# APPENDIX C. SOUTH FORK FLATHEAD RIVER BOUNDARY CONDITION

## CONTENTS



## TABLES

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# ACRONYMS

| | |
|---|---|
| BOR | U.S. Bureau of Reclamation (U.S. Department of the Interior) |
| DEQ | Montana Department of Environmental Quality |
| FLBS | Flathead Lake Biological Station |
| LSPC | Load Simulation Program in C++ |
| SSC | suspended sediment concentration |
| TN | total nitrogen |
| TP | total phosphorus |
| TPN | total persulfate nitrogen |
| TSS | total suspended solids |
| USGS | U.S. Geological Survey (U.S. Department of the Interior) |
| WY | Water Year (starts on October 1st - WY2014 would be 10/1/13 through 9/30/14) |

# UNITS OF MEASURE

| | |
|---|---|
| cfs | cubic feet per second |
| mg/L | milligram per liter |

# C-1. INTRODUCTION

While the North and Middle forks of the Flathead River and Swan River were explicitly modeled in LSPC, the South Fork Flathead River upstream of Hungry Horse Dam (**Figure C-1**) was modeled as a point source boundary condition. Monitored water quality and flow data from U.S. Geological Survey (USGS) flow gage 12362500 and Flathead Lake Biological Station (FLBS) long-term sampling site FBC02011 were used to develop a daily time series boundary condition for the South Fork Flathead watershed; the time series was input to the model at the location of gage 12362500. The South Fork Flathead River boundary condition time series was created for 1/1/1998 through 9/30/2012. Hydrological calibration was performed for 1/1/2000 through 9/30/2012; water quality calibration, 1/1/2002 through 9/30/2012. The boundary condition time series was developed prior to the finalization of the model calibration periods; hence the boundary condition time series includes a few years that were not part of the modeling period.

The watershed downstream of the gage to the mainstem of Flathead River near Hungry Horse was modeled by the Loading Simulation Program in C++ (LSPC). A map showing the location of the monitoring stations downstream of Hungry Horse Reservoir is presented as **Figure C-2**, and the following sections of the of the report provide a detailed discussion of the available data and how the boundary conditions were derived.

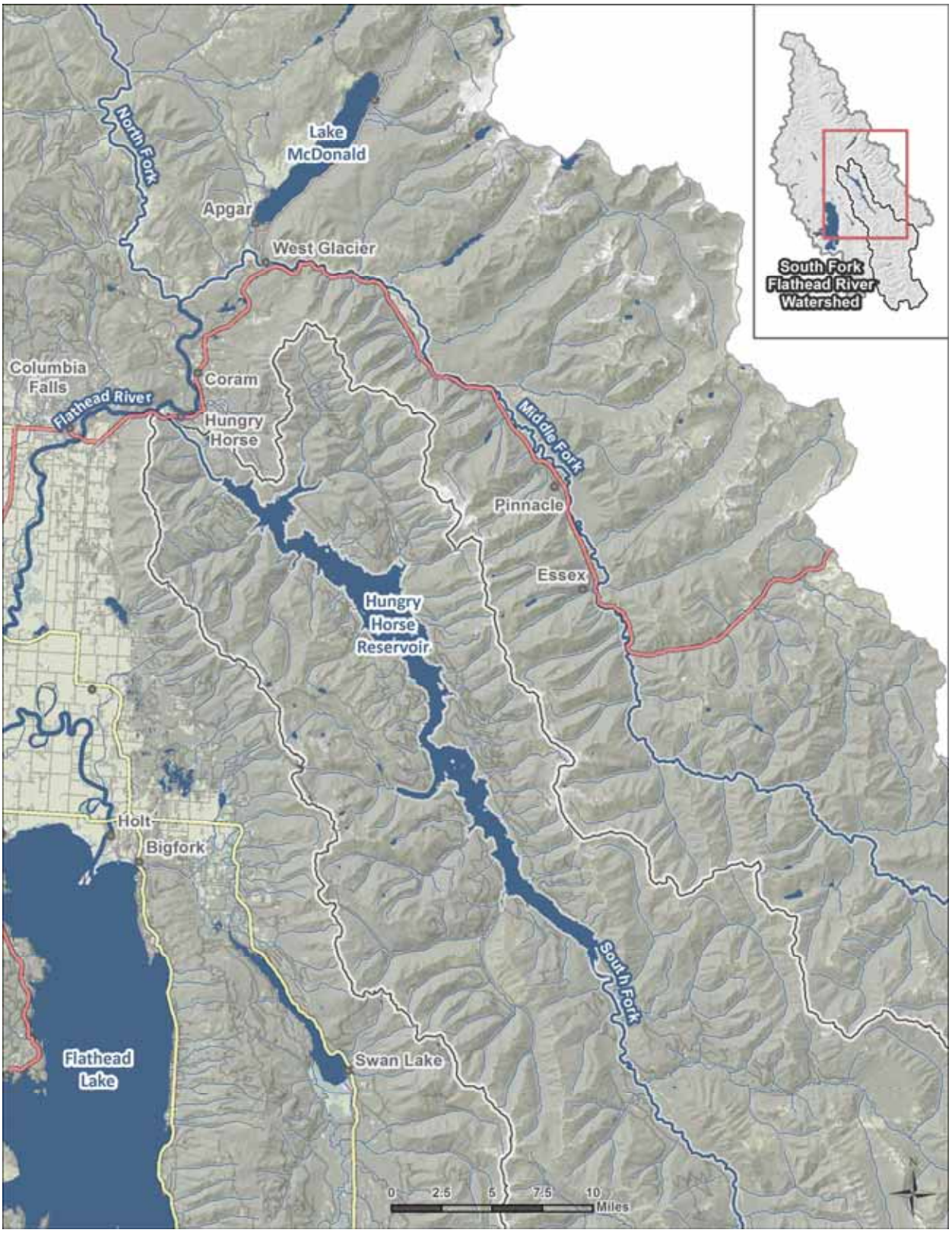



**Figure C-1. Hungry Horse Reservoir and the North, Middle, and South Forks of the Flathead River.**

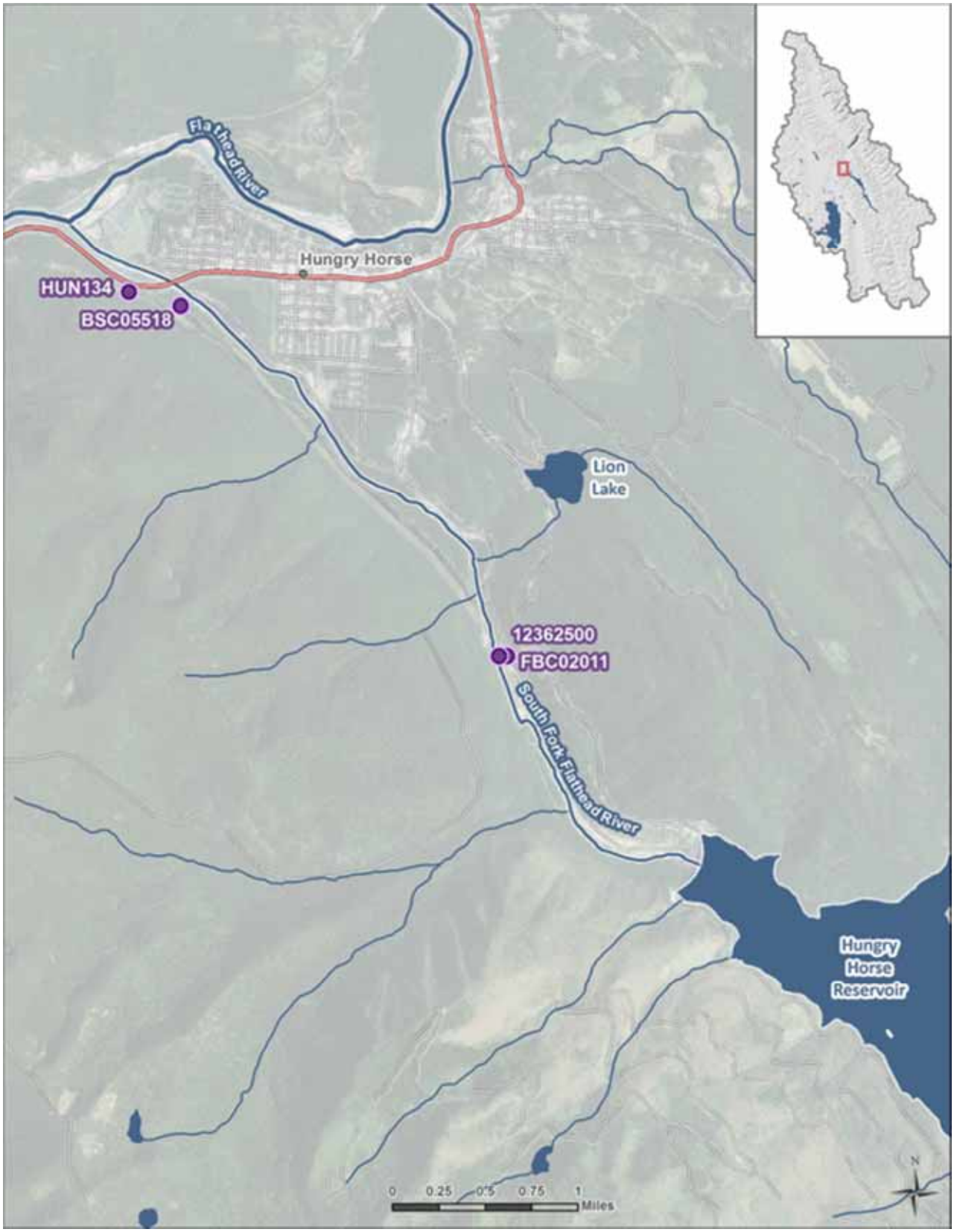



**Figure C-2. Sample Stations Along the Lower South Fork Flathead River.**

# C-2. AVAILABLE DATA

Water chemistry and flow data are available for four sample stations along the South Fork Flathead River between the outlet of the Hungry Horse Dam and the mouth on the Flathead River (**Figure C-2**). The data are summarized in **Table C-1**. A detailed discussion of the data available for each parameter is presented in the following subsections.

**Table C-1. Sample Stations Along the Lower South Fork Flathead River**

| Agency | Site ID | Site Name | Latitude | Longitude |
|---|---|---|---|---|
| USGS | 12362500 | South Fork Flathead River near Columbia Falls, MT | 48.3566 | -114.0379 |
| DEQ | BSC05518 | South Fork Flathead River at bridge | 48.3825 | -114.0772 |
| FLBS | FBC02011 | South Fork Flathead River - Columbia Falls | 48.3567 | -114.0367 |
| BOR | HUN134 | South Fork Flathead River at Highway 2 bridge | 48.3833 | -114.0833 |

*Notes*
BOR = Bureau of Reclamation; DEQ = Montana Department of Environmental Quality; FLBS = Flathead Lake Biological Station; USGS = United States Geological Survey
Geographic coordinates are reported in the North American Datum of 1983.

## C-2.1. AVAILABLE FLOW DATA

Continuous flow data were available at one location and instantaneous flow was collected twice at another location; the data are summarized in **Table C-2**. The Hungry Horse Reservoir was constructed between water year (WY) 1947 and WY 1953. A comparison of flow duration curves at USGS gage 12362500 pre-construction (WY 1912 through WY 1947) and post-construction (WY 1953 through WY 2012) is presented in **Figure C-3**. That graph shows that, on average, the reservoir generally decreases the highest and lowest 20 percent of flows, but increases the middle 60 percent of flows relative to pre-construction flow levels. It shows that the reservoir suppresses the flow energy of the river relative to pre-construction levels.

Average daily streamflow for USGS gage 12362500 for pre-construction and post-construction periods coincident with **Figure C-4** is presented in **Table C-2**. During typical dam and reservoir operations, water is withdrawn through the penstocks to power the turbines and then discharged to the South Fork Flathead River below the dam. In 1995, a selective withdrawal system was installed to the penstock system to allow for higher elevation, warmer water withdrawals. The selective withdrawal system consists of a series of gates than can be raised and lowered along the penstock system to allow for selective withdrawals at a range of depths. During normal summer operation, the selective withdrawal system is positioned depending on flow and water temperature needs. The selective withdrawal system is not used during the winter time period.

**Table C-2. Sample station with flow data on the lower South Fork Flathead River**

| Site ID | Begin date | End date | No. of flows | Min. | Median | Max. | Avg. |
|---|---|---|---|---|---|---|---|
| 12362500 (continuous) | 2/1/1911 | 9/30/2012 | 32,455 | 7 | 2,180 | 40,800 | 3,572 |
| HUN164 | 3/4/1982 | 5/24/1982 | 2 | 250 | 335 | 419 | 335 |

*Note:* Values are reported as daily average flows and are rounded to the nearest cubic feet per second.

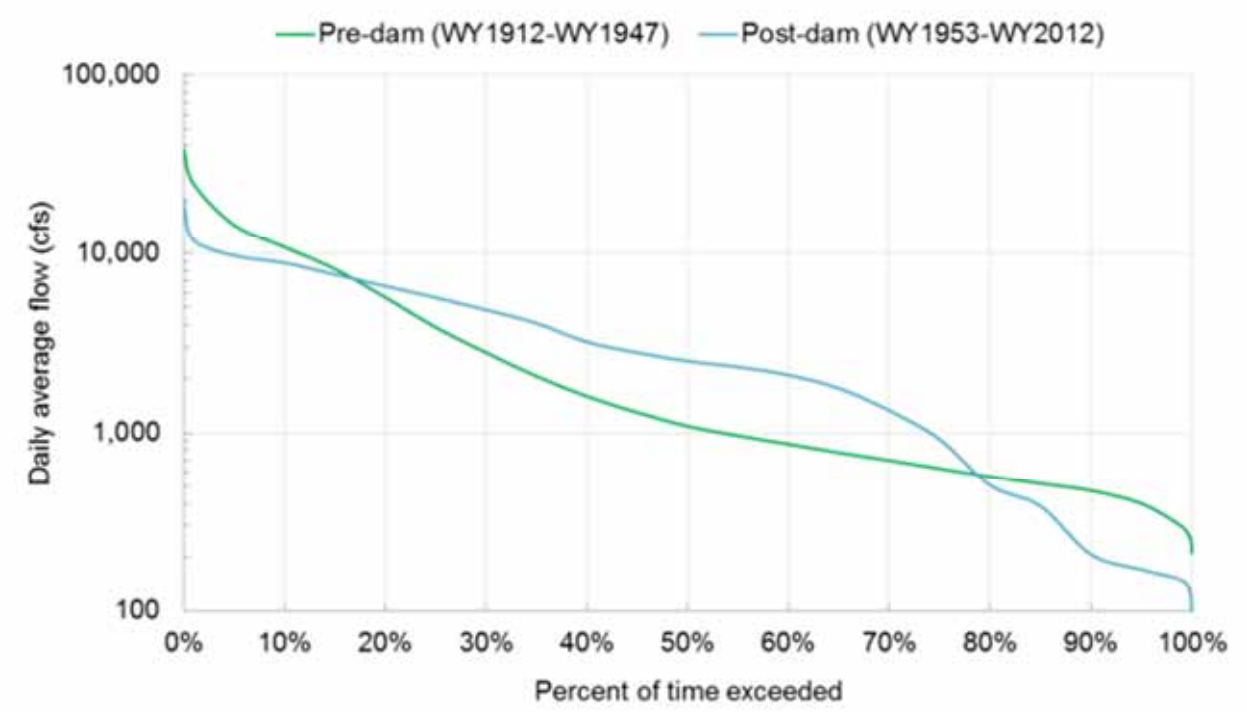



**Figure C-3. Flow Duration Curve at USGS gage 123625000 South Fork Flathead River near Columbia Falls MT.**

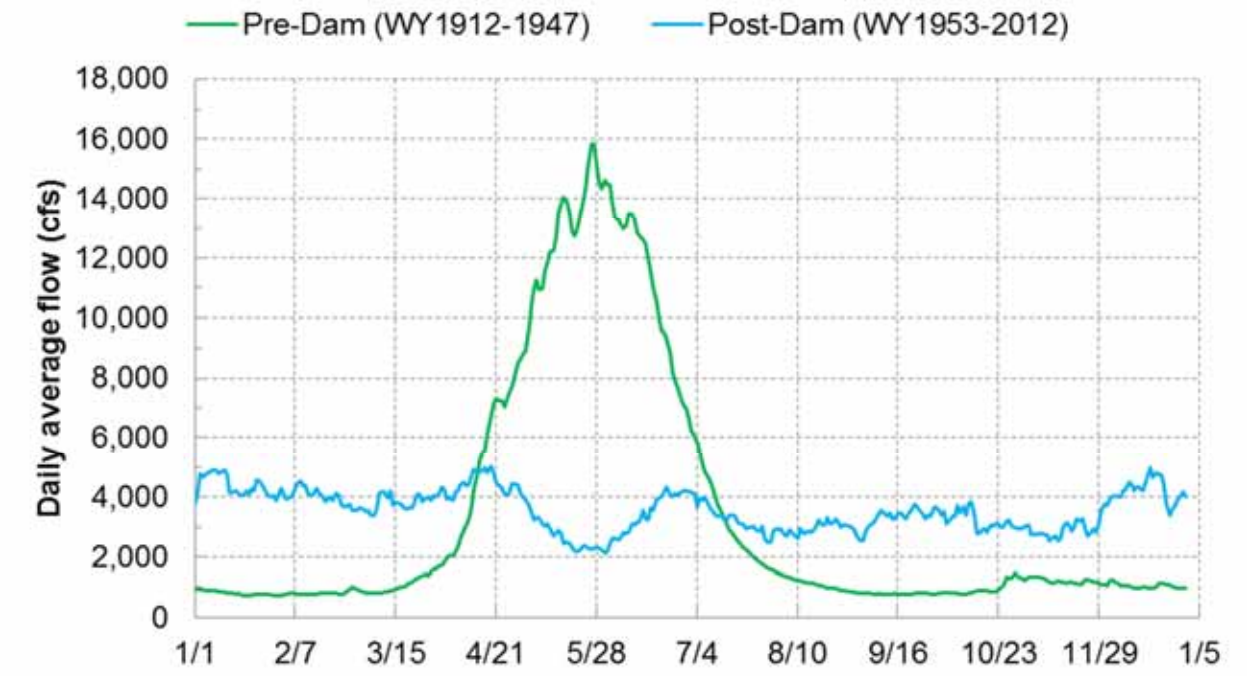



**Figure C-4. Average Daily Discharge at USGS gage 123625000 South Fork Flathead River near Columbia Falls MT.**

## C-2.2. AVAILABLE SUSPENDED SEDIMENT CONCENTRATION DATA

Suspended sediment concentration (SSC) data were collected at one location by USGS and total suspended solids (TSS) data were collected by both the U.S. Bureau of Reclamation (BOR) and the Flathead Lake Biological Station (FLBS) at two other locations (**Table C-3**). Box-and-whisker plots are shown for FLBS site FBC02011 in **Figure C-** 5.

**Table C-3. Sample Stations with SSC and TSS Data along the Lower South Fork Flathead River**

| Site ID | Begin date | End date | n | Non-Detects[a] | Min. | Median | Max. | Avg. |
|---|---|---|---|---|---|---|---|---|
| 12362500[b] | 3/26/2007 | 7/16/2008 | 19 | 1[c] | 1 | 1 | 1 | 1 |
| FBC02011[d] | 3/13/1978 | 6/14/2006 | 137 | 61[e] | <1 | 1 | 28 | 2 |
| HUN134[d] | 4/16/1982 | 3/23/1983 | 11 | 4[f] | 1 | 1 | 3 | 1 |

*Notes*

Values are rounded to the nearest milligram per liter (mg/L). One-half of the detection limit was used for non-detects in the calculation of statistics (i.e., min., median, max., and avg.).

[a] Number of samples for which suspended sediment concentration or total suspended solids was below the method detection limit (i.e., non-detects).

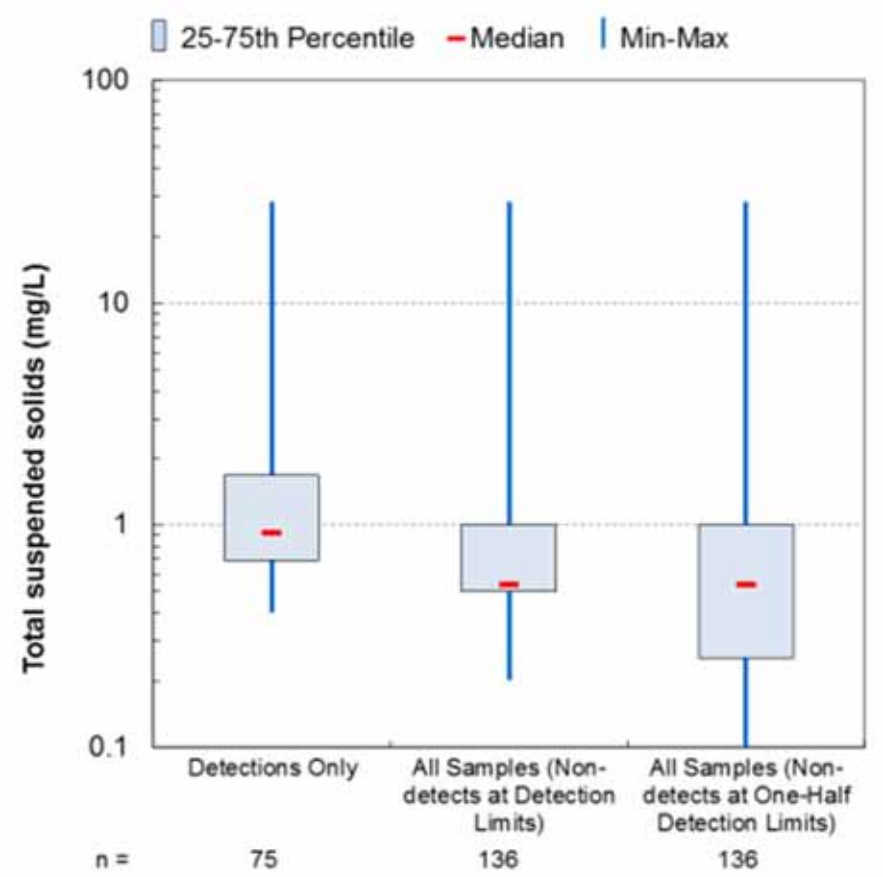
[b] USGS evaluated suspended sediment concentration at gage 12362500

[c] One suspended sediment concentration at gage 12362500 was reported as below the *minimum reporting level* (1 mg/L).

[d] FLBS and BOR evaluated total suspended solids at FBC02011 and HUN134, respectively.

[e] Sixty non-detects were reported at a method detection limit of 0.5 mg/L; one non-detect was reported at a method detection limit of 0.2 mg/L. One record was reported without a result and with no method detection limit.

[f] Four total suspended solids concentrations at HUN134 were reported with the code *K*, which is below detection limit (1 mg/L).




*Note:* One record's result was null; only the 136 records with results are shown.
**Figure C- 5. Box-and-Whisker Plots of TSS at Site FBC02011.**

## C-2.3. AVAILABLE NITROGEN DATA

Total nitrogen (TN) data were collected by four entities at three separate locations. The available nitrogen data are summarized by source agency in **Table C-4**. USGS evaluated each of 10 samples it collected in 2007 and nine samples collected in 2008 (site 1236500) for total nitrogen and the following nitrogen compounds (all as milligrams per liter [mg/L] nitrogen): ammonia (dissolved), nitrate (dissolved), nitrite (dissolved), nitrate plus nitrite (dissolved), and organic nitrogen (total).

USGS also collected eight samples in 2008 that were evaluated for nitrate plus nitrite (dissolved) and collected eight samples in the 1940s and 1950s that were evaluated for nitrate (total). Most of the samples were non-detect with the exception of nitrate and nitrate plus nitrite (due to the nitrate). BOR evaluated each of its 12 samples (site HUN134) for two nitrogen species parameters: ammonia plus organic nitrogen (total) and nitrate plus nitrite (dissolved). The largest dataset of nitrogen-species was available for FLBS site FBC02011[1]. FLBS reports data for the following parameters: ammonia (filtered), nitrate (filtered), nitrate plus nitrite (filtered), nitrite (filtered), total kjeldahl nitrogen (whole), and total persulfate nitrogen (whole).A single non-detect was collected at site BSC05518 by DEQ. The results for total nitrogen (TN) at this location are shown in **Table C-4**.

[1]

**Table C-4. Sample Stations with TN Data along the Lower South Fork Flathead River**

| Site ID | Begin date | End date | n | Non-detects[a] | Min. | Median | Max. | Avg. |
|---|---|---|---|---|---|---|---|---|
| 12362500 | 3/26/2007 | 12/10/2007 | 8 | 0 | 0.07 | 0.11 | 0.16 | 0.12 |
| BSC05518 | 4/1/1985 | 4/1/1985 | 1 | 1[b] | -- | -- | -- | -- |
| FBC02011 | 9/14/1987 | 11/8/2006 | 251 | 4[c] | 0.01 | 0.11 | 0.23 | 0.11 |
| HUN134[d] | 3/4/1982 | 3/23/1983 | 12 | 1[e] | 0.06 | 0.13 | 0.23 | 0.14 |

*Notes*

Values are rounded to the nearest milligram per liter. One-half of the method detection limit was used for non-detects in the calculation of statistics (i.e., min., median, max., and avg.); if the method detection limit was not reported, then the non-detect was not included in the calculation of statistics.

[a] Number of samples for which total nitrogen was below the method detection limit (i.e., non-detects).

[b] Both nitrate (dissolved) and nitrite (dissolved) at BSC05518 were non-detect. The method detection limit of nitrate is 0.08 mg/L nitrogen.

[c] The method detection limit was not reported for three of the four non-detects at site FBC02011.

[d] Total nitrogen at HUN134 was calculated as the summation of ammonia plus organic nitrogen (total) and nitrate plus nitrite (dissolved).

[e] In one sample collected at HUN134, both ammonia plus organic nitrogen (total) and nitrate plus nitrite (dissolved) were non-detect. In nine additional samples, nitrate plus nitrite (dissolved) were non-detect. The method detection limits were 0.05 mg/L nitrogen for ammonia plus organic nitrogen (total) and 0.1 mg/L nitrogen for nitrate plus nitrite (dissolved). One-half of the method detection limit was used in the summations of nitrogen species to calculate total nitrogen.

An additional analysis was performed that evaluated the monthly composition of observed total nitrogen (TN) as individual species at FLBS site FBC05011. The species relative to the LSPC watershed model are organic nitrogen, ammonia, and nitrate + nitrite. A total of 226 data points were available for this analysis which had enough coincident records for nitrogen parameters to estimate the distribution among those three species. The average TN composition by month derived from this analysis is presented in **Figure C-6**. Knowing the seasonal variability in TN distribution provides a means for splitting TN loads within the model boundary condition in the absence of continuous samples.

**Figure C-6** shows a well-defined seasonal signature in the distribution of nitrogen species between nitrate and organic nitrogen. Ammonia remains relatively constant between 3 percent and 5 percent of the TN distribution.

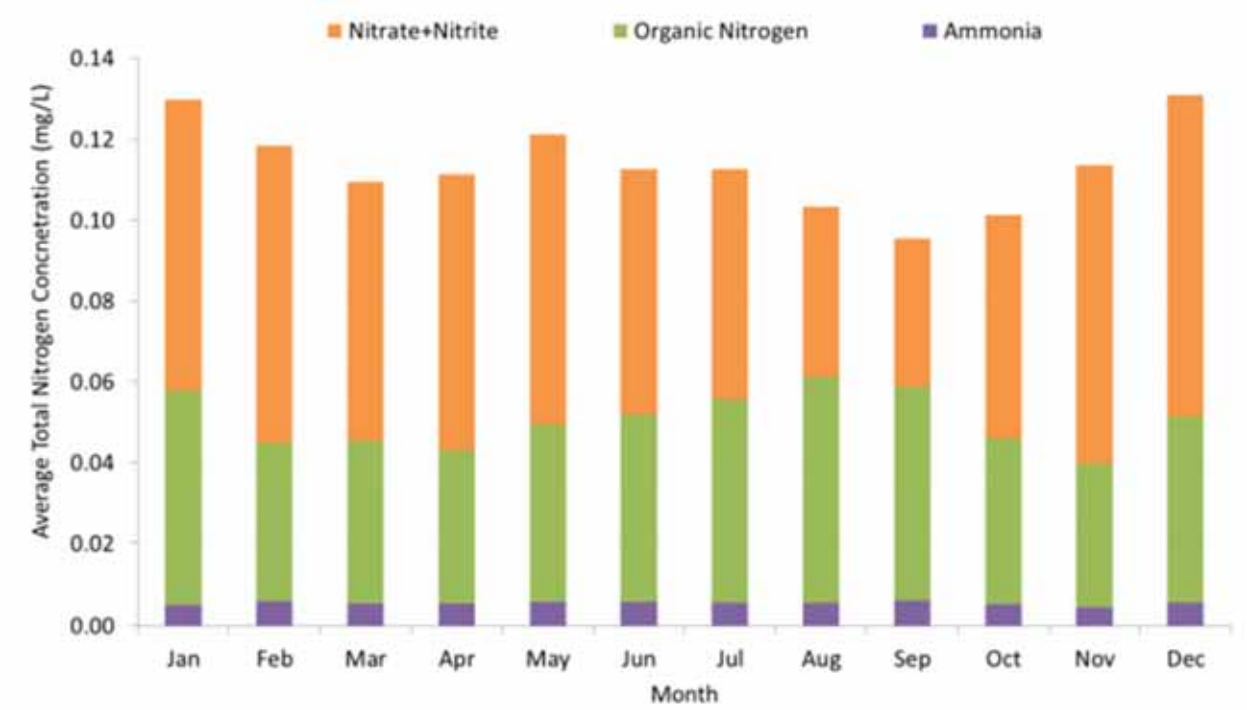



**Figure C-6. Average Monthly Distribution of Nitrogen Species at Site FBC02011 (WY 1988 – WY 2006).**

## C-2.4. AVAILABLE PHOSPHORUS DATA

Total phosphorus (TP) data were collected at three locations by four entities and the data are summarized in **Table C-5**. USGS evaluated each of its 19 samples for TP (mg/L as phosphorus, **Table C-5**) and orthophosphate (mg/L phosphorus and mg/L phosphate). BOR evaluated each of its 12 samples for TP and orthophosphate (both as mg/L phosphorus). FLBS collected the largest number of samples (n=321) over the longest time period (**Table C-5**); FLBS also collected concurrent soluble reactive phosphorus samples[2]. A single non-detect was collected at site BSC05518 by DEQ.

**Table C-5. Sample Stations with TP data along the Lower South Fork Flathead River**

| Site ID | Begin date | End date | n | Non-Detects[a] | Min. | Median | Max. | Avg. |
|---|---|---|---|---|---|---|---|---|
| 12362500 | 3/26/2007 | 7/16/2008 | 19 | 19[b] | -- | -- | -- | -- |
| BSC05518 | 4/1/1985 | 4/1/1985 | 1 | 1 | -- | -- | -- | -- |
| FBC02011 | 1/24/1978 | 11/8/2006 | 321 | 2 | 0.0009 | 0.0044 | 0.0178 | 0.0051 |
| HUN134 | 3/4/1982 | 3/23/1982 | 12 | 0 | 0.001 | 0.005 | 0.022 | 0.007 |

*Notes*

Values are rounded to the nearest milligram per liter as phosphorus.

[a] Number of samples for which total phosphorus was below the method detection limit (i.e., non-detects). Non-detects are excluded from the summary statistics.

[b] Total phosphorus was below the *laboratory reporting level* (0.008 mg/L as phosphorus) in all 19 samples but one sample was above the *long-term method detection level*.

[2] Soluble reactive phosphorus samples: n = 292; range: 0.0003 mg/L to 0.0041 mg/L; median: 0.0008 mg/L; average: 0.0009 mg/L).

An analysis of the individual phosphorus species showed that organic phosphorus typically constitutes between 75 and 80 percent of the TP load. This fraction is highest during the beginning of snowmelt around March through August. Similarly, the fraction of the TP load composed of orthophosphate typically stays between 25 and 30 percent. **Figure C-7** presents a plot showing the breakdown of the TP load by month using data from the FBC02011 station referenced in **Table C-5**.

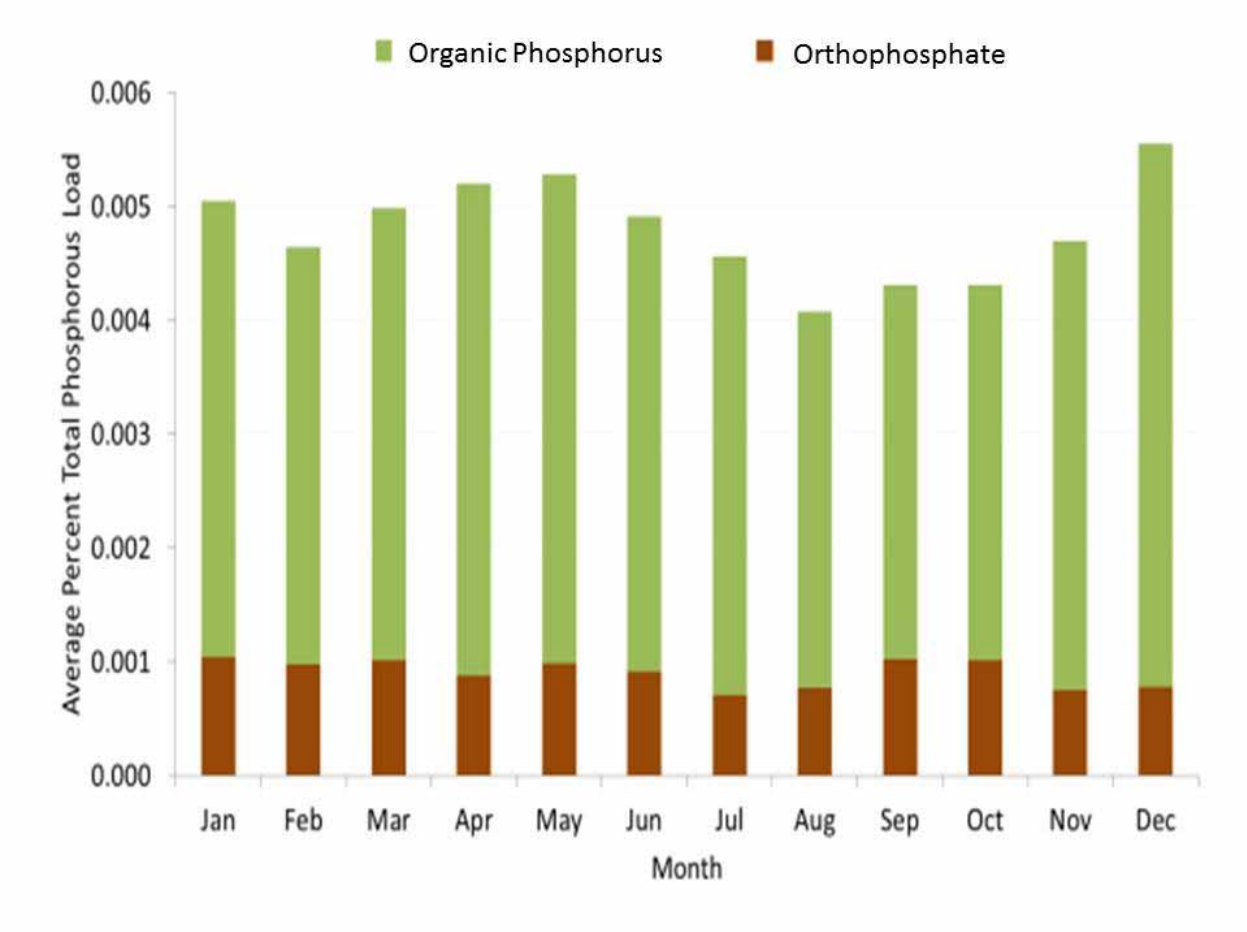



**Figure C-7. Average Monthly Distribution of Phosphorus Species at Site FBC02011 (WY 1978 - WY 2006).**

## C-2.5. AVAILABLE TEMPERATURE DATA

Continuous temperature data were collected at USGS gage 12362500 between WY 1999 and WY 2012. A statistical summary of the available observations is presented in **Table C-6**. This dataset aligns spatially and temporally with the daily streamflow dataset collected at the same location. Grab samples were collected at two additional locations presented in **Table C-7**.

**Table C-6. Daily temperature data (Celsius) at USGS gage 12362500**

| Type | Begin date | End date | n | Min. | Median | Max. | Avg. |
|---|---|---|---|---|---|---|---|
| Daily minimum | 10/1/1998 | 9/30/2011 | 4,405 | 2.5 | 4.0 | 17 | 6.8 |
| Daily maximum | 10/1/1998 | 9/30/2011 | 4,406 | 3.0 | 4.5 | 19 | 7.6 |
| Daily mean | 10/1/1998 | 9/30/2011 | 4,399 | 3.0 | 4.0 | 19 | 7.3 |

*Notes*
Values are reported in degrees Celsius.
Data for WY 2012 are provisional and not displayed.

**Table C-7. Temperature Grab Sample Data (Celsius) along the Lower South Fork Flathead River**

| Site ID | Begin date | End date | n | Min. | Median | Max. | Avg. |
|---|---|---|---|---|---|---|---|
| 12362500 | 12/16/1948 | 11/5/2012 | 112 | 0 | 4.5 | 17.5 | 6.4 |
| HUN134 | 7/15/1982 | 7/15/1982 | 1 | | -- | -- | 4.8 |

## C-2.6. AVAILABLE DISSOLVED OXYGEN DATA

Dissolved oxygen data were collected at only one location: USGS gage 12362500. USGS collected 19 samples between March 26, 2007 and July 16, 2008. Dissolved oxygen concentration ranged from 8.4 mg/L to 12.9 mg/L (median: 10.8 mg/L; average: 10.7 mg/L). Dissolved oxygen saturation ranged from 85 percent to 110 percent (median: 97 percent; average: 97 percent).

# C-3. DEVELOPMENT OF BOUNDARY CONDITIONS

Boundary conditions for the LSPC model were developed using observed data from the USGS and FLBS monitoring locations discussed previously and shown in **Figure C-2**. **Table C-8** describes in more detail which of the two sites was used for each constituents

**Table C-8. Monitoring sites used for boundary condition development**

| Agency | Site ID | Flow | Suspended solids | Nitrogen | Phosphorus | Water temperature | Dissolved oxygen |
|---|---|---|---|---|---|---|---|
| USGS | 12362500 | ● | | | | ● | ● |
| FLBS | FBC02011 | | ● | ● | ● | | |

Boundary conditions were created for the time period 1/1/1998 through 9/30/2012. This is longer than the current model period (10/1/2002 through 9/30/2012; a two year spin-up [10/1/2000 through 9/30/2002 for hydrological calibration precedes the model period) because the boundary condition time series was developed before the modeling period was decided upon. The daily streamflow observations at USGS gage 12362500 were continuous without data gaps; therefore, this time series was used directly and unmodified in the South Fork Flathead River boundary condition. Similarly, the observed water temperature dataset contained minimal data gaps between October 1, 1998 and September 30, 2006. Data gaps present during this period were filled using interpolation between observed points. Daily observed sediment, nitrogen and phosphorus datasets were not as complete.

During temporally dense periods with observed data (generally October 1, 1984 through September 30, 2006) the boundary condition was interpolated between observed data to create continuous daily time series that preserved the relative trends and magnitudes of the observed data. When interpolation was not possible because of temporally large data gaps (pre-WY 1985 and post-WY 2006), a static or seasonally variable concentration value was used based on statistics derived from the observed data as summarized in **Table C-9**. The following sub-sections describe representation of the South Fork Flathead River boundary condition beyond periods when direct data observations were available.

**Table C-9. South Fork Flathead River at the Boundary Condition**

| Parameter | Boundary Condition | Description |
|---|---|---|
| Flow | dynamic | *daily average observed flow* at USGS 12362500 |
| Temperature | dynamic | *daily average observed temperature* at USGS 12362500 |
| Nitrogen (*ammonia, nitrate, and organic*) | 0.094 – 0.128 mg/L | seasonal, based on combined data of *total nitrogen* at FLBS site FBC02011 and *total nitrogen* from USGS gage 12362500 |
| Phosphorus (*orthophosphate, organic*) | 0.005 mg/L | static, based on combined data of *total phosphorus* at FLBS site FBC02011 and *total phosphorus* from USGS 12362500 |
| Suspended solids | 1 mg/L | static, based on analysis of *total suspended solids* at FLBS site FBC02011 |
| Dissolved oxygen | dynamic | modeled LSPC time series using flow and water temperature at USGS gage 12362500 |

## C-3.1. FLOW TIME SERIES

USGS gage 12362500 is the only site with a continuous flow record located on the South Fork Flathead River between the Hungry Horse Reservoir and the confluence with the Flathead River. Therefore, due to the long-term daily flow record, which spans the full modeling period without data gaps, and location in close proximity to the outlet of Hungry Horse Reservoir, the daily average streamflow was used directly to represent the South Fork Flathead River. No modifications to these data were necessary.

## C-3.2. TEMPERATURE TIME SERIES

Water temperature data were collected at two sites: USGS gage 12362500 (112 grab samples, 13 water years of daily average temperatures) and the U.S. Bureau of Reclamation site HUN 134 (1 sample). Both grab sample datasets were insufficient to set a boundary condition as daily water temperature across the entire modeling period is necessary for the LSPC model. Therefore, the mean daily water temperature observations were used directly to develop a daily time series boundary condition between October 1, 1998 and September 30, 2012. The observed daily temperature time series was over 99 percent complete for this time period. In instances where missing records were encountered, the data gaps were filled using linear interpolation. In general, the only large continuous data gaps in the observed time series existed between the months of November and March when in-stream water temperature is relatively constant (**Figure C-8**). Monthly minimum, maximum and average temperature diurnals for data at the USGS gage 12362500 are presented in **Figure C-8**. Selective withdrawal implemented in 1996, allows the monthly temperature profile to approximate natural conditions (Christenson et al., 1995 and 1996; Marotz et al., 1996).

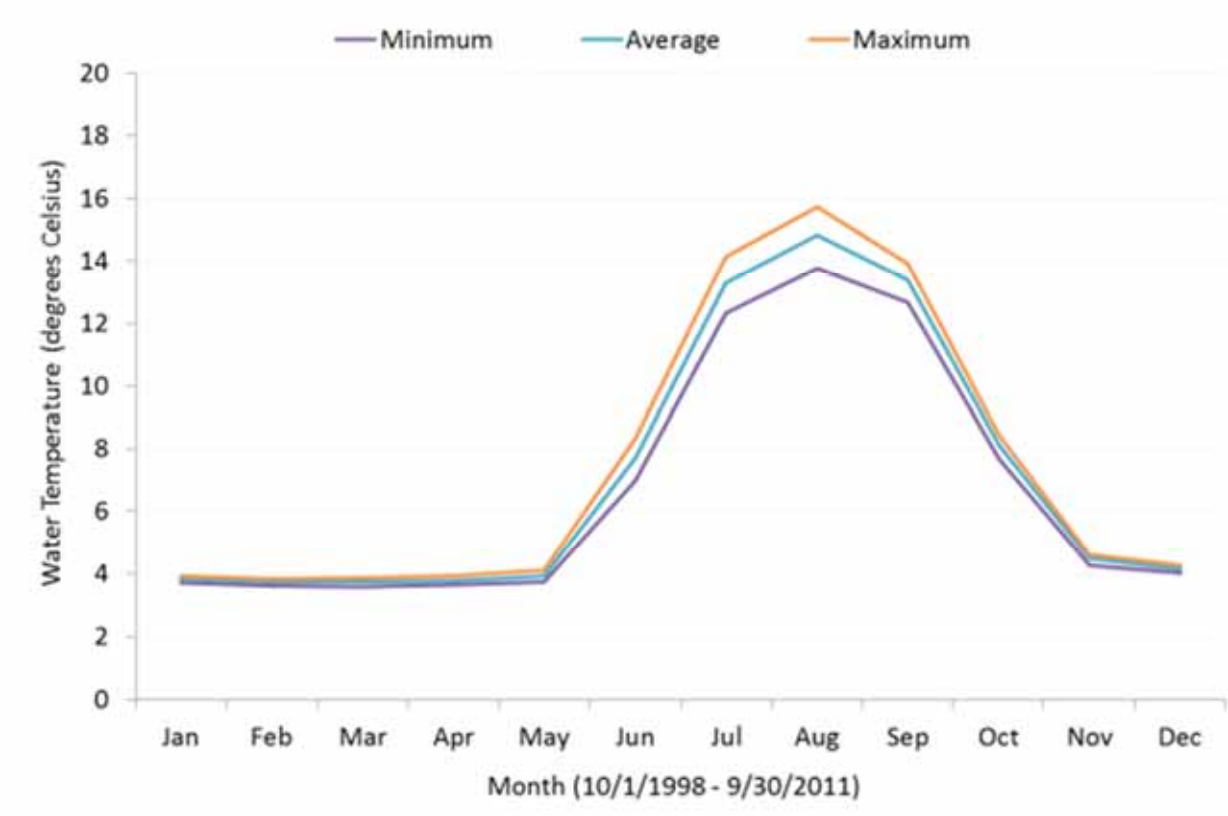



**Figure C-8. Monthly Distribution of Daily Temperatures at the USGS Gage.**

## C-3.3. SEDIMENT CONCENTRATION TIME SERIES

The sediment boundary condition was developed using SSC data collected at USGS gage 12362500 and TSS data collected at FLBS site FBC02011. TSS data collected at the U.S. Bureau of Reclamation site HUN134 were limited to 11 samples collected in 1983 and 1984; though it is noteworthy that 10 of the 11 samples resulted in detected concentrations of 1 mg/L or were below the detection limit of 1 mg/L. At site FBC02011, 137 samples were collected over almost 40 years. Nineteen samples evaluated for SSC were collected at gage 12362500, which is co-located at site FBC02011, within the boundary condition time period.

The SSC concentration was always at or below detection limit (1 mg/L) at gage 12362500. TSS ranged from less than 0.02 mg/L to 28.5 mg/L at site FBC02011. The median and average of the 75 detections of TSS at site FBC02011 were 0.9 mg/L and 2.3 mg/L. If non-detects are included either at the detection limit or at one-half of the detection limit, the 75th percentile of the 136 samples is 1.0 mg/L for both datasets. This observed dataset was used directly as a boundary condition between March 13, 1978 and June 14, 2006.

TSS data were evaluated with flow and reservoir elevation data to determine if TSS was associated with other parameters. Linear regressions of flow and reservoir elevation with TSS yielded low coefficients of determination ($R^2 < 0.1$). Therefore, during extended periods without observed data the sediment boundary condition was set to 1.0 mg/L TSS. During short periods without observed data the sediment boundary condition was set by interpolating between data points.

## C-3.4. NITROGEN TIME SERIES

The total nitrogen boundary condition was developed using nitrogen species data collected at FLBS site FBC02011. This observed dataset was used directly as a boundary condition between September 14, 1987 and November 8, 2006 by interpolating between data points. From late 2006 thorugh 2012, a constant concentration of 0.111 mg/L was used. Two methods were considered for disaggregating TN into nitrogen species. The first method was to assign a fixed distribution between the species across the entire time series. The second method was to use monthly variable distributions as reflected in the observed data. This second method was preferable for capturing some of the seasonal variability noted in the analysis of nitrogen species data. The total nitrogen concentration was distributed between ammonia, organic nitrogen, and nitrate plus nitrite. Ammonia was set at a constant ratio of 5 percent of total nitrogen. The remaining 95 percent was distributed between organic nitrogen and nitrate plus nitrite on a monthly variable basis. Fixed ratios of 80, 15, and 5 percent for organic nitrogen, nitrate plus nitrite, and ammonia (respectively) were used when the constant surrogate for TN was used.

## C-3.5. PHOSPHORUS TIME SERIES

The phosphorus boundary condition was developed using total phosphorus data collected at the FLBS site FBC02011. Total phosphorus data collected at DEQ site BSC05518 and BOR site HUN134 were not found to be representative of water quality conditions in the South Fork Flathead River below Hungry Horse Dam because only one sample was collected at site BSC05518 in 1985 and 12 samples were collected at site HUN134 in March 1982. All of the USGS data at site 12362500 were below detection. At FLBS FBC02011, 321 samples were collected over almost 40 years.

Total phosphorus ranged from less than 0.001 mg/L to 0.018 mg/L at site FBC02011. The average of the 319 samples with detected levels of phosphorus was 0.005 mg/L (the median was similar at 0.0044 mg/L). Additionally, an evaluation of data from 1978 through 1991 and from 1992 through 2006 resulted in averages of 0.005 mg/L for each time period. Thus, total phosphorus levels at site FBC02011, co-located with gage 12362500, have remained low with little variance over the past few decades. This observed dataset was used directly as a boundary condition between January 24, 1978 and November 8, 2006 by interpolating between data points. The TP was distributed between organic phosphorus and orthophosphate on a monthly variable basis, based on analysis of observed data at site FBC02011.

A constant or variable boundary concentration was needed to address periods after WY 2006. Total phosphorus data were evaluated with flow, temperature, and TSS data to determine if total phosphorus was associated with other parameters. Total phosphorus concentrations were plotted with a flow duration curve and the results showed that total phosphorus concentration varied over the same range regardless of the flow condition. Therefore, during extended periods after WY 2006 without observed data the total phosphorus boundary condition was set to a constant 0.005 mg/L, which is consistent with the central tendency of the observed total phosphorus data at site FLBS FBC02011. Fixed ratios of 0.25 and 0.75 were used to distribute phosphorus into orthophosphate and organic phosphorus, respectively, based on analysis of observed data at site FBC02011, when the static surrogate of 0.005 mg/L was used.

## C-3.6. DISSOLVED OXYGEN

DO data were collected at one site for a very short period of time: USGS gage 12362500 (19 samples taken between 3/26/2007 and 7/16/2008). This dataset was insufficient to set a boundary condition based only upon daily DO observations. The DO data were first evaluated against streamflow and temperature data to determine if a correlation model could be derived to predictively estimate the missing observed periods. Linear regressions with streamflow ($R^2$ = 0.02), air temperature ($R^2$ =0.08), and water temperature ($R^2$ = 0.50) versus DO at gage 12362500 were developed but were determined not to be representative of in-stream DO.

An alternative deterministic approach for developing a DO boundary condition was evaluated. It involved using the LSPC model DO routines to generate a representative in-stream response just downstream of the dam. The availability of flow and water temperature data and proximity to the Hungry Horse dam made this model formulation possible, with minimal assumptions. Streamflow, water temperature (available from USGS 1236500), and air temperature are the most influential boundary conditions affecting DO levels downstream of the dam. One reach was simulated representing the small (1.75 miles) segment of the South Fork Flathead River between the outlet of Hungry Horse dam and the USGS 12362500 gage. Observed streamflow and water temperature from the USGS gage were assumed to represent outflow volume and water temperature from the dam. Because of the short segment length, incremental contributions from adjacent areas are negligible compared to the outflow from the dam. DO from the outlet of Hungry Horse dam was assumed to be at saturation due to high velocities and turbulence associated with the outflow structure(s) and consequently set to a high value of 14 mg/L. **Figure C-9** presents a schematic and model sequence for how the dissolved oxygen boundary condition from Hungry Horse Reservoir was represented.

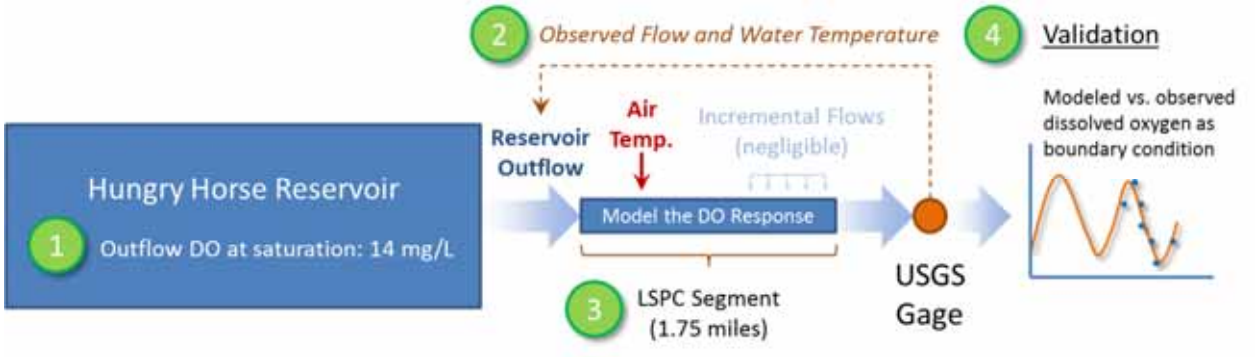



**Figure C-9. Dissolved oxygen boundary condition for Hungry Horse Reservoir.**

Streamflow, water temperature, and saturated DO were routed through the small 1.75 miles reach segment, which had an average slope of 0.025 feet/feet, a bankfull depth of 6 feet, and a bankfull width of 70 feet. This segment represents the stream between Hungry Horse dam and the USGS 12362500 gage previously shown in **Figure C-2**. The geometric representation was derived using spot measurements from GIS datasets. During transport through the reach, in-stream DO was subjected to the influences between air temperature, water temperature, stream depth, and velocity producing a dynamic trend away from the saturation state at the outlet of the dam. The daily time series simulated using LSPC was calibrated against the 19 dissolved oxygen measurements taken between 3/26/2007 and 7/16/2008 at the gage. Having modeled the DO response deterministically using LSPC, that time series was directly used as the in-stream DO boundary condition that gage on the South Fork Flathead River, along with the other interpolated observed boundary condition time series from the gage. A statistical summary comparing the observed dataset with the modeled LSPC time series is presented in **Table C-10**. Both datasets show similar characteristics with the LSPC model time series offering a narrower range with slightly higher central tendencies than the observed dataset.

**Table C-10. Observed versus modeled dissolved oxygen summary at USGS 12362500**

| Data set | Data source | Minimum (mg/L) | Mean (mg/L) | Median (mg/L) | Maximum (mg/L) |
|---|---|---|---|---|---|
| Observed Dataset | USGS 12362500 | 8.4 | 10.7 | 10.8 | 12.9 |
| Modeled Timeseries | LSPC | 8.0 | 11.1 | 11.3 | 12.7 |

## C-3.7. TIME SERIES VALIDATION

**Figure C-10** through **Figure C-14** show plots of the boundary condition flow, concentration, and temperature time series against observed data collected at FLBS site FBC02011 at South Fork Flathead River near Columbia Falls, MT (co-located at USGS 12362500) for the period from October 1, 1998 through September 30, 2006. As previously noted, this period was chosen for visual analysis of the boundary condition because it is coincident with a majority of the available water quality data points for both the South Fork and Phase II study areas.

Both modeled daily streamflow and water temperature were interpolated from continuous observed datasets with relatively minimal data gaps. The plots in **Figure C-10** and **Figure C-11** show, as expected, that the boundary condition time series tracks extremely close to the observed datasets. Modeled TSS was interpolated from observed data at USGS 12362500 until June 14, 2006, followed by a constant concentration of 1 mg/L for the period after June 14, 2006. There are two distinct outliers in observed

concentration that deviate from the otherwise relatively constant sediment concentration of about 1 mg/L: 12 mg/L on May 25, 1999 and 26 mg/L on May 30, 2003. Analysis with streamflow showed that these correspond to streamflows at the 63rd and 67th percentiles, respectively, suggesting that the cause of the spike in concentration are most likely not explainable by natural processes. Those spikes may have been caused by turbulent disturbance associated with dam releases, although this has not been confirmed.

Modeled TN and TP (**Figure C-13** and **Figure C-14**) were first interpolated as totals, disaggregated into species, and then plotted as totals from the sum of those individual species and plotted against observed data points. Both nutrients (especially TP) exhibited a narrow range of concentrations throughout the time period.

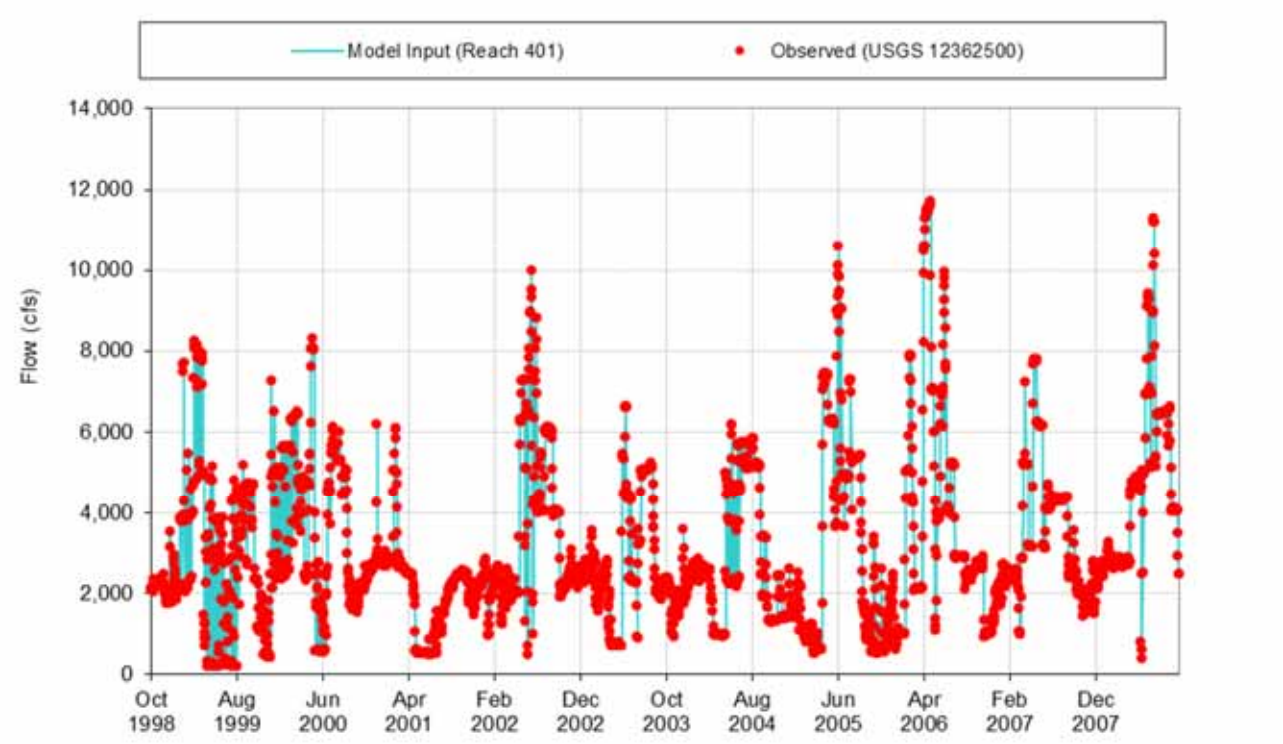



**Figure C-10. Model Input vs. Observed Flow (cfs) at USGS 12362500.**

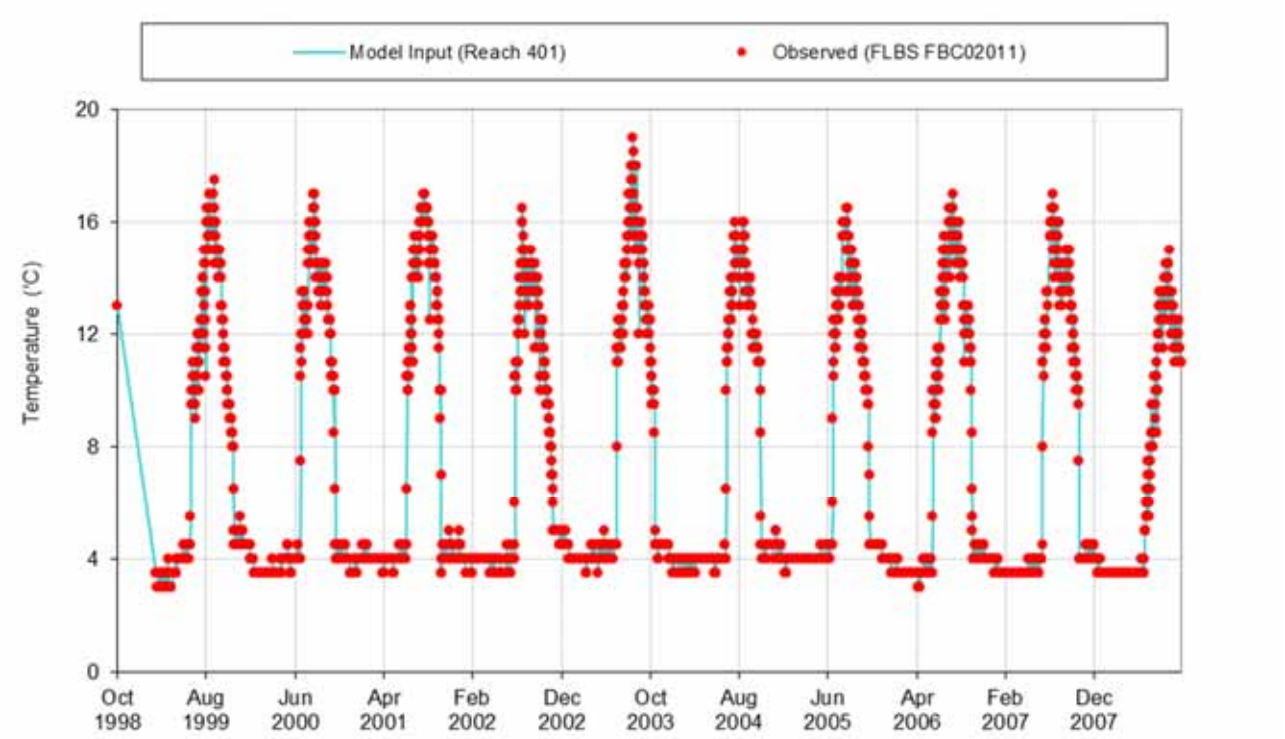



**Figure C-11. Model Input vs. Observed Water Temperature (°C) at USGS 12362500.**

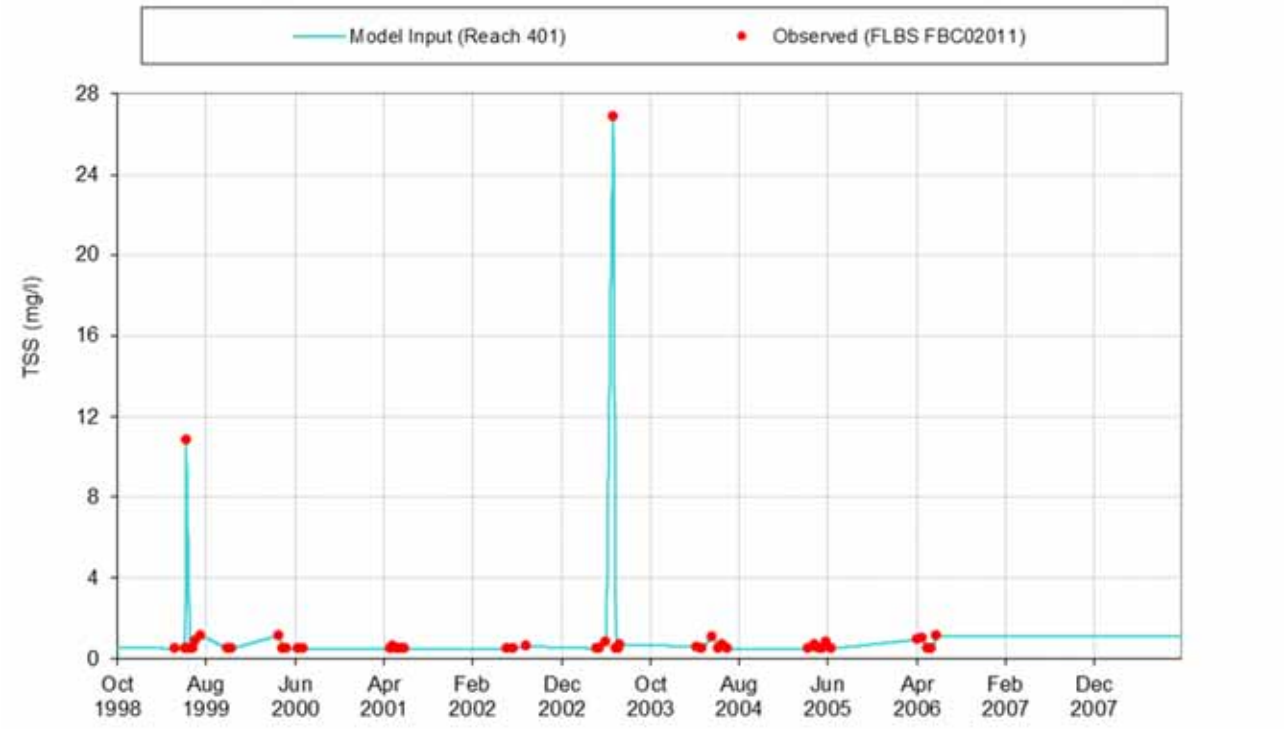



**Figure C-12. Model Input vs. Observed TSS (mg/L) at FBC02011.**

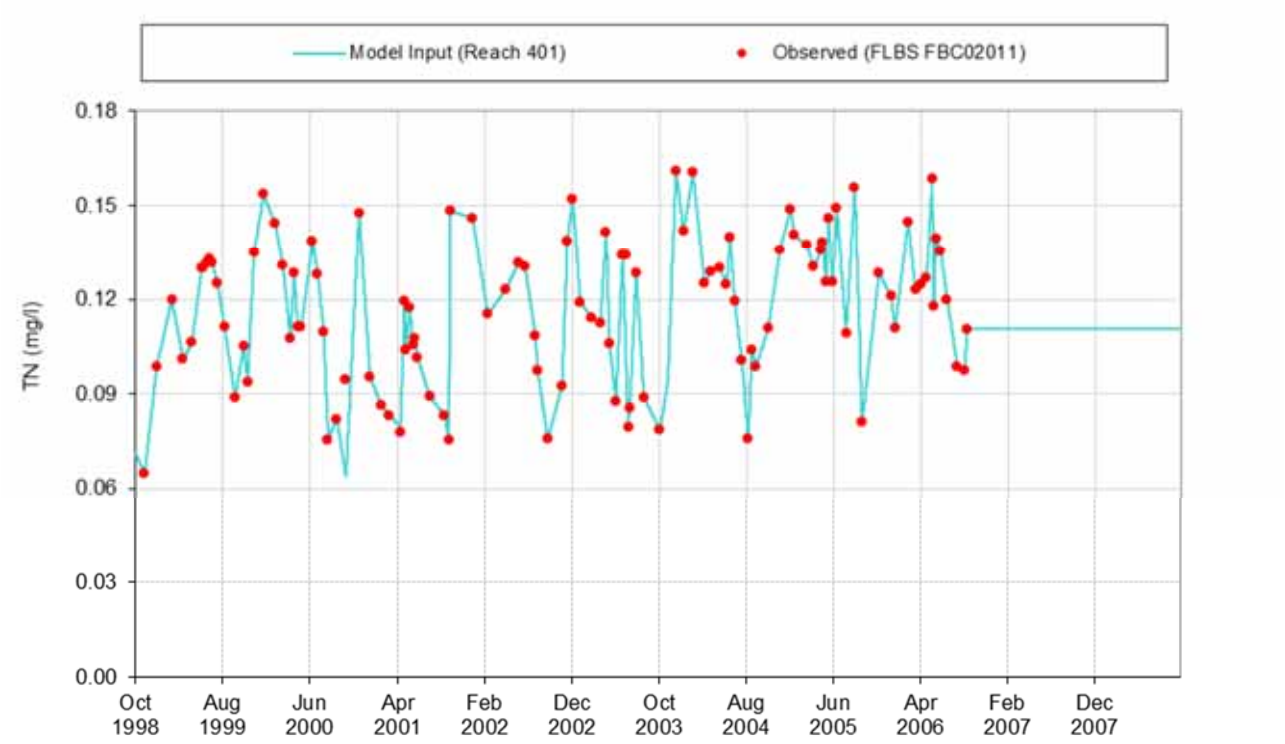



**Figure C-13. Model Input vs. Observed TN (mg/L) at FBC02011.**

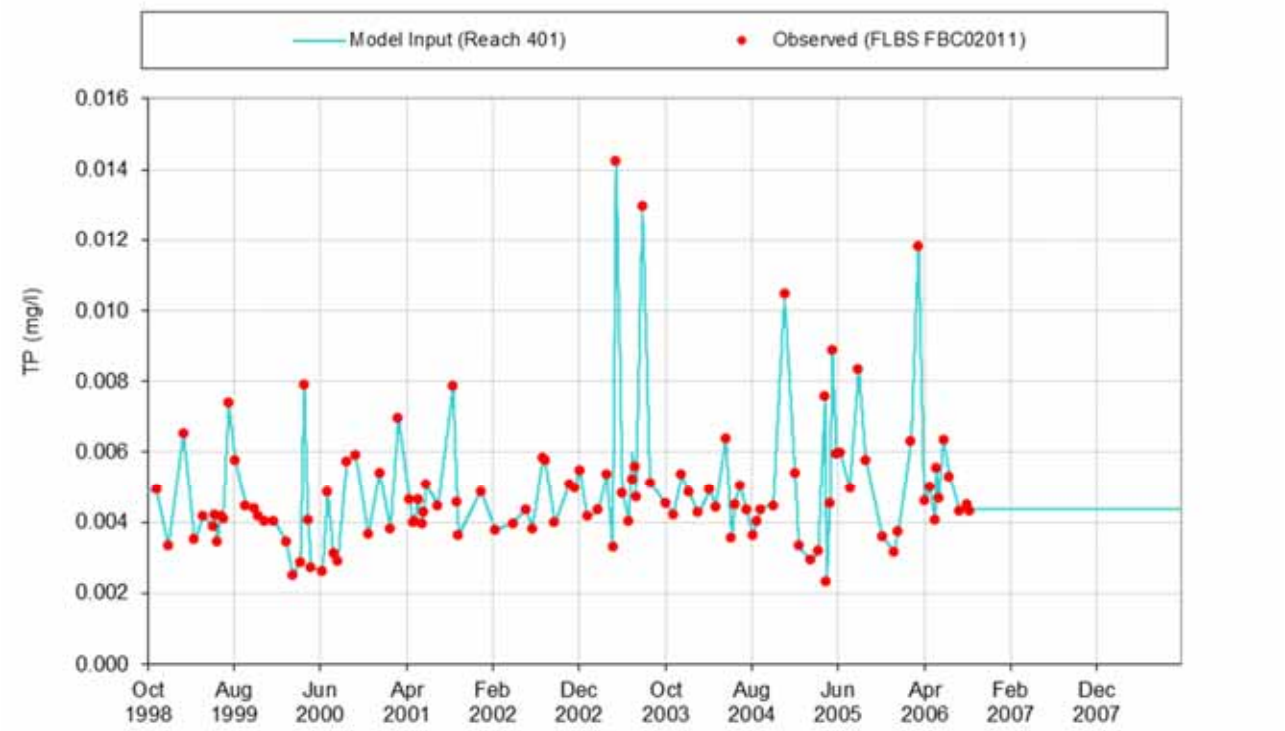



**Figure C-14. Model Input vs. Observed TP (mg/L) at FBC02011.**

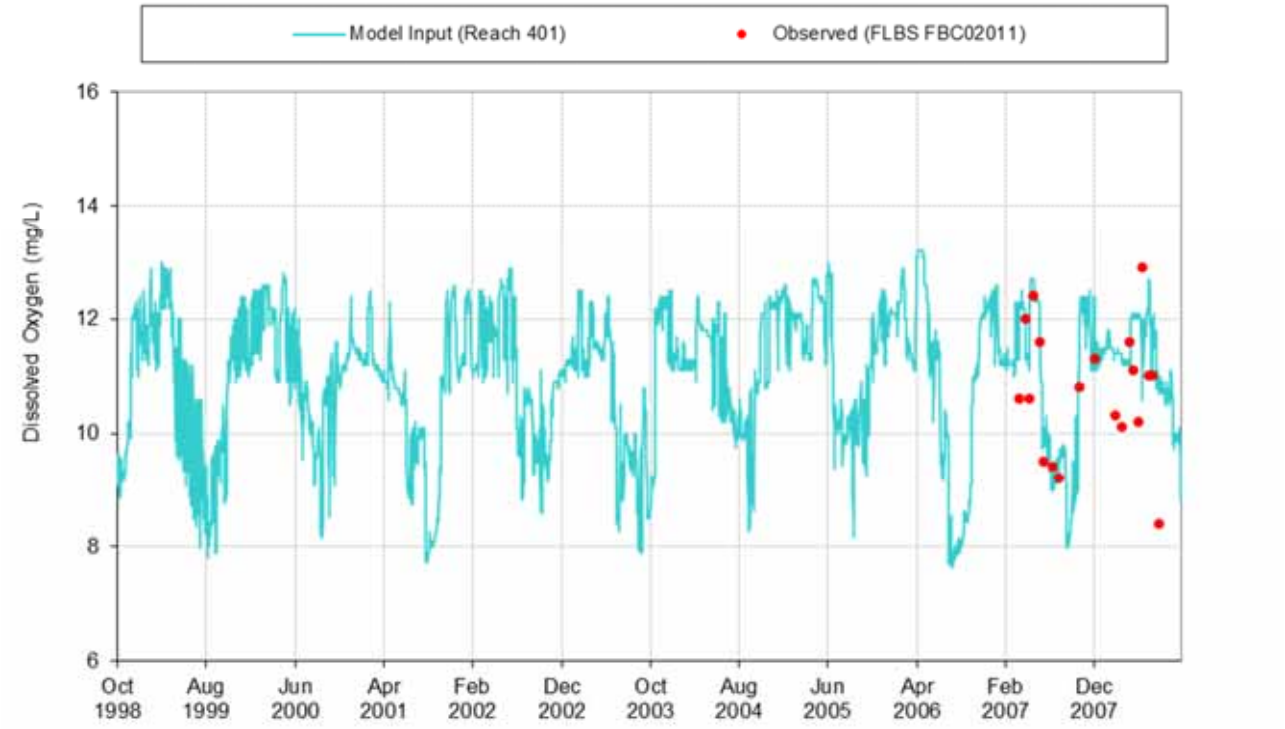



**Figure C-15. Model Input vs. Observed Dissolved Oxygen (mg/L) at FBC02011.**

# C-4. REFERENCES

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