Review of the Three Lakes Water Quality Model and the Colorado-Big Thompson RiverWare Model, Colorado

Prepared for

United States Bureau of Reclamation

Great Plains Region

Eastern Colorado Area Office

Scott Wells, Portland State University
Stewart Rounds, United States Geological Survey
Mitch Clement, University of Colorado
David Neumann, University of Colorado
Chris Berger, Portland State University
Stefan Talke, Portland State University

Bureau of Reclamation Grant # R17AP00156

October 2018

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The United States Bureau of Reclamation (USBR), Great Plains Region, Eastern Colorado Area Office manages the Three Lakes system located in Grand County, Colorado. The lake and reservoir system is composed of Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir as shown in Figure 1.

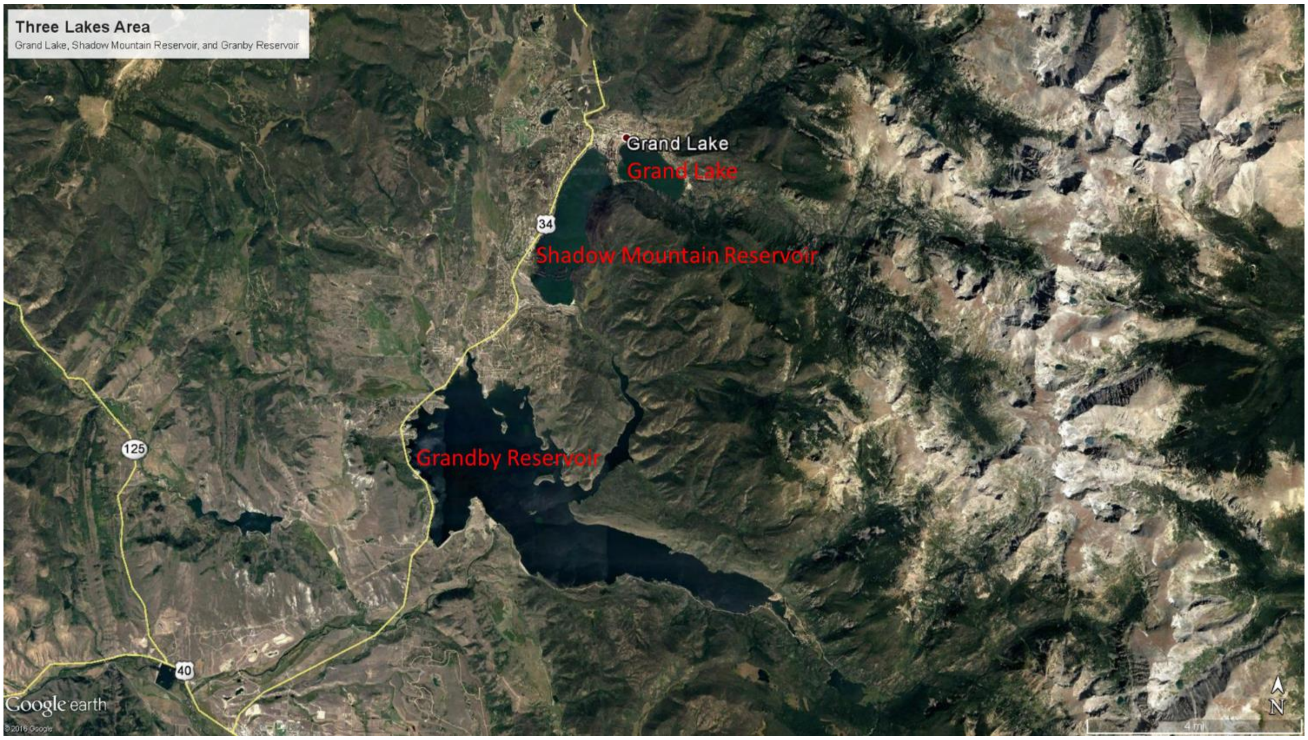


Figure 1. Three Lakes Study area (Google Earth, 2017).

Based on USBR (2017), the Three Lakes system is a conveyance system moving water from the Colorado River on the western slope for use on the eastern slope. Because of water clarity issues in the lakes, a water management question has arisen on how to improve water clarity in the lake system without adversely affecting other water quality requirements of the water. The Bureau of Reclamation, Grand County, Northern Colorado Water Conservancy District, Northwest Colorado Council of Governments, and Colorado River Water Conservation District are cooperating to improve water quality in the Three Lake system.

USBR (2017) developed a system model of the reservoirs, based on CE-QUAL-W2 V4.0 (Cole and Wells, 2017) termed 3LWQM-W2 (Three Lakes Water Quality Model CE-QUAL-W2). They also developed a model of the Colorado-Big Thompson system using RiverWare (Zagona, et. al, 2005), which is a decision support tool for water resources management. USBR (2017) was seeking an unbiased peer review of both models and wants to answer whether the models represent the system accurately in order to use them to forecast management strategies for improving water quality.

This review project involved two peer review panels. One assessed the in-stream Three Lakes system water quality model (developed using CE-QUAL-W2) as presented in this report. The other assessed the Colorado-Big Thompson (C-BT) Planning and Operations Model (developed using RiverWare software).

The C-BT Planning and Operations Model simulated flows into and through much of the Colorado-Big Thompson Project, including the Three Lakes system, defining boundary conditions for the reservoir water quality models.

The Three Lakes Water Quality Model (3LWQM) review panel is shown in Table 1, and the Colorado Big-Thompson (C-BT) RiverWare Model review panel members are shown in Table 2.

Table 1. Members of the 3LWQM (CE-QUAL-W2) peer review panel.

Panel Member	Background	Relevance to CE-QUAL-W2 Peer Review
Stewart Rounds	• Hydrologist, Water Quality Team Lead, USGS, Oregon Water Science Center, Portland, Oregon • Ph.D. Environmental Science and Engineering, Oregon Graduate Institute of Science and Technology • Application of CE-QUAL-W2 to the Tualatin River, Willamette River basin including the Santiam River, Detroit Reservoir and other reservoir systems • Peer reviewer of the Columbia River System Operation Model using CE-QUAL-W2	Expert modeler with CE-QUAL-W2 with extensive water quality modeling applications
Chris Berger	• Research Assistant Professor, Department of Civil and Environmental Engineering, Portland State University • Contributor to the CE-QUAL-W2 model • Dozens of applications of CE-QUAL-W2 to river, lake and reservoir systems • Professional Civil Engineer State of Oregon • Ph.D. Environmental Sciences and Resources Portland State University	Expert modeler using CE-QUAL-W2 with extensive water quality modeling applications
Scott Wells	• Professor, Department of Civil and Environmental Engineering, Portland State University • Ph.D. Civil and Environmental Engineering Cornell University • Over 100 applications of CE-QUAL-W2 model • Developer of CE-QUAL-W2 model • Teaches workshops and courses on CE-QUAL-W2 model • Extensive peer review of CE-QUAL-W2 and other water quality models • Professional Engineer: Civil and Environmental State of Oregon • Extensive publication record	Developer of the CE-QUAL-W2 model with extensive water quality modeling applications and teaching/training in the use of the model

Table 2. Members of the RiverWare peer review panel.

Panel Member	Background	Relevance to RiverWare Peer Review
Mitch Clement	• Professional Research Assistant, Center for Advanced Decision Support for Water and Environmental Systems, University of Colorado Boulder • M.S. Civil Engineering University of Colorado Boulder • Developed RiverWare model of Columbia basin • Software support for RiverWare	Extensive experience with RiverWare from a code level to a user-level experience
David Neumann	• Senior Research Assistant, Center for Advanced Decision Support for Water and Environmental Systems, University of Colorado Boulder • M.S. Civil Engineering University of Colorado Bolder • Professional Civil Engineer State of California • Developed RiverWare model for the Upper Rio Grande system • Provides user support for RiverWare • Teaches classes on RiverWare modeling	Extensive experience with RiverWare software and applications
Stefan Talke	• Associate Professor of Civil and Environmental Engineering, Portland State University • Extensive publication record • Ph.D. Civil and Environmental Engineering University of California, Berkeley	Expert in hydraulic and hydrodynamic systems

Each of the review panels met together by conference call or in person multiple times to discuss the model documentation and model files. The USBR conducted a meeting with both groups on May 4, 2018 to discuss the Three Lakes region and the water transfers in the basin as well as how the RIverWare model was constructed. The final documents were prepared after consulting model documentation and model files provided by USBR. The documents that were reviewed included the following:

Adams, T., and Carron, J. (2015) "Development of Daily Flows to Support the Colorado-Big Thompson Planning and Operations Model," Memorandum from Hydros Consulting to USBR and Northern Water, November 9, 2015.

Boyer J.M., Adams T., Hawley C., Bierlein K., 2017, Three Lakes Water-Quality Model Documentation—3LWQM-W2 v1.1, revised: November 27, 2017: Hydros Consulting Inc., Boulder, CO, 151 p. plus appendices.

Coleman, M. (2018) "CBTPOM Modifications for Windy Gap Firming Project," Technical Report from Precision Water Engineering to USBR, Boulder, CO, February 28, 2018.

Melander, K. (2015) "Modeled Historic Demands," Memorandum from Northern Water to USBR, Boulder, CO, September 3, 2015.

Pineda, A. and Smith, S. (2015) "Historical Potential Windy Gap Pumping (1949-2014)", Memorandum from Northern Water to USBR, Boulder, CO, August 6, 2015.

In addition to the model reports, all model files that supported the 3LWQM and the C-BT RiverWare model, including supporting files were provided to the review teams.

Each of the peer review groups produced technical review findings that are the basis for this report. The peer review was organized as follows:

- Three Lakes Water Quality Model Review
    - General and specific review points based on model documentation, the model and files
- C-BT RiverWare Model Review
    - General and specific review points based on model documentation, the model and files
- Summary of recommendations to improve the models
- References
- Appendices documenting some of the review points and summarizing comments of USBR reviews of the draft report

2. THREE LAKES WATER-QUALITY MODEL REVIEW

2.1 REVIEW OBJECTIVE

The objective of this effort was to review Hydros Consulting's Three Lakes water-quality model (3LWQM-W2, v1.1), which includes Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir near the towns of Grand Lake and Granby, Colorado.

The model used a customized version of CE-QUAL-W2, based on Version 4.0 (Cole and Wells, 2017) and was calibrated for the time period 2007-2016. Customized code changes included adding a flow-induced resuspension algorithm, parallelization of some water quality kinetic algorithms, and waterbody specific settling rates for inorganic suspended solids. Also, some model bugs were apparently corrected in the hypolimnetic aeration and pump algorithms.

The review comments are based on model documentation and associated model files found in Boyer et al. (2017).

Efforts to improve the predictive capability of the model are documented in comments presented below. Hence, we sought to comment on potential ways to improve the model performance so that it can be reliably applied to future management strategies. Also, there are a few comments on improving model documentation. Knowing that these comments are not critical to running the model, these comments are included in case the model calibration is ever revisited.

2.2 MODEL REVIEW COMMENTS

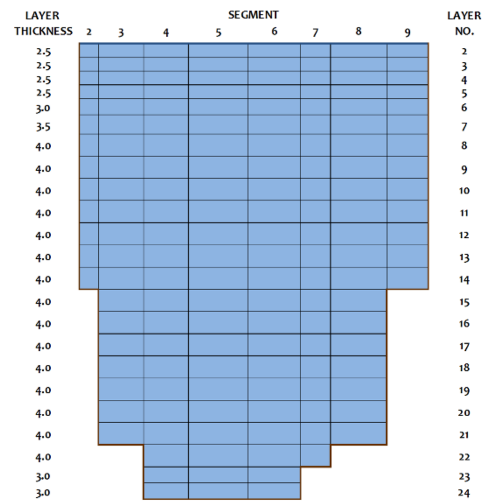
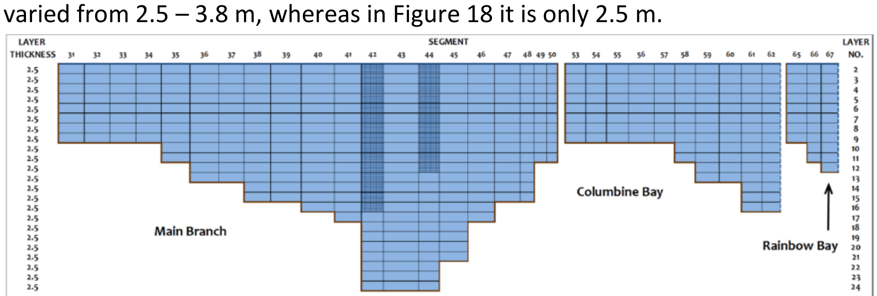
This section details comments on the report (Boyer et al. 2017) and model files. Some of these comments are important and affect our recommendations which follow the section on comments. Other comments are informational and may or may not lead to improvements in the model reliability or affect the outcome of the model results. For example, comments about model documentation would not affect the model results. The review comments are summarized in Table 3.

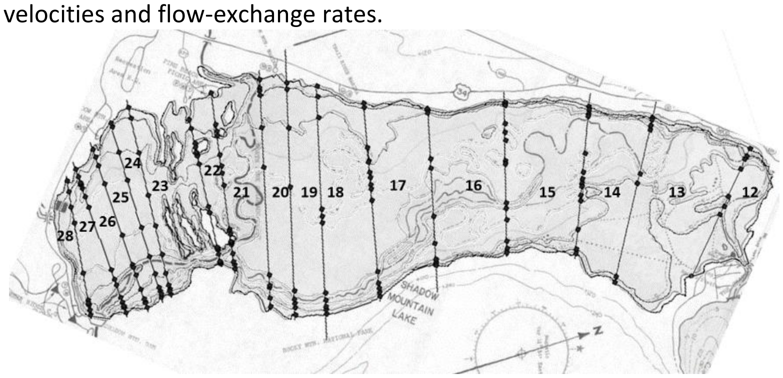
.

Table 3. Review comments based on Boyer at al. (2017) and associated model files.

#	Subject, Location	Comment
1	V, page 6	The documentation states: "Water levels in Granby Reservoir affect hypolimnetic dissolved oxygen minimum concentrations before turnover. Lower water levels lead to a smaller hypolimnion, resulting in lower oxygen minima in response to sediment oxygen demand and organic matter decay in the water column." It would be helpful to clarify this statement. How does a small hypolimnion lead to lower DO?
2	VII.1. page 9	The documentation claims that W2 does not allow for resuspension in the surface layer. That does appear to be the case and has been fixed in the latest release version (4.1).
3	VII.1. page 9	Presumably the authors have field data as the basis of their input ratios for organic:inorganic and labile:refractory characteristics of resuspended materials. A brief discussion of the field data basis or other basis would be helpful since these are very important model settings.

#	Subject, Location	Comment
4	VII.1. page 9	The documentation states that the flow-induced resuspension is based on the simulated horizontal velocity for each cell in contact with sediment. However, that horizontal velocity is computed by the model at the downstream interface of that cell with the next cell, and is based on the flow moving through the average interfacial area of those adjoining cells. Therefore, if the cell widths of the adjoining cells are dissimilar, the computed horizontal velocity acting through that averaged interfacial area will not be representative of the average horizontal velocity in contact with sediment within that cell. This is a fine distinction, and if cell widths are similar among cells of the same layer, then the use of downstream-end-of-segment horizontal velocities may not be an issue for this model's representation of velocities that affect resuspension. However, it would be more accurate to recompute the horizontal velocities acting on average over the sediment surface in each cell, and use that as the basis for the flow-induced resuspension. For the Shadow Mountain Reservoir application, the cell widths of adjacent cells are not greatly dissimilar; therefore, this point may not be problematic. However, as a general algorithm, it would be good to recompute the horizontal velocities. At the very least, flow reversals might affect the representativeness of downstream-end-of-segment horizontal velocities.
5	VII.1. page 10	Allowing the user to limit flow-induced sediment resuspension to certain segments of the model may be acceptable when that effect is known to occur and is known to be important only in certain parts of the modeled waterbodies. Is this another way of specifying which segments have sufficient sediment supply to allow for resuspension, or which segments have sufficient velocity to cause resuspension? A more general approach/algorithm would be better where the model algorithm predicts or does not predict suspension based on the computed bed shear stress. Turning ON or OFF segments where the algorithm is applied, as mentioned above, may be 'forcing' the model to match calibration data that is not sensitive to the physics.
6	VII.1. page 10	In the flow-induced resuspension algorithm, specifying different K and Limit inputs for north-to-south flows versus south-to-north flows seems to have some physical basis as stated in the documentation; however, it begins to look like this process is being overcalibrated, compensating for potential problems in the new flow-induced resuspension algorithms. As stated above, the horizontal velocities simulated by the model at cell boundaries may need to be modified to account for the geometries of the cell rather than the conditions occurring at the interface between one cell and the next. Perhaps a recomputation of this manner could account for the bottom-slope issues mentioned in the documentation?
7	VII.2. page 11	Code was added for inorganic suspended solids settling rates to vary by waterbody. It was unclear why this was necessary since particle groups should be a function of particle size and hence particle settling velocity would vary based on particle group or size which is independent of waterbody. The concern is that the model user should not take one particle group from one waterbody and change its settling velocity in another waterbody.
8	VII.3. page 11-12	W2 Code Fixes: The code fix for pumps was incomplete. A more complete fix was made in Version 4.1 for keeping the pump numbers correctly linked. The code fix for aerators does not seem to do anything different than the original code, which seems correct.

#	Subject, Location	Comment
9	VII.4. page 12	Parallelization: The added parallelization code was reviewed. It was unclear what benefit comes from using parallelization as implemented. The model took about 4 hours to run with parallel processing and used 50-60% of the computer CPU with the computer's fan buzzing. The current stock version of CE-QUAL-W2 (4.1) ran the system model and also took 4 hours to run using only 15% of the CPU using only 1 processor. Significant time savings in model running occurred though by adjusting the DLTMAX and CUF (currently set to 1) where model run times under 1 hour using a non-parallel implementation were obtained.
10	IX. A. p page 15, Figure 5	Please include contour units in caption.
11	IX.A. pages 16, 25, 28	Computational grids for Granby Reservoir and Grand Lake: The minimum grid resolution is 2.5 m in the upper sections of the lakes (see Grand Lake vertical grid to the right [Fig 6] and Granby grid below [Fig 18], from documentation). This is a coarse model resolution. Grand Lake also has a vertical grid transition from 2.5 to 3 to 3.5 to 4 and back to 3 m. The model dynamics especially stratification are affected by a coarse grid. It is unclear why the grid resolution varies as it does vertically in Grand Lake. It may have been done to reduce computational time, but at the expense of numerical accuracy. One could justify using a 2.5 m grid if the model results were the same as a 1 m grid. The overall goal is to produce a model whose predictions are not a function of the chosen grid.  Also, the documentation states that the grid varied from "2.5 meters to 3.1 meters", but the figure below and the effective grid was 2.5 meters. It was unclear from the model bathymetry file for Granby why the grid had vertical spacing of 1 m, 2.517 m, 3.1 m, and 5 m but most were not used in the active grid. Also, Table 4 says that the Granby grid varied from 2.5 – 3.8 m, whereas in Figure 18 it is only 2.5 m. 

#	Subject, Location	Comment
12	IX.A. pages 19, 22	The Shadow Mountain grid, because of the islands around segment 23 and 22, would better be served by a grid that allowed for the main conveyance volume through the islands. The documentation states that “hydrodynamic impact of these islands is known to be significant.” The model documentation also shows that scour is an important feature. Hence, resolving velocities in the island region would also be important. We recommend that the model be enhanced to model the narrow portions of Shadow Mountain Reservoir more explicitly, perhaps by using one narrow channel on one side of the islands (main branch) and another segment or two in another branch connecting to the main branch on the other side of the islands. Doing so would produce more realistic velocities and flow-exchange rates. 
13	IX.B. Table 7, page 31	The withdrawal layers indicated in the model documentation in table 7 for segment 43 (layers 2-27) do not agree with the W2 control file, which specifies layers 2-24. Also, Table 7 contains a typo for the metric designation of the centerline elevation for Granby Reservoir releases to the Colorado River (river outlet). The table lists the metric centerline elevation as 2,595.4 m, but it should be 2,495.4 m.
14	IX.B. page 31	The Three Lakes model documentation states that water-quality conditions cannot change as water is pumped from the withdrawal segment to the receiving model segment, and therefore the model cannot simulate algal growth (for example) in the connecting channel between the Farr pumping plant and the southern end of Shadow Mountain Reservoir. Actually, algal growth in the connecting channel could have been simulated by the model if that reach had been included specifically in the model as another branch, but it was not. If this sort of algal growth is important, then that channel should be included in the model.
15	IX.B. page 31	Typo: ‘These **setting** significantly improved the simulation of temperature…’ Change to ***settings.***
16	IX.B. page 31	The Three Lakes model documentation states: “The withdrawal layers for the Farr Pumping Plant intake were restricted to a subset of layers above and below the inlet while the inflow of the GPC was set to enter Shadow Mountain Reservoir at elevations associated with layers 7-15 at Segment 28 (Figure 11). These setting significantly improved the simulation of temperature and dissolved oxygen profiles at SM-DAM and may be related to simulating observed mixing patterns, given the simplified representation of the islands (Section IX.A).” Pump inflows from the Farr Pumping plant may be being used to aerate lower layers and compensate for high zeroth-order SOD rates (see comment below). Pump 1 (Farr Pump) pumps into lower layers of SMR from Granby Reservoir.

#	Subject, Location	Comment
17	IX.B. Table 8, page 32	Typos: Table 8 mistakenly sets the upstream centerline elevation for the SMR Releases to the Colorado River at 25445 m when it should be 2,544.5 m. Also, “Co” River should be “CO” or “Colorado” River.
18	IX.C. pages 32-34	Water balance: The water balance is a critical part of the adjusting flows so that the model water level is correctly predicted. The procedure is described on page 34. Apparently the gains were added to tributary inputs and the losses were subtracted as distributed flows. Why were there 2 inflows accounting for gains in Grand Lake? Table 5 and 6 show that the gains are included for both North Inlet and East Inlet – how were these split between the two? It is essential to document what fraction of gains and losses were added/subtracted relative to the actual measured flows into/out from the water body. Generally, when flows are within 5-10% of the overall flow during non-run-off precipitation events, this is attributable to gage error. Errors above that point to perhaps other errors that may need further study to resolve. The mass balance errors – both in gains and losses could be a part of one file – the distributed flow file. Hence one is only dealing with one file rather than both gains and losses in separate files. Also, what do bank storage gain and losses represent and are they measureable or is this a mass balance error accounting in the CBT model? Since the W2 model accounts for evaporation, how was the evaporation not double counted in losses/gains? Comparing Figure 20 (inflows to Grand Lake, Granby, and Shadow Mountain) and Figure 60 (Distributed mass balance flows) in the Appendix B shows that for Grand Lake there are minimal mass balance losses, but for Shadow Mountain and Granby the mass balance losses can be significant as a percentage of the tributary inflows. For Granby, at times the losses are of the same order of magnitude as the Arapaho Creek flow + Gains.

#	Subject, Location	Comment
19	IX.D.4. page 39	The report states that cloud cover was computed from measured solar insolation data by applying the following formula: $Solar_{obs} = Solar_{clearSky} * (1.0 - 0.0145 * C^2)$ which means: $C = \sqrt{\frac{1.0 - \frac{Solar_{obs}}{Solar_{clearSky}}}{0.0145}}$ where $Solar_{obs}$ is the measured solar radiation flux, $Solar_{clearSky}$ is the theoretical clear-sky solar insolation, and C is cloud cover (0-10 scale, where 10 is completely cloudy). That equation is in contrast to the formula used in CE-QUAL-W2, which specifies that $Solar_{obs} = Solar_{clearSky} * (1.0 - 0.0065 * C^2)$ which means: $C = \sqrt{\frac{1.0 - \frac{Solar_{obs}}{Solar_{clearSky}}}{0.0065}}$ This difference in the coefficients for cloud cover means that the cloud cover generated for the Three Lakes model may result in less of a cloud-cover effect in W2. The effect would not be on solar radiation, as that is read in from measurements in the Three Lakes model. But, cloud cover is still used in the computation of long-wave atmospheric radiation inputs, and a lower cloud cover would result in a slightly lower long-wave input. For consistency, the computed R value from field data (R=0.0145) should also be used in the W2 model for computing long-wave atmospheric radiation. As mentioned above, it is currently set as 0.0065 in the model code.
20	IX.D.4, Page 40	The statement: "The approach used accounts for variation through the night which affect reflection of long-wave solar radiation back to the surface" needs to be revised since there is no reflection of solar radiation at night. There is though long-wave atmospheric radiation that is a function of cloud cover at night.
21	IX, G, page 44	Algal Biomass: A brief discussion of each of the 4 algal groups and what groups they represent would be helpful. Perhaps the mention of the 4 algae groups on p. 93 could be used here.
22	IX, G, page 45	The 10% labile assumptions seem unusually low for organic matter. But this depends on the nature of the organic matter and the studies that were cited in the documentation.
23	IX.H. page 46	The report states that the wind sheltering coefficients (WSC) for Shadow Mountain Reservoir were set to 1.0 for October through March and to 1.4 for April through September. The wind-sheltering coefficient input file, however, has errors in the dates here and there, such that these dates are not adhered to exactly. It appears that the WSCs for Shadow Mountain Reservoir are set to 1.4 for April 1 through September 29 rather than September 30, and 1.0 for September 30 through March 31.
24	IX.H. page 46	SOD rates and temperature dependence. The model documentation tries to justify the lack of a temperature dependence for SOD in Granby Reservoir. This is certainly allowable, but quite odd and not particularly realistic. See the comments on SOD rates and temperature rate multipliers below.
25	IX.H. page 46	Because of the choice of user-specified temperature control points (ST1, ST2, SK1, SK2) that affect the temperature multipliers for sediment oxygen demand (SOD), the modeled SOD rates vary over a huge range. The value of FSOD, the temperature

#	Subject, Location	Comment
		coefficients (ST1,ST2,SK1,SK2), and the first order SOD rates from the file w2_con.npt are shown below:

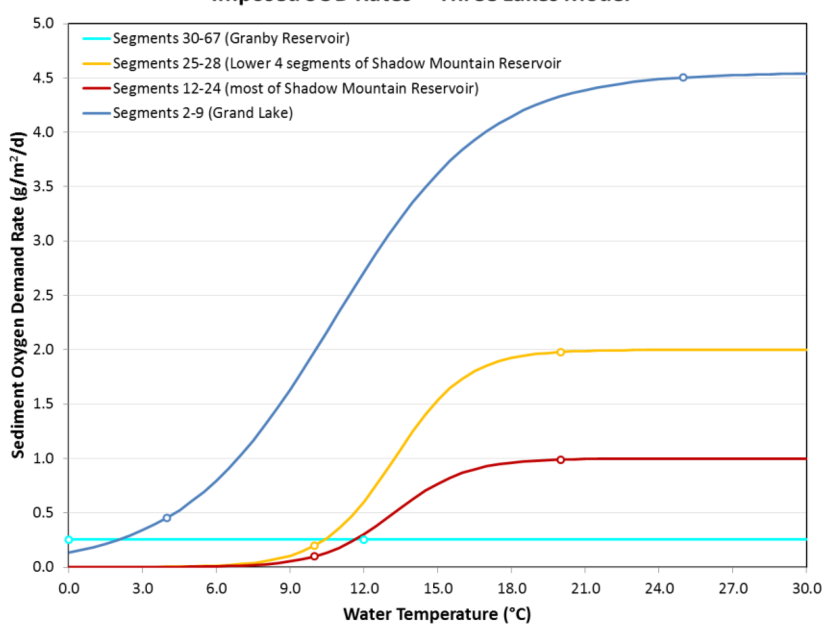
SEDIMENT	SEDC	SEDPRC	SEDCI	SEDK	SEDS	FSOD	FSED	SEDB	DYNSEDK
WB 1	ON	OFF	1.0	0.1	0.1	1.3	1.0	0.01	ON
WB 2	ON	OFF	2.0	0.3	0.1	1.0	1.0	0.01	ON
WB 3	ON	OFF	1.0	0.1	0.0	0.15	1.0	0.01	ON

SOD RATE	ST1	ST2	SK1	SK2
Wb 1	4.	25.	.10	.99
Wb 2	10.	20.	.10	.99
Wb 3	0.	12.	.85	.85

S DEMAND	SOD	SOD	SOD	SOD	SOD	SOD	SOD	SOD	SOD
	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	3.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0
	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	2.0	2.0	2.0	2.0	2.0				

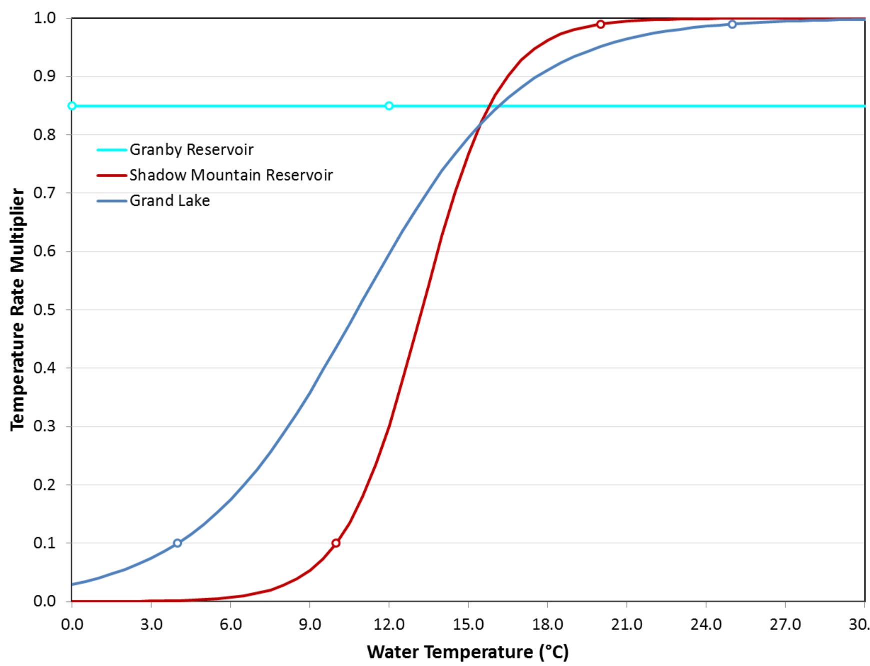
The graph below shows the variability of SOD rates based on the temperature coefficients for each water body and the first order specified rates according to segment.

Imposed SOD Rates -- Three Lakes Model



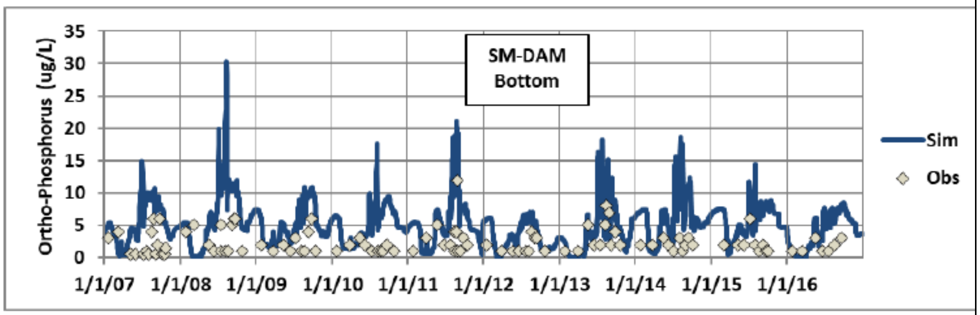
Note also that the segment-specific zero-order SOD rates specified in the control file do not fall neatly at waterbody boundaries. As a result, the modeled SOD rates in Shadow Mountain Reservoir, which spans model segments 12-28, are quite different in adjoining segments 24 and 25. The southern-most 4 segments of Shadow Mountain Reservoir have imposed SOD rates that are quite different from those in the rest of that reservoir, with rates in segments 25-28 that are twice as large as those imposed in segments 12-24. The rates in the graph above take into account the user-specified values of FSOD.

Imposing a constant and temperature-invariant SOD rate in Granby Reservoir does not

#	Subject, Location	Comment
		seem appropriate. The SOD rate should vary with temperature. A maximum zero-order SOD rate of 0.3 $g/m^2/d$ for Granby Reservoir is possible, but on the low side. On the other end of the scale, imposing a fairly large zero-order SOD rate in Grand Lake, with a temperature-adjusted maximum rate of 4.55 $g/m^2/d$ seems excessively high. Is it known that large amounts of labile organic matter are decomposing in the sediments of that lake? Of course, most of the sediment surface area may be associated with lower-level layers in the lake that are cooler, but that baseline SOD rate in cold water still seems rather high relative to this reviewer's experience and published rates in the literature. Note that these zero-order SOD rates are in addition to the fact that the first-order sediments compartment also is activated, with nonzero sediment decomposition rates. The effective SOD rate, therefore, is larger than the rates in the graph above.
26	IX.H. page 46	The user-specified temperature control points (ST1, ST2, SK1, SK2) set the temperature multipliers for zero-order sediment oxygen demand as well as the temperature multipliers for first-order sediment oxygen demand and sediments decomposition. **Temperature Rate Multiplier for SOD -- Three Lakes Model**  Again, it seems odd to impose a flat temperature-rate multiplier for these processes in Granby Reservoir.
27	IX.H. page 48	Note that the ammonia release rate from the sediments, as a fraction of the temperature-adjusted SOD rate, will have an odd boundary between segments 24 and 25 in Shadow Mountain Reservoir, due to the specification of very different baseline SOD rates in the control file. The 4 southern-most segments in Shadow Mountain Reservoir will have a higher ammonia release rate from anoxic sediments than the rest of the segments in Shadow Mountain Reservoir.

#	Subject, Location	Comment
28	XII. Model Results	Model results for water levels and water temperature look good. Dissolved oxygen results match the patterns in the data relatively well, but are poorer for Grand Lake (GL-MID TOP), where the model fails to reproduce late summer oxygen levels in most years. The authors point this out, but do not speculate as to the cause. Overall, the model results matched general patterns for temperature, oxygen, chlorophyll, and suspended sediment. Some of the nutrient predictions were not particularly good, and hopefully do not have a large effect on the predictions of oxygen and chlorophyll and secchi depth. It might be useful to compute the Nash-Sutcliffe coefficient for some of these results, just to assure the audience that the model is reproducing more of the measured variability than would be captured through the use of a mean of the measurements. The approach to computation of secchi depth from the model results was reasonable. The main question that we considered is whether the calibration of the model was done for the right reasons and was limnologically valid so that the secchi disk depth and other measures could be used for future model scenarios.
29	XII.B. Model Results page 56, Table 14	Mean error temperature statistics for the vertical profile comparisons would be helpful to show the amount of bias.
30	XII.C. Model Results page 63, Table 16	Mean error dissolved oxygen statistics for the vertical profile comparisons would be helpful to show the amount of bias.

<table>
<tr><th>#</th><th>Subject, Location</th><th>Comment</th></tr>
<tr><td>31</td><td>XII.D. Model Results pages 74-77</td><td>
Orthophosphate results are over predicted at most sites. This is apparent in the goodness-of-fit statistics as well as in the graphs. For example, Shadow Mountain predictions at the bottom near the dam are compared with data:

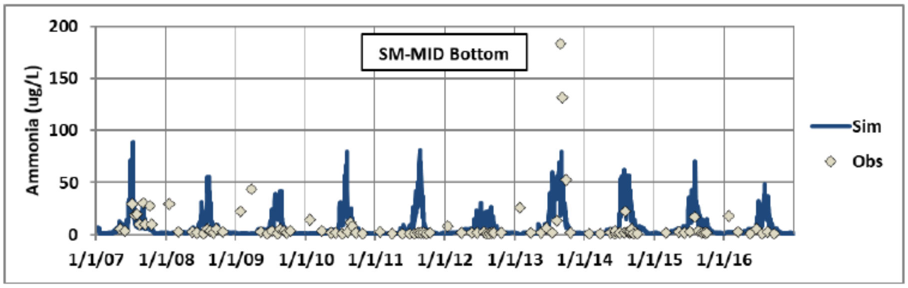
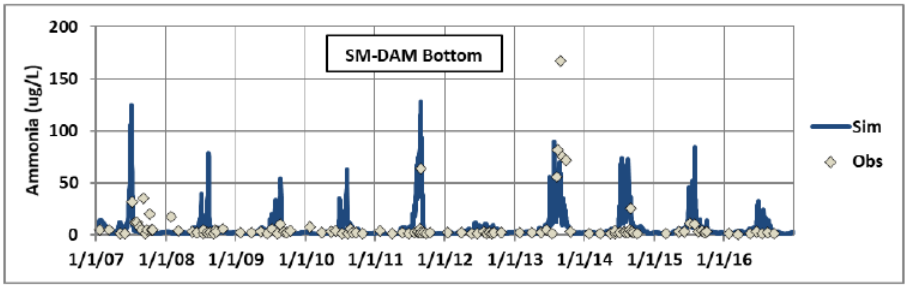
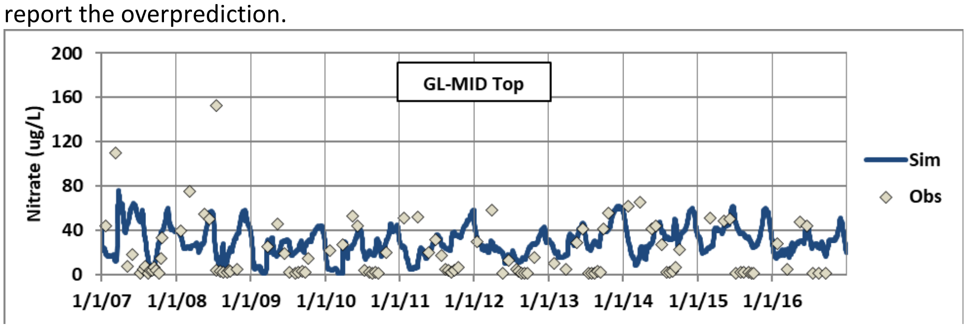


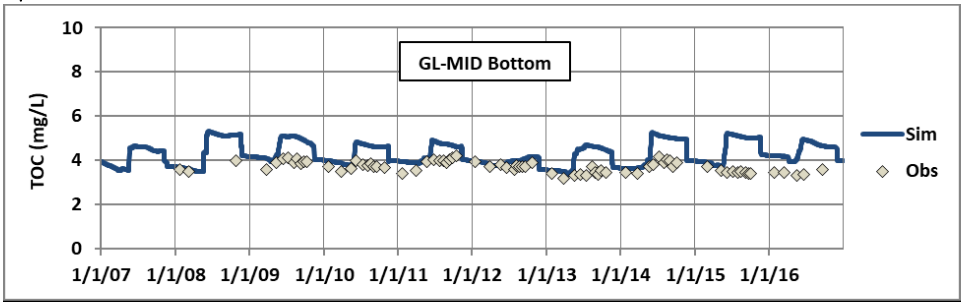
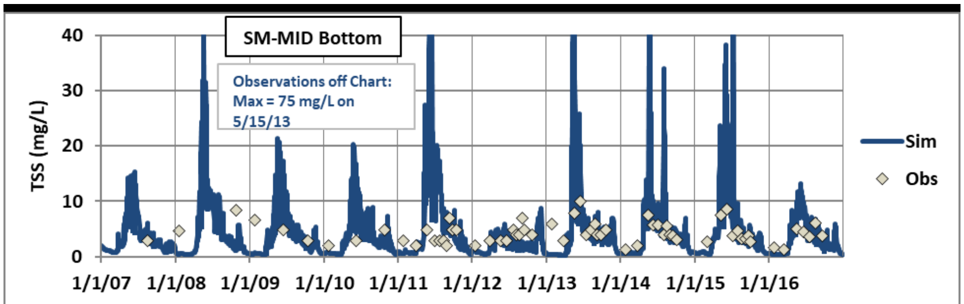
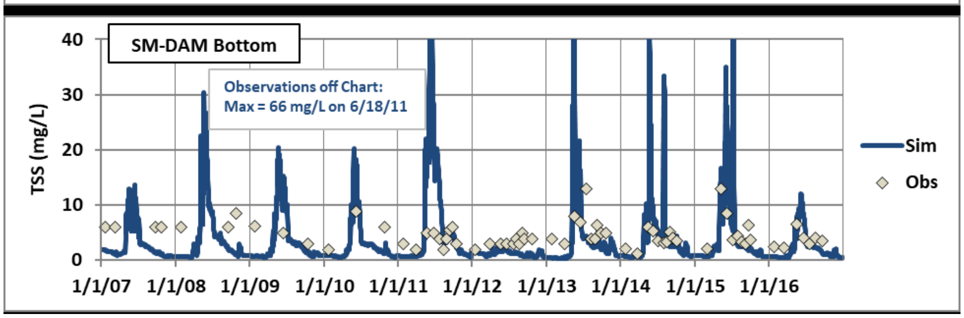
The mean error approaches the magnitude of the mean absolute error, which is indicative of the fact that most of the errors are in the same direction, and that the model has a systematic bias for overpredicting the orthophosphate concentration at most sites. Why? Is this related to releases from sediments? Insufficient uptake by algae?

Table 19. Error Statistics for Ortho-Phosphorus Considering Key Calibration Locations

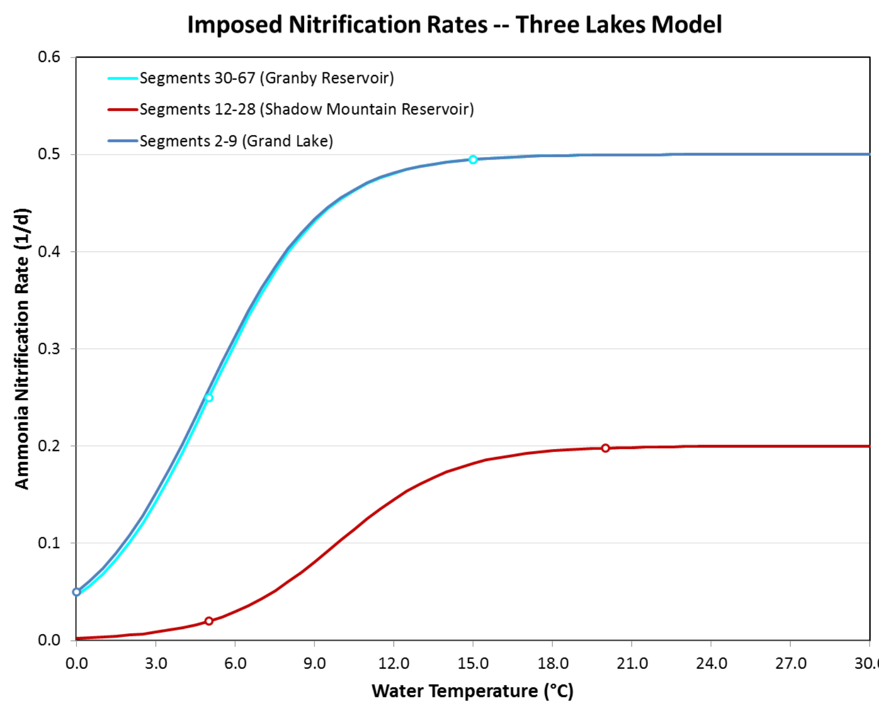
<table>
<tr><th>Water Body</th><th>Number of Observations</th><th>Mean Error (ug/L)</th><th>MAE (ug/L)</th><th>RMSE (ug/L)</th><th>MAE (% of Range)</th></tr>
<tr><td>Grand Lake</td><td>206</td><td>1.79</td><td>2.30</td><td>2.89</td><td>35%</td></tr>
<tr><td>Shadow Mountain Reservoir</td><td>410</td><td>3.11</td><td>3.63</td><td>4.75</td><td>32%</td></tr>
<tr><td>Granby Reservoir</td><td>206</td><td>1.55</td><td>2.37</td><td>3.28</td><td>13%</td></tr>
</table>

As shown in the nutrient flux section in Appendix A (Figure 37 through Figure 39), releases of ortho-phosphate due to first-order sediment decay are a relatively large source in Shadow Mountain when compared to Grand Lake and Shadow Mountain Reservoir. Calibration would likely be improved if this large source was decreased by reducing the fraction of POM settling out of the water column and/or reducing the P fraction in POM.
</td></tr>
</table>

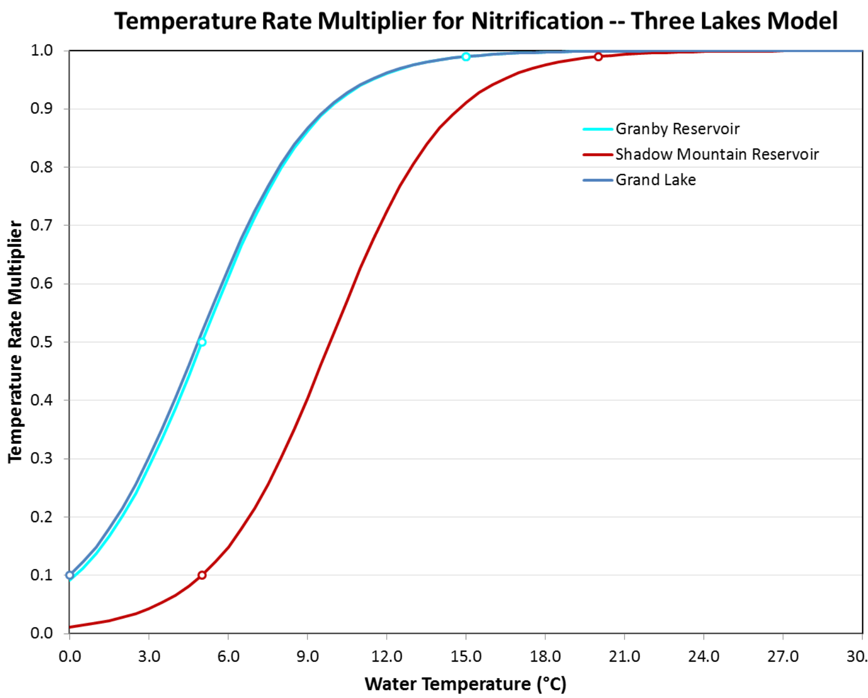
#	Subject, Location	Comment
32	XII.E. Model Results page 84, Figure 54	Similarly to ortho-phosphate, ammonia was also over predicted in Shadow Mountain Reservoir during summer periods. This may also be caused by releases from the first-order sediment compartment being too high. Nitrogen fluxes plotted in Figure 40 through Figure 42 in Appendix A show that the proportion of first order sediment ammonia releases are relatively high in Shadow Mountain Reservoir.  
33	XII.E. Model Results page 87	Nitrate is overpredicted at the surface, particularly in mid- to late-summer. What is the cause of this disagreement? It is important for the model developers to try to figure out why this disagreement occurs and speculate on potential process-based causes (boundary conditions, release rates, mixing issues, algal uptake, …) rather than just report the overprediction. 

#	Subject, Location	Comment
34	XII.G. Model Results page 99	TOC at GL-MID Bottom (page 99) show a clear pattern in the simulated results that is not reflected in the measurements. Does this provide some sort of clue regarding the effects of pumps, withdrawals, or mixing on the model results that can be fixed or updated? 
35	XII.H. Model Results page 103	The authors state that the model resuspension of TSS resulted in too much TSS near the bottom of Shadow Mountain Reservoir (see plots below). But, this is the result of the new algorithm added to the model to simulate resuspension. Perhaps the model coefficients need to be adjusted to decrease the amount of resuspension?  

<table>
<tr><th>#</th><th>Subject, Location</th><th>Comment</th></tr>
<tr><td>36</td><td>XV. Internal Loading</td><td>The internal loading for ammonia seems high, and yet the simulated ammonia concentrations do not seem high. Are any measurements of internal loading rates available for these waterbodies? The fact that the simulated nitrification rate was relatively large for Grand Lake and Granby Reservoir (0.5/d) may explain the fact that predicted ammonia concentrations do not attain high concentrations, and this perhaps could help to explain why dissolved oxygen concentrations are a bit low in late summer. The nitrification rates in CE-QUAL-W2 are based on the base rate and the variation in temperature. The control file uses the following information to compute nitrification rates as a function of temperature:
<pre>
AMMONIUM   NH4R   NH4DK
Wb 1   0.0068   0.50
Wb 2   0.015   0.20
Wb 3   0.008   0.50

NH4 RATE   NH4T1   NH4T2   NH4K1   NH4K2
Wb 1   0.0   15.0   0.1   0.99
Wb 2   5.0   20.0   0.1   0.99
Wb 3   5.0   15.0   0.5   0.99
</pre>
A graph of the variation of nitrification rates as a function of temperature in each of the 3 waterbodies is shown below:


These temperature rate multipliers combine with the imposed ammonia nitrification rates to produce temperature-adjusted nitrification rates that are much higher for Grand Lake and Granby Reservoir than they are in Shadow Mountain Reservoir. What is the basis for this difference?</td></tr>
</table>

<table>
<tr><th>#</th><th>Subject, Location</th><th>Comment</th></tr>
<tr><td>37</td><td>XV. Internal Loading</td><td>The temperature rate multiplier functions for ammonia nitrification for Grand Lake and Granby Reservoir (waterbodies 1 and 3) are almost identical, and yet the inputs to achieve them in the control file were quite different. Below is the information presented in the control file:
NH4 RATE NH4T1 NH4T2 NH4K1 NH4K2
Wb 1 0.0 15.0 0.1 0.99
Wb 2 5.0 20.0 0.1 0.99
Wb 3 5.0 15.0 0.5 0.99


These temperature rate multipliers combine with the imposed ammonia nitrification rates to produce temperature-adjusted nitrification rates that are much higher for Grand Lake and Granby Reservoir than they are in Shadow Mountain Reservoir. What is the basis for this difference? Why should the temperature effects be so different in Grand Lake and Granby Reservoir compared to Shadow Mountain Reservoir?</td></tr>
<tr><td>38</td><td>XVII.A. Sensitivity Tests</td><td>The sensitivity tests were useful, but did not reveal many parameter values of importance, other than some of the new parameters related to resuspension. Note that mixing solar radiation from 2016 with cloud cover from 2012 is inconsistent. As a sensitivity test, it may be okay, but it may also produce some inconsistent results when meteorological conditions are mixed from different years.</td></tr>
<tr><td>39</td><td>Model Refinements</td><td>The authors provided some recommendations for future sampling and model refinements. It seems premature to add macrophytes when the simulation of nutrients is not yet impressive. More work could be done to nail down the nutrient budgets, and that would seem to be more important than adding macrophytes. Before trying to simulate pH, ask whether pH is an important parameter affecting water quality or decision-making for these lakes. If not, don't waste your time on pH. If it is important, then it is critical to have a good alkalinity dataset.</td></tr>
</table>

#	Subject, Location	Comment
40	Appendix A	When using seasonal or monthly regression models, how were the transitions between the time periods handled? Often in such cases, the predictions of one month or season at the boundary of the next month or season will produce a discontinuity, and it is useful to "ease" from one month or season to the next with a multi-day transition period using weighted results from both regression models.
41	Possible Addition to report: Section on General Insights	In addition to the section on Recommendations, it would be good to include a section in the report on general insights. Certainly, one of the goals of the modeling effort was to produce a model that could be used to predict the effects of water-resource management activities on water quality. However, building and testing a model invariably produces some general insights that tend to be true and useful, regardless of the accuracy of model predictions. The effects of Farr pumping on water clarity, for example, was pointed out as an important influence. The location of the Farr pumping intake relative to the floating or sinking of inputs from Stillwater Creek are another example of an important influence on water quality.
42	Control file, w2_con.npt	The simulation stops one day short of the end of calendar year 2016 (day 4383.0); the end of that year is 4384.0.

43	Control file, w2_con.npt	The model control file (see below) shows that the turbulence closure schemes are different for each waterbody. The 'W2N' closure scheme is really more adapted to a river system since it uses Nickuradse's mixing length. For these reservoirs, the TKE model is preferred always, but the W2 scheme is also appropriate and perhaps at a slightly less computational cost.
		
		`EDDY VISC    AZC   AZSLC   AZMAX`
		`WB 1         W2N     IMP    1.00`
		`WB 2         TKE     IMP    1.00`
		`WB 3         W2N     IMP    1.00`

44	Control file, w2_con.npt	The reaeration rate formulae for the 3 lakes you would think would be consistent. But the setting in the control file shows different formulae used in Granby Reservoir compared to the other 2 waterbodies:
		
		`REAERATION  TYPE    EQN#`
		`Wb 1        LAKE       6`
		`Wb 2        LAKE       6`
		`Wb 3        LAKE       1`

45	Control file, w2_con.npt	PO4R=0. This is not justified since during anoxic conditions there will be release of PO4 unless it is 100% sequestered. It is clear the modeling team had trouble reducing PO4. This seems more like a fix to match data rather than understanding what may be happening in the system.
		
		`PHOSPHOR    PO4R   PARTP`
		`Wb 1         0.0     0.0`
		`Wb 2         0.0     0.0`
		`Wb 3         0.0     0.0`

46	Precipitation temperature, file 'Tair.npt'	Generally, rainfall temperature is a complex function of the formation temperature and the heating (more typical) as it falls to earth. Ideally at steady-state during a rain event, the air temperature should equal the dew point temperature if there is 100% moisture. In order to account for the fact that often the rain is cooler than the air temperature in cases where the dew point temperature is not yet equal to the air temperature, we often just use the dew point temperature. But since rainwater inputs are usually very small, using dew point or air temperature probably has little impact on the model dynamics. We though usually use dew point temperature rather than air temperature.

#	Subject, Location	Comment
47	Precipitation concentration, file 'Cin_Precip.npt'	Dissolved oxygen concentrations in the precipitation are often above 20 mg/L and are too high (Appendix B, Figure 52). A saturated DO concentration in freshwater at sea level at $0^{o}C$ is about 14.6 mg/L and would be lower at higher elevations due to decreased barometric pressure.
48	East Inlet Branch Constituent Inflow, file 'cin_el.npt'	Constituent concentrations are repeated after Julian Day 4017 – see Appendix B Figure 59 through Figure 62.
49	North Fork Constituent Inflow, file 'cin_NF.npt'	At low concentrations of LPOM or RPOM (0.0025 mg/L), LPOM < LPOM_P+LPOM_N and RPOM < RPOM_P+RPOM_N. Total organic matter mass cannot be less than the sum of organic matter nitrogen and phosphorus (see Appendix B Figure 67 and Figure 68).

3 C-BT RiverWare Model Review

3.1 Introduction

The review team was tasked to review the U.S. Bureau of Reclamation's Colorado – Big Thompson RiverWare planning and operations model. This daily timestep model, is used for long term planning and analysis in a NEPA-like process to compare alternatives. The stated objectives of this model are to:

- Analyze different operations (e.g., not moving water when warm) and facilities (such as new pipelines, new reservoirs)
- Provide flows into and between Grand Lake, Shadow Mountain, and Granby Reservoir and boundary conditions to the Three Lakes CE-QUAL-W2 water quality model. Variables of interest include water quality parameters (from W2 model), hydropower production, deliveries, spills, and flow regimes.

The following files were initially provided to the review team by the USBR Eastern Colorado Area Office:

- **CBTPOM_v2.0-noResults.mgl.gz**: The RiverWare model file for the Colorado-Big Thompson Planning and Operations model, last saved on February 28, 2018 using RiverWare 7.1.4; the model file was saved without output data. The review team was able to run the model to view the outputs.
- **CBTPOM_v2.0.rls**: The ruleset that goes with the model, representing the operational policy of the system.
- **CBTPlanningAndOpsModelDocumentation_Final.pdf**: A document drafted by Precision Water Resources Engineering (PWRE) dated February 28, 2018, describing recent work by PWRE on the model to incorporate the Windy Gap Firming Project and enhancements to make the model useful for a multiple decade planning horizon.
- **CBTPlanningAndOpsModelDocumentation_Final.docx**: A Microsoft Word version of the same document.

After reviewing the initial files, the review team requested the following files, which were provided by the USBR Eastern Colorado Area Office.

- **CBTPOM Daily Hydrology Final Report.docx**: A technical memorandum from Hydros Consulting (Hydros)dated November, 2015, documenting work by Hydros to develop historic daily flow time series for the Colorado-Big Thompson West Slope Collection System and the inclusion of the Red Top Ditch system in the Colorado-Big Thompson RiverWare model.
- **C-BT Model Demand Memo.docx**: A memorandum from Northern Water describing the sources of the historic East Slope demand data used in the Colorado-Big Thompson RiverWare model.
- **Windy Gap Pumping Memo.pdf**: A memorandum from Norther Water describing the sources of the Wind Gap Pumping data used in the Colorado-Big Thompson RiverWare model.
- Six RiverWare system control tables (SCTs) – configured views of select data in the Colorado-Big Thompson RiverWare model:
  - AccountDetails.sct
  - AnnualWindyGapValues.sct
  - Deliveries_Fees.sct
  - GranbyFlowDetail.sct
  - GranbySpillDetail.sct

    - RequestsShortages.sct
- Data files of daily data developed by Hydros in their work in 2015 and referenced in the document CBTPOM Daily Hydrology Final Report.docx
    - Granby_Reservoir.csv
    - Grand_Lake.csv
    - Miscellaneous.csv
    - Shadow_Mountain_Reservoir.csv
    - Willow_Creek_Reservoir.csv
- Data files originally provided to Hydros for their work in 2015 and referenced in the document CBTPOM Daily Hydrology Final Report.docx
    - 1.1 DailyOps Data.xlsx
    - 3.1 USBR_Data Request.dv
    - 5.1 USBR_Data Request.dv
    - 13.1 spoct_2015.pdf
    - 13.2 USBR_Data_Request2.dv
    - 14.1 spoct_2015.pdf
    - 14.2 USBR_Data_Request2.dv

This review attempts to answer the question: Does this RiverWare model meet the needs of the stated purpose above? To answer this question, this review attempts to determine:

- Does the model adhere to the current state-of-the-art in River Ware model applications?
- Do the objects and physical process methods make sense as used?
- Are the data used appropriate for the timestep and objectives?
- Do the RiverWare rules and other policies make sense and have reasonable logic?

This review was limited to reviewing the RiverWare model, associated documentation, and input data. Additional assumptions are as follows:

- We trust the data provided in tables is reasonable. For example, we did not verify that the Elevation Volume Table correctly represents the reservoir.
- We are not experts in this basin so we do not know if the correct policies are modeled, only that the rules represent reasonable logic.
- We did not review the CE-QUAL-W2 model or the inputs required by that model as other reviewers were tasked with that purpose.

This document provides general comments on the model, comments on the physical processes modeled and use of objects, comments on the implemented policy logic, and comments on the data used as inputs to the model. Follow-on comments address the performance, utility and miscellaneous aspects of the model. Potential critical issues are shown in red text. Red-lined items indicate a possible problem with correctness, issues that could affect the mass balance in the system or could modify the flows that are transferred to the CE-QUAL-W2 model.

3.2 GENERAL COMMENTS

Following are general comments on the model, run range and workspace views.

3.2.1 OVERALL IMPRESSIONS

The model is a succinct representation of a very complex system. The rule logic is reasonable and efficient in its calculations. The run time performance of the model is very fast for a model of this scale. The model will be a very useful tool for decision making, planning, and analysis. With the exception of the issues identified in red text in the following sections, the numeric outputs of the RiverWare model appear to be reasonable and correct. Many simplifications were made to the layout and physical processes. In general, these are fine, but in a few cases, the simplifications are unnecessary; in such cases, a more explicit representation would make the model easier to understand. We also note some inconsistencies and possible sources of error in the input data.

Further, the model appears to be in a development state. Changes appear to have been proposed by Hydros and PWRE (with changes noted and documented) but have only been partially incorporated into the model. No real documentation was provided, although there are many comments scattered throughout the model. With a few model changes and some further documentation, this model would meet the stated objectives.

3.2.2 VERSION AND RUN RANGE

The provided model was last saved in version 7.1.4. We recommend moving the model to the latest RiverWare version.

The provided model, CBTPOM_v2.0-noResults.mdl.gz, has the following features:

- Daily time step
- Run Range is from Jan 1, 2015 to Sep 30, 2072, 21,093 time steps

When the model is ready for “alternatives analysis,” the dates should be moved forward to truly be in the future. Having any dates in the past tends to confuse stakeholders who think the model must somehow be showing what actually happened.

3.2.3 WORKSPACE VIEWS

The workspace shown in Figure 2 shows the layout of the network. The following are minor comments on the network, layout and views, which can help make the model more accessible to new users. These do not impact the numerical correctness of the model. They are only suggestions as places for possible improvement.

- Orientation on the workspace could be made more consistent. On the West Slope, north is up. On the East Slope, north is to the right. This could potentially be confusing to a user that is unfamiliar with the model.

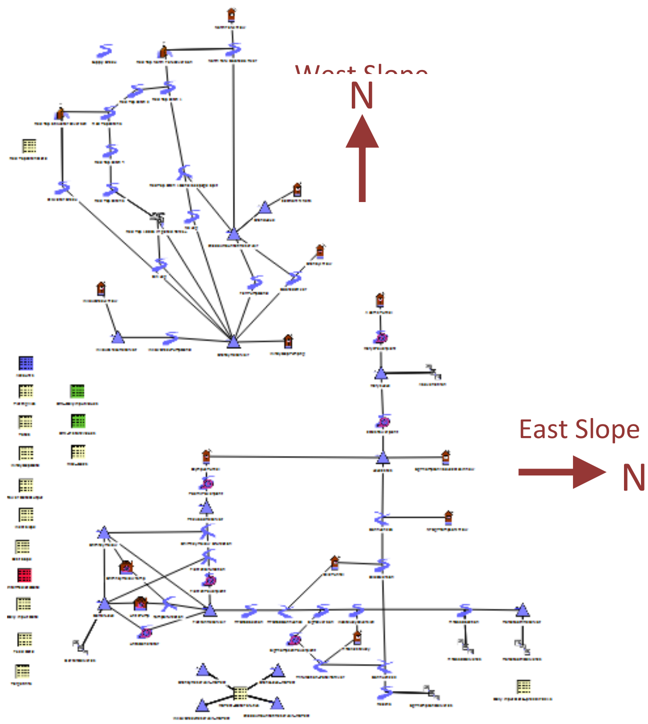


Figure 2: RiverWare workspace orientation

- To someone not familiar with your system, it may be confusing that the Grand Lake object is not linked to the Adams Tunnel object. Linking the two objects would provide an improved visual representation of the physical system, and it would streamline system logic by removing the need for the rule that sets both values. Note, the numeric values for Grand Lake Diversion and Adams Tunnel Inflow are always equal, as they should be. We recommend showing at least a visual indicator that represents the GrandLake diversion to Adams Tunnel, such as text on the workspace or a small image showing a connection to the Adams Tunnel gage.
- Arrows on links would be nice to show the direction of flow. Also, color coding links could make it clear which links are channels, which are pipes, and which are diversions/returns.
- The Geospatial view would require further effort to make it useful; however, a useful Geospatial is not a necessary component of a functioning model. Improvements to the Geospatial view only need to be undertaken if it would potentially provide benefit when sharing the model with "stakeholders" or other interested parties.
- The object naming is fairly consistent except for:
  - "Chimney Hollow Bifurcation", "Adams Tunnel" and a few "Red Top Ditch" objects which have spaces in their names.
  - Trifurcation_TotalToRiver is the only physical object name that has an underscore.
  - Generic "Confluence3" and "Reach5" could be given more descriptive names.
  - BigTDiversion could be given a name consistent with other Big Thompson objects.
- In some cases, more consistent object and slot naming would make it possible to simplify rule logic by using a FOR loop over a list of objects and/or slots.

3.2.4 Documentation

Documentation was provided in the file CBTPlanningAndOpsModelDocumentation_Final.pdf and associated *.doc. Although the file name indicates that this is Planning and Ops Model Documentation, this document is titled "CBTPOM Modifications for Windy Gap Firming Project" and is really a description of the changes made to the model by PWRE to model Windy Gap firming. The documentation does have some background and description of the logic but is not a comprehensive documentation of the model or ruleset.

There is quite a bit of descriptive text within the model itself. Many rules, functions, and slots have descriptions or notes. RPL logic also has in-line comments in many places. To enhance transparency, usability, and make consistent future changes to system logic easier, we recommend that the descriptive text be enhanced and improved. We also highly recommend that the source of all data be documented in the slot itself (in the Slot Description field) or in separate documentation.

We recommend that comprehensive documentation be developed as a way of preserving and memorializing system understanding and intellectual know-how. This documentation should provide an overview of the basin and its physical/hydrological processes, a description of land-use and infrastructure, the origin and present-day state of operating policy, and how it is represented in RiverWare. In particular, it would be good to identify key assumptions, thresholds, and legal requirements (e.g., for rule logic), and describe how the system might be run differently during times of surplus, drought, or other relevant extremes. RPL Report groups and then Model Reports in RiverWare can be used to generate documentation that is contained in the model as an HTML file for inclusion in the documentation.

3.3 Physical Model

The following are comments on the physical model, the use of objects, general data comments, comments on diagnostic messages and input data. Then, we comment on the specifics of certain objects or groups of objects.

3.3.1 Use of Objects

In general, the use of objects is appropriate and workable. Comments on the use of objects include:

- In many cases, reach objects are used to represent conveyances that could be more directly modeled by other RiverWare objects, including pipelines, distribution canals, inline pumps and groundwater objects. The numeric results using the reach objects are correct. Use of the other object types would simply improve the visual representation of the system.
- On the East Slope, Bifurcations are used, but on the West Slope, Diversion objects are used. It would be better if these were consistent, but the numeric results are correct as is.
- Although it does not make a difference in the model results, it might be nice to show the Colorado River below Granby with a reach object so it is clear that it is there.

3.3.2 General Data Comments

The following are general comments on data or parameters:

- Max Iterations slots on all reservoir objects should be increased to 100 (currently 20) to prevent potential issues if running with alternative inputs (See Figure 3).

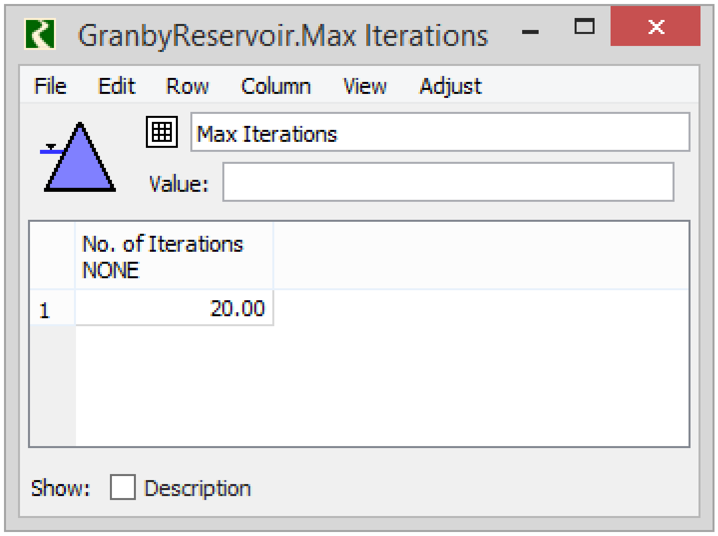


Figure 3: Max Iterations slot

- Max Iterations (EngrObjs) in the Rule-based Simulation Run Parameters should also be increased to 100 (currently 40, see Figure 4).

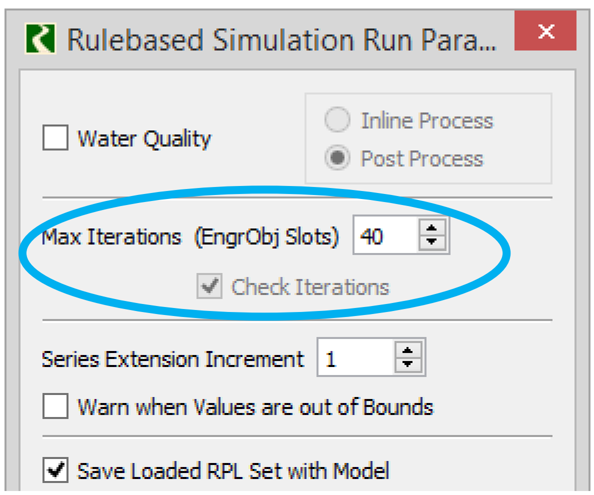


Figure 4: Max Iteration on RBS Run Parameters

3.3.3 Diagnostics

When a run is made, there are over 13,000 messages about negative values for Outflow on GranbyReservoir_MBTest. These are distracting at best and could hide important messages at worst. The negative outflow should be addressed, or the dispatching of GranbyReservoir_MBTest should be disabled for standard runs if its outputs are not being used.

3.3.4 Input Data

All time series input data are on custom slots on data objects and then transferred over to simulation objects by rules. The only exception is Reservior.Storage, which is a manual input at the initial timestep.

One way to approach this is to have an initialization rule set the initial Storage/Pool Elevation from a historical time series. This allows you to more easily change the time range of the run.

Marys, Lake Estes, and Flatiron are all modeled as constant elevation, but they still dispatch given Inflow and Outflow. We were expecting these to dispatch given Pool Elevation or Storage, but setting Outflow with a rule is a valid way to dispatch these reservoirs.

All table, scalar and other parameter data should have the source documented in the Slot Description.

3.3.5 Comments on Specific Objects

The following sections provide specific comments on select objects or groups of objects.

3.3.5.1 Red Top Ditch

There is more documentation on this area than on other parts of the model. The following are comments on the objects and structure of these objects:

- The source of many of the parameters are not listed. This includes:
    - Minimum Efficiency
    - Maximum Flow Capacity
    - Maximum Soil Moisture
    - Maximum Infiltration Rate
    - Evapotranspiration coefficients – These appear to come from the Hydros study, but this is not noted in the model.
- The “No Lag” reach appears to be unnecessary. A link would be sufficient.
- Red Top Ditch 2: This object does not appear to be necessary. Maybe it is there for linking Supply Creek, but Supply Creek could also be linked to Red Top Ditch 3 Local Inflow.
- The Red Top Ditch objects (reaches) could be replaced with an Agg Distribution Canal(s). They have the same basic functionality as reaches but provide better visual distinction between streams and canals. (The same is true for the East Slope.)
- The Red Top Ditch 4 reach object uses the Step Response routing method to represent water spread out to reach soil moisture. This approach is somewhat non-standard. It is not incorrect, but itdoes not really represent a delay of consumption by the soil moisture. For example, Red Top 10825 Irrigated Parcels use soil moisture which takes care of the soil moisture storage and delayed consumption.
- The Groundwater Return Flow and Seepage return from Red Top Ditch to Granby and Shadow Mountain reservoirs is relatively crude compared with the detailed modeling of other components of the system. Irrigation return flow is modeled with a simple 90-day lag to Granby, and canal seepage is divided 50% to Shadow Mountain and 50% to Granby with no lag. However, these flows into the reservoirs represent less than 0.02% of the total inflows, so these rough approximations are not significant.
- The 90-day groundwater lag from Red Top 10825 Irrigated Area to Granby could be represented directly on the Red Top 10825 Irrigated Area water user object using a Return Flow Routing method rather than routing on a reach object or with a groundwater object. A reach object is an indirect approach.

3.3.5.2 Granby

Following are comments on the Granby reservoir object:

Bank Storage Coefficients (Figure 5) do not match the values in the Hydros memo. The Hydros values were 0.1068 and 0.0347 (CBTPOM Daily Hydrology Final Report.docx). The reviewers recognize that the deviations from the Hydros values may be intentional changes to the model made by Reclamation modelers. These parameters affect the overall mass balance, and thus, they should be checked by Reclamation models for correctness to verify whether the deviations are intentional. The source and/or means of deriving the final parameter values should be documented.

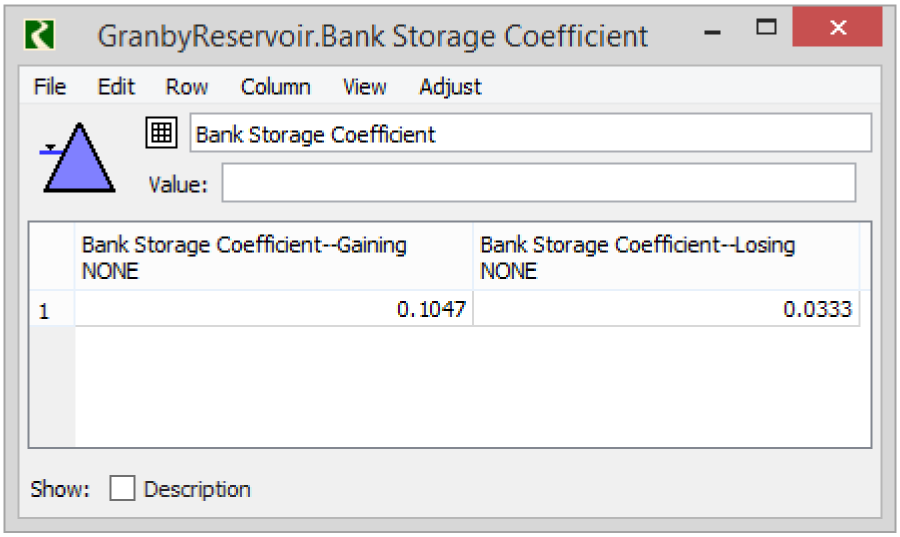


Figure 5: Granby.Bank Storage Coefficient slot

- There is a bias in Change in Bank Storage (**Error! Reference source not found.**), 15.53 cfs average, total 650,000 ac-ft (loss). This should be net zero over long term. If this is a real physical loss, it would be more appropriate to represent it as Seepage rather than Bank Storage.

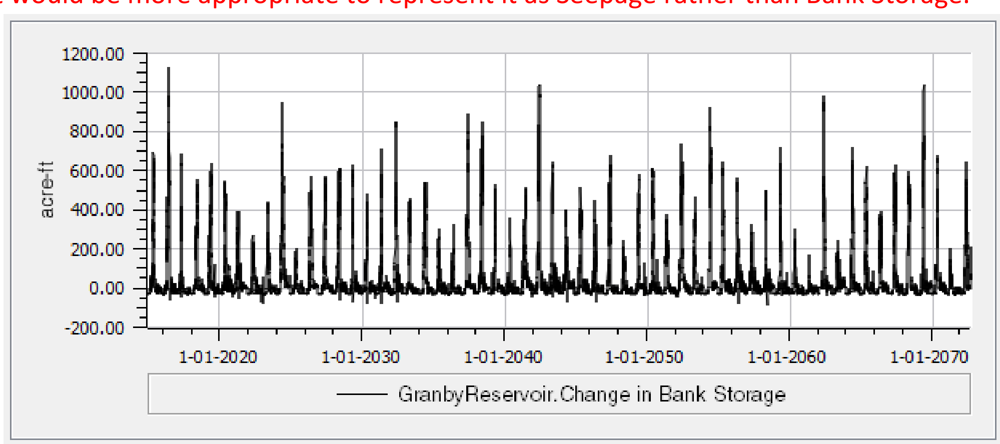


Figure 6: Granby Change in Bank Storage showing positive bias

- Elevation Area Table: There are many extra digits of display precision in Surface Area column. These could be eliminated by deleting the display unit exception for the slot in the Unit Scheme Manager.
- Evaporation and Precipitation

- The Input Evaporation method is currently selected on Granby for the Evaporation and Precipitation category. There are currently no data in the input slots for Input Evaporation (i.e. evaporation is always zero; see Figure 7); there are data with an annual repeating period in the input slots for the Daily Evaporation method, but they do not appear to correspond to the Hydros calculated daily values. (The source of the Daily Evaporation method data is not documented.) The reviewers recognize that the deviations from the Hydros values and the method selection may be intentional changes to the model made by Reclamation modelers, and the additional comments regarding the Evaporation and Precipitation method and inputs should be read with that understanding. These parameters affect the overall mass balance, and thus, they should be checked by Reclamation modelers for correctness to verify whether the deviations are intentional. We also recommend that the basis for the method selection and the source of the input data be documented.

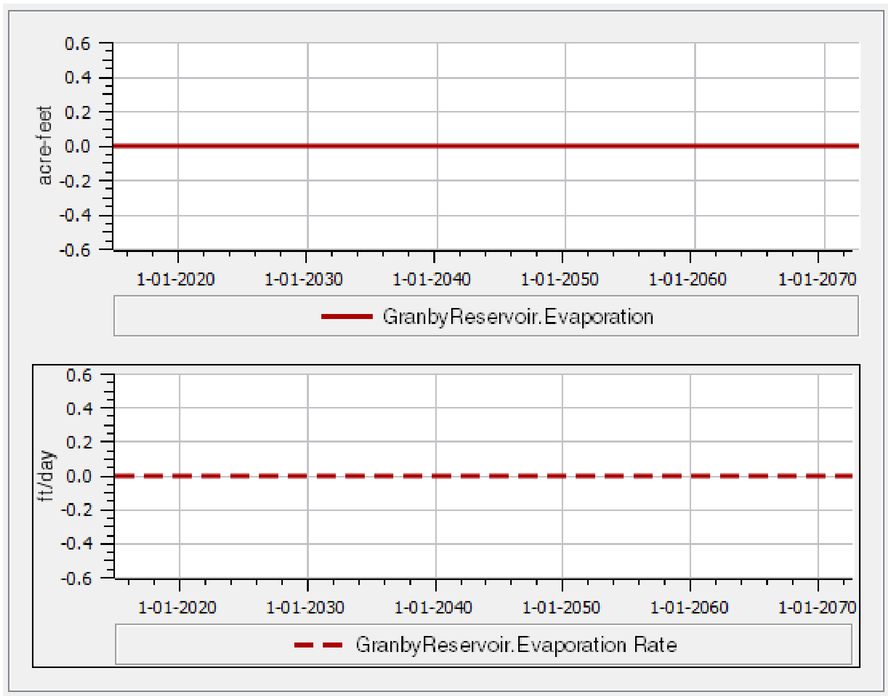


Figure 7: Granby Evaporation and Evaporation Rate, both zero

- Based on the analysis and data provided by Hydros, the Pan and Ice method would be more appropriate.
- Hydros also produced precipitation data that are not currently used in the model. A sample of these data are shown in Figure 8. (Precipitation is always zero in the model.)
- There are daily evaporation and precipitation rate values stored in the DMI_HistoricValues.Granby slot (are these the Hydros values?), but Evaporation and Precipitation should be explicit rates (in/day), not length (in). It is not clear if the evaporation values in this slot are raw pan evaporation, or if they are the values applying the pan coefficient.

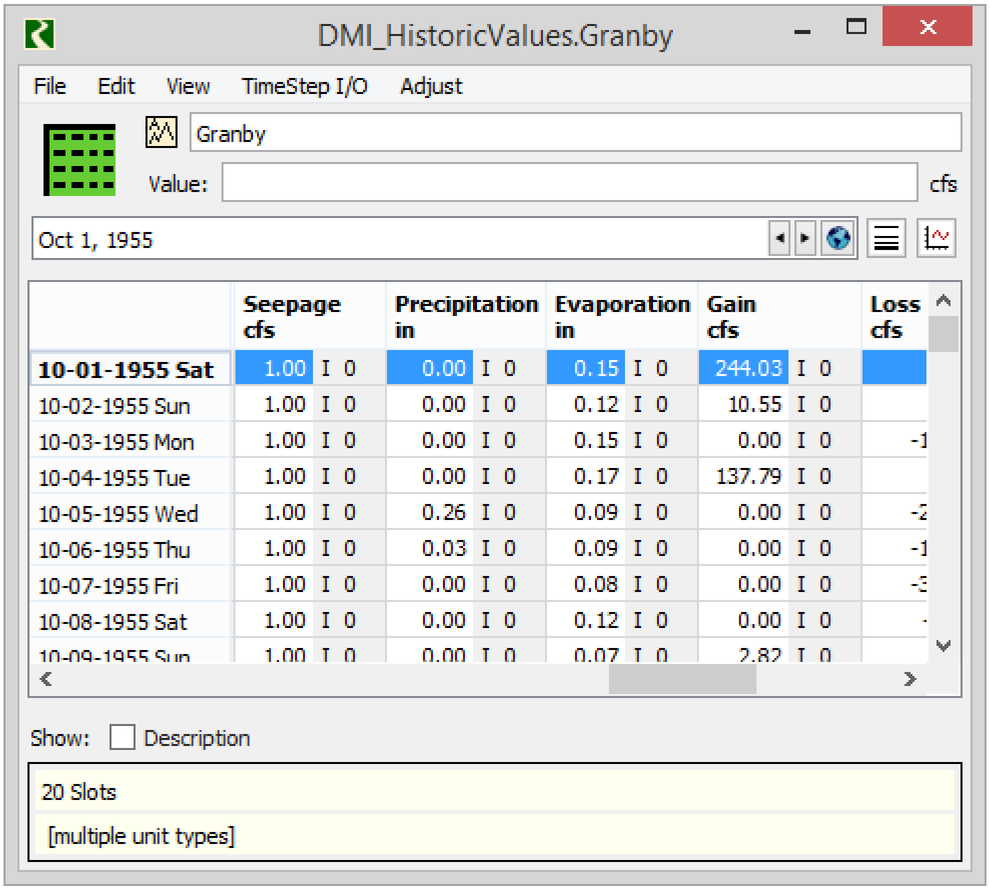


Figure 8: Granby historic Precipitation and Evaporation values, not currently used in the simulation

- If using the values from the DMI_HistoricValues.Granby slot directly, and if they already incorporate the Pan Coefficient, the Input Evaporation method would be okay. The values would simply need to be transferred over to the input slots for the Evaporation and Precipitation method using initialization rules, similar to other historical inputs.
- Hydrologic Inflow
- For the Hydrologic Inflow category, the Input Hydrologic Inflow method could be used instead of Hydrologic Inflow and Loss. Hydrologic Inflow and Loss is intended for use when negative Inflows are changed to zero, and the negative value is shifted to Hydrologic Inflow Adjust. The Input Hydrologic Inflow method will still allow for negative input values on the Hydrologic Inflow slot, which is necessary for the use of the Hydrologic Inflow slot for mass balance closure.
- Mass balance closure is being applied through Hydrologic Inflow. It appears that these mass balance closure values are those that were calculated from the Hydros data (DMI_HistoricValues.Granby.MBClosure). However, not every flow in and out in the mass balance closure calculation is incorporated on the reservoir object for simulation (e.g. Evaporation). In other words, the mass balance closure inputs applied as Hydrologic Inflow are not consistent with the other inputs on the reservoir object.
- The Hydrologic Inflow data shows a high level of variability with significant “spikes” in the data, both positive and negative (Figure 9). We recommend investigating the reason for these spikes, and to ascertain whether they point to any systematic biases or errors in input data, or whether they can be justified by natural system cycles. While making mass-balance

work through the Hydrologic Inflow variable ensures that the RiverWare model works, it does not guarantee that other models which rely on RiverWare flow values—such as a water quality model—work correctly. In particular, it is unclear what the boundary conditions of the "hydrologic inflow" should be in terms of water temperature, turbidity, and other important variables.

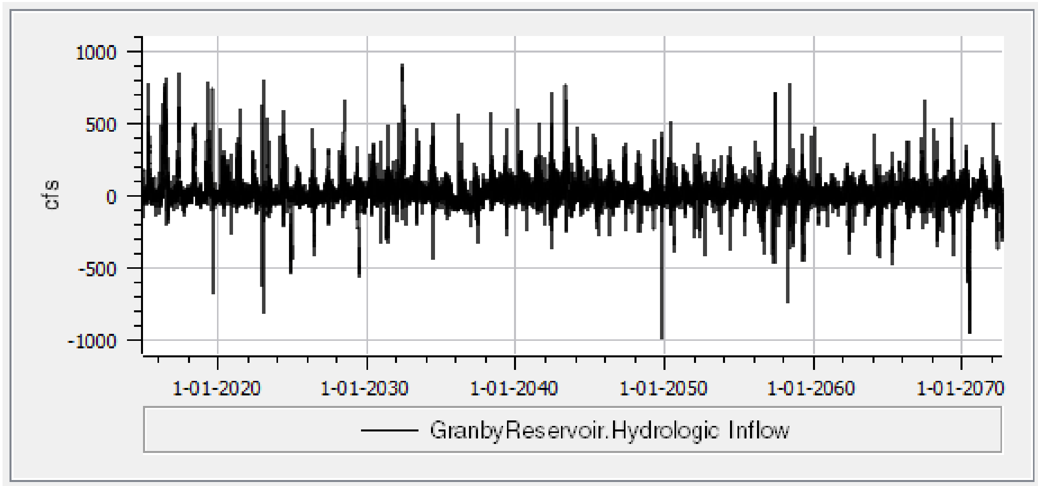


Figure 9: Granby Hydrologic Inflow

- In some cases, this Hydrologic Inflow correction is the dominating component of the total Inflow, particularly during low flow periods when water quality conditions might be at their most critical. For example, see the -683 cfs Hydrologic Inflow on September 1, 2019 shown in Figure 10. Again, we reiterate that the water quality parameters assigned to the "Hydrologic Inflow" condition are potentially ambiguous, but may drive water quality results when the "Hydrologic Inflow" is a dominant part of the water balance. For example, the water temperature assigned to this flow may be very different depending on whether the source of the flow is river flow, groundwater or precipitation. For this reason, we recommend (a) making sure that all physical processes are included in the model; (b) re-checking input data and improving imputation, where necessary, and (c) identifying time periods in which "Hydrologic Inflow" dominates over other parts of the mass-balance, and determining whether these are anomalies that are due to data issues or whether there are persistent issues that can be identified or fixed.

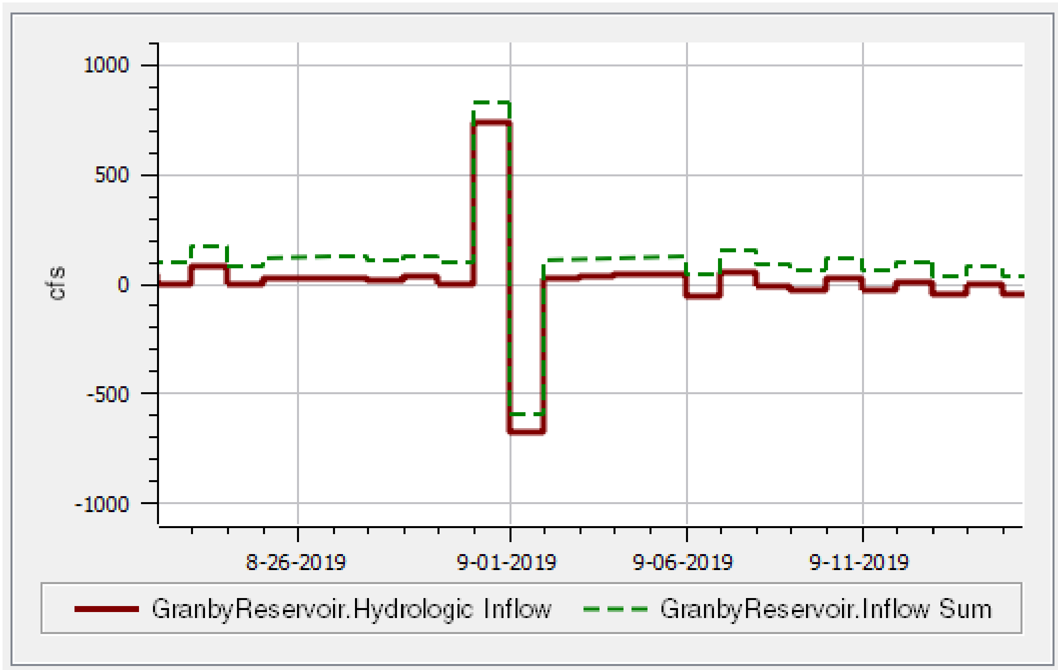


Figure 10: Granby Hydrologic Inflow and Inflow Sum (total inflow) showing Hydrologic Inflow as the dominating component of the total inflow on two timesteps

  - In addition, there are a number of cases in which a large Hydrologic Inflow on one day is followed by a correspondingly large negative Hydrologic Inflow on the following day, or a large negative followed by a large positive (see August 31, 2019 and September 1, 2019 in Figure 10). The origin of these spikes should be investigated, as possible, and if justified, these large spikes in Hydrologic Inflow should be smoothed to prevent potential issues in the water quality model.
- Seepage
  - There are no seepage inputs in the model (i.e., Seepage is always zero); the documents suggest that seepage should be accounted for. The reviewers recognize that the omission of seepage may be an intentional choice by Reclamation modelers. We recommend that the basis for the method selection and the source of the input data be documented.
  - The source of Seepage data in DMI_HistoricValues should be documented. These values are not applied on the reservoir object.
- Max Release: The Granby.Max Release slot has the same Max Release values for all Pool Elevations. This is probably not true physically, but this should not matter for overall mass balance calculations. It only changes the distribution of water between Release and (physical) Spill.

3.3.5.3 <u>Shadow Mountain</u>

Many of the comments and detailed recommendations made for Granby Reservoir also pertain to Shadow Mountain Reservoir. The following are succinct comments on the Shadow Mountain reservoir object (see Granby Reservoir for full discussion):

- Evaporation and Precipitation

- The Daily Evaporation method is selected. This uses data with an annual repeating period. It does not use the daily values referenced by Hydros, and it does not use a pan coefficient (the Pan Evaporation Coefficient slot is currently set to 1). The reviewers recognize that the deviations from the Hydros values and the method selection may be intentional changes to the model made by Reclamation modelers, and the additional comments regarding the Evaporation and Precipitation method and inputs should be read with that understanding. These parameters affect the overall mass balance, and thus, they should be checked by Reclamation modelers for correctness to verify whether the deviations are intentional. We also recommend that the basis for the method selection and the source of the input data be documented.
- Based on the analysis and data provided by Hydros, the Pan and Ice method would be more appropriate.
- Hydros also produced precipitation data that are not currently used in the model. (Precipitation is always zero in the model.)
- There are daily precipitation rate values stored in the DMI_HistoricValues.ShadowMtn slot (are these the Hydros values?), but Evaporation and Precipitation should be explicit rates (in/day), not length (in). It is not clear if the evaporation values in this slot are raw pan evaporation or if they are the values applying the pan coefficient.
- If using the values from the DMI_HistoricValues.ShadowMtn slot directly, and if they already incorporate the Pan Coefficient, the Input Evaporation method would be okay. The values would simply need to be transferred over to the input slots for the Evaporation and Precipitation method using initialization rules, similar to other historical inputs.

- Hydrologic Inflow
  - For the Hydrologic Inflow category, the Input Hydrologic Inflow method could be used instead of Hydrologic Inflow and Loss. Hydrologic Inflow and Loss is intended for use when negative Inflows are changed to zero, and the negative value is shifted to Hydrologic Inflow Adjust. The Input Hydrologic Inflow method will still allow for negative input values on the Hydrologic Inflow slot, which is necessary for the use of the Hydrologic Inflow slot for mass balance closure.
  - Mass balance closure is being applied through Hydrologic Inflow. It appears that these mass balance closure values are those that were calculated from the Hydros data (DMI_HistoricValues.ShadowMtn.MBClosure). However, not every flow in and out in the mass balance closure calculation is incorporated on the reservoir object for simulation (e.g., Evaporation). In other words, the mass balance closure inputs applied as Hydrologic Inflow are not consistent with the other inputs on the reservoir object.
  - Shadow Mountain also includes cases of significant negative Hydrologic Inflows, similar to those described for Granby. These should be further evaluated for correctness and smoothed, if justified. See Granby reservoir comments for reasons why it is desirable to minimize “hydrologic inflows” for a water quality model.

3.3.5.4 Grand Lake

Following are comments on the Grand Lake reservoir object (again, see Granby Lake section for full discussion):

- In one case, GrandLake.Outflow is negative (Figure 11; 12/1/2043). Rules 33 and 34 should be revised to prevent this (see comments in the Rulebased Simulation Rules section).

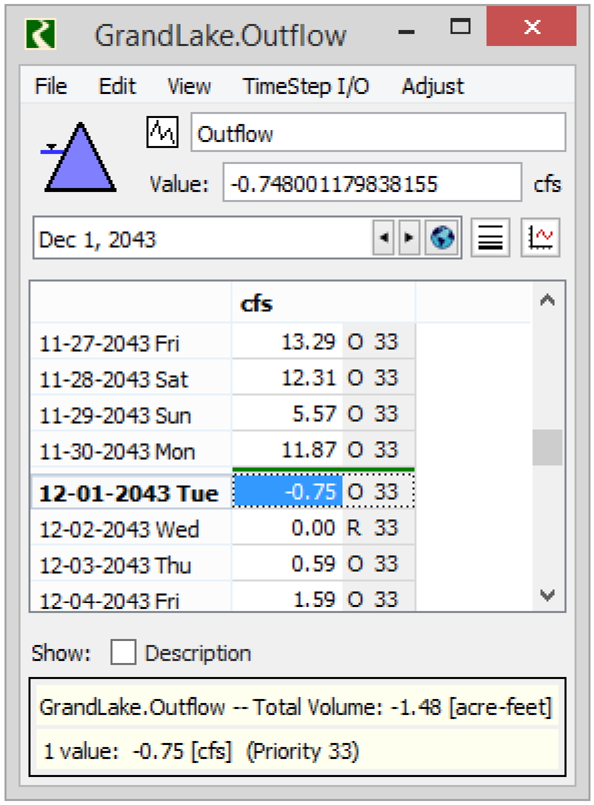


Figure 11: Grand Lake negative Outflow on December 1, 2043

- Evaporation and Precipitation
  - The Daily Evaporation method is selected. This uses data with an annual repeating period. It does not use the daily values referenced by Hydros, and it does not use a pan coefficient (the Pan Evaporation Coefficient slot is currently set to 1). The reviewers recognize that the deviations from the Hydros values and the method selection may be intentional changes to the model made by Reclamation modelers, and the additional comments regarding the Evaporation and Precipitation method and inputs should be read with that understanding. These parameters affect the overall mass balance, and thus, they should be checked by Reclamation modelers for correctness to verify whether the deviations are intentional. We also recommend that the basis for the method selection and the source of the input data be documented.
  - Based on the analysis and data provided by Hydros, the Pan and Ice method would be more appropriate.
  - Hydros also produced precipitation data that are not currently used in the model. (Precipitation is always zero in the model.)
  - There are daily precipitation rate values are stored in the DMI_HistoricValues.GrandLake slot (are these the Hydros values?), but Evaporation and Precipitation should be explicit rates (in/day), not length (in). It is not clear if the evaporation values in this slot are raw pan evaporation or if they are the values applying the pan coefficient.

    - If using the values in the DMI_HistoricValues.GrandLake slot directly, and if they already incorporate the Pan Coefficient, the Input Evaporation method would be okay. The values would simply need to be transferred over to the input slots for the Evaporation and Precipitation method using initialization rules, similar to other historical inputs.
- Hydrologic Inflow
    - For the Hydrologic Inflow category, the Input Hydrologic Inflow method could be used instead of Hydrologic Inflow and Loss. Hydrologic Inflow and Loss is intended for use when negative Inflows are changed to zero, and the negative value is shifted to Hydrologic Inflow Adjust. The Input Hydrologic Inflow method will still allow for negative input values on the Hydrologic Inflow slot, which is necessary for the use of the Hydrologic Inflow slot for mass balance closure.
    - Mass balance closure is being applied through Hydrologic Inflow. It appears that these mass balance closure values are those that were calculated from the Hydros data (DMI_HistoricValues.GrandLake.MBClosure). However, not every flow in and out in the mass balance closure calculation is incorporated on the reservoir object for simulation (e.g. Evaporation). In other words, the mass balance closure inputs applied as Hydrologic Inflow are not consistent with the other inputs on the reservoir object.
    - Grand Lake also includes cases of significant negative Hydrologic Inflows, similar to those described for Granby. These should be smoothed or should be further evaluated for correctness.

3.3.5.5 Carter Lake Deliveries

Following are comments on the agg diversion site “Carter Lake Deliveries”.

Windy Gap placement is above CBT in the sequential structure. This is inconsistent with the other Agg Diversion sites, which have CBT first. This changes their relative priorities for use of the water when there is a shortage (see Figure 12).

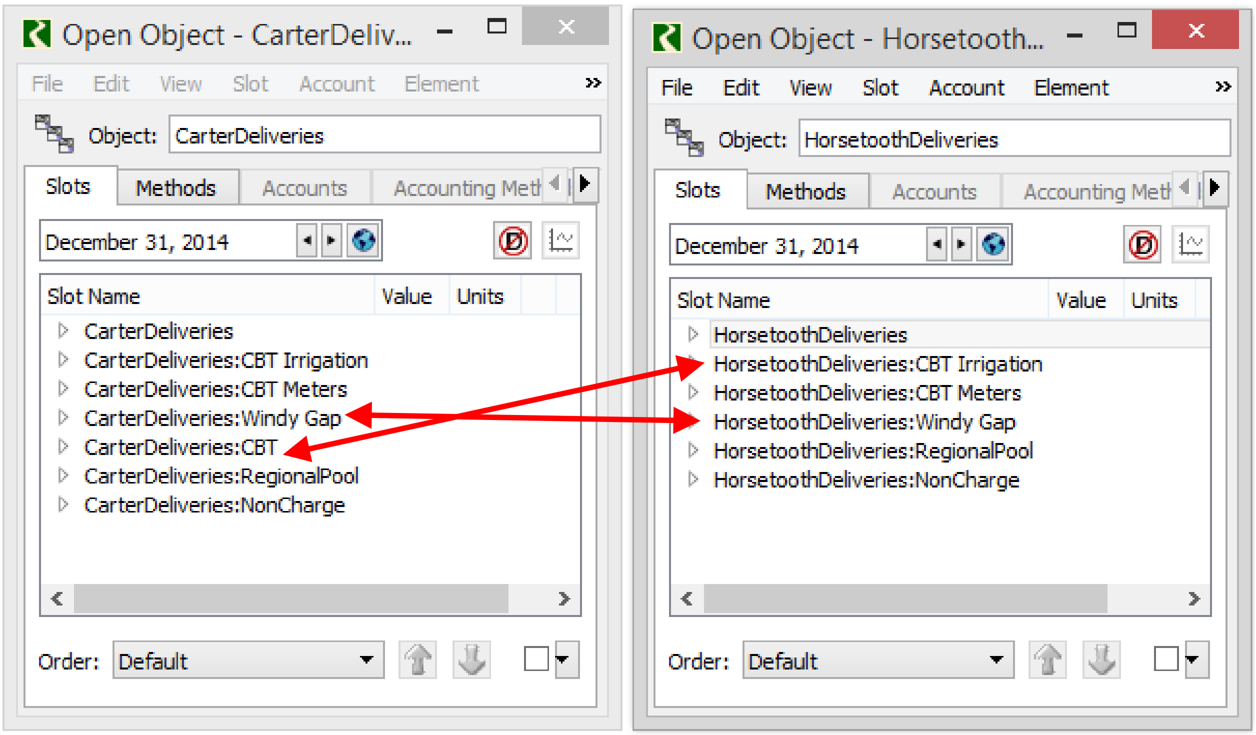


Figure 12: CarterDeliveries agg diversion site with Windy Gap water user at a higher priority than CBT (note that on the Carter Deliveries agg diversion site, the CBT water user is used, not CBT Irrigation)

3.3.5.6 Unit3Generator (Carter Lake)

Following are comments on the Unit3Geneartor below Carter Lake.

The empirical equation used to calculate power in a rule (12), could be replaced by making Carter Lake a Level Power Reservoir and using the Plant Efficiency Curve power method. In general, we recommend using the objects to model the physical processes whenever possible rather than writing the calculations for physical processes into rule logic.

3.3.5.7 Above Flatiron

The diversions for the AboveFlatiron Agg Diversion Site come off of MarysLake a significant distance upstream from Flatiron. Do these need to be distributed more? This may be okay since it is only 3-5 cfs, when powerplant flows are 500 cfs.

MarysLake.Flow TO Pumped Storage is linked to AboveFlatiron.Total Diversion. Link MarysLake Diversion instead.

3.3.5.8 Chimney Hollow

This object is not making deliveries (Diversion and Outflow are always 0), but it is losing water to seepage and evaporation (190,000 ac-ft). This object is likely a placeholder but cannot be fully evaluated at this time, as it is not modeling actual operations. It should be determined whether it is appropriate for this planned reservoir to be included in the planning model. If it is included, perhaps there should be an option to disable the modeling of Chimney Hollow.

3.3.5.9 MBTest Objects

The set of 5 MBTest objects, shown in Figure 13, are useful for testing for mass balance closure during calibration or testing of model revisions. Once satisfied with the hydrology and model revisions, these objects can be removed from the final planning model. They can be exported and re-imported as necessary to test future model revisions.

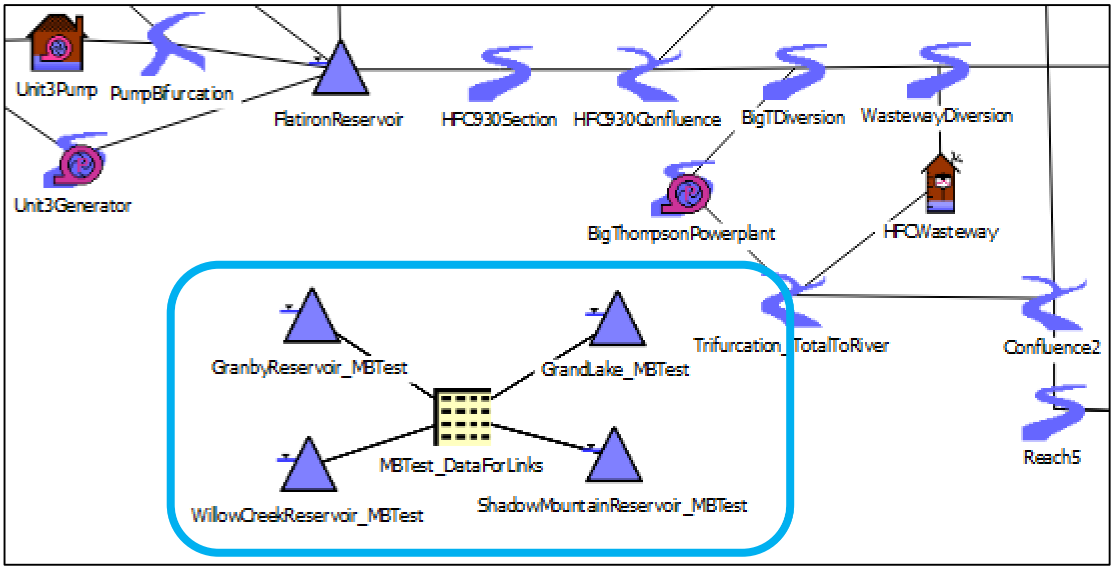


Figure 13: MBTest object

- The MassBal Slot has no Water Balances in it. This should be improved or removed.
- MBTest_DataForLinks.GranbyReservoir slot only has data in one column. Is intended data missing from the other columns?

3.3.5.10 <u>Daily Input Data</u>

Within the slot Daily Input Data.Inflows, the description appears to be out of date (Figure 14).

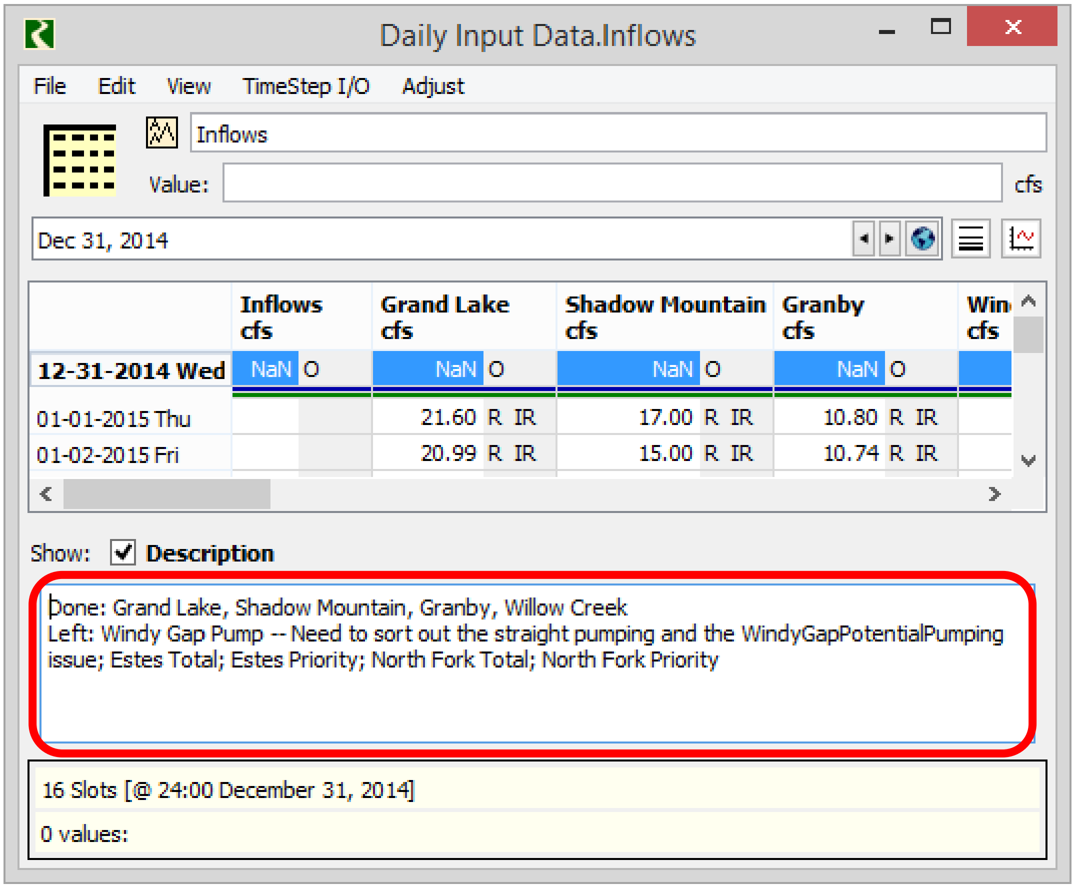


Figure 14: Daily Input Data.Inflows slot description, out of date

3.4 Operating Policy and Logic

This section reviews the operating policy and how it is implemented in the RiverWare Policy Language (RPL). First we describe the general comments, then discuss initialization rules and then rule-based simulation rules.

3.4.1 General Comments on RPL Logic and Setup

In general, the rules and RPL logic is understandable and reasonable. Following are a few minor comments on consistency:

- There is much duplication of calculations and many of the same values are set in different locations by different rules. Some of this could be consolidated to assure consistency (e.g., Windy Gap Accounting).
- There are some functions used by both the initialization rules and the rule-based simulation rules. There is the possibility to use a global functions set to prevent duplicating of functions; this would prevent inconsistencies.
- Rule names are consistent and have a reasonable naming convention.

- Function Names are reasonable. No spaces are used, which is consistent with predefined functions.

3.4.2 Comments on Initialization Rules

Many of the initialization rules have numerous assignments explicitly defined, but then rule 1 uses a FOR loop over a list of locations. Make all the initialization rules consistent in how they set values on different slots. Using FOR loops could eliminate much repeated logic in many of the rules. Use subbasins, slot groups, ColumnLabels or lists to show which locations are in use. In addition, there are many disabled assignments in the set. Delete these or better document why the assignments are disabled.

Following are comments on specific initialization rules in the order of execution, from lowest index to highest.

Rule 20: DMI_DailyInputValues—FewValuesFromExcel – The listed comment about deactivating one assignment appears to be outdated

Rule 16: DMI_HistoricalValues_for_MBTest_WC_SM_GL – This rule sets many slots on the MBTest objects. Add in more comments to make it easier to read this rule.

Rule 11: Historic Period Sums – This logic could be made more efficient and simpler (along with Target Setting RBS policy group). It works as is though.

Rule 10: Initialize Account Values –Rule 10 is empty. It should be deleted if it is not used.

Rule 8: Set Misc –This rule sets MarysPowerplant.Min Byass to -1 cfs. The physical minimum Bypass flow should be 0 cfs. If there is an exception that requires a negative minimum, it should be noted in a comment in the rule or in the rule Description field.

Rule 6: DMI_DailyInputValues_GranbyMinimumRequiredFlows – This rule calls the function **GranbyMinimumRequiredFlow,** which has a lot of data values entered explicitly in it (thresholds and parameter values, see Figure 15). These values should be moved onto a slot(s). They should not be written explicitly in the rule. In addition, it calls the **ForecastInflowVolume_forGranbyMinReduction** function. Within this function the 2,100 acre-feet value should also be in a slot.

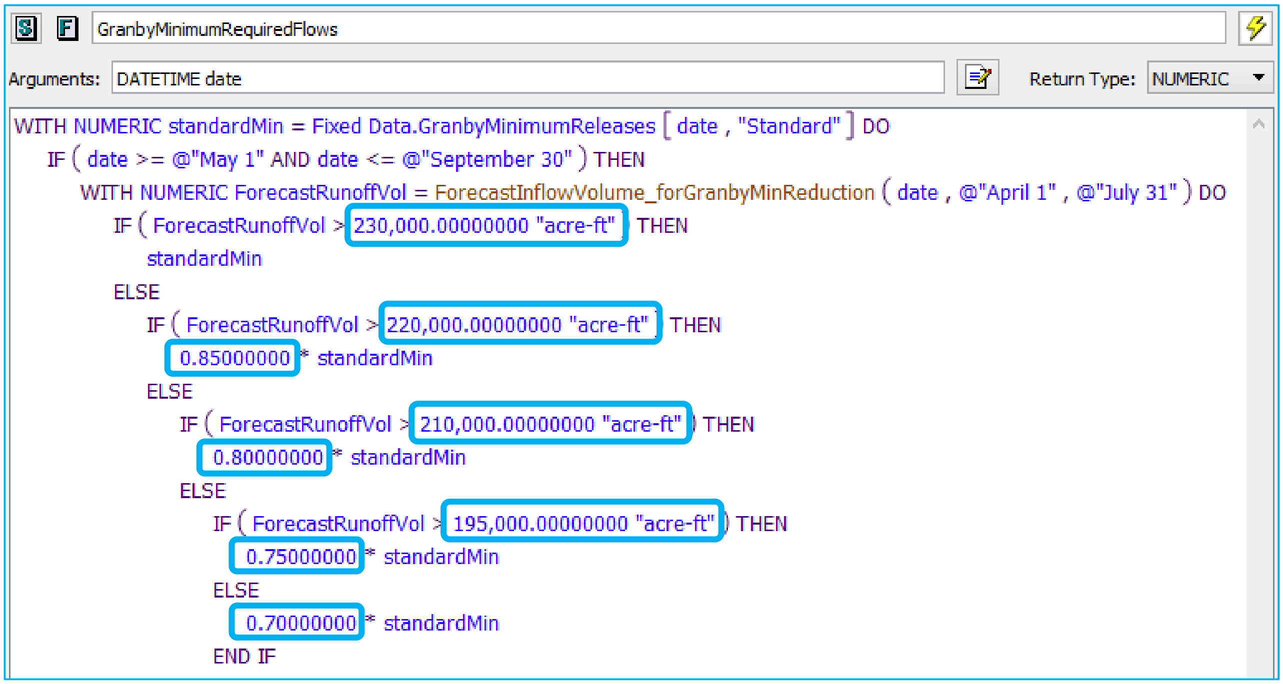


Figure 15: GranbyMinimumRequiredFlows function with explicit parameter values that should be changed to slot references

Rule 3: Set Initial East Slope Supplies – Use a WITH statement to calculate the value once and prevent inconsistencies if it changes.

Rules 2, 5, 15: These rules are disabled. They appear to be "Old" rules, no longer used, but they should be documented or deleted if no longer needed.

3.4.3 RULE-BASED SIMULATION RULES

The rule-based simulation ruleset contains the rules that are executed on each time step in a specific order. Following are general comments on this set:

- The file name of the provided ruleset is "**CBTPOM_v2.0.rls**" while the name in the RPL set is "**50 year CPTPOM_v0.33.**" These should be consistent (Figure 16).

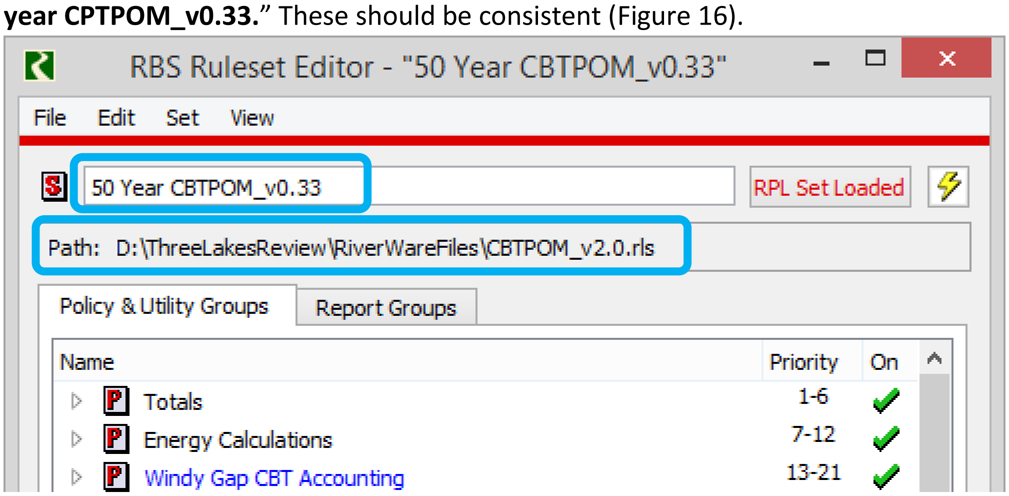


Figure 16: Ruleset with inconsistent names

- Precision for the ruleset is set to 8 (Figure 17). Reducing the precision to 2 would improve the look of the logic. (It would not change any underlying values.)

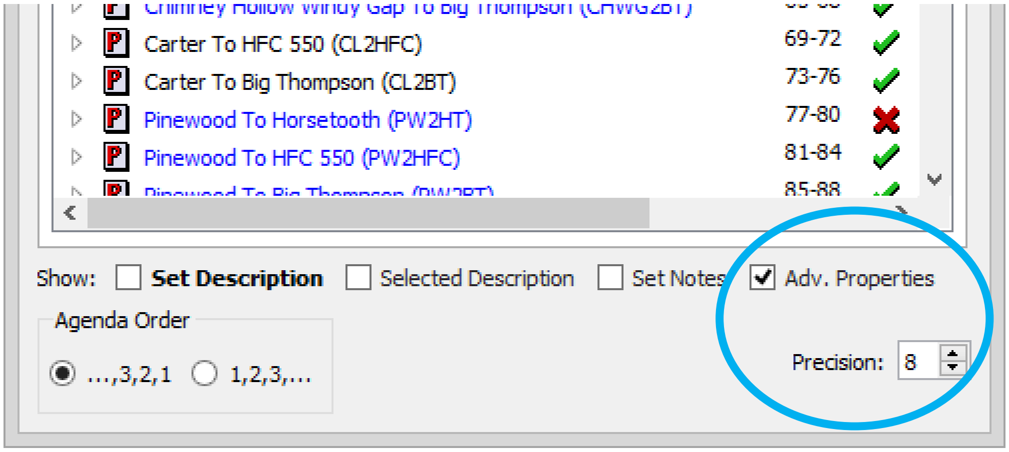


Figure 17: Ruleset precision currently set to 8

- Some rules and groups are colored blue as shown above. Presumably, these were the ones added or edited by PWRE. This should be documented or the colors should be changed to something more meaningful.

3.4.3.1 Functionality

The rules in this model are essentially an allocation of the water from the west to the east slope. The rules are structured in a way that is different than many RiverWare rulesets. The traditional way to set up a ruleset is that a rule sets a decision variable on a Simulation slot and then the system dispatches to propagate the solution throughout the system. Then the next rule on the agenda executes and sets decision variables causing the solution to propagate. The process continues, often upstream to downstream, until all rules have fired and the system has solved. In this model, each reservoir Outflow, diversion, and simulation slot is set by only one rule; these are rules 28-33 for the West slope and Rule 36 for the East Slope. But before these rules execute, there are many other rules that determine how the water should be moved through the system. These rules set values on custom slots and update those custom slots many times. In effect, these custom slots are doing a homemade allocation and distribution, which could even be called an accounting of the water. The rule ordering proceeds as follows:

1. Compute reservoir targets (Low priority rules)
2. Compute maximum available supply
3. For each East Slope source to a destination, four rules execute as follows:
   - **Source to Demand Flow**: Determine the amount of water that can be delivered to the destination from the source, based on the remaining demand at the destination, the conveyance capacity between the reservoirs, and the remaining supply of water in the source.
   - **Facility Flow**: Set the facility flows (outflow, bypass, diversion, canal flow) between the source and the destination as a result of satisfying destination demand from the source. Flows are set on the East Slope.Facility Flows agg series slot.
   - **Remaining Supply**: Update the remaining source supply based on the water delivered the destination. Supply is set on the East Slope.Remaining Supply agg series slot.
   - **Remaining Demand**: Update the remaining demand at the destination after the delivery of water from this source. Flows are set on the East Slope.Remaining Demand agg series slot.

4. Do skim calculation
5. Set Facility Flows on the East Slope
6. Set Facility Flows on the West Slope
   - Set Grand Lake Diversion
   - Set slots to move water to Grand Lake and set reservoir outflows
7. Execute Windy Gap Calculations and Accounting (High Priority rules)

This structure is adequate, it just does not make use of RiverWare's alternating solution between rules and simulation. In fact, it is quite an ingenious solution to a very complex problem.

3.4.3.2 Accounting

Our initial comment was: "Why not use RiverWare Accounting instead of home grown accounts?" We see now that RiverWare's accounting would not have directly worked with this layout. It would have required enhancements, but those enhancements would have been beneficial to this model and other similar models. The implemented system does produce the correct results; using RiverWare accounting (with enhancements) would be more elegant and easier to track.

3.4.3.3 Specifics on RBS Rules

Following are comments on specific rules:

Rule 200: Red Top Stillwater Diversion – It is not clear why the Seepage Flow Fraction is not applied on Stillwater Diversion Request like it is for North Fork (Rule 199).

Rule 198: Red Top Supply Creek Local Inflow – This rule references a slot that is not currently visible, Red Top Ditch 3.Lag Coeff, from a different routing method than the one currently selected on the Red Top Ditch 3 reach object. Perhaps the rule intends to reference Red Top Ditch 5.Lag Coeff. This slot reference should be corrected to be consistent with the selected routing method.

Rule 197: Target Dates – This rule sets datetime values in HorsetoothYearType_CalcValues.Target Date slot. We agree with the description in rule that the logic could be simplified with the use of periodic slots for the Target Parameters. All of this target setting logic could be in initialization rules.

Rule 195: Target Sum Period Volumes – If the target sum period is outside of the run period, it uses the previous year sums. This is fine if the previous year had similar conditions, but it might not be the most appropriate inflow estimate to use. It would be better to extend the inflow data out through the next target sum period or to end the run horizon once year earlier so that inflow data is available for the final year's target sum period. However, this is unlikely to have a significant impact on overall model results. Also, a FOR loop over the reservoirs could be used to simplify the rule by only writing the logic once for all three reservoirs.

Rule 192 Target Setting – This is the same logic repeated three times. Use a FOR loop.

Rule 191 – The final IF condition checks if the current timestep is January 1. Use @t == Jan 1 instead of GetDayOfYear(@t) ==1.0. The former is easier to read than the latter.

Rule 188: Override Facility Availability – Put storage thresholds for shutting off Carter pump into slots, not in the rule (Figure 18).

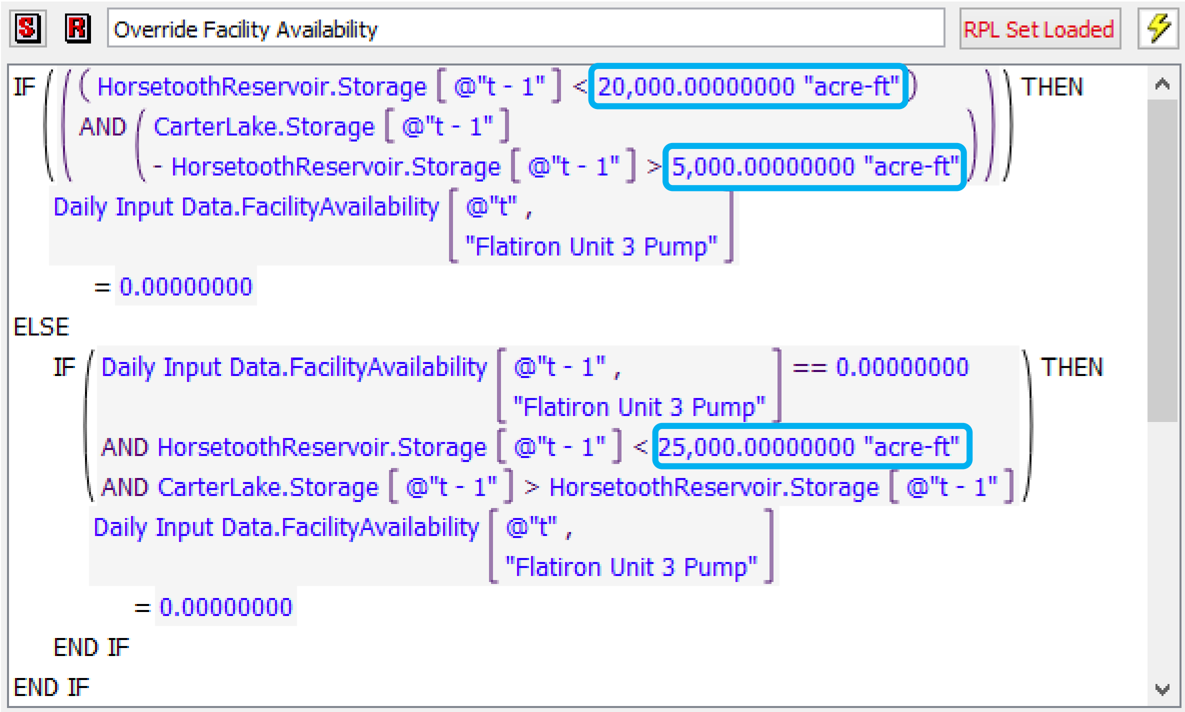


Figure 18: Override Facility Availability rule (188) with explicit parameter values that should be changed to slot references

Rule 186: Initial East Slope Supplies – The reasoning for the StorageToArea term for Carter is not clear. It appears that it is possibly intended as a buffer. If so, that should be noted in a comment or in the rule Description field (see Figure 19).

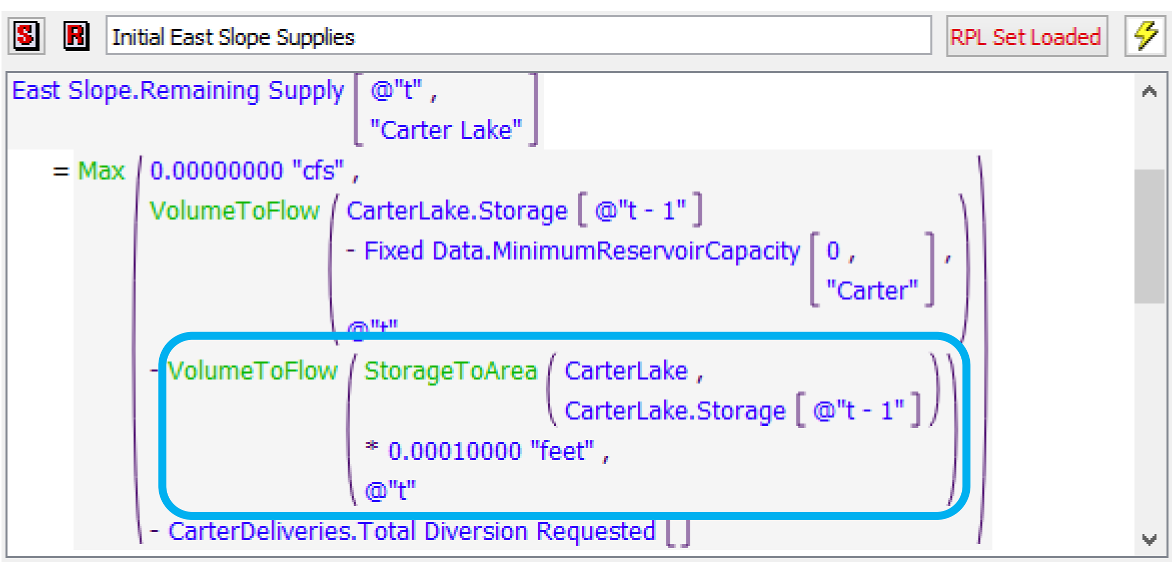


Figure 19: Initial East Slope Supplies rule (186)

Rule 185: Set Initial West Slope Maximum Supplies – In the **EstimateTargetEvaporation** function (Figure 20), Storage[t-1] alone would be a better estimate for calculating evaporation at t than using the average with the target storage at t, especially for Granby where the storage can deviate significantly from the target (the description in the rule acknowledges this potential issue).

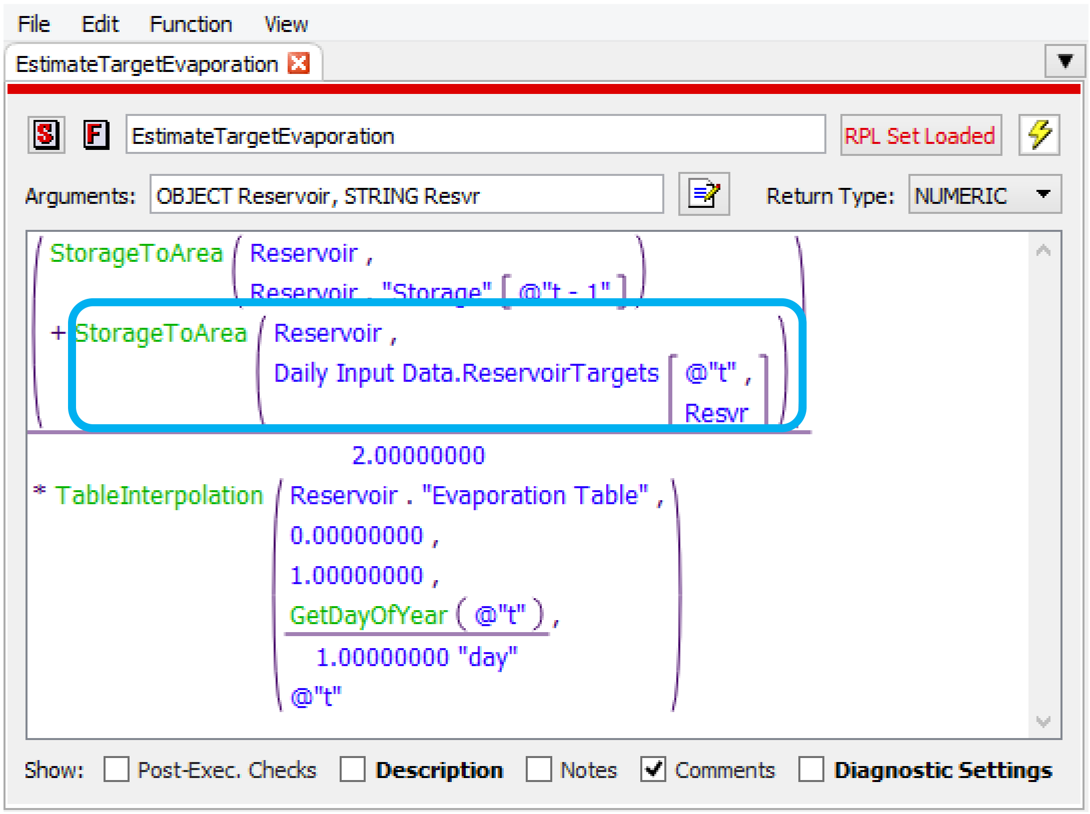


Figure 20: EstimateTargetEvaporation function

Also, Granby does not consider any of the flows from Red Top Ditch. It appears that this rule has not been updated since the addition of the Red Top Ditch objects in the model. The rule assumes that all Red Top Ditch flow is actually coming in through Shadow Mountain (North Fork Inflow). This rule should be updated to correspond to current modeling of Red Top Ditch.

Rule 184: Initialize Diversion Requested and Depletion Requested – This would be more appropriate as an initialization rule.

Rule 183: Initialize East Slope Remaining Demands – Add an execution constraint to only execute once (HasRuleFiredSuccessfully(“ThisRule”)). This would provide a moderate run time improvement.

Rule 182: Windy Gap Pumping Accounting – The logic calculates CurrentYearMiddleParkVolume but never uses the value. The logic of this rule should be reviewed to make sure it was not an oversight. If the value is intentionally unused, then the calculation could be deleted from the rule. It appears that the CurrentYearMiddleParkVolume calculated should be the same as the Accounts.MiddleParkAccrual.

Source to Demand Flow Rules: All of these rules should have a check to prevent negative flows. Dille Tunnel has a -12.5 cfs flow (from rule 144 NF to BT via Dille). The negative value is due to a case that the initial NF Priority is less than the Estes Priority. These Priority values are set by initialization rules 3 and 7. (See comment on rule 44)

Facility Flow Rules: Add an execution constraint to only execute once (HasRuleFiredSuccessfully(“ThisRule”)). This will reduce run time significantly (by more than half). This should also be done for the Remaining Supply and Remaining Demand rules, but there will be a smaller impact on run time with these. These rules will never be able to set a value a second time due to priorities. Also due to the way the rules are formulated, with cumulative calculations, the value they would set a second time would be incorrect. They are currently re-executing many times and calculating many values without setting slots. See section below on performance.

Rule 108: Source to Demand Flow—AT2CLU3 (and similar rules) – The EstimateFutureGranbyStorage function does not include any outflow or diversion in the estimate. This is somewhat conservative, and it might be okay for the purposes of this rule. It means that water might be diverted from Granby to the East Slope in some cases that it is not actually necessary (or earlier than necessary) because it overestimates the Granby Storage.

After **Rule 97: Remaining Demand—AT2PW** – Rules could update the Remaining Supply in Pinewood to account for the water just added, unless you only want to consider water present on the previous day as available for supply. This is also true for other East Slope transfers (e.g. Carter to Horsetooth). In general the rules have an implicit assumption that water delivered to a reservoir on a given day is not available as a supply from that reservoir until the following day.

Rule 77: Remaining Demand—PW2HT – This rule is currently disabled, but it would need to be revised to match other Remaining Demand rules for Horsetooth in order to use it.

Rule 44: Source to Demand Flow—Dille Skim – This rule results in negative flows in Dille Tunnel (look at multiple days in 12/2020 for examples; see Figure 21). While rule 44 sets the final value for Dille Tunnel, the negative flow initially comes from Rule 144: NF Priority to BT via Dille. The cause of the negative flows can be traced back to a North Fork Priority value that is less than the Estes Priority value. These values are set by initialization rules 3 and 7.

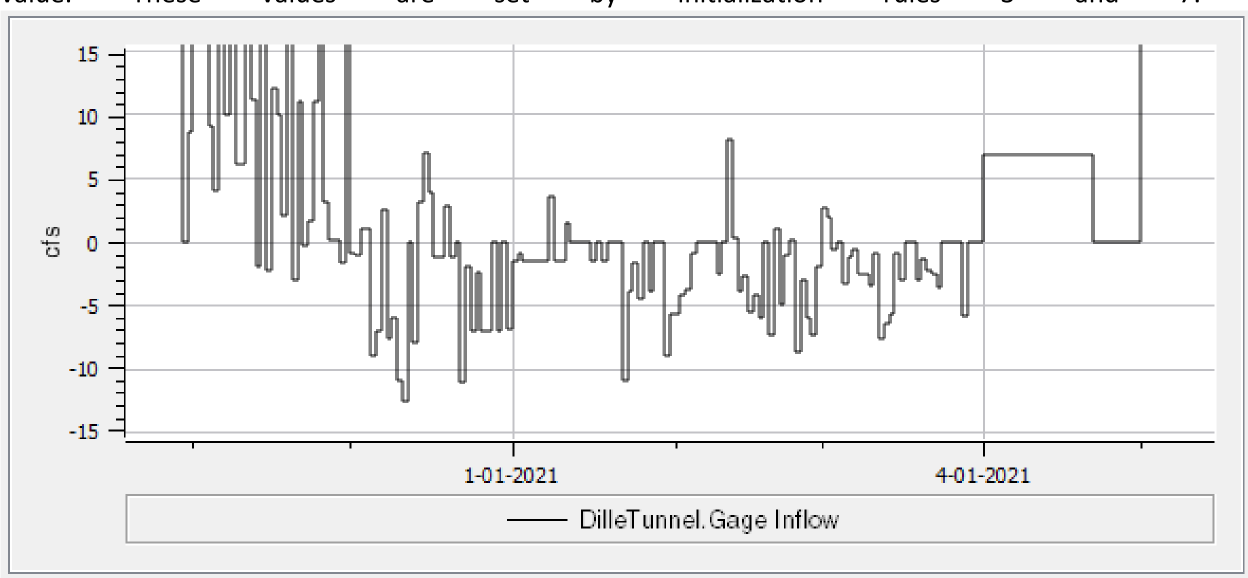


Figure 21: Negative flows at Dille Tunnel

Rule 43: Facility Flow Using Dille Skim – It looks like this rule should also update the Facility Flow for HFC Wasteway (UpdateBypassFlow(HFC Wasteway, Big Thompson Powerplant, Dille Skim))

Rule 42: Source to Demand Flow—AT2CH – The logic indicates that you cannot fill and withdraw from Chimney Hollow at the same time. Is this correct? I.e. on a given day, water can go either into or out of Chimney Hollow, not both.

Rule 41: Facility Flow—AT2CH – In the ELSE condition, it needs to update Flatiron Bypass and Flatiron

Powerplant flows too. Currently it only updates Flatiron Powerplant Total).

Rule 37: Deliveries From All Sources – This rule is missing Chimney Hollow Windy Gap to Big Thompson when adding up all Big Thompson deliveries, and it is missing Chimney Hollow Windy Gap to HFC 550 when adding up all HFC 550 deliveries.

Rule 36: East Slope Facility Flows – The assignment for Dille Diversion calculates the flow value in the rule. This value was already calculated and set in the Facility Flows slot, so it could be used directly instead of recalculating. Unit3Generator Bypass or Turbine Release needs to be set directly in this rule. The simulated values do not match the values in the Facility Flow slot because the object simulates assuming full capacity, but the Facility Flow values were calculated by rules that accounted for outages. See Figure 22.

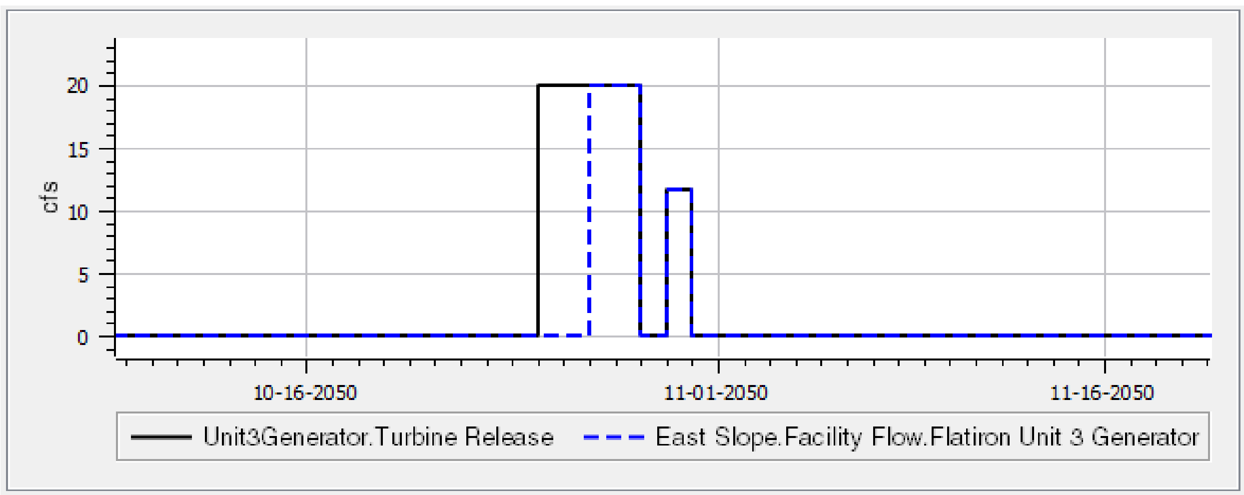


Figure 22: Unit 3 Generator Turbine Release with different values, simulated vs. calculated within a rule, October 25-26, 2050

Rule 35: Grand Lake Diversion – It would be better to set GrandLake Diversion equal to Adams Tunnel Gage Inflow (set by the previous rule). Even better would be to simply link Grand Lake Diversion and Adams Tunnel Gage Inflow. They should always match. This would guarantee consistency and would provide a better visual representation of the physical system.

Rule 34: Grand Lake Need – This rule does not look correct. It appears that the calculation for Grand Lake Need should be: Target[t] – Storage[t-1] + Adams Tunnel + Minimum Required Flow – Maximum Supply.

Rule 33: Shadow Mountain Diversion and Grand Lake Outflow or Storage – The assignment to Grand Lake Storage in the ELSE condition is okay if you know that no other rules will ever set Grand Lake slots. If there could be other rules that set slots on the Grand Lake object and cause Grand Lake to re-dispatch, then you should not set Grand Lake Storage. That assignment should be changed to set Grand Lake Outflow using the SolveOutflow function given the Storage Target. The formulation of the assignments in the true condition are okay as long as Grand Lake MinimumRequiredFlow is always zero. Otherwise you could potentially have both Grand Lake Outflow and Shadow Mountain Diversion be non-zero (flow in two directions in a single structure). This is actually covered by rule 179, which sets Shadow Mountain to Grand Lake available to 0 when the Grand Lake MinimumRequiredFlow is greater than 0, but it should at least be referenced by a comment in rule 33. The ELSE condition should also include a check for Grand Lake Minimum Required Flow. Otherwise you can (and do in one case) end up with a negative Outflow (12/1/2043, see Figure 23).

Rule 32: Shadow Mountain Need – see comments for Rule 34

Rule 31: Granby Diversion and Shadow Mountain Outflow or Storage – The Granby Diversion in the true condition should be set to Min(MaxAvailability, SMR Need + SMR MinimumRequiredFlow), or the Minimum Required Flow should be included in the Reservoir Need calculation. Also, see the comment on Rule 33 about setting Storage. The ELSE condition should include a check for Minimum Required Flow. Otherwise you can (and do on multiple occasions) end up with a negative Outflow (e.g. 5/4/2039; see Figure 23). This is another reason for setting Outflow instead of Storage.

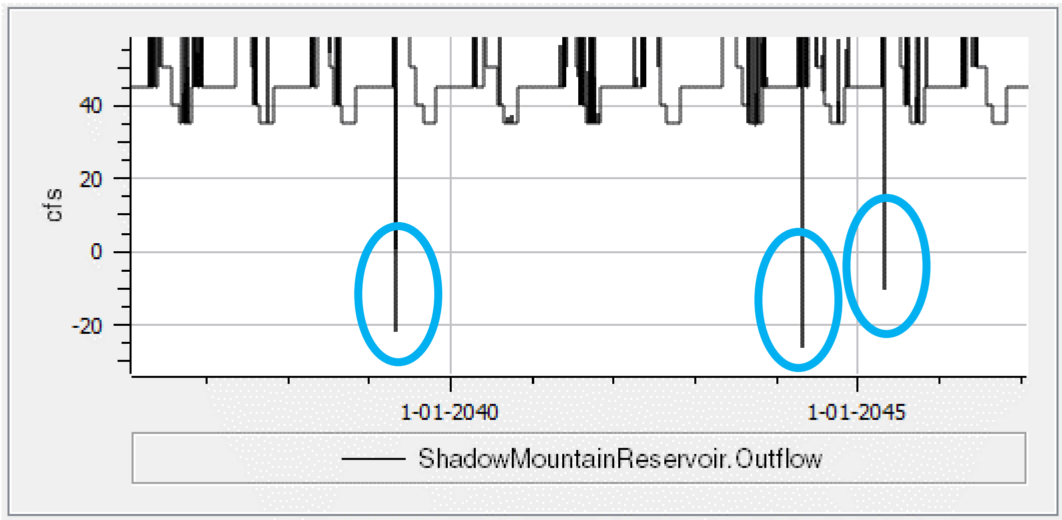


Figure 23: Shadow Moutain Outflow with occasional negative values

Rule 29: Willow Creek Need – See comments for Rule 34

Rule 28: Willow Creek Diversion and Outflow or Release – It is inconsistent to set Outflow in one case and Release in the other. If there is there a reason for this, it should be documented in a comment or the rule Description field. If there is not a reason, it would be better to be consistent and set Outflow in both cases. In the ELSE condition, it needs a check to prevent overfilling in the case that the canal does not have capacity. In the true condition, it needs a check to prevent emptying (going below the Elevation Volume table). It seems that Willow Creek should check for storage capacity in Granby before pumping. Otherwise you could pump to Granby and end up spilling it at the same time; although maybe this is the actual operation. Also, Willow Creek rules should execute before Granby rules. Willow Creek rules set one of the components of Granby Inflow, so Granby cannot solve until Willow Creek Diversion is set. They do this functionally already because the Granby rules re-execute after Willow Creek solves, but it would be more efficient if the rules were arranged so that Willow Creek executes first.

Rule 25: Windy Gap Loss – The calculation of Windy Gap Loss in this rule is inconsistent with Rule 19. Rule 19 excludes current calendar year pumping from the Rollover Charge on April 1 (but it looks like pumping from January 1 to March 31 is always zero, so maybe it does not matter), and it uses a different loss fee (5%). The loss used in this rule (10%) should be in a slot, not an explicit number in a rule. This would help prevent inconsistencies. Also, this rule does not account for all project fees, only pumping. Rules 13-21 provide an alternative accounting for Windy Gap and include additional project fees. It does not look like the values from this rule (Rule 19) get used in the solution. It is only for reporting, so maybe these differences do not matter.

Rule 23: Windy Gap Spill – The IFs are redundant. All that is needed is the second assignment. (Also see the comment on Rule 13 regarding inconsistencies in the calculation of Windy Gap Spill.)

Rule 22: Windy Gap Account – This calculation does not account for all of the project fees that are accounted for in rules 13-21, but it looks like the values from this rule never get used in the solution.

Rule 20: Account Physical Flows Update – In the IF condition, it could simply reference Granby.CalcSpill instead of recalculating whether there is "spill".

Rule 19: Rollover Charge – See comments for Rule 25 regarding inconsistencies in the two versions of Windy Gap accounting. Rule 19 is the rule that is actually used in the solution.

Rule 18: WG Delivery Accounting – Chimney Hollow Physical – This rule is okay as long ChimneyHollow Outflow is always only Windy Gap water. Otherwise the calculation of WGtoFlatiron would need to be revised to distinguish between Windy Gap and CBT water from Chimney Hollow to Flatiron.

Rule 17: WG Delivery Accounting – Granby Exchange > 0 – The **CBTExchangeCapacity** function is incorrect. It should divide by 1+ProjectUseCharge, not ProjectUseCharge (Figure 24).

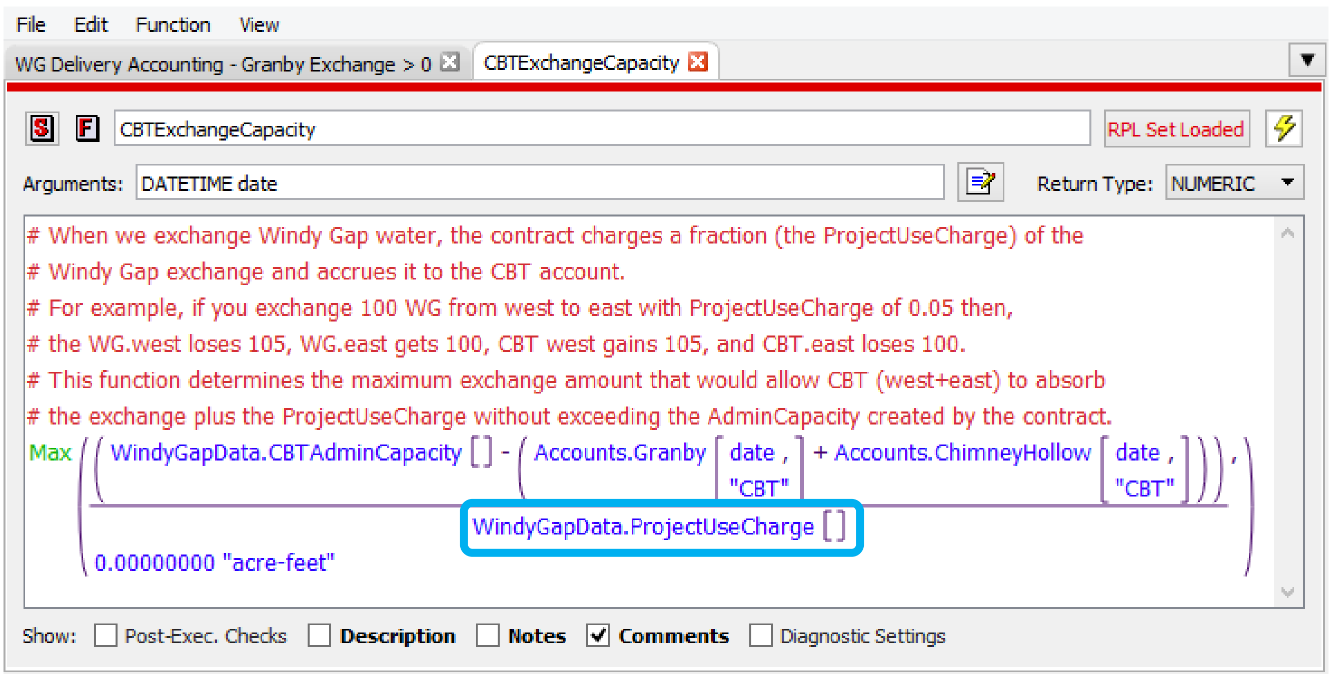


Figure 24: CBTExchangeCapacity function, divides by the incorrect value

Rule 15: WG Delivery Accounting – Granby Exchange < 0 – This rule calculates a negative project fee in some cases (e.g. see 6/2031. Figure 26). It is possible that the ProjectFee calculation needs a Max(Min(…), 0) check (see Figure 25). However it is not clear to us if there are real cases that the project fee should actually be negative.

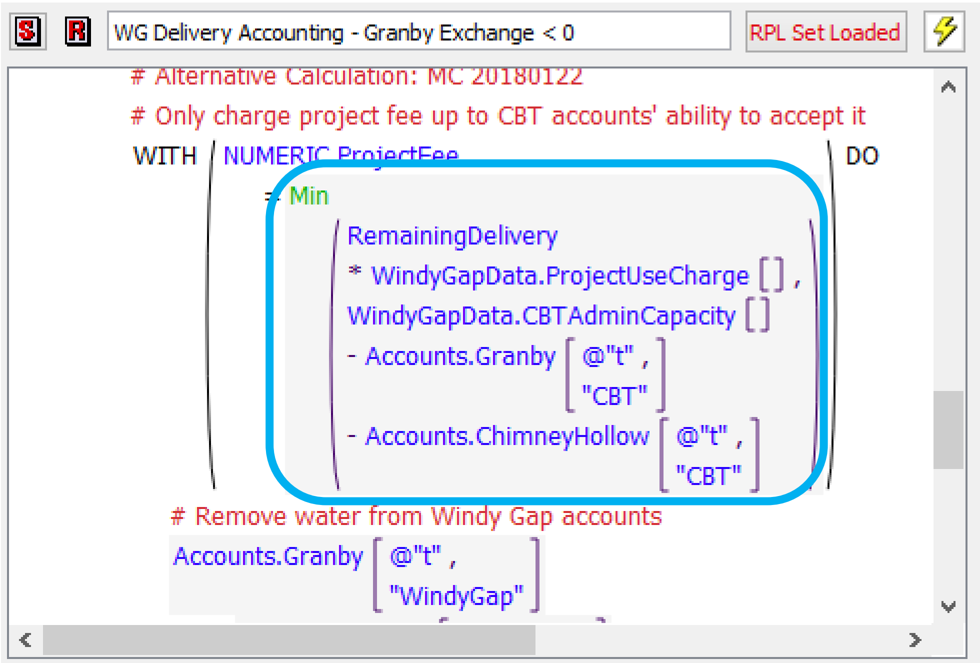


Figure 25: WG Delivery Account - Granby Exchange < 0 rule (15), possibly needs a check to prevent negative values

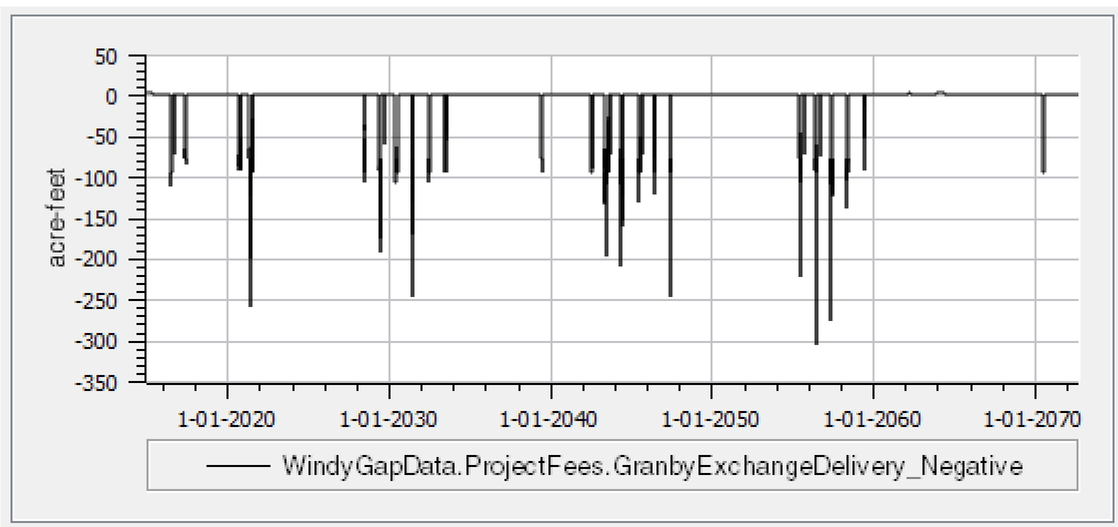


Figure 26: Project Fee for Granby Exchange with the Granby Exchange is negative, showing numerous cases of negative Project Fees set by rule 15

Rule 13: Granby Spill Accounting – This rule is inconsistent with Rule 23: Windy Gap Spill. Rule 13 says that CBT Excess is counted as CBT spill first. Rule 23 simply attributes any spill to Windy Gap first as long as Windy Gap account is positive. This is the rule that is actually used in the solution.

Rules 13-21 and 22-26 – It appears that there are two groups of rules doing essentially the same thing, but they are inconsistent in how they calculate the Windy Gap account. Perhaps one group is an older version that is no longer used. The reasons for the differences should be documented if they are intentional, or the outdated rules should be deleted if that is the case.

Rule 12: ComputePowerCoeffs – Parameter values should go in slots. Document the source of the parameters. The rule description comments on this, but apparently the source is unknown. (See the comment on the Unit3Generator object regarding the use of objects to model physical processes.)

Rule 11: MaxEnergyCalcs – FOR loops could simplify this rule. Flatiron powerplant max flow (550 cfs) should be in a slot reference. This rule makes an assumption of a daily time step in the power to energy conversions. This is fine as long as these rules are not used in a model with a different time step.

Rule 9: EnergyCalcs – The rule should be updated to include ChimneyHollowPump. This rule makes an assumption of a daily time step in the power to energy conversions. This is fine as long as these rules are not used in a model with a different time step.

Rule 8: NetEnergyCalcs – TotalPumping calc should be updated to include ChimneyHollowPump. WITH statements could simplify the final calculation.

Rule 5: East Slope Reservoir Flow Path Remaining Capacities – Earlier rules could be simplified by using the FacilitiesList functions (or similar functions) that are used in this rule.

Rule 2: Totals--Shadow Mountain Reservoir Native and Total Inflow – This rule indicates that all North Fork flow goes to Shadow Mountain, but that is not true because of Red Top Ditch. This rule should be updated to reflect the diversions to Red Top Ditch. It also does not include canal seepage from Red Top Ditch.

Rule 1: Totals—Granby Reservoir Inflow – This rule does not include Red Top Ditch groundwater flows and canal seepage.

3.5 DMIs and Data Transfer

This model is used as part of larger decisions support systems and analysis tools. Moving data between models and databases is an important step. Following are comments on the RiverWare's model use of Data Management Interface (DMI) and data transfer in general.

3.5.1 Input DMIs

Input DMIs are all Control File-Executable DMIs. We were not given control files or data files so we did not review them. It is our understanding that all input DMIs import data to custom slots. This is a good approach. We always recommend using the "Record Invocations" option so that you can track which DMIs brought in data.

3.5.2 Output DMIs

There is one Control File-Executable DMI, one output DMI to HDB, and three output DMIs to Excel.

The Excel_WaterQualityInputs DMI was further reviewed as it provides input to the CE-QUAL-W2 model. The DMI appears to export the data necessary for the CE-QUAL-W2 model, but it would be useful for someone with CE-QUAL-W2 knowledge to make sure these are correct variables and map to the WQ model correctly. One issue that raises a concern is that Grand Lake and Granby inflows exported by the DMI are the aggregated flows at fictitious gages in the RiverWare model and DMI. For example, EastNorthInlets represents the aggregated flows from both the East Inlet and North Inlet. Are these aggregated or disaggregated in the CE-QUAL-W2 model? We believe they should be disaggregated as the WQ model would require more resolution. It appears that the disaggregated inflow data are available in the model in the DMI_HistoricValues.Granby and DMI_HistoricValues.GrandLake agg series slots. See Figure 27 for more info.

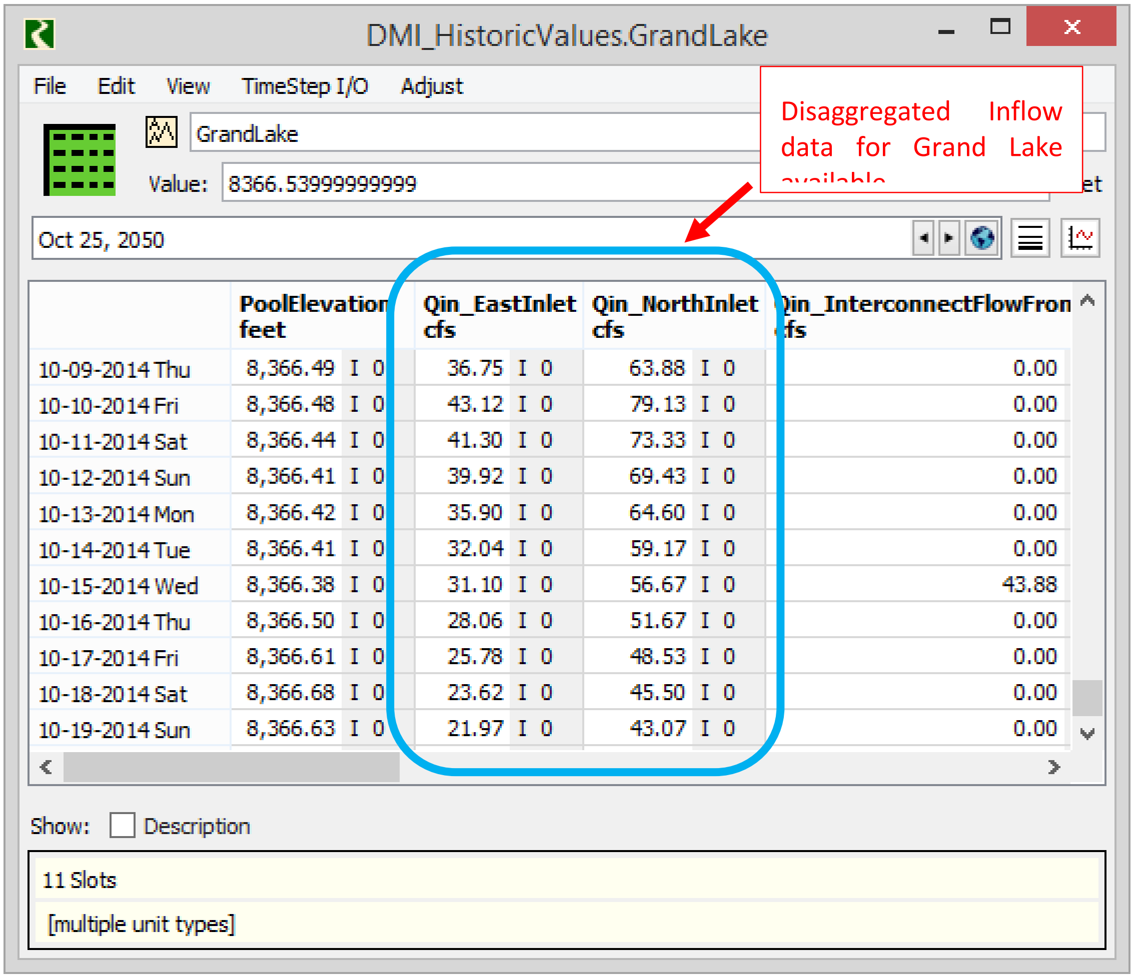


Figure 27: Grand Lake disaggregated inflow data on DMI_HIstoricValues data object

The screenshot (Figure 28) shows the slots exported:

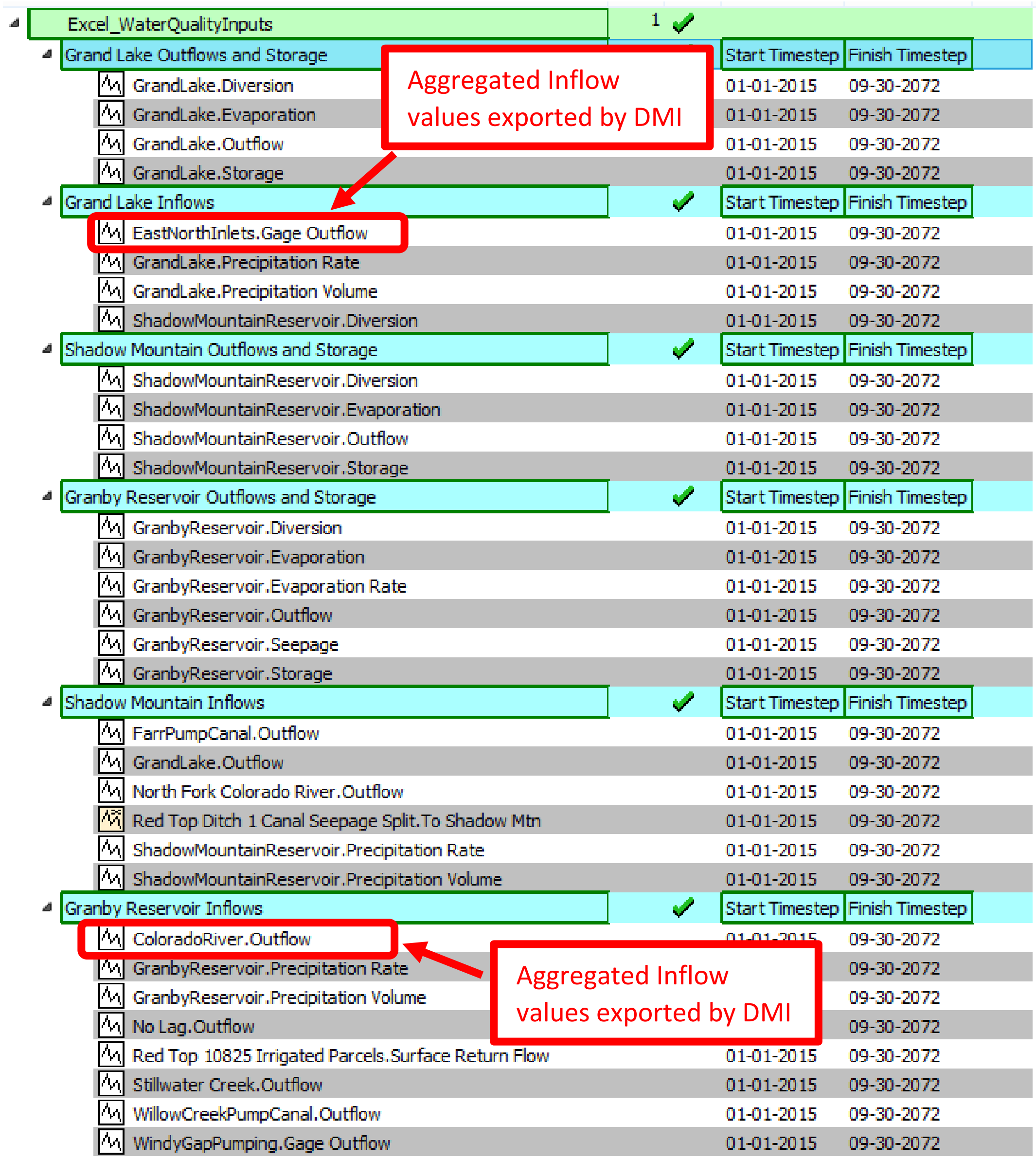


Figure 28: Slots exported by Excel_WaterQualityInputs DMI; Grand Lake and Granby Inflows are aggregated values

3.6 General Usability and Misc Tools

This section describes general usability and miscellaneous tools. Many of the comments are about niceties versus core modeling functionality.

3.6.1 Output Summary Slots

The following comments deal with slots which produce summary output data:

- **Power Data Output.Energy Utilization Ratio Annual Average** – This slot uses the wrong calculation. The annual energy utilization ratio should not average the daily ratios (as is done in a time aggregation series slot) but rather AnnualSum(TotalGen)/AnnualSum(TotalMax). This should be changed to an expression slot (or series slot set by a rule) with this corrected calculation, not a time aggregation series slot.

- **WindyGapData.WindyGapPumpingVolume_AnnualNet** – The expression slot does not evaluate automatically because it references a time aggregation series slot, and time aggregation series slots evaluate after expression slots. It can be evaluated manually after the run has completed.
- Is the cost of pumping considered?

3.6.2 OUTPUTS DEVICES

There are 11 plot pages defined in the Output Manager. These are nicely formatted and show commonly accessed variables. Otherwise, there is only one Excel File output device: AOP. It is not clear why this is an Output Device instead of an Excel based Database DMI. Either is fine.

No model reports, charts, or output canvasses are in the output manager. Consider using these for outputs.

3.6.3 SCTS

Six SCTs were provided that were developed by PWRE. These mainly had to do with Windy Gap water and the West slope. It would be useful to have pre-built SCT for other areas in the model.

3.7 PERFORMANCE

The run time for this model is very good. This section documents the performance and presents a few areas for improvements.

3.7.1 MODEL SIZE AND LOAD/SAVE TIMINGS

Model and ruleset file sizing was investigated with the following results:

- The model size with no outputs in a compressed format is 3.5MB.
- The model size with outputs in a compressed format is 32.6MB
- The ruleset, not zipped is 291KB.

These files sizes are reasonable.

Next, the load and save time was measured. The results are as follows:

- Without results, the model **loads** in about 2 seconds.
- With results, the model **loads** in about 5 seconds.
- The **ruleset loads** nearly instantaneously
- With results, the model **saves** in 19 seconds.

These timings are reasonable for a 24,000 timestep model. No further analysis was made.

3.7.2 RUN TIME

The run has 21,093 daily time steps. The run takes 692 seconds = 11.5 minutes (on David's machine) using RiverWare 7.2.5. The breakdown for the run is as follows:

Item	Time (s)	% of total
Initialization Rules	29	4
Other Initialization	2	0.3

Item	Time (s)	% of total
RBS Rule Evaluation (From RPL Set analysis tool)	588	85
Dispatching	21	3
Other	52	7.7
Run Time from Diagnostics Output	692	100

This breakdown is fairly common in a rule-based Simulation model with 200 rules.

The time required per time step is relatively constant as shown in the following plot:

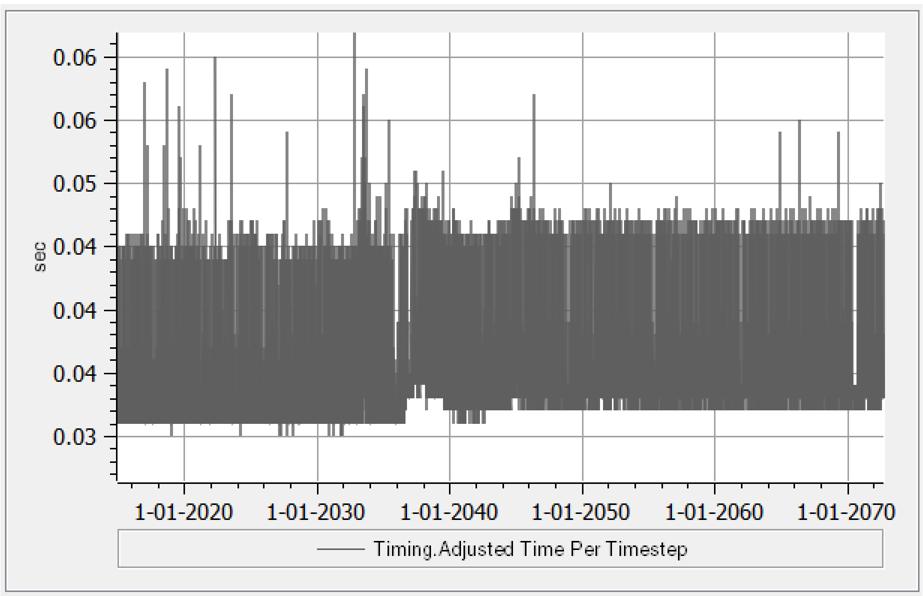


Figure 29: Execution time required per timestep

Thus, there is no significant growth in execution time over the course of the run.

3.7.3 RPL EVALUATION TIME

Since RPL evaluation is the majority of the run, we did additional analysis on the RBS RPL set.

The following table shows the most time consuming rules/functions sorted by time (most to least)

Name	Priority	Time (s)	Evaluations
50 Year CBTPOM_v0.33 – TOTAL RBS RPL time	Set	587.5	16780226
UpdateBypassFlow	function	91.8	14195361
MinimumAvailableCapacity	function	87.2	29303950

Name	Priority	Time (s)	Evaluations
UpdateConveyanceFlow	function	83.6	40729875
UpdatePowerplantFlow	function	81.5	14343021
Facility Flow--EP2BTF	171	47.5	632783
Facility Flow--AT2BTF	127	43.9	442946
Facility Flow--EP2HFCF	167	34.9	611690
Facility Flow--EP2HTFH	159	32.1	569504
Facility Flow--AT2HFCF	115	30.9	379667
Facility Flow--AT2BTD	123	23.1	421853
Facility Flow--AT2HTF	95	22.6	274202
Facility Flow--EP2CLU3	175	17.6	337486
Initialize East Slope.Remaining Demands	183	16.6	84369
Facility Flow--AT2CLU3	107	15.8	210928
Target Sum Period Historical Percent Exceedances	194	15.4	21093
Facility Flow--EP2BTD	155	14.0	464039
Facility Flow--NFP2BTD	143	11.9	400760
Facility Flow--PW2BT	87	10.8	210923
Facility Flow--AT2HTD	91	9.7	253109
Facility Flow--AT2HFC550MinFlowF	59	9.3	105464
Facility Flow--CL2BT	75	8.7	168737
Facility Flow--AT2CLB	103	8.1	147651

The obvious question: why do all of the Facility Flow rules need to execute so many times? The rules only need to compute successfully one time per time step. Adding execution constraints to fire only once would have significant performance improvements. Preliminary testing indicated that this could reduce run time by more than half. (See additional comments on Facility Flow Rules in the Rule-based Simulation Rules section.)

3.8 MODEL RUN AUTOMATION

We did not find any evidence of automated runs between the RiverWare and CE-QUAL-W2 model. Thus, we cannot comment on how the interaction of the two models is performed.

3.9 C-BT RIVERWARE MODEL: HYDROLOGIC DATA

We recognize that the primary goal of the hydrologic data in the RiverWare model is to have reasonable and consistent set of inputs, such that different scenarios and management alternatives can be compared to a baseline. Here we include a detailed review of the input data. Overall, the modelling effort has made a laudatory effort to include inputs from the many poorly gaged creeks and estimate hard-to-measure variables such as flow into and out of groundwater. Remaining errors or inconsistencies in the input data might be of relatively small consequence for the daily operations and planning model, particularly when the model is being used to analyze a range of hydrologic scenarios; however, these errors could be much more significant in the context of providing inputs to a water quality model. For example, what are the appropriate water quality parameters to assign to mass-balance correction flows ("Hydrologic Inflows")? This uncertainty in the water quality parameters becomes especially critical in periods when the mass-balance correction terms dominate the overall mass-balance. The potential impacts on a linked water quality model are the primary consideration for the issues that are highlighted in red text in this section. The comments below are meant to highlight possible areas of inconsistencies, as a way of continuing to improve the input data quality.

In general, models cannot improve upon the quality of their initial and boundary conditions. Errors in the input data can propagate through a system. The CBT-POM model contains little or no documentation of the effect of uncertain boundary conditions on model results and management of the system. Particularly when a small change in a measured flow might push the system above or below a threshold (e.g., as encapsulated in rule-logic), the consequences of a small error or mismatch can be amplified. It is possible that errors in river inputs, reservoir losses (e.g., by seepage), or other ungaged flows may not appreciably affect the mass balance in the RiverWare software, since any imbalances are added/subtracted through a correction term based on the (accurately known) reservoir water level. The implicit assumption that uncertainties in input data are accounted for by the mass-balance correction should be assessed by stress testing the system, e.g., by rerunning the model by perturbing inputs with random error or systematic bias, recalculating and applying the mass balance correction, and determining whether modeled outcomes change.

Beyond the (probably small) possible effect of the mass-balance correction on the diversion and management of water, improving or rather minimizing the known residual at every lake is desirable. Reducing the magnitude of the correction term will minimize its effect on modeled water quality in the downstream CE-QUAL-W2 models.

Our analysis suggests there could be multiple possible sources of errors in hydrologic forcing to the model, including measurement errors, errors in data-infilling (imputation), and the possibility that some flows are not represented. It may be advisable to quantify the uncertainty in input variables and test the sensitivity of model results and management outcomes to both (estimated) random input errors or systematic biases. We recommend assigning confidence intervals to the hydrologic data, with larger bounds applied to less certain data. Error for imputed or calculated data would ideally include both the underlying error in the driving data plus the error associated with the statistical model used for imputation. Then one could propagate errors through the RiverWare model, for example through a Monte-Carlo approach or similar, to see whether different approaches for the imputed data make a difference in modeled outcomes. Possible biases could then be identified. The effect of perturbing system inputs could also be tested on the CE-QUAL-W2 model that will use the RiverWare output.

For imputed data, we note that linear regression (in general) works well on average, but does not always model low or high extremes. To the extent that the extremes are important for driving scenarios, it would be useful to figure out the magnitude of error. Is error a function of flow magnitude, how does it propagate through the model, and is there bias in either high or low flow? A general question that is good to have an idea about, is "what is the error driven by boundary conditions, and what is the error driven by system-internal logic?" Answering this question can help address how to best allocate resources to improve the model in the future.

We also recommend transparent documentation of data sources, error estimates, and description of how mass balances were made.

3.9.1 MEASURED DATA

The Hydros document (CBTPOM Daily Hydrology Final Report) describes the methods used to impute missing data. A detailed quality assurance on digital data files was performed and appears to have caught many errors caused by data transcription. This laborious exercise is necessary and appears to have caught many problems in the input data.

Beyond this quality assurance, some additional tests may help shed light on data quality and help provide understanding about the patterns described for the "Hydrologic Inflow" variable in Section 4 of this report. We recommend investigating the following factors in case they may impact the RiverWare mass balance errors for new data incorporated into the model:

- Quality flags in USGS data should be consulted, as well as any reports or other meta-data (such as direct manual measurements or calibrations) associated with river gages. A relatively quick check of available quality information or other data assessments can identify possible issues that are not easily apparent by other means
- A common issue with hydrologic data is the "hysteresis" effect, i.e., the tendency for the same water level to represent a different flow rate, depending on whether it is the rising or falling limb of a freshet (flood). Typically, the rising limb has a greater flow than the falling limb, for the same water level. If there is available water level data, it can be checked whether or not the hysteresis effect has been represented in estimates of flow. If not represented, it would be good to investigate whether this helps to account for observed seasonal patterns in the "hydrologic inflow" variable, and correct as necessary.
- Another possible source of error is the time lag between the gage location and the inlet to a reservoir. Even a few hours of travel time between a gage and an inlet could make a difference in the applied daily average if the flow hydrograph is changing relatively quickly. During a rising freshet, input may be over-estimated, and vice-versa for falling water levels.
- Related to this source of error, some parts of each watershed may be ungaged, even if a flow measurement exists. This is because there is often a certain distance between a gage and the inlet to a lake, which means that a certain proportion of any given watershed is ungaged. Therefore, flow may need to be adjusted to account for any gains (or losses) through the reach. We recommend determining what percentage of the flow in the watershed is below a gage or is otherwise not accounted for (e.g., it is

possible that some small areas/creeks are not represented). This analysis can form the basis for additional flow corrections, if necessary, and improve the mass balance errors.

We have not investigated these sources of possible error in detail but mention them as possibilities to check. Beyond these issues, any flow measurement is typically assumed, by convention, to be accurate to about 10%. It would be advisable to flag time periods in which the Mass Balance correction (the "hydrologic inflow" variable) exceeds this 10% level, as a period requiring additional quality assurance or explanation.

We note that it is assumed that there is no change in the elevation/storage relationship in reservoirs over the past 60 years. While probably a reasonable assumption, this should be checked against both qualitative local knowledge and (to the extent possible) quantitative measurements, particularly in shallow reservoirs such as Shadow Mountain where it is possible that sedimentation has occurred.

3.9.2 Imputed Data

Many of the smaller streams in the watershed are poorly measured, and data was inferred or "imputed" in order to improve the mass balance. While a necessary step, we make the obvious point that it would be good to make modern measurements and monitor these streams, rather than impute data. This is particular true for streams like Stillwater Creek that are significant proportions of the total flow, and for which fewer than 5 years of measured data exist.

Overall, one issue with evaluating data quality (and therefore model efficacy) is that it is difficult to infer from the input data files whether the input data is measured or imputed. Since it is possible that imputed data produces more model error or artifacts than measured data, it would be good to somehow convey the "Imputation status" of the input data (e.g., percent inferred) as a guide-post for quality-assuring results. Another option would be to assign greater uncertainty. If periods with a high preponderance of imputed data show more variability (e.g. in the mass-balance correction), that would be an indication that data inference could/should be improved. On the other hand, if there is little change in statistics, it is possible that the errors and artifacts described below have little material effect on results (though if possible they should be corrected).

The statistics of measured and imputed data could be systematically compared to each other to assess any errors. Data that is imputed (estimated) by a statistical model may contain additional errors due to inaccuracies in the regression, which aggregate on top of the inherent inaccuracy of the underlying data used for imputation. For a similar reason, it would be recommended to make sure that the RiverWare model works well under conditions with different amounts of imputed data. We also recommend estimating rms error as a function of flow for imputed data. Some of the Hydros documents suggest that the envelope of possible flow extends from 20 to 200 cfs, for a flow of 100 cfs, suggesting a possible bias towards overestimation at low flow. Carefully evaluating residual errors may help identify if that is an issue, and whether it matters to model functioning.

In addition to these overview comments, we have uncovered a number of non-physical artifacts in the imputed data. We recommend assessing if these artifacts require fixing:

1) First, we note that the y-intercept in a regression model of flow may not be physically meaningful. We therefore suggest that imputed flow be carefully vetted for plausibility, particular at the low and high flow extremes. Linear regression, while a good first estimate, is an imperfect tool. In fact, many of the y-intercepts given in the *Hydros* document are negative, meaning that the statistical model suggests negative (uphill) flow when the driving flow tends

towards zero. A similar implausibility exists when the y-intercept is quite positive; in this case, a large imputed flow is estimated when the driving flow is small. Hence, the greater the variation of the y-intercept from zero, the less likely that low flow periods are correctly modeled. Either data errors, differences between the imputed watershed and the measured watershed, or differences in forcing (e.g., precipitation) prevent an ideal regression. One can, however, force the y-intercept to be (close to) zero, and see if that does a better job of capturing the hydrology. Another approach might be to determine the base flow (lowest possible flow) for the imputed and regressor variables, and force the regression through that point. Finally, we note that one could consider bin-averaging or otherwise weighting points carefully, such that the regression is not biased towards fitting a cluster of points all near each other, at the expense of not fitting outliers (e.g., high flow conditions) well.

2) In general, a regression works best when there is a physical basis function. While applying different regressions for each month does capture seasonal variability, there is also a bit of arbitrariness to this decision that leads to some artifacts (why not use 20 days? 6 weeks?). As shown in Figure 30 below, the use of separate regressions for each month of the year results in a non-physical discontinuity between the first and last day of the month. Essentially, a slightly different statistical model with a slightly different slope and intercept is used, resulting in both an average and an absolute difference between the first and last day of each month. For Arapaho Creek, a negative bias is introduced on the first of the month that is greater than the value observed during other days of the month. The magnitude of the bias is largest during the spring freshet, when the average absolute flow difference is approximately 50% more than other days (Figure 30). We note that using a monthly regression model is preferable to using an annual model, since the processes producing discharge vary through the year. On the other hand, figuring out a way to reduce the "first-day" bias—e.g., by using monthly models that overlap each other in time, or by using some sort of weighted average—would be advisable. One way to test efficacy of any model would be to subdivide any statistical model into a 'training data set' and a 'validation' data set.

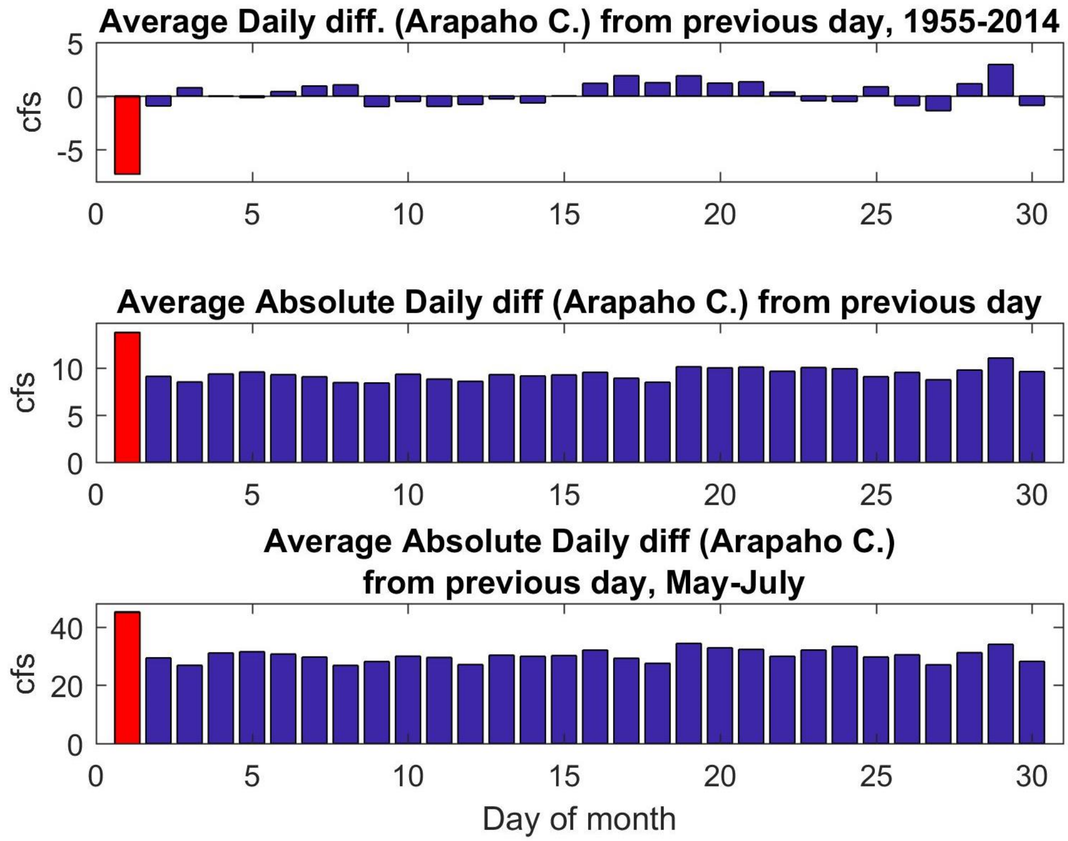


Figure 30: Average daily difference between the labeled day of month and the previous day. Because most the Arapaho data is imputed based off of monthly regressions, there is a bigger difference at the transition between months and other days.

3) Naturalized flow data produced by imputation (or by adjusting measured data by accounting for withdrawals and additions) should be checked for consistency. A first assumption might be that statistics should be stationary between two time periods, unless climate change effects, natural variability or land-use patterns justify a change in hydrograph shape. However, our analysis of naturalized flow shows ambiguous results which may indicate problems with the underlying data. As shown in Figure 31 below, the naturalized hydrographs for the North Fork at Baker Gulch and Grand Lake do not agree with each other in terms of how peak timing and magnitude differed in the pre-and-post 1980 period, despite being fairly close to each other. The naturalized Stillwater creek hydrograph, which is almost entirely imputed, shows the most variability in the pre and post-1980 periods in terms of spring freshet timing and magnitude. Hence, based on these data, one might conclude that the Stillwater creek watershed exhibited non-stationarity over the past 60 years, whereas the North Fork at Baker Gulch did not. A physical explanation might be found, but a data issue is also possible. We recommend (a) determining the source of the divergence between hydrograph shapes pre and post 1980, since it may help explain some of the mass-balance corrections which are required to be applied to the RiverWare model and (b) determining, by other means such as precipitation measurements or snowpack, whether the system is statistically stationary or not. In other words, should one expect a non-stationary hydrograph that looks more like Stillwater Creek or should the system exhibit approximate stationarity, as at Baker Gulch? If this methodology is applied to all the different "naturalized" inflows to the system, one might be able to identify whether there are

any systematic biases over time. Or, stated differently, the variable "undepleted inflow total" in Miscellaneous.csv suggests a difference in the timing and magnitude of the peak freshet pre and post 1980 (Figure 32). Is this correct? If not, then there is a bias in the total flow.

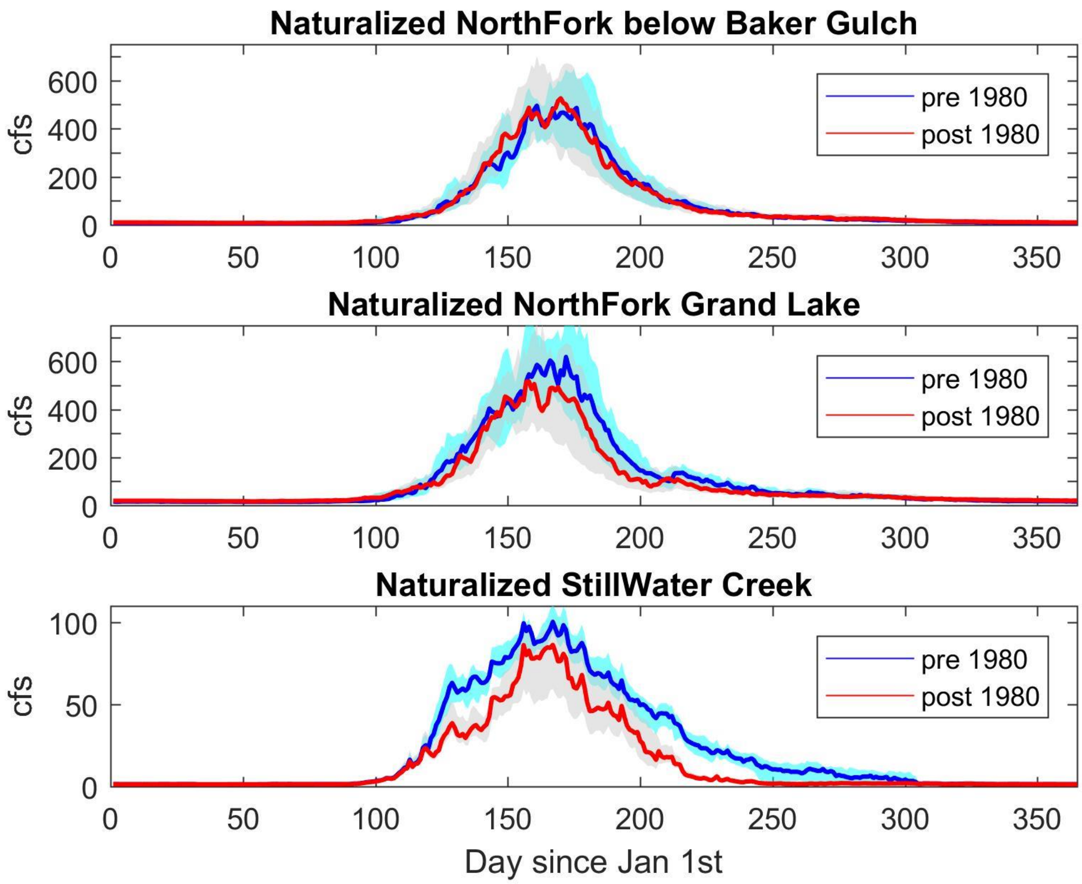


Figure 31: Different estimates of Naturalized flow, obtained from Hydros document. The Naturalized Flow estimates at Baker Gulch, which are perhaps the most complete and accurate, show little long term change in the magnitude or timing of spring freshets (a slight forward shift in time cannot be seen at this resolution). However, the hydrographs for Grand Lake and Stillwater Creek show a distinct shift in timing and magnitude over time, possibly indicating errors in measurement and/or imputation. The 25th and 75th percentiles pre and post-1980 are shown in cyan and grey, respectively.

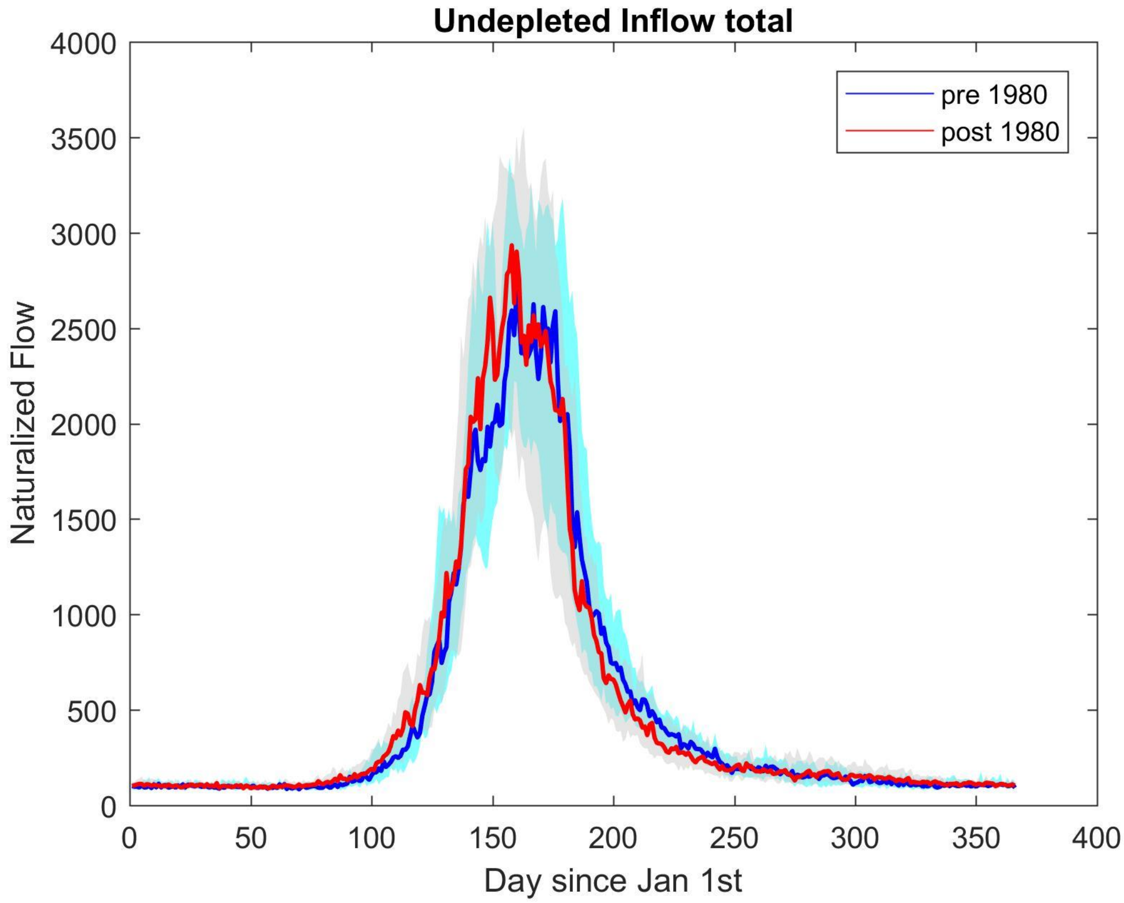


Figure 32: Undepleted Inflow total, from Miscellaneous.csv. The 25th and 75th percentiles pre and post-1980 are shown in cyan and grey, respectively.

4) Some of the creeks flowing into the reservoirs have unrealistic hydrographs or unexplained features, as shown in Figure 33 below. The most obvious is the stair-case type profile that is observed during low flow conditions, probably as a result of using monthly averages. We note however that there is an unexplained maximum during the low flow periods that is at a different time between Columbine and Roaring Fork creeks, at least in the plotted data. Neither of these maxima is reproduced in Arapaho data. Similarly, a few extreme low flows are estimated for Columbine Creek, likely at the junction between daily interpolation and monthly averaged flows. Because the relative magnitudes of these low-season fluctuations are small, it is possible that it doesn't matter much in the overall mass balance; however, if possible it would be good to quantify the effect and determine whether a better estimate of the flow rate during these time periods can/should be made. It might be advisable to actually gage these flows, if they turn out to be a source of significant uncertainty.

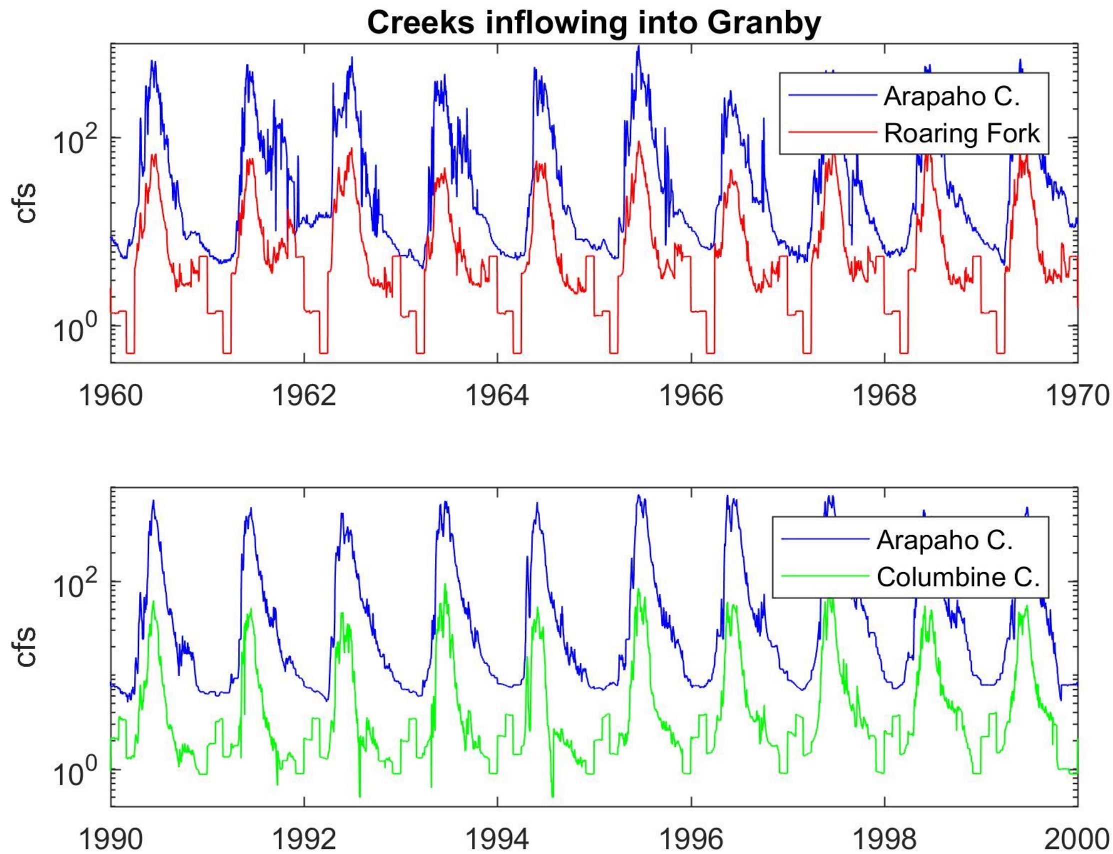


Figure 33: Snapshot of creek inflow into Granby at different time periods. As shown, the low period flow periods have unrealistic "staircase" type profiles. The annual cycle of the staircase also has an unrealistic repetition and unexplained low-season maximum. The Columbine Creek inflow also has some periods of unrealistically low inflow.

5) We have recommended that evaporation and precipitation values estimated by Hydros be used in the RiverWare model. While this may improve the mass-balance calculation, the data should be quality assured/validated to ensure that daily and seasonal variations are reasonable, and improvements made if necessary. As an example, are there residual errors in the modeled water level of a reservoir (or rather, the gain/loss used to keep mass balance) that correlate with estimated evaporation/precipitation rates, or proxies thereof such as air temperature or humidity? If so, this could indicate that some of the assumptions in the data (such as the pan factor for evaporation) should be revisited. It would also be good to justify parameters used. For example, why is a pan factor of 0.73 used, and how do we know that the pan factor of 0.73 is correct? Hence, more details would help. Such details as how complete was the monthly water temperature data used for pan-evaporation rates, and what sorts of differences are introduced by using monthly averages rather than daily data? How accurate and complete were these monthly climatologies? How important a variable was interannual variation? Monthly water temperature could vary significantly from daily temperature, especially in shoulder seasons.

As shown in Figure 34, the evaporation ratio calculated in Granby, Grand Lake, and Shadow

Mountain Reservoir vary seasonally. It would be good to document whether this is a realistic feature of the data, or is an artifact of calculation. While it is possible/probable that this is a feature of water temperature in the different lakes, it would be recommended to determine whether a variable ratio makes sense, given available physical data. Moreover, it can be seen that the ratio varies month to month in a staircase pattern, not smoothly as might be expected. The implications of the "stair-case" structure on results, while probably not a huge factor, should be considered.

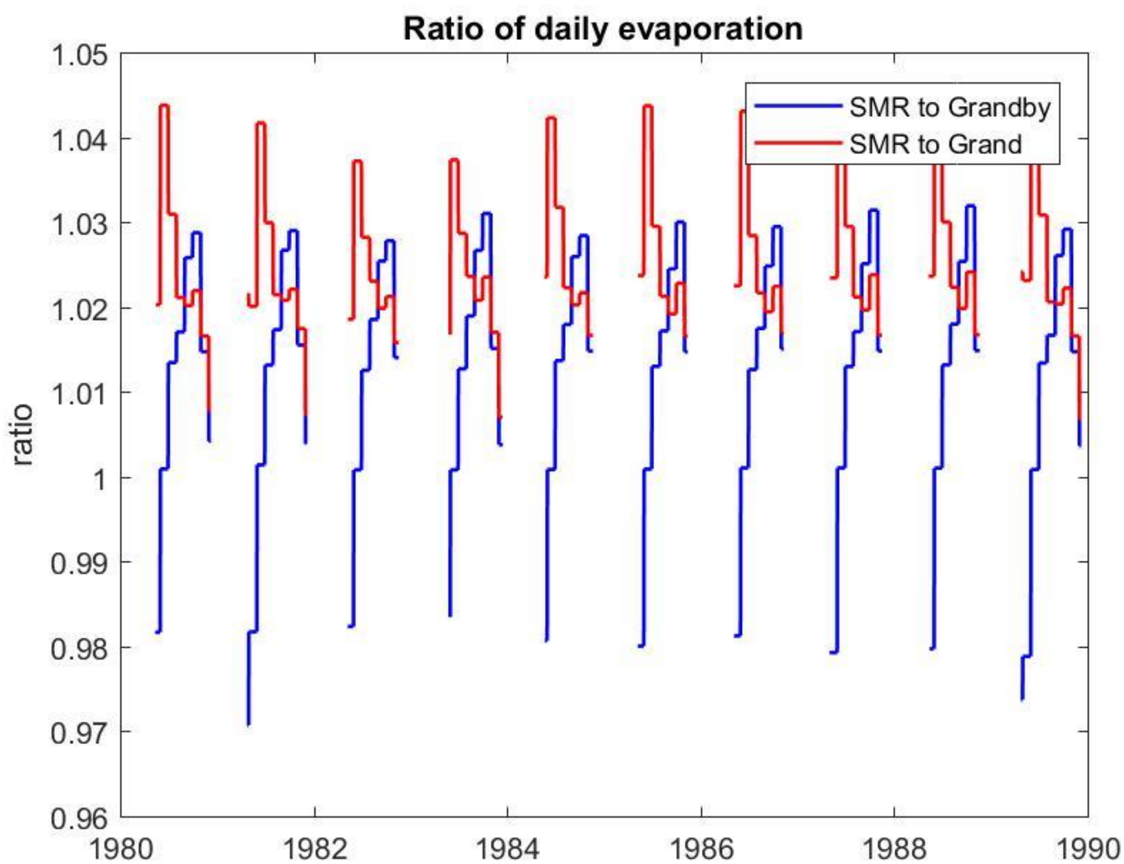


Figure 34: Ratio of daily evaporation in 3 lakes

6) The actual precipitation and evaporation values produced by Hydros should be checked for consistency (see Figure 35). For example, there is no evaporation during some months which is probably due to ice formation. That assumption though is not in the documentation. Similarly, the first and last months with evaporation are often block averages, rather than day-to-day values. It would seem that better estimates could be made, especially as there seems to be an inverse correlation between precipitation and evaporation. Comparing precipitation values, some events occur in Granby but not in Shadow Mountain, or vice versa. While this may be the effect of locally variable precipitation (e.g., thunderstorms), it is a legitimate question to ask whether the precipitation values which are measured at stations removed from the lake are

correct for the lake, or whether local variability produces error. One could consider checking the precipitation values with reanalysis data or other sources of data, if available.

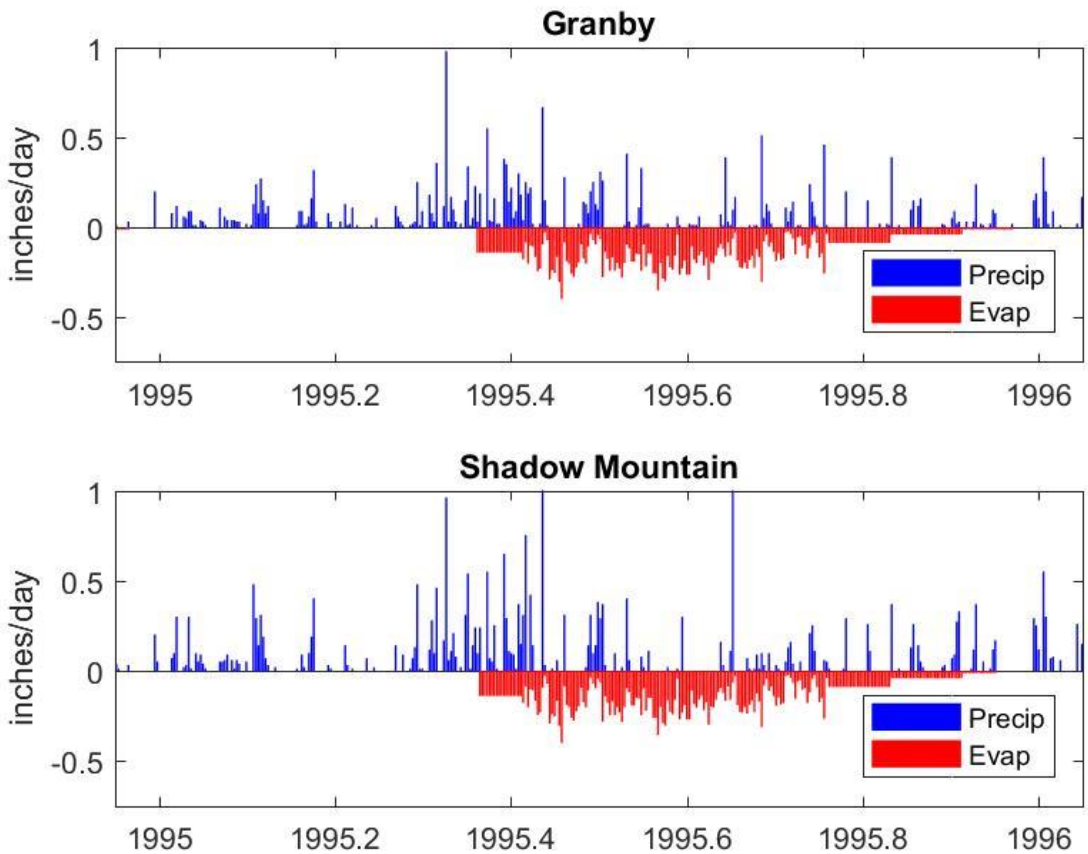


Figure 35: Precipitation and Evaporation into Granby and Shadow Mountain reservoir, from Hydros data.

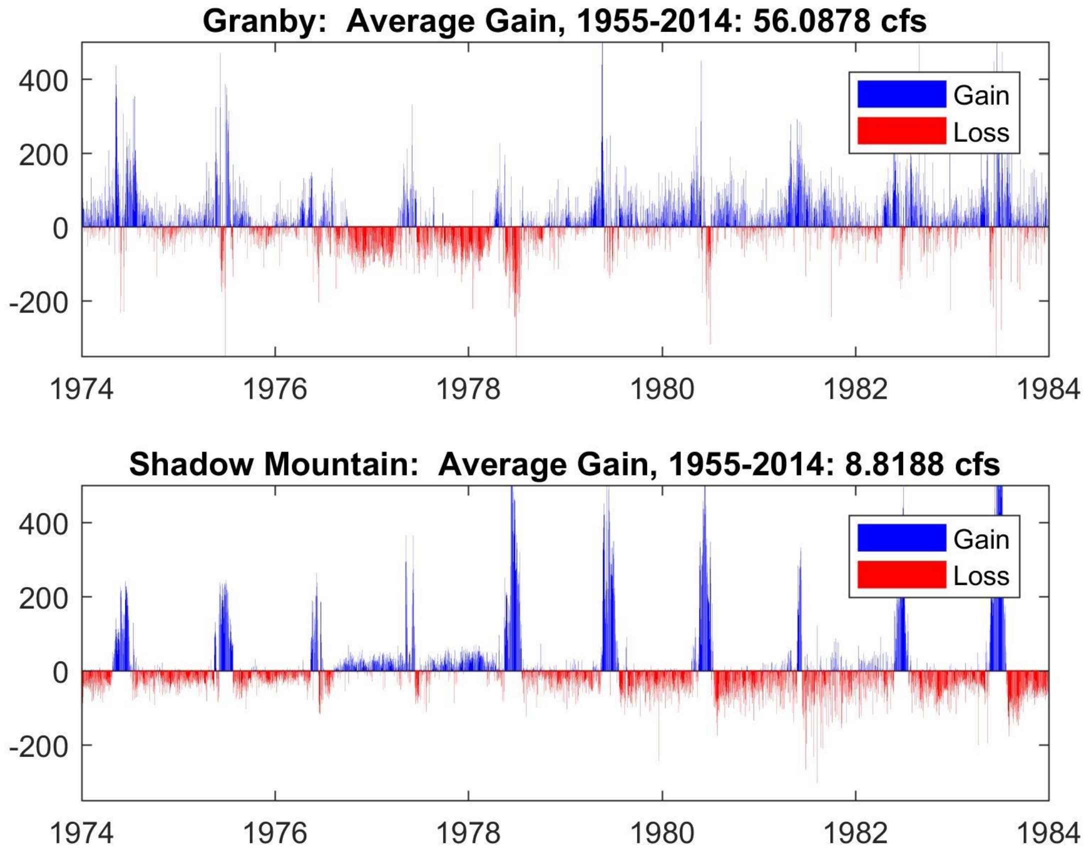


Figure 36: Snapshot of average Gain/Loss for Granby and Shadow Mountain Reservoirs. For Granby, some periods are mostly negative, others most positive. Shadow Mountain shows both a seasonal trend (with freshets a time for gain), but is also often anti-correlated with Granby, suggesting that some flows between the two are not correctly accounted for.

Overall, the patterns of "loss" and "gain" in the reservoirs (the correction term) should be investigated. By figuring out the reasons, one may determine the best way to improve the model. For example, the average gain/loss for Shadow Mountain and Granby are sometimes inversely correlated, in a way that might suggested ungaged or unrecognized flows from one lake to the other (see Figure 36). If so, these might be investigated to determine the reason. One possibility is the observation (p. 17 of Hydros document) that the imputation for the Shadow Mountain dam radial gate release is fairly large, percentage-wise, for low flow--an envelope of +/- 500 cfs or so. If such errors are auto-correlated over time, it might lead to periods of bias or greater error. The observed increase in residuals to Granby after 1990 per the Hydros document (p. 20) should be investigated.

In addition, the gain to Shadow Mountain appears to be related to the spring freshet, which is largest during large flow periods and may therefore be related to an underestimation of flows to the lake. This suggests either measurement error or that there is an ungaged watershed contributing to the water level. The gain/loss to Granby is less obvious in form, but still shows a seasonal imprint that would be good to investigate, as a way of understanding what is controlling terms in the mass balance correction.

3.9.3 CLIMATE CHANGE AND NATURAL VARIABILITY; EFFECTS OF EXTREMES

A preliminary, unsophisticated check of the "naturalized" 1955-2014 flows on the North Fork of the Colorado River near Baker Gulch did not reveal any certain evidence of climate-induced change, though the timing of the spring freshet appeared to be about half a week earlier in the 1980-2014 period than the 1955-1979 period (Figure 31). Nonetheless, it appears probable that climate change effects may become more prominent in the next 50-100 years. In terms of managing the system, it might be advantageous to also model a climate change scenario in which the timing and magnitude of river inputs into the system change over time. This might help indicate if there are any long-term changes to water distribution throughout the system due to the climate change and help USBR get out in front of any emerging issues. In a warming climate, drought conditions may become more severe and occur over longer time scales. At the same time, some regions may see more precipitation, or rain on snow events. In any system there is also the possibility of naturally occurring extremes that fall outside the time period of measurement. What sorts of long-term non-stationarity, as well as natural variability, is the CBT system sensitive to?

To put it differently, one reason to make a 60 year run (1955-2014) is to test the CBT system under a multitude of likely conditions, and document/analyze how the system performs. However, to what extent does the underlying data over that 60-year period reflect possible modes of stress and failure to the system, also as it pertains to water quality? And, to what extent has system performance to the extremes during these 60 years been quantified? We recommend that USBR analyze specific markers of natural variability (such as the 100-year and 500-year event). We also recommend that USBR simulate/analyze how the system performs under an extreme drought (of multiple years, as has occurred recently in California) or in years of elevated precipitation. To facilitate analysis, some objective criterion of system success would be good to define. Such an analysis would help 'stress-test' the rule-logic. One way to do this is to test the system under the 100-year 'design' event, as is generally done with any structure. It is possible that the 100-year drought and the 100-year flood is already inherent in the 1955-2014 model run, in which case some analysis of model output and system functioning during those conditions is recommended.

4 SUMMARY AND RECOMMENDATIONS

4.1 THREE LAKES WATER QUALITY MODEL

The Three Lakes Water Quality Model documentation and model files were reviewed in Section 2. Setting up and calibrating a model for a 10-year period is a test of a model's ability to reproduce hydraulic and water quality phenomena occurring in the system over a wide range of conditions. Boyer et al. (2017) invested substantial effort in evaluating all of the field data and how well the model matched those data. Their work was thorough, well-documented, and logically organized. The use of graphics and tables in the report were excellent. Model calibration error goals were reasonable and were met. But this does not necessarily mean that the calibration effort was done in such a way that it would be a reliable predictor of the future state of the system.

This section summarizes recommendations for improving the Three Lakes model based on comments presented in Table 3. Our summary list of recommendations for improving the model are shown in Table 4.

Table 4. List of recommendations.

#	Recommendation	Addressing comment # in Table 3
1	**Model grid** (1) Explore using for Shadow Mountain Reservoir a different grid around the islands where the main conveyance path needs to be modeled accurately. This could require using 2 branches in the model or a main branch or weirs to simulate flow outside the main conveyance path. (2) Explore the effect of using 1 m vertical grid resolution as a minimum for Grand Lake and Granby Reservoir. A 2.5 m grid is too coarse unless testing shows similar results with a coarser grid.	11, 12
2	**Model input files** Some of the model input files need to be revised: (1) precipitation concentration, file 'Cin_Precip.npt', (2) the East Inlet constituent inflow file 'cin_el.npt', and (3) the North Fork constituent inflow file 'cin_NF.npt' (4) the precipitation air temperature in Tair.npt could be adjusted to dew point temperature	46, 47, 48, 49
3	**Model source code and run time** (1) Compare model results from the customized model to the release model of CE-QUAL-W2. If results are similar, then the release version should be used since it is actively maintained. Based on the documentation, it is not clear how the customizations were effective in improving model performance. (2) The effect of parallelization was not effective in improving model run times; hence we would recommend not using this feature. Changing CUF from 1 to 10 would significantly reduce run times as would increasing DLTMAX.	4, 5, 6, 7, 8, 9

#	Recommendation	Addressing comment # in Table 3
4	**Model coefficients** (1) The unusual temperature rate multiplier coefficients and other coefficients (such as PO4R being set to zero) seem to show that there is not a consistent limnological approach to model calibration. There still is an issue with too much PO4 that needs to be resolved particularly in Shadow Mountain. Hence, the current calibration may not be sufficiently general and responsive to be predictive of future conditions. Using waterbody dependent settling rates for ISS also seems inappropriate. We recommend setting most if not all model coefficients so that they are all similar between waterbodies unless there is a clear rationale as to why they should be different. (2) Model sediment dynamics need to be evaluated since nutrient fluxes show proportionally higher first order sediment release rates of ortho-phosphate and ammonia in Shadow Mountain relative to Grand Lake and Granby Reservoir. Decreasing these release rates would likely improve ortho-phosphate and ammonia predictions in Shadow Mountain Reservoir. (3) We recommend using similar reaeration formulae and turbulence closure (TKE) for the waterbodies (4) Ideally, the new scour algorithm in Shadow Mountain should be ON for all segments rather than only for segments 12-16. If the scour based algorithm was working it should be generally applicable to all model segments. The TSS results also show that too much TSS scour is occurring. A comparison with the scour predicted in the release model would also be helpful. (5) Review zeroth order SOD rates, which appear too high, and adjust Granby Reservoir SOD temperature rate multipliers so that they vary with temperature. Lower SOD rates may allow Farr Pumping Plant inflows into Shadow Mountain Reservoir to be distributed throughout the water column rather than in user specified layers.	5, 7, 24, 25, 26, 27, 36, 37, 43, 44, 45
5	**Water Balance** (1) The water balance flows seemed to be a high percentage of the inflow rates of tributaries. Hence, more research needs to be accomplished on the effect of the water balance flows on model calibration and ways to reduce the magnitude of the flow error. The flow error needs to be documented. (2) As a sensitivity, one distributed flow file rather than separate gains and losses may make the translation of flow information from the CBT RiverWare model easier.	18
6	**Address Typographical errors and add further explanations to the report**	1, 2, 10, 13, 15, 17, 20, 21, 22, 23, 24, 29, 30
7	**Future recommendations** The current calibration should be stable before modeling macrophytes, pH, total inorganic carbon, and alkalinity, which would complicate understanding the current model calibration.	41

4.2 COLORADO-BIG THOMPSON OPERATIONS MODEL

This report reviews the Colorado – Big Thompson Planning and Operations Model (CBT-POM) used by the U.S. Bureau of Reclamation (USBR). This RiverWare-based model is used to compare different operating and facility-management alternatives and to provide inputs to the Three Lakes CE-QUAL-W2 model. Overall, our review found that the model well represents most aspects of a complex system and that the operating policy is reasonable and defensible. A few critical issues may impact the correctness of the RiverWare data that are passed to the CE-QUAL-W2 model:

- There are inconsistencies between the physical process model and the documentation provided by Hydros and PWRE. Any inconsistencies should be resolved to ensure that the model is running as intended. Any intentional differences should be documented.
- Certain rule logic needs to be modified to produce the intended computational results and prevent negative outflows from reservoirs.
- Inflows to Lake Granby and Grand Lake are spatially aggregated in the RiverWare model. Based on the data transfer tools, it appears that RiverWare is providing these aggregated inflows to the CE-QUAL-W2 model. We understand that the CE-QUAL-W2 model was likely calibrated with disaggregated inflows. In future modeling exercises where RiverWare is providing flows to the CE-QUAL-W2 model, it is critical that the appropriate disaggregated data are passed from the RiverWare model to the CE-QUAL-W2 model.
- Overall, the quality of input data used in the model can be improved and made more consistent. We recommend that USBR consider continual improvement of input data by either additional modeling or measurements of the tributary inflows for which little or no data are available.

Hydrologic inputs were reviewed, and recommendations are provided to improve the quality of input data and better understand inconsistencies and possible sources of errors.

In addition, we recommend that more comprehensive documentation on data sources should be added to the model and stand-alone documentation should be developed which describes model operation and assumptions. Finally, we note throughout the document where improvements can be made for usability, understandability, and performance.

Although there are many comments listed in this document, this model is close to meeting the stated objectives of analyzing alternative operating and facility development scenarios and providing flow inputs for a water quality model. The model will be a very useful tool for decision making, planning, and analysis. With the exception of the critical issues identified above (and detailed in red text in the following sections), the numeric outputs of the RiverWare model appear to be reasonable and correct.

The critical issues that are highlighted in red text should be addressed. These issues potentially affect the numeric correctness of the model results, with possible trickle-down effects into linked water-quality models. The remaining issues identified deal only with usability, execution efficiency, model appearance and documentation. With minor changes, the model will be a very useful tool for decision making, planning, and analysis for years to come.

5 REFERENCES

Adams, T., and Carron, J. (2015) "Development of Daily Flows to Support the Colorado-Big Thompson Planning and Operations Model," Memorandum from Hydros Consulting to USBR and Northern Water, November 9, 2015.

Boyer J.M., Adams T., Hawley C., Bierlein K., 2017, Three Lakes Water-Quality Model Documentation—3LWQM-W2 v1.1, revised: November 27, 2017: Hydros Consulting Inc., Boulder, CO, 151 p. plus appendices.

Cole, T. and Wells, S., 2017. "CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 4.0" Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Coleman, M. (2018) "CBTPOM Modifications for Windy Gap Firming Project," Technical Report from Precision Water Engineering to USBR, Boulder, CO, February 28, 2018.

Melander, K. (2015) "Modeled Historic Demands," Memorandum from Northern Water to USBR, Boulder, CO, September 3, 2015.

Pineda, A. and Smith, S. (2015) "Historical Potential Windy Gap Pumping (1949-2014)", Memorandum from Northern Water to USBR, Boulder, CO, August 6, 2015.

United States Bureau of Reclamation (2017) "Requests for Statements of Interest", Great Plains Region, Eastern Colorado Area Office, Colorado.

Zagona, E., T. Magee, D. Frevert, T. Fulp, M. Goranflo and J. Cotter (2005). RiverWare. In: V. Singh & D. Frevert (Eds.), Watershed Models, Taylor & Francis/CRC Press: Boca Raton, FL, pp. 527-548.

Appendix A – Three Lakes Model Nutrient Fluxes

Ortho-phosphate

Ortho-phosphate fluxes in Grand Lake, Shadow Mountain Reservoir and Granby Reservoir are plotted in Figure 37 through Figure 39. Algae growth was a large sink of ortho-phosphate, and large sources include first-order sediment decay, dissolved organic matter decay and particulate organic matter decay. Ortho-phosphate releases from first-order sediment decay was particularly large in Shadow Mountain Reservoir (Figure 38). Ortho-phosphate releases due to sediment release rate of phosphorus under anaerobic conditions (PO4SOD) were zero because the release rates were set to zero.

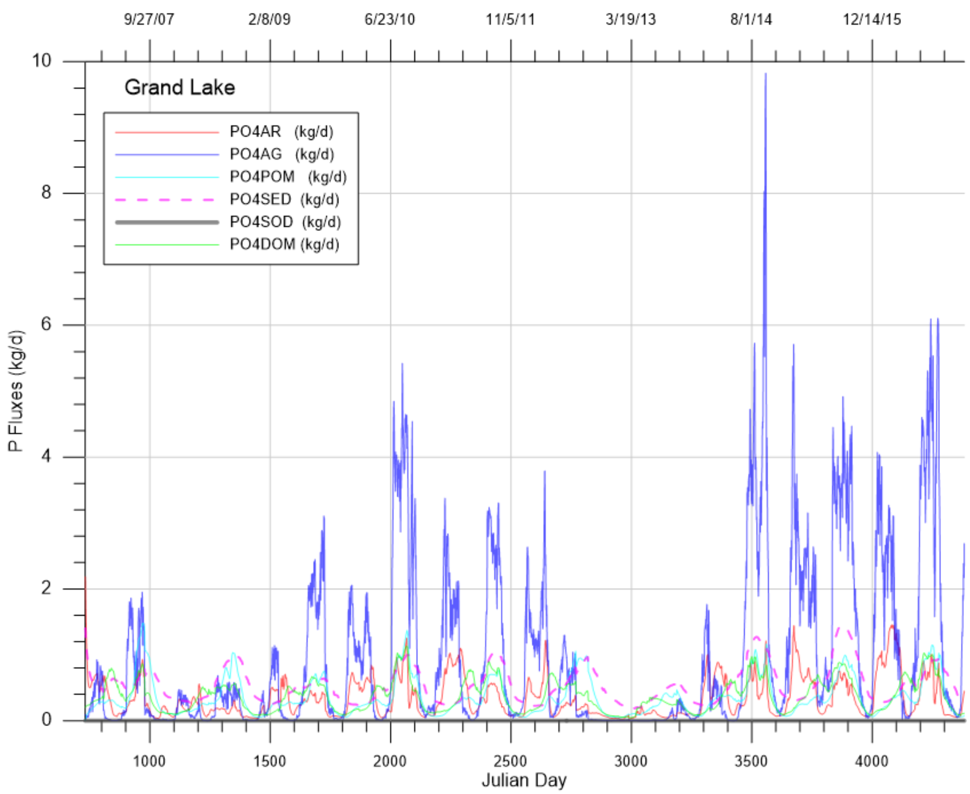


Figure 37. Model predicted ortho-phosphate fluxes in Grand Lake.

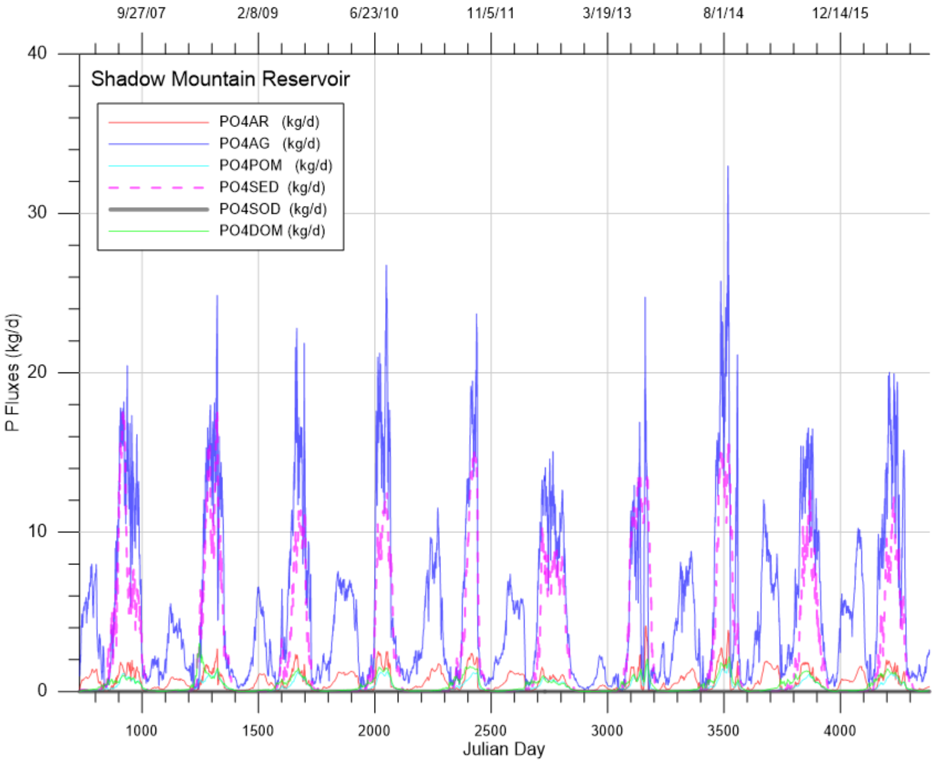


Figure 38. Model predicted ortho-phosphate fluxes in Shadow Mountain Reservoir.

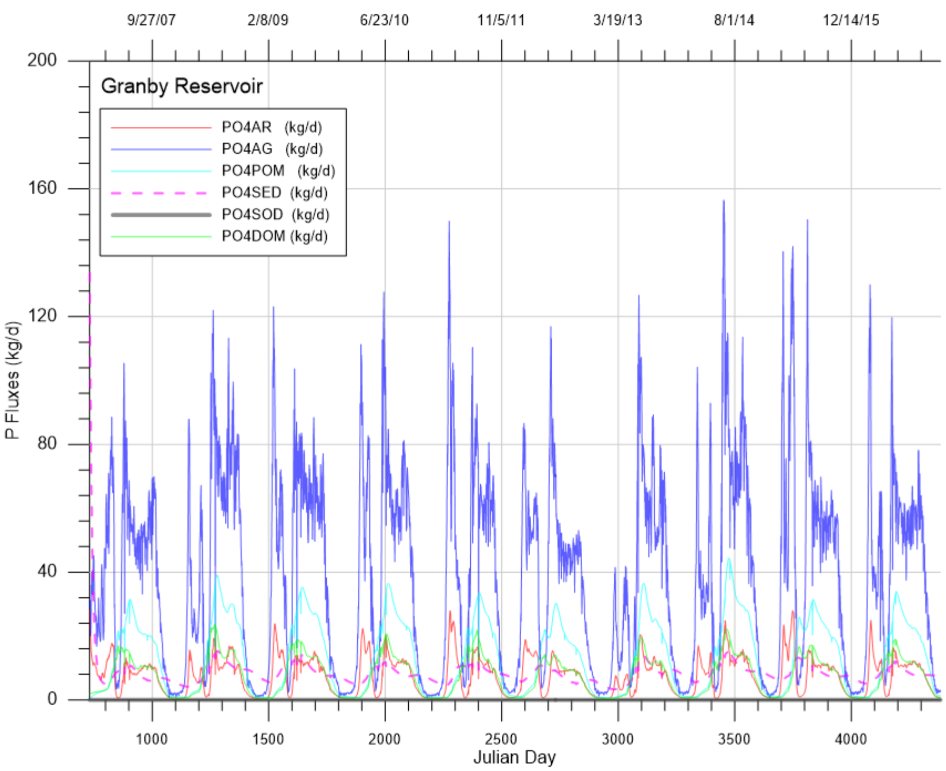


Figure 39. Model predicted ortho-phosphate fluxes in Granby Reservoir.

NITROGEN FLUXES

Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir nutrient fluxes are plotted in Figure 40 through Figure 42. Algae uptake of NH4-N and NOx-N were both significant. Similarl to ortho-phosphate releases, ammonia-nitrogen releases from the first-order sediment compartment were particularly large in Shadow Mountain Reservoir. Anoxic releases of ammonia were relatively small (but significant) in Grand Lake and Shadow Mountain Reservoir, but less significant in Granby Reservoir. In Grand Lake, denitrification was a particularly large nitrogen sink.

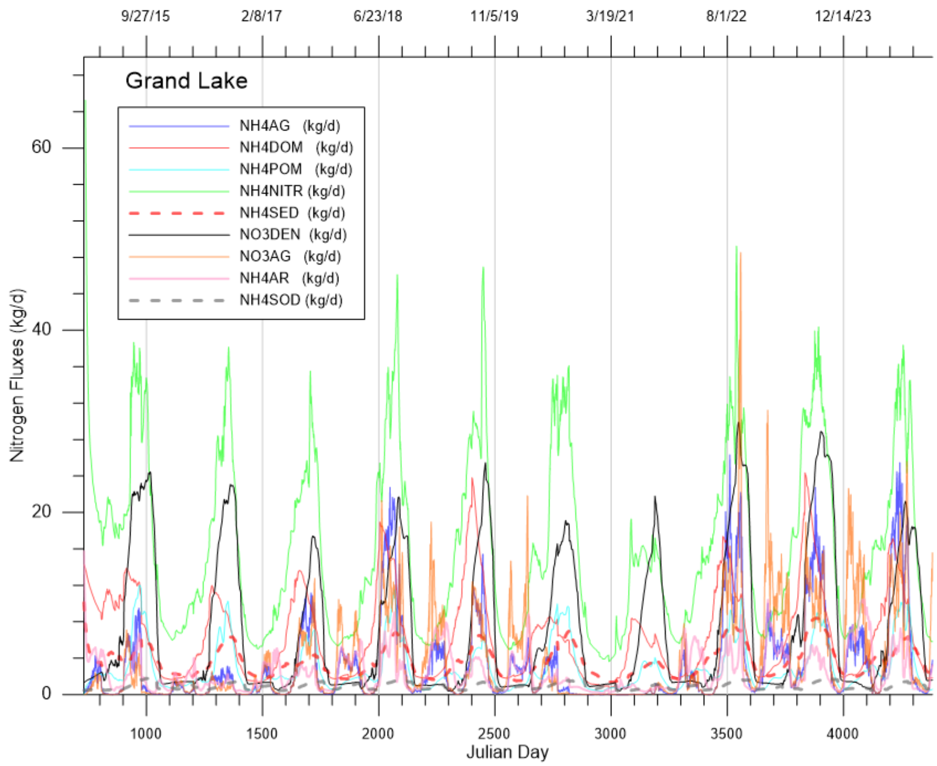


Figure 40. Model predicted nitrogen fluxes in Grand Lake.

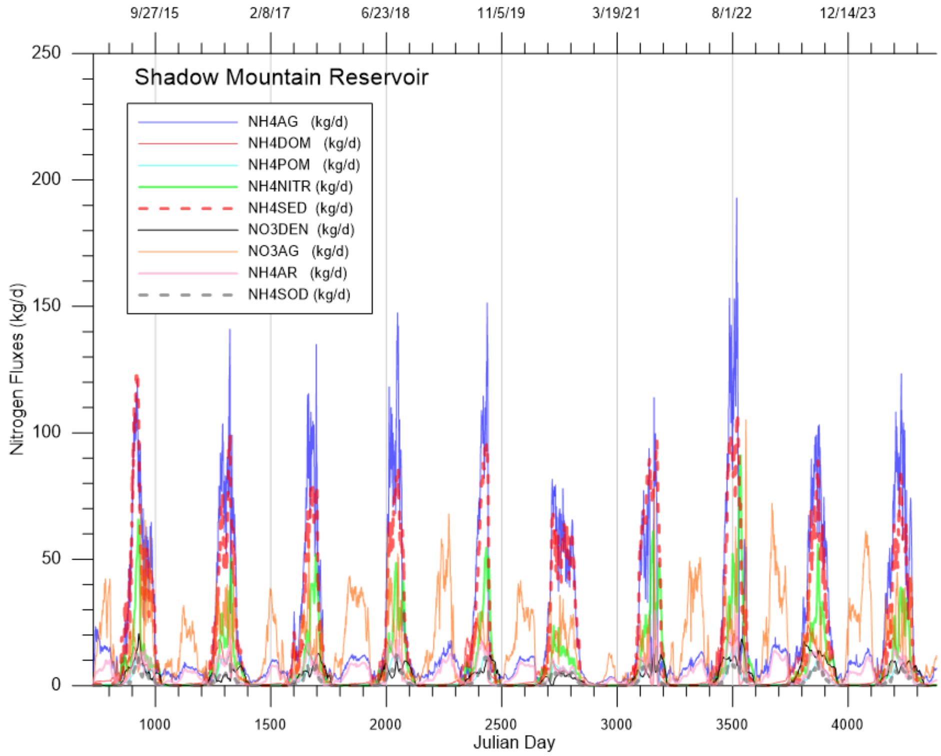


Figure 41. Model predicted nitrogen fluxes in Shadow Mountain Reservoir.

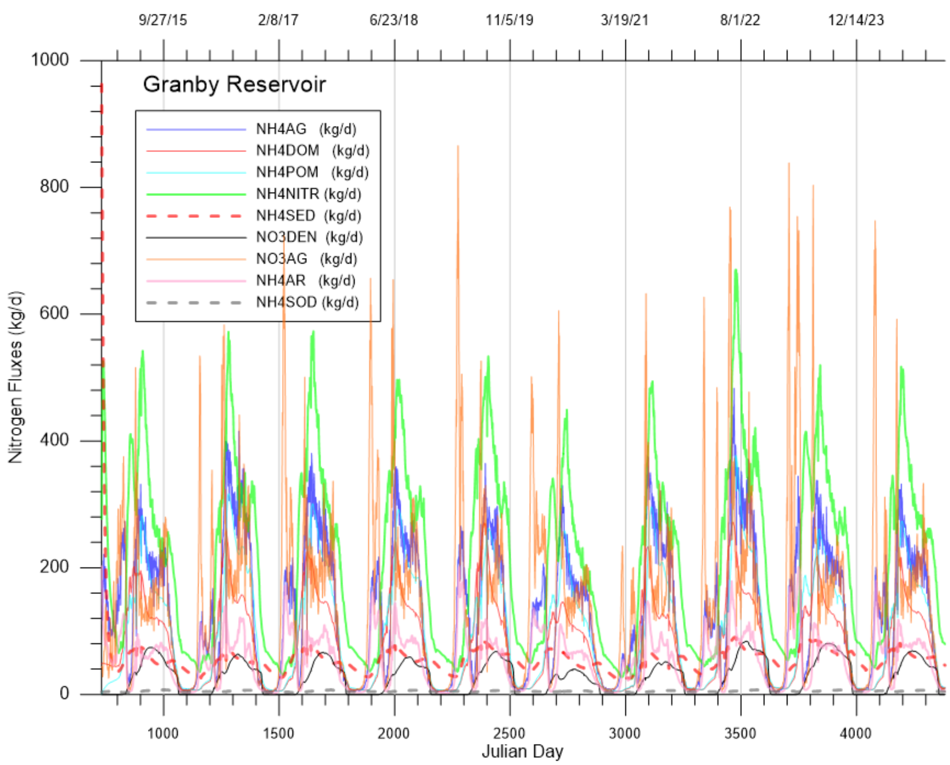


Figure 42. Model predicted nitrogen Fluxes in Granby Reservoir.

APPENDIX B – THREE LAKES MODEL BOUNDARY CONDITION PLOTS

The boundary condition time series input files were plotted and evaluated. The model input files were relatively clean and error free. Comments 46-49 in Table 1 were based on an evaluation of the input files. Figure 43 through Figure 97 show the boundary condition plots.

METEOROLOGICAL INPUTS

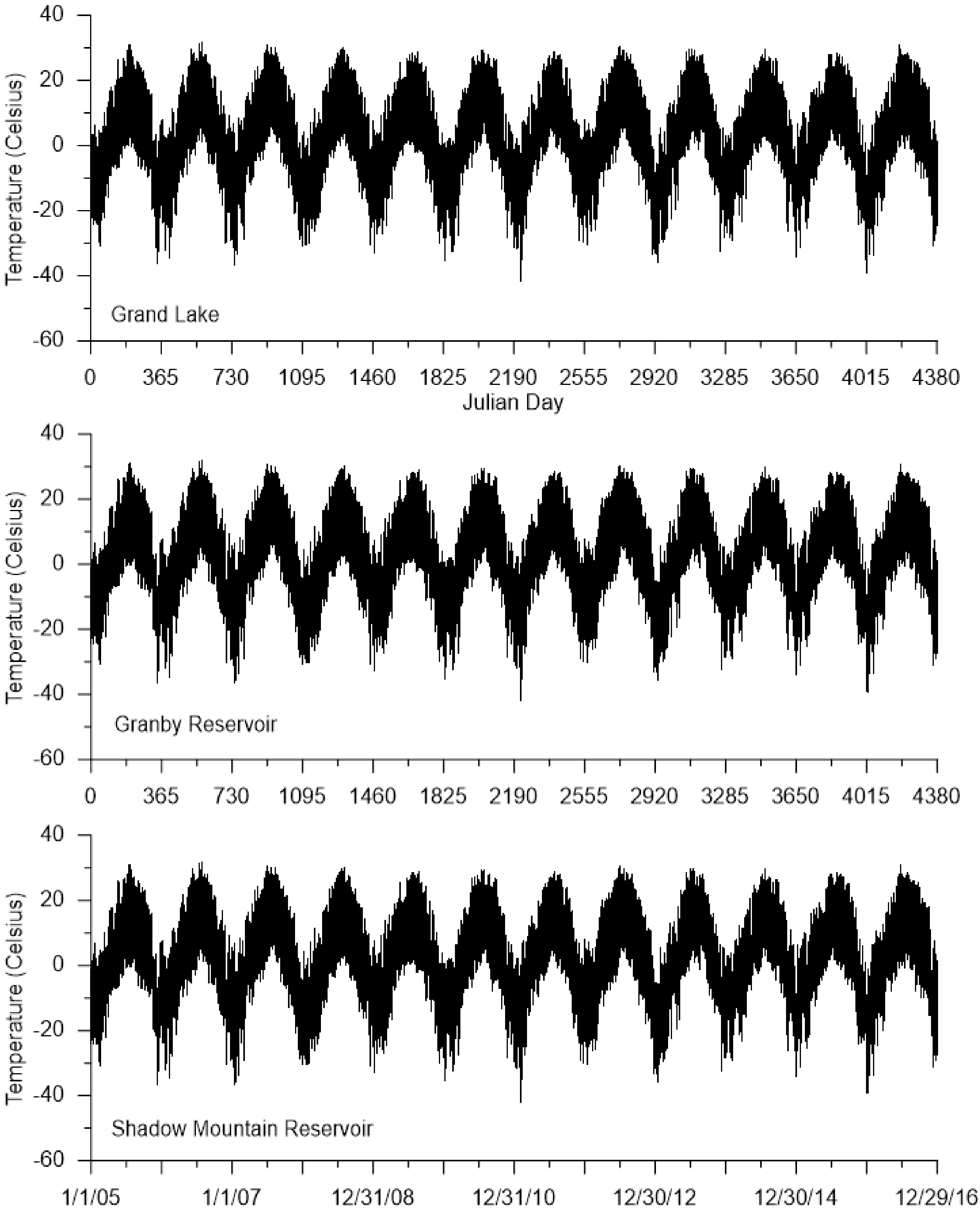


Figure 43. Air temperature in meteorological input files.

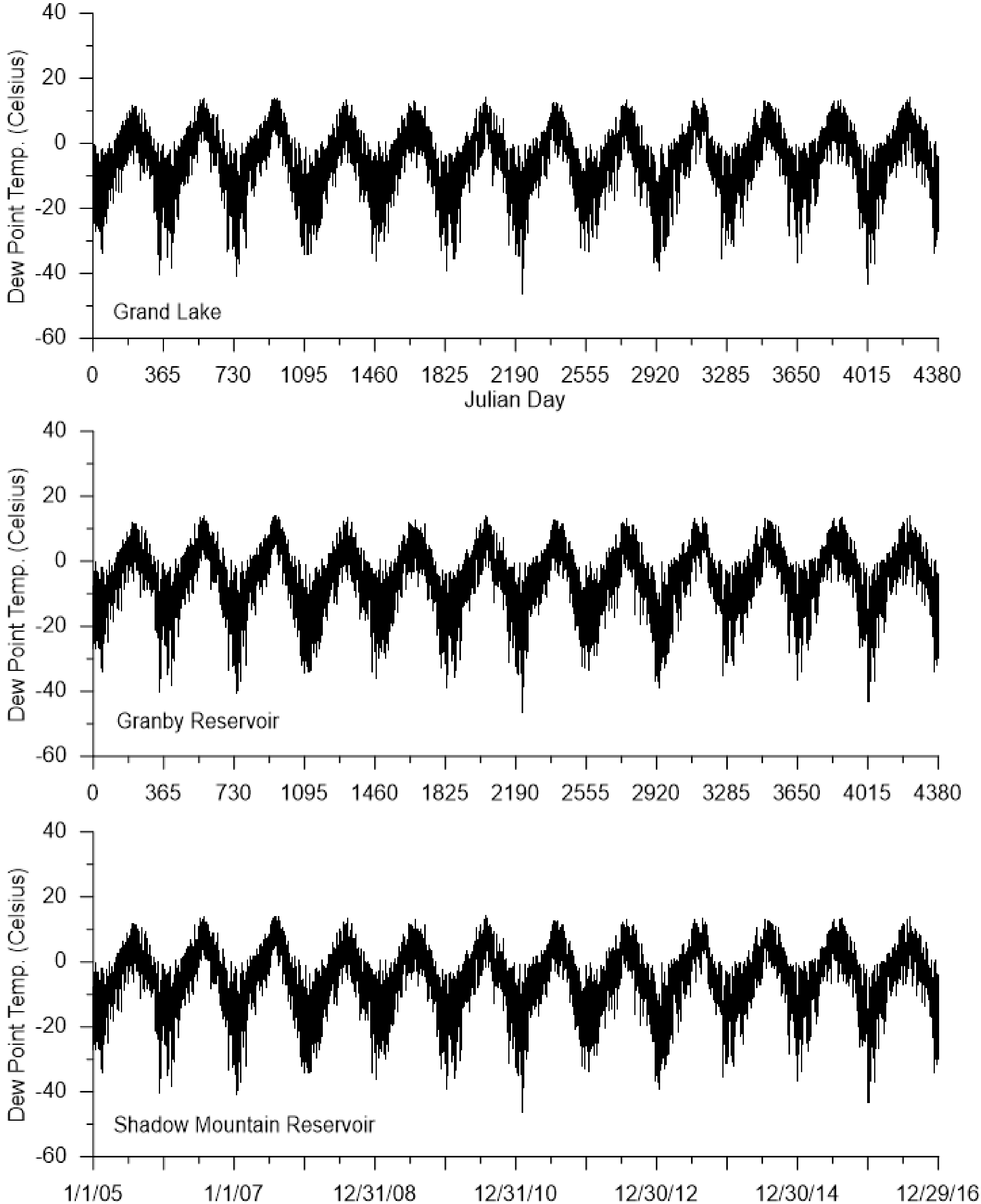


Figure 44. Dew point temperature in meteorological input files.

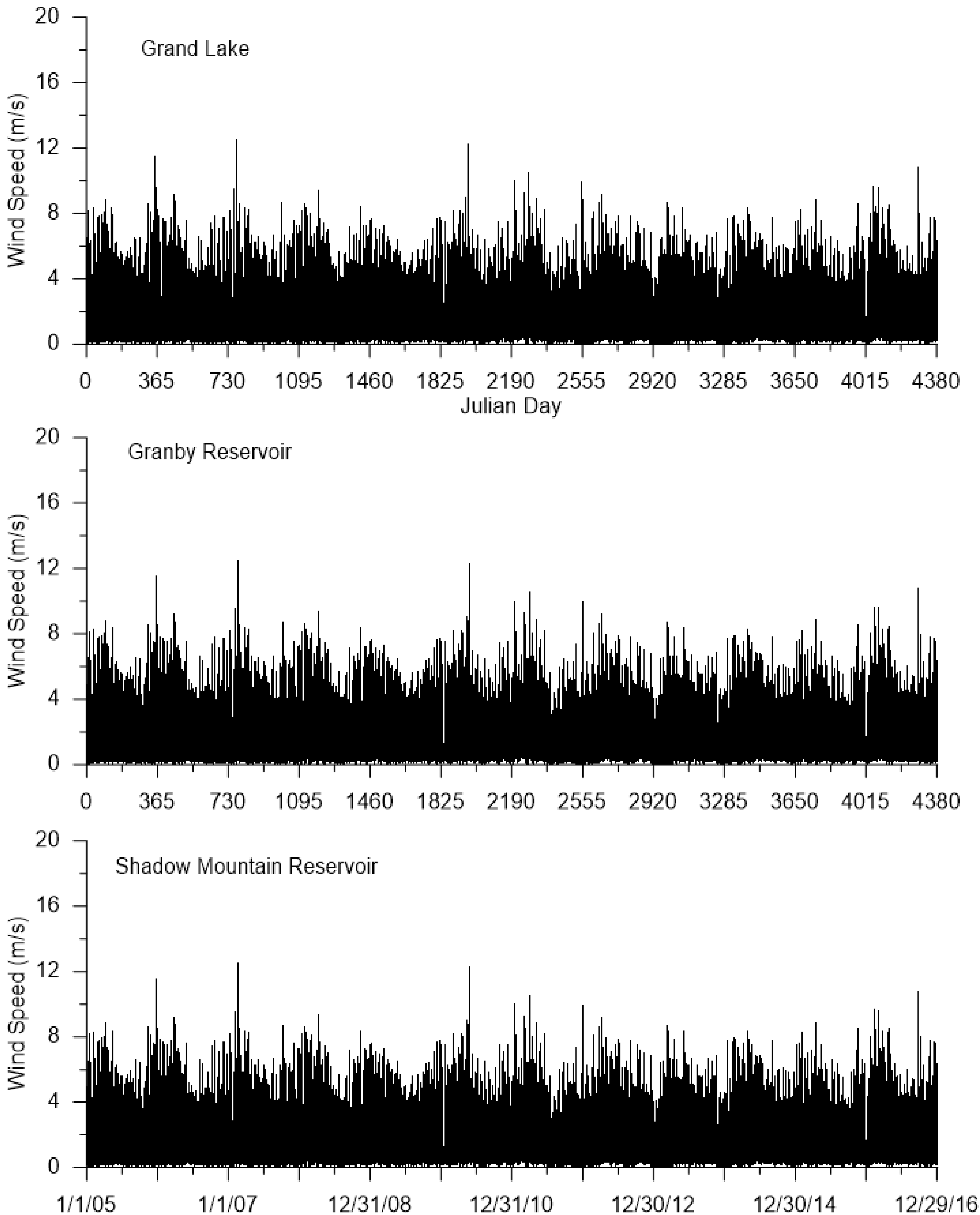


Figure 45. Wind speed in meteorological input files.

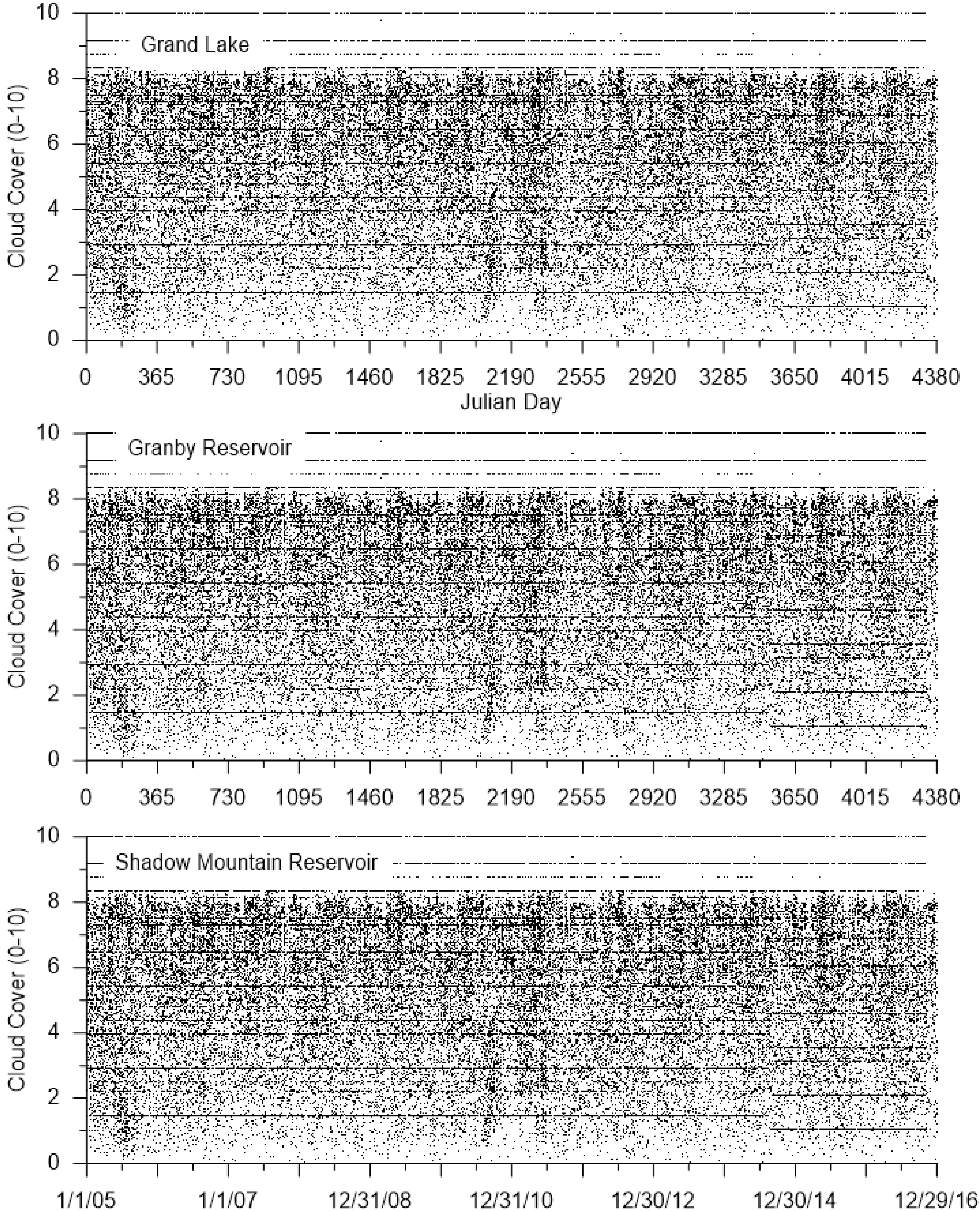


Figure 46. Cloud cover in meteorological input files.

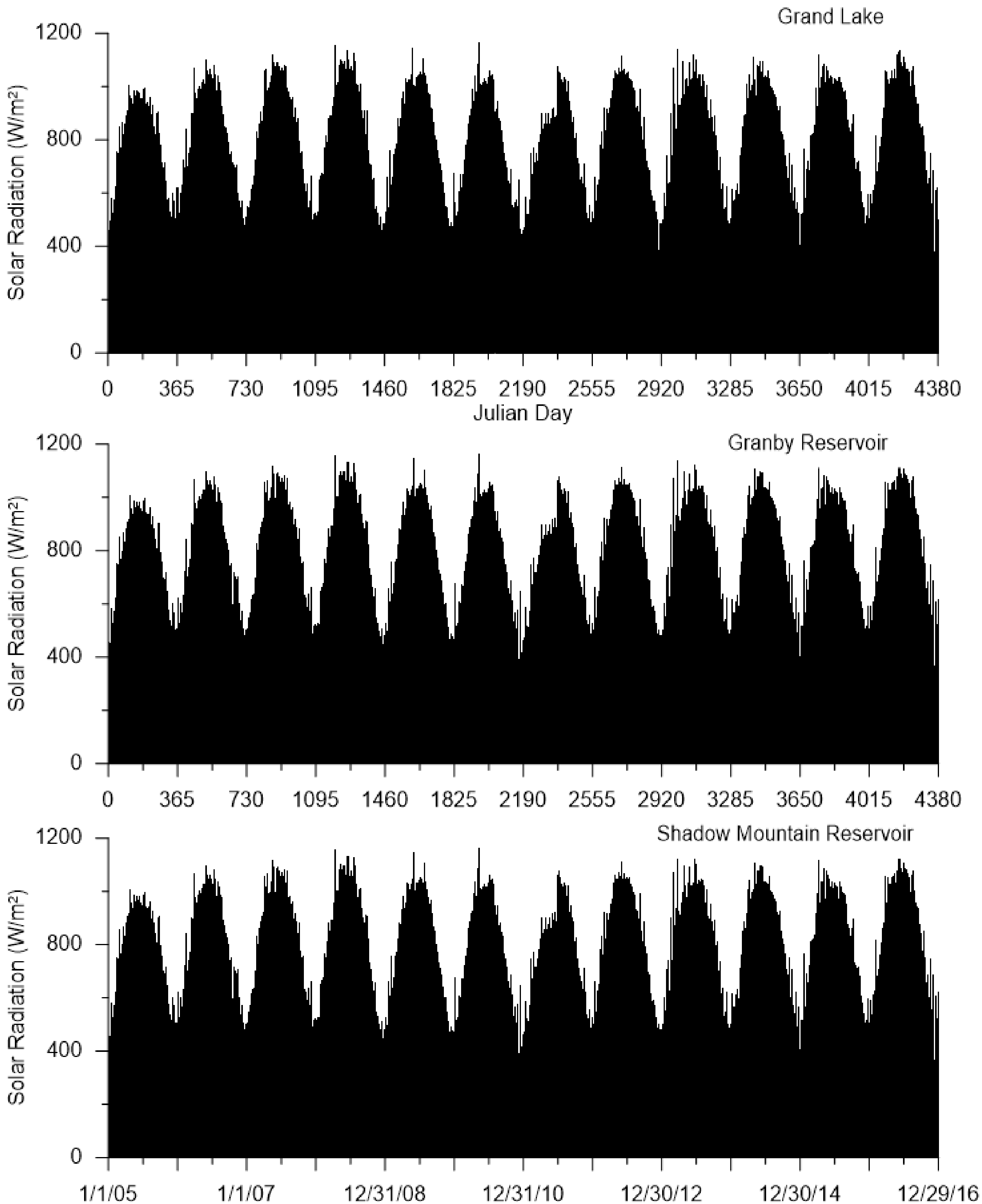


Figure 47. Solar radiation in meteorological input files.

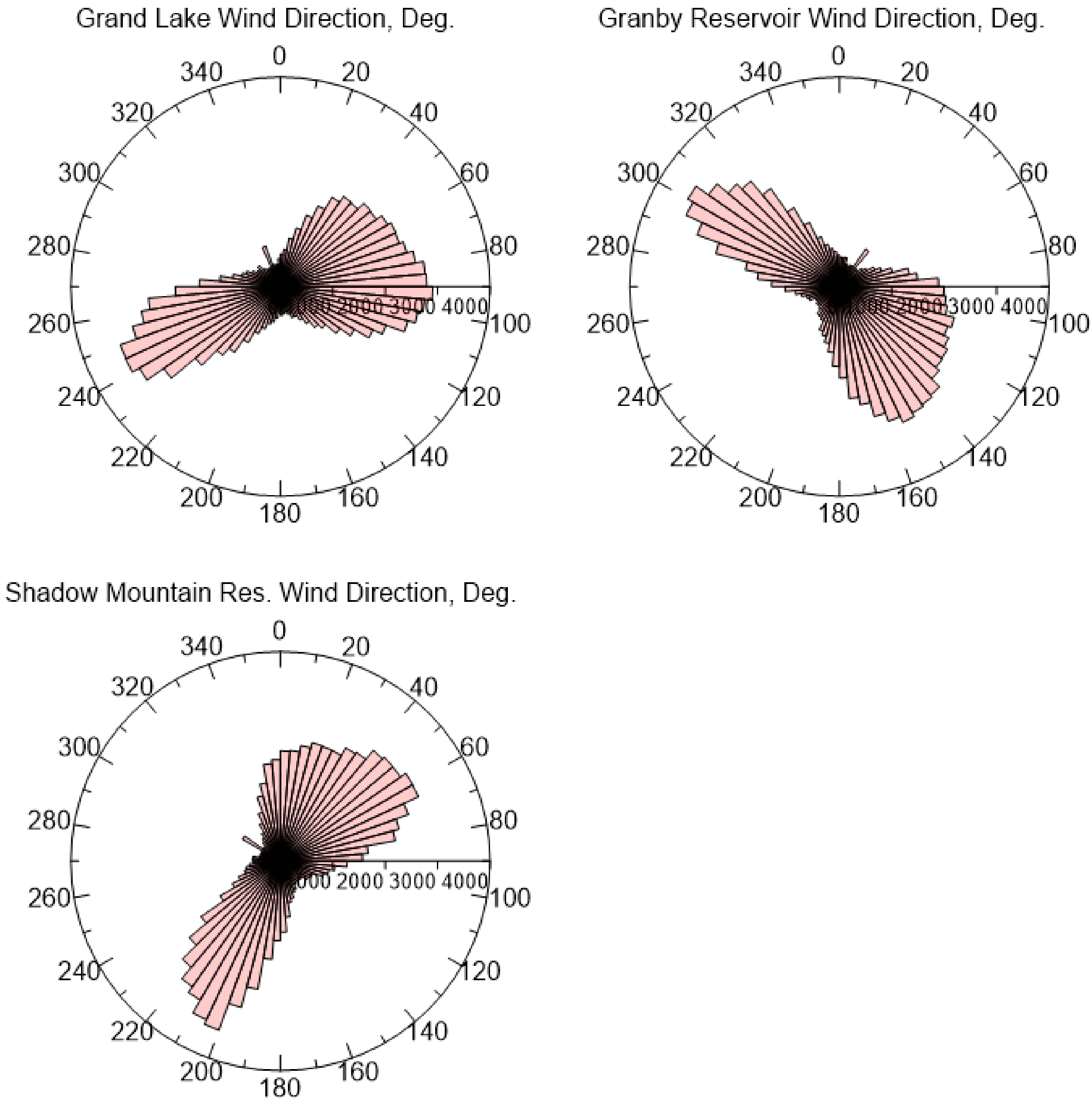


Figure 48. Wind direction in meteorological input files.

PRECIPITATION

RATE

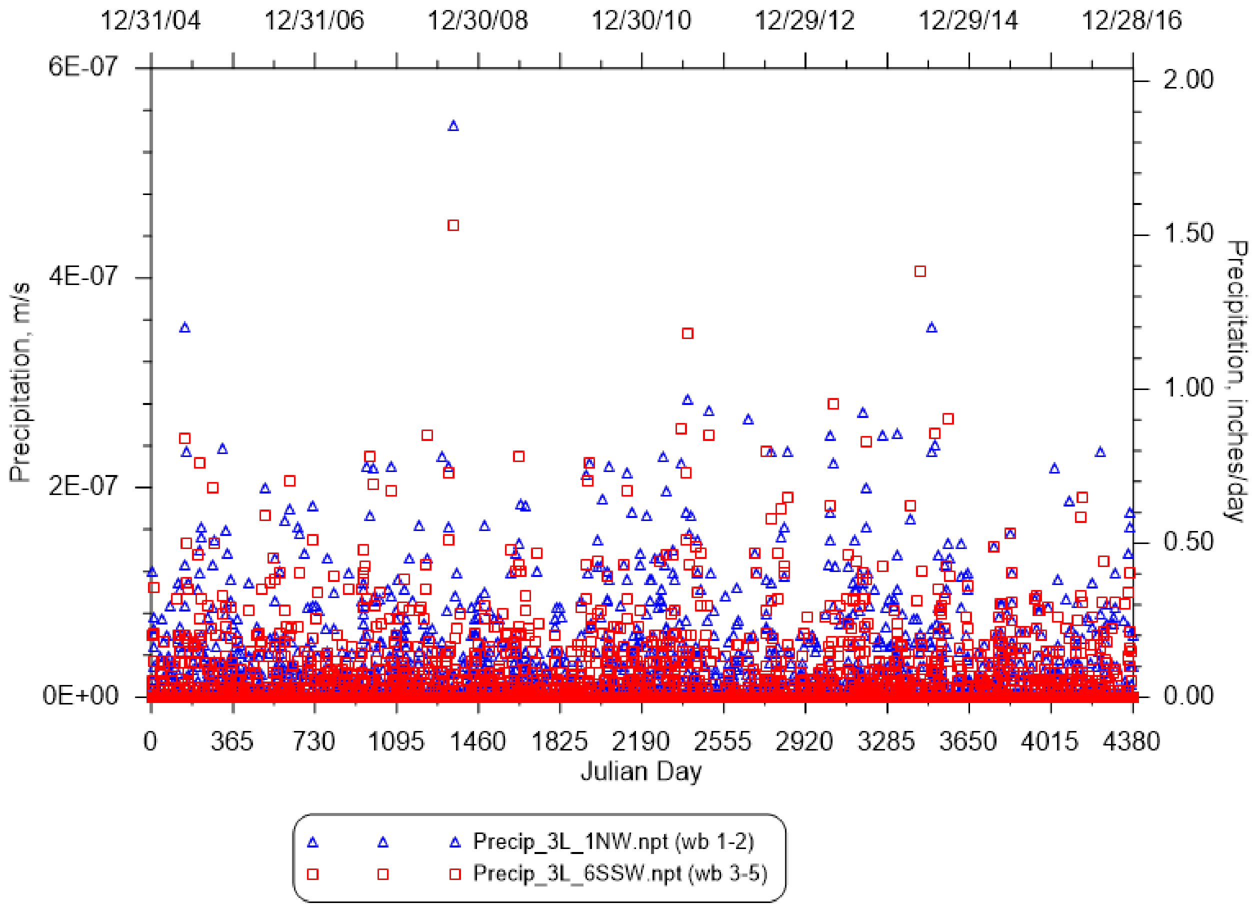


Figure 49. Precipitation rate.

Temperature

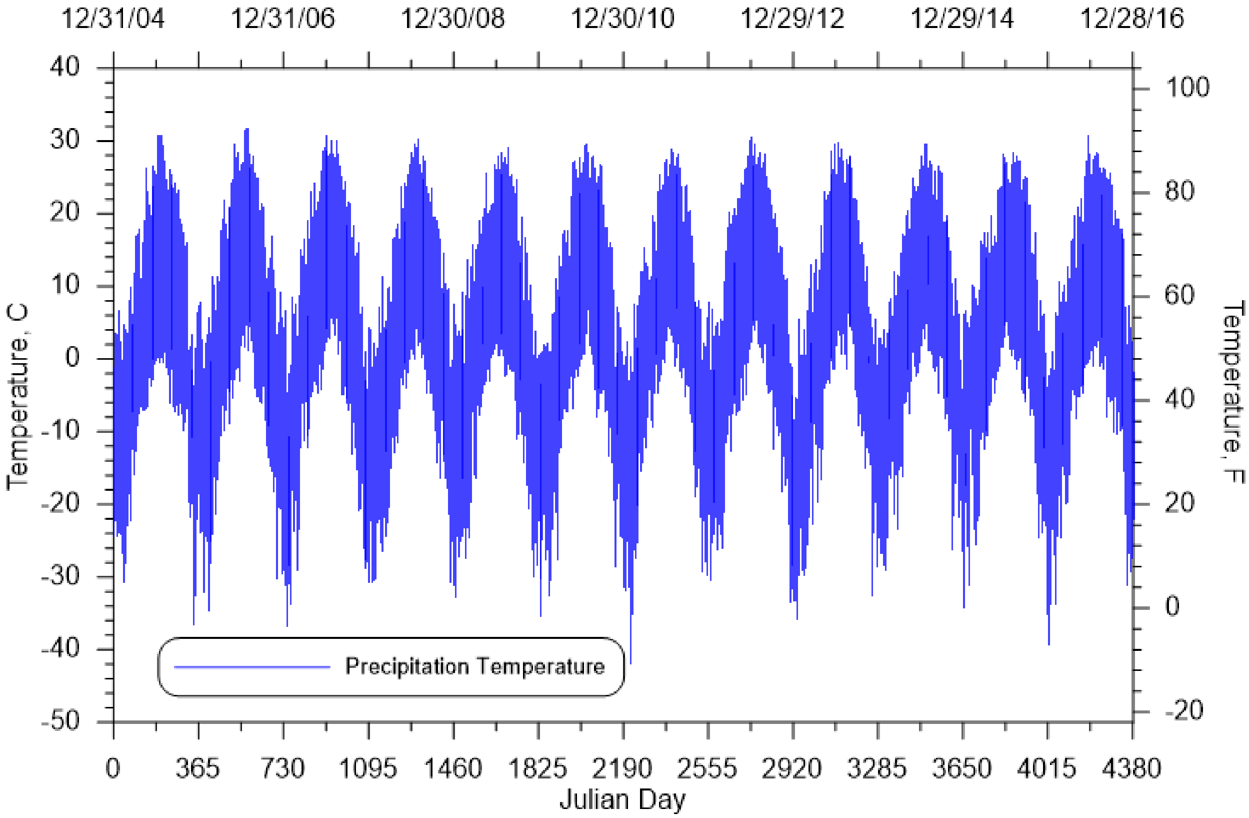


Figure 50. Precipitation temperature.

CONSTITUENTS

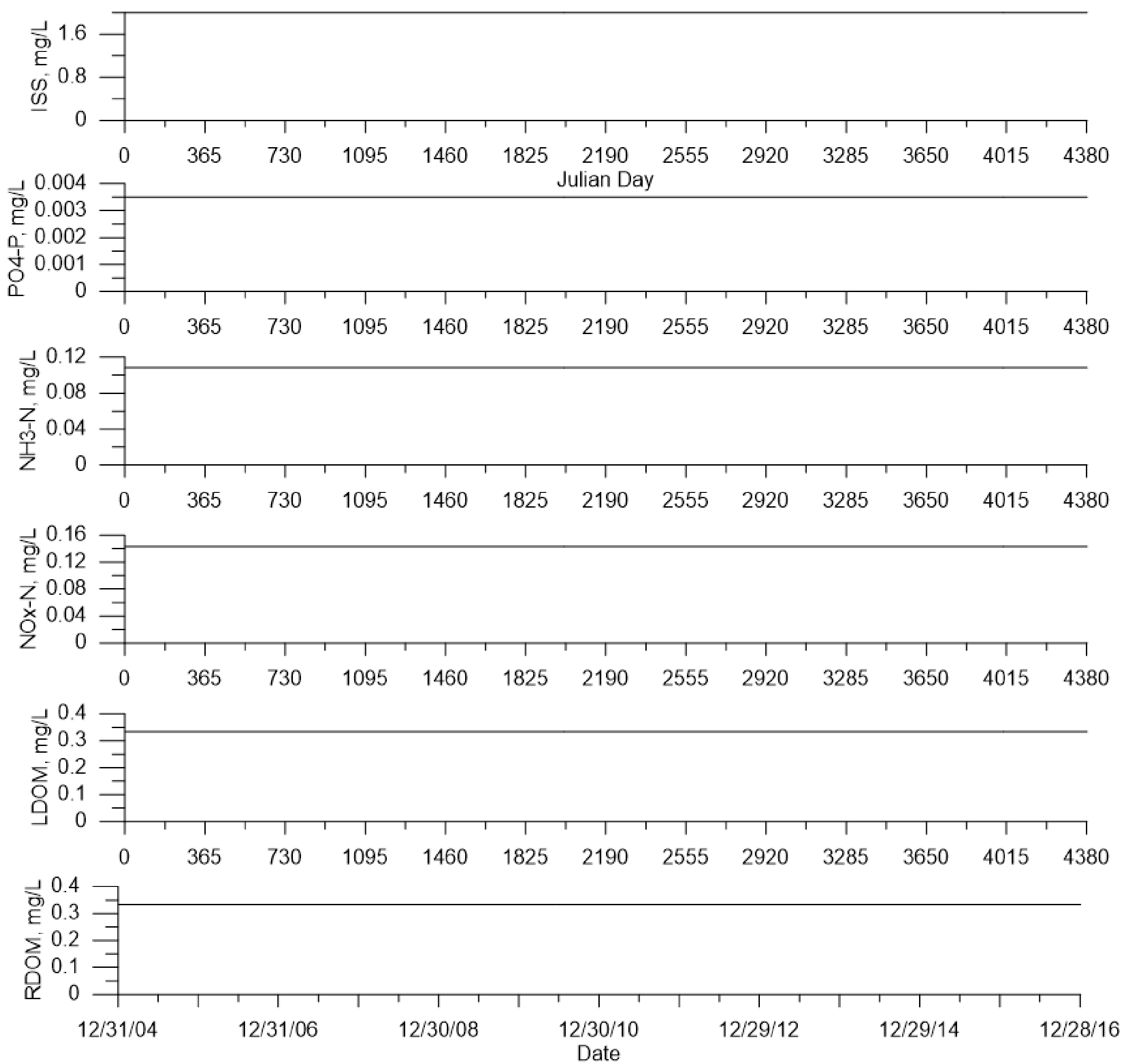


Figure 51. Precipitation constituents 1 (Solid flat lines imply a constant value of the constituent over time).

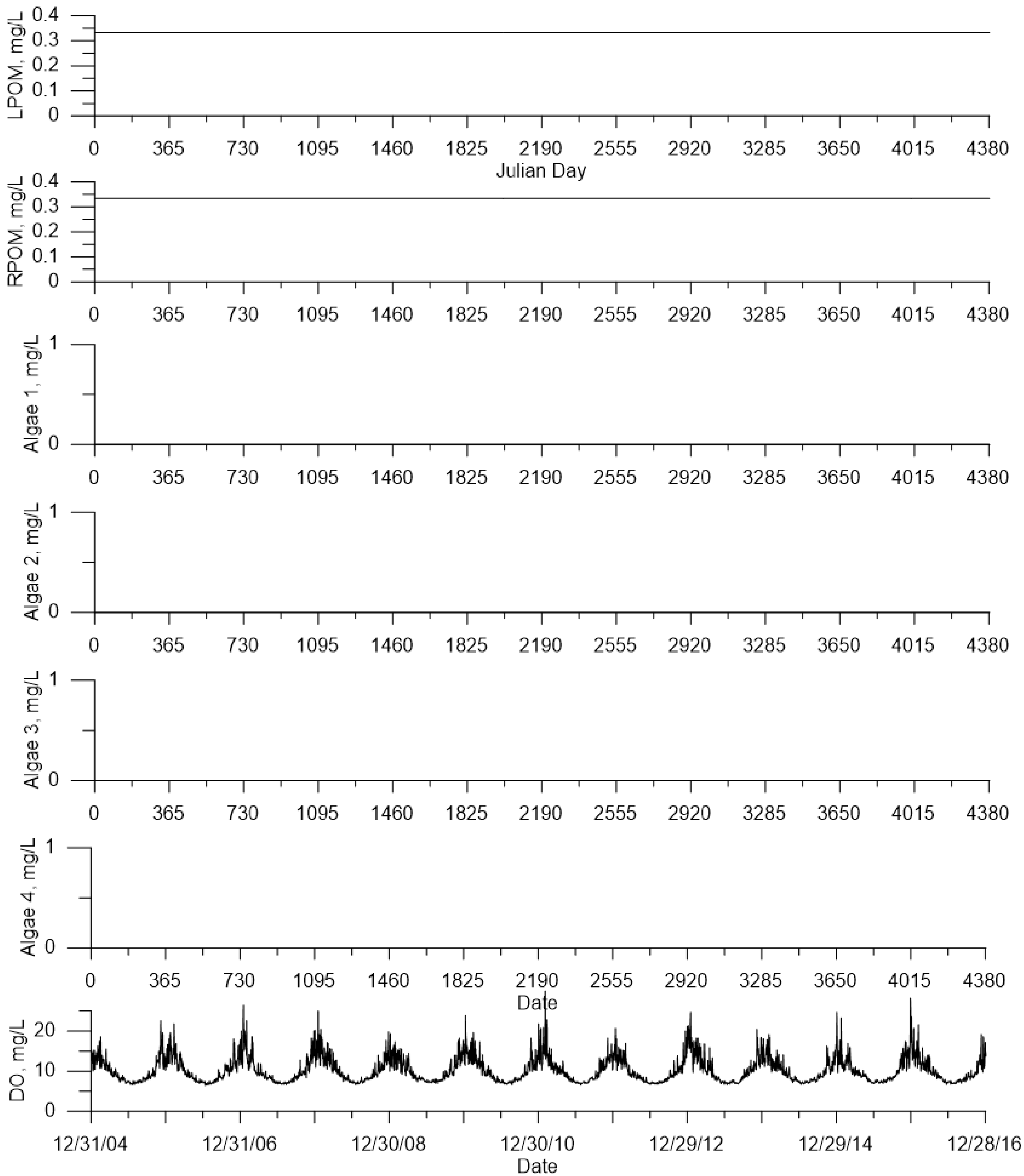


Figure 52. Precipitation constituents 2 (Solid flat lines imply a constant value of the constituent over time).

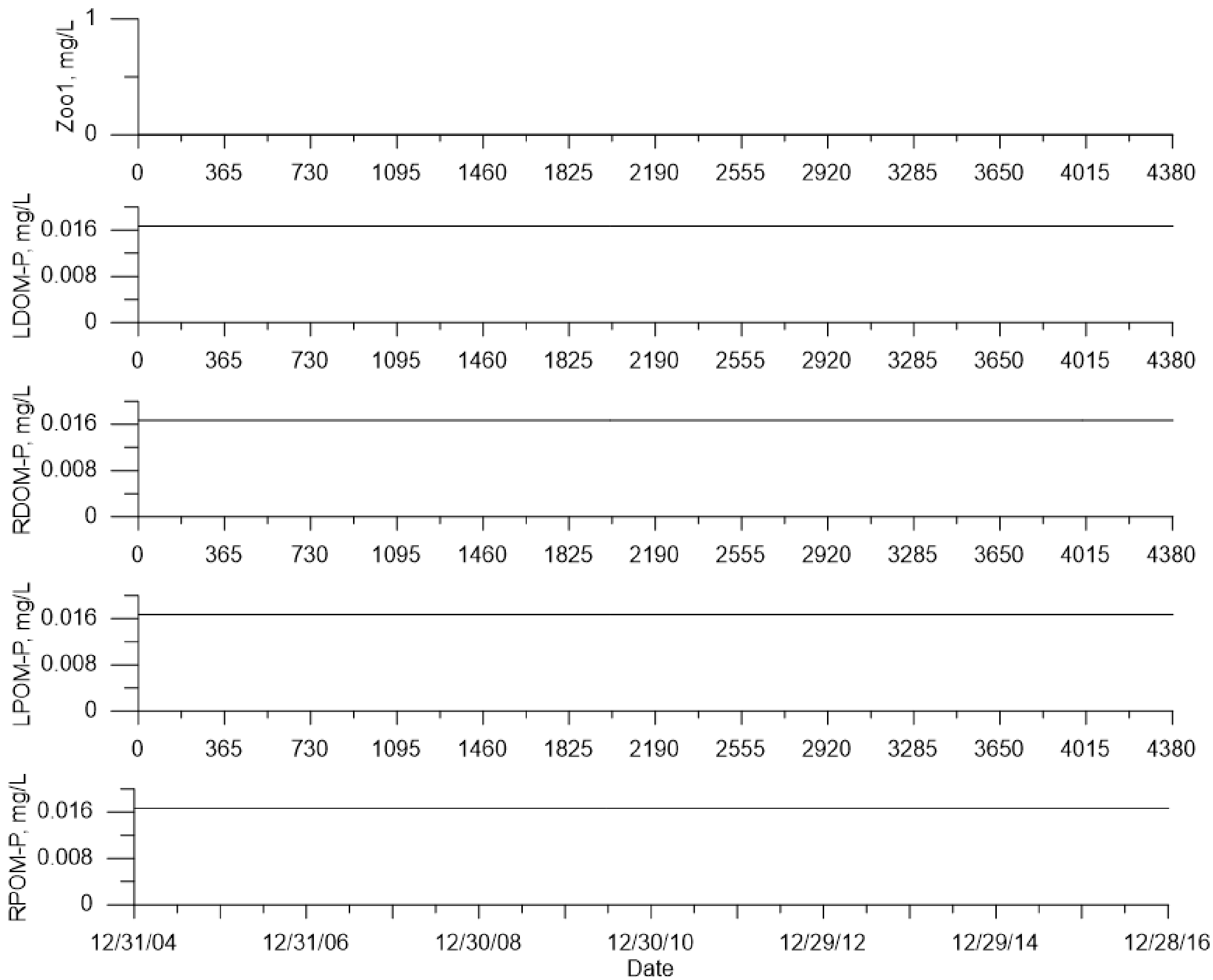


Figure 53. Precipitation constituents 3 (Solid flat lines imply a constant value of the constituent over time).

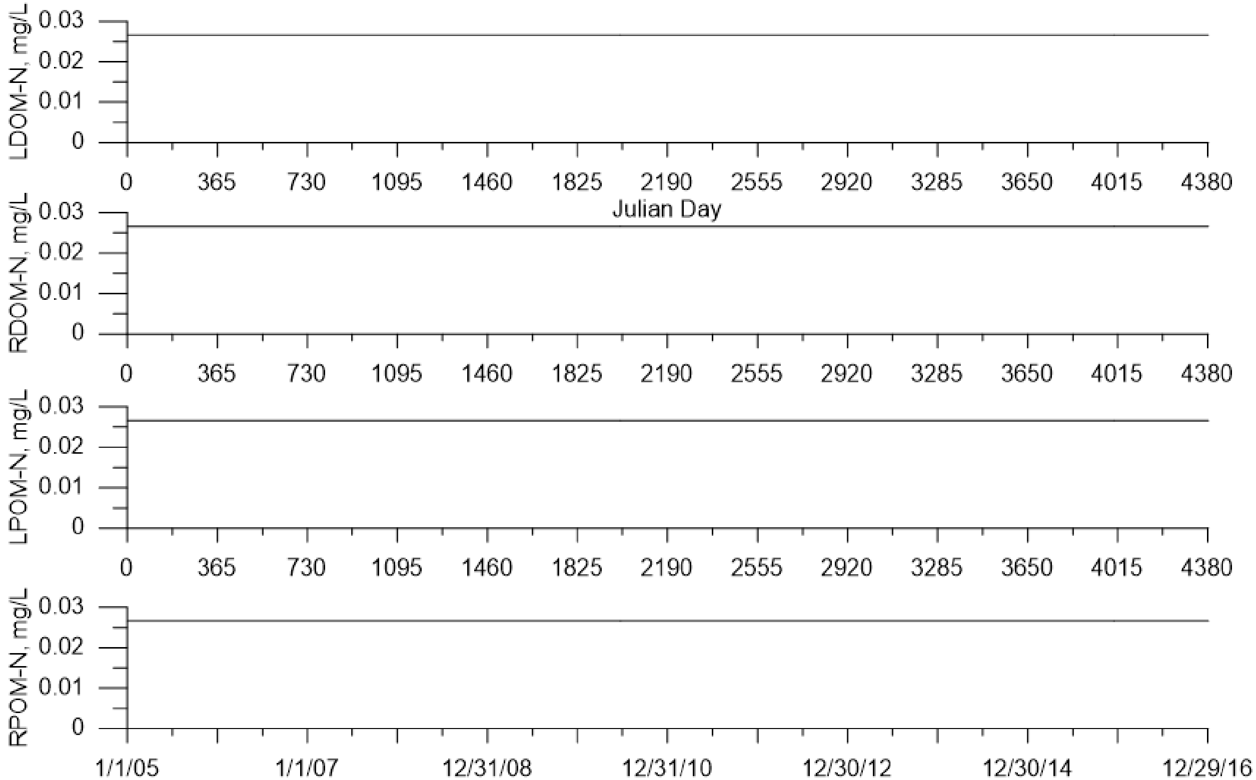


Figure 54. Precipitation constituents 4 (Solid flat lines imply a constant value of the constituent over time).

Branch Inflows and Tributaries

Flow Rate

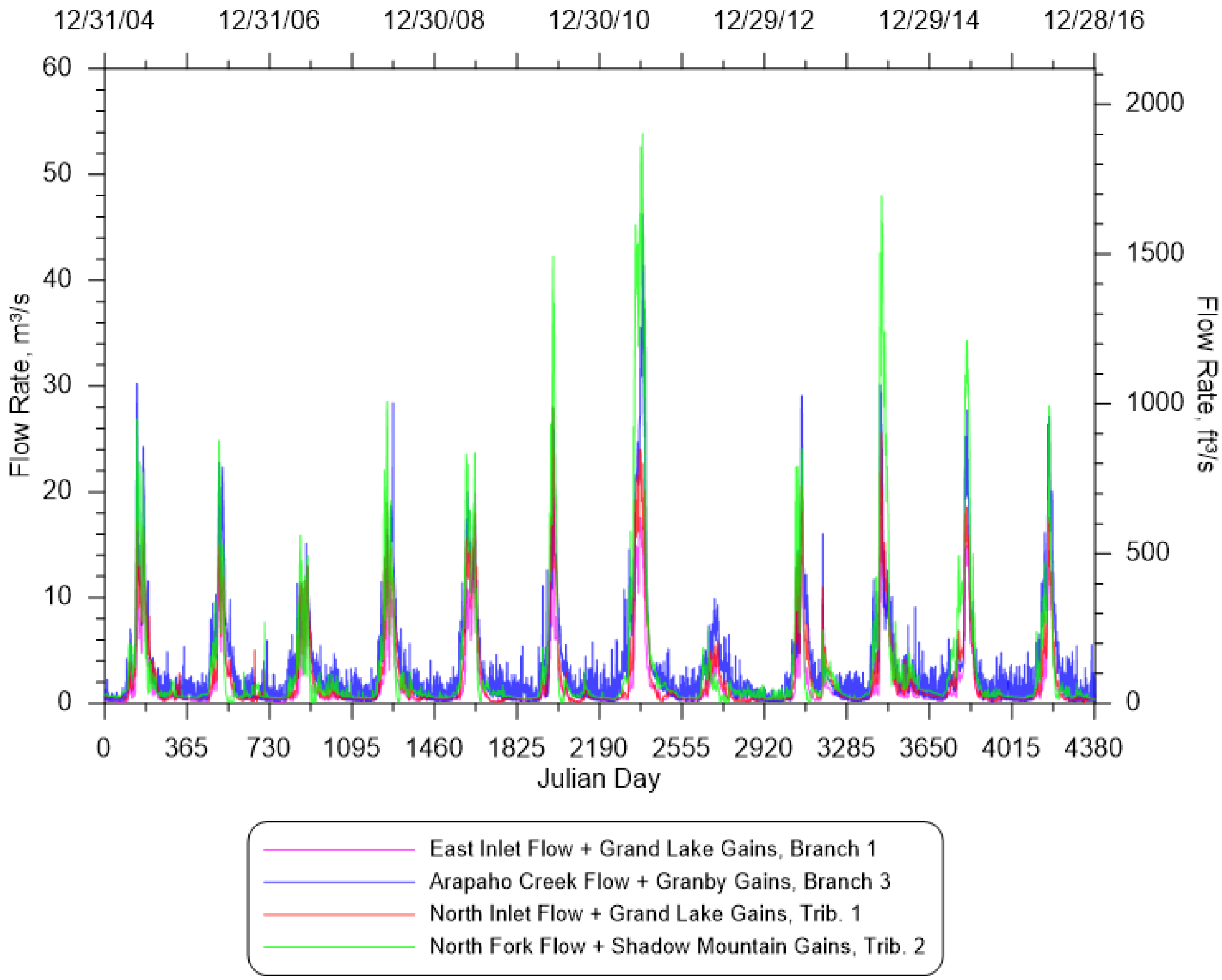


Figure 55. Branch and tributary inflow rates (1).

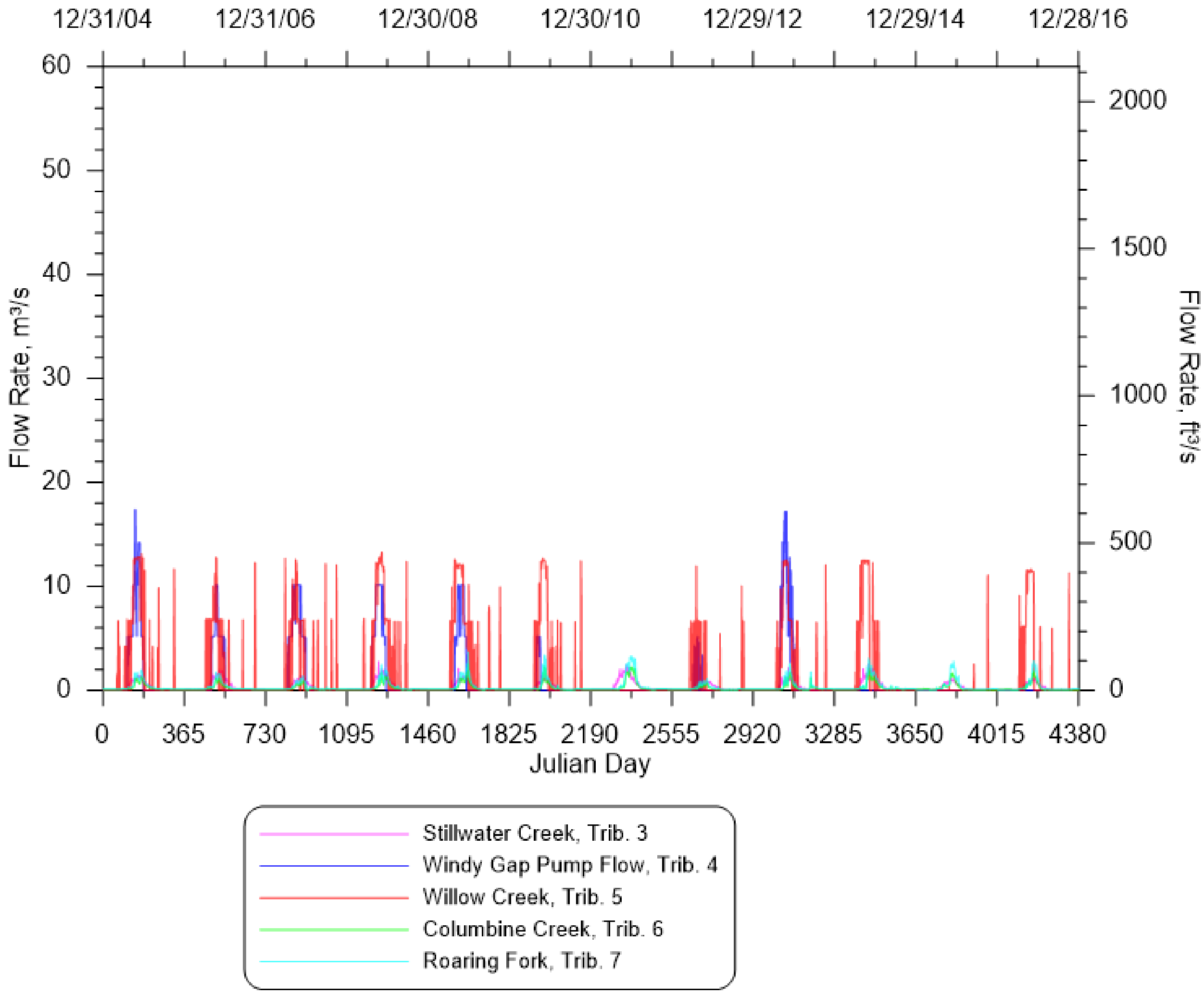


Figure 56. Branch and tributary inflow rates (2).

TEMPERATURE

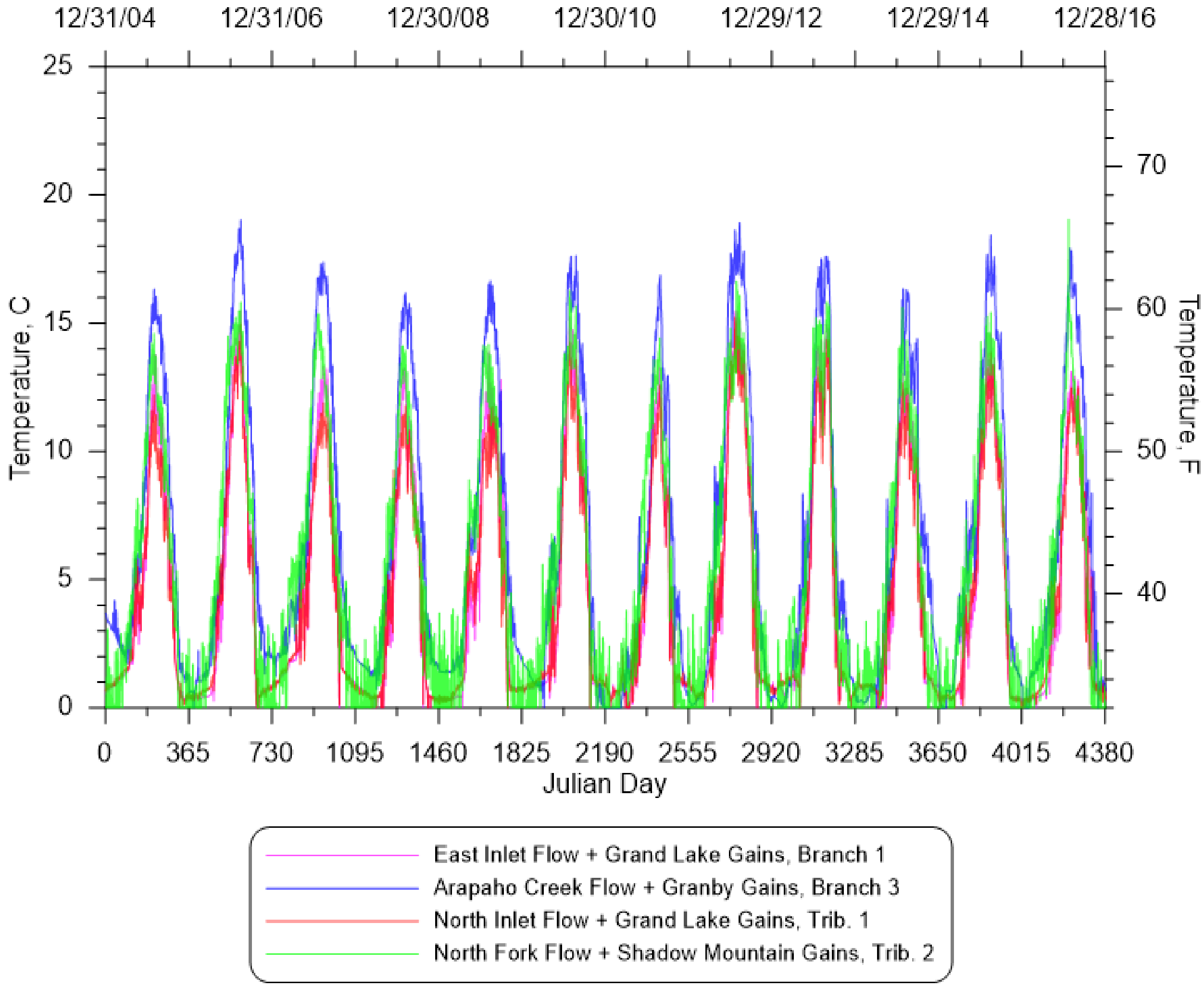


Figure 57. Branch and tributary inflow temperatures (1).

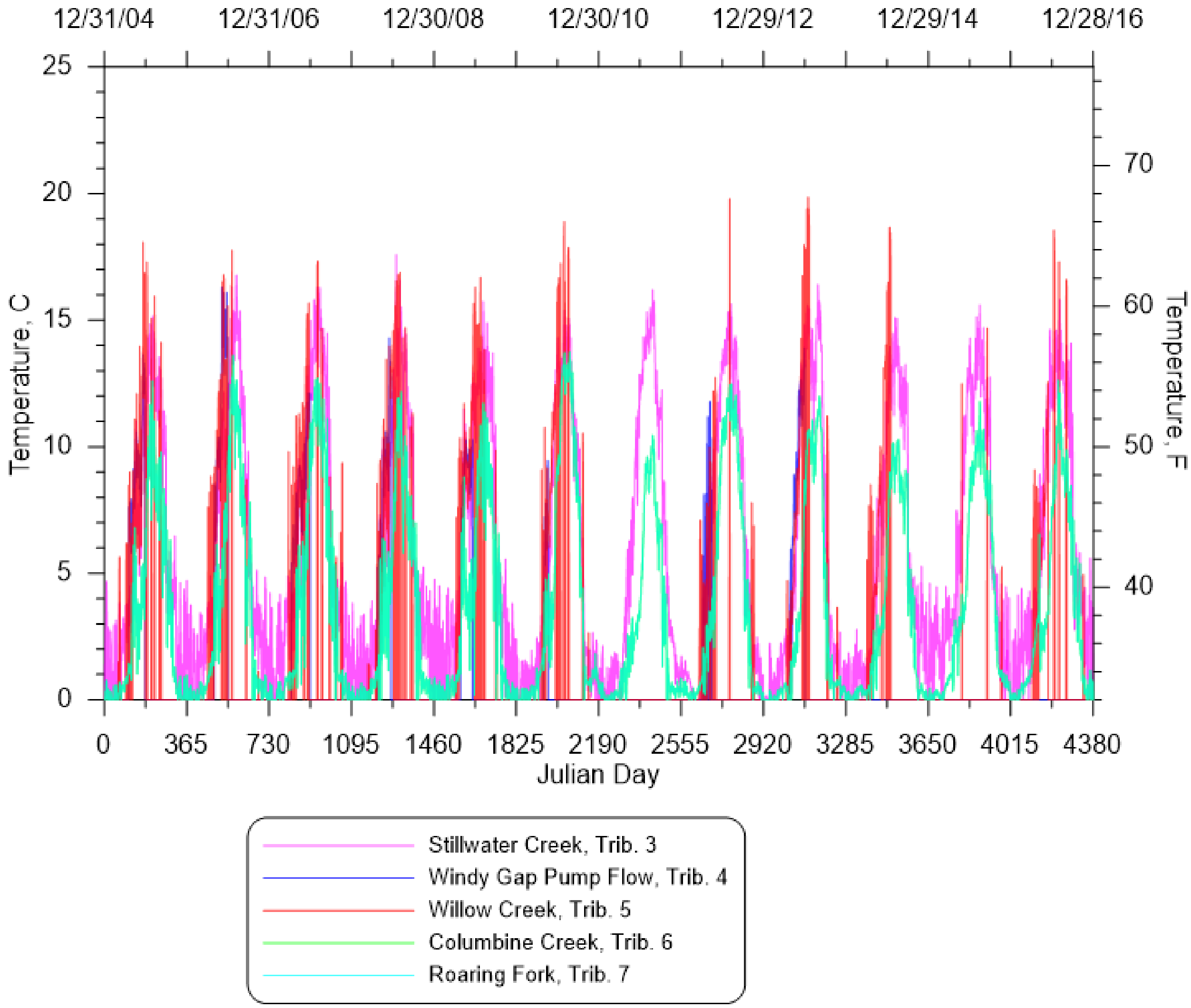


Figure 58. Branch and tributary inflow temperatures (2).

CONSTITUENTS

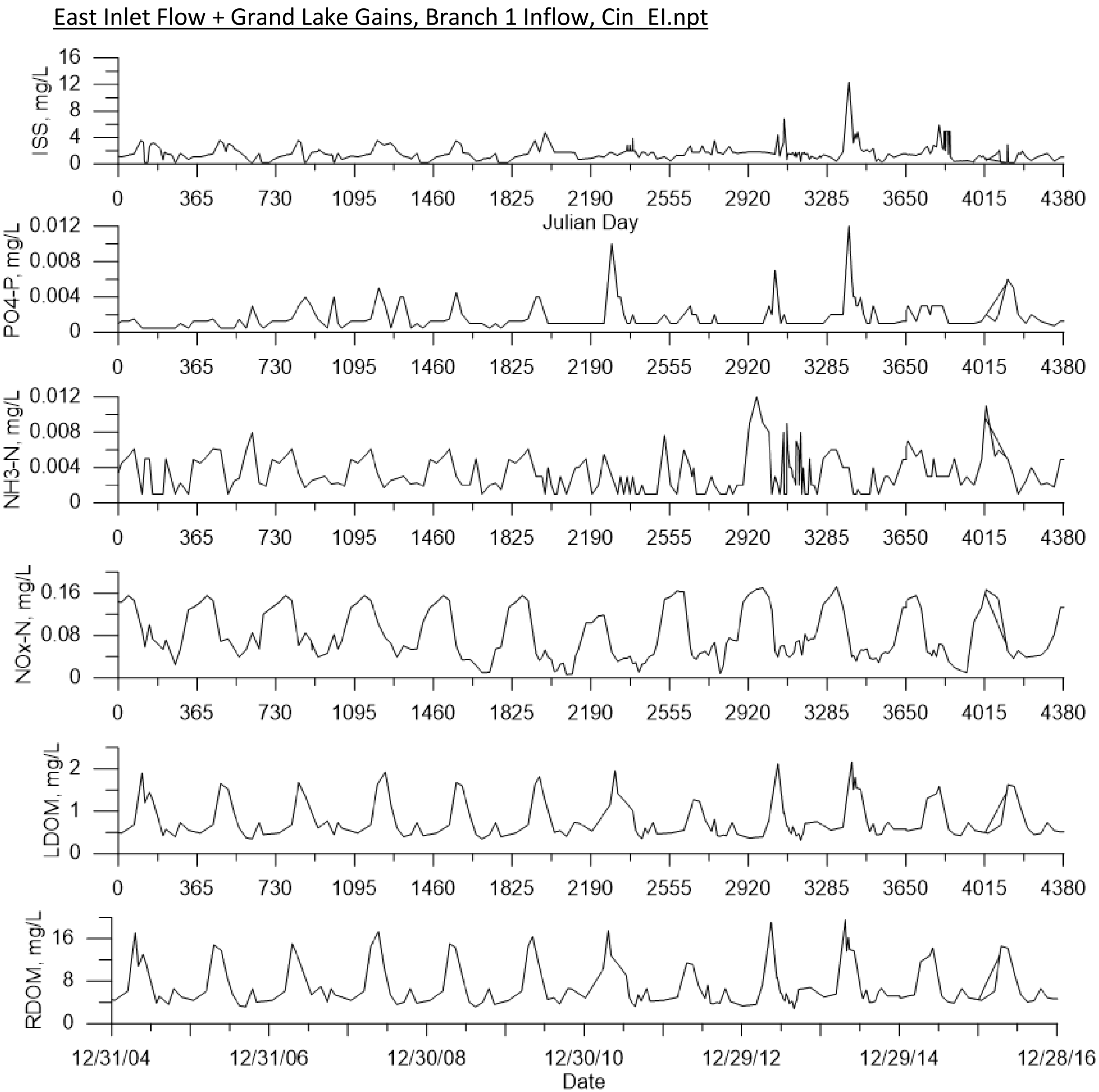


Figure 59. East inlet inflow constituent concentrations (1).

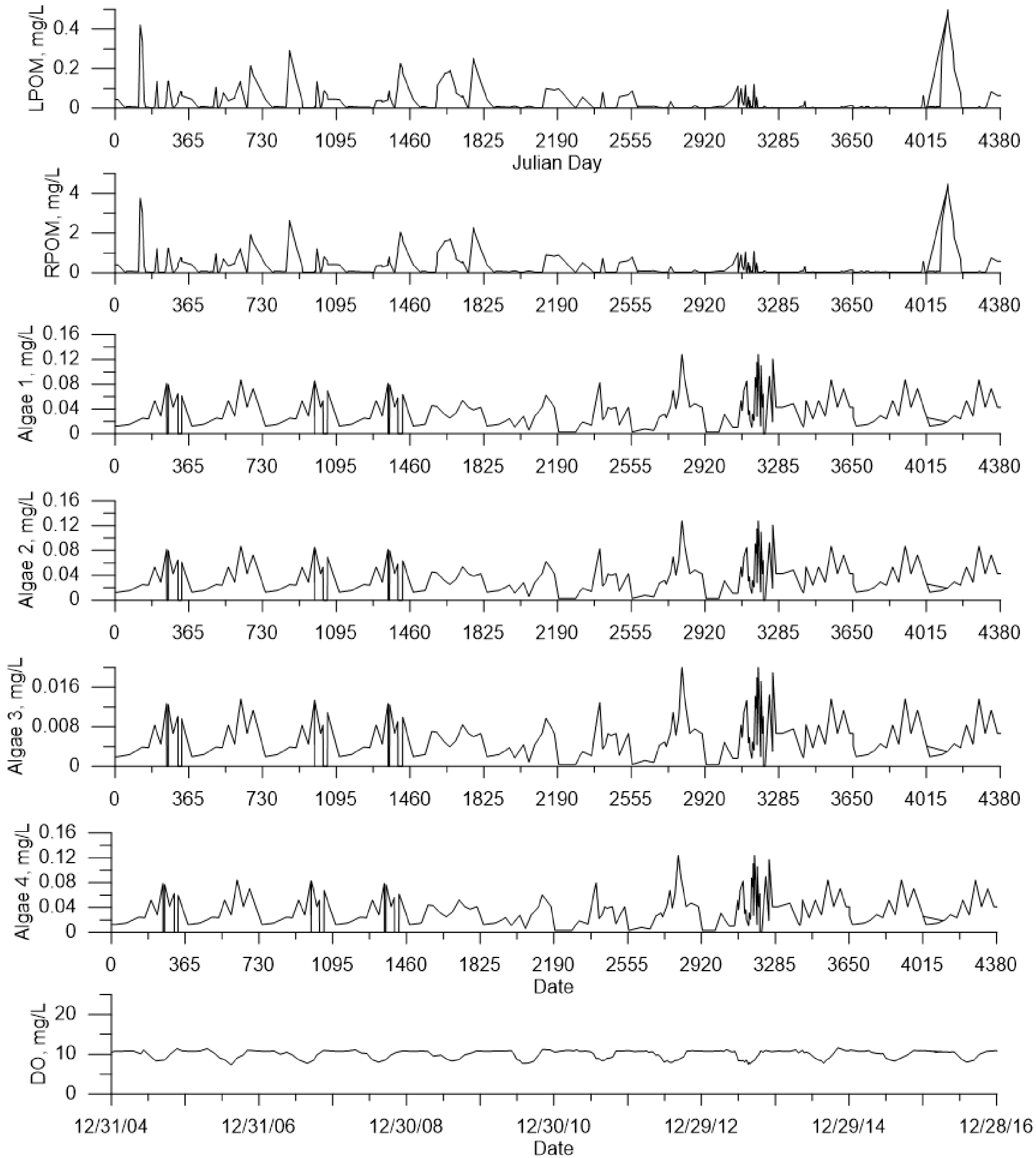


Figure 60. East inlet inflow constituent concentrations (2).

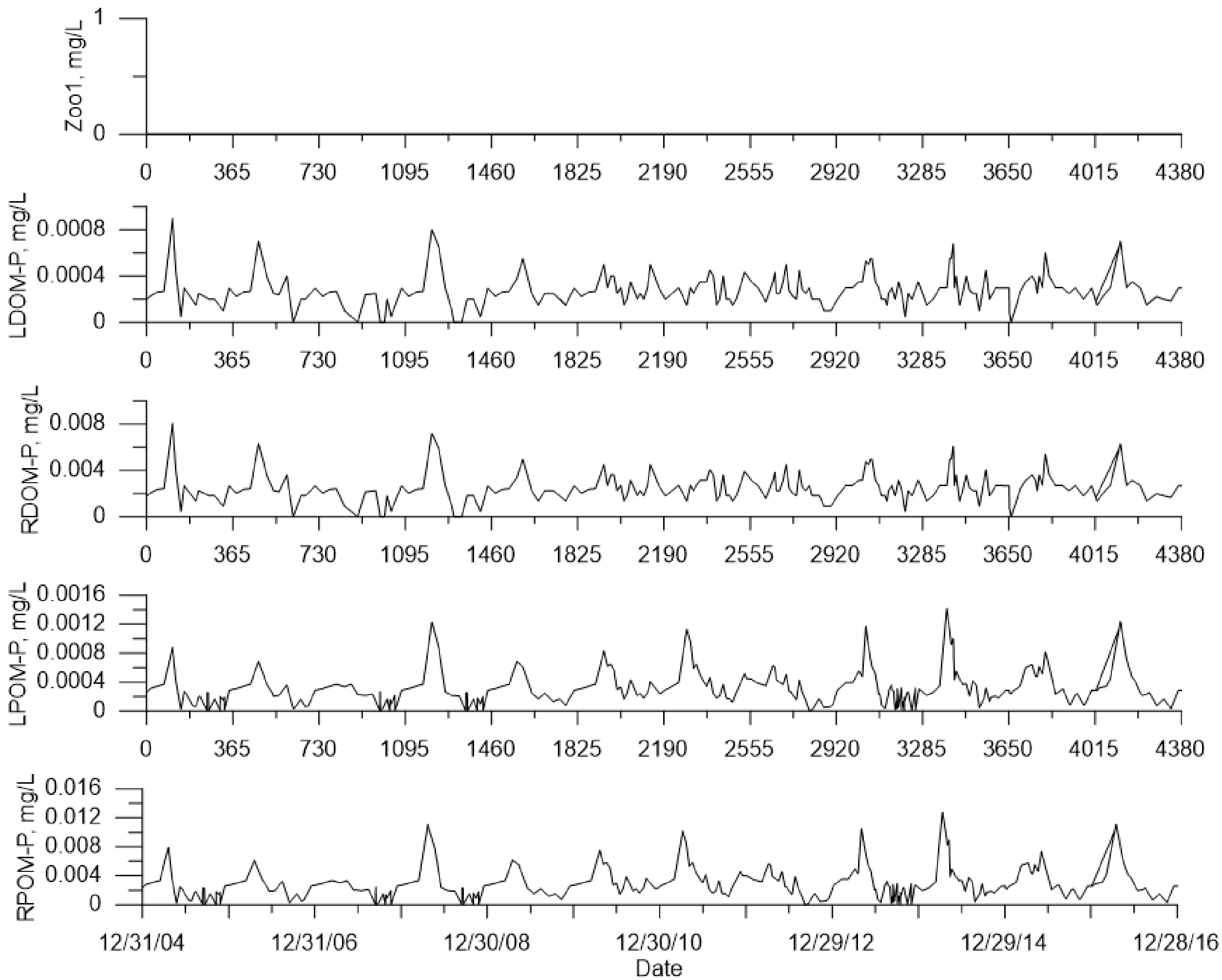


Figure 61. East inlet inflow constituent concentrations (3).

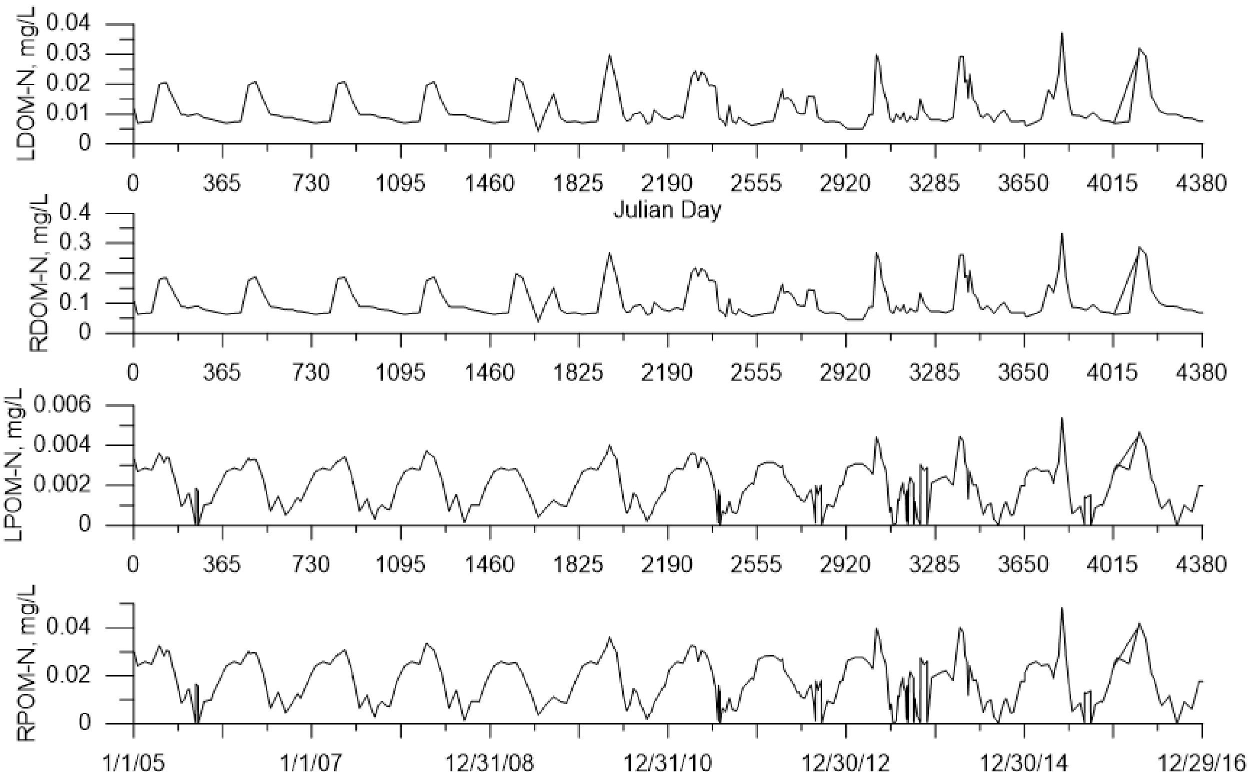


Figure 62. East inlet inflow constituent concentrations (4).

Arapaho Creek Flow + Granby Gains, Branch 3 Inflow, Cin_AC.npt

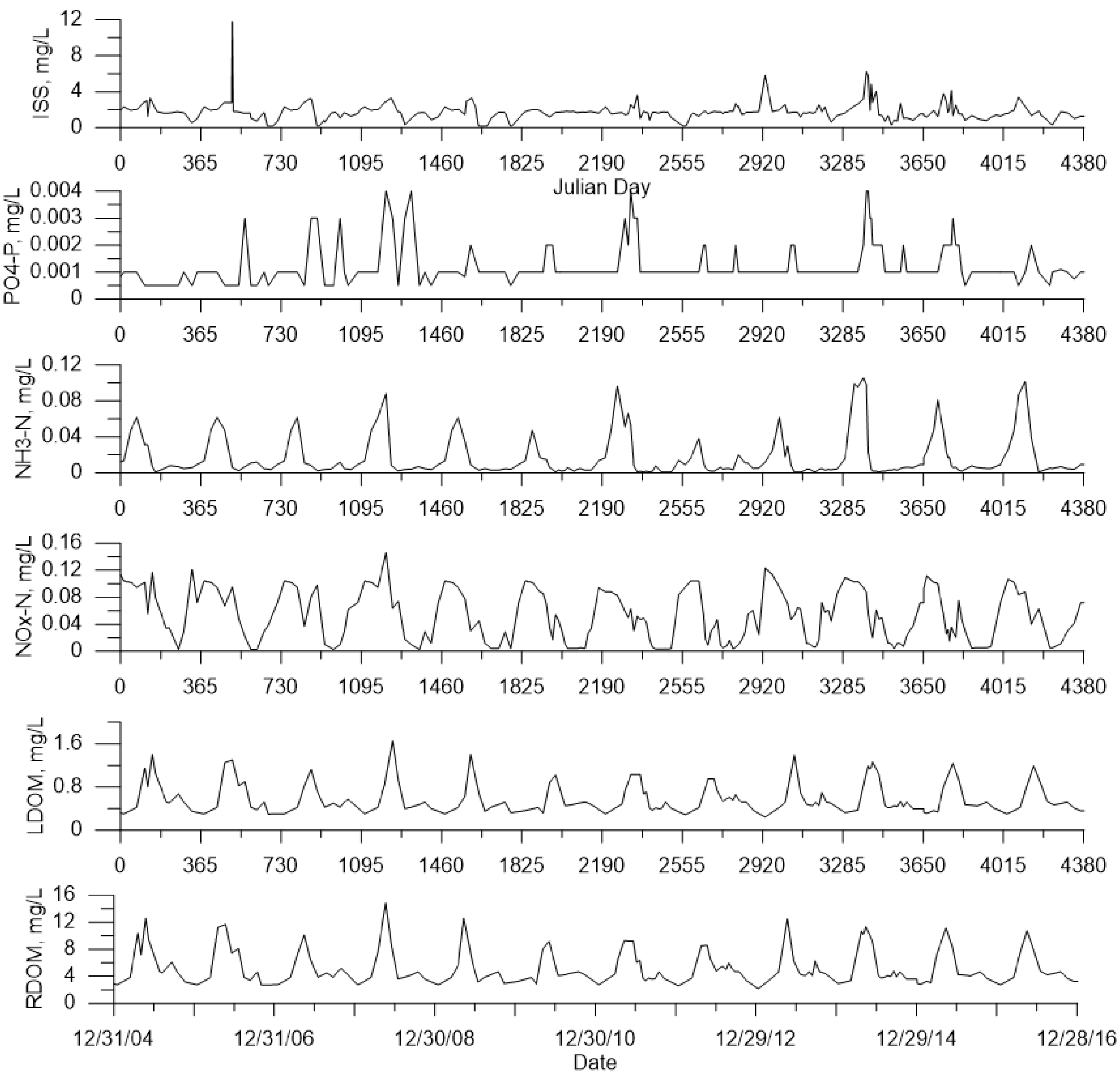


Figure 63. Arapaho Creek constituent concentrations (1).

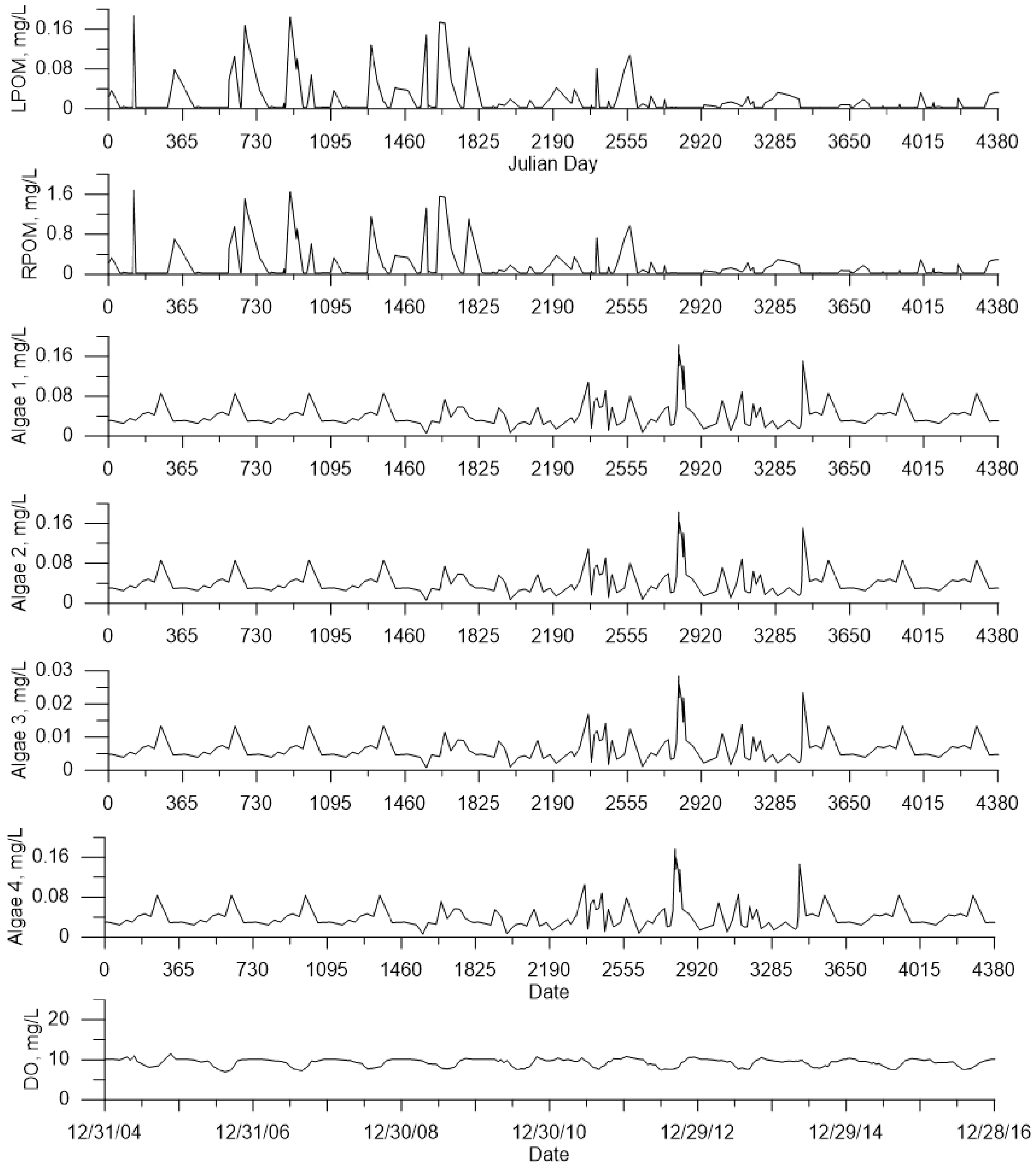


Figure 64. Arapaho Creek constituent concentrations (2).

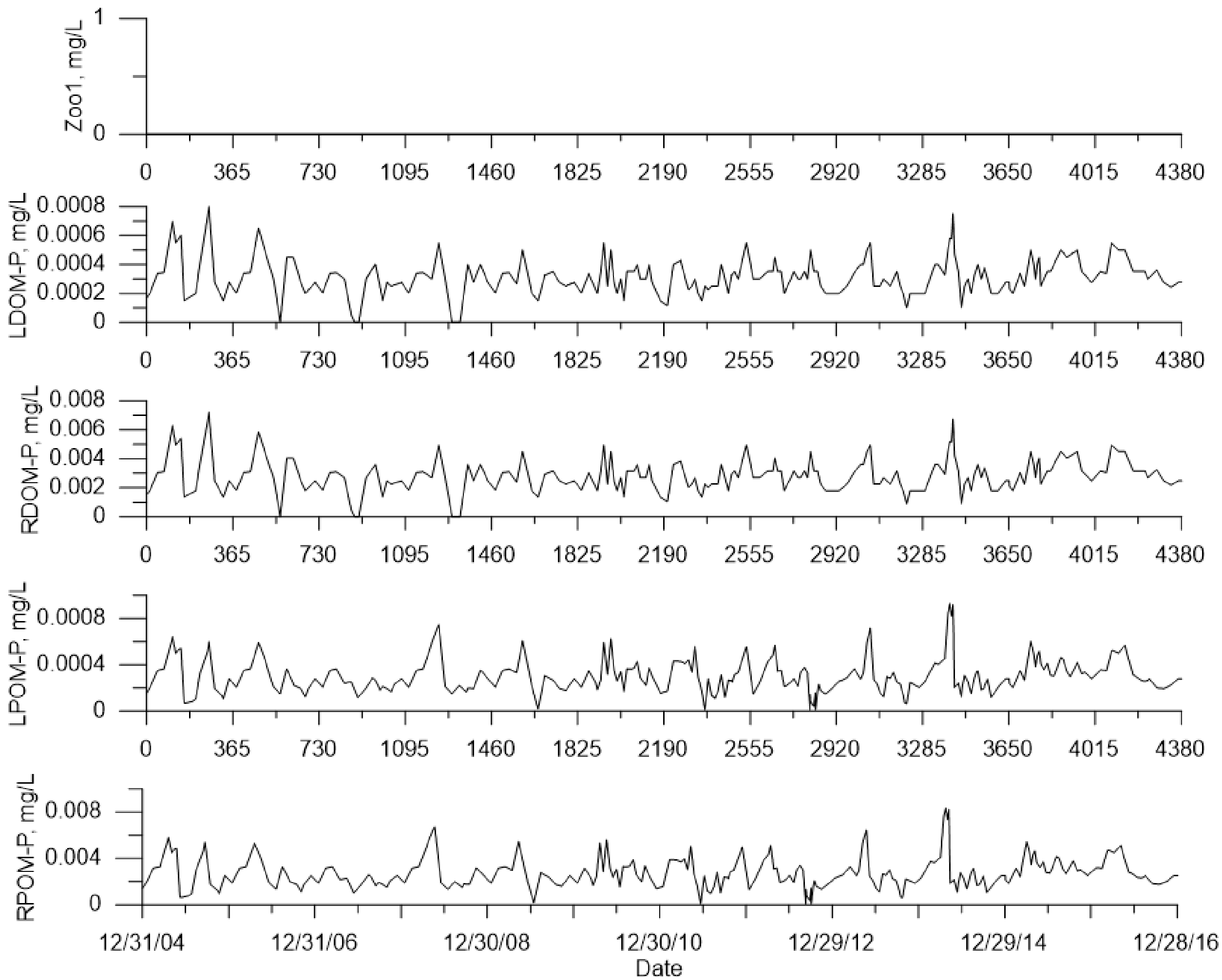


Figure 65. Arapaho Creek constituent concentrations (3).

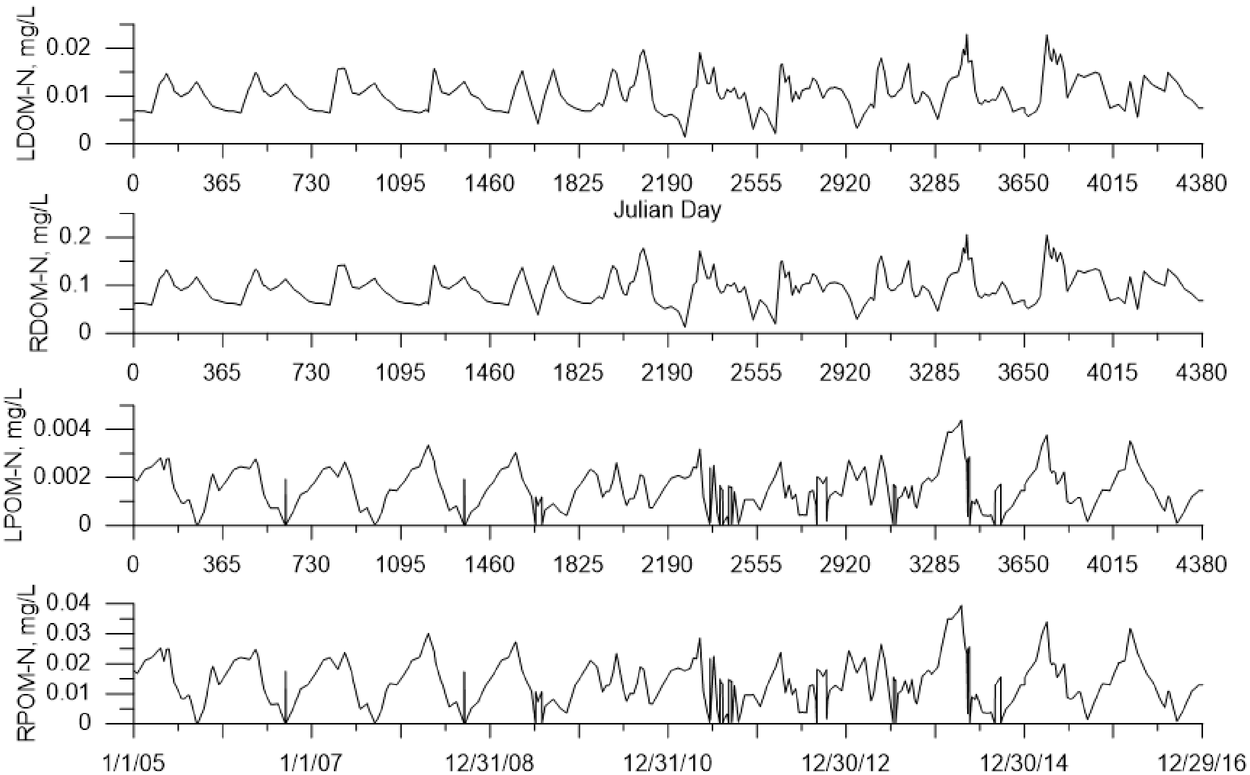


Figure 66. Arapaho Creek constituent concentrations (4).

North Inlet Flow + Grand Lake Gains, Tributary 1, Cin_NI.npt

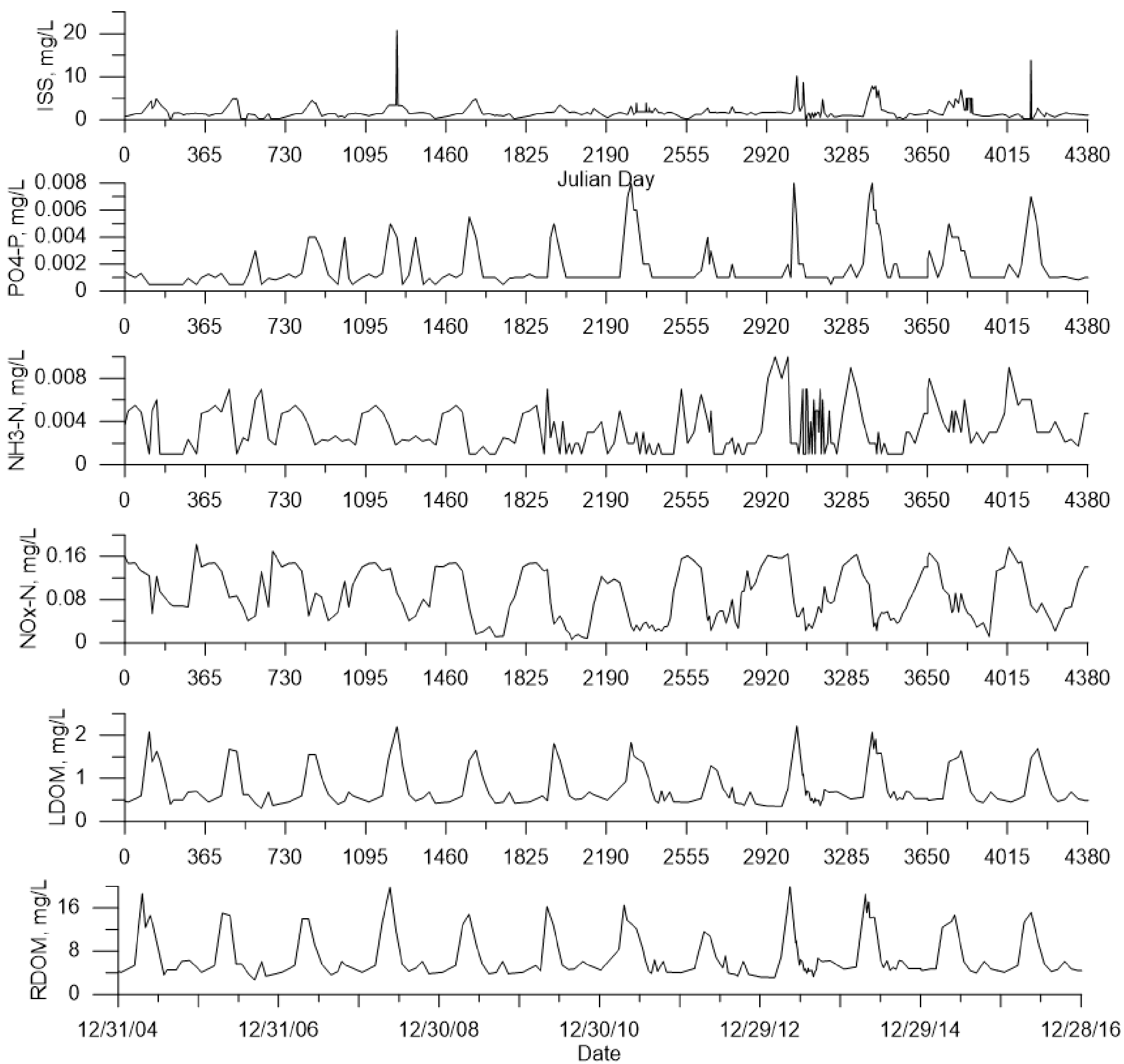


Figure 67. North inlet constituent concentrations (1).

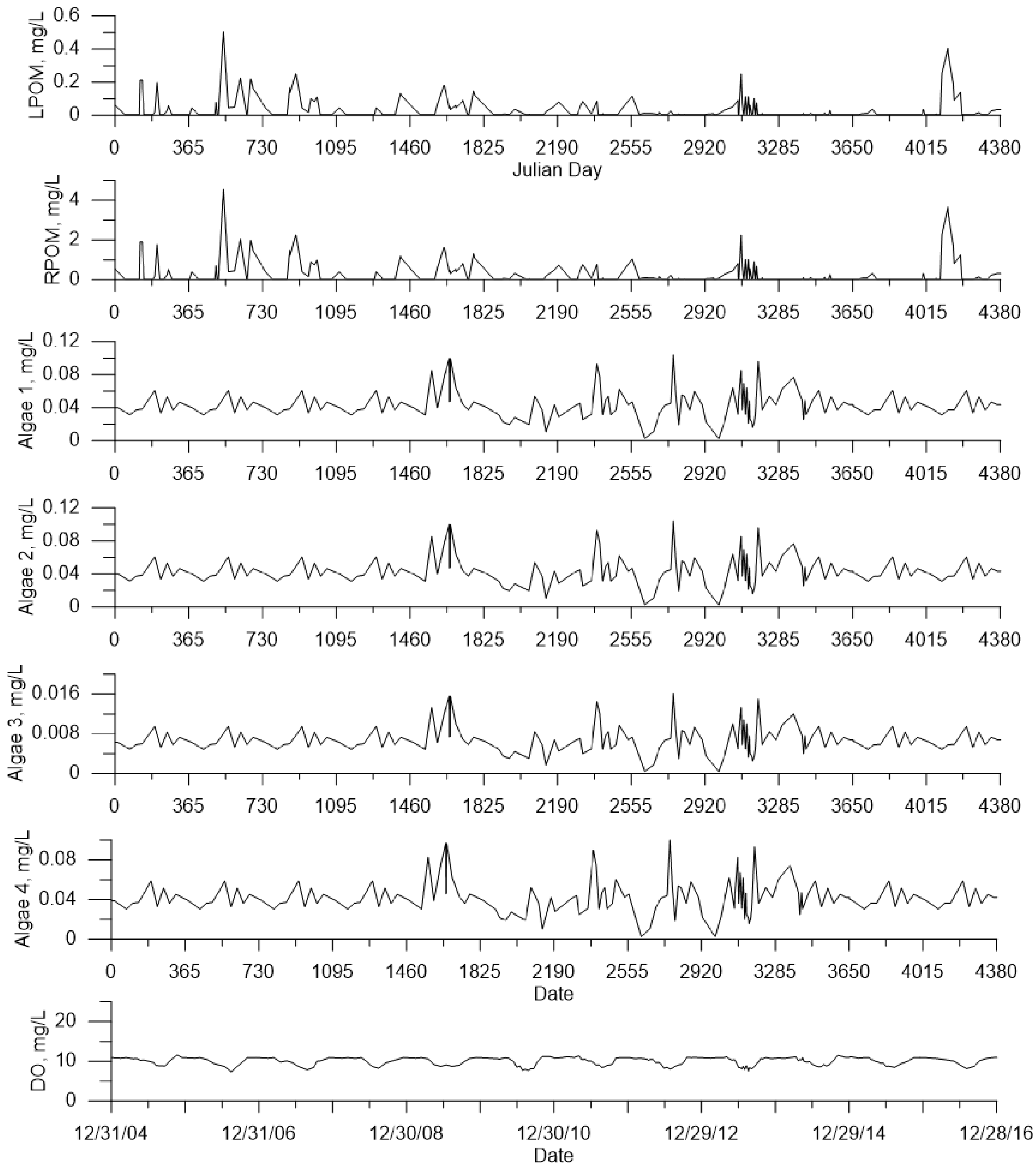


Figure 68. North inlet constituent concentrations (2).

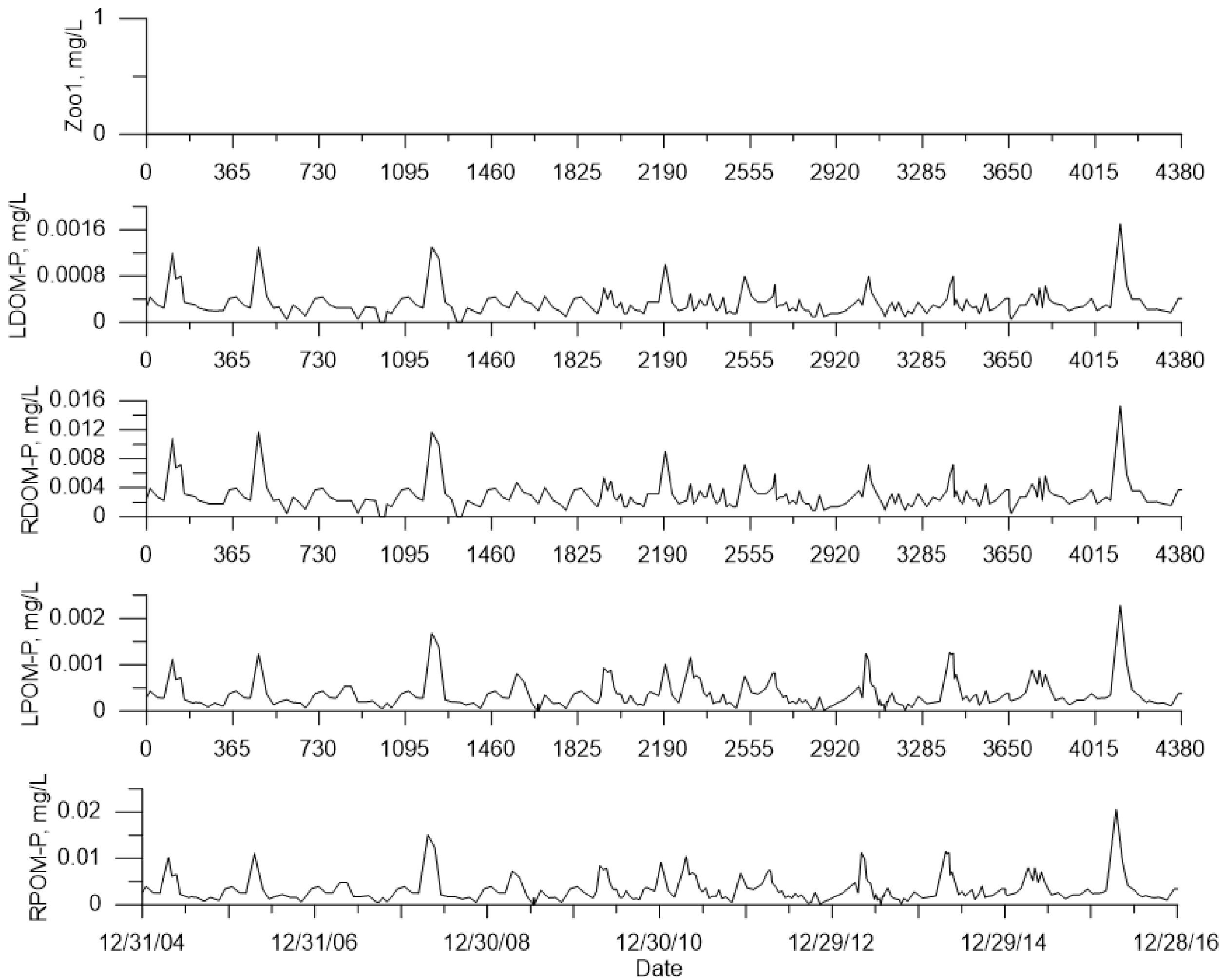


Figure 69. North inlet constituent concentrations (3).

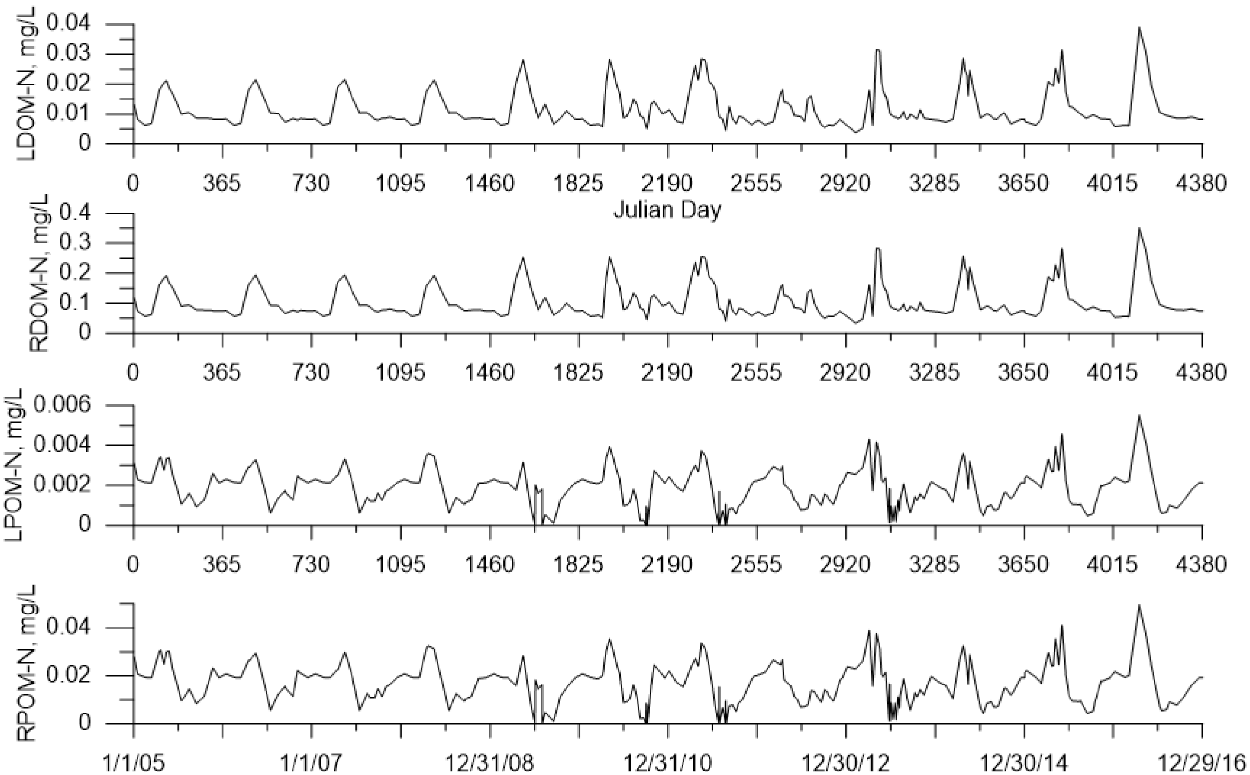


Figure 70. North inlet constituent concentrations (4).

North Fork Flow + Shadow Mountain Gains. Tributary 2, Cin_NF.npt

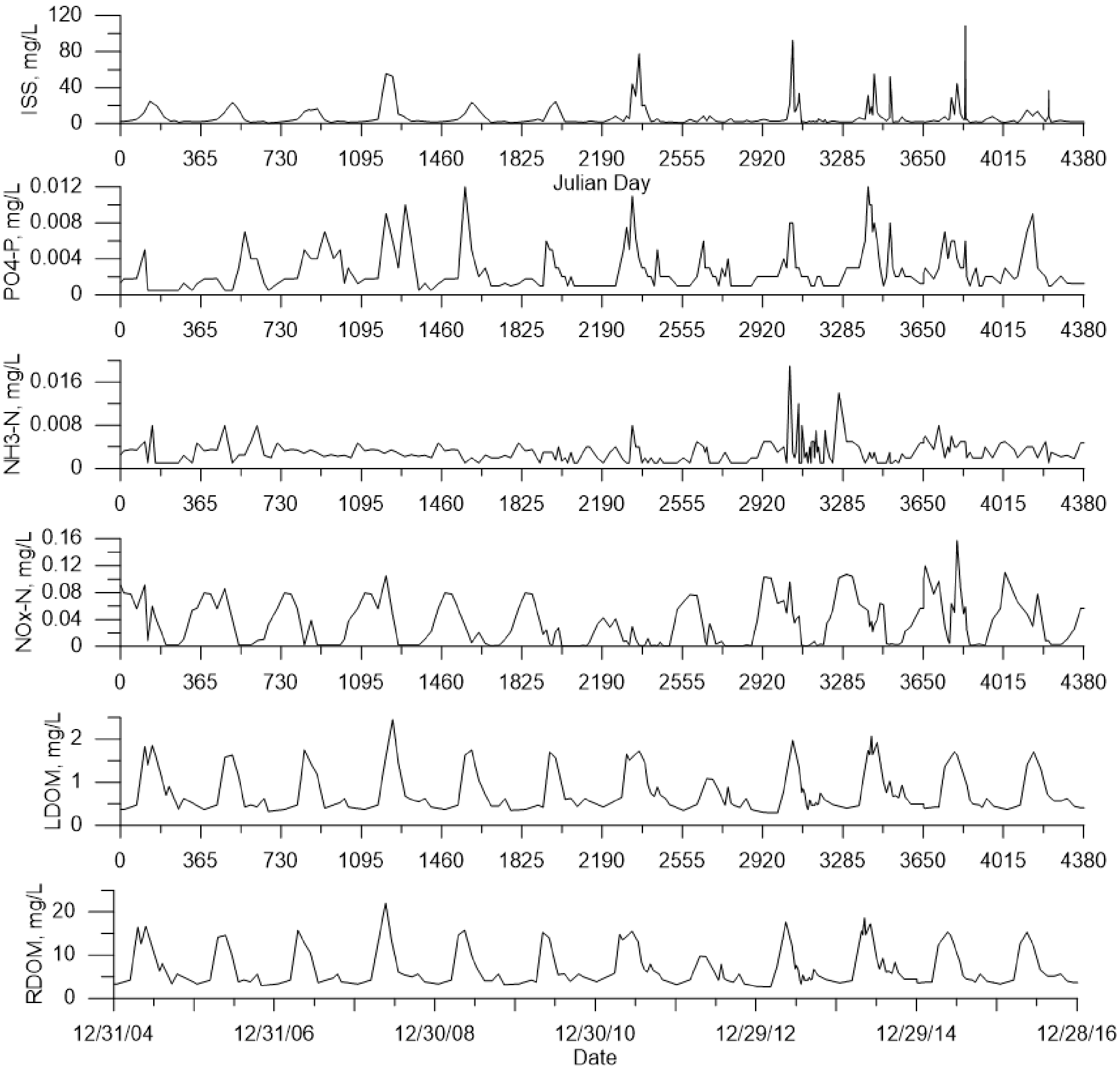


Figure 71. North Fork constituent concentrations (1).

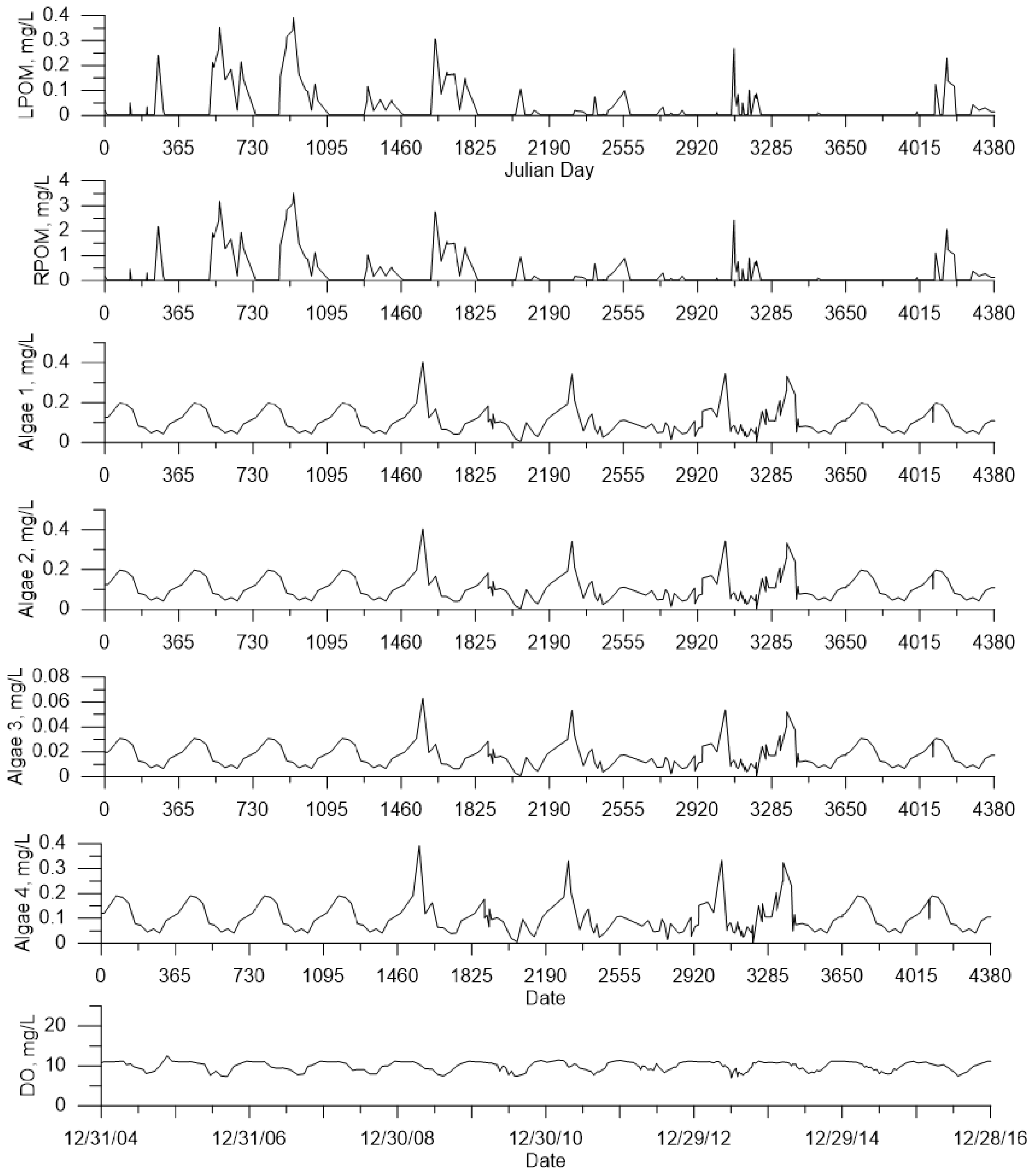


Figure 72. North Fork constituent concentrations (2).

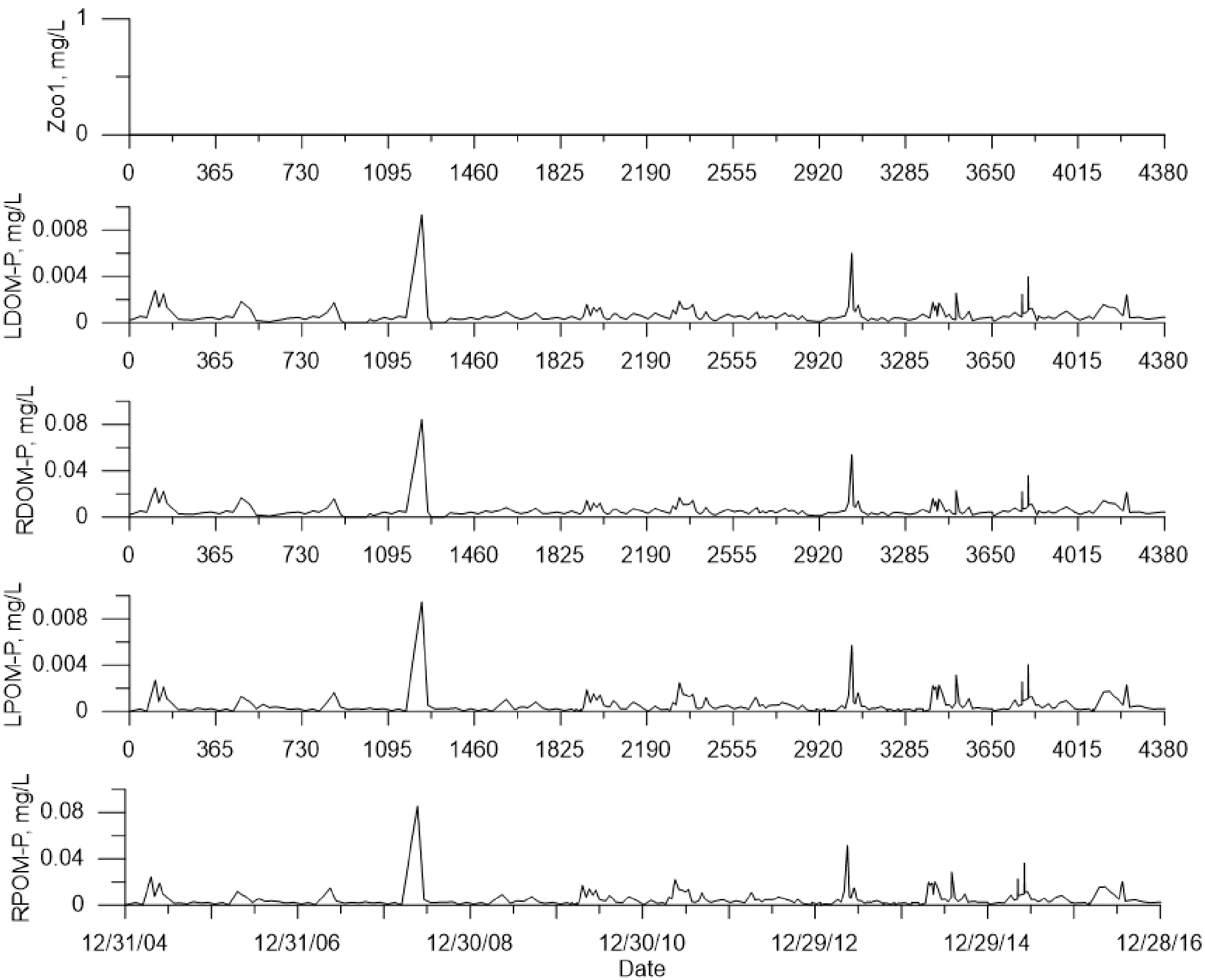


Figure 73. North Fork constituent concentrations (3).

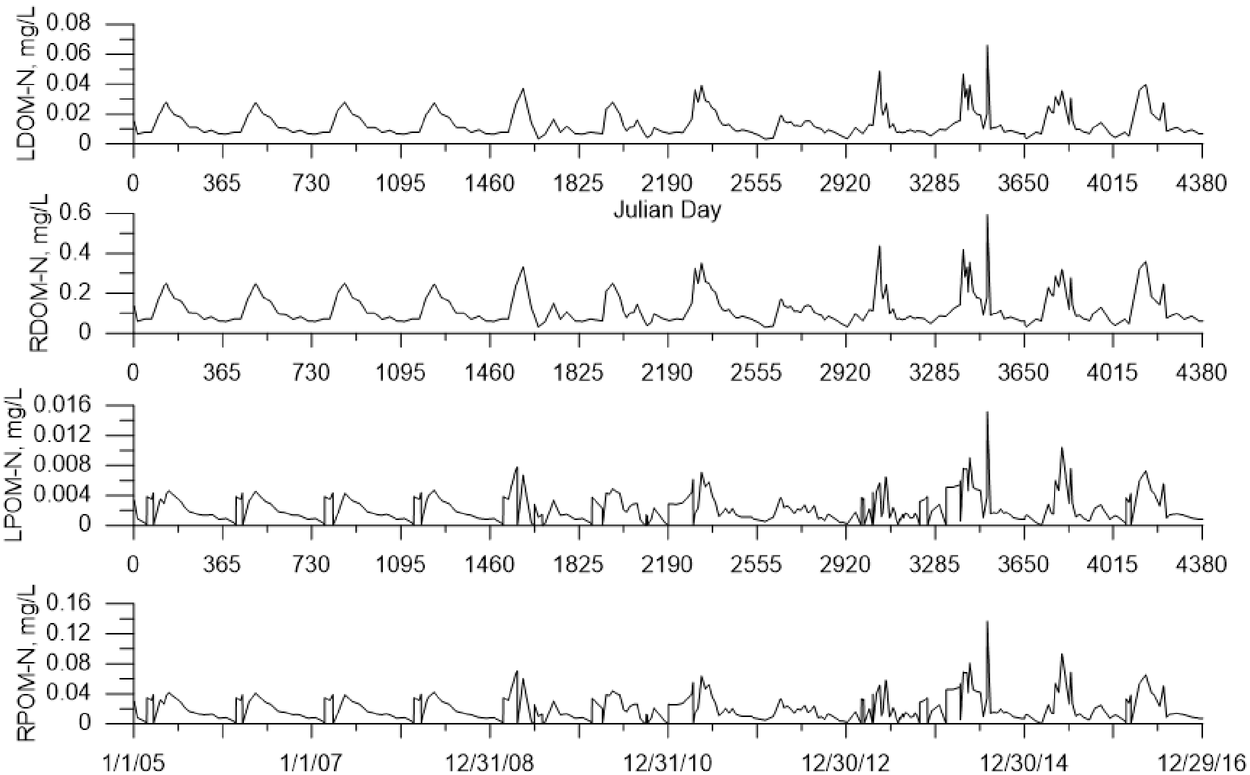


Figure 74. North Fork constituent concentrations (4).

Stillwater Creek, Tributary 3, Cin_SW.npt

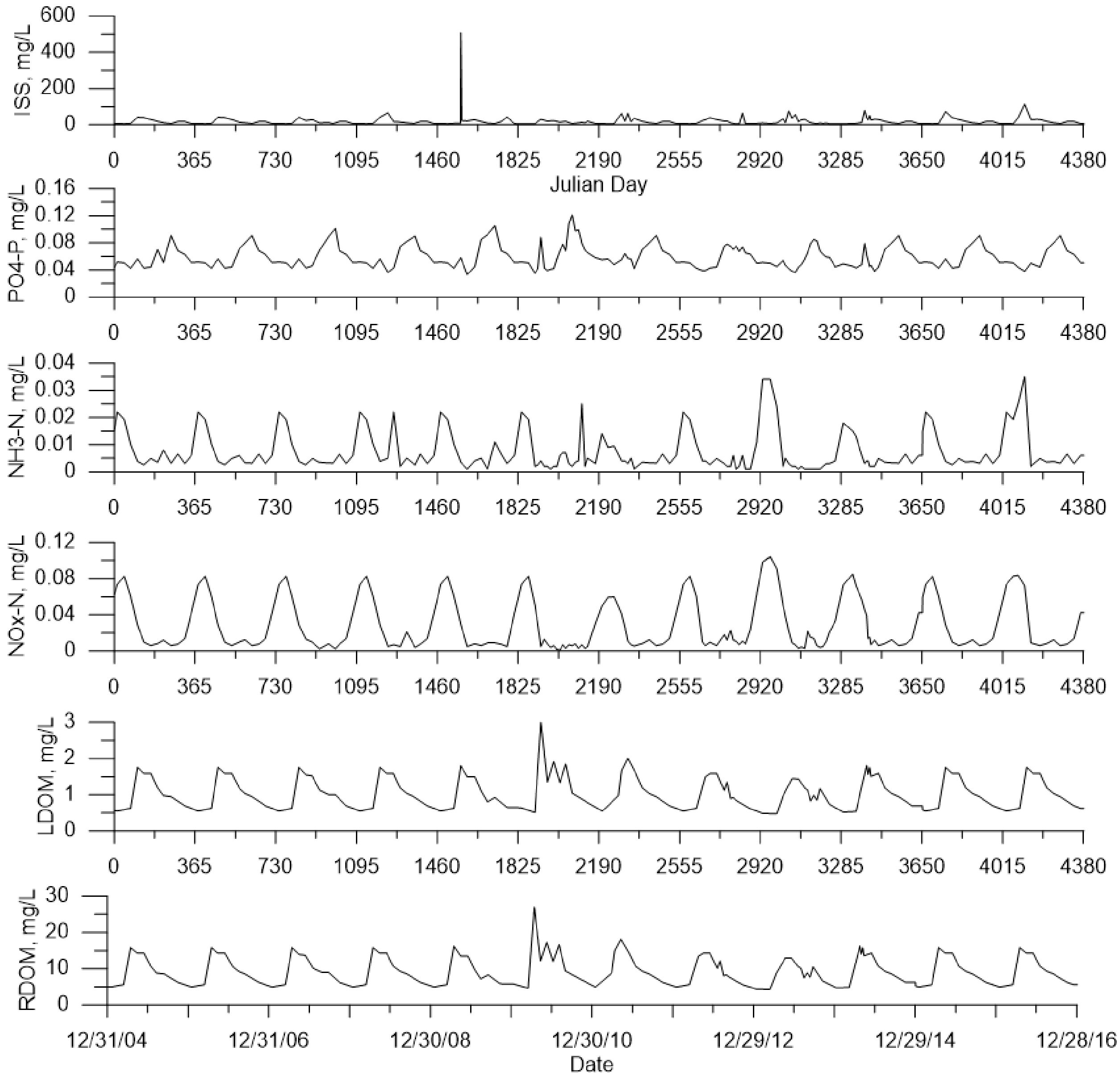


Figure 75. Stillwater Creek constituent concentrations (1).

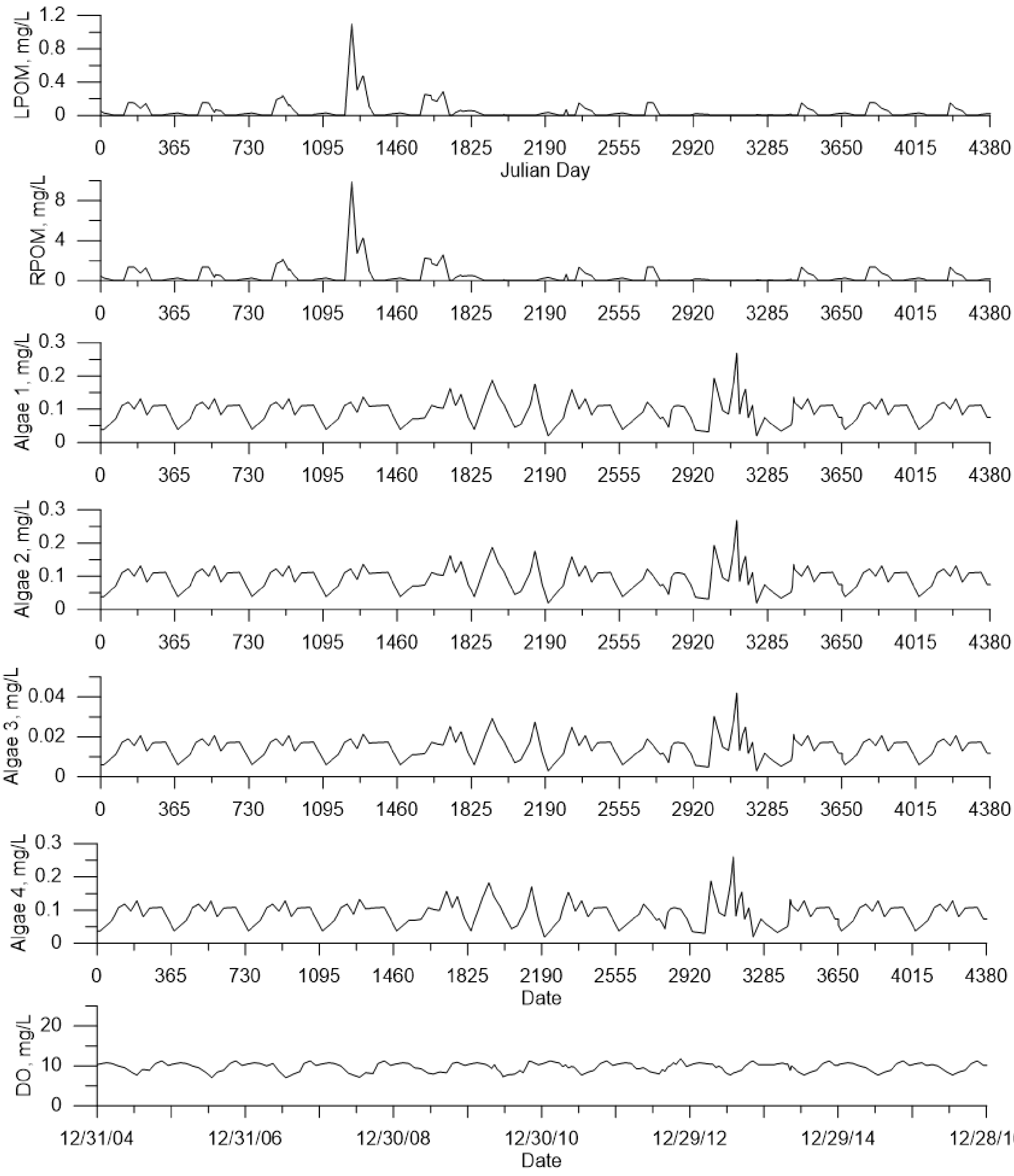


Figure 76. Stillwater Creek constituent concentrations (2).

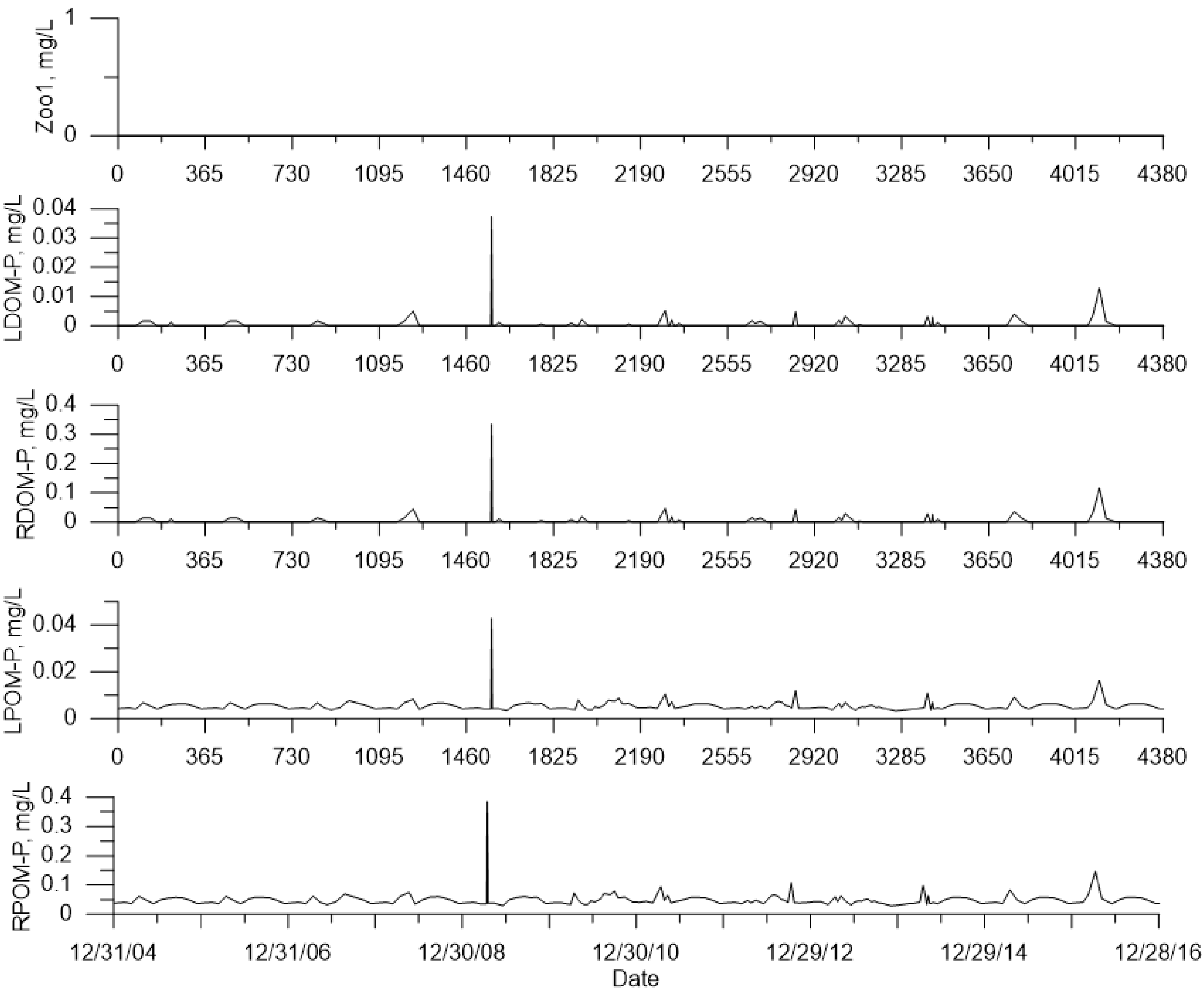


Figure 77. Stillwater Creek constituent concentrations (3).

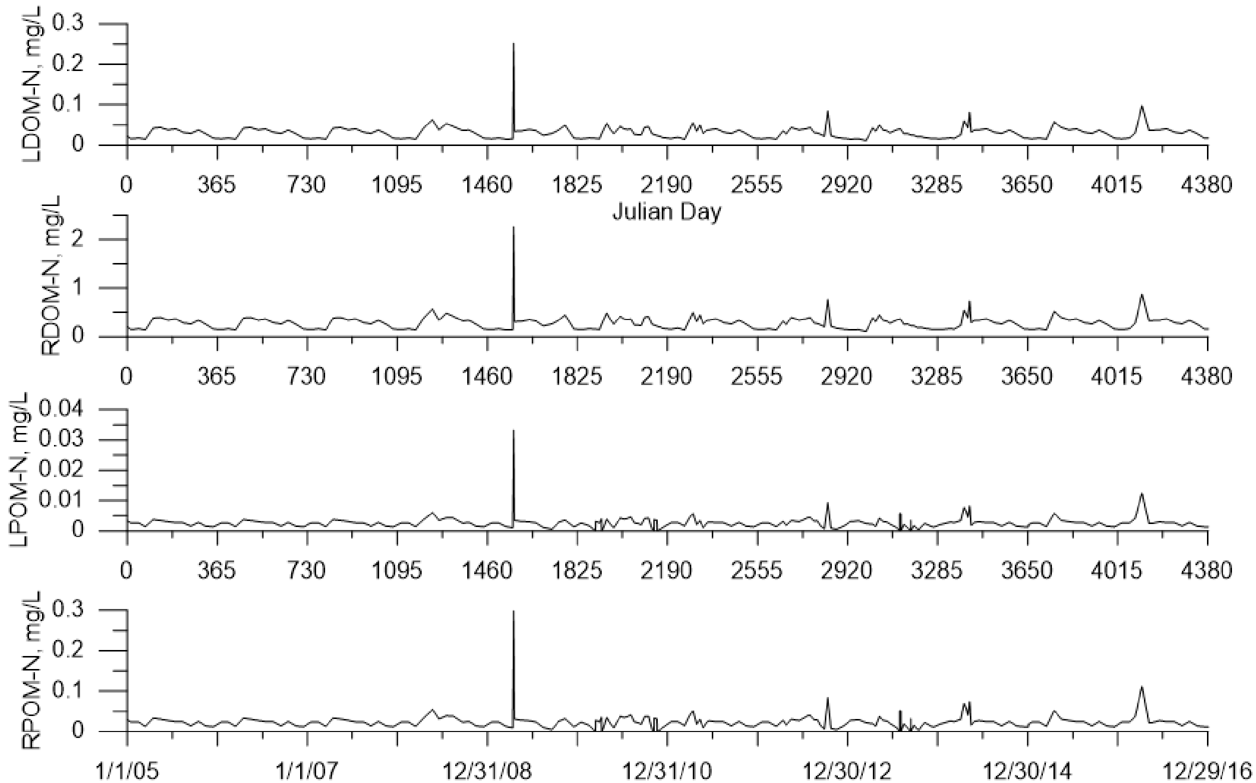


Figure 78. Stillwater Creek constituent concentrations (4).

Windy Gap Pump Flow, Tributary 4, Cin_WG.npt

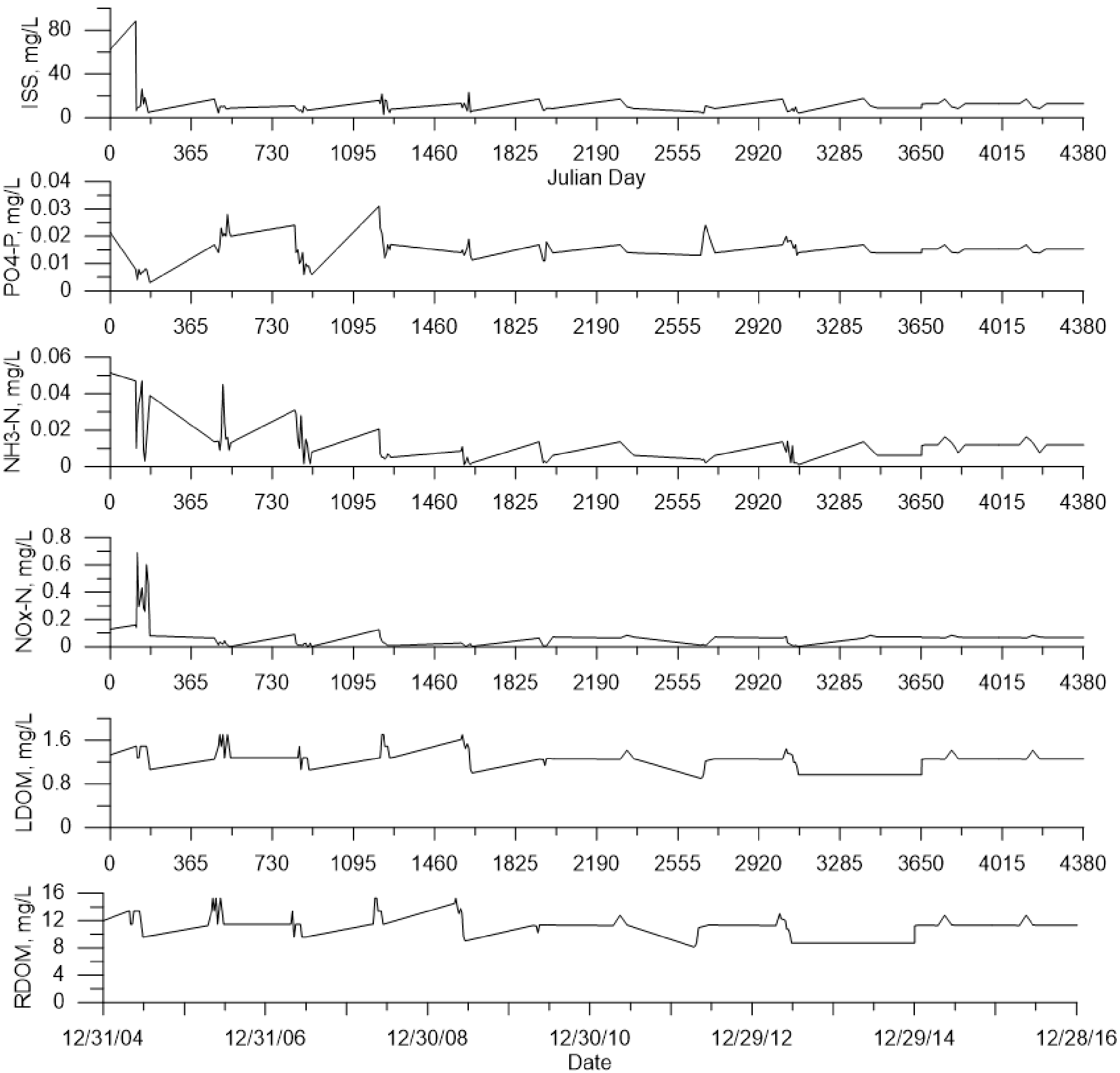


Figure 79. Windy Gap Pump Flow constituent concentrations (1).

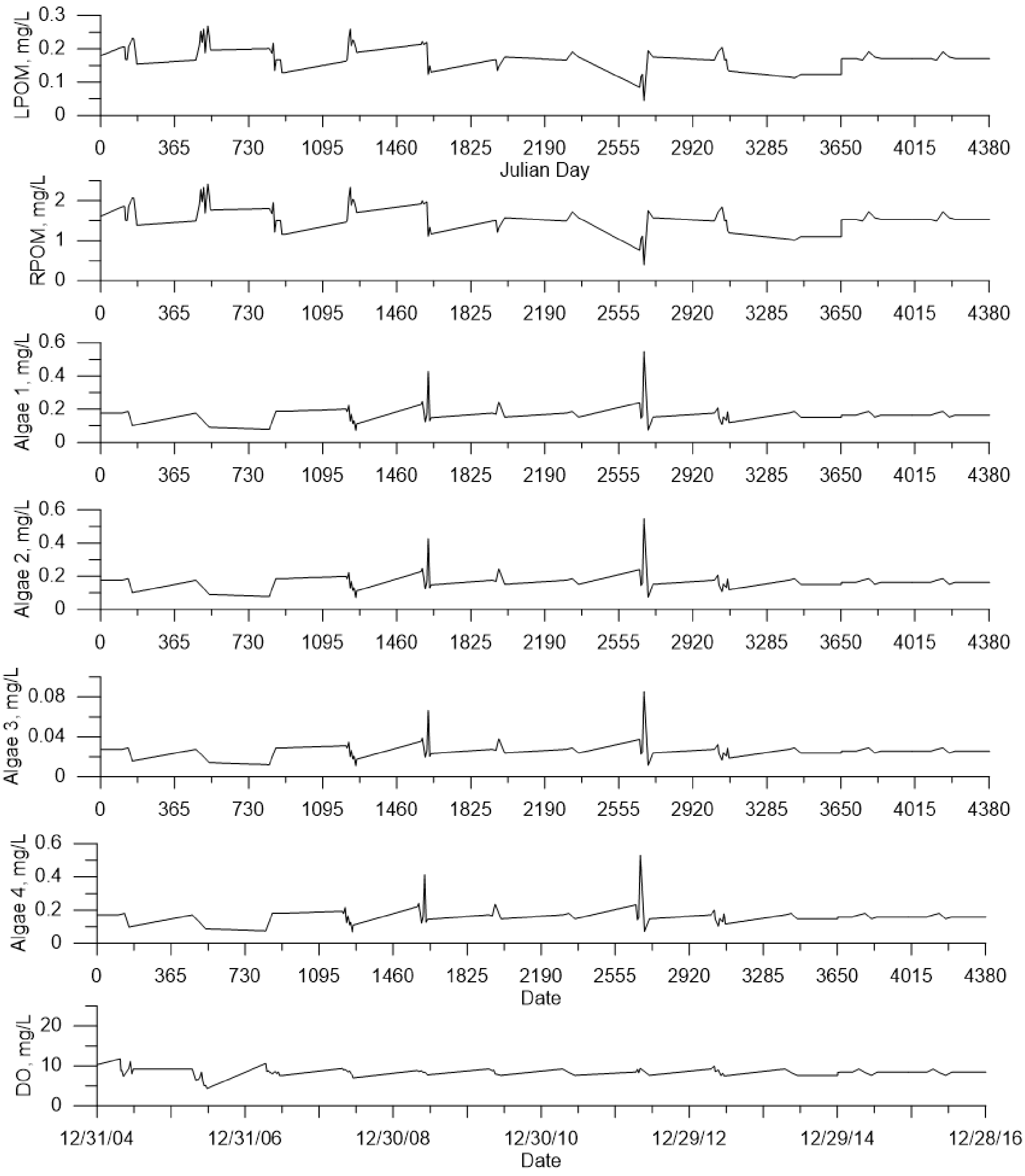


Figure 80. Windy Gap Pump Flow constituent concentrations (2).

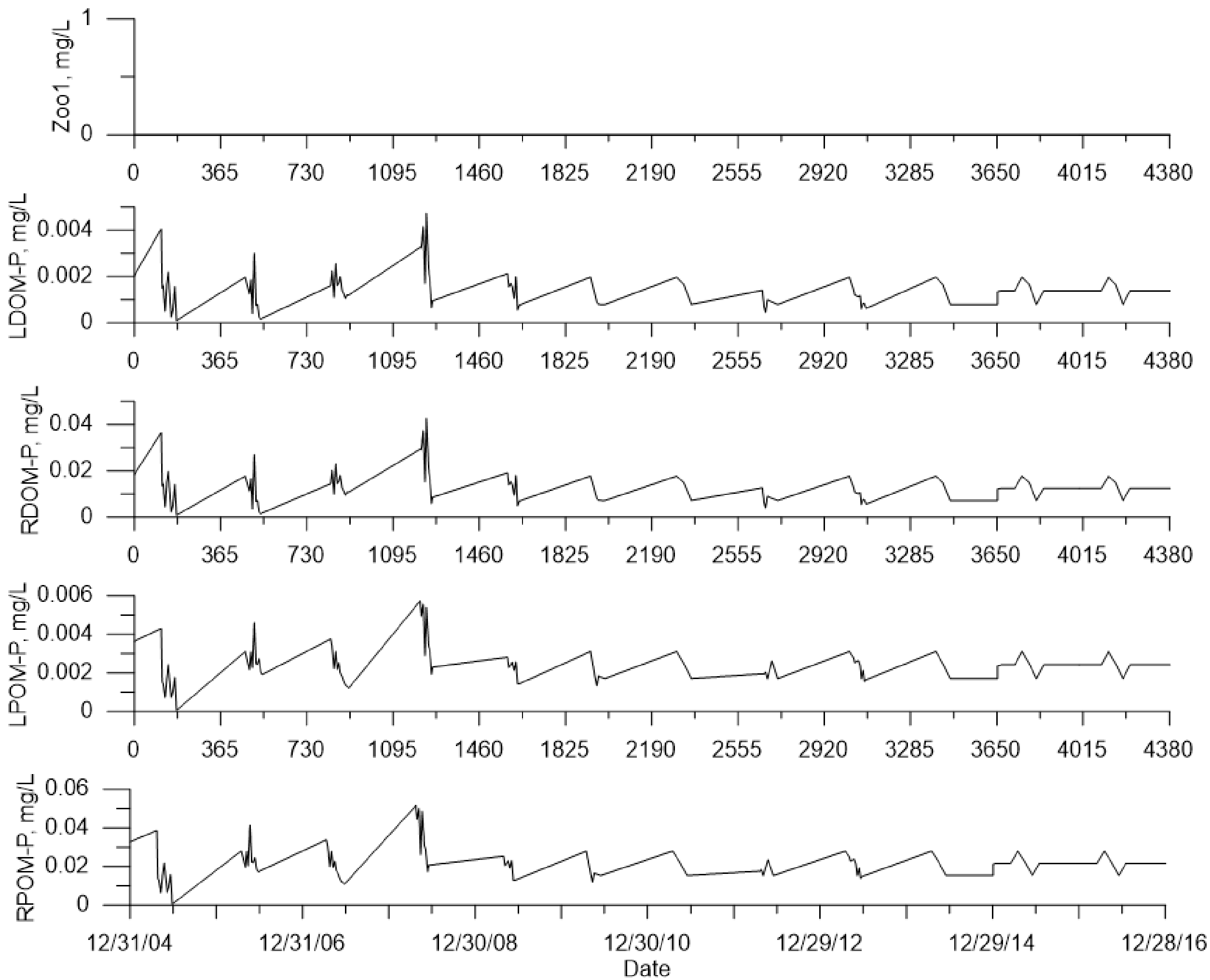


Figure 81. Windy Gap Pump Flow constituent concentrations (3).

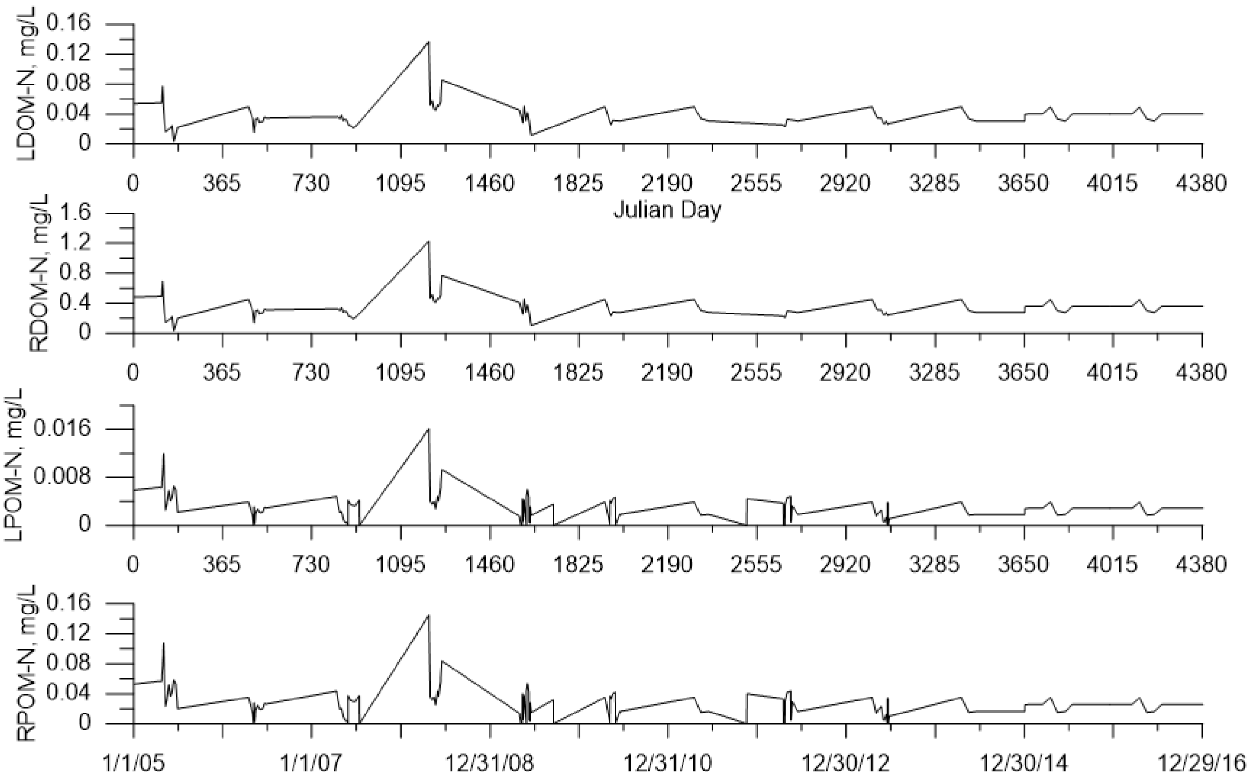


Figure 82. Windy Gap Pump Flow constituent concentrations (4).

Willow Creek, Tributary 5, Cin_WC.npt

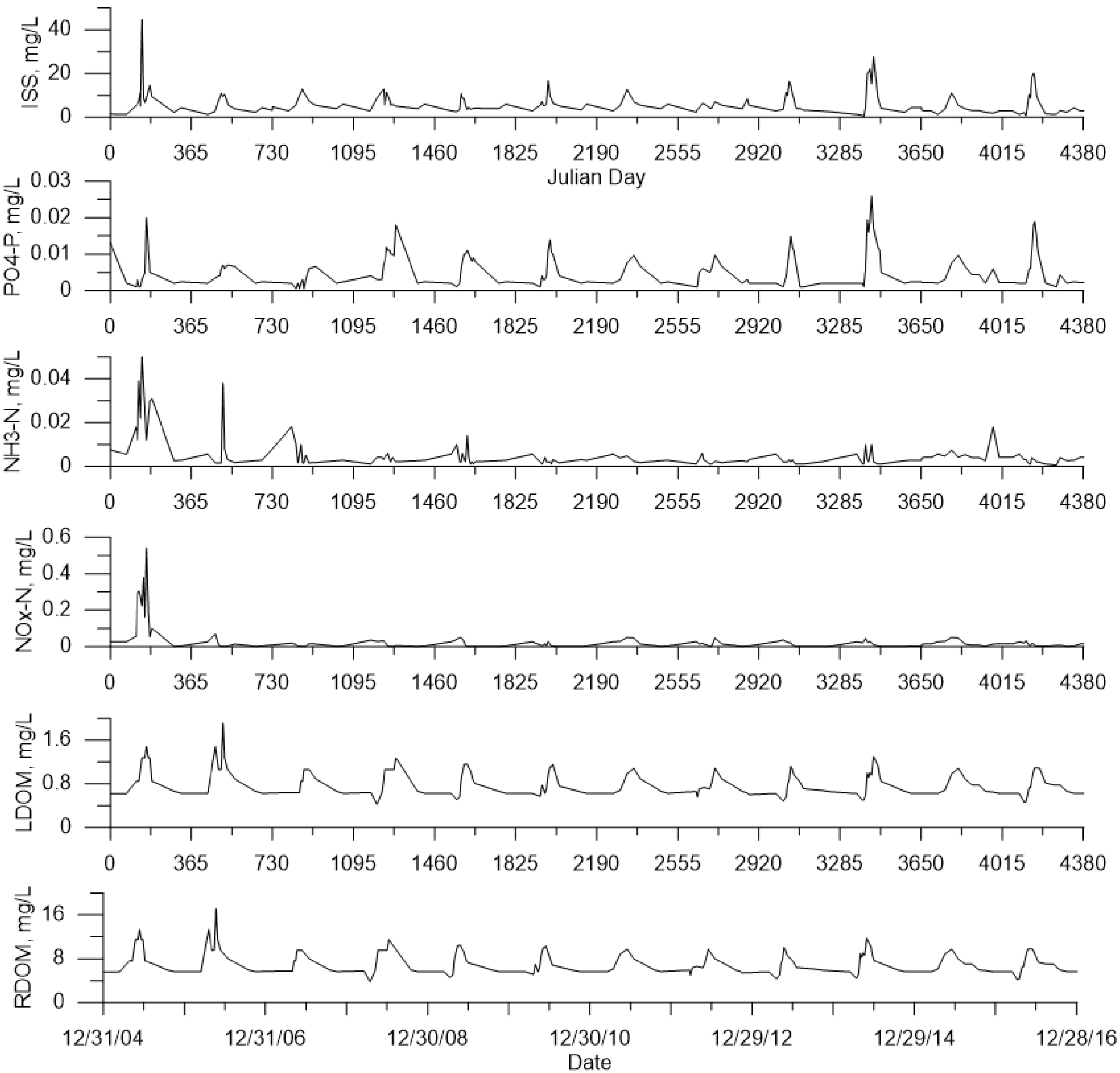


Figure 83. Willow Creek constituent concentrations (1).

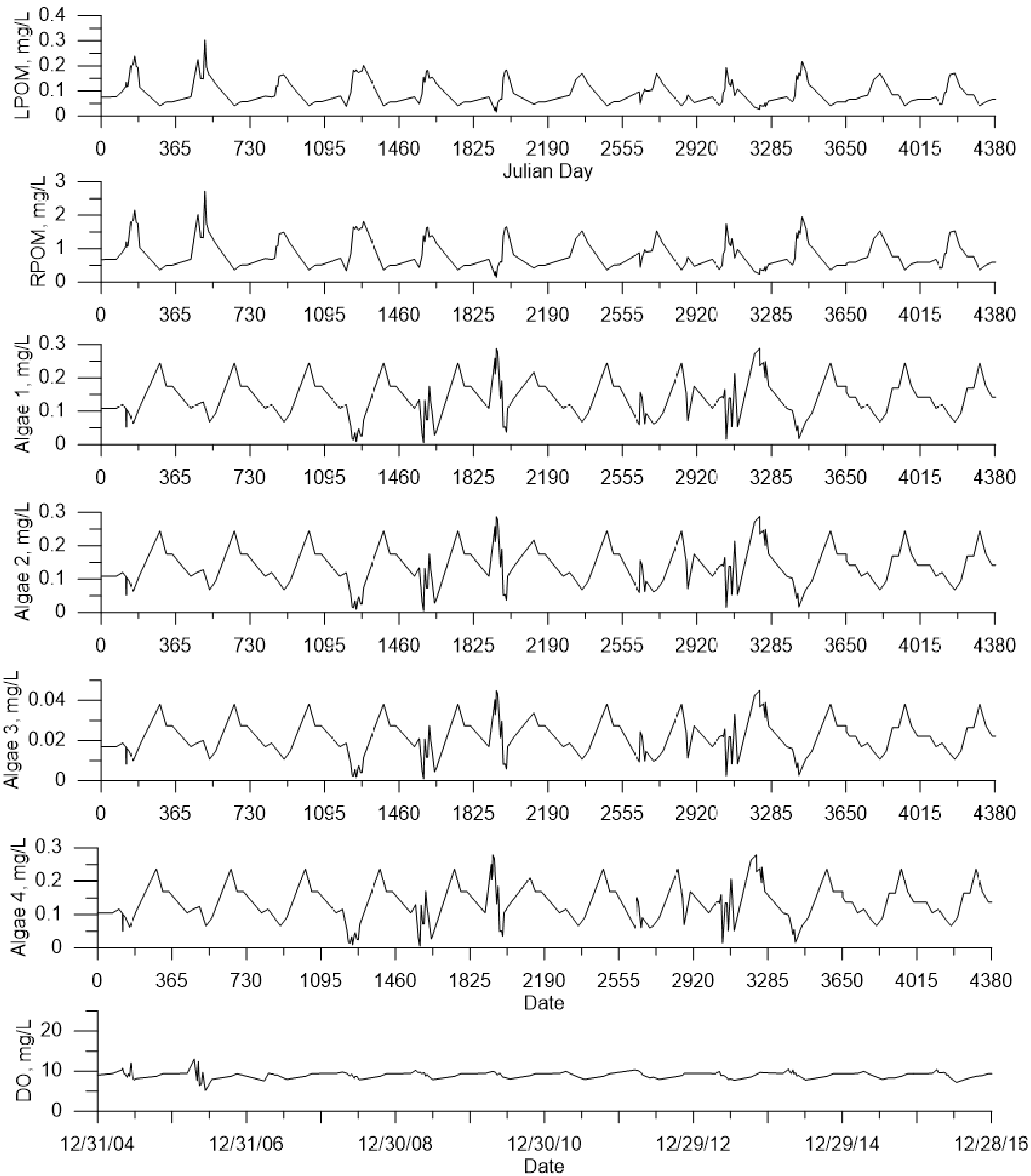


Figure 84. Willow Creek constituent concentrations (2).

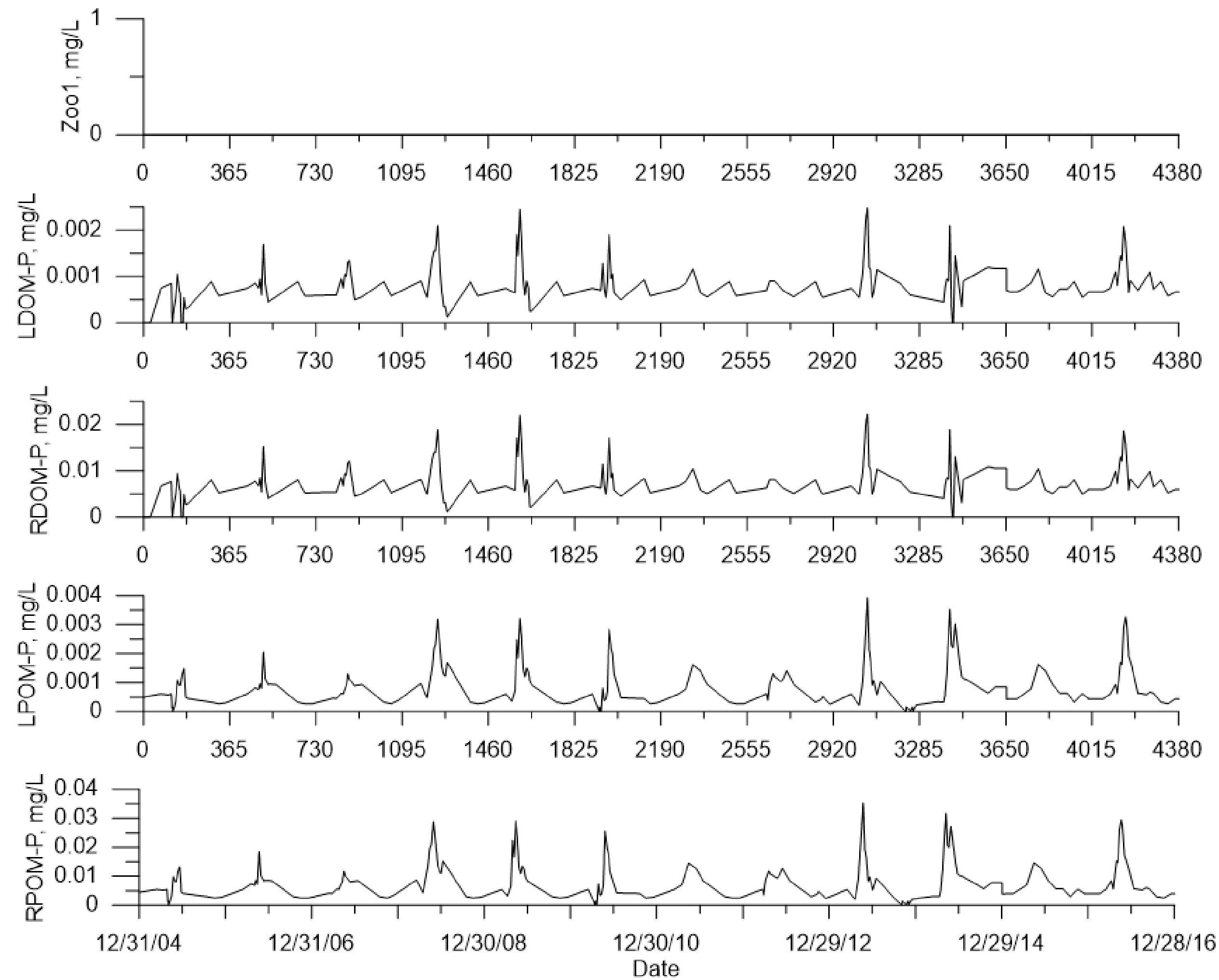


Figure 85. Willow Creek constituent concentrations (3).

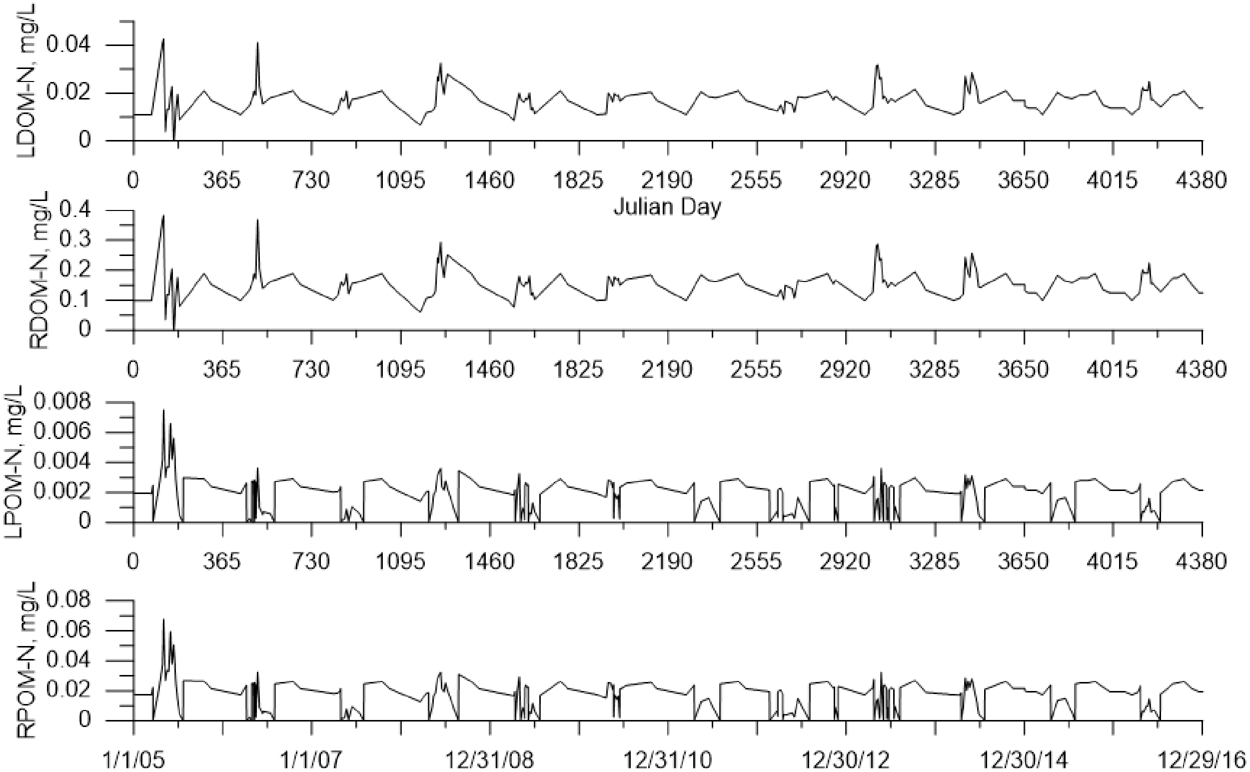


Figure 86. Willow Creek constituent concentrations (4).

Columbine Creek, Tributary 6, Cin_COL.npt

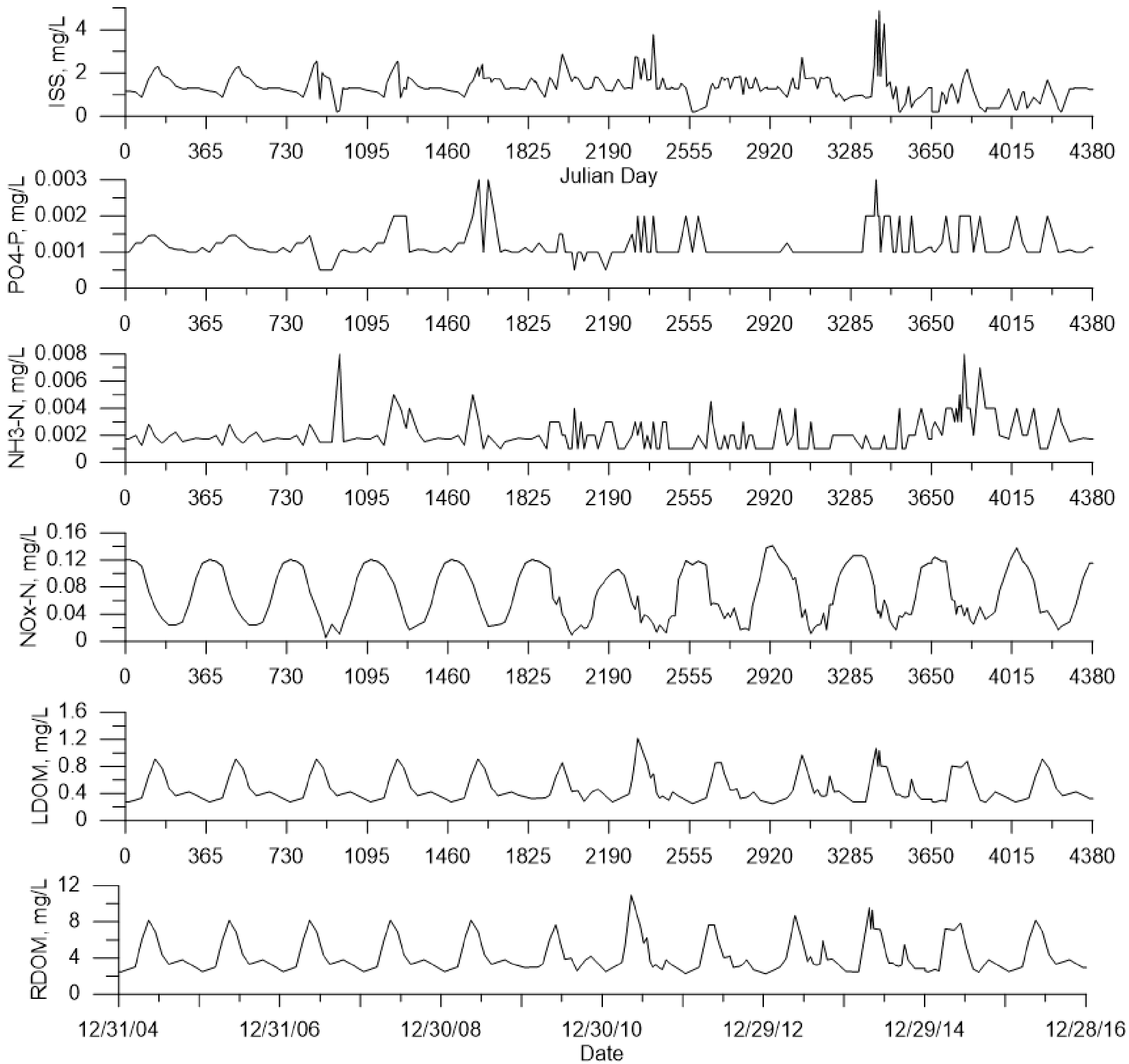


Figure 87. Columbine Creek constituent concentrations (1).

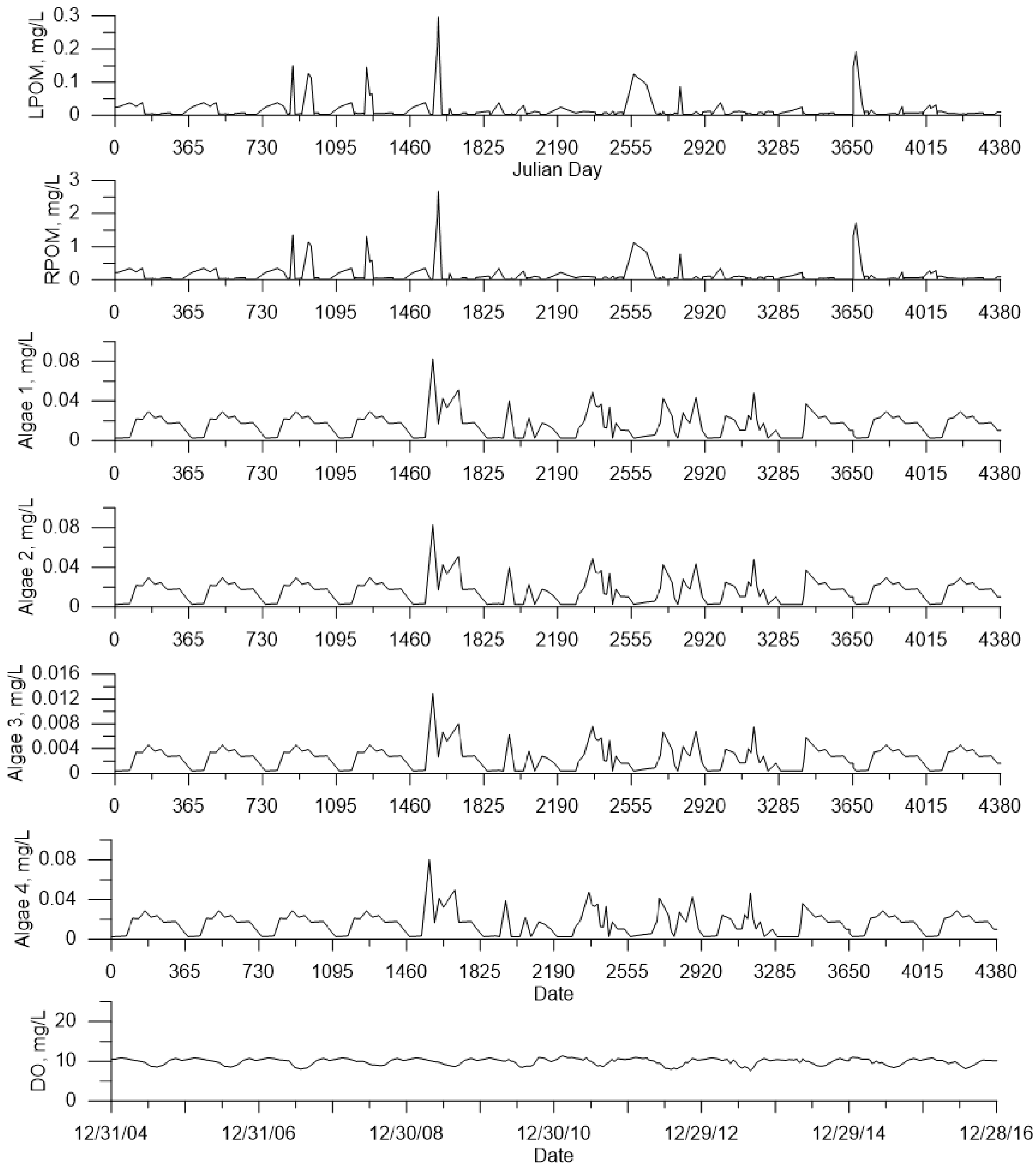


Figure 88. Columbine Creek constituent concentrations (2).

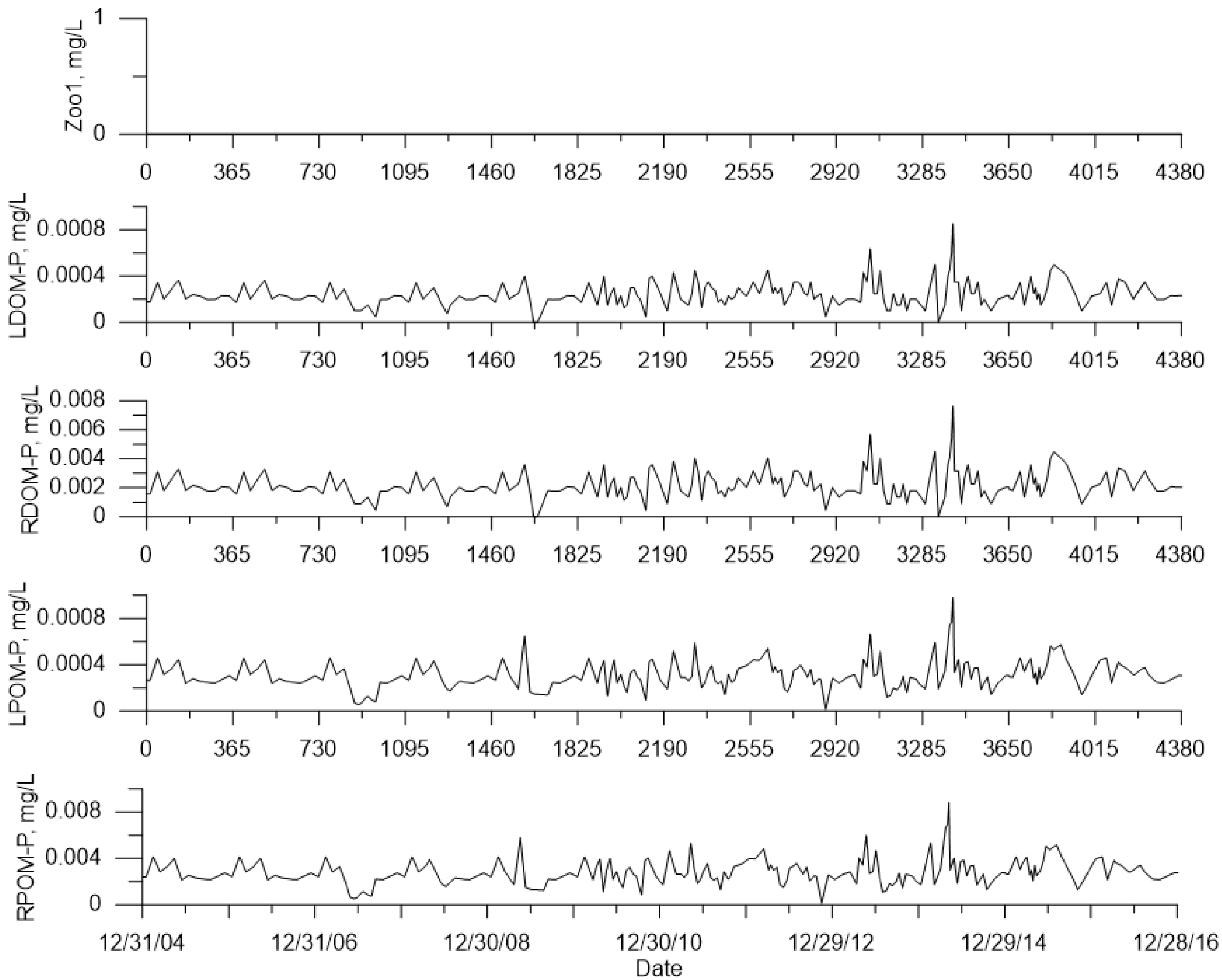


Figure 89. Columbine Creek constituent concentrations (3).

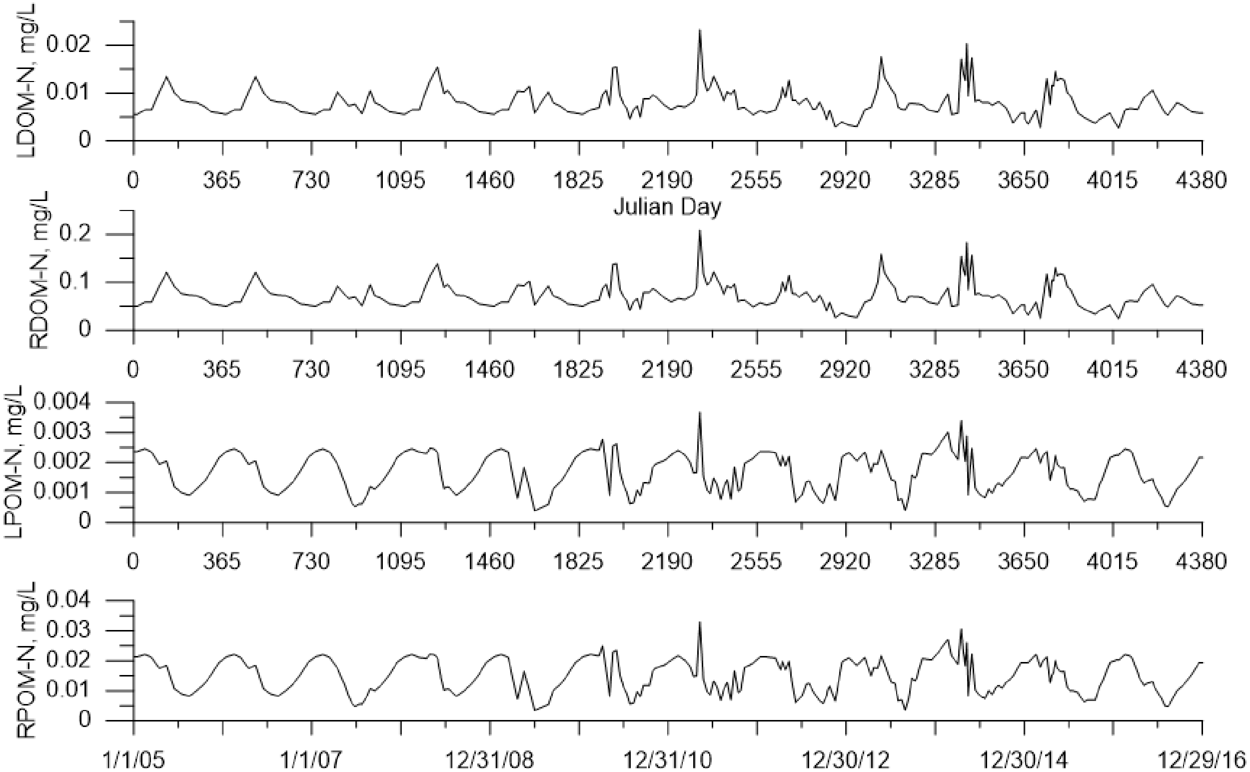


Figure 90. Columbine Creek constituent concentrations (4).

Roaring Fork, Tributary 7, Cin_RF.npt

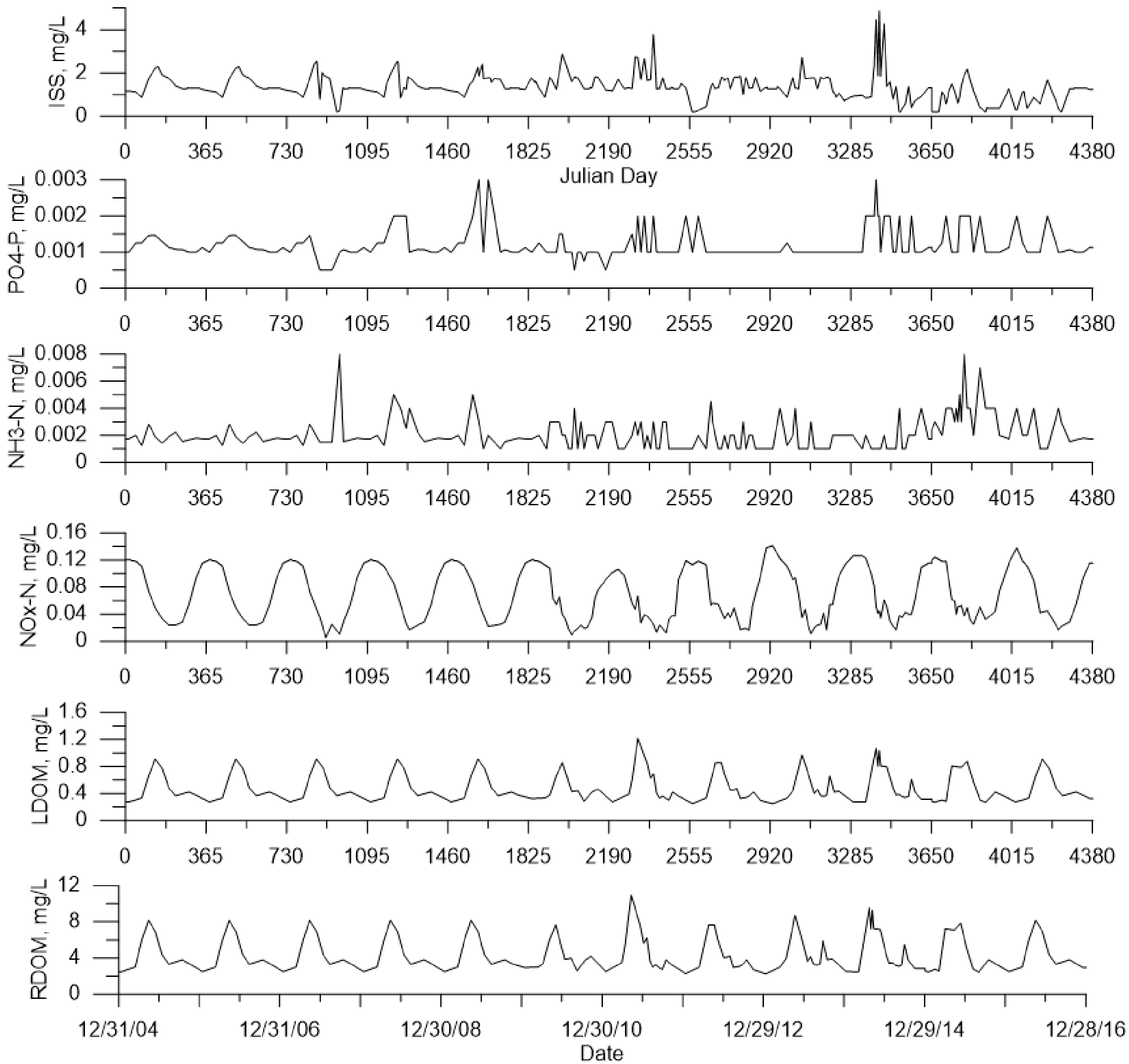


Figure 91. Roaring Fork constituent concentrations (1).

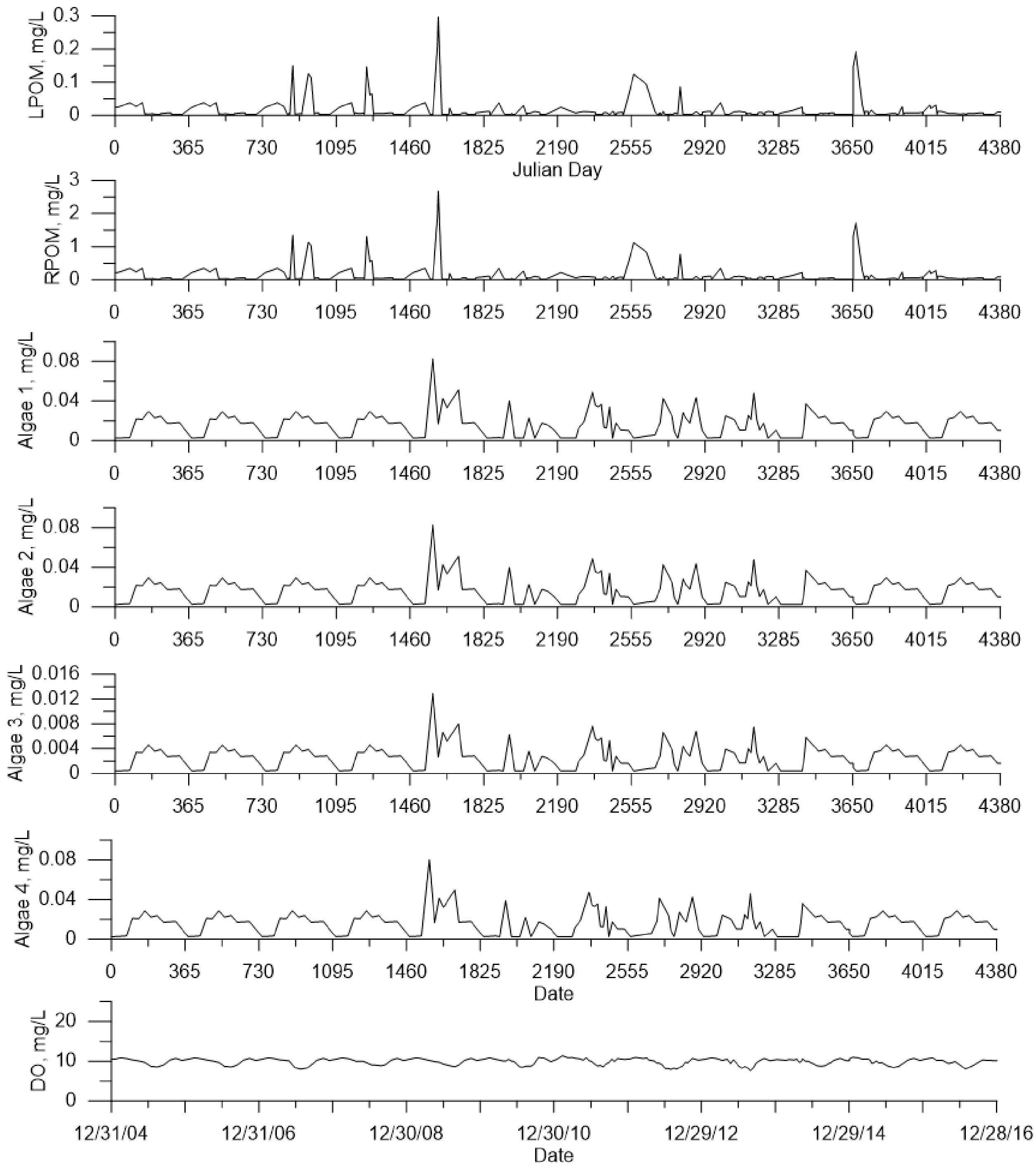


Figure 92. Roaring Fork constituent concentrations (2).

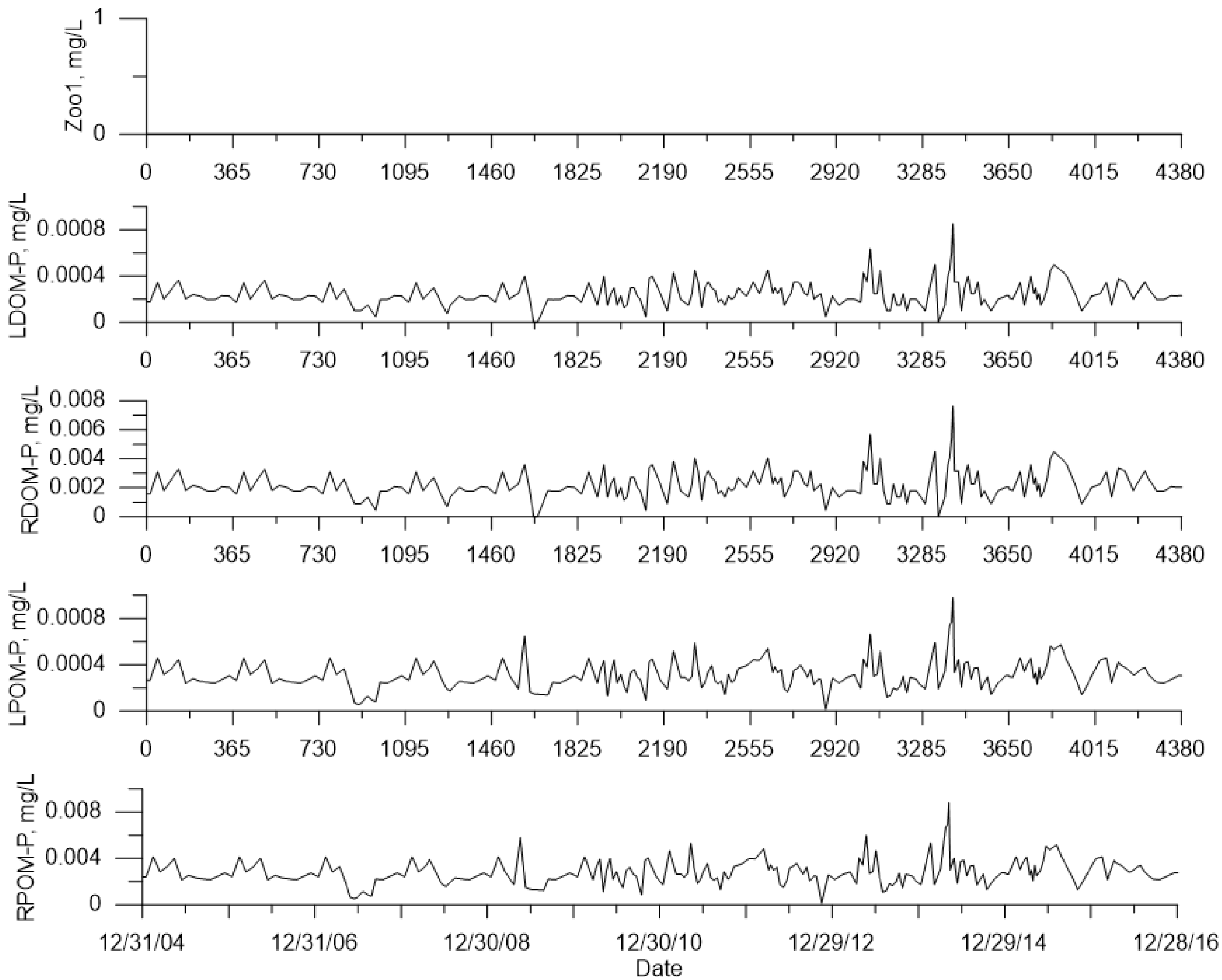


Figure 93. Roaring Fork constituent concentrations (3).

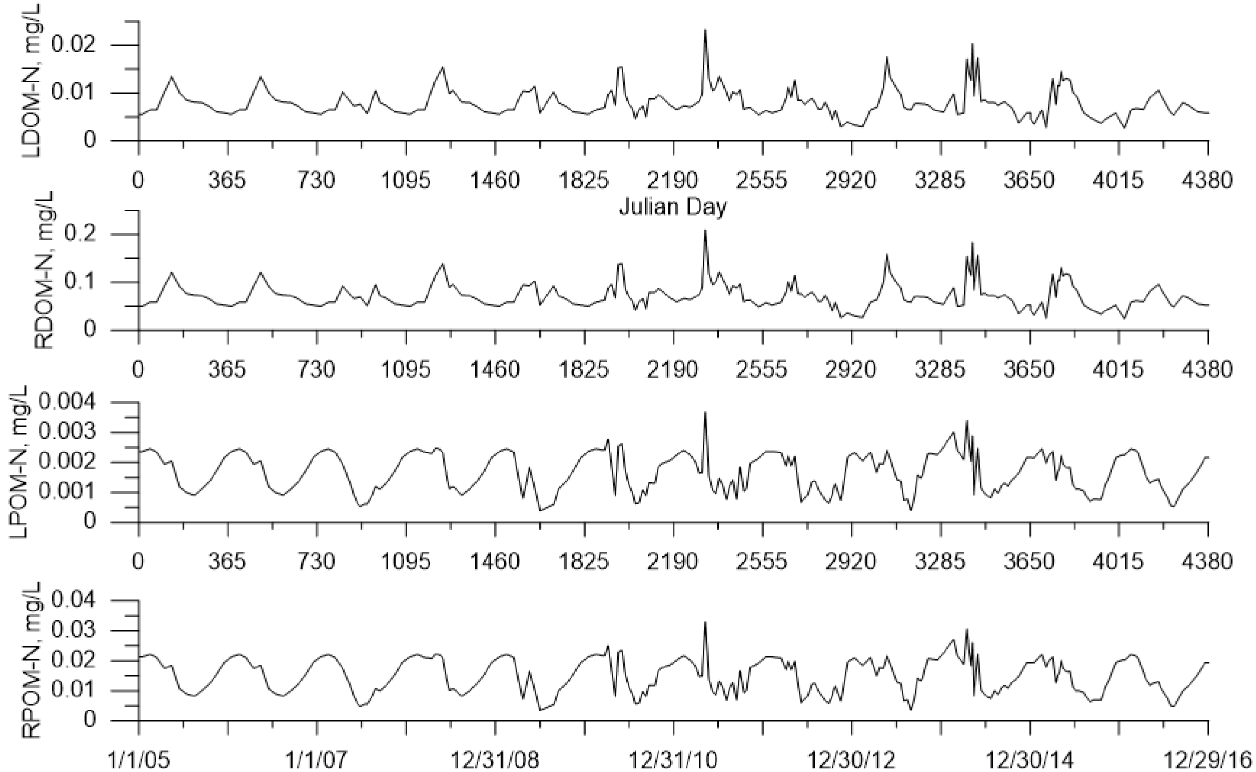


Figure 94. Roaring Fork constituent concentrations (4).

Distributed Tributaries

Flow

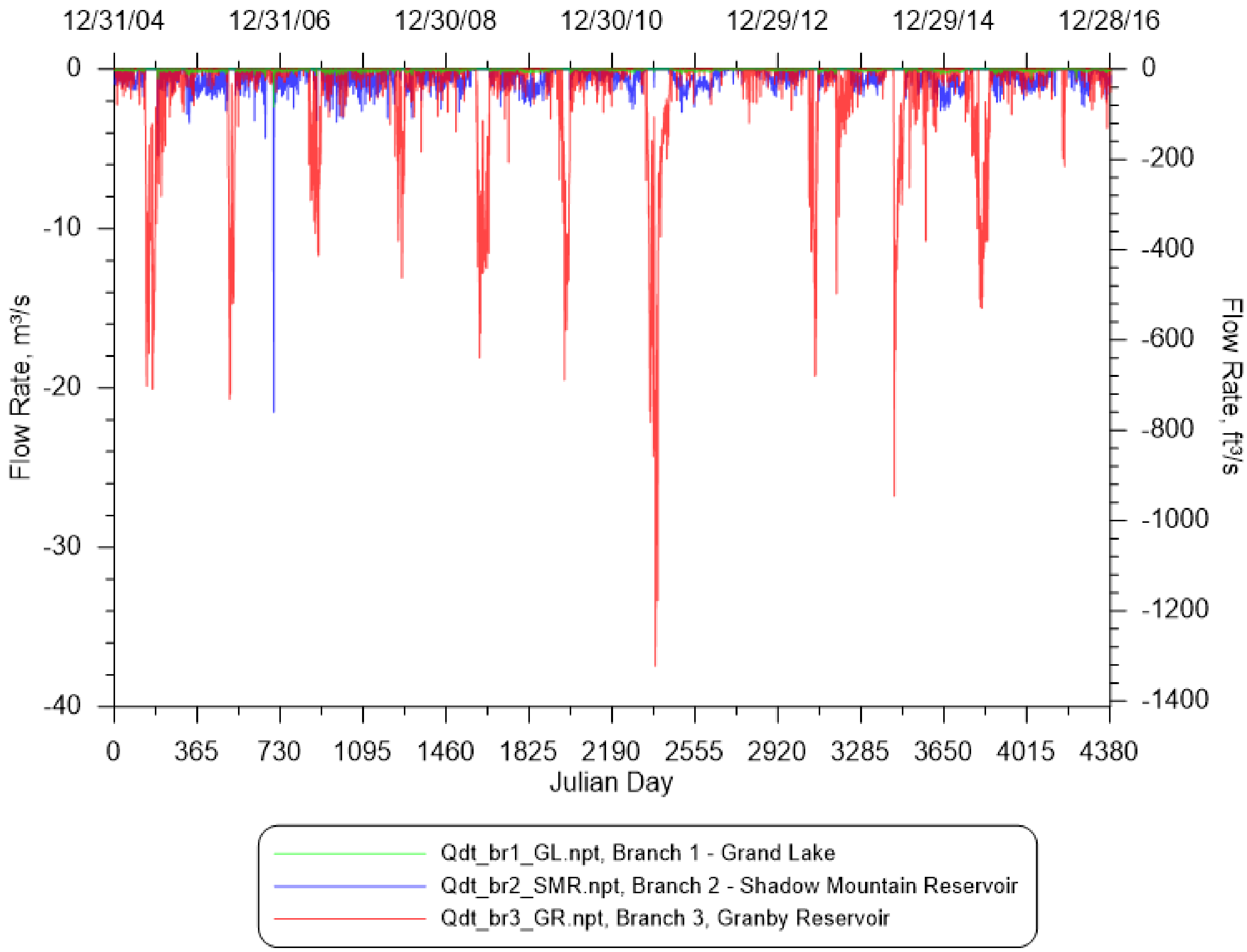


Figure 95. Distributed tributary flow rates.

Withdrawals

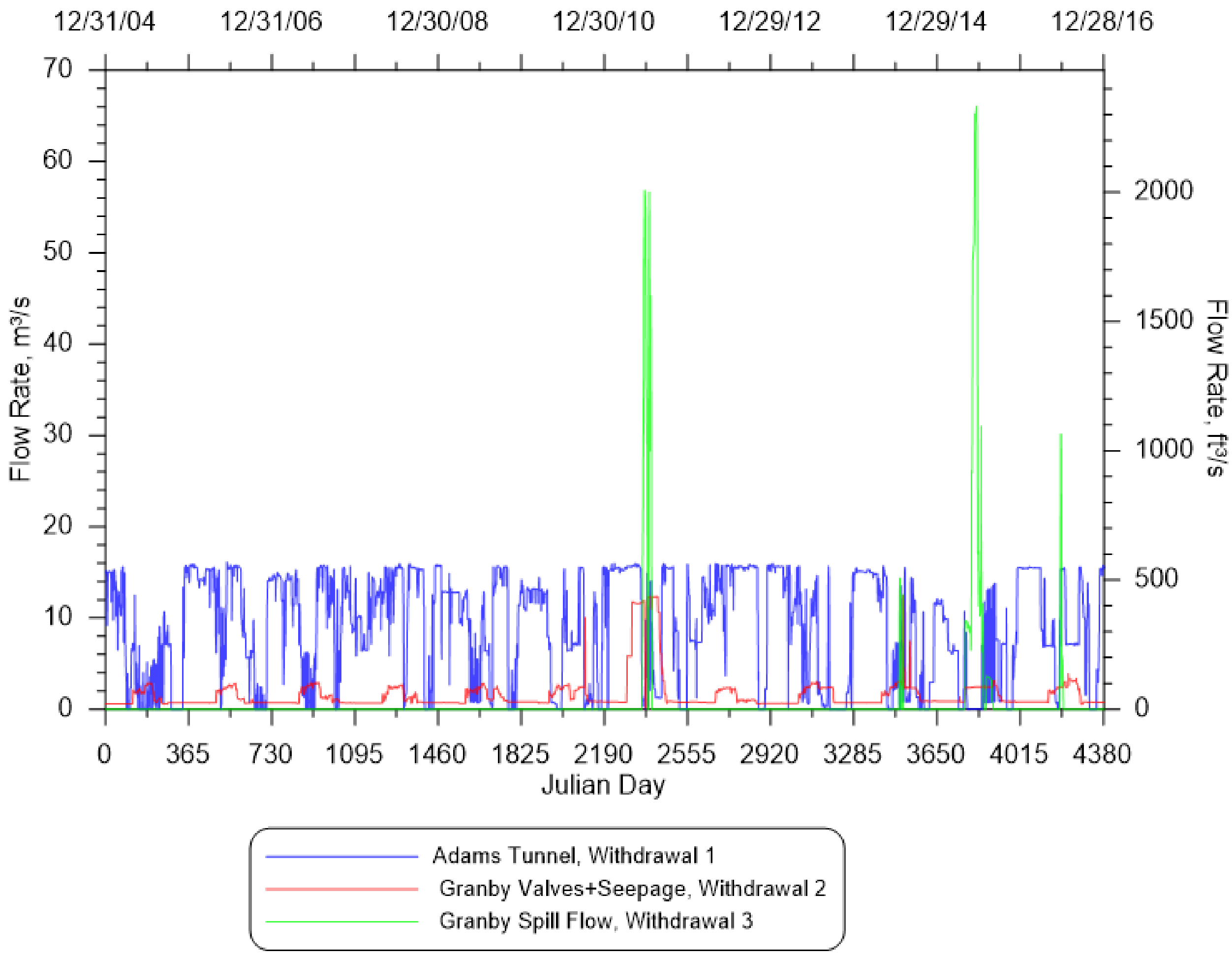


Figure 96. Withdrawals flow rate.

PUMPS

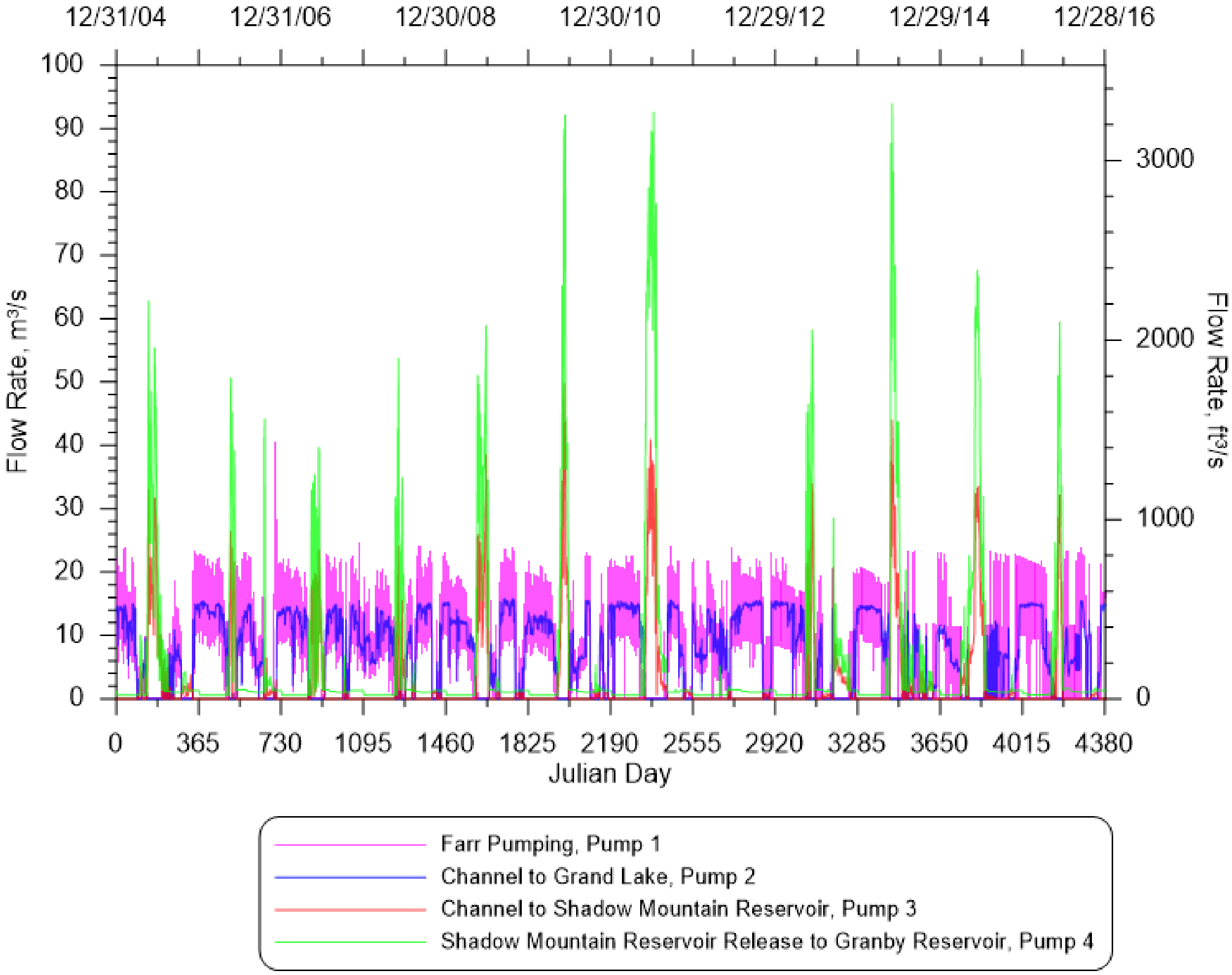


Figure 97. Pump flow rates.

APPENDIX C: REVIEW COMMENTS FROM USBR ON THREE LAKES WATER QUALITY MODEL AND RESPONSES FROM REVIEW TEAM

During the initial review process, the Three Lakes Water Quality Model review was a separate document from the RIverWare Model review. The USBR provided review comments on this draft review document. Table 5 is a summary of these review comments from USBR and the response of the Three Lakes Water Quality Model review team.

Table 5. USBR Comments on draft Three Lakes Water Quality Model review and responses of review team.

#	Location in Review	Summary	USBR Commentary		Response
1	Title page	typographic error	Should be Great Plain Region (not Office)	CBG	Revised
2	Pg 5 of 83	Typographic Error	Should be 'Eastern Colorado Area Office'	LAB	Revised
3	Page 5 of 83	word choice	In the last full paragraph, please consider revising the sentence to read "The review project involved two peer review panels. One assessed the in-stream Three Lakes system water quality model (developed using CE-QUAL-W2) as presented in this report. The other assessed the C-BT Planning and Operations Model (developed using RiverWare software). The C-BT Planning and Operations Model simulated flows into and through much of the Colorado-Big Thompson Project, including the Three Lakes system, defining boundary conditions for the reservoir water quality model." This recommendation corrects concerns about A) the use of the phrases "distribution in the basin" and "hydrology model", B) identifying the models by the software used to create them, and C) understanding what the other model's role is in our overall effort.	JRV	Revised
4	Page 6 of 83	typographic error	"Customized code changes included adding a flow-induced resuspension algorithm, parallelization of some ~~of~~ water quality kinetic algorithms,"	CBG	Revised

#	Location in Review	Summary	USBR Commentary		Response
5	Page 6 of 83	General comment	The last 2 paragraphs under Review Objective section *imply* model has good foundation but could/should be better if recommendations implemented. It would be more clear to all readers if authors were a bit more direct in their language.	CBG	Added more explanatory text
6	Page 8 of 83	General comment	Parts of the comments in this table suggest improvements to the Hydros documentation. Please consider making a judgement as to whether such enhancement is necessary to achieve our objective of having a model acceptable for our proposed NEPA application. FYI, the Hydros documentation was prepared by a consultant who is no longer contracted to Reclamation as that work and report have been finalized.	JRV	Added more explanatory text
7	Page 10 of 83, point 12	General comment	Consider revising the last sentence to be more forceful, if reflective of the reviewers views. For example, "We recommend that the model be enhanced to model the narrow portions of Shadow Mountain Reservoir more explicitly, perhaps by using one narrow channel on one side of the islands (main branch) and another segment or two in another branch connecting to the main branch on the other side of the islands. Doing so would produce more realistic velocities and flow-exchange rates."	JRV	Revised
8	Page 10 of 83, point 14	General comment	Consider revising the final sentence to be more forceful, if reflective of the reviewers views. For example, eliminate "perhaps" and replace "have been" with "be".	JRV	Revised

#	Location in Review	Summary	USBR Commentary		Response
9	Pg 11 of 83, point 17	Typographic Error	'The gains for each water body were added to the major tributaries as described in Section IX.C' should be Section IX.B (pg 34 of 151 3LWQM v1.1 documentation).	LAB	Checked reference for Point 17 and 18 - both are correct references to the documentation.
10	Page 11 of 83, point 18	General comment	Water Balance concerns reflect issues also identified in the CBT P&OM review. In both reviews it is apparent that reviewers are uncertain about what was done in developing these models. Accepting both this uncertainty and need for improvement, would you accept an explanation of what was done so that your commentary can reflect a more accurate understanding and your recommendations more useful to us in correcting these issues?	JRV	An explanation would have been useful. Our review was based only on the documentation and model files given to the reviewers.
11	Page 13 of 83	General comment	The graph is very helpful but sources for the data point being graphed required some work to determine. Suggest a screen capture (similar to those provided with review comments #37, #43, #44 and #45) to source of data points being graphed.	CBG	Revised
12	Page 13 of 83	Calculation comment	"On the other end of the scale, imposing a fairly large zero-order SOD rate in Grand Lake, with a temperature-adjusted maximum rate of 4.55 $g/m^2/d$ seems excessively high." **Comment:** 1.3 [FSOD] * 3.5 [SOD for Grand Lake] * 0.99 [SODK2] = 4.505	CBG	The 4.55 is correct. At temperatures above 25oC the temperature correction goes above 0.99 to 0.99999 or 1 leading to 4.55 as the maximum rate.
13	Pg 14 of 83	General Comment	#28 - This is the only reference to secchi depth made by the reviewers. Given that this metric controls passing or failing multiple water quality goals, I would be interested to know if the reviewers thought it was	LAB	Added comment.

#	Location in Review	Summary	USBR Commentary		Response
			handled robustly in the modeling approach.		
14	Page 15 of 83	General comment	Although each figure in the review document has a unique number, there are two appendices (A & B). Navigation to referenced figures would be easier if the location of the referenced figure was provided. For example, "As shown in the nutrient flux section in ~~the~~ Aappendix A (Figure 2 through Figure 4), releases of ortho-phosphate".	CBG	Revised
15	Page 15 of 83	typographic error	Calibration would likely be improved i~~s~~f this large source was decreased by reducing the fraction of POM settling out of the water column and/or reducing the P fraction in POM.	CBG	Revised
16	Page 16 of 83	General comment (relates to comment #13 (Page 15 of 83) above)	"Nitrogen fluxes plotted in Figure 5 through Figure 7 (Appendix A) show that the"	CBG	Revised
17	Page 16 of 83	typographic error	"that the proportion of first order sediment compartment ammonia releases are relatively high in Shadow Mountain Reservoir."	CBG	Revised
18	Page 18 of 83	General comment (relates to comment #10 above)	The graph is very helpful but sources for the data point being graphed required some work to determine. Suggest a screen capture (similar to those provided review comments #37, #43, #44 and #45) to source of data points being graphed.	CBG	Revised
19	Pg 20 of 83	General Comment	Please provide additional justification for using dewpoint temperature. (See also comment for Pages 28, 29 and 30 of 83 below.)	LAB	Added
20	Page 21 of 83	General comment (relates to comment #13 above)	Add (Appendix B, Figure . . .) for reviewer comments 47, 48 and 49	CBG	Revised

#	Location in Review	Summary	USBR Commentary		Response
21	Pg 22 of 83	General Comment	According to the review, you may wish to add the recommendation that Tair.npt also need to be revised per reviewer comment #46 on page 20 and 28.	LAB	Revised
22	Page 22 of 83, part 4	General comment	There are several nearby comments similar to "We recommend setting most if not all model coefficients so that they are similar between waterbodies unless there is a clear rationale as to why they should be different" including at points 43 and 44 on page 20. It would be useful to know more specifically what might constitute a clear rationale per the reviewer. As it stands, the review makes me wonder if the reviewer recognizes that Granby and Grand Lake are deep water bodies and Shadow Mountain is very shallow; that Grand Lake is a natural lake and the others are man-made reservoirs. Those physical realities suggests justification for most any difference, at least without a higher understanding of things possessed by the reviewer.	JRV	The reviewers disagree with the premise that the 3 water bodies justify different coefficient values such as nitrification. If these water bodies are connected, the populations of nitrifying bacteria for example would be interconnected regardless if they are a lake or a reservoir, shallow or deep.
23	Page 24 of 83	General Comment	Please rename the graphs as "Simulated Ortho-phospate fluxes in ***" to clarify the modeling as the source for these data (assuming they are, in fact, not observations).	JRV	Revised
24	Page 26 of 83	typographic error	Similar~~ly~~ to ortho-phosphate releases, ammonia-nitrogen releases from the first-order sediment compartment were particularly large in Shadow Mountain Reservoir.	CBG	Revised
25	Pages 28, 29 and 30 of 83	General Comments	A comment about dew point and air temperatures refers to Figure 15 (Precipitation Temperature) instead of Figures 8 and 9. Please consider explaining the reasoning behind this statement as it appears models constructed by the reviewer's agency	JRV	Revised

#	Location in Review	Summary	USBR Commentary		Response
			seems to use both air and dew temperatures in different models.		
26	Page 36 of 83	formatting improvement	Subheading title "CONSTITUENTS" at bottom of page should be adjusted to be next to the content beginning on page 37 of 83.	JRV	Revised
27	Page 37 of 83	General comment	The flat, black lines appearing in this figure is confusing as it creates the illusion of an empty plotting area. Consider revising the horizontal line to be a different color so it stands out. This comment applies to subsequent constituent figures. (Of course once I figured it out, I could better understand the figures.)	JRV	Added explanatory text to the figure captions.

APPENDIX D: REVIEW COMMENTS FROM USBR ON COLORADO BIG THOMPSON RIVERWARE MODEL AND RESPONSES FROM REVIEW TEAM

During the initial review process, the Colorado Big Thompson RiverWare Model review was a separate document from the 3 Lakes Water Quality Model review. The USBR provided review comments on this draft review document. Table 6 is a summary of these review comments from USBR and the response of the Colorado Big Thompson RiverWare review team.

Table 6. USBR comments on draft review document on the Big Thompson RiverWare model and responses of the review team.

#	Location in Review	Summary	Reclamation Commentary	Response
1	Numerous		A number of reviewer comments suggest ways that the reviewer would do things differently. (See most of 3.3, especially fifth and sixth bullets; 3.4 documentation paragraphs; 4.1, etc.) While Reclamation accepts these, perhaps it would be better to contextualize this with an early history of the model, which might explain why these ideals were not followed. It would also soften the reviewers comments to "places for possible improvement", reducing the likelihood of misunderstanding these as "requirements for current application objectives". Reclamation could provide an overview of the history beyond identification of the AOP as the starting point for C-BT P&OM (as reported in the model documentation delivered by Precision), if desired by the reviewer.	These comments were revised. The comments are all suggestions based on the review team. We have revised some of the wording to make it more explicit that these are only suggestions for possible improvement and do not affect correctness. We do feel that comprehensive model documentation is important, and that recommendation has not been softened (though it is still only a recommendation that does not affect model correctness). We agree that it would be good to contextualize these issues with an early history of the model, but this should be a task undertaken by Reclamation as part of the model documentation. It is not something that could or should be completed by the model reviewers.
2	3.3, fourth bullet	The Geospatial view requires significant organization to make it useful.	Because the geospatial view has not been created for use, please consider softening the comment, e.g. 'The Geospatial view does not appear to have been developed to the level of usefulness."	Revised text.

#	Location in Review	Summary	Reclamation Commentary	Response
3	4.5.1	First Sentence	Red Top ditch structure was created and proposed by Hydros without access to the AOP or C-BT P&OM models. Reclamation incorporated into the C-BT P&OM (which began with Reclamation's AOP model) with necessary tweaks. As such, some differences exist from what is documented in Hydros' report. The sections in Precision's report were written by Reclamation because it was an addition to the starting point AOP model. See also 4.5.2 items below for related issues.	We accept the explanation. This shows the need for updating the systemwide documentation as was one of the recommendations. The first sentence of 4.5.1 has been edited based on this description.
4	4.5.2, 4.5.3 and 4.5.4		Much of the review presented in 4.5.2, 4.5.3 and 4.5.4 reflect a mistaken understanding of these issues as based on understanding gleaned from Hydros Report. Because Reclamation incorporated Red Top Ditch pieces into the AOP, we did not accept Evaporation, Precipitation approaches used by Hydros. Bank Storage was adopted, with Reclamation reservation. This was expressed to the reviewers to explicitly consider mass balance concerns on the west slope. Hydrologic Inflow issues are also part of this broader concern. To improve this review section, Reclamation proposes clarifying the development path to the reviewers. We also hope the reviewers could help us know a better path forward, but that will require the reviewer possess a better understanding of things than they were able to gain from the disparate documentation sources.	Again, an updated source of documentation would help in understanding the history of this tool and why decisions were made. We always prefer to model 'real' processes if possible. Our review was based on the documents and RiverWare files provided. As such we felt obligated to note any inconsistencies between the two. We have revised some of the language on these points where we identified differences to state that the method selections and parameter values should be checked by Reclamation modelers to verify that the differences are intentional, and the sources of all data should be documented. Also, we feel that it was beyond our scope to provide a "better path forward." We were not charged with devising a revised approach, and this would fall more

#	Location in Review	Summary	Reclamation Commentary	Response
				under the category of a "model development support" task rather than a "model review" task.
5	4.5.9, paragraph	Remove MBTest Objects	We agree with the reviewer comments. We reserved them for your and our use in describing and resolving the mass balance questions we explicitly identified as needing reviewer attention. Perhaps the presentation of these recommentations could reflect that need, utility and future intention.	Revised the wording.
6	Section 5	Entire section - Proposed Reassignment	Overall tone and approach in this section is distinctly different from the rest of the review. The first paragraph of the section reads like a disclaimer for Section 5's inclusion in C-BT P&OM review. We suggest that the entire section be removed from the C-BT P&OM review and added as a new, separate section of suggested potential enhancements and recommendations to improve the linkage between the two models. In other words we suggest the single, final peer review document be three primary sections: 1) Peer review of C-BT P&OM 2) Peer review of 3 Lakes WQ model and 3) suggested linkage improvements to strengthen the two models (currently Section 5 of C-BT P&OM). Doing so may address many of the comments provided to us regarding this section of the C-BT P&OM draft review (see comments #7-20 below).	Revised some of the text and suggest that this is all about boundary conditions to the RiverWare model not really to linkage to the CE-QUAL-W2 models - even though it affects them. In the final document, we may adjust the location of this section within the RiverWare review section. We agree with Reclamation's comments that this section is distinctly different than the rest of the model review, and we agree that it is more suitable as its own section. However we think it is better characterized as "suggested improvements for hydrologic inputs to the RiverWare C-BT P&OM to strengthen the two models".

#	Location in Review	Summary	Reclamation Commentary	Response
7	5, first paragraph	Indicates that the following suggestions come from questions about how this model may interact with the other model.	Recognizing how this project (review of two models) was conducted, Reclamation sees a lost opportunity for the two teams to collaborate within the single contract to answer the questions about how will the RiverWare-based C-BT P&OM model interacts with the CE-QUAL W2-based water quality model. We see that the intended approach to take 'Scenario A compared to a baseline vs. Scenario B compared to a baseline' is understood in the C-BT P&OM context. We also see that the reviewers do not understand the impact of "errors" in the CE-QUAL-W2 context. Reflecting concern in the CE-QUAL-W2, the reviewers of the C-BT P&OM model identify all kinds of issues that might be detrimental to the CE-QUAL-W2 modeling phase, while not having that concern in the C-BT P&OM context. This only serves to weaken the perceived of the value of the C-BT P&OM model by including this discussion with the C-BT P&OM review. If there are concerns about the CE-QUAL-W2 model, we suggest that 1) those concerns should be raised in context of that model even if the origin of the issue is in the C-BT P&OM model, 2) someone with CE-QUAL-W2 expertise could emphasize it in the C-BT P&OM review, or 3) the administrative team overseeing both teams could comment on the connection between the two.	Comments were made in the CE-QUAL-W2 review on linkage issues. Besides the documentation in the CE-QUAL-W2 model, there was little description of the full details of the trade-off between the models. We acknowledge as RiverWare model reviewers that we are not experts on the CE-QUAL-W2 model, and we cannot in good faith address the impact of errors in the CE-QUAL-W2 context. Our review was intentionally limited to identifying components of the RiverWare C-BT P&OM model that might have issues with correctness. We recognize that, because the outputs from the RiverWare C-BT P&OM model feed into the inputs of the CE-QUAL-W2, any changes to the mass balance outputs from the RiverWare C-BT P&OM model could affect the CE-QUAL-W2 model but only in a general sense. This is perhaps another reason for separating section 5 from the rest of the RiverWare model review.

#	Location in Review	Summary	Reclamation Commentary	Response
8	5, second paragraph	"…models cannot improve upon the quality of their internal and boundary conditions; any error in the given data propogates through a system, and the possible cone of error espands as internal-model errors and approximations add to the uncertain boundary condition. Given this truism,..."	Reclamation modelers categorically reject this assertion as a "truism". Some of the errors present in the intial and boundary conditions of the C-BT P&OM model cancel each other. Likewise, the logic and operational instructions almost necessarily transition toward the average or perhaps a median condition. They do not necessarily expand and blow up becoming worse and worse.	The wording has been adjusted. But errors in initial and boundary conditions should not necessarily cancel each other, nor do they necessarily blow up. These errors would though have implications for the passage of information to the CE-QUAL-W2 model.
9	5, second paragraph	"…the mass-balance correction should be assessed by stress testing the system…"	I feel this is an academic exercise that expands our scope, cost and time requirement within the C-BT P&OM effort context with very little promise of improvement. It may help identify weakness with the model and subsequently explain some model result. Although not explicitly stated in the documentation, we're using the model in terms of comparing run A with run B -- both runs begin with the errors and flaws of the base model. We can attribute the differences between A and B not to these errors, but to the differences in policy or configuration between A and B. Given the intention to analyze using the "deltas" between two scenarios as compared with some base case, does the review team maintain their stated position?	This comment was not part of the charge of the review committee to analyze the impacts of deltas between scenarios. The suggestion wording has been altered somewhat to make it an optional exercise. The main import of these comments was to understand how decisions on boundary conditions affects model predictions.

#	Location in Review	Summary	Reclamation Commentary	Response
10	5, fourth paragraph	Perform a thorough modeling analysis of errors and modeled outcomes (including a Monte-Carlo approach)	I feel this is an academic exercise that expands our scope, cost and time requirement within the C-BT P&OM effort context with very little promise of improvement. It may help identify weakness with the model and subsequently explain some model result. Although not explicitly stated in the documentation, we're using the model in terms of comparing run A with run B -- both runs begin with the errors and flaws of the base model. We can attribute the differences between A and B not to these errors, but to the differences in policy or configuration between A and B. Given the intention to analyze using the "deltas" between two scenarios as compared with some base case, does the review team maintain their stated position?	This comment was not part of the charge of the review committee to analyze the impacts of deltas between scenarios. The suggestion wording has been altered somewhat to make it an optional exercise. The main import of these comments was to understand how decisions on boundary conditions affects model predictions.
11	5.1		This section reads like an academic article disconnected from an understanding of what was done, the relative (in)significance of the various recommendations, and the objectives of the modeling effort.	They were meant to provide general guidelines to look more carefully at the mass balance errors. We feel the guidelines may or may not lead to changes in the way the RiverWare model was set up and used. Some of the text was adjusted.
12	5.1, second paragraph	We recommend investigating these factors because of their possible influence on water quality model inputs	Given the intention to analyze using the "deltas" between two scenarios as compared with some base case, do the reviewers maintain their stated position? Do the reviewers have a sense of scale for the problem at hand to contextualize the possible benefit of these items within the larger known sources of error?	If the intent is to minimize mass balance errors, then the items listed could be useful. Many of these may already have been considered. But sometimes once when has a model structure in place, one needs an out-of-the-box look again at one's inputs. That was the purpose of this section.

#	Location in Review	Summary	Reclamation Commentary	Response
13	5.1, first, second and third bullets		Suggestion of these as worthwhile recommendations to address our issue betrays a lack of understanding of the problems at hand and the system being considered.	See above comment.
14	5.1, fourth bullet	Analysis of ungaged watershed contribution	USGS and Reclamation believe that this, in fact, represents the largest source of gaging / inflow error, dwarfing the possible influence of the previous three bullets. The recommended "determining what percentage of the flow in the watershed is below a gage or otherwise not accounted for" is representative in the correction time series that is calculated by mass balance. The statement "...some parts of each watershed may be ungaged" undermines our confidence in this review. Did the reviewer have a map of the area?	Yes, we had a map. The purpose was to minimize mass balance errors. High positive and negative flows in the mass balance are usually not acceptable for downstream models.
15	5.1, last paragraph	Apply system knowledge and other data sources as an inherent "sanity check" on input data.	Please rewrite this to change tone, and what we can only hope is its unintended theme. We accept that "some formalization through data analysis and documentation would help convey this level of confidence in the data." As this paragraph currently stands, it suggests to the reader that "applying system knowledge" and a "sanity check" are not done continuously by Reclamation and its partners, which is not an accurate suggestion.	Text was revised.
16	5.2, number 4	Revisit certain unrealistic / unexplained features in inflow hydrographs	Reclamation accepts the views presented herein. These data were created under contract by competent consulting engineers / hydrologists and these "irregularities" reflect a variety of data limitations and system constraints. Can the reviewer provide some confidence that	If the staircase flows during low flow periods are so low that they do not affect model accuracy or the mass balance errors, then this point of revision is optional.

#	Location in Review	Summary	Reclamation Commentary	Response
			either A) what the reviewer recommends is necessary to achieve our C-BT P&OM modeling objectives or B) these irregularies are unlikely (or simply won't) be significant in achieving our modeling objectives?	
17	5.2, number 5, A	Use Hydros values for evaporation, precipitation; investigate relationship of these values to mass balance residuals (errors). Consider revisiting assumptions; explain them.	The reviewer does not recognize that these methods reflect those used in our operational environment. Reclamation understands this and recognizes it as a piece of the misunderstanding identified above relating to the west slope reservoirs, Hydros' report and Precision's report. Please mark this for reconsideration following a discussion of those issues.	Yes, this points to the need to have Reclamation develop a more updated documentation showing their current practices.
18	5.2, number 5, 6	Provide thorough details of the data-sources, handling processes, etc. and conduct a thorough analysis of the data themselves. More ways to improve and legitimize values used. Loss and gain analysis etc.	In creating a list such as this (questions, possible considerations, generic data handling procedures), the reviewer introduces doubt into our efforts without responsibly considering whether or not what has been done is sufficient for the C-BT P&OM modeling purposes. If the reviewer is not willing or able to make such a judgement, we would prefer removing this type of review comment in the numerous places they are found.	All of these comments are included to point the need for continued refinement of the data and source data if such exist. If Reclamation is satisfied that they have input data that meets their quality criterion, then these comments do not need to be acted upon.
19	5.2, number 6	Possible underestimation of flows "suggests either measurement error or that	See our comment associated with 5.1, fourth bullet above.	See above comment.

#	Location in Review	Summary	Reclamation Commentary	Response
		there is ungaged watershed contributing to the water level".		