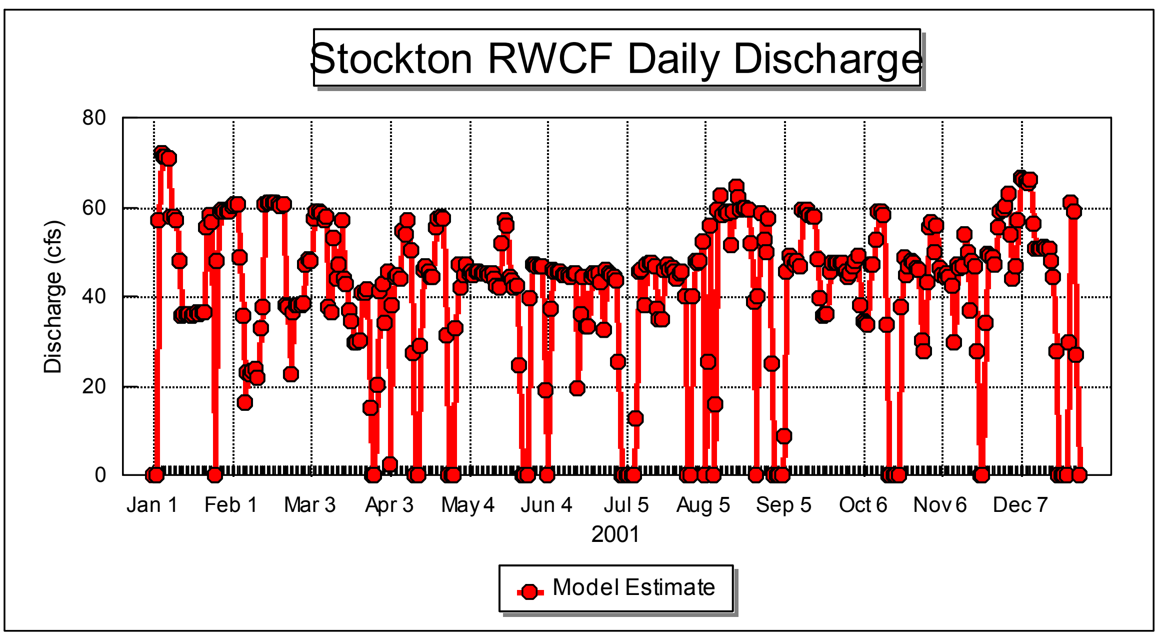

Figure 3. San Joaquin River Mean Daily EC Measurements for 2001.

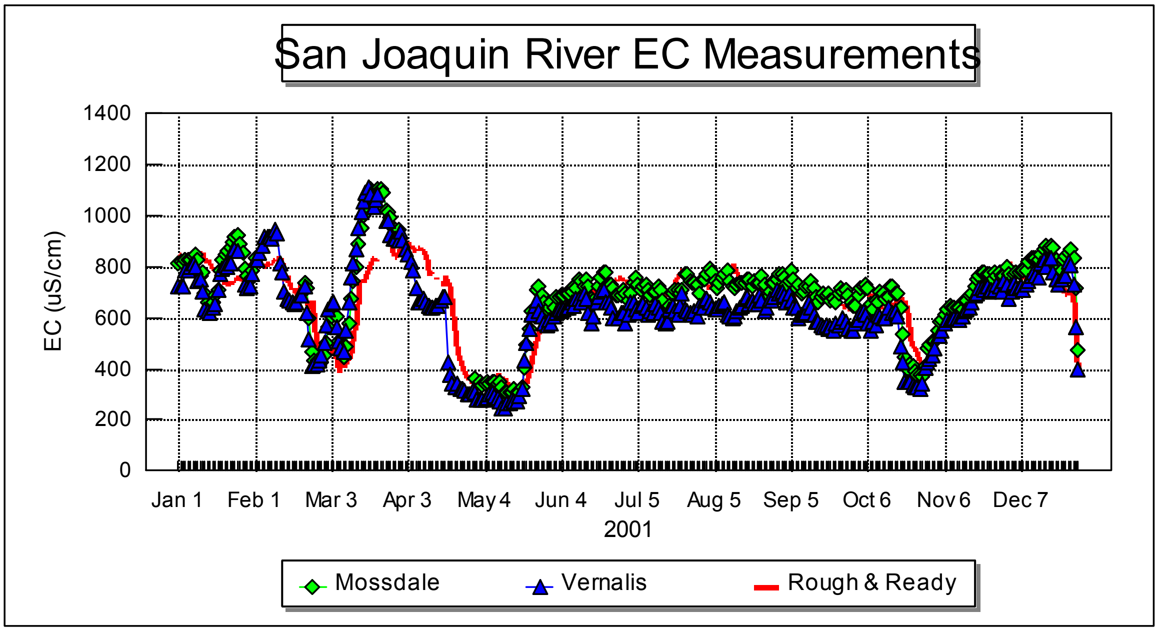

Figure 4. San Joaquin River Mean Daily Temperature Measurements for 2001.

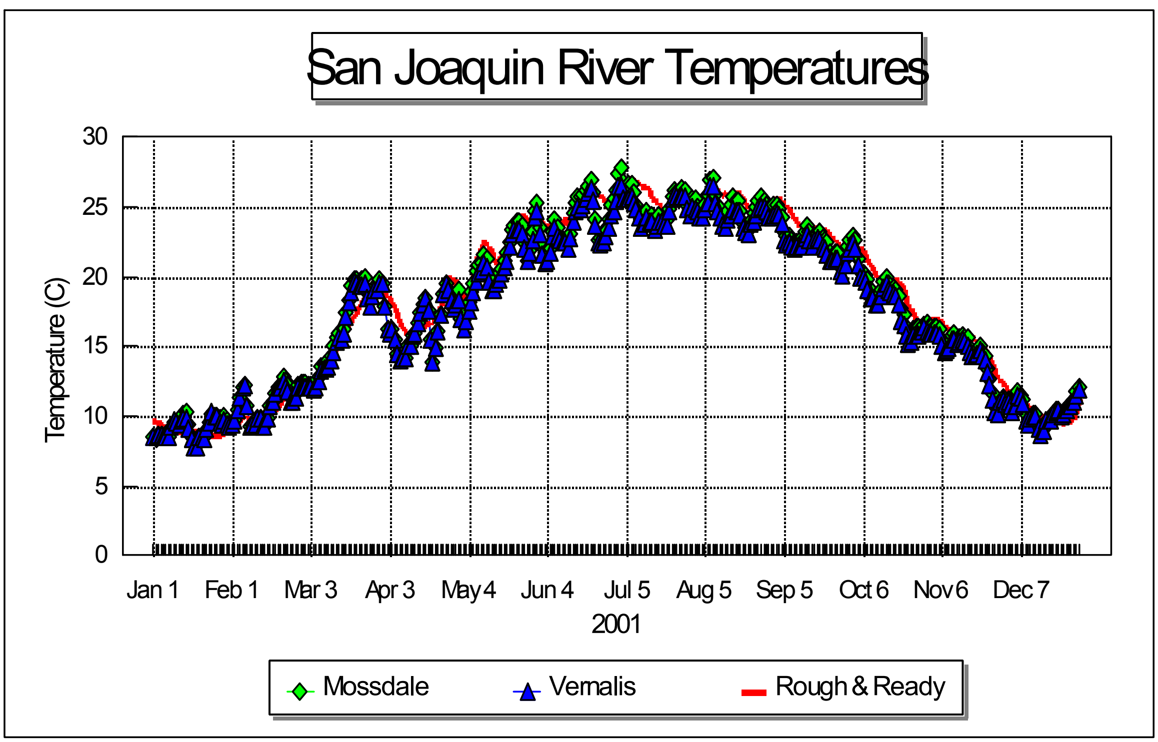

Figure 5. Mossdale Daily Average DO Compared to Saturated DO and Minimum and Maximum DO Measurements for 2001.

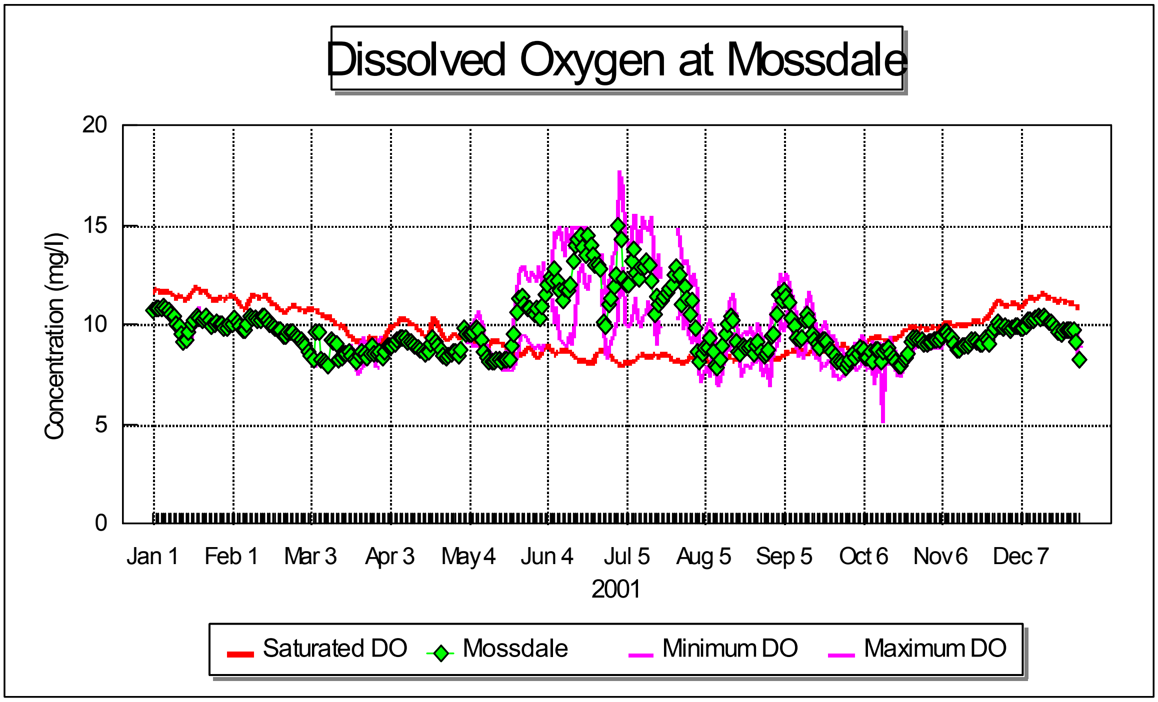

Figure 6. Daily Minimum and Maximum pH at Mossdale and Rough & Ready Island

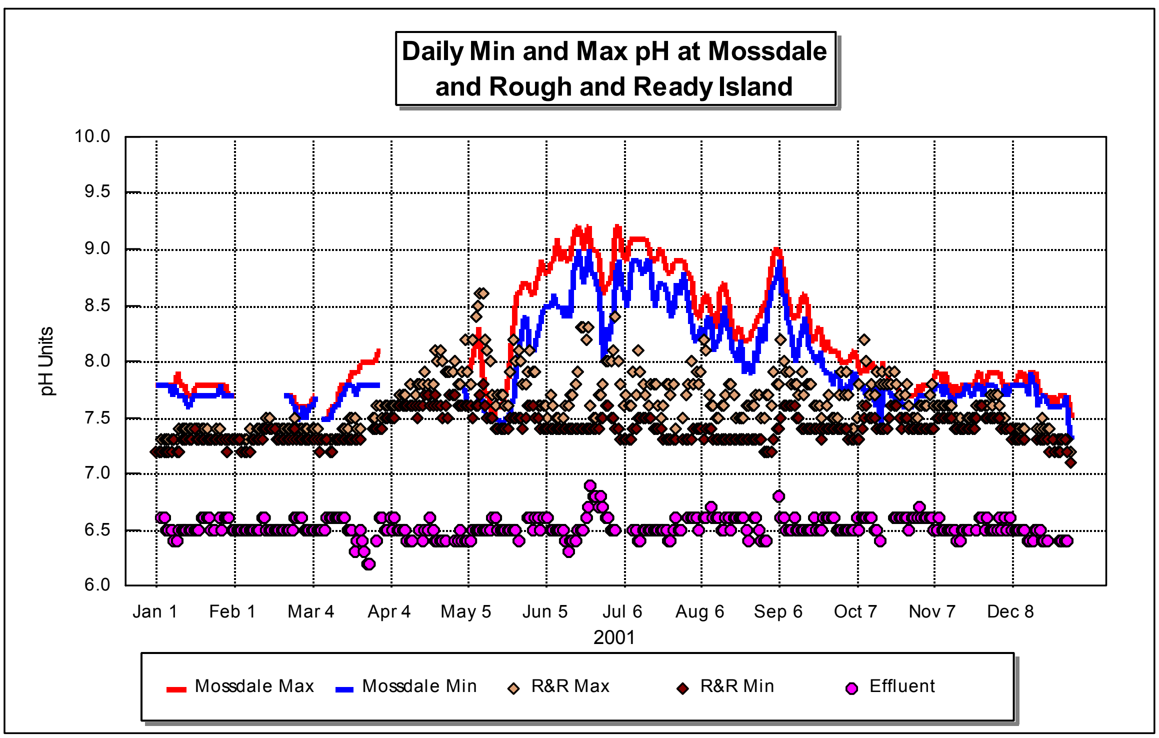

Figure 7. Measured and Estimated Turbidity (TSS) Values at Mossdale in 2001.

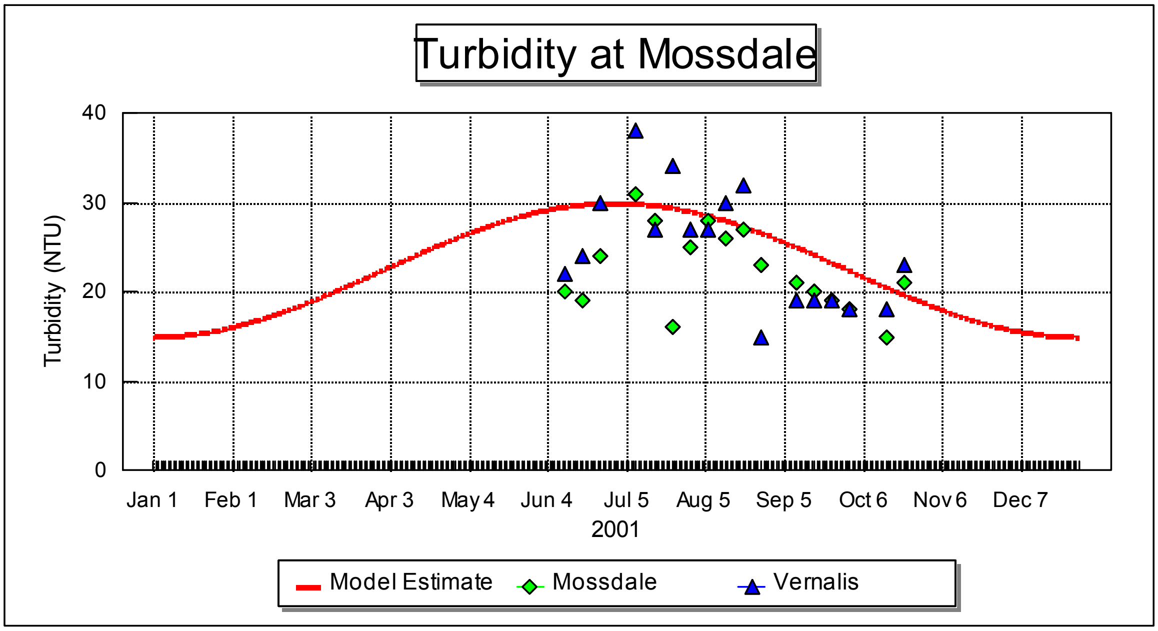

Figure 8. Measured VSS and Estimated Detritus and Algae Concentrations for 2001.

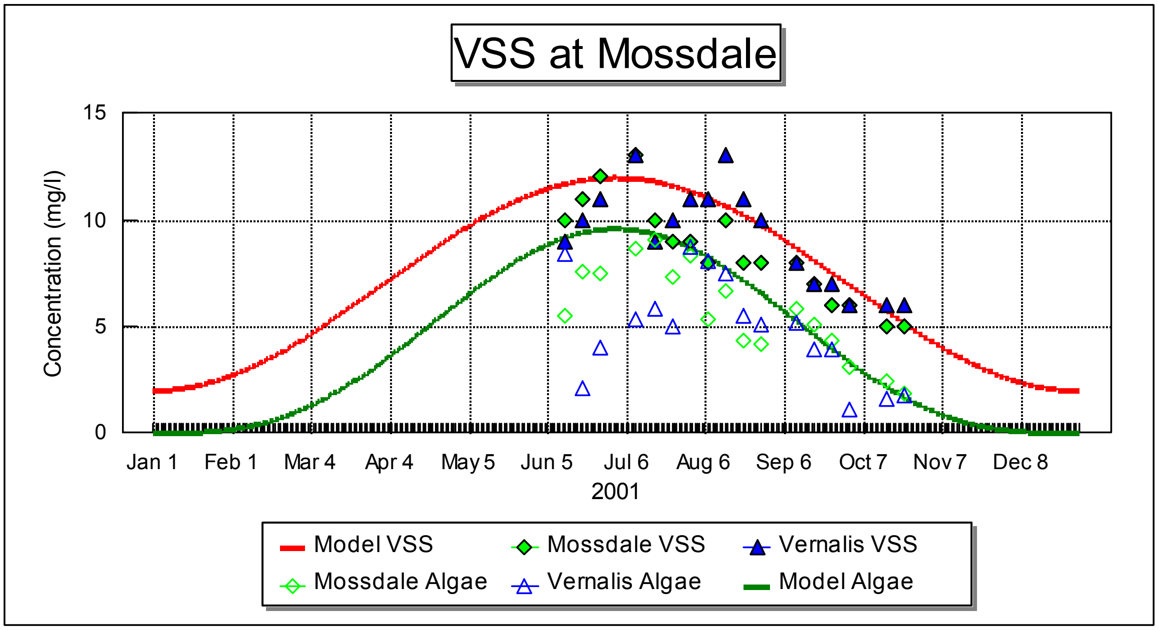

Figure 9. Measured and Estimated Chlorophyll Concentrations for 2001.

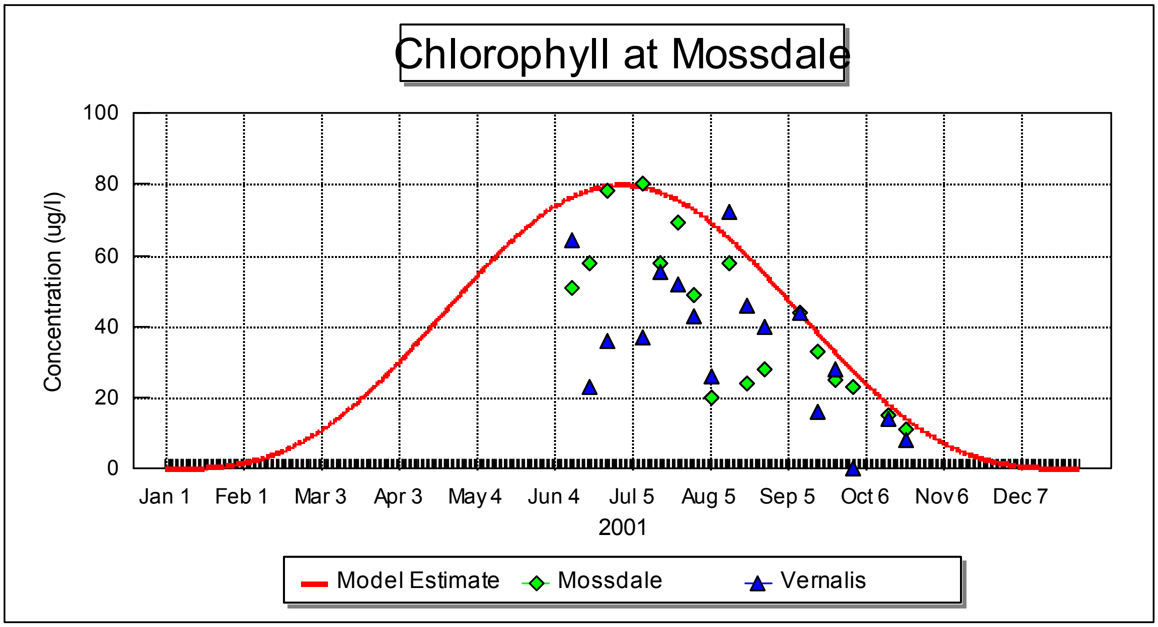

Figure 10. Measured and Estimated Phaeophytin Concentrations for 2001.

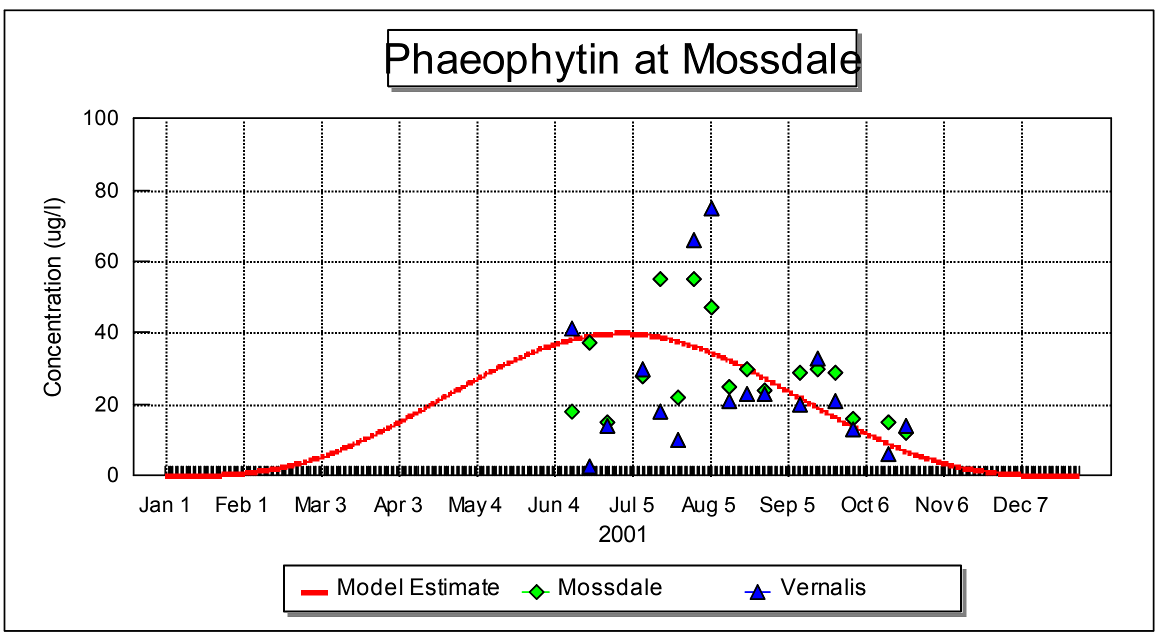

Figure 11. Measured and Estimated 5-day BOD and 5-day CBOD Estimates for 2001.

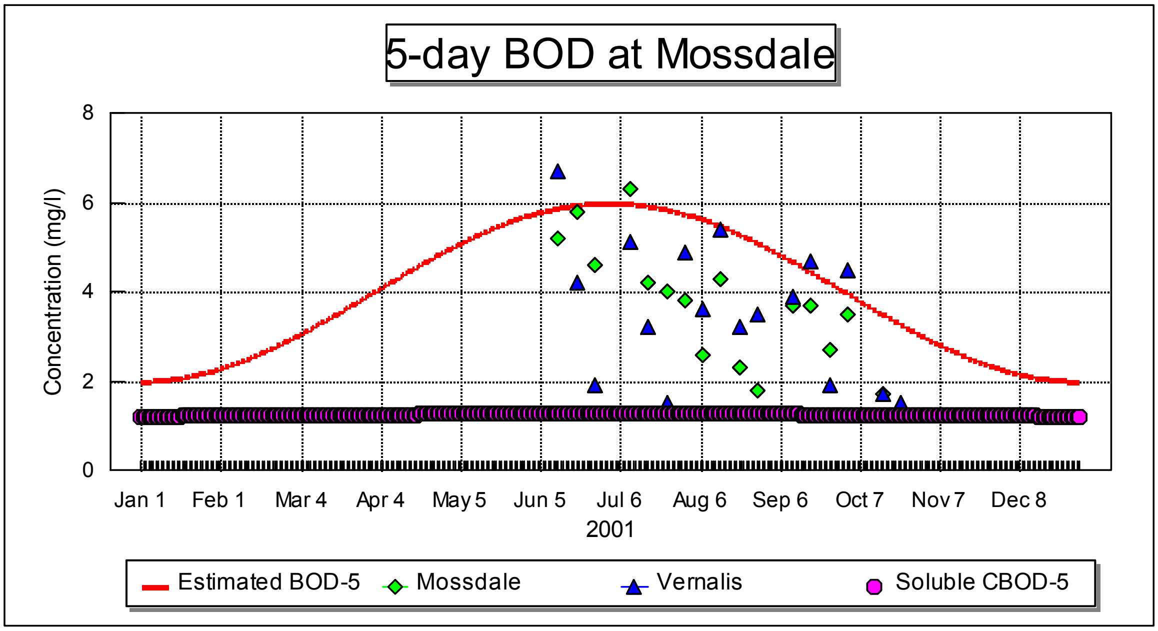

Figure 12. Estimated Stockton RWCF Ultimate CBOD from 5-day CBOD and VSS Data

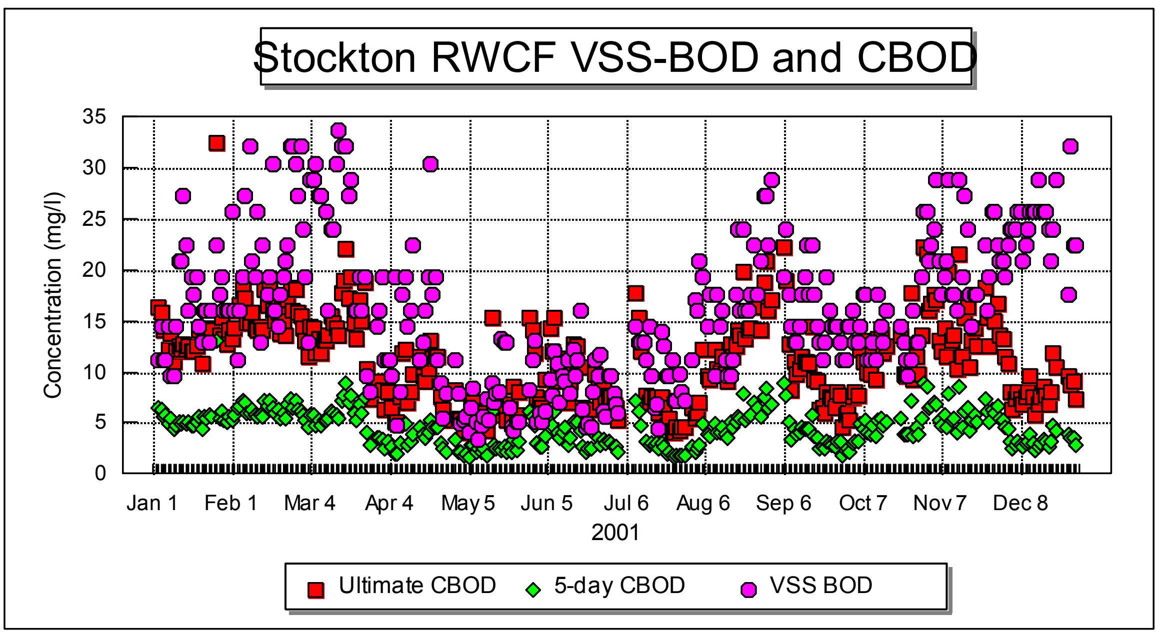

Figure 13. Daily Measurements of RWCF Ammonia-N and TKN Concentrations for 2001

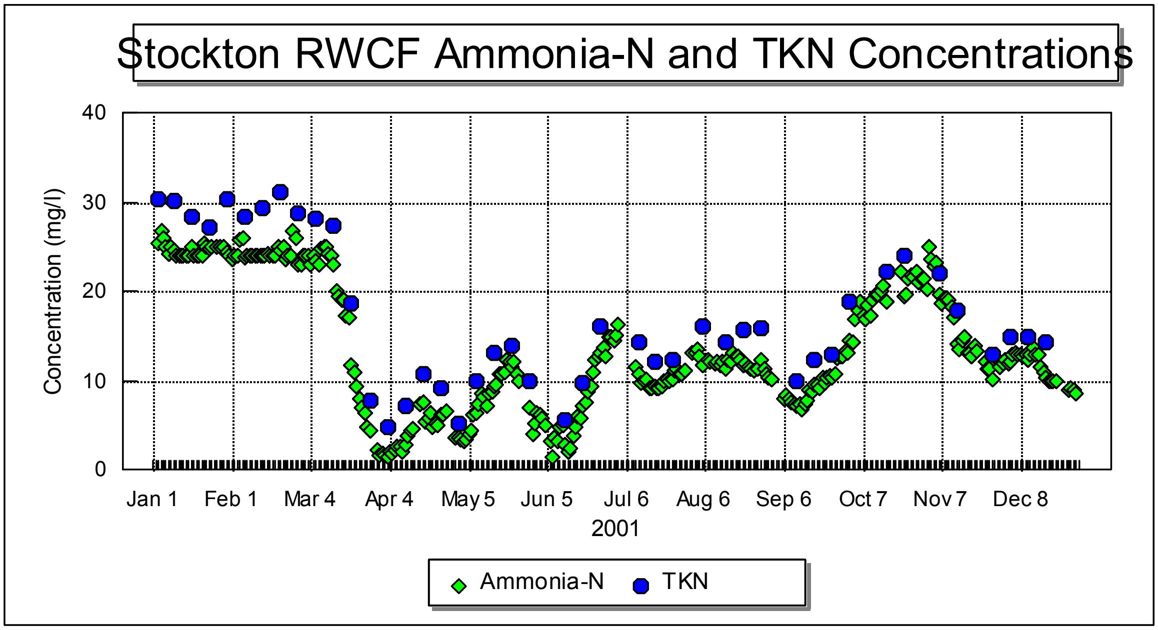

Figure 14. Comparison of Ultimate CBOD and Ultimate NBOD from RWCF

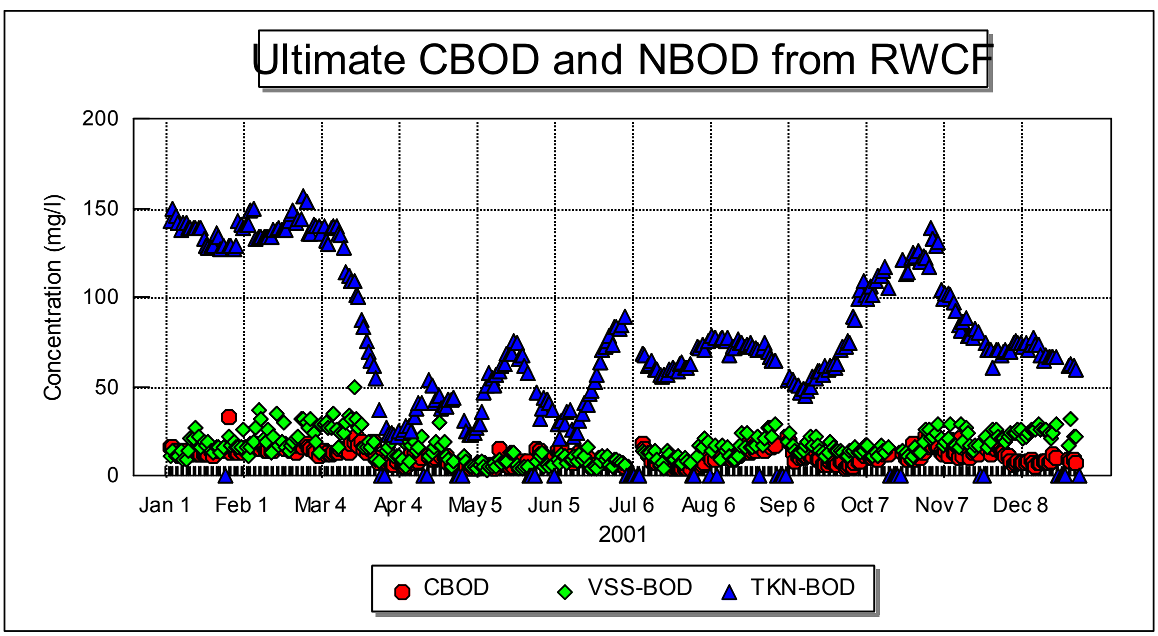

Figure 15. Estimates of Total Ultimate BOD concentrations entering DWSC from RWCF Discharge.

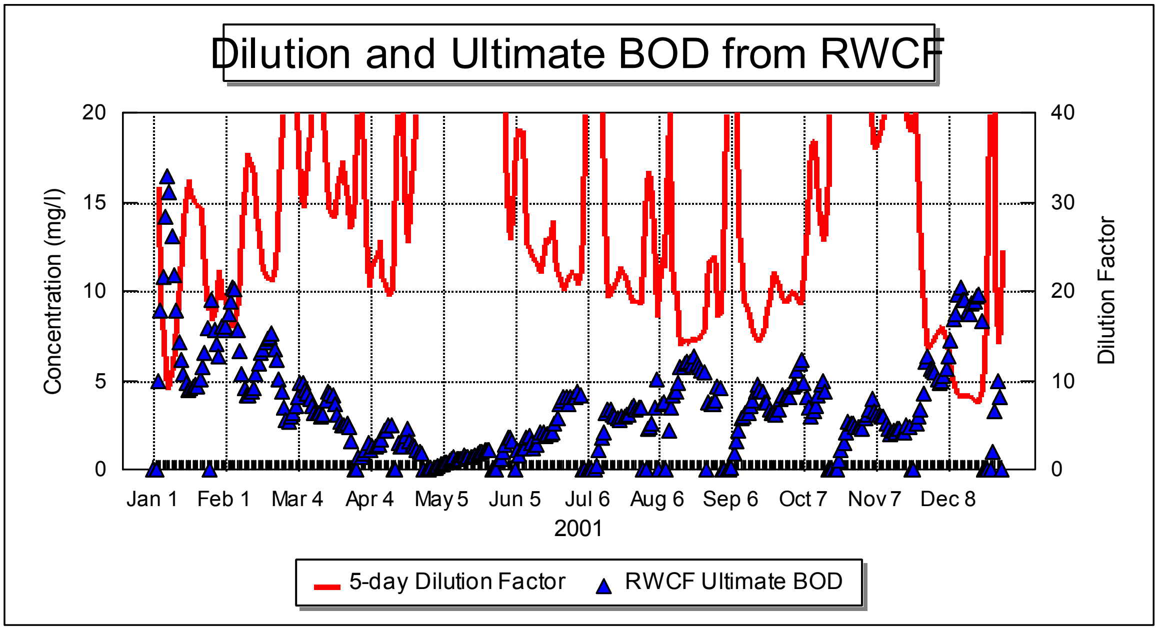

Figure 16. Daily DO Deficit at Rough & Ready Island in 2001 Compared to Ultimate BOD Entering DWSC from Mossdale and RWCF.

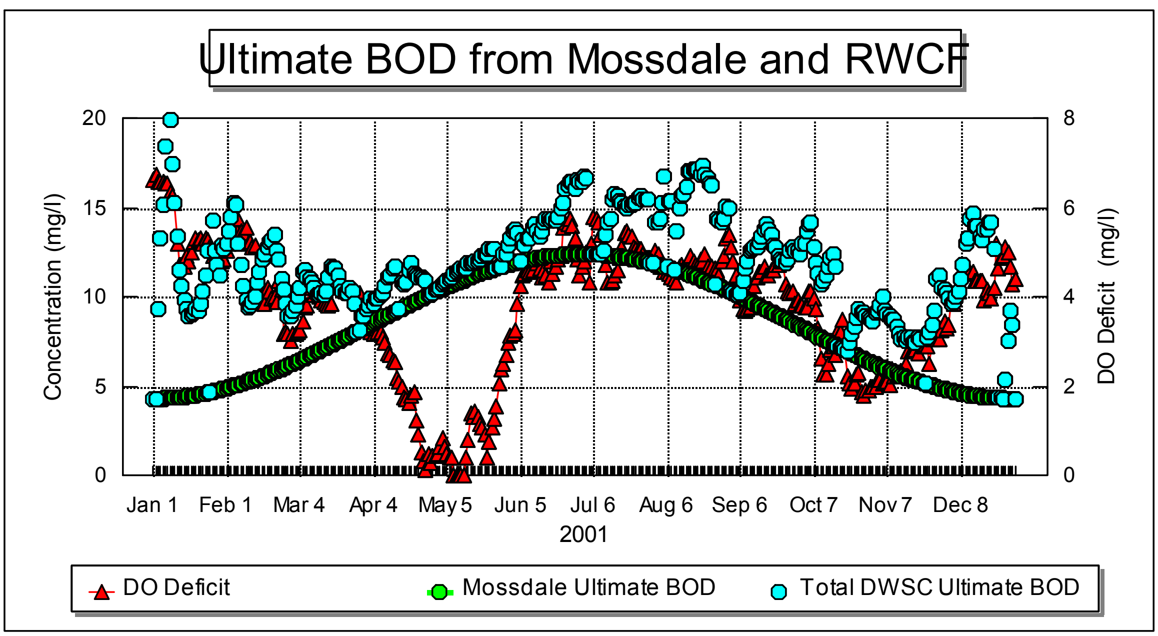

Figure 17. Model Simulated Ammonia-N Concentrations Compared with Ammonia-N Measurements in DWSC at R3 and R5 in 2001.

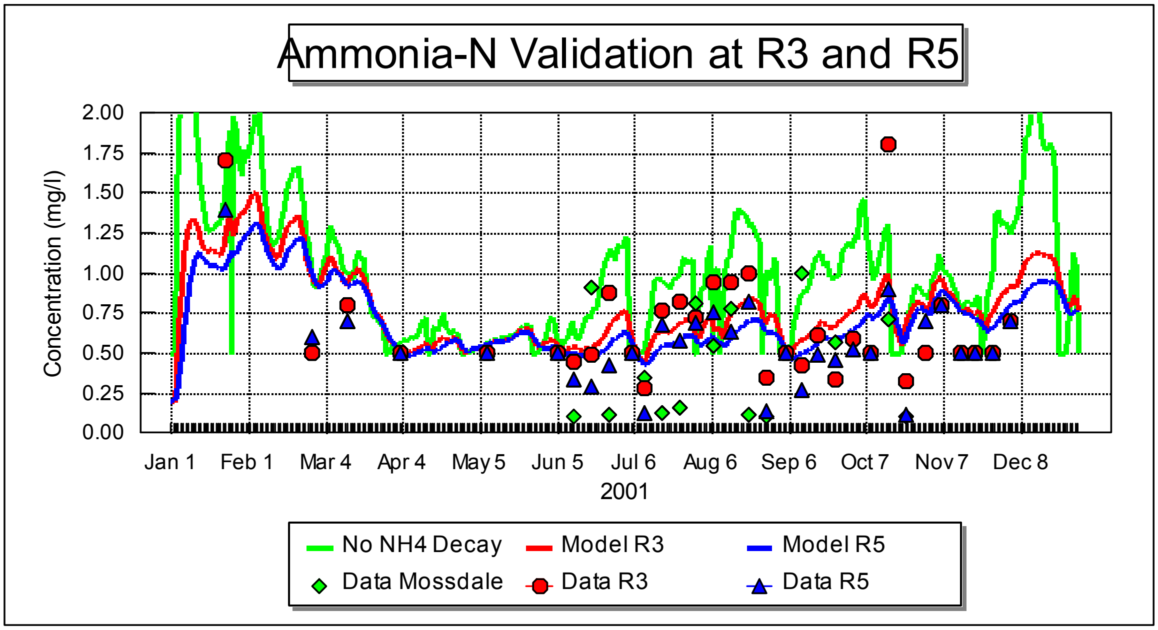

Figure 18. Model Simulated VSS Concentrations Compared with VSS Measurements in DWSC at R3 and R5 in 2001.

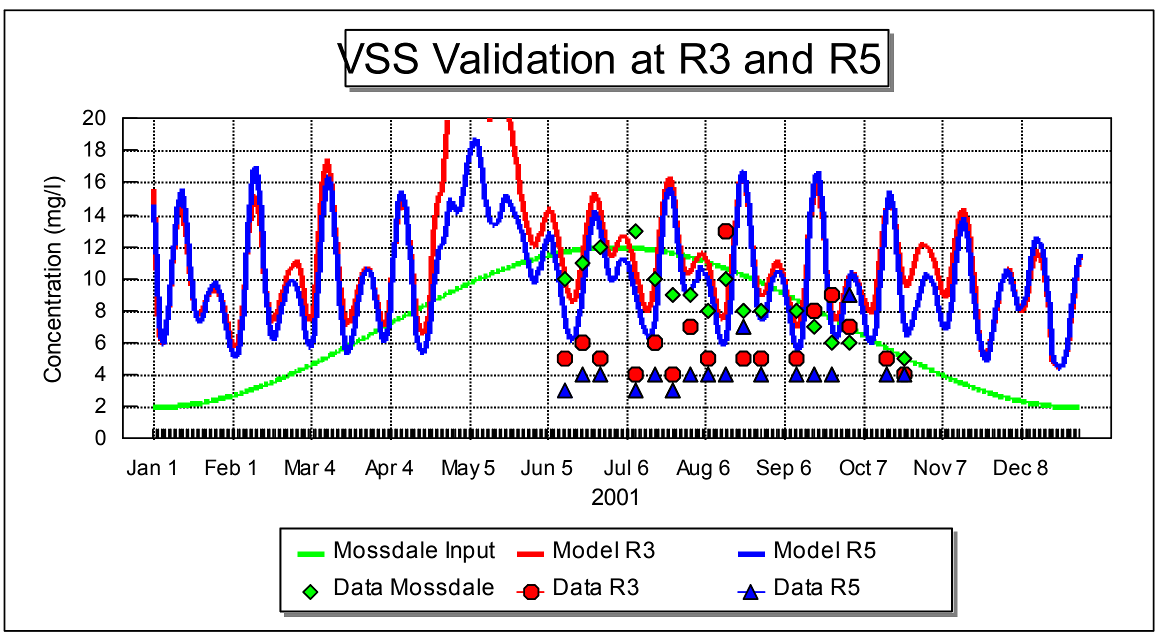

Figure 19. Model Simulated Chlorophyll Concentrations Compared with Chlorophyll Measurements in DWSC at R3 and R5 in 2001.

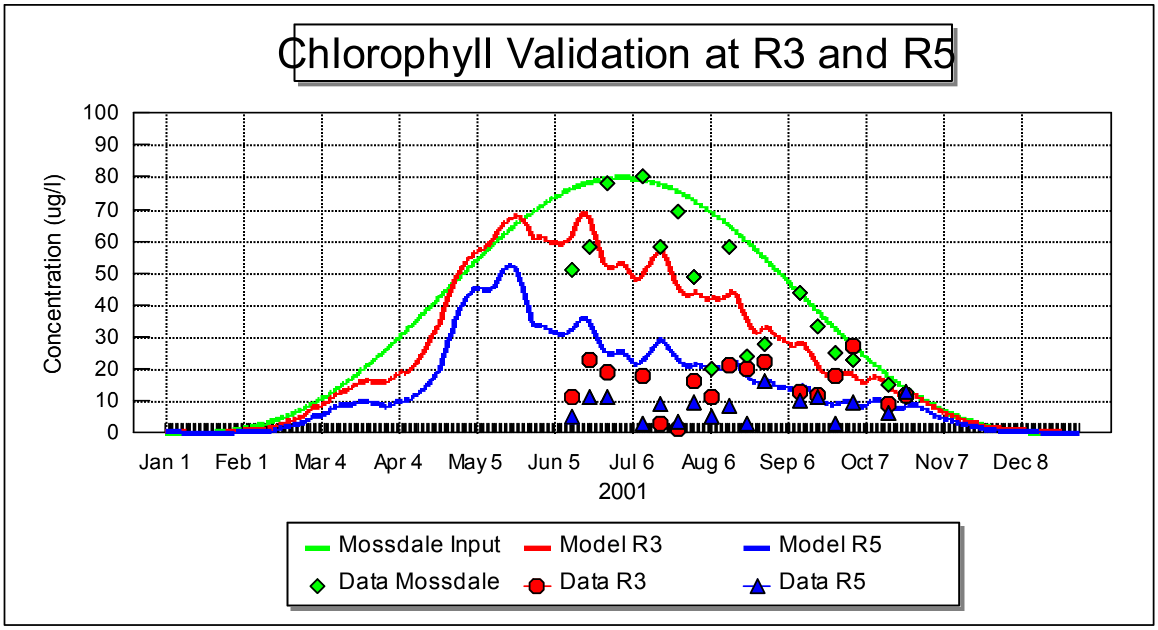

Figure 20. Model Simulated Phaeophytin Concentrations Compared with Phaeophytin Measurements in DWSC at R3 and R5 in 2001.

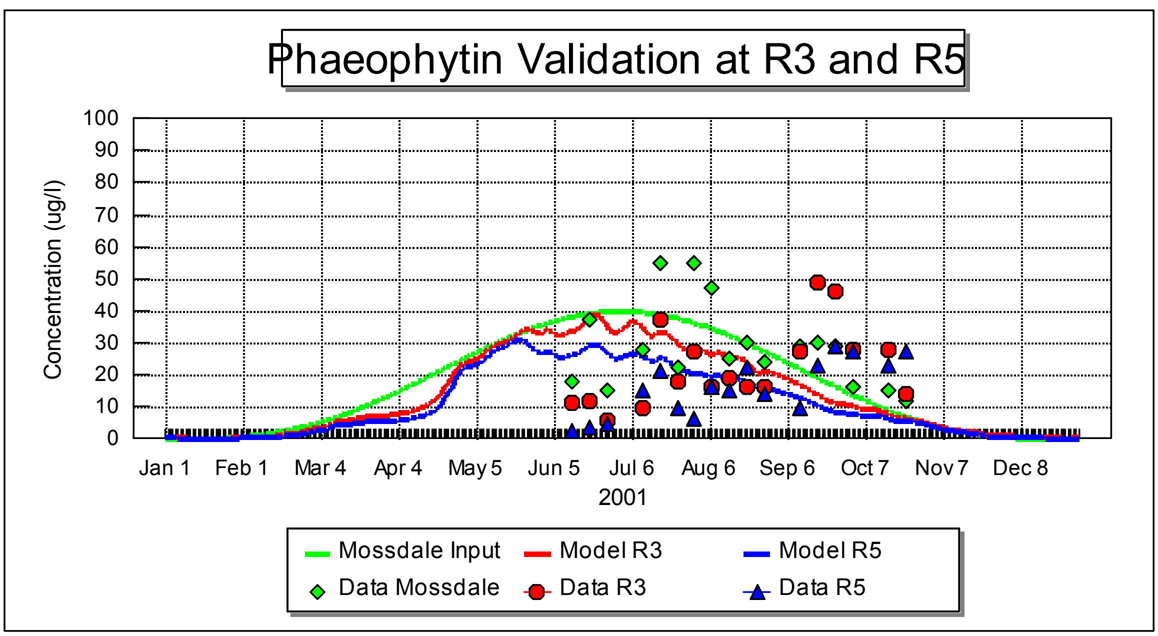

Figure 21. Model Simulated DO Concentrations Compared with DO Measurements in DWSC at R3 and R5 (Rough & Ready Island) in 2001.

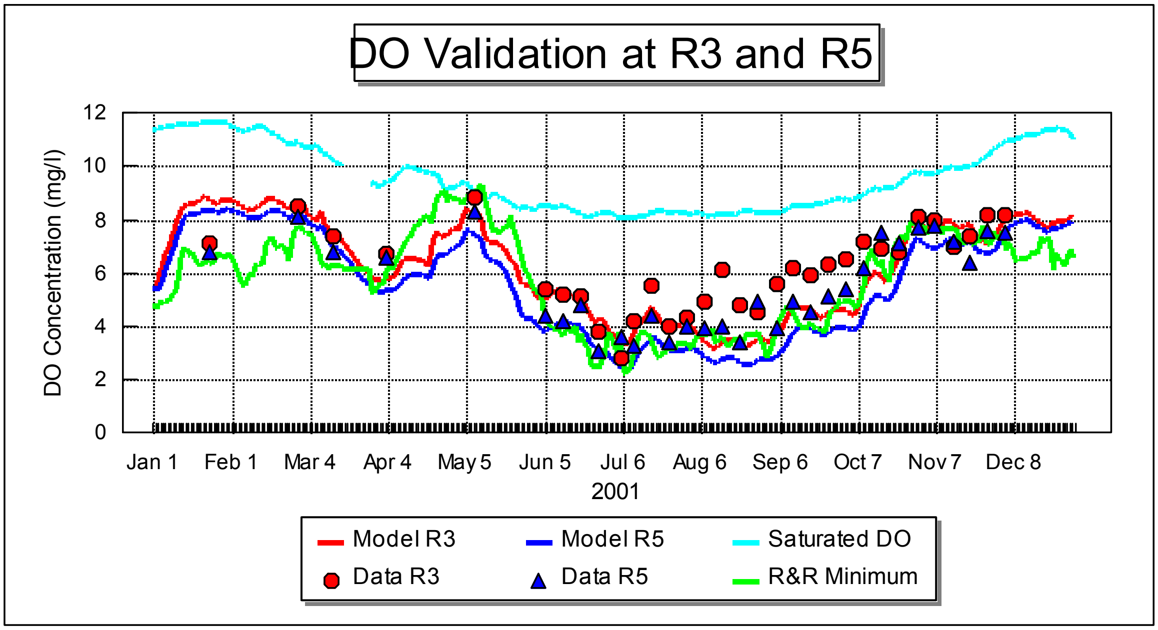

Figure 22. Simulated Travel Time Between Mossdale and DWSC at R3 and R5.

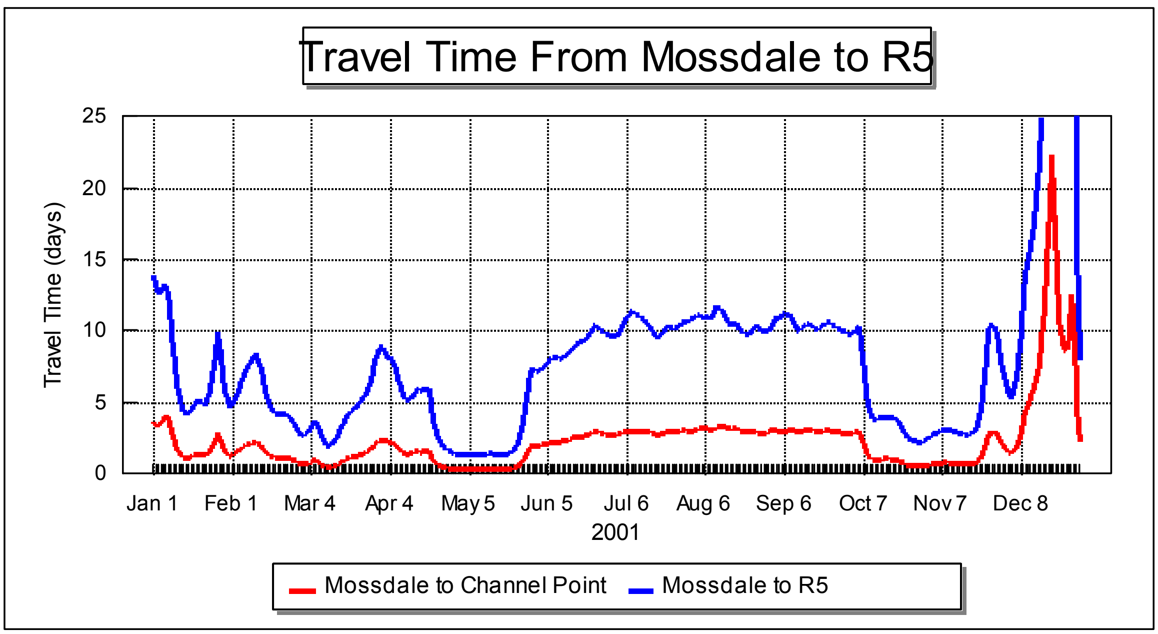

Figure 23. Sensitivity of Simulated DO at R3 to DWSC Flows.

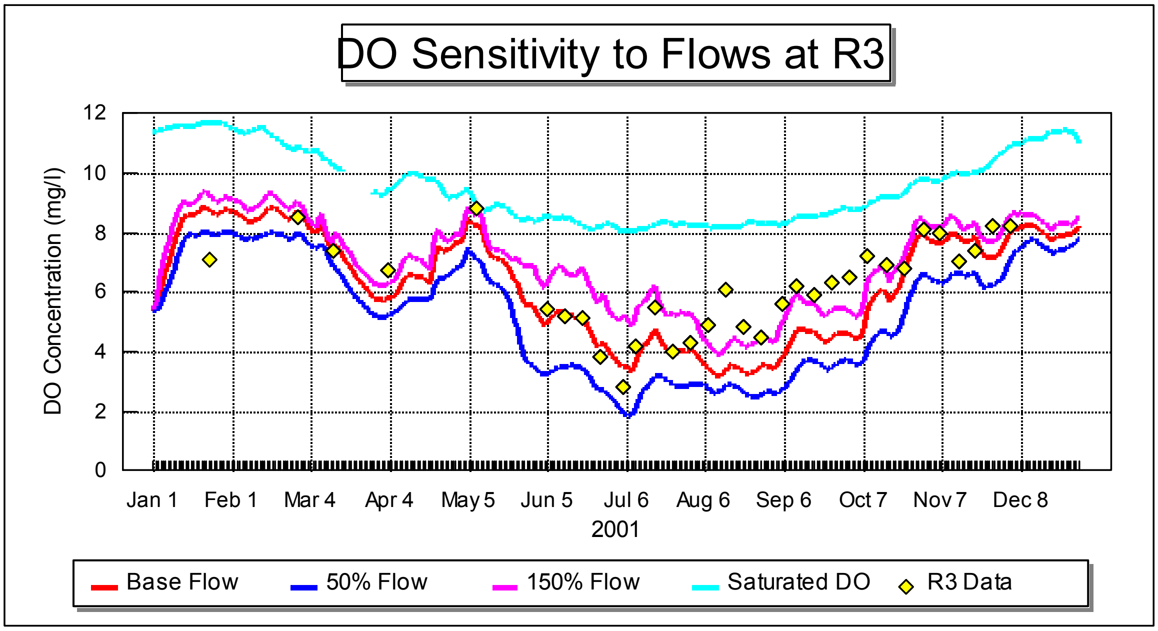

Figure 24. Sensitivity of Simulated DO at R5 (Rough & Ready) to DWSC Flows.

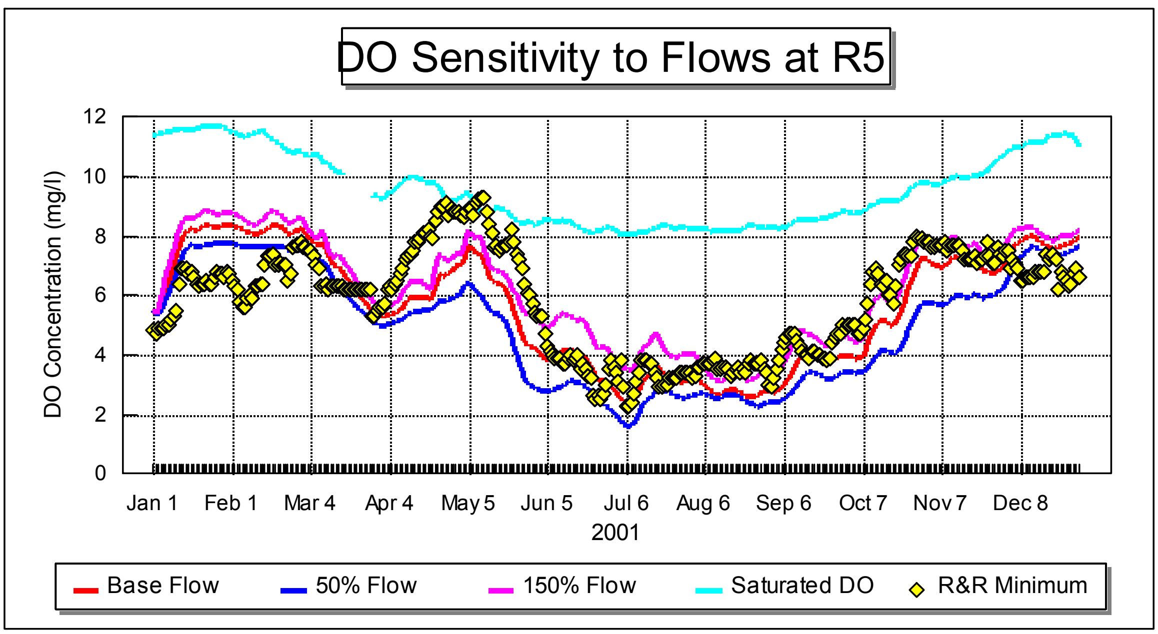

Figure 25. Sensitivity of DO at R3 to VSS and Algae Settling Rates.

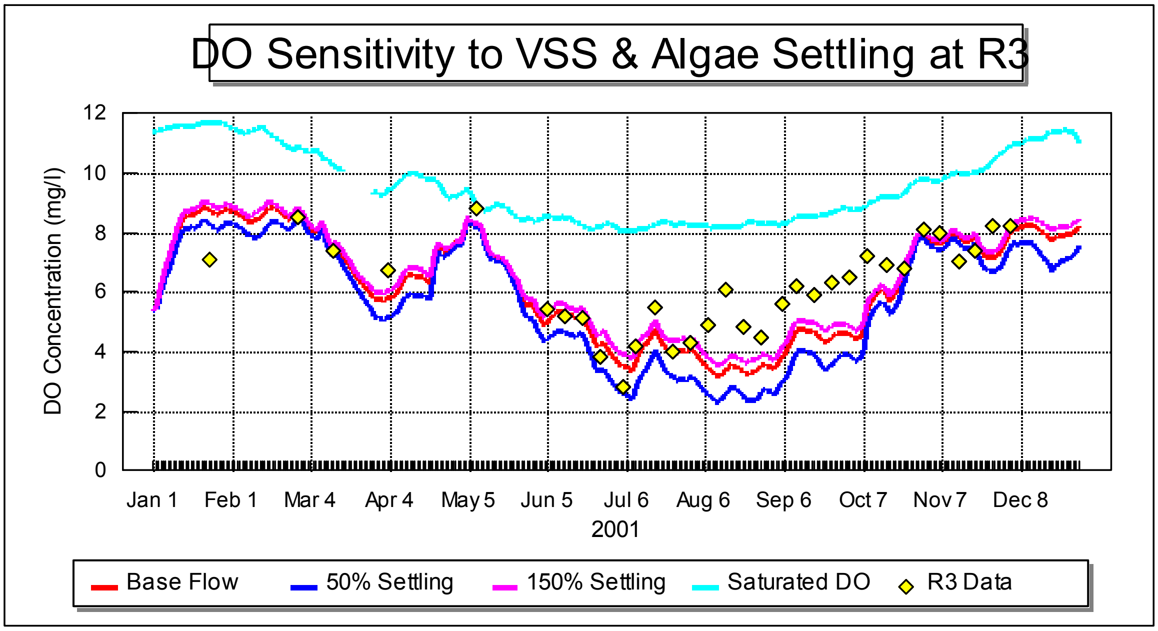

Figure 26. Sensitivity of Simulated DO at R5 to VSS and Algae Settling Rates.

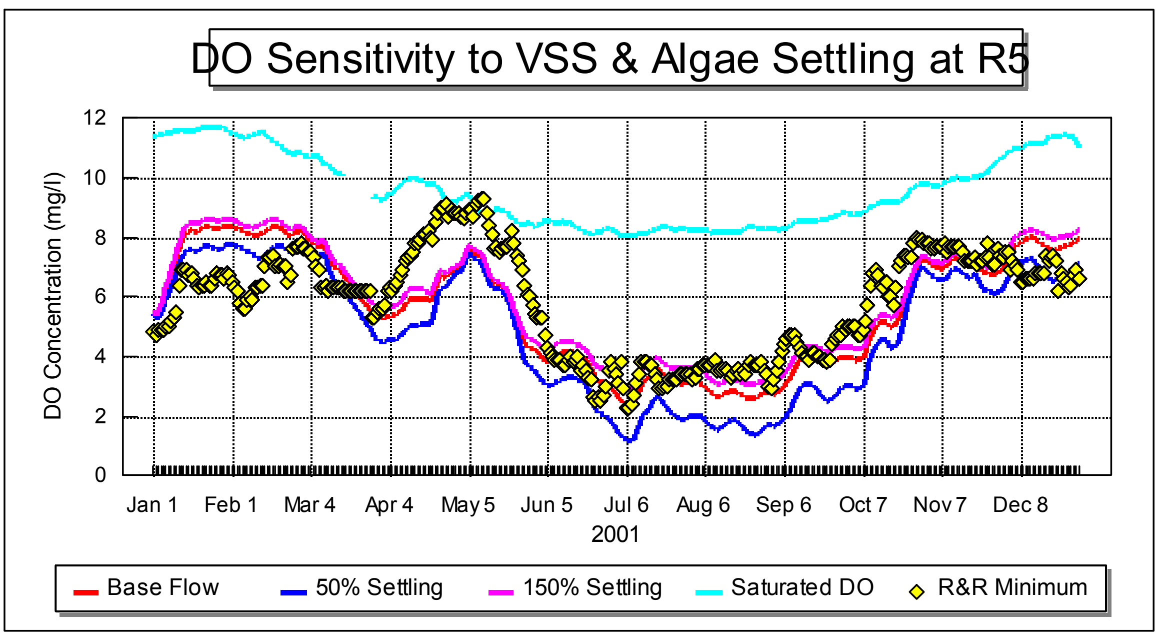

Figure 27. Sensitivity of Simulated DO at R3 to Algae Growth Rate.

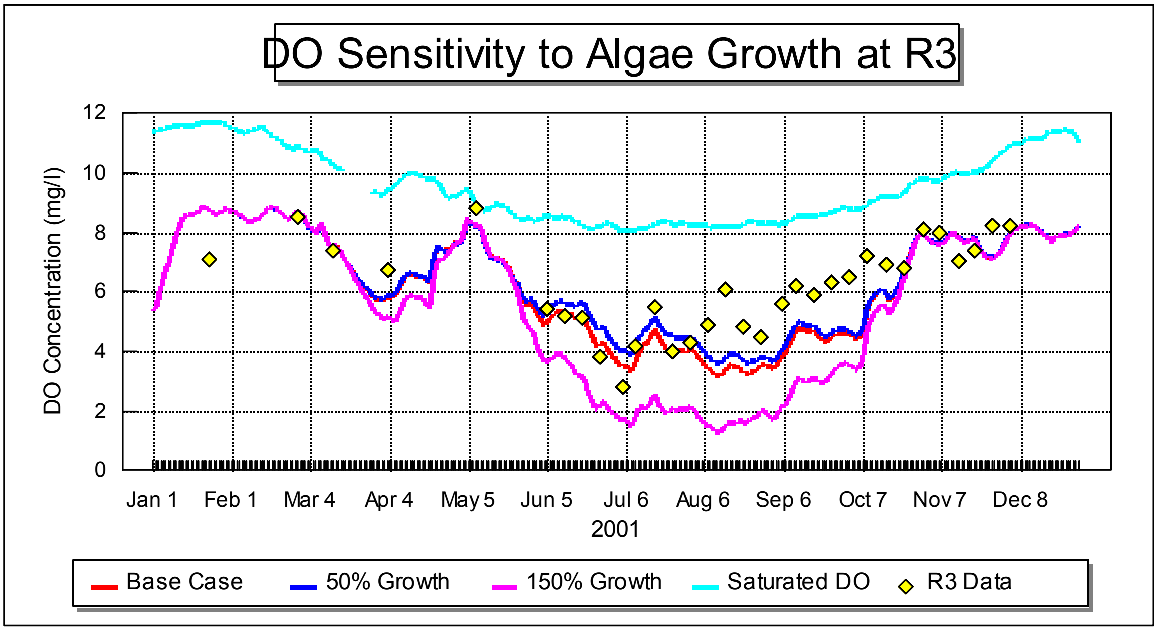

Figure 28. Sensitivity of Simulated DO at R5 to Algae Growth Rate.