Forward

Ecology requested that EPA convene 3rd party independent review of the Budd Inlet and Capitol Lake modeling. Two peer reviews were completed and are included in this PDF.

- Cadmus Group and Portland State University (2008 – 2011)
    - Dr. Scott Wells is a professor at Portland State University (http://web.cecs.pdx.edu/~scott/). Dr. Wells is the Chair and Professor of the Department of Civil and Environmental Engineering. His expertise is modeling surface water hydrodynamics and water quality. He teaches graduate courses in surface water quality modeling, numerical methods, and environmental fluid mechanics.

- Cadmus Group and HDR-HydroQual (2012) starts pg. 171
    - Jim Fitzpatrick is a national expert on hydrodynamic and water quality models. He has developed and applied numerical models to water bodies across the country and internationally.

All comments from both reviews were completed to the satisfaction of both independent reviewers.

Budd Inlet/Capitol Lake/Deschutes River Total Daily Maximum Load Study Model Review

Prepared for:

U. S. Environmental Protection Agency Region 10

Prepared by:

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and

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Introduction

The goal of this project was to provide an external peer review of the *Generalized Environmental Modeling System for Surface Waters (GEMSS)* water quality and hydrodynamic models used for the TMDL study for Budd Inlet, Capitol Lake, and the Deschutes River. The purpose of this review was to provide guidance on how the model application may be improved in the future. If the suggestions presented in this review were implemented in the modeling study, the management conclusions from the present modeling study may not change. Hence, these suggestions are presented to focus on directions for later improvement in the model's ability to represent existing field data.

The primary TMDL document reviewed for this study was Roberts et al. (2008). This included summaries of the field data, modeling approach, and TMDL approaches. This review focused primarily on the modeling approach. In addition, reports, memos, model documents, and files for the model were made available for this review. The review consisted of 3 main parts, as follows:

1. Model Development Review

The review of the model development includes the review of the model set-up, boundary conditions, documentation, and source codes. Specific tasks include:

1. Review of Budd Inlet, Capitol Lake, and Deschutes River Model set-up
    a. Review model set-up files for calibration and verification years, which includes the examination of the model structure and assumptions inherent in the model based on how the model was set up, making sure that the model 'plumbing' is correct.
    b. Review appropriateness of model grid for numerical accuracy and review the bathymetry used in the model grid development.
2. Review of Boundary conditions
    a. Review meteorological files, and conduct graphical and statistical analysis of all meteorological variables; examine how data gaps were filled and if the technique were sound; evaluate potential errors in the input files as a result of incorrect values.
    b. Review all hydrodynamic and water quality input files, and conduct graphical and statistical analysis of all inflows, outflows, temperature, and water quality state variables; assess for potential errors due to data gaps and incorrect values.
3. Review of Source Code
    a. Review the source code of the Capitol Lake/Budd Inlet GEMSS water quality subroutines for macrophytes. This will not be an exhaustive code review; rather, it will be just a check of a few water quality routines.
4. Assessment of the model set-ups
    a. Prepare a summary assessing the appropriateness of the model set-up.
    b. Provide suggestions on how the model set-up may be improved (if at all).

2. Model Calibration Review

The model calibration review includes the review of the Budd Inlet, Capitol Lake, and Deschutes River models calibration and verification years. Model documentation, input, and output files will be used in the calibration review. Specific tasks include:

1. Review model calibration/verification years
    a. Review the model-data error statistics for flow, water level, and water quality; review how the model-data errors in this study compare with model-data errors from other water quality studies; analyze whether the model calibration is reasonable based on the given data.
2. Review of model kinetic coefficients
    a. Review all model coefficients used in the water quality calibration and compare them to literature values (if possible); perform a check on whether all model coefficients are within typical water quality modeling ranges.
3. Assessment of model calibration
    a. Prepare a summary assessing the appropriateness of the model calibration.
    b. Provide suggestions for further improvement in the model calibration (if at all).

3. Model Scenario Review

The four loading scenarios discussed in Appendix I of the TMDL technical report will be reviewed (Roberts et al., 2008). This will include the review of model set-ups and results. Specific tasks include:

1. Review model set-up for the scenario runs
    a. Verify that the calibration model was used for the scenario runs; verify that the same files were used for the calibration and the scenarios, such as kinetic coefficients and model grid.
    b. Examine the input boundary conditions for the scenario runs, and graphically and statistically examine all input files to make sure they correspond to the model calibration or, if from a different time period, do not contain errors as a result of filling in data gaps or in incorrect values.
    c. Examine the different scenarios as described in the model documentation and verify that these were reflected in the input files run for the model.
    d. Provide an assessment of the appropriateness of the model scenario simulations.
2. Review model scenario results
    a. Examine the model output for the scenario runs and verify that the statistical analyses performed on the model results were valid.
    b. Provide an assessment of the appropriateness of the model scenario post-processing procedure.

Each of the following sections provides information on the review of the different model elements.

Model Development Review

Information from past modeling studies

A modeling study of Budd Inlet was discussed in LOTT (1998). This model is the same basic model as used in the current TMDL study (Roberts et al., 2008). It appears that the hydrodynamic model in LOTT (1998) was not changed in the current TMDL modeling since no further adjustment in the hydrodynamics was noted in later studies. The LOTT (1998) study was superseded by another study for LOTT done by Aura Nova and J. E. Edinger (1999) where improvements were made in the water quality model. Both the water quality and hydrodynamic model of Budd Inlet were used in the current TMDL study reviewed in later sections of this report.

Table 1 shows a list of issues raised in this older model study that could also be asked of the current TMDL study.

Table 1. Comments on TMDL modeling based on the Aura Nova and J. E. Edinger (1999) report.

Comment #	Comment
1	Were the criticisms of this model study resolved in the current model study? These points were: (1) over-estimating bottom dissolved oxygen in inner inlet, (2) under-estimating algae biomass, (3) not reproducing observed algae biomass, (4) not reproducing vertical gradients in chlorophyll and dissolved oxygen, (5) model predictions of increasing dissolved oxygen with increasing nutrient levels.

A follow-up letter report from Edinger and Associates (2000) corrected further water quality calibration errors.

A model of Capitol Lake was developed by CH2MHill (2001). This study prepared for Miller Brewing Company included a field study in 2000/2001 and model development to determine the impact of treated effluent disposal from the Miller Brewing Company Tumwater facility. The model used during their study was a two-dimensional hydrodynamic model, RMA2, which is a 2D horizontal model assuming vertically well-mixed conditions. This was coupled with the EPA water quality model WASP5, which included dissolved oxygen-BOD-nutrient-algae interactions. The WASP5 model also was developed using a 2D horizontal grid, but without a macrophyte algorithm. These models, even though dynamic, were used in a steady-state configuration to evaluate the water quality impacts of the Tumwater treated waste discharge. This model did not account for stratification effects, nor did it account for macrophyte impacts on hydrodynamics, which in this system seems important (see for example Figure 3.11 in CH2MHill, 2001). Table 2 shows a list of important considerations from this older model study that could be considered in the current TMDL study.

Table 2. Comments on TMDL modeling based on CH2MHill (2001) report.

Comment #	Comment
2	A very important dye study was conducted in 2001 in Capitol Lake. 16.3 liters of Rhodamine WT dye was injected and concentrations were measured at the outflow of Capitol Lake to Budd Inlet over a 10-day period. These data are available to verify the hydrodynamics of the current Capitol Lake model. Were these data used to verify the GEMMS model hydrodynamics in Capitol Lake?
3	Salt water leakage through the tide gate apparently occurs. Specifically 2 factors are responsible for this leakage: (1) during high Spring tides, the tidal level in Budd Inlet is above the fish ladder and salt water goes into Capitol Lake, and (2) a siphon created to promote circulation allows flows in both directions (about 5 cfs). Since this is critical in understanding the stratification dynamics in Capitol Lake, did the GEMMS model of Capitol Lake include these sources of salinity?
4	The field work in 2001 led to the following conclusions or big picture look at productivity in Capitol Lake: (1) There is high-algae growth in the North basin vs. the Southern basin, (2) macrophyte densities ranged from 40-500 g/m^2, (3) roughly 67% of primary productivity was a result of macrophytes and 33% was a result of phytoplankton. Does the current TMDL model also show similar features?

Model set-up

Two models were used for the TMDL study: QUAL2K and GEMMS. QUAL2K was applied to the Deschutes River and is a 1D steady-state model that allows for evaluating diurnal changes in heating/cooling and algae dynamics. The GEMMS model was applied to Budd Inlet and Capitol Lake and is a 3D hydrodynamic and water quality model.

Table 3 shows some considerations regarding the model choices and set-up for the Deschutes-Capitol Lake-Budd Inlet study.

Table 3. Comments on TMDL modeling set-up using QUAL2K and GEMMS.

Comment #	Comment
5	QUAL2K is a steady-state model applied to the Deschutes River. Having time-varying flow rates and boundary conditions is a limitation of the QUAL2K modeling framework. There did not appear to be field data to support or not support this assumption. During application of the model during August 2003 it appears a storm event occurred that resulted in unsteady flows. Was there an attempt to evaluate whether the limitations of QUAL2K affected the model-data comparisons during non-steady-state conditions?

Model boundary conditions

All model boundary conditions were evaluated in the Appendix. Files were compared between calibration and verification runs as well as between scenario runs. A summary of differences or lack of differences was presented in the Appendix.

Source code check

The source code of the Capitol Lake/Budd Inlet GEMSS water quality subroutines used to simulate macrophytes was reviewed. This was not an exhaustive code review; rather, it was a check of the water quality routines contained in the module Water Quality–ADD module (WQADD). Also, the source code is quite complicated, and some of these comments may be the result of misreading the code. Comments are listed in Table 4.

Table 4. Issues in source code of WQADD module.

Comment #	Issue/Comment
6	The module WQADD only simulates macrophytes/bottom algae in the bottom-most active layer. Although this may not affect the net water column dissolved oxygen production due to photosynthesis, it may affect the prediction of vertical variations of dissolved oxygen and temperature. The model does not match the stratification of temperature and dissolved oxygen shown in vertical profiles measured at stations CL3 and CL4 on 7/13/2004 and stations CL1 and CL3 on 8/18/2004 (Roberts et al, 2008, figures H-21 through H-24). Rooted macrophytes, or macrophytes attached to the bottom, will generally grow vertically through the water column toward the surface and greater light availability. In areas of high macrophyte biomass, a large fraction of the biomass will be near the surface with deeper water consisting mostly of stems rather than leaves. The macrophyte biomass near the surface will attenuate light energy and could influence stratification. For instance, the measured macrophyte density on July 4, 2004 in Capitol Lake was 65.3 g/m2 (from Table C2-4, Roberts et al., 2008). Assuming that most of the macrophyte biomass is in the upper 2 meters near the surface (say 75%), this gives a macrophyte concentration 75%*65.3 g/m^2/2 m of 24.5 g/m^3, or 24.5 mg/l. The resulting light extinction due to macrophytes at the water surface can be estimated assuming a light extinction due to macrophyte concentration coefficient value of 0.01 $m3m^{-1}g^{-1}$ for Myriophyllum spicatum, which predominated on July 4 (Ikusima, 1970). The resultant light extinction contribution would be: Light extinction (from macrophytes)= 24.5 g/m^3*0.01 m^3m^{-1}g-1=0.25 m^{-1}. The total light extinction for a typical eutrophic water body might be 0.5 m^{-1}. Macrophytes in Capitol Lake could contribute a large fraction to light extinction. It is also possible that the model's prediction of stratification could be improved by reducing turbulent mixing due to bottom friction (decrease bottom friction) and wind (decrease wind speed). Model predicted dissolved oxygen concentration profiles could be affected by having macrophytes/bottom algae grow at the bottom rather than throughout the water

Comment #	Issue/Comment
	column. With the dissolved oxygen source due to macrophyte photosynthesis always at the bottom rather than closer to the surface, the model may over predict dissolved oxygen/bottom algae near the sediments. The scenarios are analyzed on a cell by cell basis, so the model may not be capturing the full extent of water quality violations occurring in Capitol Lake. Despite have all macrophyte DO production on the bottom, the model may adequately predict dissolved oxygen production for the whole water column. However, on page 202 of Roberts et al. (2008) states that "Capitol Lake stratifies and it was necessary to reproduce the vertical profiles of temperature and DO as well as the nutrient forms." If it is more important to capture net DO concentrations in Capitol Lake rather than all extreme minimums and maximums, it could be stated so that the TMDL and model will be more defensible. The lowest DO measurement in Capitol Lake that could be found was approximately 6 mg/l (measured at CL5 on 6/13/2001), and the absolute DO standard for Inner and Outer Budd Inlet were 5 and 6 mg/l, respectively. However, it was also stated on page 207 of the TMDL technical document that "For Capitol Lake, water quality standards are based on a maximum of 0.2 mg/L DO change from natural conditions, regardless of the magnitude of the DO under natural conditions." Without running some test simulations it may be hard to determine how over-prediction of DO on the bottom will affect the scenario analysis of 0.2 mg/L DO change from natural conditions. The scenarios with increased loadings may result in increased organic deposition to the sediments, causing increased DO depletion at the bottom that the model may not capture because of DO production from macrophytes is fixed at the bottom and masks potential minimums. The macrophyte algorithm does not seem to have a link to model hydrodynamics or blocking area of the plants. This could significantly affect circulation in the hydrodynamic portion of the model in Capitol Lake.
7	The macrophyte/bottom algae compartment appears to obtain nutrients from the water column. Some of the species common in Capitol Lake (Myriophyllum spicatum and Elodea) have developed root systems and could obtain a significant portion of nutrients from the sediments rather than water column (Barko et al., 1991; Chambers et al., 1989).

Summary

In this section there were 7 comments on the model set-up and code. Most of these were focused on a review of the macrophyte model in the GEMMS model. Some of the issues raised about the macrophyte compartment include: no apparent linkage to hydrodynamics, obtaining nutrients from water column instead of sediment, and the inability of the macrophytes to move vertically in the water column. One comment mentioned using a dye study data set from a 2001 study to evaluate the hydrodynamics of Capitol Lake. This was encouraged if this had not been accomplished.

Model Calibration Review

Model calibration

A review was made of the model calibration of the Budd Inlet, Capitol Lake, and Deschutes River water quality models. This included a review of the model-data error statistics in flow, water level and water quality; a review of how the model-data errors in this study compare with other water quality studies; and an analysis of whether the model calibration is reasonable based on the given data. Table 5 summarizes comments.

Table 5. Comments on model calibration of the Capitol Lake/Budd Inlet model.

Comment #	Issue/Comment
8	Capitol Lake temperature predictions for profiles on 8/18/04 at sites CL1 and CL3 are too warm by more than 5 degrees C (see figure H-11 of TMDL technical report, Roberts et al., 2008), but as stated in the report this might be due to inadequately described boundary conditions (for instance, a storm). If boundary conditions are the cause of this model error, it could be helpful to list which boundary conditions (meteorological or tributary) are the cause, and the model error at this date and location is not reflective of the whole model heat budget over the summer. Macrophytes at surface might help temperature stratification, or perhaps not if model predicted vertical mixing is controlled by bottom friction or wind shear (see discussion in source code section).
9	Vertical variation in dissolved oxygen concentrations was not captured in Capitol Lake on several days (see figure H-12 of Roberts et al., sites CL3 and CL4 on 7/13/04, CL1 and CL3 on 8/18/04, and CL3 on 9/29/04). Possibly this is caused by macrophytes/bottom algae only being in the bottom layer (see discussion in source code section). With macrophytes exclusively on the bottom, the photosynthetic DO production occurs only at the bottom rather than throughout the water column and at the surface.
10	Continuous temperature comparisons with field data at CL4 are too warm by several degrees Celsius for a few days, and it is stated that this may be due to inadequate boundary conditions (page 52 in appendix H of Roberts et al., 2008). The Deschutes River and Percival were continuous for temperature and appear to be good (figure H-3 of Roberts et al., 2008). Was there a storm during that period that was not adequately represented in the flow boundary condition?
11	Model versus data macrophyte plots use units of mg A/m^2 (mg chlorophyll a per m^2). How was the dry weight biomass in data (g/m^2) of appendix C.1 converted to chlorophyll a (mg A/m^2)? Since model versus data plots values appear to have a July maximum of ~70 mg A/m^2 (figure H-8 of Roberts et al.) and the maximum mean biomass measurement was 65.3 g/m^2 in July (Table C1-3 of Roberts et al.), it looks like a factor of ~1000 mgD/mgA. The model coefficient values for bottom algae/macrophytes were 100 mgD (mg dry weight biomass) and 1 mgA (mg chlorophyll a), or a ratio of 100 mg dry weight biomass per mg chlorophyll a. It would be helpful to list assumptions made (and cite literature values) in converting macrophyte biomass to chlorophyll a.

Comment #	Issue/Comment
12	QUAL2K apparently predicted pH in the Deschutes River. There did not appear similar pH predictions in Budd Inlet and Capitol Lake. Were there reasons why the inorganic carbon balance (the basis for modeling pH) was not performed in Budd Inlet and Capitol Lake?
13	On p. 203 in Roberts et. al. (2008), dissolved oxygen concentrations after macrophytes were killed off did not decrease. If according to CH2MHill (2001), macrophytes are 67% of all primary production, it would seem that dissolved oxygen would be significantly affected as the organic matter is decayed. There appears to be a significant release of nutrients but no dissolved oxygen decline. Is there enough organic matter release from the macrophytes or is this a result of very robust wind driven surface exchange keeping dissolved oxygen constant during this die-off? [This may be related to an issue with the C stoichiometry of the macrophytes. See comment #32 below.]
14	The graphs in Figure 78 in Roberts et. al. (2008) show model predictions versus field data over time. Since the scale of the y-axis is often very large and the graphs are physically small, there is not a good sense of how good or bad the model to field data comparison is. For example, one dissolved oxygen field data 'dot' almost takes up 3 mg/l on the y-axis scale – this is not a good way to assess errors.
15	Systematic error in calibration of Capitol Lake model seen in Figure 78 in Roberts et. al. (2008): dissolved oxygen diurnal swings not correct, POP, PON, and DOP always too much in the model compared to field data. The dissolved oxygen error appears to be systematic and appears to be too low in Figure 79. This is also shown in Appendix H Figure H-8 and H-9 and Table H-1 where there are very high bias estimates for DOP, PON, POP, and PO4.
16	In Appendix G in Roberts et. al. (2008) on pp. 11-15, there is a discussion of stations BI-5 and BI-6 compared to water level data. This discussion is not clear and there do not seem to be clear conclusions from this that the model is reproducing water level data accurately. For example in Figure G-5, no instantaneous model comparisons to field data were presented, hence there can be no conclusions made about the ability of the model to reproduce the field data correctly.
17	Calibration error statistics presented in Roberts et. al. (2008) relied on a REME statistic, as well as the standard deviation of the REME. These error statistics only give an idea of bias of the measurement compared to the model. None of these give an unbiased error statistic that could be used for assessing the average magnitude of the error of the estimate. While the REME statistic is necessary to look at overall bias, it does not give any indication of the overall magnitude of the error. This could be easily obtained by using the absolute mean error or root mean square error in addition to REME (which is similar to just the mean error). For example, the mean error for dissolved oxygen could be 0 mg/l, but the absolute mean error could be 5 mg/l implying that the precision in estimating the dissolved oxygen is +/- 5 mg/l, not 0 mg/l. No such estimates or errors were provided.
18	In Roberts et. al. (2008) in Appendix G on p. 26, the chlorophyll a vertical profiles often show a spike mid-depth, but the model does not reproduce that spike. Often this is a result of photo-inhibition. Was this tried in the model calibration to reproduce this vertical profile?

Comment #	Issue/Comment
19	In Roberts et. al. (2008) in Appendix G on p. 33 in Table G-6, the title of the table is incorrect since it also includes chlorophyll a, dissolved oxygen, etc. in addition to NO_3-N.
20	In Roberts et. al. (2008) in Appendix G in Table G-6, the chlorophyll a results show a strong negative bias and the ammonia results show a strong positive bias. Since there was no unbiased statistic to evaluate the estimated error, these strong systematic biases should be evaluated with the idea of eliminating such strong biases.
21	In Roberts et. al. (2008) in Appendix G in Table G-16 on p. 34, 35, there was a strong systematic bias in surface dissolved oxygen (too much DO on the surface compared to field data). This bias was also evident in the DO vertical profiles.
22	In Roberts et. al. (2008) in Appendix H in Figures H-11 and H-12, profiles of temperature and dissolved oxygen often show some stratification, but the model does not seem to be able to predict this. Was wind mixing too high or was the impact of the salinity in coming into Capitol Lake from Budd Inlet not reproduced? [Note that this is similar to Comment #8 and #9.]
23	In Roberts et. al. (2008) in Appendix H, there appears to be high systematic biases in temperature and algae (Table H-4 and H-5). Were there efforts to reduce that systematic error and if so to what were they attributed? For example at CL-3 on the surface the average algae error was 3.2 and temperature error was 2.1.
24	In Roberts et. al. (2008) in Appendix H in Figures H-21, H-22, and H-23, the model predicted water level and the field data appear to be significantly different, unless we are misinterpreting the figure. For example, in Figure H-21 for Station CL-4 at 13:00, does this mean that the water level in the field data was at 0 m but the model predicted a 4 m water level? If this is so, then a re-examination of the hydrodynamic model is necessary to ensure that water levels in the model and lake match.
25	In Roberts et. al. (2008) in Appendix H in Tables H-13, H-15, H-17, and H-21, why were the time varying kinetics used in some basins but not all the basins? Was this just an attempt to improve model-data comparisons or was there some other basis for the adjustments?

Table 6 summarizes comments on the QUAL2K Deschutes River model calibration.

Table 6. Comments on model calibration of the Deschutes River model.

Comment #	Issue/Comment
26	In Roberts et. al. (2008) on p. 132, there appears to be a typo or a statement that is not clear. The sentence says: "Winds were stronger, averaging 0.24 m/s." 0.24 m/s is about 0.5 mph, which is basically no wind at all. Any winds in that range are not strong at all. Apparently there was a typo or a mistake in the sentence.
27	The procedure for calibration of temperature in the Deschutes River included varying the channel width. Why was the channel width not 'set-in-stone' based on field measurements of channel width? At a minimum there needs to be a comparison of measured channel width to modeled channel width to have confidence in the calibration procedure.

Comment #	Issue/Comment
28	The goal in modeling temperature is to have almost zero bias in the temperature error and an unbiased error of less than 1^{o}C on average. Temperature error statistics for Deschutes River were based on evaluating the RMS error, or the root mean square error. This is an unbiased estimate of the model error. The mean error was apparently not computed. The calibration period was only over a short time, July 21-27, 2004 which is a limitation of the steady-state modeling framework. Error statistics were reasonable for that period with RMS errors less than 1^{o}C. For the validation periods RMS errors seemed to be higher and went as high as 2.19^{o}C (for the 8/20/2003 event). Is this error a problem with the steady-state model framework? What further efforts could be made to reduce the error during other time periods?
29	In Roberts et. al. (2008), the Deschutes model prediction had a consistent bias of being too high in pH, was this related to alkalinity? How was alkalinity treated in the model? This occurred also in confirmation field analysis on p. 168.
30	In Roberts et. al. (2008) on p. 166, model results of detritus were compared to field data of detritus. What was the basis for the detritus measurements? How was detritus measured?
31	In Roberts et. al. (2008) on p. 125 and on p.139, there must be an apparent typo in the discussion of the Manning's friction factor, n. Manning's n was stated as varying from 0.35 to 0.14 averaging 0.16 – that seems 10X too high according to literature values.

Kinetic coefficients

A review was made of the coefficient values used in the in the Budd Inlet, Capitol Lake, and Deschutes River water quality models. Table 7 summarizes gives comparisons of model coefficients to literature values.

Table 7. Issues in kinetic coefficients used in the Budd Inlet, Capitol Lake, and Deschutes River model.

Comment #	Issue/Comment
32	Macrophyte/bottom algae stoichiometry in WQADD more characteristic of algae rather than macrophytes. Macrophytes typically have higher carbon to phosphorus ratios than algae. For instance, the carbon:nitrogen:phosphorus ratio for marine macrophytes was measured to be 550 C: 30 N: 1 P in rooted marine macrophytes (Atkinson and Smith, 1983). By using algae stoichiometry, the model may be over estimating the internal N and P concentration in the bottom algae/macrophyte compartment, or under estimating the amount of carbon. However, the macrophyte/bottom algae compartment could be considered to capture the net effect of macrophytes and attached epiphyton, and bottom algae. A description of bottom algae/macrophyte compartment, and whether is intended to simulate bottom algae, macrophytes or both would be helpful. Table 8 lists the stoichiometry used in the WQADD module along with some literature values.

Comment #	Issue/Comment
33	In the module WQCBM the maximum growth rates of diatom was set to 0.2 day^{-1} and those for dinoflagellates was 0.1 day^{-1}. It is assumed that the low values are used to simulate salinity induced die off in Capitol Lake for marine algae originating from Budd Inlet. It would be helpful if this were stated explicitly.
34	A table summarizing algae, macrophyte and zooplankton compartments of the WQADD, WQCBM and GAM water quality modules and the intent of their application would be very helpful.
35	Maximum growth rate of phytoplankton set to 4 day^{-1} in GAM module. This is pretty high and might draw some scrutiny. There are some literature values that are higher, however (Hoogenhout and Amesz, 1965).
36	Labile and refractory organic matter decay rates, transfer rates, and settling rates look fine and within normal literature values
37	The Chen and Kanwisher surface DO reaeration formulation used for Capitol Lake is based on wind induced turbulence and may not be applicable to the estuary scenarios with the dam removed.

Table 8. Stoichiometry for macrophyte/bottom algae in Capitol Lake WQADD module.

Variable	Capitol Lake GEMMS model values[1]	Converted to fraction of dry wt. values[2]	Ratios cited in Literature
mgP, Phosphorous stoichiometry for bottom algae/macrophytes	1 g P	0.01	Algae range: 0.007 to 0.029 (Reynolds, 1993)
mgN, Nitrogen stoichiometry for bottom algae/macrophytes	7.2 g N	0.072	Algae range: 0.019 to 0.11 (Reynolds, 1993) Macrophyte range: 0.01 to 0.04 (Best, 1977)
mgN, Carbon stoichiometry for bottom algae/macrophytes	40 g C	0.40	Algae range: 0.46 to 0.56 (Reynolds, 1993) Macrophyte range: 0.249 to 0.554 for *Ceratophyllum demersum* 0.117 and 0.447 for *Elodea canadensis* (Best, 1977)
mgD, Dry weight of macrophyte/bottom algae	100 g D (Dry weight)	1	-

Variable	Capitol Lake GEMMS model values[1]	Converted to fraction of dry wt. values[2]	Ratios cited in Literature
mgA, Chlorophyll stoichiometry for bottom algae/macrophytes	1 g A (chlorophyll a)	0.01	Total algae: 0.02 to 0.10 EPA (1985) Blue –green algae: 0.0025 to 0.03 EPA (1985)

Summary

In this section there were approximately 30 comments on the model calibration and verification of the Budd Inlet, Capitol Lake, and Deschutes River models. For the Deschutes River, a check on the Manning's friction factor, applicability of the QUAL2K model during unsteady-flow events, and a comparison of river width to model width were important comments for this model section. For Capitol Lake and Budd Inlet there was an important comment on using an unbiased estimate of the error in order to assess how well the model matches field data. Also, there were several comments on the macrophyte routine: no vertical growth, no impact on hydrodynamics, and carbon stoichiometry being low. In Capitol Lake, there were issues of systematic error in several water quality state variables. Questions were also raised about the water level prediction in Capitol Lake.

Model Scenario Review

Model set-up

The model set-up included reviewing the input files for the scenario runs and evaluating changes in these files from base conditions. These file comparisons are included in Appendix.

Scenario results

The statistical analyses of the GEMMSCompare Excel worksheet tools were examined to evaluate if the statistical analyses were conducted properly. The tools were well documented, and no errors in the source code were discovered.

Conclusions

The objective of this study was to review the hydrodynamic and water quality model application in Budd Inlet, Capitol Lake, and the Deschutes River. This model was used in a TMDL study of these systems. Both written reports and model files were reviewed in order to assess potential areas where the models could be improved. The model set-up, calibration and confirmation, and scenario runs were examined. Including comments in the appendix, there were a total of 46 comments on the modeling study. The comments ranged from simple questions about whether a process was included in the model to comments about model coefficients that seemed to be outside the normal range used in modeling studies. In addition, there were several comments about boundary condition data used in the model in the appendix that may have been inconsistent.

Addressing these comments would improve confidence in the model tools as they are applied to the TMDL study area. Even if the model calibration and verification are improved though, the results of the TMDL analyses performed with the model may or may not be affected.

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Appendix File Evaluation for the GEMMS model

Overview and Summary

There was an effort to evaluate all the boundary condition files to look for errors that may have inadvertently been overlooked in the file development process. This appendix includes the methodology, the boundary condition figures, and the boundary condition tables. Table 9 presents a summary of comments after evaluating the boundary conditions presented in this appendix.

Table 9. Comments on boundary conditions in calibration, verification and scenario runs.

Comment #	File	Comment
38	bc11_BeverlyBeachWWTP_1997_wq	NO3 value was -101. Was this also treated as a null value?
39	bc13_ButlerCreek_1997_wq for Scen2	NH4 was -100. Was this also treated as a null value?
40	bc35_Deschutes River WQADD Data	pH was zero at end of time series
41	bc36_ bud005_03_result_xtab_bin1_0m and bc36_ bud005_03_result_xtab_bin1_0m_R1	pH was zero in time series, NO3-N values of as high as 32 mg/l seem incorrect, unless the units switched to µg/l. Similar comment for PO4 on 2/20/99 values jump significantly – it almost seems like a switch in units – PO4 values reach as high as 32!
42	bc11_beverlyBeachWWTP_1997_wq and bc12_wq_version2	DON concentrations are below zero in 1997 (Figure 61)
43	bc31_Deschutes River EHM WQ	PO4 concentrations end in 1997, although P might be included in other fields (Figure 78)
44	bc31_Deschutes River EHM WQ and bc32_Percival Creek EHM WQ	Zero dissolved oxygen concentrations in 1997 seem incorrect (Figure 81)
45	bc34_PercivalCreek WQ	Conductivity goes to zero around 1/01 (Figure 85)
46	PercivalCreek_2003-2004 DO 2p5plus NO T_DO	pH seems very low in 1992 and 2001 (Figure 119)

Methodology

An inventory of each subdirectory labeled ‘Boundary Conditions’ from folders ‘BICL_Calib_277’, ‘BICL_Ver_277’ and ‘BICL_093008’ (which itself contains 8 different model scenario runs) was taken to compile a list of unique file names and locations. Individual files sharing the same name from each directory were then compared to each other. Files found in directory “BICL_Calib_277” were treated as the ‘control’ files and were labeled ‘version 1’. In the event that a file did not appear in this directory, the next file directory that contained this file would be labeled ‘version 1’. When differences were detected between files of the same name, they were visually inspected and classified as either a ‘Data’ or ‘Header’ variation, depending on how they differed. When the header of two files differed, but the data were identical, the second file was labeled ‘version 1a’. When the data itself differed between files, the second file was labeled ‘version 2’. This process was carried out for each of the 150 unique file names contain in the three directories. The detailed list of file names and versions is shown in Table 10. The files that have multiple versions are highlighted. A detailed description of the file differences is shown in Table 11.

After inventorying the files, all text files (including ‘version 2’ files) were loaded into Excel spreadsheets to facilitate graphing. The composite date was calculated in each spreadsheet from the individual year, month, day, hour, and minute columns to allow graphing software to read it. All files containing time-series data were then plotted in order to visually inspect the information. Files containing model coefficients or data best displayed in tabular form where grouped together into sheets of tables.
[Note: The folder “BuddInlet_ver_236” contains unique files and has not yet been reviewed.]

Table 10. File Inventory

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
3ctsb1997wq	1	BCFiles1-16	WQGraph1	*	*	1	1	1	1	1	1	1	1
3ctst1997wq	2	BCFiles1-16	WQGraph1	*	*	1	1	1	1	1	1	1	1
bc01_CapitalLake_1997_flow	3	BCFiles1-16	FlowGraph 1	*	*	1	1	1	1	1	1	1	1
bc01_CapitolLake_1997_wq	4	BCFiles1-16	WQGraph2 (1-7)	*	*	1	1	1	1	1	1	1	1
bc02_MoxieCreek_1997_flow	5	BCFiles1-16	FlowGraph 1	*	*	1	1	1	1	1	1	1	1
bc02_MoxieCreek_1997_wq	6	BCFiles1-16	WQGraph2 (1-7)	*	*	1	1	2	2	2	2	2	2
bc03_MiissionCreek_1997_wq	7	BCFiles1-16	WQGraph3 (1-7)	*	*	1	1	2	2	2	2	2	2
bc03_MissionCreek_1997_flow	8	BCFiles1-16	FlowGraph 1	*	*	1	1	1	1	1	1	1	1
bc04_EllisCreek_1997_flow	9	BCFiles1-16	FlowGraph 1	*	*	1	1	1	1	1	1	1	1
bc04_EllisCreek_1997_wq	10	BCFiles1-16	WQGraph3 (1-7)	*	*	1	1	2	2	2	2	2	2
bc05_SeashoreVillaWWTP_1997_flow	11	BCFiles1-16	FlowGraph 2	*	*	1	1	1	1	2	2	1a	1a
bc05_SeashoreVillaWWTP_1997_wq	12	BCFiles1-16	WQGraph4 (1-7)	*	*	1	1	1	1	2	2	1a	1a
bc06_SouthCreek_GullHarbor_1997_flow	13	BCFiles1-16	FlowGraph 2	*	*	1	1	1	1	1	1	1	1
bc06_SouthCreek_GullHarbor_1997_wq	14	BCFiles1-16	WQGraph4 (1-7)	*	*	1	1	2	2	2	2	2	2
bc07_AdamsCreek_1997_flow	15	BCFiles1-16	FlowGraph 2	*	*	1	1	1	1	1	1	1	1

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
bc07_AdamsCreek_1997_wq	16	BCFiles1-16	WQGraph5 (1-7)	*	*	1	1	2	2	2	2	2	2
bc08_NorthCreek_GullHarbor_1997_flow	17	BCFiles17-32	FlowGraph 2	*	*	1	1	1	1	1	1	1	1
bc08_NorthCreek_GullHarbor_1997_wq	18	BCFiles17-32	WQGraph5 (1-7)	*	*	1	1	2	2	2	2	2	2
bc09_BostonHarborWWTP_1997_flow	19	BCFiles17-32	FlowGraph 3	*	*	1	1	1	1	2	2	1a	1a
bc09_BostonHarborWWTP_1997_wq	20	BCFiles17-32	WQGraph6 (1-7)	*	*	1	1	1	1	2	2	1a	1a
bc10_TamoshanWWTP_1997_flow	21	BCFiles17-32	FlowGraph 3	*	*	1	1	1	1	2	2	1a	1a
bc10_TamoshanWWTP_1997_wq	22	BCFiles17-32	WQGraph6 (1-7)	*	*	1	1	1	1	2	2	1a	1a
bc11_BeverlyBeachWWTP_1997_flow	23	BCFiles17-32	FlowGraph 3	*	*	1	1	1	1	1	1	1	1
bc11_BeverlyBeachWWTP_1997_wq	24	BCFiles17-32	WQGraph7 (1-7)	*	*	1	1	1	1	1	1	1	1
bc12_LittletykleCreek_1997_flow	25	BCFiles17-32	FlowGraph 3	*	*	1	1	1	1	1	1	1	1
bc12_LittletykleCreek_1997_wq	26	BCFiles17-32	WQGraph7 (1-7)	*	*	1	1	2	2	2	2	2	2
bc13_ButlerCreek_1997_flow	27	BCFiles17-32	FlowGraph 4	*	*	1	1	1	1	1	1	1	1
bc13_ButlerCreek_1997_wq	28	BCFiles17-32	WQGraph8 (1-7)	*	*	1	1	2	2	2	2	2	2
bc14_SchneiderCreek_1997_flow	29	BCFiles17-32	FlowGraph 4	*	*	1	1	1	1	1	1	1	1
bc14_SchneiderCreek_1997_wq	30	BCFiles17-32	WQGraph8 (1-7)	*	*	1	1	2	2	2	2	2	2
bc15_LOTT_WWTP_1997_flow	31	BCFiles17-32	FlowGraph 4	*	*	1	1	1	1	2	2	1a	1a

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
bc15_LOTTWWTP_1997_wq	32	BCFiles17-32	WQGraph9 (1-7)	*	*	1	1	1	1	2	2	1a	1a
bc22_3ctst1997wq	33	BCFiles33-50	WQGraph10	1	1	1	1	1	1	1	1	1	1
bc26_bf31997dnutrwq	34	BCFiles33-50	Multiple Bins	1	1	1	1	1	1	1	1	1	1
bc28_2003-04_dummy	35	null values	-	1	1	*	*	1	1	1	1	1	1
bc28_3CTDOCHL1997WQ	36	BCFiles33-50	WQGraph11	1	1	1	1	1	1	1	1	1	1
bc28_3CTDOCHL1997WQ R1	37	BCFiles33-50	WQGraph11	*	*	1	1	1	1	1	1	1	1
bc29_2003-04_dummy	38	null values	-	1	1	1	1	1	1	1	1	1	1
bc29_3CBDOCHL1997WQ	39	BCFiles33-50	WQGraph11	1	1	1	1	1	1	1	1	1	1
bc29_3CBDOCHL1997WQ R1	40	BCFiles33-50	WQGraph11	*	*	1	1	1	1	1	1	1	1
bc31_Deschutes River EHM WQ Data Version 1	41	BCFiles33-50	WQGraph12	1	1	1	1	1	1	1	1	1	1
bc32_Percival Creek EHM WQ Data Version 1	42	BCFiles33-50	WQGraph12	1	1	1	1	1	1	1	1	1	1
bc33_Deschutes River WQADD Data	43	BCFiles33-50	WQGraph13	1	1	1	1	1	1	1	1	1	1
bc34_PercivalCreek WQData	44	BCFiles33-50	WQGraph14	1	1	1	1	1	1	1	1	1	1
bc35_Open Boundary WQADDData	45	BCFiles33-50	WQGraph13	1	1	1	1	1	1	1	1	1	1
bc36_ bud005_03_result_xtab_bin1_0m	46	BCFiles33-50	WQGraph15(1-9)	1	1	1	1	1	1	1	1	1	1
bc36_	47	BCFiles33	WQGraph1	*	*	1	1	1	1	1	1	1	1

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
bud005_03_result_xtab_bin1_0m_R1		-50	5(1-9)										
bc37_bi4_surface_avg	48	BCFiles33-50	Display?	1	1	1	1	1	1	1	1	1	1
bc38_DeschutesRiver_1997_flow	49	BCFiles33-50	FlowGraph 5	*	*	1	1	1	1	1	1	1	1
bc38_DeschutesRiver_1997_wq	50	BCFiles33-50	WQGraph16(1-6)	*	*	1	1	2	2	2	2	2	2
bc39_PercivalCreek_1997_flow	51	BCFiles51-66	FlowGraph 5	*	*	1	1	1	1	1	1	1	1
bc39_PercivalCreek_1997_wq	52	BCFiles51-66	WQGraph17(1-5)	*	*	1	1	1	1	1	1	1	1
bc40_DeschutesRiver_2003-2004_avg	53	BCFiles51-66	WQGraph18(1-6)	1	1	1	1	1	1	1	1	1	1
bc41_PercivalCreek_2003-2004_avg	54	BCFiles51-66	WQGraph18(1-9)	1	1	1a	1a	1a	1a	1a	1a	1a	1a
bdino.wdg	55	BCFiles51-66	Zero values	*	*	1	1	1	1	1	1	1	1
bf11997dctdwq.wdg	56	tl/BCFiles51-66	ExcelTable 8	*	*	1	1	1	1	1	1	1	1
bf11997dnutrwq.wdg	57	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1
bf21997dctdwq.wdg	58	tl/BCFiles51-66	ExcelTable 8	*	*	1	1	1	1	1	1	1	1
bf21997dnutrwq.wdg	59	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1
bf31997chlrwq.wdg	60	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1
bf31997dctdwq.wdg	61	tl/BCFiles51-66	ExcelTable 8	*	*	1	1	1	1	1	1	1	1
bf31997dnutrwq.wdg	62	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
bf31997dnutrwq_gp	63	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1
bf41997chlrwq	64	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1
bf41997dnutrwq	65	BCFiles51-66	Open BC - NG	*	*	1	1	1	1	1	1	1	1
BI_TVRates Verification 2	66	BCFiles51-66	ExcelTable 1	*	*	1	1	1	1	1	1	1	1
CL CB Calibration GAM 02 Run 082 New	67	BCFiles67-85	ExcelTable 1	1	*	1a	*	1a	*	1a	*	1a	*
CL CB Verification GAM 02 Run 082 New	68	BCFiles67-85	ExcelTable 1	*	1	*	*	*	*	*	*	*	*
CL Gate Operations 2001	69	csv file	Rules of Op.	1	1	*	*	*	*	*	*	*	*
CL Gate Operations 2004	70	csv file	Rules of Op.	1	1	*	*	*	*	*	*	*	*
CL NB Calibration GAM 02 Run 041.kdg	71	BCFiles67-85	ExcelTable 1	*	*	*	1	1	1	*	1	1	1
CL NB Calibration GAM 02 Run 082 New	72	BCFiles67-85	ExcelTable 1	1	*	1a	*	1a	*	1a	*	1a	*
CL NB Calibration GAM 02 Run 2001_02.kdg	73	BCFiles67-85	ExcelTable 2	*	*	*	1	1	1	*	1	1	1
CL NB Calibration WQADD 02 Run 041.kdg	74	BCFiles67-85	ExcelTable 2	*	*	*	1	1	1	*	1	1	1
CL NB Calibration WQADD 02 Run 066 New	75	BCFiles67-85	ExcelTable 2	1	*	1a	*	1a	*	1a	*	1a	*
CL NB Calibration WQADD 02 Run 2001_02.kdg	76	BCFiles67-85	ExcelTable 2	*	*	*	1	1	1	*	1	1	1
CL NB Calibration WQCBM 02 Run 041.kdg	77	BCFiles67-85	ExcelTable 2	*	*	*	1	1	1	*	1	1	1
CL NB Calibration WQCBM 02 Run 066 New	78	BCFiles67-85	ExcelTable 2	1	*	1a	*	1a	*	1a	*	1a	*

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
CL NB Calibration WQCBM 02 Run 2001_02.kdg	79	BCFiles67-85	ExcelTable 2	*	*	*	1	1	1	*	1	1	1
CL NB Template GAM 02 Run 001.kdg	80	BCFiles67-85	ExcelTable 3	*	*	*	1	1	1	*	1	1	1
CL NB Template GAM 02 Run 002.kdg	81	BCFiles67-85	ExcelTable 3	*	*	*	1	2	1	*	1	1	1
CL NB Template WQADD 02 Run 001.kdg	82	BCFiles67-85	ExcelTable 3	*	*	*	1	1	1	*	1	1	1
CL NB Template WQADD 02 Run 002.kdg	83	BCFiles67-85	ExcelTable 3	*	*	*	1	1	1	*	1	1	1
CL NB Template WQCBM 02 Run 001.kdg	84	BCFiles67-85	ExcelTable 3	*	*	*	1	1	1	*	1	1	1
CL NB Template WQCBM 02 Run 002.kdg	85	BCFiles67-85	ExcelTable 3	*	*	*	1	1	1	*	1	1	1
CL NB Verification GAM 02 Run 010 New	86	BCFiles86-100	ExcelTable 3	1	1	*	*	*	*	*	*	*	*
CL NB Verification GAM 02 Run 082 New	87	BCFiles86-100	ExcelTable 4	*	1	*	*	*	*	*	*	*	*
CL NB Verification WQADD 02 Run 010 New	88	BCFiles86-100	ExcelTable 4	1	1	*	*	*	*	*	*	*	*
CL NB Verification WQADD 02 Run 066 New	89	BCFiles86-100	ExcelTable 4	*	1	*	*	*	*	*	*	*	*
CL NB Verification WQCBM 02 Run 010 New	90	BCFiles86-100	ExcelTable 4	1	1	*	*	*	*	*	*	*	*
CL NB Verification WQCBM 02 Run 066 New	91	BCFiles86-100	ExcelTable 4	*	1	*	*	*	*	*	*	*	*
CL SB Calibration GAM 02 Run 041.kdg	92	BCFiles86-100	ExcelTable 4	*	*	*	1	1	1	*	1	1	1
CL SB Calibration GAM 02 Run 082 New	93	BCFiles86-100	ExcelTable 5	1		1a	*	1a	*	1a	*	1a	*
CL SB Calibration GAM 02 Run 2001_02.kdg	94	BCFiles86-100	ExcelTable 5	*	*	*	1	1	1	*	1	1	1

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
CL SB Calibration WQADD 02 Run 041.kdg	95	BCFiles86-100	ExcelTable5	*	*	*	1	1	1	*	1	1	1
CL SB Calibration WQADD 02 Run 066 New	96	BCFiles86-100	ExcelTable5	1		2	*	2	*	2	*	2	*
CL SB Calibration WQADD 02 Run 2001_02.kdg	97	BCFiles86-100	ExcelTable5	*	*	*	1	1	1	*	1	1	1
CL SB Calibration WQCBM 02 Run 041.kdg	98	BCFiles86-100	ExcelTable5	*	*	*	1	1	1	*	1	1	1
CL SB Calibration WQCBM 02 Run 066 New	99	BCFiles86-100	ExcelTable6	1		2	*	2	*	2	*	2	*
CL SB Calibration WQCBM 02 Run 2001_02.kdg	100	BCFiles86-100	ExcelTable6	*	*	*	1	1	1	*	1	1	1
CL SB Template GAM 02 Run 001.kdg	101	BCFiles101-118	ExcelTable6	*	*	*	*	1	1	*	1	1	1
CL SB Template GAM 02 Run 002.kdg	102	BCFiles101-118	ExcelTable6	*	*	*	*	1	2	*	1	1	1
CL SB Template WQADD 02 Run 001.kdg	103	BCFiles101-118	ExcelTable6	*	*	*	*	1	1	*	1	1	1
CL SB Template WQADD 02 Run 002.kdg	104	BCFiles101-118	ExcelTable6	*	*	*	*	1	1	*	1	1	1
CL SB Template WQCBM 02 Run 001.kdg	105	BCFiles101-118	ExcelTable6	*	*	*	*	1	1	*	1	1	1
CL SB Template WQCBM 02 Run 002.kdg	106	BCFiles101-118	ExcelTable6	*	*	*	*	1	1	*	1	1	1
CL SB Verification GAM 02 Run 010 New	107	BCFiles101-118	ExcelTable7	1	1	*	*	*	*	*	*	*	*
CL SB Verification GAM 02 Run 082 New	108	BCFiles101-118	ExcelTable7	*	1	*	*	*	*	*	*	*	*
CL SB Verification WQADD 02 Run 010 New	109	BCFiles101-118	ExcelTable7	1	1	*	*	*	*	*	*	*	*
CL SB Verification WQADD 02 Run 066 New	110	BCFiles101-118	ExcelTable7	*	1	*	*	*	*	*	*	*	*

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
CL SB Verification WQCBM 02 Run 010 New	111	BCFiles101-118	ExcelTable 7	1	1	*	*	*	*	*	*	*	*
CL SB Verification WQCBM 02 Run 066 New	112	BCFiles101-118	ExcelTable 7	*	1	*	*	*	*	*	*	*	*
CLGateOperations1997-2007.csv	113	csv file	Rules of Op.	*	*	1	1	1	1	1	1	1	1
CLGateOperations1997-2007.xls	114	excel file	Rules of Op.	*	*	1	1	1	1	1	1	1	1
Deschutes River Gate Hyd Model	115	BCFiles101-118	FlowGraph 6	1	1	*	*	*	*	*	*	*	*
Deschutes River Gate Hyd Model 2001	116	BCFiles101-118	FlowGraph 6	1	1	*	*	*	*	*	*	*	*
DeschutesRiver	117	BCFiles101-118	FlowGraph 6	*	*	1	1	1	1	1	1	1	1
DeschutesRiver_2003-2004 DO 2p5plus No T_DO	118	BCFiles101-118	WQGraph 21(1-6)	1	1	*	*	*	*	*	*	*	*
FluxA1997wq	119	BCFiles119-134	FluxGraph1 (1-2)	*	*	1	1	1	1	1	1	1	1
FluxB1997wq	120	BCFiles119-134	FluxGraph1 (1-2)	*	*	1	1	1	1	1	1	1	1
FluxC1997wq	121	BCFiles119-134	FluxGraph1 (1-2)	*	*	1	1	1	1	1	1	1	1
FluxD1997wq	122	BCFiles119-134	FluxGraph1 (1-2)	*	*	1	1	1	1	1	1	1	1
Marine_boundary	123	BCFiles119-134	QualifierGraph1	*	*	1	1	1	1	1	1	1	1
oly_ppn1985_2007	124	BCFiles119-134	WQGraph19(1-2)	1	1	1	1	1	1	1	1	1	1
Oly_ppn1985_97hd	125	BCFiles119-134	PrecipGraph1	*	*	1	1	1	1	1	1	1	1
oly_ppn1985_97wq	126	BCFiles119-134	WQGraph19(1-2)	*	*	1	1	1	1	1	1	1	1

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
Percival Creek Gate Hyd Model	127	BCFiles119-134	FlowGraph7	1	1	*	*	*	*	*	*	*	*
Percival Creek Gate Hyd Model 2001	128	BCFiles119-134	FlowGraph7	1	1	*	*	*	*	*	*	*	*
PercivalCreek	129	BCFiles119-134	FlowGraph7	*	*	1	1	1	1	1	1	1	1
PercivalCreek_2003-2004 DO 2p5plus No T_DO	130	BCFiles119-134	WQGraph21(1-6)	1	1	*	*	*	*	*	*	*	*
precip_olympia_20001031-20010613	131	BCFiles119-134	PrecipGraph1	1	1	*	*	*	*	*	*	*	*
precip_olympia_20030601-20041231	132	BCFiles119-134	PrecipGraph1	1	1	1	1	1	1	1	1	1	1
pstide_seg053_2000-01_5min	133	BCFiles119-134	TideGraph1	1	1	*	*	*	*	*	*	*	*
pstide_seg053_2003-04_5min	134	BCFiles119-134	TideGraph1	1	1	*	*	*	*	*	*	*	*
Region A FD Sediment Flux 1997	135	BCFiles135-150	FluxGraph2(1-2)	*	*	1	1	1	1	1	1	1	1
Region A FD Sediment Flux 2001	136	BCFiles135-150	FluxGraph3(1-2)	1	1	*	*	*	*	*	*	*	*
Region A FD Sediment Flux 2004	137	BCFiles135-150	FluxGraph4(1-2)	1	1	*	*	*	*	*	*	*	*
Region B FD Sediment Flux 1997	138	BCFiles135-150	FluxGraph2(1-2)	*	*	1	1	1	1	1	1	1	1
Region B FD Sediment Flux 2001	139	BCFiles135-150	FluxGraph3(1-2)	1	1	*	*	*	*	*	*	*	*
Region B FD Sediment Flux 2004	140	BCFiles135-150	FluxGraph4(1-2)	1	1	*	*	*	*	*	*	*	*
Region C FD Sediment Flux 1997	141	BCFiles135-150	FluxGraph2(1-2)	*	*	1	1	1	1	1	1	1	1
Region C FD Sediment Flux 2001	142	BCFiles135-150	FluxGraph3(1-2)	1	1	*	*	*	*	*	*	*	*

File Name	Column2	File Location	Graph/Table #	Calib_277	Ver_277	Scen 1	Scen1_wo	Scen2	Scen2_wo	Scen3	Scen3_wo	Scen4	Scen4_wo
Region C FD Sediment Flux 2004	143	BCFiles135-150	FluxGraph4 (1-2)	1	1	*	*	*	*	*	*	*	*
Region D FD Sediment Flux 1997	144	BCFiles135-150	FluxGraph2 (1-2)	*	*	1	1	1	1	1	1	1	1
Region D FD Sediment Flux 2001	145	BCFiles135-150	FluxGraph3 (1-2)	1	1	*	*	*	*	*	*	*	*
Region D FD Sediment Flux 2004	146	BCFiles135-150	FluxGraph4 (1-2)	1	1	*	*	*	*	*	*	*	*
shoreline	147	BCFiles135-150	QualifierGraph1	*	*	1	1	1	1	1	1	1	1
tidbit_2004_deschutes_plusDO	148	BCFiles135-150	WQGraph20-1	1	1	*	*	*	*	*	*	*	*
tidbit_2004_percival_plusDO	149	BCFiles135-150	WQGraph20-1	1	1	*	*	*	*	*	*	*	*
Tide1997hd	150	BCFiles135-150	TideGraph 1	*	*	1	1	1	1	1	1	1	1

Table 11. Description of Differences

File Name	# of Versions	Location of Difference	Comparison of Version 1 and 2	Header Version 1	Header Version 1a
bc02_MoxieCreek_1997_wq	2	Data	See WQGraph2(1-7)		
bc03_MiissionCreek_1997_wq	2	Data	See WQGraph3(1-7)		
bc04_EllisCreek_1997_wq	2	Data	See WQGraph3(1-7)		
bc05_SeashoreVillaWWTP_1997_flow	3	Header; Data	See FlowGraph2	'2,0,2,0,0,0.0,0.0,FlowRate,Flow Rate'	2,0,2,1.0,0,0.0,0.0,FlowRate,Flow Rate''
bc05_SeashoreVillaWWTP_1997_wq	3	Header; Data	See WQGraph4(1-7)	'17,0,0,0.5,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.5,0,0.0,0.0,BODu_mg/L,I_CBOD_F'	'17,0,0,0.232,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.232,0,0.0,0.0,BODu_mg/L,I_CBOD_F'
bc06_SouthCreek_GullHarbor_1997_wq	2	Data	See WQGraph4(1-7)		
bc07_AdamsCreek_1997_wq	2	Data	See WQGraph5(1-7)		
bc08_NorthCreek_GullHarbor_1997_wq	2	Data	See WQGraph5(1-7)		
bc09_BostonHarborWWTP_1997_flow	3	Header; Data	See FlowGraph3	'2,0,2,0,0,0.0,0.0,FlowRate,Flow Rate'	2,0,2,1.0,0,0.0,0.0,FlowRate,Flow Rate''
bc09_BostonHarborWWTP_1997_wq	3	Header; Data	See WQGraph6(1-7)	'17,0,0,0.5,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.5,0,0.0,0.0,BODu_mg/L,I_CBOD_F'	'17,0,0,0.232,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.232,0,0.0,0.0,BODu_mg/L,I_CBOD_F'
bc10_TamoshanWWTP_1997_flow	3	Header; Data	See FlowGraph3	'2,0,2,0,0,0.0,0.0,FlowRate,Flow Rate'	2,0,2,1.0,0,0.0,0.0,FlowRate,Flow Rate''
bc10_TamoshanWWTP_1997_wq	3	Header; Data	See WQGraph6(1-7)	'17,0,0,0.5,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.5,0,0.0,0.0,BODu_mg/L,I_CBOD_F'	'17,0,0,0.232,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.232,0,0.0,0.0,BODu_mg/L,I_CBOD_F'
bc12_LittletykleCreek_1997_wq	2	Data	See WQGraph7(1-7)		

File Name	# of Versions	Location of Difference	Comparison of Version 1 and 2	Header Version 1	Header Version 1a
bc13_ButlerCreek_1997_wq	2	Data	See WQGraph8(1-7)		
bc14_SchneiderCreek_1997_wq	2	Data	See WQGraph8(1-7)		
bc15_LOTT_WWTP_1997_flow	3	Header; Data		'2,0,2,0,0,0.0,0.0,FlowRate,Flow Rate'	2,0,2,1.0,0,0.0,0.0,FlowRate,Flow Rate''
bc15_LOTTWWTP_1997_wq	3	Header; Data		'17,0,0,0.5,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.5,0,0.0,0.0,BODu_mg/L,I_CBOD_F'	'17,0,0,0.232,0,0.0,0.0,BODu_slow,I_CBOD_S 16,0,0,0.232,0,0.0,0.0,BODu_mg/L,I_CBOD_F'
bc38_DeschutesRiver_1997_wq	2	Data	See WQGraph16(1-6)		
bc41_PercivalCreek_2003-2004_avg	2	Header		'32,0,1,1.0,0,0.0,0.0,Chla (ug/L),I_GAM1'	'32,0,0,1.0,0,0.0,0.0,Chla (ug/L),I_GAM1'
CL CB Calibration GAM 02 Run 082 New	2	Header		Year: '2004'	Year: '1994'
CL NB Calibration GAM 02 Run 082 New	2	Header		Year: '2004'	Year: '1994'
CL NB Calibration WQADD 02 Run 066 New	2	Data	See ExcelTable2		
CL NB Calibration WQCBM 02 Run 066 New	2	Data	See ExcelTable2		
CL NB Template GAM 02 Run 002.kdg	2	Data	See ExcelTable3		
CL SB Calibration GAM 02 Run 082 New	2	Header		Year: '2004'	Year: '1994'
CL SB Calibration WQADD 02 Run 066 New	2	Data	See ExcelTable5		
CL SB Calibration WQCBM 02 Run 066 New	2	Data	See ExcelTable6		
CL SB Template GAM 02 Run 002.kdg	2	Data	See ExcelTable6		

Boundary Condition Figures

A visual review of the files listed in Table 12 was conducted to check for errors and inconsistencies in boundary condition data by plotting.

Table 12. Index of all boundary condition graphs

Graph Title	File name
FlowGraph1	bc01_CapitalLake_1997_flow
FlowGraph1	bc02_MoxieCreek_1997_flow
FlowGraph1	bc03_MissionCreek_1997_flow
FlowGraph1	bc04_EllisCreek_1997_flow
FlowGraph2	bc05_SeashoreVillaWWTP_1997_flow
FlowGraph2	bc06_SouthCreek_GullHarbor_1997_flow
FlowGraph2	bc07_AdamsCreek_1997_flow
FlowGraph2	bc08_NorthCreek_GullHarbor_1997_flow
FlowGraph3	bc09_BostonHarborWWTP_1997_flow
FlowGraph3	bc10_TamoshanWWTP_1997_flow
FlowGraph3	bc11_BeverlyBeachWWTP_1997_flow
FlowGraph3	bc12_LittletykleCreek_1997_flow
FlowGraph4	bc13_ButlerCreek_1997_flow
FlowGraph4	bc14_SchneiderCreek_1997_flow
FlowGraph4	bc15_LOTT_WWTP_1997_flow
FlowGraph5	bc38_DeschutesRiver_1997_flow
FlowGraph5	bc39_PercivalCreek_1997_flow
FlowGraph6	Deschutes River Gate Hyd Model
FlowGraph6	Deschutes River Gate Hyd Model 2001
FlowGraph6	DeschutesRiver
FlowGraph7	Percival Creek Gate Hyd Model
FlowGraph7	Percival Creek Gate Hyd Model 2001
FlowGraph7	PercivalCreek
FluxGraph1(1-2)	FluxA1997wq
FluxGraph1(1-2)	FluxB1997wq
FluxGraph1(1-2)	FluxC1997wq
FluxGraph1(1-2)	FluxD1997wq
FluxGraph2(1-2)	Region A FD Sediment Flux 1997
FluxGraph2(1-2)	Region B FD Sediment Flux 1997
FluxGraph2(1-2)	Region C FD Sediment Flux 1997
FluxGraph2(1-2)	Region D FD Sediment Flux 1997
FluxGraph3(1-2)	Region A FD Sediment Flux 2001
FluxGraph3(1-2)	Region B FD Sediment Flux 2001
FluxGraph3(1-2)	Region C FD Sediment Flux 2001
FluxGraph3(1-2)	Region D FD Sediment Flux 2001
FluxGraph4(1-2)	Region A FD Sediment Flux 2004
FluxGraph4(1-2)	Region B FD Sediment Flux 2004
FluxGraph4(1-2)	Region C FD Sediment Flux 2004
FluxGraph4(1-2)	Region D FD Sediment Flux 2004

Graph Title	File name
PrecipGraph1	Oly_ppn1985_97hd
PrecipGraph1	precip_olympia_20001031-20010613
PrecipGraph1	precip_olympia_20030601-20041231
QualifierGraph1	Marine_boundary
QualifierGraph1	shoreline
TideGraph1	pstide_seg053_2000-01_5min
TideGraph1	pstide_seg053_2003-04_5min
TideGraph1	Tide1997hd
WQGraph1	3ctsb1997wq
WQGraph1	3ctst1997wq
WQGraph2(1-7)	bc01_CapitolLake_1997_wq
WQGraph2(1-7)	bc02_MoxieCreek_1997_wq
WQGraph3(1-7)	bc03_MiissionCreek_1997_wq
WQGraph3(1-7)	bc04_EllisCreek_1997_wq
WQGraph4(1-7)	bc05_SeashoreVillaWWTP_1997_wq
WQGraph4(1-7)	bc06_SouthCreek_GullHarbor_1997_wq
WQGraph5(1-7)	bc07_AdamsCreek_1997_wq
WQGraph5(1-7)	bc08_NorthCreek_GullHarbor_1997_wq
WQGraph6(1-7)	bc09_BostonHarborWWTP_1997_wq
WQGraph6(1-7)	bc10_TamoshanWWTP_1997_wq
WQGraph7(1-7)	bc11_BeverlyBeachWWTP_1997_wq
WQGraph7(1-7)	bc12_LittletykleCreek_1997_wq
WQGraph8(1-7)	bc13_ButlerCreek_1997_wq
WQGraph8(1-7)	bc14_SchneiderCreek_1997_wq
WQGraph9(1-7)	bc15_LOTTWWTP_1997_wq
WQGraph10	bc22_3ctst1997wq
WQGraph11	bc28_3CTDOCHL1997WQ
WQGraph11	bc28_3CTDOCHL1997WQ R1
WQGraph11	bc29_3CBDOCHL1997WQ
WQGraph11	bc29_3CBDOCHL1997WQ R1
WQGraph12(1-7)	bc31_Deschutes River EHM WQ Data Version 1
WQGraph12(1-7)	bc32_Percival Creek EHM WQ Data Version 1
WQGraph13	bc33_Deschutes River WQADD Data
WQGraph13	bc35_Open Boundary WQADDData
WQGraph14	bc34_PercivalCreek WQData
WQGraph15(1-9)	bc36_ bud005_03_result_xtab_bin1_0m
WQGraph15(1-9)	bc36_ bud005_03_result_xtab_bin1_0m_R1
WQGraph16(1-6)	bc38_DeschutesRiver_1997_wq
WQGraph17(1-5)	bc39_PercivalCreek_1997_wq
WQGraph18(1-6)	bc40_DeschutesRiver_2003-2004_avg
WQGraph18(1-9)	bc41_PercivalCreek_2003-2004_avg
WQGraph19	oly_ppn1985_2007
WQGraph19	oly_ppn1985_97wq
WQGraph20	tidbit_2004_deschutes_plusDO
WQGraph20	tidbit_2004_percival_plusDO
WQGraph21(1-6)	DeschutesRiver_2003-2004 DO 2p5plus No T_DO
WQGraph21(1-6)	PercivalCreek_2003-2004 DO 2p5plus No T_DO

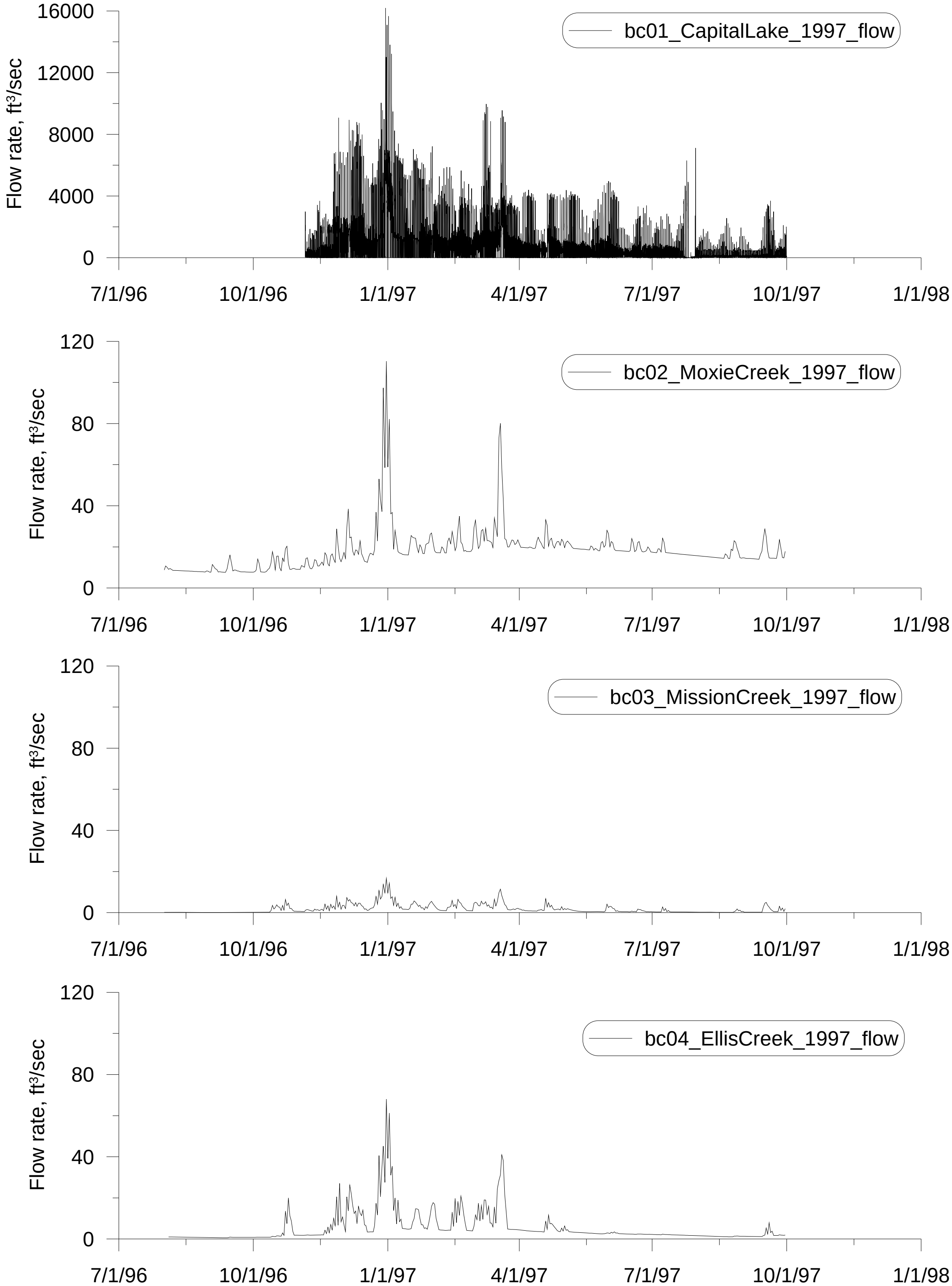


Figure 1. FlowGraph1

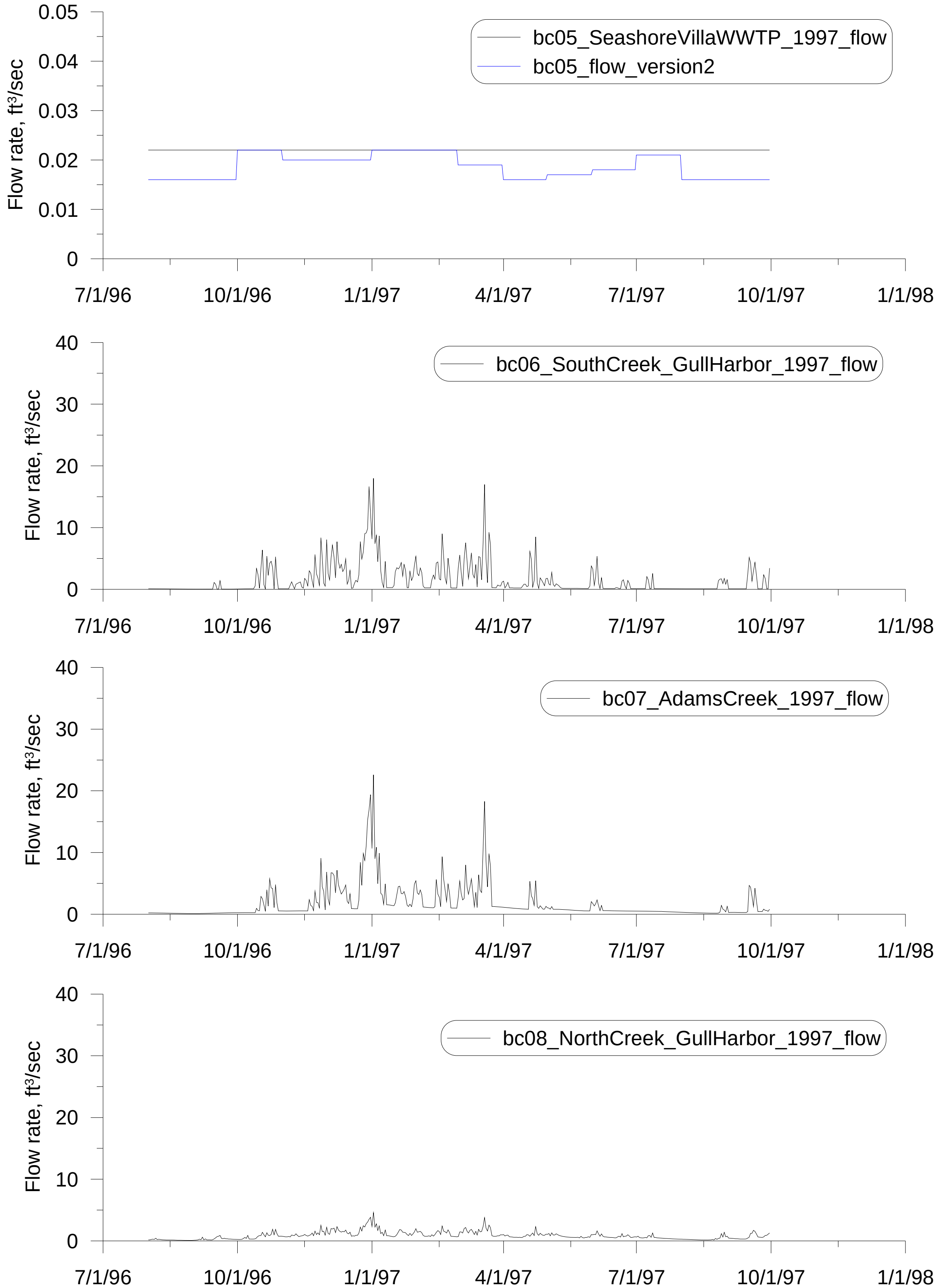


Figure 2. FlowGraph2

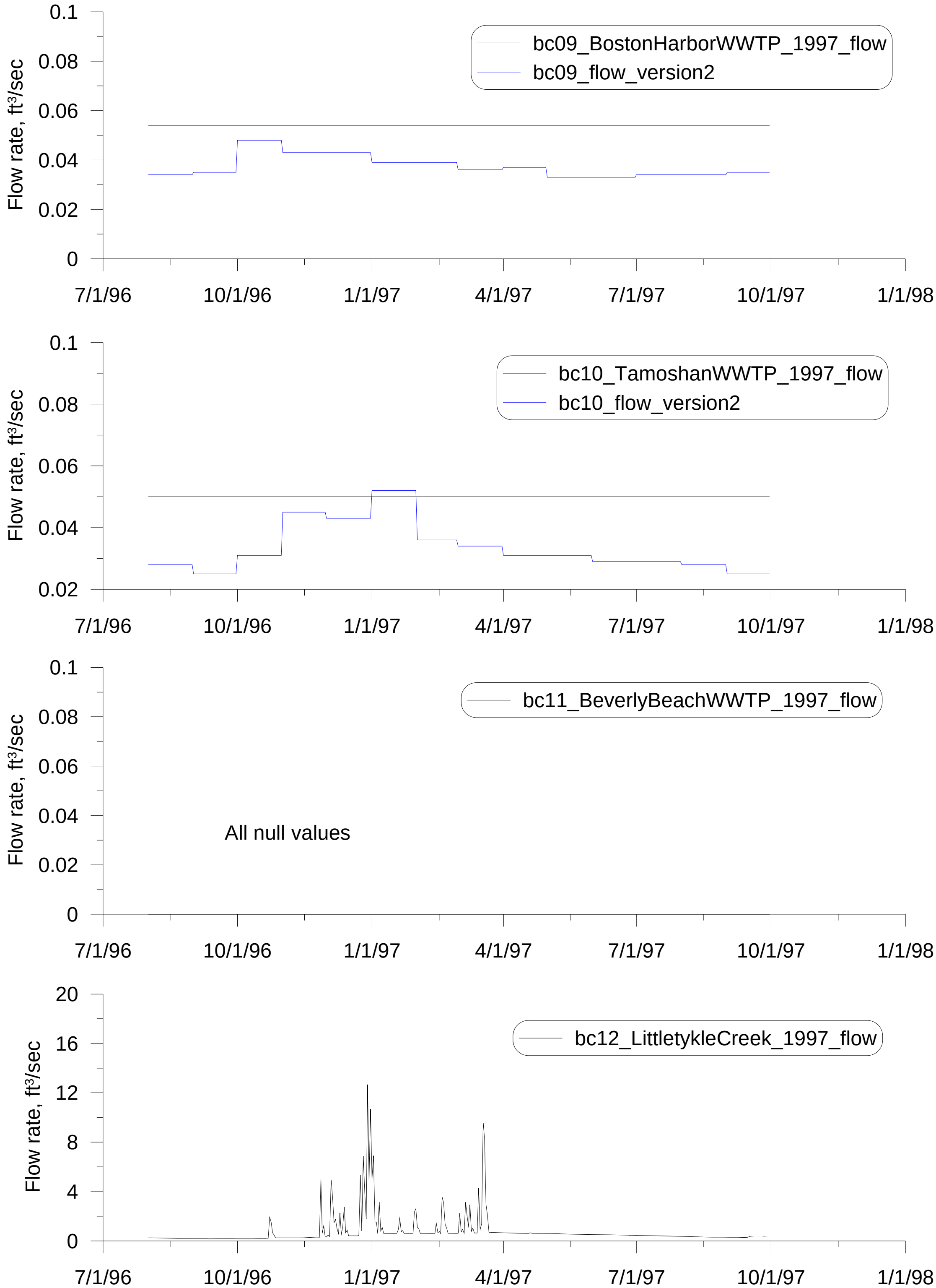


Figure 3. FlowGraph3

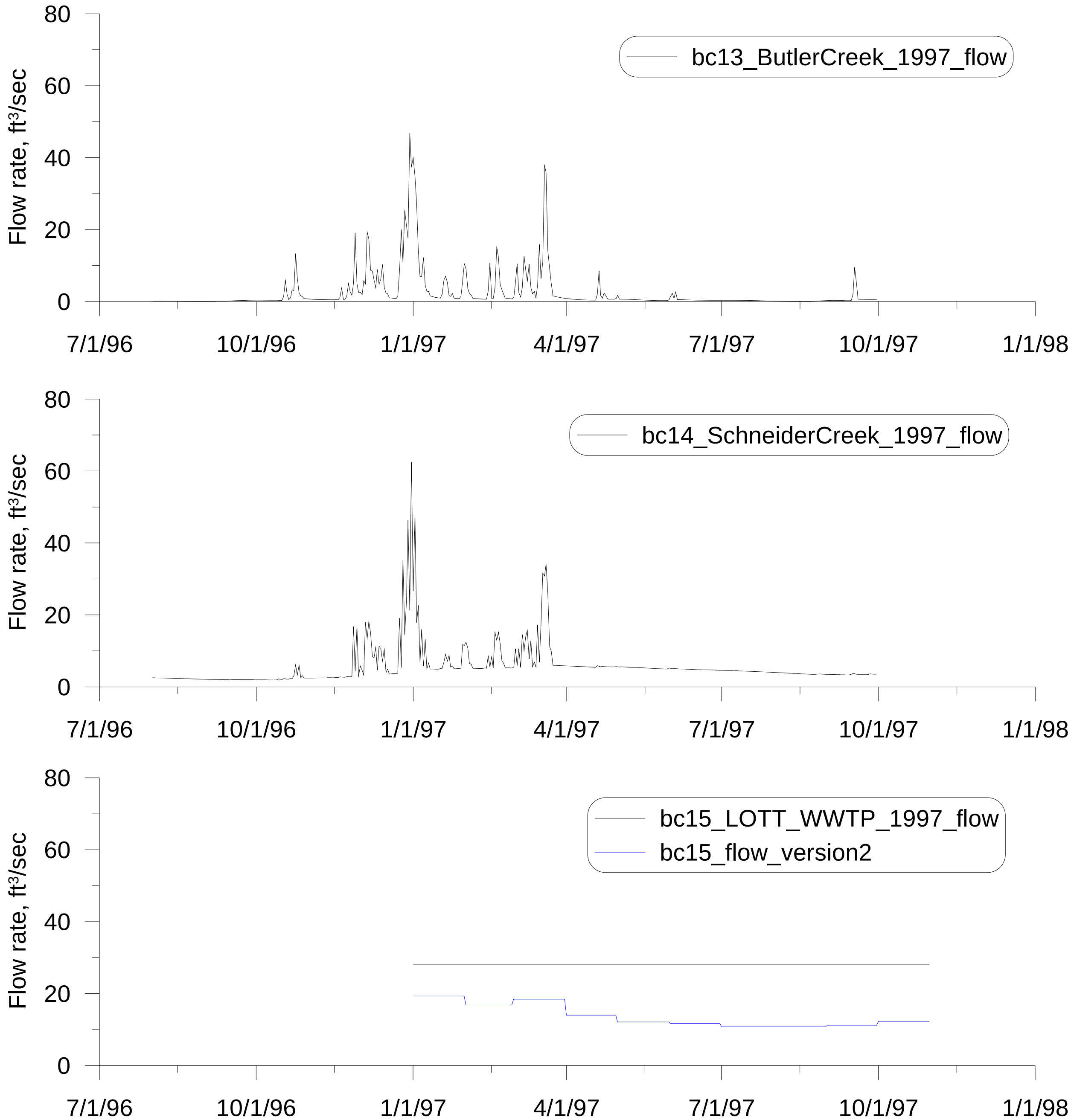


Figure 4. FlowGraph4

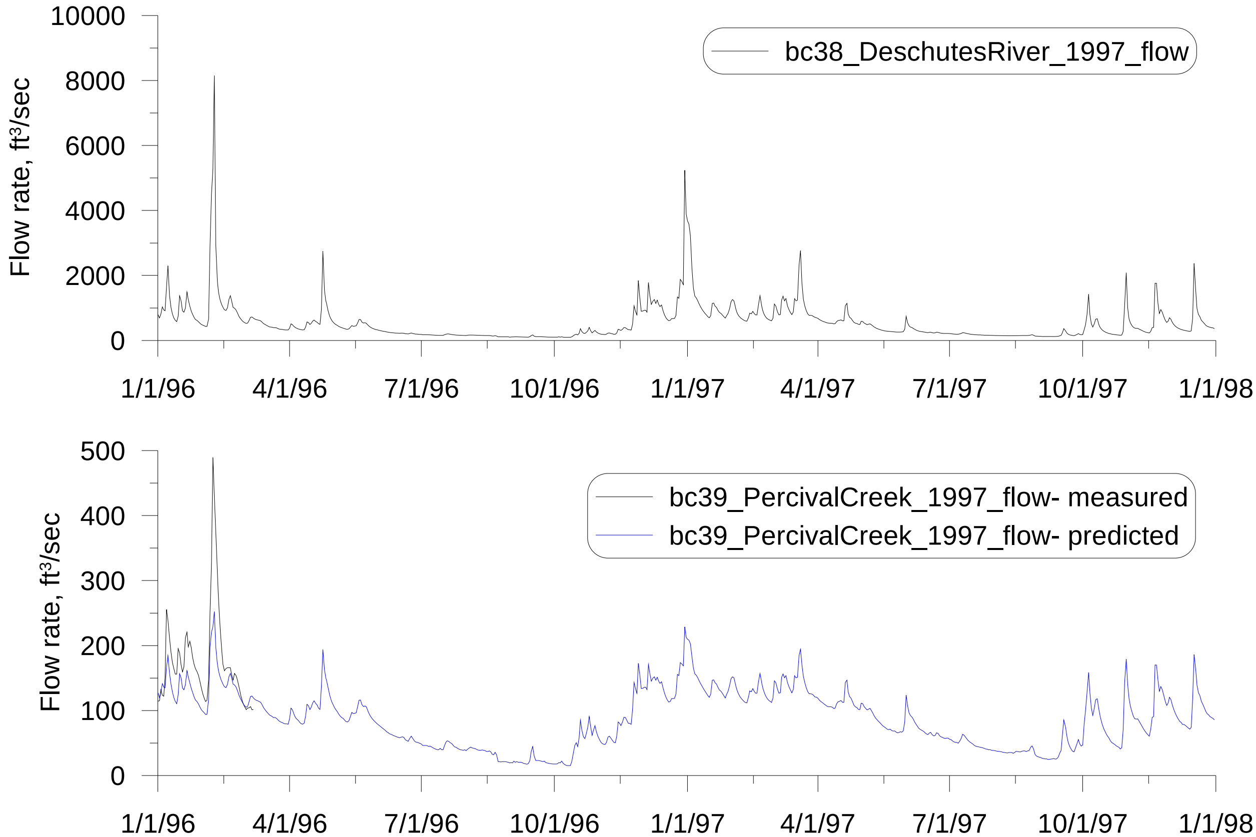


Figure 5. FlowGraph5

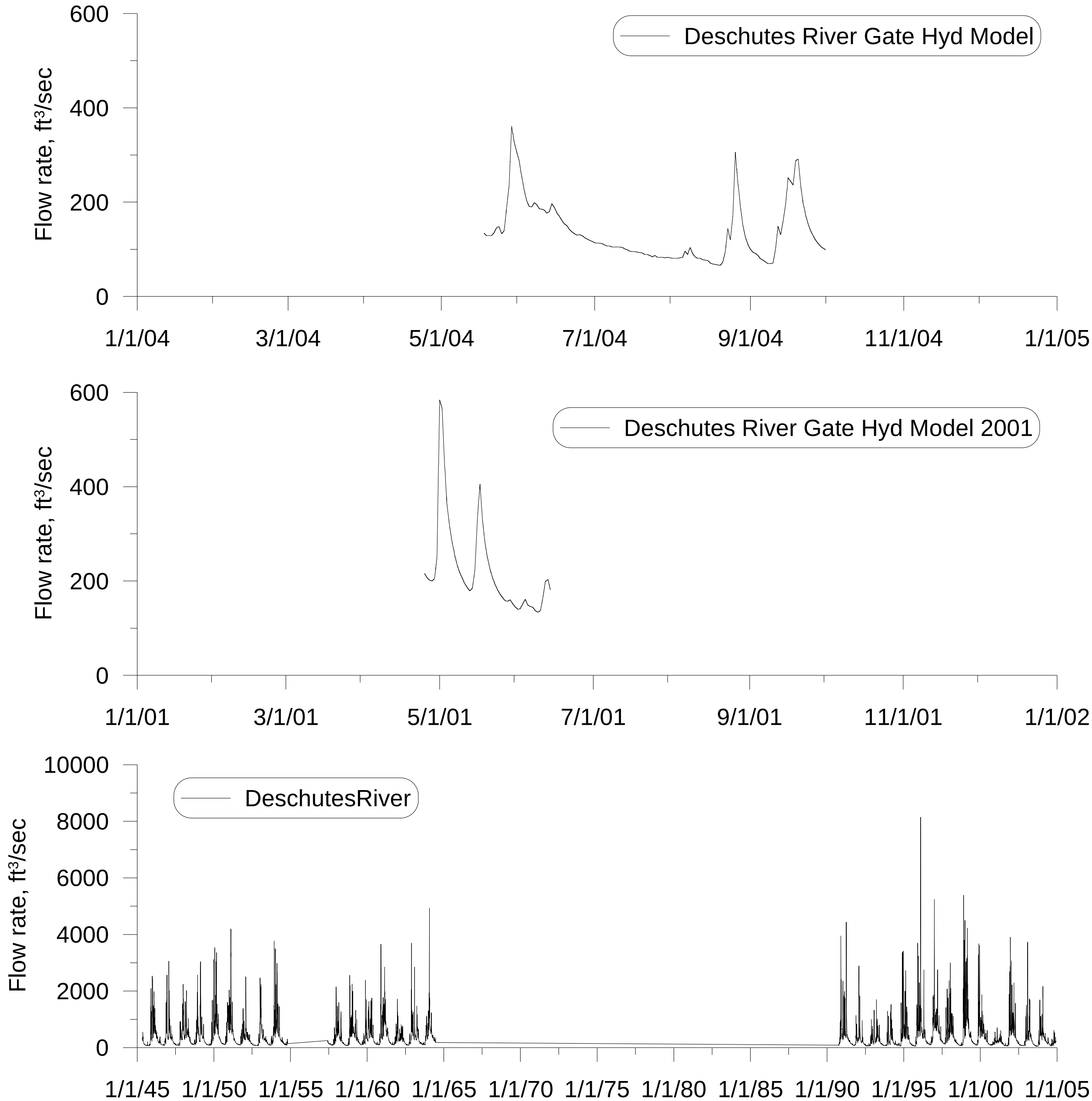


Figure 6. FlowGraph6

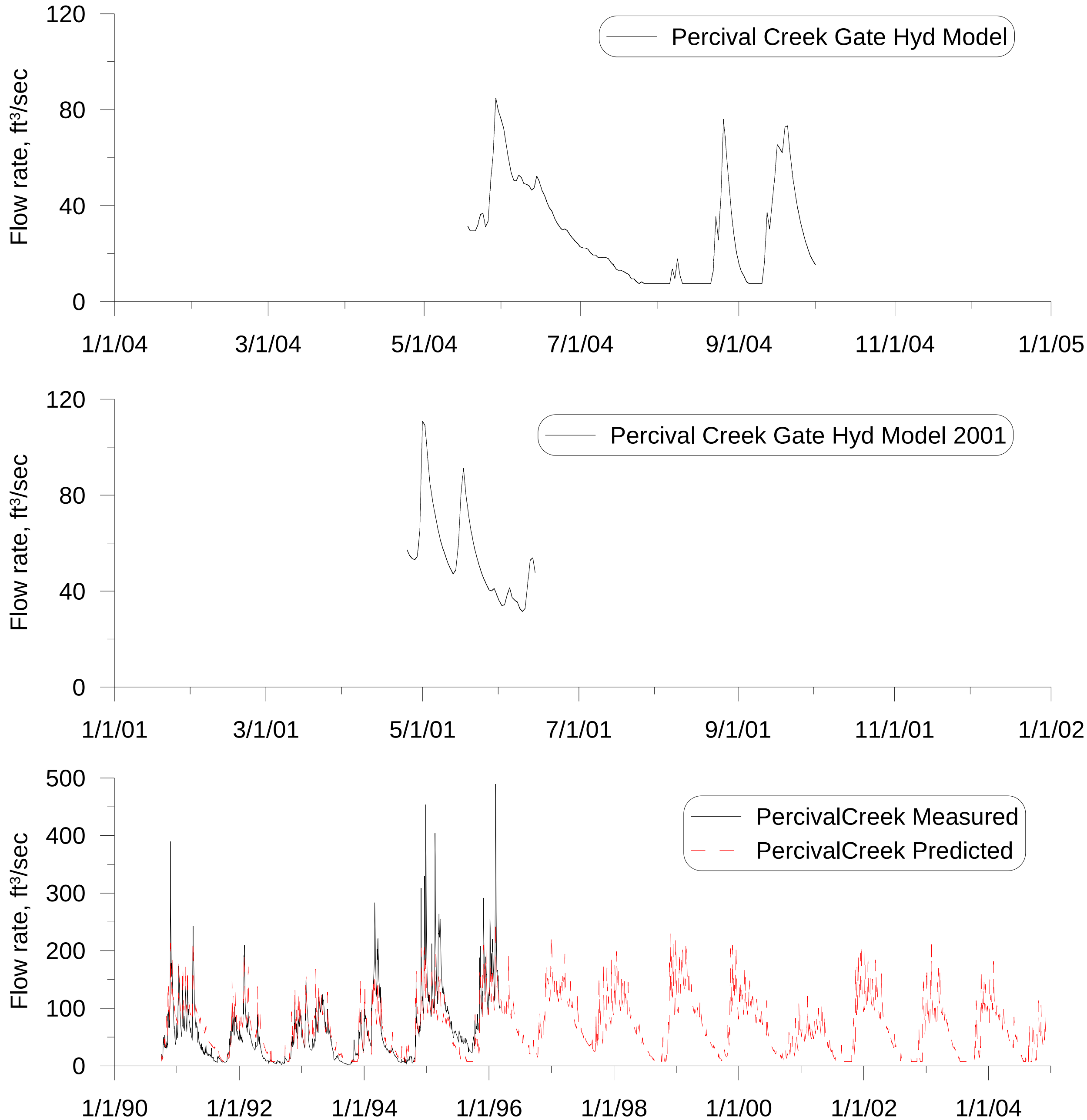


Figure 7. FlowGraph7

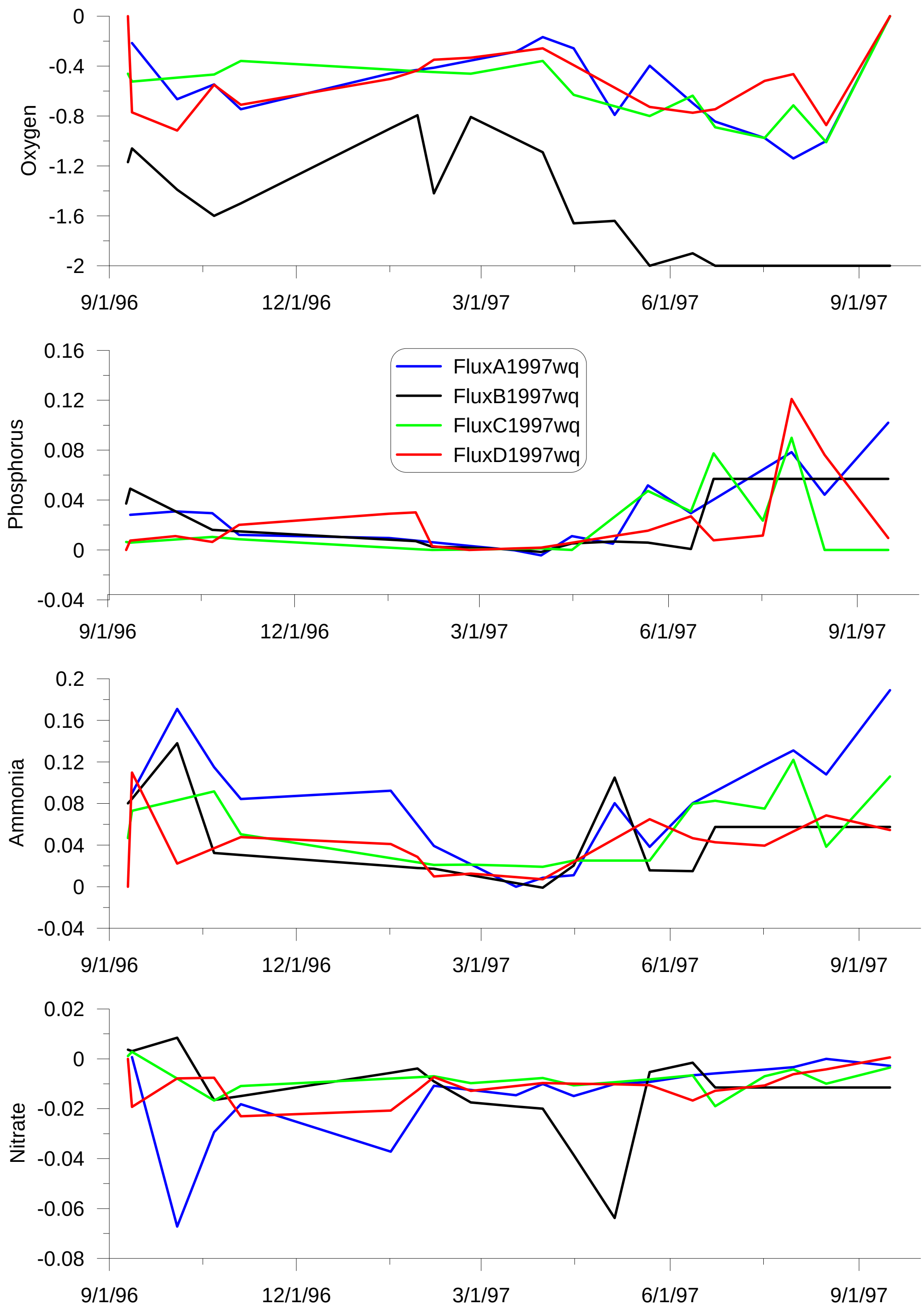


Figure 8. FluxGraph1

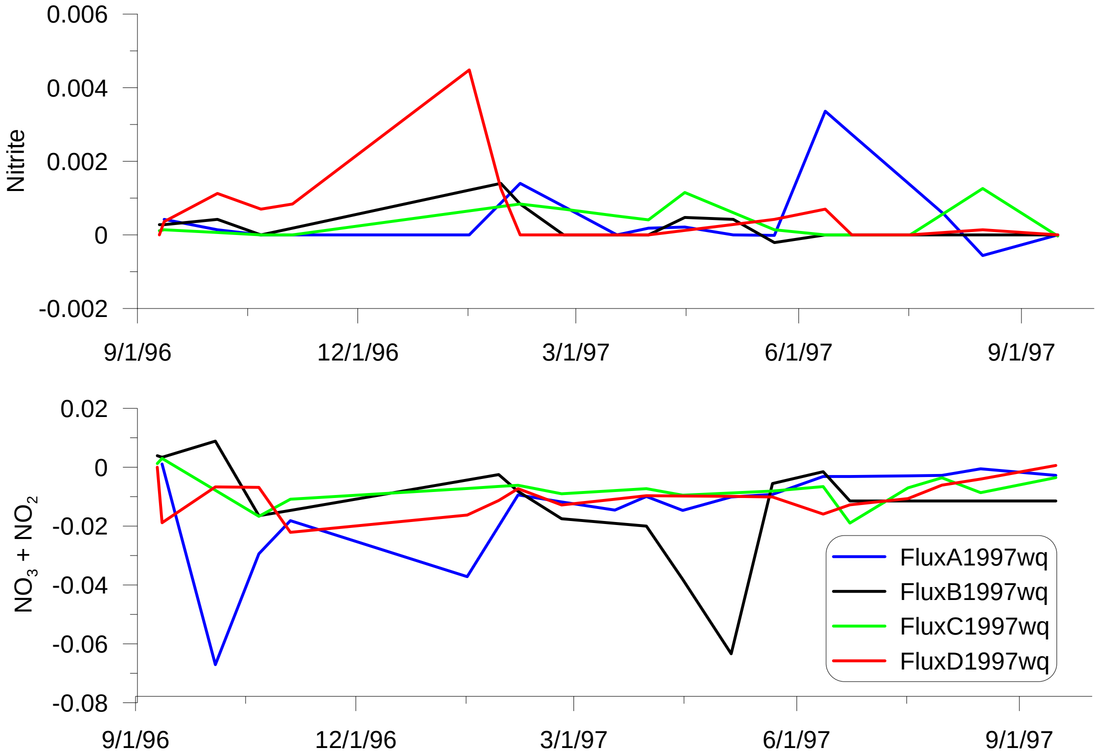


Figure 9. FluxGraph1-2

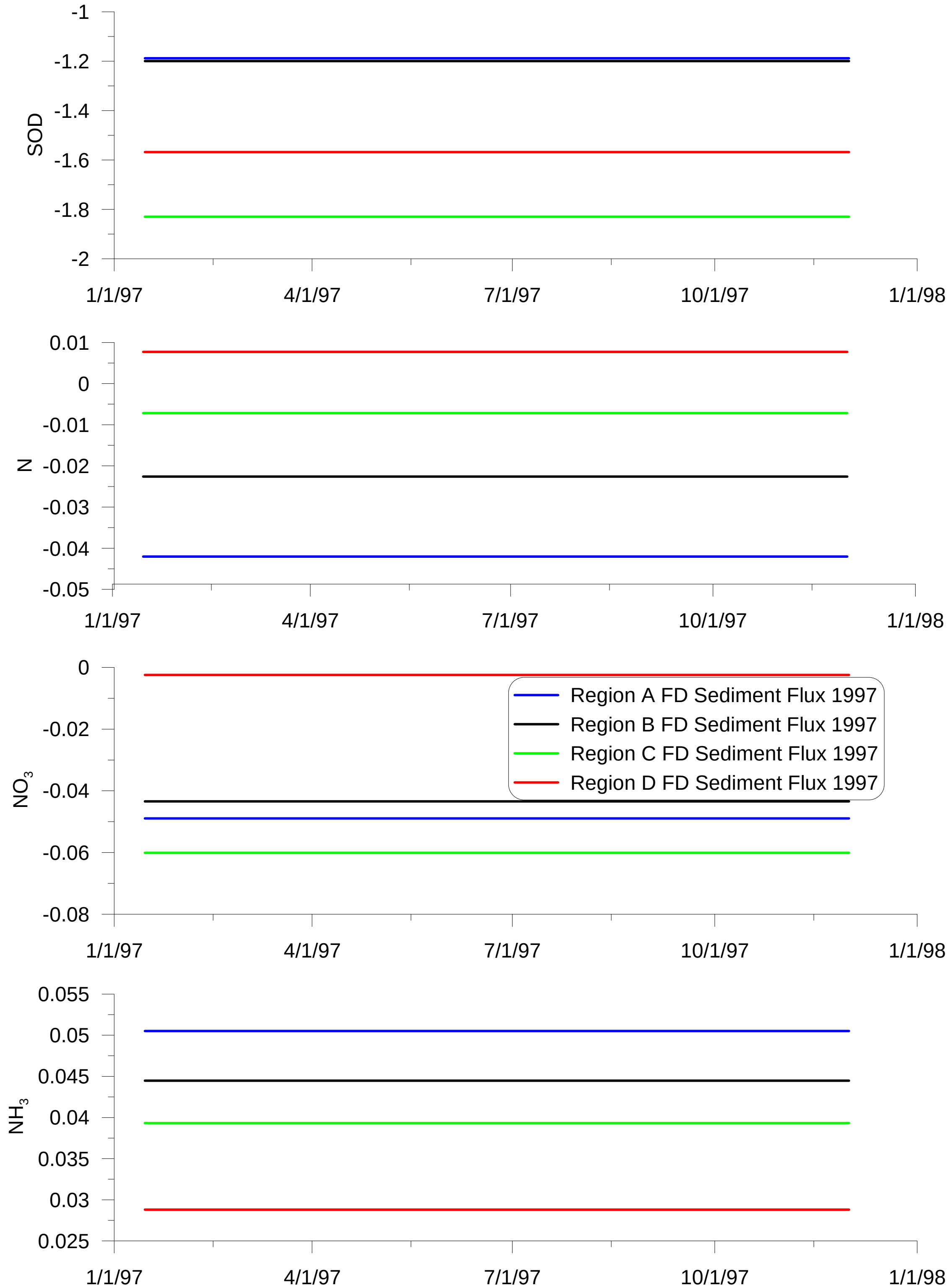


Figure 10. FluxGraph2-1

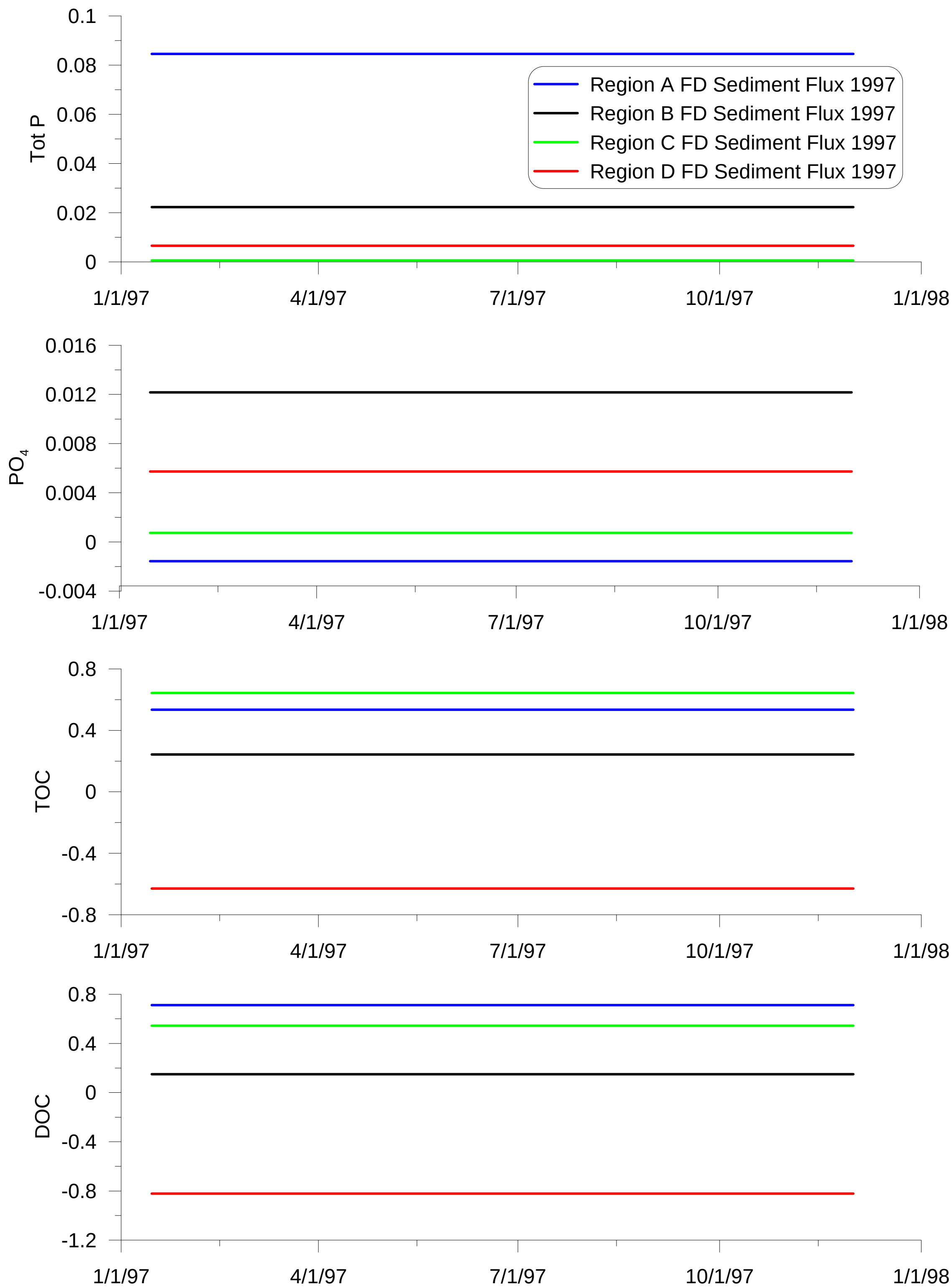


Figure 11. FluxGraph2-2

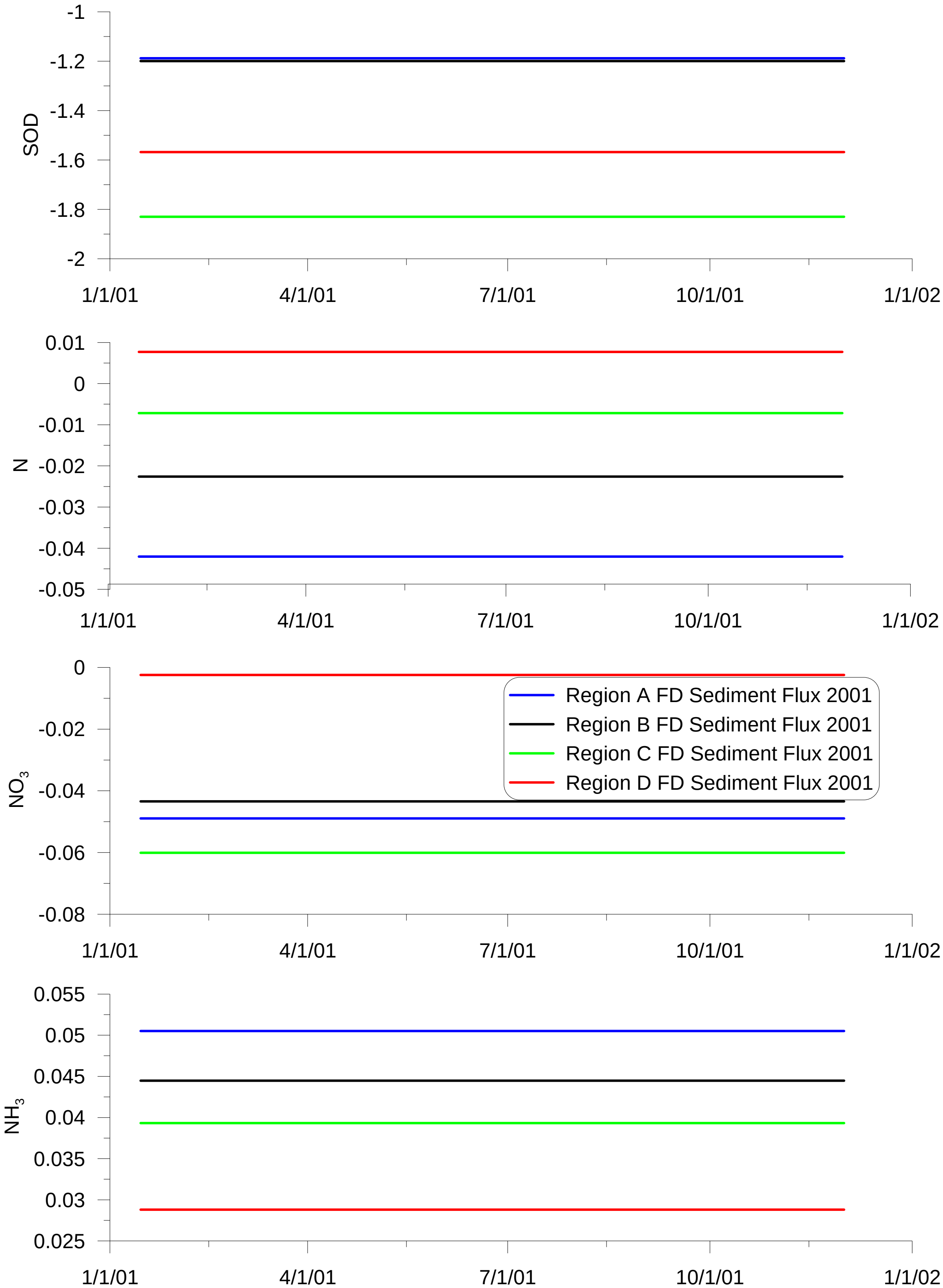


Figure 12. FluxGraph3-1

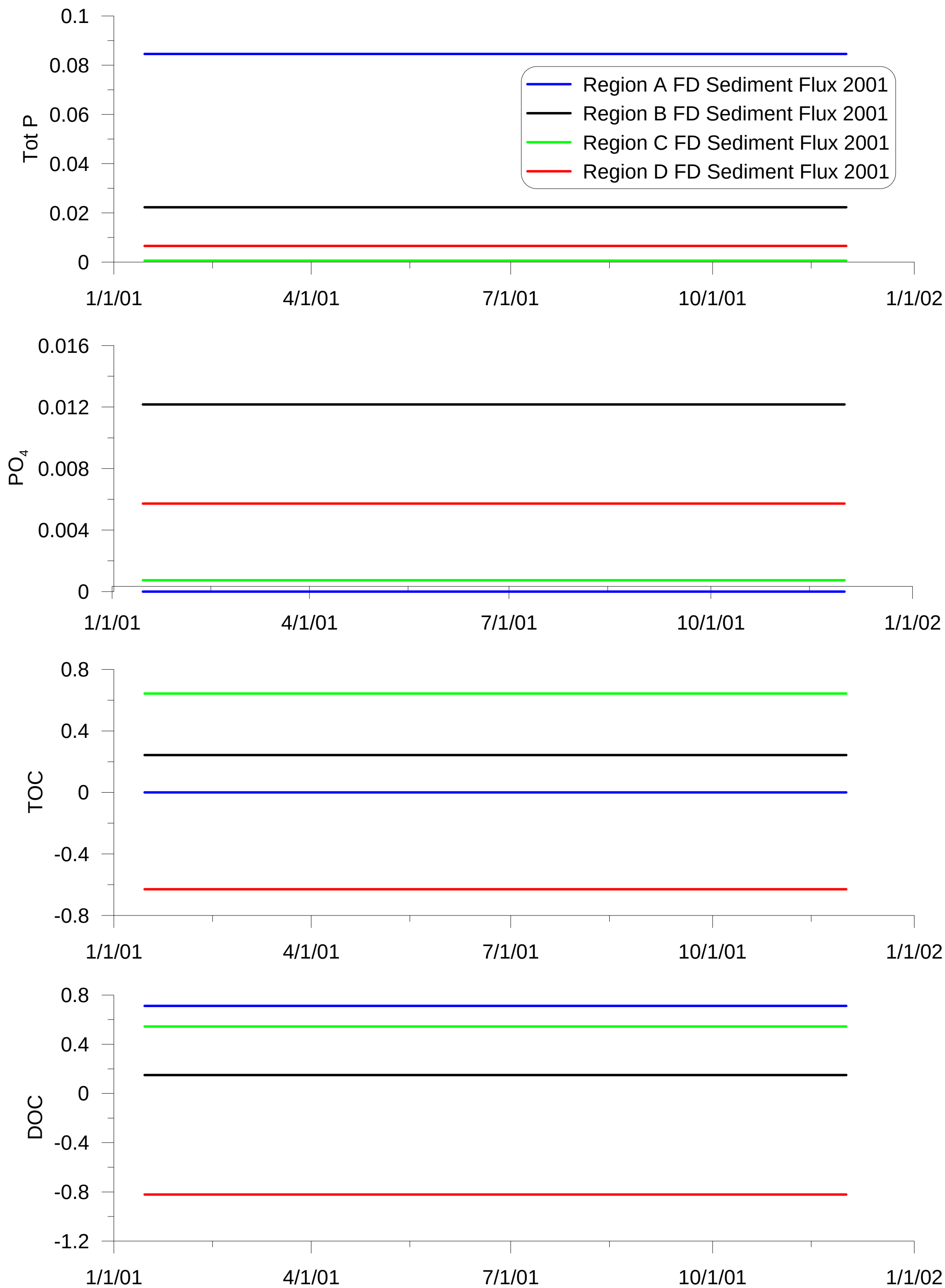


Figure 13. FluxGraph3-2

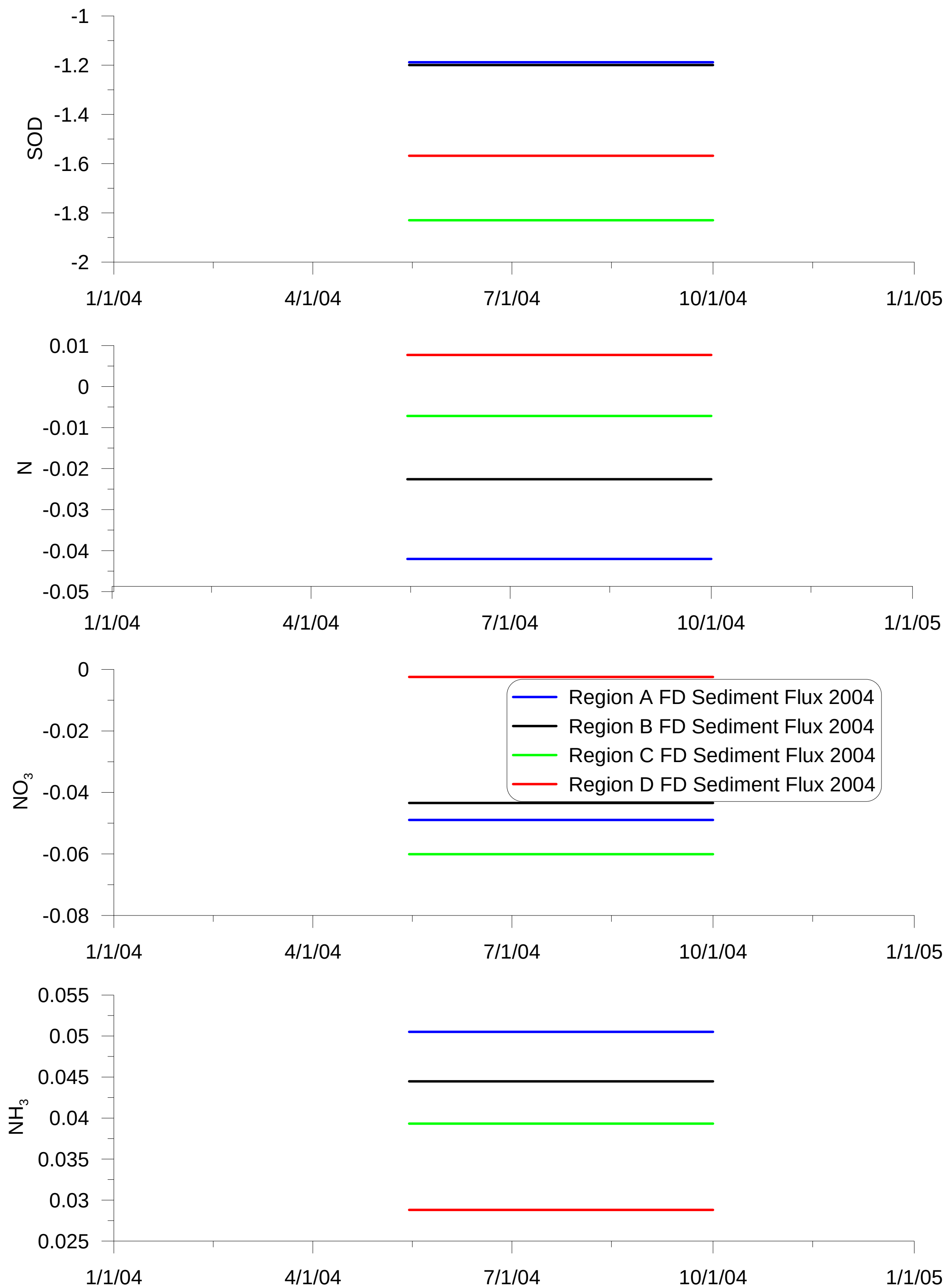


Figure 14. FluxGraph4-1

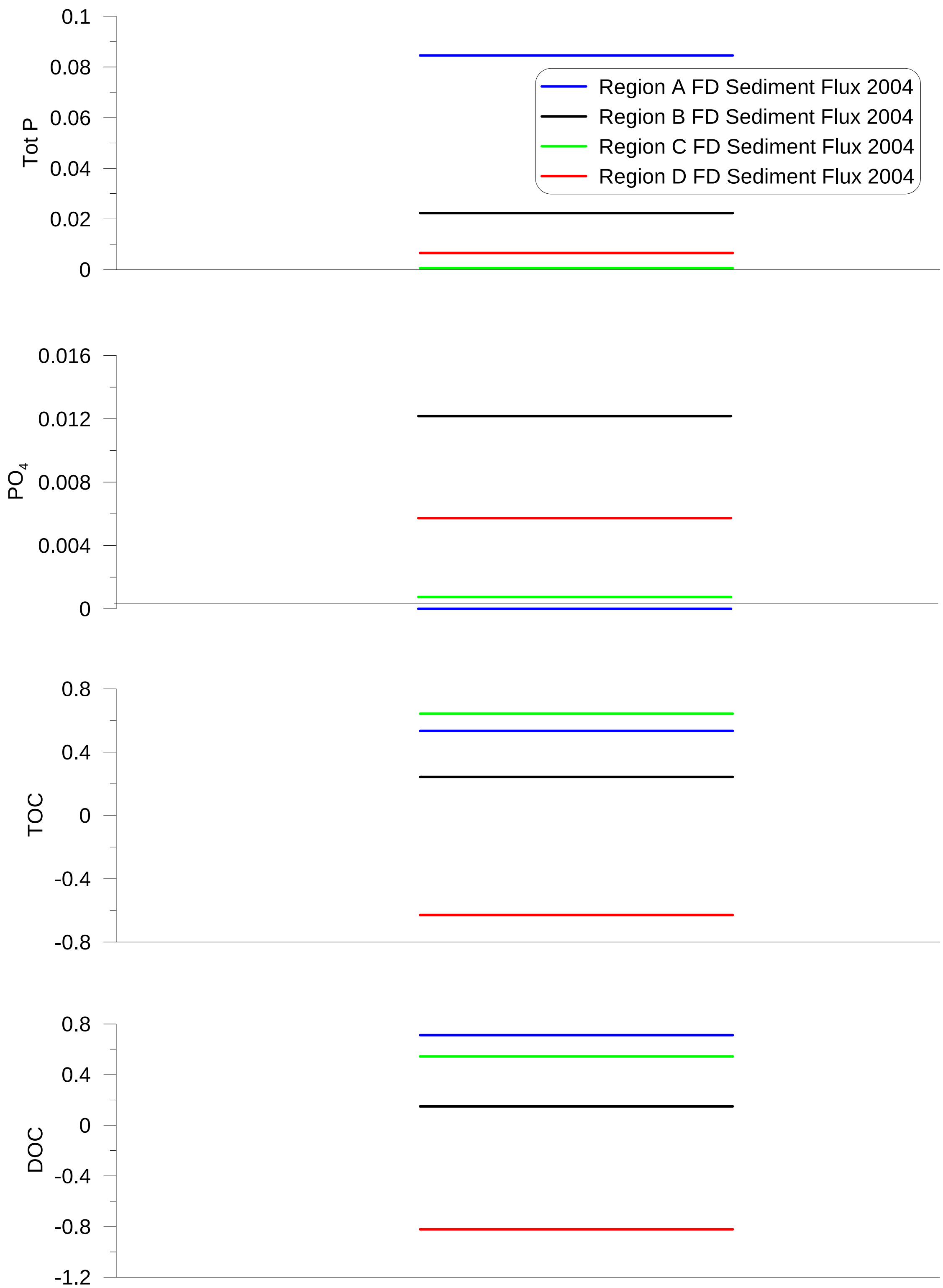


Figure 15. FluxGraph4-2

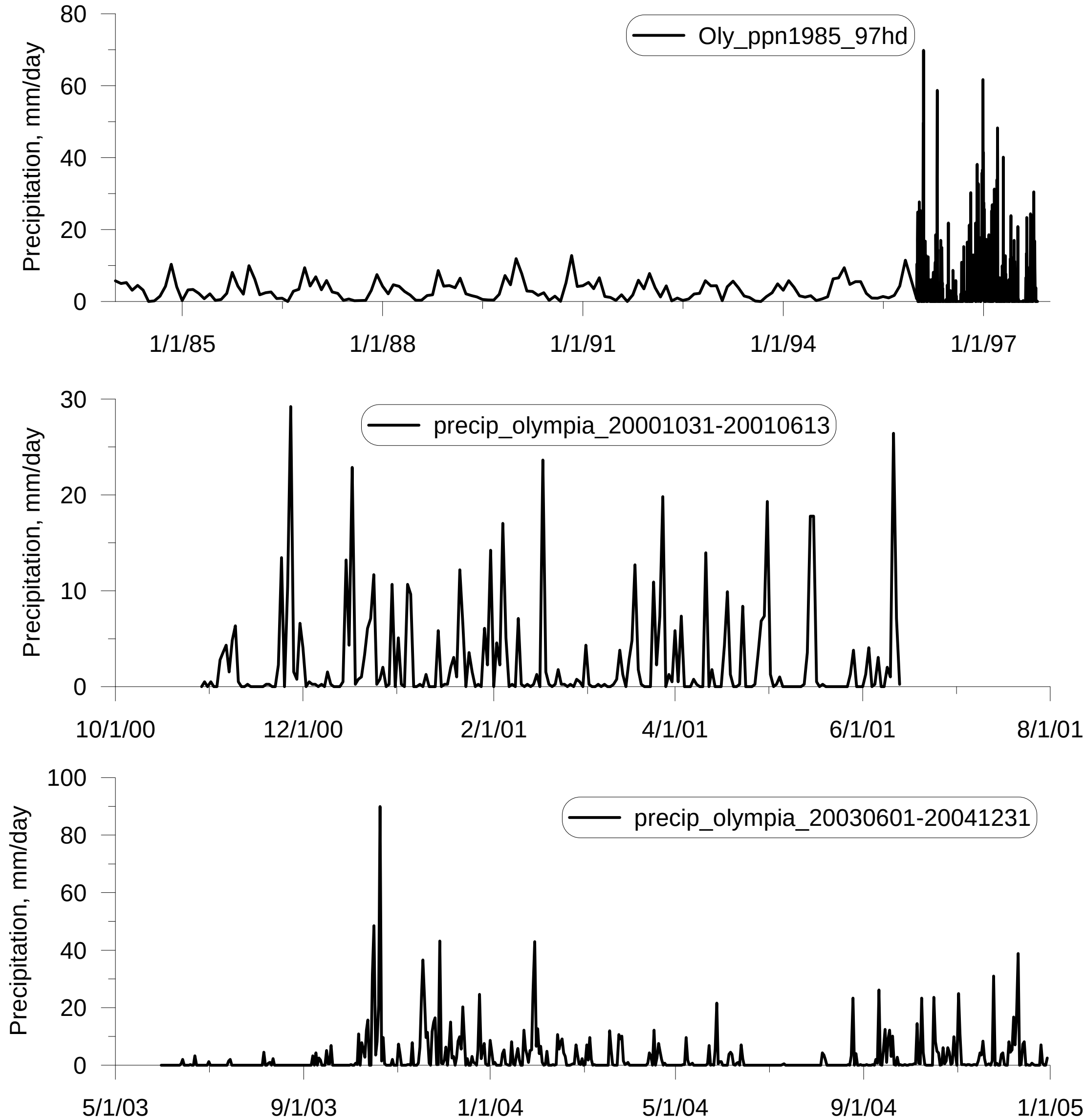
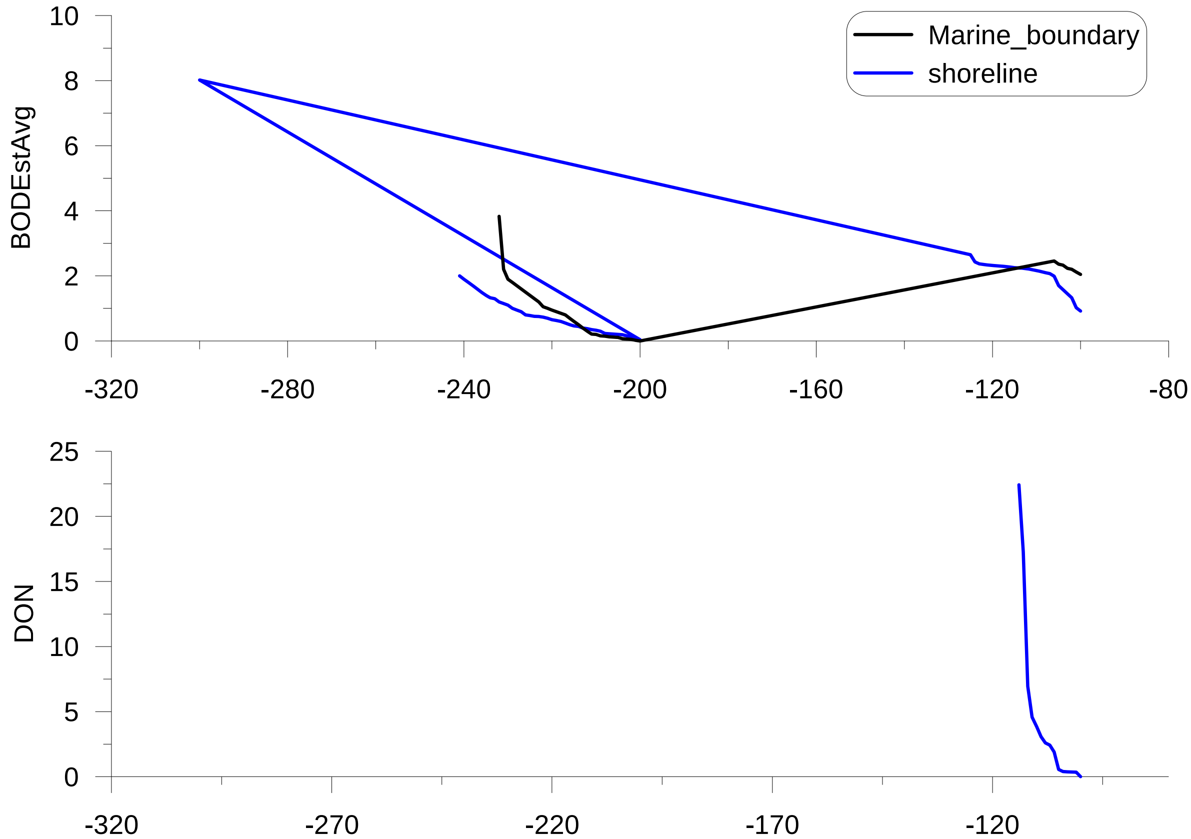


Figure 16. PrecipGraph1



Additional non-null values:

Marine_boundary

Qualifier	NH3	NO3	NO2	PO4	DOP	DON	TPP	Phyt	Phyt2
-100	0.0007	0.0014	0.00028	0.0006	0.002	0.004	0.002	-999	-999
-300	-999	-999	-999	-999	-999	-999	-999	75	75

Shoreline

Qualifier	NH3	NO3	NO2	PO4	DOP	DON	TPP
-100	0.0007	0.0014	0.00028	-999	0.002	0.004	0.002

Figure 17. QualifierGraph1

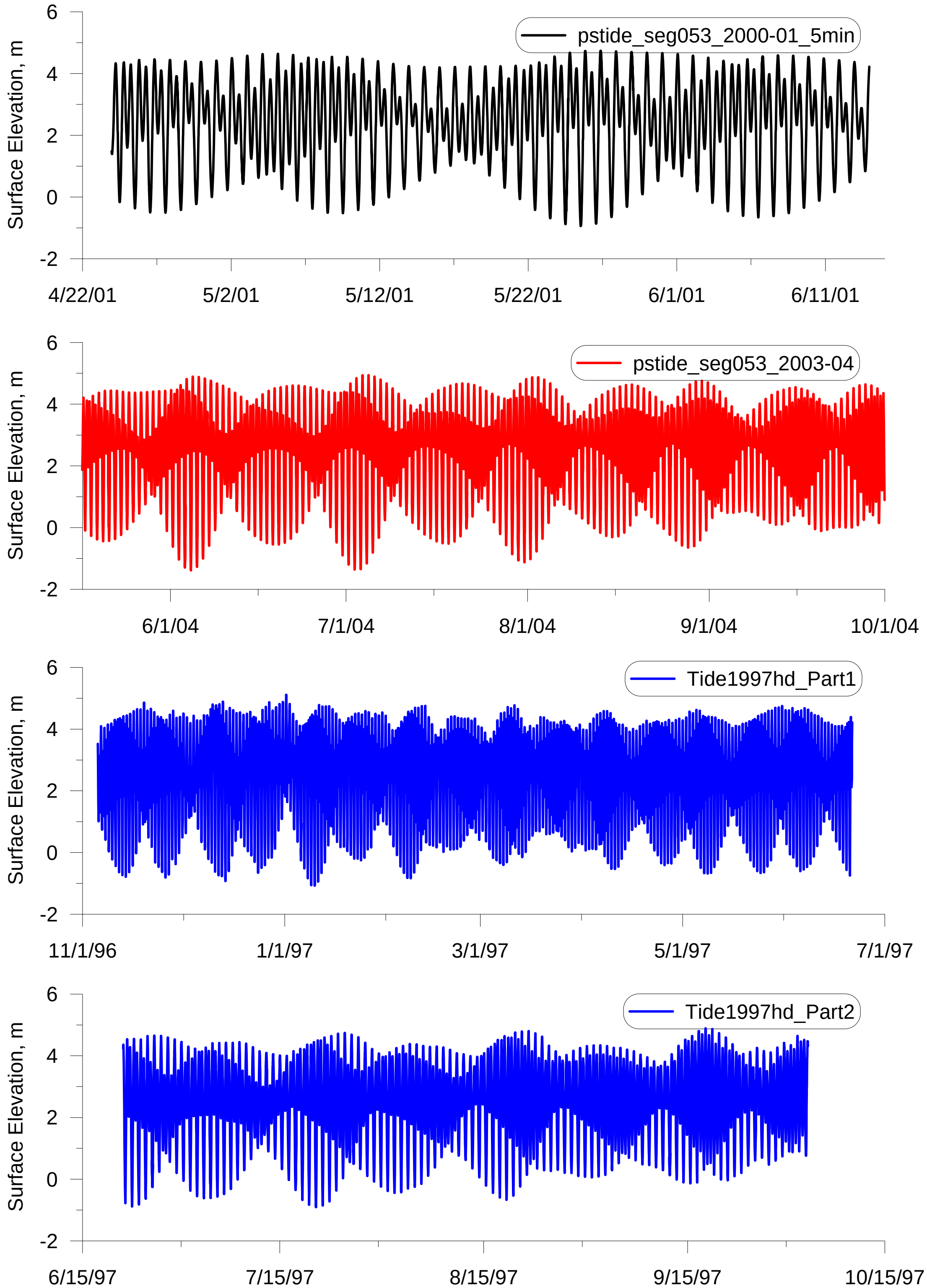


Figure 18. TideGraph1

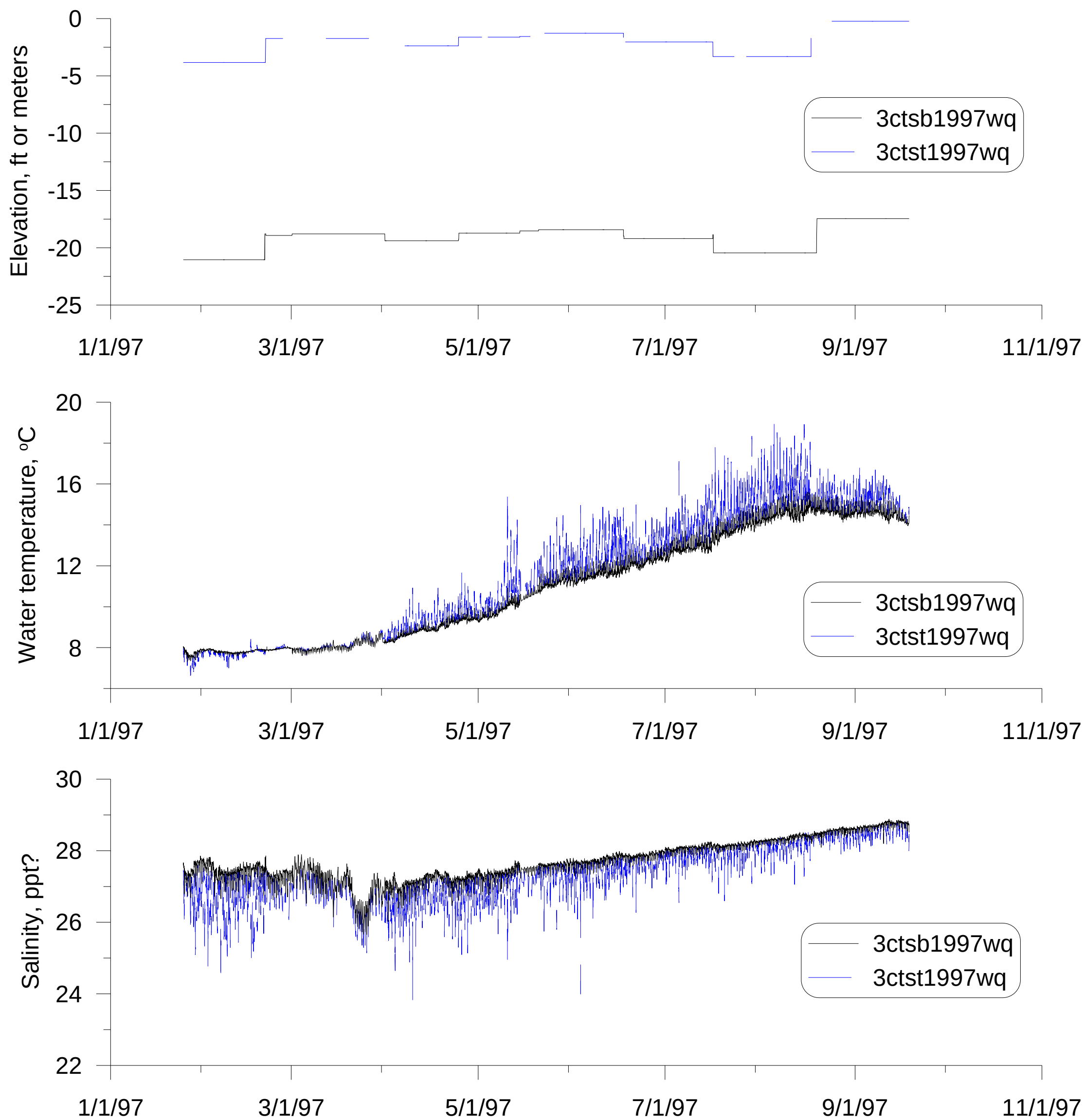


Figure 19. WQGraph1

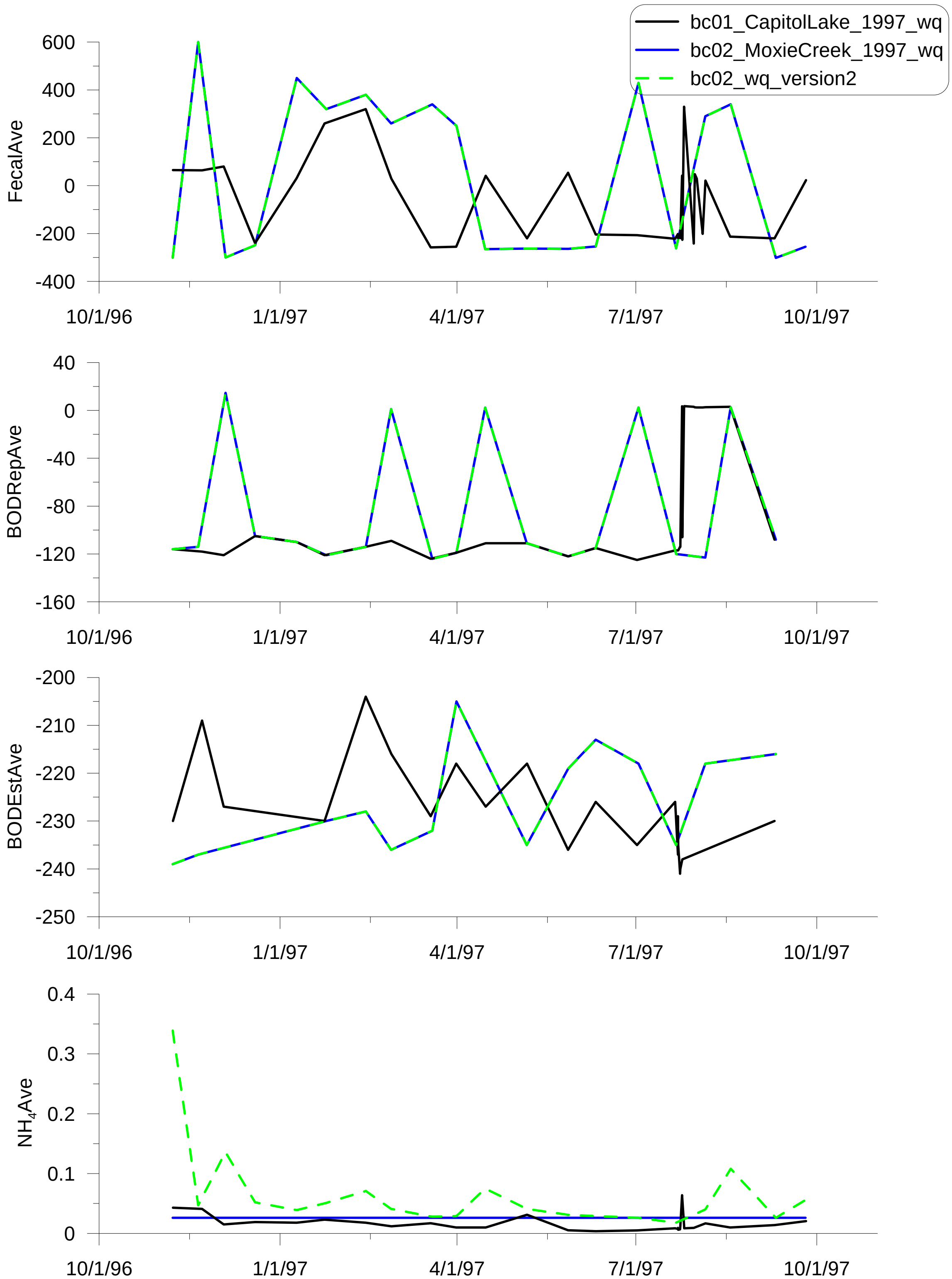


Figure 20. WQGraph2-1

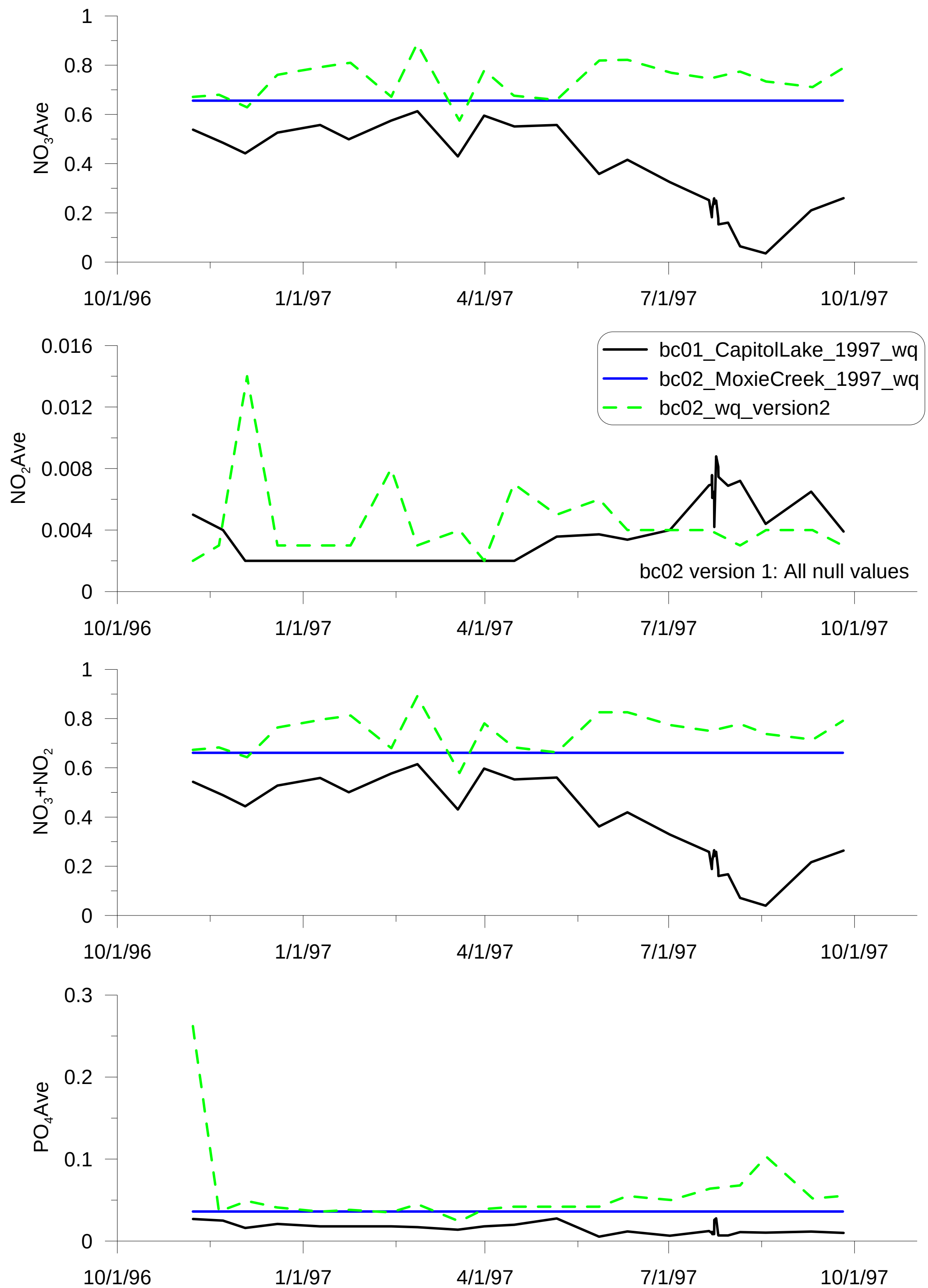


Figure 21. WQGraph2-2

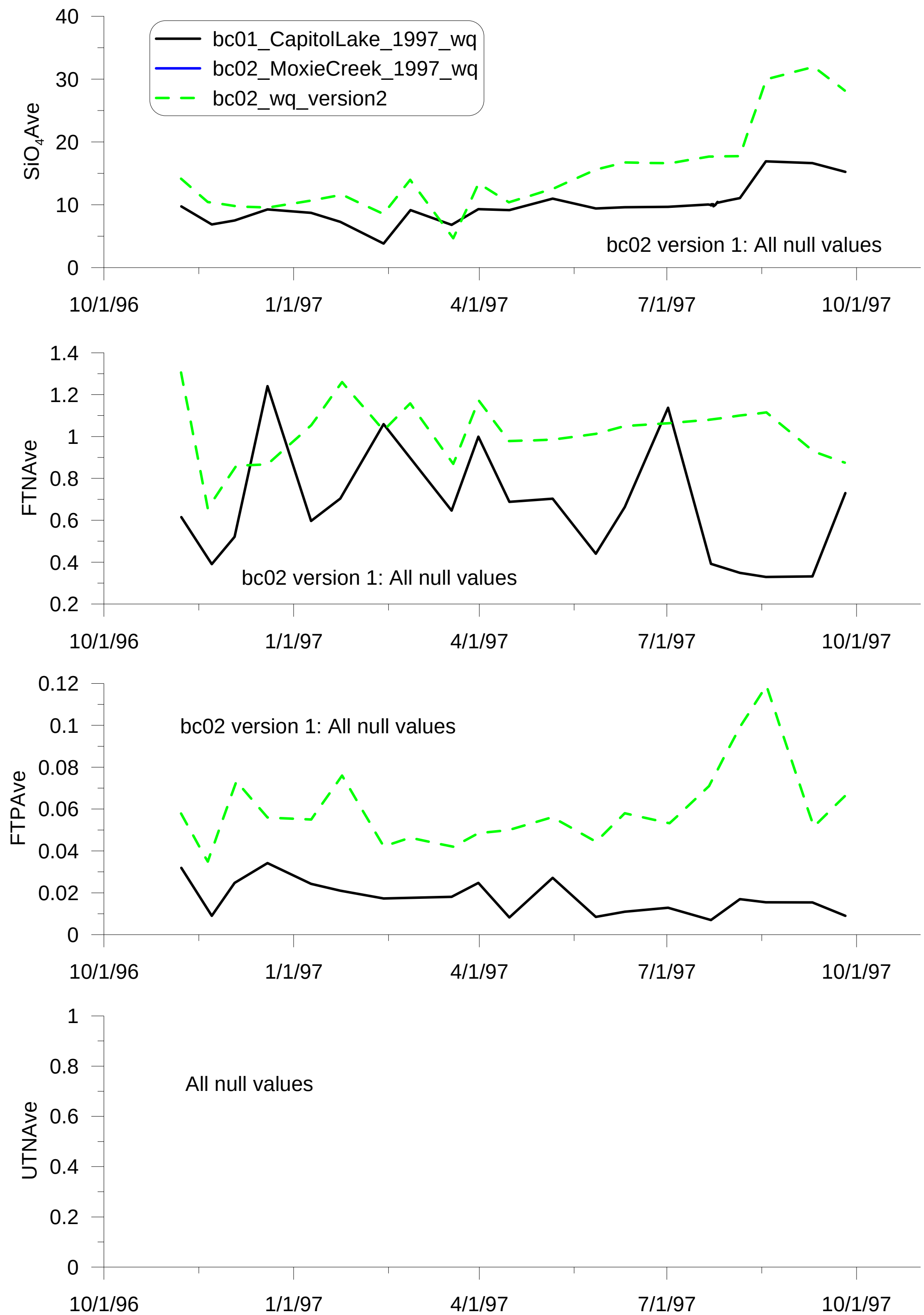


Figure 22. WQGraph2-3

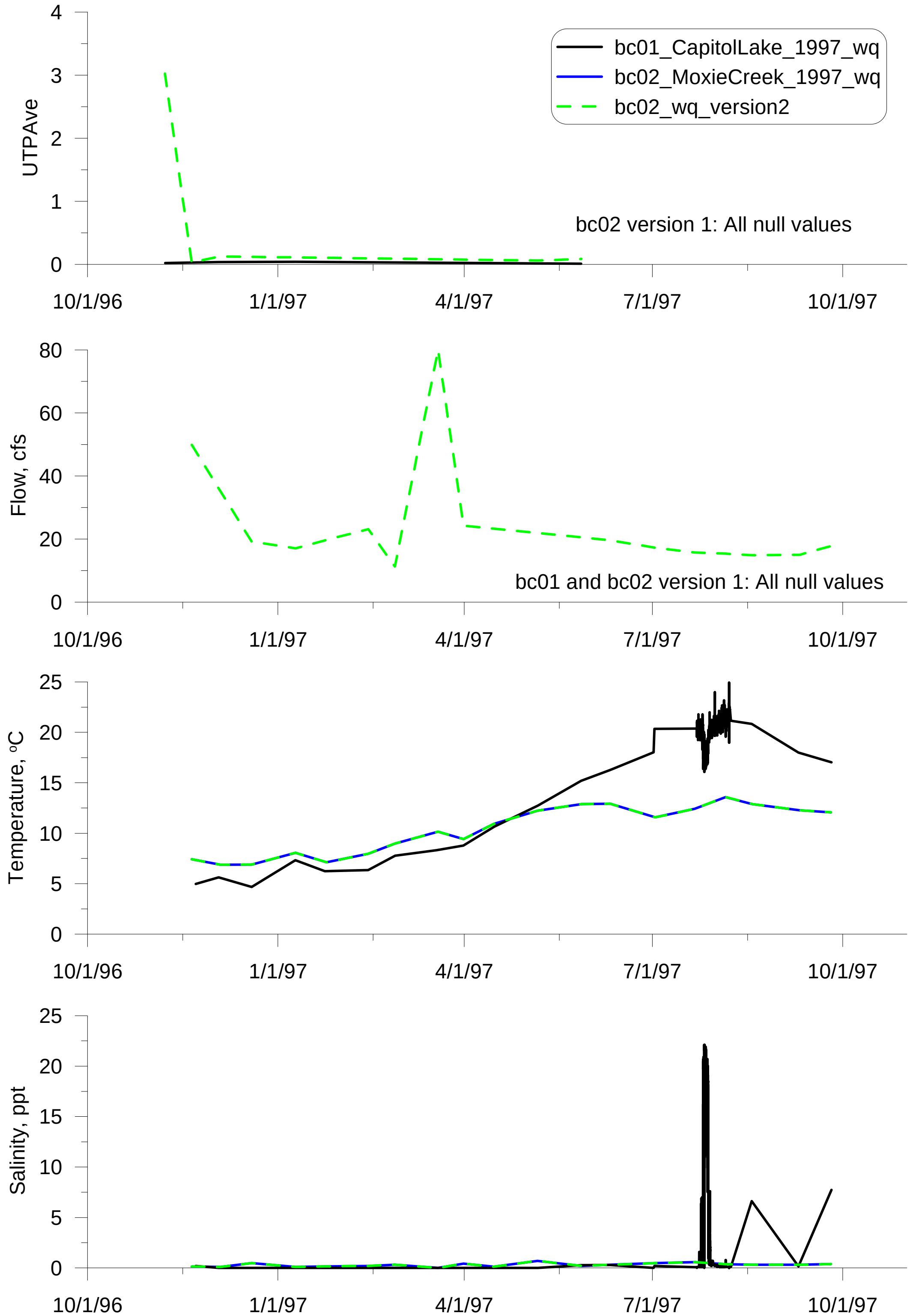


Figure 23. WQGraph2-4

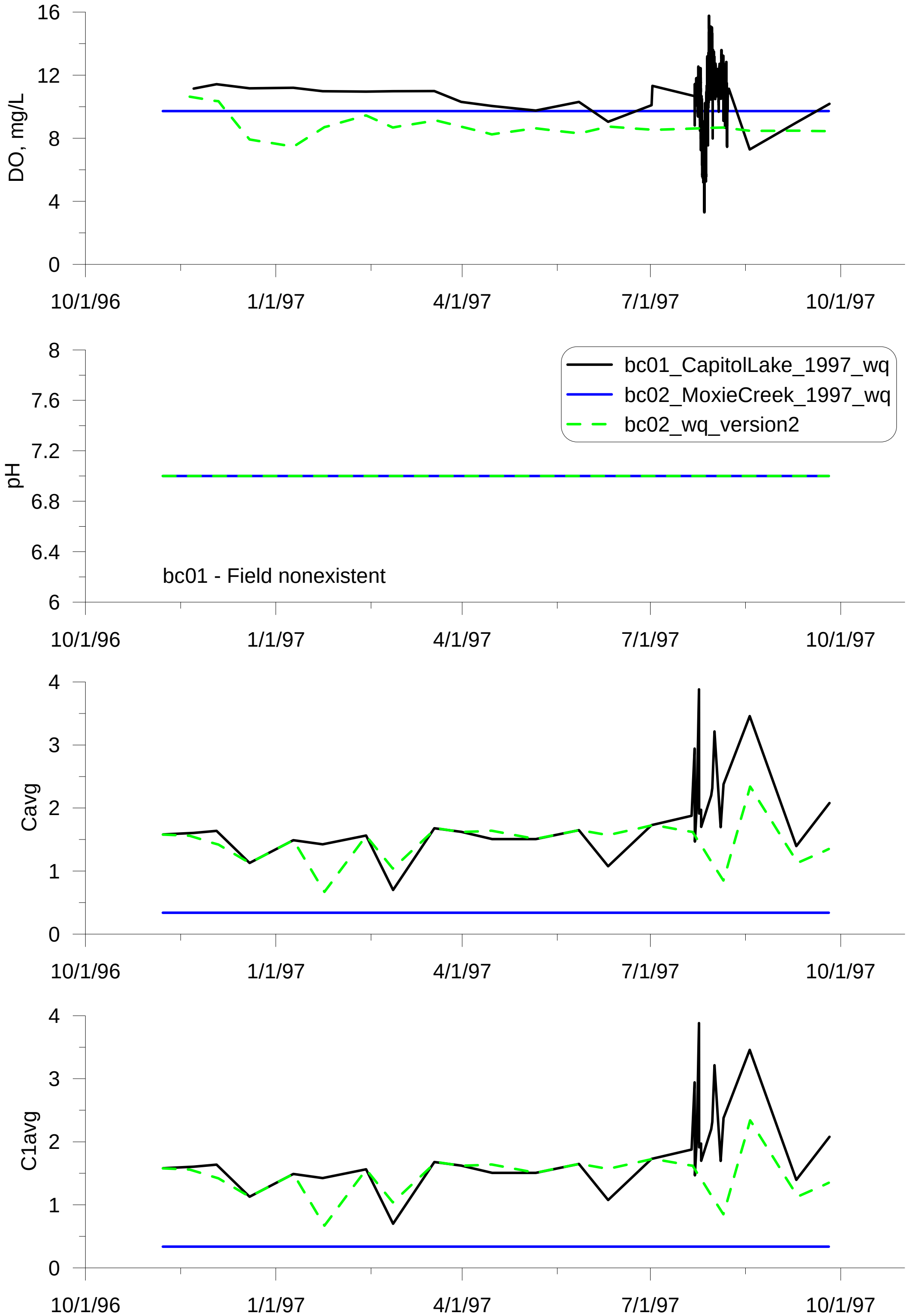


Figure 24. WQGraph2-5

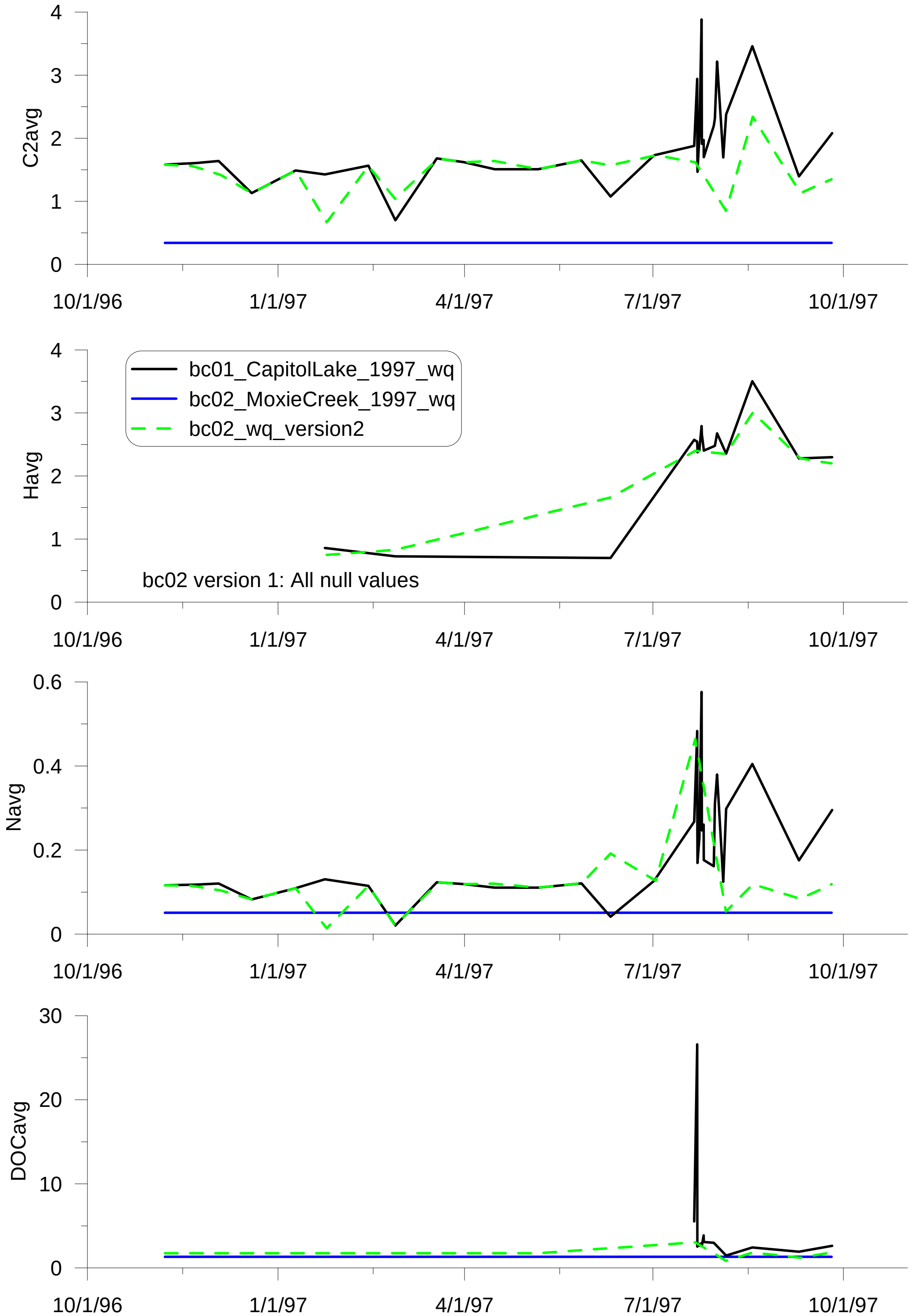
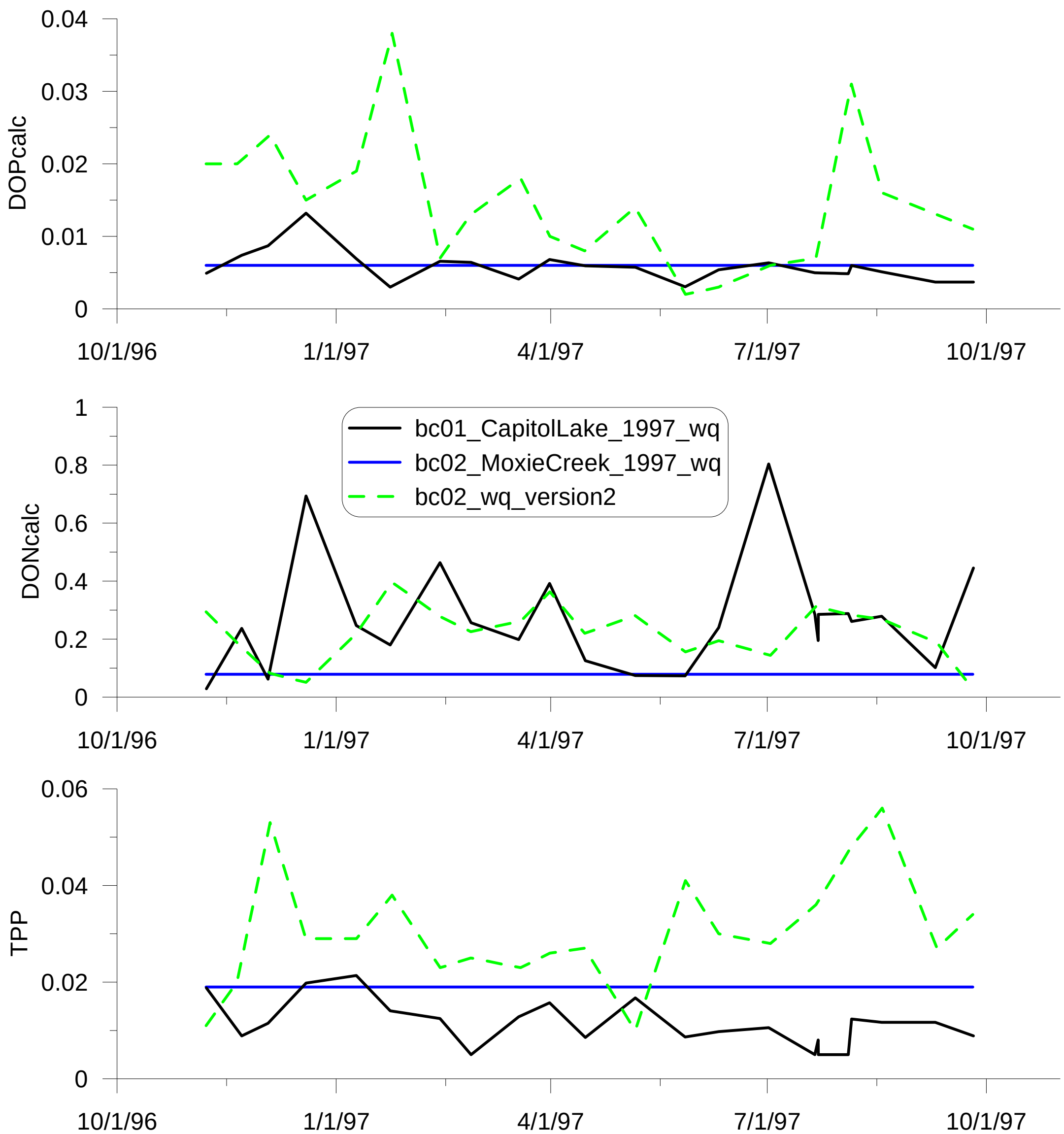


Figure 25. WQGraph2-6



Additional fields: Chlorophyll, Dinoflag, Diatoms - all null values

Figure 26. WQGraph2-7

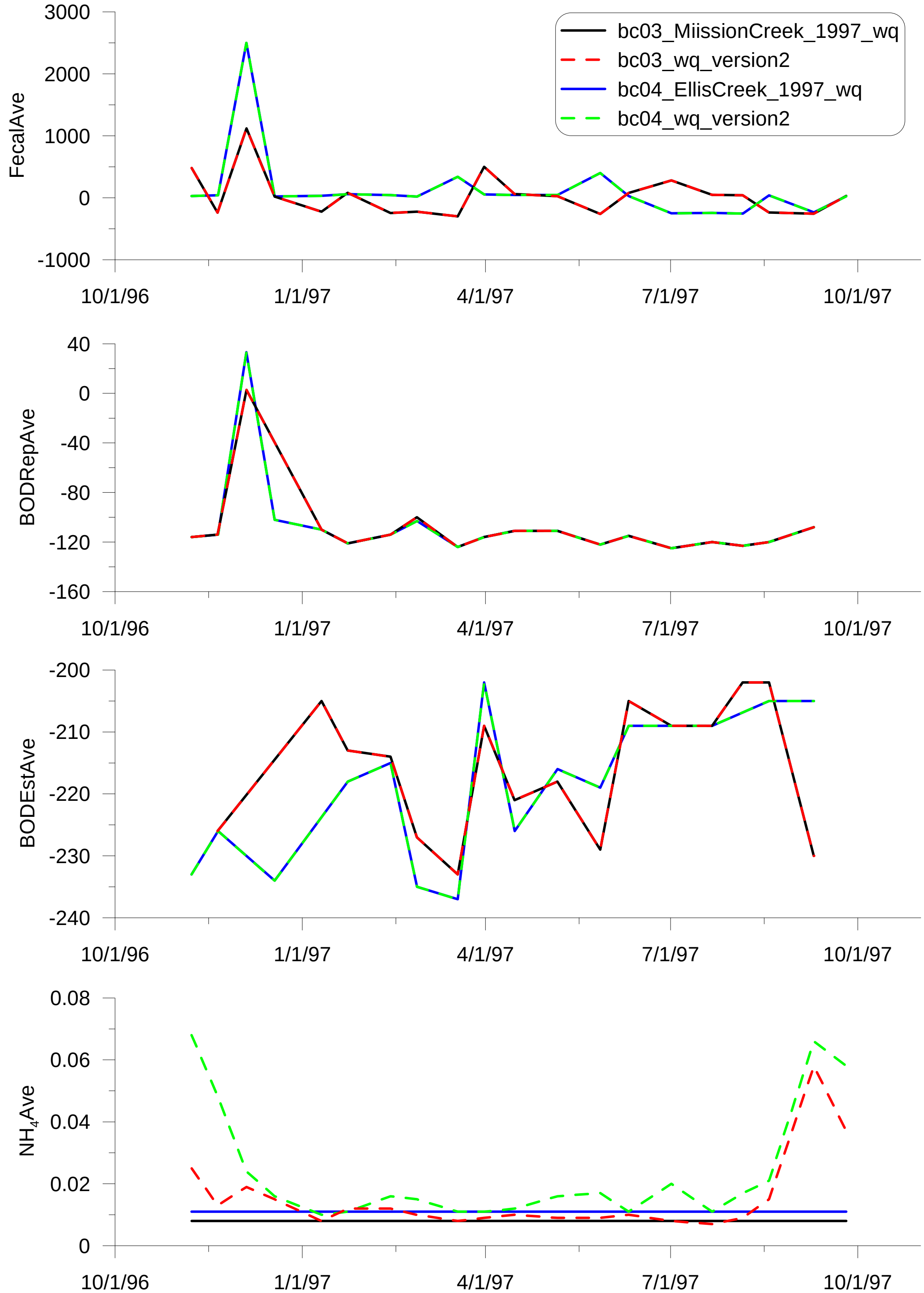


Figure 27. WQGraph3-1

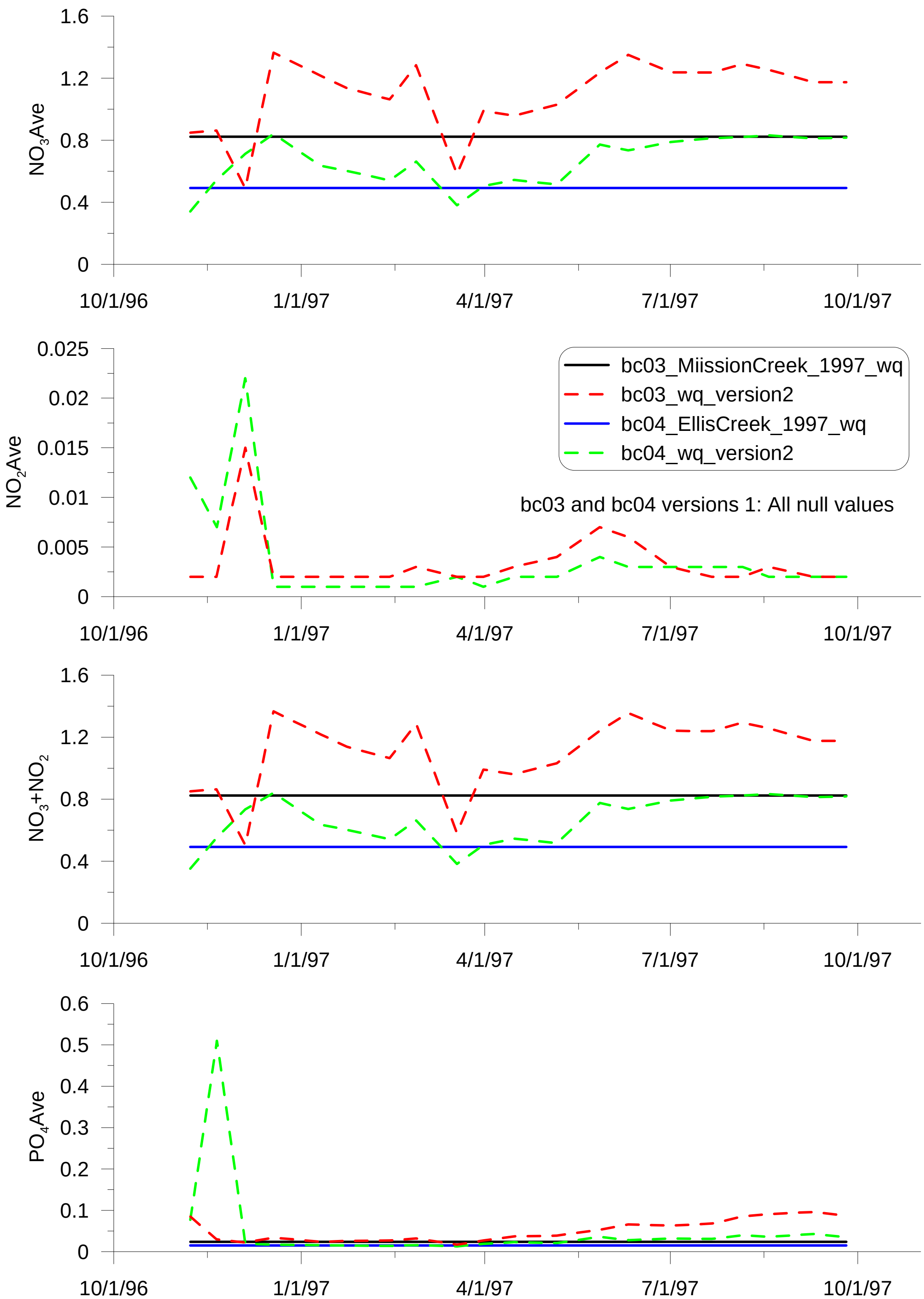


Figure 28. WQGraph3-2

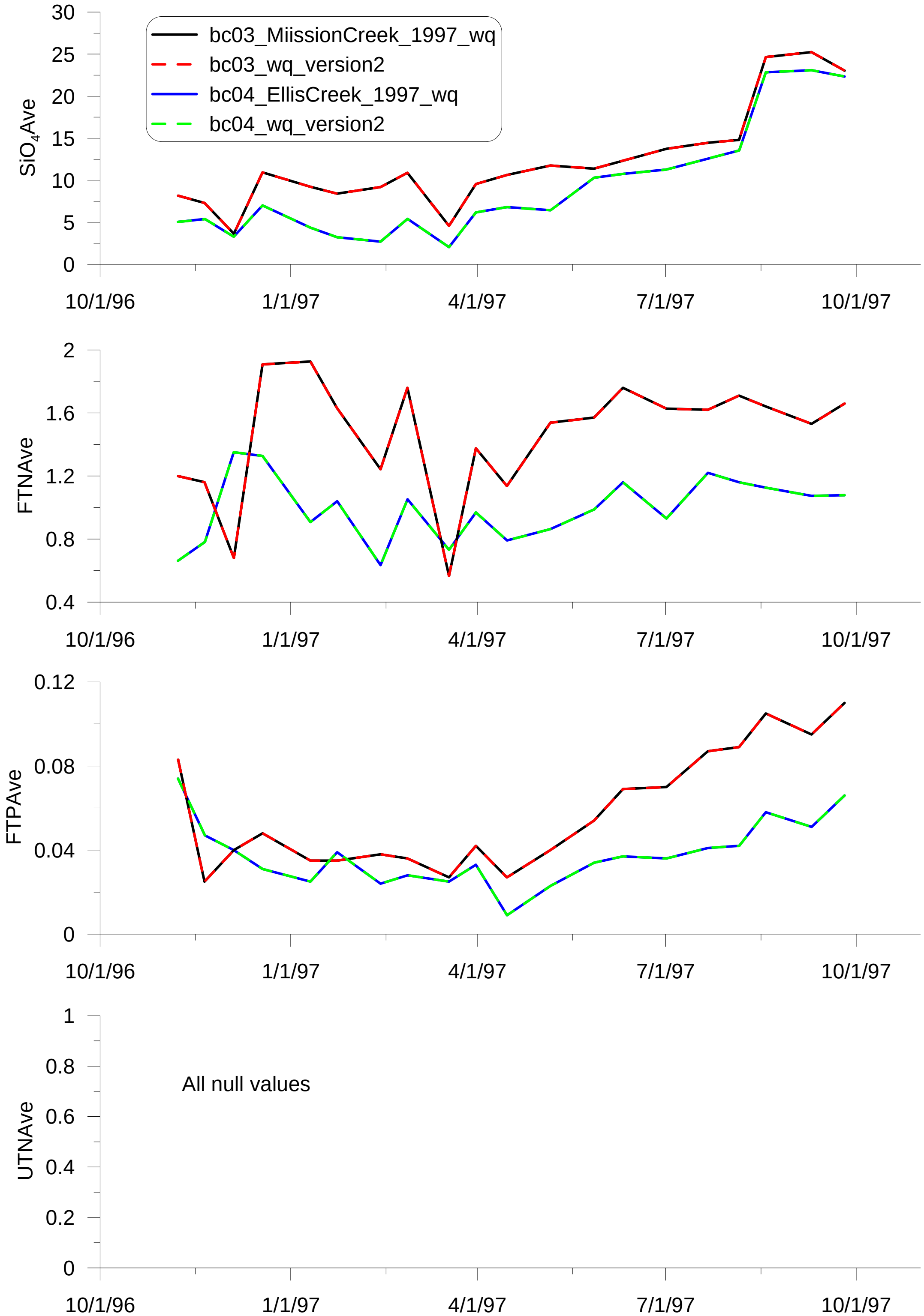


Figure 29. WQGraph3-3

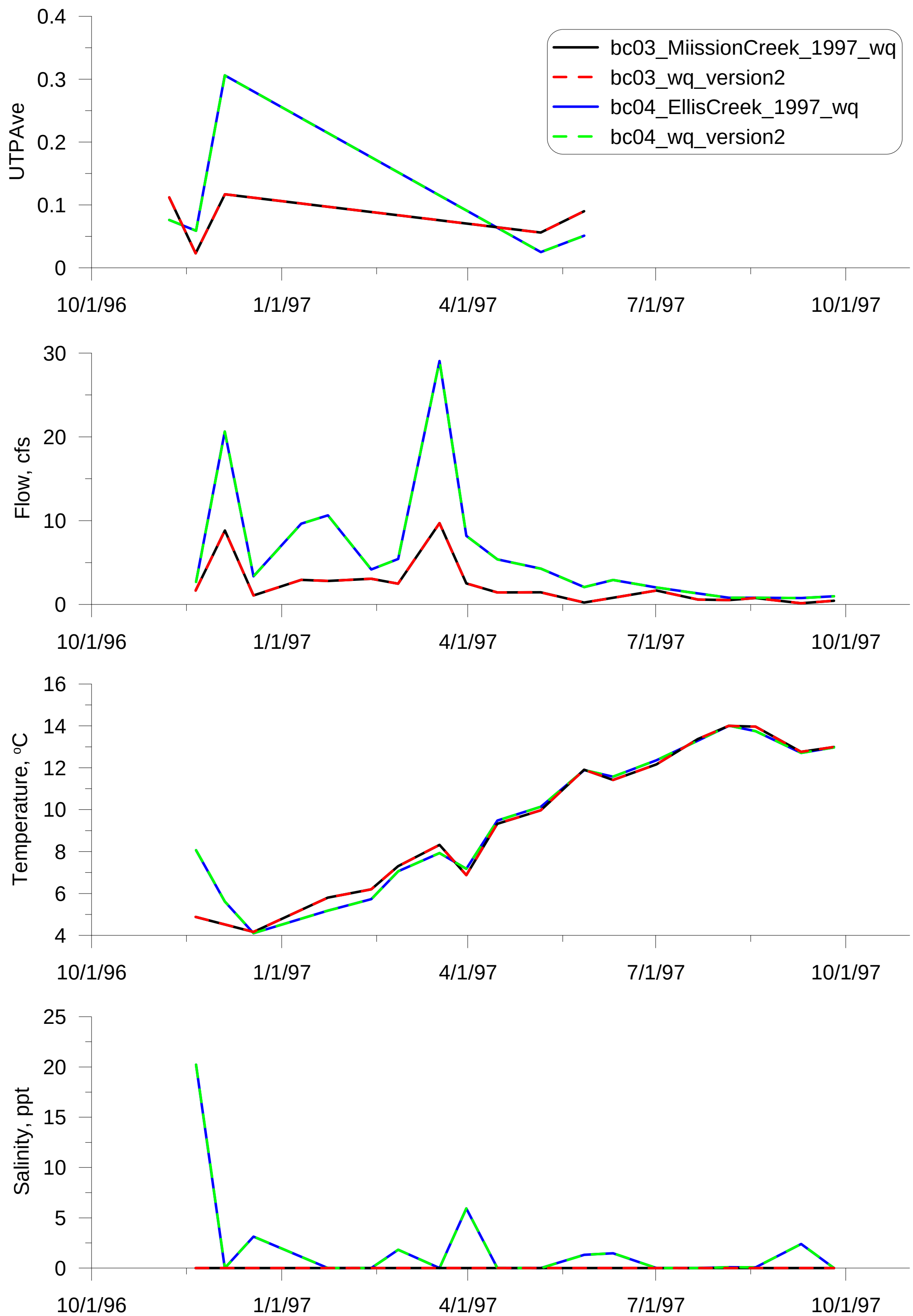


Figure 30. WQGraph3-4

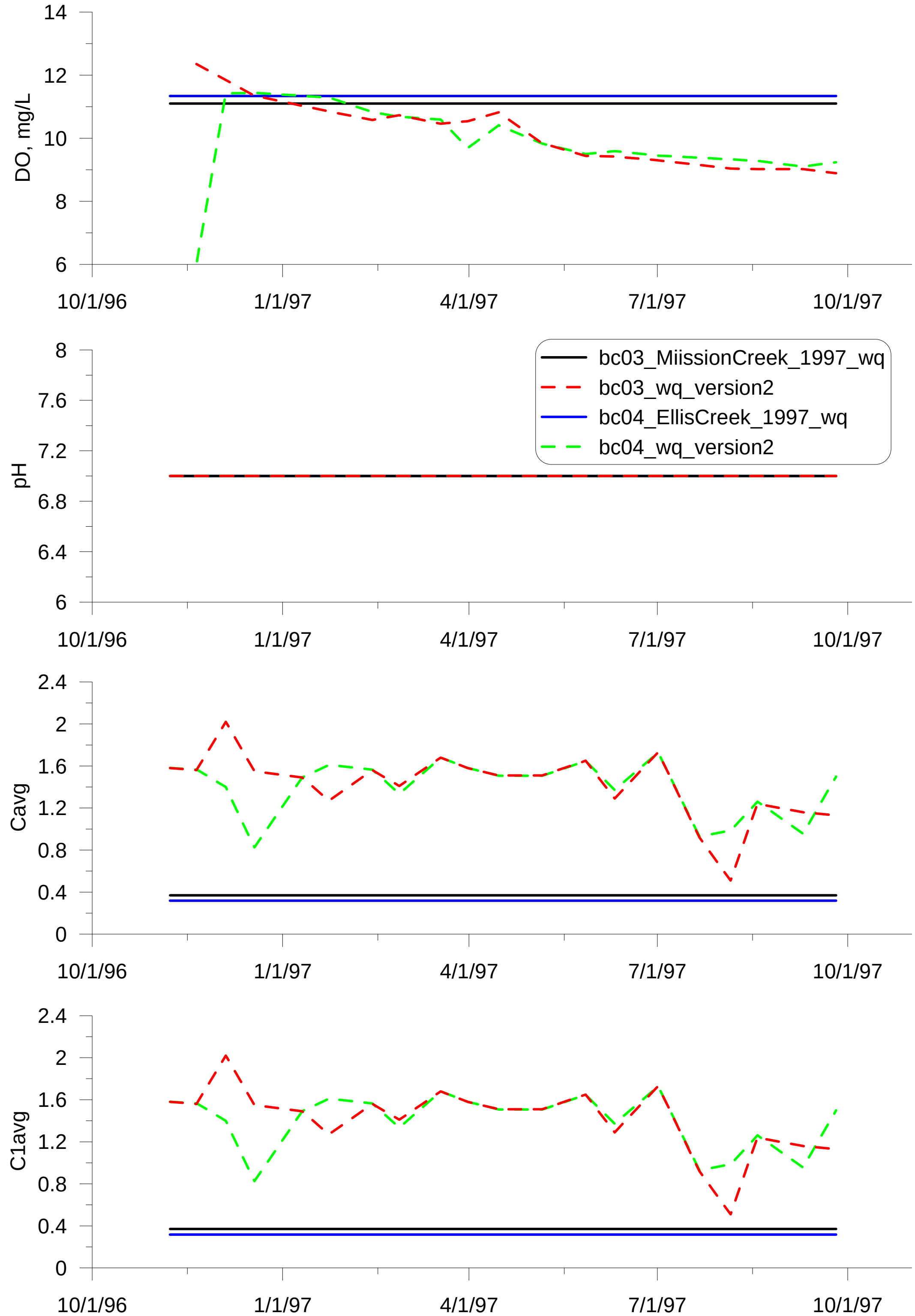


Figure 31. WQGraph3-5

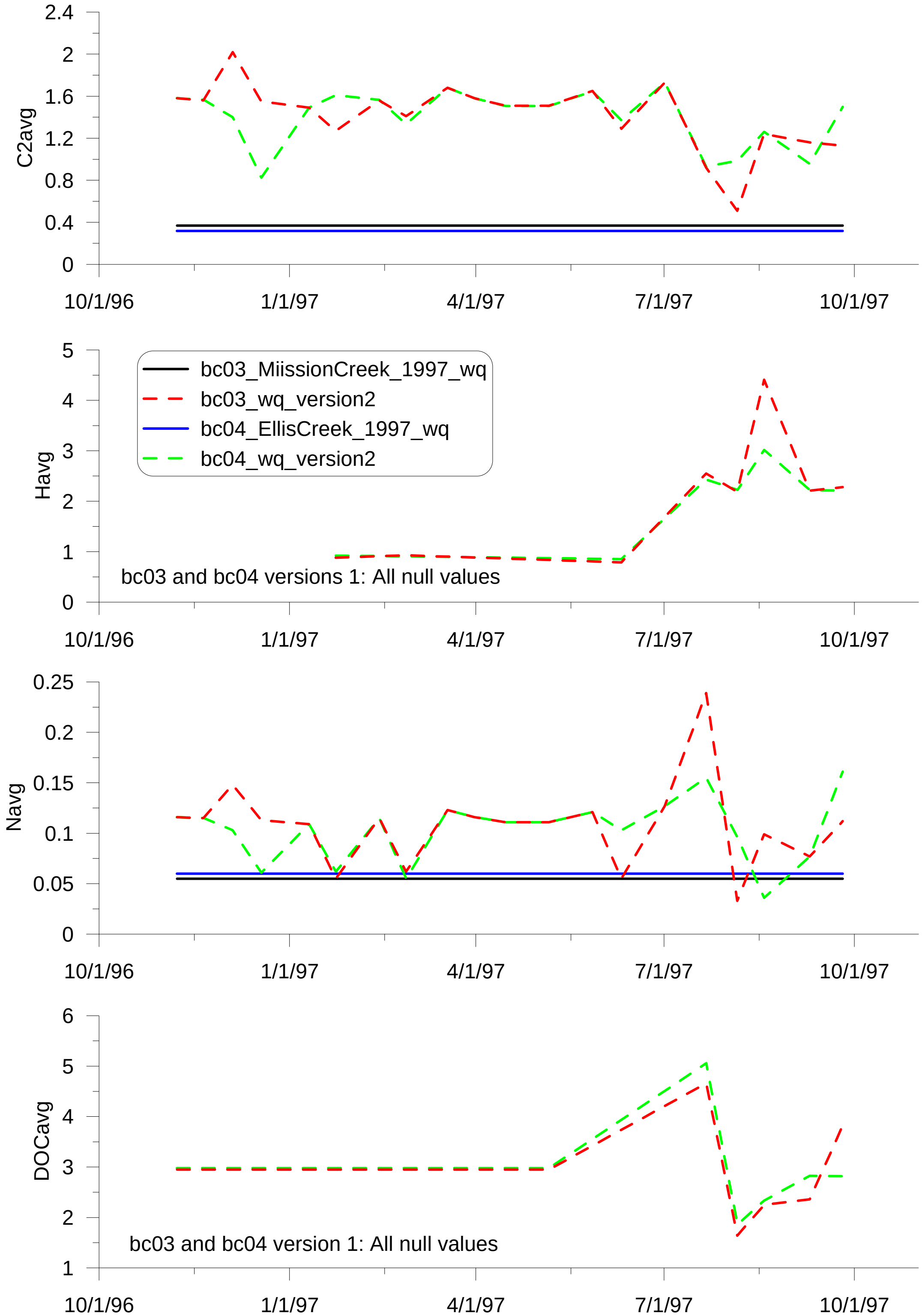
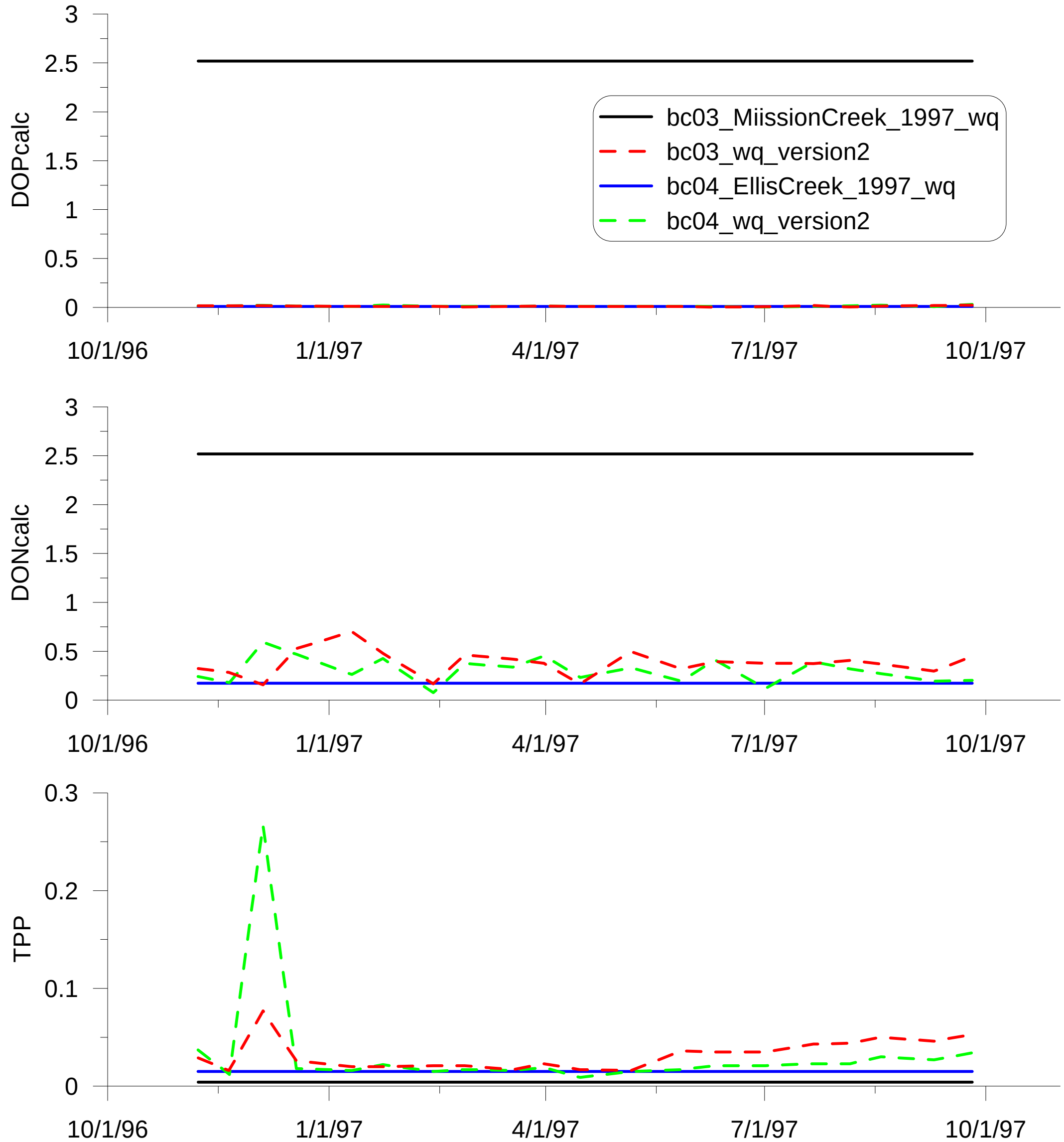


Figure 32. WQGraph3-6



Additional fields: Chlorophyll, Dinoflag, Diatoms - all null values

Figure 33. WQGraph3-7

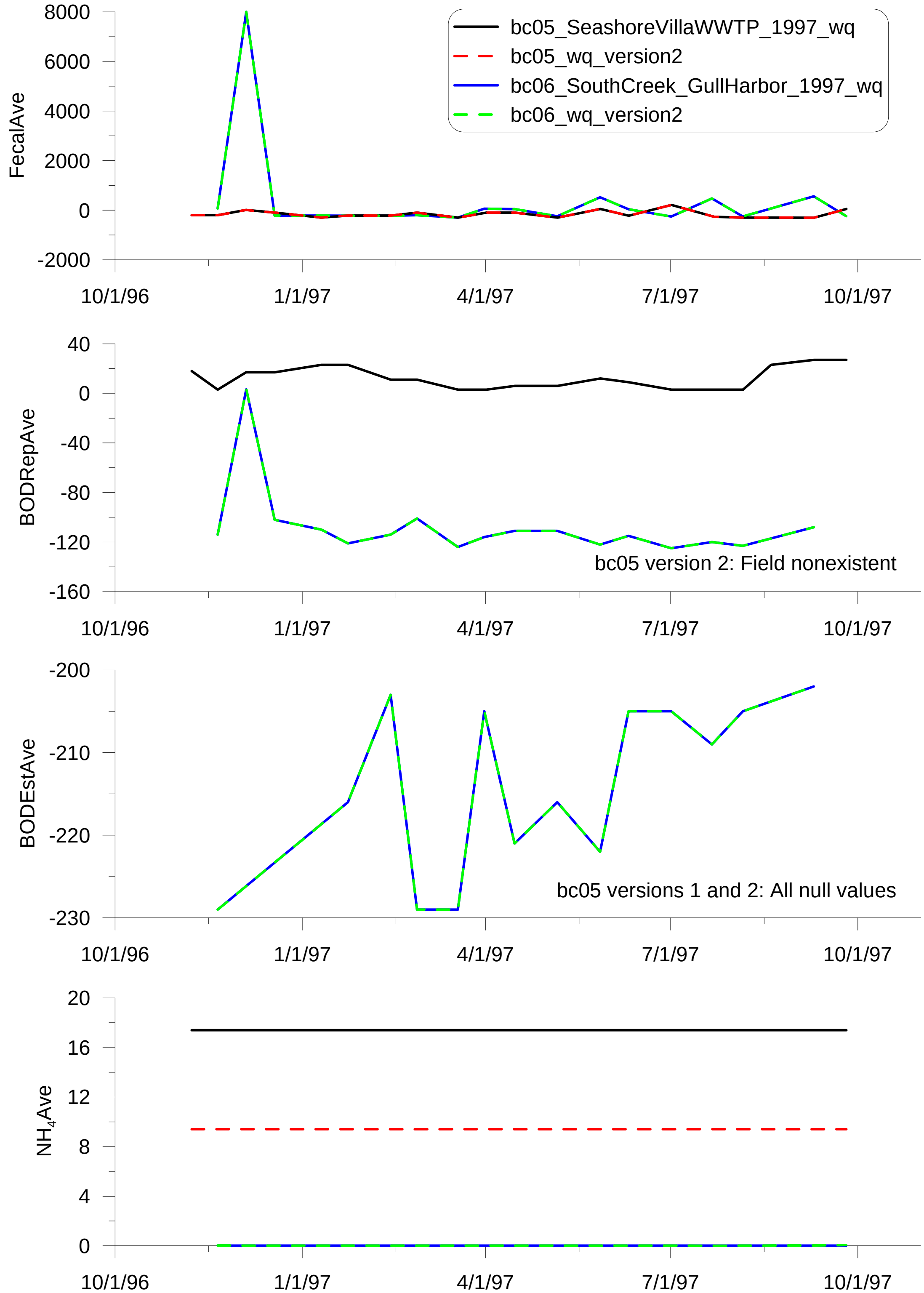


Figure 34. WQGraph4-1

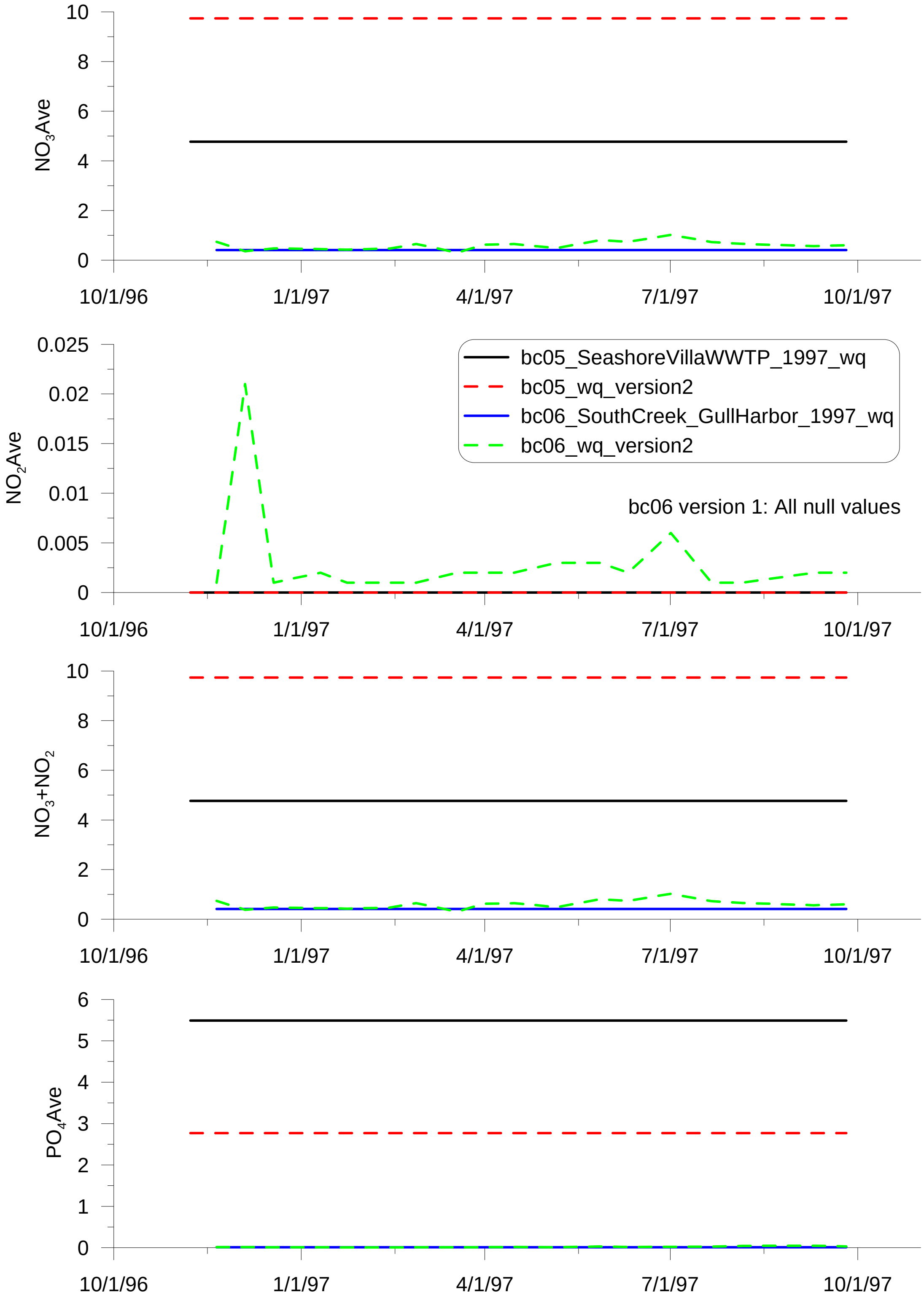


Figure 35. WQGraph4-2

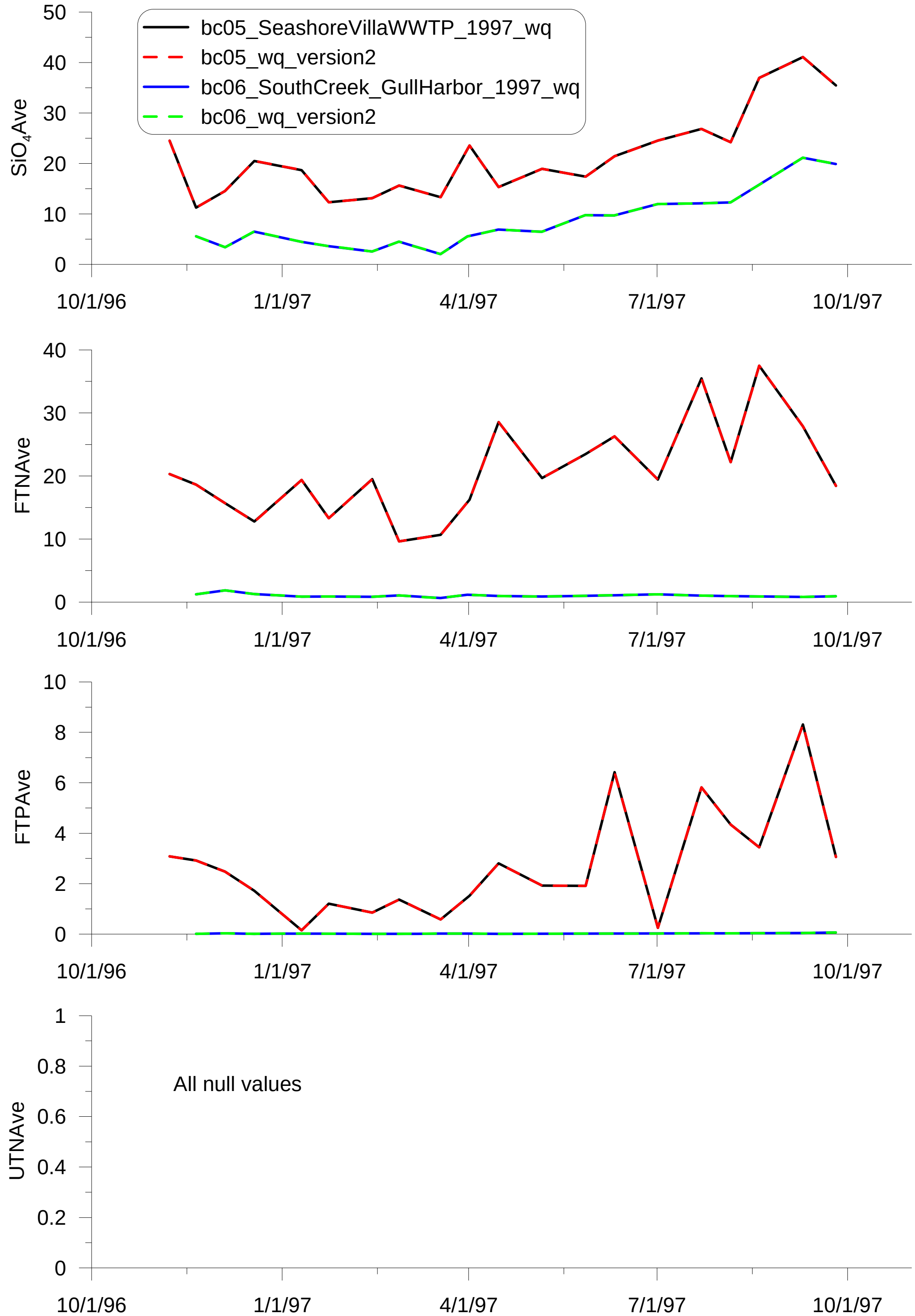


Figure 36. WQGraph4-3

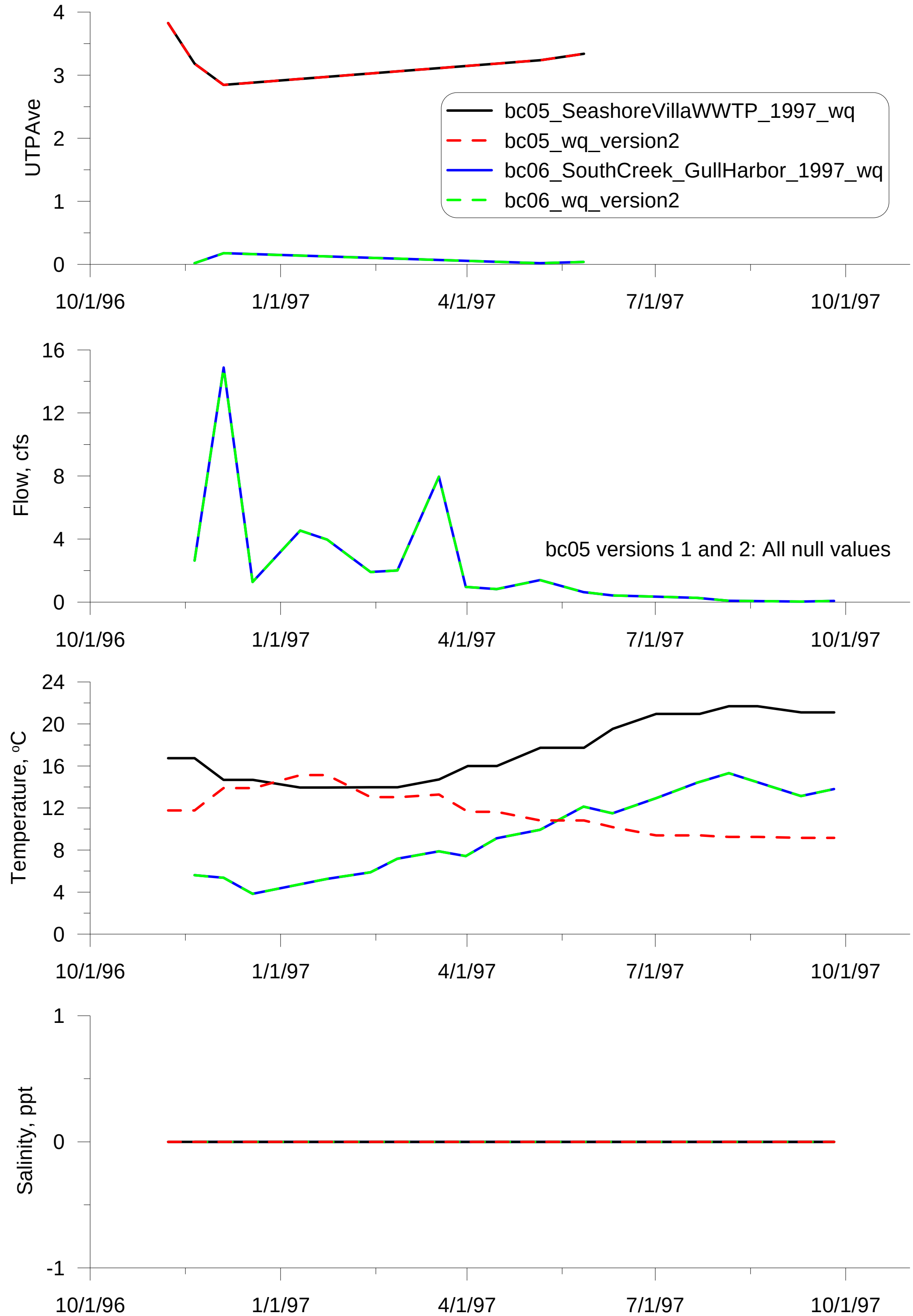


Figure 37. WQGraph4-4

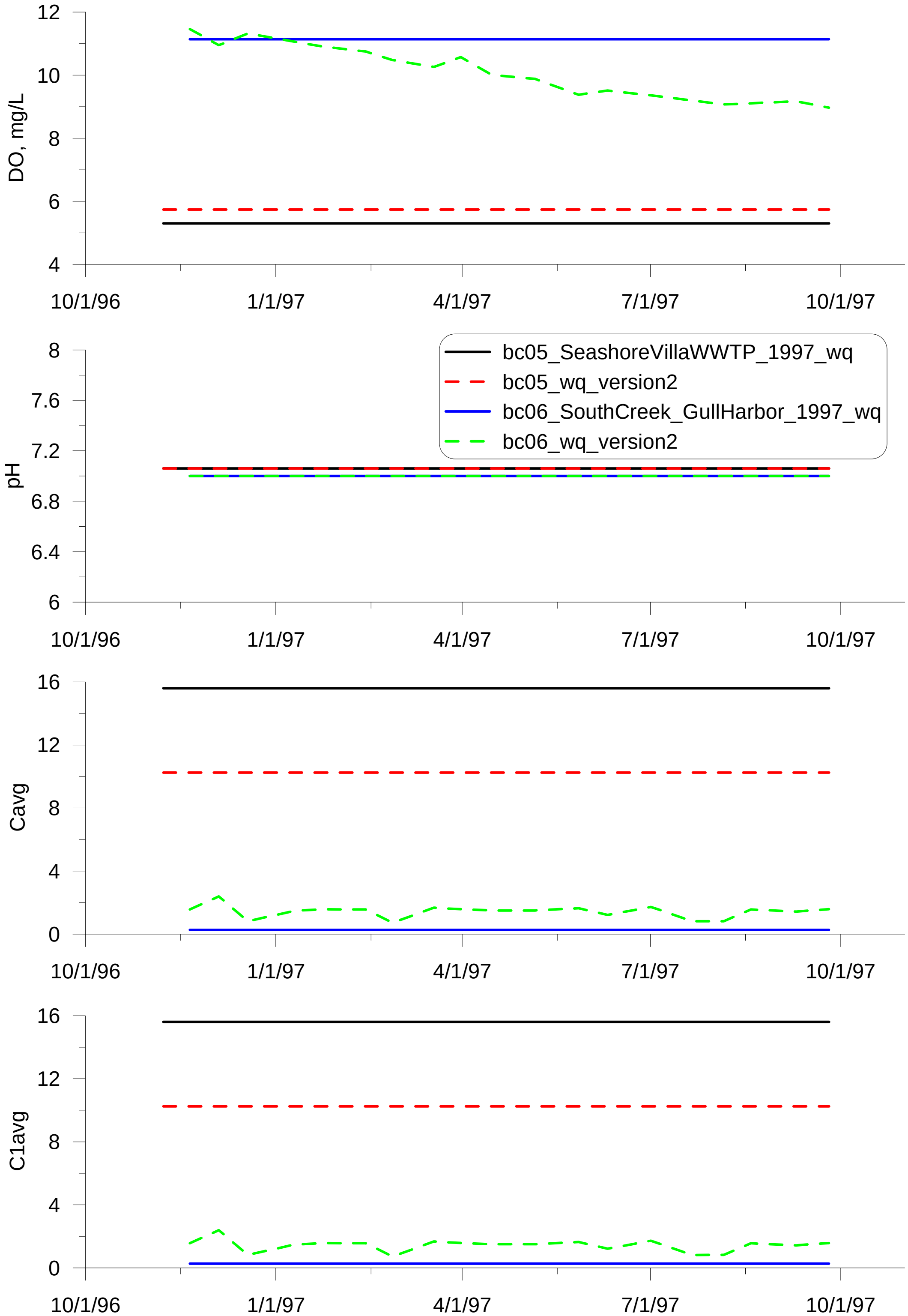


Figure 38. WQGraph4-5

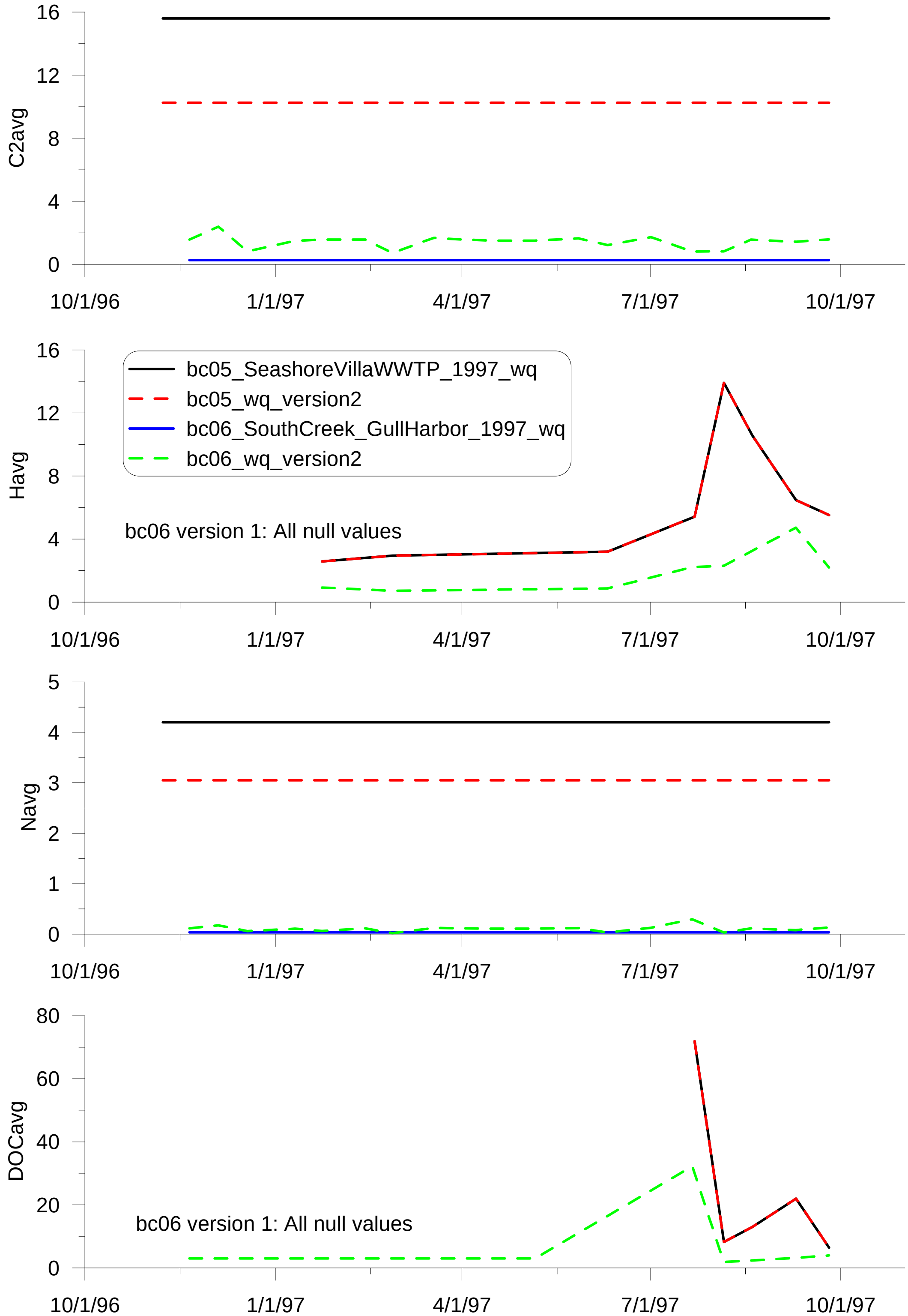
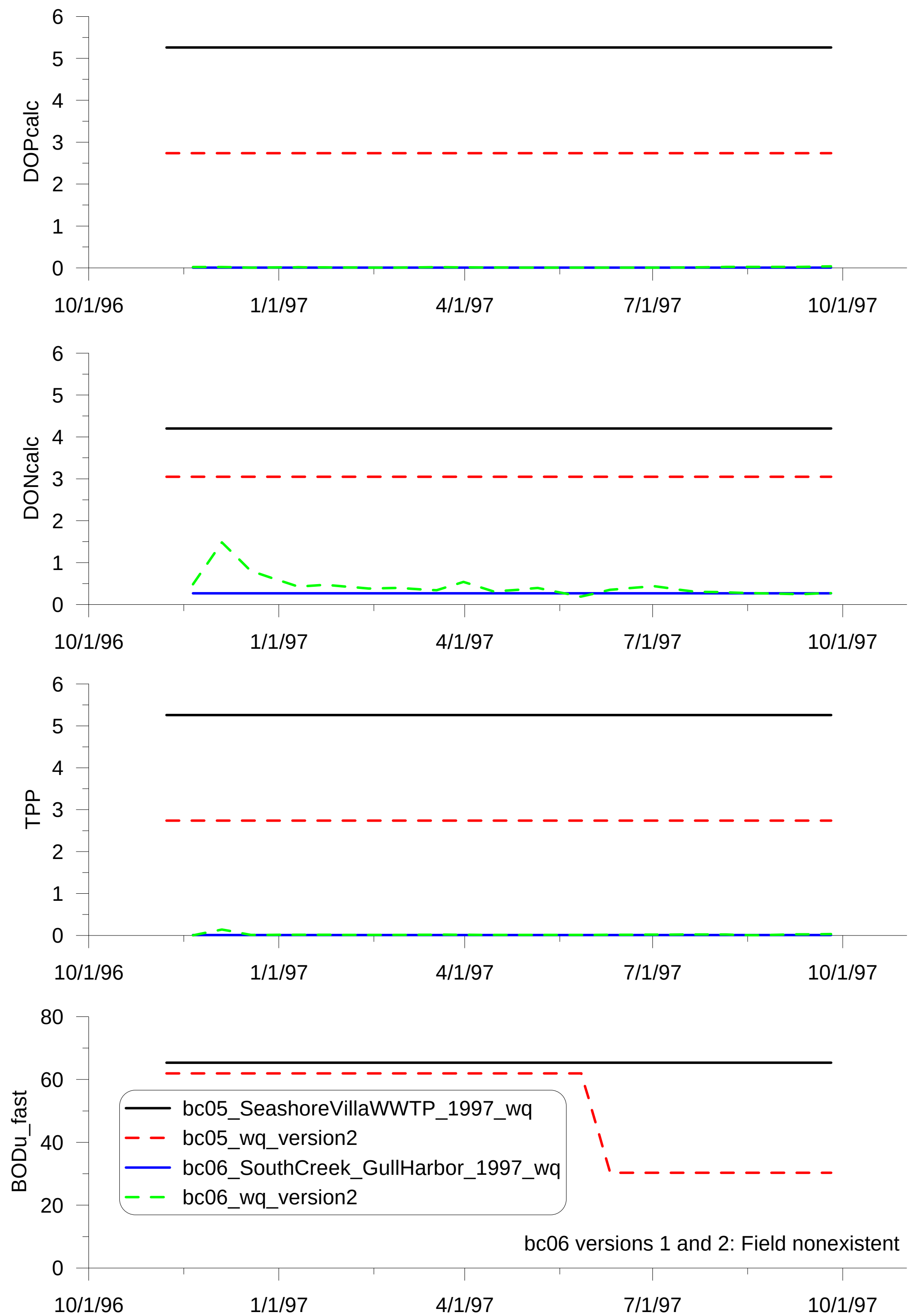


Figure 39. WQGraph4-6



Additional fields in bc06 versions 1 and 2: Chlorophyll, Dinoflag, Diatoms - all null values

Figure 40. WQGraph4-7

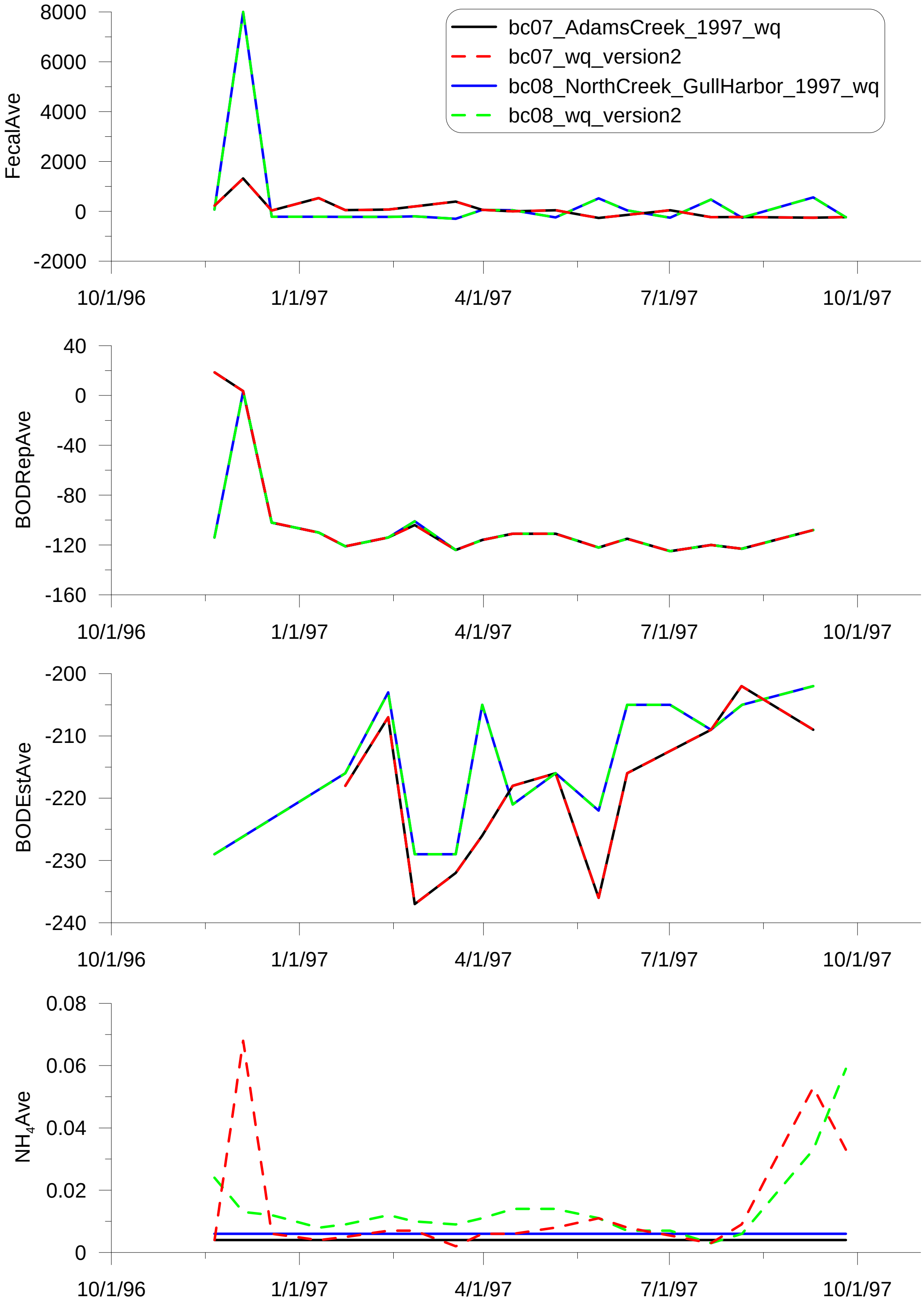


Figure 41. WQGraph5-1

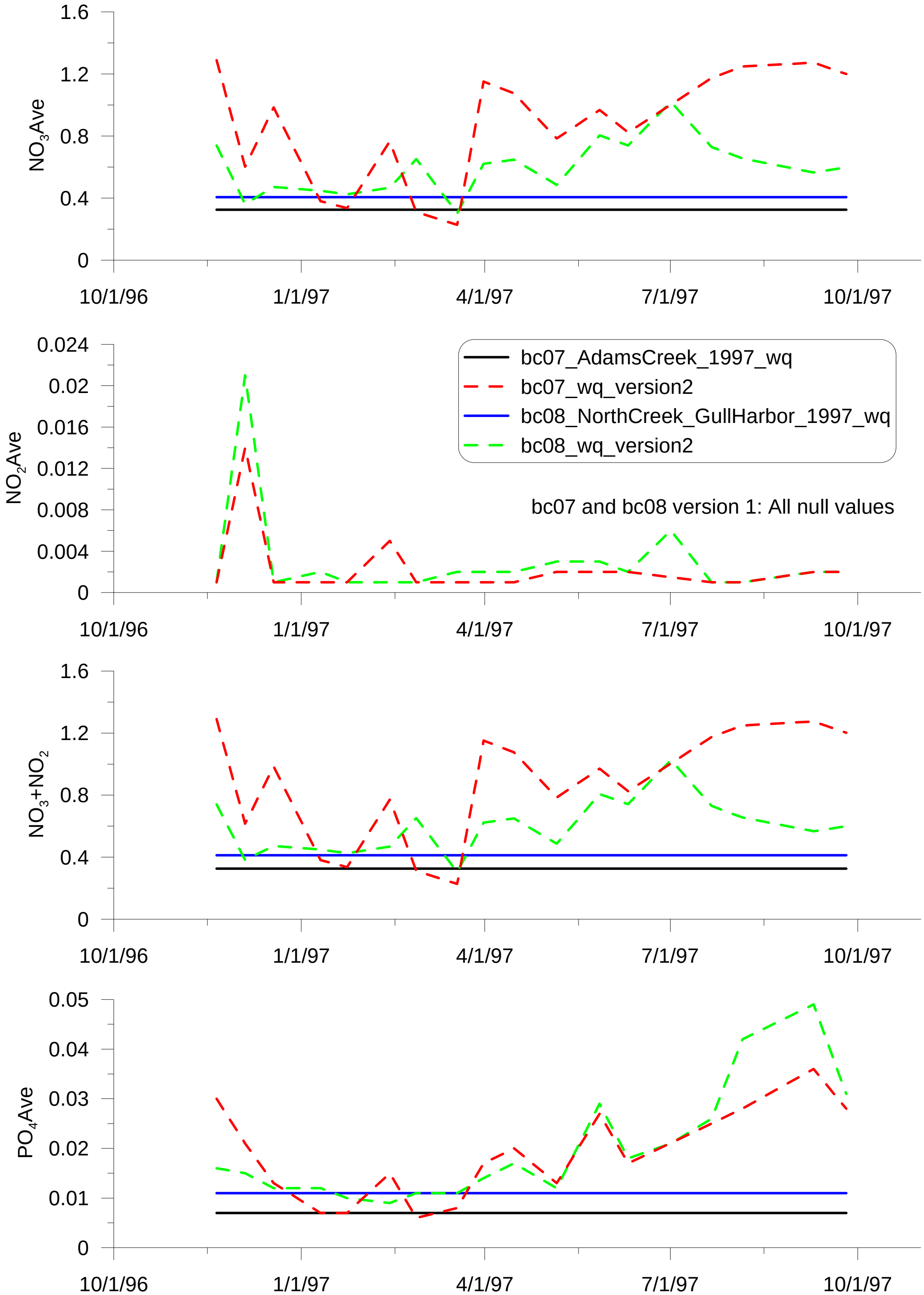


Figure 42. WQGraph5-2

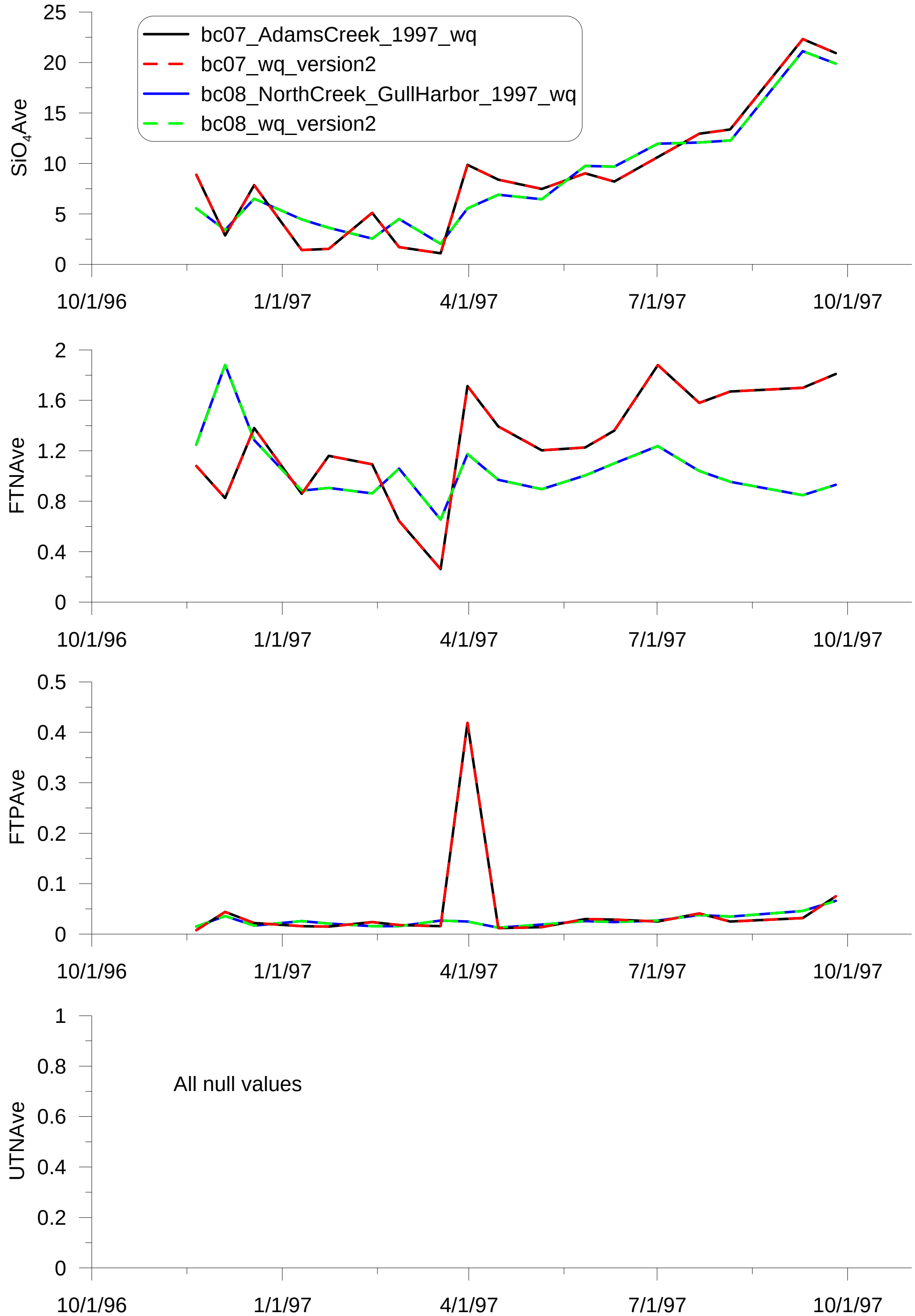


Figure 43. WQGraph5-3

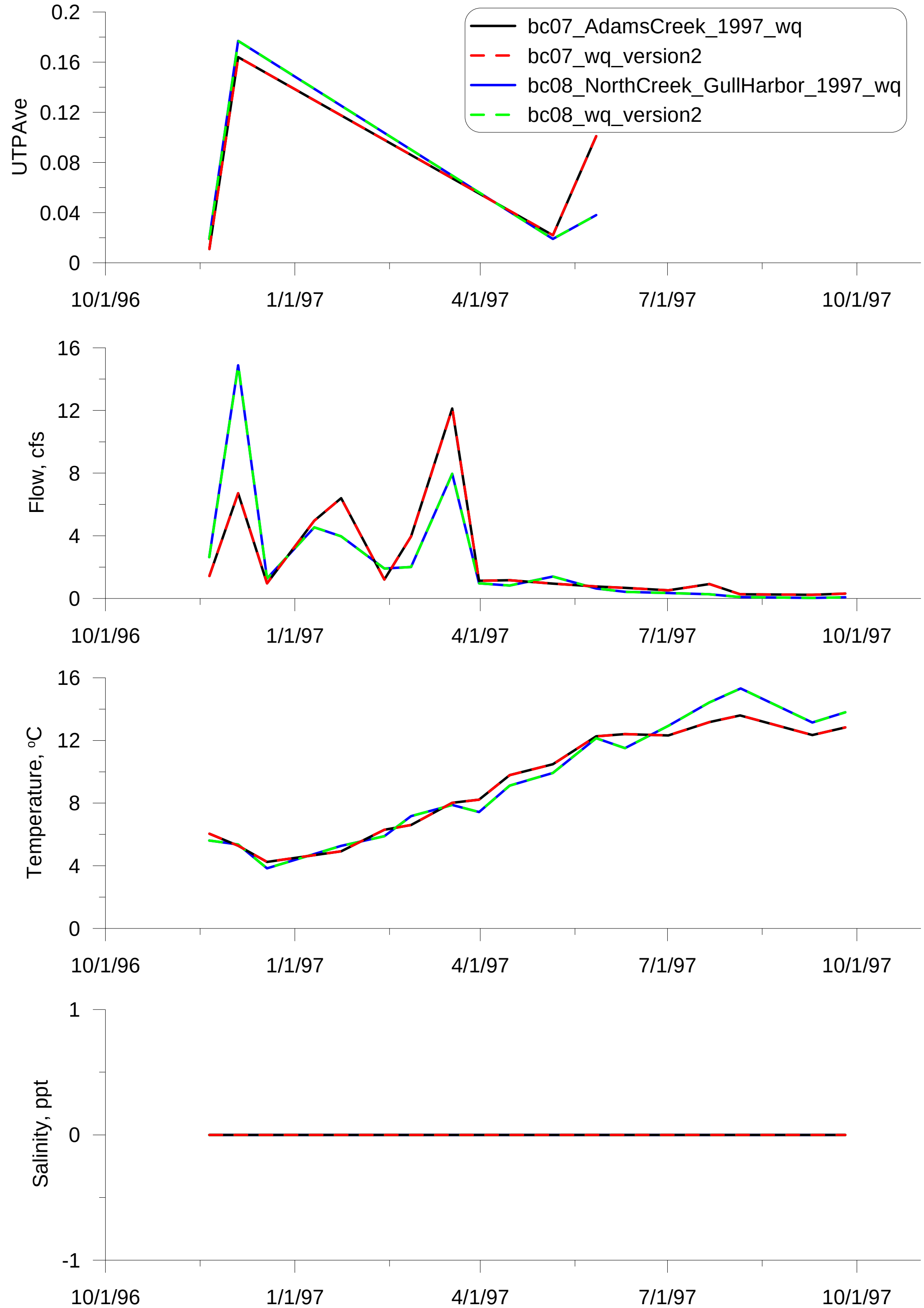


Figure 44. WQGraph5-4

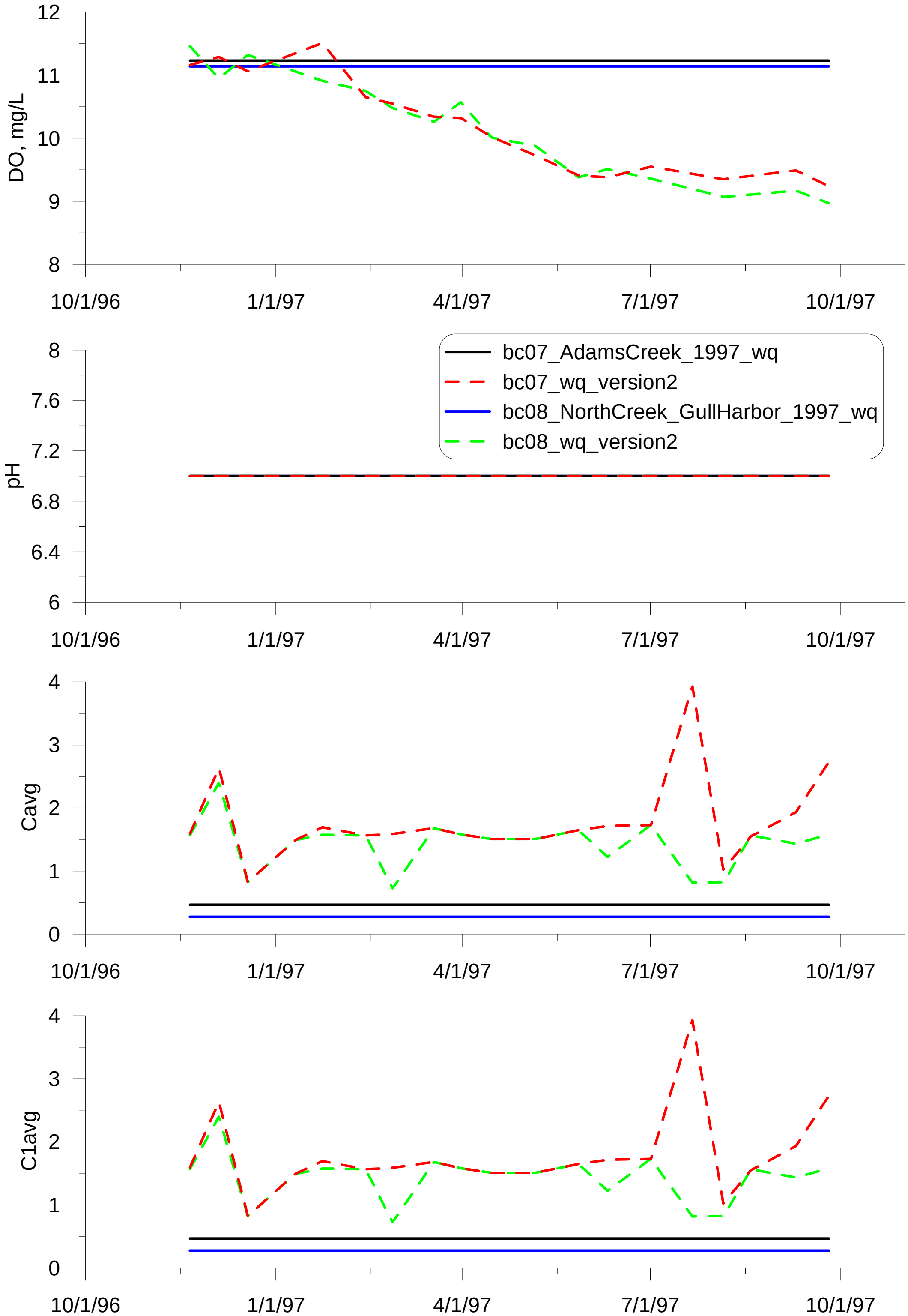


Figure 45. WQGraph5-5

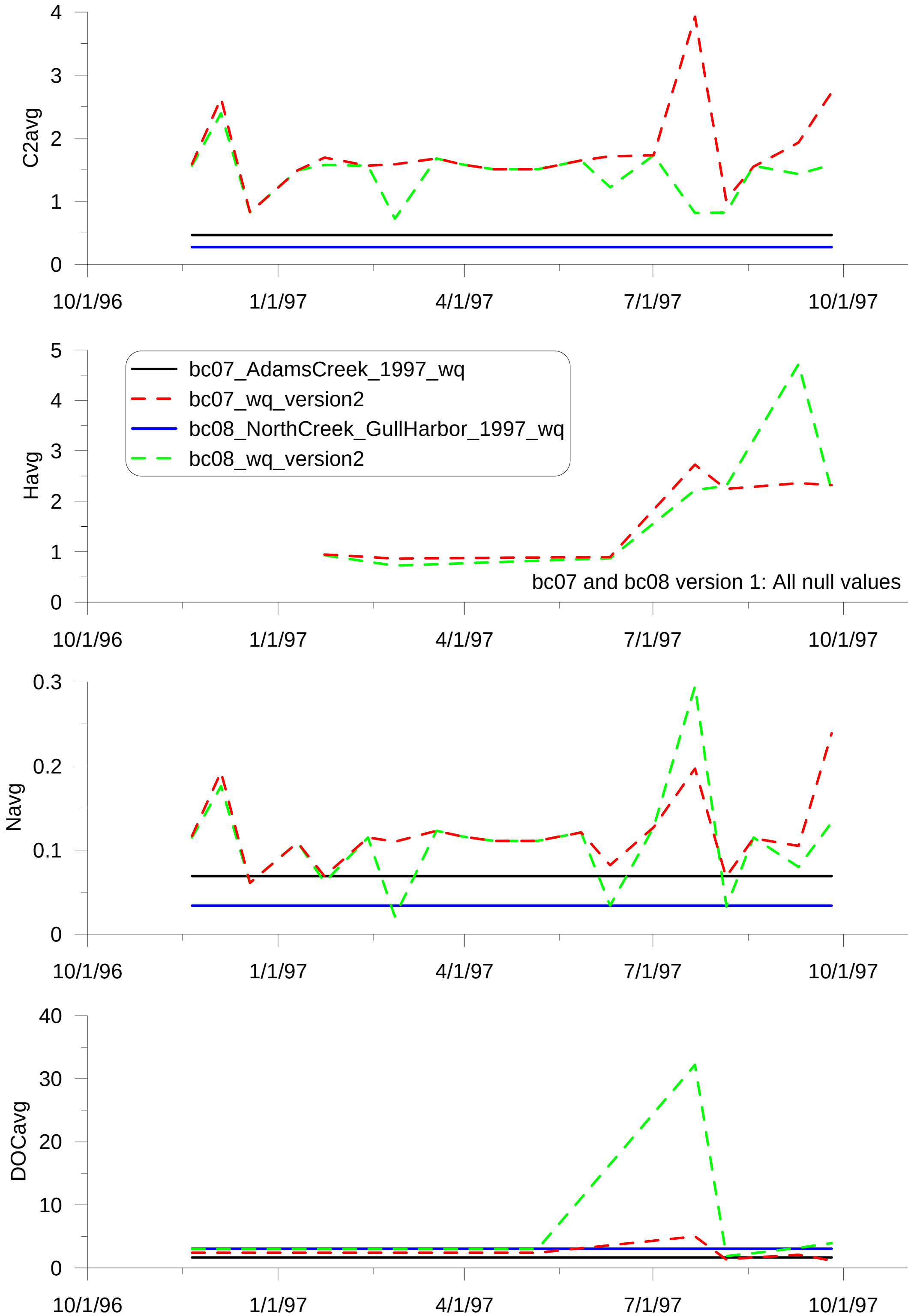
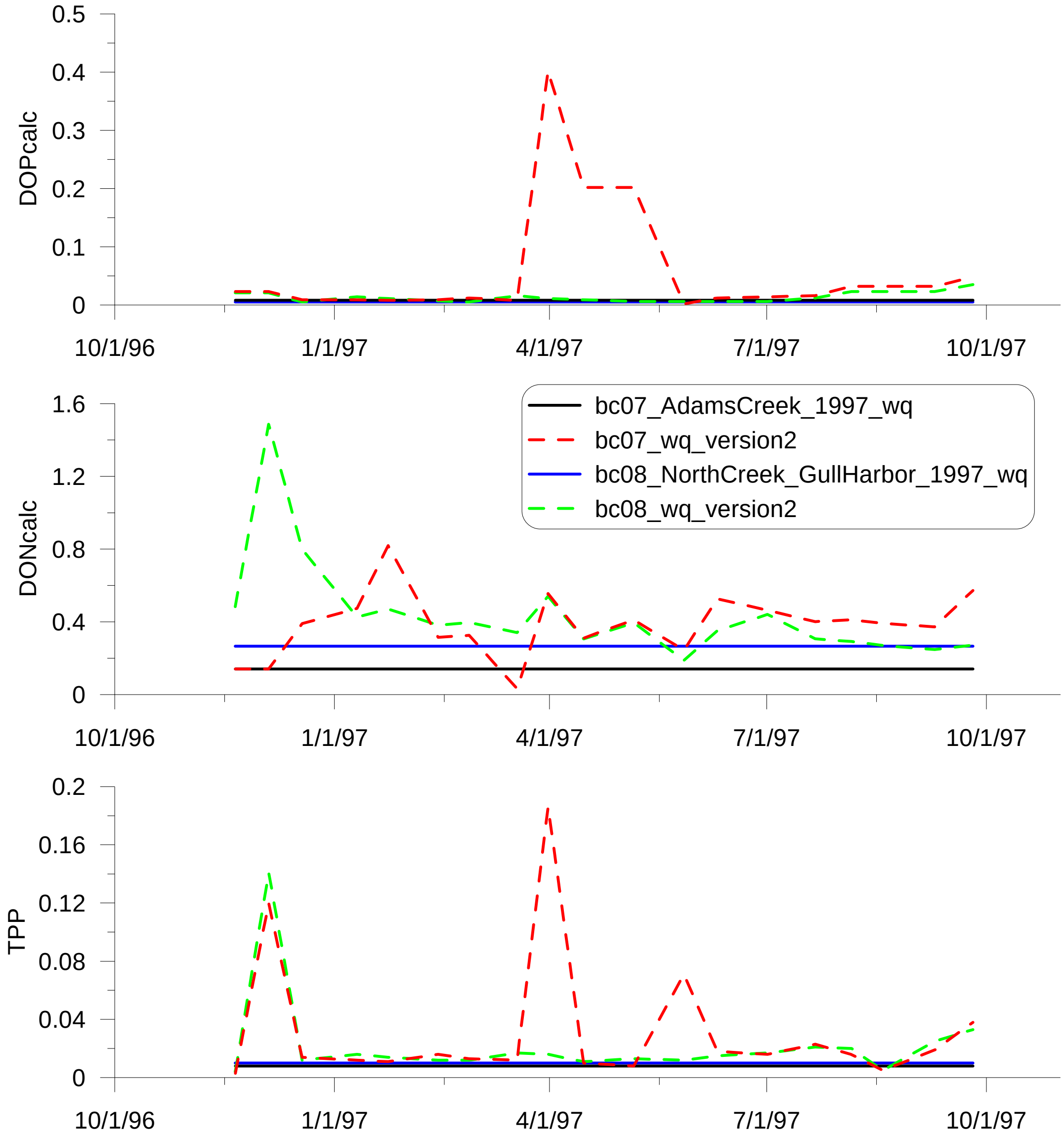


Figure 46. WQGraph5-6



Additional fields: Chlorophyll, Dinoflag, Diatoms - all null values

Figure 47. WQGraph5-7

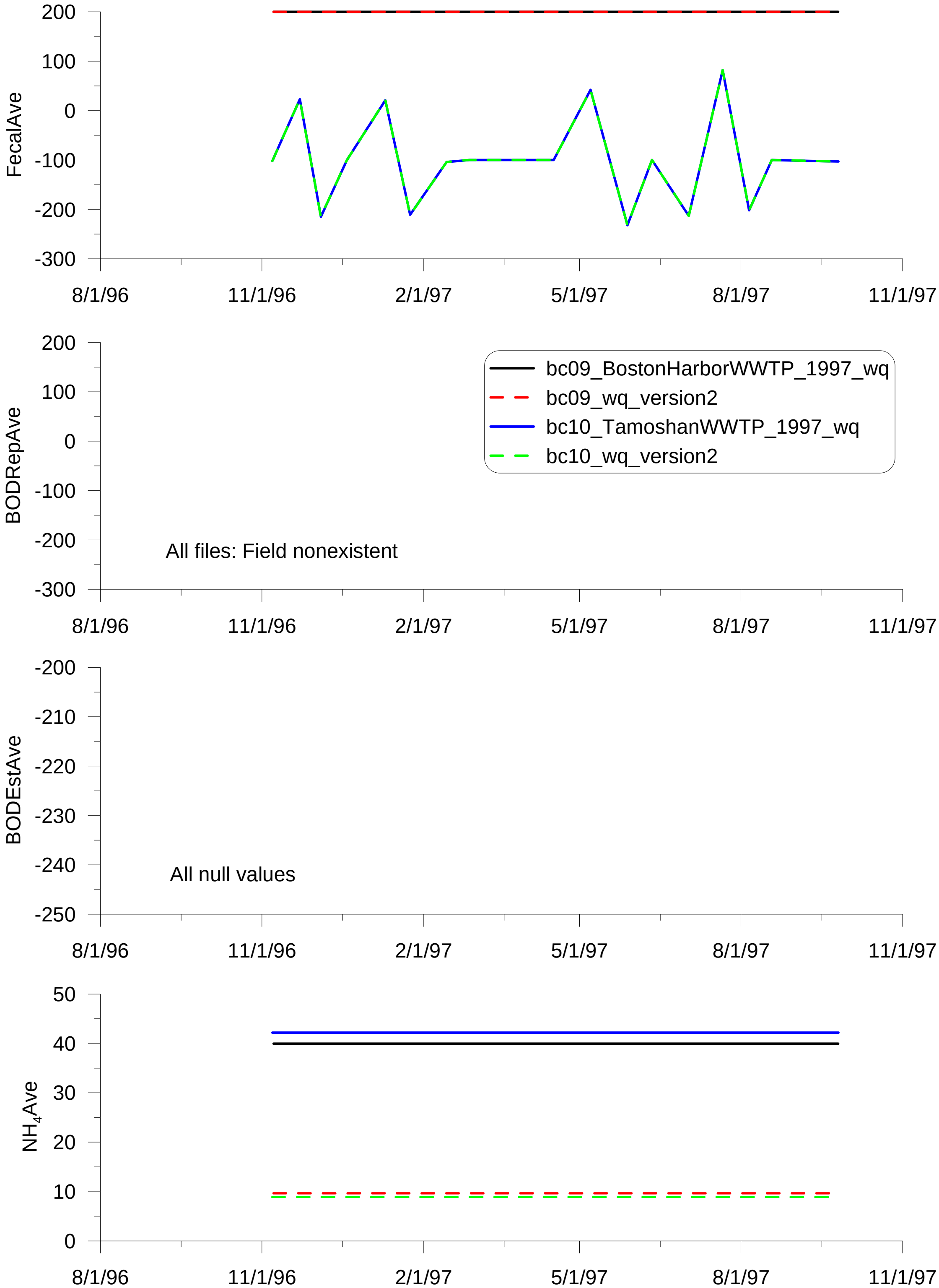


Figure 48. WQGraph6-1

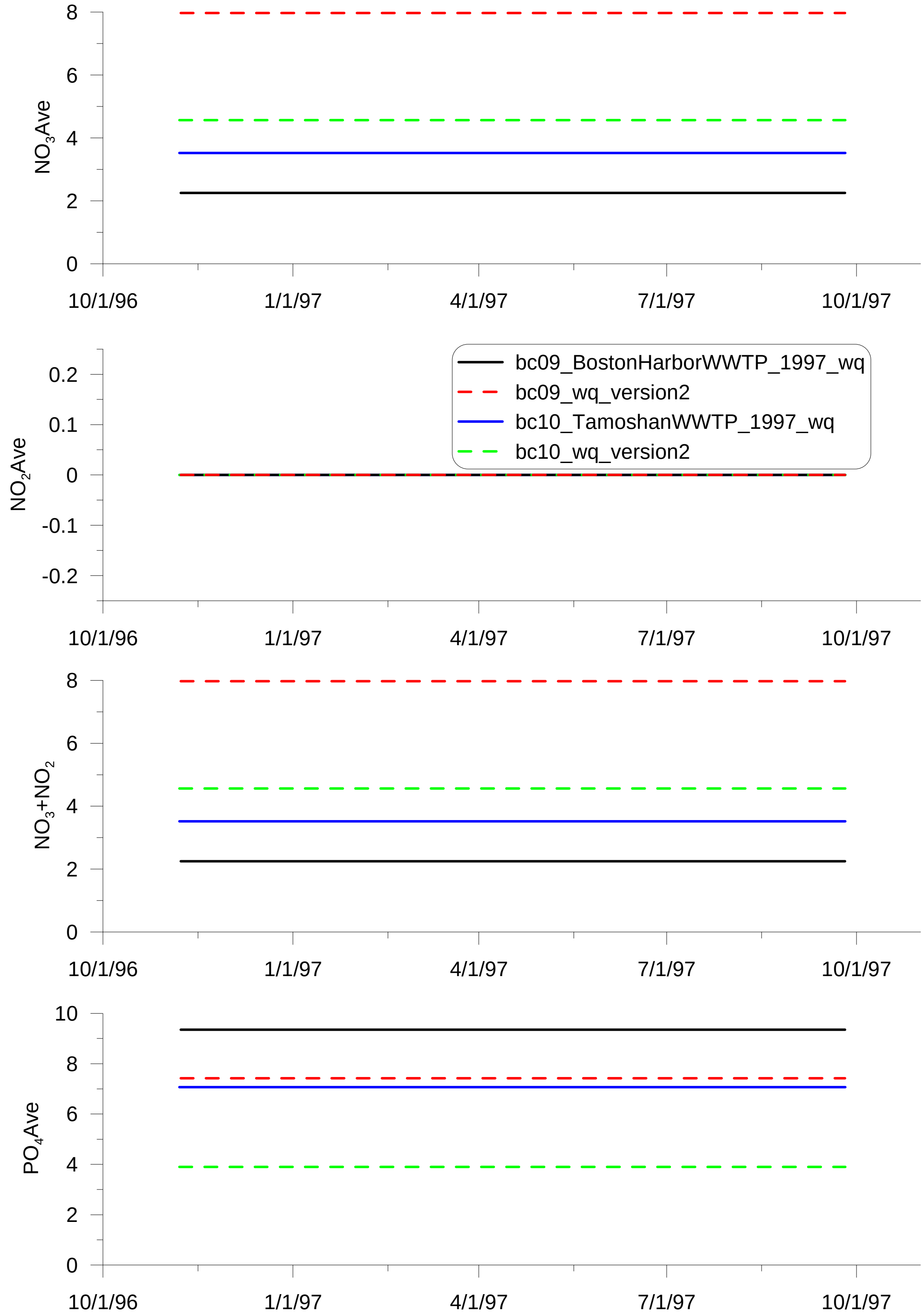


Figure 49. WQGraph6-2

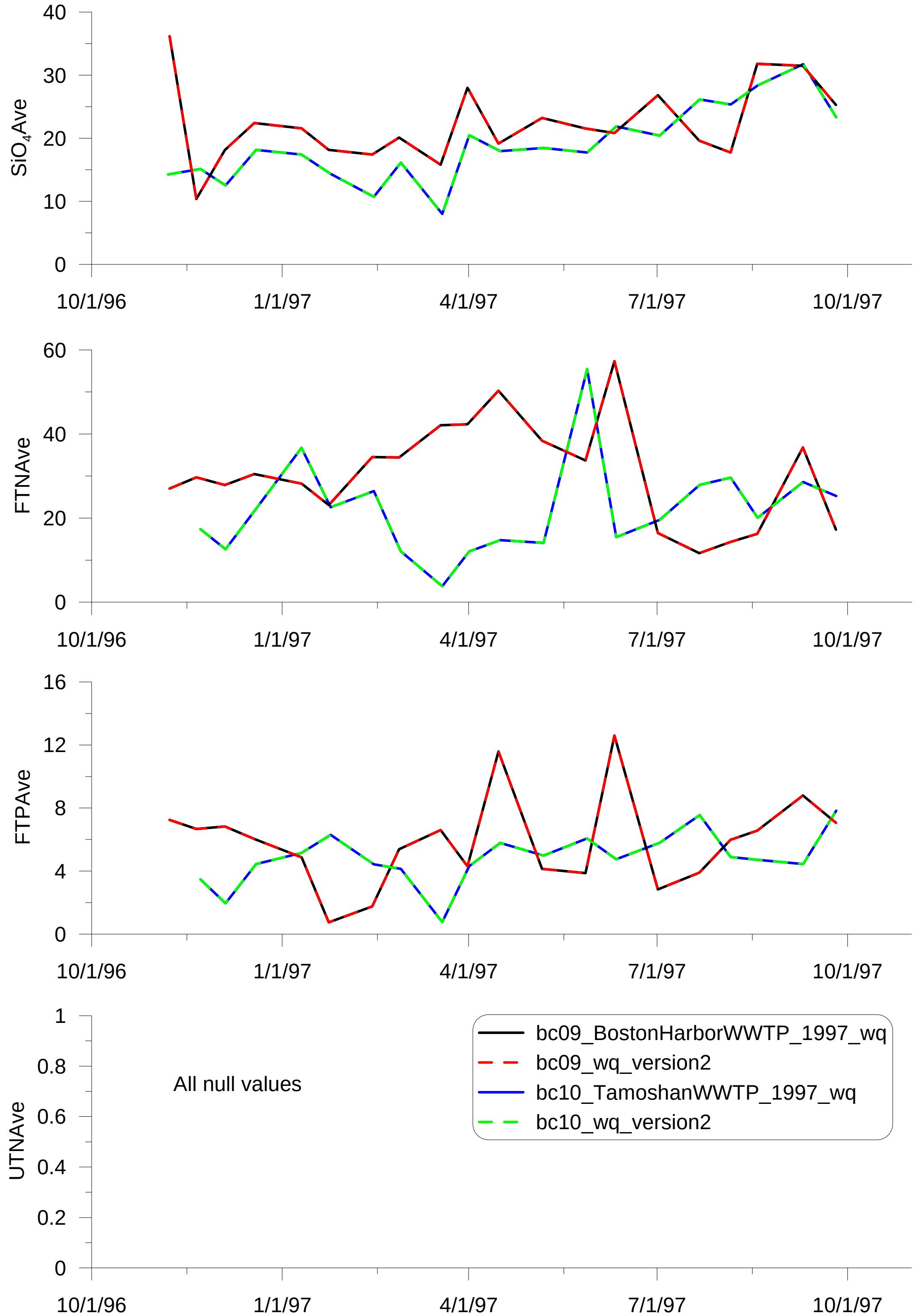


Figure 50. WQGraph6-3

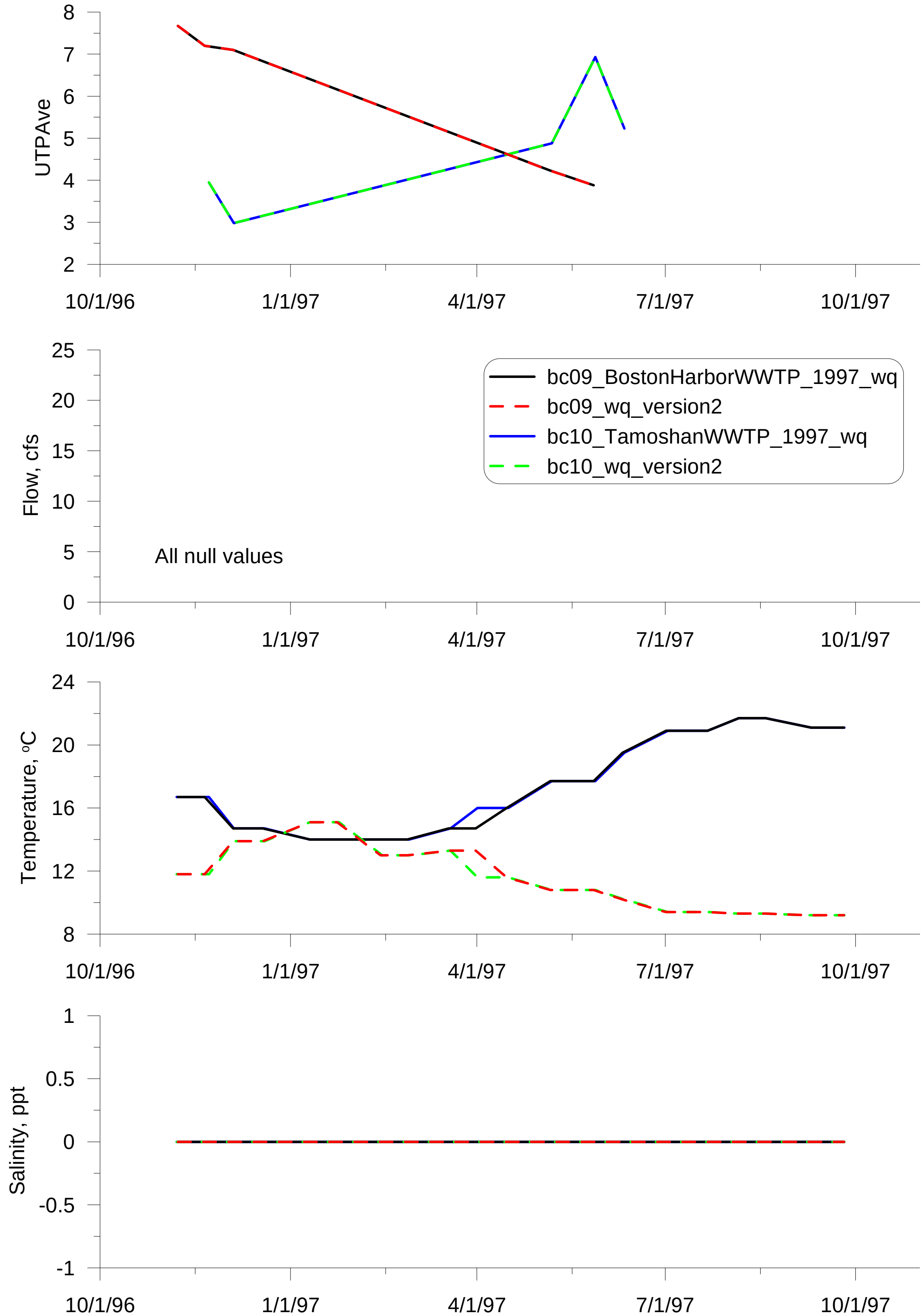


Figure 51. WQGraph6-4

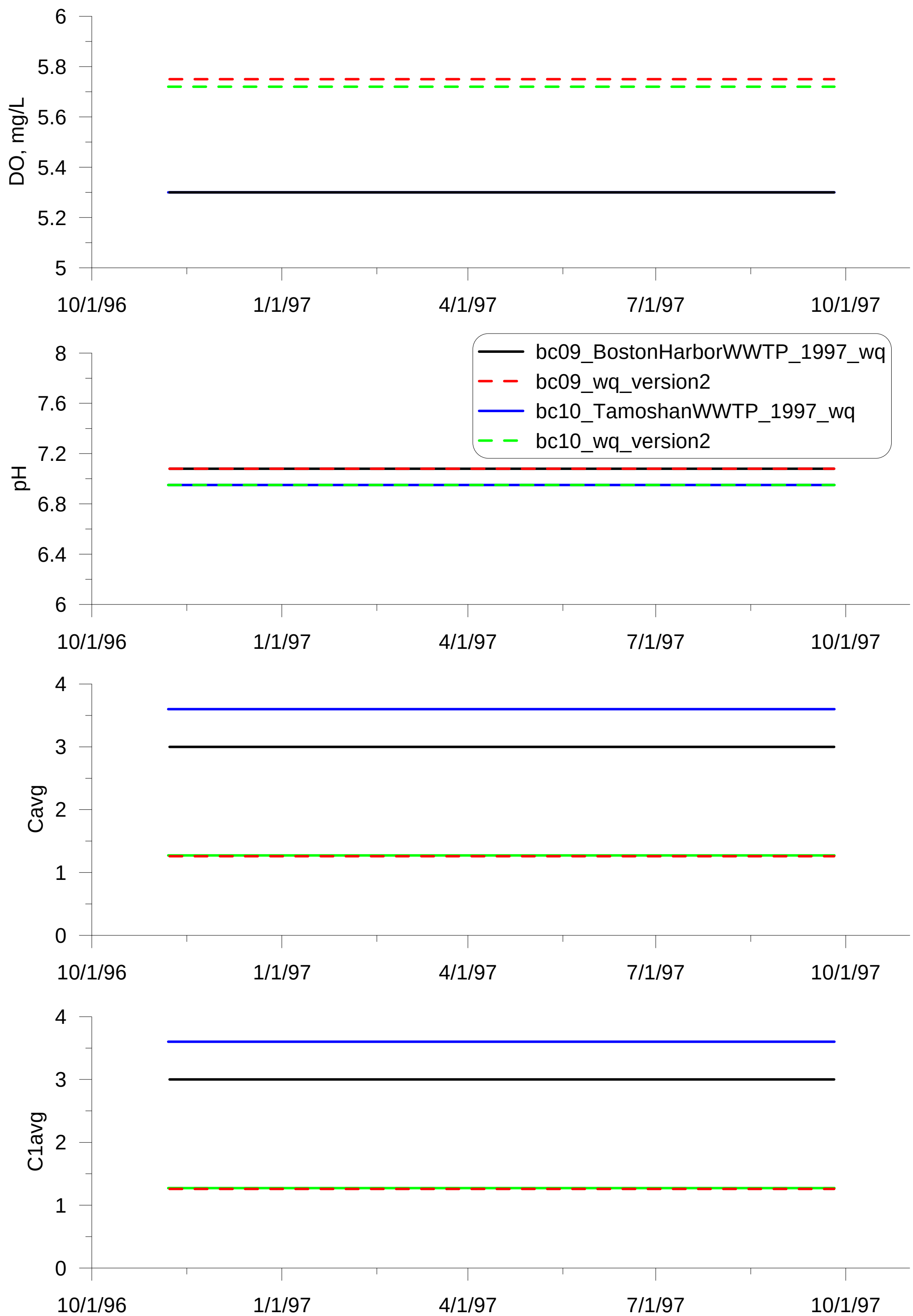


Figure 52. WQGraph6-5

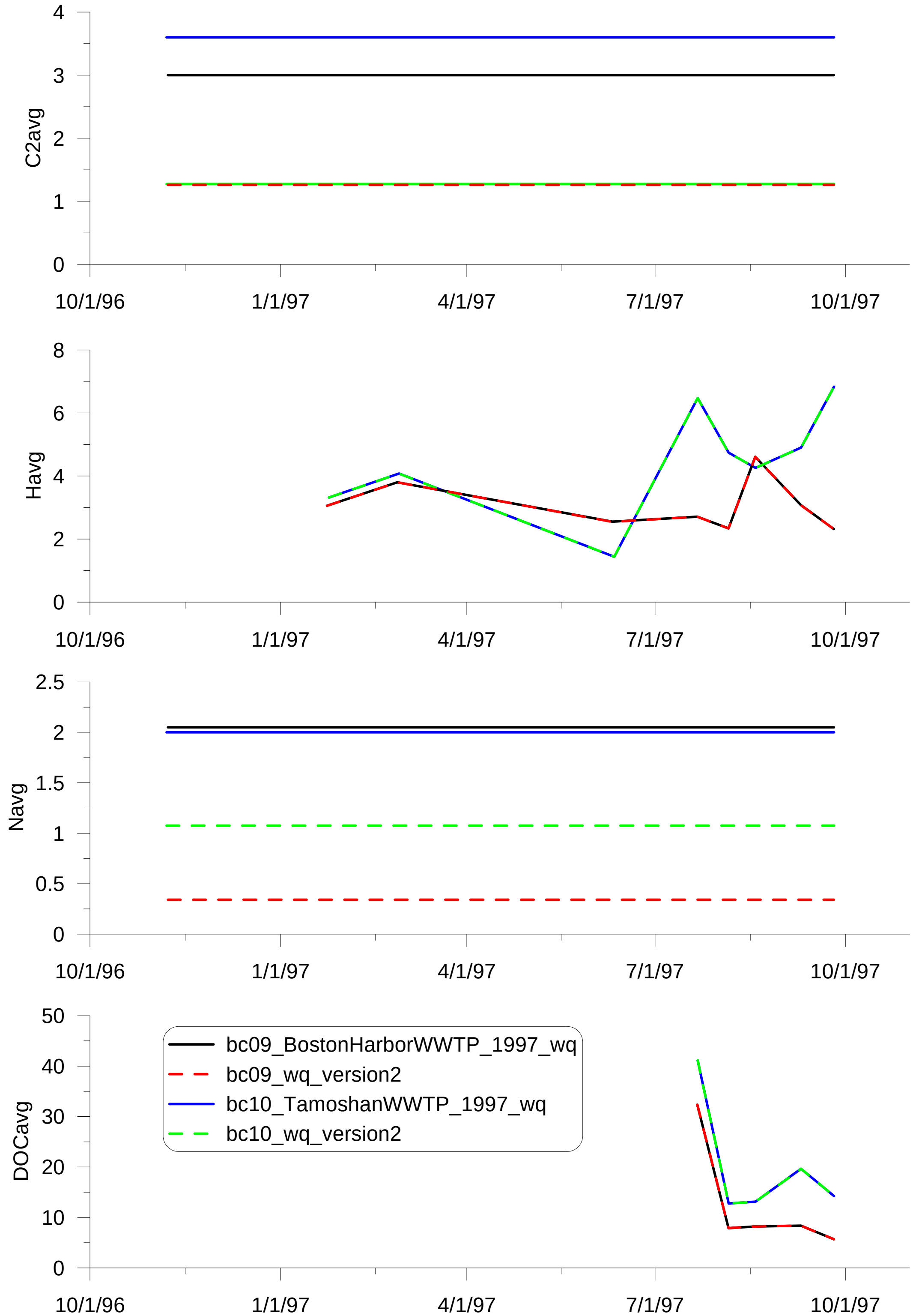


Figure 53. WQGraph6-6

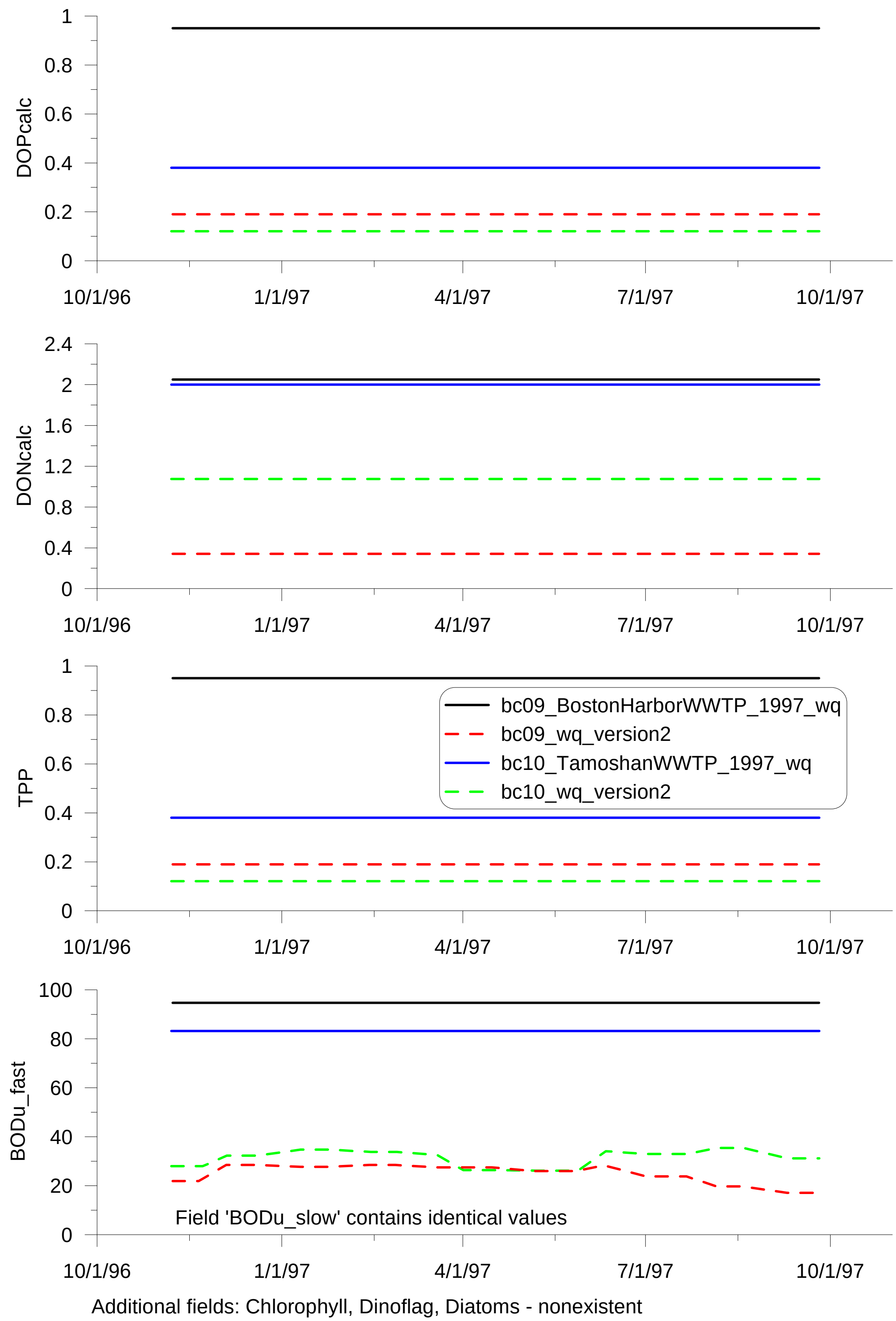


Figure 54. WQGraph6-7

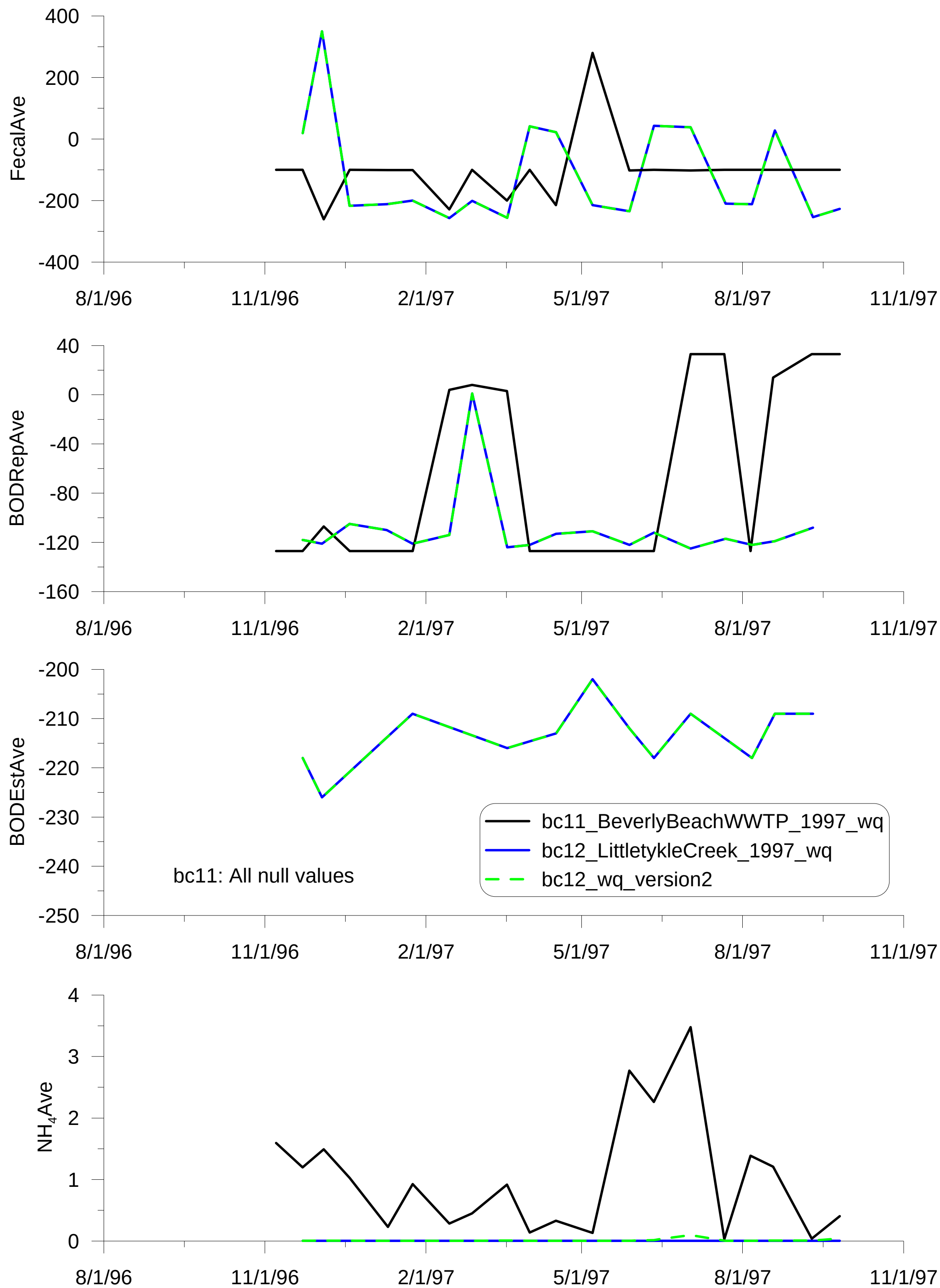


Figure 55. WQGraph7-1

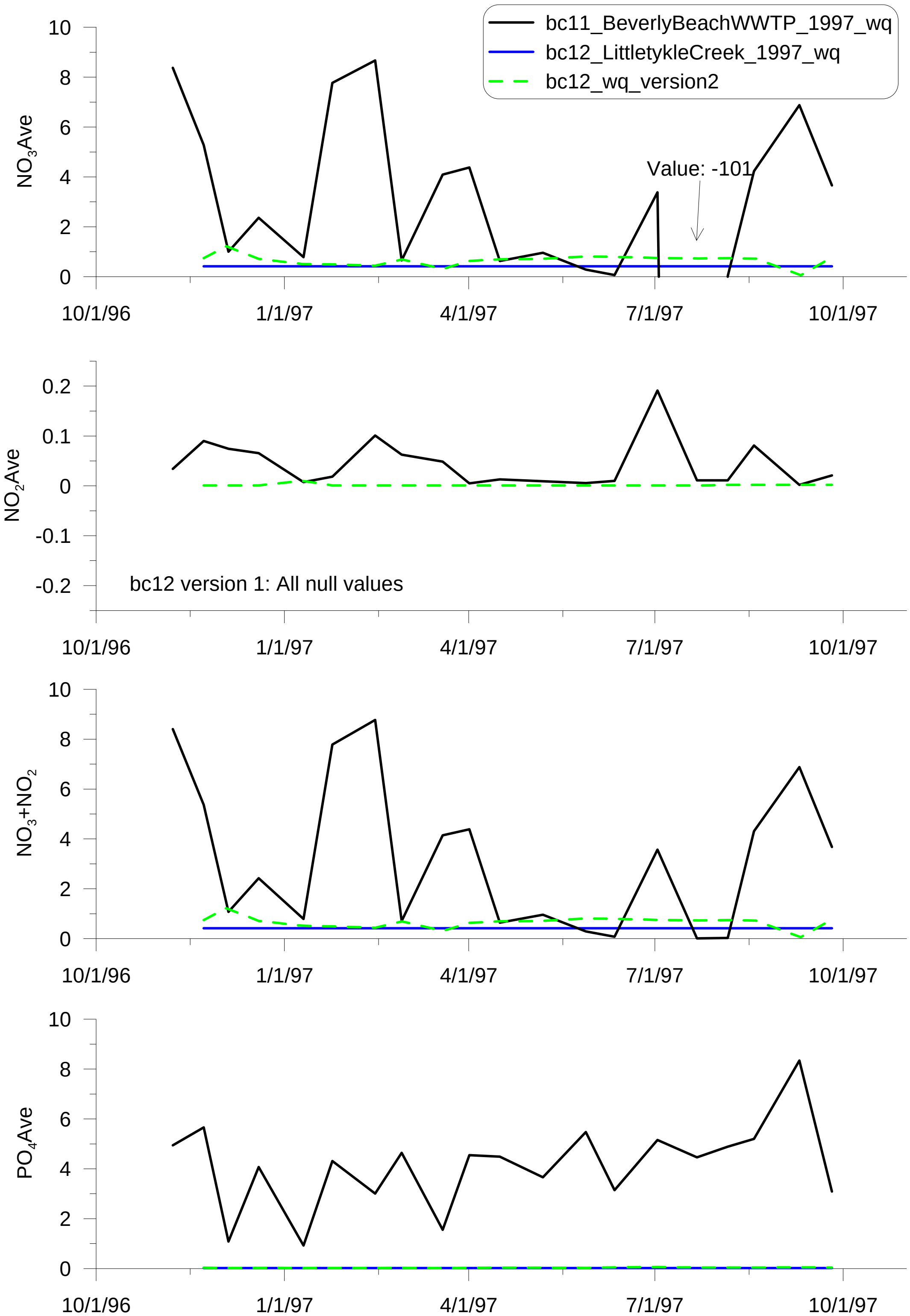


Figure 56. WQGraph7-2

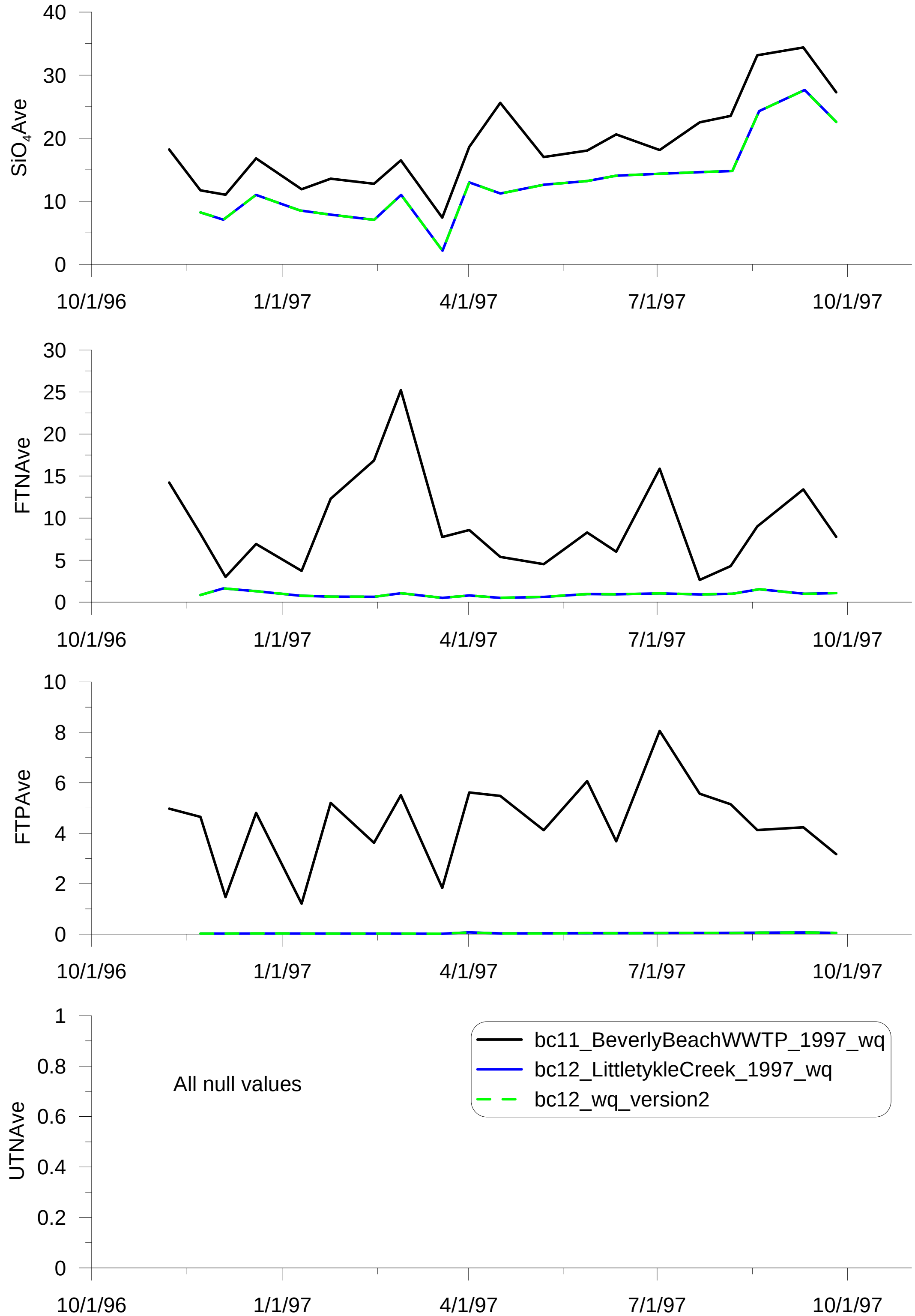


Figure 57. WQGraph7-3

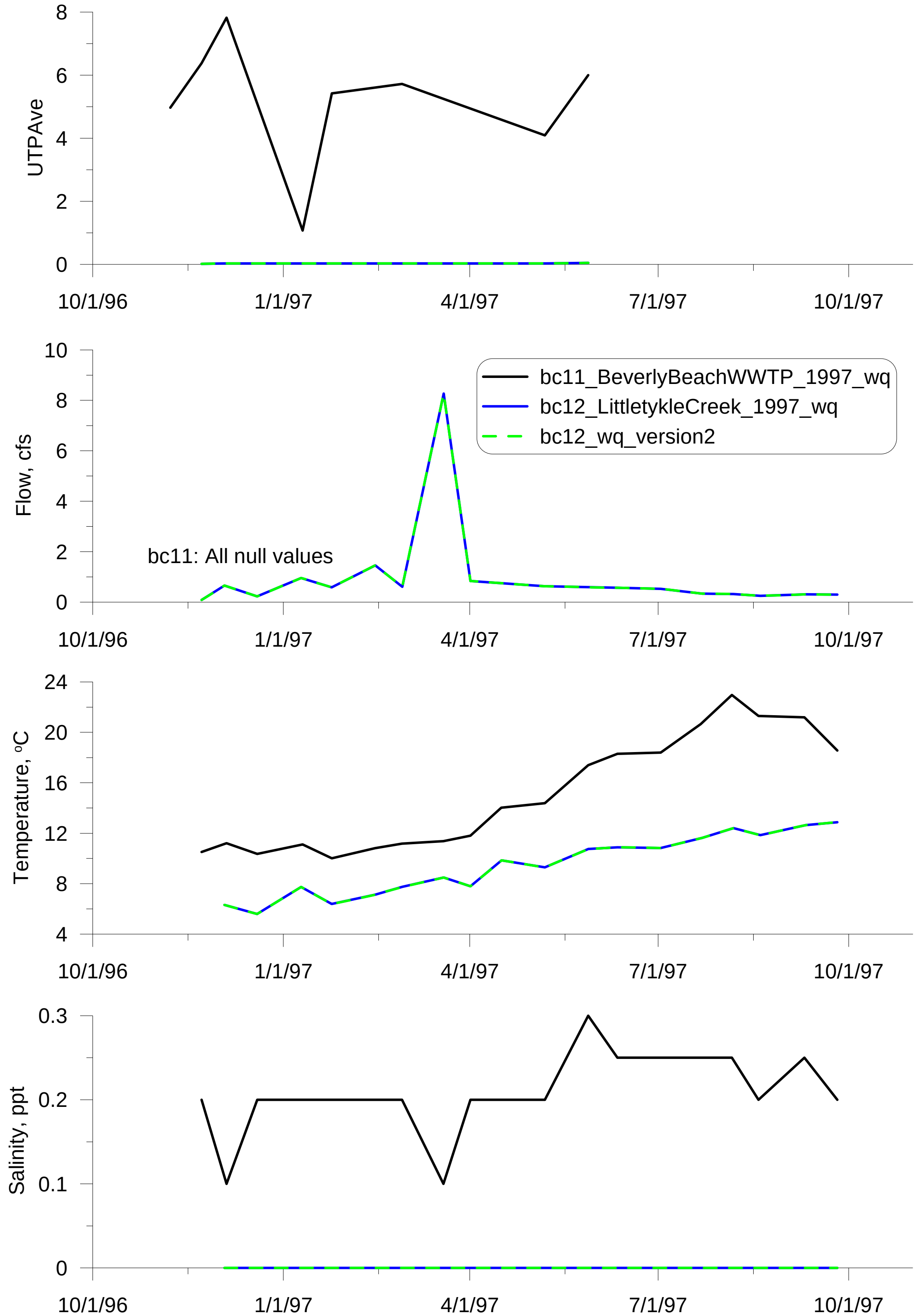


Figure 58. WQGraph7-4

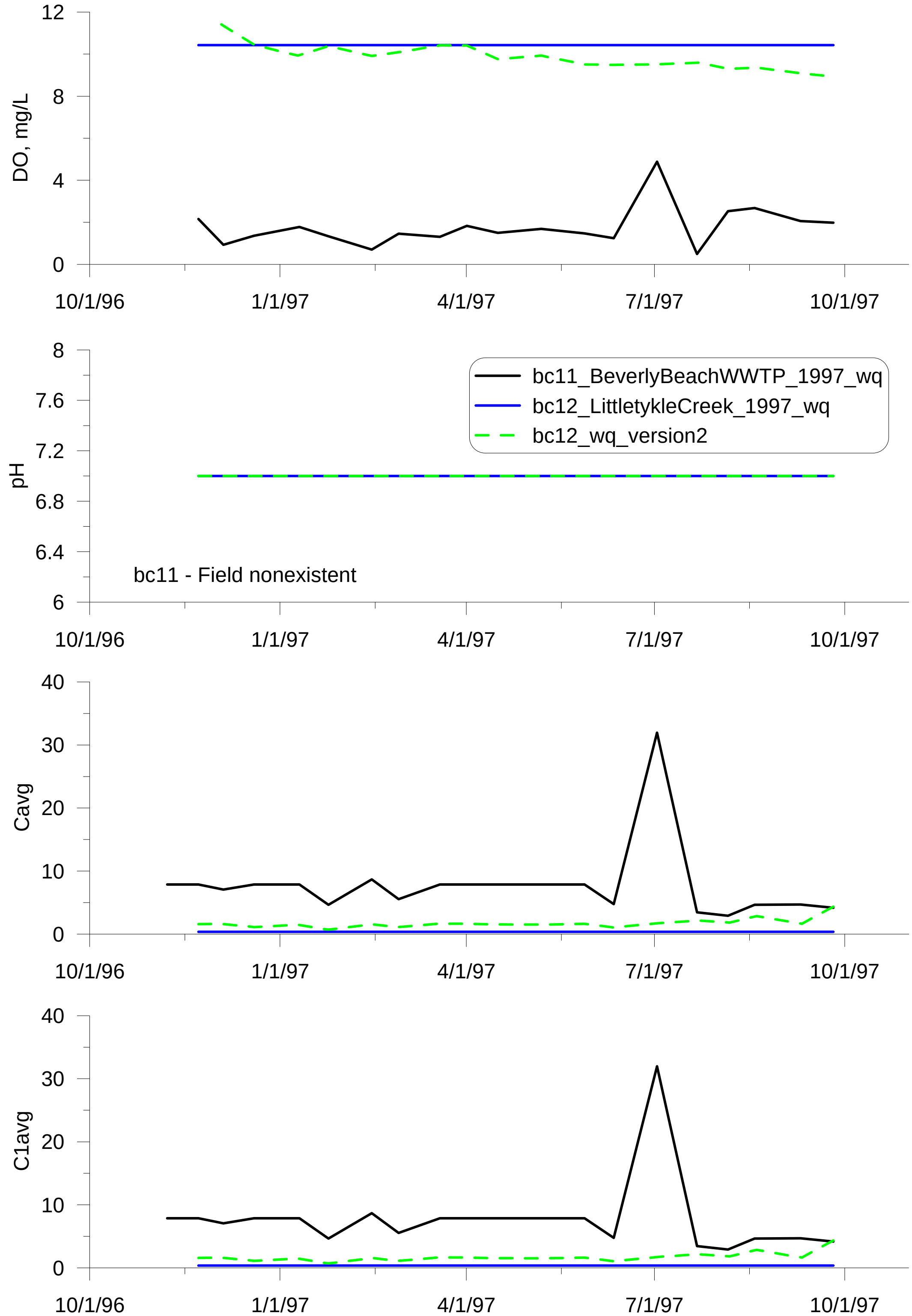


Figure 59. WQGraph7-5

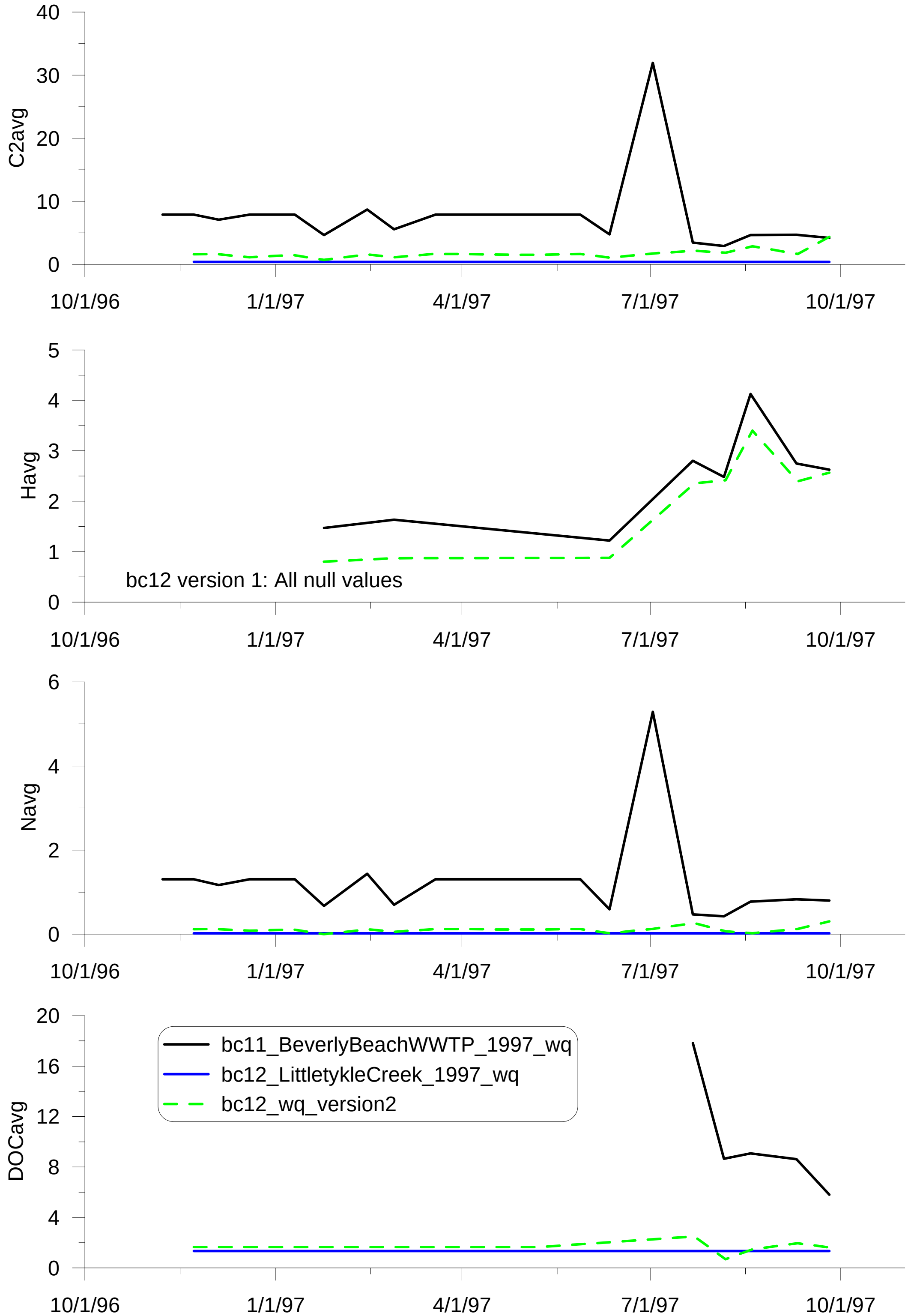
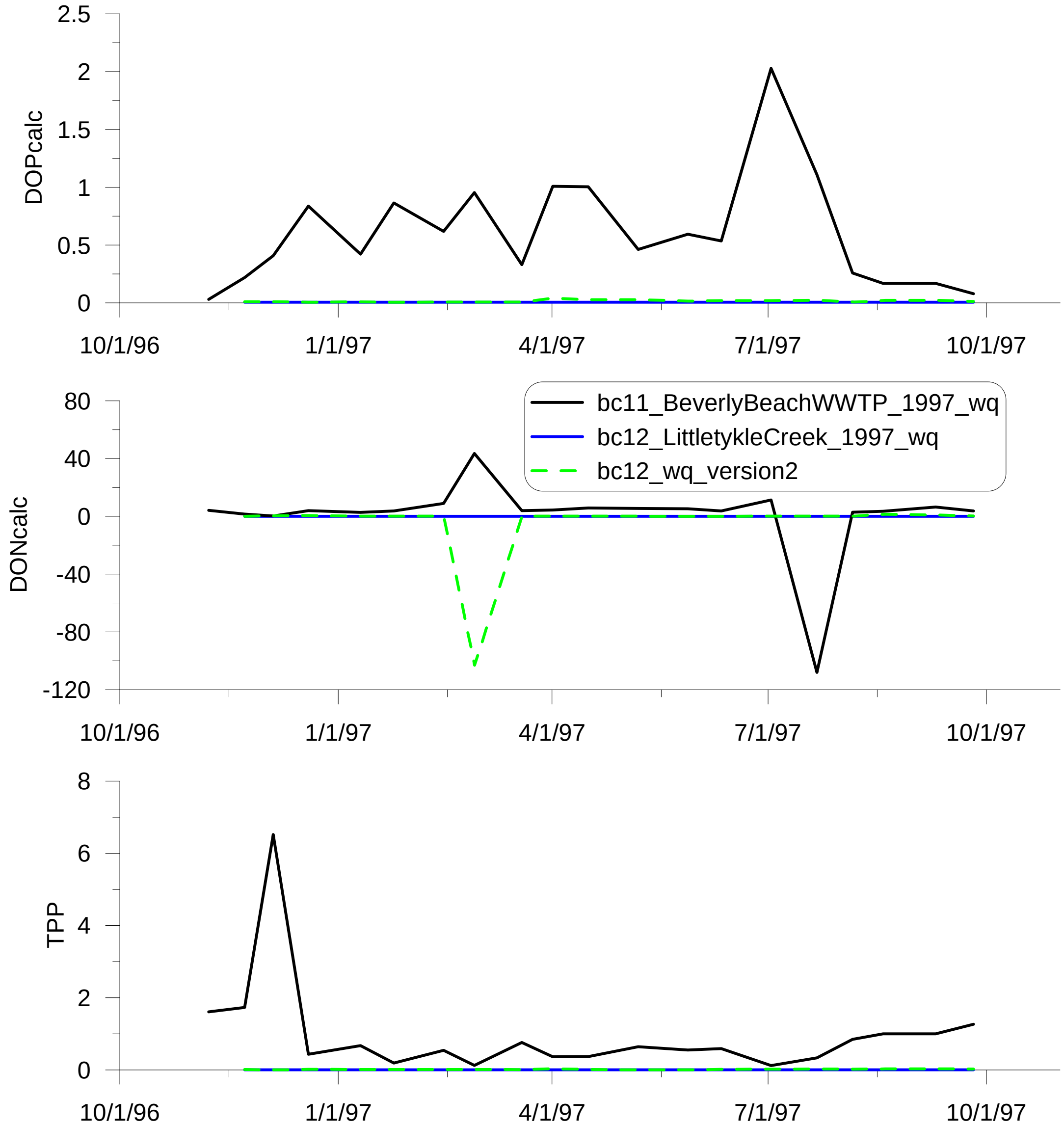


Figure 60. WQGraph7-6



bc12 versions 1 and 2 additional fields: Chlorophyll, Dinoflag, Diatoms - all null values

Figure 61. WQGraph7-7

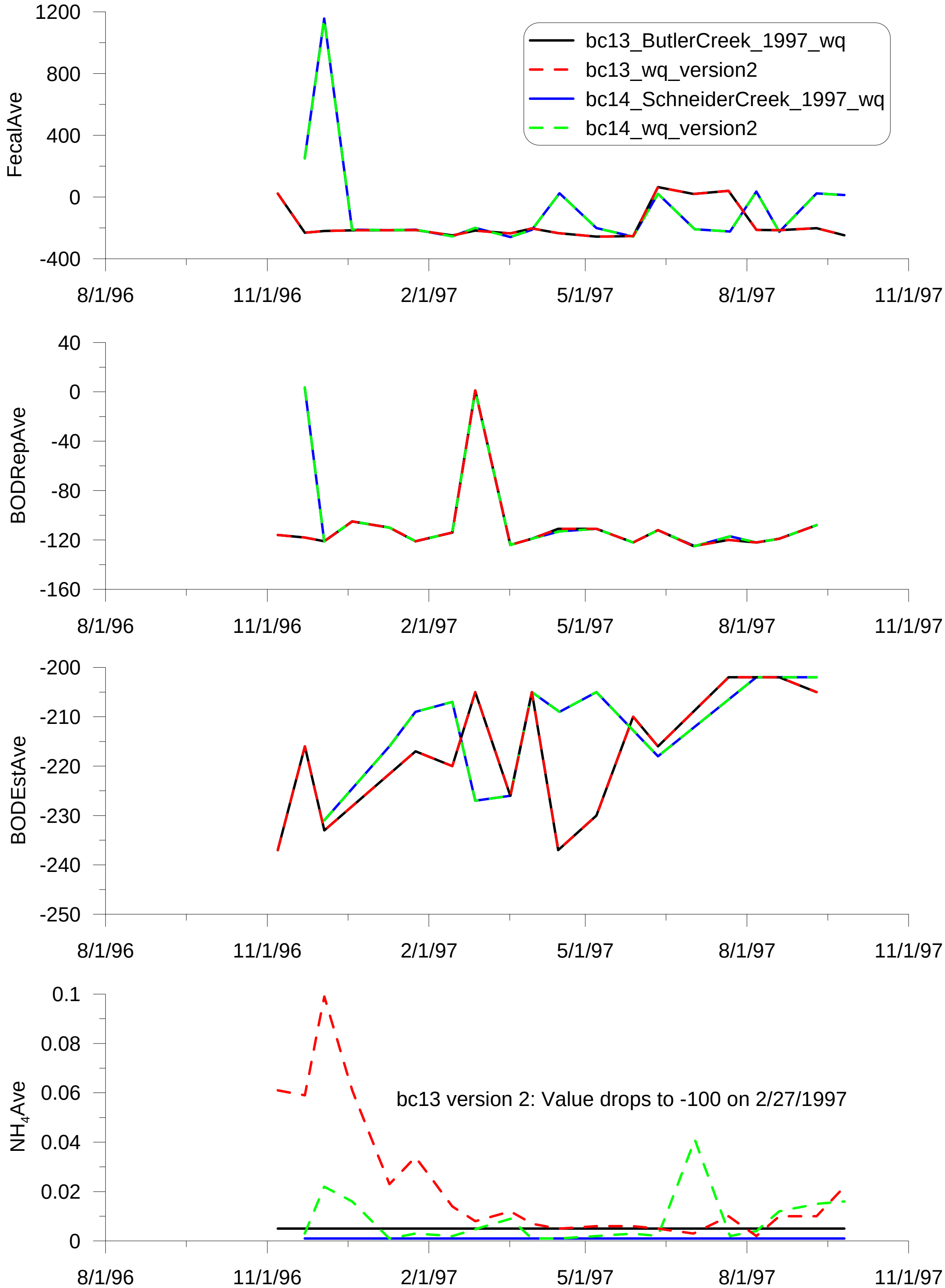


Figure 62. WQGraph8-1

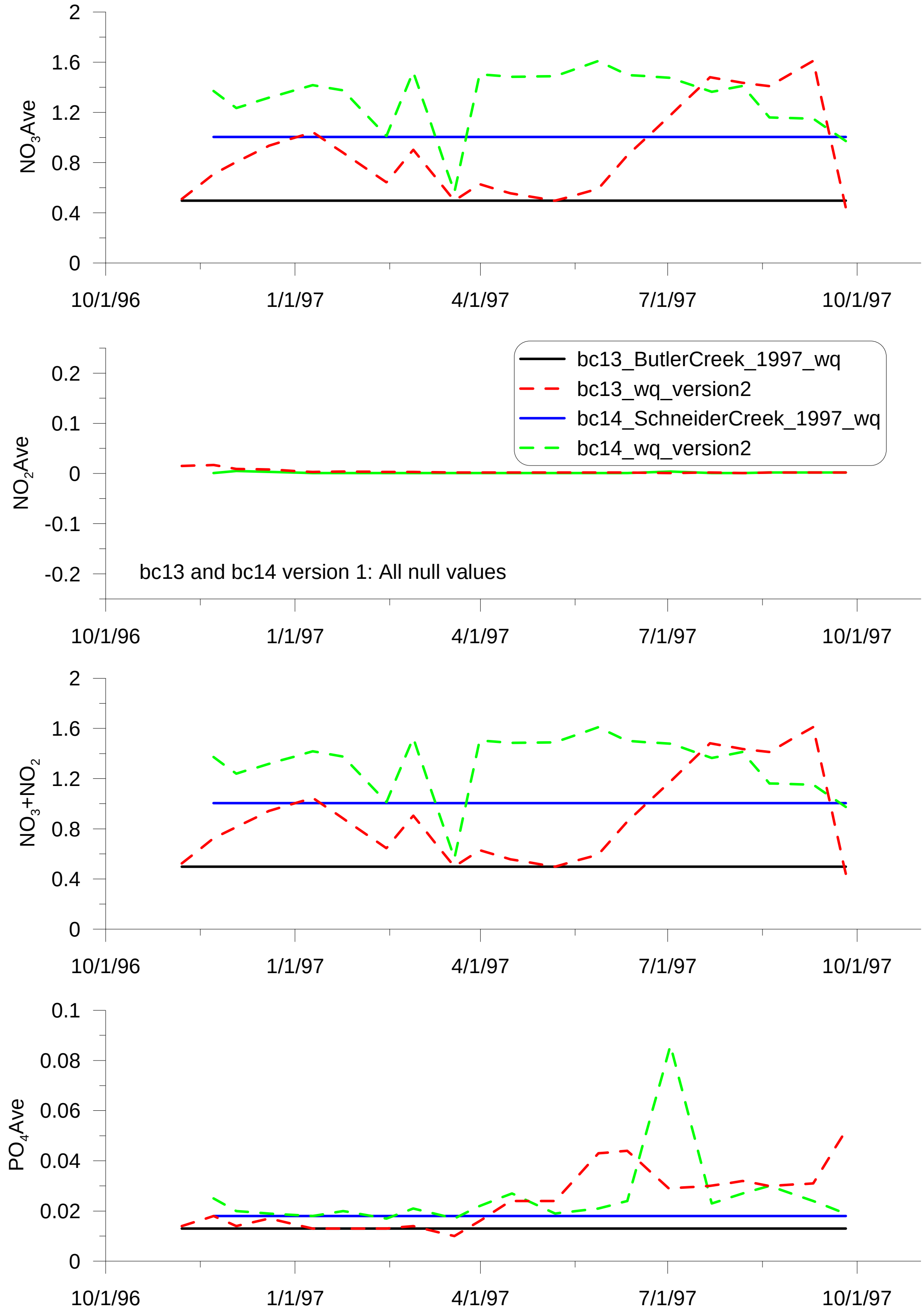


Figure 63. WQGraph8-2

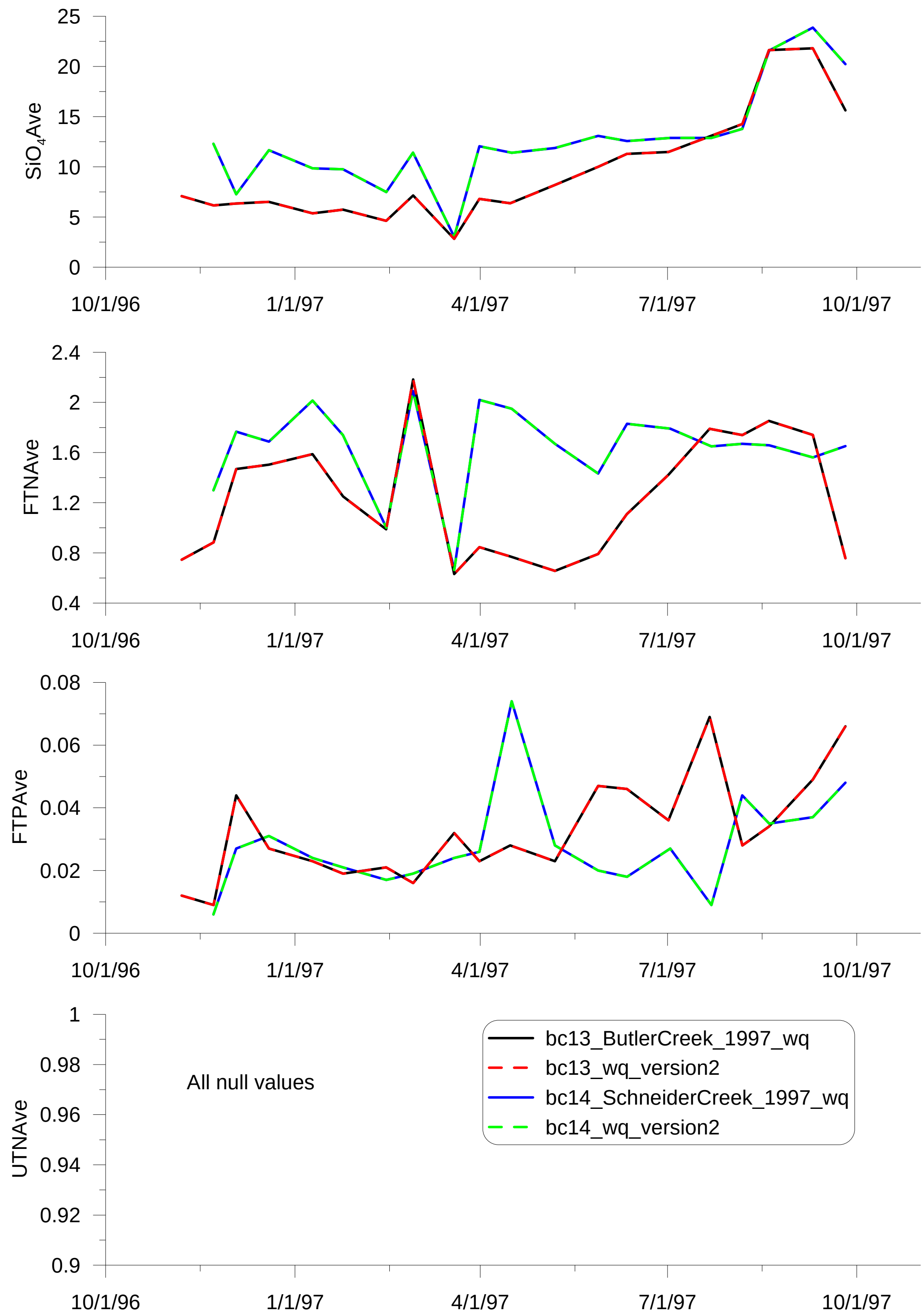


Figure 64. WQGraph8-3

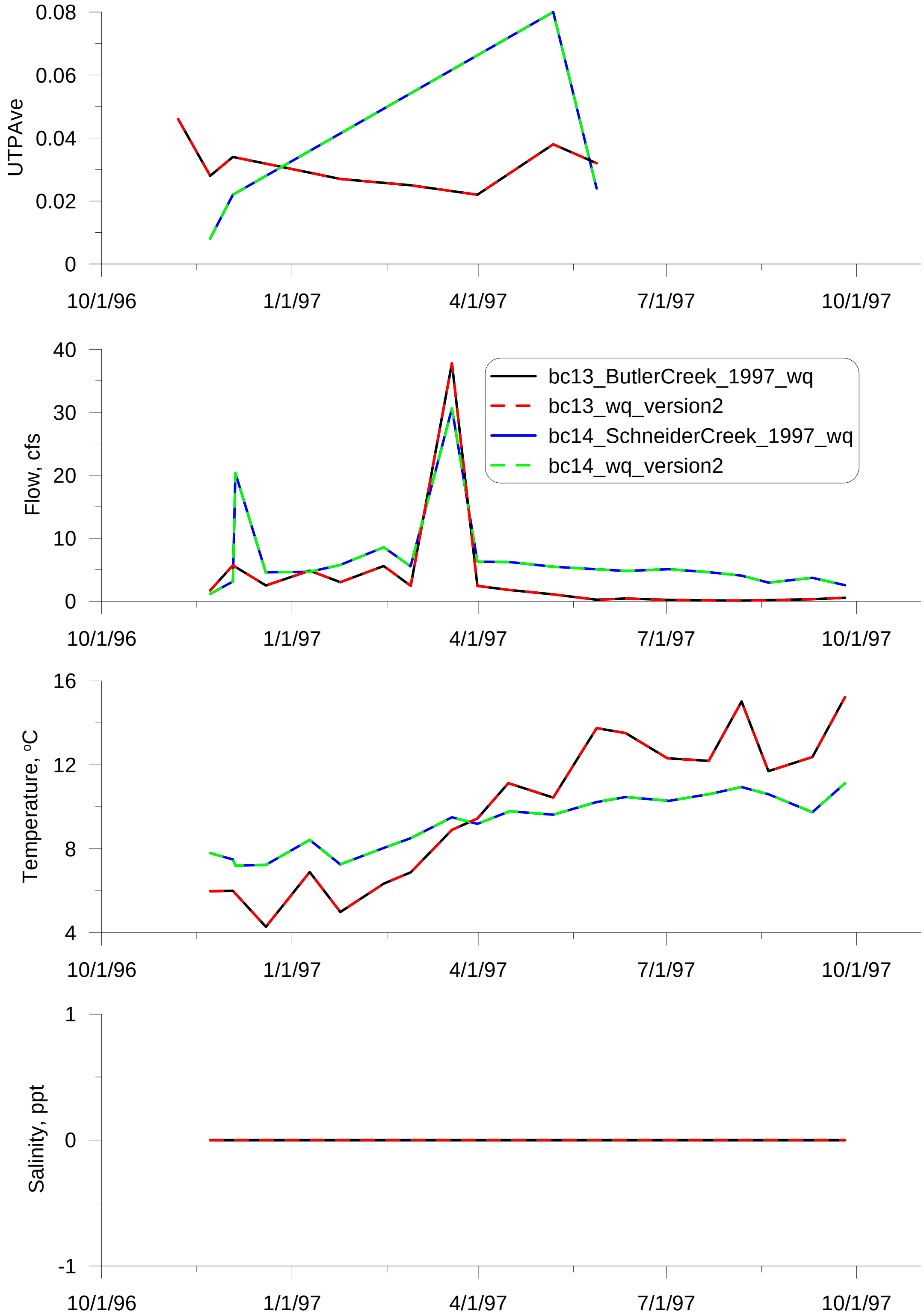


Figure 65. WQGraph8-4

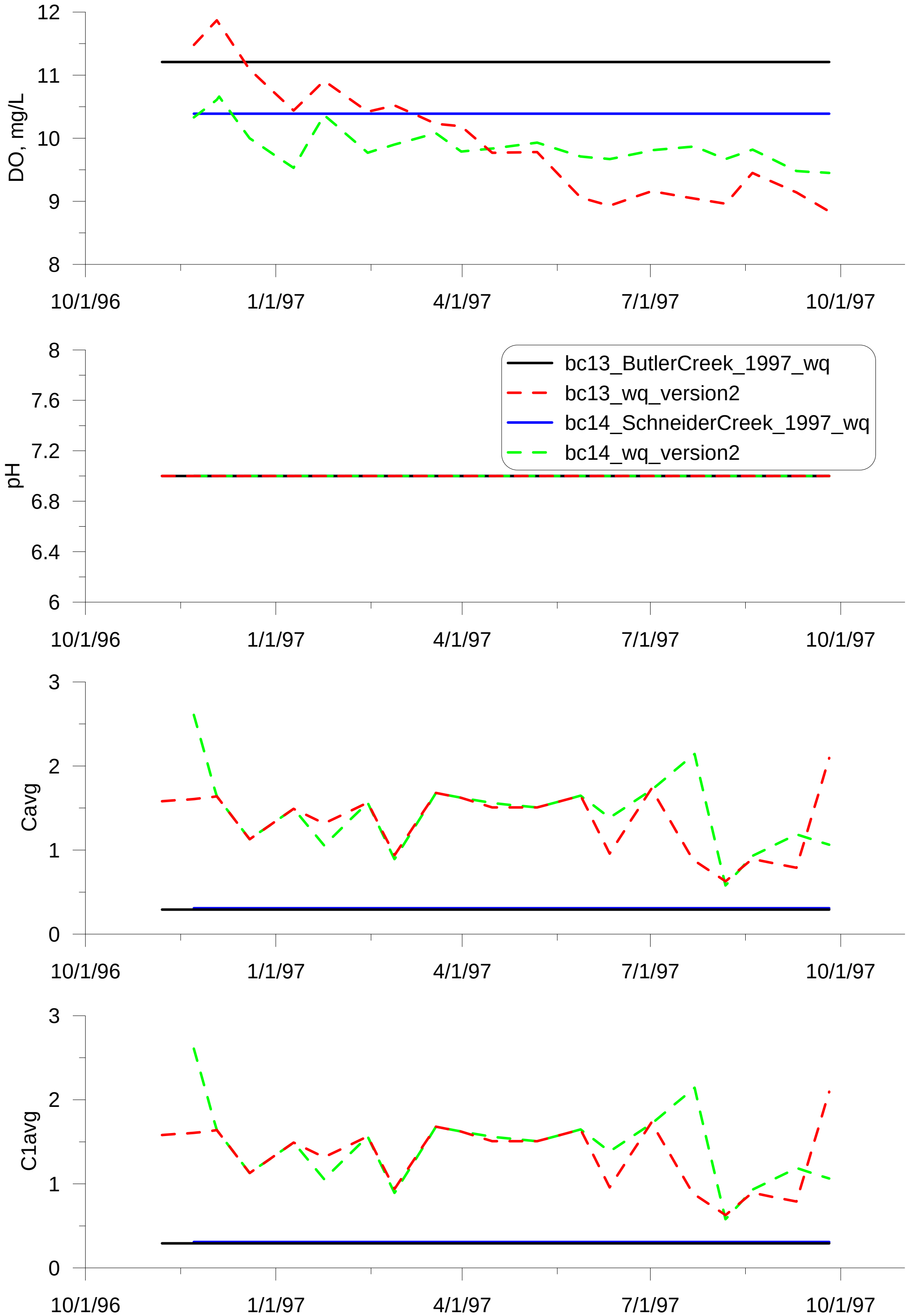


Figure 66. WQGraph8-5

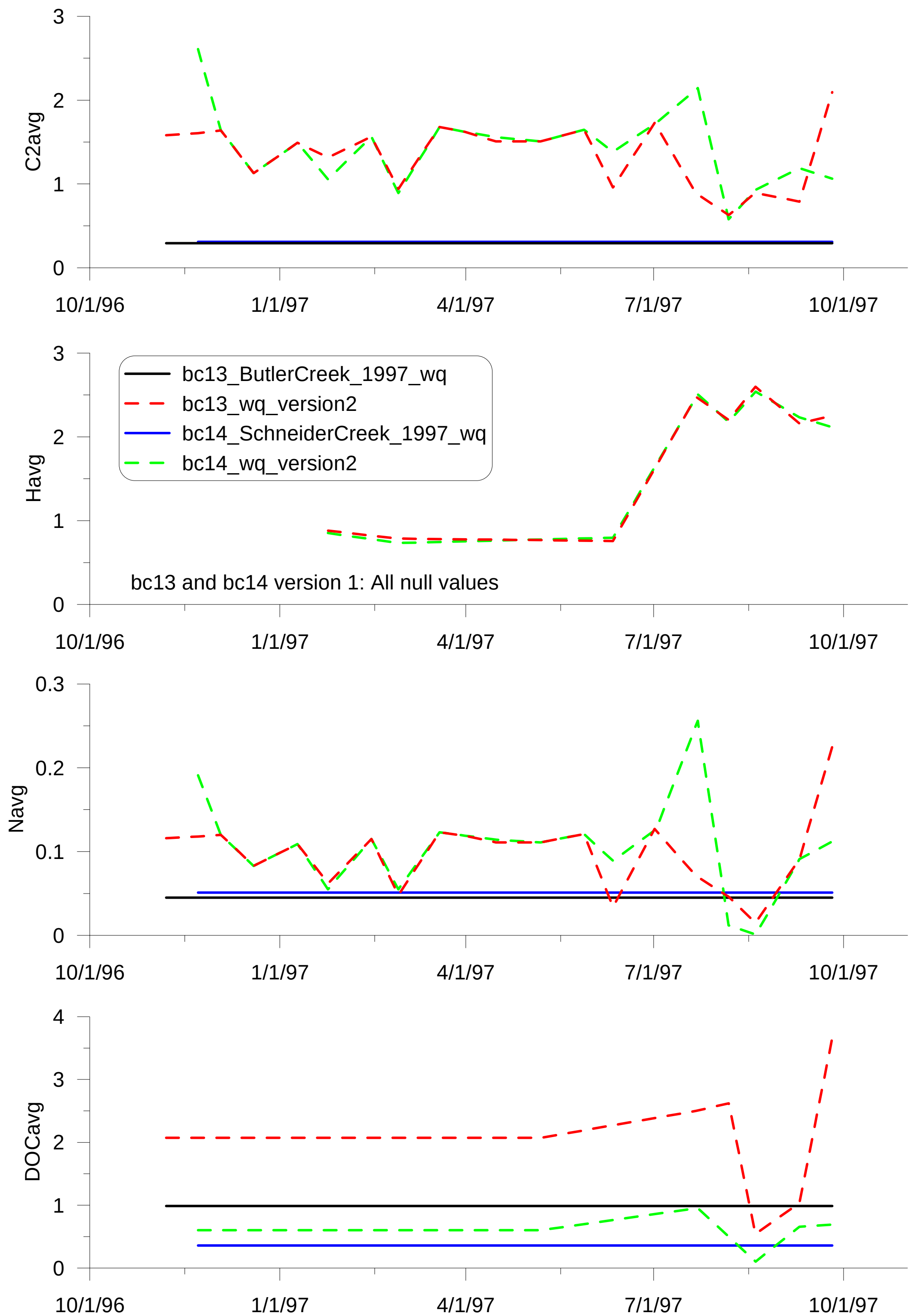


Figure 67. WQGraph8-6

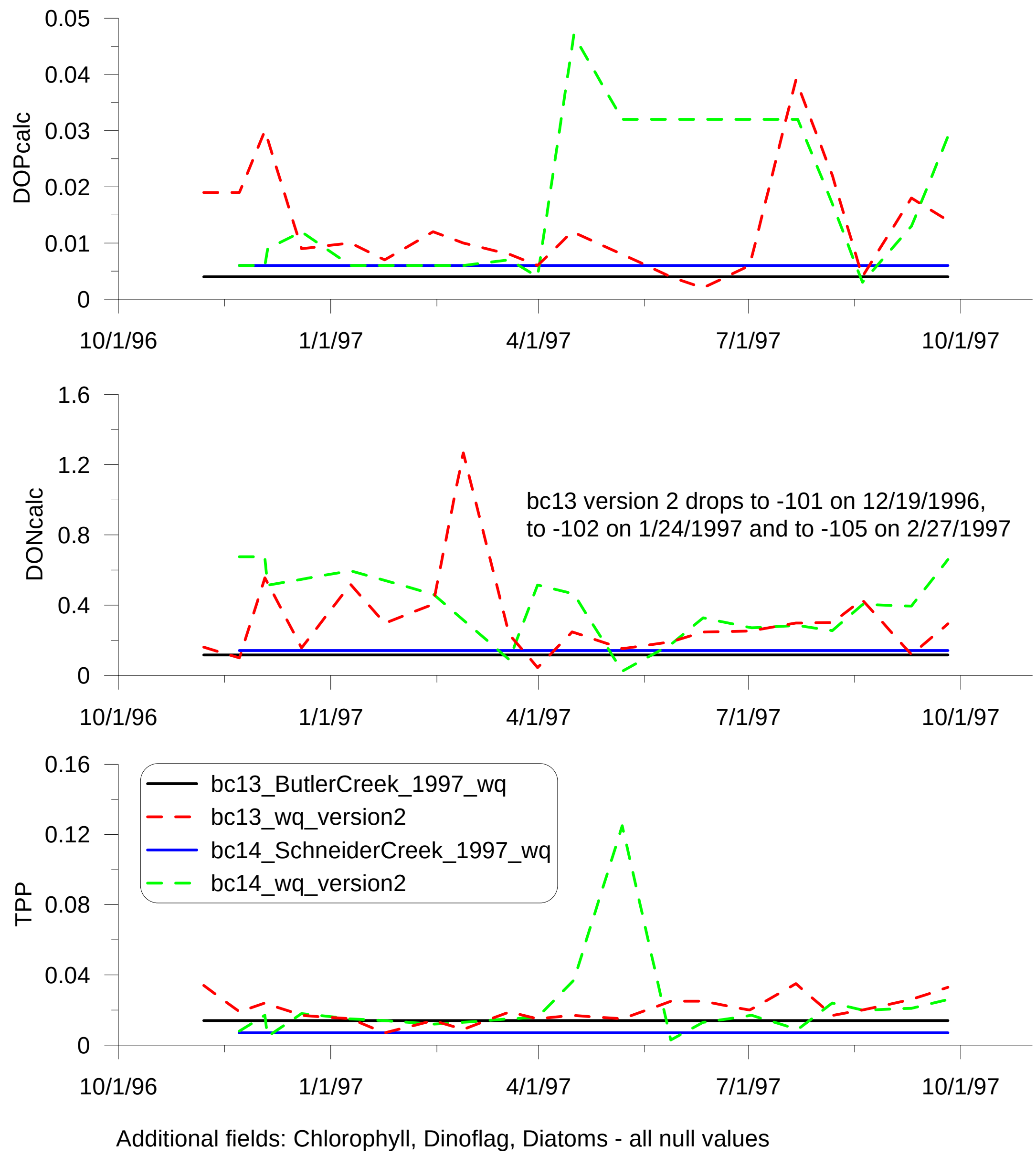


Figure 68. WQGraph8-7

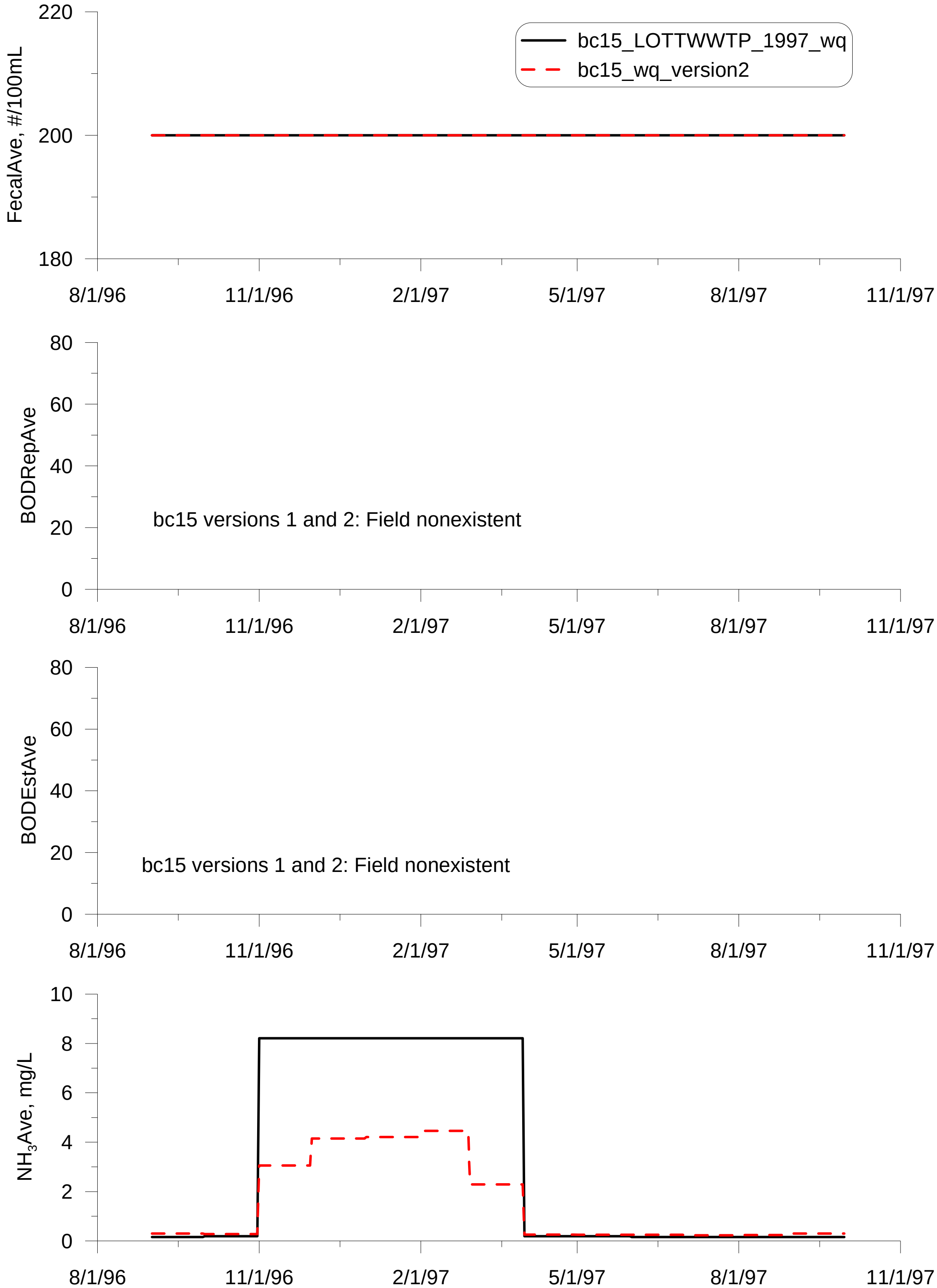


Figure 69. WQGraph9-1

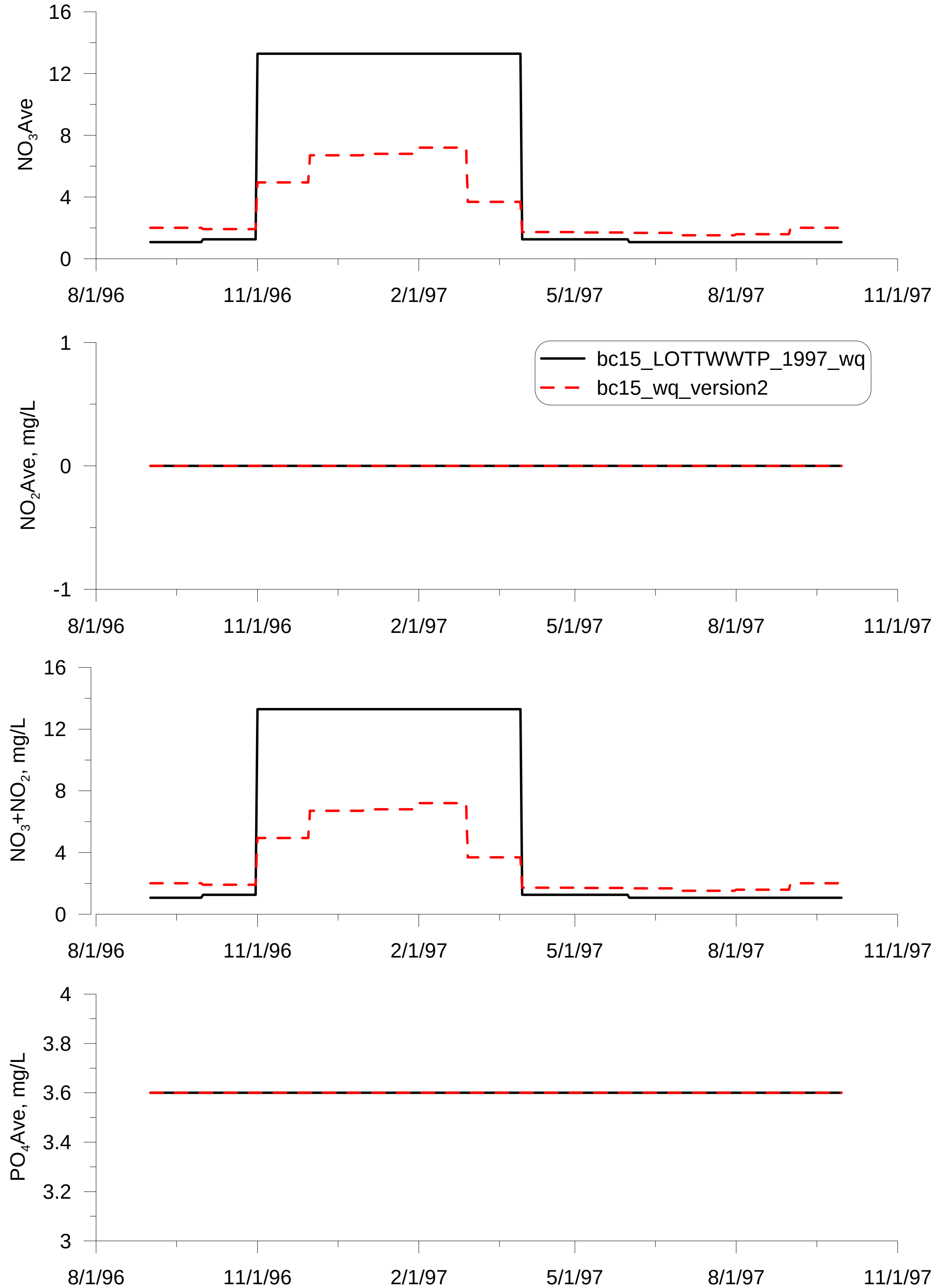


Figure 70. WQGraph9-2

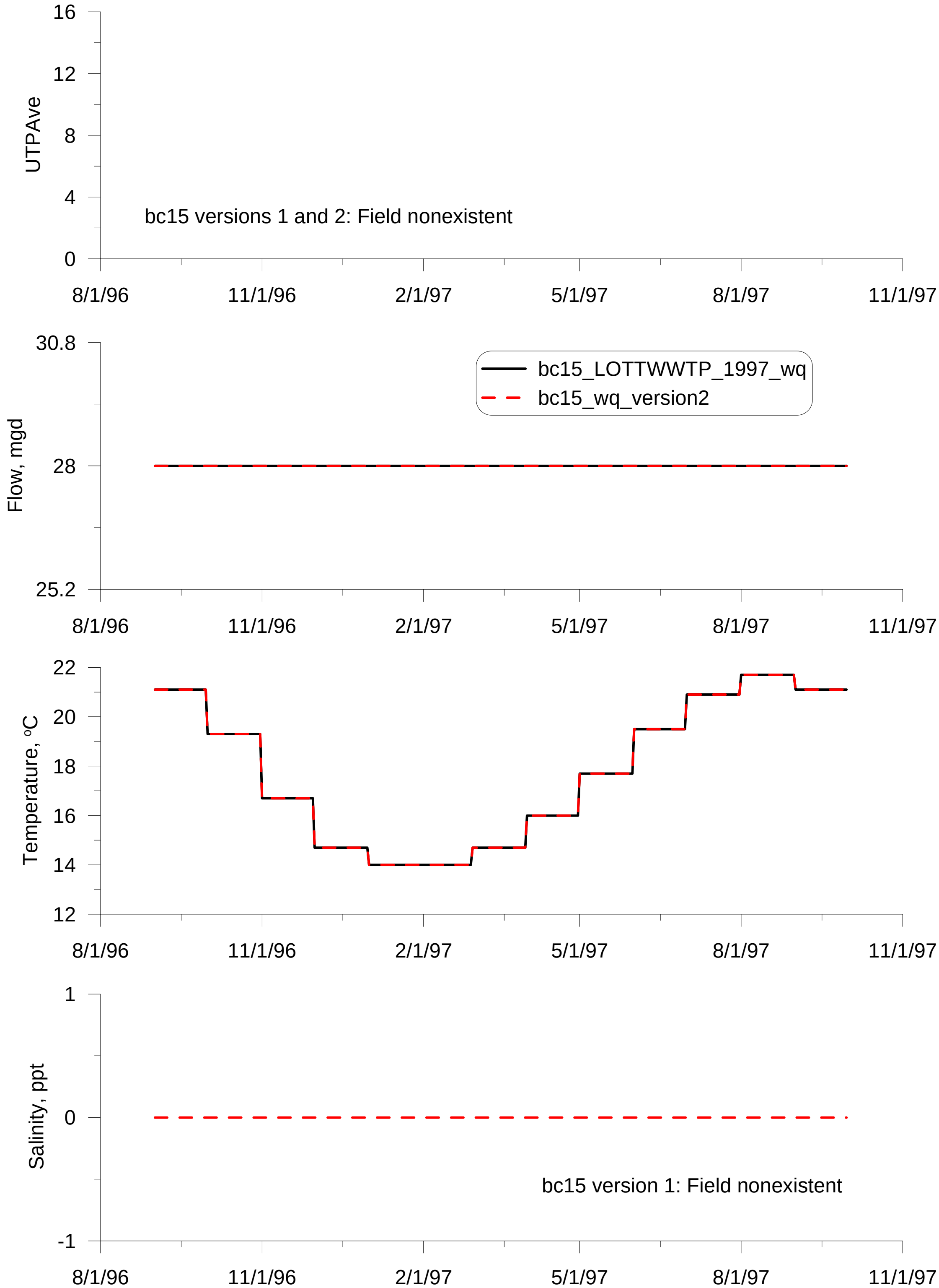


Figure 71. WQGraph9-3

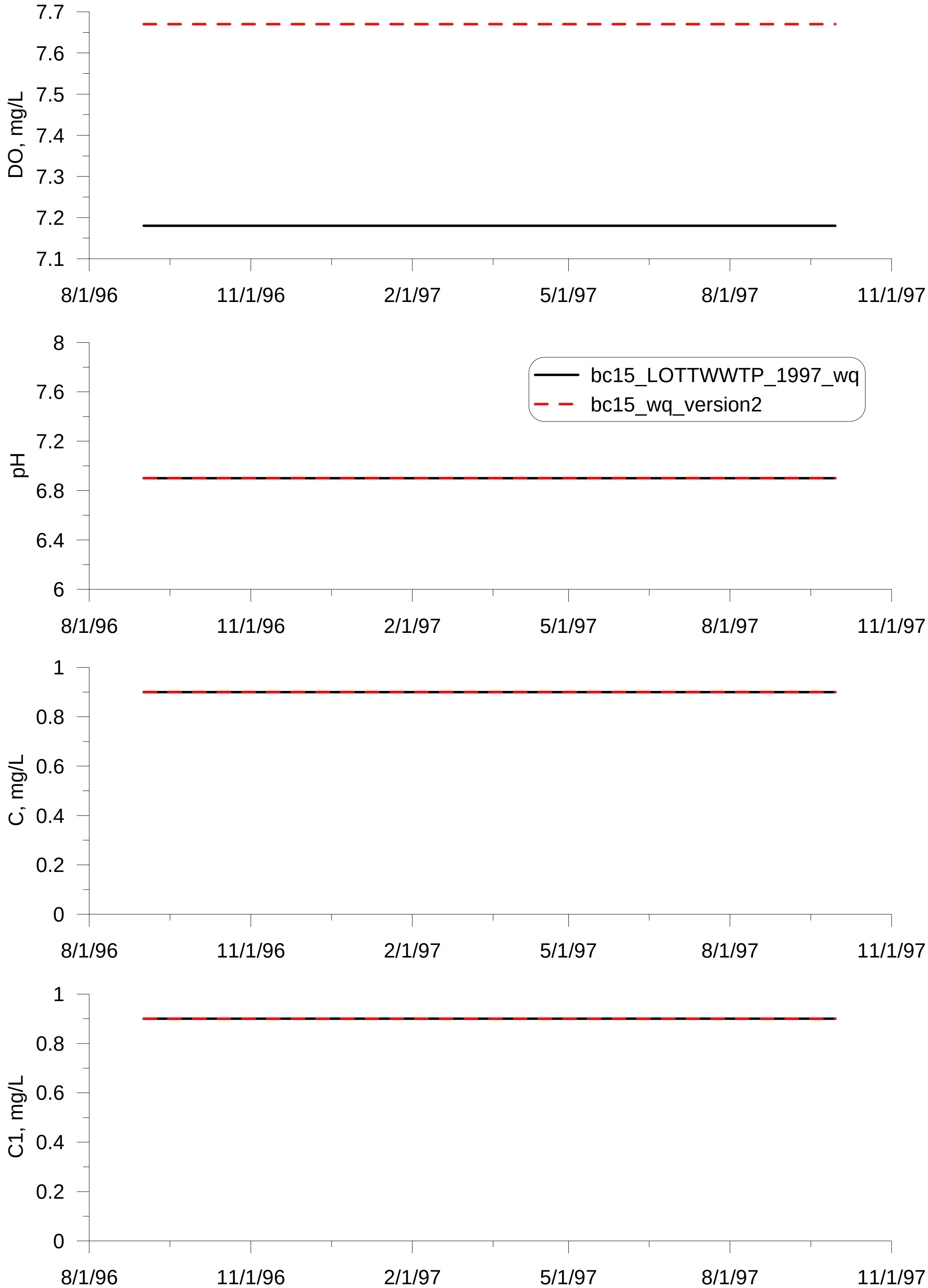


Figure 72. WQGraph9-4

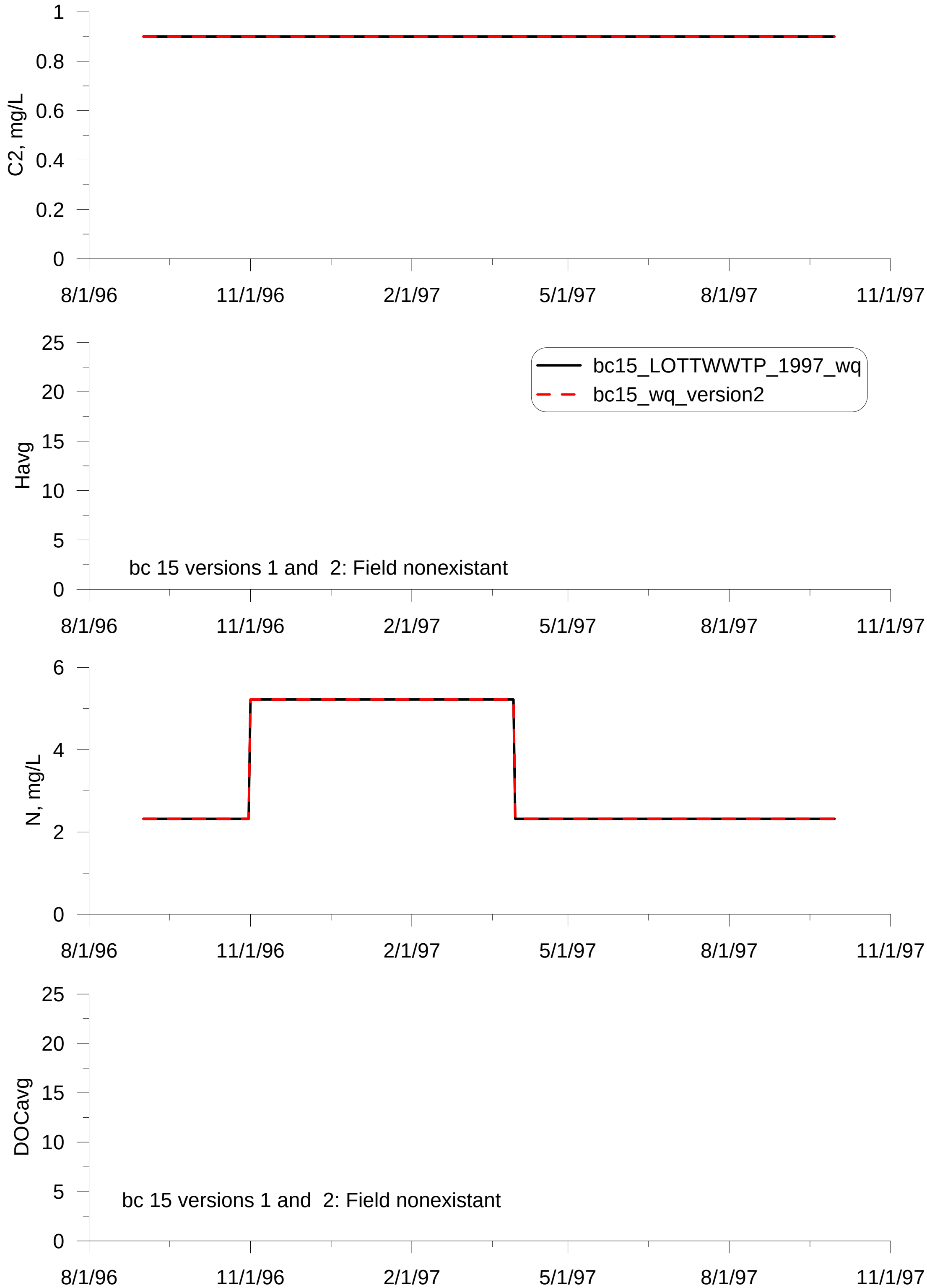


Figure 73. WQGraph9-5

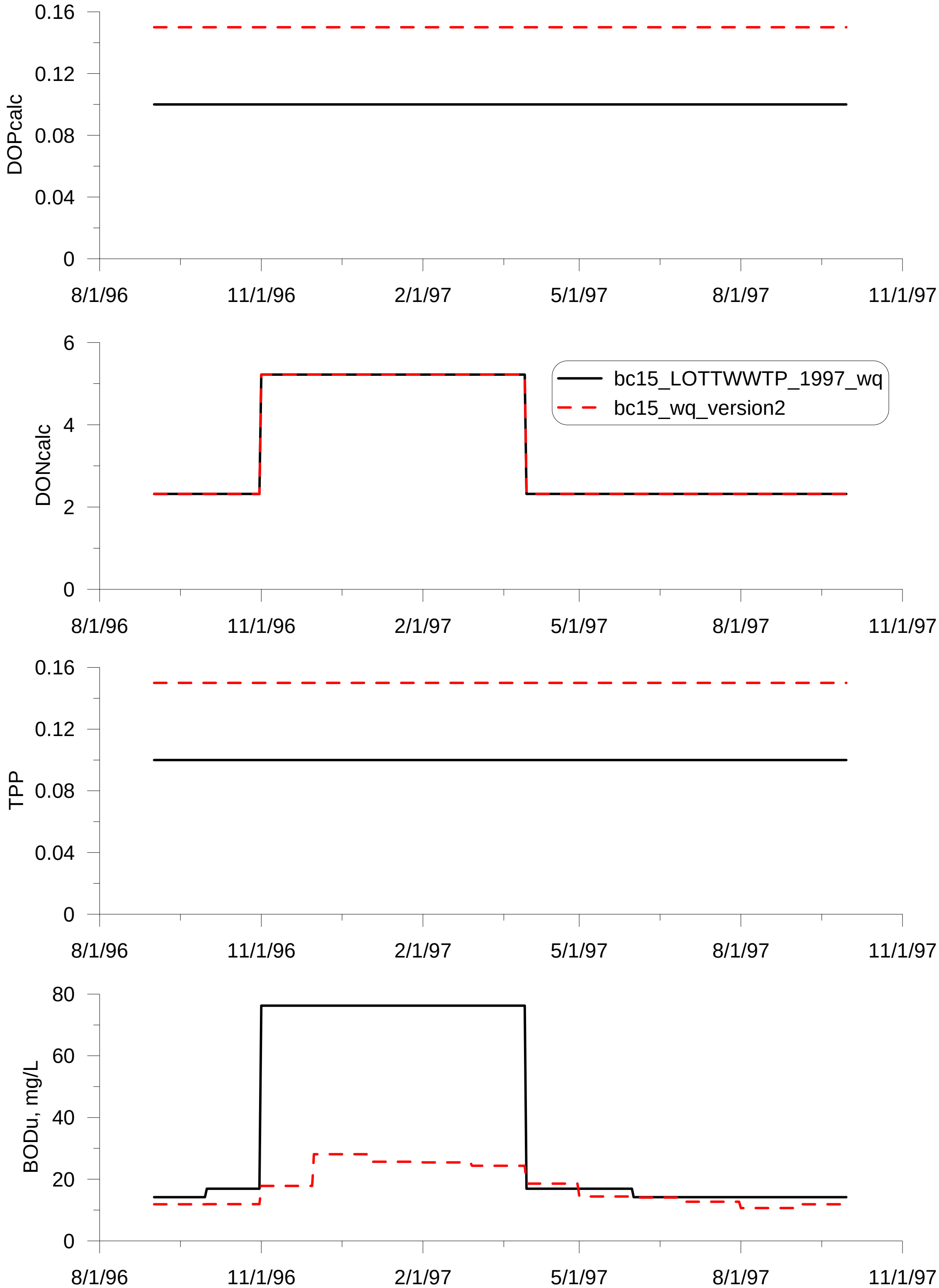


Figure 74. WQGraph9-6

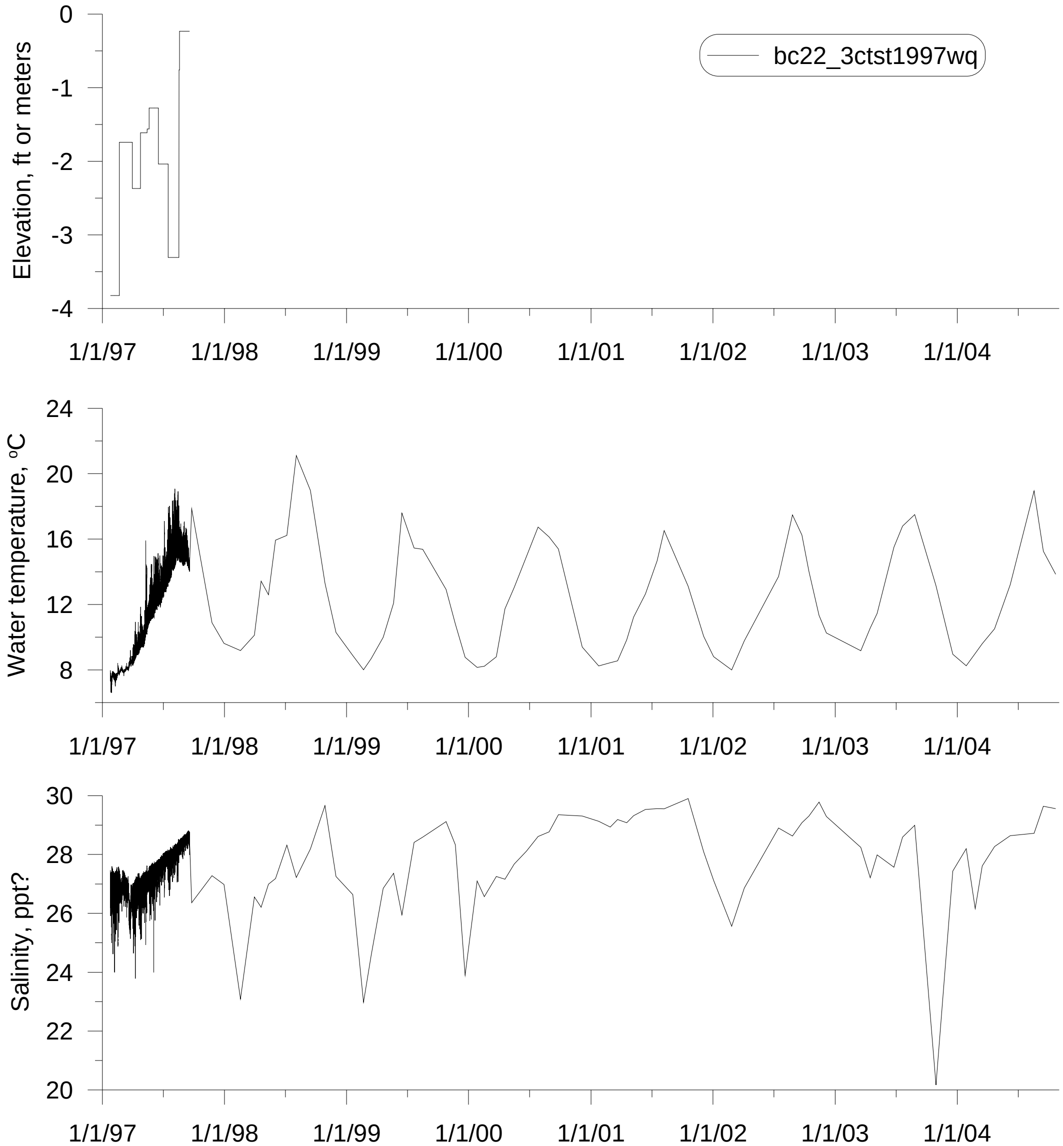


Figure 75. WQGraph10

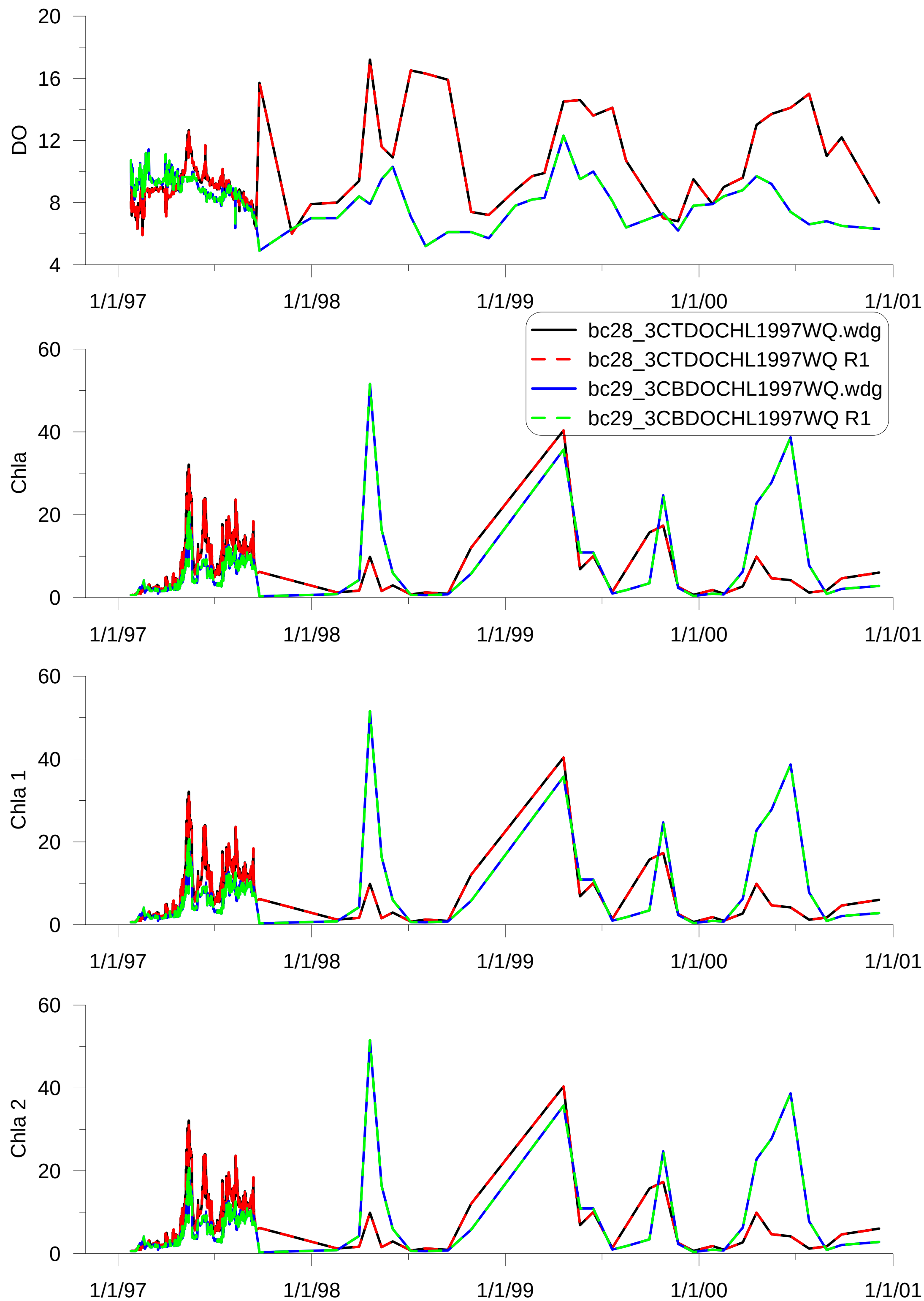


Figure 76. WQGraph11

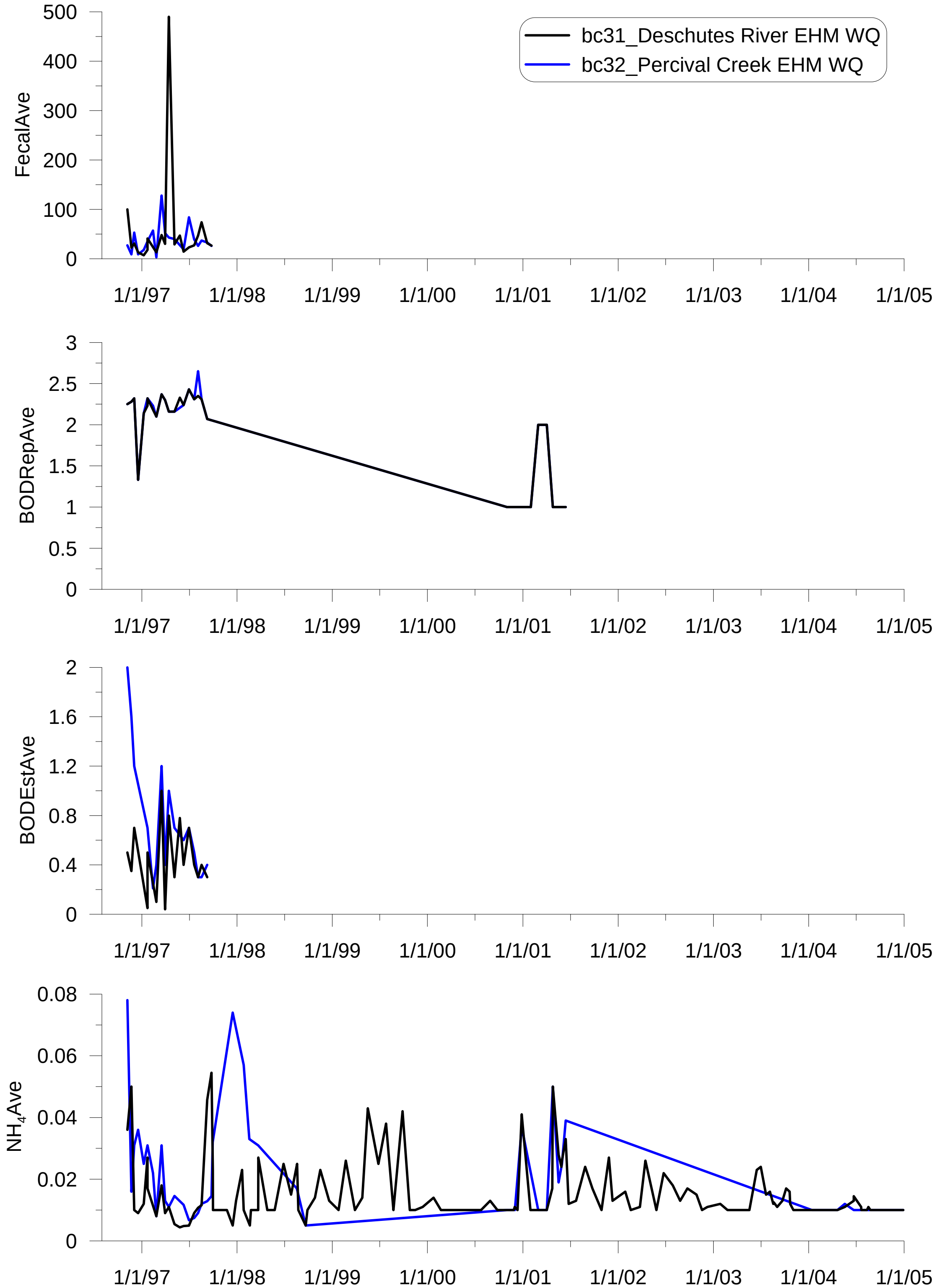


Figure 77. WQGraph12-1

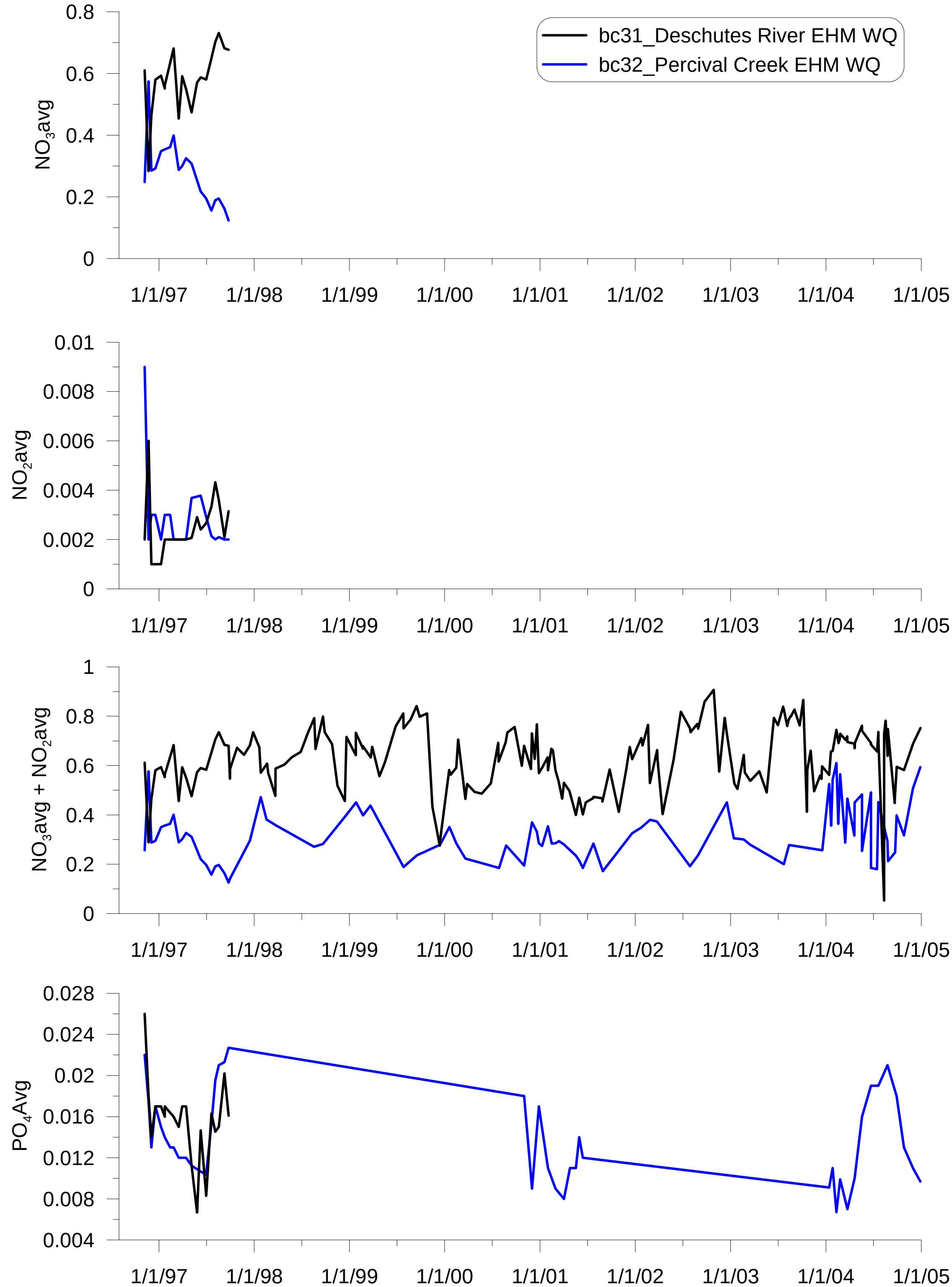


Figure 78. WQGraph12-2

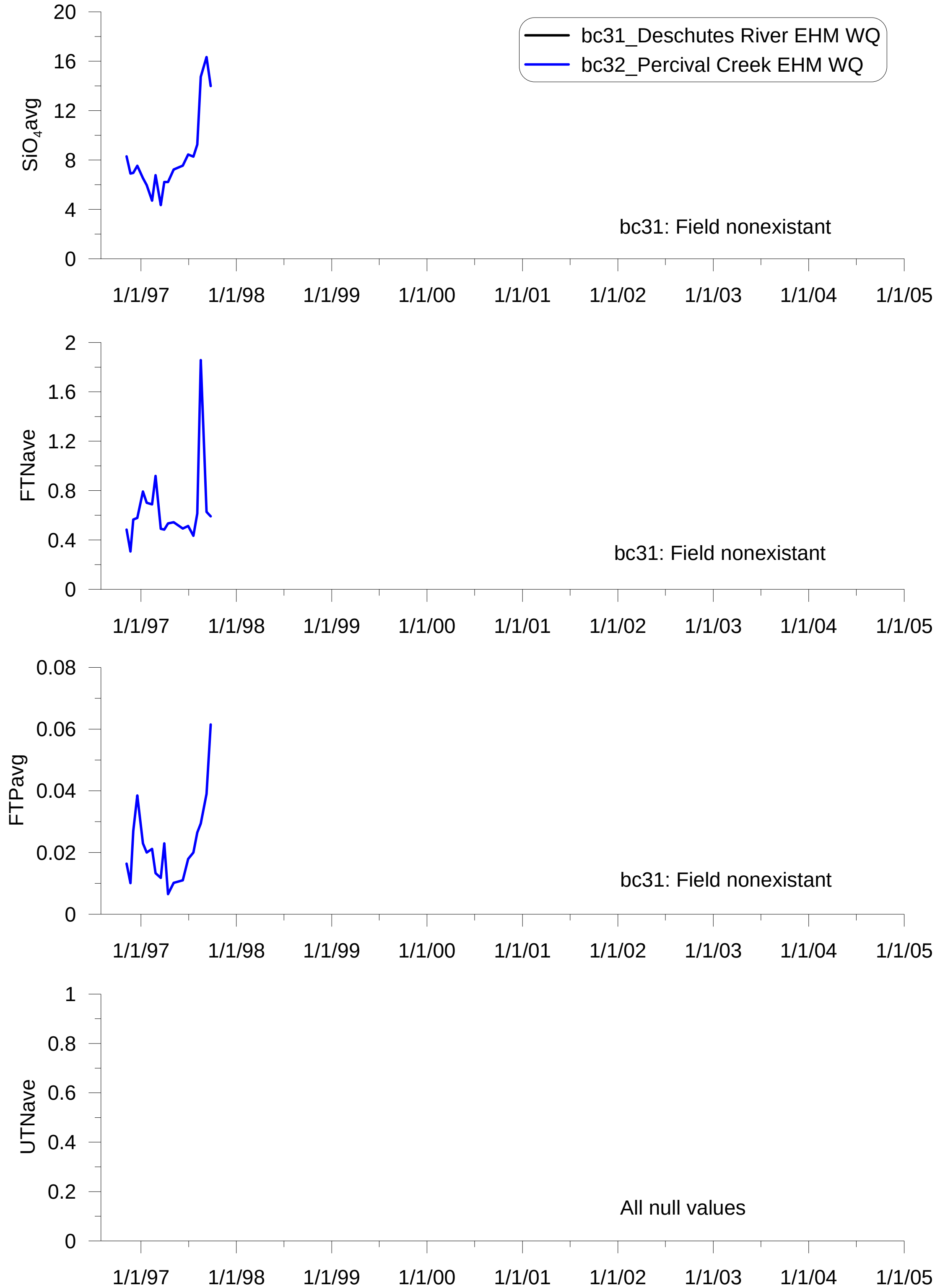


Figure 79. WQGraph12-3

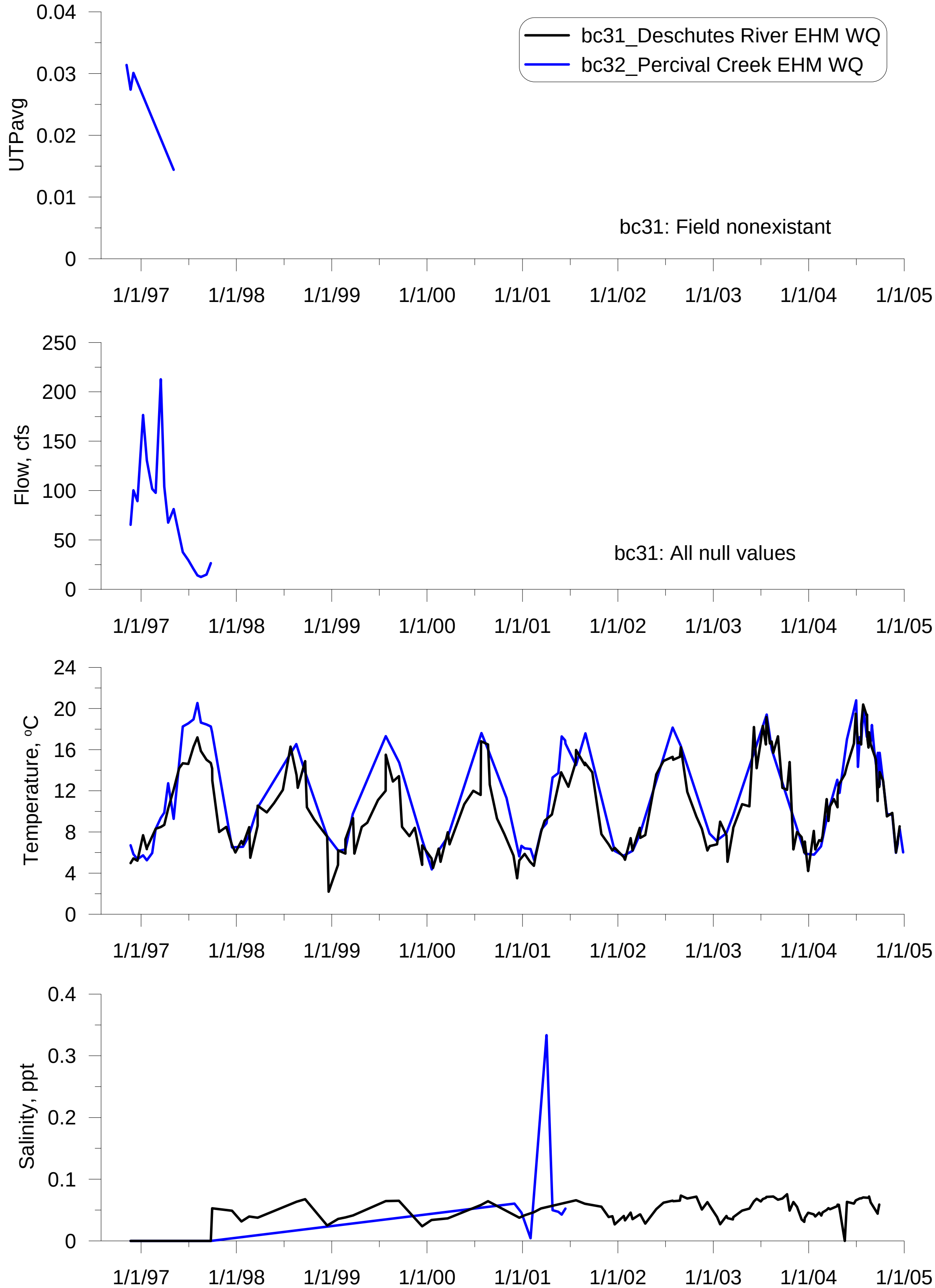


Figure 80. WQGraph12-4

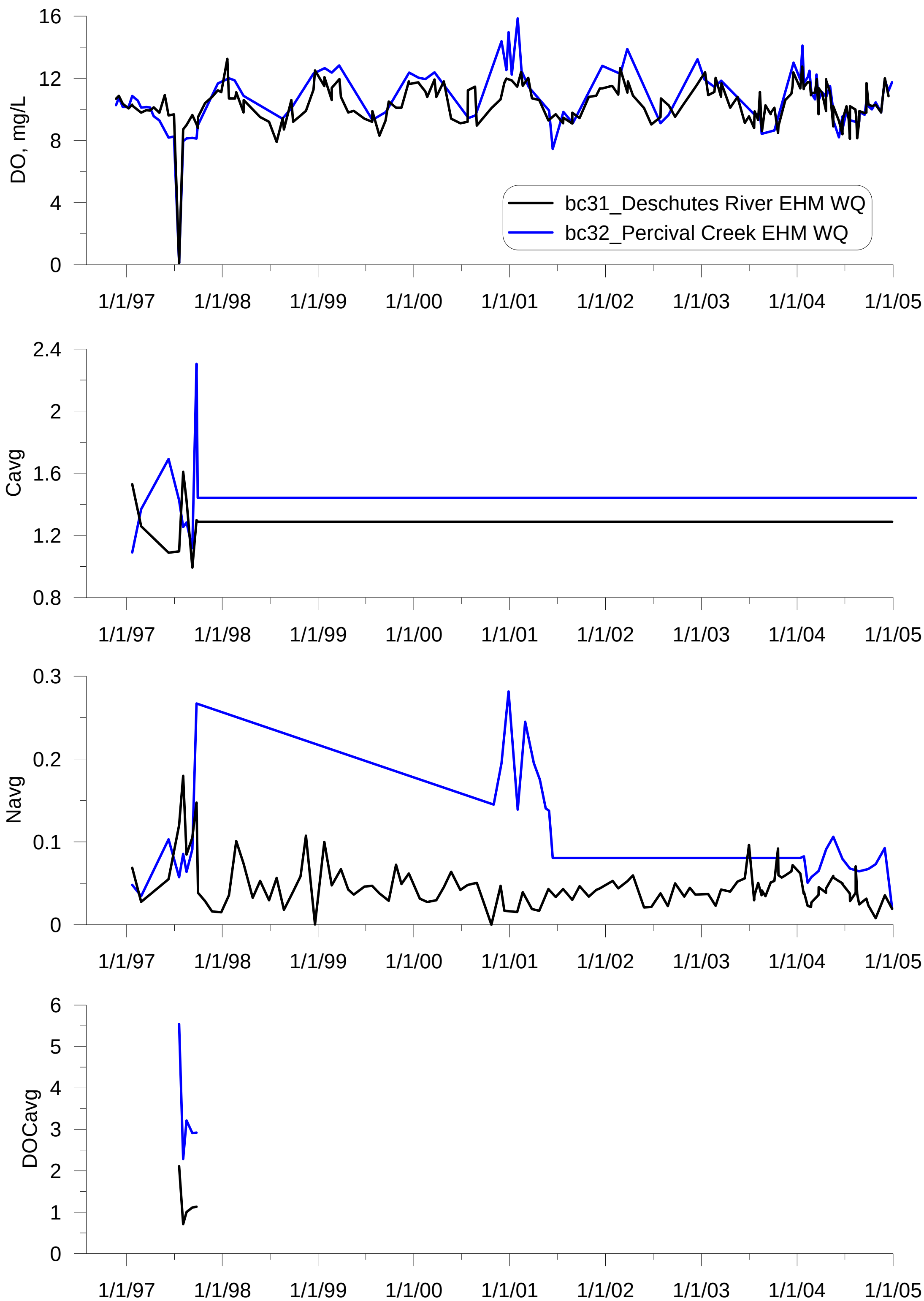


Figure 81. WQGraph12-5

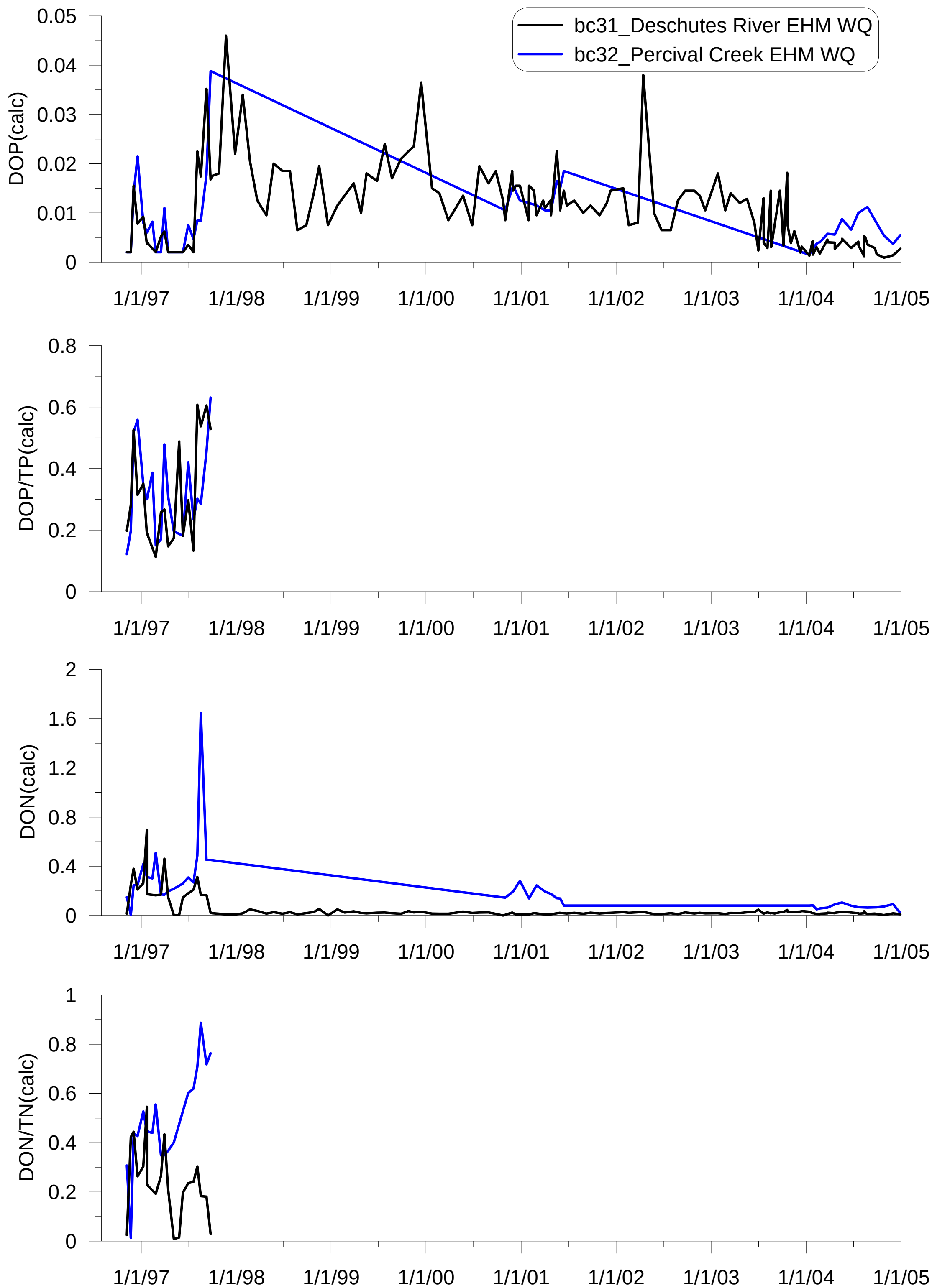
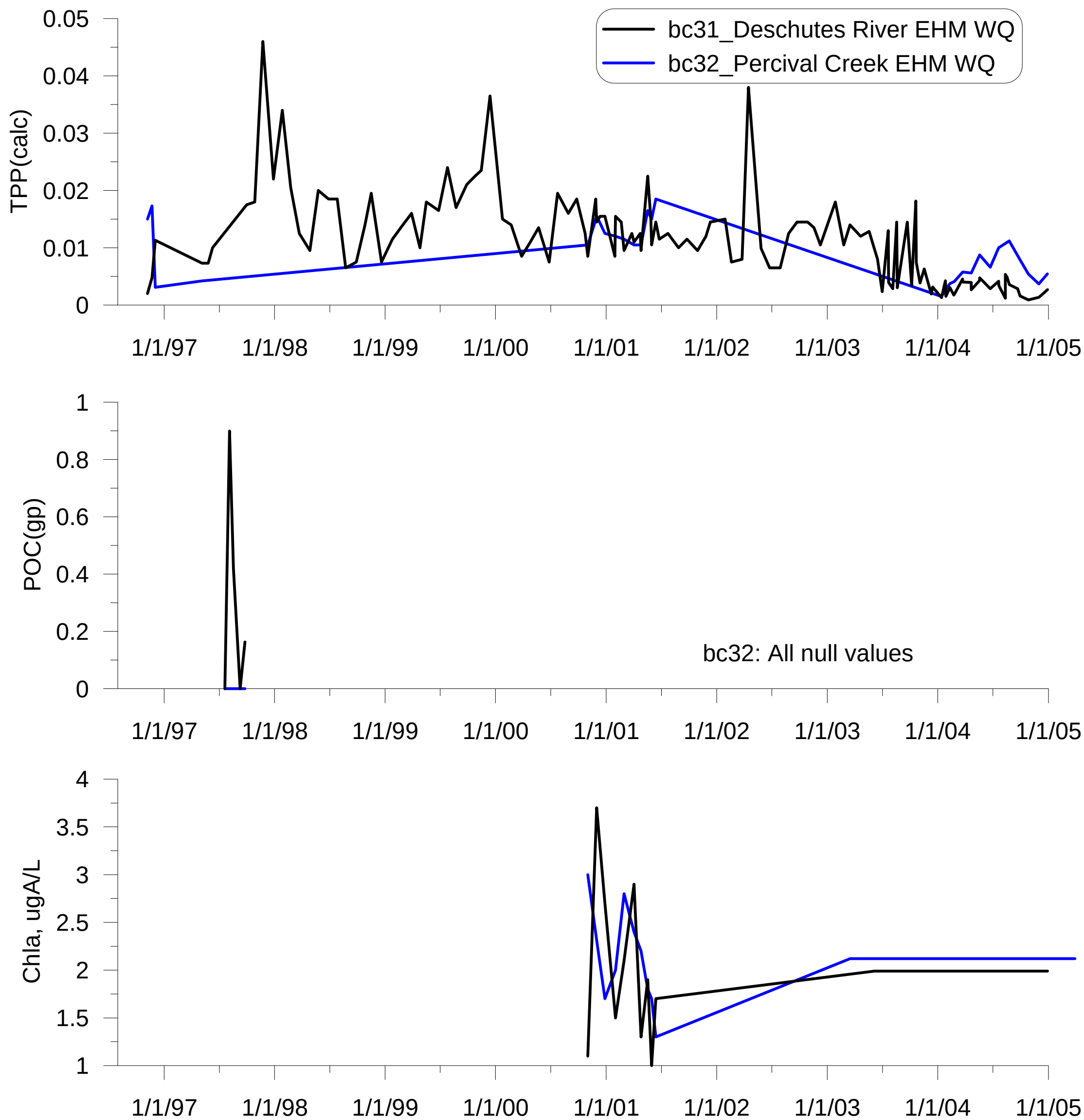


Figure 82. WQGraph12-6



bc32: Additional files OC_P_F and OC_P_R all null values

Figure 83. WQGraph12-7

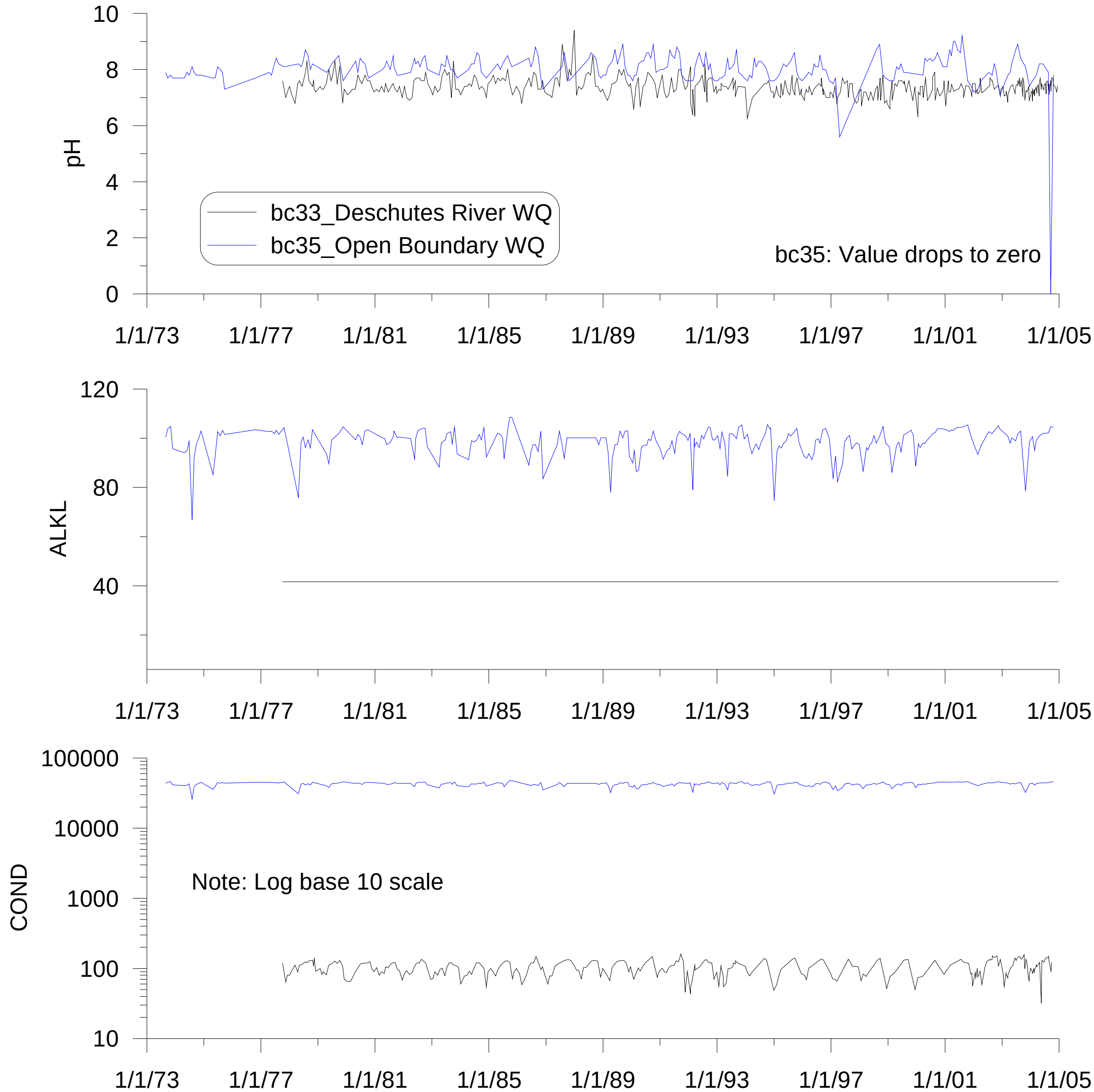


Figure 84. WQGraph13

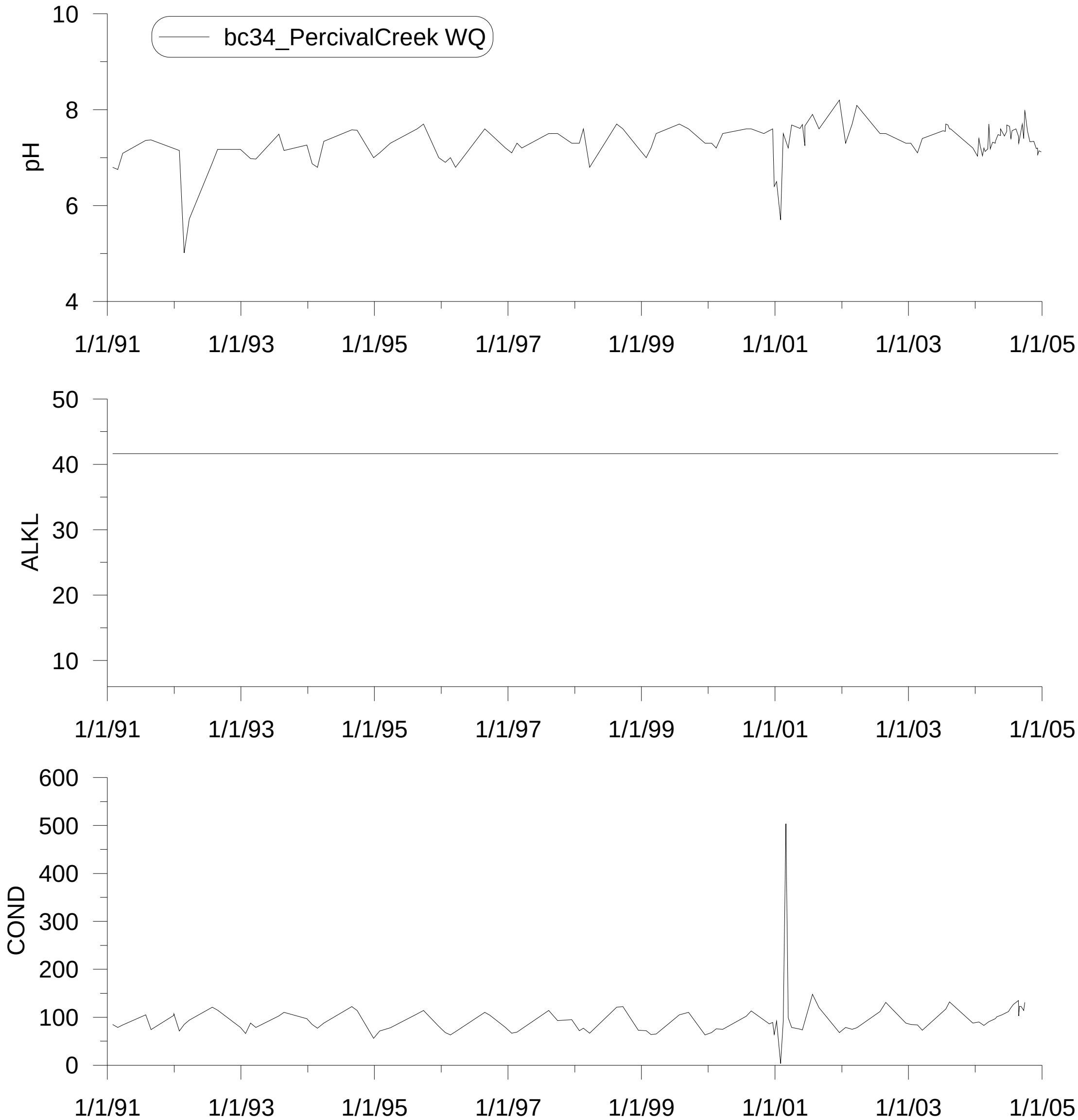


Figure 85. WQGraph14

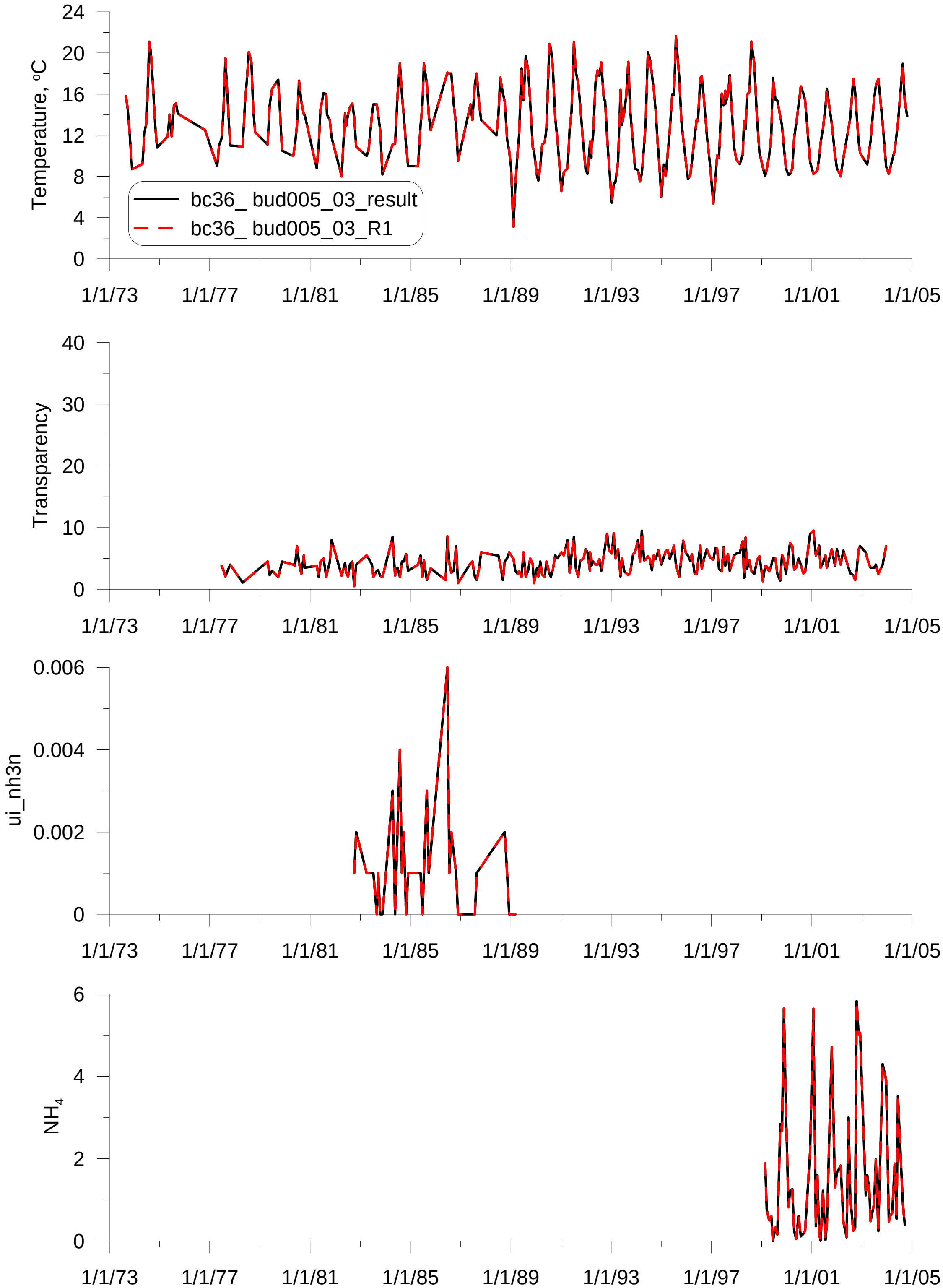


Figure 86. WQGraph15-1

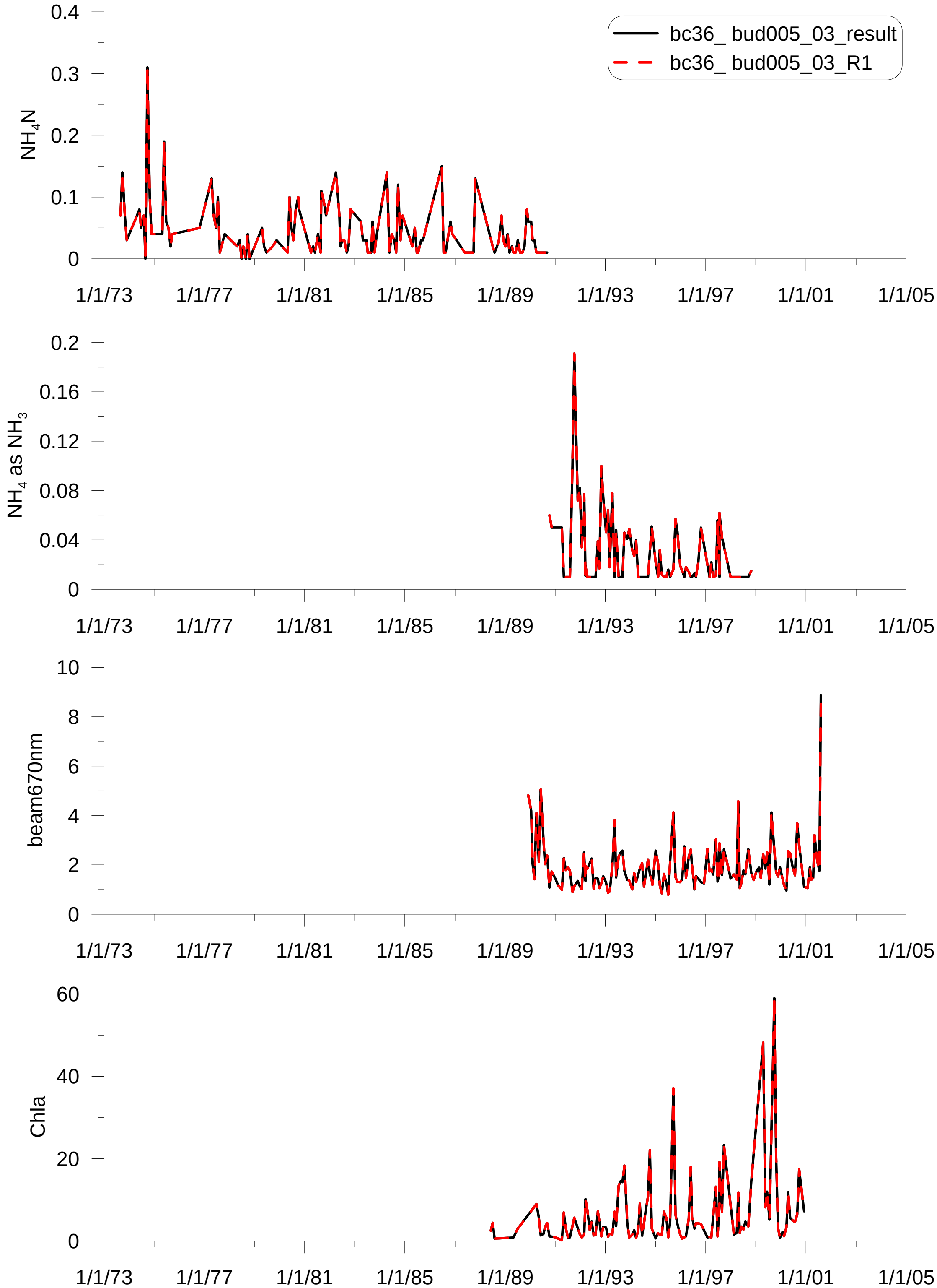


Figure 87. WQGraph15-2

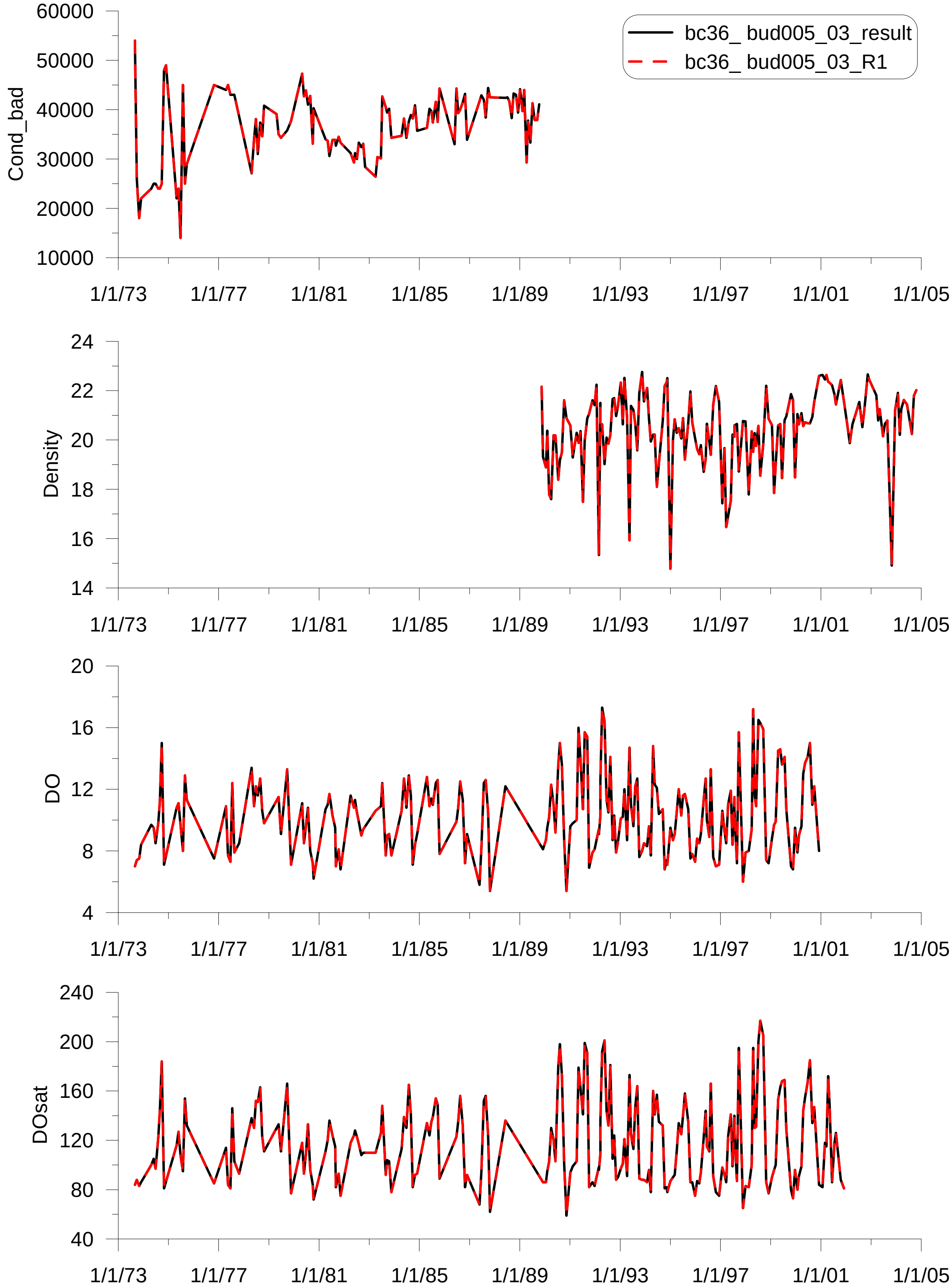


Figure 88. WQGraph15-3

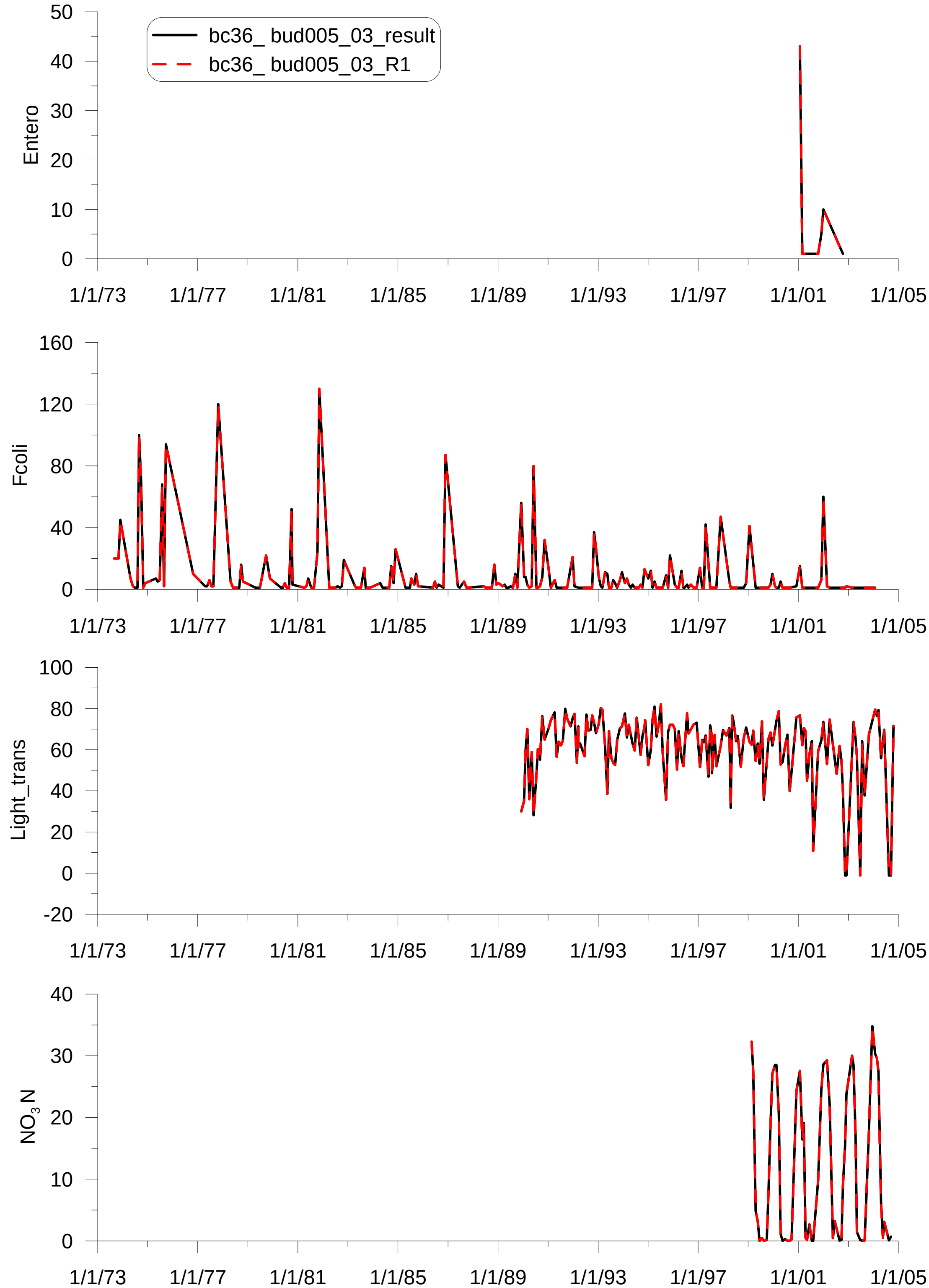


Figure 89. WQGraph15-4

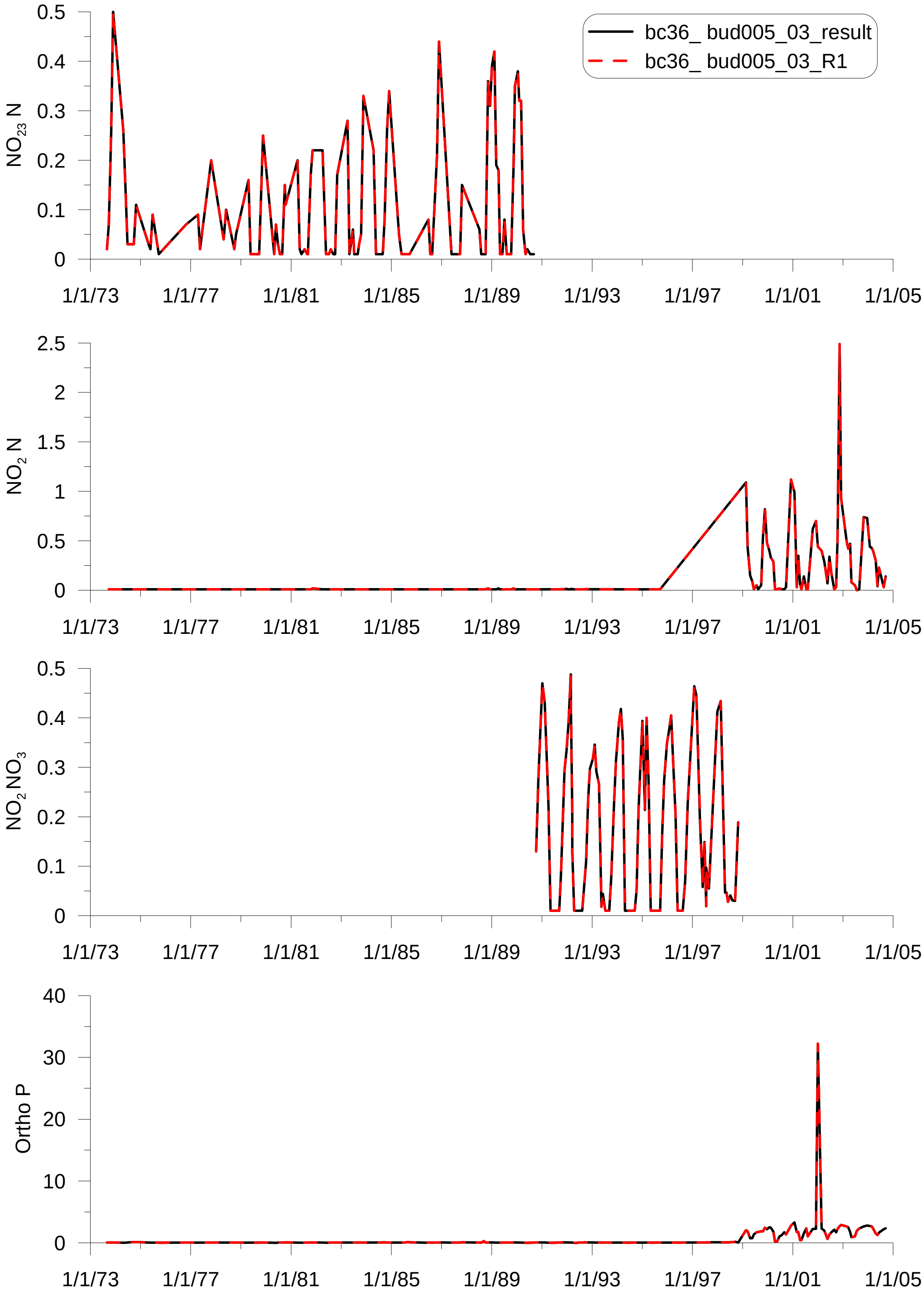


Figure 90. WQGraph15-5

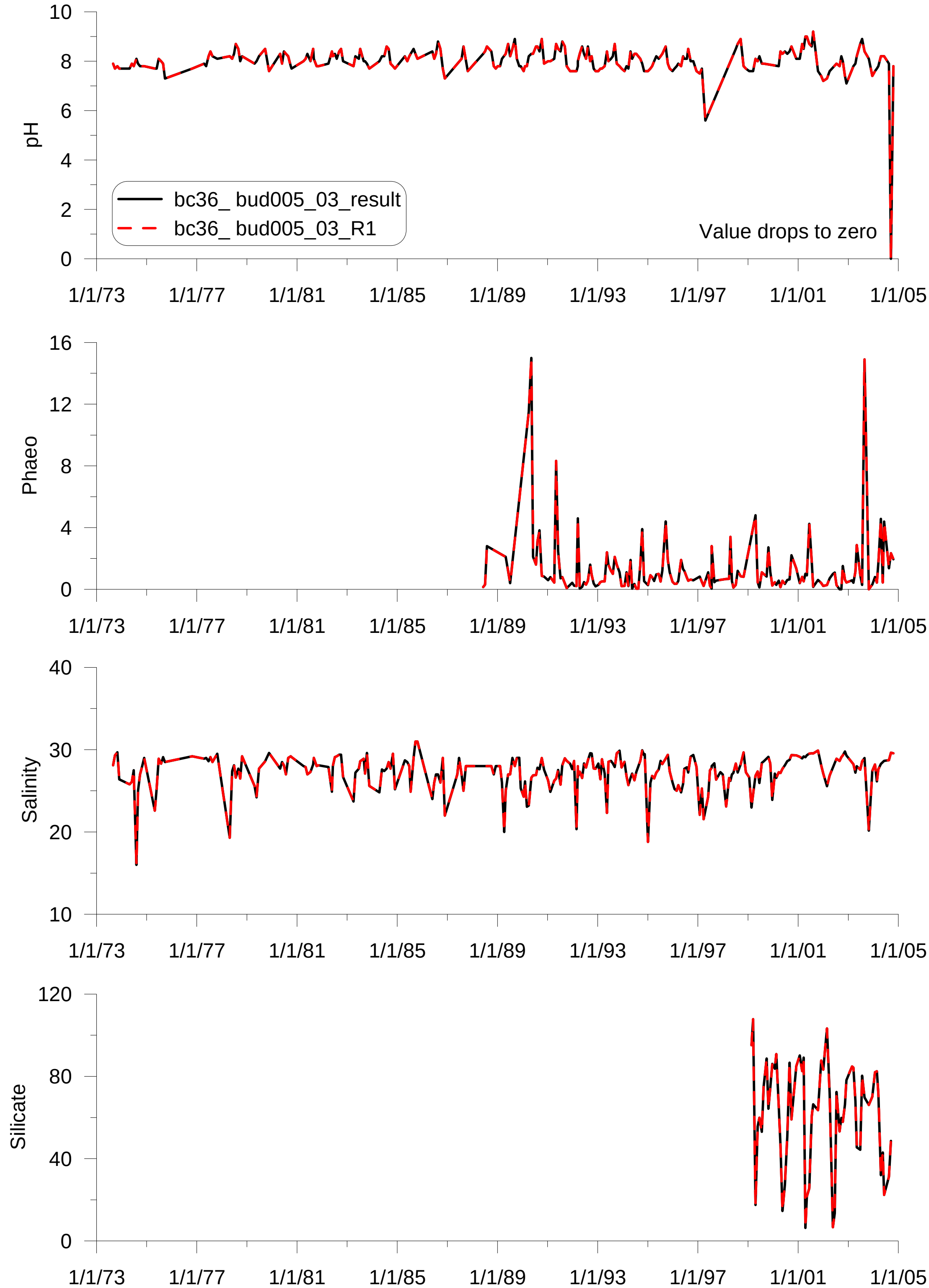


Figure 91. WQGraph15-6

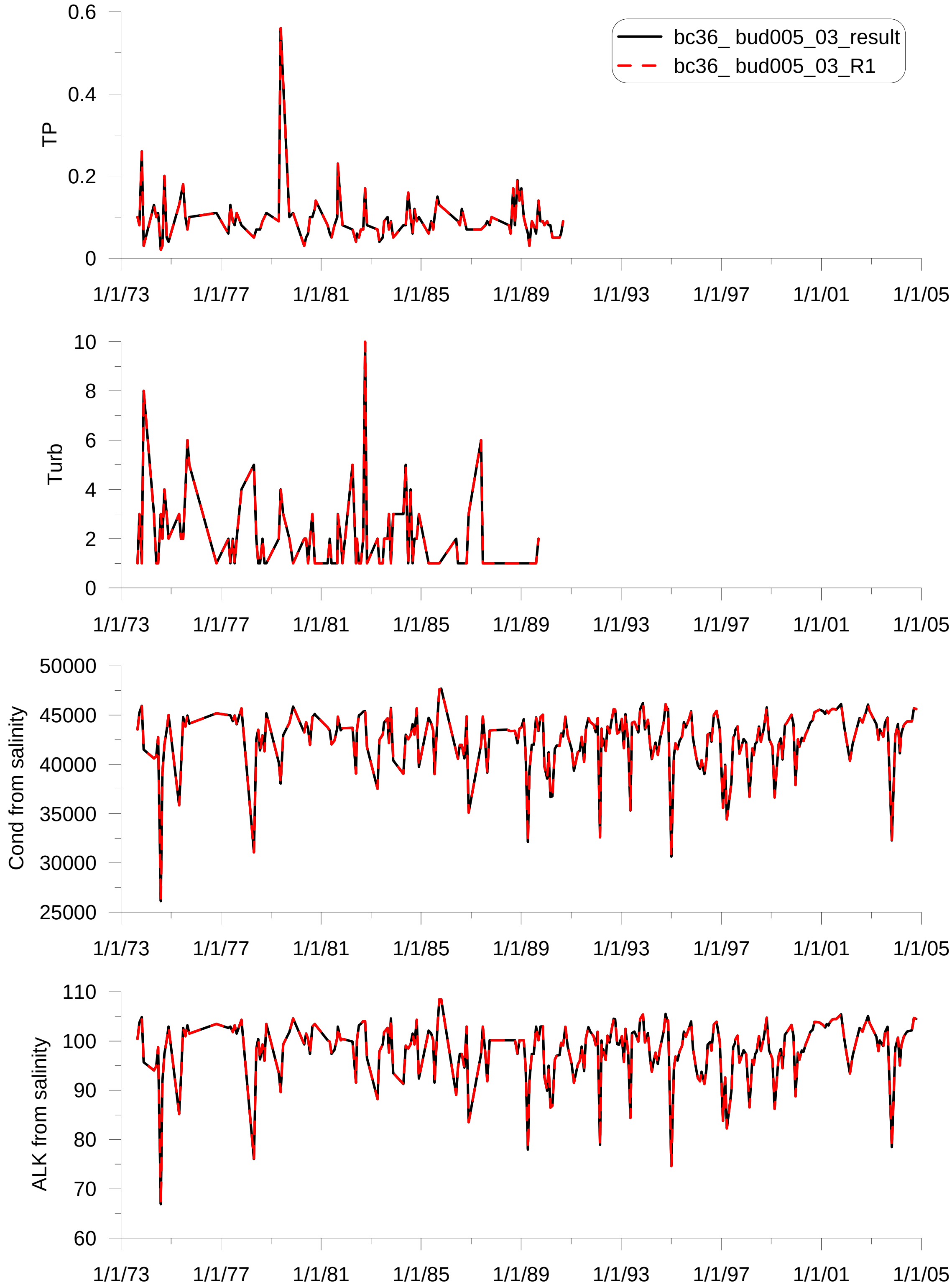


Figure 92. WQGraph15-7

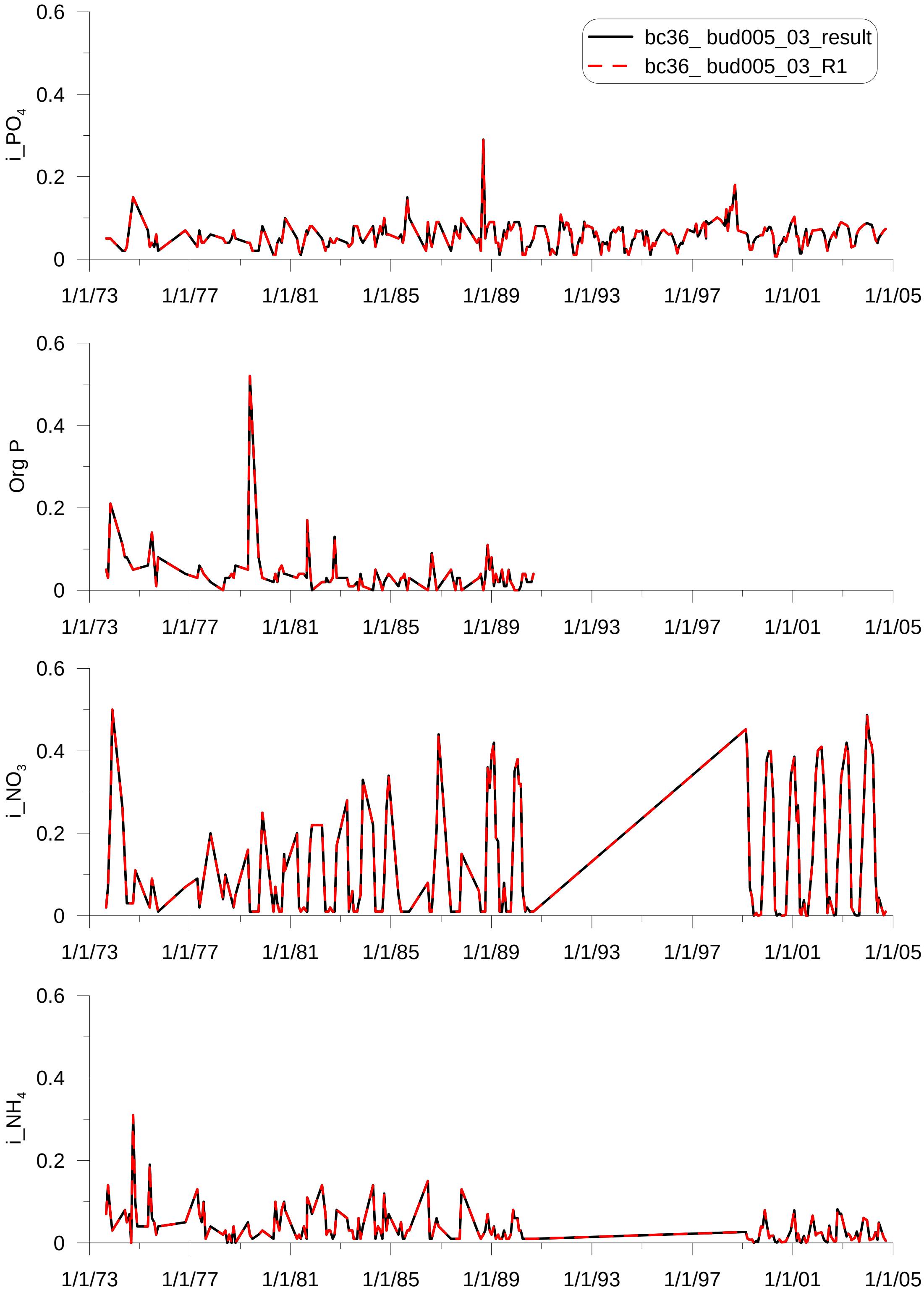


Figure 93. WQGraph15-8

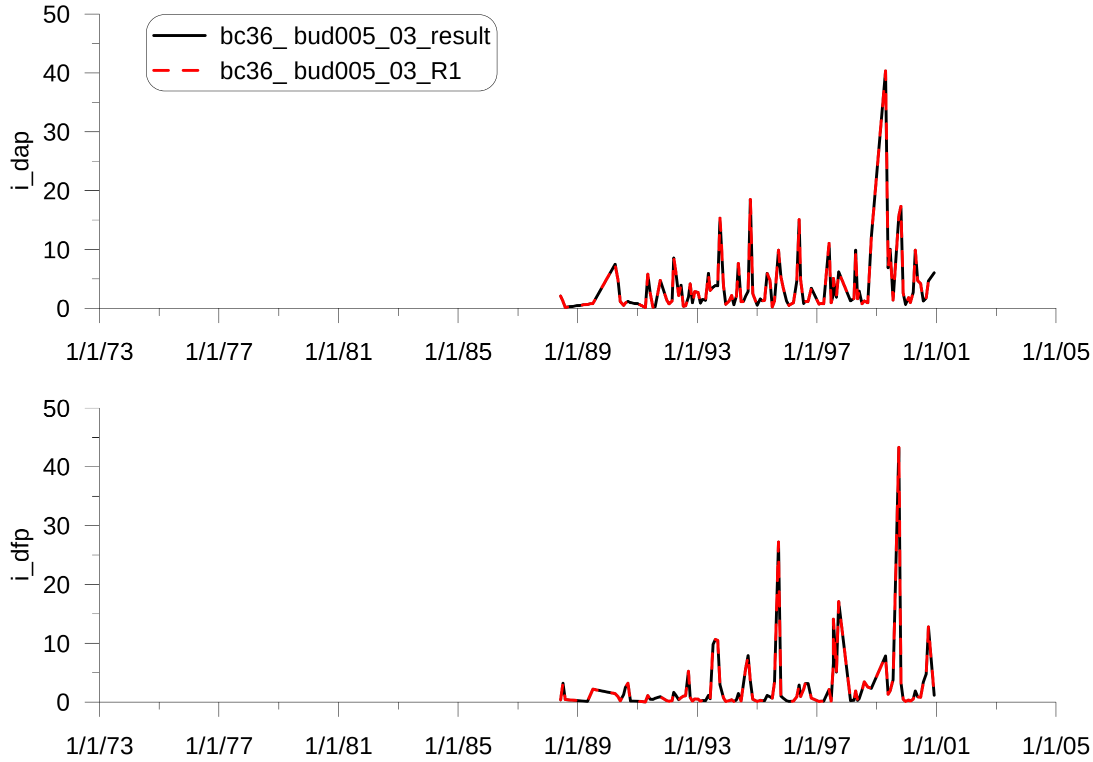


Figure 94. WQGraph15-9

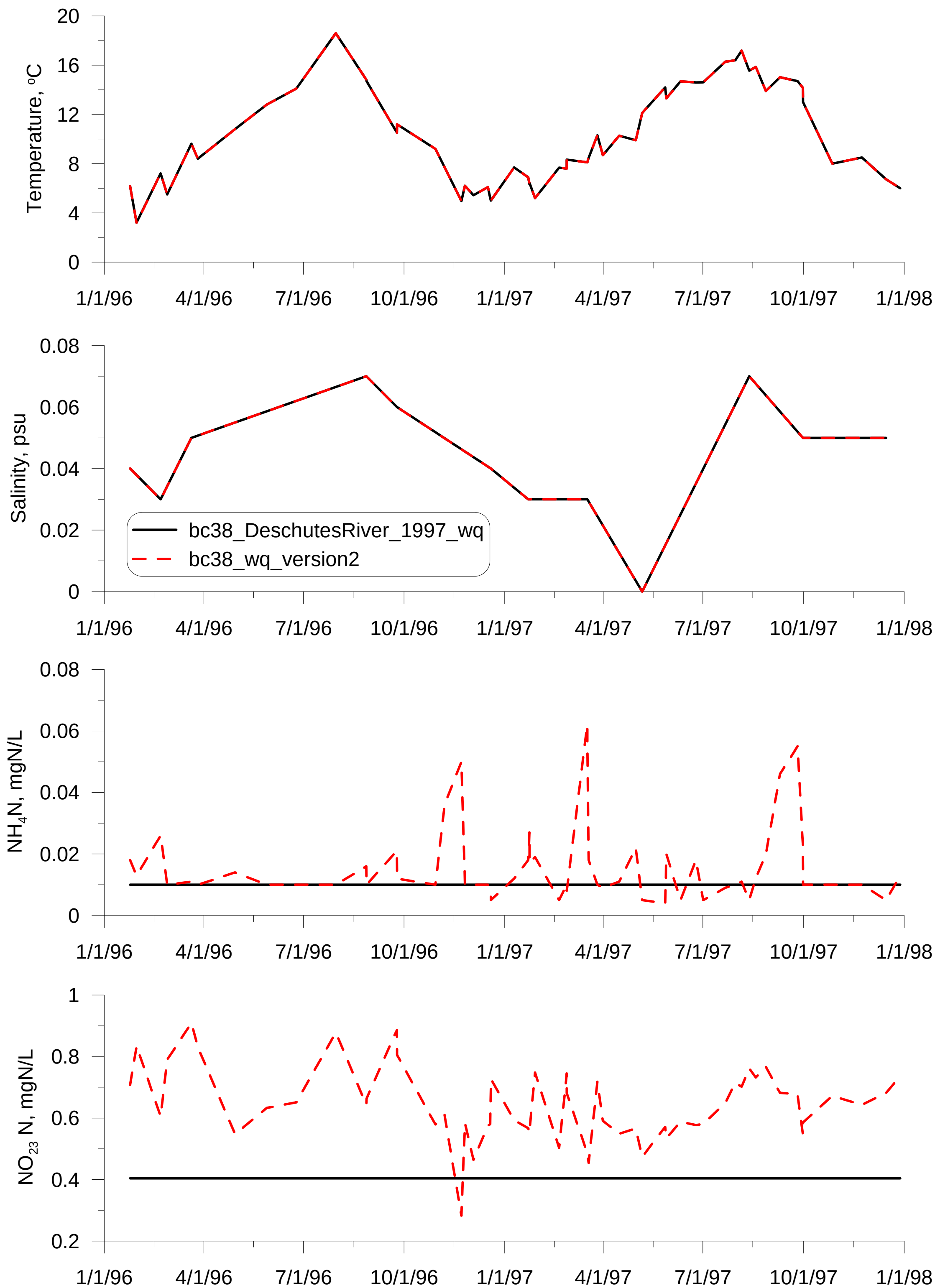


Figure 95. WQGraph16-1

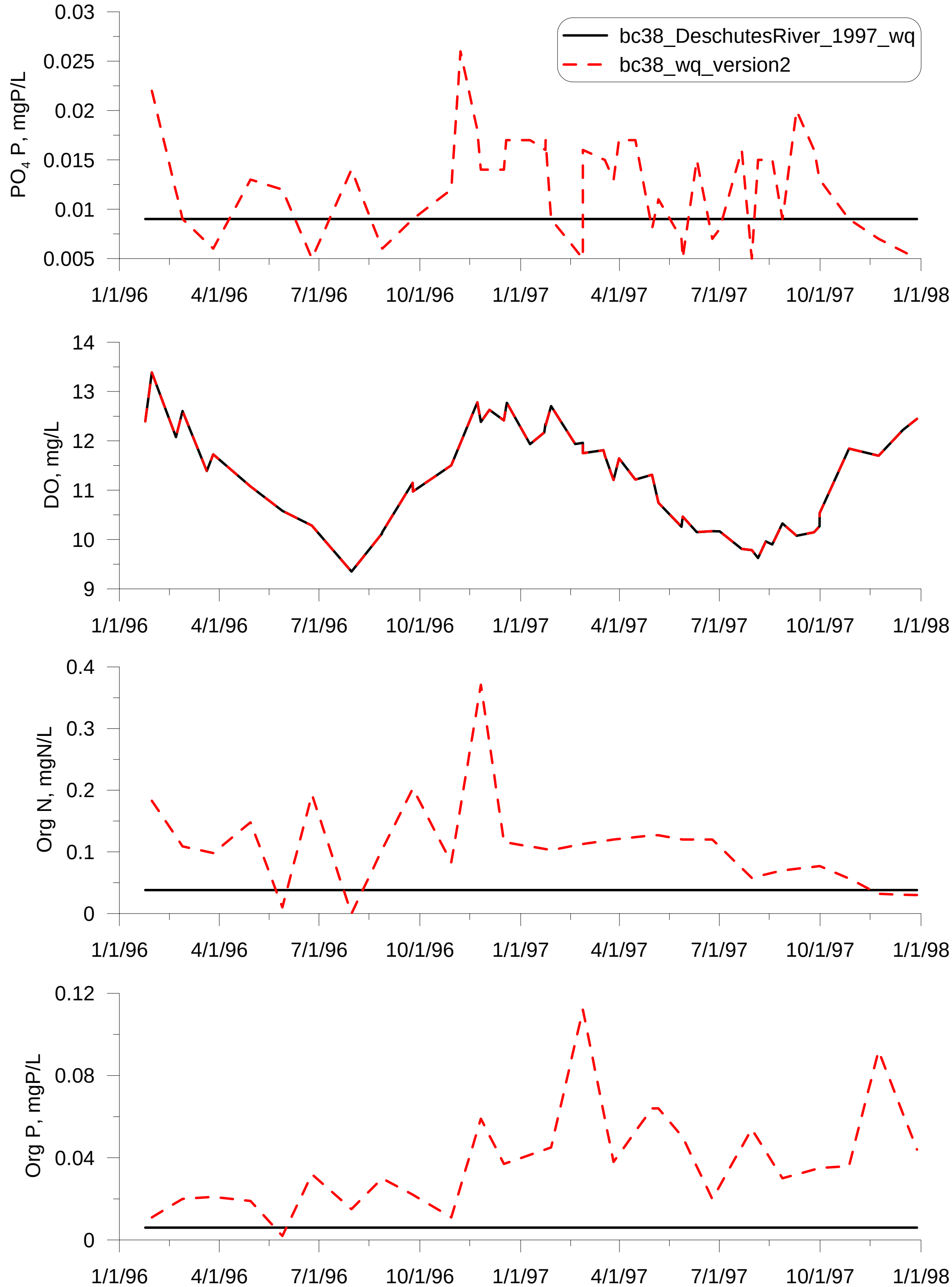


Figure 96. WQGraph16-2

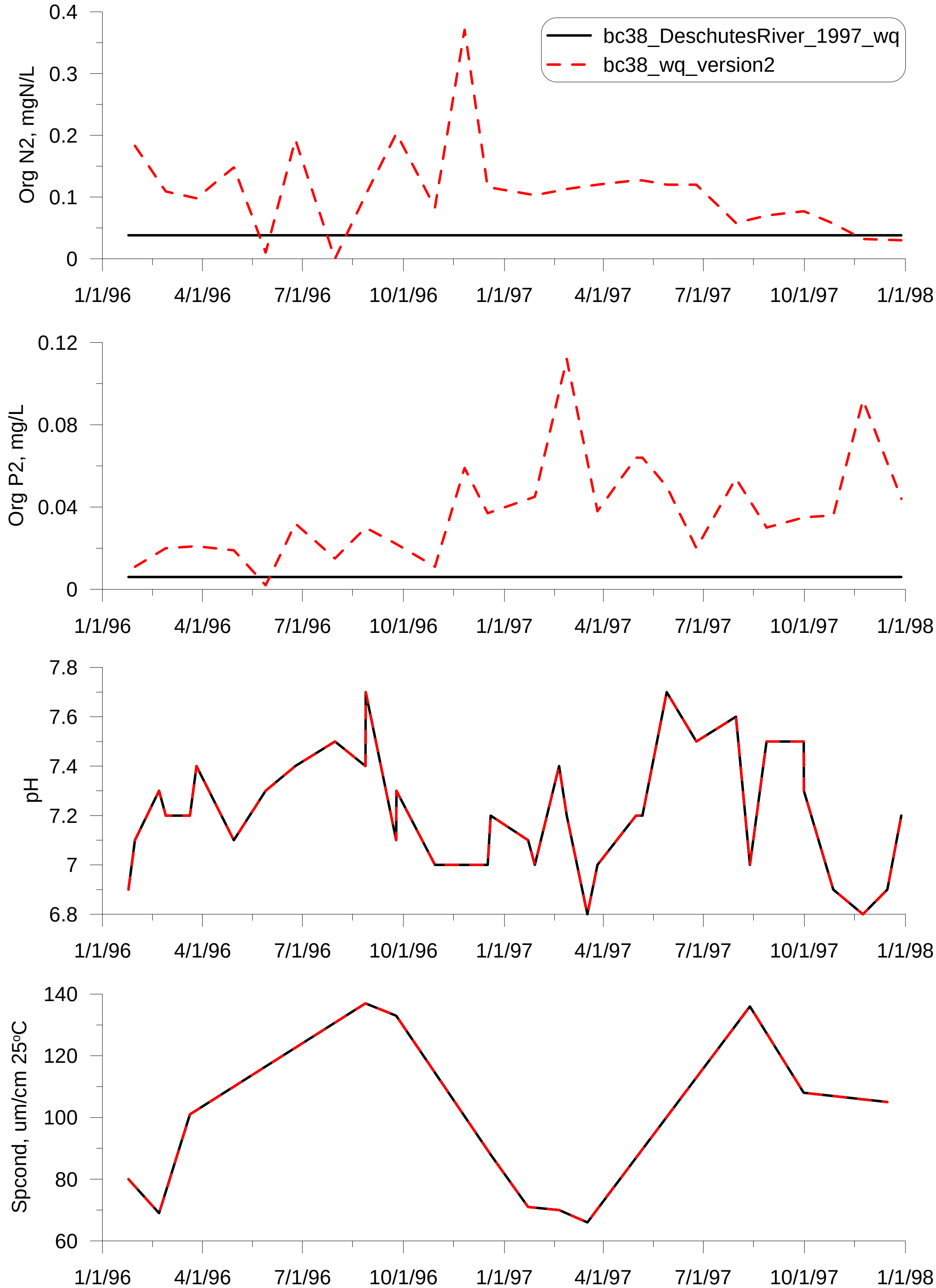


Figure 97. WQGraph16-3

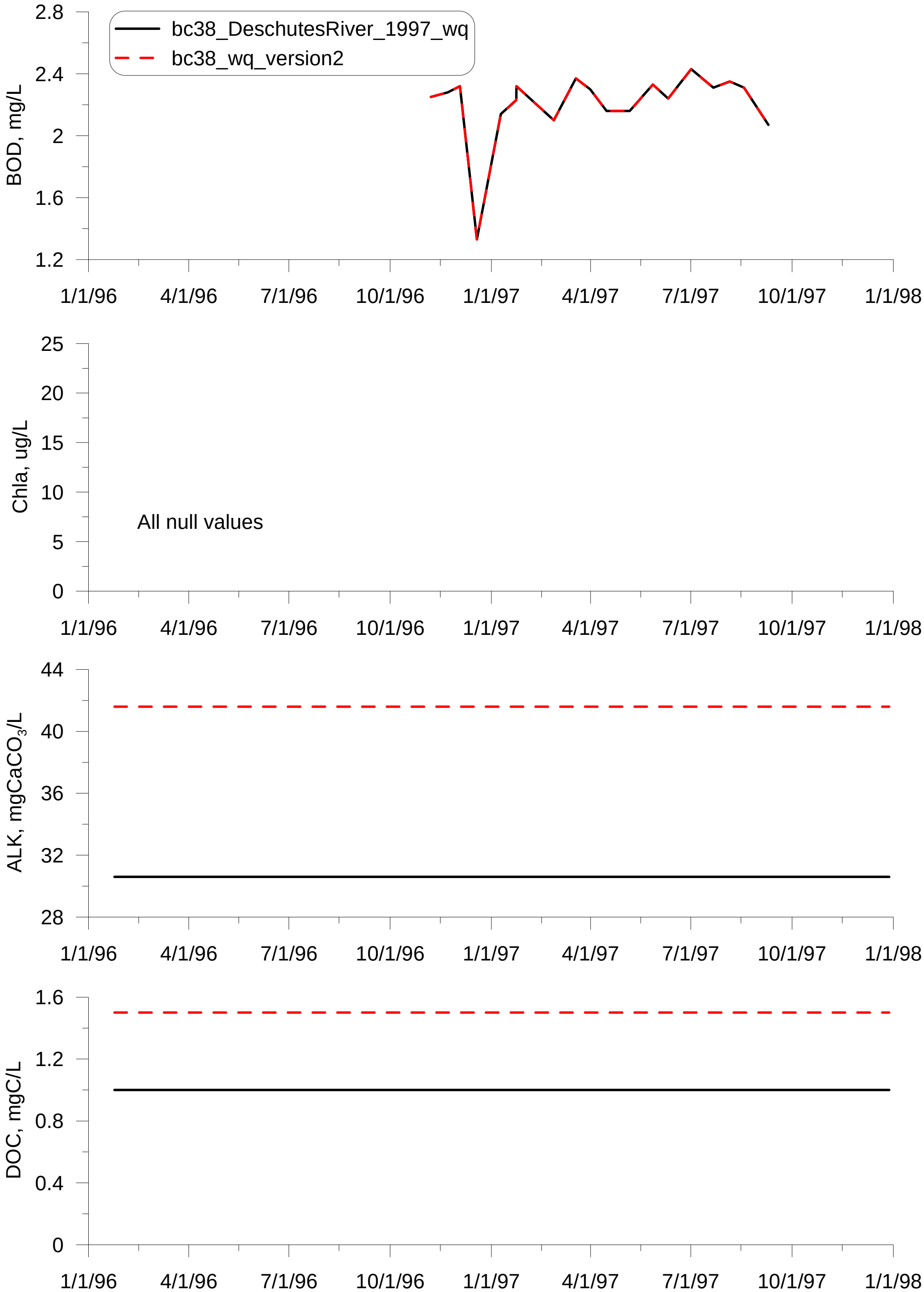


Figure 98. WQGraph16-4

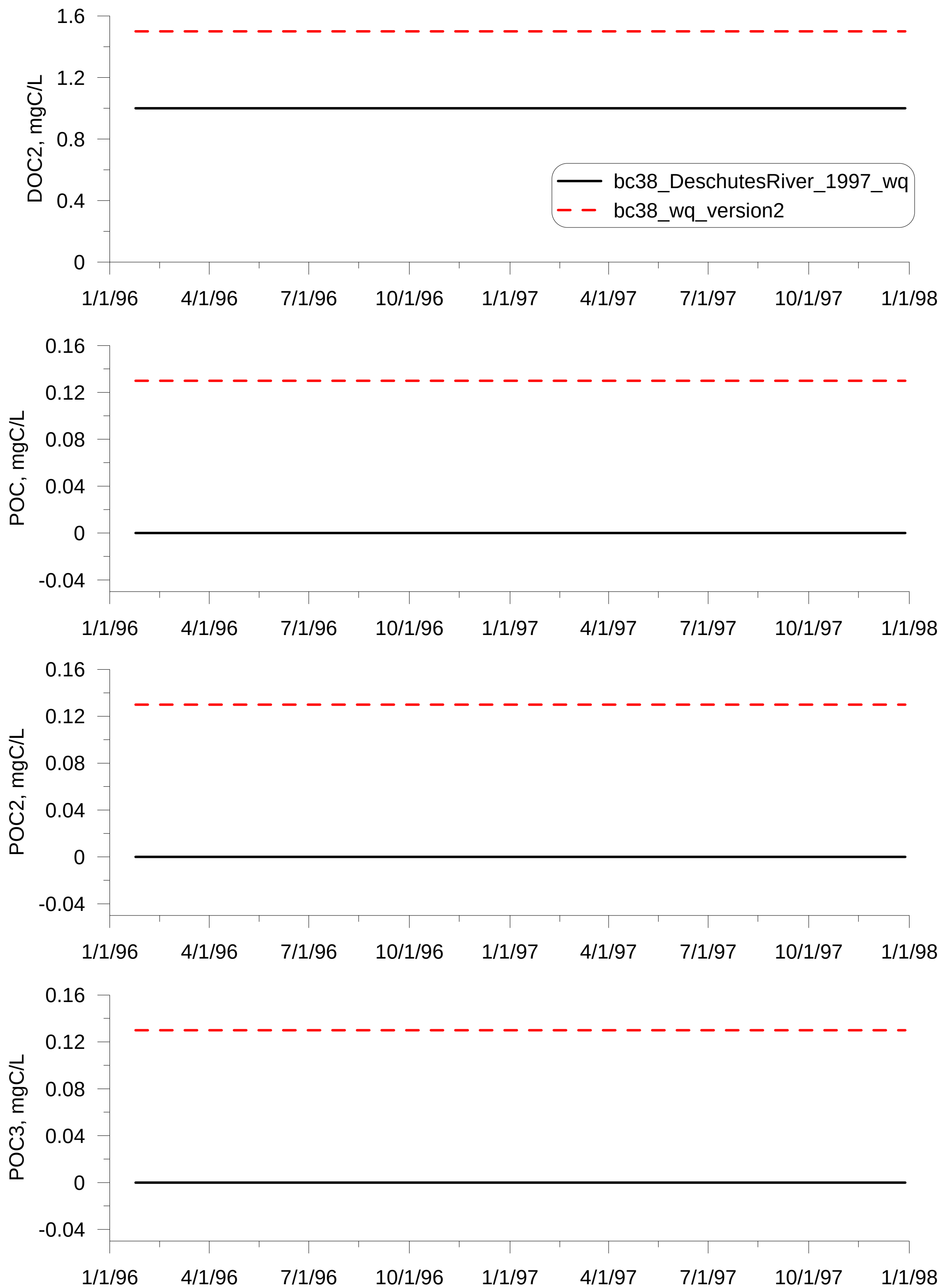


Figure 99. WQGraph16-5

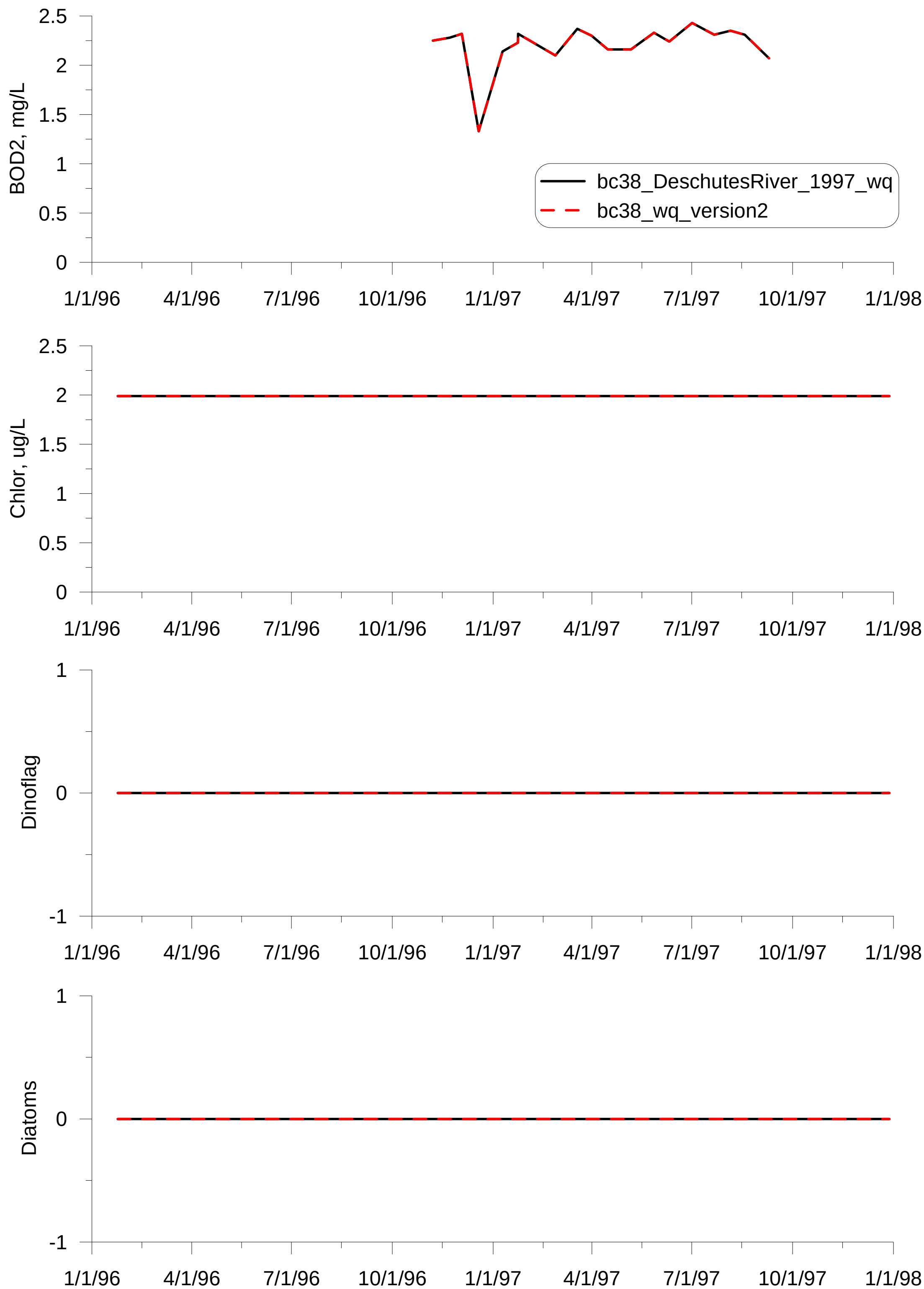


Figure 100. WQGraph16-6

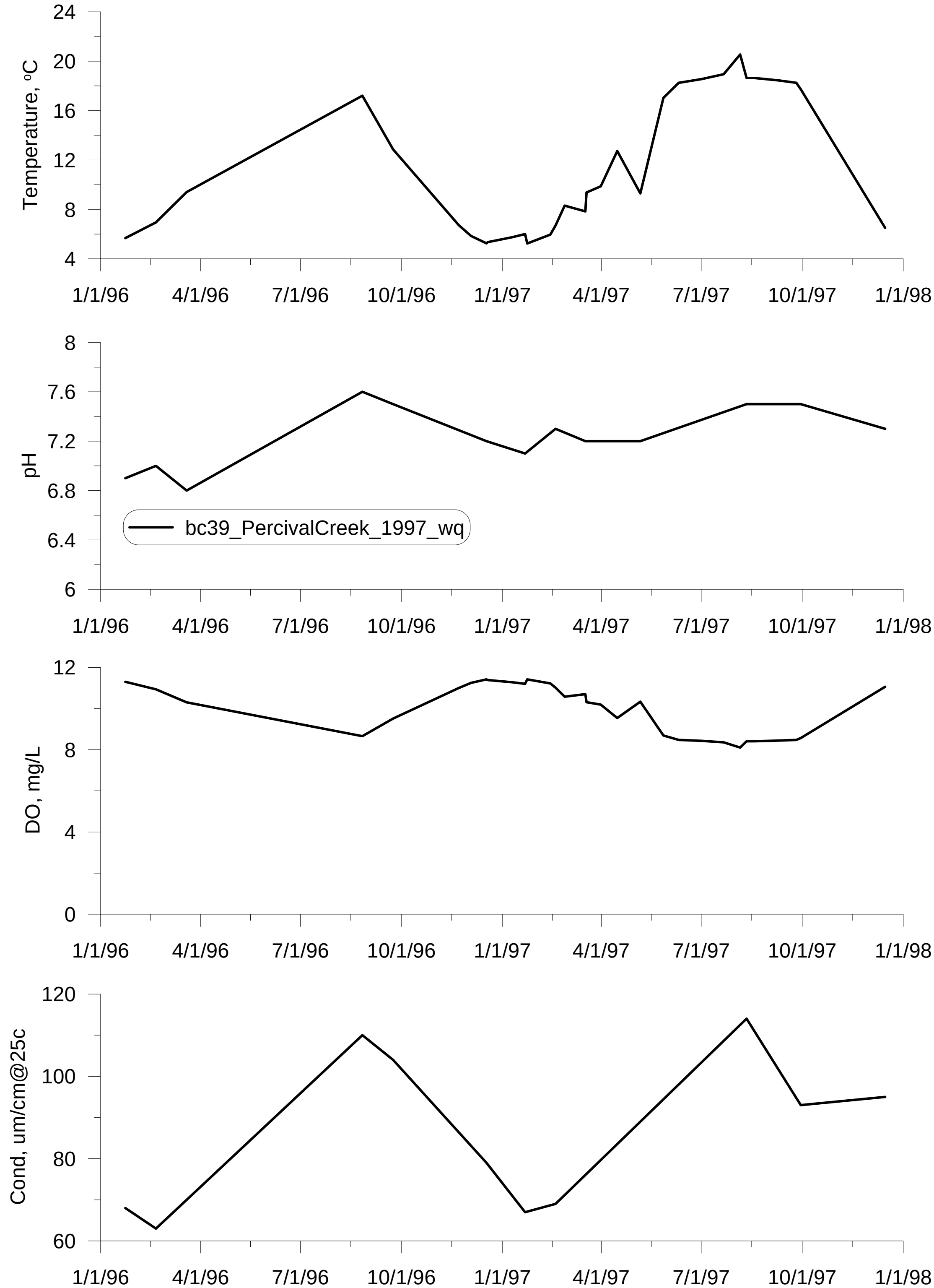


Figure 101. WQGraph17-1

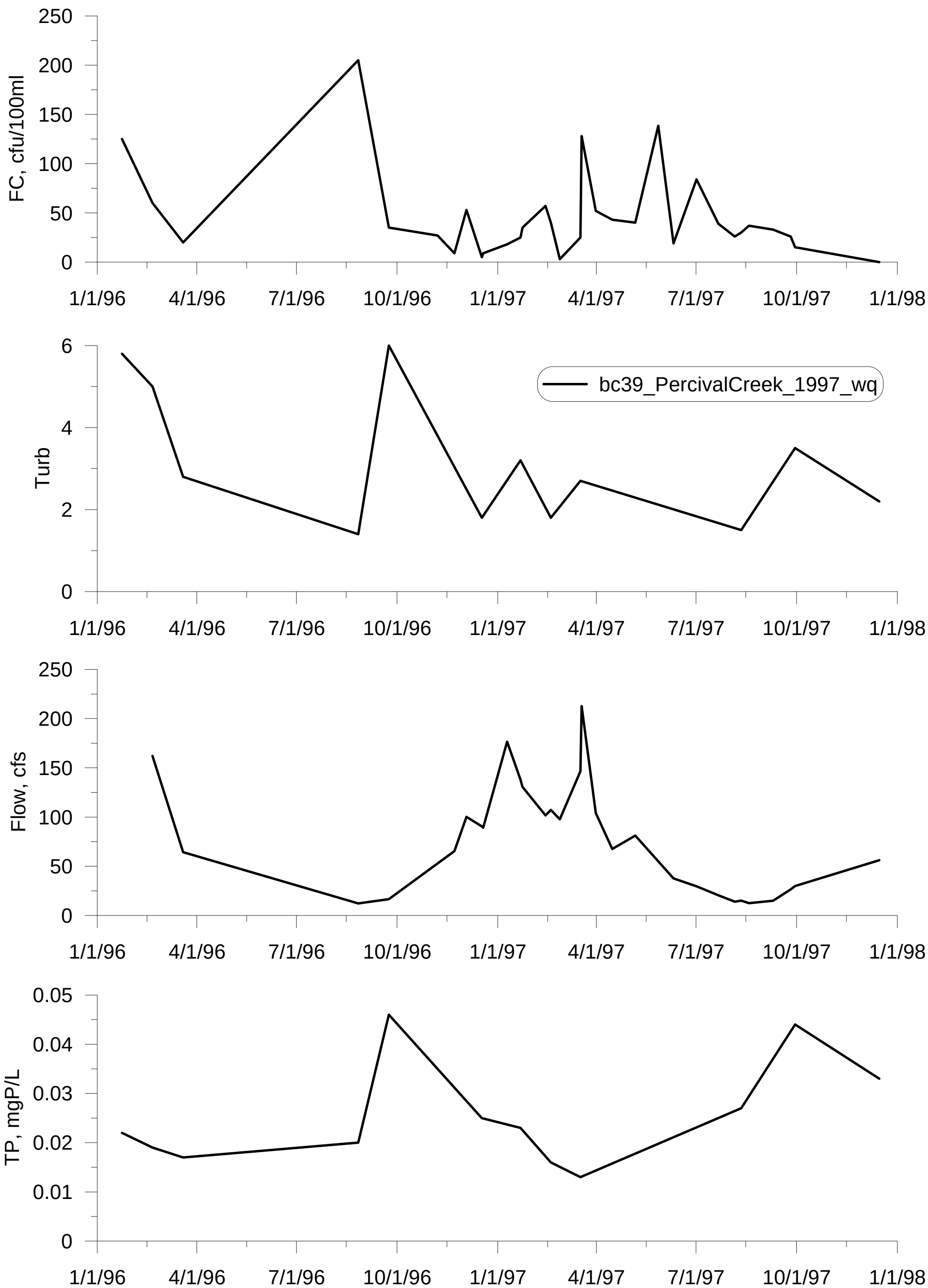


Figure 102. WQGraph17-2

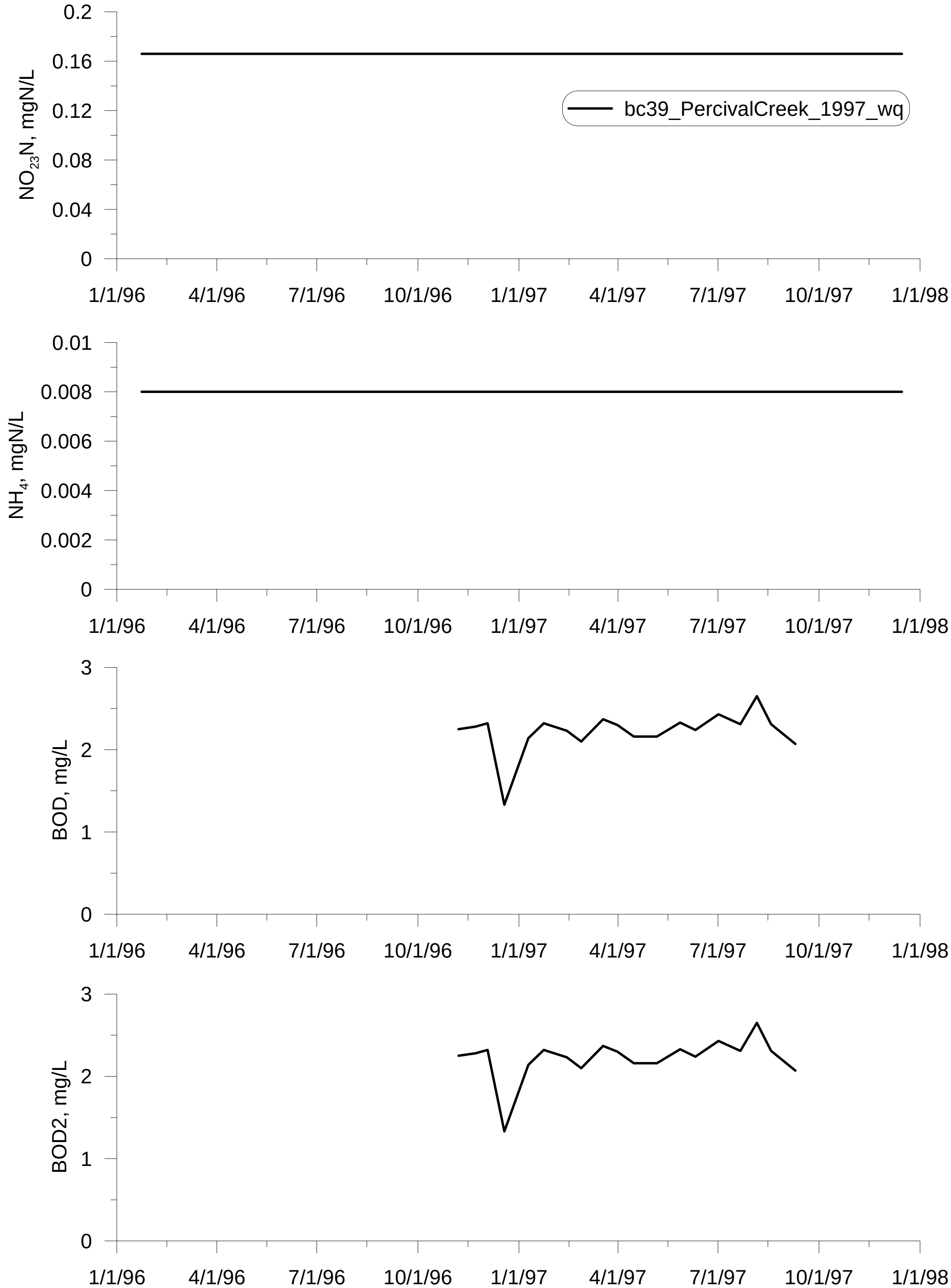


Figure 103. WQGraph17-3

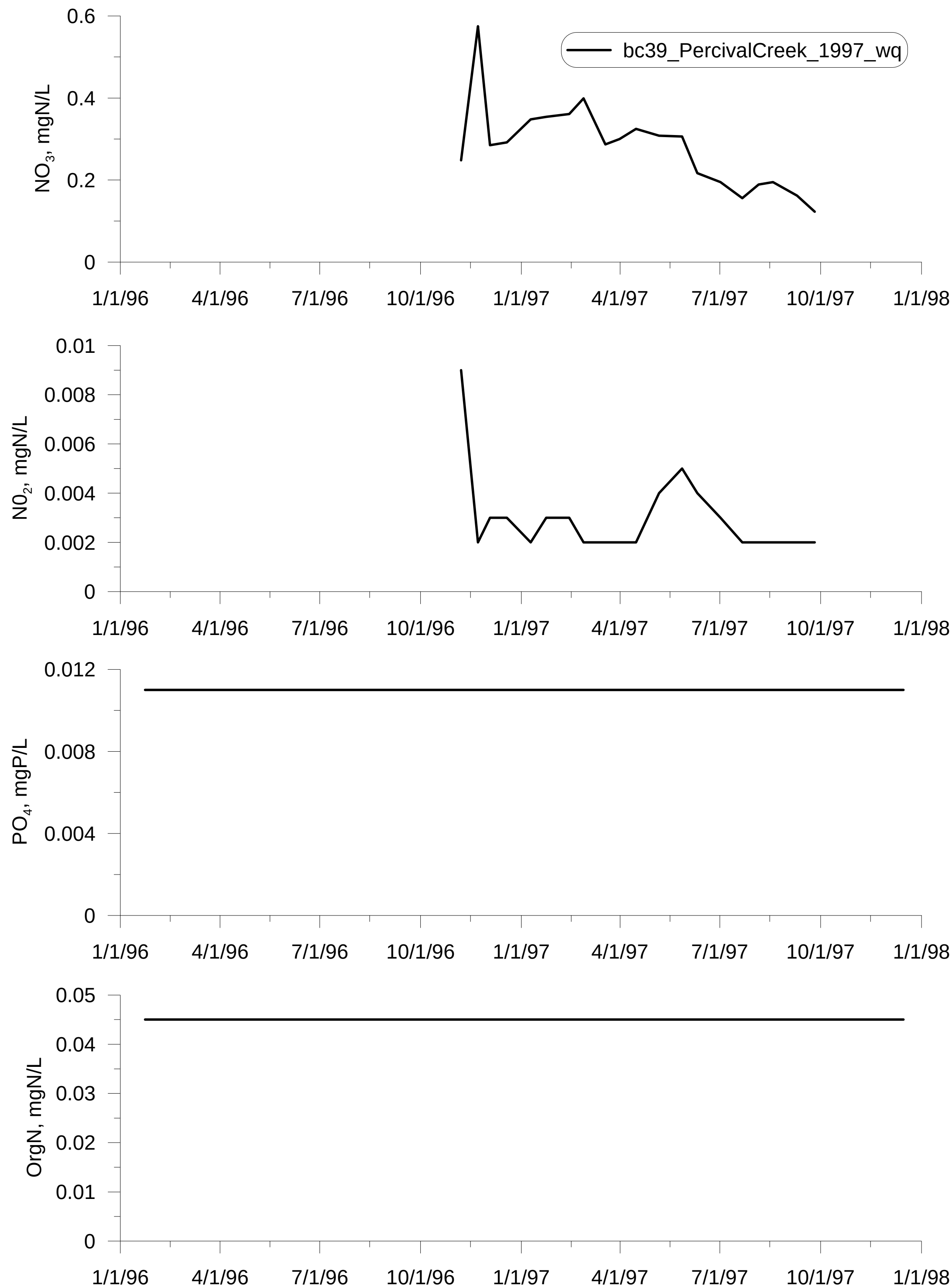


Figure 104. WQGraph17-4

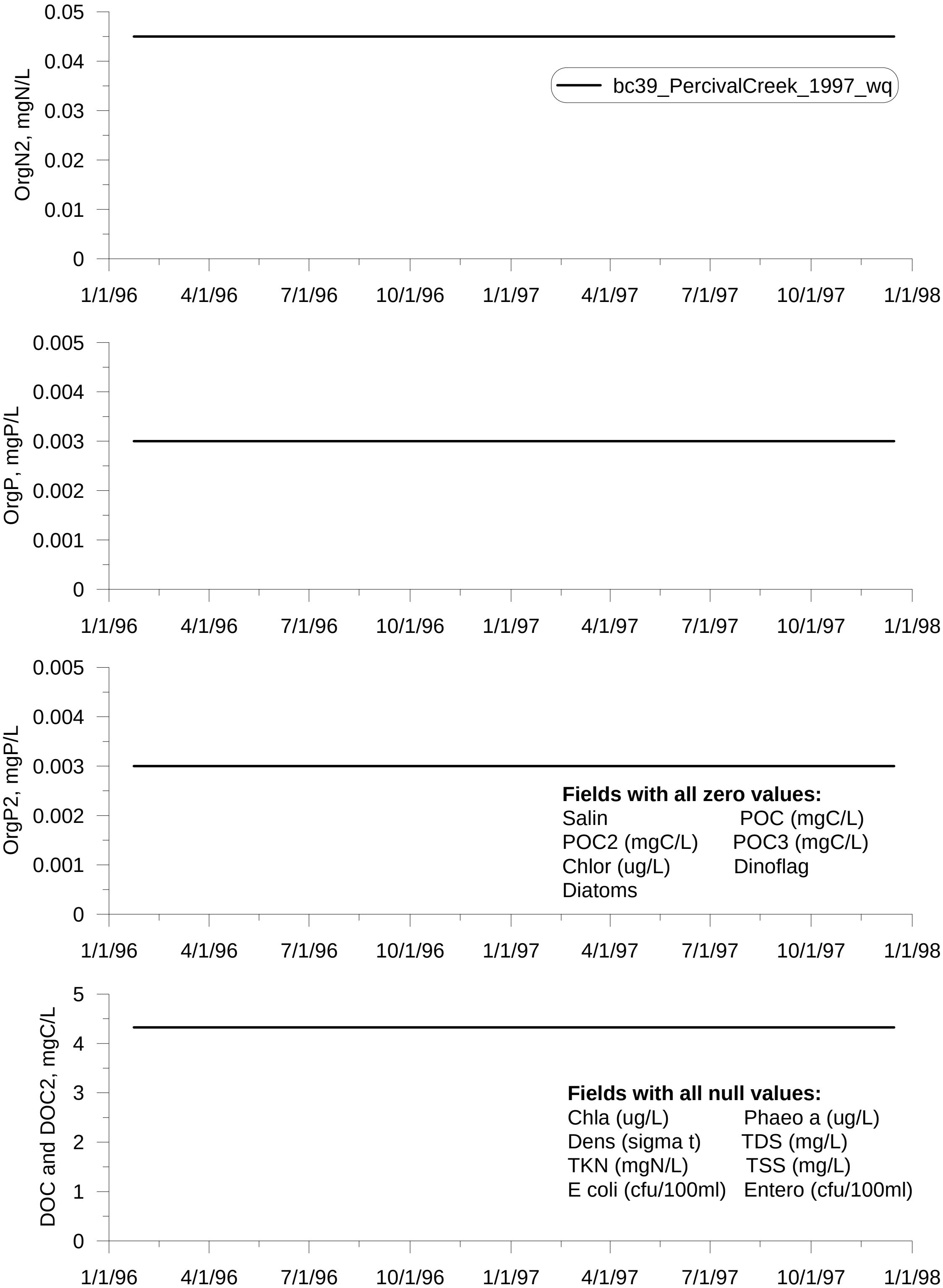


Figure 105. WQGraph17-5

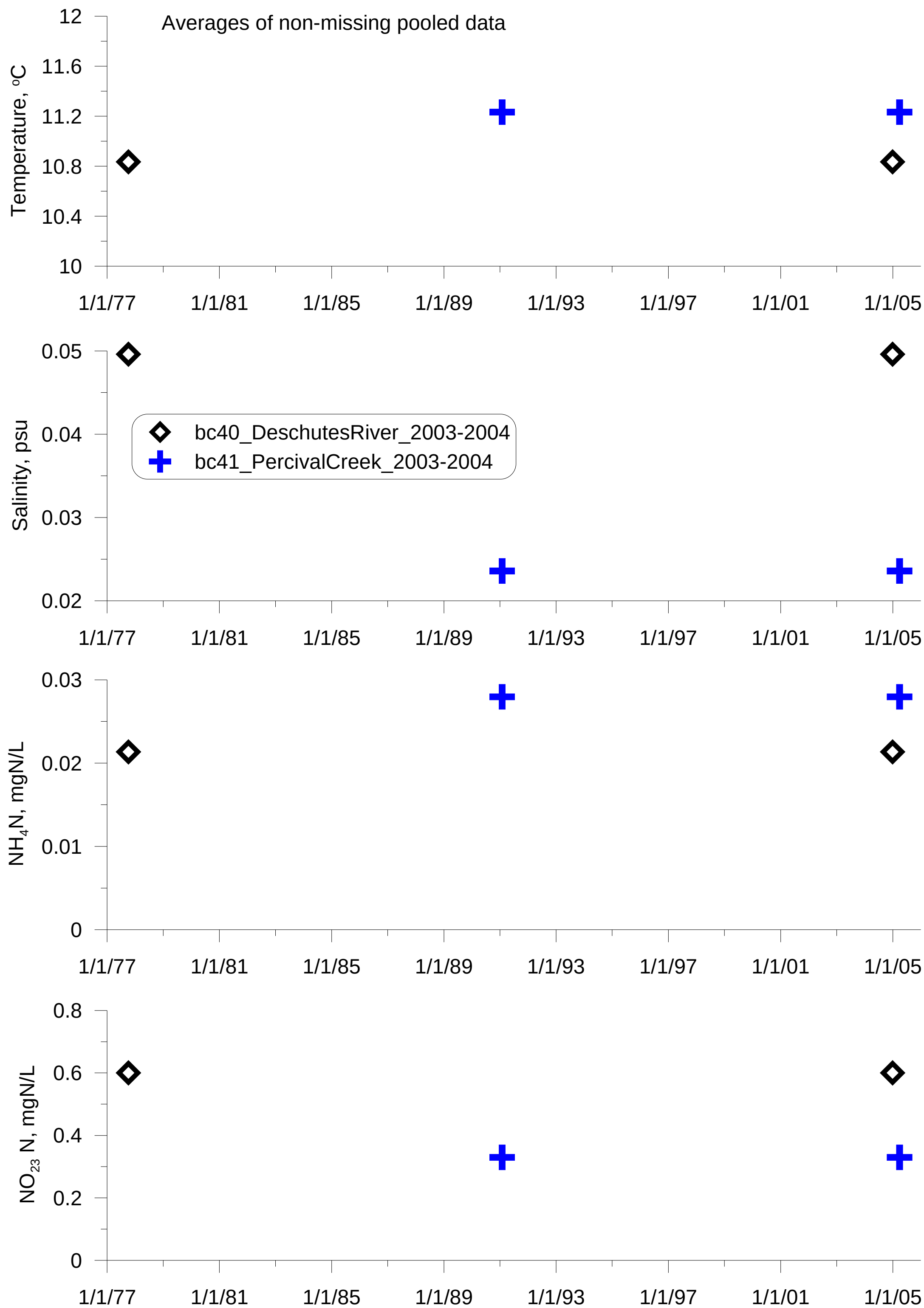


Figure 106. WQGraph18-1

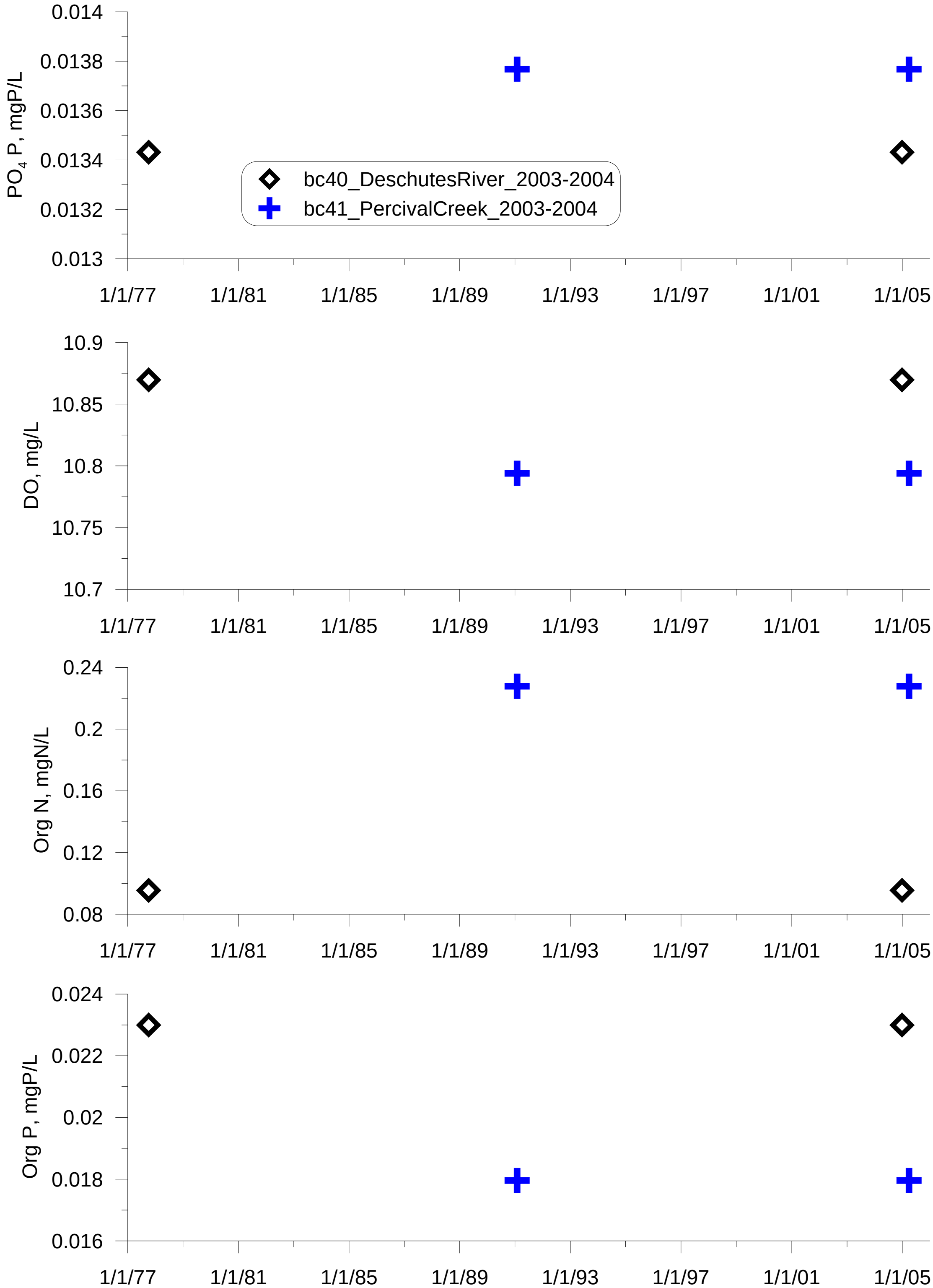


Figure 107. WQGraph18-2

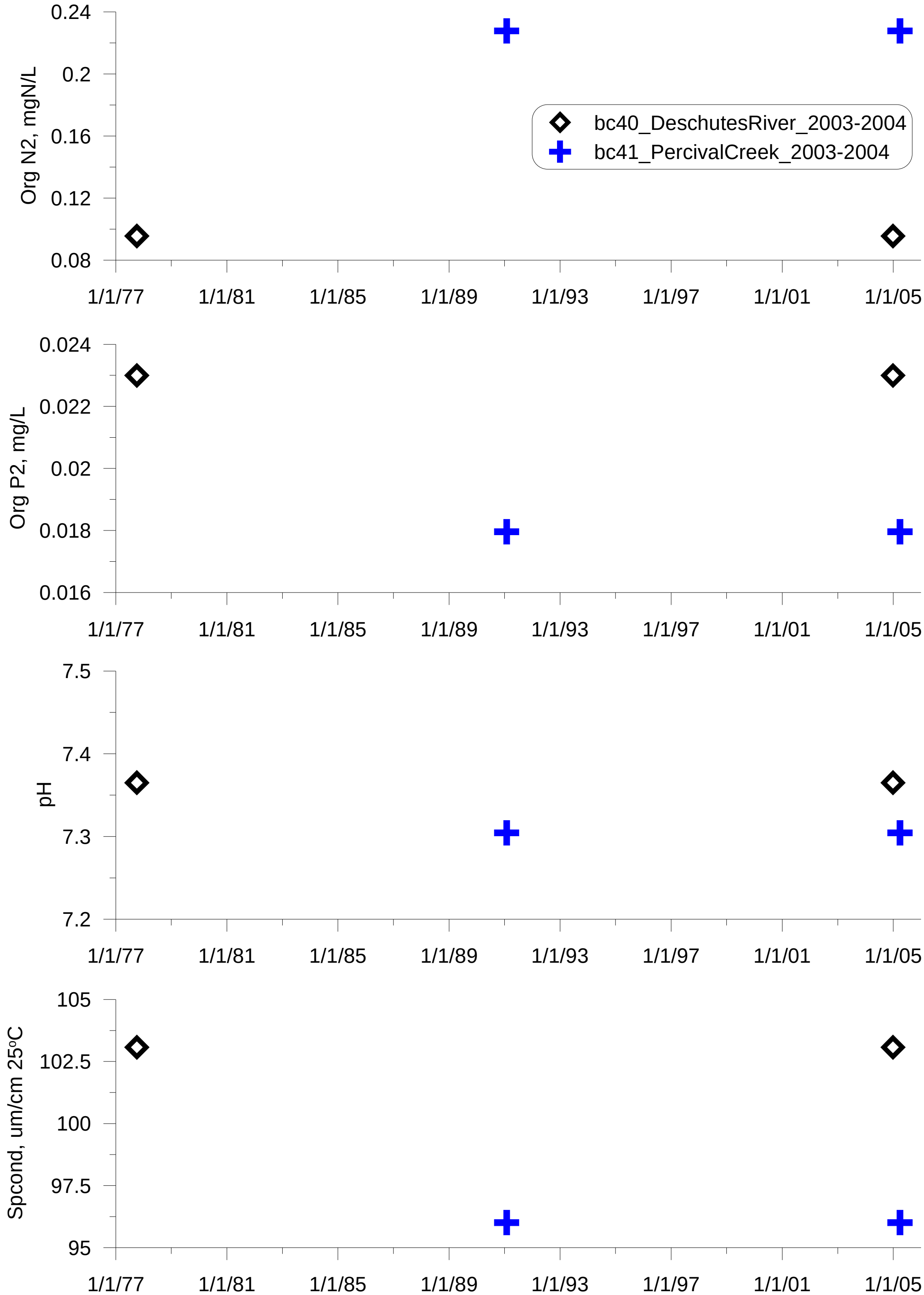


Figure 108. WQGraph18-3

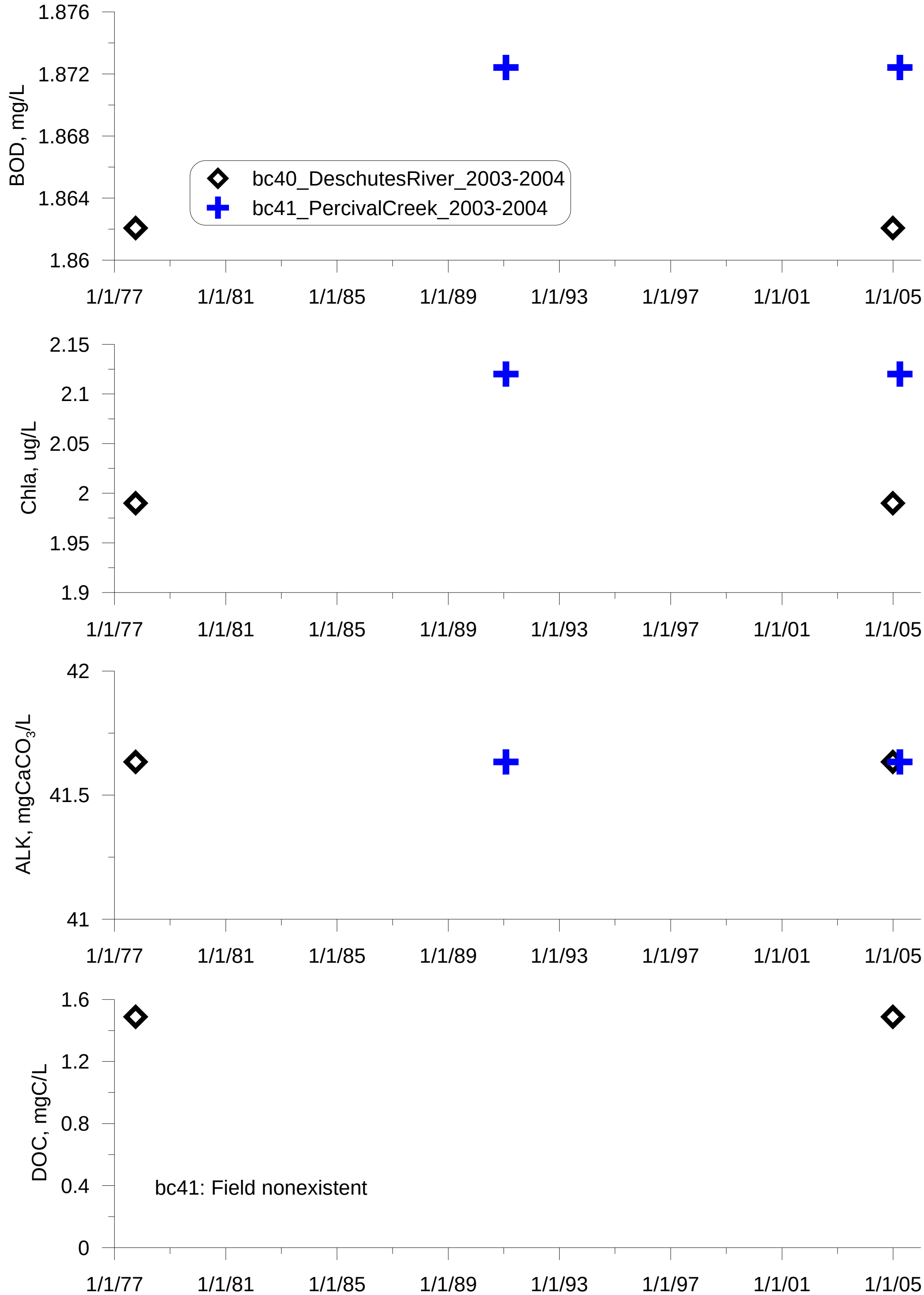


Figure 109. WQGraph18-4

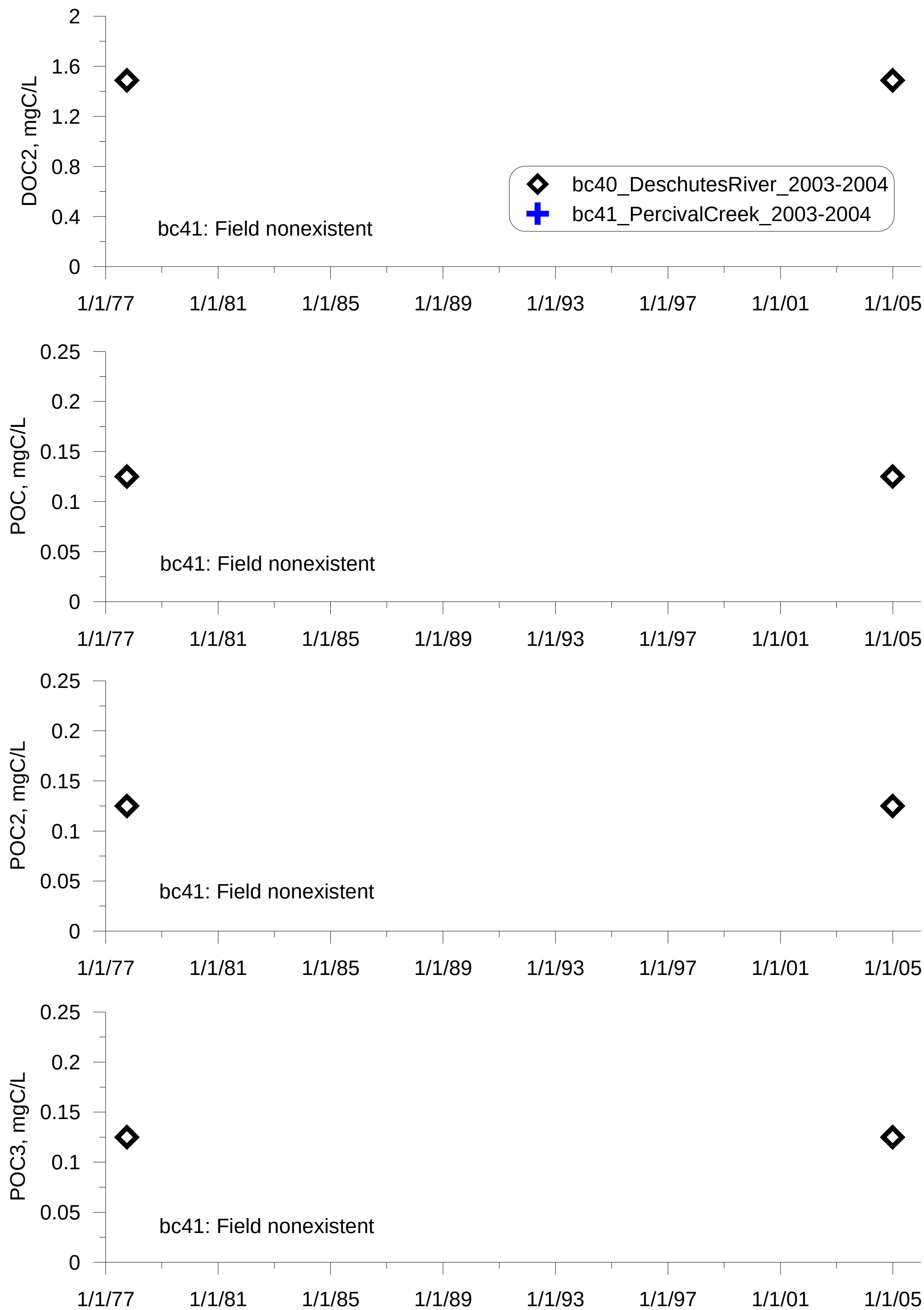


Figure 110. WQGraph18-5

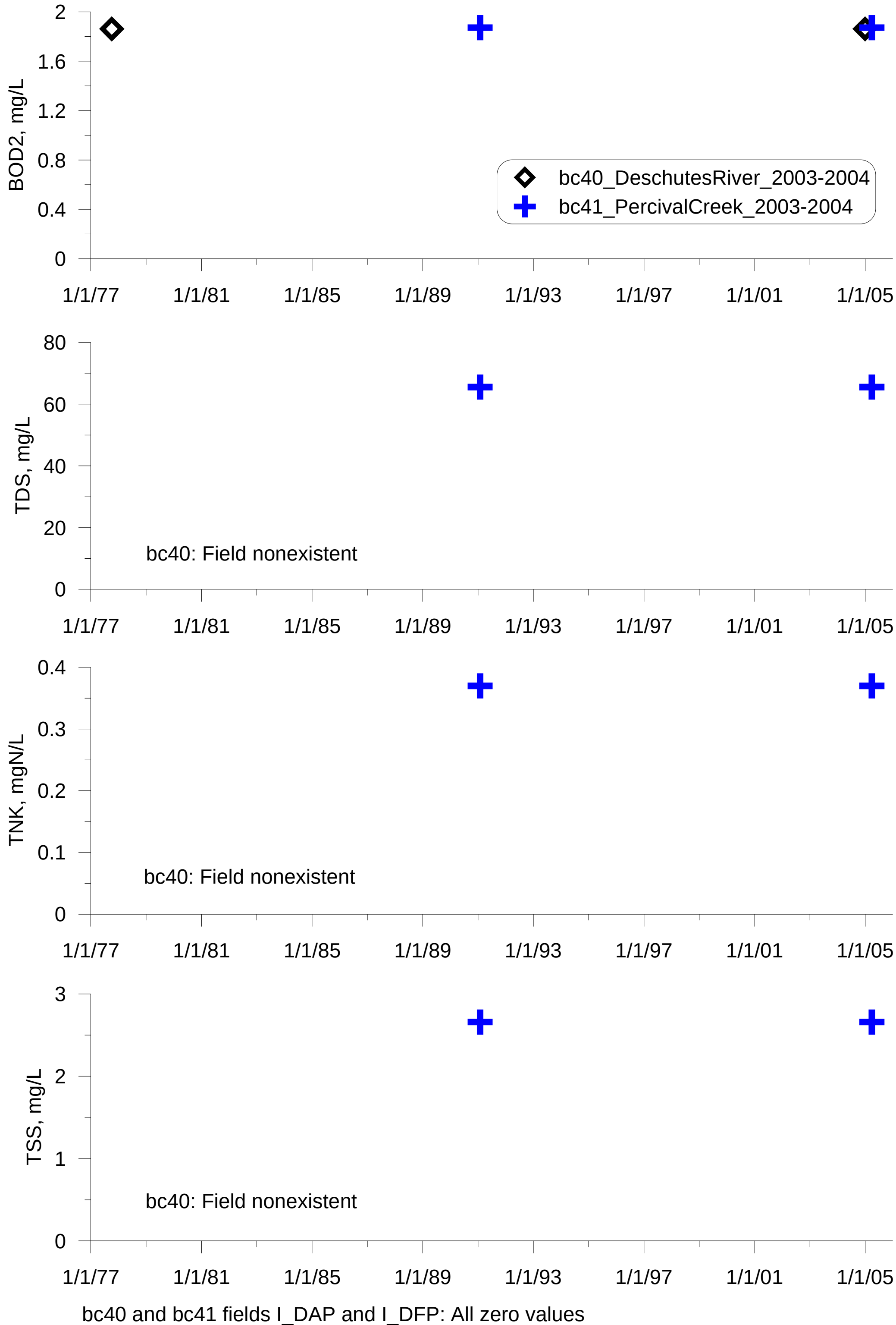


Figure 111. WQGraph18-6

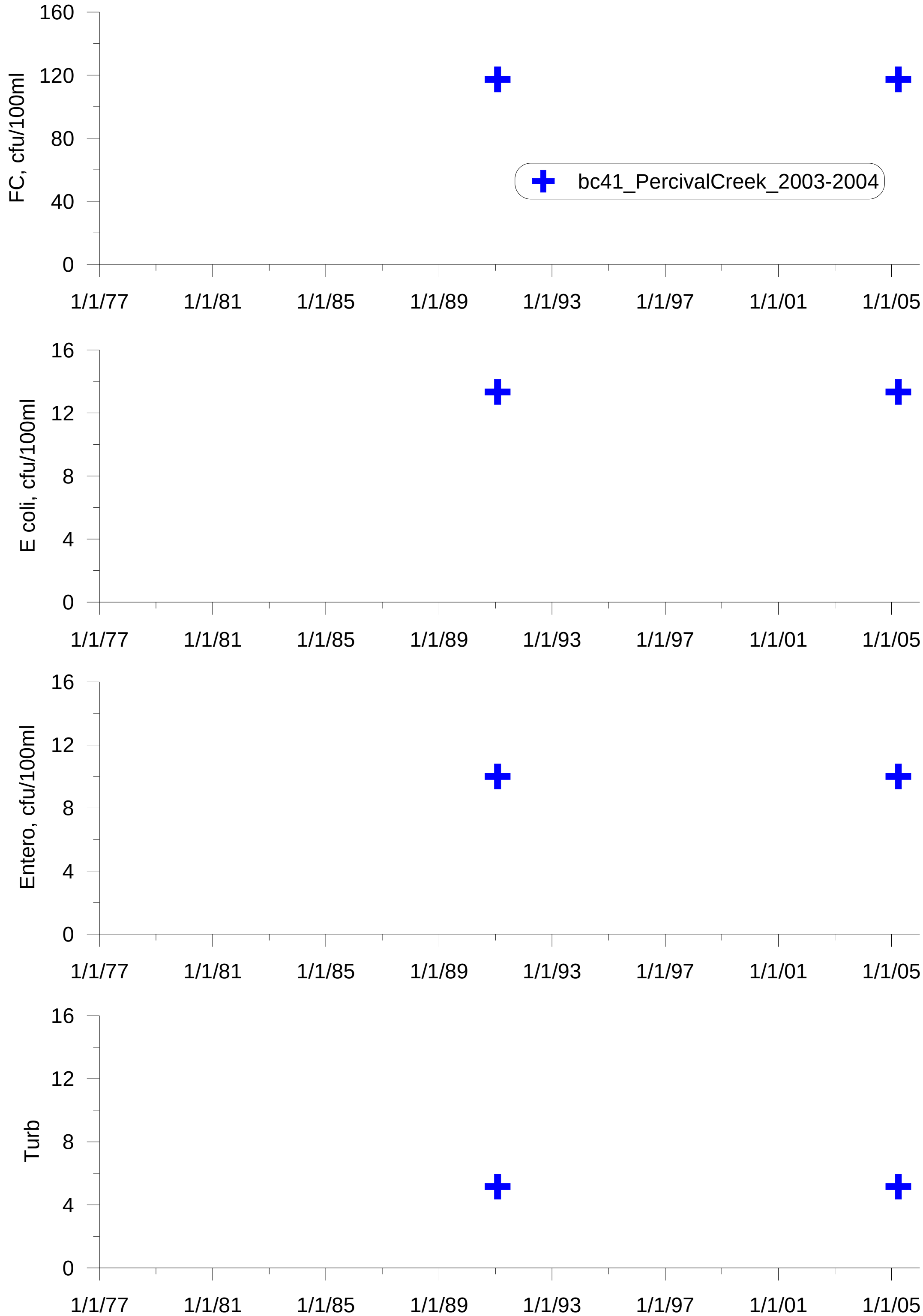


Figure 112. WQGraph18-7

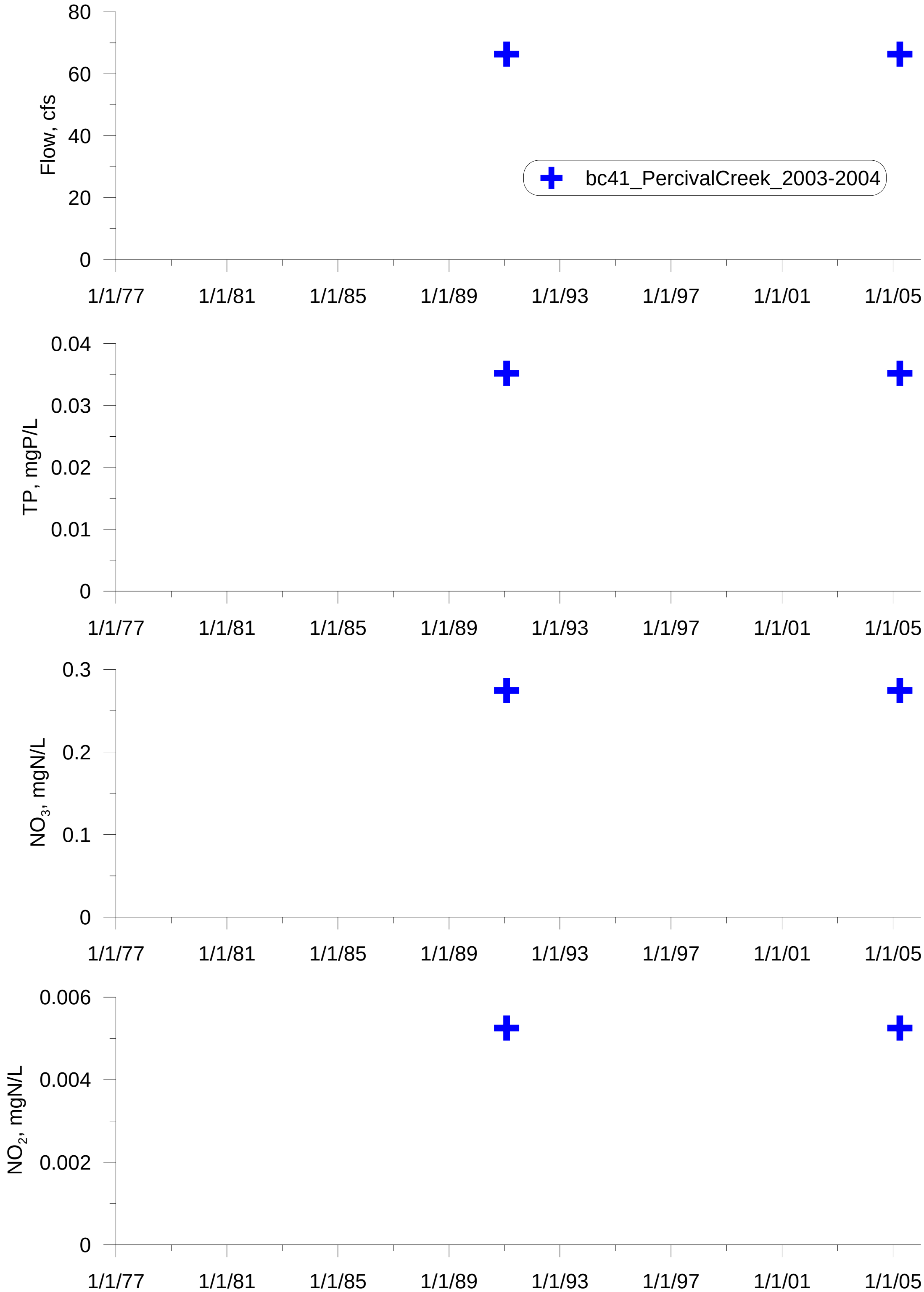


Figure 113. WQGraph18-8

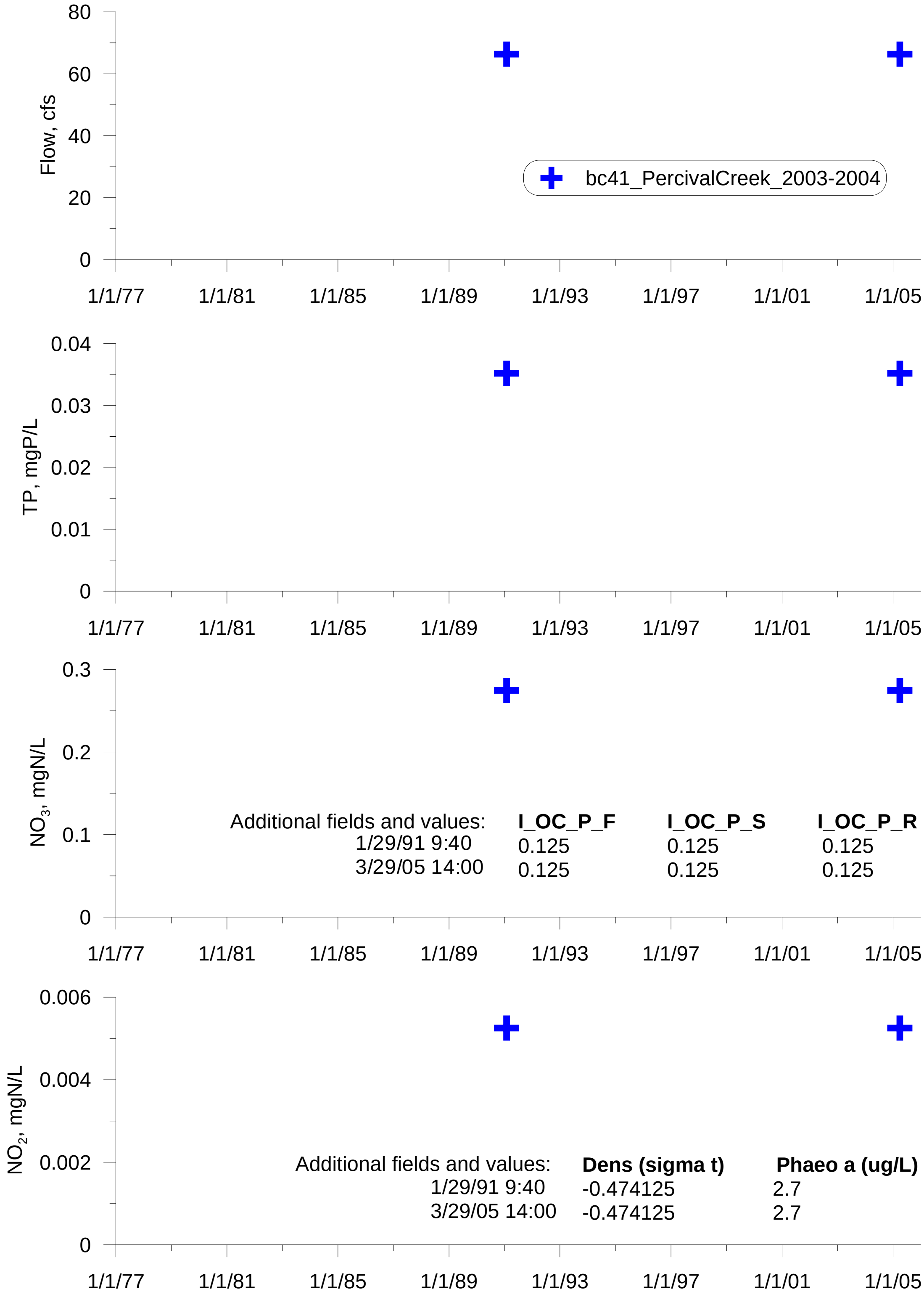


Figure 114. WQGraph18-9

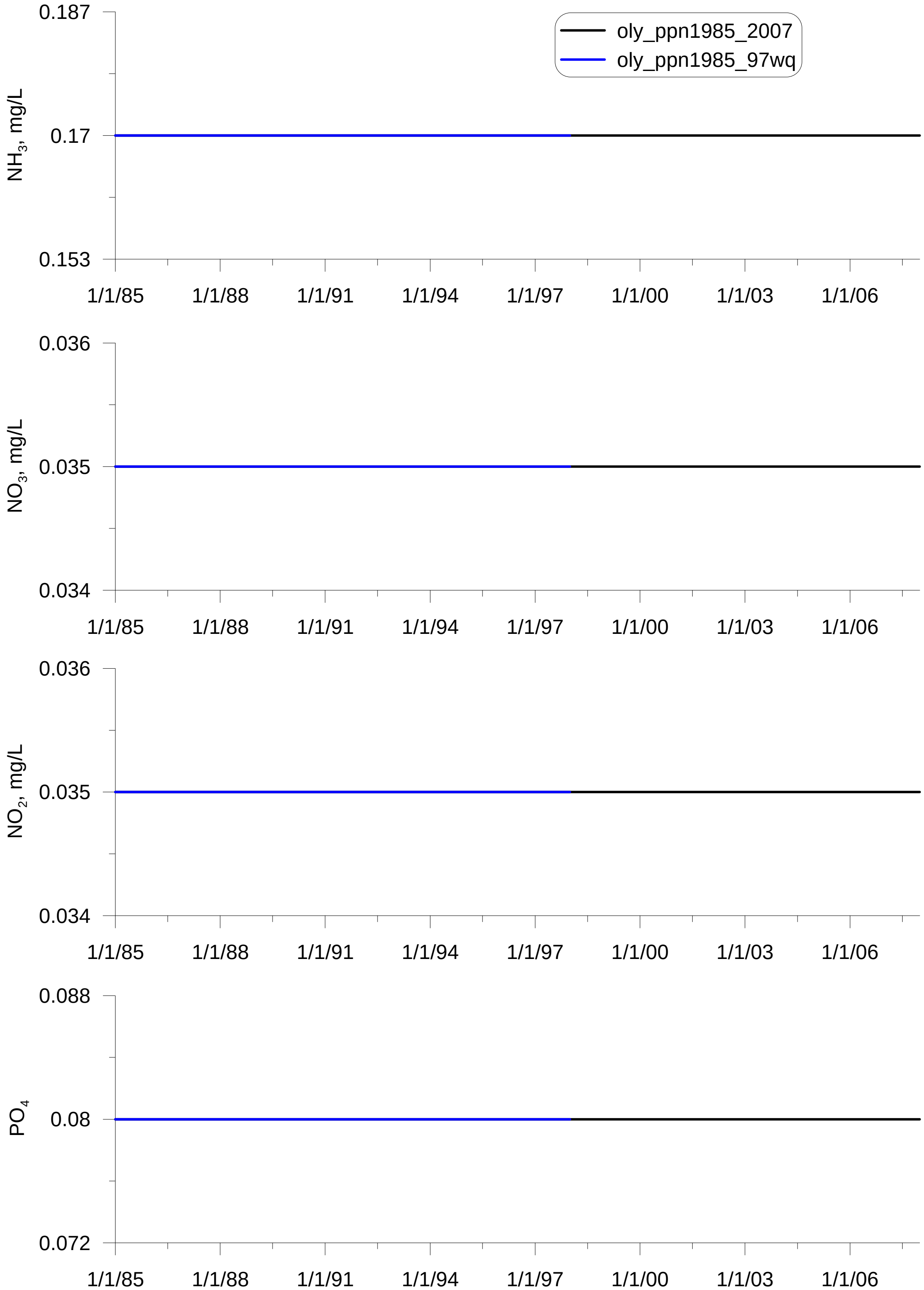


Figure 115. WQGraph19

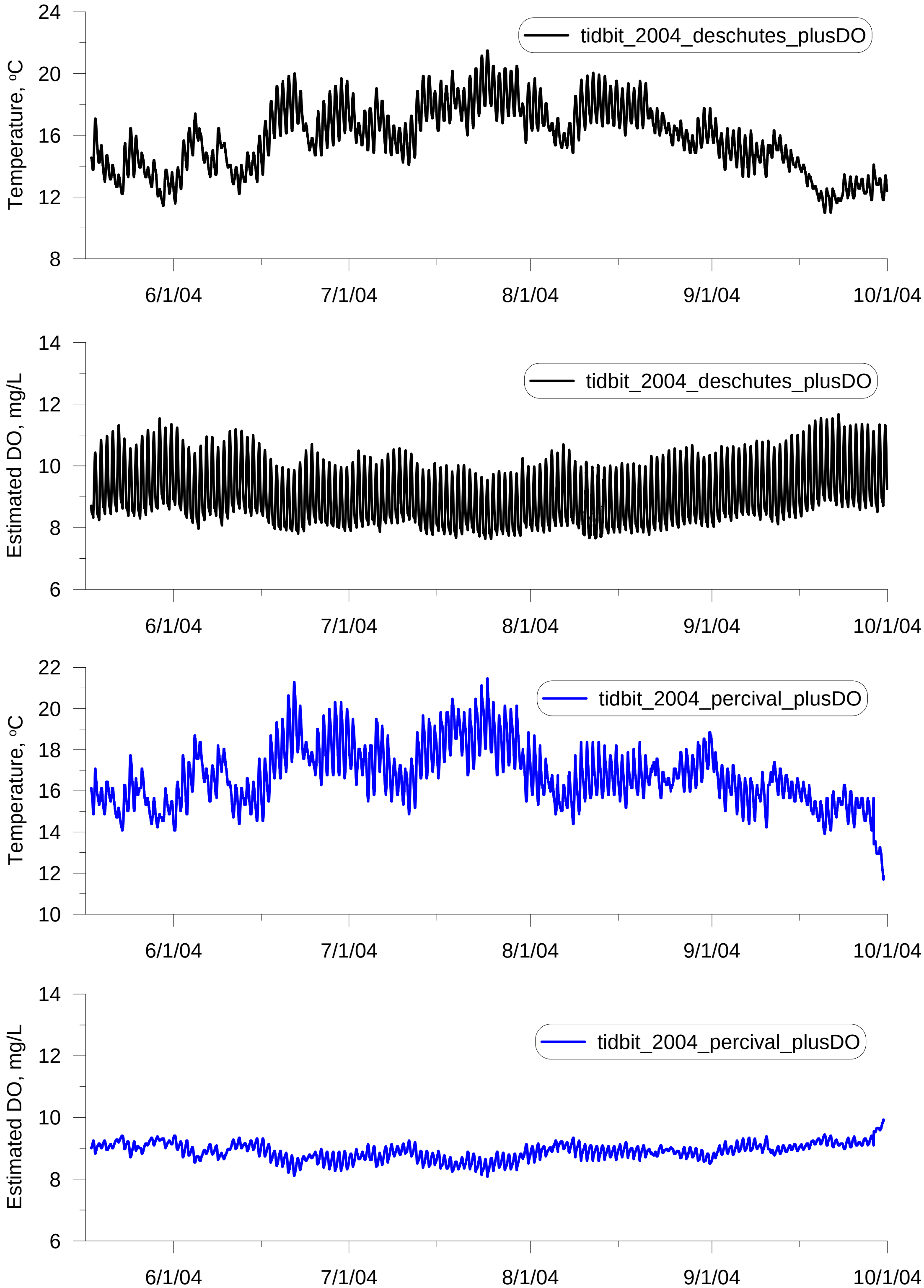


Figure 116. WQGraph20

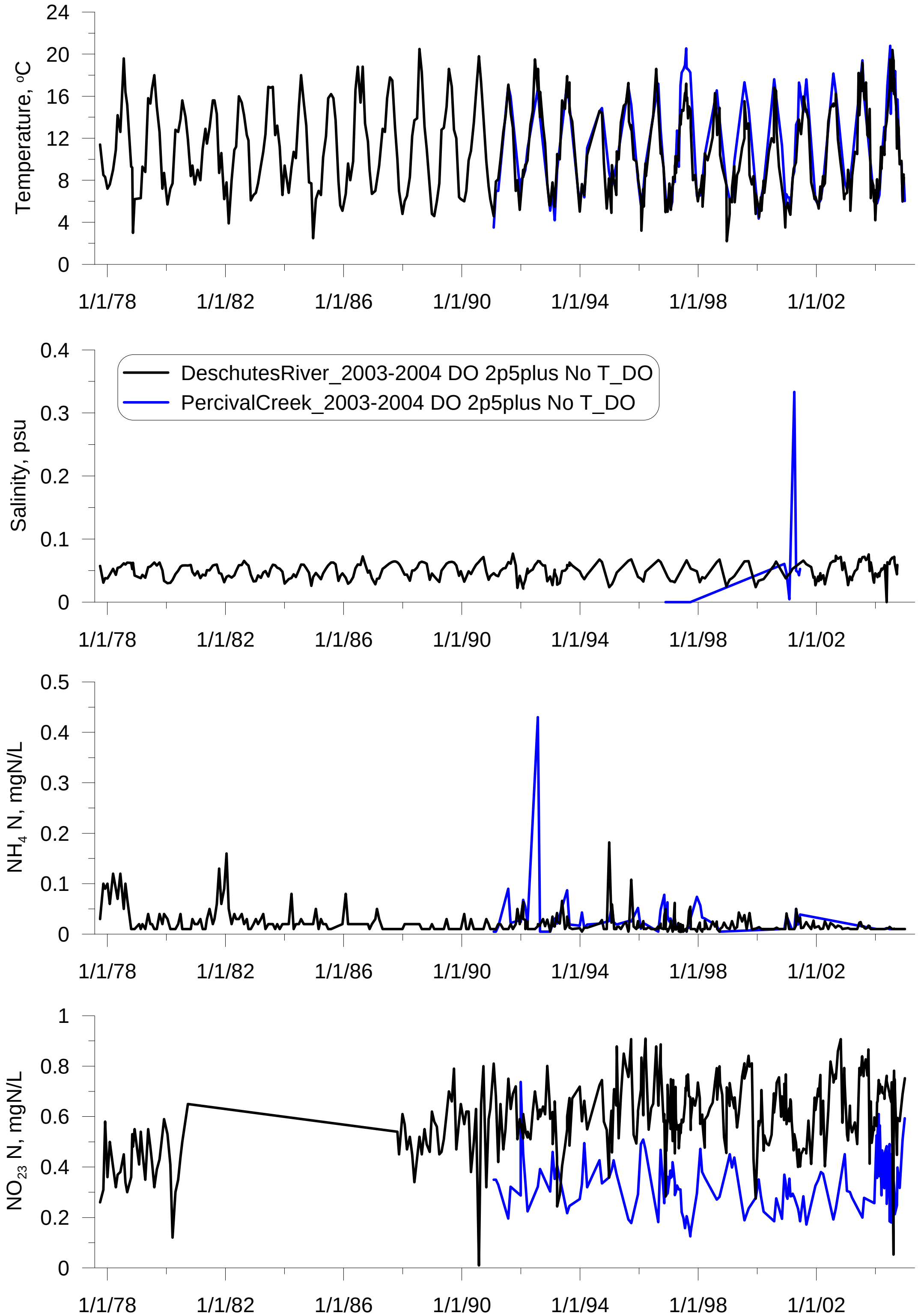


Figure 117. WQGraph21-1

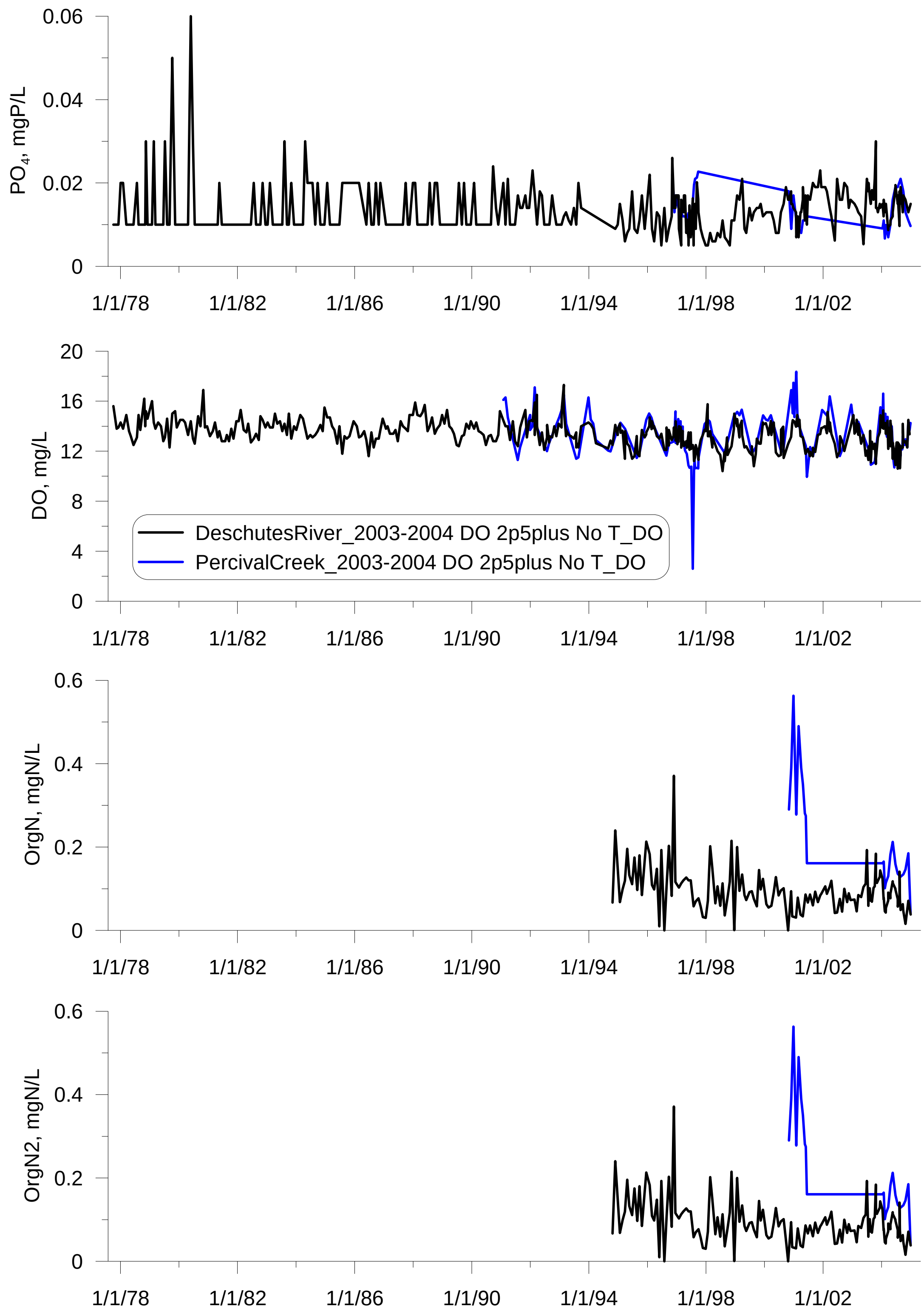


Figure 118. WQGraph21-2

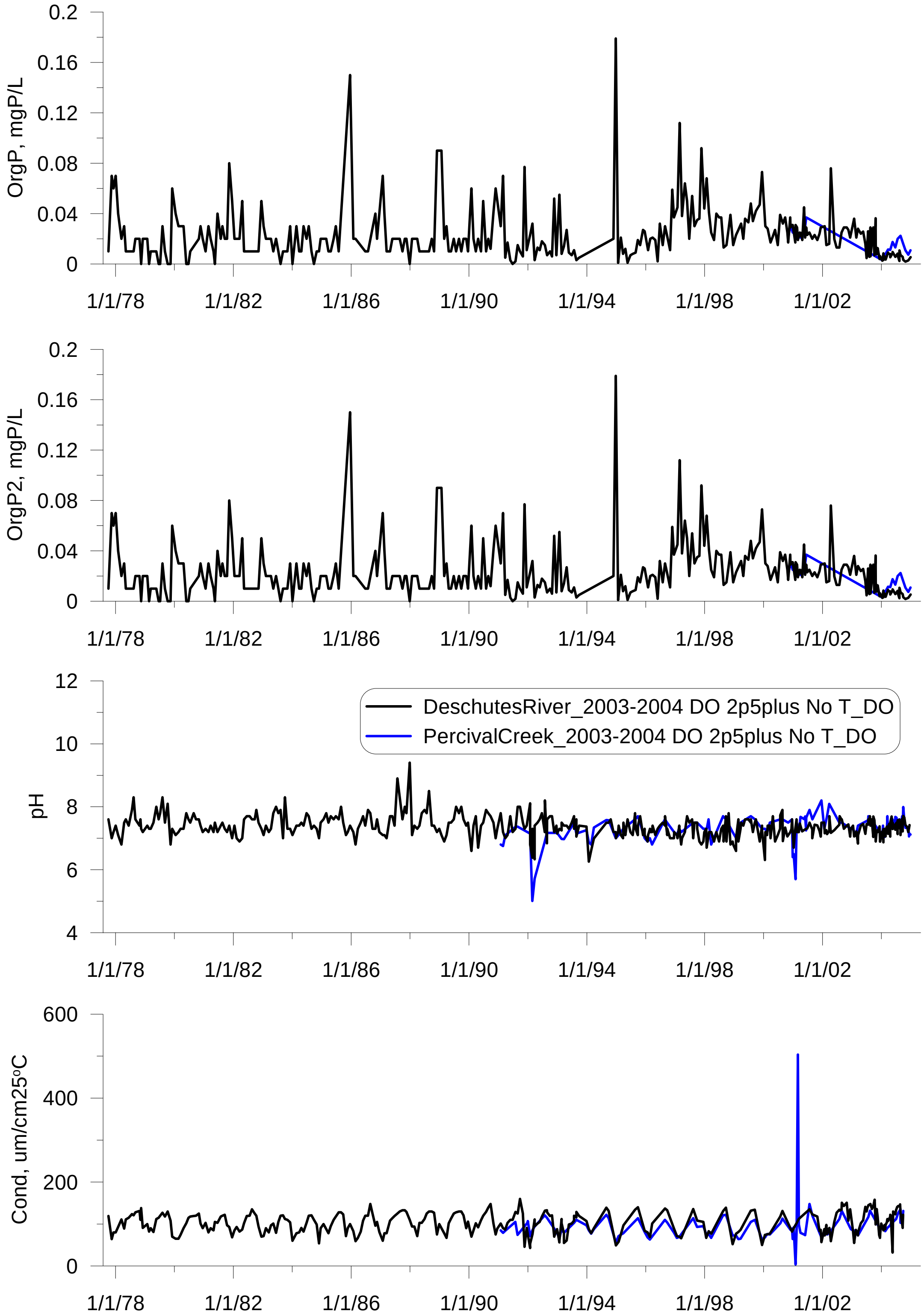


Figure 119. WQGraph21-3

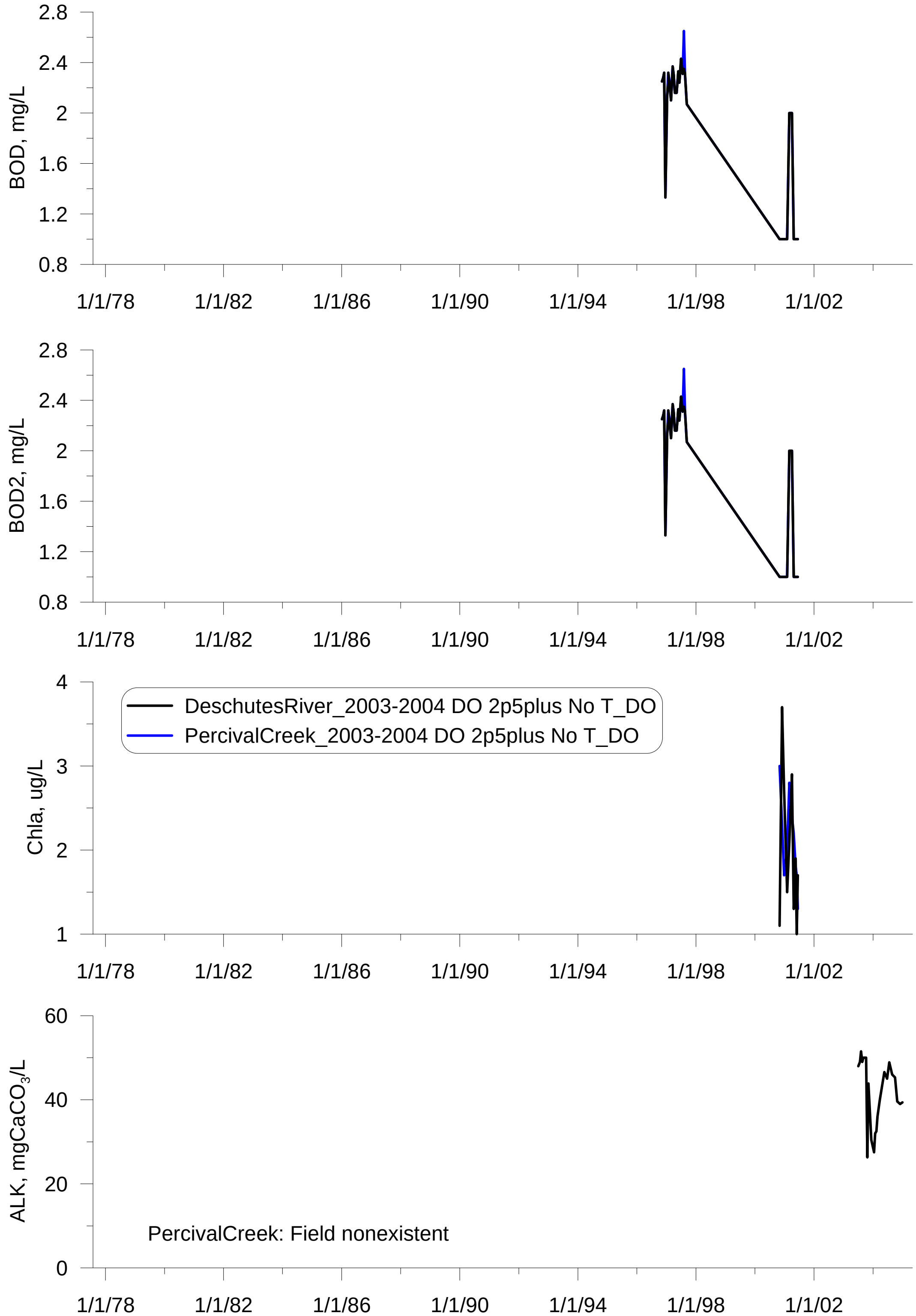


Figure 120. WQGraph21-4

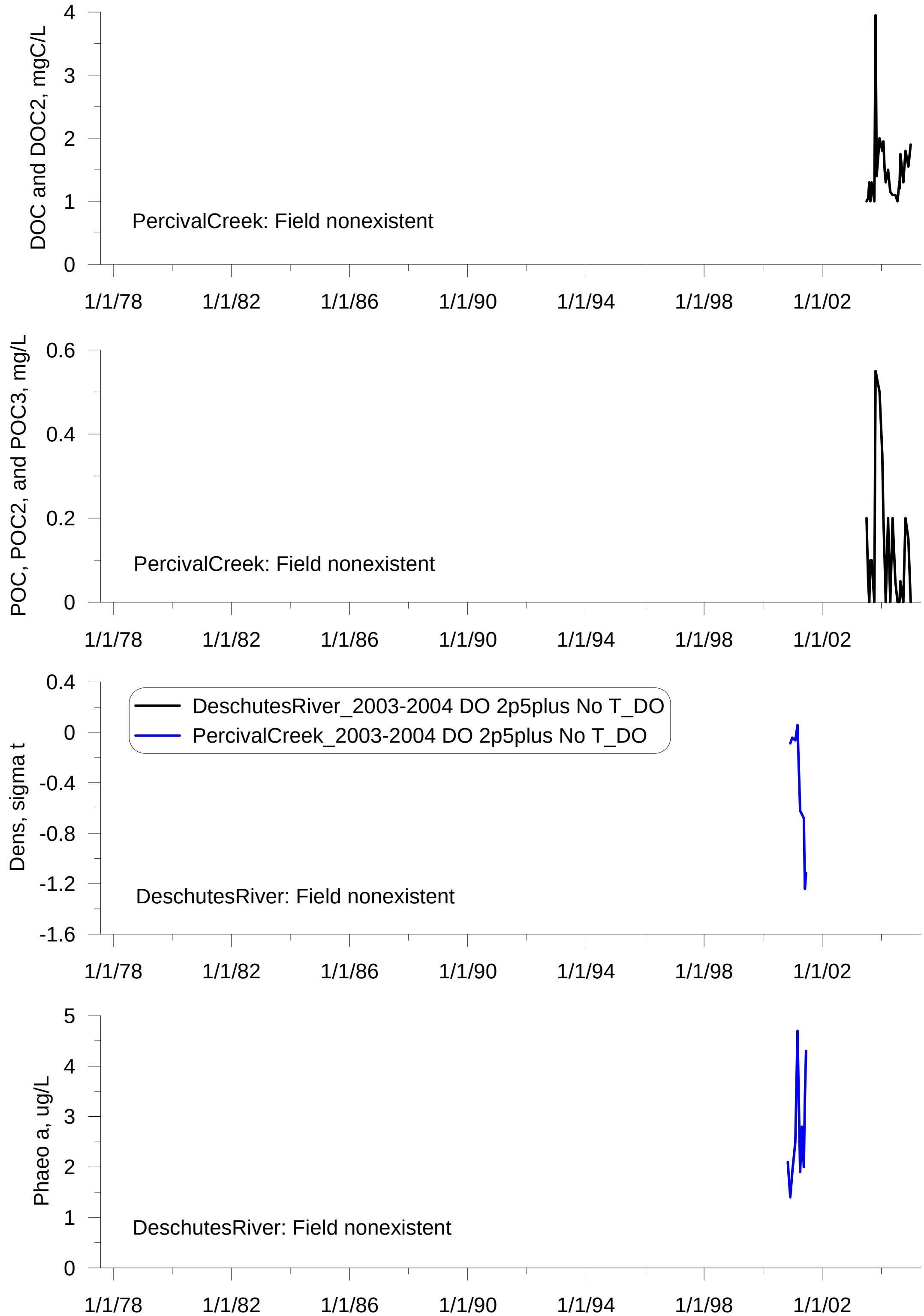


Figure 121. WQGraph21-5

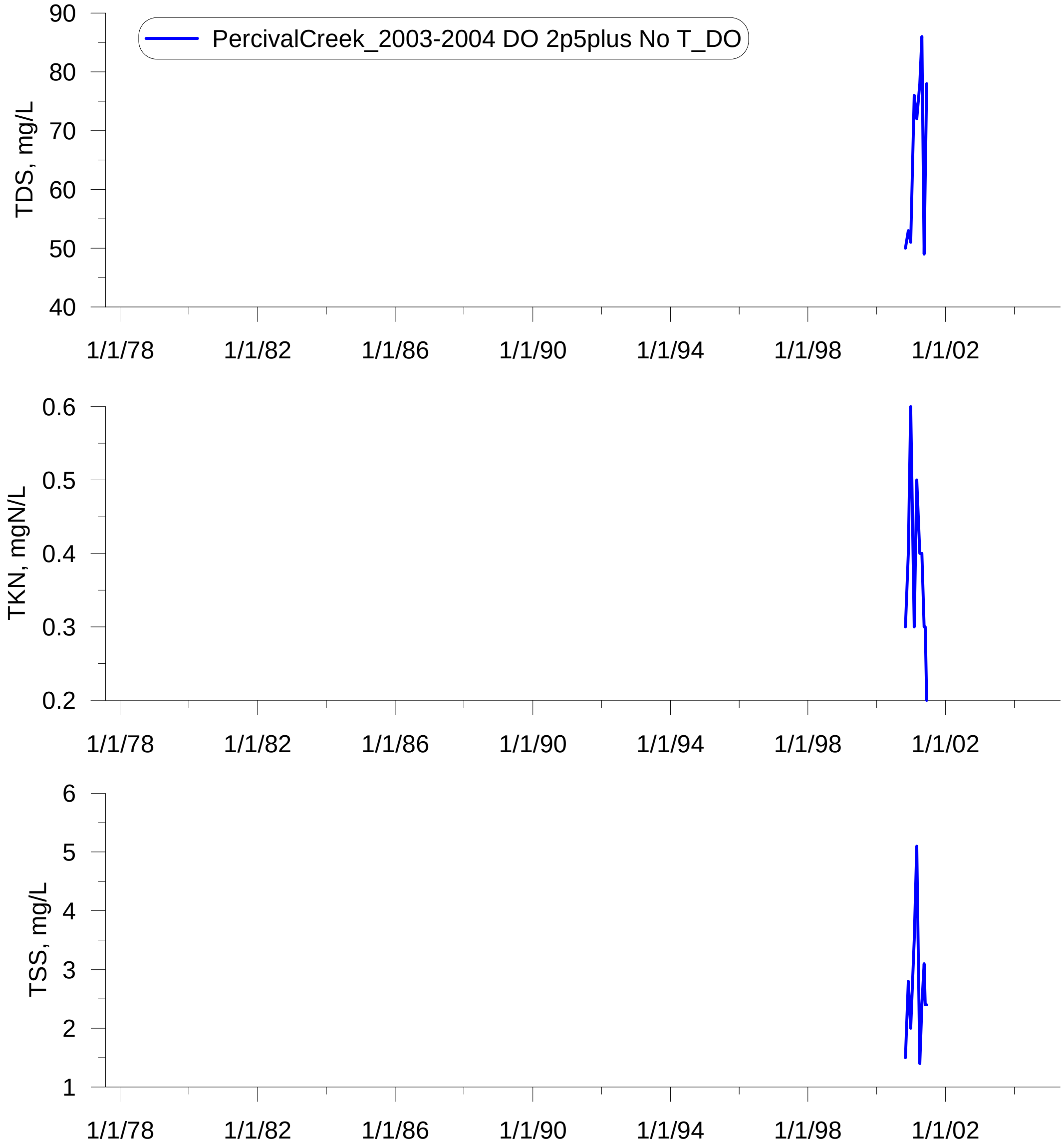


Figure 122. WQGraph21-6

Boundary Condition Tables

Table 13. BI_TVRates Verification 2

Date	k71	k12	knit	k1c_d	k1r_d	k1r_f
1/1/97 0:00	0.2496	0.0699	1	4	0.05	0.7
4/10/97 0:00	0.2496	0.0699	1	4	0.05	0.7
5/6/97 0:00	0.2496	0.0699	1	4	0.05	0.7
6/1/97 0:00	0.2496	0.0699	1	4	0.05	0.7
12/1/97 0:00	0.2496	0.0699	1	4	0.05	0.7

Table 14. CL CB Calib GAM 02 Run 082

Date	GAM1 - k1c	GAM1 - k1d	GAM1 - ws
5/15/04 0:00	2	0.01	1
6/25/04 0:00	1.5	0.01	0.5
8/5/04 0:00	2	0.01	0
8/15/04 0:00	1	0.01	0
8/26/04 0:00	2	0.005	0.5
9/26/04 0:00	2	0.005	0.5
10/10/04 0:00	2	0.005	1

Table 15. CL CB Verif GAM 02 Run 082 New

Date	GAM1 - k1c	GAM1 - k1d	GAM1 - ws
4/15/01 0:00	2	0.01	1
6/25/01 0:00	1.5	0.01	0.5
8/5/01 0:00	2	0.01	0
8/15/01 0:00	1	0.01	0
8/26/01 0:00	2	0.005	0.5
9/26/01 0:00	2	0.005	0.5
10/10/01 0:00	2	0.005	1

Table 16. CL NB Calib GAM 02 Run 041

Date	k1c
5/15/04 0:00	3.5
6/25/04 0:00	3.5
7/29/04 0:00	1.5
10/1/04 0:00	1.5

Table 17. CL NB Calib GAM 02 Run 082 New

Date	GAM1 - k1r	GAM1 - k1c	GAM1 - k1d	GAM1 - ws
5/15/04 0:00	0.2	1	0.01	1
6/25/04 0:00	0.2	1	0.01	0.5
8/5/04 0:00	0.2	1.5	0.01	0.5
8/15/04 0:00	0.2	1.5	0.005	0
8/26/04 0:00	0.2	2	0.005	0
9/26/04 0:00	0.2	1	0.005	0.05
10/10/04 0:00	0.2	1	0.005	0.05

Table 18. CL NB Calib GAM 02 Run 2001_02

Date	k1c
4/15/01 0:00	3.5
10/1/01 0:00	3.5

Table 19. CL NB Calib WQADD 02 Run 041

Date	q0N	q0P	kdb	Cgb20
5/15/04 0:00	0.15	0.1	0.15	600
7/29/04 0:00	0.15	0.1	9.5	600
8/13/04 0:00	0.15	0.1	0.15	700
10/1/04 0:00	0.15	0.1	0.15	700

Table 20. CL NB Calib WQADD 02 Run 066

Date	q0N	q0P	kdb	Cgb20	NUpWCFactor
5/15/04 0:00	0.03	0.005	0.05	150	0.8
7/29/04 0:00	0.03	0.005	9.5	150	0.8
8/13/04 0:00	0.03	0.005	0.05	200	0.4
10/1/04 0:00	0.03	0.005	0.05	200	0.4

Table 21. CL NB Calib WQADD 02 Run 066 – version 2

Date	q0N	q0P	kdb	Cgb20	NUpWCFactor
1/1/97 0:00	0.03	0.005	0.05	150	0.8
1/1/98 0:00	0.03	0.005	0.05	150	0.8

Table 22. CL NB Calib WQADD 02 Run 01_02

Date	q0N	q0P	kdb	Cgb20
4/15/01 0:00	0.15	0.1	0.15	600
10/1/01 0:00	0.15	0.1	0.15	600

Table 23. CL NB Calib WQCBM 02 Run 041

Date	k71	k83	k2d	kNO3
5/15/04 0:00	0.25	1.05	0.09	0.5
6/18/04 0:00	0.3	1.05	0.15	0.5
7/29/04 0:00	0.3	1.05	0.15	0.5
10/1/04 0:00	0.3	1.05	0.15	0.5

Table 24. CL NB Calib WQCBM 02 Run 066

Date	k71	k83	k2d	kNO3	ReaerFac
5/15/04 0:00	1.2	0.3	0.15	5	1
6/18/04 0:00	1.2	0.3	0.15	5	1
7/29/04 0:00	1.2	0.3	0.15	5	1
8/13/04 0:00	1.2	0.3	0.05	5	1
10/1/04 0:00	1.2	0.3	0.15	5	1

Table 25. CL NB Calib WQCBM 02 Run 066 version 2

Date	k71	k83	k2d	kNO3	ReaerFac
1/1/97 0:00	1.2	0.3	0.15	5	1
1/1/98 0:00	1.2	0.3	0.15	5	1

Table 26. CL NB Calib WQCBM 02 Run 01_02

Date	k71	k83	k2d	kNO3
5/15/04 0:00	0.25	1.05	0.09	0.5
6/18/04 0:00	0.3	1.05	0.15	0.5
7/29/04 0:00	0.3	1.05	0.15	0.5
10/1/04 0:00	0.3	1.05	0.15	0.5

Table 27. CL NB Calib GAM 02 Run 2001_02

Date	k1c
1/1/97 0:00	1
1/1/98 0:00	1

Table 28. CL NB Temp GAM 02 Run 002

Date	k1c	khn	khp
1/1/97 0:00	0.5	0.007	0.0001
1/1/98 0:00	0.5	0.007	0.0001

Table 29. CL NB Temp GAM 02 Run 002 - version 2

Date	k1c	khn	khp
1/1/97 0:00	0.5	0.007	0.002
1/1/98 0:00	0.5	0.007	0.002

Table 30. CL NB Temp WQADD 02 Run 001

Date	q0N	q0P	kdb	Cgb20
1/1/97 0:00	0.05	0.05	0.15	600
1/1/98 0:00	0.05	0.05	0.15	600

Table 31. CL NB Temp WQADD 02 Run 002

Date	q0N	q0P	kdb	Cgb20
1/1/97 0:00	0.05	0.05	0.15	600
1/1/98 0:00	0.05	0.05	0.15	600

Table 32. CL NB Temp WQCBM 02 Run 001

Date	k71	k83	k2d	kNO3
1/1/97 0:00	0.3	1.25	0.25	5
1/1/98 0:00	0.3	1.25	0.25	5

Table 33. CL NB Temp WQCBM 02 Run 002

Date	k71	k83	k2d	kNO3	ReaerFac
1/1/97 0:00	0.3	1.25	0.25	5	1
1/1/98 0:00	0.3	1.25	0.25	5	1

Table 34. CL NB Verif GAM 02 Run 010

Date	k1c	khn	khp
4/15/01 0:00	0.5	0.007	0.002
10/1/01 0:00	0.5	0.007	0.002

Table 35. CL NB Verif GAM 02 Run 082 New

Date	GAM1 - k1r	GAM1 - k1c	GAM1 - k1d	GAM1 - ws
4/15/01 0:00	0.2	1	0.01	1
6/25/01 0:00	0.2	1	0.01	0.5
8/5/01 0:00	0.2	1.5	0.01	0.5
8/15/01 0:00	0.2	1.5	0.005	0
8/26/01 0:00	0.2	2	0.005	0
9/26/01 0:00	0.2	1	0.005	0.05
10/10/01 0:00	0.2	1	0.005	0.05

Table 36. CL NB Verif WQADD 02 Run 010

Date	q0N	q0P	kdb	Cgb20
4/15/01 0:00	0.05	0.05	0.15	600
10/1/01 0:00	0.05	0.05	0.15	600

Table 37. CL NB Verif WQADD 02 Run 066 N

Date	q0N	q0P	kdb	Cgb20	NUpWCFactor
4/15/01 0:00	0.03	0.005	0.05	150	0.8
7/29/01 0:00	0.03	0.005	0.05	150	0.8
8/13/01 0:00	0.03	0.005	0.05	150	0.8
10/1/01 0:00	0.03	0.005	0.05	150	0.8

Table 38. CL NB Verif WQCBM 02 Run 010

Date	k71	k83	k2d	kNO3	ReaerFac
4/15/01 0:00	0.3	0.8	0.25	5	1
10/1/01 0:00	0.3	0.8	0.25	5	1

Table 39. CL NB Verif WQCBM 02 Run 066 New

Date	k71	k83	k2d	kNO3	ReaerFac
4/15/01 0:00	1.2	0.3	0.15	5	1
6/18/01 0:00	1.2	0.3	0.15	5	1
7/29/01 0:00	1.2	0.3	0.15	5	1
8/13/01 0:00	1.2	0.3	0.15	5	1
10/1/01 0:00	1.2	0.3	0.15	5	1

Table 40. CL SB Calib GAM 02 Run 041

Date	k1c
5/15/04 0:00	3.5
6/25/04 0:00	3.5
7/19/04 0:00	1.5
10/1/04 0:00	1.5

Table 41. CL SB Calib GAM 02 Run 082 New

Date	GAM1 - k1r	GAM1 - k1c	GAM1 - k1d	GAM1 - ws
5/15/04 0:00	0.2	0.4	0.2	1
6/25/04 0:00	0.2	0.4	0.2	1
7/7/04 0:00	0.2	0.4	0.2	1
7/19/04 0:00	0.2	0.4	0.2	1
8/3/04 0:00	0.2	0.4	0.2	1
8/23/04 0:00	0.2	0.4	0.2	1
10/10/04 0:00	0.2	0.4	0.2	1

Table 42. CL SB Calib GAM 02 Run 2001_2002

Date	k1c
4/15/01 0:00	3.5
10/1/01 0:00	3.5

Table 43. CL SB Calib WQADD 02 Run 041

Date	q0N	q0P	kdb	Cgb20
5/15/04 0:00	0.15	0.1	0.15	600
7/19/04 0:00	0.15	0.1	9.5	600
8/3/04 0:00	0.15	0.1	0.15	700
10/1/04 0:00	0.15	0.1	0.15	700

Table 44. CL SB Calib WQADD 02 Run 066

Date	q0N	q0P	kdb	Cgb20	NUpWCFactor
5/15/04 0:00	0.03	0.005	0.05	150	0.8
7/19/04 0:00	0.03	0.005	9.5	150	0.8
8/3/04 0:00	0.03	0.005	0.05	200	0.4
10/1/04 0:00	0.03	0.005	0.05	200	0.4

Table 45. CL SB Calib WQADD 02 Run 066 New - version 2

Date	q0N	q0P	kdb	Cgb20	NUpWCFactor
1/0/00 0:00	0.03	0.005	0.05	150	0.8
1/0/00 0:00	0.03	0.005	0.05	150	0.8

Table 46. CL SB Calib WQADD 02 Run 2001_2002

Date	q0N	q0P	kdb	Cgb20
4/15/01 0:00	0.15	0.1	0.15	600
10/1/01 0:00	0.15	0.1	0.15	600

Table 47. CL SB Calib WQCBM 02 Run 041

Date	k71	k83	k2d	kNO3
5/15/04 0:00	0.25	1.05	0.09	0.5
6/18/04 0:00	0.3	1.05	0.15	0.5
7/19/04 0:00	0.3	1.05	0.15	0.5
10/1/04 0:00	0.3	1.05	0.15	0.5

Table 48. CL SB Calib WQCBM 02 Run 066 New

Date	k71	k83	k2d	kNO3	ReaerFac
5/15/04 0:00	1.2	0.3	0.15	5	1
6/18/04 0:00	1.2	0.3	0.15	5	1
7/19/04 0:00	1.2	0.3	0.15	5	1
8/3/04 0:00	1.2	0.3	0.05	5	1
10/1/04 0:00	1.2	0.3	0.15	5	1

Table 49. CL SB Calib WQCBM 02 Run 066 New version 2

Date	k71	k83	k2d	kNO3	ReaerFac
1/1/97 0:00	1.2	0.3	0.15	5	1
1/1/98 0:00	1.2	0.3	0.15	5	1

Table 50. CL SB Calib WQCBM 02 Run 2001_2002

Date	k71	k83	k2d	kNO3
4/15/01 0:00	0.25	1.05	0.09	0.5
10/1/01 0:00	0.25	1.05	0.09	0.5

Table 51. CL SB Temp GAM 02 Run 001

Date	k1c
1/1/97 0:00	1
1/1/98 0:00	1

Table 52. CL SB Temp GAM 02 Run 002

Date	k1c	khn	khp
1/1/97 0:00	1	0.007	0.002
1/1/98 0:00	1	0.007	0.002

Table 53. CL SB Temp GAM 02 Run 002 - version 2

Date	k1c	khn	khp
1/1/97 0:00	1	0.007	0.0001
1/1/98 0:00	1	0.007	0.0001

Table 54. CL SB Temp WQADD 02 Run 001

Date	q0N	q0P	kdb	Cgb20
1/1/97 0:00	0.05	0.05	0.15	600
1/1/98 0:00	0.05	0.05	0.15	600

Table 55. CL SB Temp WQADD 02 Run 002

Date	q0N	q0P	kdb	Cgb20
1/1/97 0:00	0.05	0.05	0.15	600
1/1/98 0:00	0.05	0.05	0.15	600

Table 56. CL SB Temp WQCBM 02 Run 001

Date	k71	k83	k2d	kNO3
1/1/97 0:00	0.3	1.25	0.15	5
1/11/98 0:00	0.3	1.25	0.15	5

Table 57. CL SB Temp WQCBM 02 Run 002

Date	k71	k83	k2d	kNO3	ReaerFac
1/1/97 0:00	0.3	1.25	0.15	5	1
1/1/98 0:00	0.3	1.25	0.15	5	1

Table 58. CL SB Verif GAM 02 Run 010 New

Date	k1c	khn	khp
4/15/01 0:00	1	0.007	0.002
10/25/01 0:00	1	0.007	0.002

Table 59. CL SB Verif GAM 02 Run 082 New

Date	GAM1 - k1r	GAM1 - k1c	GAM1 - k1d	GAM1 - ws
4/15/01 0:00	0.2	0.4	0.2	1
6/25/01 0:00	0.2	0.4	0.2	1
7/7/01 0:00	0.2	0.4	0.2	1
7/19/01 0:00	0.2	0.4	0.2	1
8/3/01 0:00	0.2	0.4	0.2	1
8/23/01 0:00	0.2	0.4	0.2	1
10/10/01 0:00	0.2	0.4	0.2	1

Table 60. CL SB Verif WQADD 02 Run 010 N

Date	q0N	q0P	kdb	Cgb20
4/15/01 0:00	0.05	0.05	0.15	600
10/1/01 0:00	0.05	0.05	0.15	600

Table 61. CL SB Verif WQADD 02 Run 066 New

Date	q0N	q0P	kdb	Cgb20	NUpWCFactor
4/15/01 0:00	0.03	0.005	0.05	150	0.8
7/19/01 0:00	0.03	0.005	0.05	150	0.8
8/3/01 0:00	0.03	0.005	0.05	150	0.8
10/1/01 0:00	0.03	0.005	0.05	150	0.8

Table 62. CL SB Verif WQCBM 02 Run 010 New

Date	k71	k83	k2d	kNO3	ReaerFac
4/15/01 0:00	0.3	0.8	0.15	5	1
10/1/01 0:00	0.3	0.8	0.15	5	1

Table 63. CL SB Verif WQCBM 02 Run 066 New

Date	k71	k83	k2d	kNO3	ReaerFac
4/15/01 0:00	1.2	0.3	0.15	5	1
6/18/01 0:00	1.2	0.3	0.15	5	1
7/19/01 0:00	1.2	0.3	0.15	5	1
8/3/01 0:00	1.2	0.3	0.15	5	1
10/1/01 0:00	1.2	0.3	0.15	5	1

Table 64. Summary of bf11997dctdwq

Parameter	#	Average	Maximum	Minimum
Temp	153	10.535	14.856	7.722
Salinity	149	27.861	29.497	25.468
Density	149	21.251	22.572	19.523
Oxygen	153	7.987	10.448	4.084
Alg1	132	5.895	31.344	0.41
Alg2	132	5.895	31.344	0.41
Alg3	132	5.895	31.344	0.41

Table 65. Summary of bf21997dctdwq

Parameter	#	Average	Maximum	Minimum
Temp	427	10.334	15.25	7.611
Salinity	427	27.604	28.949	25.341
Density	427	21.094	22.283	19.389
Oxygen	430	8.493	10.559	6.748
Alg1	373	6.287	32.399	0.356
Alg2	373	6.287	32.399	0.356
Alg3	373	6.287	32.399	0.356

Table 66. Summary of bf31997dctdwq

Parameter	#	Average	Maximum	Minimum
Temp	420	10.324	14.756	7.677
Salinity	420	27.97	29.735	26.032
Density	420	21.385	22.646	19.952
Oxygen	417	7.753	10.214	4.021
Alg1	357	5.451	29.64	0.364
Alg2	357	5.451	29.64	0.364
Alg3	357	5.451	29.64	0.364

2-13-12

Cadmus Group and HDR-HydroQual Review

GEMSS/WQ3DCB Code Review

Dinoflagellate Equations and Literature Review

James Fitzpatrick (HDR|HydroQual), subcontractor to The Cadmus Group, Inc.

Introduction

At the request of the U.S. Environmental Protection Agency and the State of Washington's Department of Ecology, a review of the dinoflagellate kinetics used in the Budd Inlet/Capitol Lake water quality model was performed. The review included the following tasks:

1. Review of Model Theory
    a. Review the Kamykowski et al. (1988) paper upon which the dinoflagellate phytoplankton state-variable in the Budd Inlet/Capitol Lake model is based.
2. Review of Source Code
    a. Review the WQ3DCB module within the GEMSS model code to establish consistency between the theory presented in Kamykowski et al. paper and its implementation within the GEMSS model.
    b. Review Appendix J.1 (GEMSS Code Review as performed by Robert Ambrose) and Appendix J.2 (GEMSS code corrections by Ecology).
3. Review of Verification Tests for GEMSS
    a. Review the Verification Tests performed by the State of Washington's Department of Ecology on the GEMSS model as an additional confirmation of the correctness of the GEMSS phytoplankton code.
4. Review of Model Calibration Results
    a. A limited review of the model calibration results was performed. The purpose of this review was to evaluate whether the model responded as expected to variations in various model parameters related to phytoplankton growth dynamics.

Task 1. Review of Model Theory

The Kamykowski et al. (1988) paper was reviewed. The paper presents a summary of experimental findings concerning the swimming ability of *Gyrodinium dorsum*, a photosynthetic marine dinoflagellate, in response to changes in temperature, light intensity and buoyancy. In addition, the paper presents the results of the application of a computer model to predict the instantaneous translational velocity of *G. dorsum* against observed data. The paper presents the development of a model framework that characterizes swimming speed as a non-linear function of temperature (without time lag), a hyperbolic function of light, and Stokes' law dependent equation for settling. The resulting model framework essentially establishes a temperature and phototaxic dependency for swimming. Although the reviewer is not familiar with the implementation of such a model framework in other commonly accepted computer codes (such as WASP, EFDC, CE-QUAL-ICM, RCA, Delft3D), the theoretical basis presented in the Kamykowski paper appears reasonable and is supported by the experimental data. Further, the

Kamykowski et al. paper has been cited in at least 18 other peer-reviewed journal articles, as found by a Google Scholar search. In addition, a number of papers have reported similar observations of diel vertical migration for dinoflagellates that support the model framework developed by Kamykowski et al. (ex., Kamykowski and Yamazaki, 1997, MacIntyre et al., 1997, Ralston et al., 2007, Hall and Paerl, 2011).

A difference between the phototaxic-based swimming model for dinoflagellates developed by Kamykowski et al., (1988) and more recent models of dinoflagellate swimming is the addition of metabolism influences, i.e., nutrient-based affects (Kamykowski and Yamazaki, 1997, Liu et al., 2001). However, as reported by Aura Nova Consultants and J.E. Edinger Associates (1999), field data in the Budd Inlet seldom indicated nutrient depletion, therefore, including metabolism influences on swimming behavior of dinoflagellates is likely not necessary.

Review of Source Code

The GEMSS WQ3DCB module was reviewed to establish consistency between the theory presented in the Kamykowski et al. (1988) paper and its implementation within the GEMSS model. This reviewer found that the theory presented in the Kamykowski et al. paper was properly implemented in the GEMSS code, but did identify the following issues:

1. In converting radiation from Watts/m^2 to µEinstein/m^2-sec, a conversion factor of 4.15 (lines 369 and 425) was used. Assuming that PAR represents the 400-700 nm spectral range of solar radiation used for photosynthesis and assuming that 550 nm as the average of that range and which is typically used for the conversion, a value of 4.6 should be used for the conversion factor. However, as will be shown below, the value of 4.15, which was used in the model, is unlikely to have a significant affect on the model computations.

   The value of 4.6 results from the following computations:

   or 1 Watt/m^2 = 0.3976 Einstein/m^2-day $\quad 10^6$ µEinstein/Einstein × day/86400 sec = 4.6 µEinstein/m^2-sec

   (ref: http://www.seabird.com/pdf_documents/ApplicationNotes/appnote11GeneralFeb11.pdf)

2. The Kamykowski et al. (1988) paper provided a functional description of the light dependency of the swimming speed for *G. dorsum* as

   $S_L = S_M[\tanh(\alpha I/S_M)]$,

   where S_L is the swimming speed at light intensity I, S_M is the asymptotic maximum swimming speed and α is the initial slope.

   For G. dorsum, Kamykowski et al. reported a value of S_M = 109.89 µm/sec and α = 0.55 µm m^2/µEinstein. The values reported and used in the Washington Department of Ecology model were S_M = 35 µm/sec and α = 10 µm m^2/µEinstein. Figure 1 presents a comparison between the

Kamykowski et al. coefficient set and the Washington Ecology coefficient set. As can be seen, the Kamykowski coefficient set (Figure 1a) provides more of a hyperbolic shape than does the Washington Department of Ecology coefficient set (Figure 1b) for the range of PAR presented in the Kamykowski et al paper. It is not until you get to low values of PAR that the hyperbolic shape becomes evident (Figure 1c). This is not a problem with the implantation of the Kamykowski et al theory, but rather, apparently reflects a choice in model coefficients necessary to achieve satisfactory calibration to observed field data. The end result is that the coefficient set reflects more of an "on/off" or binary switch for swimming speed as a function of ambient light, i.e., if there is any light then the dinoflagellates will begin swimming and will swim at an almost constant speed of 35 μm/sec.

As mentioned in (1) above, the conversion factor of 4.15 as opposed to a value of 4.6 has almost no affect on the resulting model computations for swimming speed (see Figure 2). The difference between swimming speeds using the 4.15 vs. 4.6 conversion factor is less than a few percent and only at very low light intensities.

Review of Verification Tests for GEMSS

A review of the verification tests for the GEMSS code was performed and all tests results verify that the model code is performing in a mass conserving and functionally expected manner.

Review of Model Calibration Results

A limited review of the model calibration results, including the by Aura Nova Consultants and J.E. Edinger Associates (1999) report, indicates that the model modifications to include vertical swimming for the dinoflagellates appears to be functioning correctly and has resulted in an improved model calibration.

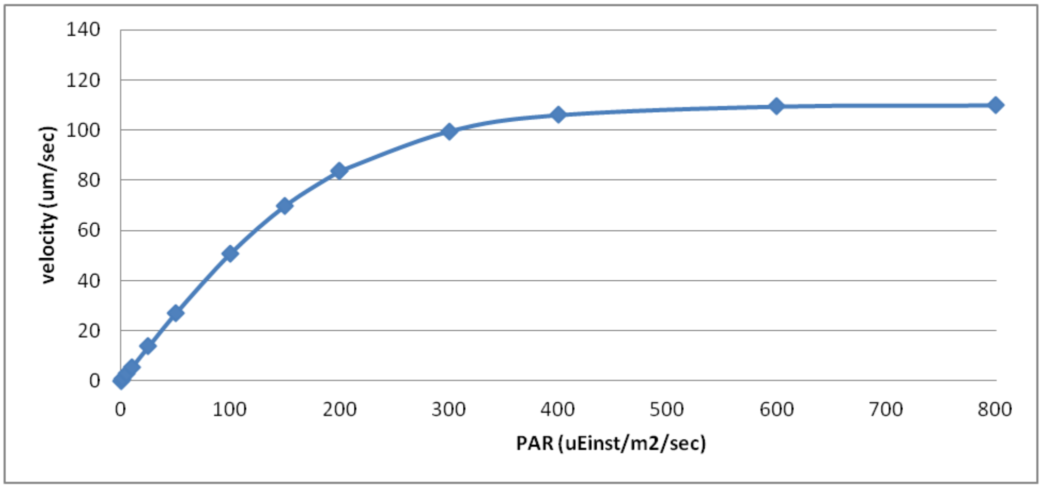


Figure 1a. Kamykowski et al. (1988) Coefficient Set

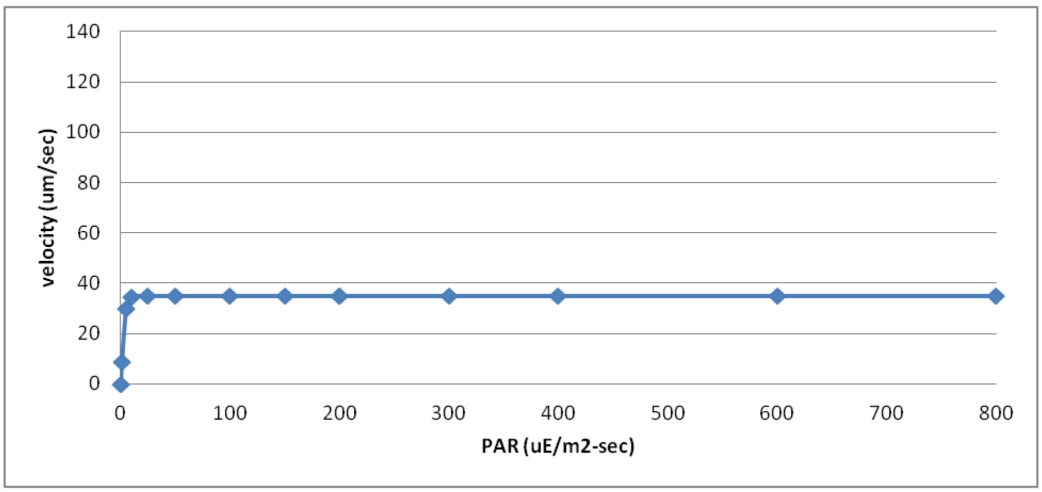


Figure 1b. Washington Dept. of Ecology Coefficient Set

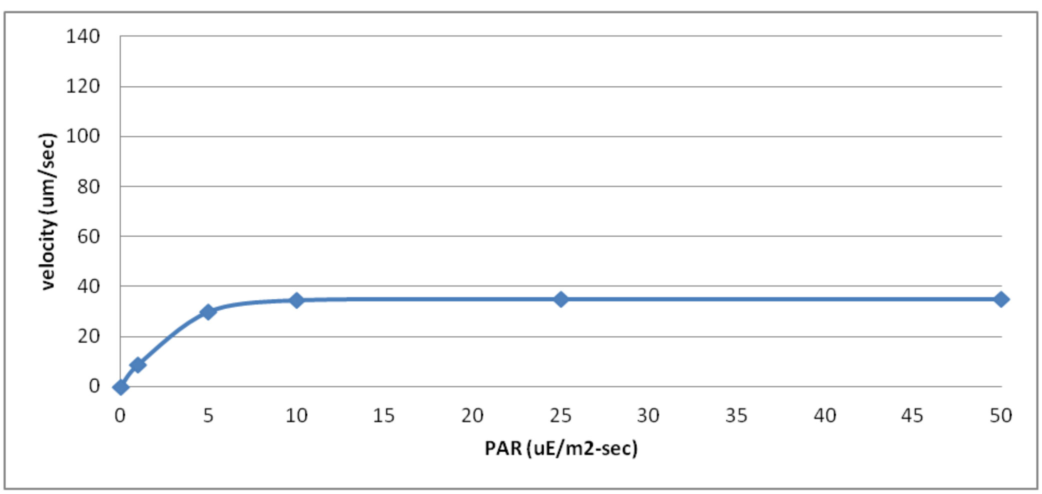


Figure 1c. Washington Dept. of Ecology Coefficient Set – Compressed PAR scale

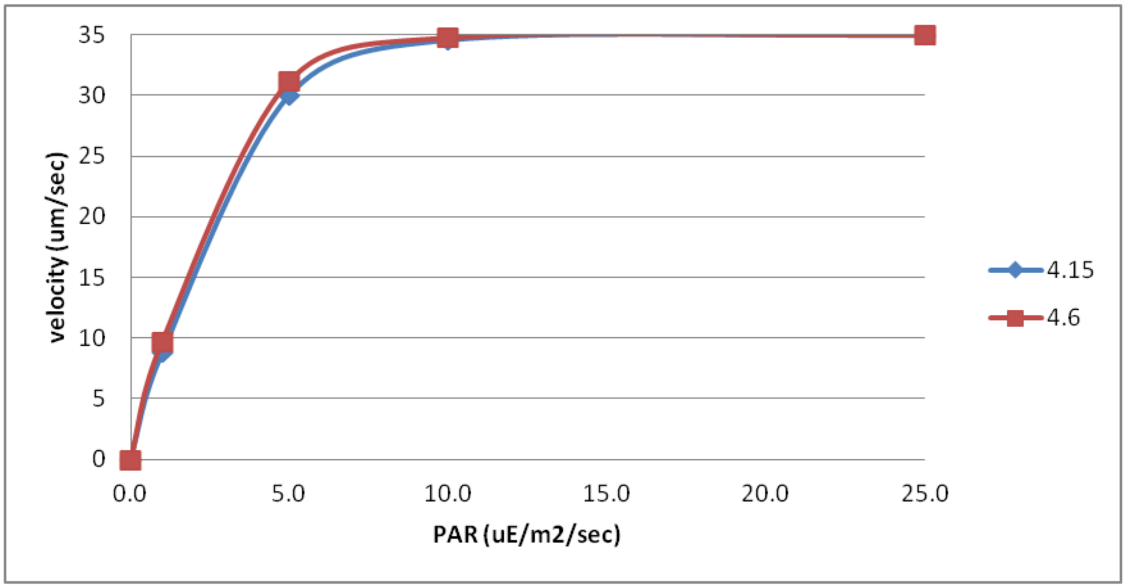


Figure 2. Comparison of Swimming Speed as a Function of Light Conversion Factor

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