Appendices

Wide Hollow Creek Temperature, Dissolved Oxygen, and pH Water Quality Study for Aquatic Life, 2013-2014

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Appendices

Wide Hollow Creek Temperature, Dissolved Oxygen, and pH Water Quality Study for Aquatic Life. 2013-2014

by

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Appendix A. Groundwater Study

Glossary for Appendix A

Anisotropy: A condition where one or more of the hydraulic properties of an aquifer vary according to the direction of measurement.

Anoxic: Depleted of oxygen.

Baseflow: The component of total streamflow that originates from direct groundwater discharge to a stream.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Groundwater discharge: Movement of groundwater from the subsurface to the surface by the advective (physical) flow of water.

Hydraulic conductivity: A coefficient that describes the rate at which water moves through permeable material such as sediments or fractured rock.

Hyporheic (zone): The area beneath and adjacent to a stream where surface-water and groundwater intermix.

Isotropic: A condition where the hydraulic properties of an aquifer are the same regardless of the direction of measurement

Piezometer: A small-diameter, non-pumping well used during this study to (1) measure depth to groundwater, (2) measure streambed water temperatures, and (3) periodically collect groundwater quality samples.

Data Qualifier Codes Used in Appendix A - Data Tables and Figures

U The analyte was not detected at or above the reported value.

Introduction

This appendix summarizes the data collection and analysis undertaken to assess groundwater's influence on the quantity and quality of water in Wide Hollow Creek. Groundwater was specifically targeted for evaluation during this study since nutrient-rich groundwater can contribute to problematic instream aquatic plant growth and biomass production (Angier and McCarty, 2008; Dahm et al., 1998). Left unchecked, such growth can lead to increased biological and chemical oxygen demand and ultimately to a reduction in the amount of oxygen available to support fish and other aquatic organisms.

The primary goals of the groundwater investigation were to:

- Evaluate and quantify groundwater discharge volumes to Wide Hollow Creek during critical conditions.
- Characterize local groundwater quality just prior to its discharge into the creek.

Area Description

The Wide Hollow Creek drainage is part of the greater Moxee/Ahtanum Valley, which encompasses an area of about 160 square miles, west of the Yakima River, and includes most of the City of Yakima and several outlying communities including Union Gap, Tampico, Wiley City, and Ahtanum. The valley is one of several east-west trending structurally-controlled valleys within the Yakima area.

The Moxee/Ahtanum Valley rises steadily toward the west, from an altitude of about 940 feet at the Yakima River to 4,100 feet at the crest of Cowiche Mountain. Near the Yakima River, the valley bottom is about five miles wide and is characterized by relatively flat terrain. About 6 miles west of the Yakima River the valley is bisected by a remnant terrace that raises as much as 100 feet above the valley floor (Foxworthy, 1962). This terrace effectively separates the Ahtanum Creek drainage (to the south) from the Wide Hollow Creek drainage (to the north).

The Wide Hollow Creek drainage has a semi-arid continental climate with hot, dry summers and relatively cool, wet winters. Average annual precipitation ranges from greater than 30 inches near the eastern Cascade Foothills to less than 10 inches near the City of Yakima. About 50% of the annual precipitation falls from November to February, with relatively little precipitation during the summer growing season. Land use on the upland terraces is dominated by orchards, while the valley bottoms are used primarily for pasturelands and residential/commercial development.

Hydrogeologic Setting

The Wide Hollow Creek drainage lies within an east-west trending synclinal[1] trough and is bounded by steep sided anticlinal[2] ridges to the south (Ahtanum ridge) and west/northwest (Cowiche Mountain/ Sedge ridge). The present Wide Hollow drainage was once part of an extensive, flat plain that formed during Miocene time, when huge volumes of basalt were extruded from fissures centered southeast of the study area (Foxworthy, 1962). During this period andesite rich sediments

[1] Syncline - A large fold whose limbs are higher than its center; a fold with the youngest strata in the center (Press and Siever, 1978).
[2] Anticline - A large fold that is convex upward with the oldest strata at the center (Press and Siever, 1978)

were deposited along and upon the western portion of this plain by eastward flowing streams that emanated from a volcanically active upland to the west. These geologic processes continued through numerous flow events, resulting in inter-bedded deposits of basalt and sedimentary rock along the western margin of the basalt plain. When the basalt flows ceased in early Pliocene time, uplift of the Cascade Range to the west provided a heavy sediment load to eastward flowing streams which deposited sediments along and upon the western portion of the basalt plain.

Beginning in early Pliocene time, this assemblage of basalt flows and andesite-rich sediments was slowly folded to form the broad anticlines and synclines of the Yakima fold belt (of which the greater Moxee/Ahtanum Valley is part). As folding progressed, sediments were eroded from the up-folded ridges and deposited in adjacent valley bottoms. With continued erosion, basalt in the anticline cores was exposed to weathering, and basaltic debris was carried down slope and deposited upon the valley-fill sediments. Although active folding probably ceased by the late Pliocene, gravel continued to accumulate in the valley interior during Pleistocene time to depths of 200 feet or more (Foxworthy, 1962). The gravel was subsequently eroded and/or reworked through alluvial processes to form the terrace complex that separates the Ahtanum and Wide Hollow Creek drainages.

The geologic materials underlying the Ahtanum and Wide Hollow drainages may be aggregated, based on lithology and age, into four principal groups: Miocene age basalts, Miocene continental sediments, Pliocene continental sediments, and Quaternary age sediments/recent alluvium (Figure A-1). The upper surface of the basalt, which comprises area bedrock, dips downward from west to east. Basalt lies at or near ground surface along the Eastern slopes of Cowiche Mountain. In the valley bottom the basalt is overlain by and, in some cases, inter-bedded with Miocene age continental sediments of the Ellensburg Formation (unit Tse in Figure A-1). The Ellensburg Formation sediments consist mostly of semi-consolidated clay, andesitic and pumiceous sandstone, and conglomerate comprised of weathered andesite pebbles (Foxworthy, 1962). These sediments tend to increase in thickness from west to east and reach a thickness of about 1,600 feet near the City of Yakima.

Ellensburg Formation sediments are overlain throughout much of the valley bottom by up to 200 feet of cemented gravel of Pliocene age (Thorp gravel unit, Figure A-1). The Thorp gravels consists mostly of rounded, basaltic pebbles and cobbles in a sand-and-silt matrix but may contain discontinuous layers of sand, silt, or clay. The Thorp gravels are overlain by extensive but relatively thin deposits of recent alluvium in the valley bottom of Wide Hollow Creek (Unit Qal, Figure A-1) and by alluvial fan and loess deposits along the flanks of Ahtanum Ridge and Cowiche Mountain (Figure A-1). The alluvial unit consists mostly of unconsolidated deposits of well-rounded cobbles, gravel, sand, and silt that vary in thickness from a few feet to more than 30 feet.

Each of these principal rock types contains aquifers that are capable of supplying groundwater to wells. Most area domestic wells are completed in either the thicker sections of recent alluvium, the Thorp Gravels, or in more permeable zones of the Ellensburg Formation. These aquifers are recharged through several mechanisms including downward percolation of local precipitation, leakage from unlined irrigation ditches or streams, percolation of unconsumed irrigation water, and by upward discharge from the underlying basalt units. Area groundwater generally moves from upland recharge zones along the ridge tops and flanks toward the valley interior, and laterally toward natural points of discharge along area streams and the Yakima River (Figure A-1).

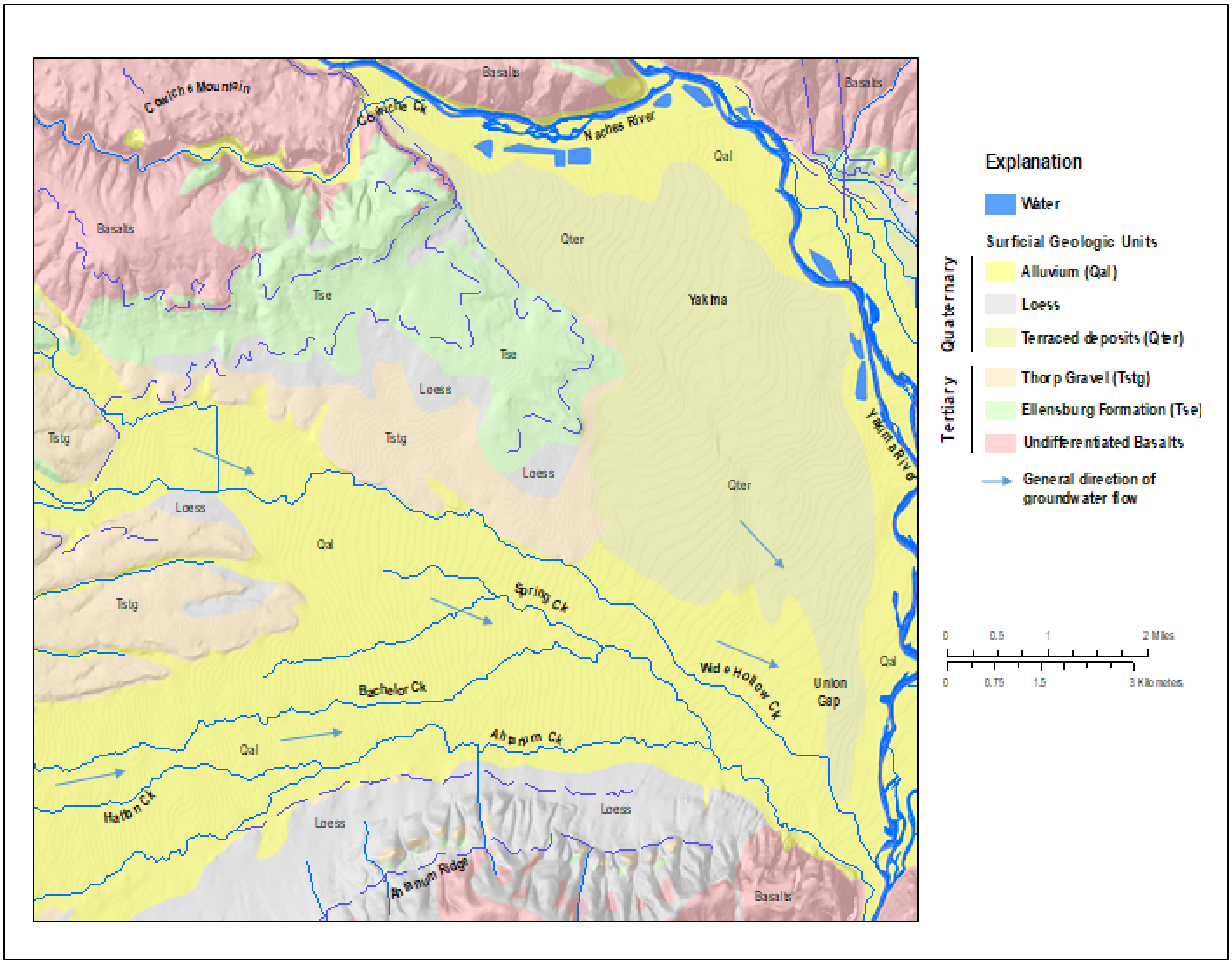


Figure A-1. Surficial geology and general direction of groundwater flow in the Ahtanum and Wide Hollow Creek drainages.

Groundwater Study Methods and Design

For this study, we used several common field methods and analytical techniques to evaluate the timing, magnitude, and spatial distribution of surface water/groundwater interactions along Wide Hollow Creek. The results of these evaluations are described in the sections that follow.

Instream Piezometers

In July/August 2013, we installed 11 shallow instream piezometers along Wide Hollow Creek using methods described by Sinclair and Pitz, 2009. The piezometers for this project consisted of an upper removable section (or extension) and a lower 5-foot section of 1-inch diameter galvanized pipe (Figure A-2 and Table A-5). The piezometers were used to monitor surface water/groundwater head relationships and near-stream groundwater quality at discrete points along the creek. Piezometers were installed into the streambed to a maximum depth of about 6 feet. Where possible, they were located in quiet water away from riffles, point bars, or other streambed features that might induce local-scale hyporheic exchanges.

The piezometers were developed after installation with a manual bladder-type bilge pump to ensure a good hydraulic connection with the streambed sediments. Piezometers were accessed monthly to make comparative stream and groundwater hydraulic head measurements. The stream stage (hydraulic head) was measured by aligning an engineer's tape parallel to the piezometer pipe and measuring the distance from the stream water surface to the top of the piezometer casing. The groundwater level inside the piezometer was measured from the same reference point using a calibrated low-displacement E-tape or steel hand tape (Marti, 2008). For angled (off-vertical) piezometers these "raw" values were corrected using simple trigonometric relationships to obtain true depth to water measurements.

Schematic of a typical instream piezometer installation and thermistor array

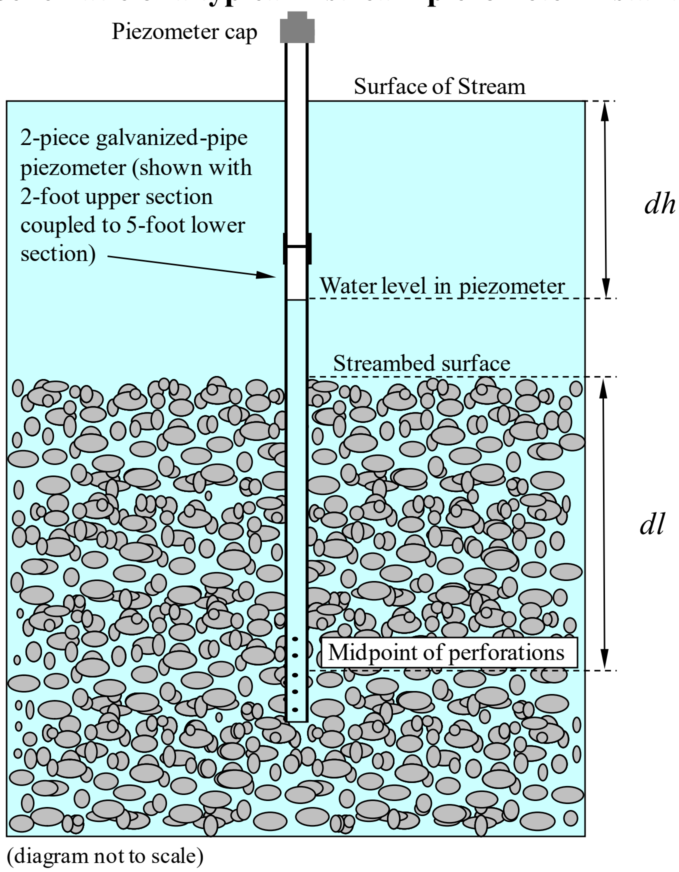


Figure A-2. Schematic of a typical instream piezometer installation and thermistor array

The water level difference (represented by the inside and outside of pipe measurements) indicates the direction and magnitude of the local hydraulic potential between the stream and underlying groundwater. When the piezometer head exceeds (is higher than) the stream stage, groundwater flow into the stream can be inferred. Similarly, when the stream stage is higher than the groundwater level in the piezometer, loss of water from the stream to groundwater can be inferred.

Equation 1 was used to derive vertical hydraulic gradients for each piezometer, from these paired groundwater level and stream stage measurements. Converting the field measured water levels to hydraulic gradients normalizes for differences in piezometer depth and screen interval between sites; thereby enabling direct comparisons to be drawn between piezometers.

$$i_v = \frac{dh}{dl} \qquad (1)$$

Where:

i_v is vertical hydraulic gradient (dimensionless)

dh is the difference in head between the stream stage and instream piezometer water level (L)

dl the distance from the streambed surface to the mid-point of the piezometer perforations (L)

and (L) is length.

By convention, negative hydraulic gradient values indicate potential loss of water from the creek to groundwater, while positive values indicate potential groundwater discharge into the creek.

Estimating Streambed Hydraulic Conductivity Values

Constant head injection tests (CHIT) were used to estimate vertical hydraulic conductivity values for the streambed sediments at each piezometer site. To perform the tests a constant head chamber was attached to the piezometer casing using a standard pipe coupler (Figure A-3).

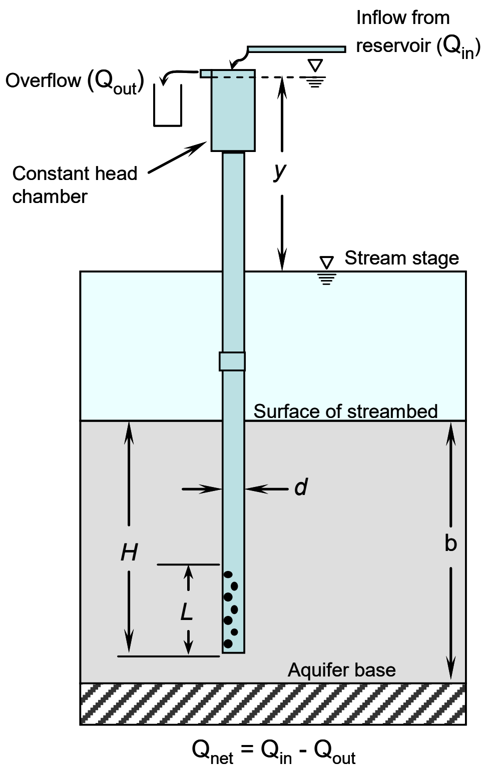


Figure A-3. Schematic of the constant head injection test (CHIT) apparatus and field measurements *(adapted from Pitz, 2006)*

Water was then added to the chamber from an adjacent graduated reservoir at a rate equal to or slightly greater than the piezometers ability to take water. Field measurements of the operating head (y), the net injection rate (Q), and piezometer construction information were used as inputs to a spreadsheet model that solves Equation 2 (Pitz, 2006; Cardenas and Zlotnik, 2003).

$$K = \frac{Q}{2\pi LPy} \quad (2)$$

Where:

K is the isotropic hydraulic conductivity of the streambed sediments adjacent to the piezometer open interval (L/t)

Q is the net injection rate required to maintain a constant head within the piezometer (L^3/t)

L is the length of the piezometer open interval (L)

P is the well shape factor (see Cardenas and Zlotnik, 2003 for the derivation of this term)

y is the height of the constant head above the stream surface (L)

The constant head test method assumes the streambed sediments are hydraulically isotropic at a sub-meter scale. In most alluvial environments sediments exhibit some degree of anisotropy; due to the preferential orientation of grains and clay minerals or to local scale inter-fingering or layering of fine and coarse grained materials (Freeze and Cherry, 1979). To adjust for well development (which preferentially removes fine material from the piezometer screen) and likely anisotropy effects, we multiplied the hydraulic conductivity values obtained from the CHIT field tests by 0.1 to obtain estimated vertical hydraulic conductivity values for the streambed sediments at each piezometer site. The CHIT results are summarized in Table A-7.

Surface-Water/Groundwater Interactions

The natural (pre-settlement) hydrology of the Wide Hollow drainage was significantly altered and reshaped with the introduction of large scale irrigated agriculture to the area in the late 1800's. In 1894 the Yakima Valley Canal Company completed the Wide Hollow Canal (Congdon Ditch) which carried water south from the Naches River, about 16 miles to Wide Hollow Creek, where it initially provided irrigation water to about 3000 acres of land. Numerous smaller canals, ditches, and other water conveyances have been constructed in Wide Hollow since then to provide additional irrigation capacity and to drain low lying areas for agricultural development and other uses (see report hydrology section for additional details).

To maximize irrigation potential and improve water conveyance for flood control, Wide Hollow Creek proper has been deepened, channelized, and in many places repositioned from its natural course in the valley bottom northward to its present location along the southern flank of Knob Hill and the associated terrace complex to the east. Because of these modifications, many reaches of the creek are now perched above the adjacent bottomlands. The totality of these changes are such that the present configuration of Wide Hollow Creek, below its confluence with the Congdon Ditch, little resembles the mostly intermittent pre-settlement drainage of the area.

To gain insights into the direction, timing, and spatial distribution of surface-water/groundwater interactions effecting Wide Hollow Creek we used three common field and analytical techniques. Reach based streamflow gains and losses were determined from streamflow measurements made during synoptic water quality surveys of the creek. These reach-based estimates were supplemented with point-based measurements of streambed vertical hydraulic gradient at a network of 11 instream piezometers installed along the creek between 101st Ave and Union Gap. Stream temperature data collected during winter baseflow conditions provided additional insights regarding where groundwater enters the creek. The results of these evaluations were combined with findings from previous studies of the area to develop a working conceptual model of surface-water/groundwater interactions for the creek. The results of these evaluations are discussed below and in the modeling section of the main report.

Seven of the 11 instream piezometers installed for this project (P2-P5, P7, P9, and P11) consistently exhibited negative (downward) vertical hydraulic gradients (VHG) between the creek and near-surface groundwater, during the study period (July 2013 to June 2014) (Figure A-4, and Table A-6). The median VHG's at these sites ranged from -0.129 to -1.11 ft/ft. This suggests the creek consistently lost flow to groundwater at these locations. Piezometer P11 near the lower end of the creek at Union Gap consistently exhibited positive (upward) VHG values (range +0.039 to +0.093 ft/ft). This suggests the creek consistently gained flow from groundwater at this location. The three remaining piezometers (P1, P6, and P8) exhibited a combination of positive and negative VHG values, suggesting the creek periodically switched between gaining and losing conditions at these locations.

The gain/loss patterns inferred from point-based piezometer hydraulic gradient measurements were generally supported by field observations of near-stream groundwater levels (Figure A-5) and stream temperature measurements made during dry winter baseflow periods when irrigation and storm water influences on the creek were minimal. The locations where groundwater discharge to the creek were identified via instream piezometer gradients generally correspond with known areas of shallow groundwater (as shown by direct measurement of groundwater levels in off stream wells or by the presence of drainage improvement structures that were installed to lower area groundwater levels) (Figure A-5). See the streamflow and water quality simulation discussion in the main body of the report for additional information and discussion of area surface water and groundwater interactions.

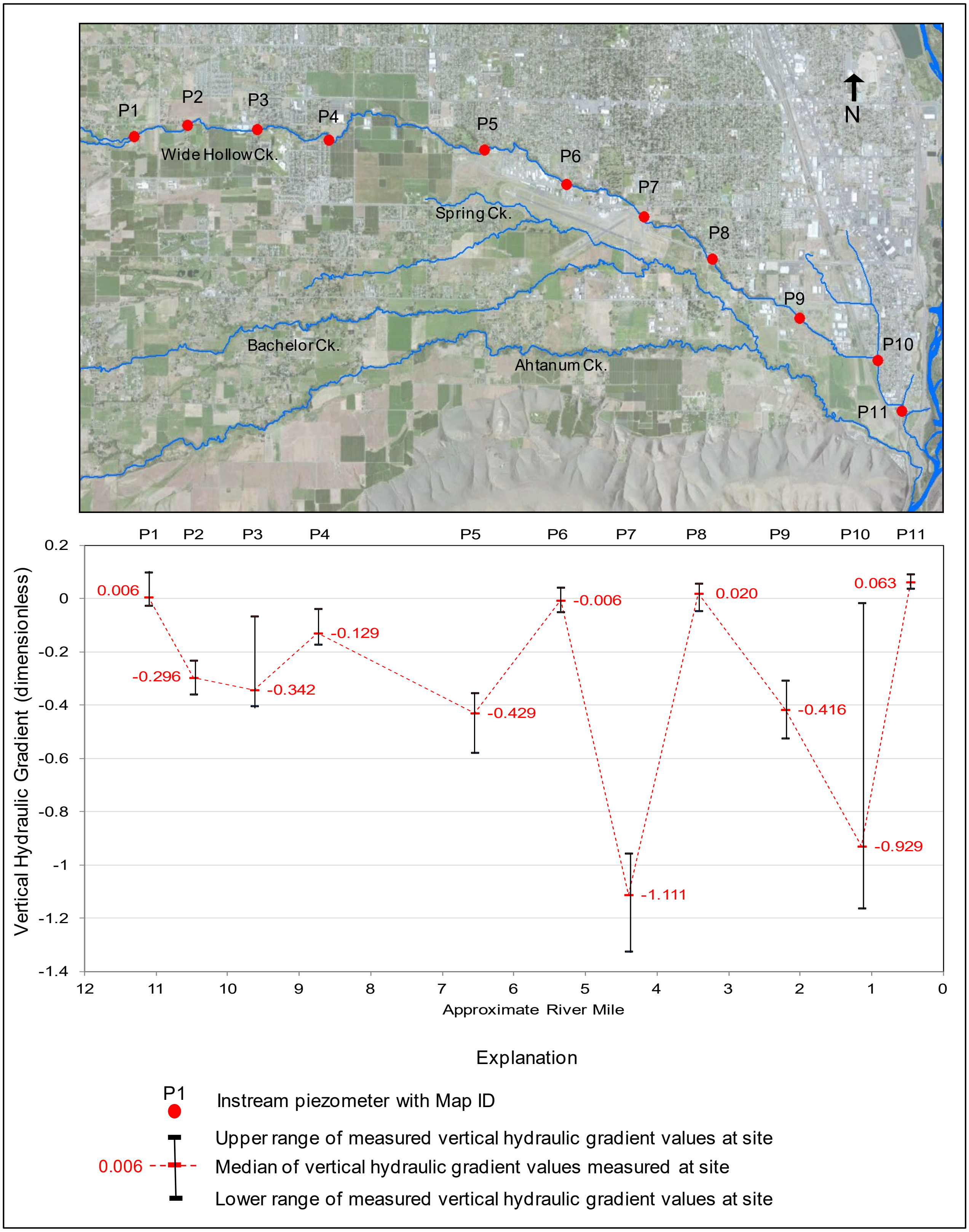


Figure A-4. Summary of streambed vertical hydraulic gradients measured between July 2013 and June 2014 at in-stream piezometer sites along Wide Hollow Creek.

Figure A-5. Depth to groundwater at time of well construction in feet below land surface (data source USGS groundwater site information system).

Evaluation of Near-Stream Groundwater Quality

To assess the concentration of phosphorous and nitrogen-based nutrients that groundwater potentially contributes to Wide Hollow Creek, we periodically sampled four instream piezometers between August 2013 and June 2014. The decision to sample individual piezometers was made based on whether a piezometer exhibited a positive or negative vertical hydraulic gradient during a scheduled sampling event. Piezometers that exhibited a positive hydraulic gradient, suggesting groundwater discharge to the creek, were sampled, while those that exhibited negative gradients (suggesting streamflow loss to groundwater) were not. Collected samples were evaluated for field parameters and a small suite of laboratory-analyzed constituents (Table A-1).

Table A-1. Target analytes, test methods, and method detection limits

Parameter	Equipment Type and Test method	Reporting limit
Field Measurements		
Water level	Calibrated E-tape	0.01 ft
Temperature	Hydrolab MS-5	0.1°C
Specific Conductance	Hydrolab MS-5	1 µS/cm
pH	Hydrolab MS-5	0.1 SU
Dissolved Oxygen	Hydrolab MS-5 Optical sensor	0.1 mg/L
Laboratory Parameters		
Alkalinity[1]	SM2320B	5 mg/L
Chloride[1]	EPA300.0	0.1 mg/L
Orthophosphate[1]	SM4500PG	0.003 mg/L
Total phosphorus[1]	SM4500PF	0.001 mg/L
Nitrate+nitrite-N[1]	SM4500NO3I	0.01 mg/L
Ammonia[1]	SM4500NH3H	0.01 mg/L
Total persulfate nitrogen-N[1]	SM4500NB	0.025 mg/L
Dissolved organic carbon[1]	SM5310B	1 mg/L
Iron[1]	EPA200.7	0.05 mg/L

[1]Dissolved fraction
SU: Standard units

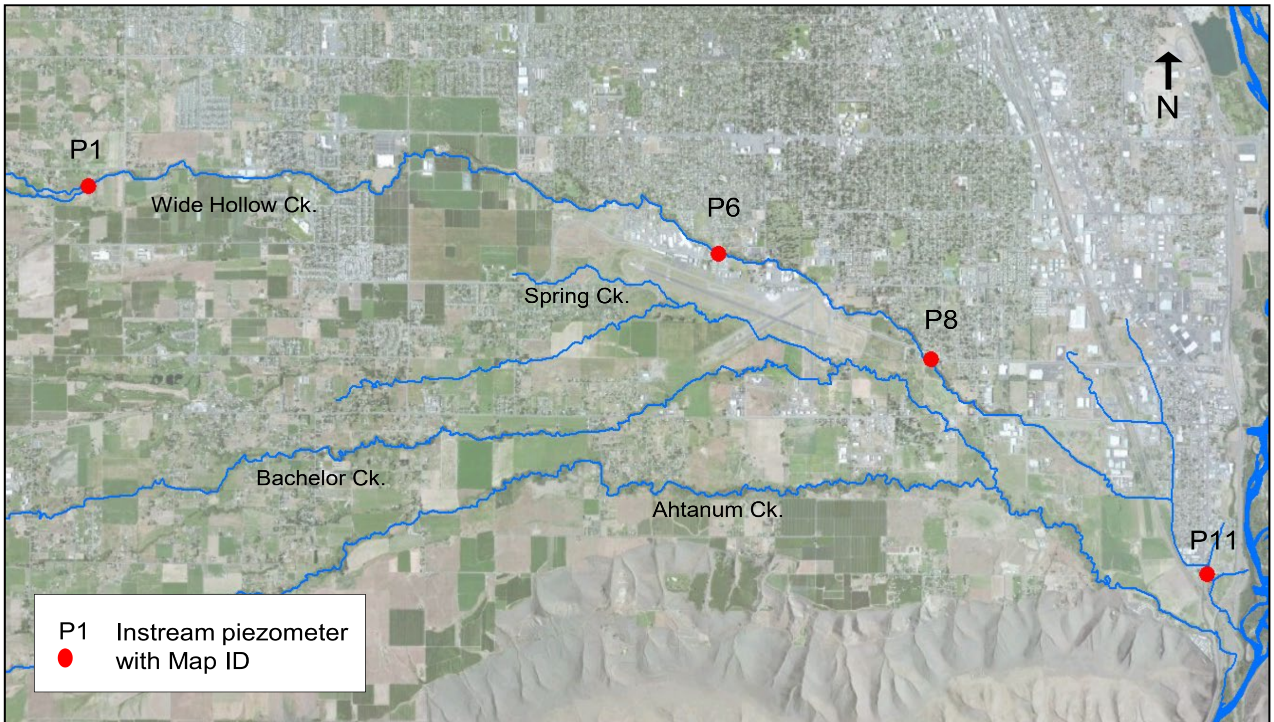
All piezometers were sampled with a peristaltic pump and a length of new ¼ inch HDPE tubing. During sampling the pump discharge was routed through a closed-atmosphere flow cell attached to a Hydrolab MS-5 multimeter to enable field parameters to be evaluated. Piezometers were purged at a rate of 0.25 to 0.5 L/min. Purging continued until the difference in measured field parameter values for 2 successive 3-minute measurement periods differed by less than 5% across all parameters: temperature, specific conductance, pH, and dissolved oxygen (DO).

At the completion of purging, laboratory bound samples were collected by disconnecting the pump discharge line from the flow cell. All samples were filtered at the time of collection using a 0.45 micron in-line-capsule filter. Samples for DOC, nitrate+nitrite-N, total persulfate nitrogen (TPN), ammonia, and dissolved total phosphorus (DTP) were collected in pre-acidified bottles containing sulfuric acid. Samples for iron analysis were collected in bottles pre-acidified with nitric acid. The samples collected for chloride, alkalinity, and orthophosphate analysis were not acidified. Filled sample bottles were tagged and stored on ice pending their arrival at the lab.

Groundwater Quality Results

The results of this sampling effort are summarized in Figure A-6 and presented by well and sample event in Table A-6. The associated data quality assessment is presented in Appendix A. Measurable concentrations of nitrate+nitrite-N and orthophosphate were found in all sampled piezometers at values ranging from 0.159 to 3.78 mg/L and 0.264 to 0.017 mg/L respectively.

Since most of the sampled piezometers are completed a few feet below the streambed, the water quality values reported here do not account for biological or geochemical processes that can potentially attenuate nitrate and phosphorous concentrations in groundwater as it flows through the final few feet of streambed sediments (Hem, 1985; Jones and Mulholland, 2000). Accordingly, these values should be considered upper bound estimates. The actual concentration of nitrate-N and phosphorous that enters the creek with discharging groundwater may be lower than reported here.



Water Quality Parameter	Sampling location by map ID P1	P6	P8	P11
pH (std units)	6.81	7.06	7.06	6.97
Specific conductance (us/cm @ 25C)	496	582	579	365
Dissolved Oxygen (mg/L)	2.09	0.68	0.32	2.89
Total Alkalinity (mg/L)*	215	256	269	143
Total Chloride (mg/L)*	17	21.9	19.45	14.8
Ortho-phosphate (mg/L) *	0.157	0.261	0.037	0.115
Total phosphorus (mg/L) *	0.141	0.251	0.128	0.105
Nitrate+nitrite-N (mg/L) *	1.21	2.81	0.18	2.420
Ammonia (mg/L) *	0.01 U	*0.014*	0.063	0.01 U
TPN-N (mg/L) *	1.34	2.91	0.39	2.470
Dissolved organic carbon (mg/L) *	2.6	1.45	2.15	*1.1 U*
Iron (mg/L) *	0.05 U	*0.053*	1.935	0.05 U
Approximate Rive Mile (RM)	11.1	5.35	3.42	0.46

* Dissolved sample fraction

Note: Sites P6 and P8 were sampled twice, site P1 3 times, and site P11 4 times over the study period. Non-detect values were used, as reported, to calculate the values shown in italics. See Table B2 for a listing of the individual sample results that were used to derive these values.

Figure A-6. Average analyte concentrations in groundwater from sampled instream piezometers

References for Appendix A

Study Quality Assurance Project Plan

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Data Quality Review for Appendix A

Field-Meter Calibration and Verification

Water quality field meters were calibrated in accordance with the manufacturer's instructions at the start of each sampling event. Fresh commercially prepared buffer solutions and reference standards were used for all pH and specific conductance calibrations respectively. The DO sensor was calibrated against theoretical water saturated air using the manufacturer supplied air chamber.

The initial meter calibrations for pH and specific conductance were checked by evaluating the difference between the calibrated meter values and check standards (Table A-2). The pH calibration was considered acceptable if the meter pH values differed by less than ± 0.05 pH units from the standards. The specific conductance calibration was accepted if the meter values deviated by no more than ± 5% from the check standards.

At the end of each sampling event, the meter was rechecked against reference standards to confirm the initial calibration had not drifted unacceptably during use. Based on this assessment the results for each parameter were either accepted, qualified as estimates, or rejected as unusable (Table A-2). The meter results for this study were all within the defined post-used acceptance criteria and are reported here without further qualification

.

Table A-2: Field meter calibration records for the 2013 and 2014 synoptic groundwater quality surveys.

		pH				Specific conductance				Dissolved oxygen		
Date	Status	Reference standard (pH)	Meter reading (pH)	Difference from standard (pH units)	Accept or reject calibration/ results [1]	Reference standard (µS/cm)	Meter reading (µS/cm)	Deviation from standard (%)	Accept or reject calibration/ results [1]	Meter reading (mg/L	saturation (percent)	Accept or reject calibration/ results [1]
8/5/2013	Pre-use	4.01	4.01	0	Accept	100	101.1	1.1	Accept	8.7	100.1	Accept
		7.01	6.98	-0.03	Accept							
8/7/2013	Post-use	4.01	4.03	0.02	Accept	100	102.3	2.3	Accept	8.61	99.9	Accept
		7.01	6.97	-0.04	Accept							
11/12/2013	Pre-use	4.01	4.05	0.04	Accept	99.4	99.4	0.0	Accept	8.94	100	Accept
		7	7	0	Accept							
11/14/2013	Post-use	7	7.11	0.11	Accept	99.4	101.5	2.1	Accept	8.89	100.6	Accept
		4.01	4.12	0.11	Accept							
3/3/2014	Pre-use	4	4.03	0.03	Accept	100	100	0	Accept	8.56	100	Accept
		7.01	7.02	0.01	Accept							
3/6/2014	Post-use	4	4.04	0.04	Accept	100	99.7	0.3	Accept	8.54	100.6	Accept
		7.01	7.07	0.06	Accept							
5/30/2014	Pre-use	4.01	4.06	0.05	Accept	99.5	98.4	-1.1	Accept	8.59	100	Accept
		7	7.03	0.03	Accept							
6/5/2014	Post-use	4.01	4.09	0.08	Accept	99.5	9.3	-0.02	Accept	8.65	101	Accept
		7	7.05	0.05	Accept							

[1] Calibration acceptance criteria by parameter

pH

Deviation from check standards following initial calibration:
≤ ± 0.05 pH deviation from all standards = accept calibration
> ± 0.05 pH deviation from any standard = reject calibration

Specific conductance
≤ ±5% deviation from all standards = accept calibration
> ±5% deviation from any standard = reject calibration

Dissolved Oxygen (saturation percent)
≥ 99.7% and ≤ 100.3% = accept calibration
< 99.6% or > 100.4% = reject calibration

[1] Post-use acceptance criteria - deviations from check standards

pH

Deviation from check standards following initial calibration:
≤ ±0.25 pH deviation from all standards = accept results
> ±0.25 and ≤ ±0.5 pH deviation from any standard = qualify results as estimates ("J" code)
> ±0.5 pH deviation from any standard = reject results

Specific conductance
≤ ±5% deviation from all standards = accept results
> ±5% and ≤ ±10% deviation from any standard = qualify results as estimates ("J" code)
> ±10% deviation from any standard = reject results

Dissolved oxygen (saturation percent)
≥ 95% and ≤ 105% = accept calibration
< 94.9% or > 105% = qualify results as estimates ("J" code)

Review of Water Quality Data for Groundwater Assessment

All piezometers were sampled using properly calibrated field meters, dedicated sample tubing, and new in-line-cartridge filters, as appropriate. Samples were collected in clean bottles supplied by Manchester Environmental Laboratory (MEL). Pre-acidified bottles were used for preserved samples. Filled sample bottles were labeled, bagged, and then stored in clean, ice-filled coolers pending their arrival at the lab. Sample chain-of-custody procedures were followed throughout the project.

Laboratory Quality Assurance (QA) for Groundwater Assessment

MEL follows strict protocols to both ensure and later evaluate the quality of their analytical results (MEL, 2016). Where appropriate, instrument calibration was performed by laboratory staff before each analytical run and checked against initial verification standards and blanks. Calibration standards and blanks were analyzed at a frequency of 10% during each analytical run and then again at the end of each run. The lab also evaluates procedural blanks, spiked samples, and lab control samples (LCS) as additional checks of data quality. The results of these analyses were summarized in a case narrative and submitted to the field investigator along with each analytical data package.

The lab's QA narratives and supporting data for this project indicate that all samples arrived at the lab in good condition and were analyzed within accepted EPA holding times. Constituent concentrations for laboratory blank samples consistently fell below the analytical detection limit for target analytes. In addition, matrix spike samples and LCS analyses all met applicable acceptance criteria. The precision of lab duplicate and field replicate analyses was quantified by evaluating the percent relative standard deviation[3] (%RSD) for each duplicate sample pair. The resulting values (Table A-4) were tabulated and compared to the project data quality objectives (Table A-3).

Based on this evaluation, two lab samples slightly exceeded the project acceptance criteria for replicate samples (see shaded results in Table A-4). In both cases, the sample concentrations were only slightly above the method reporting limit. Accordingly, these exceedances are not considered significant.

Field QA for Groundwater Assessment

To assess sampling bias and overall analytical precision, field equipment blanks and replicate samples were collected and submitted "blind"[4] to the lab during each sample event. Equipment blanks were prepared using laboratory-grade de-ionized water and were handled and filtered in the same manner as other samples. None of the field blanks collected during this evaluation contained measurable concentrations of the target analytes. The %RSD for field duplicate samples were all less than the applicable project acceptance criteria, except for a single sample pair collected for dissolved organic carbon analysis (Table A-4). The reported concentrations for the sample pair were at or just above the method reporting limit for DOC. Accordingly, the exceedance isn't considered significant.

[3] Calculated for a pair of results, x_1 and x_2, as
100 * (S/Average of x_1 and x_2) where S is the standard deviation of the sample pair.

[4] The term "blind" refers to "identical" samples that were submitted to the lab under different sample numbers, in order to maintain sample anonymity during lab analysis.

The combined results of the laboratory and field QA reviews indicate that the water quality data generated during this study are of high quality and can be used as reported, without further qualification.

Table A-3: Data quality objectives for groundwater samples.

Parameter	Check standards (% recovery limits)	Field duplicate sample (%RSD)	Matrix spikes (% recovery limits)	Matrix spike duplicates (RPD)
Field Parameters				
pH	± 0.2 SU	± 0.1 SU	NA	NA
Specific conductance	± 10 µS/cm	± 10%	NA	NA
Temperature	± 0.1 C	± 5%	NA	NA
Dissolved oxygen	± 0.2 mg/L	NA	NA	NA
Laboratory Analyses				
Alkalinity	80-120%	± 10%	75-125%	± 10%
Chloride	90-110%	± 5%	75-125%	± 5%
Orthophosphate	80-120%	± 10%	75-125%	± 10%
Total phosphorus	85-115%	± 10%	75-125%	± 10%
Nitrate+nitrite-N	80-120%	± 10%	75-125%	± 10%
Ammonia	80-120%	± 10%	75-125%	± 10%
TPN-N	80-120%	± 10%	75-125%	± 10%
Dissolved organic carbon	80-120%	± 10%	75-125%	± 10%
Iron	85-115%	± 10%	75-125%	± 10%

RPD - relative percent difference
%RSD - percent relative standard deviation

Table A-4: Summary of field and laboratory duplicate samples and blanks

Sample date		Total alkalinity (mg/L)	Total chloride (mg/L)	Dissolved organic carbon (mg/L)	Dissolved Ortho-phosphate (mg/L	Dissolved total phosphorus (mg/L)	Dissolved nitrate+ nitrite-N (mg/L)	Dissolved ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved iron (mg/L)
Field Duplicate Samples and Filter Blanks										
8/6/2013	Sample	226	17.9	2.90	0.164	0.148	0.967	0.01 U	1.11	0.05 U
	Rep/Duplicate	225	17.8	3.00	0.164	0.147	0.982	0.01 U	1.1	0.05 U
	%RSD	0.31	0.40	2.40	0.00	0.48	1.09	nc	0.64	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
11/13/2013	Sample	229	17.3	1.70	0.264	0.253	1.85	0.010 U	1.98	0.055
	Rep/Duplicate	228	17.4	1.60	0.266	0.253	1.82	0.010 U	1.75	0.056
	%RSD	0.31	0.41	4.29	0.53	0.00	1.16	nc	8.72	1.27
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
3/5/2014	Sample	1.89	16	2.10	0.141	1.300	1.52	0.010 U	1.62	0.05 U
	Rep/Duplicate	1.89	16	2.10	0.141	1.320	1.58	0.010 U	1.62	0.05 U
	%RSD	0.00	0.00	0.00	0.00	1.08	2.74	nc	0.00	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
6/4/2014	Sample	1.29	15	1.0 U	0.111	0.102	2.39	0.010 U	2.42	0.05 U
	Rep/Duplicate	1.3	15.4	1.20	0.110	0.101	2.4	0.010 U	2.48	0.05 U
	%RSD	0.55	1.86	12.86	0.64	0.70	0.30	nc	1.73	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
Mean % RSD by analyte		**0.29**	**0.67**	**4.88**	**0.29**	**0.56**	**1.32**	**nc**	**2.77**	**1.27**
Laboratory Replicates and Blanks										
8/6/2013	Sample	46.9	2.47	1.39	0.0259	0.007	-	0.01 U	1.11	-
	Rep/Duplicate	46.7	2.44	1.40	0.0254	0.006	-	0.01 U	1.1	-
	%RSD	0.30	0.86	0.51	1.38	10.88	nc	nc	0.64	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
11/13/2013	Sample	229	20.6	1.80	0.190	0.253	0.285	0.004	1.98	-
	Rep/Duplicate	229	20.6	1.81	0.190	0.254	0.287	0.01 U	1.96	-
	%RSD	0.00	0.00	0.39	0.00	0.28	0.494	nc	0.72	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
3/5/2014	Sample	166	15.2	1.73	0.118	1.300	3.45	0.015	1.62	-
	Rep/Duplicate	165	15.2	1.74	0.118	1.260	3.45	0.013	1.62	-
	%RSD	0.43	0.00	0.41	0.00	2.21	0.000	10.10	0.00	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
6/4/2014	Sample	39.20	1.78	1.25	0.0438	0.101	0.285	0.009 U	2.48	-
	Rep/Duplicate	39.50	1.73	1.23	0.0443	0.102	0.283	0.010 U	2.41	-
	%RSD	0.54	2.01	1.14	0.80	0.70	0.498	nc	2.02	nc
	Sample blank	5.0 U	0.10 U	1.0 U	0.003 U	0.005 U	0.010 U	0.010 U	0.025 U	0.05 U
Mean % RSD by analyte		**0.32**	**0.72**	**0.61**	**0.55**	**3.52**	**0.33**	**nc**	**0.85**	**nc**

nc - not calculated
U -analyte not detected at or above the reported value.
Highlited values indicate an exceedence of the project quality assurance criteria.

Tabular Data Summaries for Appendix A

Most of the field and laboratory data presented in this appendix are available in digital format from the Department of Ecology's Environmental Information Management (EIM) database. Readers can access EIM from the "databases" link provided on Ecology's home page at: www.ecy.wa.gov

The data for this study are archived in EIM under the following study name and user study ID:

EIM study name:
Wide Hollow Creek Water Quality Study for Aquatic Life Use

EIM user study ID:
JICA0002

Table A-5: Physical description and location of instream piezometers.

Map ID [1]	Well tag ID number	Location name	Approximate river mile location (mile)	Well location (TRS)	Latitude (decimal degrees)	Longitude (decimal degrees)	Site elevation (feet)	Piezometer stickup (feet above streambed)[1]	Piezometer depth (feet below streambed)	Length of perforated interval (feet)	Depth to midpoint of piezometer perforations (feet below streambed)[1]	Piezometer inclination angle (degrees from vertical)
P1	AHT083	Wide Hollow Ck. near 101st Ave	11.11	13N/17E-25 SE	46.58042	-120.64125	1239	3.6	3.45	0.5	3.20	10
P2	AHT077	Wide Hollow Ck. near 91st Ave	10.48	13N/18E-30 SW	46.58195	-120.62970	1208	2.5	4.22	0.5	3.99	22
P3	AHT076	Wide Hollow Ck. at 80th Ave	9.63	13N/18E-29 SW SW	46.58138	-120.61473	1183	2.8	4.19	0.5	3.94	4
P4	AHT075	Wide Hollow Ck. at 67th Ave	8.74	13N/18E-29 SE SW	46.57990	-120.59913	1162	1.3	5.80	0.5	5.55	0
P5	AHT084	Wide Hollow Ck. near 40th Ave	6.55	13N/18E-27 SW SE	46.57858	-120.56556	1103	2.7	4.40	0.5	4.15	2
P6	AHT074	Wide Hollow Ck near 24th Ave Texaco	5.35	13N/18E-35 NW	46.57389	-120.54783	1083	2.1	5.00	0.5	4.75	0
P7	AHT080	Wide Hollow Ck at Cub Crafters, near 16th Ave	4.4	13N/18E-35 SE NE	46.56944	-120.53109	1047	2.7	4.36	0.5	4.11	8
P8	AHT081	Wide Hollow Ck at 10th Ave and Pioneer Ave	3.42	13N/18E-36 SE SW	46.56356	-120.51629	1024	2.7	4.26	0.5	4.01	8
P9	AHT078	Wide Hollow Ck near Ahtanum Business Park	2.21	12N/19E-6 SW NW	46.55541	-120.49750	995	2.5	4.49	0.5	4.24	4
P10	AHT079	Wide Hollow Ck at White St	1.14	12N/19E-7 NE NE	46.54961	-120.48065	975	3.4	3.60	0.5	3.35	0
P11	AHT082	Wide Hollow Ck below Union Gap city shop	0.46	12N/19E-8 NW SW	46.54264	-120.47530	960	3.4	3.60	0.5	3.35	0

[1] - These values based on measurements made during piezometer installation.

Table A-6: Summary of water levels, water quality results, and streambed hydraulic gradients measured at instream piezometer sites.

					Groundwater Field Parameters					Laboratory Analyses [2]								
Map ID	Location description	River Mile	Well tag ID number	Sample date	Vertical hydraulic gradient [1] (dimensionless)	Water temperature (deg C)	pH (standard units)	Specific conductance (µS/cm @ 25 °C)	Dissolved oxygen (mg/L)	Total alkalinity (mg/L	Total chloride (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved total phosphorus (mg/L)	Dissolved nitrate+ nitrite-N (mg/L)	Dissolved ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved organic carbon (mg/L)	Dissolved iron (mg/L)
P1	Near 101st Ave	11.1	AHT083	07/10/2013	0.006	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	0.000	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	0.006	13.54	6.68	515.5	1.51	226	17.9	0.164	0.148	0.967	0.01 U	1.11	2.9	0.05 U
				08/27/2013	0.000	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.010	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	0.023	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	0.013	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/13/2013	-	12.56	6.87	520.6	2.48	229	17.1	0.166	0.147	1.14	0.01 U	1.3	2.8	0.05 U
				12/10/2013	0.013	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	0.100	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/05/2014	0.019	9.03	6.89	451.7	2.3	189	16	0.141	0.130	1.52	0.01 U	1.62	2.1	0.05 U
				06/02/2014	-0.025	-	-	-	-	-	-	-	-	-	-	-	-	-
P2	91st Ave	10.5	AHT077	07/11/2013	-0.296	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.281	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.289	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.231	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.317	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	-0.358	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	-0.350	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/11/2013	-0.321	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	-0.290	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	-0.256	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/02/2014	-0.342	-	-	-	-	-	-	-	-	-	-	-	-	-
P3	80th Ave	9.63	AHT076	07/11/2013	-0.309	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.349	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.342	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.370	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.402	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	-0.310	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	Creek dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/10/2013	Creek frozen	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	-0.065	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	-0.093	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/02/2014	-0.348	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A-6: continued

					Groundwater Field Parameters					Laboratory Analyses [2]								
Map ID	Location description	River Mile	Well tag ID number	Sample date	Vertical hydraulic gradient [1] (dimensionless)	Water temperature (deg C)	pH (standard units)	Specific conductance (µS/cm @ 25 °C)	Dissolved oxygen (mg/L)	Total alkalinity (mg/L	Total chloride (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved total phosphorus (mg/L)	Dissolved nitrate+ nitrite-N (mg/L)	Dissolved ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved organic carbon (mg/L)	Dissolved iron (mg/L)
P4	67th Ave	8.74	AHT075	07/11/2013	-0.075	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.107	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.155	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.151	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.171	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	Creek dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	-0.037	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/10/2013	Creek nearly dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	Creek dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	Creek nearly dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/03/2014	-0.130	-	-	-	-	-	-	-	-	-	-	-	-	-
P5	40th Ave at Bergen Screen	6.55	AHT084	07/10/2013	-0.456	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.394	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.523	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.577	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.538	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	-0.423	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	-0.422	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/10/2013	-0.429	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	-0.422	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	-0.353	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/02/2014	-0.478	-	-	-	-	-	-	-	-	-	-	-	-	-
P6	Texaco near 24th Ave	5.35	AHT074	07/10/2013	0.009	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.045	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.049	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.006	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.030	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	0.043	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	0.042	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/13/2013	-	14.88	7.07	512.3	0.55	229	17.3	0.264	0.253	1.85	0.01 U	1.98	1.7	0.056
				12/10/2013	-0.015	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	0.032	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/05/2014	0.030	14.21	7.05	651.8	0.81	282	26.5	0.258	0.249	3.78	0.027	3.83	1.2	0.05 U
				06/02/2014	-0.015	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A-6: continued

Map ID	Location description	River Mile	Well tag ID number	Sample date	Groundwater Field Parameters: Vertical hydraulic gradient [1] (dimensionless)	Water temperature (deg C)	pH (standard units)	Specific conductance (µS/cm @ 25 °C)	Dissolved oxygen (mg/L)	Laboratory Analyses [2]: Total alkalinity (mg/L	Total chloride (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved total phosphorus (mg/L)	Dissolved nitrate+ nitrite-N (mg/L)	Dissolved ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved organic carbon (mg/L)	Dissolved iron (mg/L)
P7	16th Ave at Cub Crafters	4.4	AHT080	07/11/2013	-1.111	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/30/2013	-1.268	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-1.323	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-1.199	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-1.208	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	-0.955	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	-0.956	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/10/2013	-1.104	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	-1.111	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	-1.100	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/02/2014	-1.289	-	-	-	-	-	-	-	-	-	-	-	-	-
P8	10th Ave and Pioneer St	3.42	AHT081	08/05/2013	-0.045	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.025	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	0.020	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	0.010	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	0.020	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	0.031	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/13/2013	-	13.02	7.08	633.6	0.38	299	19.9	0.058	0.180	0.159	0.087	0.428	2.4	2.44
				12/10/2013	0.015	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	0.058	-	-	-	-	-	-	-	-	-	-	-	-	-
				02/04/2014	0.058	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/05/2014	0.049	9.19	7.03	524.9	0.26	238	19	0.017	0.076	0.206	0.039	0.354	1.9	1.43
				06/02/2014	-0.031	-	-	-	-	-	-	-	-	-	-	-	-	-
P9	Ahtanum Business Park	2.21	AHT078	07/11/2013	-0.416	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.523	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.499	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.421	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.412	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	-0.306	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	-0.317	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/10/2013	-0.397	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	-0.420	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	-0.337	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/02/2014	-0.498	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A-6: continued

Map ID	Location description	River Mile	Well tag ID number	Sample date	Groundwater Field Parameters: Vertical hydraulic gradient [1] (dimensionless)	Water temperature (deg C)	pH (standard units)	Specific conductance (µS/cm @ 25 °C)	Dissolved oxygen (mg/L)	Laboratory Analyses [2]: Total alkalinity (mg/L	Total chloride (mg/L)	Dissolved Ortho-phosphate (mg/L)	Dissolved total phosphorus (mg/L)	Dissolved nitrate+ nitrite-N (mg/L)	Dissolved ammonia (mg/L)	Dissolved TPN-N (mg/L)	Dissolved organic carbon (mg/L)	Dissolved iron (mg/L)
P10	White St	1.14	AHT079	07/11/2013	-0.015	-	-	-	-	-	-	-	-	-	-	-	-	-
				07/29/2013	-0.295	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/06/2013	-0.386	-	-	-	-	-	-	-	-	-	-	-	-	-
				08/27/2013	-0.844	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	-0.929	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	-1.017	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/12/2013	-1.116	-	-	-	-	-	-	-	-	-	-	-	-	-
				12/10/2013	-1.161	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/23/2014	Piezometer dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/04/2014	Piezometer dry	-	-	-	-	-	-	-	-	-	-	-	-	-
				06/02/2014	-1.094	-	-	-	-	-	-	-	-	-	-	-	-	-
P11	Union Gap, city shop	0.46	AHT082	08/06/2013	0.046	15.82	6.8	348.1	2.62	136	14.4	0.100	0.091	2.35	0.01 U	2.27	1.2	0.05 U
				08/27/2013	0.042	-	-	-	-	-	-	-	-	-	-	-	-	-
				09/23/2013	0.048	-	-	-	-	-	-	-	-	-	-	-	-	-
				10/22/2013	0.062	-	-	-	-	-	-	-	-	-	-	-	-	-
				11/13/2013	0.065	15.77	7.03	366.5	2.43	148	13.8	0.127	0.118	2.27	0.01 U	2.47	1.2	0.05 U
				12/10/2013	0.039	-	-	-	-	-	-	-	-	-	-	-	-	-
				01/28/2014	0.079	-	-	-	-	-	-	-	-	-	-	-	-	-
				02/04/2014	0.070	-	-	-	-	-	-	-	-	-	-	-	-	-
				03/05/2014	0.093	13.98	7.07	409.8	3.7	159	16	0.121	0.110	2.66	0.01 U	2.73	1.0 U	0.05 U
				06/04/2014	0.064	13.82	6.96	335.7	2.82	129	15	0.111	0.102	2.4	0.01 U	2.42	1.0 U	0.05 U

[1] - Negative vertical hydraulic gradient values indicate the potential for loss of stream water to groundwater storage. Positive values indicate the potential for groundwater discharge to the stream.

[2] - Data qualifier codes:

U - analyte was not detected at or above the reported value

Table A-7: Summary of CHIT test results for instream piezometer sites

Well ID	Test Number	Piezo Screen Length (ft) L	Real or Assumed Piezo Diameter (in) d	Piezometer Penetration (ft) H	Assumed Total Saturated Thickness (ft) b	Operating Head (ft) y	Total volume of water injected into piezo during test (liters) V_{NET}	Time duration of test (min) t	Net Injection Rate V_{net}/t (L/min) Q_{NET}	Hydraulic Conductivity (ft/day) K	Average Hydraulic Conductivity (ft/day) K
AHT083 (101st)	1	0.49	1	3.34	30	1.74	6	0.99	6.1	101	9.99E+01
	2	0.49	1	3.34	30	1.74	6	0.99	6.0	100	
	3	0.49	1	3.34	30	1.74	6	1.00	6.0	99	
AHT077 (91st)	1	0.5	1	4.14	30	0.46	0.5	0.88	0.6	36	3.53E+01
	2	0.5	1	4.14	30	0.46	0.5	0.90	0.6	35	
	3	0.5	1	4.14	30	0.46	0.5	0.90	0.6	35	
	4	0.5	1	4.14	30	0.46	0.5	0.90	0.6	35	
AHT076 (80th)	1	0.4	1	4.18	30	1.93	8	0.83	9.6	163	1.89E+02
	2	0.4	1	4.18	30	1.93	6	0.75	8.0	136	
	3	0.4	1	4.18	30	1.93	4	0.35	11.4	194	
	4	0.4	1	4.18	30	1.93	6	0.47	12.8	218	
	5	0.4	1	4.18	30	1.93	6	0.43	13.9	235	
AHT075 (67th)	1	0.49	1	5.62	30	1.58	0.5	0.27	1.9	36	4.04E+01
	2	0.49	1	5.62	30	1.58	0.5	0.27	1.9	36	
	3	0.49	1	5.62	30	1.58	0.5	0.23	2.1	41	
	4	0.49	1	5.62	30	1.58	0.5	0.23	2.1	41	
	5	0.49	1	5.62	30	1.58	0.5	0.20	2.5	48	
AHT084 (Bergens)	1	0.48	1	4.34	30	1.34	4	1.20	3.3	74	7.17E+01
	2	0.48	1	4.34	30	1.34	4	1.17	3.4	76	
	3	0.48	1	4.34	30	1.34	4	1.27	3.2	70	
	4	0.48	1	4.34	30	1.34	4	1.30	3.1	69	
	5	0.48	1	4.34	30	1.34	4	1.30	3.1	69	
AHT074 (Taxaco)	1	0.48	1	4.92	30	2.55	4	0.80	5.0	59	5.79E+01
	2	0.48	1	4.92	30	2.55	4	0.82	4.9	58	
	3	0.48	1	4.92	30	2.55	4	0.85	4.7	56	
	4	0.48	1	4.92	30	2.55	4	0.82	4.9	58	
AHT080 (Cub Craft)	1	0.48	1	4	30	1.21	6	0.78	7.7	188	1.89E+02
	2	0.48	1	4	30	1.21	6	0.77	7.8	192	
	3	0.48	1	4	30	1.21	6	0.78	7.7	188	

Table A-7: continued

Well ID	Test Number	Piezo Screen Length (ft) L	Real or Assumed Piezo Diameter (in) d	Piezometer Penetration (ft) H	Assumed Total Saturated Thickness (ft) b	Operating Head (ft) y	Total volume of water injected into piezo during test (liters) V_{NET}	Time duration of test (min) t	Net Injection Rate V_{net}/t (L/min) Q_{NET}	Hydraulic Conductivity (ft/day) K	Average Hydraulic Conductivity (ft/day) K
AHT018 (10th)	1	0.38	1	4.24	30	0.62	0.5	0.67	0.7	41	3.97E+01
	2	0.38	1	4.24	30	0.62	0.5	0.68	0.7	40	
	3	0.38	1	4.24	30	0.62	0.5	0.70	0.7	39	
AHT078 (Aht. Bus)	1	0.5	1	4.47	30	2.11	2	1.47	1.4	19	1.85E+01
	2	0.5	1	4.47	30	2.11	2	1.47	1.4	19	
	3	0.5	1	4.47	30	2.11	2	1.58	1.3	18	
AHT079 (White St)	1	0.5	1	3.74	30	2.78	2	0.85	2.4	24	2.33E+01
	2	0.5	1	3.74	30	2.78	2	0.92	2.2	23	
	3	0.5	1	3.74	30	2.78	2	0.90	2.2	23	
	4	0.5	1	3.74	30	2.78	2	0.90	2.2	23	
AHT082 (U.G. Shop)	1	0.5	1	3.62	30	2.05	0.5	0.22	2.3	32	3.23E+01
	2	0.5	1	3.62	30	2.05	0.5	0.22	2.3	32	
	3	0.5	1	3.62	30	2.05	0.5	0.22	2.3	32	
	4	0.5	1	3.62	30	2.05	0.5	0.22	2.3	32	

NOTE: Prior to their use in subsequent modeling efforts, we multiplied the “isotropic” hydraulic conductivity values shown above by 0.1 to obtain estimated vertical hydraulic conductivity values for the streambed sediments at each piezometer site. This adjust was made to compensate for well development (which preferentially removes fine material from the piezometer screen) and potential streambed anisotropy effects.

Appendix B. Bioassessment Study

Introduction

During summer 2013, five sites on Wide Hollow Creek were sampled according to standard protocols (Adams 2010) for habitat, water and sediment chemistry and multiple biological communities (i.e. macroinvertebrates, periphyton, and fish). The 2013 sites were near sites established by the Department of Ecology (Ecology) (Kendra 1988) during a 1987 biological assessment of conditions in Wide Hollow Creek.

Briefly, the 2013 sampling methodology involved establishing a reach length totaling 20 times average bankfull width for 11 major transects for each site. At each of the major transects, habitat variables (i.e. substrate and riparian) were measured, while at eight randomly selected major transects, macroinvertebrates and periphyton were sampled (Adams 2010).

The five 2013 sites were compared to regional Ambient Biological and Sentinel sites that were also sampled in 2013 by Ecology. Comparisons were made of various habitat metrics and macroinvertebrate and periphyton communities (Table B-1).

Table B-1. Information for sites in the Columbia Plateau level III ecoregion where bioassessment data were collected in summer 2013.
Ambient Biological (BIO06600) and Sentinel (SEN06600) sites are used in this analysis for comparison purposes only.

Site ID	Site name	Latitude	Longitude	Date sampled
BIO06600-OAKC10	Oak Creek	46.72987	-120.8781	10/2/2013
BIO06600-DRYC10	Dry Creek	46.50574	-119.6844	8/27/2013
BIO06600-ROCK10	Rock Creek	47.00321	-117.9457	8/7/2013
BIO06600-ROCK10_R	Rock Creek	47.00321	-117.9457	9/10/2013
BIO06600-CRAB10	Crab Creek	47.29745	-118.2474	8/8/2013
BIO06600-COLE10	Coleman Creek	47.11162	-120.3952	8/27/2013
BIO06600-HOGC10	Hog Canyon Creek	47.36794	-117.8103	9/9/2013
BIO06600-SASO10	South Fork Asotin Creek	46.21515	-117.2858	8/28/2013
SEN06600-ASOT13	North Fork Asotin Creek	46.25935	-117.2991	8/6/2013
SEN06600-UMTA18	Umtanum Creek	46.85526	-120.4888	7/1/2013
SEN06600-CUMM10*	Cummings Creek	46.33298	-117.6706	8/28/2013
WHB06600-WH80TH	Wide Hollow Creek	46.58128	-120.6162	8/20/2013
WHB06600-WHRAND	Wide Hollow Creek	46.57844	-120.5683	7/25/2013
WHB06600-WHKISL	Wide Hollow Creek	46.57652	-120.5536	9/12/2013
WHB06600-WH@3RD	Wide Hollow Creek	46.55965	-120.5109	7/24/2013
WHB06600-WHMAIN	Wide Hollow Creek	46.54052	-120.4751	7/23/2013

* Cummings Creek was an Ambient Biological site and became a Sentinel site after 2013.
The site ID here reflects the current name for this site.

Analysis

Multivariate analyses of macroinvertebrate and periphyton communities with species densities were conducted using non-metric multidimensional scaling (NMDS) with Bray-Curtis dissimilarities using the vegan and labdsv packages in R statistical software version 3.0.1 (R Development Core Team 2013).

BIO-ENV procedure was performed, which selects the abiotic variable subset (environmental variables), maximizing rank correlation between biotic and abiotic dissimilarity matrices (Clark and Ainsworth 1993; Clarke 1993).

Various combinations of environmental variables can give similar fit (i.e. Pearson's correlation); therefore, a parsimonious approach was taken where the combination of environmental variables with the fewest variables and giving the best fit was chosen.

Fitting of environmental vectors was accomplished with a PCA and overlaying variables determined to be statistically significant with 999 permutations using the envfit function and scaling to NMDS. Surface fitting for select environmental variables were estimated using the ordisurf function of vegan, which uses generalized additive models in function gam of package mgcv.

Hierarchical cluster analysis using average linkage was performed on a Bray-Curtis dissimilarity matrix.

Results

Sediment Parameters

A total of 24 sediment chemistry parameters were measured at the Wide Hollow sites (Table B-2). None of the sediment chemistry parameters exceeded the proposed freshwater sediment quality values (SQVs) in Washington (Michelsen 2011). These SQVs were proposed by evaluating concentrations of various sediment chemistry parameters below which no association with toxicity was observed in the data set used to calculate the freshwater SQVs (Michelsen 2011).

Notable observations from the sediment chemistry:

- Highest arsenic was observed at WHB06600-WHMAIN.
- Highest copper and total PAHs was observed at WHB06600-WH80TH.
- Highest sediment lead concentration was observed at WHB06600-WHKISL.

Compared to the previous bioassessment of Wide Hollow Creek, which examined various metals in the sediment near WHB06600-WHMAIN and WHB06600-WHRAND (Kendra 1988):

- Arsenic values were slightly lower at WHB06600-WHRAND (2.5 to 1.57 mg/kg) and higher at WHB06600-WHMAIN (0.9 to 4.38 mg/kg).
- Copper values decreased slightly at both sites (28.6 to 23.6 mg/kg at WHB06600-WHRAND and 25.6 to 21.8 mg/kg at WHB06600-WHMAIN).
- Lead was slightly lower at WHB06600-WHRAND (32 to 24.3 mg/kg) and higher at WHB06600-WHMAIN (11 to 26.5 mg/kg).

Table B-2. Measured sediment chemistry parameters for Wide Hollow sites. *Last column contains the maximum concentration for benthic organisms for sediment quality standard/screening level 1 as recommended by Michelsen (2011).*

Parameter	WHB06600-WH80TH	WHB06600-WHRAND	WHB06600-WHKISL	WHB06600-WH@3RD	WHB06600-WHMAIN	Max. conc. benth.org.
Acenaphthene (µg/Kg)	60	24	23	25	22	N/A[b]
Acenaphthylene (µg/Kg)	60	24	23	25	22	N/A[b]
Anthracene (µg/Kg)	60	24	10	25	22	N/A[b]
Arsenic (mg/Kg)[1]	3.32	1.57	2.47	2.33	4.38	14[a]
Benz(a)anthracene (µg/Kg)	60	24	47	25	22	N/A[b]
Benzo(a)pyrene (µg/Kg)	60	19	56	30	16	N/A[b]
Benzo(b)fluoranthene (µg/Kg)	30	15	52	36	15	N/A[b]
Benzo(ghi)perylene (µg/Kg)	60	32	82	34	19	N/A[b]
Benzo(k)fluoranthene (µg/Kg)	60	9.8	44	25	7.5	N/A[b]
Carbazole (µg/Kg)	60	24	23	25	22	900[a]
Chrysene (µg/Kg)	24	13	63	31	12	N/A[b]
Copper (mg/Kg)[1]	95.6	23.6	22.8	26.1	21.8	400[a]
Dibenz(a,h)anthracene (µg/Kg)	74	31	28	25	22	N/A[b]
Dibenzofuran (µg/Kg)	60	24	23	25	22	200[a]
Fluoranthene (µg/Kg)	33	16	91	38	19	N/A[b]
Fluorene (µg/Kg)	60	24	23	25	22	N/A[b]
Indeno(123-cd)pyrene (µg/Kg)	94	46	87	49	35	N/A[b]
Lead (mg/Kg)[1]	28.3	24.3	37.3	35.1	26.5	360[a]
Methylnaphthalene (µg/Kg)	60	24	23	25	22	N/A[b]
Naphthalene (µg/Kg)	60	24	23	25	22	N/A[b]
PCN 002 (µg/Kg)	60	24	23	25	22	N/A
Phenanthrene (µg/Kg)	60	24	51	16	8.9	N/A[b]
Pyrene (µg/Kg)	41	22	110	44	20	N/A[b]
Retene (µg/Kg)	28	22	16	15	20	810,000
Total PAHs	956	395.8	836	503	328.4	17,000

[1] note that units are in mg/Kg rather than µg/Kg
[a] Sediment Quality Standard/Screening Level 1
[b] Included in Total PAHs (Sediment Quality Standard/Screening Level 1 = 17,000 µg/Kg)

Chemical Parameters

Various "point" measure water quality parameters were taken at the Wide Hollow sites during the bioassessment visits (Table B-3). Point measures provide a snapshot of conditions at the time of sampling, but do not incorporate temporal variability in conditions (i.e. diel cycles or seasonal trends) or reflect general conditions at a stream reach. A few notable results, highest chlorophyll *a* was observed at WHB06600-WH80TH, highest chloride and conductivity values were observed at the two most downstream sites (i.e. WHB06600-WH@3RD and WHB06600-WHMAIN), and highest total suspended solids and turbidity were observed at WHB06600-WHKISL, although this site was sampled later in the summer compared to the other sites. There were also no notable departures from results obtained from the 1987 bioassessment of Wide Hollow Creek.

Table B-3. Various chemical parameters measured at Wide Hollow Creek sites.

Parameter	WHB06600-WH80TH	WHB06600-WHRAND	WHB06600-WHKISL	WHB06600-WH@3RD	WHB06600-WHMAIN
Date	**8/20/2013**	**7/25/2013**	**9/12/2013**	**7/24/2013**	**7/23/2013**
Chloride ($mg \cdot L^{-1}$)	2.61	6.24	4.91	10.20	14.90
Chlorophyll *a* ($\mu g \cdot L^{-1}$)	5560	1720	2890	454	1630
Total organic carbon ($mg \cdot L^{-1}$)	7.35	1.74	1.87	2.43	1.53
Tot. persulfate nitrogen ($mg \cdot L^{-1}$)	0.305	1.140	0.878	1.660	2.260
Tot. phosphorus ($mg \cdot L^{-1}$)	0.0349	0.0774	0.1190	0.1070	0.0976
Tot. suspended solids ($mg \cdot L^{-1}$)	5	7	119	5	5
pH	7.705	7.715	7.955	7.770	7.910
Temp (°C)	18.15	20.85	11.15	19.55	19.55
DO ($mg \cdot L^{-1}$)	8.60	8.35	10.45	8.15	9.70
Conductivity ($\mu S \cdot cm$)	120.6	211.0	179.2	339.0	323.0
Turbidity (NTU)	1.6	0.0	50.9	2.1	2.0
Discharge (cfs)	8.9	13.2	25.9	14.2	25.2

Macroinvertebrate Communities

Examination of NMDS for Bray-Curtis similarities of macroinvertebrate communities indicated considerable similarity between Wide Hollow sites relative to other sites within the Columbia Plateau (Figure B-1). This is not surprising given the close proximity of the Wide Hollow sites relative to the other sites sampled in the Columbia Plateau. BIO-ENV revealed the combination of average substrate size (D50Log10), percent sands/fines (%Sand/Fines), chloride (Cl^-), and dissolved oxygen (DO) gave the best match between biotic and environmental patterns (Pearson's correlation = 0.7243).

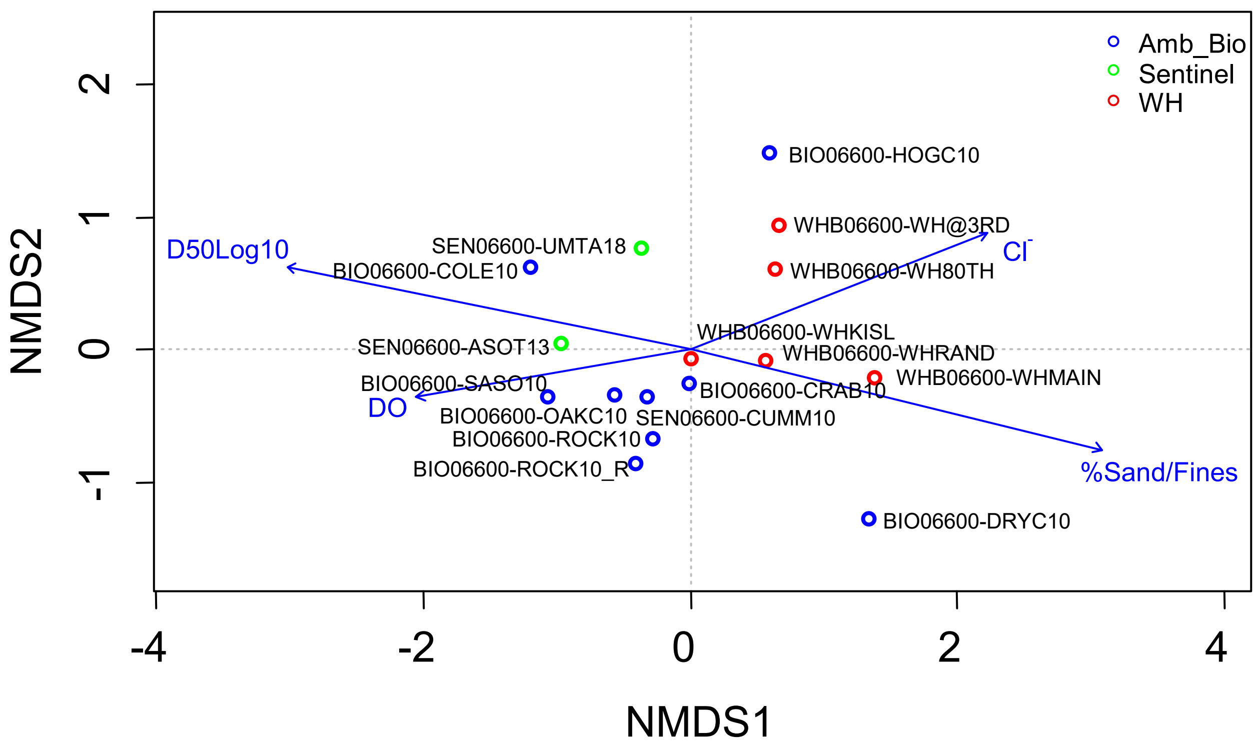

Figure B-1. NMDS ordination of Bray-Curtis dissimilarities for macroinvertebrate community data from Wide Hollow Creek relative to other sites in the Columbia Plateau Ecoregion. *Sites were sampled by Ecology in summer 2013.*

Environmental vectors revealed a strong gradient in substrate size along the first NMDS axis, with high percent sands/fines positively associated with axis 1, while average substrate size (D50Log10) was negatively associated with axis 1. Chloride was also positively associated with axis 1, while DO was negatively associated with axis 1. As such, the mean values of various substrate metrics of the Wide Hollow sites differed considerably from the Ambient Biological and Sentinel sites (Table B-4).

Table B-4. Summary statistics for various substrate metrics collected at sites in the Columbia Plateau level III ecoregion.

Ecology program		D50Log10[1]		LRBS[2]		% Sand/Fines[3]		Embededness[4]	
	n	mean	sd	mean	sd	mean	sd	mean	sd
Ambient Bio	9	0.738	0.893	-2.448	0.847	33.181	29.150	49.889	22.509
Sentinel	2	1.515	0.290	-2.125	0.064	11.690	11.017	23.450	10.253
Wide Hollow	5	-0.590	0.327	-3.904	0.531	69.954	9.413	79.040	7.767
All	16	0.420	1.010	-2.862	0.998	41.986	30.241	55.694	25.176

[1] Log_{10} of geometric mean substrate diameter (unit = log_{10} (mm))
[2] Log_{10} of relative bed stability (unit=none)
[3] Percent substrate composed of sands and fines (<2mm)
[4] Average substrate embeddedness (unit = percent)

Generally, Wide Hollow sites were associated with lower substrate size relative to the Ambient Biological and Sentinel sites in the Columbia Plateau Ecoregion as reflected by higher percent sands/fines and average substrate size (Figures B-2 and B-3, respectively). Wide Hollow sites were also associated with higher concentrations of chloride.

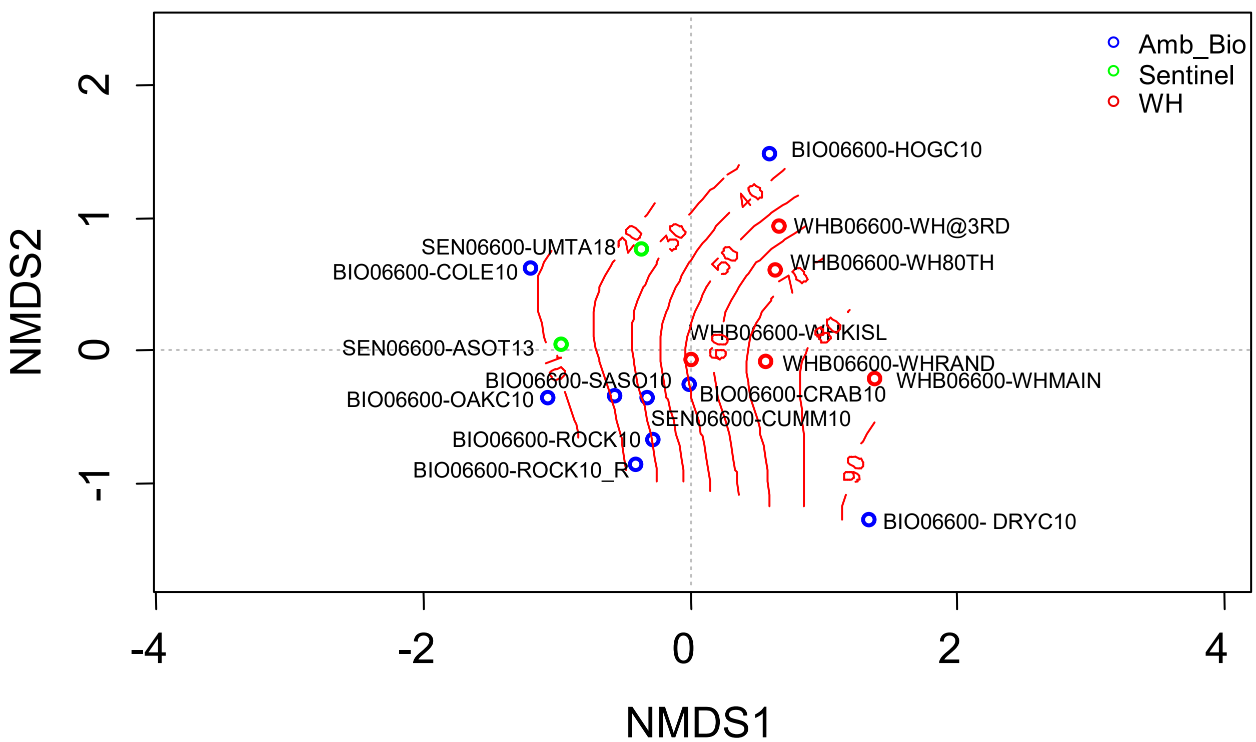

Figure B-2. NMDS ordination of Bray-Curtis dissimilarities for macroinvertebrate community data from Wide Hollow Creek relative to other sites in the Columbia Plateau Ecoregion.
Sites were sampled by Ecology in summer 2013.
Surface plot indicates the predicted percent sands/fines as modeled with a generalized additive model.

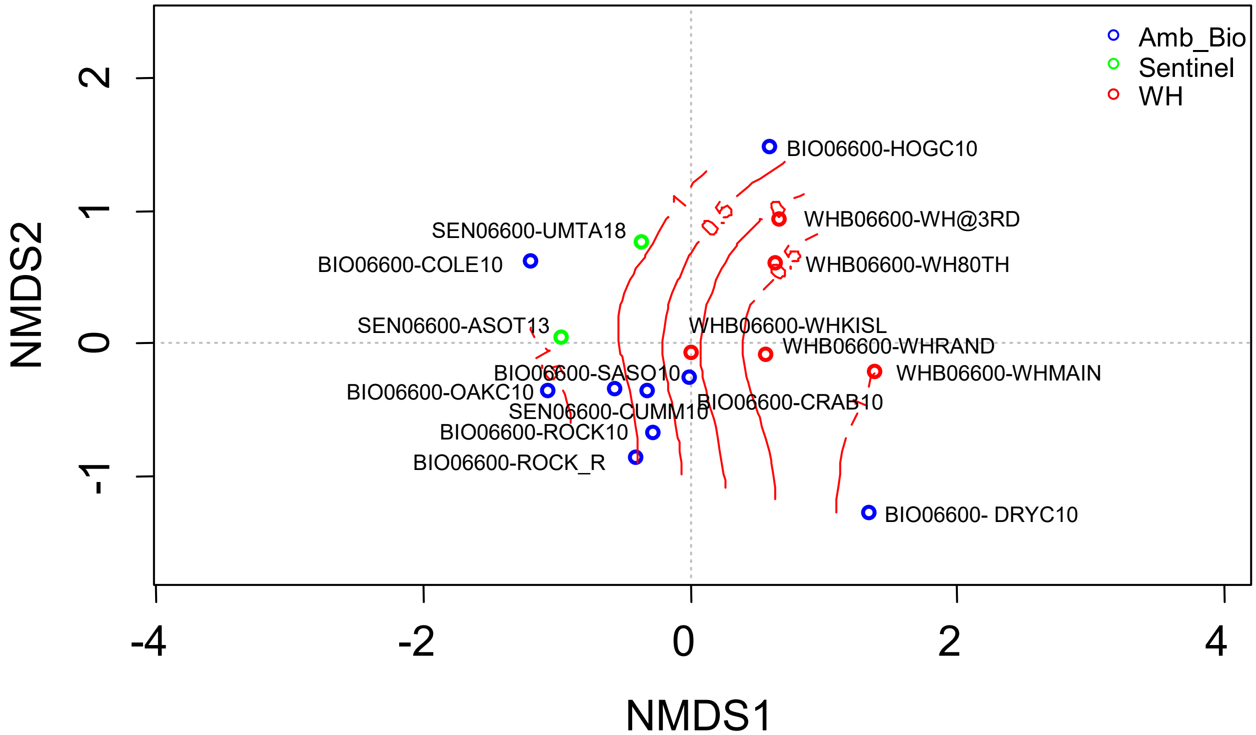

Figure B-3. NMDS ordination of Bray-Curtis dissimilarities for macroinvertebrate community data from Wide Hollow Creek relative to other sites in the Columbia Plateau Ecoregion.

Sites were sampled by Ecology in summer 2013.

Surface plot indicates the predicted average substrate size (D50Log10) as modeled with a generalized additive model.

Average B-IBI$_{10\text{-}50}$ (Benthic Index of Biotic Integrity (Kleindl 1995; Fore et al. 1996; Karr 1998; Morley & Karr 2002) scores were lower in the Wide Hollow sites relative to the Ambient Biological and Sentinel sites in the Columbia Plateau (mean ± standard deviation values of: 23.6 ± 5.2 (Wide Hollow), 29.1 ± 11.5 (Ambient Biological), and 34.0 ± 2.8 (Sentinel)), although variability among scores for the Ambient Biological sites was high (Figure B-4).

Among the Wide Hollow sites, a slight trend of B-IBI$_{10\text{-}50}$ scores decreasing at the farthest downstream sites was observed (Figure B-5). Examining the ten individual metrics comprising the B-IBI$_{10\text{-}50}$ revealed that across all of the Wide Hollow sites, no Plecoptera species (stoneflies) or species classified as pollution sensitive were observed, which would contribute to the overall low scores (Figure B-6). Going downstream, decreasing taxa richness, Ephemeroptera richness (mayflies), Trichoptera richness (caddisflies) and clinger richness was also observed at the Wide Hollow sites, all of which tend to decrease with stress (Figure B-6).

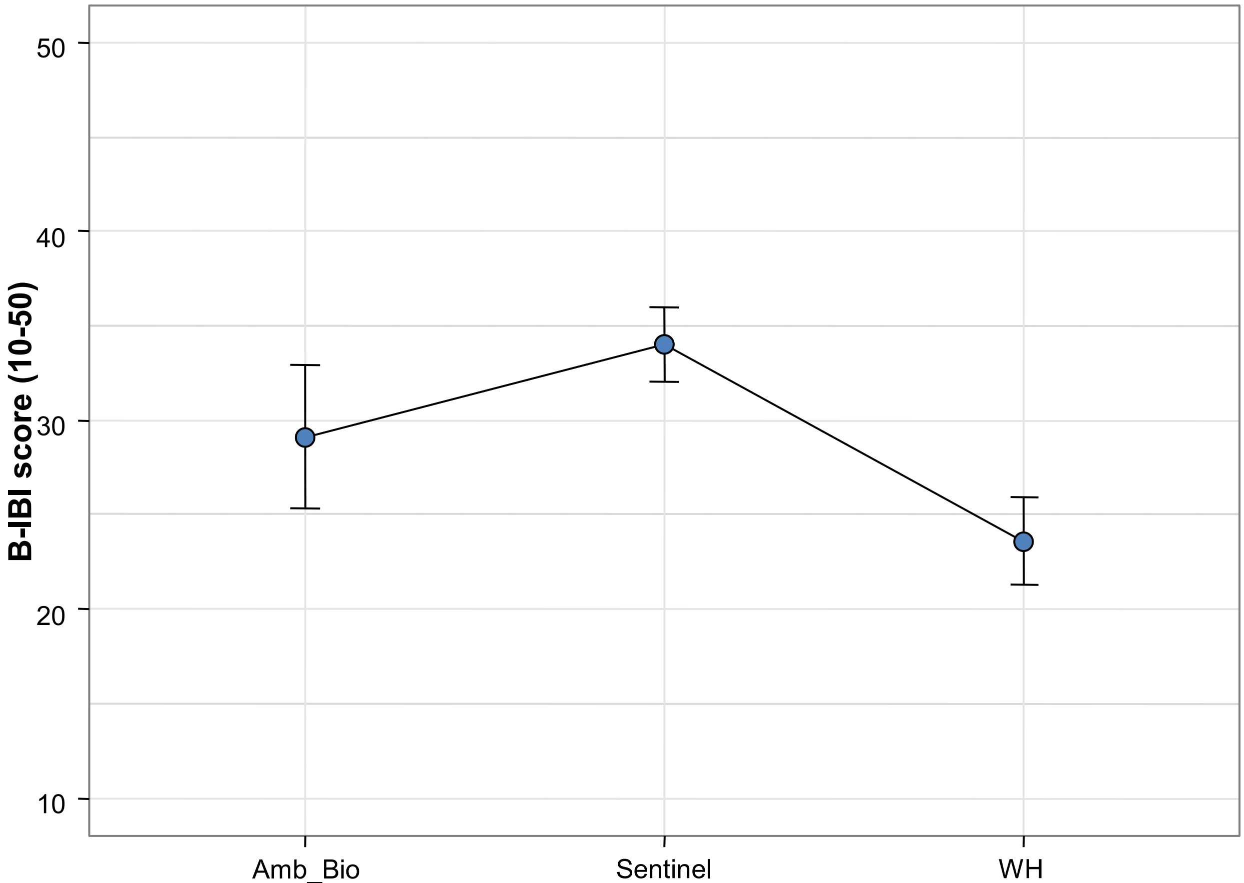

Figure B-4. Average macroinvertebrate Benthic Index of Biotic Integrity (B-IBI) scores for Wide Hollow Creek sites relative to other sites in the Columbia Plateau Ecoregion.
Sites were sampled by Ecology in summer 2013.
Error bars are ± 1 s.e.

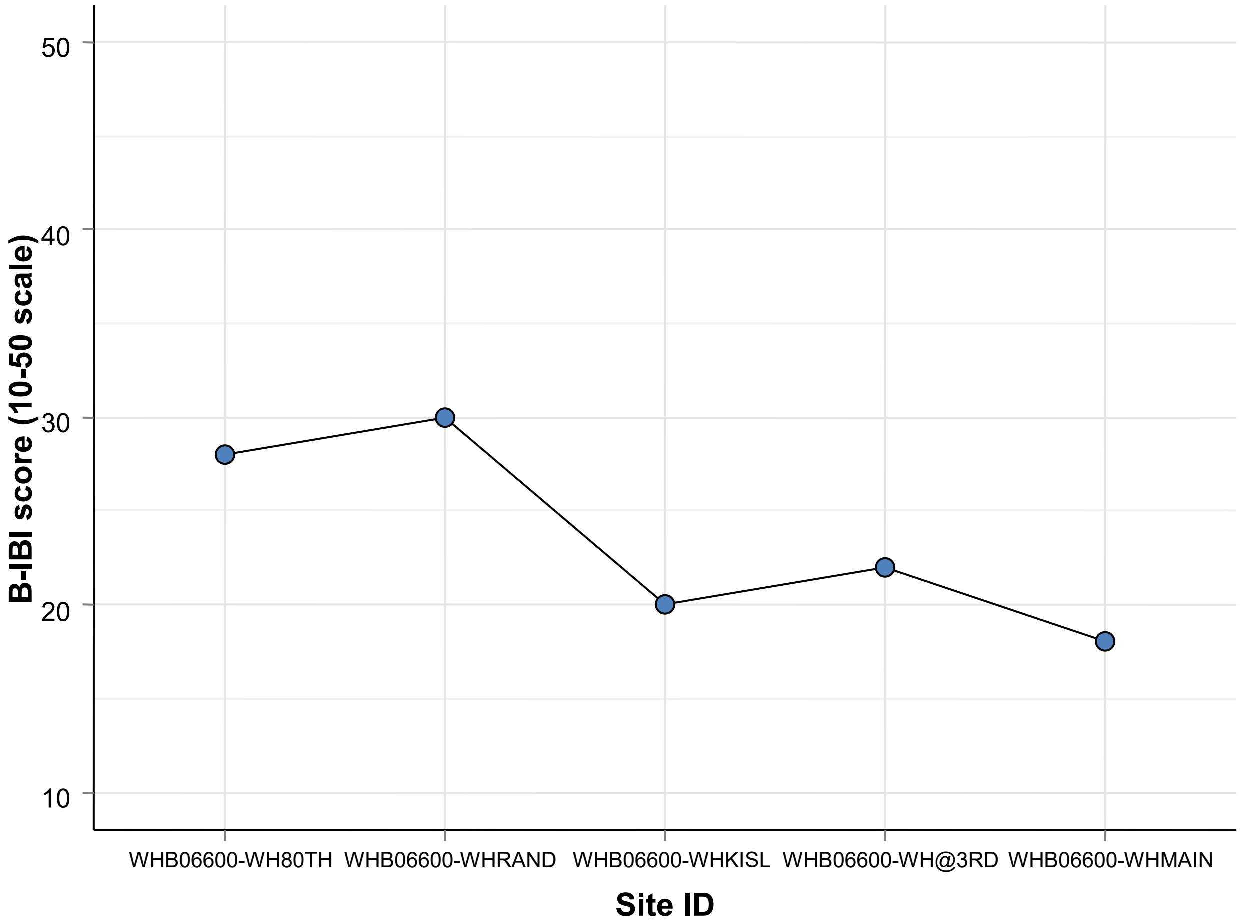

Figure B-5. B-IBI scores for Wide Hollow Creek sites.
Sites were sampled by Ecology in summer 2013.
On the x-axis, sites are arranged from upstream to downstream.

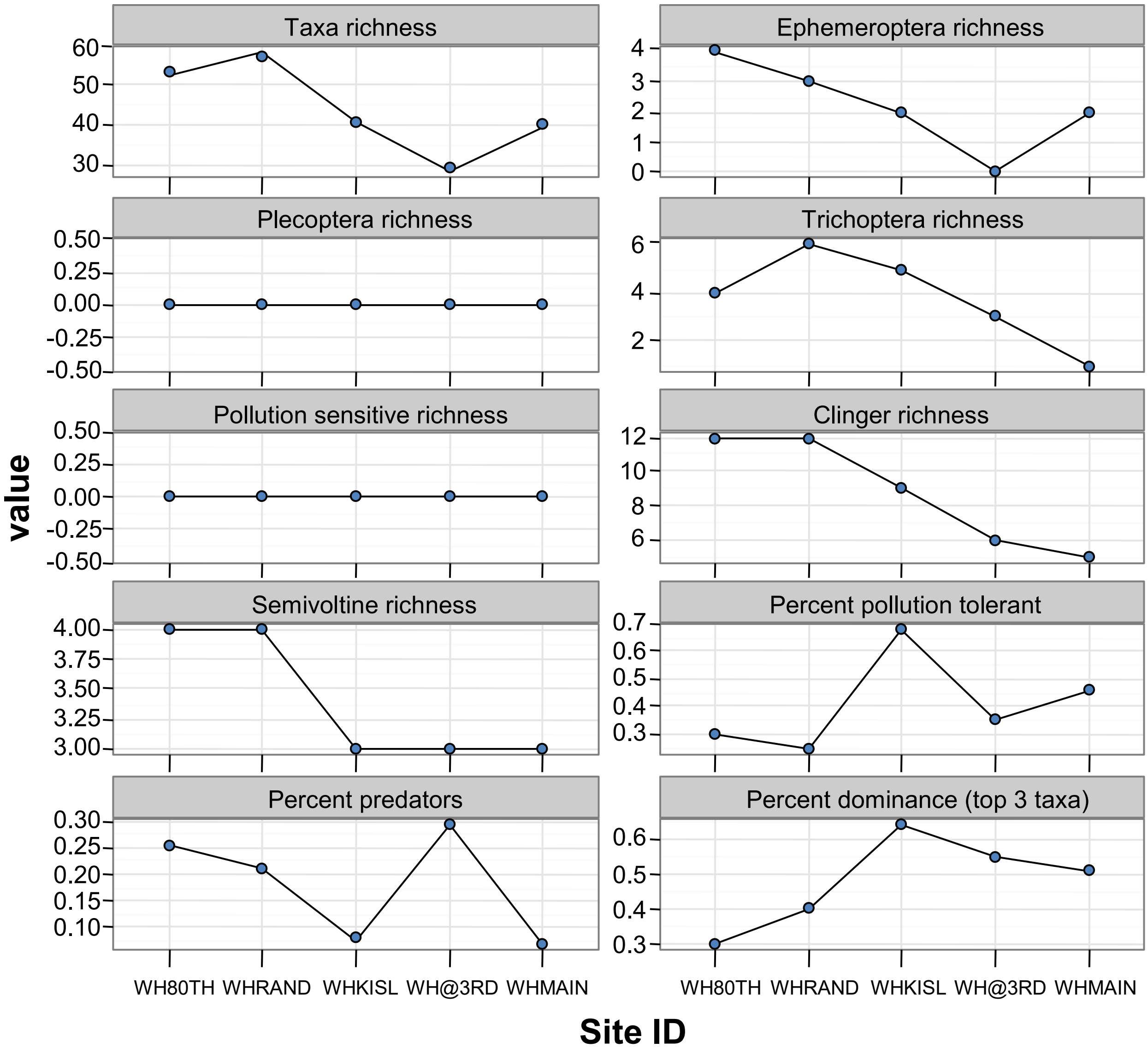

Figure B-6. Individual metrics that comprise B-IBI scores for Wide Hollow Creek sites.
Sites were sampled by Ecology in summer 2013.
On the x-axis, sites are arranged from upstream to downstream.

No downstream trend was observed among the other metrics in the B-IBI$_{10-50}$. The B-IBI$_{10-50}$ is heavily weighted towards the presence of insect species, primarily mayflies, stoneflies and caddisflies (EPT species); part of the reason for generally low B-IBI scores among Wide Hollow sites is likely due to the low proportion of EPT taxa among Wide Hollow sites (Figure B-7a) and the overall high proportion of non-insect species at the sampled sites (Figure B-7b). For all but the WHB06600-KISL site, the proportion of non-insect species counted in the collected samples was over 50% (Figure B-7b).

A total of 98 macroinvertebrate species were observed across the five Wide Hollow Sites. NMDS of Bray-Curtis similarities of only the Wide Hollow sites revealed no distinct groupings between sites (Figure B-8a). A cluster dendrogram of Bray-Curtis distances among cluster centroids (average linkage) indicated WHB06600-WHMAIN had the greatest dissimilarity in macroinvertebrate species composition to the other sites, with the highest similarity between WHB06600-WH80TH and WHB06600-WH@3RD and between WHB06600-WHKISL and WHB06600-WHRAND (Figure B-8b).

At the most upstream site WHB06600-WH80TH, the most abundant species was *Pisidium* (genus of freshwater snail), with *Lebertia* (genus of water mite), *Hyalella* (genus of amphipod crustacean), *Optioservus* (genus of riffle beetle), *Enchytraeus* (genus of oligochaete worm) and *Tricorythodes* (genus of alderfly) also abundant. At WHB06600-WHRAND, *Pisidium* was also the most abundant species, with *Radotanypus* (genus of chironomid), *Hyalella*, *Libertia*, and *Optioservus* also abundant.

At WHB06600-WHKISL, *Cheumatopsyche* (genus of caddisfly) was the most abundant species observed, with *Optioservus* and *Tricorythodes* (genus of mayfly) also abundant. At WHB06600-WH@3RD, *Pisidium* was the most abundant species observed, with *Optioservus*, *Lebertia*, and *Physa* (genus of snail) also abundant. At the most downstream site WHB06600-WHMAIN, Caecidotea (genus of isopod crustacean) was the most abundant species observed, with *Tubificinae* (subfamily of oligochaete worms), *Crangonyx* (genus of amphipod crustacean), *Gammarus* (genus of amphipod crustacean), *Physa* and *Ophidonais serpentina* (species of oligochaet worm) also abundant (Table B-5).

Due to considerable differences in sampling techniques and taxonomic resolution between this bioassessment and the previous bioassessment of Wide Hollow Creek (Kendra 1988), a detailed comparison of macroinvertebrate communities is not feasible. However, as in this bioassessment, the previous bioassessment also observed high numbers of non-insect taxa, including amphipods, oligochaetes, and snails.

a)

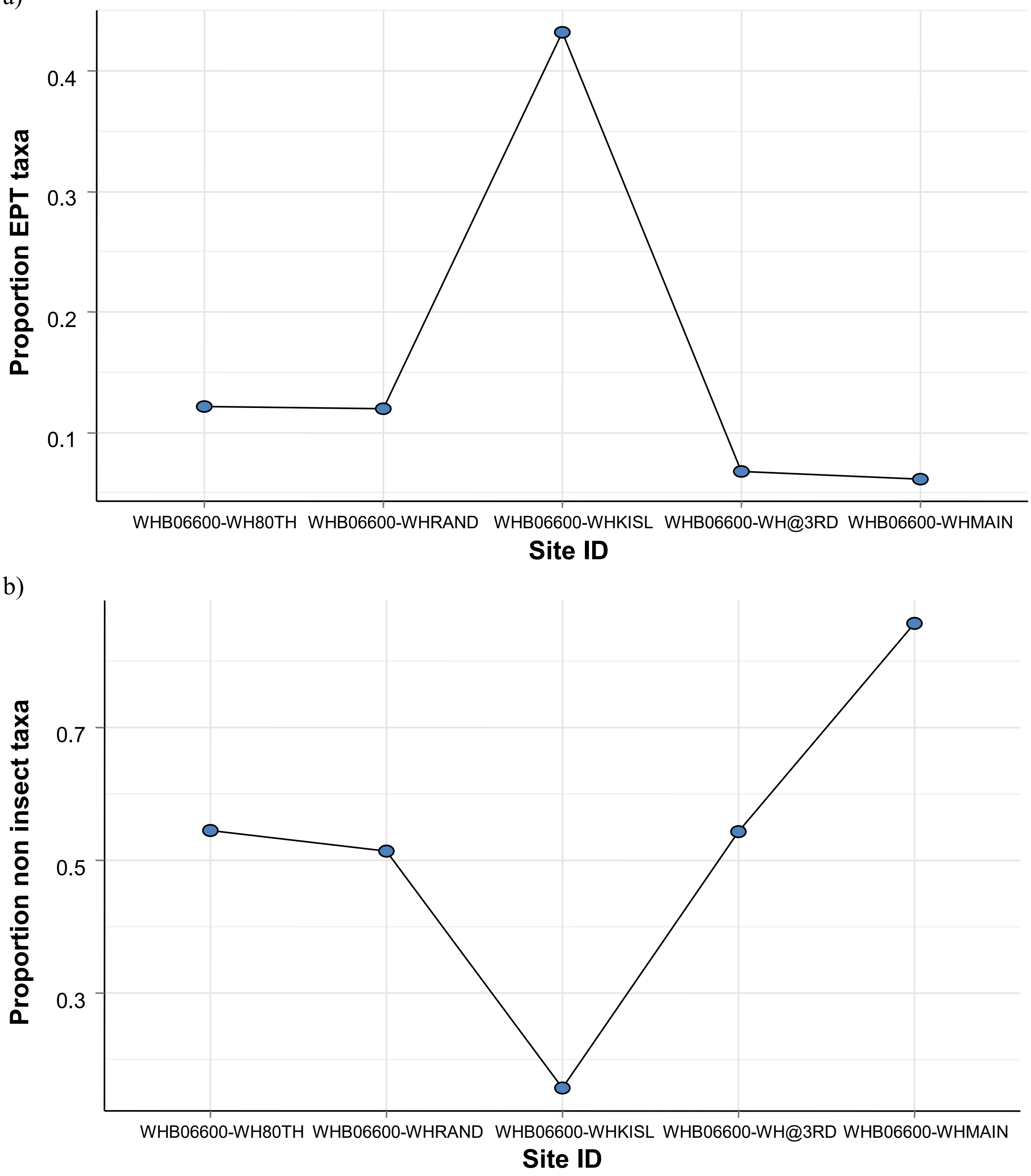

Figure B-7. Proportion of EPT taxa (mayflies, stoneflies, caddisflies) (a), and proportion of non-insect taxa (b) for Wide Hollow sites.
Sites were sampled by Ecology in summer 2013.
On the x-axis, sites are arranged from upstream to downstream.

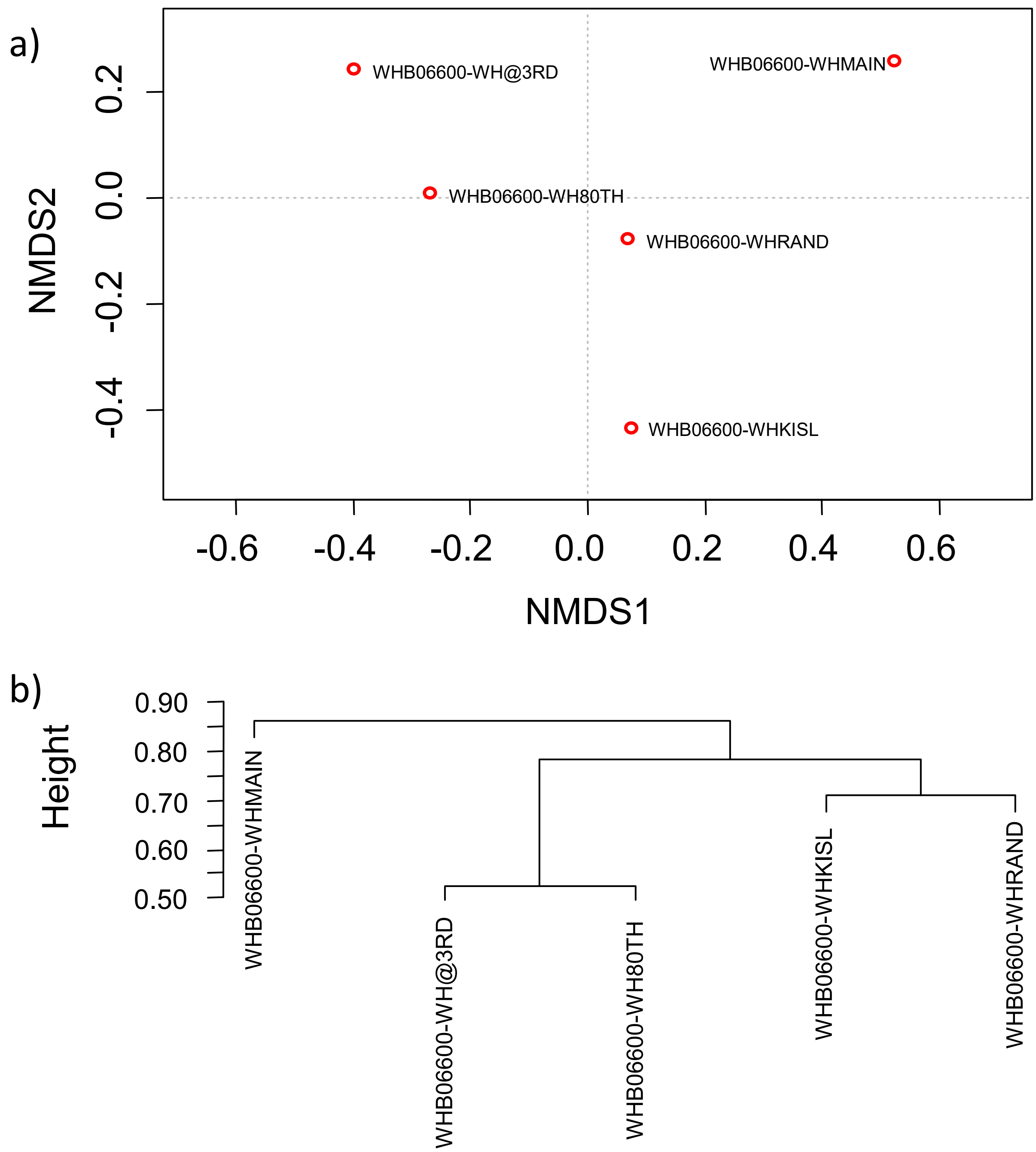

Figure B-8. NMDS ordination (a) and cluster analysis (b) of Bray-Curtis dissimilarities for macroinvertebrate community data from Wide Hollow Creek.
Sites were sampled by Ecology in summer 2013.
Cluster diagram illustrates results using average linkage method.

Table B-5. Observed densities (#/ft^2) and relative abundances (Rel. Abund.) of macroinvertebrate species from sites sampled at Wide Hollow Creek, with a minimum relative abundance across sites of at least 2% (0.02).

Empty cells indicate species that were not observed in collected sample.

	WHM06600-WH80TH		WHM06600-WHRAND		WHM06600-WHKISL		WHM06600-WH@3RD		WHM06600-WHMAIN	
	Density	Rel. Abund.	Density	Rel. Abund.	Density	Rel. Abund.	Density	Rel. Abund.	Density	Rel. Abund.
Caecidotea					1.20	0.0058			96.00	0.260
Cheumatopsyche	2.50	0.0460	4.60	0.0200	67.00	0.3100	0.62	0.0250		
Corixidae			4.60	0.0200						
Crangonyx	0.50	0.0092	1.20	0.0055					31.00	0.082
Cryptochironomus	0.50	0.0092	1.70	0.0073	3.80	0.0170	1.10	0.0450	0.75	0.002
Enchytraeus	3.00	0.0550			0.42	0.0019				
Gammarus									27.00	0.072
Gyraulus	0.75	0.0140	5.40	0.0240			0.50	0.0200		
Hyalella	4.00	0.0730	17.00	0.0730	1.70	0.0077	0.25	0.0099	3.00	0.008
Hydropsyche	1.60	0.0300	5.00	0.0220	7.90	0.0370	0.12	0.0050		
Hydroptila	1.50	0.0280	5.40	0.0240						
Hydroptilidae							0.75	0.0300	3.70	0.010
Hygrobates	0.25	0.0046	3.30	0.0150			0.75	0.0300	0.75	0.002
Lebertia	4.20	0.0780	17.00	0.0730	5.40	0.0250	2.00	0.0790	11.00	0.030
Menetus	1.80	0.0320	1.70	0.0073			0.12	0.0050		
Naididae	1.20	0.0230			0.83	0.0039	0.00	0.0000	19.00	0.050
Neoplasta							0.88	0.0350		
Ophidonais serpentina									20.00	0.054
Optioservus	3.50	0.0640	15.00	0.0680	57.00	0.2600	4.00	0.1600	0.75	0.002
Oxyethira									9.00	0.024
Parakiefferiella	0.88	0.0160	0.42	0.0018	7.90	0.0370				
Paratendipes	1.20	0.0230	7.90	0.0350	0.83	0.0039			2.20	0.006
Phaenopsectra	1.80	0.0320	4.20	0.0180	0.42	0.0019			3.00	0.008
Physa	0.38	0.0069	4.20	0.0180			1.50	0.0590	28.00	0.074
Pisidium	8.20	0.1500	58.00	0.2500	9.60	0.0440	7.50	0.3000	13.00	0.034
Radotanypus			18.00	0.0790			0.38	0.0150	2.20	0.006
Sialis	3.00	0.0550	1.70	0.0073	0.83	0.0039	0.12	0.0050	0.75	0.002
Sperchonopsis	1.00	0.0180	0.83	0.0037	0.83	0.0039	1.10	0.0450		
Thienemannimyia Group	2.00	0.0370	0.83	0.0037	0.83	0.0039	0.62	0.0250	0.75	0.002
Tricorythodes	0.38	0.0069	5.40	0.0240	12.00	0.0540			7.50	0.020
Tubificinae			1.20	0.0055	5.40	0.0250			64.00	0.170
Turbellaria	1.10	0.0210			3.30	0.0150			3.70	0.010

Periphyton Communities

NMDS of periphyton communities also revealed similarity between Wide Hollow sites relative to other sites sampled in the Columbia Plateau (Figure B-9). BIO-ENV determined the variables pH, dissolved oxygen (DO), relative bed stability (LRBS), total phosphorus (TP), and chloride (Cl^-) provided the best match between biotic and environmental patters (Pearson's correlation = 0.5853). Environmental vectors indicated a gradient in pH, DO, and substrate size (LRBS) positively associated with the second NMDS axis.

Across the five Wide Hollow Creek sites, 140 species of periphyton were observed. An NMDS of Bray-Curtis similarities of only the Wide Hollow sites revealed that WHB06600-WH@3RD and WHB06600-WHRAND had the highest similarity in periphyton species composition, yet were quite different from the other sampled sites (Figure B-10a,b). WHB06600-WHMAIN had the highest dissimilarity in periphyton community composition among the Wide Hollow sites (Figure B-10b).

Abundant species at the most upstream site (WHB06600-WH80TH) were the diatoms *Staurosira construens* var. *venter*, *Amphora pediculus*, *Nitzshia inconspicua*, and *Eolimna minima*, with two species of green algae, *Stigeoclonium* and *Oedgonium* also abundant. At WHB06600-WHRAND, a species of cyanobacterium from the genus *Phomidium* was most abundant, with the diatoms *Cocconeis placentula*, *Diatoma moniliformis* and *Encyonema silesiacum* also abundant.

At WHB06600-WHKISL, two species of cyanobacteria, *Geitlerinema* and *Scytonema* were abundant, with the diatom *Achnanthidium minutissimum* also abundant. At WHB06600-WH@3RD, *Phormidium* was the most abundant, with *Cocconeis placentula* var. *lineata* also abundant. At the most downstream site WHB06600-WHMAIN, *Oedogonium* was most abundant, with the diatoms *Cocconeis placentula*, *Cocconeis placentula* var. *lineata*, *Staurosira construens* var. *venter* and *Melosira varians* also abundant (Table B-6).

Across the Wide Hollow Creek sites, highest cell density was observed at the furthest downstream and upstream sites, WHB06600-WHMAIN and WHB06600-WH80TH respectively, with all other sites with intermediate cell densities (Figure B-11). Examining composition of the various observed algal groups revealed that across all Wide Hollow Creek sites, diatoms were the most abundant.

Cyanobacteria were observed at all but WHB06600-WHMAIN, with highest relative abundance of cyanobacteria observed at WHB06600-WHKISL. Green algae were only observed at two sites, WHB06600-WH80TH and WHB06600-WHMAIN.

No trend from upstream to downstream was observed with ash-free dry biomass (AFDM), although the highest biomass was observed at WHB06600-WH@3RD (Figure B-12). Similarly, no general trend from upstream to downstream was observed for taxa richness, although lowest richness was observed at WHB06600-WHMAIN (Figure B-12). A general trend of decreasing evenness (Pielou's evenness) was observed from upstream to downstream (Figure B-12), indicating that composition was increasingly dominated by fewer, yet abundant species.

Various diatom metrics were examined for trends across the Wide Hollow Sites (Figure B-13). A trend of decreasing percent motile and siltation taxa was observed from upstream to downstream. These metrics typically increase with the percent sands/fines and WHB06600-WHMAIN had the highest percent sands/fines of all the Wide Hollow sites. A potential explanation for low abundance of motile and siltation taxa observed at WHB06600-WHMAIN may have been a result of the method of sampling employed at this site; because of a very high abundance of macrophytes, protocol necessitated the sampling of periphyton communities associated with macrophytes (Adams 2010).

Other notable trends across the Wide Hollow sites was an increase in the percent of eutraphentic taxa (i.e. taxa associated with environments with a rich supply of nutrients) and a higher diatom pollution index score at WHB06600-WHMAIN. A trend of decreasing percent metal tolerant taxa at the downstream sites was also observed. Interestingly, the highest percent of taxa classified as tolerant to brackish conditions (i.e. percent mountains brackish taxa) was found at WHB06600-WHMAIN, the site with the highest observed chloride concentrations.

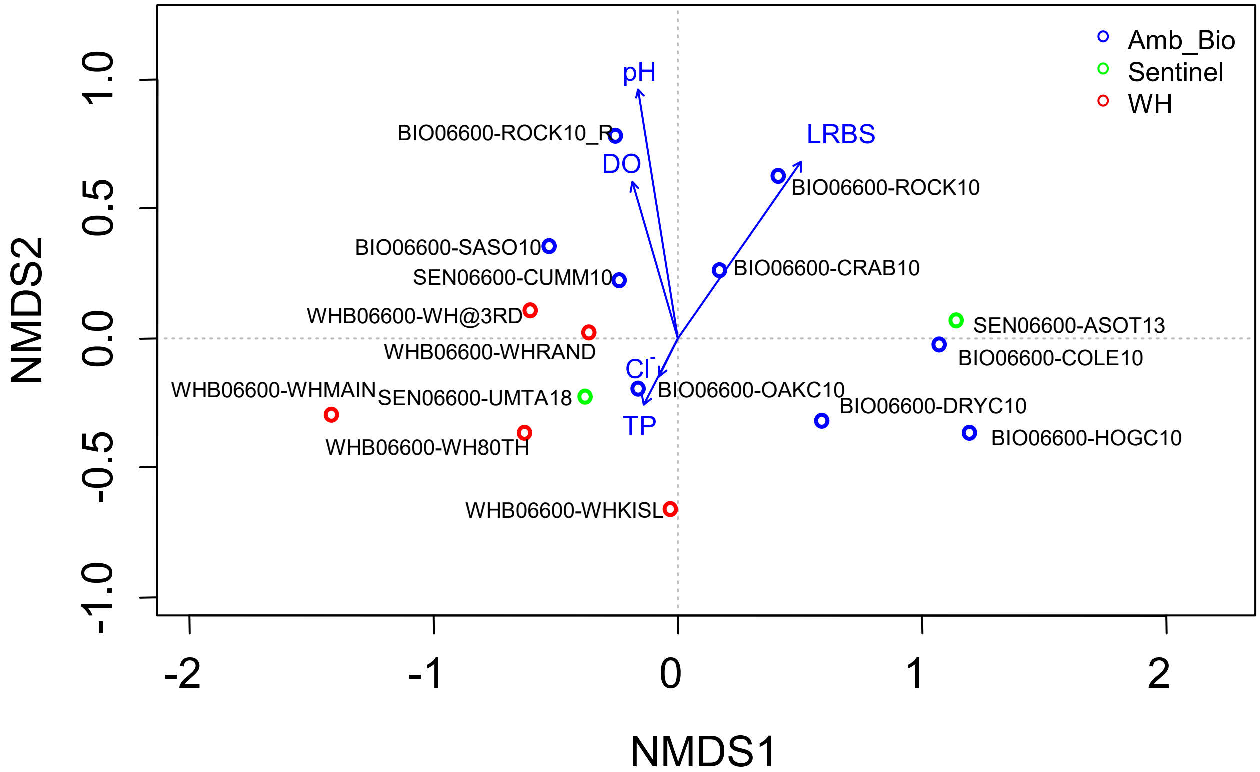

Figure B-9. NMDS ordination of Bray-Curtis dissimilarities for periphyton community data from Wide Hollow Creek relative to other sites in the Columbia Plateau Ecoregion.
Sites were sampled by Ecology in summer 2013.
Environmental vectors displayed were determined by BIO-ENV procedure, which determines the combination of environmental variables giving the highest correlation with the grouping in NMDS.

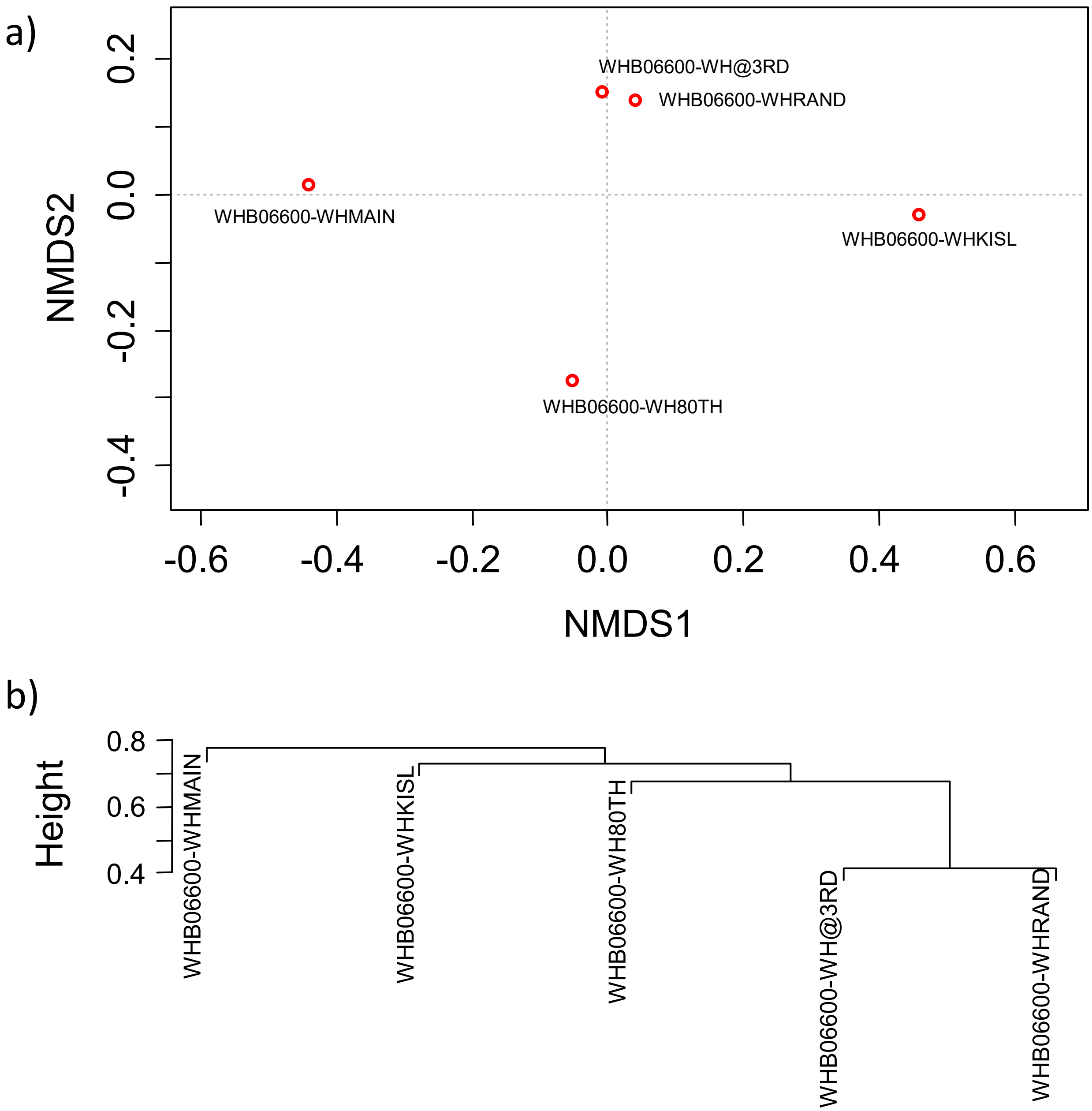

Figure B-10. NMDS ordination (a) and cluster analysis (b) of Bray-Curtis dissimilarities for periphyton community data from Wide Hollow Creek sites.
Sites were sampled by Ecology in summer 2013.
Cluster diagram illustrates results using average linkage method.

Table B-6. Densities (#/cm^2) and relative abundance for periphyton species from sites Wide Hollow sites with a relative abundance across samples of at least 2% (0.02). *Empty cells indicate species that were not observed in collected sample.*

	WH80TH		WHRAND		WHKISL		WH@3RD		WHMAIN	
	Density	Rel. Abun	Density	Rel. Abund	Density	Rel. Abund.	Density	Rel. Abund	Density	Rel. Abund.
Achnanthidium	12888.38	0.0261	9119.78	0.0264	16982.26	0.06380	5171.74	0.0119		
Amphora pediculus	52231.84	0.1057	7599.82	0.0220	8783.93	0.03300	5171.74	0.0119	1927.65	0.0033
Cocconeis placentula	2713.34	0.0055	35465.83	0.1027	2537.58	0.00953	21204.15	0.0487	127224.66	0.2156
Cocconeis placentula v	7461.69	0.0151	15706.30	0.0455	2732.78	0.01027	38270.91	0.0880	57186.84	0.0969
Diatoma moniliformis	4748.35	0.0096	22799.46	0.0660	1756.79	0.00660	18618.28	0.0428	1927.65	0.0033
Diatoma vulgaris									12850.98	0.0218
Encyonema silesiacum	8140.03	0.0165	20266.19	0.0587	2147.18	0.00807	6206.09	0.0143	2570.20	0.0044
Eolimna minima	36630.12	0.0741	2533.27	0.0073	1756.79	0.00660	8791.97	0.0202	1285.10	0.0022
Geissleria acceptata	15601.72	0.0316	1519.96	0.0044			1034.35	0.0024	3855.29	0.0065
Geitlerinema					80741.16	0.30333				
Melosira varians			5573.20	0.0161	2927.98	0.01100	16549.58	0.0380	55901.75	0.0947
Navicula capitatoradiata	2713.34	0.0055	13679.68	0.0396	3513.57	0.01320	9826.31	0.0226	5140.39	0.0087
Navicula cryptotenelloides	16280.05	0.0329	11146.40	0.0323	1561.59	0.00587	2068.70	0.0048	3855.29	0.0065
Navicula lanceolata			6586.51	0.0191	195.20	0.00073	13446.54	0.0309	642.55	0.0011
Nitzschia amphibia	8140.03	0.0165	11653.06	0.0337	5075.16	0.01907	4137.40	0.0095	3855.29	0.0065
Nitzschia dissipata	18993.40	0.0384	12159.71	0.0352	8393.53	0.03153	14480.88	0.0333	1285.10	0.0022
Nitzschia inconspicua	40021.80	0.0810	10133.09	0.0293	10150.32	0.03813	9826.31	0.0226		
Oedogonium	28012.24	0.0567							204566.55	0.3467
Phormidium	1647.78	0.0033	41453.56	0.1200	4436.33	0.01667	124701.88	0.2867		
Planothidium lanceolatum	8818.36	0.0178	13679.68	0.0396	1171.19	0.00440	7757.62	0.0178	1927.65	0.0033
Rhoicosphenia abbreviata	22385.07	0.0453	10133.09	0.0293	10150.32	0.03813	7757.62	0.0178	1927.65	0.0033
Scytonema					63883.11	0.24000				
Staurosira construens v			7599.82	0.0220			2068.70	0.0048		
Staurosira construens v	67155.22	0.1358	11653.06	0.0337	4684.76	0.01760	20169.80	0.0464	53974.10	0.0915
Stigeoclonium	36251.13	0.0733								
Unknown Bluegreen	13182.23	0.0267								

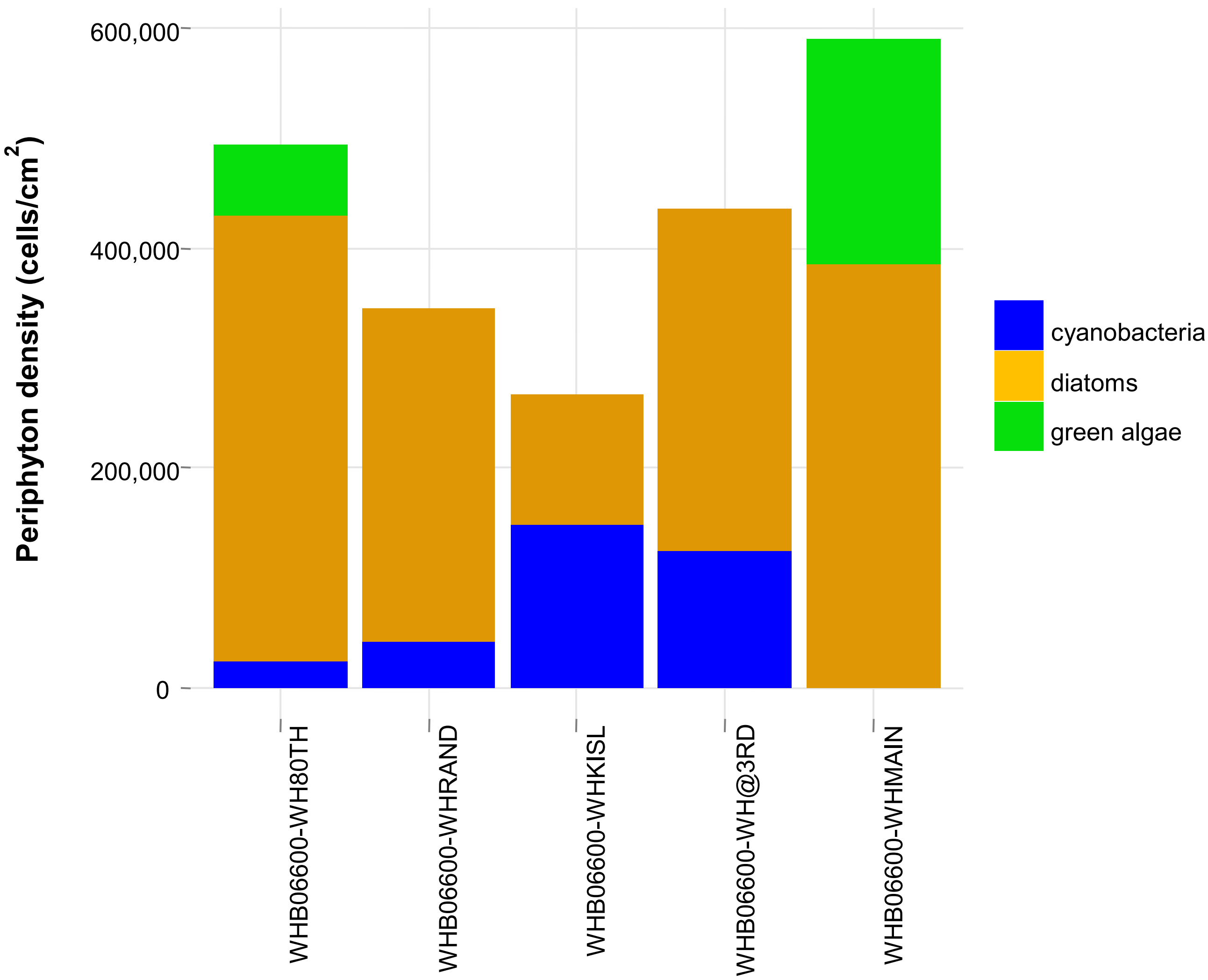

Figure B-11. Periphyton density and the relative abundance of algal groups for data from Wide Hollow Creek sites.
Sites are arranged from upstream to downstream on the x-axis.

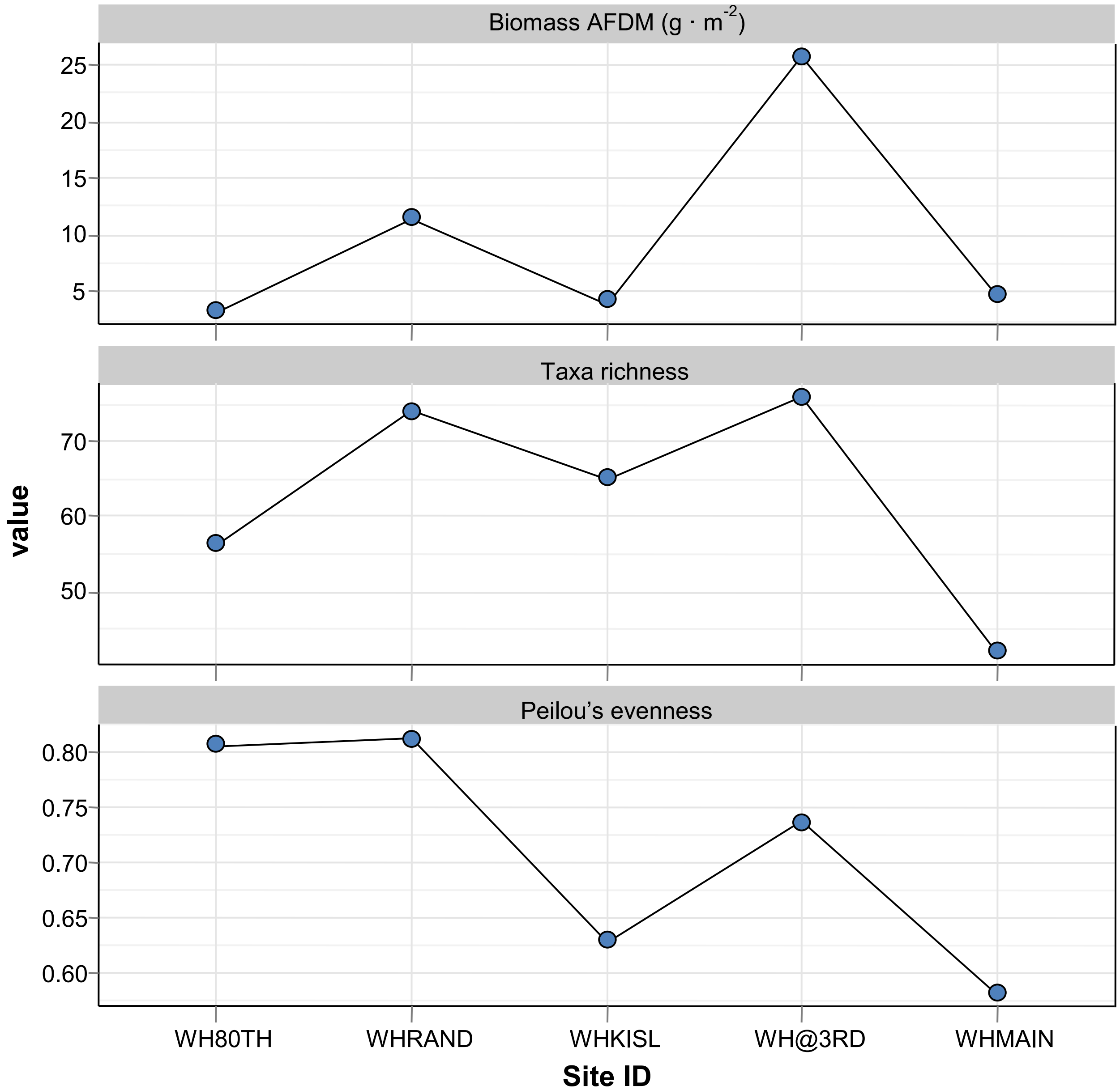

Figure B-12. Various measures related to the periphyton community data from Wide Hollow Creek sites.
Sites are arranged from upstream to downstream on the x-axis.

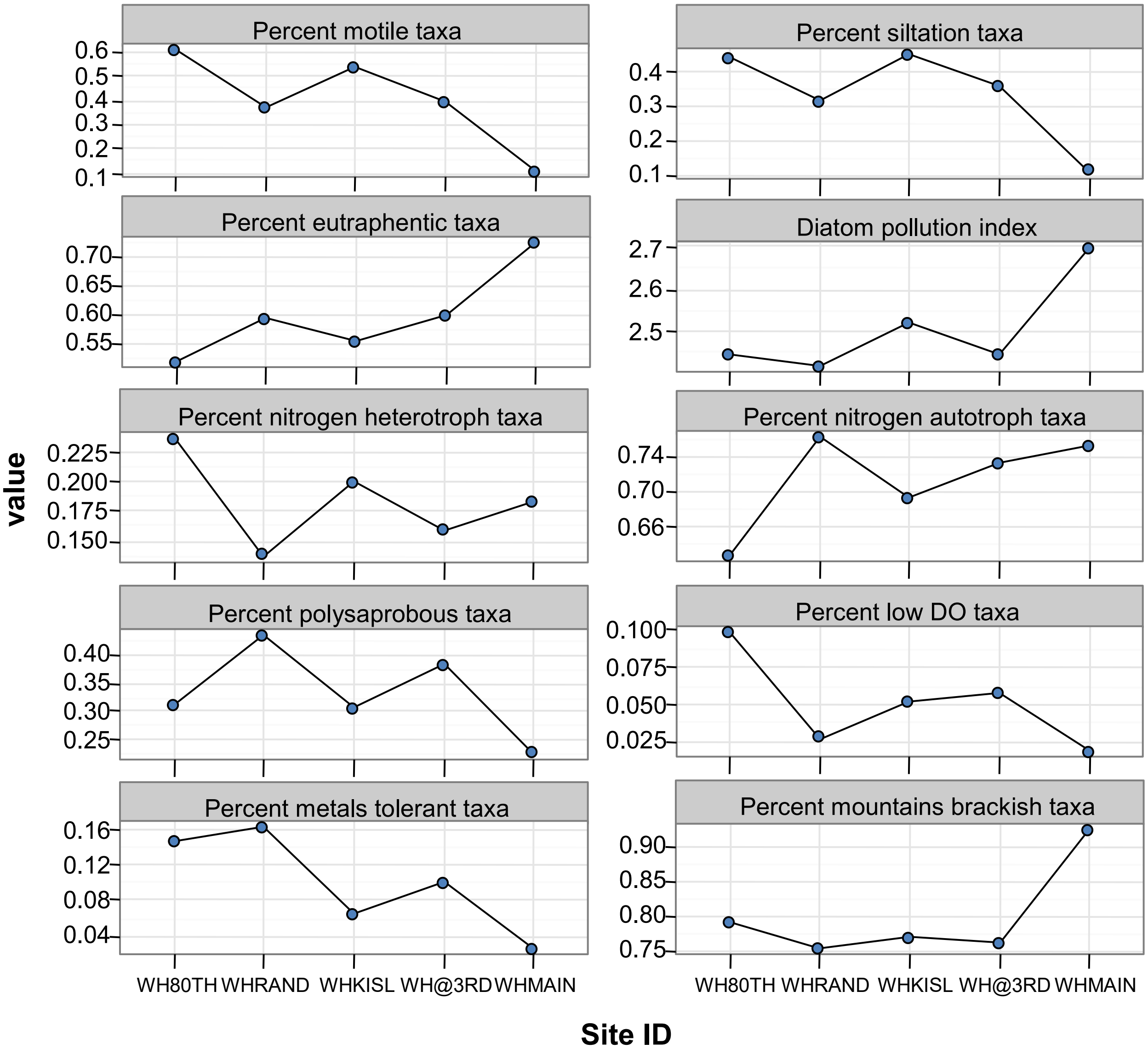

Figure B-13. Various diatom metrics from Wide Hollow Creek sites.
Sites are arranged from upstream to downstream on the x-axis.

Electrofishing Survey

Electrofishing of Wide Hollow Creek sites occurred at separate times than the sampling of habitat, water chemistry, macroinvertebrates and periphyton due in part to water temperatures being elevated over allowable safety limits for fish (Table B-7). Electrofishing was also carried out over two sampling periods for all sites except at WHB06600-WHKISL. Across all Wide Hollow Creek sites, 13 species of fish were captured. The most abundant species encountered were Speckled Dace and Redside Shiner, which were captured at all sites. Similar to the present results, dace and shiners were the most abundant species captured in the 1987 bioassessment (Kendra 1988). However, only one rainbow trout was captured during that bioassessment (near 3rd Avenue), while several species of salmonids were observed across most of the Wide Hollow sites sampled in this bioassessment.

Table B-7. Results from electrofishing surveys of Wide Hollow Creek (summer and fall 2013). *Empty cells indicate species that were not observed in collected sample.*

Site.ID	80TH	80T	RAND	RAND	KSIL	3RD	3RD	MAIN	MAIN
	8/27	11/7	8/28	11/7	11/7	8/28	11/6	8/27	11/6
Bluegill									1
Bridgelip Sucker		31	7	6	7		2		22
Chinook Salmon		1		1					5
Chiselmouth				1	2				5
Largescale Sucker	1	6			3			8	6
Longnose Dace		1						6	3
Mountain Whitefish	1								
Pikeminnow		1	1		1		1	3	6
Rainbow Trout					9	1	2		8
Redside Shiner	14	229	81	115	47	1	19	8	57
Speckled Dace	183	2583	172	252	109	20	26	10	
Three-Spine Stickleback								28	42
Torrent Sculpin								1	
Total Fish	199	2852	261	375	178	22	50	64	155
# species	4	7	4	5	7	3	5	7	10
Shocking time	574	670	433	491	2016	513	560	778	709
Distance	150	150	150	150	150	150	150	180	180
Catch/sec	0.347	4.257	0.603	0.764	0.088	0.043	0.089	0.082	0.219
Fish/m	1.327	19.01	1.740	2.500	1.187	0.147	0.333	0.356	0.861

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Appendix C. Water Quality Study Data Summary

Data qualifiers used in Appendix C

- J - The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
- U - The analyte was not detected. The value preceding the "U" represents the sample quantitation limit.
- UJ - The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately measure the analyte in the sample.
- EST - Field measurement is considered an estimate.

Abbreviations used in Appendix C

- Alk – Alkalinity
- cfs – cubic feet per second
- Cl – Chloride
- deg C – degrees Celsius
- DO (LDO) – Luminescent dissolved oxygen
- DO (Winkler) – Winkler dissolved oxygen
- DOC – Dissolved organic carbon
- DOC – Dissolved organic carbon
- Hard – Hardness
- mg/l – milligrams per liter
- NH4 – Ammonia
- NO2-NO3 – Nitrate-nitrite
- NTU – Nephelometric Turbidity Unit
- OP – Organic phosphorous
- s.u. – standard units
- Sp. Cond - Specific conductivity
- Temp – Water Temperature
- TNVSS – Total non-volatile suspended solids
- TOC – Total organic carbon
- TP – Total phosphorous
- TPN – Total persulfate nitrogen
- TSS – Total suspended solids
- Turb – Turbidity
- uS/cm – micro Siemens per centimeter

Laboratory Data

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-FW-0B	7/9/2013 17:21	1307040-26	113	0.014	11.7	1.4		1.67	0.0924	5	1.8	1.76	0.0976	7	2.6
37-FW-0B	8/7/2013 16:36	1308028-26	115	0.014	12.6	1.4	124	1.9	0.101	5	1.5	2.07	0.104	7	2.8
37-FW-0B	9/11/2013 16:19	1309026-26	101	0.013	10.1	1.3	106	1.59	0.0834	18	2	1.68	0.113	22	14
37-FW-0B	10/9/2013 15:55	1310017-26	113	0.01 U	12.8	1.2	115	1.57	0.0805	6	1.2	1.59	0.0816	7	3.3
37-FW-0B	11/13/2013 10:30	1311009-26	128	0.024	17	1 U		2.97	0.103	14	1.2	2.99	0.109	17	6.1
37-FW-0B	12/10/2013 14:15	1312009-26	123	0.033	18.9	1 U		3.02	0.105	18	1.1	3.09	0.114	22	7.1
37-FW-0B	3/5/2014 15:48	1403011-26	129	0.015	21.8	1.1		2.65	0.0965	8	1.2	2.76	0.102	12	3.4
37-FW-0B	3/26/2014 15:03	1403001-26	116	0.016	16.6	1.4		2.1	0.0966	6	1.5	2.14	0.104	9	2.8
37-FW-0B	4/30/2014 15:11	1404001-26	91.9 J	0.011 J	10.2 J	1.4 J		1.34 J	0.059 J	16 J	1.5 J	1.31 J	0.0874 J	22 J	7.5 J
37-FW-0B	4/30/2014 15:20	1404001-45	92.2 J	0.013 J	10.2 J	1.4 J		1.34 J	0.0589 J	15 J	1.5 J	1.4 J	0.0866 J	19 J	7.7 J
37-FW-0B	6/4/2014 14:55	1406001-26	90.8	0.015	10.1	1.4		1.38	0.0745	5	1.5	1.52	0.0827	7	3.4
37-FW-13	3/4/2014 8:40	1403011-01	166	0.018	15.2	2.6		0.704	0.0413	1 U	2.7	0.857	0.0452	1 U	0.5 U
37-FW-1B	7/9/2013 16:00	1307040-23	115	0.013	8.95	1.9 J		1.37	0.0943	3	1.9	1.52	0.0953	5	1.8
37-FW-1B	7/9/2013 16:15	1307040-45	114	0.012	8.83	1.4		1.38	0.0931	3	1.9	1.51	0.0912	5	2
37-FW-1B	8/7/2013 14:02	1308028-23	118	0.01	9.11	1.4	118	1.55	0.108	6	1.6	1.59	0.111	7	2.7
37-FW-1B	8/7/2013 14:22	1308028-45	118	0.01 U	9.03	1.4	122	1.57	0.107	5	1.6	1.6	0.109	8	2.9
37-FW-1B	9/11/2013 14:50	1309026-45	97.8	0.012	7.11	1.4		1.23	0.0854	19	2	1.3	0.118	23	19
37-FW-1B	9/11/2013 15:00	1309026-23	97.8	0.011	6.98	1.3		1.19	0.0844	21	2.1	1.26	0.12	25	20
37-FW-1B	10/9/2013 14:00	1310017-23	115	0.01 U	8.95	1.3	109	0.884	0.0815	3	1.4	0.938	0.0802	5	2.9
37-FW-1B	10/9/2013 14:19	1310017-45	116	0.01 U	8.94	1.3	112	1.57	0.08	3	1.4	1.61	0.0805	4	2.8
37-FW-1B	11/13/2013 12:30	1311009-23	188	0.019	16.9	1.3	182	3.44	0.163	2	1.4	4.3	0.151	3	1.5
37-FW-1B	11/13/2013 12:52	1311009-45	189	0.017	16.9	1.4	183	3.33	0.16	2		3.95	0.154	3	1.4
37-FW-1B	12/11/2013 13:20	1312009-23	178	0.022	17.9	1.2		3.26	0.164	5	1.3	3.38	0.158	6	3
37-FW-1B	12/11/2013 13:32	1312009-44	179	0.023	17.9	1.2		3.32	0.162	5	1.3	3.4	0.16	7	3.2
37-FW-1B	3/5/2014 14:10	1403011-23	222	0.016	32.6	1.5		3.3	0.166	3 J	1.8	3.1	0.168	5 J	1.3
37-FW-1B	3/5/2014 14:26	1403011-45	223	0.014	32.8	1.5 J		2.79	0.166	3	1.7	3.12	0.169	4	1.3
37-FW-1B	3/26/2014 12:46	1403001-23	123	0.01	10	1.8		1.26	0.106	5	2.1	1.31	0.114	6	2.6
37-FW-1B	3/26/2014 12:46	1403001-45	124	0.01 U	10	1.8		1.27	0.106	4	2.1	1.34	0.112	6	2.9
37-FW-1B	4/30/2014 13:30	1404001-23	82.9	0.012	5.44	1.5		0.729	0.0479	22	1.6	0.804	0.0825 J	27	11
37-FW-1B	4/30/2014 13:38	1404001-44	83	0.01 UJ	5.4	1.5		0.728 J	0.0488	19	1.6 J	0.797 J	0.0804	25	10
37-FW-1B	6/4/2014 12:30	1406001-23	82.7	0.012	5.96	1.5		0.95	0.0679	11	1.7	1.05	0.0788	15	5.4
37-FW-1B	6/4/2014 12:40	1406001-45	82.3	0.013	5.96	1.5		0.952	0.0682	16	1.6	1.07	0.0868	19	7

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-FW-1C	7/9/2013 15:00	1307040-22	115	0.012	8.5	1.6		1.32	0.0924	3	1.8	1.42	0.0927	5	3.1
37-FW-1C	8/7/2013 12:41	1308028-22	119	0.01 U	8.68	1.4		1.49	0.103	5	1.7	1.59	0.107	7	3
37-FW-1C	9/11/2013 13:55	1309026-22	96.4	0.012	6.5	1.4		1.12	0.0837	23	2.3	1.27	0.125	28	23
37-FW-1C	10/9/2013 12:39	1310017-22	118	0.01 U	8.6	1.3		1.53	0.0792	3	1.4	1.54	0.0802	4	3.4
37-FW-1C	11/13/2013 11:42	1311009-22	264	0.02	21	1.9		4.03	0.198	7	1.8	3.8	0.189	9	4.3
37-FW-1C	12/11/2013 12:07	1312009-22	267	0.025	22.4	1.6		4.1	0.213	16	1.8	5.96	0.214	20	7.8
37-FW-1C	3/5/2014 13:05	1403011-22	264	0.011	39	1.7		3.37	0.185	3	1.9	3.53	0.186	5	1.4
37-FW-1C	3/5/2014 13:20	1403011-44	267	0.015	39	1.7		3.45	0.187	4	1.9	3.56	0.182	6	2.1
37-FW-1C	3/26/2014 11:04	1403001-22	123	0.011	9.26	1.8		1.2	0.103	3	2	1.3	0.111	5	2.5
37-FW-1C	4/30/2014 12:02	1404001-22	80.2	0.021	5.01	1.5		0.686	0.0485	74	1.6	0.773	0.107	88	22
37-FW-1C	6/4/2014 11:55	1406001-22	83	0.013	5.76	1.5		0.961	0.0684	11	1.5	1.07	0.0846	15	6.4
37-FW-2	7/9/2013 16:50	1307040-25	80.3	0.024	17.5	2 J		2.16	0.0615	9	1.8 J	2.26	0.0732	11	4.3
37-FW-2	8/7/2013 16:30	1308028-25	84.3	0.021	17.6	1.3		2.36	0.0621	7	1.5	2.57	0.0658	9	1.6
37-FW-2	9/11/2013 14:15	1309026-25	86.2	0.022	16.9	1.2		2.34	0.0599	8	1.3	2.46	0.0747	10	6.1
37-FW-2	10/9/2013 11:30	1310017-25	89.3	0.016	18.9	1		2.76	0.0619	4	1.2	2.75	0.0597	5	1.8
37-FW-2	11/13/2013 11:25	1311009-25	88.4	0.021	18	1 U		3.06	0.0739	11	1.1	2.97	0.073	13	2.5
37-FW-2	12/10/2013 14:50	1312009-25	88.8	0.033	20.1	1 U		3.13	0.0761	16	1 U	3.62	0.0877	19	5
37-FW-2	3/5/2014 14:00	1403011-25	85.9	0.014	21	1		2.68	0.0755	10	1.1	2.66	0.0899	13	3.4
37-FW-2	3/26/2014 14:45	1403001-25	87.9	0.014	22	1.1		2.75	0.0766	12 J	1.2	2.85	0.0892	15 J	3.2
37-FW-2	4/30/2014 14:45	1404001-25	81.8	0.017	18.2	1.2		2.28	0.0557	27	1.4	2.37	0.0986	35	7.8
37-FW-2	6/4/2014 14:30	1406001-25	78.2	0.014	17.5	1.2		2.1	0.055	10	1.4	2.22	0.0775	14	5.5
37-FW-2B	7/9/2013 16:50	1307040-24	131	0.028	22.4	1.5 J		4.06	0.111	1 U	1.3	4.01	0.0996	1	0.6
37-FW-2B	8/7/2013 16:00	1308028-24	139	0.019	21.5	1.1		3.82	0.121	1 U	1.2	4.04	0.111	1 U	0.5 U
37-FW-2B	9/11/2013 15:32	1309026-24	140	0.019	22.3	1 U	162	3.84	0.111	1 U	1.1	3.97	0.113	1 U	0.5 U
37-FW-2B	10/9/2013 15:05	1310017-24	138	0.016	22.1	1 U		3.84	0.116	1 U	1	4.03	0.105	1 U	0.5 U
37-FW-2B	11/13/2013 12:25	1311009-24	136	0.014	20.8	1		3.94	0.126	1 U	1 U	5.7	0.113	1	0.5 U
37-FW-2B	12/10/2013 15:10	1312009-24	133	0.013	21.2	1 U		3.75	0.133	1 U	1 U	3.9	0.118	1 U	0.5 U
37-FW-2B	3/5/2014 15:09	1403011-24	130	0.013	21.4	1 U		3.62	0.107	1 U	1.1	3.72	0.0995	1	0.5 U
37-FW-2B	3/26/2014 14:10	1403001-24	190	0.059	21.1	1 U		3.75	0.105	1 U	1 U	3.71	0.0983	1	0.5 U
37-FW-2B	4/30/2014 14:15	1404001-24	125	0.01 U	19	1 U		4.02	0.0988	1 U	1 U	3.85	0.0906	1	0.5 U
37-FW-2B	6/4/2014 14:32	1406001-24	133	0.022	21.2	7.4		3.64	0.137	1 U	6.5	3.75	0.15	1 U	0.5 U
37-FW-3B	7/9/2013 13:08	1307040-21	103	0.01 U	7.09	2 J		1.07	0.0801	6	1.7	1.13	0.0854	8	3.1
37-FW-3B	8/7/2013 12:18	1308028-21	105	0.01 U	7.23	1.4		1.2	0.0907	6	1.5	1.27	0.0955	8	3.2
37-FW-3B	9/11/2013 11:34	1309026-21	85.4	0.011	5.31	1.3		0.858	0.072	23	2.1	0.928	0.115	29	25
37-FW-3B	10/9/2013 10:36	1310017-21	101	0.01 U	6.81	1.3		1.1	0.0618	3	1.4	1.16	0.0626	4	3.5

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-FW-3B	11/13/2013 10:15	1311009-21	278	0.017	20.9	1.9		3.64	0.19	1 U	2	3.67	0.176	1	0.6
37-FW-3B	11/13/2013 10:18	1311009-44	278	0.012	20.8	1.8		3.57	0.19	1 U		3.54	0.178	1	0.6
37-FW-3B	12/11/2013 11:04	1312009-21	279	0.019	22.5	1.7		4.04	0.209	5	1.9	4.81	0.197	7	3.5
37-FW-3B	3/5/2014 11:34	1403011-21	267	0.013	42.4	1.8		3.12	0.17	2	2	3.31	0.163	3	1.2
37-FW-3B	3/26/2014 9:33	1403001-21	108	0.01 U	7.58	1.8		0.939	0.0899	5	1.9	1.02	0.0993	6	3.2
37-FW-3B	3/26/2014 9:38	1403001-44	108	0.01 U	7.57	1.8		0.944	0.0892	4	1.9	1.03	0.0984	6	3.2
37-FW-3B	4/30/2014 10:15	1404001-21	70.2 J	0.011 J	3.9 J	1.4 J		0.479 J	0.0422 J	8	1.6 J	0.548 J	0.0582 J	10	4.4 J
37-FW-3B	6/4/2014 10:09	1406001-21	69.6	0.034	4.22	1.5		0.701	0.0608	9	1.5	0.828	0.0712	12	4.8
37-FW-4	7/9/2013 10:23	1307040-16	86.8	0.01 U	5.56	1.3		0.818	0.0699	6	1.6 J	0.881	0.0775	8	3.1
37-FW-4	8/7/2013 10:04	1308028-16	91.9	0.01 U	5.95	1.4		0.907	0.0852	10	1.7	1.01	0.097	13	5.3
37-FW-4	9/11/2013 8:45	1309026-16	68.8	0.01 U	3.99	1.3		0.585	0.0627	38	2.2	0.656	0.114	45	33
37-FW-4	9/11/2013 9:00	1309026-44	69	0.012	4.01	1.4		0.581	0.0626	36	2.5	0.656	0.114	42	32
37-FW-4	10/9/2013 8:27	1310017-16	88.8	0.01 U	5.71	1.2		1.97	0.0466	4	1.4	2.03	0.0527	6	4.5
37-FW-4	11/13/2013 9:15	1311009-16	284	0.01 U	22.1	1.7		3.57	0.173	1 U	1.9	3.57	0.159	1 U	0.5 U
37-FW-4	12/11/2013 9:11	1312009-16	293	0.026	24.1	1.7		4.24	0.188	1 U	1.9	4.28	0.171	1 U	0.6
37-FW-4	3/5/2014 10:00	1403011-16	288	0.011	33.2	2.1		3.36	0.219	1 U	2.2	3.57	0.214	1	1.3
37-FW-4	3/26/2014 8:39	1403001-16	98.9	0.01 U	6.8	1.7		0.849	0.0842	3	1.8	0.921	0.0898	4	3.1
37-FW-4	4/29/2014 15:55	1404001-16	62.9	0.01 U	3.6	1.5		0.327	0.0375	8	1.6	0.384	0.0511	10	5.2
37-FW-4	6/3/2014 15:37	1406001-16	61.7	0.019	3.7	1.5		0.508	0.0644	12 J	1.5	0.634	0.0811	15	7.1
37-FW-5B	7/9/2013 9:08	1307040-15		0.011	5.21	2 J		0.784	0.0687	7	1.7 J	0.842	0.0773	9	3.2
37-FW-5B	7/9/2013 9:30	1307040-44	83.1	0.011	5.19	1.3		0.796	0.0699	6	1.7 J	0.843	0.0773	8	3.5
37-FW-5B	8/7/2013 7:43	1308028-15	87.3	0.016	5.42	1.4	86.2	0.856	0.0829	14	1.6	0.969	0.102	18	7.1
37-FW-5B	8/7/2013 7:55	1308028-44	85.2	0.015	5.19	1.4	86.4	0.831	0.08	12	1.7	0.884	0.0937	16	6.1
37-FW-5B	9/10/2013 15:53	1309026-15	62.7	0.014	3.48	1.3	63.3	0.517	0.0501	44	2.4	0.592	0.113	53	38
37-FW-5B	10/8/2013 16:05	1310017-15	96.2	0.01 U	6.21	1.4	89.8	0.936	0.0527	6	1.5	0.987	0.0594	8	5.2
37-FW-5B	11/12/2013 15:53	1311009-15	299	0.016	22.6	2.2		3.89	0.154	5	2.4	3.78	0.168	7	1.7
37-FW-5B	12/10/2013 15:30	1312009-15	303	0.065	25.6	1.9		4.5	0.178	1 U	2	4.63	0.161	1 U	1
37-FW-5B	3/5/2014 9:20	1403011-15	298	0.018	51.1	2.2		3.45	0.224	2	2.3	3.71	0.223	3	1.4
37-FW-5B	3/25/2014 16:00	1403001-15	87.9	0.01 U	6.02	1.9		0.67	0.101	8	2	0.748	0.113	10	5.9
37-FW-5B	4/29/2014 14:51	1404001-15	61.6	0.01 U	3.4	1.6		0.279	0.0335	8	1.6	0.362	0.0501	10	5
37-FW-5B	6/3/2014 15:12	1406001-15	59.4	0.023	3.35	1.5		0.486	0.0643	17	1.6	0.594	0.0885	21	8.1
37-FW-6B	7/8/2013 16:00	1307040-13	67.4	0.013	3.76	1.3		0.528	0.0471	3	1.5	0.598	0.0513	4	2.1
37-FW-6B	7/8/2013 16:10	1307040-42	67.6	0.012	3.78	1.3		0.539	0.0473	3	1.5	0.603	0.052	4	2
37-FW-6B	8/6/2013 15:11	1308028-13	62.5	0.011	3.32	1.3	60	0.444	0.0393	6	1.5	0.544	0.049	8	3.3
37-FW-6B	8/6/2013 15:30	1308028-42	62.7	0.013	3.22	1.3	62.9	0.445	0.0401	6	1.7	0.548	0.0481	8	2.9

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-FW-6B	9/10/2013 14:06	1309026-13	59.9	0.014	3.17	1.3	61.5	0.488	0.0369	40	2.6	0.572	0.0998	48	37
37-FW-6B	9/10/2013 14:25	1309026-42	61	0.016	3.14	1.3	60	0.486	0.0359	42	2.2	0.549	0.0923	49	39
37-FW-6B	10/8/2013 14:45	1310017-13	91.4	0.01 U	5.73	1.4	85.1	0.876	0.0507	4	1.6	0.927	0.0554	5	4.4
37-FW-6B	10/8/2013 14:58	1310017-42	92.1	0.01 U	5.77	1.4	87.1	0.872	0.055	4	1.7	0.927	0.0558	5	4.4
37-FW-6B	11/12/2013 14:05	1311009-13	273	0.011	20.5	2.2	261	3.46	0.18	1 U	2.4	4.35	0.178	2	0.8
37-FW-6B	11/12/2013 14:42	1311009-42	275	0.013	20.6	2.2	257	3.33	0.178	1 U	2.3	3.45	0.18	1	0.9
37-FW-6B	12/10/2013 13:57	1312009-13	277	0.031	21.8	2.1		3.98	0.206	1 U	2.2	4.15	0.191	1	1
37-FW-6B	12/10/2013 14:07	1312009-42	276	0.037	21.8	1.9		4.01	0.203	1 U	2	4.19	0.194	1	1
37-FW-6B	3/4/2014 14:30	1403011-13	271	0.011	44.9	2		3.26	0.19	1 U	2.2	3.53	0.188	3	1.2
37-FW-6B	3/4/2014 14:50	1403011-42	272	0.017	42.6	2.2		3.38	0.188	2	2.1	3.49	0.191	4	1.2
37-FW-6B	3/25/2014 14:28	1403001-13	73.7	0.01	4.66	1.8		0.472	0.0466	8	1.9	0.553	0.0642	11	5.8
37-FW-6B	3/25/2014 14:40	1403001-42	73	0.013	4.6	1.8		0.471	0.0454	9	2	0.523	0.0633	12	5.9
37-FW-6B	4/29/2014 13:45	1404001-13	60.3	0.01 U	3.02	1.4		0.206	0.0222	7	1.6	0.293	0.0353	9	5.1
37-FW-6B	4/29/2014 13:46	1404001-42	58.3	0.01 U	3.04	1.5		0.207	0.021	7	1.6	0.26	0.0355	9	4.6
37-FW-6B	6/3/2014 13:49	1406001-13	56.4	0.018	3.06	1.5		0.465	0.0416	11 J	1.6	0.573	0.0567	13	6.1
37-FW-6B	6/3/2014 13:55	1406001-42	55.9	0.019	2.91	1.4 J		0.465	0.0411	11	1.6	0.574	0.057	13	5.7
37-FW-8	7/8/2013 11:52	1307040-06	57.4	0.014	2.81	1.5		0.318	0.0261	4	1.5	0.377	0.0313	6	2.8
37-FW-8	7/8/2013 12:09	1307040-41	57.6	0.015	2.78	1.4		0.315	0.0263	4	1.5	0.377	0.0323	5	2.7
37-FW-8	8/6/2013 10:52	1308028-06	59.1	0.013	2.72	1.4		0.357	0.0281	5	1.5	0.464	0.0342	7	2.8
37-FW-8	9/10/2013 9:56	1309026-06	54.5	0.015	2.52	1.2		0.352	0.0271	27	2.1	0.436	0.0742	32	35
37-FW-8	10/8/2013 11:05	1310017-06	57.7	0.01 U	2.59	1.2		0.348	0.0179	10	1.5	0.397	0.0281	12	6.4
37-FW-8	3/4/2014 10:55	1403011-06	170	0.01 U	14.5	2.1		0.811	0.0388	2	2.2	0.964	0.039	3	1.6
37-FW-8	3/25/2014 10:41	1403001-06	51.6	0.01 U	2.73	1.6		0.217	0.0187	9	1.7	0.265	0.0357	11	6.4
37-FW-8	4/29/2014 10:03	1404001-06	48.7	0.01 U	2.26	1.5		0.024	0.0074	4	1.5	0.094	0.0158	5	3.3
37-FW-8	6/3/2014 10:00	1406001-06	45.6	0.025	2.03	1.5		0.331	0.0267	9 J	1.5	0.443	0.0363	12	5.4
37-IS-12C	7/9/2013 14:03	1307040-20	244	0.01 U	23.2	1.3		5.38	0.236	1 U	1.4	5.15	0.214	1 U	0.5 U
37-IS-12C	8/7/2013 12:35	1308028-20	233	0.01 U	21.9	1.3		5.09	0.23	1 U	1.3	5.35	0.216	1 U	0.5 U
37-IS-12C	9/11/2013 12:28	1309026-20	232	0.01 U	22.4	1.3		4.92	0.229	1 U	1.3	5.07	0.219	1	0.5 U
37-IS-12C	10/9/2013 11:15	1310017-20	235	0.01 U	22.3	1.3		4.98	0.237	1 U	1.3	4.99	0.221	1 U	0.5 U
37-IS-12C	11/13/2013 10:56	1311009-20	243	0.01 U	21.1	1.3		5.08	0.245	1 U	1.3	4.73	0.228	1 U	0.5 U
37-IS-12C	12/11/2013 11:30	1312009-20	248	0.01 U	22.1	1.3		4.73	0.256	1 U	1.3	5.37	0.232	1 U	0.5 U
37-IS-12C	3/5/2014 12:04	1403011-20	267	0.01	25.8	1.3		5.08	0.258	1 U	1.3	5.15	0.238	1 U	0.5 U
37-IS-12C	3/26/2014 10:01	1403001-20	270	0.01 U	25.9	1.3		5.38	0.251	1 U	1.4	5.38	0.236	1 U	0.5 U
37-IS-12C	4/30/2014 10:43	1404001-20	263	0.01 U	22.4	1.3		5.51	0.245	1 U	1.3	6.01	0.226	1 U	0.5 U
37-IS-12C	6/4/2014 10:24	1406001-20	261	0.01 U	25	1.3		5.56	0.238	1 U	1.3	5.7	0.216	1 U	0.5 U

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-IS-13	7/9/2013 15:25	1307040-38	282	0.01 U	23.2	1.4		5.58	0.203	1 U	1.4	5.43	0.18	1 U	0.5 U
37-IS-13	8/7/2013 13:30	1308028-38	253	0.01 U	20.9	1.4		4.83	0.198	1 U	1.4	4.78	0.184	1 U	0.5 U
37-IS-13	10/9/2013 9:15	1310017-38	228	0.01 U	16.9	1.4		3.72	0.193	1	1.4	3.7	0.176	2	0.5 U
37-IS-13	11/12/2013 11:10	1311009-38	222	0.01 U	14.9	1.3		3.6	0.191	1 U	1.3	3.58	0.178	1 U	0.5 U
37-IS-13	12/10/2013 9:30	1312009-38	239	0.01 U	17.8	1.4		4	0.208	1 U	1.3	4.85	0.189	1 U	0.5 U
37-IS-13	3/5/2014 10:30	1403011-38	316	0.01 U	28.6	1.5		6.57	0.29	1 U	1.4	6.43	0.27	1 U	0.5 U
37-IS-13	3/26/2014 11:00	1403001-38	395	0.01 U	28.2	1.4		6.13	0.294	1 U	1.5	6.27	0.267	1 U	0.5 U
37-IS-13	6/4/2014 11:10	1406001-38	328	0.01 U	25.9	1.6		7.63	0.216	1 U	1.6	7.66	0.193	1 U	0.5 U
37-IS-15	9/10/2013 16:00	1309026-36	368	0.013	23.8	2		4.74	0.158	1 U	2	4.73	0.157	1	0.9
37-IS-15	10/8/2013 11:15	1310017-36	370	0.01 U	23.3	1.9		5.12	0.147	2	2	4.85	0.136	3	0.8
37-IS-15	10/22/2013 14:20	1310029-05	395	0.01 U	23.4	1.8		5.33	0.141	2	1.9	5.3	0.131	2	0.8
37-IS-15	11/12/2013 10:40	1311009-36	400	0.01 U	22.3	1.7		5.87	0.154	1 U	1.7	5.82	0.145	2	0.9
37-IS-15	12/10/2013 10:25	1312009-36	433	0.046	23.3	2		6.48	0.247	2	2	6.48	0.225	3	1.6
37-IS-15	3/5/2014 9:25	1403011-36	383	0.105	124	2.4		6.6	0.237	1 U	2.5	6.71	0.224	1 U	0.9
37-IS-16	7/8/2013 9:54	1307040-03	43.1	0.016	1.68	1.1		0.213	0.0141	3	1.3	0.262	0.0197	5	2.2
37-IS-16	8/6/2013 8:45	1308028-03	46.9	0.01 U	1.89	1.2	45.3	0.287	0.0172	4	1.5	0.373	0.0248	5	2.1
37-IS-16	8/19/2013 13:30	1308070-03	43.2	0.01 U	2	1.6		0.215	0.0146	7	1.5	0.265	0.027 J	10	3.6
37-IS-16	9/10/2013 8:45	1309026-03	43.6	0.024	1.81	1.1	43.4	0.298	0.0201	51	1.8	0.369	0.0781	58	45
37-IS-16	9/24/2013 10:20	1309058-01	46.8	0.01 U	2.13	1.1	45.7	0.293	0.0149	7	1.3	0.327	0.0256	8	7.1
37-IS-16	10/8/2013 9:53	1310017-03	47.8	0.01 U	1.9	1.2	44	0.289	0.0138	5	1.4	0.327	0.0243	6	6.3
37-IS-16	3/25/2014 8:06	1403001-03	42.3	0.011	1.89	1.4		0.167	0.014	4	1.6	0.209	0.02	6	4.3
37-IS-16	4/29/2014 8:51	1404001-03	43.1	0.01 U	1.75	1.3		0.013	0.005	6	1.5	0.068	0.0176	9	4.2
37-IS-16	6/3/2014 8:35	1406001-03	39.2	0.012	1.53	1.3		0.299	0.0123	30 J	1.4	0.371	0.0581	37 J	13
37-IS-16B	7/8/2013 10:47	1307040-04	53.3	0.026	2.79	1.4		0.197	0.0203	6	1.5	0.256	0.028	7	2.7
37-IS-16B	8/6/2013 10:10	1308028-04	52.7	0.017	2.47	1.4	50.7	0.288	0.0205	4	1.5	0.393	0.025	6	2.3
37-IS-16B	8/6/2013 10:18	1308028-41	52.6	0.016	2.41	1.3	53	0.286	0.0192	4	1.3	0.409	0.0239	5	1.7
37-IS-16B	9/10/2013 9:00	1309026-04	47.1	0.026	2.13	1.2	47.7	0.319	0.0216	42	1.8	0.368	0.0769	49	45
37-IS-16B	9/10/2013 9:15	1309026-41	47.1	0.026	2.08	1.2	47.2	0.304	0.0215	37	2	0.378	0.08	43	45
37-IS-16B	10/8/2013 10:15	1310017-04	52.3	0.01 U	2.28	1.3	47.7	0.308	0.0153	4	1.5	0.341	0.026	5	5.4
37-IS-16B	10/8/2013 10:33	1310017-41	52.1	0.01 U	2.59	1.4	48.9	0.306	0.0166	5	1.5	0.353	0.0299	6	6.3
37-IS-16B	10/22/2013 11:10	1310029-01	214	0.039	16.9	2.5	200	1.1	0.0886	10	2.7	1.33	0.114	13	3.5
37-IS-16B	11/12/2013 9:25	1311009-04	202	0.023	14.6	2.5	199	0.618	0.103	1 U	2.4	0.746	0.111	1	0.6
37-IS-16B	11/12/2013 9:32	1311009-41	202	0.026	14.5	2.5	195	0.599	0.103	1 U	2.4	0.751	0.111	2	0.8
37-IS-16B	12/10/2013 9:31	1312009-04	192	0.088	16	2.6		0.517	0.079	25	3.5	0.833	0.14	32	13
37-IS-16B	12/10/2013 9:45	1312009-41	194	0.084	16	2.6		0.519	0.0737	25	3.6	0.82	0.136	32	13

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Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-IS-16B	3/4/2014 9:40	1403011-04	169	0.012	14.9	2.1		0.694	0.0796	5	2.3	0.839	0.0981	9	3.2
37-IS-16B	3/4/2014 10:00	1403011-41	168	0.011	15	2.2		0.676	0.0781	4	2.2	0.847	0.0967	7	3
37-IS-16B	3/25/2014 10:00	1403001-04	44.8	0.01 U	2.11	1.4		0.173	0.0153	4	1.6	0.213	0.0231	5	3.8
37-IS-16B	3/25/2014 10:15	1403001-41	46.3	0.012	2.18	1.5		0.168	0.0151	4	1.5	0.205	0.0248	5	4
37-IS-16B	4/29/2014 9:15	1404001-04	46.4	0.01 U	2.13	1.4		0.018	0.0066	5	1.6	0.072	0.0174	7	4.1
37-IS-16B	4/29/2014 9:16	1404001-41	47.3	0.01 U	2.13	1.3		0.016	0.0066	4	1.5	0.078	0.0172	7	3.5
37-IS-16B	6/3/2014 9:00	1406001-04	41.5	0.021	1.75	1.3		0.296	0.0137	20 J	1.4	0.367	0.0403	25 J	8.6
37-IS-16B	6/3/2014 9:20	1406001-41	42	0.016	1.78	1.3		0.293	0.0136	17 J	1.4	0.363	0.029	22 J	4.9
37-IS-16C	8/7/2013 9:15	1308028-28	41.4	0.01 U	1.69	1.2	40.7	0.238	0.0148	2	1.2	0.294	0.0176	3	1.7
37-IS-16C	9/10/2013 9:30	1309026-28	39.4	0.019	1.68	1.1	40.1	0.245	0.0168	38	1.7	0.274	0.072	44	35
37-IS-16C	10/8/2013 8:50	1310017-28	41.2	0.01 U	1.63	1.2	39	0.232	0.0143	7	1.3	0.266	0.027	9	7.1
37-IS-17	7/8/2013 17:17	1307040-14	223	0.023	17.3	1.8		4.29	0.103	1 U	1.7	4.27	0.086	1	0.7
37-IS-17	8/6/2013 15:58	1308028-14	244	0.014	18.5	2.1		4.4	0.12	1 U	2.3	4.57	0.109	1 U	0.7
37-IS-17	8/19/2013 15:24	1308070-14	160	0.01 U	11.5	1.4		2.7	0.057	1 U	1.5	2.62	0.0605 J	2	0.9
37-IS-17	9/10/2013 15:01	1309026-14	217	0.028	15.2	1.5		3.79	0.084	13	1.7	4.02	0.1	15	16
37-IS-17	9/24/2013 14:20	1309058-04	236	0.01 U	18.4	1.6		4.38	0.0845	2	1.6	4.36	0.0797	3	3
37-IS-17	10/8/2013 15:33	1310017-14	299	0.01 U	23.9	1.7		5.96	0.105	1	1.8	5.85	0.0939	2	1.6
37-IS-17	10/22/2013 13:10	1310029-03	406	0.033	32.6	2		8.44	0.135	1 U	2	8.49	0.118	1	0.5 U
37-IS-17	11/12/2013 15:01	1311009-14	407	0.012	30.3	2.1		8.82	0.136	1 U	2	8.53	0.124	1 U	0.5 U
37-IS-17	12/10/2013 14:59	1312009-14	409	0.115	34.3	2.1		8.72	0.159	1 U	2.2	8.86	0.137	1 U	0.5 U
37-IS-17	3/5/2014 8:39	1403011-14	388	0.081	121	4.1		8.71	0.137	3	4.5	8.26	0.142	5	8.3
37-IS-17	3/25/2014 15:05	1403001-14	417	0.01 U	34.6	1.9		9.15	0.143	1 U	1.9	9.08	0.124	1 U	0.5 U
37-IS-17	4/29/2014 14:12	1404001-14	176	0.041	12.5	2.3		3.11	0.0755	2	2.3	4.35	0.0773	3	2.4
37-IS-17	6/3/2014 14:37	1406001-14	183	0.013	13.8	1.6		3.24	0.0731	1 J	1.6	3.34	0.0691	2	2.3
37-IS-17	6/3/2014 14:40	1406001-44	78.4	0.016	18	1.2		2.12	0.055	12	1.4	2.22	0.0745	17	5
37-IS-17.5	7/8/2013 15:20	1307040-12	106	0.186	12.2	3.3		0.21	0.318	22 J	4.1	0.706	0.403	31 J	10
37-IS-17.5	8/6/2013 14:43	1308028-12	101	0.188	7.68	3.2		0.13	0.91	14	3.9	0.642	0.9	20	7.2
37-IS-17.5	9/10/2013 13:46	1309026-12	110	0.17	13.3	5.1		0.331	2.36	15	5.5	0.725	2.54	22	15
37-IS-17.5	10/8/2013 14:15	1310017-12	120	0.189	9.17	2.6		0.264	0.329	22 J	3	0.711	0.365	29 J	6.2
37-IS-17.5	11/12/2013 12:21	1311009-12	237	0.931	36.3	7.3		0.327	3.85	32 J	8.4	1.98	3.79	48 J	13
37-IS-17.5	12/10/2013 12:28	1312009-12	366	0.598	36.6	10.3		1.96	3.58	5 U	11.4	3.38	3.41	5 U	5.3
37-IS-17.5	3/4/2014 13:55	1403011-12	233	1.07	118	8.3		0.573	3.4	10	10.1	4.98	3.71	25	8.8
37-IS-17.5	3/25/2014 13:45	1403001-12	241	0.984	32.1	7.6		0.127	7.3	6	8.3	1.36	7.09	10	7
37-IS-17.5	4/29/2014 13:01	1404001-12	127	0.255	10	3.3		0.231	1.16	5	3.4	0.71	1.23	8	4.6
37-IS-17.5	6/3/2014 13:12	1406001-12	120	0.089	16.8	3.9		0.186	2.08	9 J	4	0.666	2.09	15 J	2.4

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Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-IS-20A	7/9/2013 11:33	1307040-17	33.1	0.01 U	1.35	1 U		0.034	0.0112	1	1 U	0.085	0.0134	2	1.2
37-IS-20A	9/11/2013 9:14	1309026-17	33.9	0.01 U	1.71	1 U	35.2	0.115	0.0142	31	1.6	0.165	0.0619	35	35
37-IS-20A	10/9/2013 9:18	1310017-17	35.9	0.01 U	1.56	1 U	33.1	0.048	0.0091	4	1.1	0.094	0.019	5	4.6
37-IS-20A	10/9/2013 9:31	1310017-44	36.3	0.01 U	1.66	1.1	33.8	0.051	0.0091	4	1.2	0.081	0.0192	5	4.9
37-IS-20A	4/30/2014 9:00	1404001-17	33.1 J	0.01 UJ	1.36 J	1.2 J		0.01 UJ	0.0103 J	4 J	1.3 J	0.038 J	0.0202 J	6 J	4.3 J
37-IS-20A	6/4/2014 7:56	1406001-17	26.8	0.01 U	1.06	1.1		0.014	0.0149	7 J	1.1	0.056	0.0231	10	5.6
37-IS-20B	7/9/2013 11:55	1307040-30	32.8	0.01 U	1.33	1.7 J		0.027	0.0128	1 U	1.9 J	0.078	0.0134	2	1
37-IS-20B	8/6/2013 13:45	1308028-30	36.3	0.01 U	1.72	1.1	35.5	0.039	0.0086	1 U	1.1	0.105	0.012	1	1
37-IS-20B	8/19/2013 16:08	1308070-30	33.4	0.01 U	1.67	1		0.018	0.0126	2	1.2	0.058	0.0155 J	3	1.6
37-IS-20B	9/10/2013 10:30	1309026-30	33.6	0.024	1.63	1.1	34.6	0.077	0.0141	42	1.9	0.189	0.0826	48	45
37-IS-20B	9/24/2013 15:07	1309058-05	34.2	0.018 J	1.9	1 U	32.5	0.086	0.0129	10	1.2	0.132	0.0298	12	10
37-IS-20B	10/8/2013 10:15	1310017-30	37.2	0.01 U	1.64	1.4	35.2	0.057	0.0102	8	1.1	0.125	0.0246	10	7.8
37-IS-20B	4/30/2014 9:00	1404001-30	32.9	0.01 U	1.33	1.3		0.01 U	0.0108	4	1.4	0.046	0.0187	5	4.9
37-IS-20B	6/4/2014 9:20	1406001-30	5 U	0.01 U	1.04	1.5		0.01 U	0.0119	12	1.5	0.143	0.0286	15	7.7
37-IS-20C	8/7/2013 8:41	1308028-27	35.4	0.01 U	1.62	1 U	33.7	0.047	0.0078	3	1.1	0.109	0.0116	4	1.6
37-IS-20C	9/10/2013 10:00	1309026-27	31.6	0.019	1.54	1 U		0.057	0.0109	44	1.6	0.084	0.0729	51	38
37-IS-20C	10/8/2013 9:25	1310017-27	34.1	0.01 U	1.43	1		0.049	0.0081	8	1.1	0.092	0.0227	10	7.6
37-IS-20D	8/7/2013 10:45	1308028-46	36.9	0.01 U	1.63	1 U	35.1	0.056	0.0087	2	1	0.105	0.0138 J	3	1.2
37-IS-21	7/9/2013 10:21	1307040-40	89.9	0.01 U	12.2	1.3 J		2.73	0.105	1 U	1.1 J	2.7	0.0911	1 U	0.5 U
37-IS-21	8/7/2013 15:15	1308028-40	87.1	0.01 U	11.3	1 U		2.48	0.107	1 U	1 U	2.43	0.097	1 U	0.5 U
37-IS-21	9/11/2013 9:00	1309026-40	87.4	0.01 U	10.5	1		2.39	0.103	1 U	1 U	2.31	0.0994	1 U	0.5 U
37-IS-21	9/11/2013 10:50	1309026-38	235	0.01 U	17.2	1.5		4.05	0.19	1 U	1.4	4.16	0.189	1 U	0.5 U
37-IS-21	10/9/2013 13:35	1310017-40	82.2	0.01 U	9.42	1.1		1.99	0.0807	1	1.1	2.01	0.0767	2	0.7
37-IS-21	11/12/2013 12:40	1311009-40	98	0.01 U	13.7	1 U		3.28	0.0954	1 U	1 U	3.62	0.0894	1 U	0.5 U
37-IS-21	12/10/2013 11:30	1312009-40	101	0.01 U	13.9	1 U		3.3	0.1	6	1 U	3.12	0.0866	7	0.5 U
37-IS-21	3/5/2014 13:00	1403011-40	104	0.01 U	18.2	1 U		3.52	0.0907	1 U	1 U	3.49	0.0786	1 U	0.5 U
37-IS-21	3/26/2014 13:40	1403001-40	105	0.012	16.4	1 U		3.57	0.0917	1 U	1 U	3.59	0.0815	1 U	0.5 U
37-IS-21	4/30/2014 13:15	1404001-40	106	0.01 U	13.9	1 U		3.39	0.0895	1 U	1 U	3.41	0.0808	1 U	0.5 U
37-IS-21	6/4/2014 13:55	1406001-40	78.8	0.01 U	9.16	1.2		1.8	0.0785	1 U	1.1	1.85	0.0732	1 U	0.9
37-IS-22	7/9/2013 9:27	1307040-39	200	0.014	16.4	3.4 J		0.704	0.0452	4	3.3 J	0.915	0.0527	5	2.9
37-IS-22	8/7/2013 14:00	1308028-39	176	0.01 U	12.6	3.6		0.401	0.0973	1 U	3.8	0.71	0.104	2	2.3
37-IS-22	9/11/2013 12:10	1309026-39	153	0.01 U	9.68	2.7		0.335	0.0639	1 U	2.9	0.543	0.0754	1	1.4
37-IS-22	10/9/2013 10:15	1310017-39	203	0.012	17.4	2.2		2.04	0.058	1	2.4	2.1	0.059	2	2.1
37-IS-22	10/22/2013 15:16	1310029-06	193	0.011	17.4	2.6		1.74	0.0485	5	2.9	1.95	0.0662	7	4.4
37-IS-22	4/30/2014 12:15	1404001-39	156	0.022	10.4	2.5		1.13	0.119	8	2.5	1.34	0.137	11	4.2

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-IS-22	6/4/2014 11:55	1406001-39	189	0.013	16.5	2.5		1.08	0.0463	4	2.7	1.33	0.0555	6	3
37-IS-23	7/9/2013 11:55	1307040-18	188	0.024	15.6	2		2.15	0.0996	4	2.5	2.36	0.0949	6	2.3
37-IS-23	9/11/2013 10:00	1309026-18	174	0.021	13.7	1.6	162	2.01	0.0823	20 J	1.9	2.15	0.113	24 J	12
37-IS-23	12/11/2013 10:20	1312009-18	205	0.028	16.7	1.4		3.33	0.121	33	1.5	3.43	0.118	38	3.1
37-IS-23	3/5/2014 10:55	1403011-18	204	0.01 U	18.1	6.2		3.22	0.11	6	6.2	3.39	0.108	8	2.1
37-IS-23	3/26/2014 9:14	1403001-18	178	0.012	14.9	1.6		2.91	0.0989	7	1.7	2.95	0.107	10	3.3
37-IS-23	4/30/2014 9:41	1404001-18	114 J	0.01 UJ	7.63 J	1.5 J		1.43 J	0.0523 J	12 J	1.7 J	1.52 J	0.07 J	16 J	6.1 J
37-IS-23	6/4/2014 8:45	1406001-18	196	0.038	17.1	1.5		3	0.105	14 J	1.6	3.13	0.116	18	6.7
37-IS-26	7/9/2013 12:25	1307040-35	85.8	0.01 U	5.41	2 J		0.808	0.0743	12	1.6 J	0.875	0.0859	15	6.5
37-IS-26	8/6/2013 15:20	1308028-35	75	0.01 U	4.12	1.3		0.618	0.0655	11	1.7	0.743	0.0783	14	5.4
37-IS-26	9/10/2013 15:00	1309026-35	71.9	0.01 U	3.97	1.5		0.634	0.052	66	3 J	0.706	0.164	79	60
37-IS-26	10/8/2013 13:15	1310017-35	89.8	0.01 U	5.71	1.4		0.864	0.0447	6	1.5	0.918	0.0532	7	5.8
37-IS-26	10/22/2013 13:55	1310029-04	250	0.014	19.9	1.8		3.44	0.111	6	1.9	3.6	0.12	7	3.8
37-IS-33	7/8/2013 14:15	1307040-10	41.6	0.01 U	1.55	1.1		0.226	0.0145	5	1.2	0.271	0.0186	7	2.6
37-IS-33	8/7/2013 10:00	1308028-10	43.9	0.01 U	1.73	1.1	41.7	0.267	0.0154	3	1.3	0.345	0.018	5	1.8
37-IS-33	9/10/2013 13:00	1309026-10	43.2	0.022	1.75	1.1		0.274	0.0181	37	2	0.316	0.0692	43	35
37-IS-33	10/9/2013 8:30	1310017-10	45.8	0.01 U	1.84	1.1		0.292	0.0146	7	1.4	0.335	0.025	9	6
37-IS-33	6/4/2014 8:20	1406001-10	38.9	0.01 U	1.43	1.3		0.32	0.0141	16 J	1.3	0.368	0.0336	20	8.7
37-SS-11	7/8/2013 15:05	1307040-11	61.5	0.01 U	3.43	1.2		0.455	0.0411	4	1.4	0.51	0.0495	5	2.5
37-SS-11	8/6/2013 14:11	1308028-11	59.4	0.01	3.13	1.3		0.404	0.0346	6	1.3	0.498	0.043	7	3
37-SS-11	9/10/2013 13:03	1309026-11	58.7	0.017	3.04	1.3		0.458	0.034	44	2.4 J	0.531	0.101	52	45
37-SS-11	10/8/2013 13:47	1310017-11	88.8	0.01 U	5.54	1.4		0.831	0.0477	5	1.6	0.898	0.055	7	5.1
37-SS-11	11/12/2013 11:25	1311009-11	280	0.015	21.9	2.2		3.72	0.181	1 U	2.6	3.7	0.183	2	1.1
37-SS-11	12/10/2013 11:42	1312009-11	286	0.038	23.4	2.1		4.22	0.207	4	2.1	4.37	0.206	6	3.2
37-SS-11	3/4/2014 13:00	1403011-11	275	0.014	58.5	2.2		3.63	0.191	7 J	2.4	3.84	0.227	12 J	1.7
37-SS-11	3/25/2014 12:50	1403001-11	70.6	0.01 U	4.53	1.8		0.475	0.0429	9	1.9	0.531	0.0606	12	5.5
37-SS-11	4/29/2014 12:07	1404001-11	56.8	0.01 U	2.95	1.4		0.212	0.0184	7	1.5	0.278	0.0303	10	4.4
37-SS-11	6/3/2014 12:19	1406001-11	55.1	0.023	2.77	1.5		0.457	0.0381	10 J	1.5	0.598	0.0526	13	5.2
37-SS-11B	3/4/2014 13:25	1403011-47	225	0.01 U	12.3	1.3		2.2	0.239	1 U	1.3	2.24	0.212	1 U	0.5 U
37-SS-11B	3/25/2014 13:15	1403001-47	224	0.013	12	1.3		2.26	0.236	1 U	1.5	2.43	0.212	1 U	0.5 U
37-SS-11B	4/29/2014 12:17	1404001-47	217	0.01 U	11.7	1.2		2	0.23	1 U	1.2	2.5	0.217	1 U	0.5 U
37-SS-11B	6/3/2014 12:30	1406001-47	204	0.01 U	11.8	1.3		2.26	0.235	1 U	1.3	2.26	0.214	1 U	0.5 U
37-SS-12	7/8/2013 12:55	1307040-07	67.1	0.026	4.04	1.5		0.357	0.0449	3	1.8	0.49	0.0543	4	2.3
37-SS-12	8/6/2013 11:34	1308028-07	58.7	0.013	2.97	1.4	55.8	0.259	0.0298	5	1.6	0.384	0.0377	7	3
37-SS-12	9/10/2013 10:30	1309026-07	58.9	0.018	2.97	1.4	61.8	0.358	0.0289	23	2.1	0.448	0.0755	27	34

Table C-1. Laboratory results.

Location ID	Date Time	Sample ID	Alk (mg/l)	NH4 (mg/l)	Cl (mg/l)	DOC (mg/l)	Hard (mg/l)	NO2-NO3 (mg/l)	OP (mg/l)	TNVSS (mg/l)	TOC (mg/l)	TPN (mg/l)	TP (mg/l)	TSS (mg/l)	Turb (NTU)
37-SS-12	10/8/2013 12:05	1310017-07	68.6	0.01 U	3.75	1.3	63.2	0.408	0.0288	4	1.6	0.485	0.0386	5	4.8
37-SS-12	11/12/2013 10:25	1311009-07	230	0.01 U	19.9	1.9	217	3.62	0.198	6	2.1	4.67	0.221	8	2.7
37-SS-12	12/10/2013 10:48	1312009-07	208	0.014	19.2	1.7		2.47	0.165	2	2	2.67	0.197	3	3.3
37-SS-12	3/4/2014 11:25	1403011-07	185	0.011	22.7	1.7		1.54	0.122	7	1.9	1.67	0.16	11	3
37-SS-12	3/25/2014 11:19	1403001-07	53.3	0.013	3	1.7		0.153	0.0236	2	1.8	0.223	0.0289	3	2.9
37-SS-12	4/29/2014 10:30	1404001-07	58.1	0.011	3.01	1.5		0.091	0.0164	1	1.6	0.181	0.0222	2	2
37-SS-12	6/3/2014 10:37	1406001-07	53.1	0.03	2.46	1.7		0.286	0.0348	2 J	1.8	0.436	0.0431	3	2.1
37-SS-38	7/8/2013 13:00	1307040-09	70	0.01 U	4.33	1.3		0.94	0.0493	9	1.5	1.02	0.0556	12	4.2
37-SS-38	8/6/2013 11:59	1308028-09	44.6	0.01 U	1.75	1.2		0.266	0.0162	4	1.2	0.342	0.0205	5	2.2
37-SS-38	8/19/2013 14:35	1308070-09	101	0.01 U	7.37	5.7		1.77	0.577 J	91	6.4	1.92	0.467	114	39
37-SS-38	9/10/2013 11:07	1309026-09	88.3	0.01 U	5.82	1.3		1.39	0.0764	31	2	1.47	0.12	37	30
37-SS-38	9/24/2013 13:35	1309058-03	90.4	0.01 U	7.03	1.5		1.5	0.0754	20	2.1	1.53	0.102	24	13
37-SS-38	10/8/2013 12:23	1310017-09	171	0.01 U	13.6	1.6		3.47	0.159	3	1.8	3.59	0.156	3	3.7
37-SS-38	10/22/2013 12:22	1310029-02	328	0.01 U	28.8	2		7.65	0.331	1 U	2.1	7.74	0.307	1 U	0.5 U
37-SS-38	11/12/2013 10:46	1311009-09	304	0.01 U	24.2	1.8		6.51	0.51	1 U	1.9	6.53	0.289	1 U	0.5 U
37-SS-38	12/10/2013 10:57	1312009-09	317	0.01 U	26.4	1.9		7.25	0.343	1 U	1.9	7.31	0.311	1 U	0.5 U
37-SS-38	3/4/2014 11:48	1403011-09	323	0.024	153	2.2		7.47	0.328	1 U	2.3	7.48	0.307	1	1.1
37-SS-38	3/25/2014 11:40	1403001-09	191	0.01 U	20.6	1.8		4.26	0.198	6	1.9	4.37	0.179	7	2.3
37-SS-38	4/29/2014 11:15	1404001-09	80.6	0.011	5.15	1.4		1.03	0.0507	5	1.5	1.12	0.0613	7	4.2
37-SS-38	6/3/2014 11:04	1406001-09	73.7	0.01 U	4.87	1.3		1.19	0.0548	10 J	1.3	1.25	0.0729	13	5.2
37-SS-48	7/8/2013 13:09	1307040-08	41.9	0.01 U	1.7	1.3		0.237	0.016	6	1.3	0.29	0.0208	8	2.7
37-SS-48	8/6/2013 12:03	1308028-08	73.7	0.01 U	4.33	1		0.976	0.0475	7	1.3	1.06	0.054	8	3.3
37-SS-48	8/19/2013 14:16	1308070-08	48.1	0.01 U	2.27	1.2		0.263	0.0273	6	1.6	0.309	0.0392 J	9	3.8
37-SS-48	9/10/2013 11:04	1309026-08	46.3	0.012	1.98	1		0.303	0.0228	35	1.6	0.347	0.0652	40	34
37-SS-48	9/24/2013 13:45	1309058-02	45	0.01 U	2.04	1.1		0.301	0.0162	7	1.2	0.308	0.0304	8	7.7
37-SS-48	10/8/2013 12:36	1310017-08	45.6	0.01 U	1.72	1.2		0.286	0.0151	6	1.3	0.303	0.0275	8	6.8
37-SS-48	3/25/2014 11:35	1403001-08	39.6	0.01 U	1.74	1.4		0.125	0.0137	8	1.4	0.173	0.0247	10	5
37-SS-48	4/29/2014 11:06	1404001-08	40.7	0.01 U	1.69	1.3		0.053	0.0055	6	1.4	0.102	0.0195	8	4.4
37-SS-48	6/3/2014 10:58	1406001-08	39.1	0.01 U	1.49	1.2		0.329	0.0167	16 J	1.2	0.394	0.034	20 J	8.6
37-SS-6	9/11/2013 12:00	1309026-19	55.2	0.013	7.96	4.4		0.619	0.173	7	5	0.797	0.206	10	12
37-SS-6	10/9/2013 10:54	1310017-19	43.8	0.141	2.91	1.4		0.545	0.0488	1 U	1.6	0.871	0.0532	1	3.3

Table C-2. Comparison of water chemistry samples at canal diversions versus outfalls.

Yakima Valley Canal		Average		6-Aug-2013				10-Sep-2013				8-Oct-2013			
Parameter	Units	Diff	RPD	In	Out	Diff	RPD	In	Out	Diff	RPD	In	Out	Diff	RPD
Ammonia	ug/L	5	23	10 U	10 U	NC	NC	19	24	5.0	23	10 U	10 U	NC	NC
Nitrate-Nitrite as N	ug/L	53	20	238	287	49	19	245	298	53	20	232	289	57	22
Total Persulfate Nitrogen	ug/L	78	25	294	373	79	24	274	369	95	30	266	327	61	21
Ortho-Phosphate	ug/L	1.7	10	14.8	17.2	2.4	15	16.8	20.1	3.3	18	14.3	13.8	-0.5	-4
Total Phosphorus	ug/L	3.5	11	17.6	24.8	7.2	34	72.0	78.1	6.1	8	27.0	24.3	-2.7	-11
Dissolved Organic Carbon	mg/L	0	0	1.2	1.2	0	0	1.1	1.1	0	0	1.2	1.2	0	0
Total Organic Carbon	mg/L	0.17	12	1.2	1.5	0.30	22	1.7	1.8	0.10	6	1.3	1.4	0.1	7
TNVSS	mg/L	4	21	2	4	2	67	38	51	13	29	7	5	-2	-33
Total Suspended Solids	mg/L	4	12	3	5	2	50	44	58	14	27	9	6	-3	-40
Alkalinity, Total	mg/L	5	12	41	47	6	12	39	44	4	10	41	48	7	15
Turbidity	NTU	3.2	11	1.7	2.1	0.40	21	35	45	10	25	7.1	6.3	-0.8	-12
Conductivity	uS/cm	12	13	91	105	14	14	90	99	9	10	91	104	14	14
Naches-Cowiche Canal		Average		6-Aug-2013				10-Sep-2013				8-Oct-2013			
Parameter	Units	Diff	RPD	In	Out	Diff	RPD	In	Out	Diff	RPD	In	Out	Diff	RPD
Ammonia	ug/L	5	23	10 U	10 U	NC	NC	19	24	5	23	10 U	10 U	NC	NC
Nitrate-Nitrite as N	ug/L	7	9	47	39	-8	-19	57	77	20	30	49	57	8	15
Total Persulfate Nitrogen	ug/L	45	35	109	105	-4	-4	84	189	105	77	92	125	33	30
Ortho-Phosphate	ug/L	2	19	7.8	8.6	0.8	10	10.9	14.1	3.2	26	8.1	10.2	2.1	23
Total Phosphorus	ug/L	4	8	11.6	12.0	0.4	3	72.9	82.6	9.7	12	22.7	24.6	1.9	8
Dissolved Organic Carbon	mg/L	0.4	33	1 U	1.1	NC	NC	1 U	1.1	NC	NC	1	1.4	0.4	33
Total Organic Carbon	mg/L	0.1	6	1.1	1.1	0	0	1.6	1.9	0.3	17	1.1	1.1	0	0
TNVSS	mg/L	-1	-2	3	1 U	NC	NC	44	42	-2	-5	8	8	0	0
Total Suspended Solids	mg/L	-2	-42	4	1	-3	-120	51	48	-3	-6	10	10	0	0
Alkalinity, Total	mg/L	2	6	35	36	1	3	32	34	2	6	34	37	3	9
Turbidity	NTU	2.2	-9	1.6	1	-0.6	-46	38	45	7	17	7.6	7.8	0.2	3
Conductivity	uS/cm	4	5	79	81	2	3	71	74	3	4	74	81	7	9

Notes: U = Not detected
TNVSS = Total non-volatile suspended solids
NC = Not calculated due to one or more values being below reporting limit
In = Respective river diversion locations
Out = Respective canal outfall locations
Diff = Difference (outfall value - diversion value)
RPD = Relative Percent Difference
Diff and RPD not calculated if one or more pairs are non-detects

Field Measurements of Water Quality and Flow

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-FW-0B	6/18/2013 13:35				29.89		
37-FW-0B	7/9/2013 16:21	288.2	8.82		30.94	7.94	20.09
37-FW-0B	7/31/2013 10:57	297.2			20.13	7.58	17.3
37-FW-0B	8/7/2013 15:36	293.4	8.9		26.79	7.76	20.16
37-FW-0B	8/28/2013 10:02	302			25.17	7.68	17.42
37-FW-0B	9/11/2013 15:19	259.8	8.52		33.61	7.73	18.91
37-FW-0B	9/25/2013 10:32	285.2			20.64	7.69	14.97
37-FW-0B	10/9/2013 14:55	291.6	10.09		30.47	7.83	13.52
37-FW-0B	10/31/2013 15:00	355.8			14.97	7.47	14.49
37-FW-0B	11/13/2013 10:30	351.6	8.57	8.6	15.76	7.74 EST	12.49
37-FW-0B	11/27/2013 11:01	348.6			14.85	7.61	10.08
37-FW-0B	12/10/2013 14:15	344.2	9.31	9.2	14.38	7.42	9.84
37-FW-0B	3/5/2014 15:48	361.7	9.16		12.83	7.7	13.82
37-FW-0B	3/26/2014 14:03	313.2	11.82		4.63	8.23	13.5
37-FW-0B	4/30/2014 14:11	240.9	11.55		25.99	8.27	16.04
37-FW-0B	6/4/2014 13:55	236.8	10.63		25.4	8.21	18.41
37-FW-0B	6/4/2014 14:25	236.9	10.37	10.3		8.14	18.5
37-FW-13	3/4/2014 8:40	398.5	8.32		0.05	7.19	3.51
37-FW-1B	6/18/2013 11:00				22.65		
37-FW-1B	7/9/2013 15:24	276.7	10.01	10	26.06	8.2	20.02
37-FW-1B	7/31/2013 9:00	301.6			11.17	7.77	18.21
37-FW-1B	8/7/2013 14:00	282.7	9.44	9.3	19.2	7.94	20.39
37-FW-1B	8/28/2013 9:30	294.5			14.97	7.8	17.46
37-FW-1B	9/11/2013 14:00	235.4	8.75	8.7	27.47	7.8	18.54
37-FW-1B	9/25/2013 9:45	268.2	9.4	9.4	18.48	7.76	14.54
37-FW-1B	10/9/2013 13:00	273.7	10.74	10.7	18.68	7.89	12.05
37-FW-1B	10/31/2013 14:45	456	9.04	9.2	3.53	7.72	13.92
37-FW-1B	11/13/2013 12:30	461.1	10.03	10.1	3.42	7.76 EST	13.18
37-FW-1B	11/27/2013 9:30	456			2.71	7.63	9.75
37-FW-1B	12/11/2013 13:30	440.9	11.17	11	2.03	7.74	8.92
37-FW-1B	3/5/2014 14:15	562.1	14.26	14.4	1.99	8.43	12.78
37-FW-1B	3/26/2014 12:46	289.1	14.55		6.05	8.73	10.78
37-FW-1B	4/30/2014 12:30	195.5	12.37	12.1	20.14	8.34	13.25
37-FW-1B	6/4/2014 11:30	196.4	11.53	11.62	20.26	8.39	17.07
37-FW-1C	6/18/2013 9:55				8.54		
37-FW-1C	7/9/2013 14:00	275.8	9.61		5.02	8.03	19.67
37-FW-1C	7/30/2013 15:15	258.6			5.7	7.91	19.65
37-FW-1C	8/7/2013 11:41	281.6	9.41		7.95	7.98	19.94
37-FW-1C	8/28/2013 9:09	303.5			8.66	7.87	17.09
37-FW-1C	9/11/2013 11:45	234.7	9.13	9.2	9.35	7.82	18
37-FW-1C	9/25/2013 9:08	267.5			6.22	7.82	14.07
37-FW-1C	10/9/2013 11:39	273.7	11.04		6.24	8.07	11.23
37-FW-1C	10/31/2013 13:35	591.9			3.31	7.95	12.77
37-FW-1C	11/13/2013 11:47	608.6	10.22		4.42	8.15 EST	11.44
37-FW-1C	11/26/2013 15:52	622.9			3.1	8.16	8.1

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-FW-1C	12/11/2013 12:07	614.3	12.46		3.35	8.14	5.21
37-FW-1C	3/5/2014 13:05	659.9	14.59	14.6		8.38	12.07
37-FW-1C	3/26/2014 11:04	284.3	13.04		7.7	8.36	8.89
37-FW-1C	4/30/2014 11:02	190	11.23	11.2		7.96	11.74
37-FW-1C	6/4/2014 10:55	196.5	10.26		8.61	7.95	15.7
37-FW-1E	11/26/2013 16:00	620.7			1.12	8.19	7.91
37-FW-1E	12/11/2013 12:36				0.91		
37-FW-1E	3/5/2014 13:38				1.45		
37-FW-1E	3/26/2014 11:56	284.5	13.02		5.49	8.35	9.62
37-FW-1E	4/30/2014 11:47	190.3	11.29		21	8	12.09
37-FW-1E	6/4/2014 7:24	196.1	10.15		17	7.99	15.92
37-FW-2	6/18/2013 12:45				5.51		
37-FW-2	7/9/2013 15:50	257.4	11.46	11.1	5.99	8.08	21.03
37-FW-2	7/31/2013 10:27	252.5			3.61	7.48	16.59
37-FW-2	8/7/2013 15:30	267.6	10.19	10.3	6.86	7.5	20.36
37-FW-2	8/28/2013 10:32	271.4			3.78	7.39	17.47
37-FW-2	9/11/2013 13:15	268.7	10.21	10.1	4.41	7.47	18.85
37-FW-2	9/25/2013 9:59	273.1			4.66	7.39	15
37-FW-2	10/9/2013 10:30	279.8	9.4	9.4	7.8	7.34	13.49
37-FW-2	10/31/2013 14:28	290.8			4.33	7.47	14.21
37-FW-2	11/13/2013 11:25	283.6	9.12	9.1	7.05	7.62 EST	12.16
37-FW-2	11/27/2013 10:52	283.6			6.79	7.61	9.02
37-FW-2	12/10/2013 14:50	289	10.34	10.4	7.95	7.3	8.87
37-FW-2	3/5/2014 14:00	283.9	12.51		6.03	8.11	14.97
37-FW-2	3/26/2014 13:45	289.7	14.2		5.62	8.44	15.5
37-FW-2	4/30/2014 13:45	267.6	13.92		7.18	8.48	19.82
37-FW-2	6/4/2014 13:45	251.5	13.13		5.97	8.44	20.71
37-FW-2B	6/18/2013 12:11				2.19		
37-FW-2B	7/9/2013 15:50	387.9	4.27		1.7	6.99	16.14
37-FW-2B	7/31/2013 11:35	380.4			2.28	6.95	15.74
37-FW-2B	8/7/2013 15:06	386.5	5.6		2.82	6.97	16.4
37-FW-2B	8/28/2013 11:03	402.1			1.96	7	16.73
37-FW-2B	9/11/2013 14:32	396.9	5.21		3.1	7.02	17.14
37-FW-2B	9/25/2013 11:03	391.6			1.67	7.09	16.94
37-FW-2B	10/9/2013 14:05	395.6	5.58		2.61	7.11	16.36
37-FW-2B	10/31/2013 14:05	393.1			1.97	7.06	16.41
37-FW-2B	11/13/2013 12:25	390.4	6.41		2.28	7.32 EST	15.52
37-FW-2B	11/27/2013 10:19	389.4			1.63	7.26	14.42
37-FW-2B	12/10/2013 15:10	385.2	7.37		2.51	7.06	13.95
37-FW-2B	3/5/2014 15:09	373.6	7.56		2.2	7.2	14.04
37-FW-2B	3/26/2014 13:22	372.6	11.96		2.02	7.45	14.7
37-FW-2B	4/30/2014 13:15	370.6	12.19		2.01	7.28	16.25
37-FW-2B	6/4/2014 13:32	358.1	7.76		2.19	7.06	16
37-FW-3.5	3/26/2014 8:03				12.22		
37-FW-3.5	4/29/2014 15:17				26.54		
37-FW-3.5	6/3/2014 15:29				22.5		
37-FW-3B	6/18/2013 8:33				27.21		

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-FW-3B	7/9/2013 12:08	242.9	8.38		26.1	7.82	18.93
37-FW-3B	7/30/2013 16:23	222.9			26.25	7.73	19.97
37-FW-3B	8/7/2013 11:18	246.7	8.61	8.6	24.75	7.66	19.51
37-FW-3B	8/27/2013 15:13	266.8			19.16	7.71	17
37-FW-3B	9/11/2013 10:34	200.3	8.53		28.5	7.71	17.54
37-FW-3B	9/24/2013 15:24	221.9			21.49	7.72	14.99
37-FW-3B	10/9/2013 9:36	234	10.27		20.67	7.83	10.31
37-FW-3B	10/31/2013 13:00	614.4			2.88	7.67	11.88
37-FW-3B	11/13/2013 10:15	631.5	8.89	9	2.38	7.85 EST	10.91
37-FW-3B	11/26/2013 13:47	644.1			2.51	7.99	6.57
37-FW-3B	12/11/2013 11:04	632.1	12.08		2.55	7.93	3.75
37-FW-3B	3/5/2014 11:34	666.6	12.43		2.78	8.06	8.85
37-FW-3B	3/26/2014 9:33	248.5	11.63		11.7	8.07	7.9
37-FW-3B	4/30/2014 9:15	160.5	10.78		28.5	7.69	10.44
37-FW-3B	6/4/2014 9:09	162.2	9.13		27.6	7.65	14.71
37-FW-4	6/17/2013 14:55				23.97		
37-FW-4	7/9/2013 10:25	204.1	9.01		19.72	7.91	18.51
37-FW-4	7/30/2013 13:00	177.6			20.88	8.03	19.78
37-FW-4	8/7/2013 9:04	213.4	8.83		20.79	7.88	19.3
37-FW-4	8/27/2013 13:36	215.8			13.34	8.06	17.39
37-FW-4	9/11/2013 7:45	159.5	8.71	8.8	23.8	7.79	17.33
37-FW-4	9/24/2013 14:34	178.2			17.41	7.91	15.12
37-FW-4	10/9/2013 7:27	203.9	10.78	10.6	15.64	7.87	9.6
37-FW-4	10/31/2013 11:25	622.2			0.97	7.75	10.53
37-FW-4	11/13/2013 9:15	645.7	9.53	9.5	2.24	7.65 EST	11.04
37-FW-4	11/26/2013 12:58	664.2			1.08	7.98	5.56
37-FW-4	12/11/2013 9:11	663.67	11.69	12	3.66	7.72	3.84
37-FW-4	3/5/2014 10:00	677.8	11.88		2	7.97	8.99
37-FW-4	3/26/2014 7:39	228.5	10.97			7.69	7.35
37-FW-4	4/29/2014 14:55	144.5	11.24			8.05	11.62
37-FW-4	6/3/2014 14:37	143	9.35			7.78	16.63
37-FW-5B	6/17/2013 13:28				21.89		
37-FW-5B	7/9/2013 9:08	193.3	7.83	8.55	18.26	7.77	18.15
37-FW-5B	7/30/2013 12:31	167			18.92	7.87	19.89
37-FW-5B	8/7/2013 7:53	201.2	8.25	8.3	16.97	7.8	19.03
37-FW-5B	8/27/2013 13:05	206.8			11.7	7.59	17.92
37-FW-5B	9/10/2013 14:43	147.2	8.66	8.7	21.33	7.88	18.54
37-FW-5B	9/24/2013 13:45	171			15.64	7.93	15.18
37-FW-5B	10/8/2013 9:04	220.5	10.44	10.3	13.21	8.13	11.42
37-FW-5B	10/31/2013 13:33	672.6	9.51	9.4	1.86	8.09	9.73
37-FW-5B	11/12/2013 15:53	674.2	8.57	8.6	1.6	8.08 EST	11.23
37-FW-5B	11/26/2013 12:37	680.3			1.26	8.03	4.13
37-FW-5B	12/10/2013 15:30	676.2	12.24		2	8.01	1.46
37-FW-5B	3/5/2014 9:20	751.1	10.65		1.66	7.94	8.8
37-FW-5B	3/25/2014 15:00	206.8	11.42		11.9	8.25	9.41
37-FW-5B	4/29/2014 13:51	137.5	11.33		22.8	7.88	11.23
37-FW-5B	6/3/2014 14:12	139.7	9.03		17.64	7.81	16.81

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-FW-6B	6/17/2013 12:29				16.81		
37-FW-6B	7/8/2013 15:00	155.7	9.23		10.3	7.88	19.6
37-FW-6B	7/30/2013 11:00	147.5		8.9	18.03	7.77	19.37
37-FW-6B	8/6/2013 9:36	152.3		8.4			19.66
37-FW-6B	8/6/2013 14:30	149.8	8.44		10.74	8.11	21.7
37-FW-6B	8/27/2013 11:58	191.6			10.79	7.84	17.22
37-FW-6B	9/10/2013 13:06	139.7	8.91	8.8	23.29	7.74	18
37-FW-6B	9/24/2013 12:14	158.1			15.55	7.89	14.96
37-FW-6B	10/8/2013 13:45	209.9	11.06		11.05	7.98	11.38
37-FW-6B	10/31/2013 11:00	587.6	11.52	11.5	1.24	8.16	8.88
37-FW-6B	11/12/2013 14:15	618.3	12.33	12.4	1.25	8.41 EST	11.47
37-FW-6B	11/26/2013 11:41	622.9			1.07	8.17	3.53
37-FW-6B	12/10/2013 13:57	619.7	13.14	13		8.04	1.2
37-FW-6B	3/4/2014 14:30	668.7	13.6	14.5	1.31	8.42	10.2
37-FW-6B	3/25/2014 13:28	168.2	11.91	12	11.69	8.01	8.69
37-FW-6B	4/29/2014 12:45	128.6	11.95	12	21.01	8.25	10.94
37-FW-6B	6/3/2014 11:49	130.6	9.53	9.39	18.85	7.75	16.37
37-FW-8	6/17/2013 9:53				6.28		
37-FW-8	7/8/2013 10:52	128.9	7.88		3.83	7.69	18
37-FW-8	7/30/2013 8:52	124.1			5.35	7.7	18.5
37-FW-8	8/6/2013 9:52	132.7	8.36		6.11	7.69	19.52
37-FW-8	8/27/2013 9:17	143			7.33	7.65	15.5
37-FW-8	9/10/2013 8:56	124.2	8.68		8.17	7.68	16.56
37-FW-8	9/24/2013 10:20	125.1			7.23	7.41	14.3
37-FW-8	10/8/2013 10:05	128.1	10.38		7.19	7.77	10.34
37-FW-8	10/31/2013 8:40	330.9			0.02	7.89	15.16
37-FW-8	3/4/2014 10:55	400	14.74		0.32	8.41	3.93
37-FW-8	3/25/2014 9:41	116.7	11.74		12.2	7.83	6.75
37-FW-8	4/29/2014 9:03	107.3	12.05		9.33	8.1	9.15
37-FW-8	6/3/2014 9:00	104.2	9.22		10.57	7.64	14.54
37-IS-12C	6/18/2013 9:15				1.6		
37-IS-12C	7/9/2013 13:03	605.1	3.84		2.08	6.98	13.98
37-IS-12C	7/30/2013 16:45	441.7			1.74	7.04	14.48
37-IS-12C	8/7/2013 11:35	566.4	6.33		2.81	7	14.65
37-IS-12C	8/27/2013 15:36	577.1			1.63	7.03	15
37-IS-12C	9/11/2013 11:28	570.4	5.3	5.3	2.18	7	15.17
37-IS-12C	9/24/2013 15:50	569.3			2.11	7.05	15.46
37-IS-12C	10/9/2013 10:15	573.1	5.37	5.4	1.8	7.15	15.3
37-IS-12C	10/31/2013 12:35	585.6			1.45	7.06	15.41
37-IS-12C	11/13/2013 10:56	591.7	5.48	5.8	1.26	7.18 EST	15.3
37-IS-12C	11/26/2013 14:04	602.1			1.57	7.25	14.95
37-IS-12C	12/11/2013 11:30	604.13	5.72	5.8	1.37	7.24	14.72
37-IS-12C	3/5/2014 12:04	640.7	5.8		1.2	7.16	13.24
37-IS-12C	3/26/2014 10:01	652.5	6.11	6.2	0.86	7.19	13.04
37-IS-12C	4/30/2014 9:43	642.9	5.9	5.9	1.48	7.05	13.05
37-IS-12C	6/4/2014 9:29	638.9	5.97	6.16	1.31	7.07	13.56
37-IS-13	7/9/2013 14:25	679	7.74		0.49	7.1	16.91

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-IS-13	8/7/2013 12:30	592.2	7.01	7	1.15	6.89	14.8
37-IS-13	9/11/2013 9:50	538.8	6.49		0.57	6.98	15.29
37-IS-13	10/9/2013 8:15	527.5	6.47	6.6	0.95	7.24	15.52
37-IS-13	11/12/2013 11:10	520.5	6.33		0.35	7.35 EST	15.35
37-IS-13	12/10/2013 9:30	544.6	7.07	7.07	0.11	7.02	12.88
37-IS-13	3/5/2014 10:30	738.9	8.52	8.5	0.18	7.34	13.8
37-IS-13	3/26/2014 10:00	729.8	8.26		0.16	7.35	12.82
37-IS-13	4/30/2014 9:50				0.02		
37-IS-13	6/4/2014 10:10	777.5	6.55		0.11	7	13.83
37-IS-15	9/10/2013 15:00	807.9	7.66		0.34	7.62	17.61
37-IS-15	10/8/2013 10:15		8.31		0.28	8.07	16.99
37-IS-15	10/22/2013 13:20	855.8	8.12 EST	8.3	0.12	8.06	16.47
37-IS-15	11/12/2013 10:20	871.9	7.99		0.05	8.04 EST	15.78
37-IS-15	12/10/2013 10:25	865	7.97		0.06	7.7	13.81
37-IS-15	3/5/2014 9:25	1089	8.15		0.03	7.9	11.31
37-IS-16	6/17/2013 8:25				5.76		
37-IS-16	7/8/2013 9:06	96.8	9.09			7.85	17.75
37-IS-16	8/6/2013 7:45	105.1	8.77			7.87	19.62
37-IS-16	8/19/2013 12:30	97.5		9.4		8.34	19.23
37-IS-16	9/10/2013 7:45	98.6	9.28			7.85	16.59
37-IS-16	9/24/2013 9:20	106	10.2	10.2		8.09	14.5
37-IS-16	10/8/2013 8:53	104.4	11.01	10.9		7.96	10.23
37-IS-16	3/25/2014 8:06	93.3	11.73	11.8		7.67	6.25
37-IS-16	4/29/2014 7:51	91.1	11.59			7.72	8.45
37-IS-16	6/3/2014 7:35	88.9	10.05	9.9		7.74	13.53
37-IS-16B	6/17/2013 9:03				6.37		
37-IS-16B	7/8/2013 9:47	120.9	8.67	8.95	3.26	7.6	17.95
37-IS-16B	7/30/2013 7:50	117.5			3.7	7.57	18.54
37-IS-16B	8/6/2013 8:45	118	8.59	8.6	3	7.68	19.57
37-IS-16B	8/19/2013 11:56				6.41		
37-IS-16B	8/27/2013 9:05	112.2			5.66	7.74	15.72
37-IS-16B	9/10/2013 8:00	108.4	9.08	9.1	6.1	7.61	16.54
37-IS-16B	9/24/2013 9:07	113			5.17	7.93	14.24
37-IS-16B	10/8/2013 9:15	115.5	10.92		4.57	7.84	10.38
37-IS-16B	10/22/2013 10:02	483.9	7	7.4	0.22	7.3	10.93
37-IS-16B	10/31/2013 9:45	481.6	6.42	6.4	0.14	7.27	9.89
37-IS-16B	11/12/2013 9:45	478.3	6.61	6.3	0.06	7.23 EST	11.16
37-IS-16B	11/26/2013 9:45	481.8			0.17	7.3	5.3
37-IS-16B	12/10/2013 9:31	480.16	6.88	6.8	0.12	7.19	4.2
37-IS-16B	3/4/2014 9:40	401.9	10.34	10.3	0.3	7.36	4.92
37-IS-16B	3/4/2014 10:15	402	10.5	10.4		7.41	5.4
37-IS-16B	3/25/2014 9:00	102.3	11.58	11.6	12.99	7.75	6.33
37-IS-16B	4/29/2014 8:15	102.1	11.62	11.7	6.9	7.63	8.57
37-IS-16B	6/3/2014 8:30	94	10.13	10.1	8.2	7.8	13.74
37-IS-16C	8/7/2013 8:15	91.1	9.37			7.51	16.27
37-IS-16C	9/10/2013 8:30	89.6	9.39			7.44	14.96
37-IS-16C	10/8/2013 7:50	90.6	10.72	10.7		7.22	9.08

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-IS-16D	7/8/2013 9:25	455.4	6.98		0.11	7.3	17
37-IS-16D	7/30/2013 8:05	406.5			0.07	7.22	15.5
37-IS-16D	8/6/2013 7:55	460.5	5.71		0.1	7.17	15.29
37-IS-16D	8/27/2013 8:42	474.2			0.09	7.17	15.23
37-IS-16D	9/10/2013 7:53	474.4	3.67			7.18	14.74
37-IS-16D	9/24/2013 9:00	416.5	5.63		0.02	7.28	13.03
37-IS-16D	10/8/2013 8:57	464.9	6.32		0.05	7.26	10.67
37-IS-16D	10/31/2013 7:40	453			0.05	7.15	8.05
37-IS-16D	3/4/2014 9:25	395.2	9.93		0.23	7.29	4.45
37-IS-16D	3/25/2014 8:17	397	8.35		0.24	7.32	6.51
37-IS-16D	4/29/2014 7:57	386.9	9.73		0.19	7.26	8.76
37-IS-16D	6/3/2014 7:49	396.9	7.83		0.06	7.29	13.52
37-IS-17	6/17/2013 12:55				0.87		
37-IS-17	7/8/2013 16:17	534.3	7.87	8.3	0.57	7.76	16.43
37-IS-17	7/30/2013 11:35	536.9			0.45	7.74	17.85
37-IS-17	8/6/2013 14:58	539	8.28	8.2 EST	0.52	7.7	18.22
37-IS-17	8/19/2013 14:24	366.9			0.94	7.69	18.1
37-IS-17	8/27/2013 12:22	432.4			0.57	7.87	17.25
37-IS-17	9/10/2013 14:01	511.8	8.29		0.51	7.75	17.31
37-IS-17	9/24/2013 13:20	553	8.46	8.3	0.48	7.71	16.51
37-IS-17	10/8/2013 14:33	695.2	8.65		0.38	8	15.42
37-IS-17	10/22/2013 12:10	932.2	8.43 EST		0.28	7.99	16.45
37-IS-17	10/31/2013 10:05	928.8			0.37	8.05	16.29
37-IS-17	11/12/2013 15:01	939.9	8.45		0.22	8.15 EST	15.85
37-IS-17	11/26/2013 12:07	945.6			0.24	8.1	14.8
37-IS-17	12/10/2013 14:59	946.5	8.9		0.26	8.08	13.95
37-IS-17	3/5/2014 8:39	1166	7.91	7.9	0.33	7.68	11.87
37-IS-17	3/25/2014 14:05	953.8	8.7		0.34	7.93	12.17
37-IS-17	4/29/2014 13:12	418.5	9.88		0.79	7.69	10.12
37-IS-17	6/3/2014 13:37	438.5	8.92		0.55	7.59	13.56
37-IS-17.5	6/17/2013 12:00				0.44		
37-IS-17.5	7/8/2013 14:30	262	8.48		0.46	8.38	29.04
37-IS-17.5	7/30/2013 10:37	251.8			0.48	7.2	22.68
37-IS-17.5	8/6/2013 13:43	235.1	7.28		0.55	7.87	28.52
37-IS-17.5	8/27/2013 11:35	235.9			0.57	7.49	19.75
37-IS-17.5	9/10/2013 12:46	282.8	6.46		0.55	7.68	23.36
37-IS-17.5	9/24/2013 11:58	264.8			0.38	7.99	15.58
37-IS-17.5	10/8/2013 13:15	270.1	7.1		0.34	7.73	11.85
37-IS-17.5	10/31/2013 10:32	560.5			0.02	7.73	5.34
37-IS-17.5	11/12/2013 12:21	589.1	4.78		0.02	7.7 EST	9.65
37-IS-17.5	11/26/2013 10:46	770.7			0.03	7.98	1.34
37-IS-17.5	12/10/2013 12:28	801	9.07		0.02	7.77	0.38
37-IS-17.5	3/4/2014 13:55	812.6	12.52		0.06	8.49	5.94
37-IS-17.5	3/25/2014 12:45	575.8	4.56	4.6	0.06	7.77	11.44
37-IS-17.5	4/29/2014 12:01	296.9	5.62	5.5	0.21	7.55	16.8
37-IS-17.5	6/3/2014 12:12	304.5	8.18		0.36	7.98	23.43
37-IS-20A	6/18/2013 7:40				0.95		

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-IS-20A	7/9/2013 10:33	59.7	9.17		0.67	7.76	18.49
37-IS-20A	7/30/2013 13:33	54.8			1.64	8.33	19.63
37-IS-20A	8/27/2013 12:05	55			1.55	8.11	17.07
37-IS-20A	9/11/2013 8:14	68	10.3		1.49	7.56	17.68
37-IS-20A	9/24/2013 14:06	76.4			0.67	8	15.49
37-IS-20A	10/9/2013 8:18	79	11.37		1.52	7.96	10.09
37-IS-20A	4/30/2014 8:00	71.9	11.88		0.91	7.65	9.21
37-IS-20A	6/4/2014 6:56	60.4	10.58		1.32	7.52	13.37
37-IS-20B	7/9/2013 10:55	70.7	9.47			7.99	18.44
37-IS-20B	8/6/2013 13:40	80.9	9.23		0.84	8.72	20.1
37-IS-20B	8/19/2013 15:08	70.7			2.1	8.52	18.12
37-IS-20B	9/10/2013 9:30	73.9	9.22			7.75	16.72
37-IS-20B	9/24/2013 14:07	99				8.14	15.2
37-IS-20B	10/8/2013 9:15	81.3	10.57			7.84	10.65
37-IS-20B	4/30/2014 8:15	71.9	11.06			7.52	8.65
37-IS-20B	6/4/2014 8:20	57.1	10.19			7.51	12.29
37-IS-20C	8/7/2013 7:35	78.8	9.16			7.77	17.55
37-IS-20C	9/10/2013 9:00	71.2	9.55			7.73	15.57
37-IS-20C	10/8/2013 8:25	74	11			7.68	9.21
37-IS-20D	8/7/2013 9:45	79.1	8.88			7.77	19.83
37-IS-20D	6/4/2014 8:00				1.24		
37-IS-21	7/9/2013 9:21	254.6	6.98		1.3	6.84	14.93
37-IS-21	8/7/2013 14:05	239.6	5.07	5.1	1.36	6.77	16.69
37-IS-21	9/11/2013 8:00	241	4.59	4.6	1.15	6.89	18.2
37-IS-21	10/9/2013 12:35	220.1	6.01	5.9		6.88	15.97
37-IS-21	10/9/2013 12:36	220.4	6		1.99	6.71 EST	15.9
37-IS-21	11/12/2013 12:40	283.8	6.1	6.1	1.68	6.89 EST	16.65
37-IS-21	12/10/2013 11:30	286.2	7.84	7.9	1.31	6.85	15.67
37-IS-21	3/5/2014 13:00	304.2	9.87		1.08	7.23	12.52
37-IS-21	3/26/2014 12:40	302	9.7		0.4	7.16	12.4
37-IS-21	4/30/2014 12:15	299.6	9.23		0.54	6.9	12.9
37-IS-21	6/4/2014 12:30	208.9	7.98		0.72	6.98	14.63
37-IS-21.5	11/26/2014 14:45	622.8			4.12	7.85	9.07
37-IS-22	6/19/2013 10:15				0.89		
37-IS-22	7/9/2013 8:27	456.5	9.05		0.3	7.81	19.22
37-IS-22	7/30/2013 16:00	298.2			0.06	7.85	24.42
37-IS-22	8/7/2013 13:00	381.9	8.16		0.02	7.75	23.3
37-IS-22	9/11/2013 11:10	344	8.52		0.03	7.73	21.2
37-IS-22	9/24/2013 15:07	382.8			0.05	8.06	16.76
37-IS-22	10/9/2013 9:15	476.9	9.87		0.03	8.28	14.81
37-IS-22	10/22/2013 14:16	451.2	9.85 EST		0.09	8.57	12.71
37-IS-22	10/31/2013 12:20	477.7			0.06	8.13	8.74
37-IS-22	3/26/2014 15:05	315.6	7.76		4.79	6.91	13.84
37-IS-22	4/30/2014 11:15	355.8	9.31		0.19	7.6	15.67
37-IS-22	6/4/2014 10:55	434	9.27		0.19	8.88	20.2
37-IS-23	6/18/2013 8:10				0.31		
37-IS-23	7/9/2013 11:03	400.4	10.39		0.17	7.66	15.81

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-IS-23	7/30/2013 14:32	253.52			1.5	7.49	20.43
37-IS-23	8/27/2013 14:41	352.5			0.47	7.5	17.78
37-IS-23	9/11/2013 9:00	409.2	7.55		0.06	7.63	15.82
37-IS-23	12/11/2013 10:20	480.8	12.13		0.03	8.92	5.43
37-IS-23	3/5/2014 10:55	486.1	13.13		1.17	8	11.4
37-IS-23	3/26/2014 8:14	422	12.23		0.84	7.9	8.24
37-IS-23	4/30/2014 8:41	268.4	12.57		1.21	7.86	11.14
37-IS-23	6/4/2014 7:45	470.1	9.76		0.07	7.78	13.25
37-IS-26	6/19/2013 12:20				1.19		
37-IS-26	7/9/2013 12:25	204.4	9.22		0.25	7.93	18.86
37-IS-26	7/9/2013 12:45		9.13	8.8			
37-IS-26	7/30/2013 14:05	158.9			0.06	7.93	19.5
37-IS-26	8/6/2013 15:10	172.6	8.51		0.4	7.93	20.65
37-IS-26	8/27/2013 14:23	233.3			0.64	8.09	17.03
37-IS-26	9/10/2013 14:00	165.5	8.95		0.15	7.77	17.92
37-IS-26	9/24/2013 14:19	189			0.8	8.01	15.05
37-IS-26	10/8/2013 12:15	209.9	10.47		0.46	8.12	11.33
37-IS-26	10/22/2013 12:55	547			0.4	8.29	10.95
37-IS-26	10/31/2013 12:06	657.9			0.08	8.2	10.31
37-IS-33	7/8/2013 12:15	91.1	8.41			8.46	20.06
37-IS-33	8/7/2013 9:00	97.7	9.02			7.87	18.17
37-IS-33	9/10/2013 12:25	97.9	9.14			7.98	18.77
37-IS-33	10/9/2013 7:30	100.6	11.1	11.1		7.95	9.07
37-IS-33	6/4/2014 7:20	87.6	9.78			7.1	14.4
37-IS-33.5	8/7/2013 17:15	188.8	7.79			7.18	20.75
37-IS-33.5	9/10/2013 12:00	158.2	8.63			7.31	17.42
37-IS-33.5	9/11/2013 8:45	154.2	8.3	8.2		7.41	17.22
37-SS-11	6/17/2013 11:34				17.18		
37-SS-11	7/8/2013 13:45	142	9.77	9.75	12.63	8.07	19.11
37-SS-11	7/30/2013 10:05	141.8			18.84	7.72	18.92
37-SS-11	8/6/2013 13:11	134.1	8.92	9	12.57	7.86	20.81
37-SS-11	8/27/2013 11:05	183.1			10.45	7.8	16.68
37-SS-11	9/10/2013 12:03	135.6	9.14		21.55	7.77	17.54
37-SS-11	9/24/2013 11:28	153.2			16.13	7.85	14.75
37-SS-11	10/8/2013 12:47	203.8	11.31	11.1	11.23	7.91	11.27
37-SS-11	10/31/2013 9:45	615			1.18	7.88	7.71
37-SS-11	11/12/2013 11:25	639.4	10.87		1.26	8.17 EST	10.57
37-SS-11	11/26/2013 10:22	640.5			1	8.02	2.94
37-SS-11	12/10/2013 11:42	644.1	12.93		1.01	8	1.29
37-SS-11	3/4/2014 13:00	732.8	16.08	15.8	1.3	8.51	9.19
37-SS-11	3/25/2014 11:50	163.7	12.29		11.93	7.92	8.37
37-SS-11	4/29/2014 11:07	125.9	12.31	12.3	21.66	8.16	9.96
37-SS-11	6/3/2014 11:19	127.1	9.63		19.95	7.75	15.56
37-SS-11B	3/4/2014 13:25	495.7	5.13		0.19	7.09	11.17
37-SS-11B	3/25/2014 12:15	496.2	5.78		0.15	7.07	10.96
37-SS-11B	4/29/2014 11:17	477.2	6.83	7	0.19	6.95	11.1
37-SS-11B	6/3/2014 11:30	457.1	7.25	7.17	0.16	6.8	11.65

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-SS-12	7/8/2013 12:05	155.1	7.8		8.15	7.47	18.62
37-SS-12	7/11/2013 6:45			8 EST			
37-SS-12	7/30/2013 9:30	145			8.11	7.5	18.4
37-SS-12	8/6/2013 11:34	132.8	8.51		10.05	7.81	20.56
37-SS-12	8/27/2013 10:13	153.2			8.59	7.4	15.56
37-SS-12	9/10/2013 9:30	133.9	8.45		11.52	7.58	16.78
37-SS-12	9/24/2013 11:17	131.1			13.01	7.35	14.34
37-SS-12	10/8/2013 11:05	159.1	10		9.79	7.46	10.4
37-SS-12	10/31/2013 9:10	507.8			0.08	7.1	10.94
37-SS-12	11/12/2013 10:25	542.2	5.53	6.2	0.34	7.16 EST	12.6
37-SS-12	11/26/2013 9:46	460			0.08	7.12	7.83
37-SS-12	12/10/2013 10:48	459.9	4.58		1.03	7.04	6.99
37-SS-12	3/4/2014 11:25	460.3	9.54		0.87	7.13	8.69
37-SS-12	3/25/2014 10:19	121.1	11.22		12.78	7.61	6.78
37-SS-12	4/29/2014 9:30	127.8	10.69		10.56	7.43	8.92
37-SS-12	6/3/2014 9:37	123.9	8.14		13.27	7.33	15.41
37-SS-15	7/11/2013 9:50		9.18 EST	9.2 EST			
37-SS-38	6/17/2013 11:11				0.72		
37-SS-38	7/8/2013 12:13	165.3	7.76		0.89	7.02	17.61
37-SS-38	7/30/2013 9:25	224.1			0.28	7.03	18.3
37-SS-38	8/6/2013 11:59	172.4	8.02		0.52	6.89	18.98
37-SS-38	8/19/2013 13:35	221.9			0.45	7.02	18.75
37-SS-38	8/27/2013 10:33	287.9			0.45	6.95	16.29
37-SS-38	9/10/2013 10:07	212.1	8.24		0.46	7.06	16.93
37-SS-38	9/24/2013 12:35	224.1	8.38		0.75	6.87	16.69
37-SS-38	10/8/2013 11:23	408.5	8.56		0.36	7.12	14.13
37-SS-38	10/22/2013 11:22	773.2	8.8 EST		0.1	7.25	15.98
37-SS-38	10/31/2013 9:23	761.2			0.08	7.83	16.11
37-SS-38	11/12/2013 10:46	725	9.28		0.07	7.69 EST	15.9
37-SS-38	11/26/2013 10:00	749			0.07	8.25	15.45
37-SS-38	12/10/2013 10:57	746	9.75		0.04	8.26	14.79
37-SS-38	3/4/2014 11:48	1143	9.73		0.03	8.03	12.51
37-SS-38	3/25/2014 10:40	491.4	9.73		0.06	7.25	10.97
37-SS-38	4/29/2014 10:15	190.2	10.52		0.44	7.22	9.4
37-SS-38	6/3/2014 10:04	176	9.22		0.33	7	13.25
37-SS-48	6/17/2013 11:08				2.08		
37-SS-48	7/8/2013 12:15	91.7	8.67		2.91	7.62	17.91
37-SS-48	7/30/2013 9:30	99.5			1.72	7.44	18.18
37-SS-48	8/6/2013 12:03	99.9	8.77		2.76	7.7	19.55
37-SS-48	8/19/2013 13:16	108.1			1.76	7.62	18.37
37-SS-48	8/27/2013 10:35	109.6			2.14	7.66	15.83
37-SS-48	9/10/2013 10:04	104.1	9.32		2.01	7.61	16.31
37-SS-48	9/24/2013 11:14	103.8			1.15	7.61	14.85
37-SS-48	9/24/2013 12:45	103.2 EST	9.5			7.42	15.2
37-SS-48	10/8/2013 11:36	100.9	10.65		1.02	7.54	10.49
37-SS-48	3/25/2014 10:35	87.4	11.72		0.62	7.7	6.21
37-SS-48	4/29/2014 10:06	88.1	11.61		1.17	8.11	8.33

Table C-3. Field measurements of water quality and flow.

Location ID	Date and Time	Sp. Cond (uS/cm)	DO (LDO) (mg/l)	DO (Winkler) (mg/l)	Flow (cfs)	pH (s.u.)	Temp (deg C)
37-SS-48	6/3/2014 9:58	87.9	9.98		1.25	7.41	12.95
37-SS-6	9/11/2013 11:00	152.6	7.84			8.03	22.26
37-SS-6	10/9/2013 9:54	109.9	8.92			8.14	17.99

Appendix D. Data Quality

Ecology Study Data Usability

All flow, water temperature and water quality data collected by Ecology in 2013 and 2014 for the Wide Hollow Creek study are credible data as described in Ecology's Water Quality Policy 1-11 (Ecology, 2006):

- Data were collected under appropriate quality assurance (QA) and quality control (QC) procedures (see Tables D-1 and D-14).
- Data are representative of the water quality conditions at the time the data were collected.
- Data consist of an adequate number of samples.
- Data collection methods conformed to generally accepted methods and protocols in the scientific community.
- Data interpretation, statistical, and modeling methods used were acceptable in the scientific community as appropriate for use in assessing the condition of the water.

Table D-1 shows the qualification of Ecology-collected data used in the Wide Hollow study. Ecology verified that all data met the data quality objectives established in the study QAPP (Carroll, 2013). Overall, the QA review showed the Ecology data were properly qualified, met the data quality objectives for this water quality study, and were found to be appropriate for its intended use.

Table D-1. Qualification of Ecology data used in the Wide Hollow Creek study.

Data Set	Source	Year	Peer Review / Quality Control	Approved QAPP?	Formal SOPs?	QAPP reference
Discharge on Wide Hollow Creek (4 sites) and one diversion	ECY	2013-14	Yes	Yes	Yes	Ecology (2018)
Continuous water quality measurements (3 sites)	ECY	2013-14	Yes	Yes	Yes	Carroll (2013)
Synoptic water quality surveys	ECY	2013-14	Yes	Yes	Yes	Carroll (2013)
Continuous Temperature – Water	ECY	2013-14	Yes	Yes	Yes	Dugger (2013)
Continuous Temperature – Air	ECY	2013-14	Yes	Yes	Yes	Dugger (2013)

QAPP: Quality Assurance Project Plan
SOPs: Standard Operating Procedures

Data Quality Objectives for Ecology Study Data

Data collected for the Wide Hollow Creek water quality study were evaluated to determine whether data quality objectives for the project were met. QA of sample data was completed by comparing the replicate precision statistic, the pooled relative standard deviation (RSD) - to the established measurement quality objective (MQO) for each parameter (Table D-2) from the project QAPP (Carroll, 2013).

QA for field measurement data (instantaneous measurements of flow, temperature, conductivity, dissolved oxygen, and pH) was completed by comparing instrument post-calibration checks to the target measurement quality objectives (MQO) for each parameter (Table D-3) from the project QAPP (Carroll, 2013).

QA of continuous dissolved oxygen and pH time series data is presented in a separate section below, as is the continuous water temperature time series data.

Table D-2. Measurement quality objectives for laboratory analysis parameters.

Analysis	Method	Method Lower Reporting Limit[2]	Lab Blank Limit	Check Standard (% recovery limits)	Matrix Spikes (% recovery limits)	Precision – Lab Duplicates (RPD)	Precision – Field Duplicates (median)[1]
Total Alkalinity	SM2320	5 mg/L	<½ RL	80-120%	n/a	20%	10% RSD
Chloride	EPA 300.0	0.1 mg/L	<MDL	90-110%	75-125%	20%	5% RSD
Dissolved Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Persulfate Nitrogen	SM4500NO3B	0.025 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Ammonia	SM4500NH3H	0.01 mg/L	<½ RL	80-120%	75-125%	20%	10% RSD
Nitrate/Nitrite	SM4500NO3I	0.01 mg/L	<½ RL	80-120%	75-125%	20%	10% RSD
Orthophosphate	SM4500PG	0.003 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Phosphorus	SM4500PF	0.005 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Turbidity	SM2130	0.5 NTU	<1/10th RL	90-105%	n/a	20%	15% RSD
Total Suspended Solids	SM2540D	1 mg/L	±0.3 mg	80-120%	n/a	20%	15% RSD

RL: reporting limit
MDL: method detection limit
RPD: relative percent difference
[1] field duplicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately
[2] reporting limit may vary depending on dilutions

Table D-3. Measurement quality objectives for Hydrolab post-deployment and fouling checks.

Parameter	Units	Accept	Qualify	Reject
pH	std. units	< or = + 0.2	> + 0.2 and < or = + 0.8	> + 0.8
Conductivity*	uS/cm	< or = + 5%	> + 5% and < or = + 15%	> + 15%
Temperature	° C	< or = + 0.2	> + 0.2 and < or = + 0.8	> + 0.8
Dissolved Oxygen**	% saturation	< or = + 5%	> + 5% and < or = + 15%	> + 15%

* Criteria expressed as a percentage of readings: for example, buffer = 100.2 uS/cm and Hydrolab = 98.7 uS/cm; (100.2-98.7)/100.2 = 1.49% variation, which would fall into the acceptable data criteria of less than 5%.

**When Winkler data are available, they will be used to evaluate acceptability of data in lieu of % saturation criteria.

Quality Assurance for Ecology Water Samples

Ecology took replicate samples in the field to assess sample precision and overall variability. Field replicates are two samples collected from the same location and as close to the same time as possible. Ecology collects field replicates as a normal QA and QC measure (MEL, 2008).

Manchester Environmental Laboratory (MEL) processed all the samples for the Wide Hollow Creek study. MEL prepared QA memos for each sampling survey. Each memo summarized the laboratory QC procedures and results for sample transport and storage, sample holding times, and instrument calibration and laboratory QC procedures, including a report of all check standards, matrix spikes, method blanks, and laboratory duplicate samples.

With few exceptions, all samples were received by MEL from the field in good condition and were properly preserved, as necessary. The temperature of the shipping coolers was between proper ranges of 2°C - 6°C for all sample shipments except one cooler received at MEL on May 1, 2014. On that day, one cooler had an ambient temperature of 8°C. The samples from that cooler on that were qualified as estimates for being out of range.

Holding times were violated only once throughout the project, because the samples were held too long at MEL before analysis. This was for orthophosphate samples received on August 20, 2013. MEL qualified them as estimates. Some total suspended solids, total non-volatile suspended solids, and turbidity samples throughout the project frequently contained fast settling sand. For those samples, MEL qualified the results as estimates.

For the most part, data quality for this project met all laboratory QC criteria as determined by MEL QA procedures (MEL, 2012). Individual samples that had a QA issue that caused the results to be qualified were marked by MEL with a “J” qualifier (signifying an estimate) in the data tables. Results not detected at or above the reporting limits listed in Table D-2 were qualified by MEL with a “U”.

Analytical Precision (Laboratory Duplicates)

Analytical laboratory precision was determined separately in order to account for its contribution to total precision. Analytical laboratory precision was based on laboratory duplicates while total precision was based on field replicates.

Because higher %RSD is expected near the reporting limit, two tiers were evaluated. Duplicate results less than five times the reporting limit (lower tier) were considered separately from duplicate results equal to or more than five times the reporting limit (upper tier).

A pooled relative standard deviation (%RSD) was calculated for each parameter (Table D-4). Data below the reporting limit were excluded from consideration in determining analytical precision. The %RSD in the upper tier was compared to the measurement quality objective (MQO) or the precision target for each parameter for determination of whether there was unacceptable variability in duplicate precision.

Analytical precision for all parameters (Table D-4) was better than the MQO precision targets, with only total persulfate nitrogen showing a RSD over 5%, which is well below the MQO target RSD of 10%.

Table D-4. Lab precision results for the Wide Hollow Creek Water Quality Study for Aquatic Life Use. *Results at the detection limit were excluded from consideration.*

Parameter	Number of Samples	Number of Replicates	% Replicated	Target Precision[1]	Average %RSD	
					<5X DL	≥5X DL
Alkalinity	270	25	9	<10	–	0.5
Ammonia-Nitrogen	270	11	4	<10	3.5	0.8
Chloride	270	28	10	<5	1.4	0.4
Dissolved Organic Carbon	270	16	6	<10	1.2	–
Nitrite-Nitrate Nitrogen	270	21	8	<10	4.6	0.8
Total Non-Volatile Suspended Solids	270	42	16	–	0	3.4
Total Organic Carbon	270	24	9	<10	4.2	–
Total Phosphorus	270	21	8	<10	–	1.8
Total Persulfate Nitrogen	270	28	10	<10	4.9	7.2
Total Suspended Solids	270	40	15	<15	–	3.7
Turbidity	270	34	13	<15	3.2	0.8
Orthophosphate	270	24	9	<10	–	0.6

[1]Target for precision was not specified for Total Non-Volatile Suspended Solids.

MEL also has its own qualification for lab duplicates, with a target precision of less than 20% of a pooled relative percent difference (RPD) of duplicate pairs. RPD targets were also met (Table D-5), with only total persulfate nitrogen showing a RPD over 10%, which is also well below the MEL target RPD of 20%.

Table D-5. Precision for Lab Duplicates RPD for the Wide Hollow Creek Water Quality Study for Aquatic Life Use.

Parameter	Target Precision RPD (%)	Lab Duplicates RPD (%)	
		<5X DL	≥5X DL
Alkalinity	20	–	0.8
Ammonia	20	3.4	1.2
Chloride	20	1.9	0.8
Dissolved Organic Carbon	20	1.5	–
Nitrate-Nitrite	20	6.5	1.2
Total Non-Volatile Suspended Solids	20	–	4.2
Total Organic Carbon	20	3.3	–
Total Phosphorus	20	–	1.9
Total Persulfate Nitrogen	20	5.1	11.4
Total Suspended Solids	20	–	4
Turbidity	20	3.8	1.8
Orthophosphate	20	–	1.5

Total Precision (Field Replicates)

As was done for the analytical precision assessment, two tiers were also evaluated for total precision: field-replicate results less than five times the reporting limit (lower tier) and field-replicate results equal to or more than five times the reporting limit (higher tier). A %RSD was calculated for each parameter tier (Table D-6). Data below the reporting limit were excluded from consideration in determining analytical precision.

The %RSD in the upper tier was compared to the measurement quality objectives (MQO) to help determine whether there was unacceptable variability for any one parameter.

Overall, the %RSD for field replicates were higher than the analytical %RSD because %RSD for field replicates is a measurement of total variability, including both field and analytical variability.

Higher tier precision for nitrite-nitrate nitrogen and total persulfate nitrogen did not meet the MQO precision targets, both slightly over the target by about 3%. Precision for alkalinity and chloride were just slightly above their MQO targets.

The analytical precision for total persulfate nitrogen had about 7% RSD compared to a total precision of about 13% RSD. Variability associated with the analytical precision from the laboratory may account for half of the total variability observed for this parameter.

Overall, total precision was rather good, with most of the variability related to field replicate variability rather than analytical variability. This is because concentrations for parameters within field replicate samples can be inherently variable because of patchy distributions in the environment and intermittent discharge. Total persulfate nitrogen and nitrate were not qualified, but the data variability for the two parameters can be taken into consideration when using the data for modeling and for interpreting results. For this study, it is unlikely that the total variability for these two parameters impacted model simulations of biological productivity because these nutrients were well above limiting concentrations.

Table D-6. Total precision (field and lab) results for the Wide Hollow Creek Water Quality Study for Aquatic Life Use. *Results at the detection limit were excluded from consideration*

Parameter	Number of Samples	Number of Replicates	% Replicated	Target Precision[1]	Average %RSD	
					<5X DL	≥5X DL
Alkalinity	270	38	14	<10	–	10
Ammonia-Nitrogen	270	31	11	<10	12.3	3.3
Chloride	270	39	14	<5	–	5.2
Dissolved Organic Carbon	270	39	14	<10	7.7	–
Nitrite-Nitrate Nitrogen	270	37	14	<10	5.4	12.3
Total Non-volatile Suspended Solids	270	34	13	<15	11.5	14.5
Total Organic Carbon	270	37	14	<10	4.9	–
Total Phosphorus	270	39	14	<10	–	2.7
Total Persulfate Nitrogen	270	39	14	<10	8.8	13
Total Suspended Solids	270	39	14	<15	21.1	9
Turbidity	270	38	14	<15	33.4	7.5
Orthophosphate	270	39	14	<10	–	2.9

[1]Target for precision was not specified for Total Non-Volatile Suspended Solids.

Analytical Bias

Analytical bias was evaluated by analyzing laboratory control samples once per sample batch, including method blanks, laboratory check standards, and matrix spikes. Laboratory method blanks for all parameters were below reporting limits for the entire project with the following exceptions:

- A method blank sample run with a batch of total phosphorus that was collected on August 7, 2013 was contaminated. The result in that batch (one sample) was qualified as an estimate.
- One method blank sample run with a batch of total phosphorus that was collected on August 19, 2013 was contaminated. The results in that batch (four samples) were qualified as estimates.
- A method blank sample run with a batch of total non-volatile suspended solids collected on June 3, 2014 was contaminated. The results for 12 samples in that batch were qualified as estimates.

Targets for analytical bias were set by the MEL laboratory. MEL checks bias by evaluating laboratory check standard recoveries and matrix spike recoveries. The average recoveries for each parameter were acceptable within the targeted bias ranges (Table D-7).

Table D-7. Lab Check Standard and Matrix Spike Recovery Targets for the Wide Hollow Creek Water Quality Study for Aquatic Life Use.

Parameter	Check Standard Recovery Targets	Check Standard Recovery (Average Observed % Recovery)	Matrix Spike Recovery Targets	Matrix Spike Recovery (Average Observed % Recovery)
Alkalinity	80-120%	91	N/A	N/A
Ammonia-Nitrogen	80-120%	100	75-125%	94
Chloride	90-110%	99	75-125%	98
Dissolved Organic Carbon	80-120%	98	75-125%	96
Nitrite-Nitrate Nitrogen	80-120%	103	75-125%	95
Total Organic Carbon	80-120%	98	75-125%	99
Total Phosphorus	80-120%	98	75-125%	97
Total Persulfate Nitrogen	80-120%	100	75-125%	94
Total Suspended Solids	80-120%	97	N/A	N/A
Turbidity	90-105%	97	N/A	N/A
Orthophosphate	80-120%	97	75-125%	100

Field Bias

Field blank samples were submitted to MEL blindly to determine bias from contamination in the field. Field contamination was suspected when measured values exceeded the corresponding reporting limits. Results are presented in Table D-8.

All submitted field blank measurement values were below reporting limits with the exception of the four following samples:

- One chloride blank from September 10, 2013. A review of laboratory QA/QC for chloride on that date showed no laboratory bias or contamination.
- Two total persulfate nitrogen blanks, from July 9, 2013 and November 12, 2013. A review of laboratory QA/QC for total persulfate nitrogen on those two dates showed no laboratory bias or contamination.
- One total phosphorus blank from November 12, 2013. A review of laboratory QA/QC for total phosphorus on that date showed no laboratory bias or contamination.

In review, there was minimal bias from field contamination. The four suspect field blanks were at or just slightly above their respective reporting limits. All sample values for chloride, total nitrogen and total phosphorus collected in 2013 and 2014 were generally much greater than the reporting limits. For this reason, no correction or qualifications were made for the chloride, total persulfate nitrogen, and total phosphorus results from the dates noted above.

Table D-8. Field-blank results.
Results qualified with "U" or "UJ" were not detected at the reporting limit.

Parameter	7/8/2013	8/6/2013	9/10/2013	10/8/2013	11/12/2013	12/10/2013	3/4/2014	3/26/2014	4/29/2014	6/3/2014
Alkalinity	5U	5U	5U	5U	5U	5U	5U	5U	5U	5U
Ammonia	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U
Chloride	0.1U	0.1U	0.12	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U
DOC	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U
Nitrate	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U	0.01U
Ortho-P	0.003U	0.003U	0.003U	0.003U	0.003U	0.003U	0.003U	0.003U	0.003U	0.003U
TOC	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U
Total Nitrogen	0.029	0.025U	0.025U	0.025U	0.025	0.025U	0.025U	0.025U	0.025U	0.025U
Total Phosphorus	0.005U	0.005U	0.005U	0.005U	0.007	0.005U	0.005U	0.005U	0.005U	0.005U
TSS	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U	1.0U
Turbidity	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U

Results qualified with "U" were not detected at the reporting limit.

Quality Assurance for Ecology Field Measurements

Instantaneous Flow Measurements

At the beginning of each week in the field, Marsh-McBirney FlowMate® velocity meters were zeroed out in a bucket of still water to ensure accurate measurements. No replicate flow measurements were taken in the 2013-14 study because the frequent changing flow in Wide Hollow Creek would have made the two measurements incomparable.

Instantaneous Water Quality Field Measurements

Instantaneous field measurements of water temperature, specific conductivity, dissolved oxygen, and pH were taken at each station during field surveys. Field measurements were taken with Hydrolab® multi-meters which were pre-calibrated and post-checked using NIST standards and certified buffers to assess bias. Ecology staff also minimized bias by following field measurement protocols. Measurement quality objectives for Hydrolab® post-deployment and fouling checks are listed in Table D-3 (above).

For evaluation of Hydrolab® DO measurements, Winkler DO samples were collected throughout the project for use as DO check standards. Results from Winkler titrations were used to evaluate the acceptability of Hydrolab® DO data and used to correct Hydrolab® DO measurements, as necessary. See Figure D-1 for an example of a comparison of Hydrolab® DO measurements to Winkler DO results.

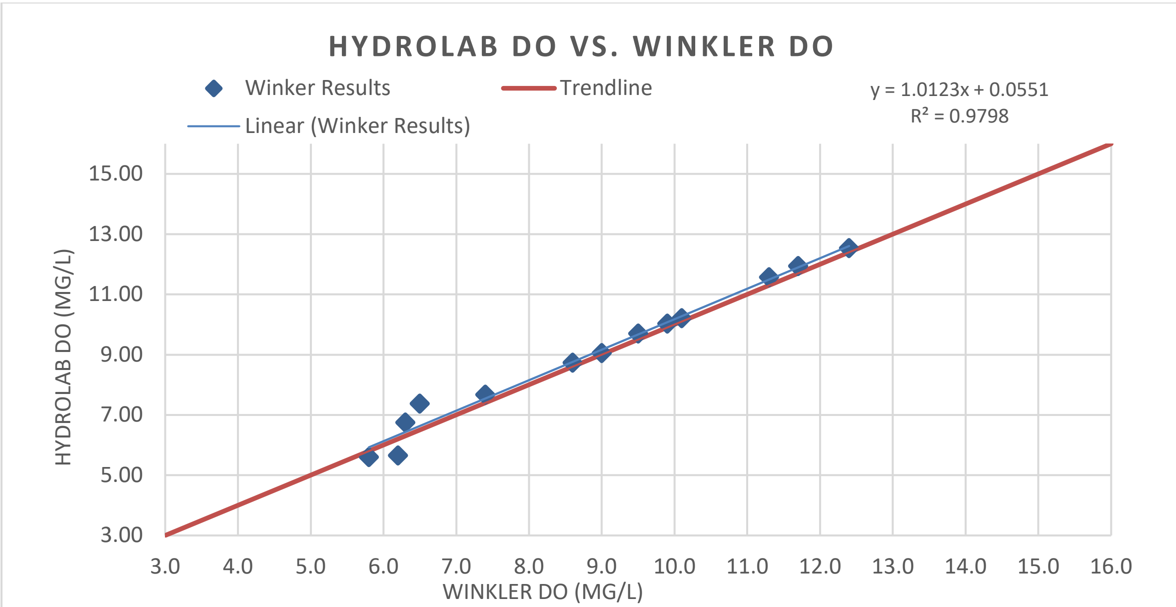

Figure D-1. Hydrolab DO vs Winkler DO (mg/L). Hydrolab E138076 – November 12-14, 2013.

Two meters (#E138076 and #31) were the primary Hydrolabs® used to collect field measurements during synoptic runs. Two others were used as either back up equipment or for taking additional field team measurements. Almost all the field measurements met the measurement quality objectives (Table D-3) with the following exceptions:

- Hydrolab® E138075
  - pH measurements made 10/10-24/2013 and 11/12-14/2013 were qualified.
- Hydrolab® #31:
  - pH measurements made 11/12-14/2013 were qualified.
- Hydrolab® #34:
  - pH measurements made 8/7-8/9/2013 were rejected, while pH measurements made 10/8-24/2013 were qualified.
  - Conductivity measurements made 8/7-8/9/2013 were qualified.

Table D-9 presents a summary of Hydrolab® data qualifications and accuracy ratings.

The quality of all data used to develop the water quality modeling was considered to be adequate and appropriate for its intended use, taking into account any data qualifications.

Table D-9. Summary of hydrolab field measurement quality objective qualifications and accuracy ratings.

	Hydrolab #E138076		Hydrolab #31		Hydrolab #34/39	
Field Use Dates	pH QA/QC	Conduct QA/QC	pH QA/QC	Conduct QA/QC	pH QA/QC	Conduct QA/QC
7/8-9/2013	accept	accept	accept	accept		
7/19-22/2013			accept	accept		
7/30-31/2013	accept	accept	accept	accept		
8/6-8/8/2013	accept	accept	accept	accept	reject/accept	Qualify/accept
8/19-22/2013			accept	accept		
8/26/2013	accept	accept	accept	accept		
9/9-11/2013	accept	accept	accept	accept	Accept/accept	Accept/accept
9/24-25/2013	accept	accept	accept	accept	Accept(39)	Accept(39)
10/8-10/2013	accept	accept	accept	accept	qualify(34)	accept(34)
10/10-24/2013	qualify	accept	accept	accept	qualify(34)	accept(34)
10/31/2013	accept	accept	accept	accept		
11/12-14/2013	qualify	accept	qualify	accept		
11/26-27/2013			accept	accept		
12/2-3/2013			accept	accept		
12/10-11/2013			accept	accept	Accept(34)	Accept(34)
3/3-5/2014	accept	accept	accept	accept		
3/13/014	accept	accept				
3/20/014	accept	accept				
3/24-26/2014	accept	accept	accept	accept		
4/3/2014	accept	accept				
4/10/2014	accept	accept				
4/17/2014	accept	accept				
4/22/2014	accept	accept				
4/29-30/2014	accept	accept	accept	accept		
5/6/2014	accept	accept				
5/13/2014	accept	accept				
5/19/2014	accept	accept				
5/29/2014	accept	accept				
6/2-4/2014	accept	accept	accept	accept		
6/11-12/2014	accept	accept				
6/18/2014	accept	accept				
6/24/2014	accept	accept				
7/2/2014	accept	accept				

Continuous Dissolved Oxygen and pH Field Measurements

Three continuous streamflow gage sites also collected continuous water quality data at the following locations:

- Wide Hollow Creek at 101st Ave (below the Yakima Valley Canal)
- Wide Hollow Creek above 40th Ave (behind Bergen's Screen Print shop)
- Wide Hollow Creek at White Street in Union Gap

A photograph of the gage station at White Street in Union Gap is seen in Figure D-2, showing the slant pipes in the water where the Hydrolab® was deployed to make continuous measurements.

Figure D-2. The stream gage station on Wide Hollow Creek at White St. in Union Gap. *One of the slant pipes going into the water secured a water quality multi-sensor datalogger.*

Continuous water quality readings for dissolved oxygen (DO), pH and conductivity were collected every 15 minutes by the sensors. Provisional (draft) data was transmitted by telemetry to a database system at Ecology and posted on Ecology's website. Periodically, a backup of the provisional data was also downloaded from the station datalogger to a laptop computer.

Ecology used the same Hydrolabs® for the 2013 and 2104 deployment time periods at each station with the exception of Wide Hollow at 101st Ave which had a failing pH sensor and was replaced on October 24, 2013 with a new Hydrolab®. Hydrolabs® were pulled on December 2nd or 3rd 2013 due to freezing conditions that could harm the equipment and re-deployed at the end of February 2014 for the remainder of the study year.

QA/QC

The Hydrolab® sensor was visited at least every other week to check the calibration. Fouling from biological growth on the sensors was minimized by frequent cleanings. During each cleaning, the datalogger was removed from the slant pipe and the sensors were cleaned. Debris collecting in or around the slant pipe holding the sensor was also cleaned. Every cleaning activity at each gage station was documented in a field notebook. In general, Ecology found that fouling error was minimized by frequent cleaning events at the stations.

QA data was usually collected during each gage station visit throughout the study period. Each QA data check was used to evaluate the quality of the calibration during the time period from the last data check to the current data check. Table D-2 has the bias measurement quality objectives for both instrument drift and fouling checks.

In addition, each time series was assigned an overall accuracy rating based on how the pooled RMSE (of the data checks versus the corrected instrument readings) compared to the accuracy rating criteria as described in Table D-10. Data assigned a 'fair' or 'poor' rating were rejected and not used in data analysis.

Table D-10. Ratings of accuracy for time series data.

Measured field parameter	Ratings of accuracy for continuous time series data			
	Excellent	Good	Fair	Poor
Water Temperature	≤ ± 0.2 °C	> ± 0.2 – 0.5 °C	> ± 0.5 – 0.8 °C	> ± 0.8 °C
Specific conductance	≤ ± 5%	> ± 5 – 10%	> ± 10 – 15%	> ± 15 %
Dissolved Oxygen	RMSE ≤ ± 0.3 mg/L or CV% ≤ ± 5%, whichever is greater	> ± 0.3 – 0.5 mg/L or > ± 5 – 10%, whichever is greater	> ± 0.5 – 0.8 mg/L or > ± 10 – 15%, whichever is greater	> ± 0.8 mg/L or > ± 15%, whichever is greater
pH	≤ ± 0.2 units	> ± 0.2 – 0.5 units	> ± 0.5 – 0.8 units	> ± 0.8 units

Continuous dissolved oxygen

Continuous DO readings at the gage stations were quality-assured using DO checks from other calibrated Hydrolabs® that were placed side-by-side of the deployed Hydrolab® as well as Winkler titration of DO in water samples taken at the site.

The luminescent dissolved oxygen (LDO) sensors on the Hydrolabs® were calibrated to 100% saturated water before they were deployed and were not recalibrated during the deployment time period. Any corrections were applied based on an evaluation of the QA checks. In general, Ecology has found that LDO sensors do not drift in calibration when deployed.

Ecology used the same Hydrolabs® for the 2013 and 2104 deployment time periods at each station with the exception of Wide Hollow at 101st Ave which had a failing pH sensor and was replaced on October 24, 2013 with a new Hydrolab®.

For each location, all of the QA check readings were pooled (or grouped) in order to make slope and bias corrections. There were between 33 and 41 QA checks for the all of the meters except for the replaced Hydrolab® at 101st Ave (n=8).

Correction procedure:

1. First, the residuals of each QA check and corresponding LDO reading were averaged to calculate an overall mean bias.
2. The overall mean bias was then subtracted from the absolute value of each individual residual to come up with a residual prime.
3. All residual primes greater than the MQO of ±0.3 mg/L were not used to correct the LDO readings. These first 3 steps were used to check for residuals that depart widely from the main body of other residuals, and would skew the correction if left for consideration in the data check set. (The discarded residuals are important though and were used later to qualify parts of the time series when the corresponding data check occurred.)
4. Next, the remaining pairs of QA checks and LDO readings (of the accepted residual primes) were pooled and regressed to make slope and bias corrections to the LDO time series (Figure D-3).
5. The overall accuracy rating for each corrected LDO time series was based on the pooled RMSE of the residuals of the QA checks and corrected LDO readings.
6. Parts of the LDO time series that had QA checks censored due to residual primes not meeting the MQO of ±0.3 mg/L were rated separately. The time series was qualified as estimates if residual primes were greater than ±0.3 mg/L and rejected if residual primes were greater than ±0.8 mg/L. The qualified periods extended backwards and forwards in time to the next known good data checks.
7. Finally, in addition to QA corrections to the time series, there were times that the data was compromised because sensors were impacted by sediment or debris that collected on or near the sensor. LDO readings would sometimes severely decline, often to zero during these events and remain that way until the debris was manually cleared during a station visit. Each LDO time series was qualitatively censored by the project manager by visual assessment of the plotted time series for these periods. Notes from the station visits, indicating when debris was cleared from the sensors, were also used to determine when readings were compromised.

Table D-11 shows the quality rating for each LDO time series before and after correction was applied to the LDO time series data for each separate Hydrolab® at each location.

The LDO time series at most stations were considered to have an excellent rating even without a correction, but still a small correction was applied to minimize the bias as much as possible. A few LDO time series were improved from good ratings to excellent ratings with a correction.

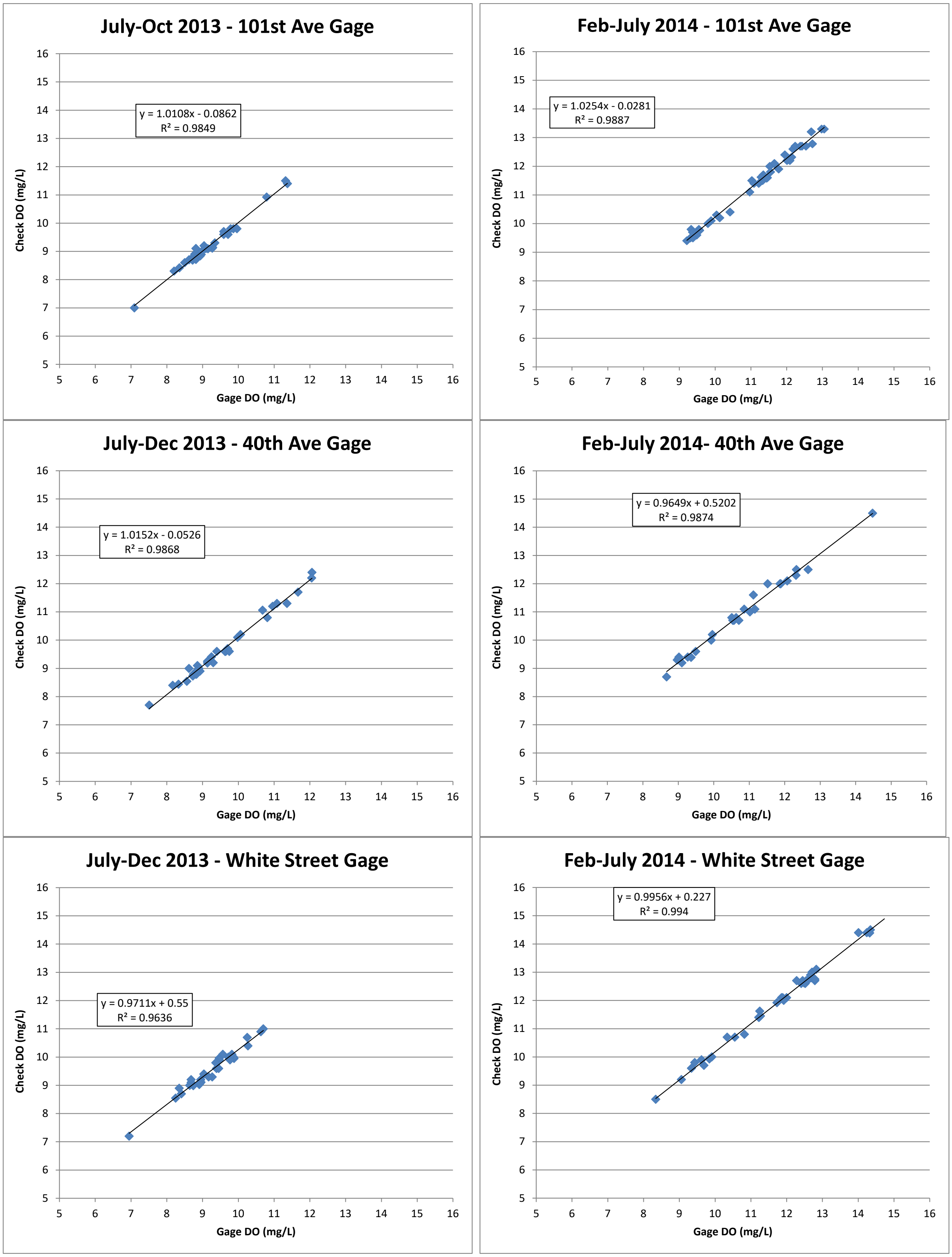

Figure D-3. Regressions of dissolved oxygen QA checks versus gage LDO readings.

Table D-11. Quality assurance results for continuous dissolved oxygen time series.

Location and Time Period	Hydrolab Meter ID	Ratings of Bias and Accuracy for Continuous Dissolved Oxygen Measurements			
		Pooled Bias, RMSE and CV% before correction	Accuracy rating before correction and bias acceptance status	Pooled Bias, RMSE and CV% after correction	Accuracy rating after correction and bias acceptance status
Wide Hollow at 101st Ave Jul-Oct 24, 2013	28	Bias = -0.02 mg/L RMSE = 0.12 mg/L CV = 0.7%	Excellent / Accept	Bias = 0.00 mg/L RMSE = 0.10 mg/L CV = 0.6%	Excellent / Accept
Wide Hollow at 101st Ave Oct 24-Dec 2013	136269	Bias = 0.06 mg/L RMSE = 0.29 mg/L CV = 2.1%	Excellent / Accept	Bias = 0.00 mg/L RMSE = 0.28 mg/L CV = 2.0%	Excellent / Accept
Wide Hollow above 40th Ave July-Dec 2013	138080	Bias = -0.11 mg/L RMSE = 0.21 mg/L CV = 1.1%	Excellent / Accept	Bias = 0.00 mg/L RMSE = 0.13 mg/L CV = 0.8%	Excellent / Accept
Wide Hollow at White St July-Dec 2013	138079	Bias = -0.29 mg/L RMSE = 0.33 mg/L CV = 2.2%	Good / Qualify	Bias = 0.00 mg/L RMSE = 0.14 mg/L CV = 0.9%	Excellent / Accept
Wide Hollow at 101st Ave Feb-July 2014	136269	Bias = -0.27 mg/L RMSE = 0.31 mg/L CV = 1.7%	Good / Qualify	Bias = 0.00 mg/L RMSE = 0.16 mg/L CV = 0.7%	Excellent / Accept
Wide Hollow above 40th Ave Feb-July 2014	138080	Bias = -0.24 mg/L RMSE = 0.46 mg/L CV = 2.1%	Good / Qualify	Bias = 0.00 mg/L RMSE = 0.15 mg/L CV = 0.8%	Excellent / Accept
Wide Hollow at White St Feb-July 2014	138079	Bias = -0.18 mg/L RMSE = 0.22 mg/L CV = 1.2%	Excellent / Accept	Bias = 0.00 mg/L RMSE = 0.12 mg/L CV = 0.6%	Excellent / Accept

Continuous pH

The pH readings at the gage stations were quality-assured by checking the meters using standard pH buffers in the field and by using pH QA checks from other another calibrated pH meter that was placed side-by-side with the deployed Hydrolab®. Ecology used the same Hydrolabs® for the 2013 and 2104 deployment time periods at each gage station with the exception of Wide Hollow at 101st Ave which had a failing pH sensor and was replaced on October 24, 2013 with a new Hydrolab®.

The pH sensor on the gage Hydrolab® was calibrated using pH buffer standards before deployment, but was also periodically recalibrated in the field during the deployment time period, resulting in several calibration periods for each gage Hydrolab®. Each calibration period was individually assessed for a QA rating. In general, Ecology found the pH sensors tended to drift a lot and needed to be recalibrated on an ongoing basis throughout the study period.

For each calibration period, each individual pH check reading was compared to the corresponding gage pH reading to check for bias error. The pH time series was qualified as an estimate if the bias was greater than ±0.2 pH units and rejected if the bias was greater than ±0.5 pH units. The qualified periods extended backwards and forwards in time to the next known good data checks.

In a few cases, there were enough pH check readings within one calibration period to pool (or group) the pH check readings comparisons in order to make slope and bias corrections:

- 101st Ave gage from July 1, 2013 to Sept 10, 2013 (n = 16 pH checks)
- 40th Ave gage from March 1, 2014 to July 1, 2014 (n = 29 pH checks)
- White St gage from April 10, 2014 to May 6, 2014 (n = 7 pH checks)
- White St gage from May 6, 2014 to July 1, 2014 (n = 19 pH checks)

Figure D-4 shows the individual regressions for each of the pooled comparisons listed above.

Table D-12 indicates QA assessment result for each calibration time period at each gage. Much of the pH data collected in 2013 was qualified or rejected because it did meet the MQO target objectives.

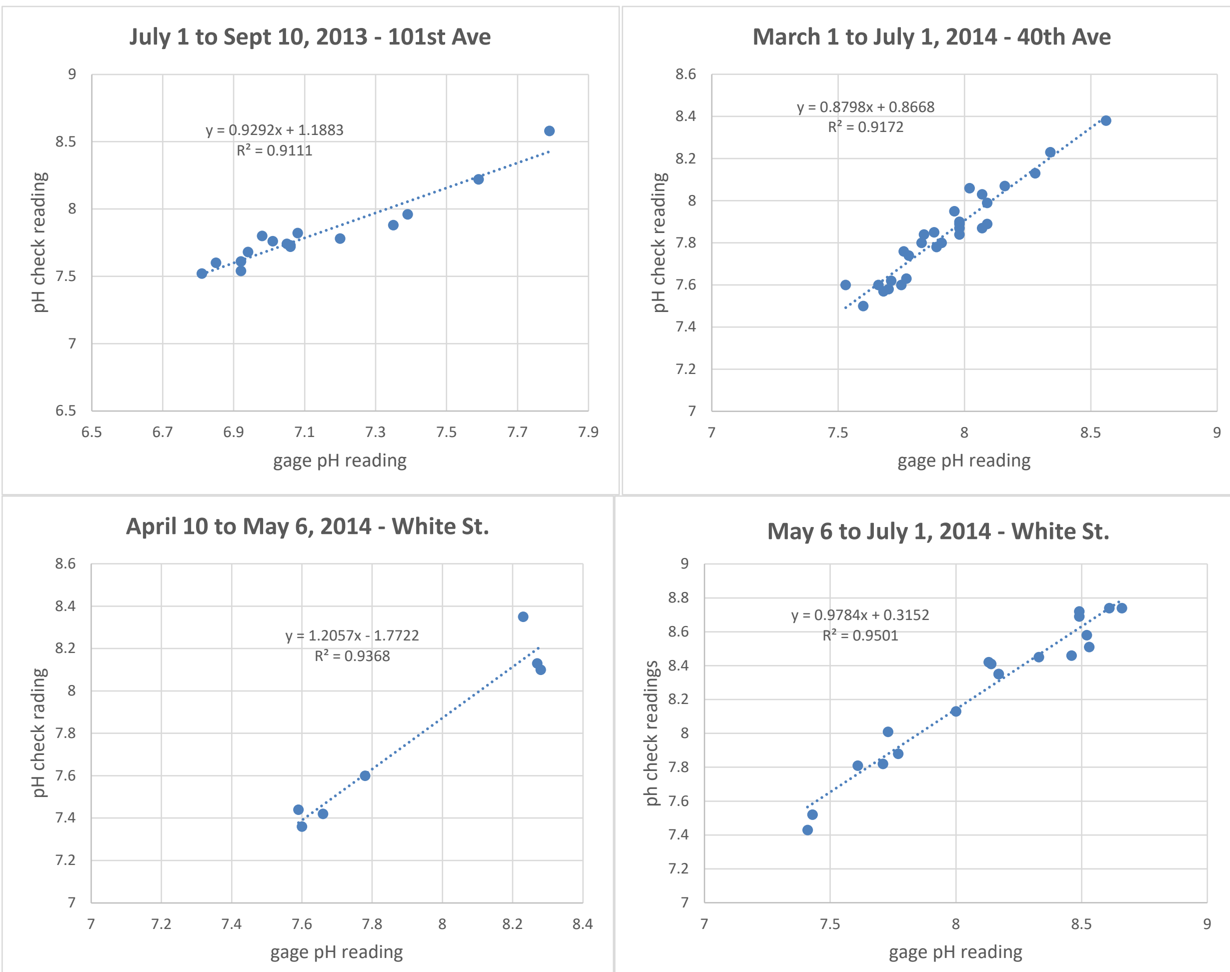

Figure D-4. Regressions of pH check readings versus gage pH readings.

Table D-12. Results of quality assurance assessment of pH time series at gage stations.

Station	Time Period	Correction Applied?	Bias / RMSE of Correction	Potential Bias	Accuracy Rating
101st Ave	7/1/13 to 7/30/13	YES	0.00 / 0.08	-0.08	Excellent
101st Ave	7/30/13 to 8/22/13	YES	0.00 / 0.08		Good
101st Ave	8/22/13 to 8/26/13	YES	0.00 / 0.08		Rejected
101st Ave	8/26/13 to 9/10/13	YES	0.00 / 0.08		Good
101st Ave	9/10/13 to 10/24/13	YES	0.00 / 0.08		Rejected
101st Ave	10/24/13 to 12/2/13	NO	N/A		Excellent
101st Ave	2/27/14 to 4/3/14	NO	N/A		Excellent
101st Ave	4/3/14 to 4/10/14	NO	N/A		Good
101st Ave	4/10/14 to 4/28/14	NO	N/A		Excellent
101st Ave	4/28/14 to 5/6/14	NO	N/A		Good
101st Ave	5/6/14 to 5/13/14	NO	N/A		Excellent
101st Ave	5/13/14 to 6/2/14	NO	N/A		Rejected
101st Ave	6/2/14 to 6/24/14	NO	N/A		Good
101st Ave	6/24/14 to 7/1/14	NO	N/A		Excellent
40th Ave	7/1/13 to 7/6/13	NO	N/A		Excellent
40th Ave	7/6/13 to 7/8/13	NO	N/A		Rejected
40th Ave	7/8/13 to 7/19/13	NO	N/A		Excellent
40th Ave	7/19/13 to 7/30/13	NO	-0.21	-0.21	Good
40th Ave	7/30/13 to 9/9/13	NO	N/A	N/A	Rejected
40th Ave	9/9/13 to 9/25/13	NO	0.42	0.42	Good
40th Ave	9/25/13 to 10/10/13	NO	N/A	N/A	Rejected
40th Ave	10/10/13 to 11/13/13	NO	-0.25	-0.25	Good
40th Ave	11/13/13 to 12/2/13	NO	N/A	-0.15	Excellent
40th Ave	3/1/14 to 4/29/14	NO	N/A		Excellent
40th Ave	4/29/14 to 5/6/14	NO	N/A	N/A	Rejected
40th Ave	5/6/14 to 7/1/14	YES	0.00 / 0.06		Excellent
White St.	7/19/13 to 7/19/13	NO	N/A		Excellent
White St.	7/1/13 to 7/30/13	NO	N/A		Good
White St.	7/30/13 to 8/22/13	NO	N/A		Rejected
White St.	8/2213 to 9/25/13	NO	N/A		Good
White St.	9/25/13 to 10/10/13	NO	N/A		Rejected
White St.	10/10/13 to 10/24/13	NO	N/A		Good
White St.	10/24/13 to 11/20/13	NO	N/A		Excellent
White St.	11/20/13 to 11/27/13	NO	N/A		Rejected
White St.	11/27/13 to 12/1/13	NO	N/A		Excellent
White St.	3/1/14 to 3/5/14	NO	N/A		Good
White St.	3/5/14 to 3/14/14	NO	N/A		Rejected
White St.	3/14/14 to 4/10/14	NO	N/A		Good
White St.	4/10/14 to 4/14/14	YES	0.00 / 0.10		Excellent
White St.	4/14/14 to 4/17/14	YES	0.00 / 0.10		Rejected
White St.	4/17/14 to 4/20/14	YES	0.00 / 0.10		Excellent
White St.	4/20/14 to 4/22/14	YES	0.00 / 0.10		Rejected
White St.	4/22/14 to 7/1/14	YES	0.00 / 0.09		Excellent

Continuous Temperature Field Measurements

The continuous temperature data was collected by a separate monitoring project (Dugger, 2013), collecting continuous temperature data in some mid-Yakima River basin tributaries, including Wide Hollow Creek, Moxee Creek, and Cowiche Creek. The temperature time series data was uploaded to Ecology's Environmental Information Management (EIM) database under the EIM Study ID# DDUG0002.

Table D-13 shows where the temperature dataloggers were deployed in Wide Hollow Creek during the 2013-14 study period. Summary results of the QC field checks and the post-calibration water bath check for each datalogger are also presented in Table D-13.

The MQO for temperature data collection (Table D-3, above) for data quality acceptance is bias less than 0.8 °C. All temperature dataloggers collected acceptable data. Several locations were deemed to have qualified time series temperature data because they were slightly over a bias of 0.2°C, as highlighted in Table D-13. The temperature data from these few dataloggers were used "as is" and not corrected because they were just slightly biased.

Table D-13. Summary of quality control results for field checks and post calibration bath for Wide Hollow Creek temperature dataloggers.

		Field Measurements			Water Bath
Location_Name	**Location_ID**	**Count**	**Bias**	**RMSE**	**Post-check Bias**
Yak Valley Canal	37-IS-16	20	0.0	0.4	0.1
WHC at 80th	37-FW-8	11	0.1	0.4	0.1
WHC at 64th	37-SS-12	10	0.0	0.1	0.2
DID #38	37-SS-38	13	-0.1	0.1	0.1
DID #48	37-SS-48	12	-0.1	0.2	0.2
Randall Pond	37-IS-17.5	15	0.5	0.9	0.3
WHC at 40th	37-FW-6B	18	0.2	0.4	0.1
DID #40	37-IS-17	9	-0.1	0.1	0.2
NC Canal at 32nd	37-IS-20B	9	0.0	0.2	0.1
WHC at 24th	37-FW-5B	15	0.3	0.7	0.3
WHC at 16th	37-FW-4	6	-0.1	0.3	0.2
NC Canal at 12th	37-IS-20A	8	-0.2	0.2	0.1
Spring Ck Irrig	37-IS-23	7	0.0	0.2	0.1
WHC at 3rd	37-FW-3B	15	0.1	0.3	0.1
DID #24 at 3rd	37-IS-12	7	-0.1	0.1	0.1
Fines Ditch	37-FW-1C	15	0.1	0.3	0.2
WHC at White St	37-FW-1B	19	0.2	0.5	0.2
Un-named Creek	37-FW-2B	15	-0.1	0.3	0.3
East Spring Creek	37-FW-2	8	0.1	0.1	Lost
WHC mouth	37-FW-0B	16	0.1	0.3	0.2

External Data Usability

In addition to data collected by Ecology, data from other external sources were used in this study. Table D-14 indicates the external data used in the study and which data sets had established quality assurance/quality control (QA/QC) programs to ensure data reliability.

The only external water quality data that Ecology was unable to do a QA assessment of was the turbidity data from the Yakima Water Treatment Plant. While the actual turbidity data was not used in the modeling analysis, the relative levels were used to develop a regression for suspended particles (inorganic and detritus) in the irrigation water that was delivered to Wide Hollow Creek. The turbidity level was used as the independent variable that was related to the Ecology collected suspended particle data (dependent variable). The Ecology suspended particle data were collected under the QAPP and quality assessed. The quality of the data generated from the regression has more to do with the accuracy of the dependent data and the power of the regression than the accuracy of the turbidity data.

Table D-14. External data sources used to develop inputs to Wide Hollow Creek models.

Data Set	Source	Year	Peer Review / QC	Approved QAPP?	Formal SOPs?	Comments
Daily Turbidity Measurements on Naches River	Yakima Water Treatment Plant	2013-14	Unk	Unk	Unk	Used for regression to estimate turbidity time series
Temperature – Air	AgriMet / NOAA	2013-14	Yes	Yes	Yes	For critical conditions
Vegetation coverage	Bing Maps	???	Unk	Unk	Unk	Digitized coverage from GIS ortho-photos
Meteorological	AgriMet/ NOAA	2013-14	Yes	Yes	Yes	Yakima airport

Unk: Unknown
QC: Quality Control
QAPP: Quality Assurance Project Plan
SOPs: Standard Operating Procedures

Data Management Procedures

Field measurement data were entered into a field sheets and field notebooks with waterproof paper and then entered into Excel® spreadsheets as soon as practical after returning from the field. Data were entered into Excel to perform preliminary analysis and to create a table to upload data into Ecology's database system - Environmental Information Management (EIM) System.

Ecology sent all water samples to Ecology's Manchester Environmental Laboratory (MEL) for analyses. Sample result data received from MEL by Ecology's Laboratory Information Management System (LIMS) was exported prior to entry into EIM and added to a cumulative Excel spreadsheet for laboratory results. This spreadsheet was used to review and analyze the data during the course of the project.

An EIM user study (JICA0002) was created for this study and all monitoring data is available via the internet. The URL address for this geospatial database is: www.ecy.wa.gov/eim/. All data were uploaded to EIM after review for proper QA.

References for Appendix D

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Appendix E. Stream Heating Mechanisms

The temperature of a stream reflects the amount of heat energy in the water. Changes in water temperature within a particular segment of a stream are induced by the balance of the heat exchange between the water and the surrounding environment during transport through the segment. If there is more heat energy entering the water in a stream segment than there is leaving, the temperature will increase. If there is less heat energy entering the water in a stream segment than there is leaving, then the temperature will decrease. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer), and stream temperature change is outlined in Figure E-1.

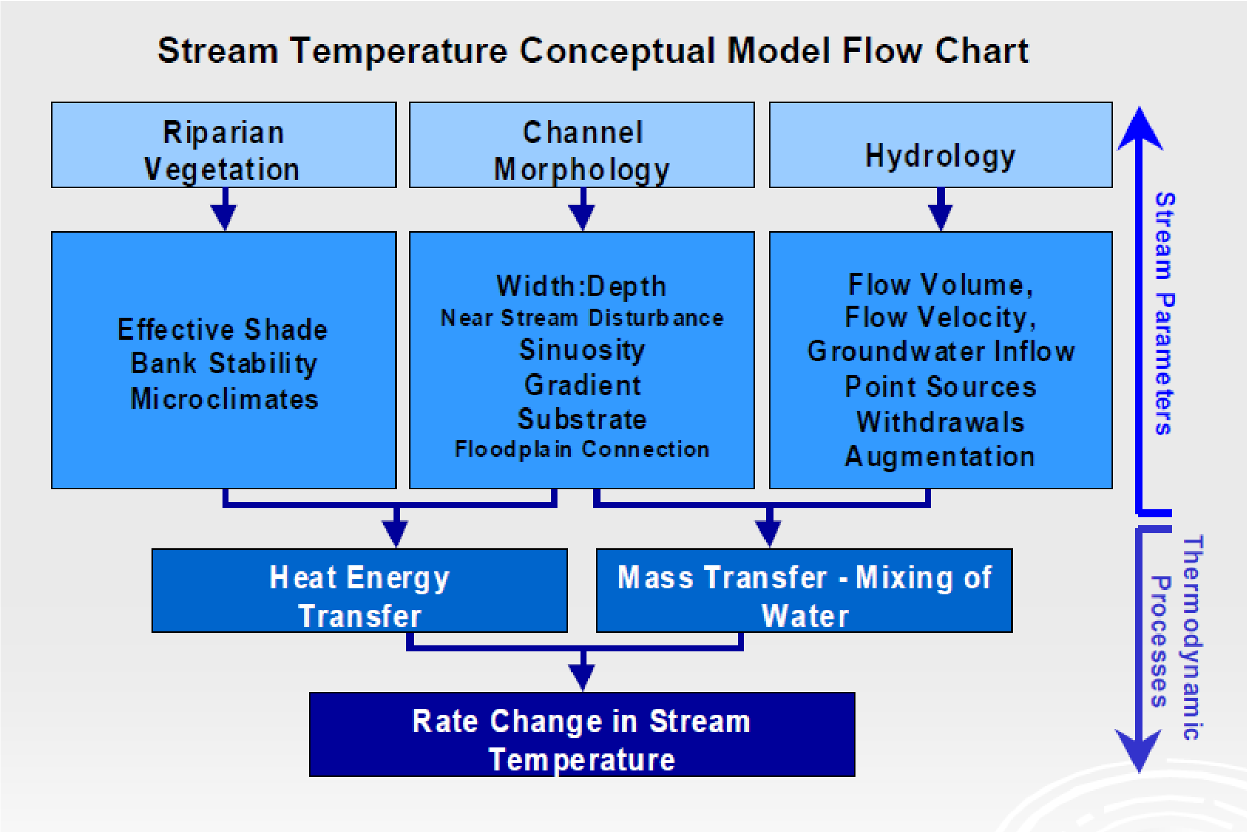

Figure E-1. Conceptual model of factors that affect stream temperature.

Adams and Sullivan (1989) reported that the following environmental variables were the most important drivers of water temperature in forested streams:

- **Stream depth.** Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.
- **Air temperature.** Daily average stream temperatures and daily average air temperatures are both highly influenced by incoming solar radiation (Johnson, 2004). When the sun is not shining, the temperature in a volume of water tends toward the dew-point temperature (Edinger et al., 1974).
- **Solar radiation and riparian vegetation.** The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily average temperatures are less affected by removal of riparian vegetation.
- **Groundwater.** Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative to the flow in the stream and the difference in temperatures between the groundwater and the stream.

Water temperature can also be strongly affected by tributaries and human discharges, depending on their temperature. In lakes and reservoirs, water temperatures can be affected by thermal stratification and wind.

Heat Budgets and Temperature Prediction

Heat exchange processes occur between the water body and the surrounding environment, and these processes control stream temperature. Edinger et al. (1974) and Chapra (1997) provide thorough descriptions of the physical processes involved. Figure E-2 shows the major heat energy processes or fluxes across the water surface or streambed.

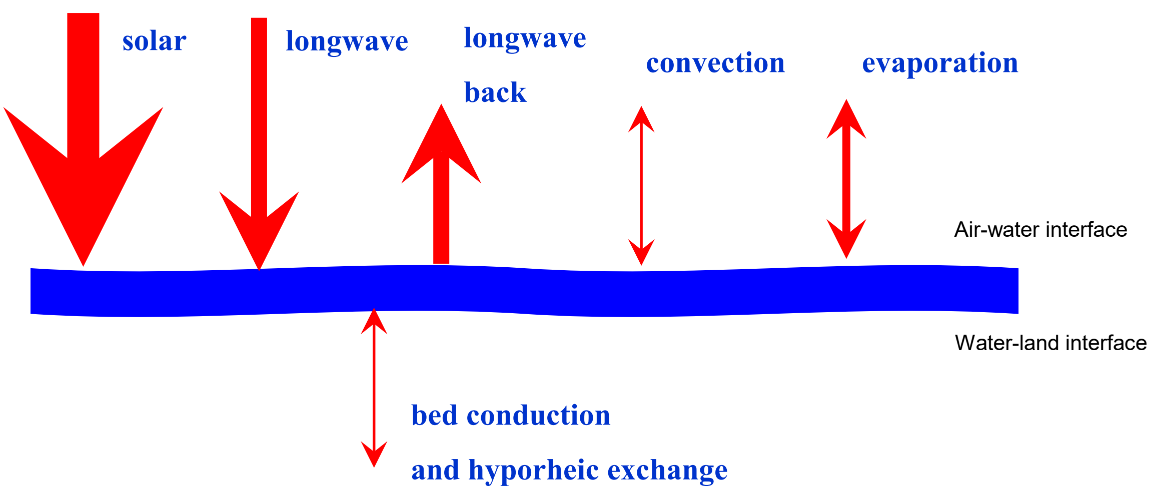

Figure E-2. Surface heat exchange processes that affect water temperature.
Net heat flux = solar + longwave atmosphere + longwave back + convection + evaporation + bed. Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- **Shortwave solar radiation**. Shortwave solar radiation is the radiant energy, which passes directly from the sun to the earth. Shortwave solar radiation is contained in a wavelength range from 0.14 um to about 4 um. At Ecology's weather station on the Palouse River near the mouth of Union Flat Creek (34PAL33.4), the daily average global shortwave solar radiation for July-August 2007 was 271 W/m^2. The peak values during daylight hours are typically about 3 times higher than the daily average. Shortwave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear. Solar exposure was identified as the most influential factor in stream heating processes (Sinokrot and Stefan, 1993; Johnson and Jones, 2000; Danehy, 2005).
- **Longwave atmospheric radiation.** The longwave radiation from the atmosphere ranges in wavelength from about 4 to 120 um. Longwave atmospheric radiation depends primarily on air temperature and humidity, and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm, cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes (Edinger et al., 1974). Another source of longwave radiation used in this model, though much smaller than atmospheric radiation, was longwave radiation from riparian vegetation.
- **Longwave back radiation from the water to the atmosphere.** Water sends heat energy back to the atmosphere in the form of longwave radiation in the wavelength range from about 4 to 120 um. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 W/m^2 (Edinger et al., 1974).

The remaining heat exchange processes generally have less magnitude and are as follows:

- **Evaporation flux at the air-water interface** is influenced mostly by wind speed and the vapor pressure gradient between the water surface and the air. When the air is saturated, the evaporation stops. When the gradient is negative (vapor pressure at the water surface is less than the vapor pressure of the air), condensation, the reversal of evaporation takes place; this term then becomes a gaining component in the heat balance.
- **Convection flux at the air-water interface** is driven by the temperature difference between water and air and by wind speed. Heat is transferred in the direction of decreasing temperature.
- **Streambed conduction flux and hyporheic exchange** component of the heat budget represents the heat exchange through conduction between the bed and the water body and the influence of hyporheic exchange. The magnitude of streambed conduction is driven by the size and conductance properties of the substrate. The heat transfer through conduction is more pronounced when thermal differences between the substrate and water column are higher. This heat transfer usually affects the temperature diel profile, rather than the magnitude of the maximum daily water temperature.

  Hyporheic exchange can be an important mechanism for stream cooling in some basins (Johnson and Jones, 2000; Poole and Berman, 2000; Johnson, 2004). The hyporheic zone is defined as the region of saturated substrate located beneath the channel characterized by complex hydrodynamic processes that combine stream water and groundwater. The resulting fluxes can have significant implications for stream temperature at different spatial and temporal scales. For example, studies in the Walla Walla River in Oregon have shown water temperatures declining downstream in a section of the river as hyporheic interstitial flow cools in a riffle reach and then remixes into the stream in a pool reach.

Figures E-3 and E-4 show surface heat flux in a relatively unshaded stream reach and in a more heavily shaded stream reach, respectively.

Figure E-3 shows an example of the estimated diurnal pattern of the surface heat fluxes in one of Washington's coastal rivers for the week of August 8-14, 2001. The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar shortwave heat flux (Adams and Sullivan, 1989). The solar shortwave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream.

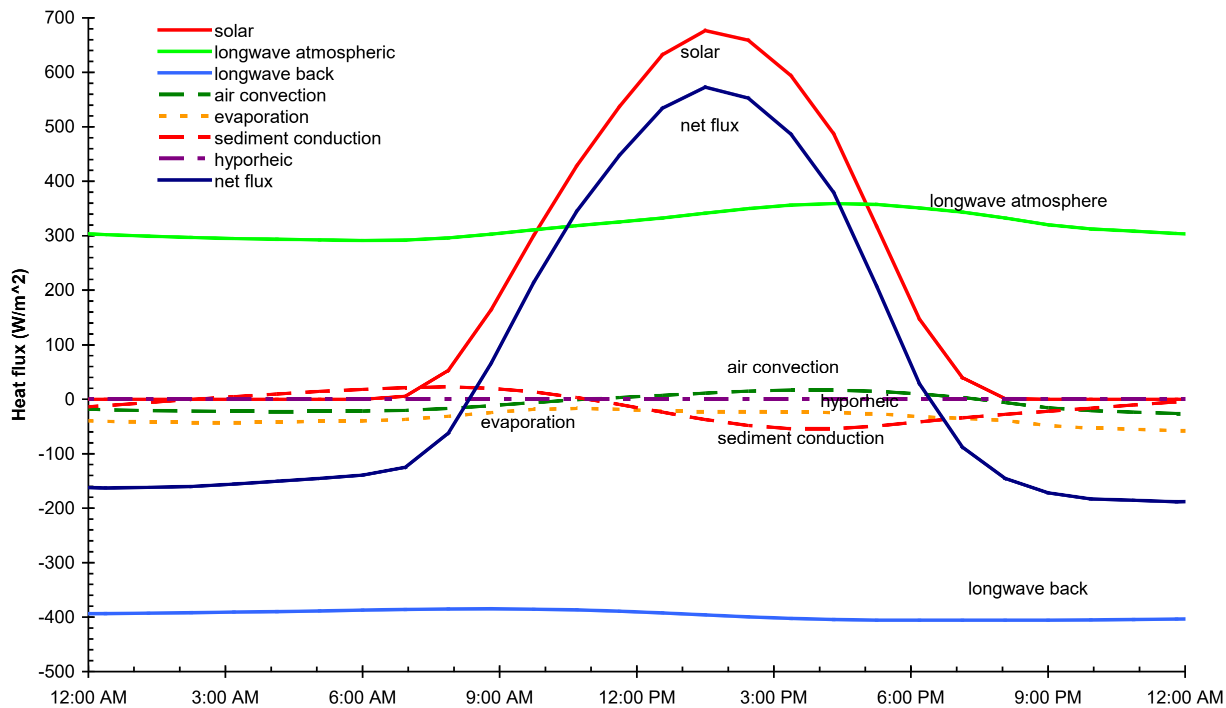

Figure E-3. Estimated heat fluxes in a river during August 8-14, 2001.

Net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic.

Figure E-4 shows an example of the estimated diurnal pattern of the surface heat fluxes in a more heavily shaded location in the same river. Shade that is produced by riparian vegetation or topography can reduce the solar shortwave flux. Other processes – such as longwave radiation, convection, evaporation, bed conduction, or hyporheic exchange – also influence the net heat flux into or out of a stream.

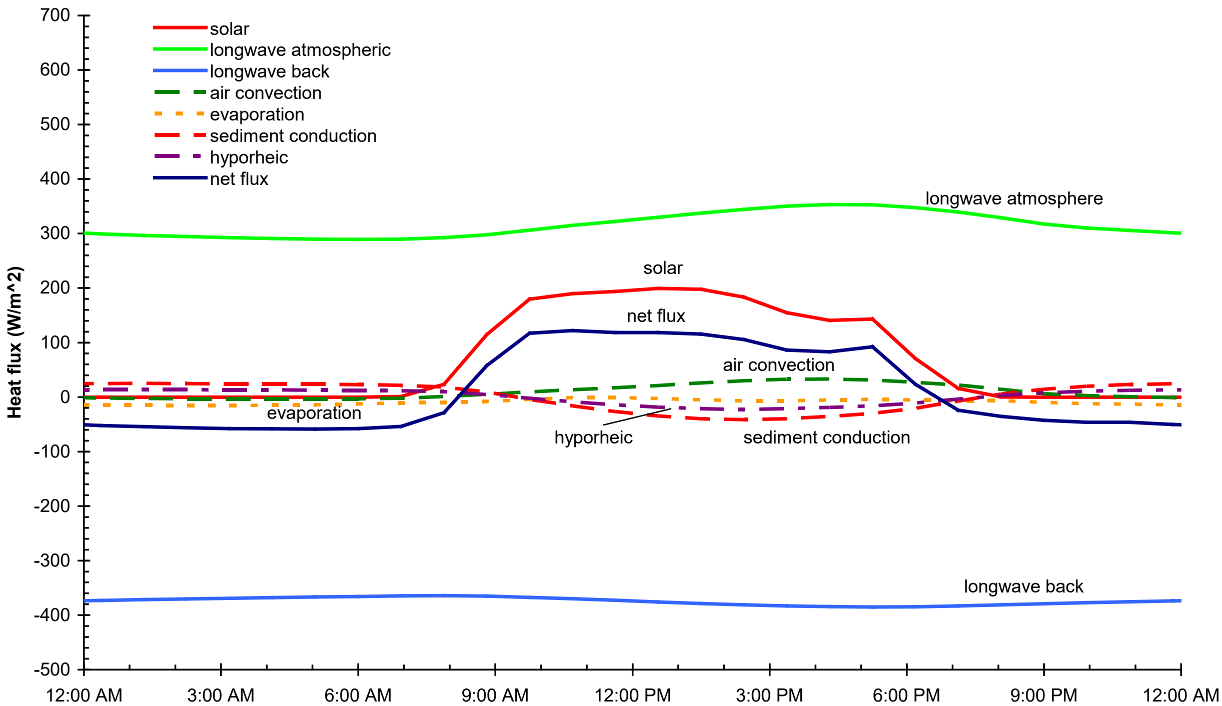

Figure E-4. Estimated heat fluxes in a more shaded section of a river during August 8-14, 2001.

Net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic.

Heat exchange between the stream and the streambed has an important influence on water temperature. The temperature of the streambed is typically warmer than the overlying water at night and cooler than the water during the day (Figure E-5). Heat is typically transferred from the water into the streambed during the day, then back into the stream during the night (Adams and Sullivan, 1989). This has the effect of dampening the diurnal range of stream temperature variations without affecting the daily average stream temperature.

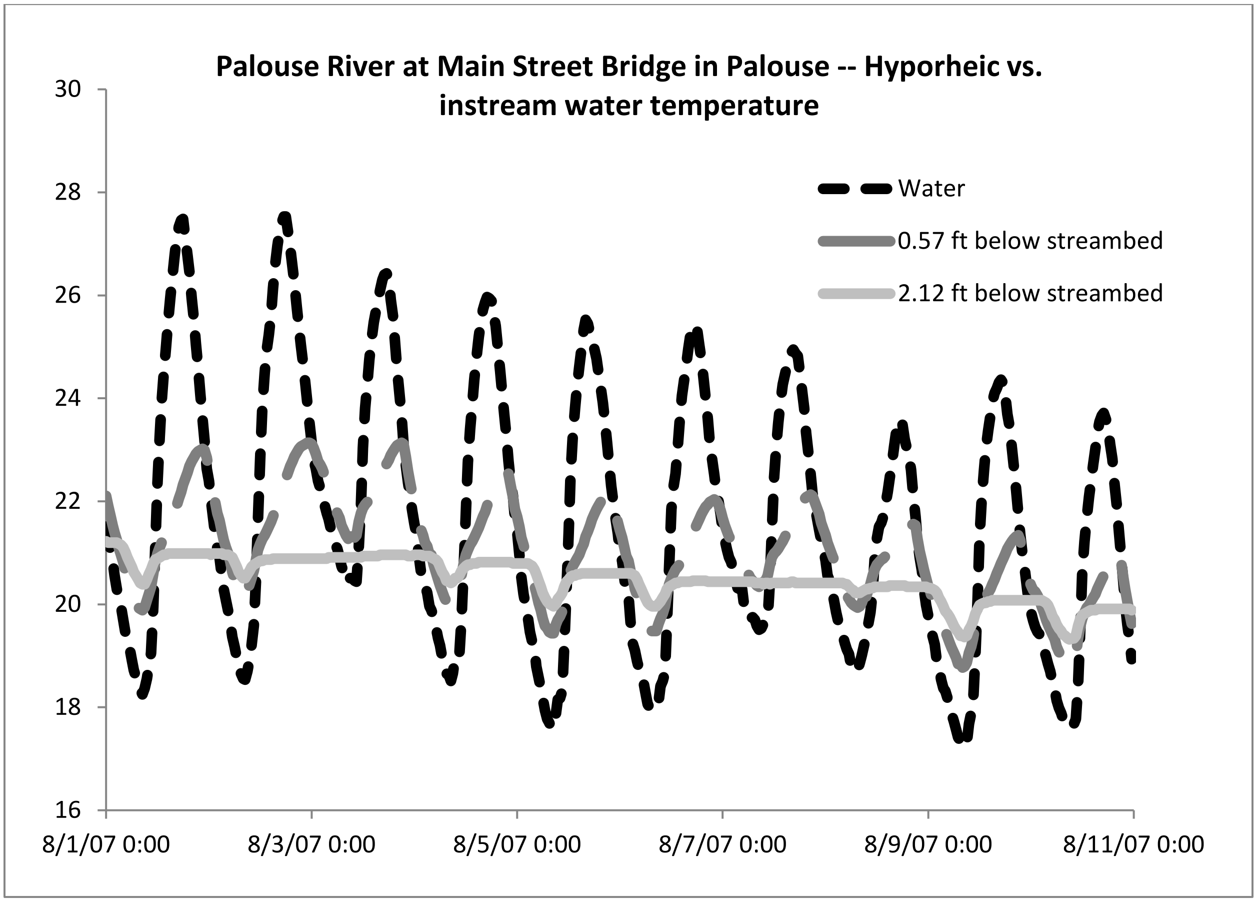

Figure E-5. Water and streambed temperatures in early August 2007 in the Palouse River at Main Street Bridge in Palouse (station 34PAL120.0).

The bulk temperature of a vertically mixed volume of water in a stream segment under natural conditions tends to increase or decrease with time during the day according to whether the net heat flux is either positive or negative. When the sun is not shining, the water temperature tends toward the dew-point temperature (Edinger et al., 1974; Brady et al., 1969). The equilibrium temperature of a natural body of water is defined as the temperature at which the water is in equilibrium with its surrounding environment and the net rate of surface heat exchange would be zero (Edinger et al., 1968; 1974).

The dominant contribution to the seasonal variations in the equilibrium temperature of water is from seasonal variations in the dew-point temperature (Edinger et al., 1974). The main source of hourly fluctuations in water temperature during the day is solar radiation. Solar radiation generally reaches a maximum during the day when the sun is highest in the sky unless cloud cover or shade from vegetation interferes.

The complete heat budget for a stream also accounts for the mass transfer processes which depend on the amount of flow and the temperature of water flowing into and out of a particular volume of water in a segment of a stream. Mass transfer processes in open channel systems can occur through advection, dispersion, and mixing with tributaries, human discharges and withdrawals, and groundwater inflows and outflows. Mass transfer relates to transport of flow volume downstream, instream mixing, and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water.

Thermal Role of Riparian Vegetation

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation are well documented (e.g., Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patrick, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in direct, unobstructed solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al., 1992; Beschta et al., 1987; Bolton and Monahan, 2001; Castelle and Johnson, 2000; CH2M Hill, 2000; GEI, 2002; Ice, 2001; and Wenger, 1999. All of these summaries recognize that the scientific literature indicates that riparian vegetation plays an important role in controlling stream temperature. Important benefits that riparian vegetation has upon the stream temperature include:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.
- Channel morphology can be strongly affected by near-stream vegetation. Specifically, stream vegetation is often part of human impacts on land-cover type and condition, which can affect flood plain and instream roughness, the contribution of coarse woody debris, sedimentation, stream substrate composition, and streambank stability.

Although the warming of water temperatures as a stream flows downstream can be a natural process, the rates of heating can be dramatically lower when high levels of shade exist and heat flux from solar radiation is minimized. There is a natural maximum potential level of vegetation and associated shade that a given stream is capable of attaining in an undisturbed situation. In general, the importance of shade decreases as the width of a stream increases.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

Effective Shade

Stream shade may be measured or calculated using a variety of methods (Chen, 1996; Chen et al., 1998; Ice, 2001; OWEB, 1999; Teti, 2001; Teti and Pike, 2005). Effective shade is defined as the fraction or percentage of the total possible solar radiation heat energy that is prevented from reaching the surface of the water:

$$\text{effective shade} = (J_1 - J_2)/J_1$$

where J_1 is the potential solar heat flux above the influence of riparian vegetation and topography, and J_2 is the solar heat flux at the stream surface.

Canopy cover is the percent of sky covered by vegetation and topography at a given point. Shade is influenced by cover but changes throughout each day, as the position of the sun changes spatially and temporally with respect to the canopy cover (Kelley and Krueger, 2005).

In the Northern Hemisphere, the earth tilts on its axis toward the sun during the summer, allowing longer day length and higher solar altitude. Both are functions of solar declination, a measure of the earth's tilt toward the sun (Figure E-6). Latitude and longitude positions fix the stream to a position on the globe, while aspect provides the direction of streamflow. Near-stream vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation, producing shade (Table E-1). The solar position has a vertical component – solar altitude – and a horizontal component – solar azimuth – that are both functions of time, date, and the earth's rotation.

While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The shade from riparian vegetation can be measured with a variety of methods, including:

- Hemispherical photography
- Angular canopy densiometer
- Solar pathfinder

(Ice, 2001; OWEB, 1999; Boyd, 1996; Teti, 2001; Teti and Pike, 2005.)

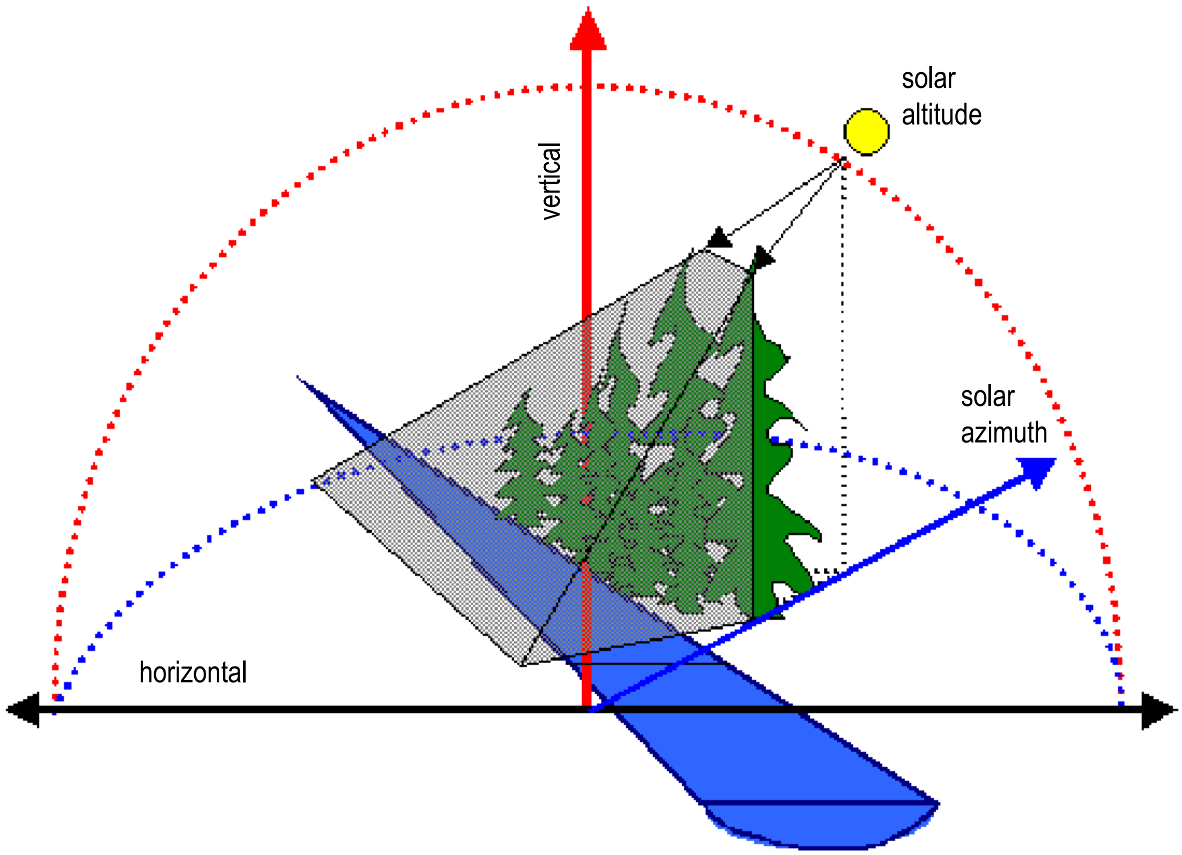

Figure E-6. Parameters that affect shade and geometric relationships.
Solar altitude is a measure of the vertical angle of the sun's position relative to the horizon.
Solar azimuth is a measure of the horizontal angle of the sun's position relative to north. (Boyd and Kasper, 2003.)

Hemispherical photography is generally regarded as the most accurate method for measuring shade, although the equipment that is required is significantly more expensive compared with other methods. Angular canopy densiometers (ACD) and solar pathfinders provide a good balance of cost and accuracy for measuring the importance of riparian vegetation for preventing increases in stream temperature (Beschta et al., 1987; Teti, 2001, 2005). Whereas canopy density is usually expressed as a vertical projection of the canopy onto a horizontal surface, the ACD is a projection of the canopy measured at an angle above the horizon at which direct beam solar radiation passes through the canopy. This angle is typically determined by the position of the sun above the horizon during that portion of the day (usually between 10 A.M. and 2 P.M. in mid to late summer) when the potential solar heat flux is most significant. Typical values of the ACD for old-growth stands in western Oregon have been reported to range from 80% to 90%. (Brazier and Brown, 1973; Steinblums et al., 1984).

Computer programs for the mathematical simulation of shade may also be used to estimate shade from measurements or estimates of the key parameters listed in Table E-1 (Ecology, 2003; Chen, 1996; Chen et al., 1998; Boyd, 1996; Boyd and Park, 1998).

Table E-1. Factors that influence stream shade.

Description	Parameter
Season/time	Date/time
Stream characteristics	Aspect, **channel width**
Geographic position	Latitude, longitude
Vegetative characteristics	**Riparian vegetation height, width, and density**
Solar position	Solar altitude, solar azimuth

Bold indicates influenced by human activities.

Riparian Buffers and Effective Shade

Trees in riparian areas provide shade to streams and minimize undesirable water temperature changes (Brazier and Brown, 1973; Steinblums et al., 1984). The shading effectiveness of riparian vegetation is correlated to riparian area width (Figure E-7). The shade as represented by angular canopy density (ACD) for a given riparian buffer width varies over space and time because of differences among site potential vegetation, and forest development stages (e.g., height and density, and stream width). For example, a 50-foot-wide riparian area with fully developed trees could provide from 45% to 72% of the potential shade in the two studies shown in Figure E-7.

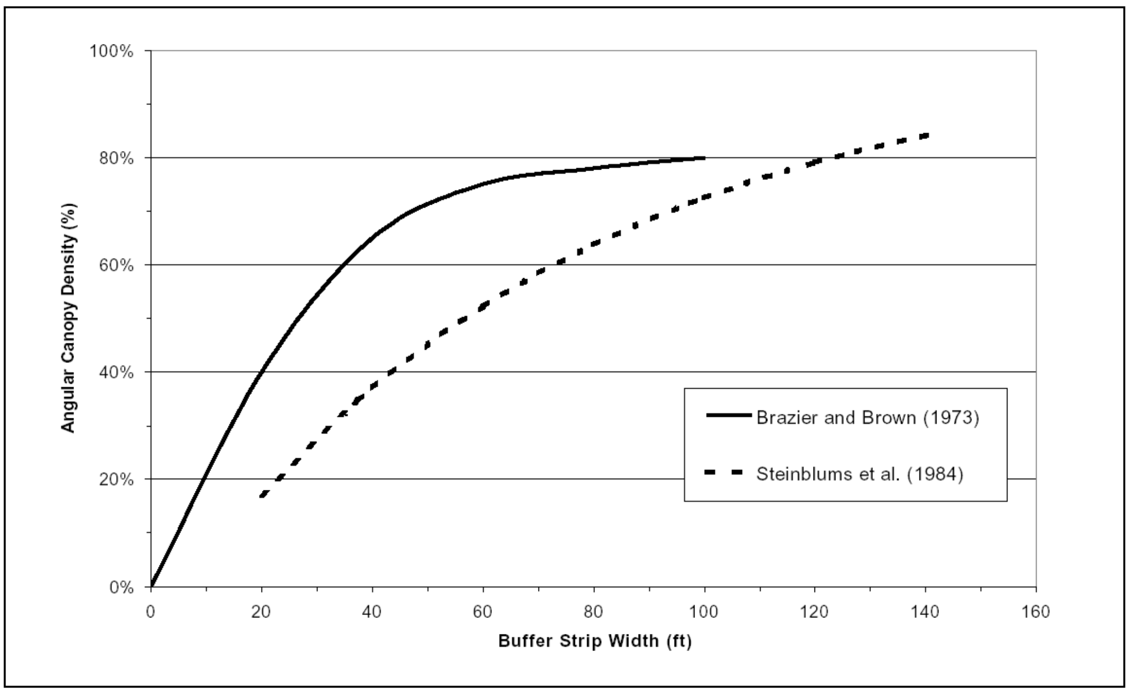

Figure E-7. Relationship between angular canopy density and riparian buffer width for small streams in old-growth riparian stands.
(after Beschta et al., 1987; and CH2M Hill, 2000)

The Brazier and Brown (1973) shade data show a stronger relationship between ACD and buffer strip width than the Steinblums et al. (1984) data: The r^2 correlation for ACD and buffer width was 0.87 and 0.61 in Brazier and Brown (1973) and Steinblums et al. (1984), respectively. This difference supports the use of the Brazier and Brown curve as a base for measuring shade effectiveness under various riparian buffer proposals. These results reflect the natural variation among old-growth sites studied, and show a possible range of potential shade.

Several studies of stream shading report that most of the potential shade comes from the riparian area within about 75 feet (23 m) of the channel (CH2M Hill, 2000; Castelle and Johnson, 2000):

- Beschta et al. (1987) report that a 98-foot-wide (30-m) buffer provides the same level of shading as that of an old-growth stand.
- Brazier and Brown (1973) found that a 79-foot (24-m) buffer provides maximum shade to streams.
- Steinblums et al. (1984) concluded that a 56-foot (17-m) buffer provides 90% of the maximum ACD.
- Corbett and Lynch (1985) concluded that a 39-foot (12-m) buffer should adequately protect small streams from large temperature changes following logging.
- Broderson (1973) reported that a 49-foot-wide (15-m) buffer provides 85% of the maximum shade for small streams.
- Lynch et al. (1984) found that a 98-foot-wide (30-m) buffer maintains water temperatures within 2°F (1°C) of their former average temperature in small streams (channel width less than 3 m).

GEI (2002) reviewed the scientific literature related to the effectiveness of buffers for shade protection in agricultural areas in Washington and concluded that buffer widths of 10 m (33 feet) provide nearly 80% of the maximum potential shade in agricultural areas. Wenger (1999) concluded that a minimum continuous buffer width of 10-30 m should be preserved or restored along each side of all streams on a municipal or county-wide scale to provide stream temperature control and maintain aquatic habitat. GEI (2002) considered the recommendations of Wenger (1999) to be relevant for agricultural areas in Washington.

Steinblums et al. (1984) concluded that shade could be delivered to forest streams from beyond 75 feet (22 m) and potentially out to 140 feet (43 m). In some site-specific cases, forest practices between 75 and 140 feet from the channel have the potential to reduce shade delivery by up to 25% of maximum. However, any reduction in shade beyond 75 feet would probably be relatively low on the horizon, and the impact on stream heating would be relatively minimal because the potential solar radiation decreases significantly as solar elevation decreases.

Microclimate – Surrounding Thermal Environment

A secondary consequence of near-stream vegetation is its effect on the riparian microclimate. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity, and lower wind speeds are characteristic. Riparian microclimates tend to moderate daily air temperatures. Evapotranspiration by riparian plant communities increases relative humidity. Physical blockage by riparian vegetation reduces wind speed.

Riparian buffers commonly occur on both sides of the stream, compounding the edge influence on the microclimate. Brosofske et al. (1997) reported that a buffer width of at least 150 feet (45 m) on each side of the stream was required to maintain a natural riparian microclimate environment in small forest streams (channel width less than 4 m) in the foothills of the western slope of the Cascade Mountains in Western Washington with predominantly Douglas-fir and western hemlock.

Bartholow (2000) provided a thorough summary of literature of documented changes to the environment of streams and watersheds associated with extensive forest clearing. Changes summarized by Bartholow (2000) are representative of hot summer days and indicate the mean daily effect unless otherwise indicated:

- **Air temperature**. Edgerton and McConnell (1976) showed that removing all or a portion of the tree canopy resulted in cooler terrestrial air temperatures at night and warmer temperatures during the day, enough to influence thermal cover sought by elk (*Cervus canadensis*) on their eastern Oregon summer range. Increases in maximum air temperature varied from 5 to 7°C for the hottest days (estimate). However, the mean daily air temperature did not appear to have changed substantially since the maximum temperatures were offset by almost equal changes to the minima.

  Similar temperatures have been commonly reported (Childs and Flint, 1987; Fowler et al., 1987), even with extensive clearcuts (Holtby, 1988). In an evaluation of buffer strip width, Brosofske et al. (1997) found that air temperatures immediately adjacent to the ground increased 4.5°C during the day and about 0.5°C at night (estimate). Fowler and Anderson (1987) measured a 0.9°C air temperature increase in clearcut areas, but temperatures were also 3°C higher in the adjacent forest. Chen et al. (1993) found similar (2.1°C) increases.

  All measurements reported here were made over land instead of water, but in aggregate support about a 2°C increase in ambient mean daily air temperature resulting from extensive clearcutting.

- **Relative humidity**. Brosofske et al. (1997) examined changes in relative humidity within 17 to 72 m buffer strips. The focus of their study was to document changes along the gradient from forested to clearcut areas, so they did not explicitly report pre- to post-harvest changes at the stream. However, there appeared to be a reduction in relative humidity at the stream, estimated at 7% during the day and 6% at night. Relative humidity at stream sites increased exponentially with buffer width. Similarly, a study by Chen et al. (1993) showed a decrease of about 11% in mean daily relative humidity on clear days at the edges of clearcuts.

- **Wind speed**. Brosofske et al. (1997) reported almost no change in wind speed at stream locations within buffer strips adjacent to clearcuts. Speeds quickly approached upland conditions toward the edges of the buffers, with an indication that wind actually increased substantially at distances of about 15 meters from the edge of the strip, and then declined farther upslope to pre-harvest conditions. Chen et al. (1993) documented increases in both peak and steady winds in clearcut areas; increments ranged from an estimated 0.7 to 1.2 meters per second.

Thermal Role of Channel Morphology

Changes in channel morphology impact stream temperatures. As a stream widens, the surface area exposed to heat flux increases, resulting in increased energy exchange between a stream and its environment (Chapra, 1997). Further, wide channels are likely to have decreased levels of shade due to the increased distance created between vegetation and the wetted channel and the decreased fraction of the stream width that could potentially be covered by shadows from riparian vegetation. Conversely, narrow channels are more likely to experience higher levels of shade.

Channel widening is often related to degraded riparian conditions that allow increased streambank erosion and sedimentation of the streambed, both of which correlate strongly with riparian vegetation type and condition (Rosgen, 1996). Channel morphology is not solely dependent on riparian conditions. Sedimentation can deposit material in the channel, fill pools, and aggrade the streambed, reducing channel depth and increasing channel width.

Channel modification usually occurs during high-flow events. Land uses that affect the magnitude and timing of high-flow events may negatively impact channel width and depth. Channel straightening can increase flow velocities and lead to deeply incised streambanks and washout of gravel and cobble substrate. Riparian vegetation conditions will affect the resilience of the streambanks/flood plain during periods of sediment introduction and high flow. Disturbance processes may have differing results depending on the ability of riparian vegetation to shape and protect channels.

Channel morphology can also be the result of upland land practices or disconnection of the flood plain. Erosion in the watershed can result in high bed load and shallower, wider channels downstream. The separation of the flood plain from the main channel of a river can result in sediment being carried in the channel that would otherwise be deposited in the flood plain. It can also increase velocities and bank erosion.

Channel morphology is related to riparian vegetation composition and condition by:

- **Building streambanks**. Traps suspended sediments, encourages deposition of sediment in the flood plain, and reduces incoming sources of sediment.
- **Maintaining stable streambanks**. High rooting strength and high streambank and flood plain roughness prevent streambank erosion.
- **Reducing flow velocity** (erosive kinetic energy). Supplies large woody debris to the active channel, provides a high pool-to-riffle ratio, and adds channel complexity that reduces shear stress exposure to streambank soil particles.

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Appendix F. QUAL2Kw Model Inputs

Point Source and Groundwater Input Plots for QUAL2Kw

This appendix presents plots of all continuous source terms in the QUAL2Kw model. These source terms represent tributaries and groundwater flow into Wide Hollow Creek.

The parameters on the following plots are arranged in the order shown in Table F-1 below:

Table F-1. Order of plot parameters in figures below.

Flow (cfs)	Ammonia (ug/l)	Organic Phosphorous (ug/l)	Dissolved Oxygen (mg/l)	Inorganic Suspended Solids (mg/l)
Specific Conductivity (uS/cm)	Organic N (ug/l)	Inorganic Phosphorous (ug/l)	pH (units)	Detritus (mg/l)
Temperature (°C)	Nitrate-Nitrite (ug/l)	CBOD Slow (ug/l)	Alkalinity (mg/l)	Legend

The plots show the daily average of model input values as blue lines. Synoptic measurements or sample results (observations) are shown as red dots for each day (all observations are shown). For detritus, different colored dots show results by gravimetric method (red dot), carbon method (blue dot), and the average value (black dot).

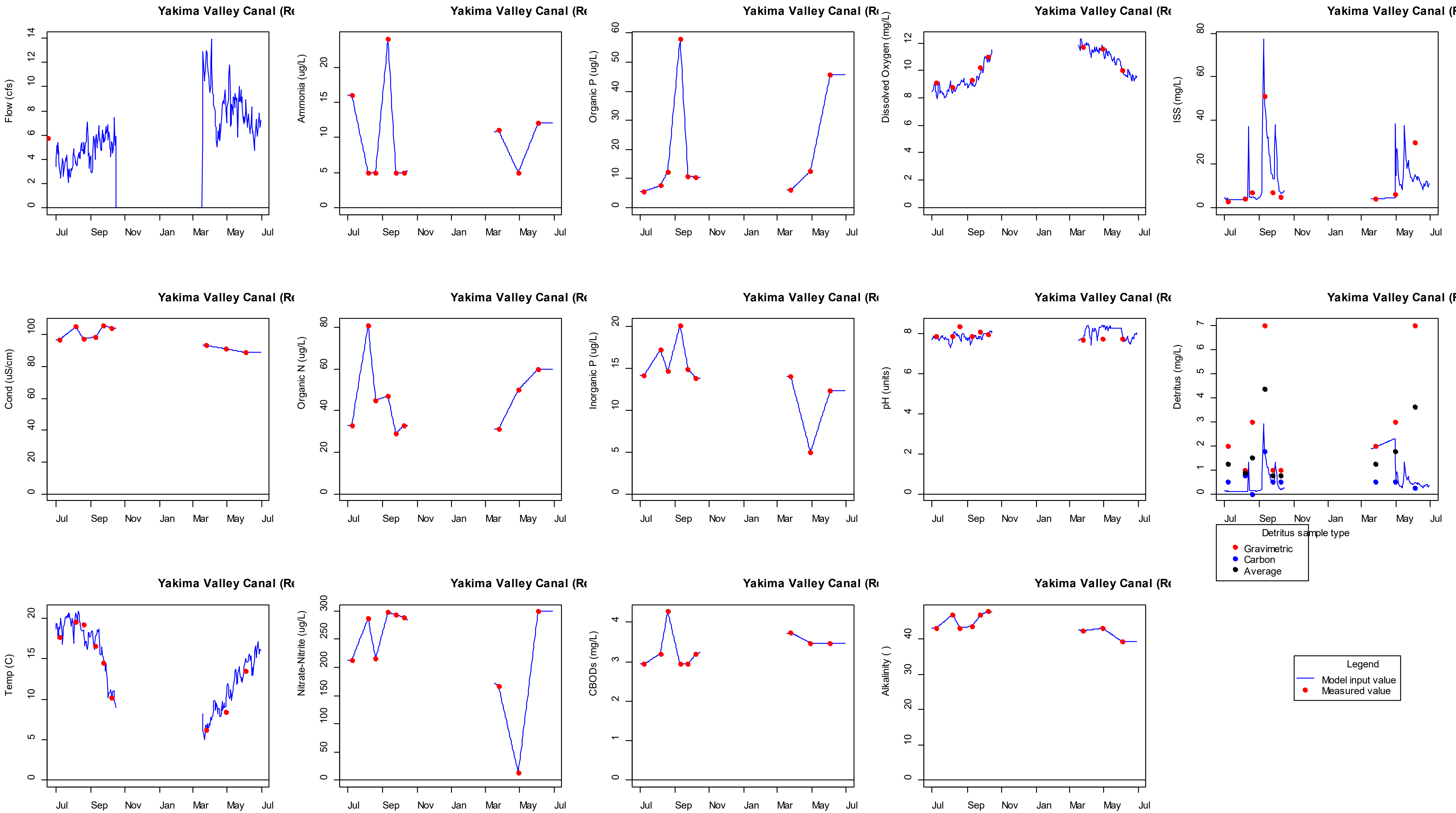

Figure F-1. Yakima Valley Canal (Reach #1 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

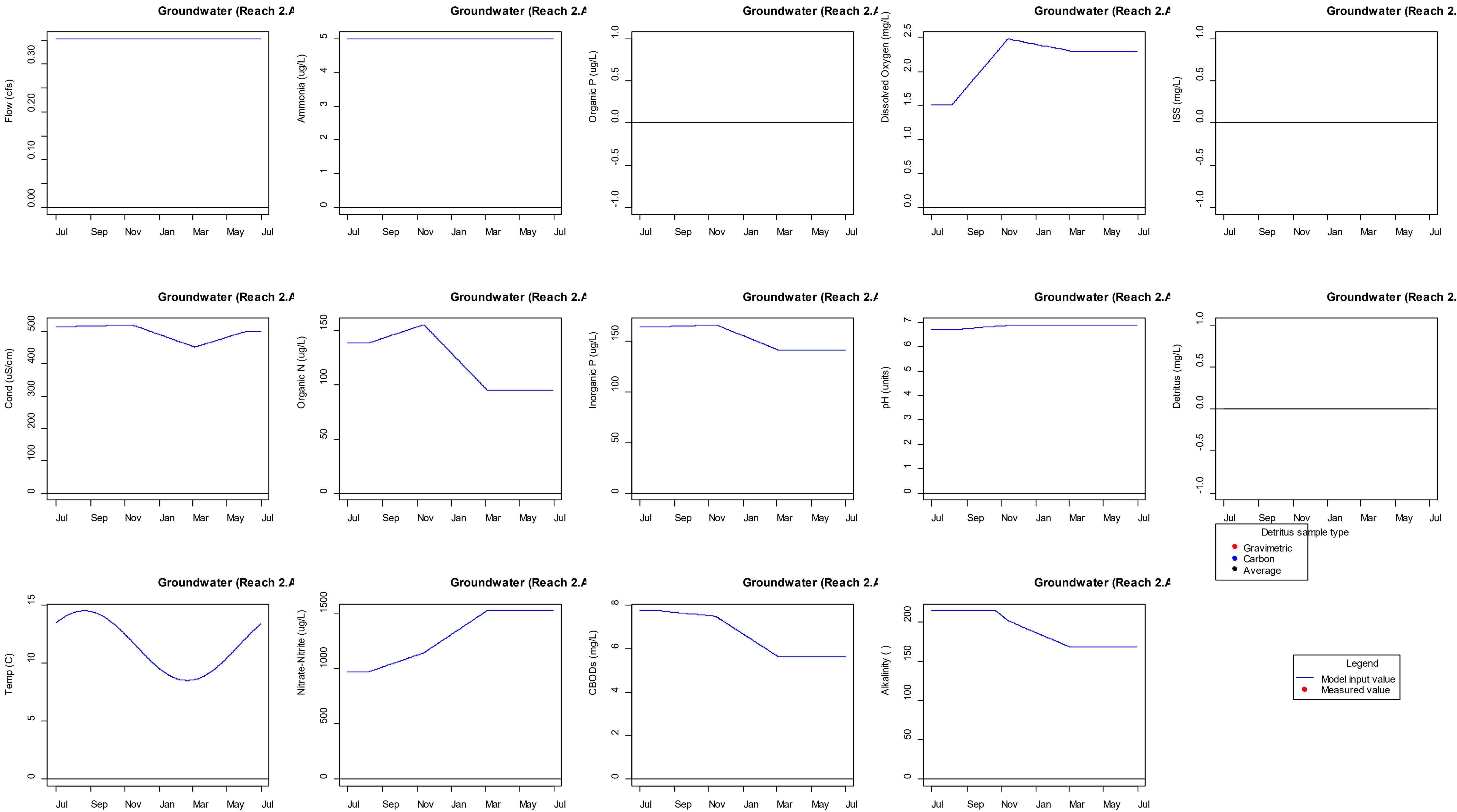

Figure F-2. Groundwater (Reach #2 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

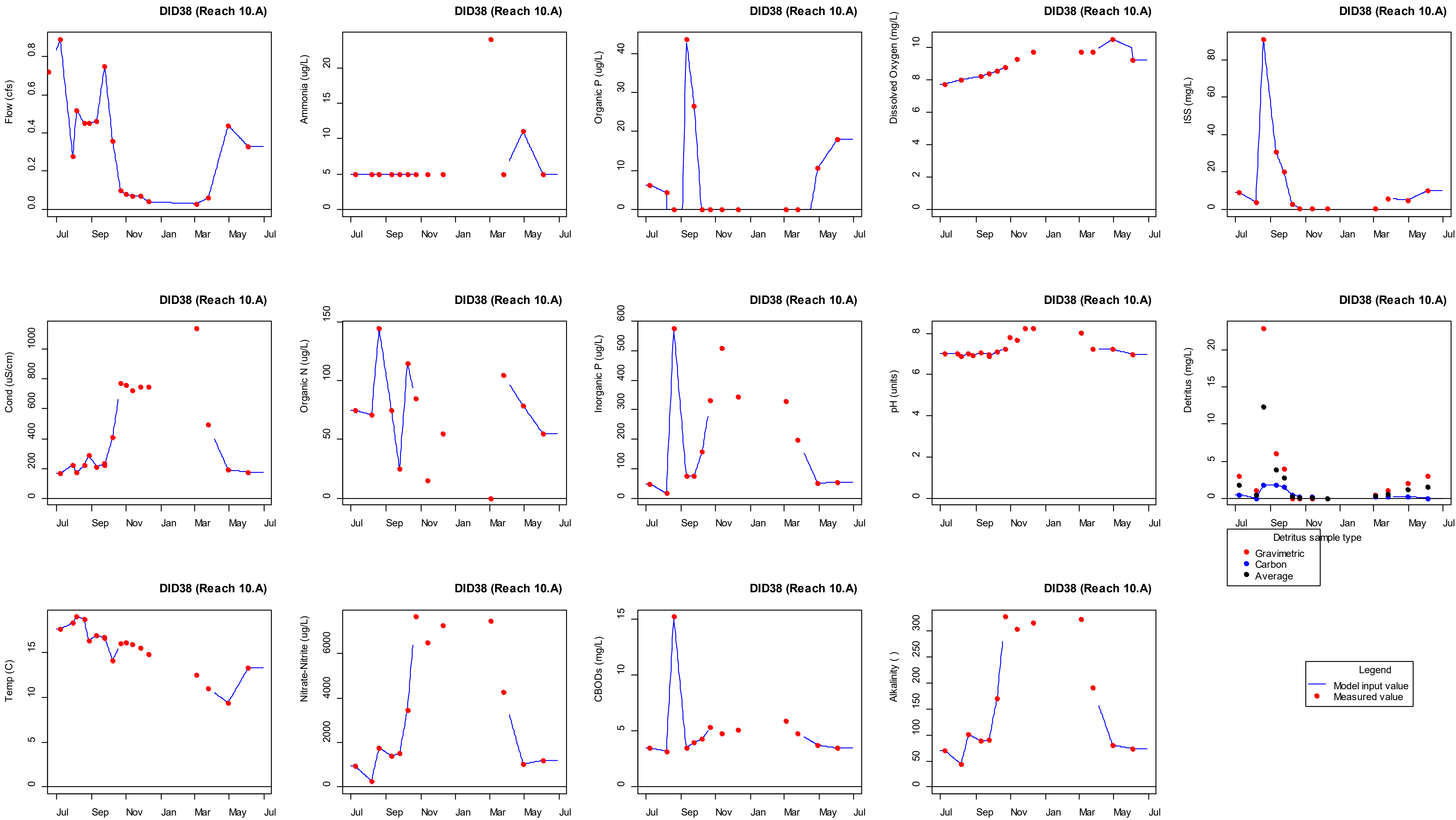

Figure F-3. DID#38 (Reach #10 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

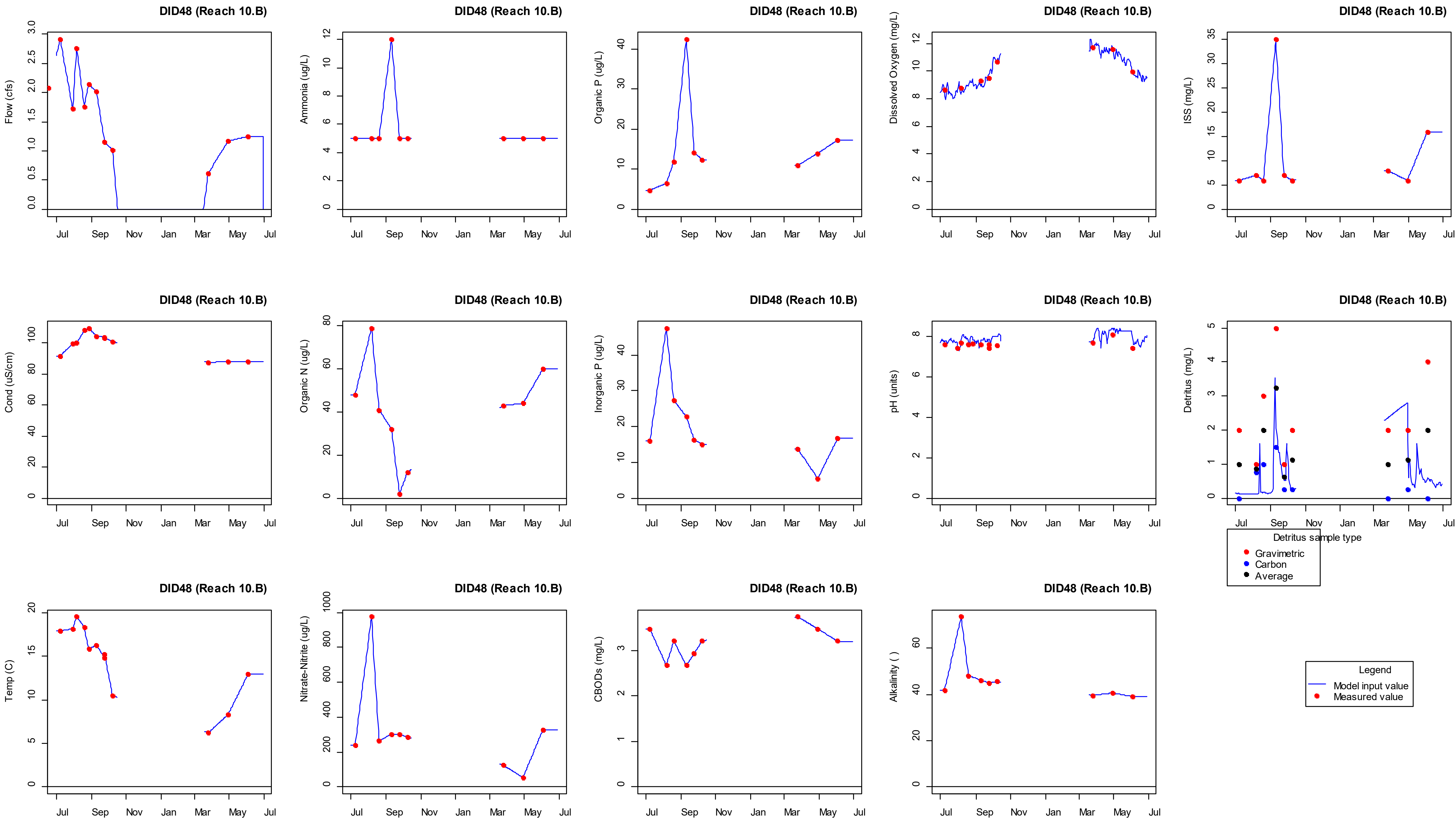

Figure F-4. DID#48 (Reach #10 Source B): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

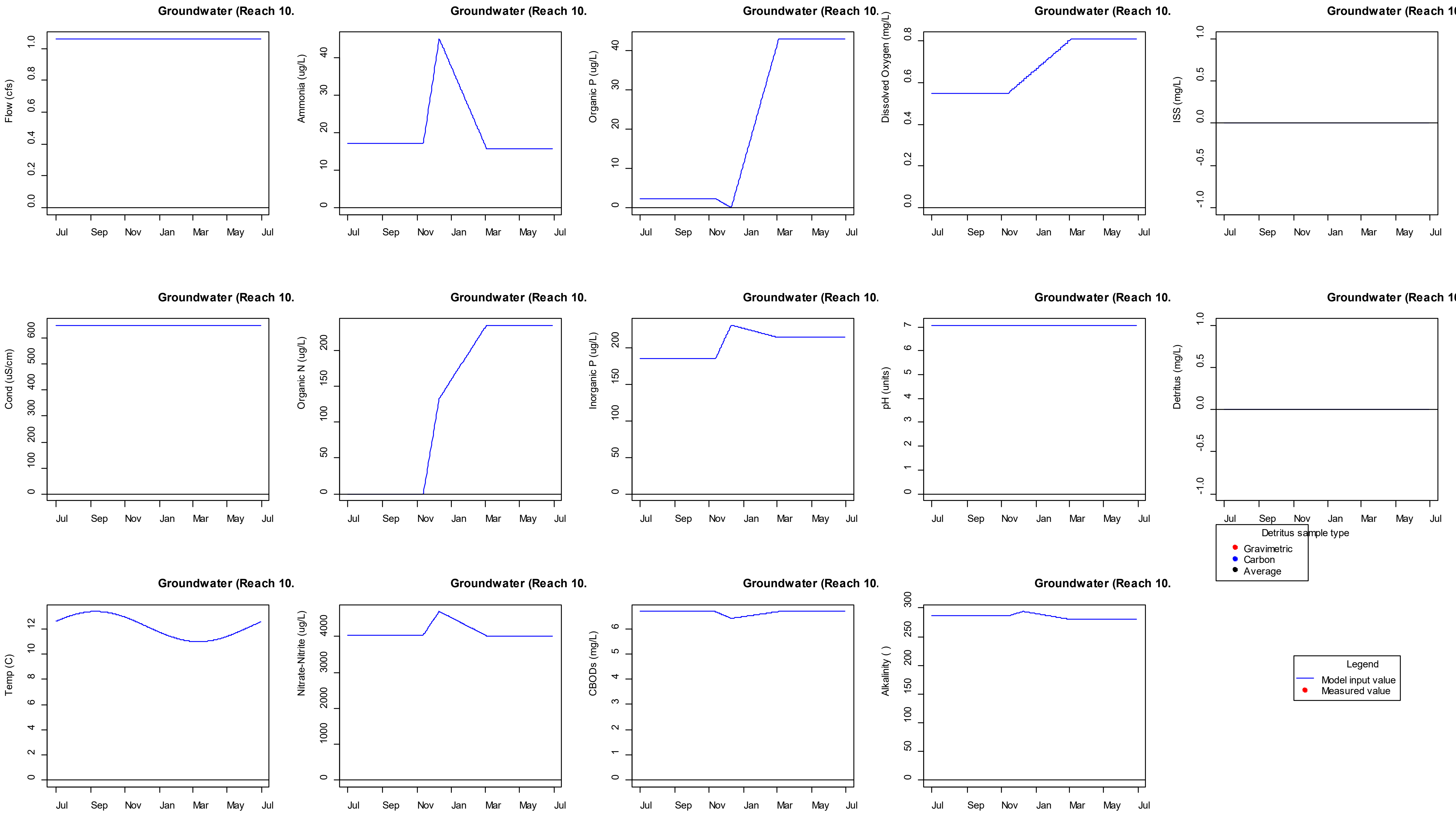

Figure F-5. Groundwater (Reach #10 Source C): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

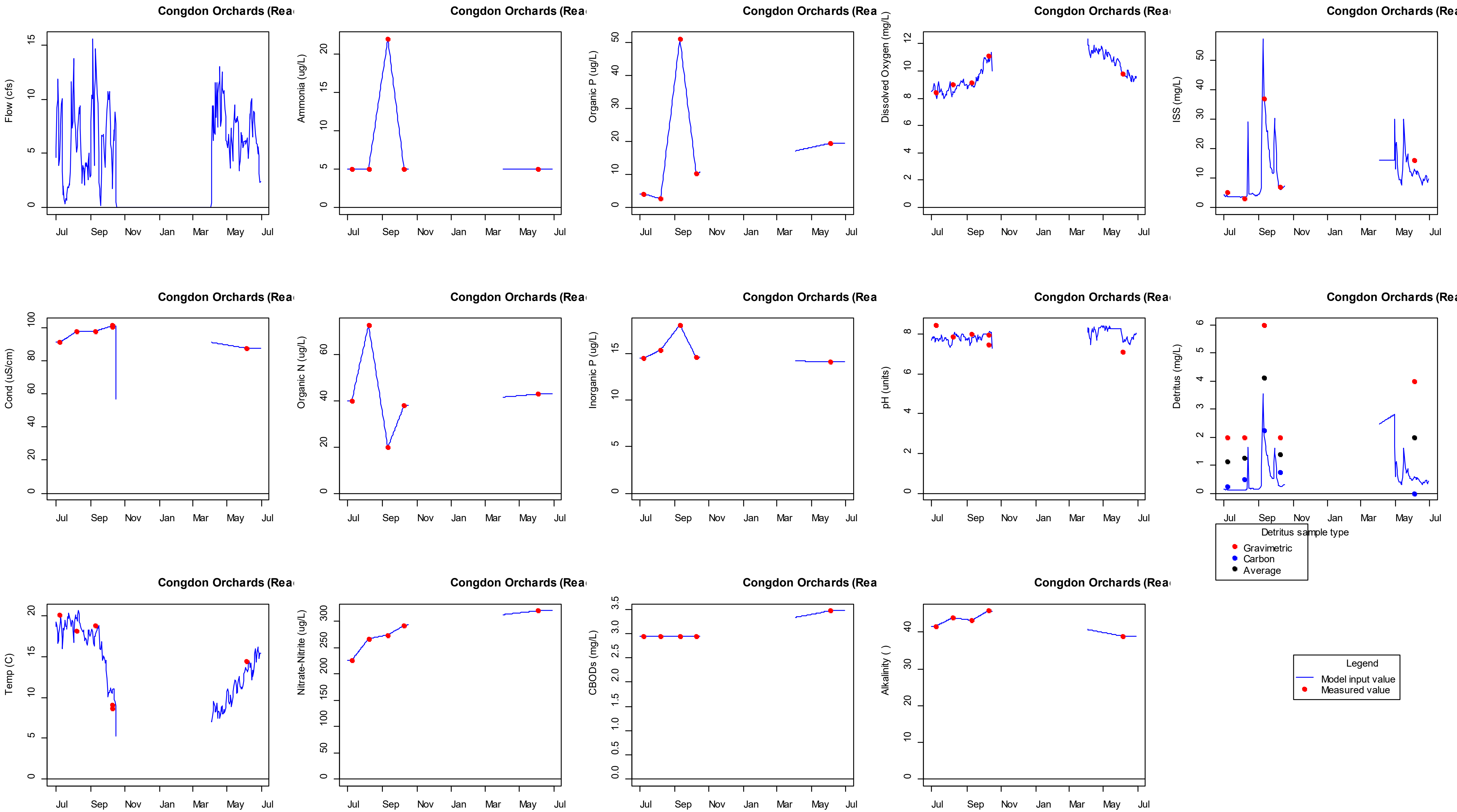

Figure F-6. Congdon Orchards (Reach #11 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

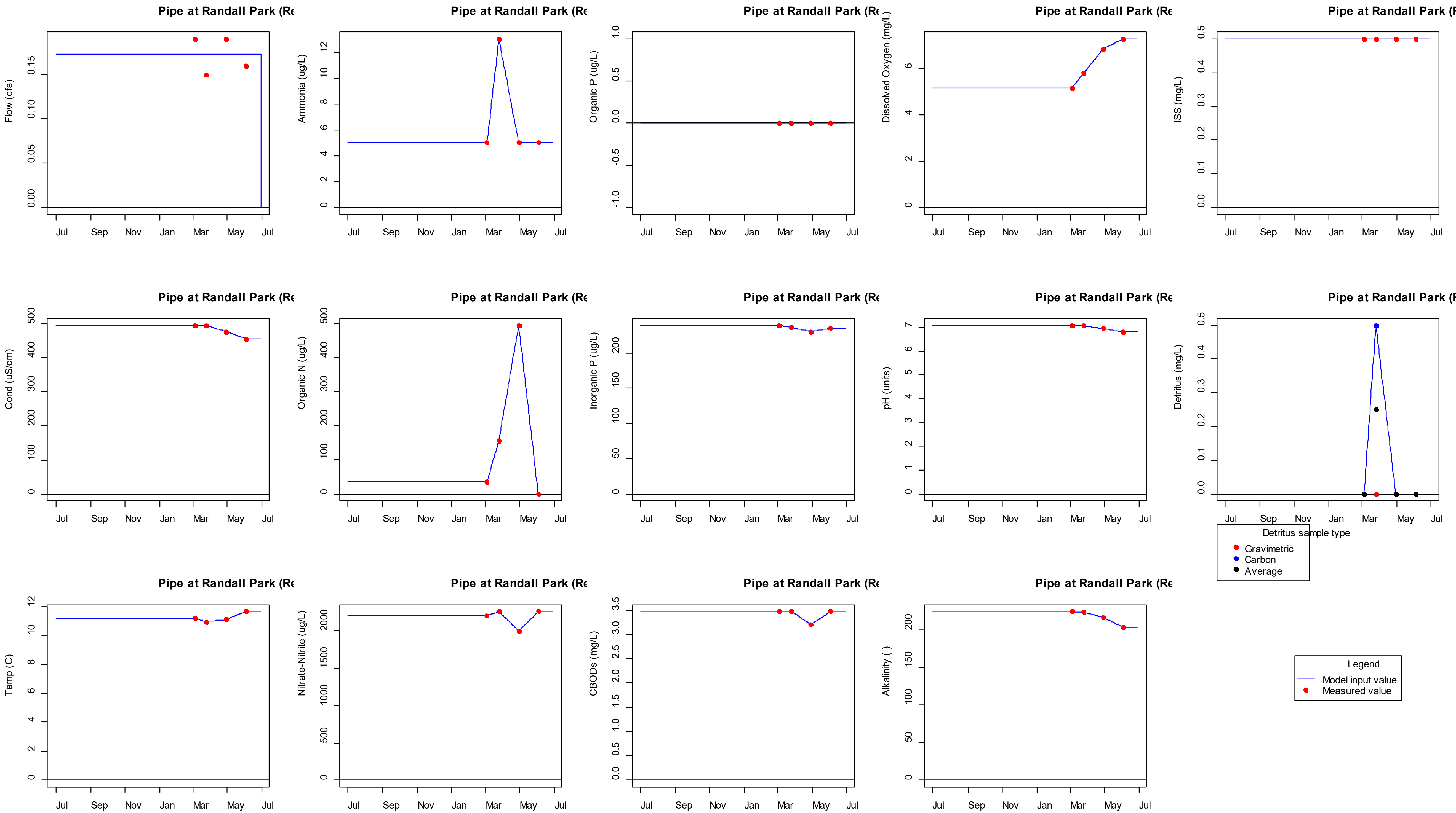

Figure F-7. Pipe at Randall Park (Reach #15 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

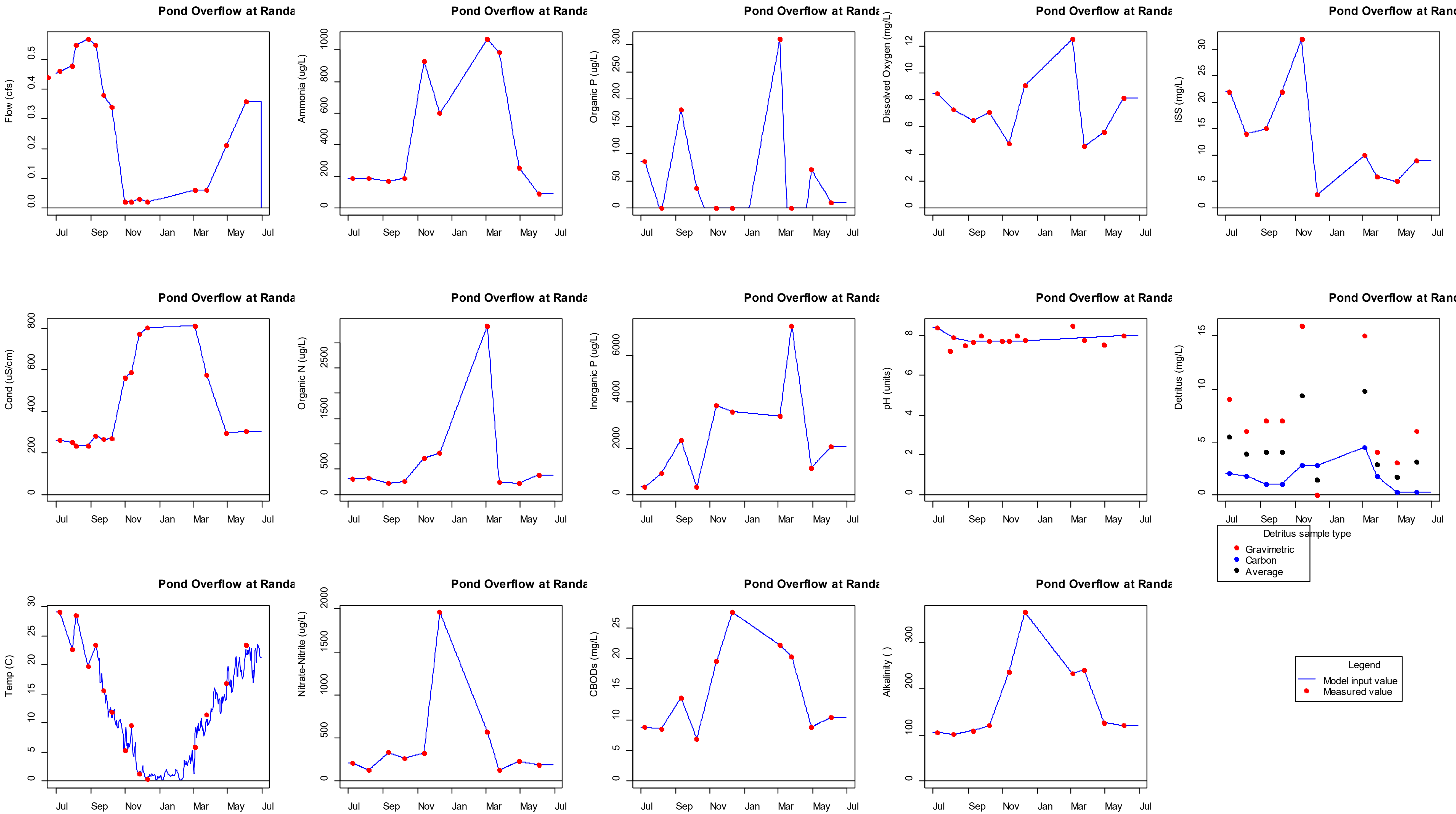

Figure F-8. Pond Overflow at Randall Park (Reach #16 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

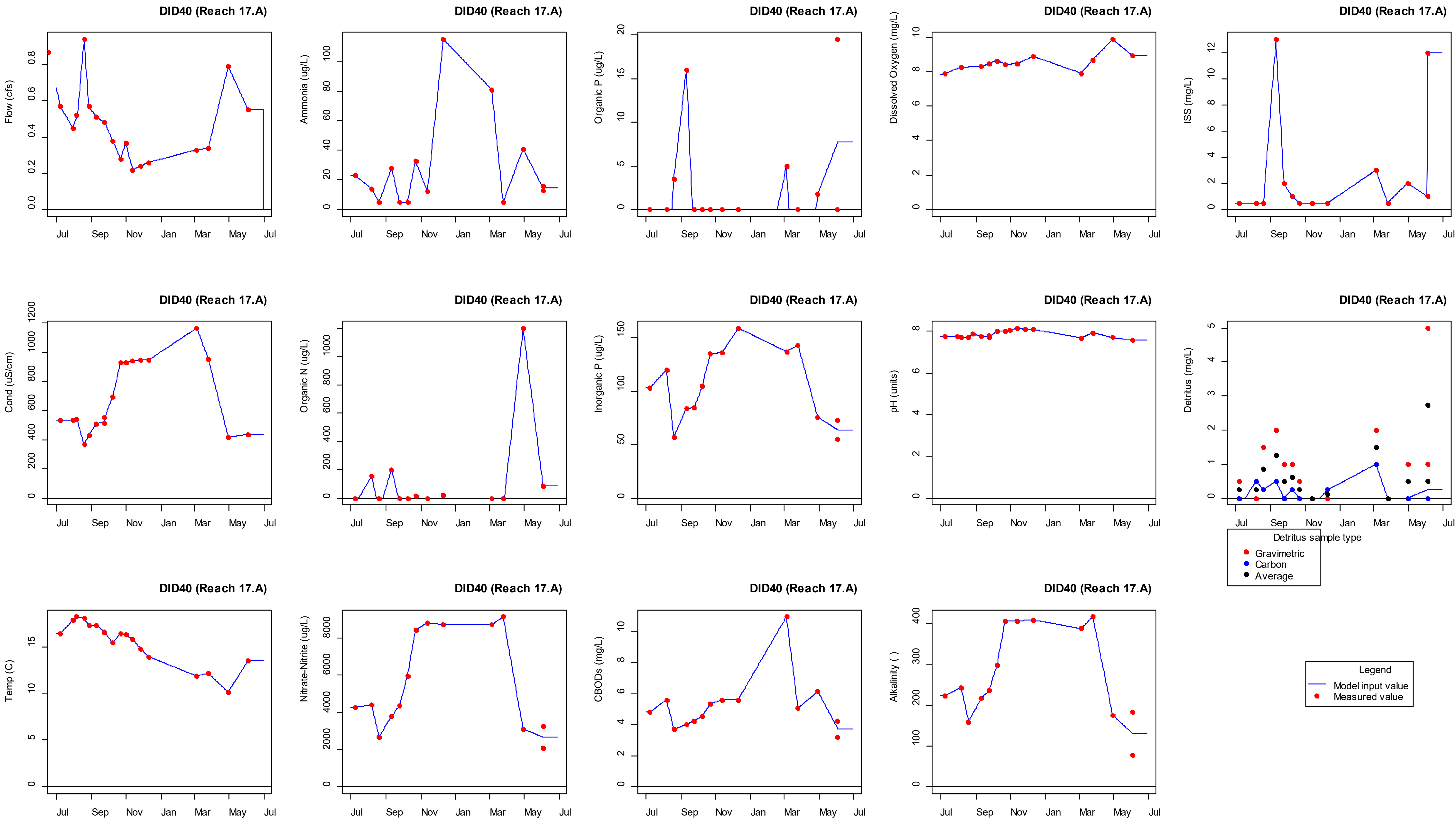

Figure F-9. DID#40 (Reach #17 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

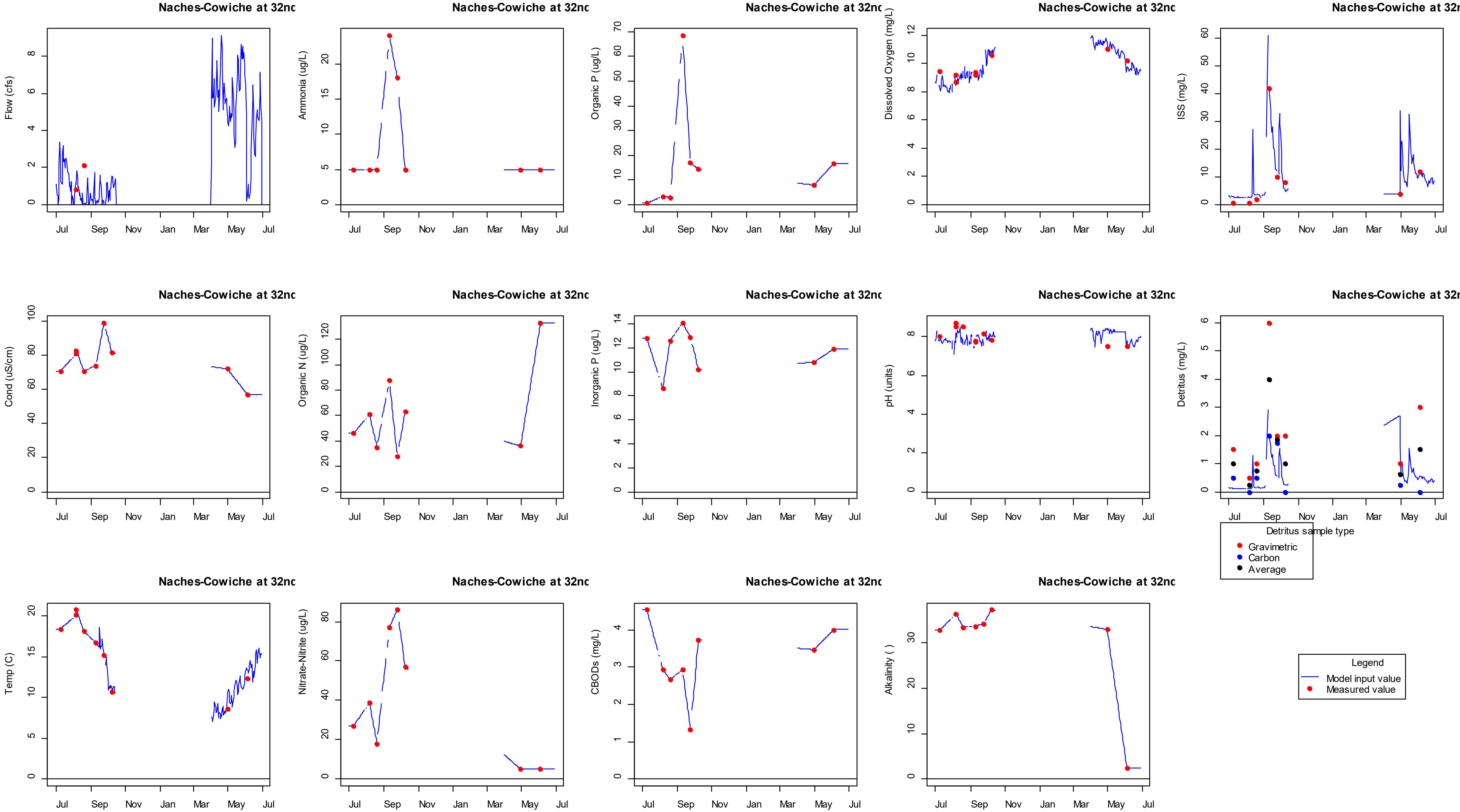

Figure F-10. Naches-Cowiche at 32nd Ave (Reach #18 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

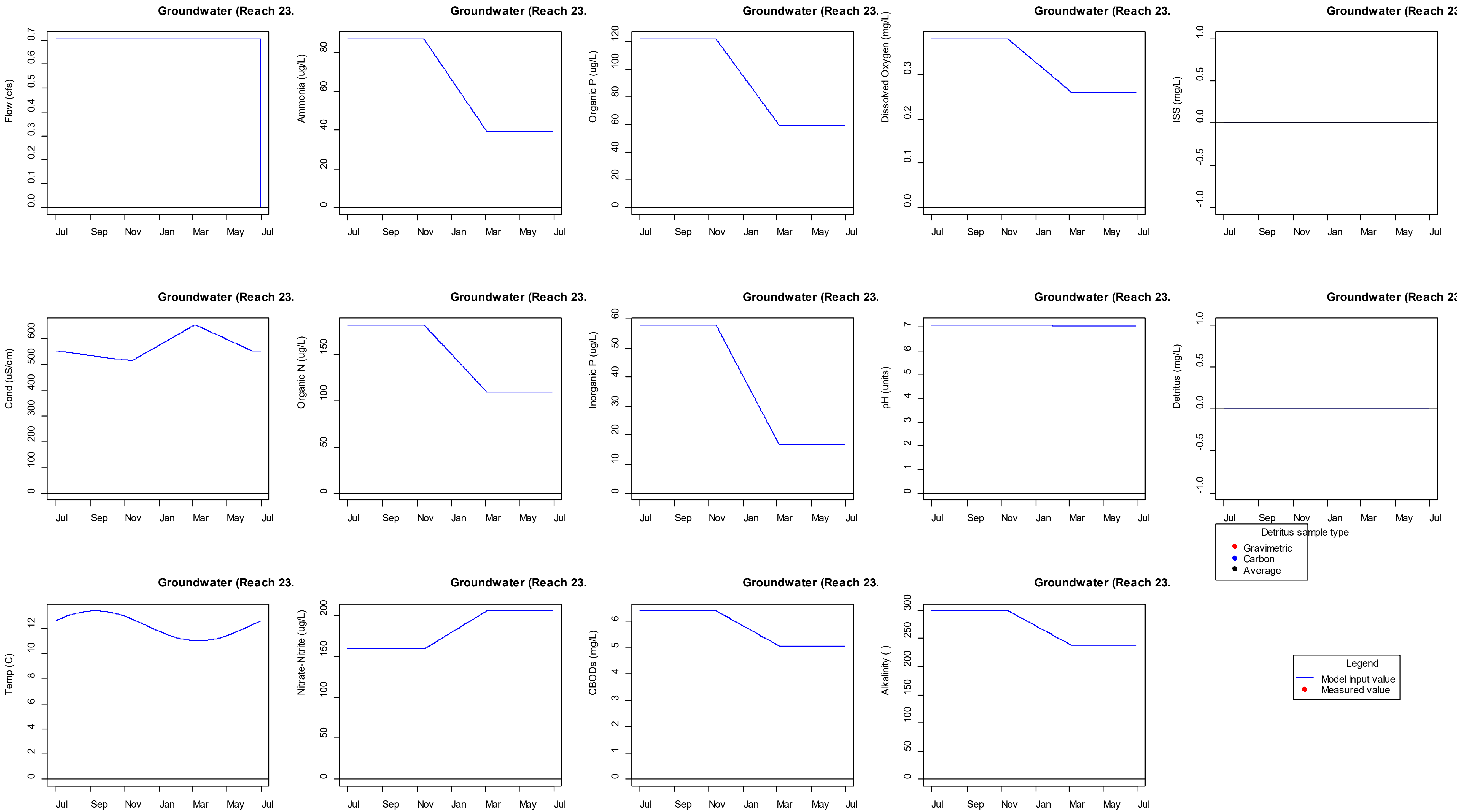

Figure F-11. Groundwater (Reach #23 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

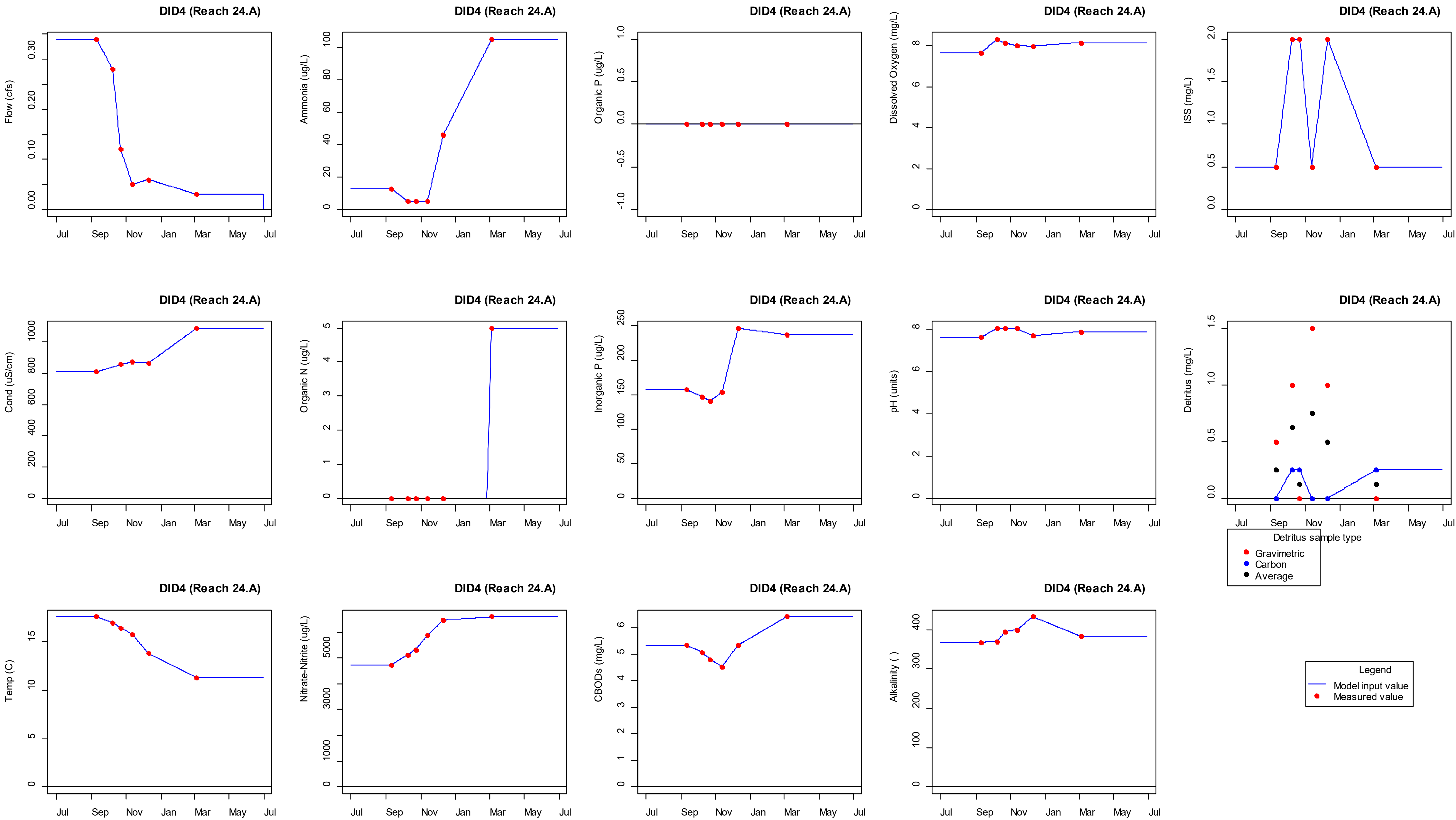

Figure F-12. DID#4 (Reach #24 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

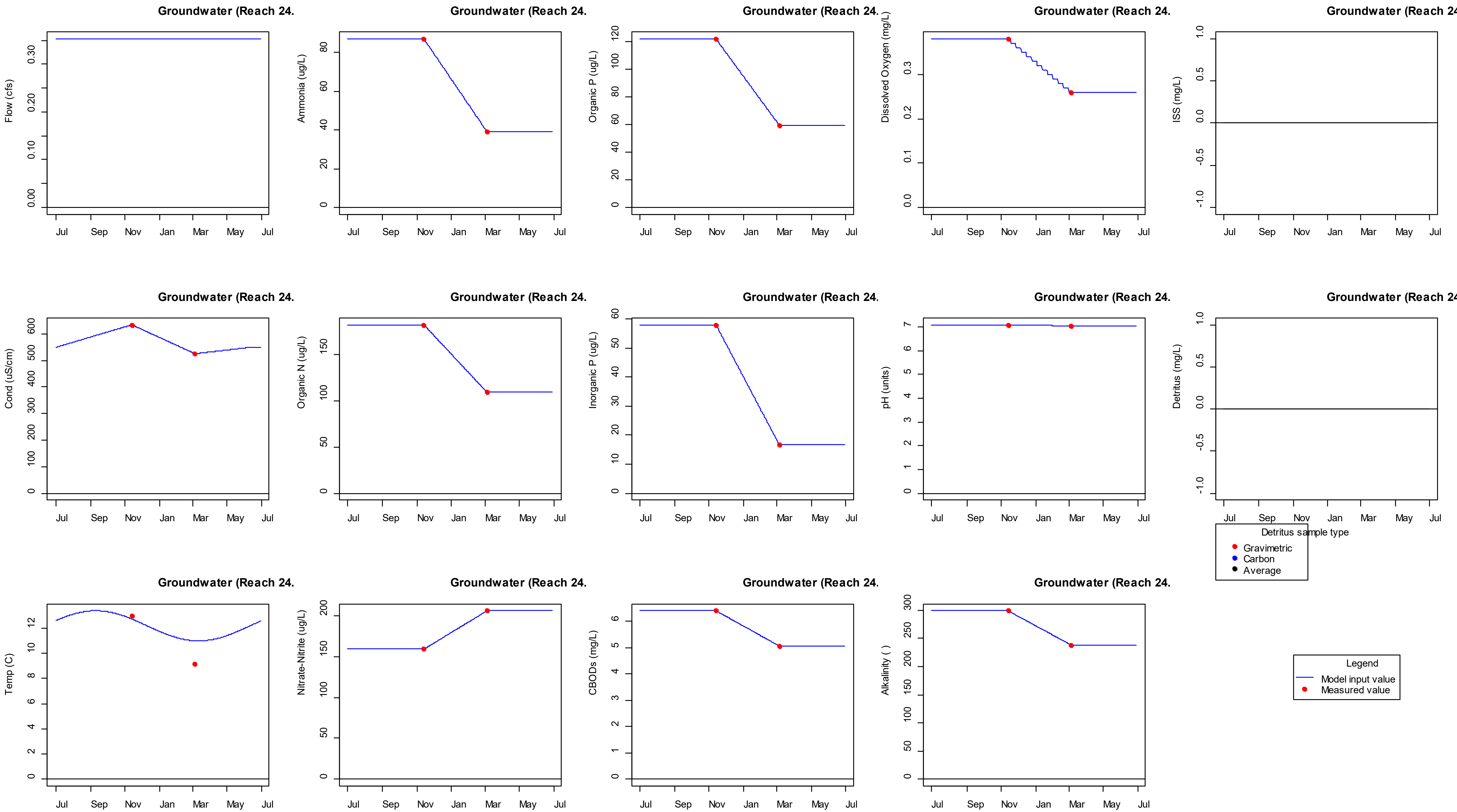

Figure F-13. Groundwater (Reach #24 Source B): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

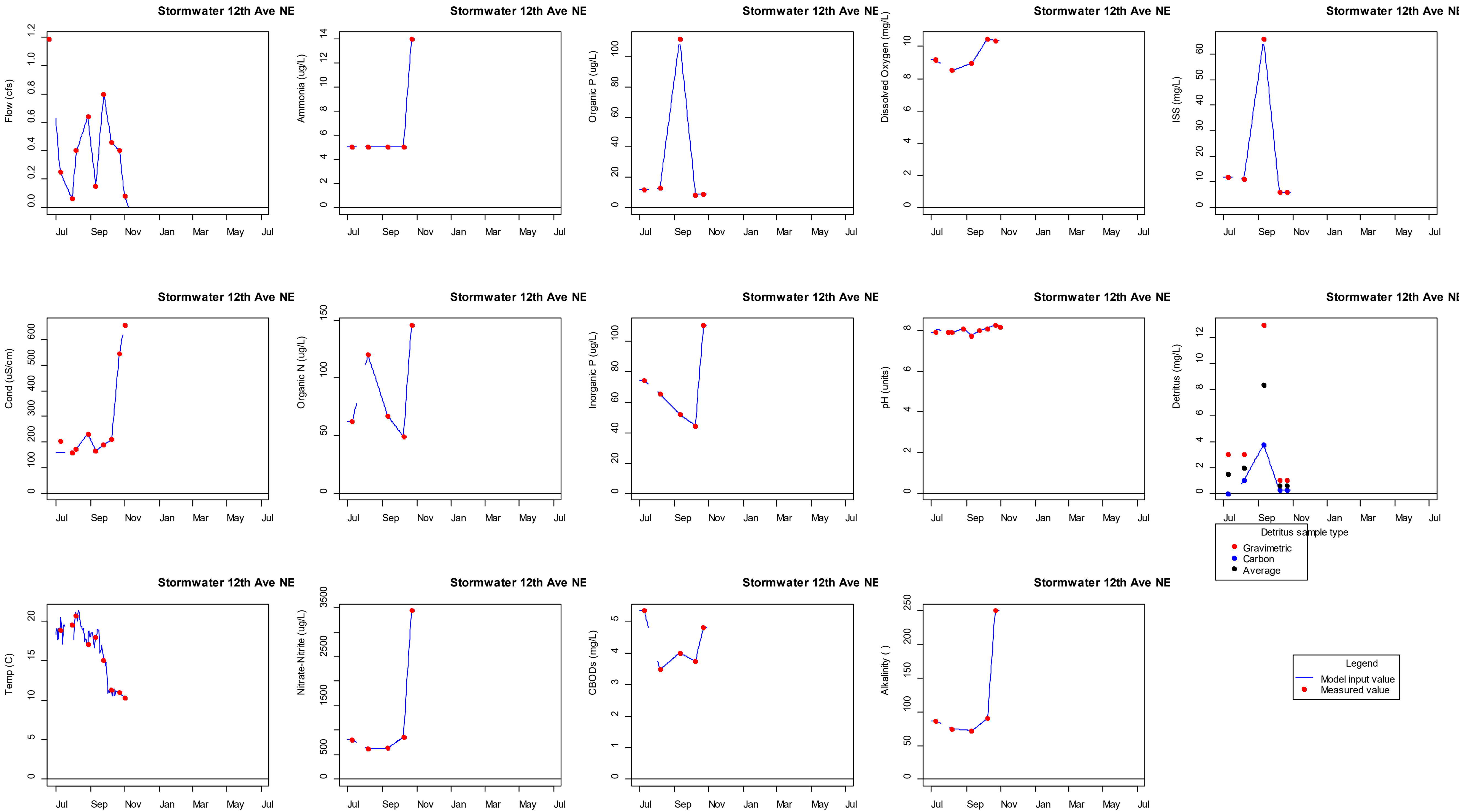

Figure F-14. Stormwater 12th Ave NE (Reach #24 Source C): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

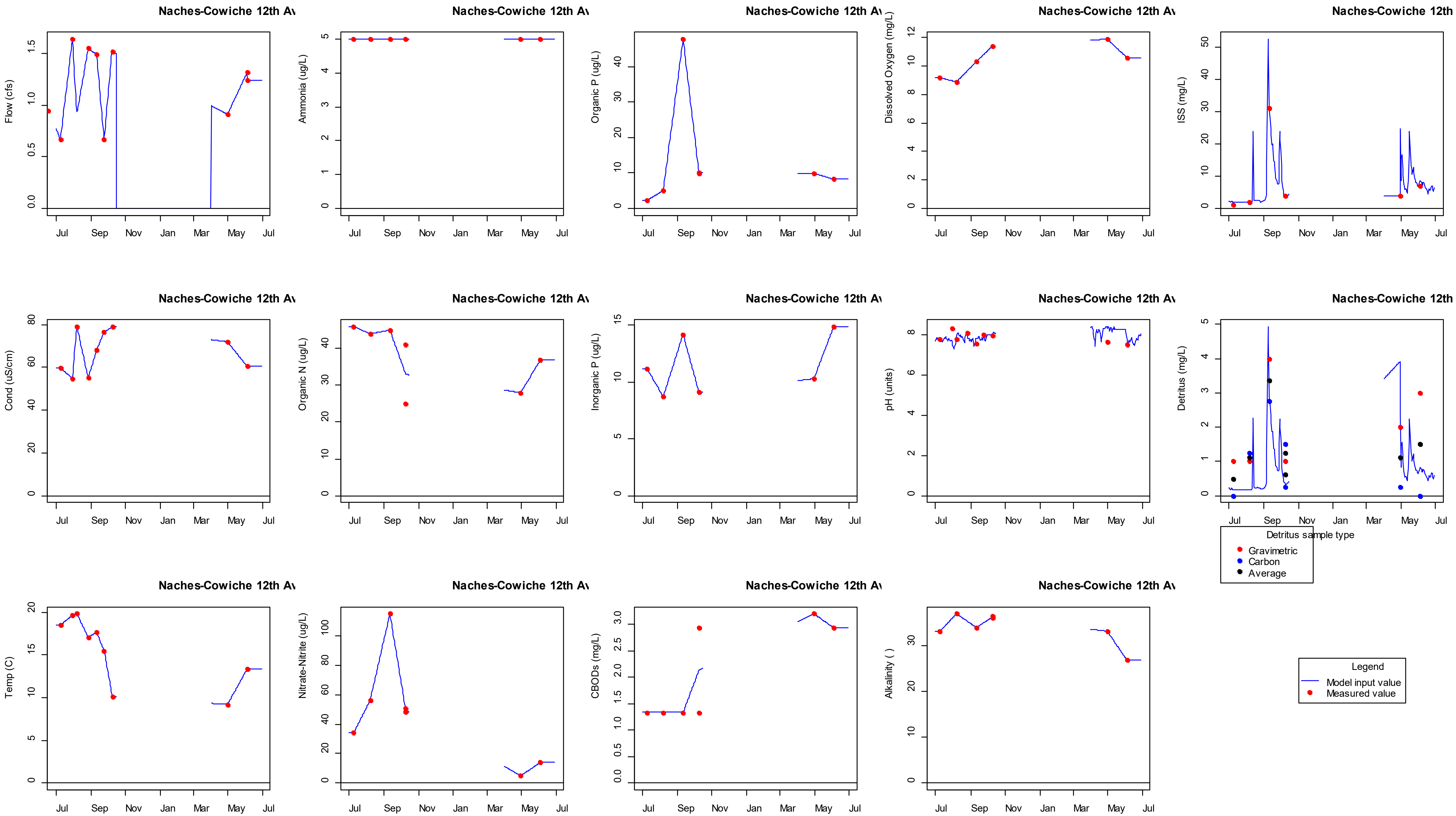

Figure F-15. Naches-Cowiche 12th Ave (Reach #24 Source D): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

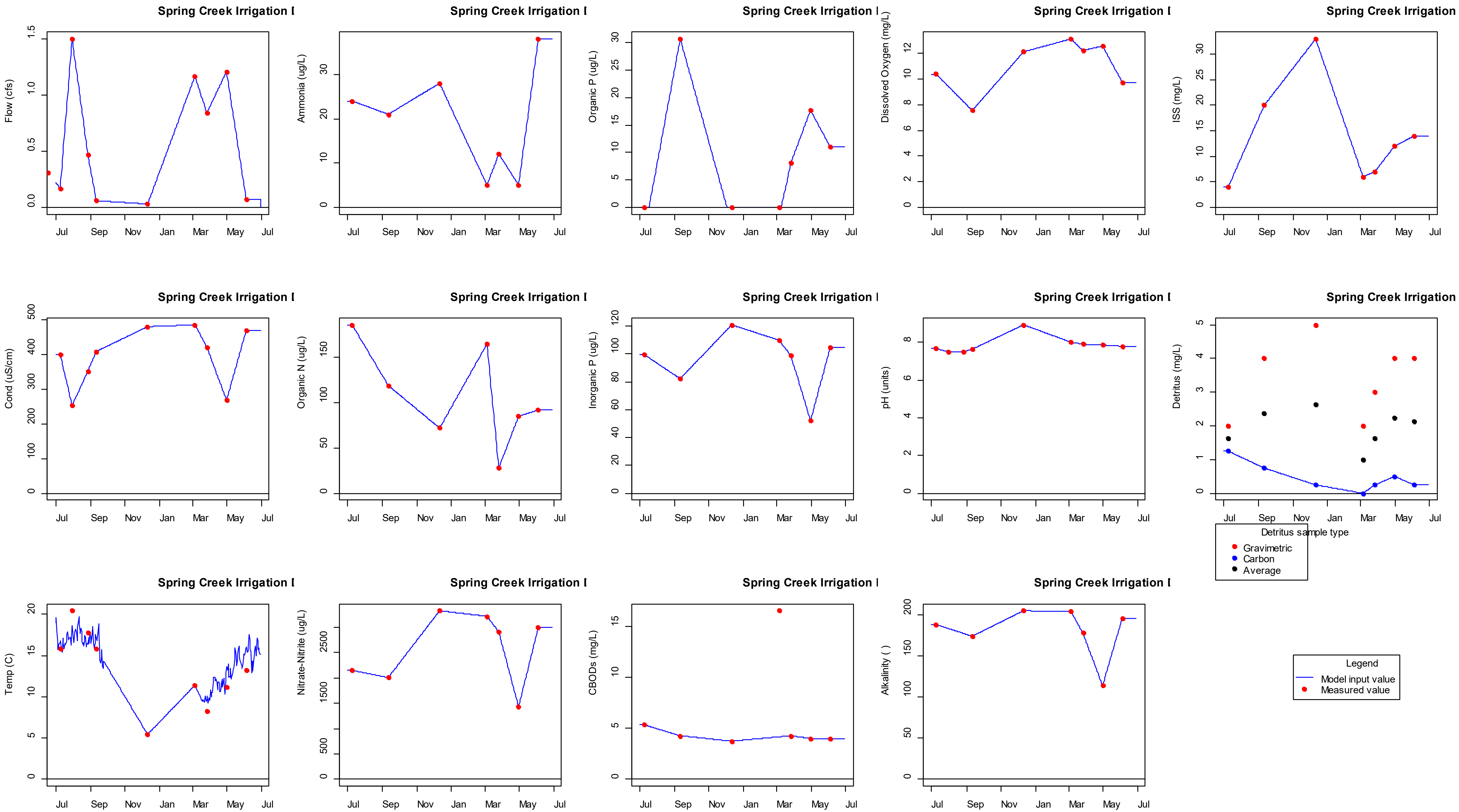

Figure F-16. Spring Creek Irrigation District (Reach #25 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

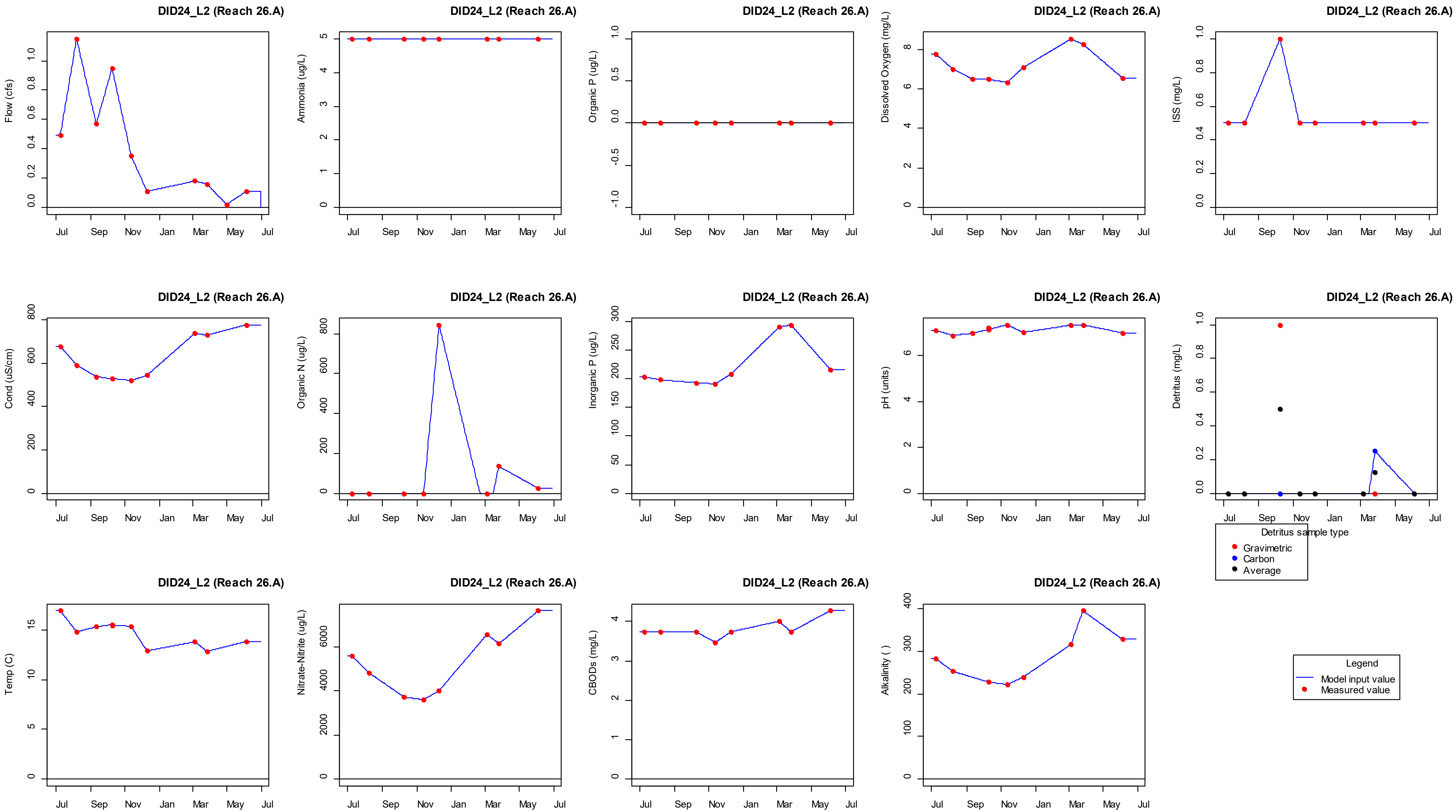

Figure F-17. DID#24 L2 (Reach #26 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

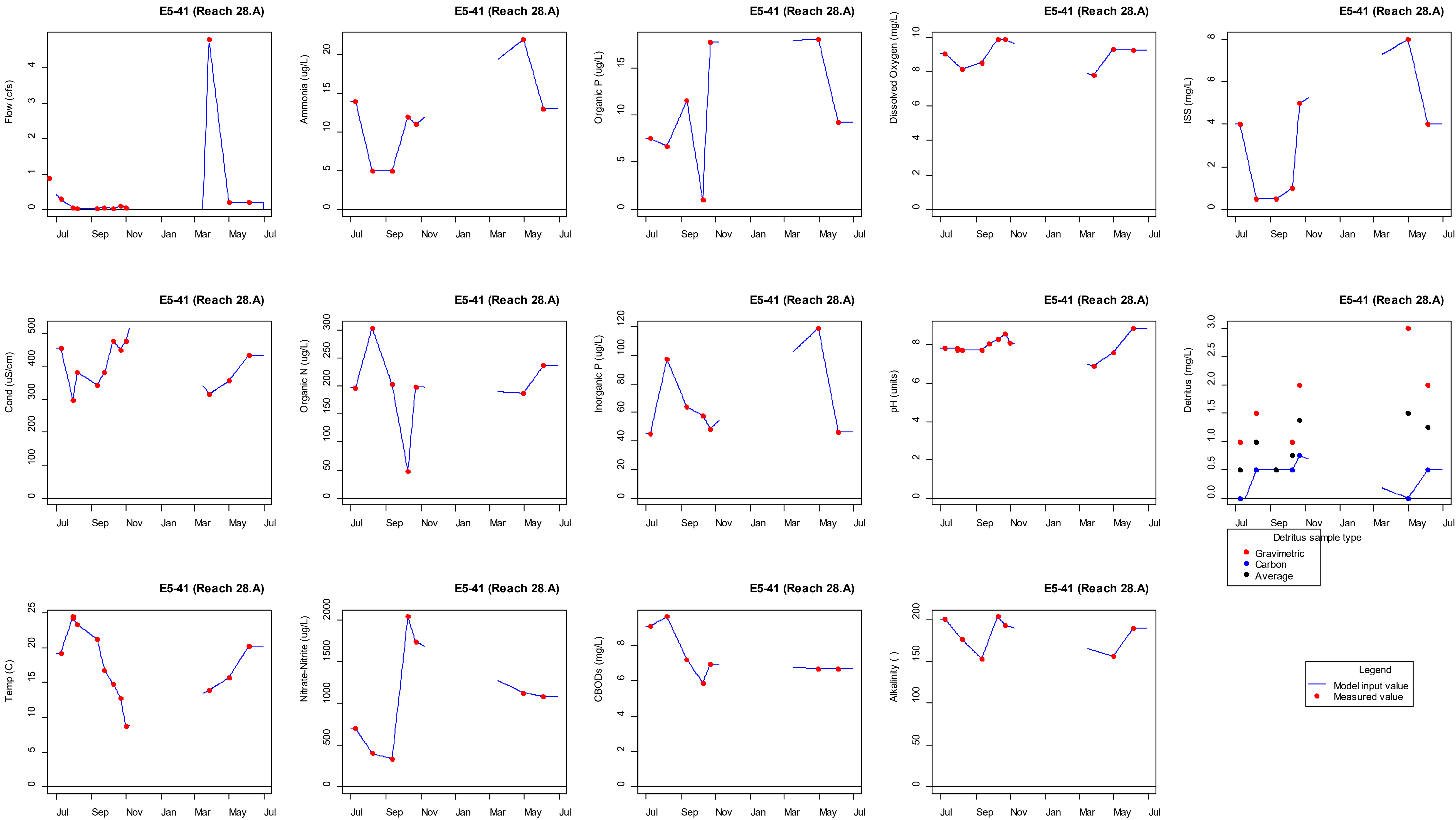

Figure F-18. E5-41 (Reach #28 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

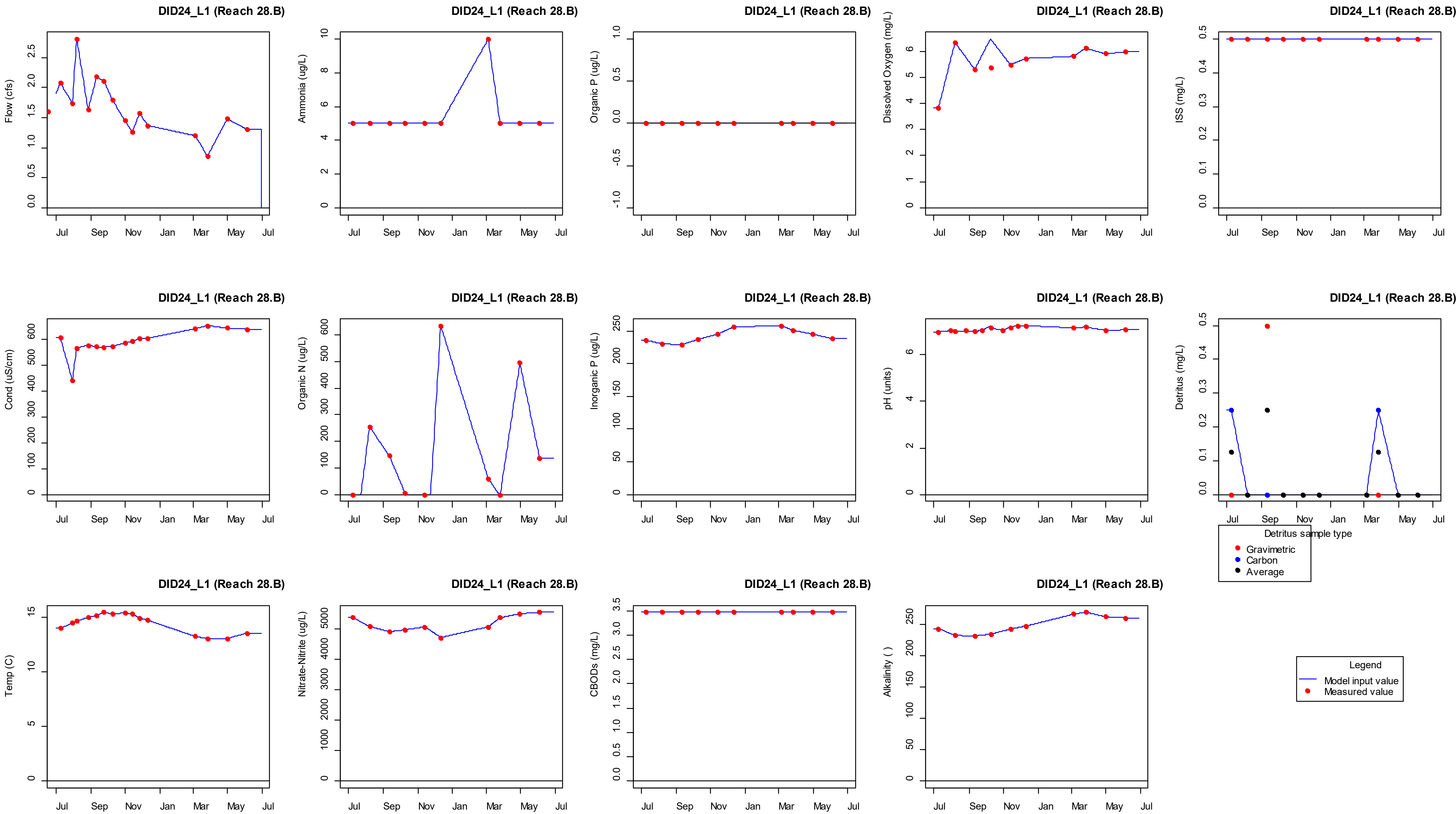

Figure F-19. DID#24 L1 (Reach #28 Source B): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

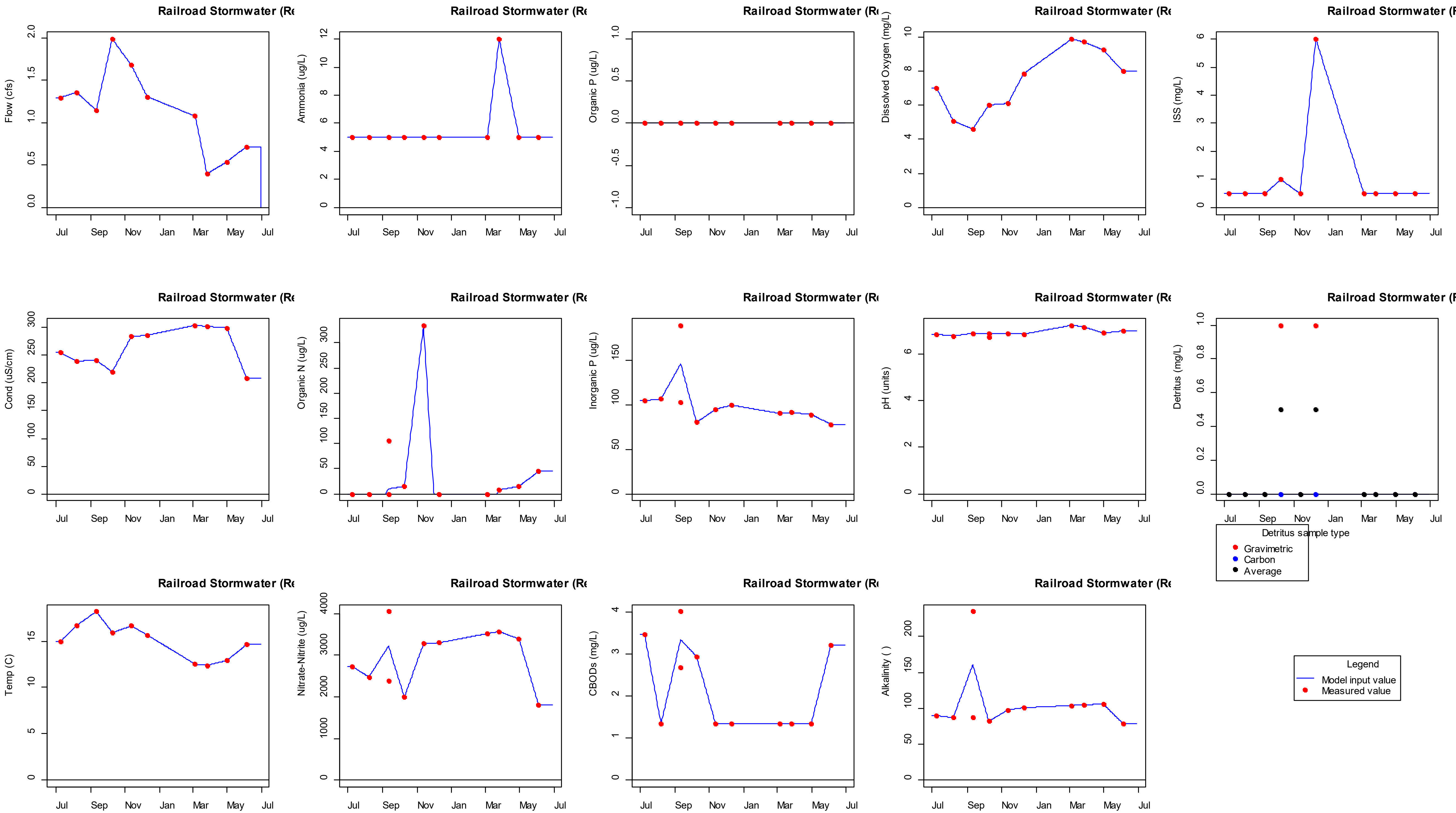

Figure F-20. Railroad Stormwater (Reach #31 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

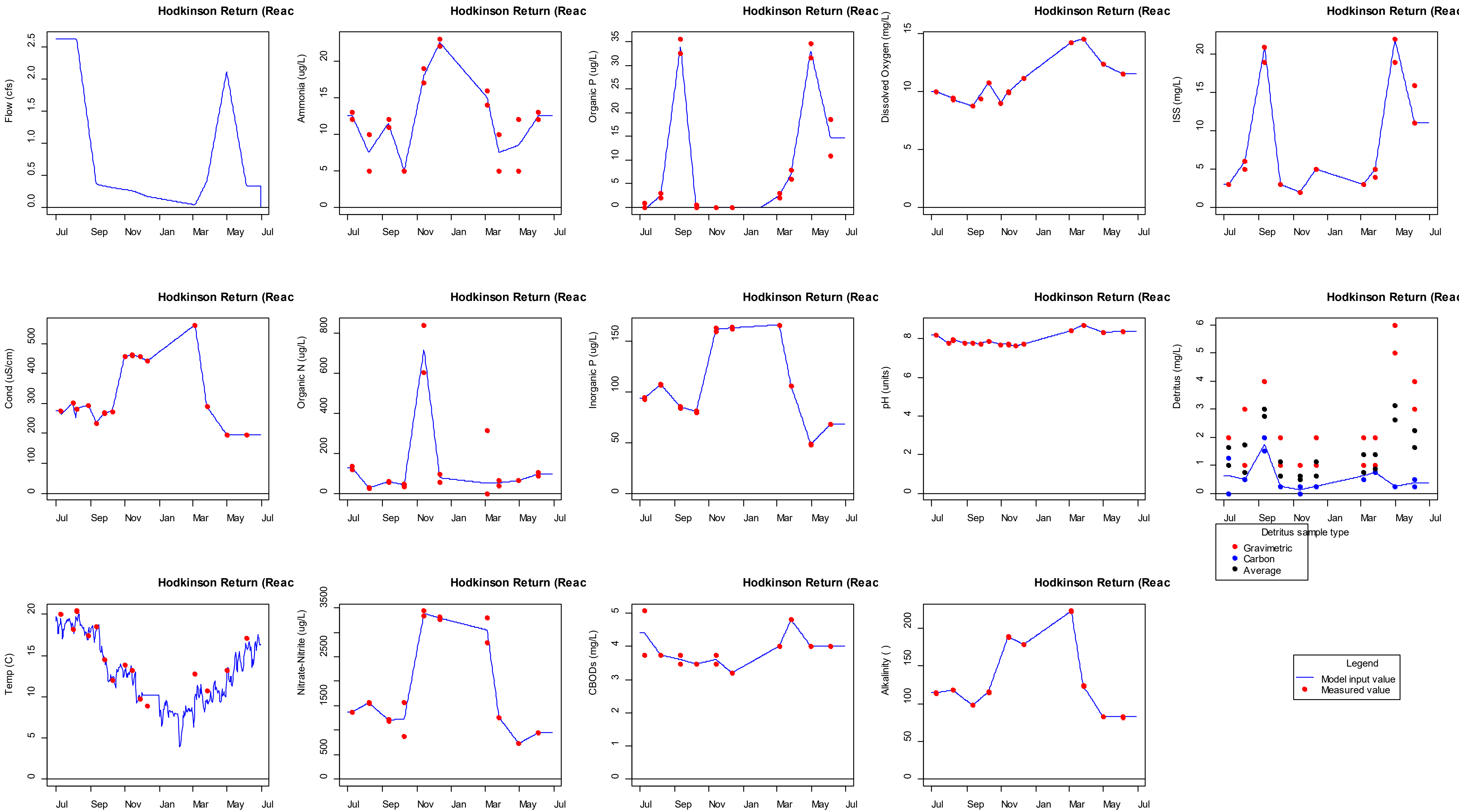

Figure F-21. Hodkinson Return (Reach #34 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

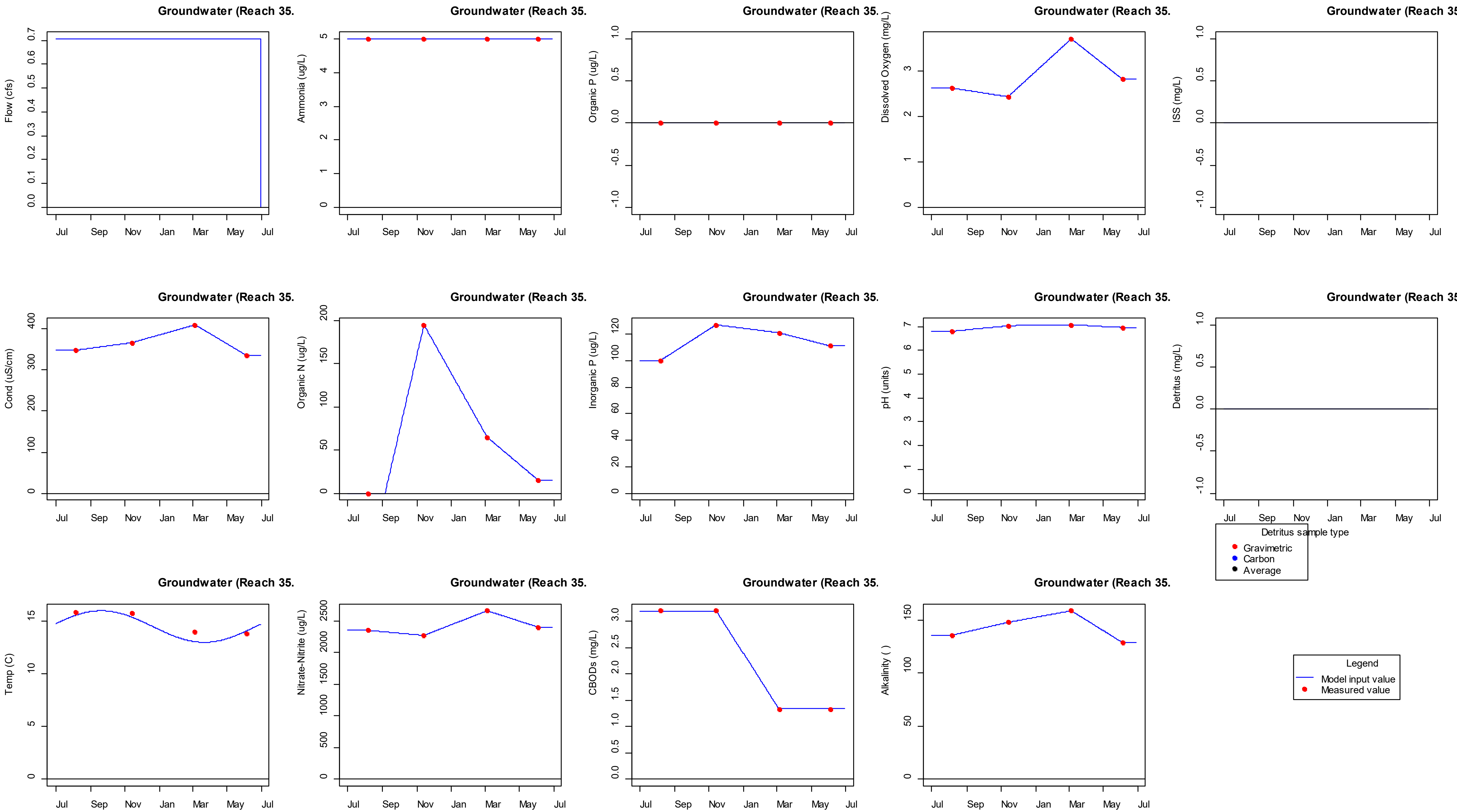

Figure F-22. Groundwater (Reach #35 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

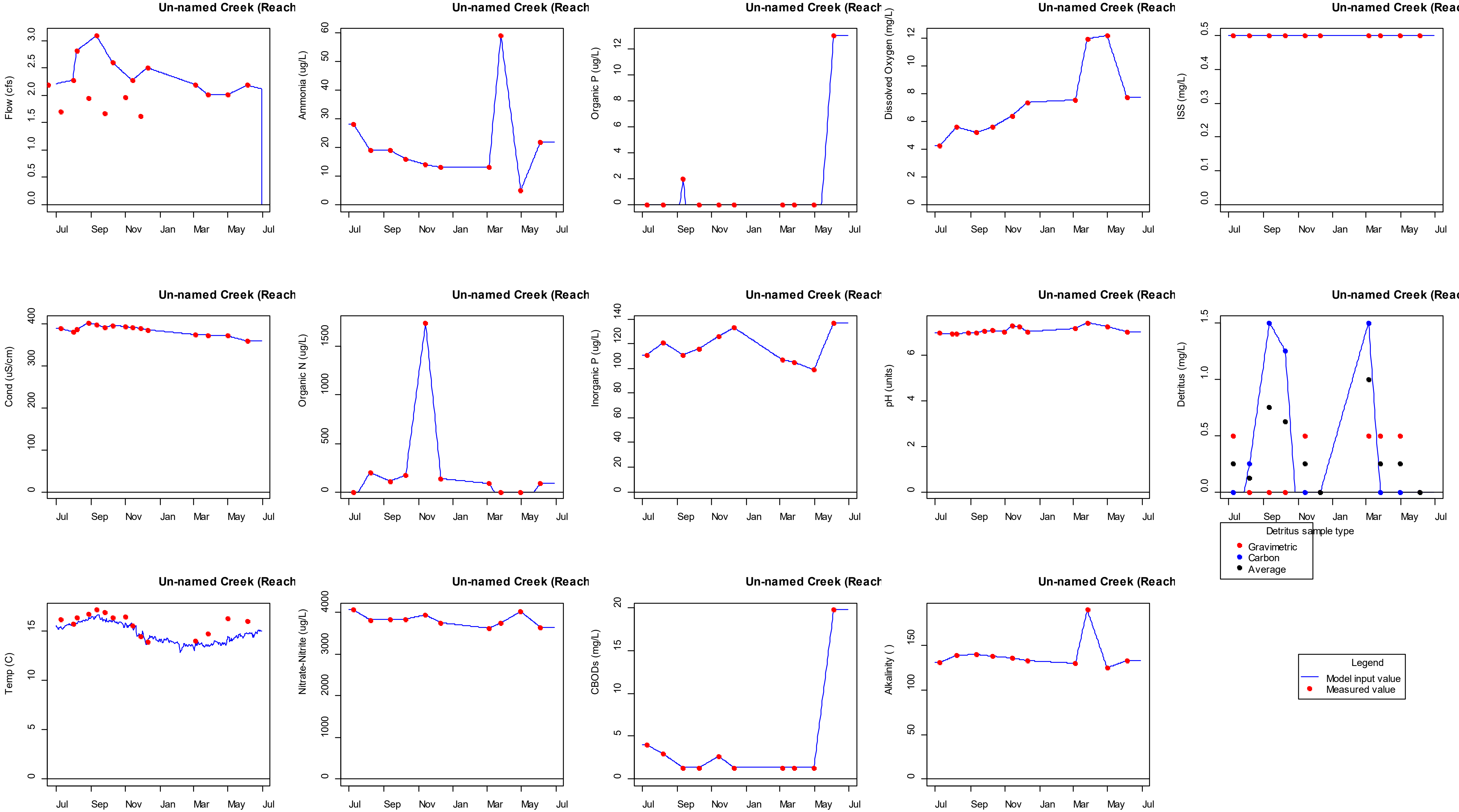

Figure F-23. Un-named Creek (Reach #35 Source B): model inputs (blue lines) compared against synoptic sample and measurement values (red points). Flow was fit to the maximum observed flow measurements to better fit the flow balance at the mouth of Wide Hollow Creek.

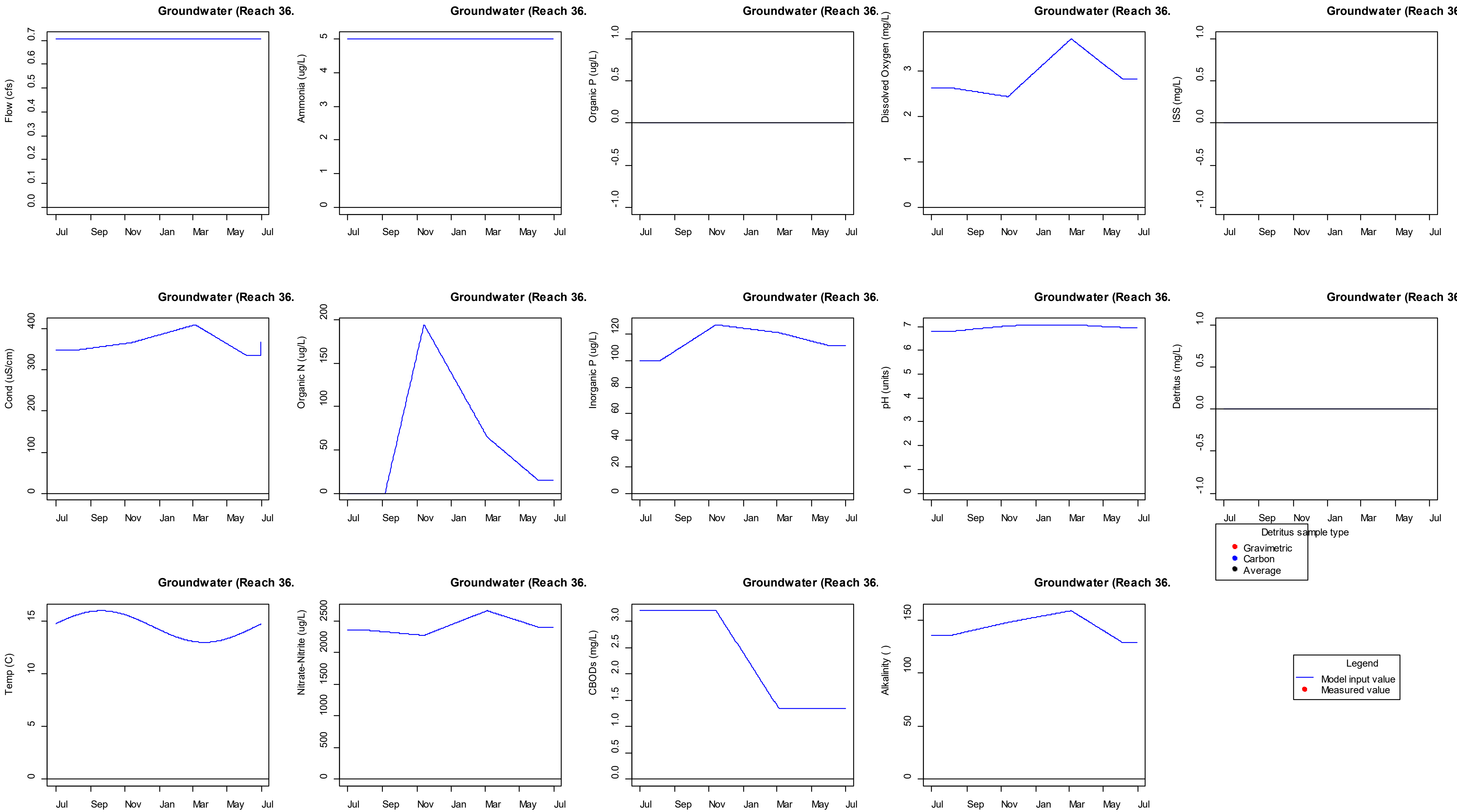

Figure F-24. Groundwater (Reach #36 Source A): model inputs (blue lines) compared against synoptic sample and measurement values (red points).

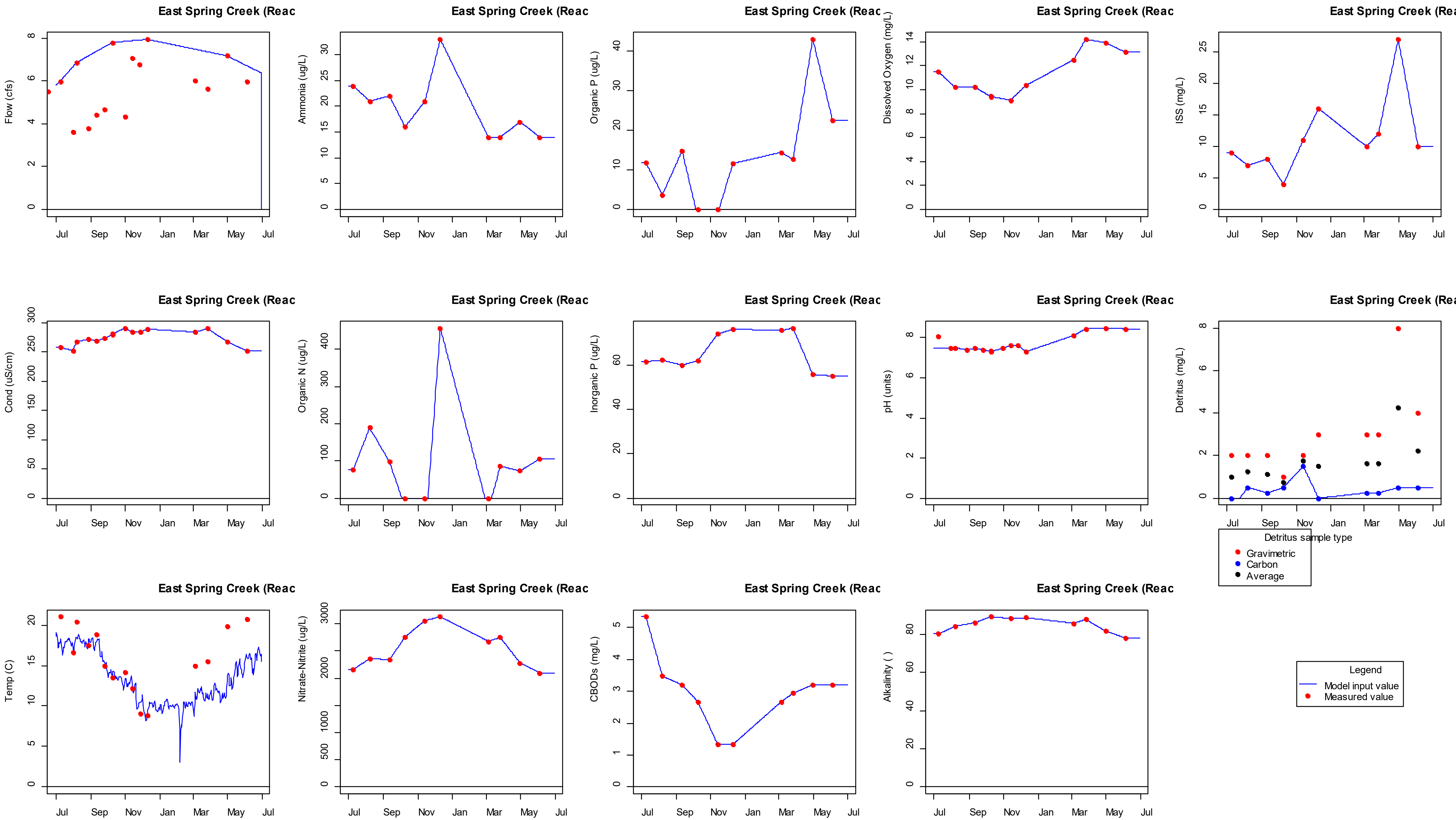

Figure F-25. East Spring Creek (Reach #36 Source B): model inputs (blue lines) compared against synoptic sample and measurement values (red points). Flow was fit to the maximum observed flow measurements to better fit the flow balance at the mouth of Wide Hollow Creek.

Appendix G. QUAL2Kw Model Calibration

QUAL2Kw Modeling Framework

The QUAL2Kw 6.0 modeling framework (Pelletier and Chapra, 2008) was used to simulate water temperature, dissolved oxygen (DO), and pH and to make predictions about water quality under various scenarios. The QUAL2Kw model framework and complete documentation are available at http://www.ecy.wa.gov/programs/eap/models.html.

The QUAL2Kw 6.0 modeling framework has the following characteristics:

- One-dimensional. The channel is well-mixed vertically and laterally.
- Non-steady, non-uniform flow using kinematic wave flow routing. Continuous simulation with time-varying boundary conditions for periods of up to one year.
- Dynamic heat budget. The heat budget and temperature are simulated as a function of meteorology on a continuously varying or repeating diel time scale.
- Dynamic water-quality kinetics. All water quality state variables are simulated on a continuously varying or repeating diel time scale for biogeochemical processes.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.
- Bottom algae in the water column are simulated.
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of N and P.

Figure G-1 shows a schematic of the model kinetics and mass transfer processes in QUAL2Kw. Table G-1 lists these processes as well as the state variables.

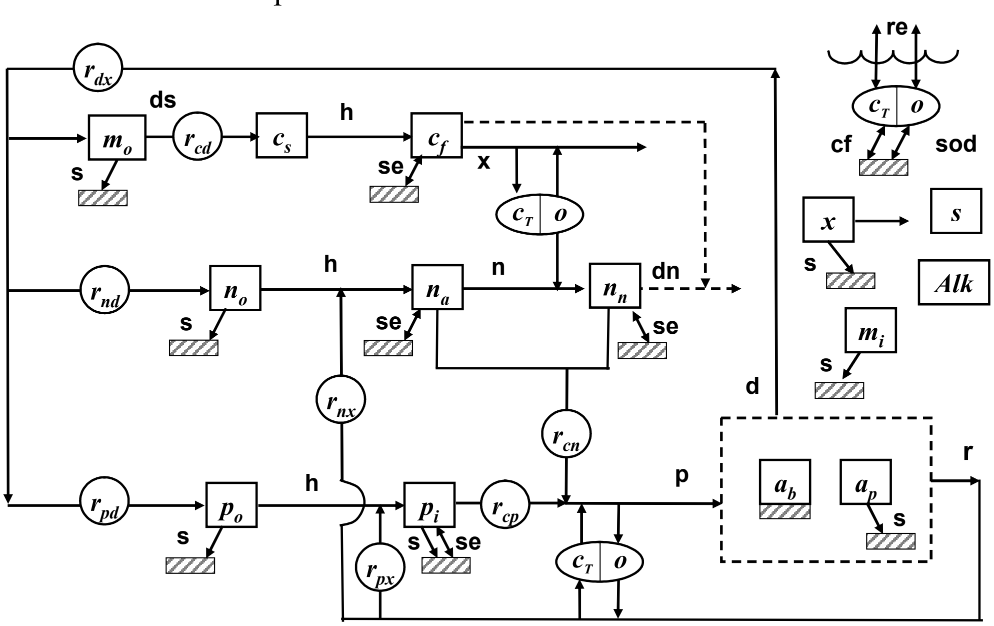

Figure G-1. Model kinetics and mass transfer processes in QUAL2Kw.

In Figure G-1 and Table G-1:
r_{xx} refers to a stoichiometric ratio.
The letters used in the subscripts are: c = carbon; d = dry weight; n = nitrogen; p = phosphorus.
The same letters (in caps) are used in the Units column in Table G-1.

Table G-1. Processes and state variables in QUAL2Kw.

State Variables			
Variable	**Symbol**	**Units**	**Measured as**
Conductivity	S	μmhos	COND
Inorganic suspended solids	m_i	mgD/L	TNVSS
Dissolved oxygen	o	mgO_2/L	DO
Slow-reacting CBOD	c_s	mg O_2/L	r_{oc} * DOC
Fast-reacting CBOD	$c_{f,}$	mg O_2/L	r_{oc} * DOC
Organic nitrogen	n_o	μgN/L	TN – NO_3N NO_2N– NH_4N
Ammonia nitrogen	n_a	μgN/L	NH_4N
Nitrate nitrogen	n_n	μgN/L	NO_3N+NO_2N
Organic phosphorus	p_o	μgP/L	TP - Orthophosphate
Inorganic phosphorus	p_i	μgP/L	Orthophosphate
Phytoplankton	a_p	μgA/L	Chlorophyll *a*
Detritus	m_o	mgD/L	r_{dc} (TOC – DOC)
Alkalinity	Alk	$mgCaCO_3/L$	ALK
Total inorganic carbon	c_T	mole/L	Calculation from pH and alkalinity
Bottom algae biomass	a_b	gD/m^2	Periphyton biomass dry weight
Bottom algae nitrogen	IN_b	mgN/m^2	Periphyton biomass N
Bottom algae phosphorus	IP_b	mgP/m^2	Periphyton biomass P

Kinetic Processes		Mass Transfer Processes	
Process	**Symbol**	**Process**	**Symbol**
dissolution	ds	reaeration	re
hydrolysis	h	settling	s
oxidation	x	sediment oxygen demand	SOD
nitrification	n	sediment exchange	se
denitrification	dn	sediment inorganic carbon flux	cf
photosynthesis	p		
Death	d		
respiration/excretion	r		

QUAL2Kw Channel Geometry and Rating Curves

The QUAL2Kw model of Wide Hollow Creek simulates the portion of the creek between 101st Ave and near the mouth. This length of river was divided into 36 model segments, each 500 meters in length (see Figures 33 and 34 in the main report). Channel geometry for each model segment was calculated as power functions relating width, depth, and velocity to flow. Table G-2 shows the power functions for each model segment.

Table G-2. Power functions used to define channel geometry in QUAL2Kw model of Wide Hollow Creek.

Model Segment	Location	Depth		Velocity	
		Coefficient	Exponent	Coefficient	Exponent
1	101st Ave	0.5270	0.155	0.2110	0.400
2		0.5270	0.155	0.2110	0.400
3		0.5270	0.155	0.2110	0.400
4		0.5270	0.155	0.2110	0.400
5	80th Ave	0.5270	0.155	0.2857	0.429
6		0.5270	0.155	0.2857	0.429
7		0.5270	0.155	0.2857	0.429
8		0.8000	0.300	0.2400	0.500
9		0.8000	0.300	0.2400	0.500
10	64th Ave	0.8000	0.300	0.2630	0.596
11		0.8000	0.300	0.2630	0.596
12		0.8000	0.300	0.2630	0.596
13		0.8000	0.300	0.2630	0.596
14	Randall Park	0.8000	0.300	0.2630	0.596
15	40th Ave	0.5270	0.155	0.3710	0.615
16		0.5270	0.155	0.3710	0.615
17		0.5270	0.155	0.3710	0.615
18		0.5270	0.155	0.3710	0.615
19	28th Ave	0.5270	0.155	0.3710	0.615
20		0.5270	0.155	0.3710	0.615
21		0.5270	0.155	0.3710	0.615
22		0.5270	0.155	0.4700	0.813
23	16th Ave	1.0000	0.100	0.2490	0.813
24		1.0000	0.100	0.2490	0.813
25		0.9000	0.150	0.2490	0.813
26		0.9000	0.150	0.2490	0.813
27	3rd Ave	0.9000	0.150	0.2490	0.813
28		0.8000	0.300	0.2780	0.313
29		0.8000	0.300	0.2780	0.313
30		0.8000	0.300	0.2780	0.313
31		0.8000	0.300	0.2780	0.313
32		0.8000	0.300	0.2090	0.408
33	White Street	0.8000	0.300	0.2090	0.408
34		0.8000	0.300	0.2090	0.408
35		0.8000	0.300	0.2090	0.408
36	Mouth	0.8000	0.300	0.2090	0.408

Note: only the velocity and depth power functions were used for input to the QUAL2Kw model. The model software calculates the width function based on the continuity equation.

QUAL2Kw Rate Parameters

After calibrating to observed flow, water temperature, and solids data, the Department of Ecology (Ecology) began calibrating the model for pH, DO, nutrients, and bottom algae. Ecology used compiled rate sets from 35 calibrated QUAL2Kw models developed throughout the Western U.S. (Tables G-3 and G-4) to guide parameterization. These models were all developed for TMDLs by, or for, state agencies including:

- Washington State Department of Ecology (Carroll et al., 2006; Mohamedali and Lee, 2008; Sargeant et al., 2006; Snouwaert and Stuart, 2015).
- Oregon Department of Environmental Quality (DEQ) (Turner et al., 2006).
- Utah DEQ (Neilson et al., 2014).
- Montana DEQ (Flynn and Suplee, 2011).
- California Regional Water Quality Board (Butkus, 2011; Tetra Tech, 2009).

Table G-3. Statistics for select parameters from calibrated QUAL2Kw models in the Western U.S.

Parameter	n	Min	25th Percentile	Median	75th Percentile	Max
Stoichiometry:						
Carbon	26	28.5	40	40	40	70
Nitrogen	26	2.8	7.2	7.2	7.2	10
Phosphorus	26	0.4	1	1	1	1
Dry weight	26	100	100	100	100	107
Chlorophyll	26	0.3	0.5	1	1	3
Inorganic suspended solids:						
Settling velocity	34	0.00	0.20	0.59	1.17	2.00
Slow CBOD:						
Hydrolysis rate	32	0.00	0.10	0.25	1.13	4
Oxidation rate	17	0.00	0.05	0.15	0.32	3.57
Fast CBOD:						
Oxidation rate	26	0.00	0.05	1.76	4.0	6.0
Organic N:						
Hydrolysis	35	0.00	0.07	0.20	0.65	3.90
Settling velocity	26	0.00	0.09	0.17	0.26	1.83
Ammonium:						
Nitrification	35	0.01	0.92	2.50	4.73	10
Nitrate:						
Denitrification	35	0.00	0.10	1.00	1.13	2.0
Sed denitrification transfer	35	0.00	0.01	0.05	0.58	0.99
Organic P:						
Hydrolysis	35	0.00	0.10	0.25	2.00	4.21
Settling velocity	27	0.00	0.09	0.11	0.50	1.85
Inorganic P:						
Settling velocity	27	0.00	0.07	0.55	1.74	2.0
Sed P oxygen attenuation	28	0.00	0.23	1.12	1.64	2.0
Detritus (POM):						
Dissolution rate	35	0.00	0.47	1.00	3.14	5.0
Settling velocity	33	0.00	0.11	0.42	1.00	1.96

Table G-4. Statistics for select bottom algae parameters from calibrated QUAL2Kw models in the Western U.S.

Parameter	n	Min	25th Percentile	Median	75th Percentile	Max
Max Growth rate	32	8.60	11.94	29.2	60	161
Basal respiration rate	32	0.01	0.10	0.20	0.45	1.20
Photo-respiration rate parameter	15	0.00	0.01	0.01	0.39	0.58
Excretion rate	31	0.00	0.05	0.20	0.36	0.48
Death rate	32	0.00	0.02	0.22	0.50	4.46
External N half sat constant	32	15	180	300	430	500
External P half sat constant	32	10	52	72	100	178
Inorganic C half sat constant	31	0	1.30E-05	3.10E-05	9.00E-05	1.30E-04
Light constant	32	1.69	50.0	58.6	75.0	110
Ammonia preference	32	1.20	11.0	20.3	25.0	81
Subsistence quota for N	31	0.70	1.40	7.20	22.7	72
Subsistence quota for P	31	0.10	0.20	1.00	4.2	10
Maximum uptake rate for N	31	28	108	427	750	1405
Maximum uptake rate for P	31	4.0	43.2	75.6	145	232
Internal N half sat ratio	31	0.90	1.06	1.60	3.68	9.00
Internal P half sat ratio	31	0.13	1.30	1.40	3.83	5.00

Ecology inserted the 25th and 75th percentile values into the Wide Hollow Creek QUAL2Kw model as ranges for calibration. Ecology performed manual calibration by iteratively adjusting one rate and comparing improvements in fit mathematically and visually. After finding the best fit to the observed data, the final calibration rates were within the published 25th to 75th range, with only 3 exceptions, which were chosen because they fit the observed data best:

- Bottom plants ammonia preference (5 ug/L)
- Inorganic phosphorus settling velocity (0.07 m/d)
- Inorganic suspended solids settling rate (0.15 m/d)

Table G-5 presents QUAL2Kw rate parameters used in the Wide Hollow Creek model.

Table G-5. QUAL2Kw rate parameters used for the Wide Hollow Creek model.

Parameter	Value	Units	Symbol
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	0.5	gA	gA
Inorganic suspended solids:			
Settling velocity	0.15	m/d	v_i
Oxygen:			
Reaeration model	User model		
User reaeration model parameter A	15		
User reaeration model parameter B	-0.275		
User reaeration model parameter C	0.359		
Temp correction for reaeration	1.024		θ_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.67	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.1	/d	k_{hc}
Temp correction	1.047		θ_{hc}
Oxidation rate	0.15	/d	k_{dcs}
Temp correction	1.047		θ_{dcs}
Fast CBOD:			
Oxidation rate	0.05	/d	k_{dc}
Temp correction	1.047		θ_{dc}
Organic N:			
Hydrolysis	0.07	/d	k_{hn}
Temp correction	1.07		θ_{hn}
Settling velocity	0.15	m/d	v_{on}
Ammonium:			
Nitrification	0.1	/d	k_{na}
Temp correction	1.07		θ_{na}
Nitrate:			
Denitrification	0.1	/d	k_{dn}
Temp correction	1.07		θ_{dn}
Sed denitrification transfer coeff	0.01	m/d	v_{di}
Temp correction	1.07		θ_{di}
Organic P:			
Hydrolysis	0.1	/d	k_{hp}
Temp correction	1.07		θ_{hp}
Settling velocity	0.1	m/d	v_{op}

Parameter	Value	Units	Symbol
Inorganic P:			
Settling velocity	0.07	m/d	v_{ip}
Sed P oxygen attenuation half sat constant	1.6	mgO_2/L	k_{spi}
Bottom Plants:			
Growth model	Zero-order		
Max Growth rate	60	$gD/m^2/d$ or /d	C_{gb}
Temp correction	1.07		θ_{gb}
First-order model carrying capacity	150	gD/m^2	$a_{b,max}$
Basal respiration rate	0.4	/d	k_{r1b}
Photo-respiration rate parameter	0.5	unitless	k_{r2b}
Temp correction	1		θ_{rb}
Excretion rate	0.05	/d	k_{eb}
Temp correction	1		θ_{db}
Death rate	0.01	/d	k_{db}
Temp correction	1		θ_{db}
Scour function	Flow		
Coefficient of scour function	0	/d/cms	cdet
Exponent of scour function	0		ddet
Minimal biomass after scour event	0	gD/m^2	X0
Catastrophic scour rate during flood event	0	/d	Kcat
Critical flow or vel for catastrophic scour	0	cms or m/s	Qcrit
External nitrogen half sat constant	430	ugN/L	k_{sNb}
External phosphorus half sat constant	100	ugP/L	k_{sPb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Bottom algae use HCO3- as substrate	Yes		
Light model	Half saturation		
Light constant	75	langleys/d	K_{Lb}
Ammonia preference	5	ugN/L	k_{hnxb}
Nutrient limitation model for N and P	Minimum		
Subsistence quota for nitrogen	7.2	mgN/gD	q_{0N}
Subsistence quota for phosphorus	1.91	mgP/gD	q_{0P}
Maximum uptake rate for nitrogen	108	mgN/gD/d	ρ_{mN}
Maximum uptake rate for phosphorus	43.2	mgP/gD/d	ρ_{mP}
Internal nitrogen half sat ratio	1.05		$K_{qN,ratio}$
Internal phosphorus half sat ratio	1.3		$K_{qP,ratio}$
Nitrogen uptake water column fraction	1		$N_{UpWCfrac}$
Phosphorus uptake water column fraction	1		$P_{UpWCfrac}$
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		θ_{dt}
Settling velocity	0.15	m/d	v_{dt}
pH:			
Partial pressure of carbon dioxide	395	ppm	p_{CO2}
Photosynthetic quotient and respiratory quotient for phytoplankton and bottom algae			
Photosynthetic quotient for NO3 vs NH4 use	1.29	dimensionless	PQ
Respiratory quotient	1.00	dimensionless	RQ

References for QUAL2Kw Rate Parameters

Butkus, S., 2011. Memorandum: Dissolved Oxygen Model Development and Evaluation. Laguna de Santa Rosa: TMDL Development and Planning. California Regional Water Quality Control Board North Coast Region. Santa Rosa, CA.

Carroll, J., S. O'Neal, and S. Golding, 2006. Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication 06-03-018.

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Mohamedali, T. and S. Lee, 2008. Bear-Evans Watershed Temperature and Dissolved Oxygen Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Olympia, WA. Publication 08-10-058.

Neilson, B.T., A.J. Hobson, N. vonStackelberg, M. Shupryt., and J. Ostermiller, 2014. Chapter 11: Using QUAL2Kw modeling to support nutrient Criteria Development and Wasteload Analysis in Utah. Draft: Technical Basis for Utah's Nutrient Strategy.

Sargeant, D., B. Carey, M. Roberts, and S. Brock, 2006. Henderson Inlet Watershed Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication 06-03-012.

Snouwaert, E. and T. Stuart, 2015. North Fork Palouse River Dissolved Oxygen and pH Total Maximum Daily Load: Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Spokane, WA. Publication 15-10-029.

Tetra Tech Inc., 2009. APPENDIX F: New River QUAL2K Water Quality Model for the New River Dissolved Oxygen TMDL. Prepared for: United States Environmental Protection Agency Region 9, San Francisco, California; and California Regional Water Quality Control Board, Colorado River Basin Region, Palm Desert, California. Prepared by: Tetra Tech, Imc. San Diego, CA.

Turner, D., B. Kasper, P. Heberling, B. Lindberg, M. Wiltsey, G. Arnold, and R. Michie, 2006. Appendix 3: Algae/Aquatic Weeds, Dissolved Oxygen and pH TMDL Supplemental Information. CHAPTER 4 of Umpqua Basin Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP). Oregon Department of Environmental Quality. Medford, OR.

QUAL2Kw Model Calibration Plots

Figures G-6 through G-18 below visually compare model simulations against measured concentrations of suspended solids and solutes reported by Ecology's Manchester Environmental Laboratory (MEL). These figures show simulated values as blue line and blue points. Lab-measured (observed) concentrations are shown as orange points. Vertical yellow bars on these plots highlight all dates containing observed values, providing a visual aid to help locate lab results.

Statistics comparing the fit between simulated and observed values are provided for each model reach on the figures. These statistics include RMSE (root mean squared error) and overall Bias. Units of measurement for the figures and statistics are indicated in the figure caption and shown in the title for the y-axis on the figure.

This report's main body contains additional figures and statistics documenting the calibration of flow, temperature, dissolved oxygen, and pH.

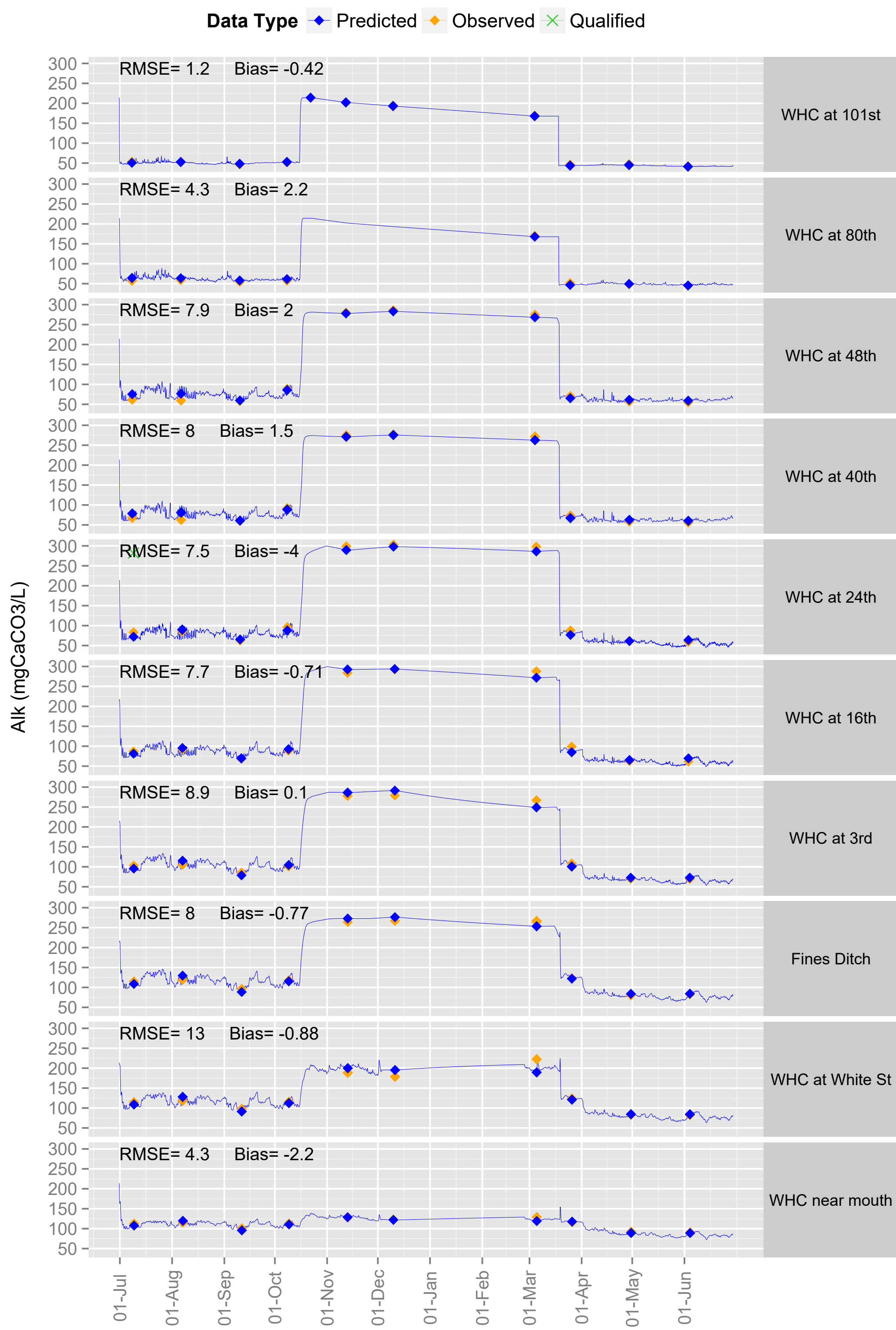

Figure G-6. Comparison between simulated (predicted) and measured values of alkalinity (mg-CaCO3/L).

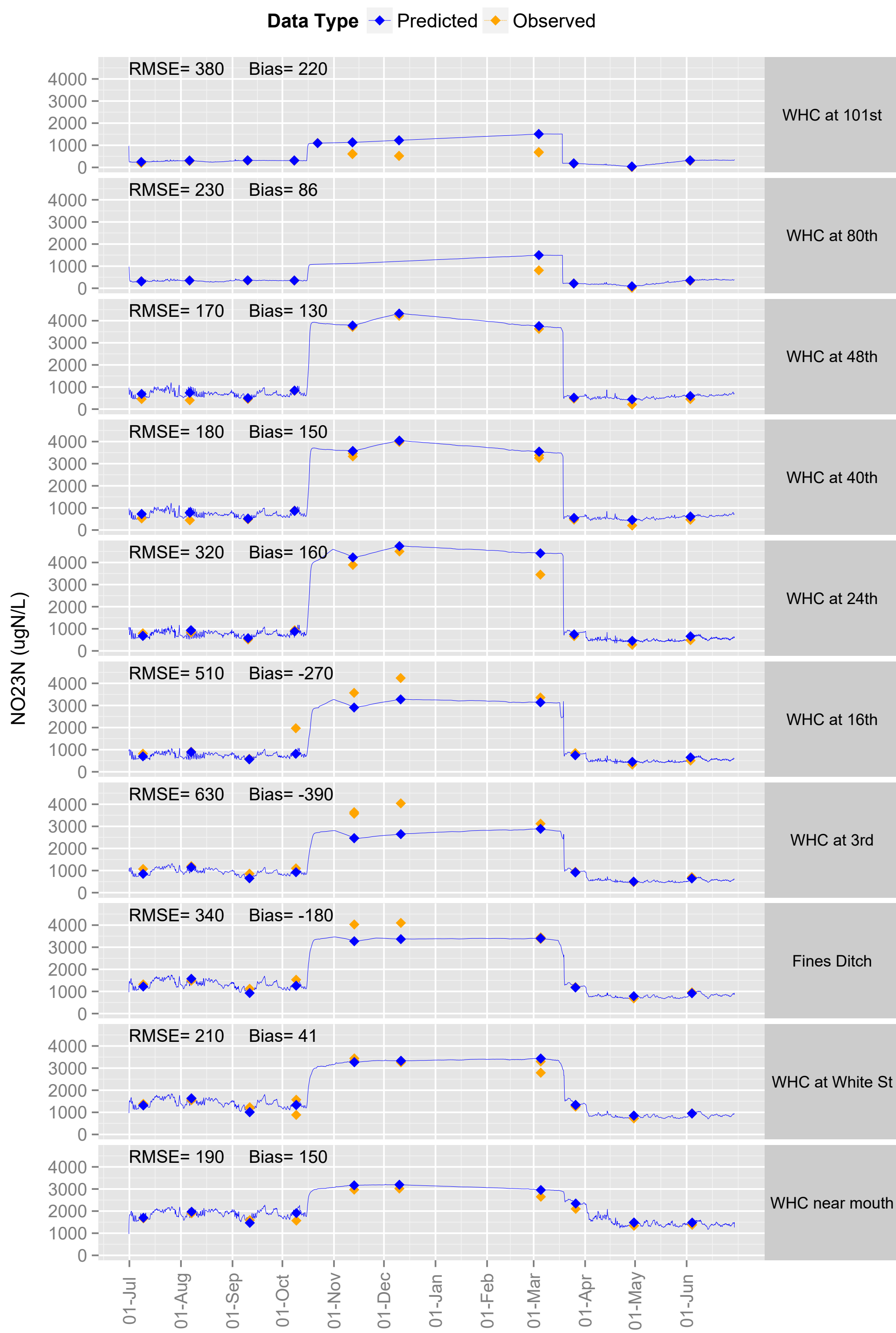

Figure G-7. Comparison between simulated (predicted) and measured values of nitrate (ug-N/L).

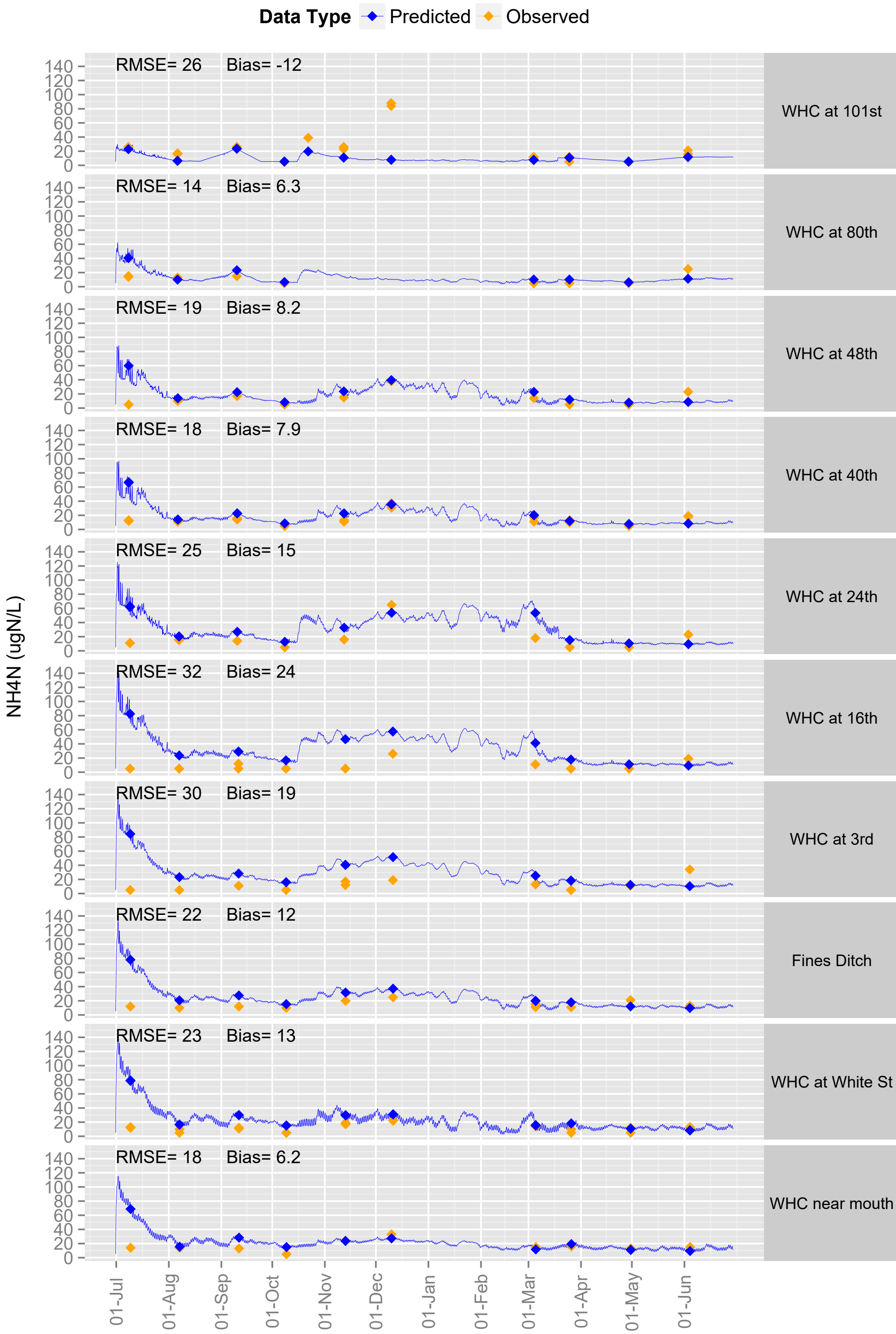

Figure G-8. Comparison between simulated (predicted) and measured values of ammonia (ug-N/L).

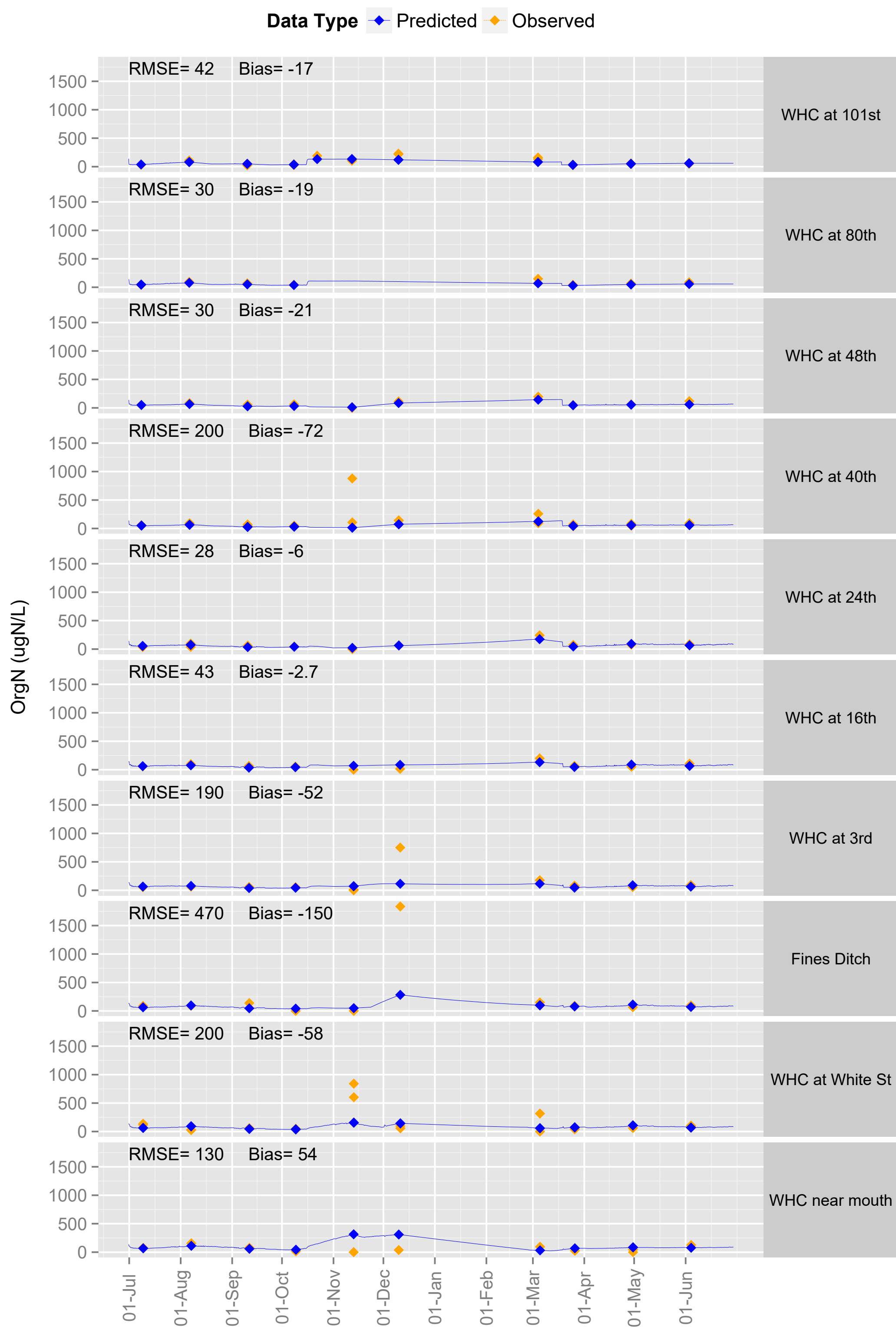

Figure G-9. Comparison between simulated (predicted) and measured values of organic nitrogen (ug-N/L).

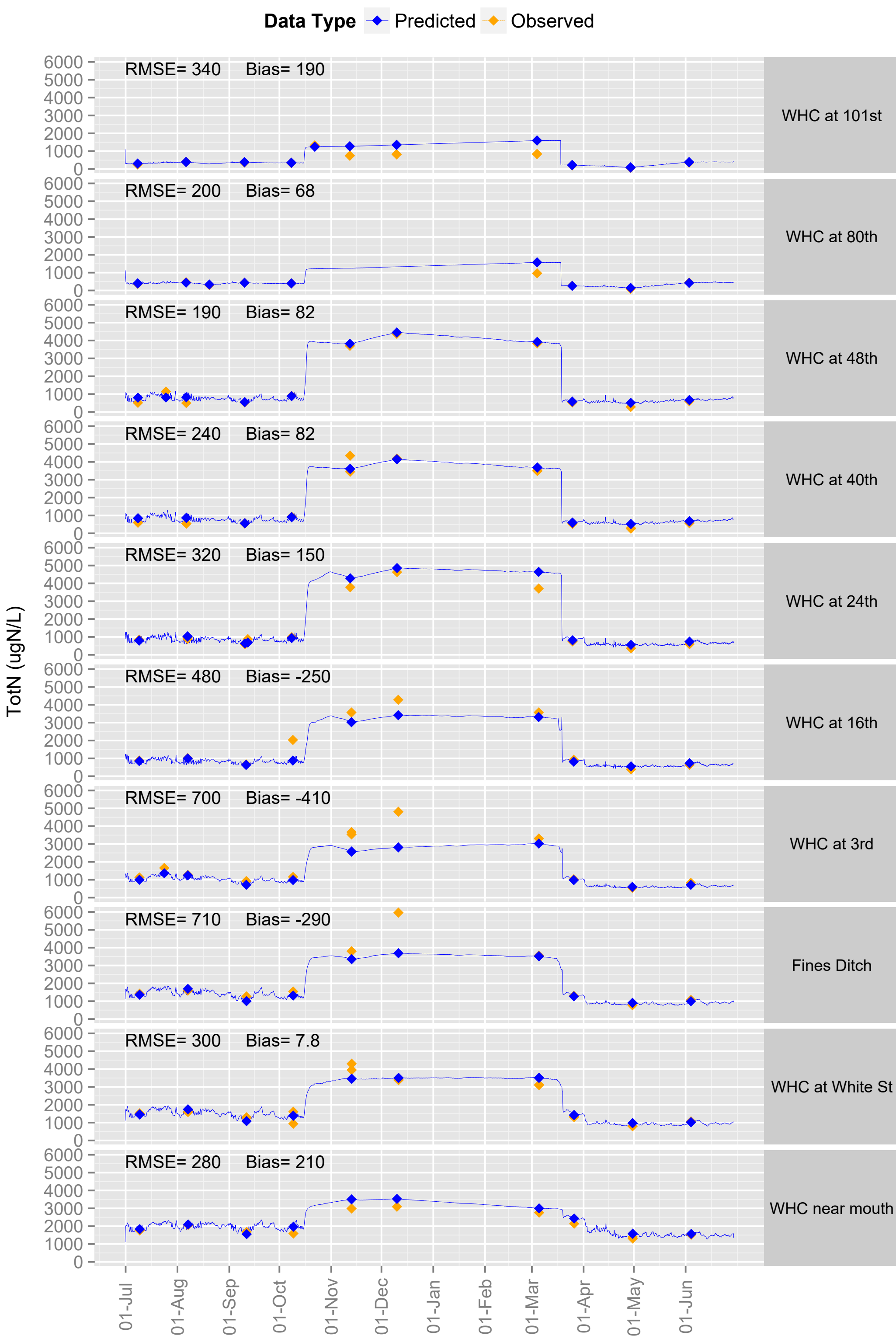

Figure G-10. Comparison between simulated (predicted) and measured values of total nitrogen (ug-N/L).

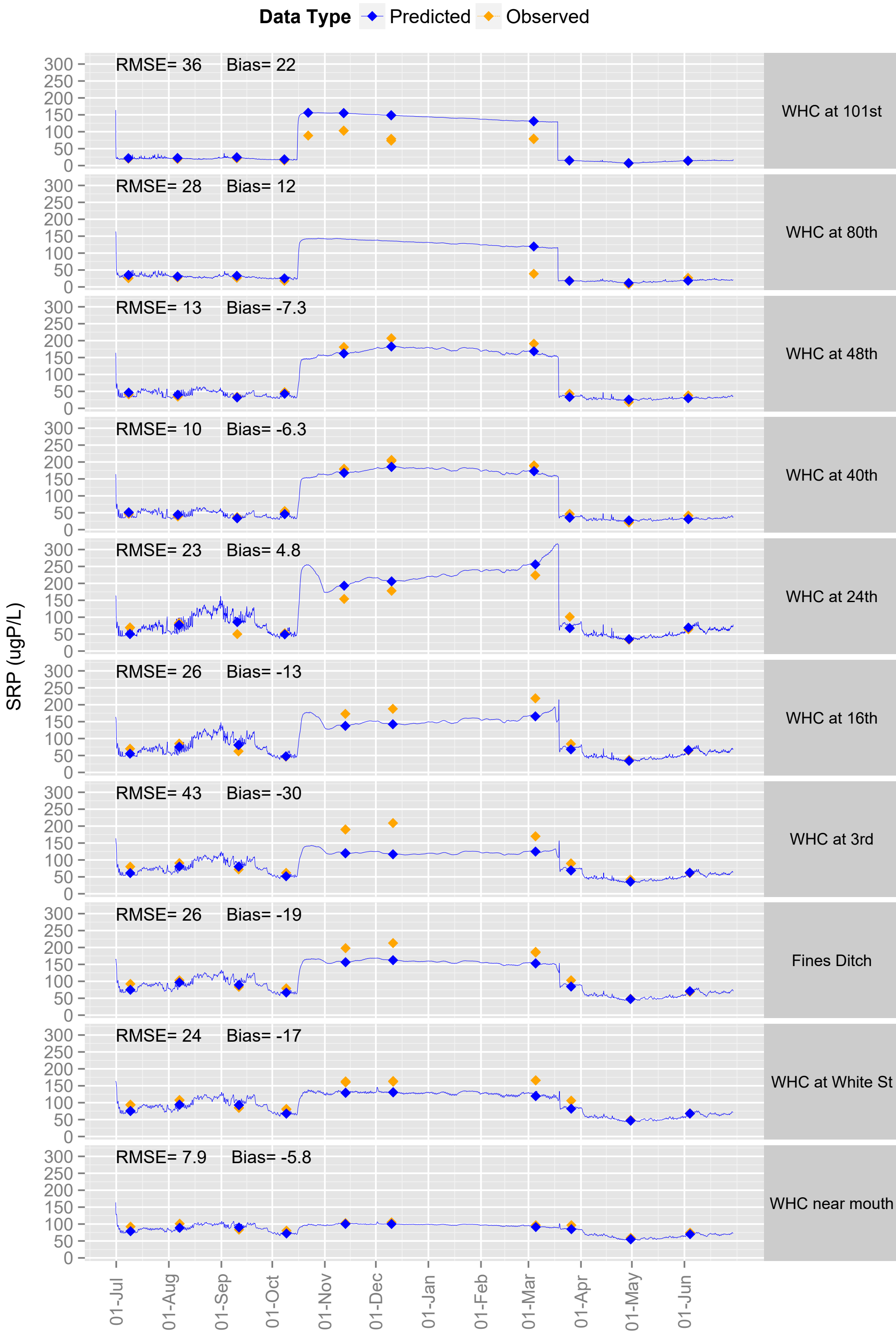

Figure G-11. Comparison between simulated (predicted) and measured values of inorganic phosphorus (ug-P/L).

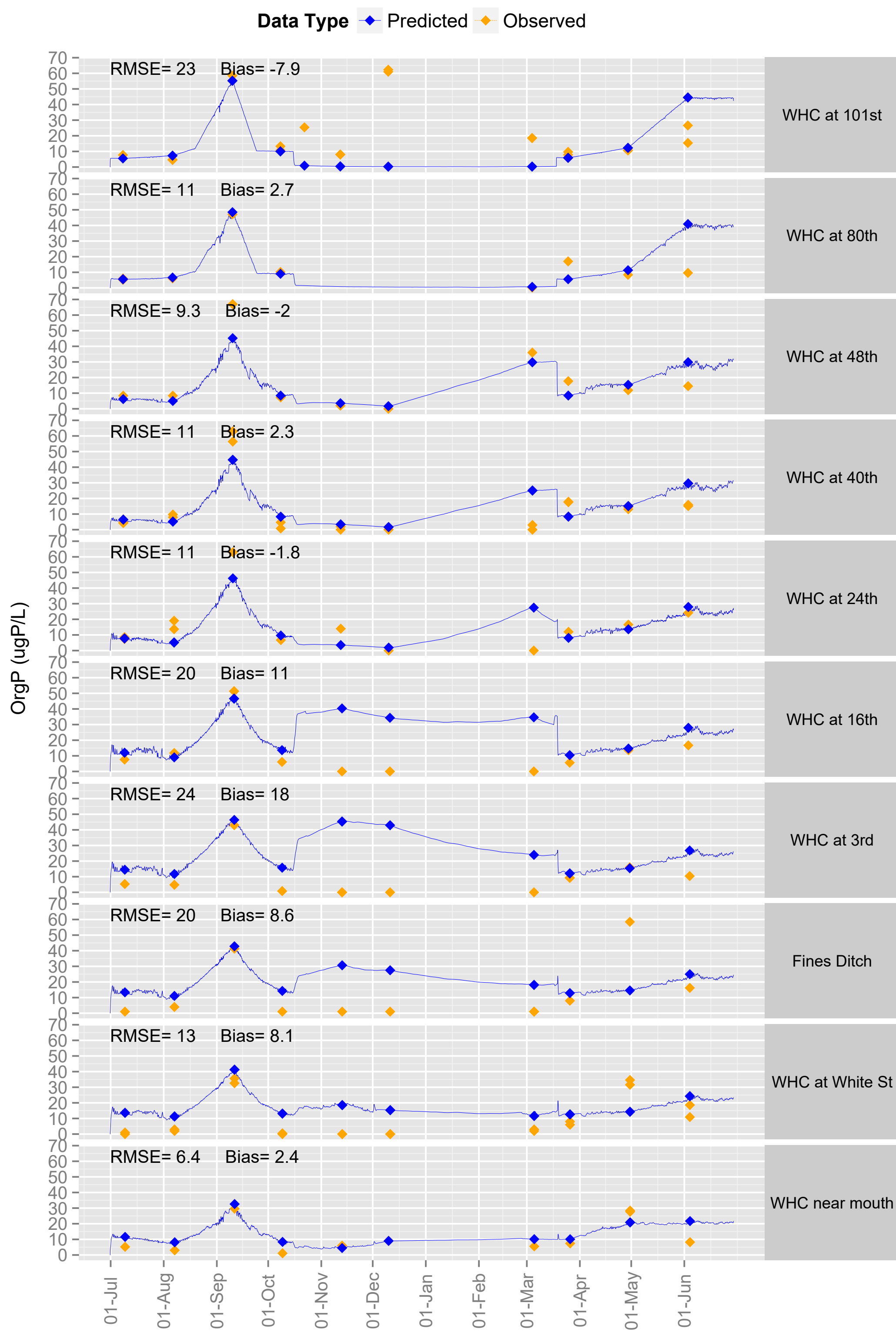

Figure G-12. Comparison between simulated (predicted) and measured values of organic phosphorus (ug-P/L).

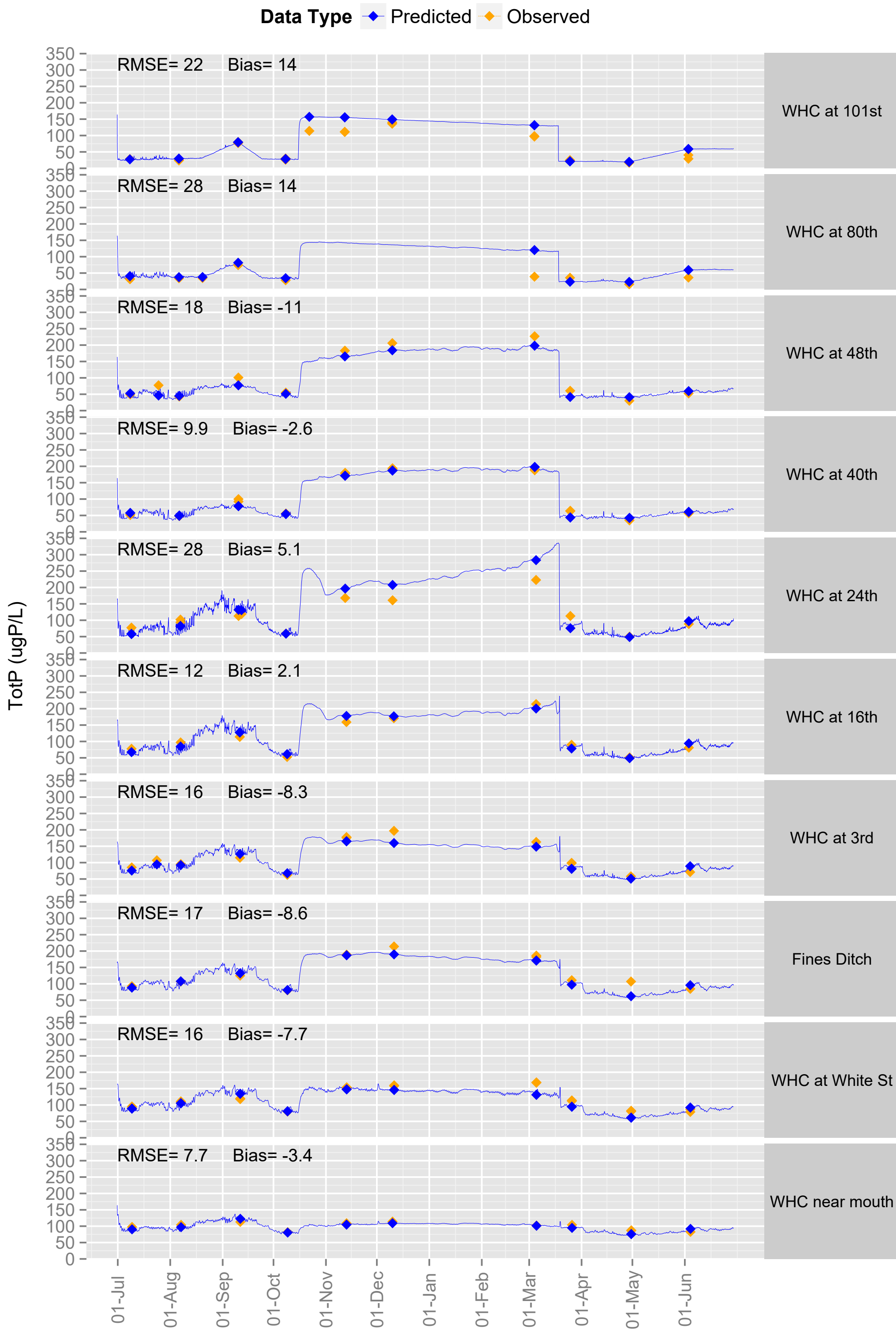

Figure G-13. Comparison between simulated (predicted) and measured values of total phosphorus (ug-P/L).

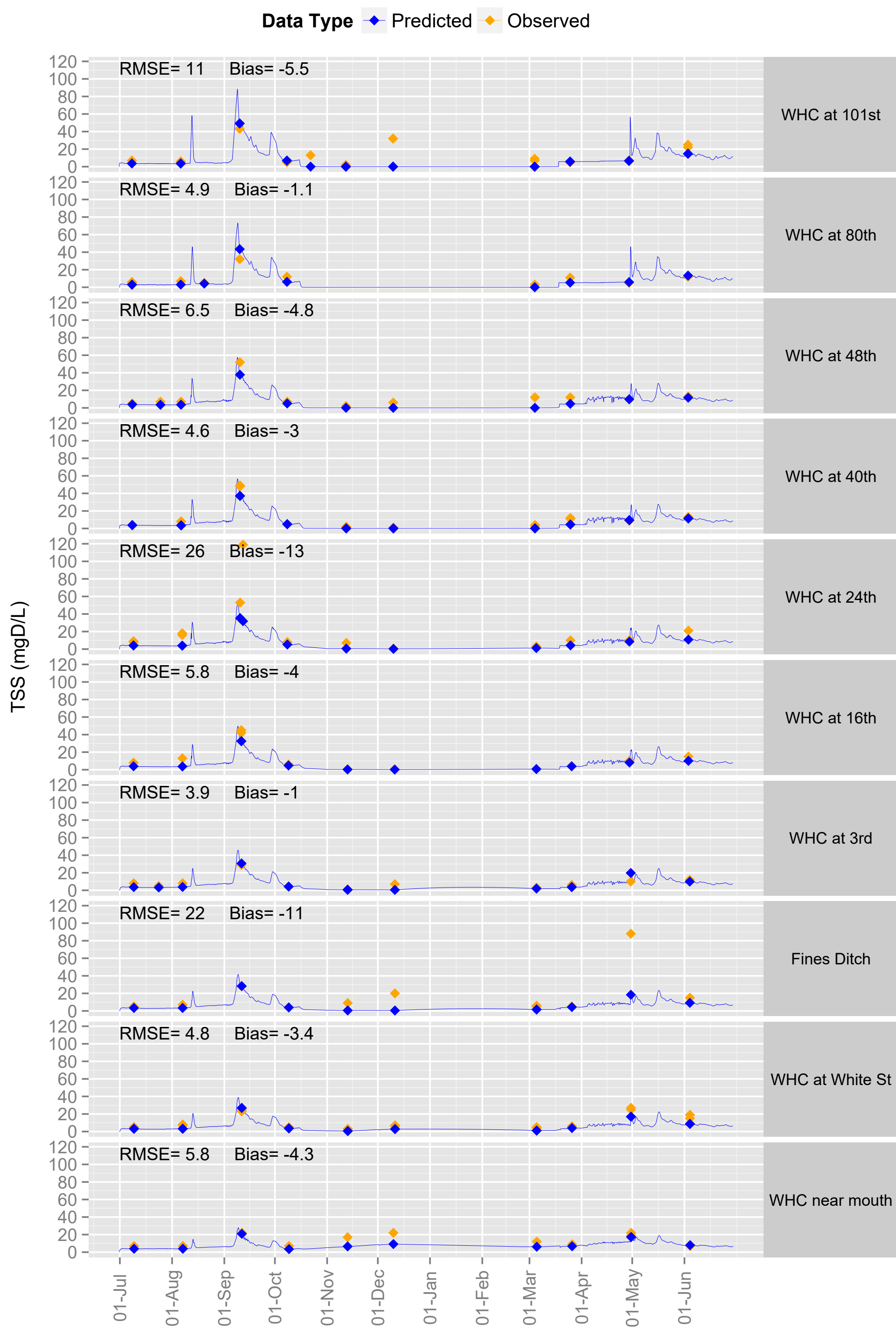

Figure G-14. Comparison between simulated (predicted) and measured values of total suspended solids (mg/L).

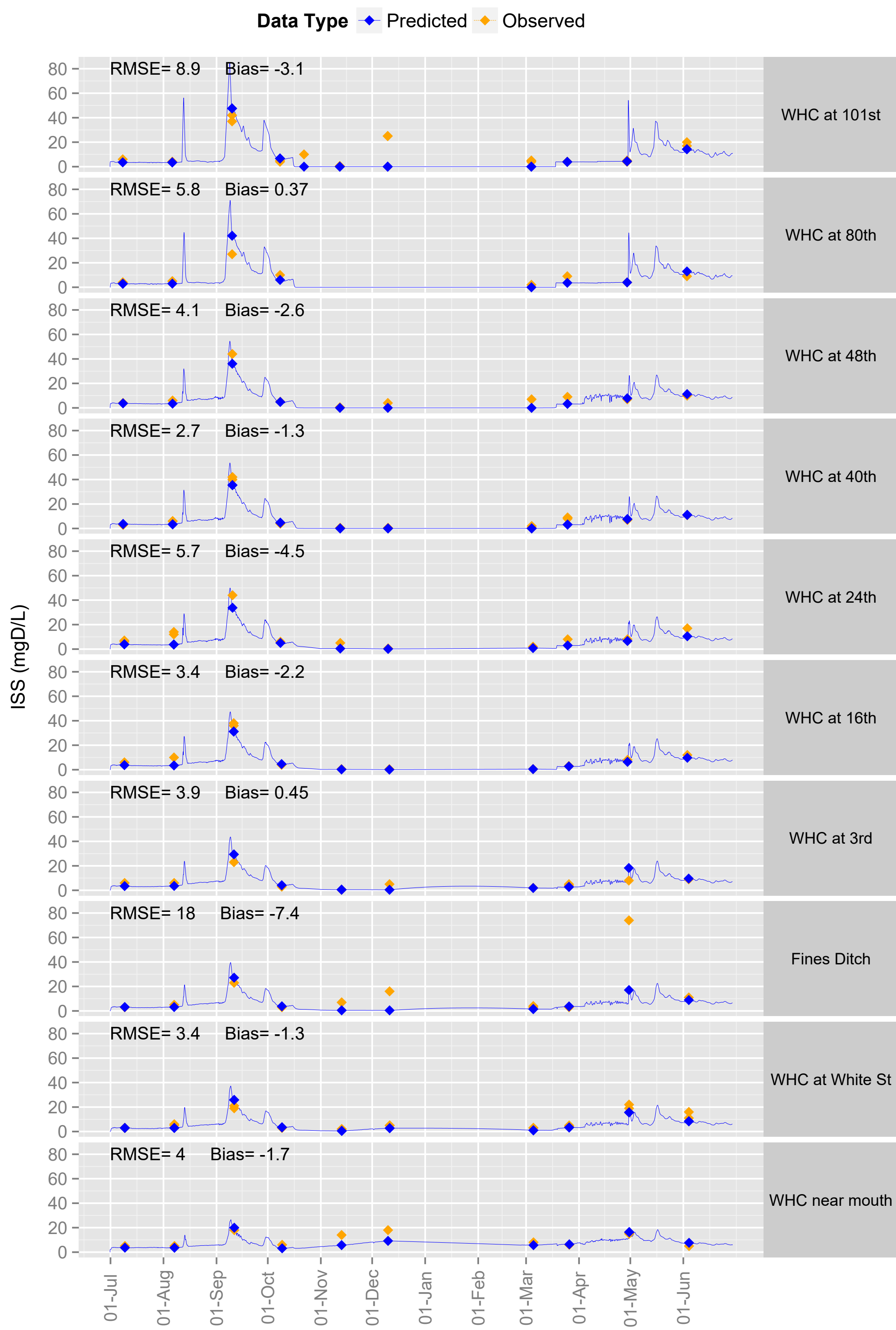

Figure G-15. Comparison between simulated (predicted) and measured values of inorganic suspended solids (mg/L).

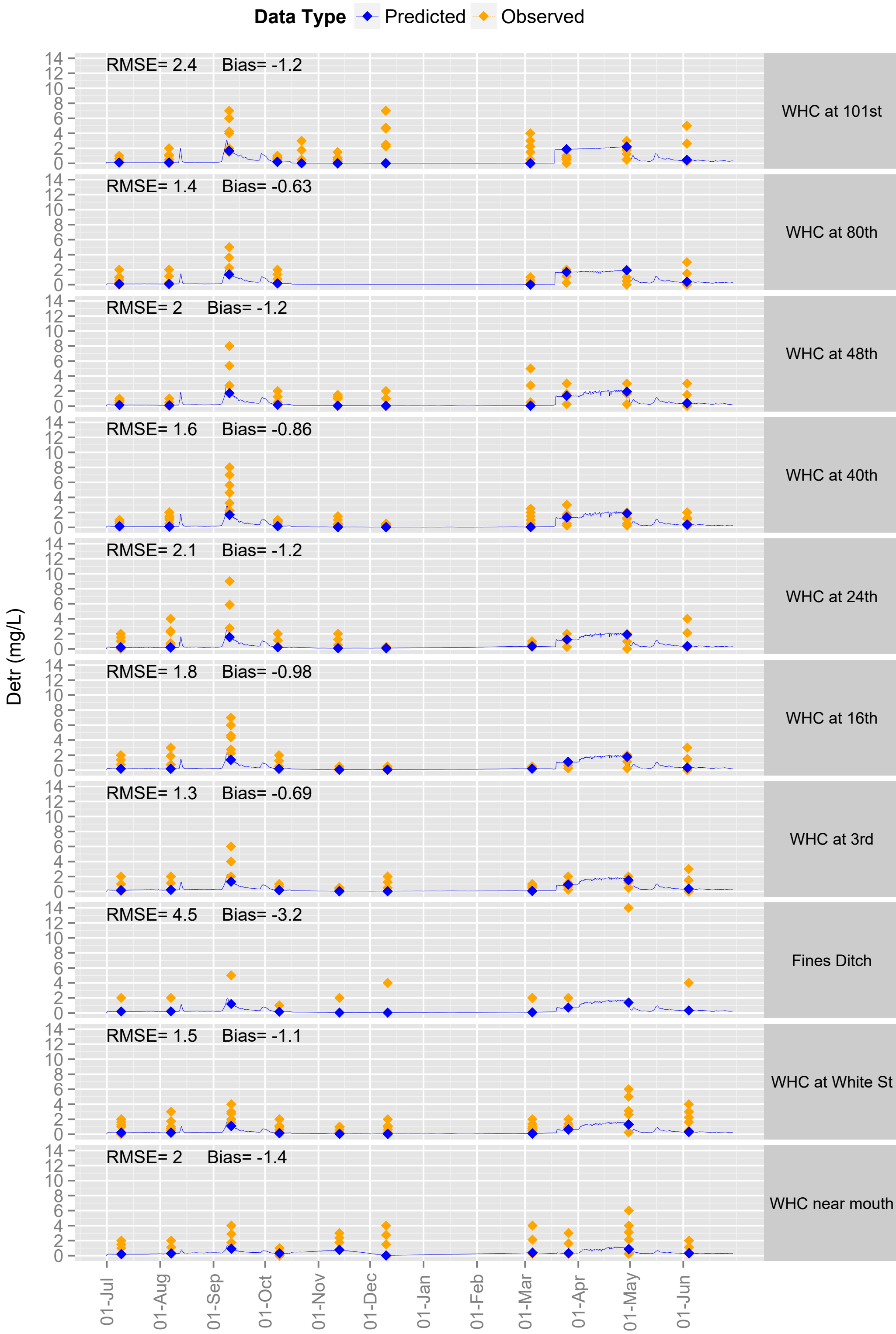

Figure G-16. Comparison between simulated (predicted) and measured values of detritus - organic suspended solids (mg/L).

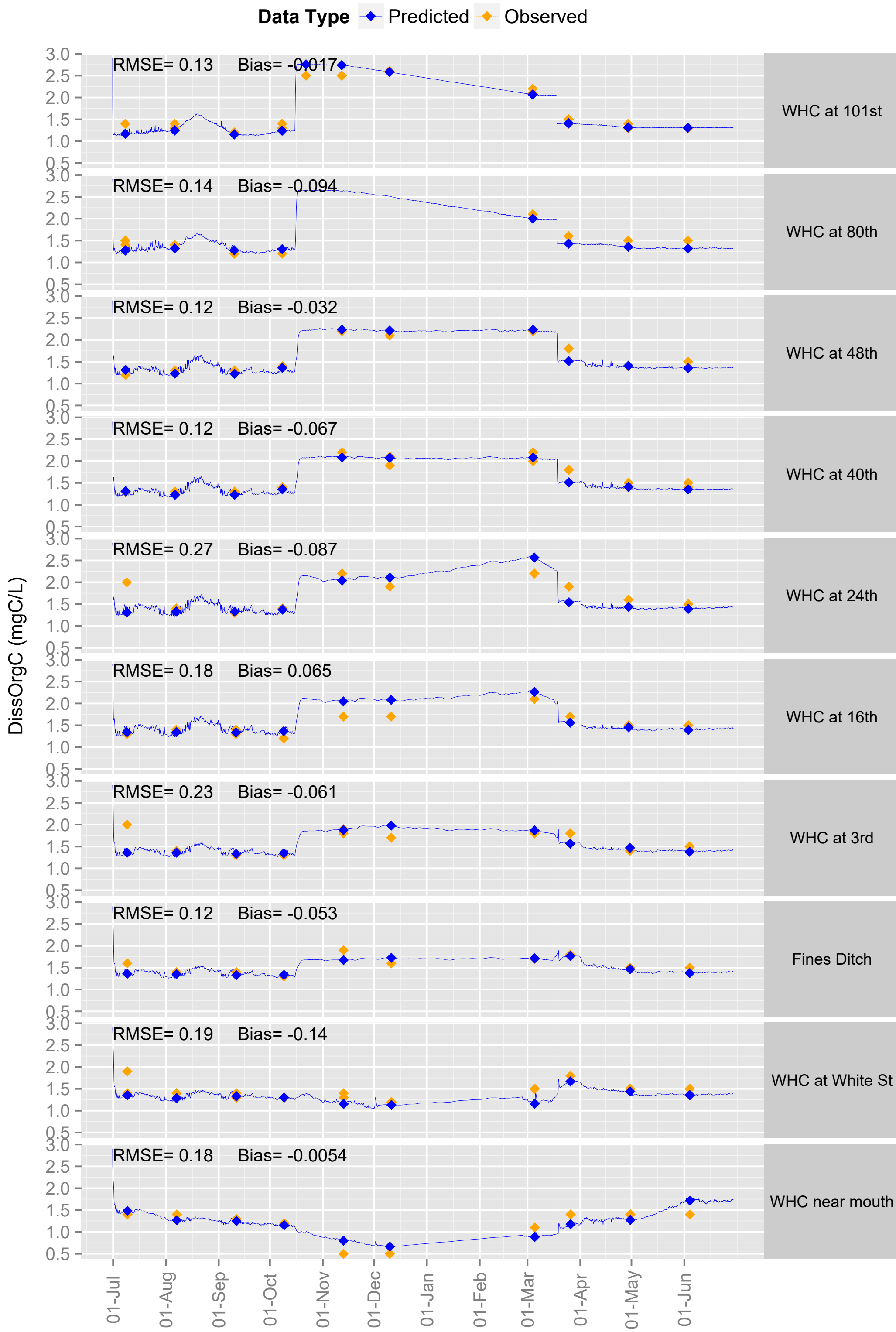

Figure G-17. Comparison between simulated (predicted) and measured values of dissolved organic carbon (mg-C/L).

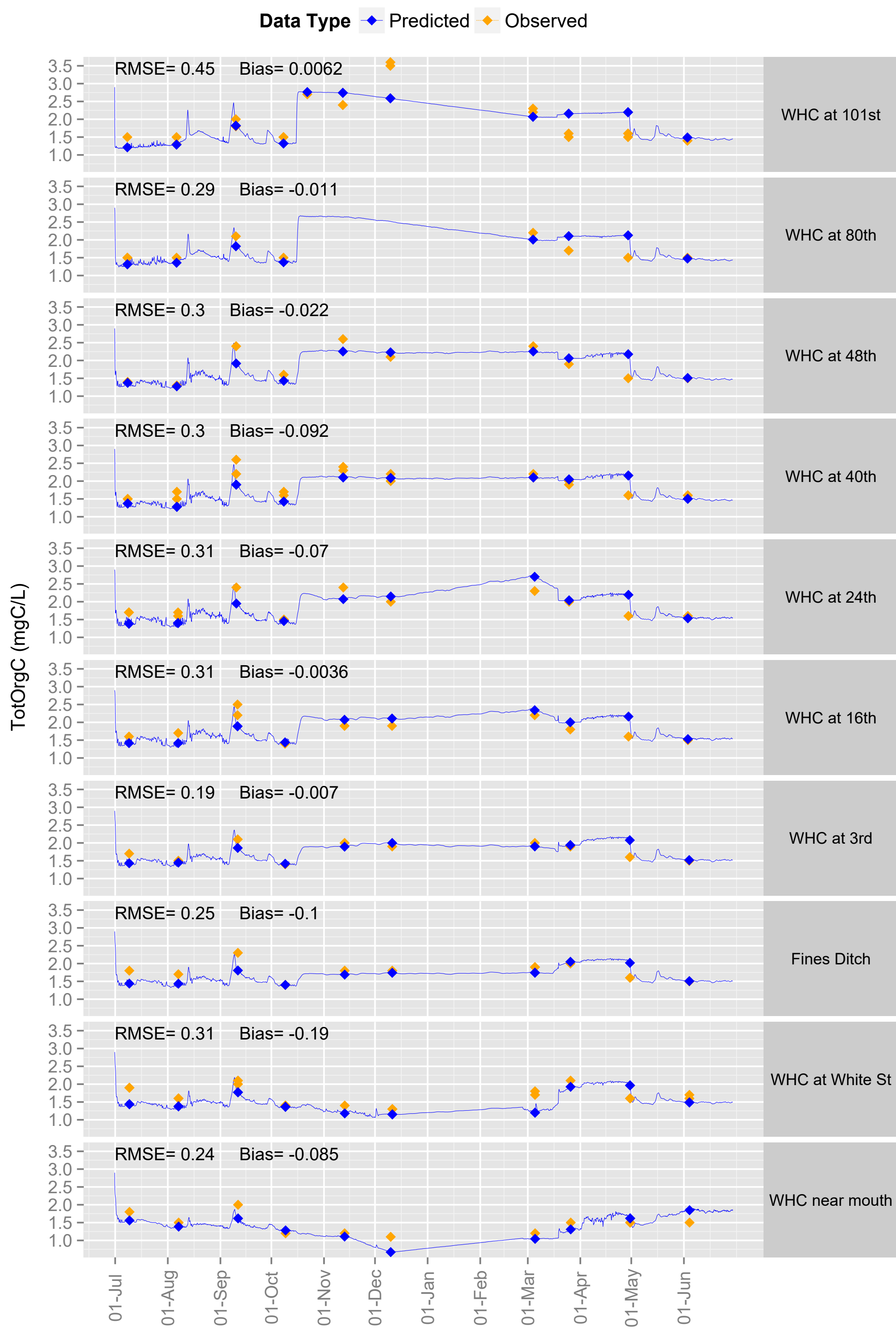

Figure G-18. Comparison between simulated (predicted) and measured values of total organic carbon (mg-C/L).

Appendix H. QUAL2Kw Model Sensitivity Analysis

Analysis of QUAL2Kw Temperature Sensitivity

The general behavior of the calibrated 2013-14 QUAL2Kw temperature model for Wide Hollow Creek was evaluated through a sensitivity analysis using simple parameter perturbation (Chapra, 1997). This analysis perturbs (raises and/or lowers) model parameters to evaluate the impact of the perturbation on simulated daily maximum and daily minimum water temperature.

Parameter perturbation was investigated for the following model parameters:

- Meteorological values (air and dew point temperature)
- Channel geometry (water depth and velocity)
- Effective shade
- Irrigation outfall temperature (temperature of water discharged to Wide Hollow Creek from the Yakima Valley, Congdon and Naches-Cowiche canals)

Water temperature was simulated with a single perturbed parameter and then simulation results were compared against the calibrated 2013-14 model (hereafter referred to as the "baseline" model) to quantify the sensitivity of the model for each of the above parameters. Changes were assessed for daily maximum and minimum water temperature on 7/23/2015 because that date had the highest water temperature. High water temperatures have the potential to negatively impact aquatic life in the creek.

The following results are based on the sensitivity analysis:

- Water temperature is most sensitive to the following parameters: effective shade, irrigation outfall water temperature and air temperature.
- Water temperature is moderately sensitive to: dew point temperature, water depth.
- Water temperature was least sensitive to: water velocity.

Air temperature

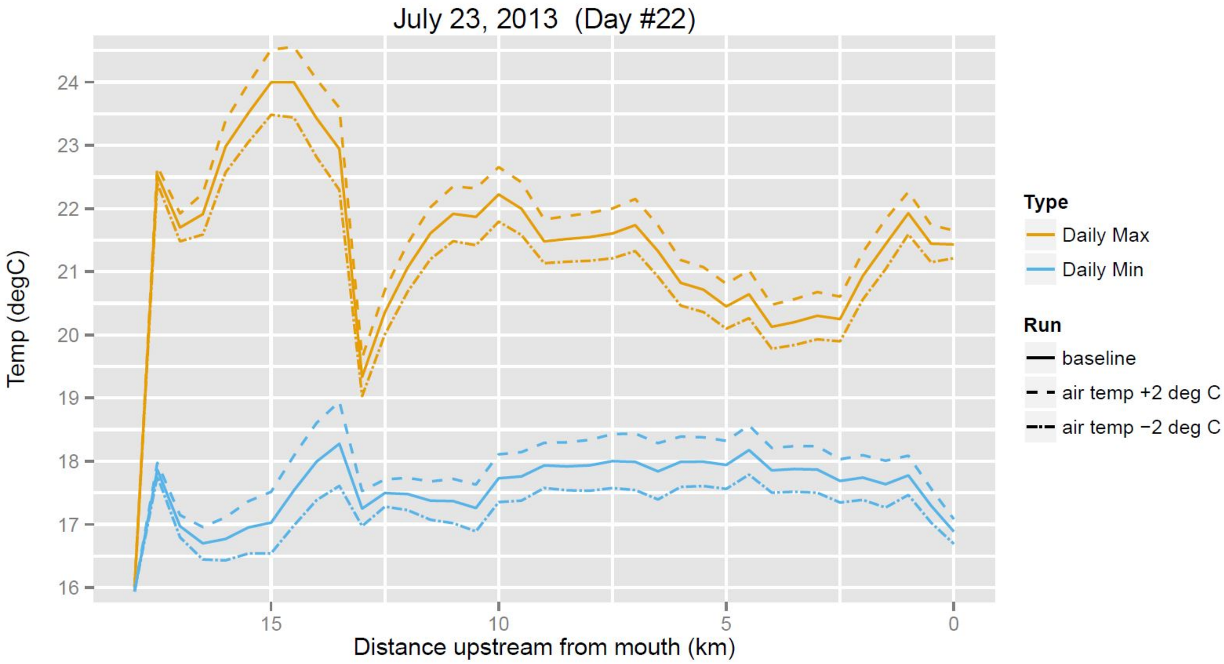

Figure H-1. Sensitivity of simulated daily maximum and minimum water temperature to air temperature on one of the hottest days (7/23/2013).

Perturbations: Hourly air temperature input values for the entire simulation were perturbed by ±2°C. Water temperature was simulated separately for each perturbation and compared to the baseline model (Figure H-1). Daily maximum temperatures are shown by orange lines. Daily minimum temperatures are shown by blue lines. The baseline (calibrated 2013-14) model is shown as a solid line, and the perturbed models are shown by broken lines (dashed and dash-dot, see figure legend for details).

Impacts due to perturbations: Air temperature (±2°C) perturbations resulted in the following impacts to simulated water temperature:

- daily-max
  - ±0.4°C (average along creek)
  - ±0.7°C (most impacted model reach)
- daily-min
  - ±0.4°C (average along creek)
  - ±0.7°C (most impacted model reach)
- Impacts were similar for both daily maximum and minimum temperature.

Distribution: Perturbation impacts are distributed more or less uniformly along the length of the creek. The least impacted reaches occur immediately downstream of large irrigation inputs to the creek. This is because the air temperature perturbations did not affect the water temperature from irrigation inputs or other tributaries to the creek.

Dew point temperature

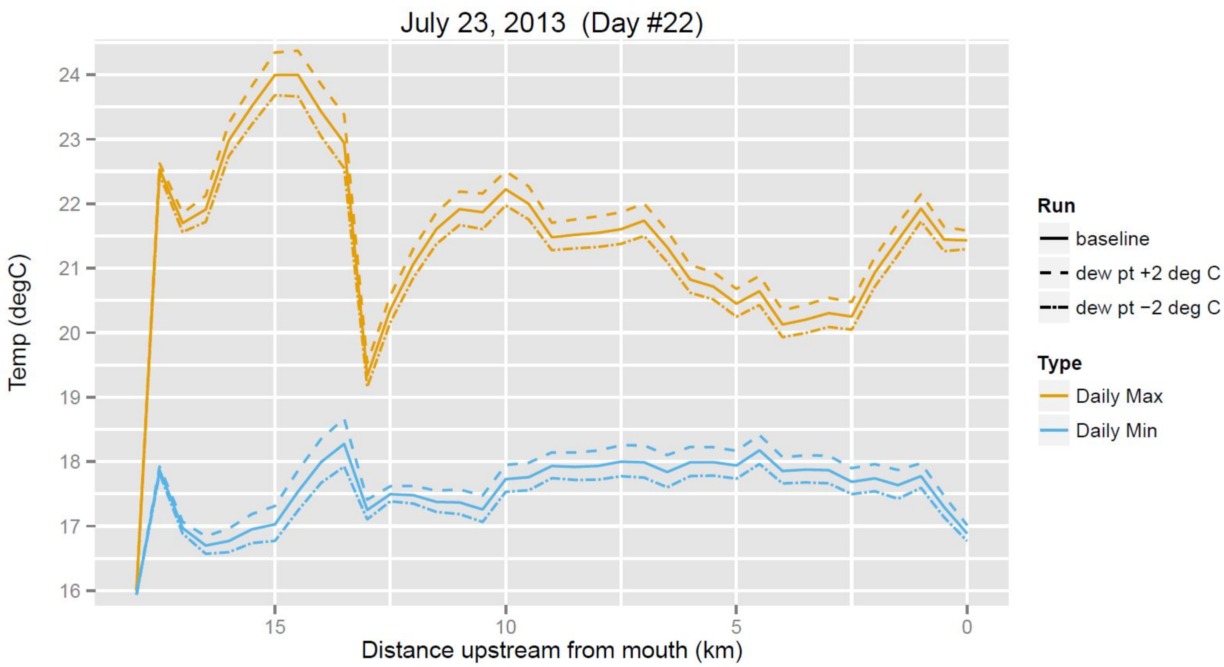

Figure H-2. Sensitivity of simulated daily maximum and minimum water temperature to dew point temperature on one of the hottest days (7/23/2013).

Perturbations: Hourly dew point temperature input values for the entire simulation were perturbed by ±2°C. Water temperature was simulated separately for each perturbation and compared to the baseline model (Figure H-2). Daily maximum temperatures are shown by orange lines. Daily minimum temperatures are shown by blue lines. The baseline (calibrated 2013-14) model is shown as a solid line, and the perturbed models are shown by broken lines (see figure legend).

Impacts due to perturbations: Dew point temperature (±2°C) perturbations resulted in the following impacts to simulated water temperature:

- daily-max
  - ±0.2°C (average along creek)
  - ±0.4°C (most impacted model reach)
- daily-min
  - ±0.2°C (average along creek)
  - ±0.4°C (most impacted model reach)
- Impacts were similar for both daily maximum and minimum temperature.

Distribution: Similar to air temperature, the perturbation impacts are distributed more or less uniformly along the length of the creek. The least impacted reaches occur immediately downstream of large irrigation inputs to the creek. This is because the dew point temperature perturbations did not affect the water temperature from irrigation inputs or other tributaries to the creek.

Water depth

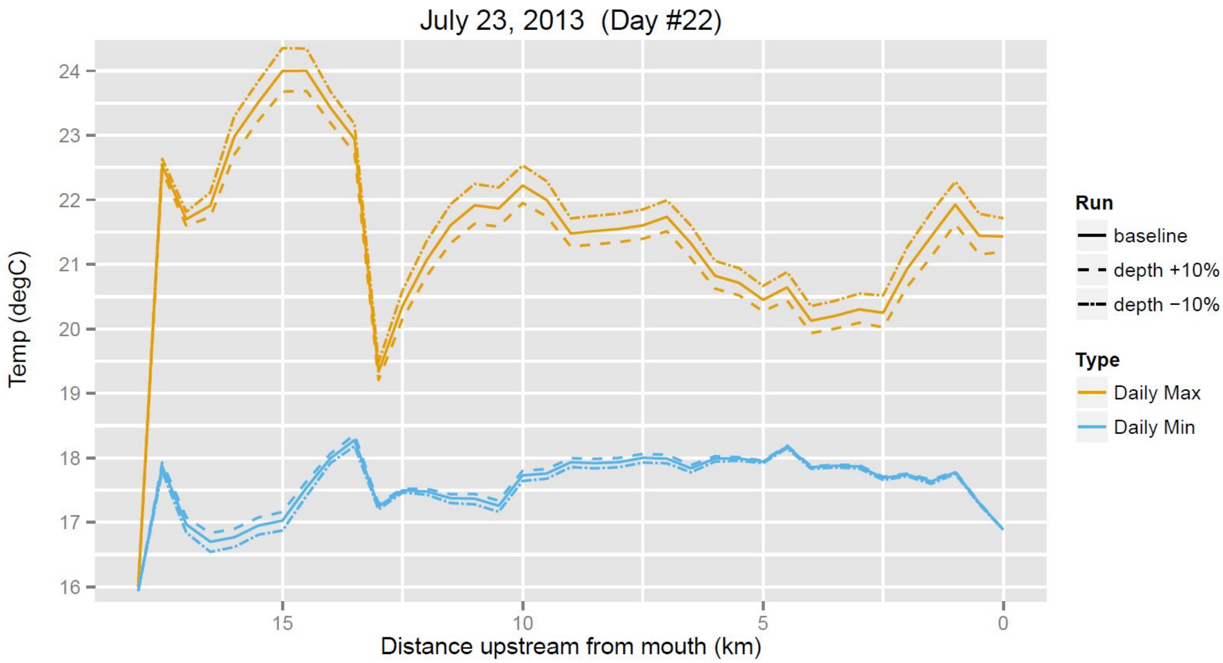

Figure H-3. Sensitivity of simulated daily maximum and minimum water temperature to water depth on one of the hottest days (7/23/2013).

Perturbations: Depth rating curves for the entire simulation were perturbed by ±10%. Water temperature was simulated separately for each perturbation and compared to the baseline model (Figure H-3). Daily maximum temperatures are shown by orange lines. Daily minimum temperatures are shown by blue lines. The baseline (calibrated 2013-14) model is shown as a solid line, and the perturbed models are shown by broken lines (see figure legend).

Impacts due to perturbations: Water depth (±10%) perturbations resulted in the following impacts to simulated water temperature:

- daily-max
  - +0.3°C and -0.2°C (average along creek)
  - +0.4°C and -0.3°C (most impacted model reach)
- daily-min
  - ±0.1°C (average along creek)
  - +0.1°C and -0.2°C (most impacted model reach)
- Impacts were larger for daily maximum water temperature.

Distribution: Perturbation impacts are distributed more or less uniformly along the length of the creek. The least impacted reaches occur immediately downstream of large irrigation inputs to the creek. This is because the air temperature perturbations did not affect the water temperature from irrigation inputs or other tributaries to the creek.

Water velocity

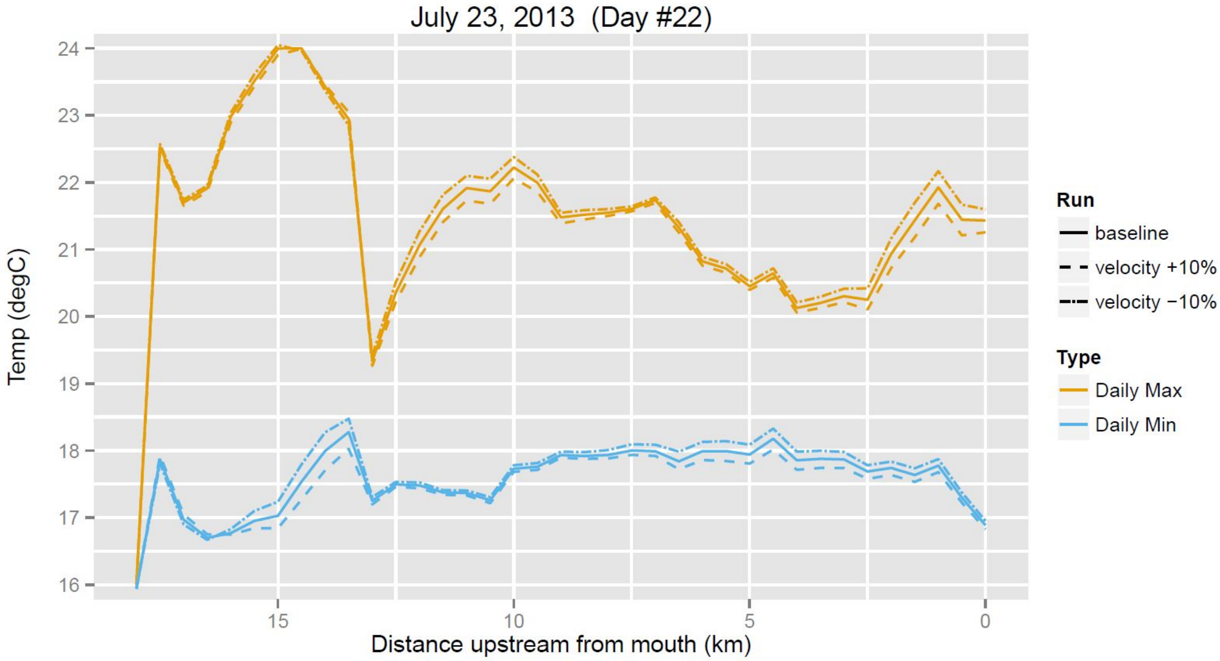

Figure H-4. Sensitivity of simulated daily maximum and minimum water temperature to water velocity on one of the hottest days (7/23/2013).

Perturbations: Velocity rating curves for the entire simulation were perturbed by ±10%. Water temperature was simulated separately for each perturbation and compared to the baseline model (Figure H-4). Daily maximum temperatures are shown by orange lines. Daily minimum temperatures are shown by blue lines. The baseline (calibrated 2013-14) model is shown as a solid line, and the perturbed models are shown by broken lines (see figure legend).

Impacts due to perturbations: Water velocity (±10%) perturbations resulted in the following impacts to simulated water temperature:

- daily-max
  - ±0.1°C (average along creek)
  - ±0.3°C (most impacted model reach)
- daily-min
  - ±0.1°C (average along creek)
  - ±0.3°C (most impacted model reach)
- Impacts were similar for both daily maximum and minimum temperature.

Distribution: Impacts vary along the length of the creek length, and daily maximum impacts occur at different locations than daily minimum impacts.

Effective shade

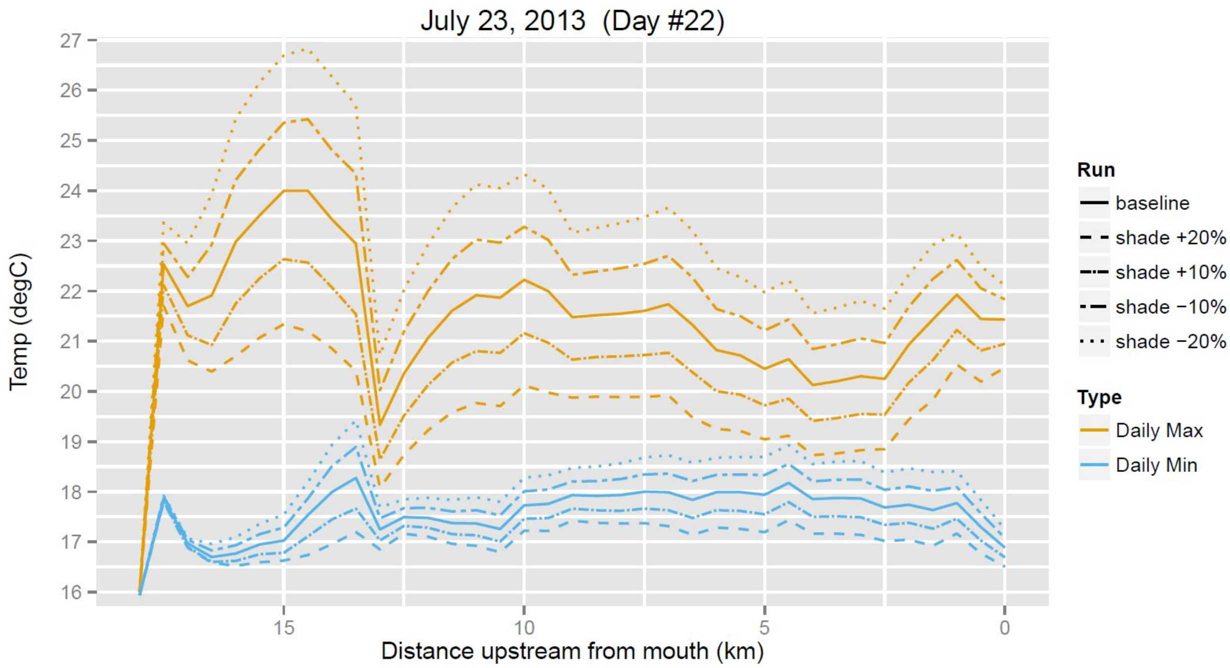

Figure H-5. Sensitivity of simulated daily maximum and minimum water temperature to effective shade on one of the hottest days (7/23/2013).

Perturbations: Hourly effective shade input values for the entire simulation were perturbed by ±10% and ±20% (perturbations were absolute changes, with limits not allowing shade to exceed 100% or go below 0%). Water temperature was simulated separately for each perturbation and compared to the baseline model (Figure H-5). Daily maximum temperatures are shown by orange lines. Daily minimum temperatures are shown by blue lines. The baseline (calibrated 2013-14) model is shown as a solid line, and the perturbed models are shown by broken lines (see figure legend).

Impacts due to perturbations: Effective shade (-20%, -10%, 10% and 20%) perturbations resulted in the following impacts to simulated water temperature:

- daily-max
  - (+1.7, +0.9, -0.9, and -1.7)°C respectively (average along creek)
  - (+2.8, +1.4, -1.4, and -2.8)°C respectively (most impacted model reach)
- daily-min
  - (+0.6, +0.3, -0.3, and -0.5)°C respectively (average along creek)
  - (+1.1, +0.6, -0.6, and -1.1)°C respectively (most impacted model reach)
- Impacts were larger for daily maximum temperature.

Distribution: Perturbation impacts are distributed more or less uniformly along the length of the creek.

Irrigation outfall water temperature

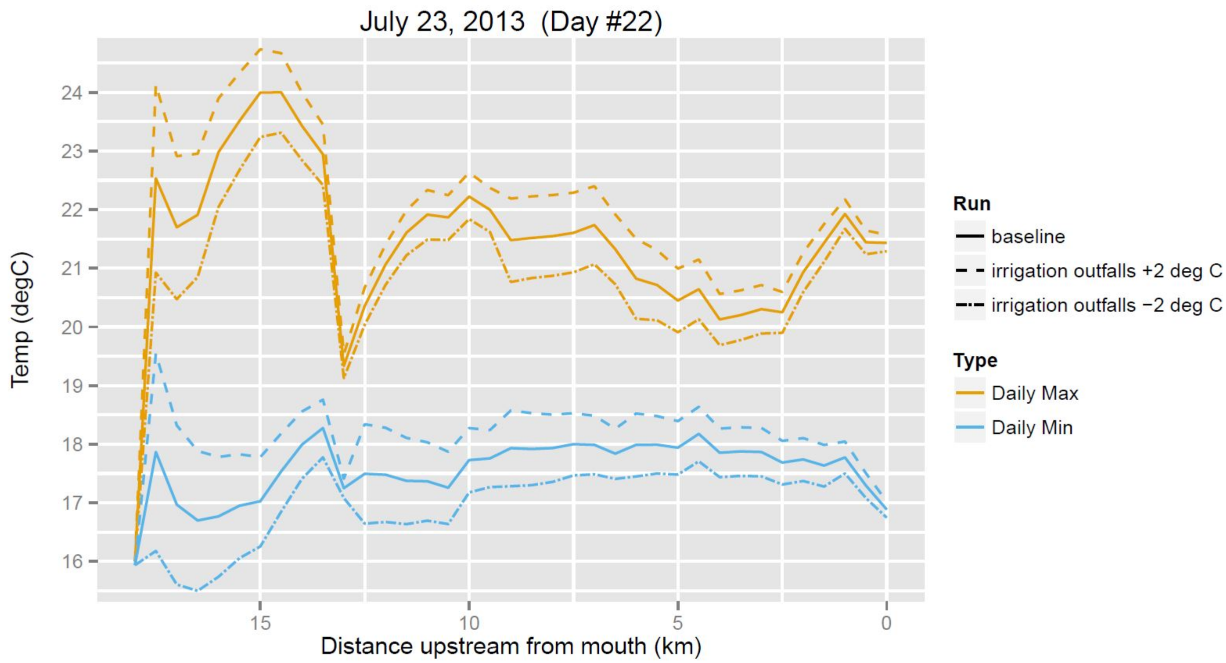

Figure H-6. Sensitivity of simulated daily maximum and minimum water temperature to irrigation outfall water temperature on one of the hottest days (7/23/2013).

Perturbations: Hourly water temperature input values for all irrigation outfall sources during the entire simulation were perturbed by ±2°C. Water temperature was simulated separately for each perturbation and compared to the baseline model (Figure H-6). Daily maximum temperatures are shown by orange lines. Daily minimum temperatures are shown by blue lines. The baseline (calibrated 2013-14) model is shown as a solid line, and the perturbed models are shown by broken lines (see figure legend).

Impacts due to perturbations: Irrigation outfall water temperature (±2°C) perturbations resulted in the following impacts to simulated water temperature:

- daily-max
  - ±0.5°C (average along creek)
  - ±1.6°C (most impacted model reach)
- daily-min
  - ±0.6°C (average along creek)
  - ±1.7°C respectively (most impacted model reach)
- Impacts were larger for daily minimum temperature.

Distribution: Perturbation impacts are largest immediately downstream of irrigation outfalls.

Analysis of QUAL2Kw Dissolved Oxygen Sensitivity

The general behavior of the calibrated 2013-14 QUAL2Kw dissolved oxygen (DO) model for Wide Hollow Creek was evaluated through a sensitivity analysis using simple parameter perturbation (Chapra, 1997). This analysis perturbs (raises and/or lowers) model parameters to evaluate the impact of the perturbation on simulated daily maximum and daily minimum DO concentrations.

Parameter perturbation was investigated for the following model parameters:

- Meteorological values (air and dew point temperature).
- Channel geometry (water depth).
- Effective shade.
- Irrigation outfall temperature (temperature of water discharged to Wide Hollow Creek from the Yakima Valley, Congdon and Naches-Cowiche canals).
- Inorganic nutrient concentrations (nitrate and soluble reactive phosphorous).

DO concentration was simulated with a single perturbed parameter and simulation results were then compared against the calibrated 2013-14 model (hereafter referred to as the "baseline" model) to quantify the sensitivity of the model for each of the above parameters. Changes were assessed for daily maximum and minimum DO on 7/23/2015 because that date had the highest water temperature. High water temperatures have the potential to negatively impact aquatic life in the creek.

Based on the sensitivity analysis results (Figure H-7 and Table H-1):

- Daily minimum DO concentration is most sensitive to the following parameters: shade, water depth.
- Daily minimum DO concentration is moderately sensitive to: irrigation outfall water temperature, air temperature.
- Daily maximum DO concentration is most sensitive to: shade, water depth, irrigation outfall temperature.
- Daily maximum DO concentration is moderately sensitive to: air temperature.
- DO (daily minimum and maximum) concentrations were least sensitive to: inorganic nutrient concentrations.

Table H-1. Largest impact of perturbation on 7/23/2015 DO concentrations (mg/L).

Perturbation	Largest impact of perturbation on 7/23/2015 DO concentrations (mg/L)	
	Daily minimum	Daily maximum
Shade -20%	-0.33	-0.13
Shade -10%	-0.18	-0.07
Depth -10%	-0.22	0.12
Irrig outfalls +2 deg C	-0.13	-0.14
Air temp +2 deg C	-0.05	-0.07
Dew point +2 deg C	-0.04	-0.04
Nitrate and SRP -20%	0.00	-0.01
Nitrate and SRP +20%	0.00	0.01
Dew point -2 deg C	0.03	0.04
Air temp -2 deg C	0.05	0.07
Irrig outfalls -2 deg C	0.14	0.15
Depth +10%	0.19	-0.10
Shade +10%	0.22	0.06
Shade +20%	0.48	0.10

The largest impact was chosen based on the greatest absolute value of the impact, either positive or negative. Increases in DO are shaded orange and decreases are shaded light blue.

Appendix I.
Flow Spikes Fall 2013 - Wide Hollow Creek

Spikes in continuously gaged streamflow Fall 2013

Short-term, temporary increases in flow (referred to as *spikes* in this section) of 2 to 4 cfs were observed at the 40th Ave gage station during late October through November 2013 (Figure I-13). Due to low flow conditions, these spikes briefly doubled or even tripled flow at 40th Ave. The spikes can also be seen at the 24th Ave gage, and some events are faintly visible at the White St. gage. The spikes were not observed at 101st Ave.

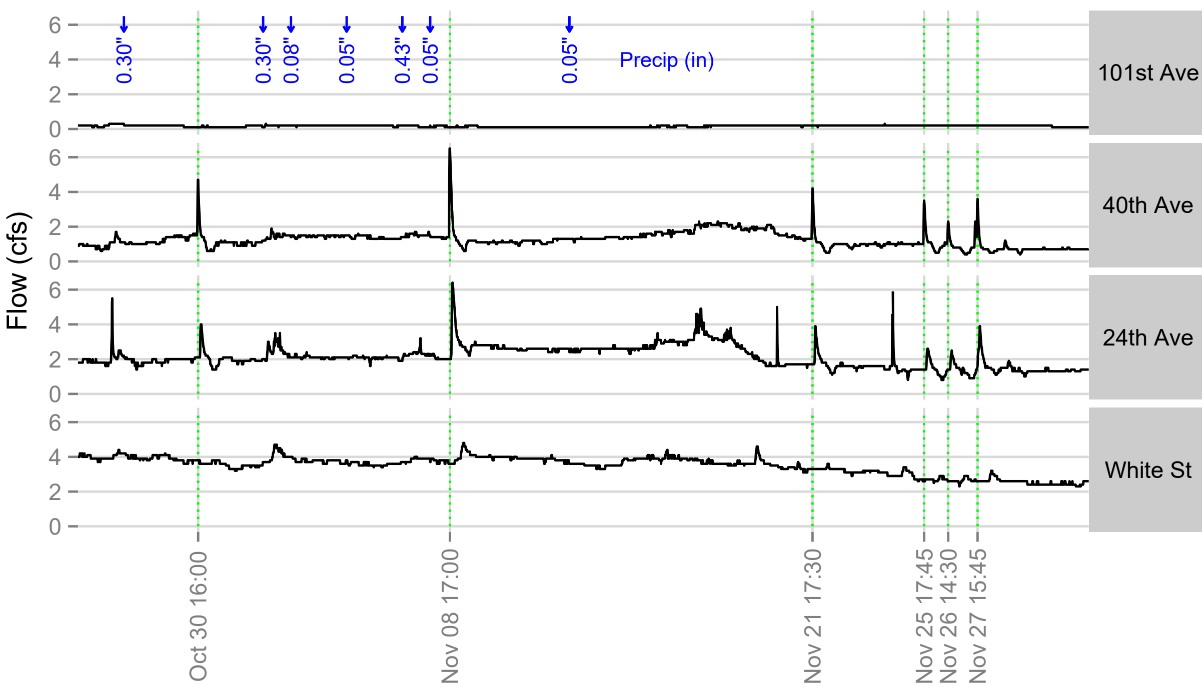

Figure I-13. Flow spikes observed by continuous gaging.
Precipitation events are noted along the top in blue text.

Increases in flow each lasted 3-4 hours. They appear unrelated to rainfall (precipitation amounts and timing from Yakima airport data are shown in blue along the top of the figure.) They arrived at relatively consistent times of day (2:30 – 5:45 pm Pacific Standard Time, shown along the bottom of the figure). The increases were followed by temporary decreases in flow (lasting 9-10 hours and centered about 10-12 hours after peak flow). The spikes were observed only on weekdays.

Specific conductivity at 40th Ave increased approximately 20-30 uS/cm during the flow spikes (Figure I-14). Specific conductivity was not recorded at the 24th Ave gage. Peaks in conductivity were consistently delayed by several hours relative to peak flow, which is the expected pattern for a plug of water moving down a stream channel (Chapra, 2002).

The observed spikes in flow appear to be caused by plugs of water moving down the creek, based on the consistency of flow between the 40th and 24th Ave gages, as well as the observance and timing of the conductivity peaks. The source of the alleged plugs of water is unknown, but does not appear to be caused by precipitation, especially since conductivity in the creek appeared to slightly increase, which implies a specific conductivity greater than 600 uS/cm in the source of water for the plug flow. The consistency in arrival time is evidence that the alleged plugs are likely anthropogenic in origin.

The delay between flow and conductivity peaks depends in part on the distance downstream from the source (Chapra, 2002). The delay of several hours indicate that the source was likely some distance upstream of 40th Ave. Calculations based on the observed delay time and velocities in the creek estimate the source of plug flows were likely located somewhere in the vicinity of 64th to 80th Avenues.

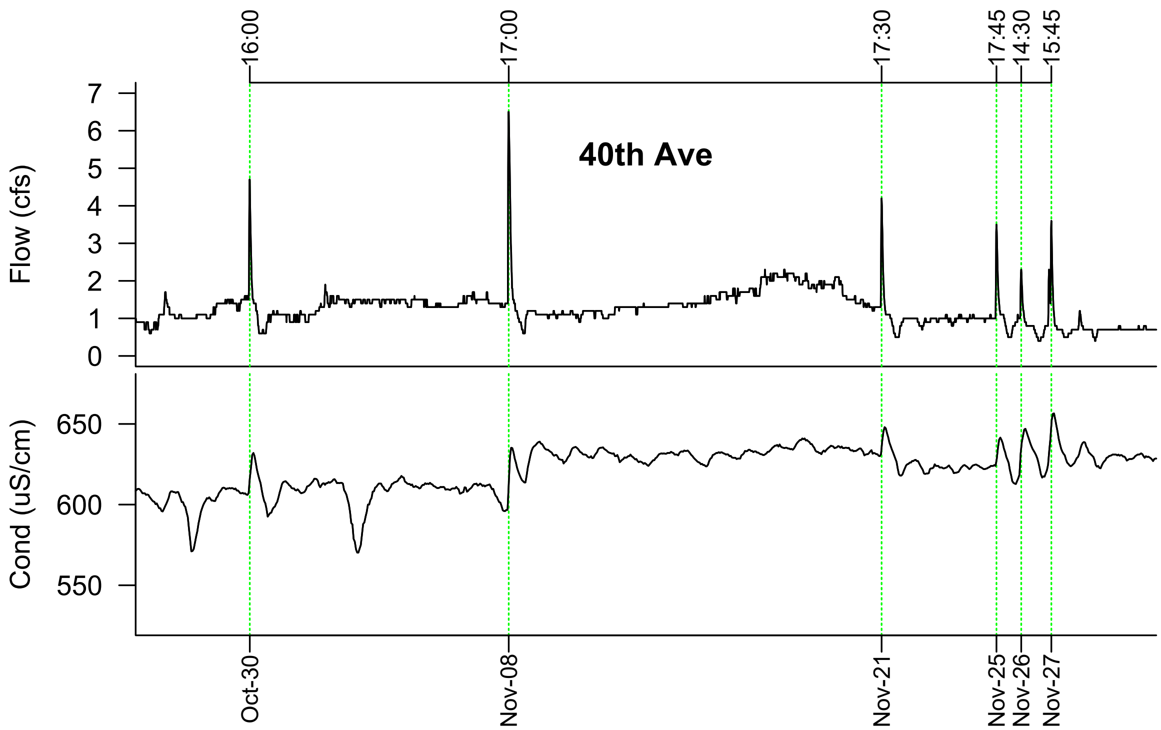

Figure I-14. Comparison of spikes in streamflow and conductivity at 40th Ave gage.