Wenck
Engineers • Scientists
Business Professionals

Wenck Associates, Inc.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, MN 55359-0249

800-472-2232
(763) 479-4200
Fax (763) 479-4242
wenckmp@wenck.com
www.wenck.com

TECHNICAL MEMORANDUM

TO: Minnesota Pollution Control Agency
Pioneer- Sarah Creek Watershed Management Organization

FROM: Jeff Strom and Diane Spector

DATE: April 2015

SUBJECT: Pioneer Creek Historic Dissolved Oxygen Data Summary

---

This technical memorandum summarizes all historic dissolved oxygen (DO) and relevant water quality data collected throughout the Pioneer Creek impaired reach (AUID 07010205-653) since 2010. The reach of Pioneer Creek from Lake Independence to the south line of T118 R24W S30 is expected to be listed on the 2016 303(d) list of impaired waters for DO. To help determine the cause of the DO violations, historical DO data from the reach were obtained from the Minnesota Pollution Control Agency's (MPCA's) EQuIS database and compared to continuous flow, nitrogen, biochemical oxygen demand (BOD), phosphorus and chlorophyll-*a* (Chl-*a*) data.

1.0 WATERSHED DESCRIPTION

The Pioneer Creek DO impaired reach is approximately 7.09 miles in length and is completely contained in Hennepin County in the South Fork Crow River watershed (Figure 1-1). The watershed of the impaired reach, including land upstream of the reach headwaters, covers approximately 18,183 acres in Hennepin County. The predominant land use types throughout the watershed are wetlands and open water (30%), forest and shrubland (22%), corn and soybeans (17%), and hay and pasture (17%) (Table 1-1).

Table 1-1. Landuse in the Pioneer Creek impaired reach watershed.

[1]Landuse Type	Pioneer Creek Direct Watershed	Pioneer Creek Watershed - All
Total area (acres)	9,788	18,183
Wetlands and Open Water	25%	30%
Forest and Shrubland	21%	22%
Corn/Soybeans	18%	17%
Hay and Pasture	21%	17%
Urban/Roads	10%	10%
Grains and other Crops	5%	4%

[1] Source: 2011 National Agriculture Statistics Services (NASS) land use dataset.

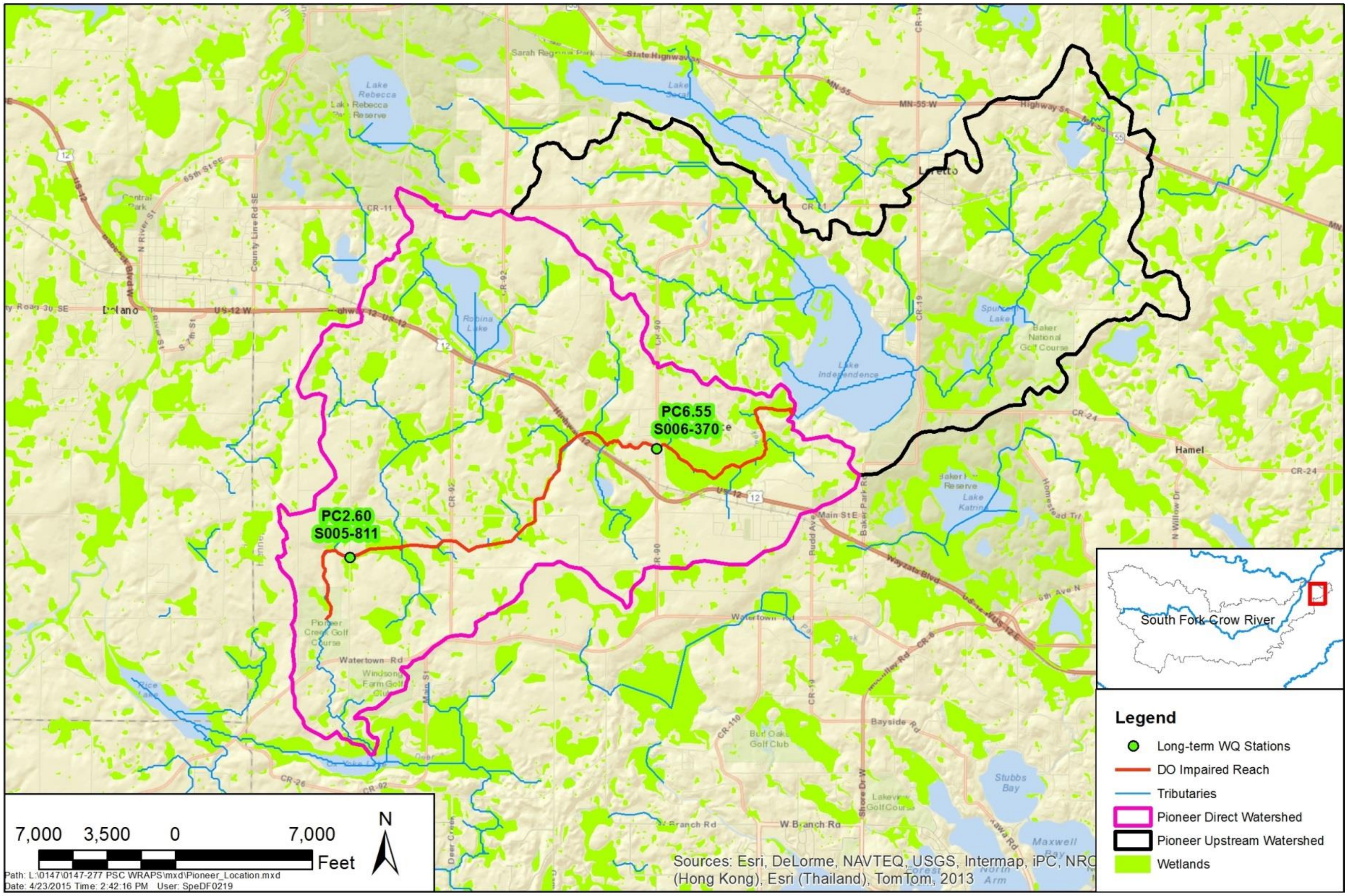

Figure 1-1. Pioneer Creek DO impaired reach and watershed.

The headwaters of Pioneer Creek are located at the outlet of Lake Independence at Independence Road in the city of Independence, MN. Upon leaving Lake Independence, the DO impaired reach flows through an 18,000-acre wetland complex located between Independence Road and County Road 90 (Figure 1-2). Air photos suggest the wetland complex is partially channelized; however the wetland is characterized by dense cattails and a series of shallow ponds and areas of standing water during wet conditions. Riparian wetland stretches tend to have slow velocities, low reaeration, long travel times and high sediment oxygen demand (SOD) due to the high organic content of wetland peat deposits.

Figure 1-2. Pioneer Creek impaired reach wetland complex between Lake Independence and PC6.55.

2.0 REVIEW OF PIONEER CREEK DISSOLVED OXYGEN DATA

Minnesota Pollution Control Agency (MPCA) and Three Rivers Park District staff have collected DO data at two stations (PC2.60 and PC6.55) on the Pioneer Creek DO impaired reach since 2010 (Figure 1-1 and Table 2-1). Continuous stream flow data are available at the PC2.60 station from 2009-2013 and at the PC6.55 station from 2010-2013.

2.1 DISSOLVED OXYGEN GRABS/FIELD MEASUREMENTS

The Pioneer Creek impaired reach is designated by state statute as a beneficial-use Class 2B warm water stream. This designation requires that DO concentrations shall not fall below 5.0 mg/L as a daily minimum to support the aquatic life and recreation of the ecosystem. Approximately 36% of the May-September DO observations collected at the PC2.60 station were below the 5.0 mg/L DO standard

(Table 2-1 and Figure 2-1). By comparison, approximately 81% of the DO observations collected at PC6.55 station were below the DO standard, likely due to the large wetland complex located upstream of this station (Figure 2-2).

Only five and three individual DO measurements were collected prior to 9:00 am at PC2.60 and PC6.55, respectively (Figures 2-3 and 2-4). Time of day records are unavailable for a few of the samples. The MPCA now recognizes measurements taken after 9:00 am do not represent daily minimums, and thus measurements greater than 5.0 mg/L DO later in the day are no longer considered to be indications that a stream is meeting state standards. Two of the five DO samples collected before 9:00 am at PC2.60 were below the DO standard. All three of the pre 9:00 am DO measurements at PC6.55 were below the 5.0 mg/L standard. By comparison, 14 of the 39 (36%) measurements at PC2.60 and 18 of the 23 (78%) measurements at PC6.55 recorded after 9:00 am were in violation of the DO standard, suggesting DO violations are common throughout the impaired reach regardless of the time of day. More DO measurements prior to 9:00 am should be collected to fully assess DO in Pioneer Creek according to the new DO protocol. Monthly plots (Figures 2-5 and 2-6) show a majority of the violations were recorded during the warmer summer months (June through August).

Table 2-1. Pioneer Creek (07010205-653) May through September DO data summary.

EQuIS ID	QUAL2K ID	Location	Impaired Reach River Mile	DO Observations	DO Violations (<5 mg/L)	Years
S005-811	PC2.60	Pioneer Creek at Copeland Road	2.60	44	16	2010-2013
S006-370	PC6.55	Pioneer Creek at County Road 90	6.55	26	21	2010-2013

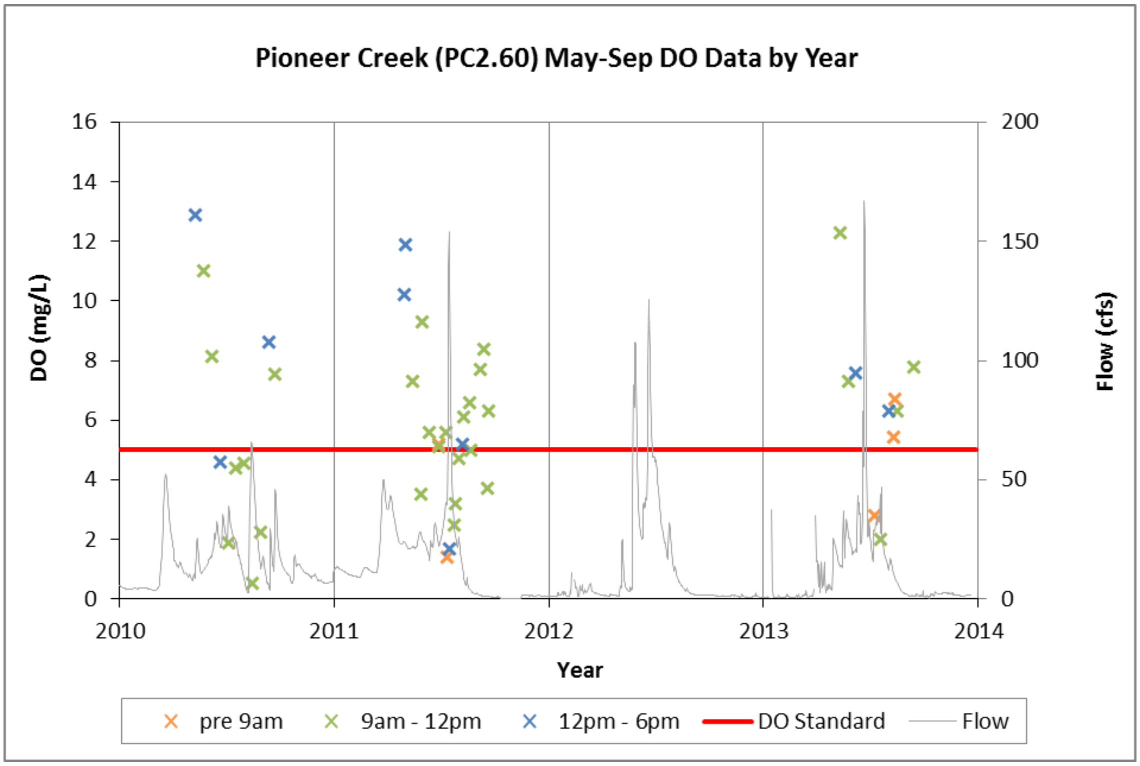

Figure 2-1. DO and flow data for PC2.60 by year, color coded by time of day.

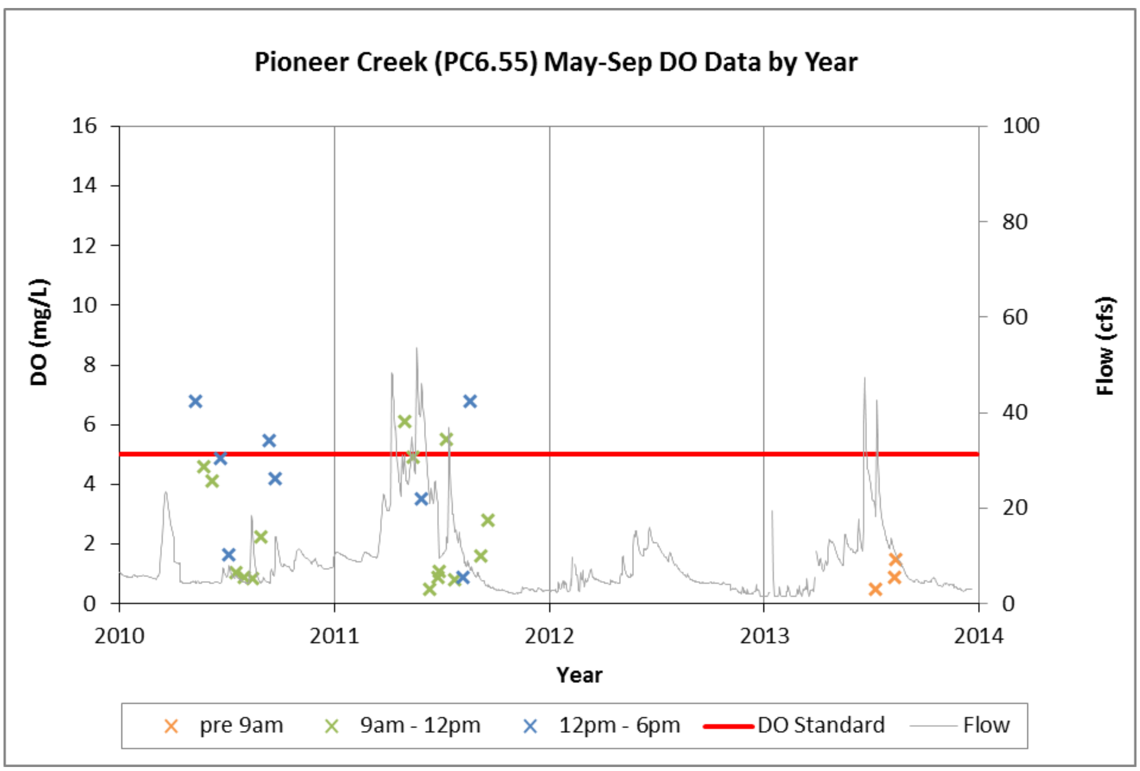

Figure 2-2. DO and flow data for PC6.55 by year, color coded by time of day.

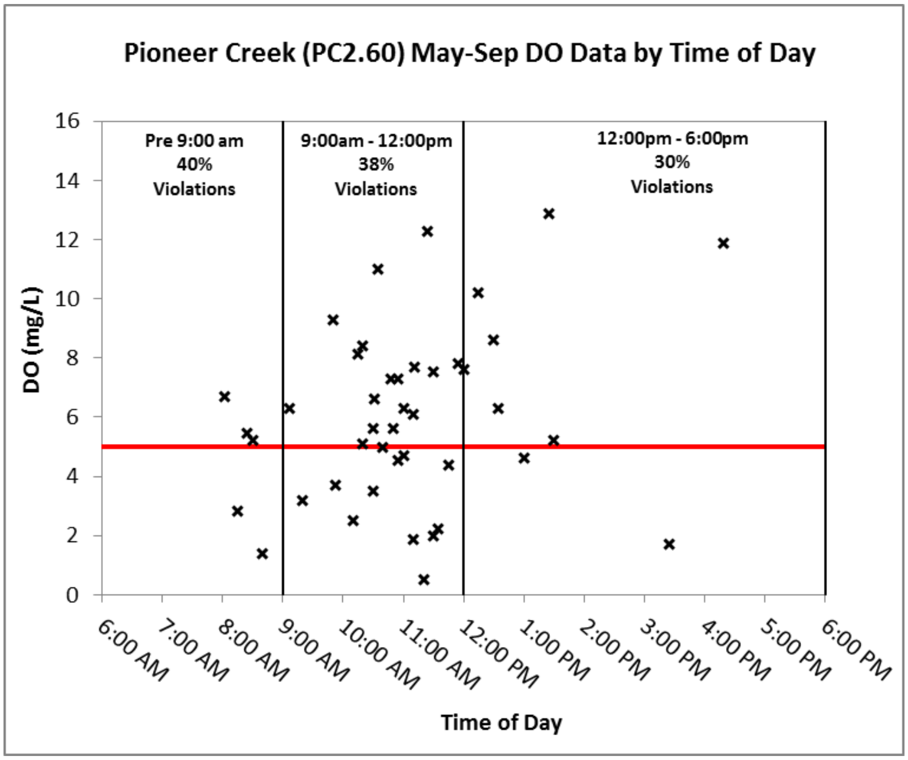

Figure 2-3. PC2.60 DO data (May-Sep) by time of day.

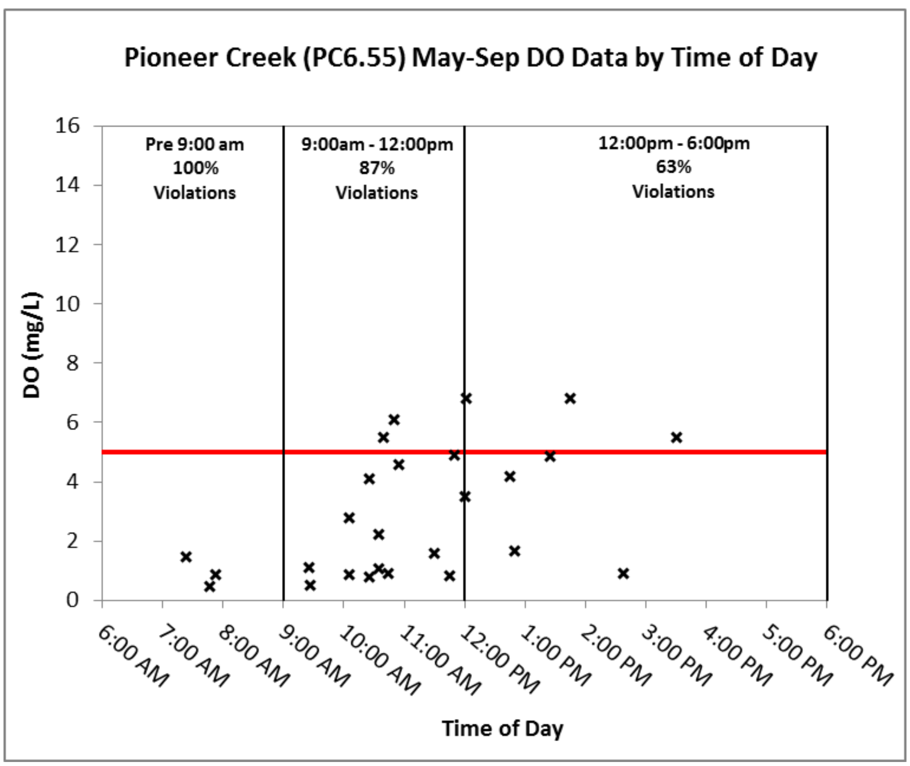

Figure 2-4. PC6.55 DO data (May-Sep) by time of day.

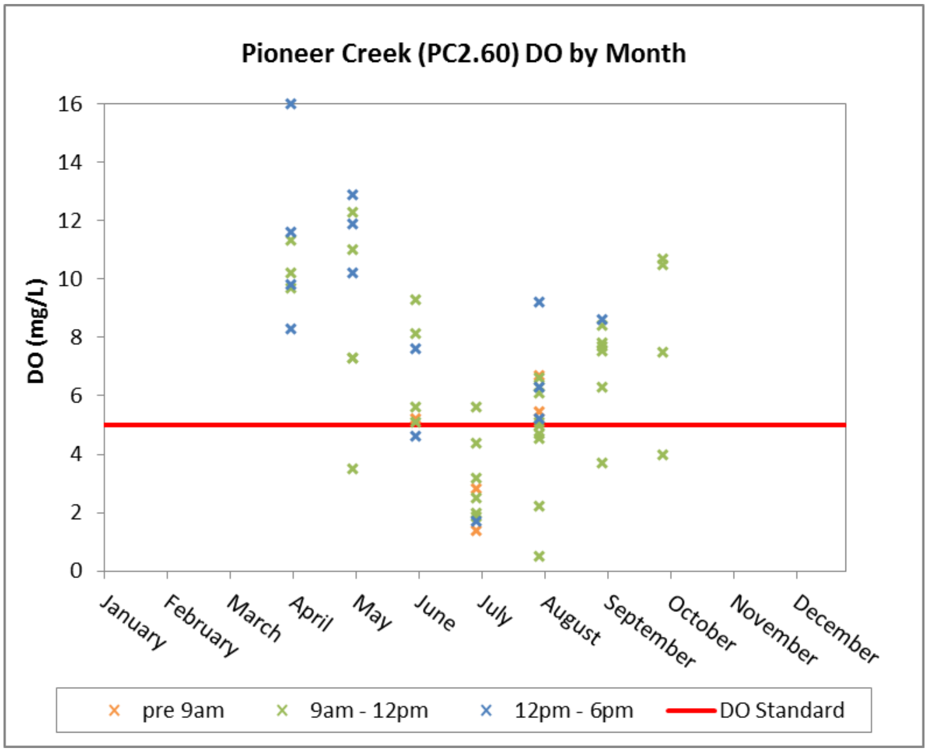

Figure 2-5. PC2.60 DO data by month.

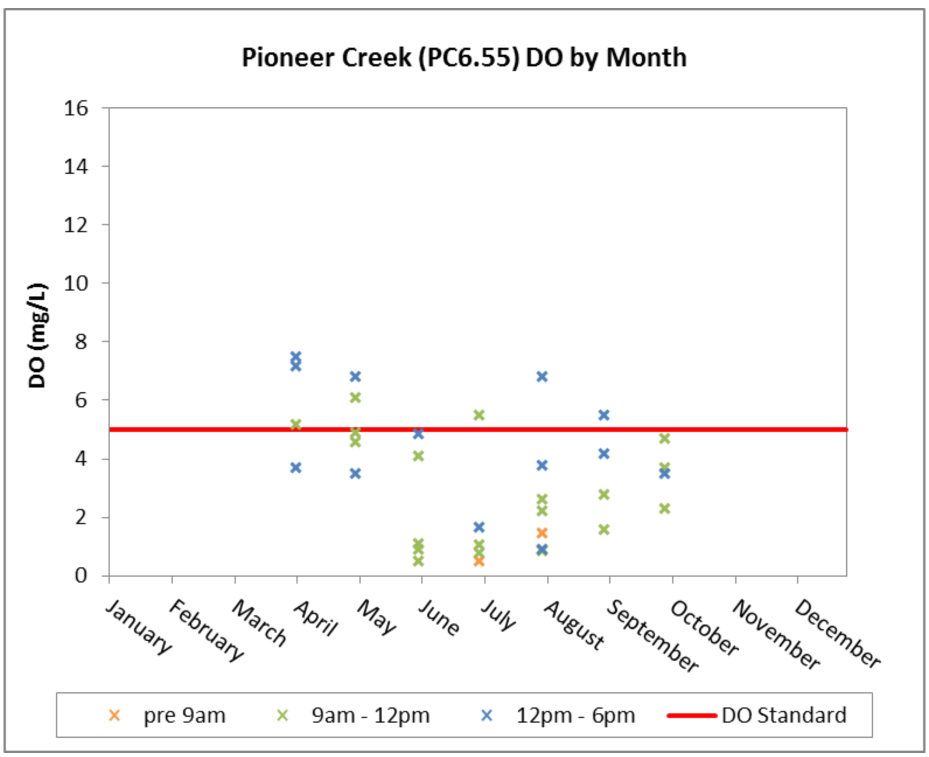

Figure 2-6. PC6.55 DO data by month.

2.2 DISSOLVED OXYGEN RELATION TO FLOW

Average daily flow for Pioneer Creek was compared to Pioneer Creek DO measurements. Figures 2-7 and 2-8 are flow duration plots that show DO violations at both sites occur under most flow conditions. At the downstream station, PC2.60, DO violations were most common under "very high" flow conditions.

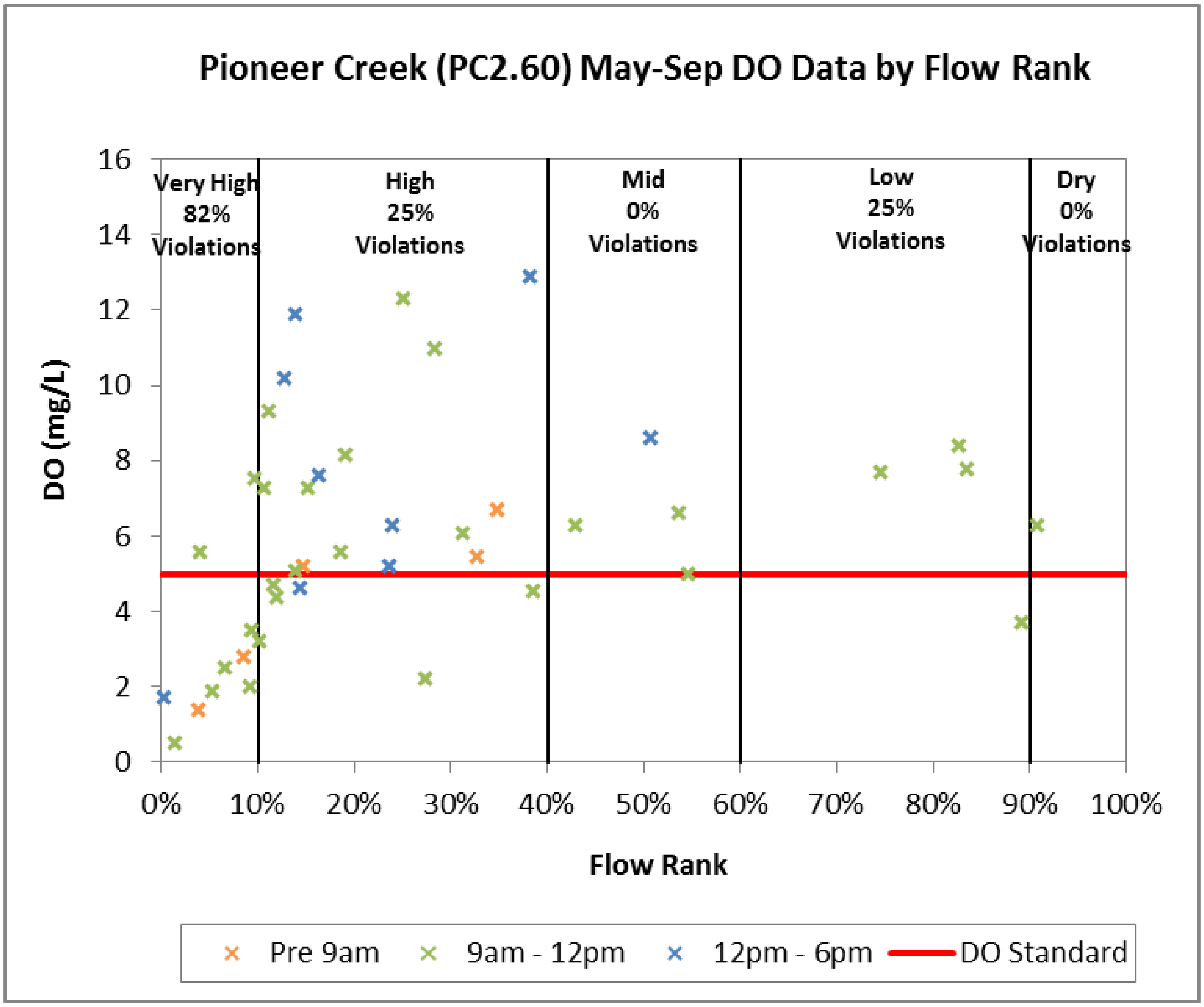

Figure 2-7. PC2.60 DO by flow condition. Flow duration was constructed using continuous average daily flow data from the PC2.60 monitoring station.

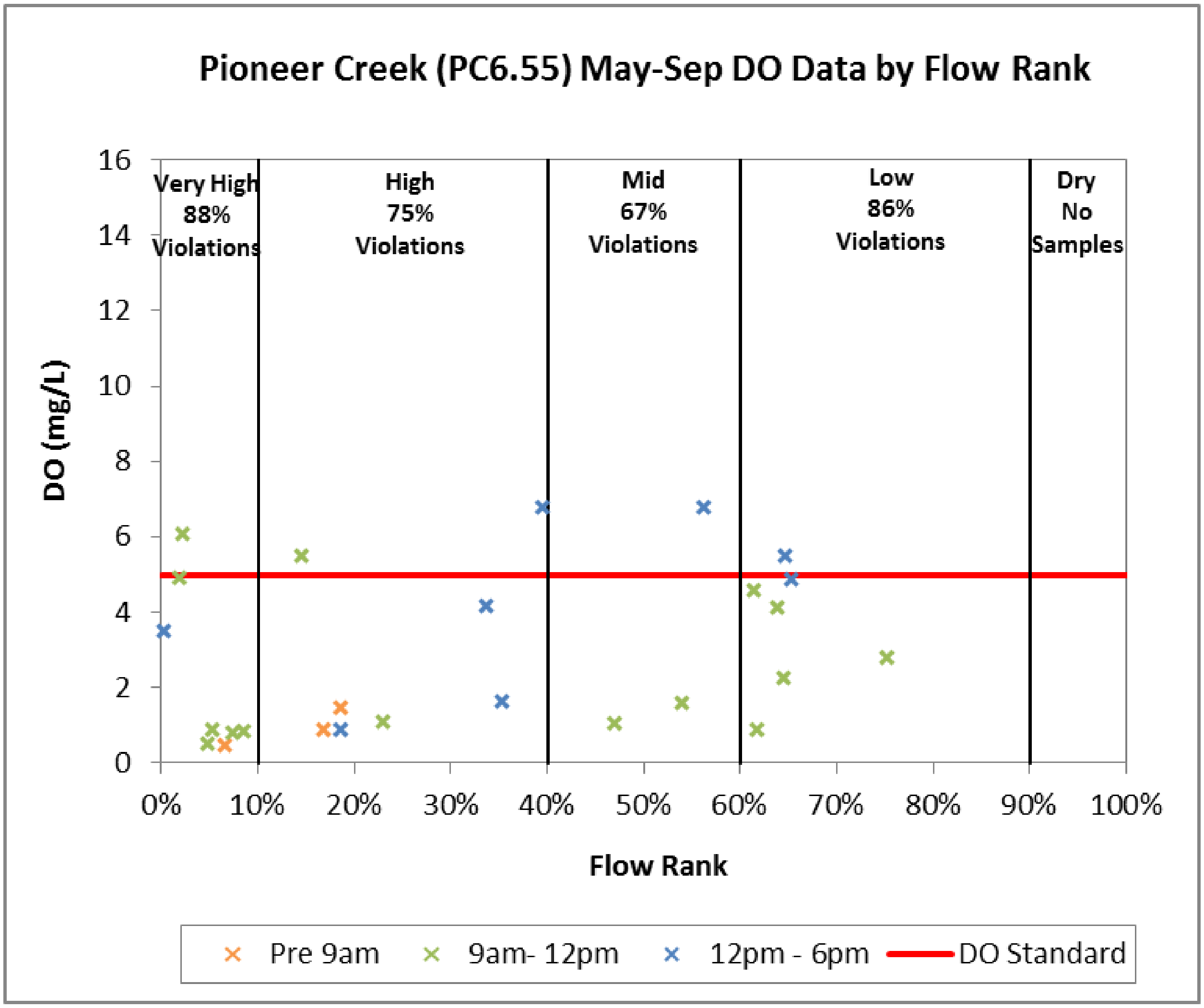

Figure 2-8. PC6.55 DO by flow condition. Flow duration was constructed using continuous average daily flow data from the PC6.55 monitoring station.

2.3 2013 DISSOLVED OXYGEN MONITORING

One data sonde with internal logging capability was deployed by Three Rivers Park staff at PC2.60 from 5/1/2013 through 10/4/2013 (Figure 2-9). The data sonde was programed to monitor continuous DO and temperature at 15-minute intervals. Results indicate Pioneer Creek daily minimum DO concentrations were below 5.0 mg/L for 94 of the 137 days the sonde was deployed. Daily minimum DO violations were common across all monitored flow conditions (Figure 2-10).

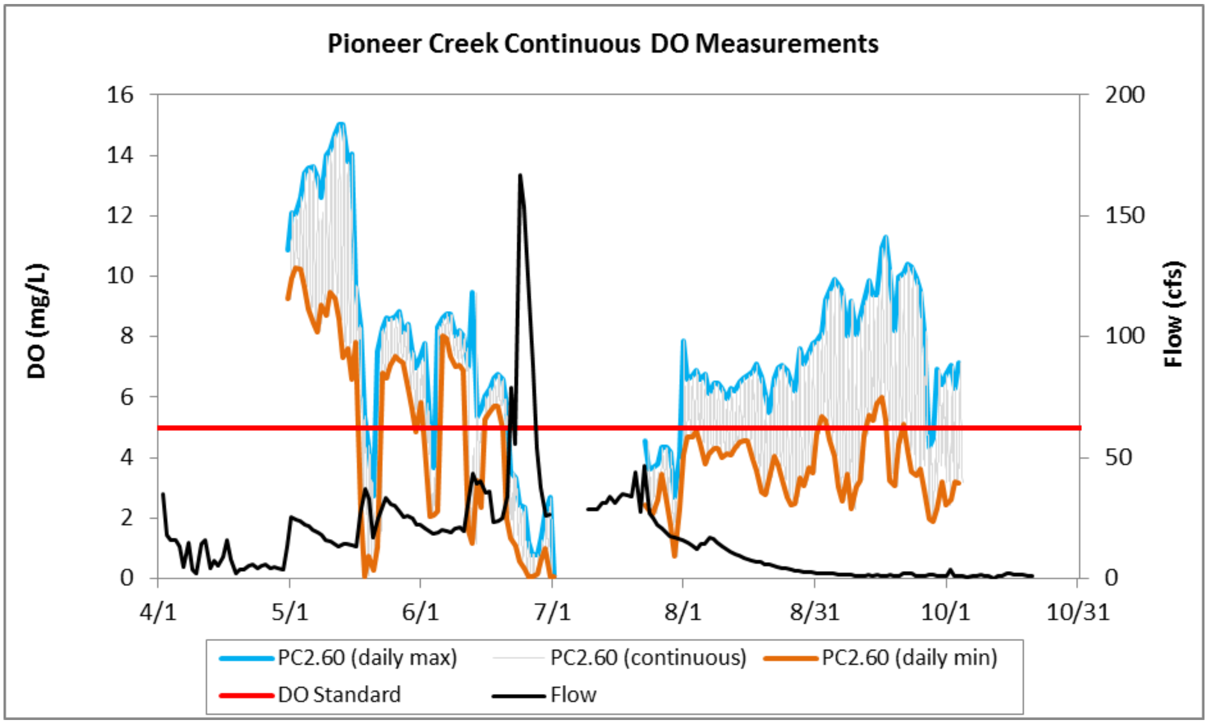

Figure 2-9. Pioneer Creek (PC2.60) 2013 continuous DO measurements.

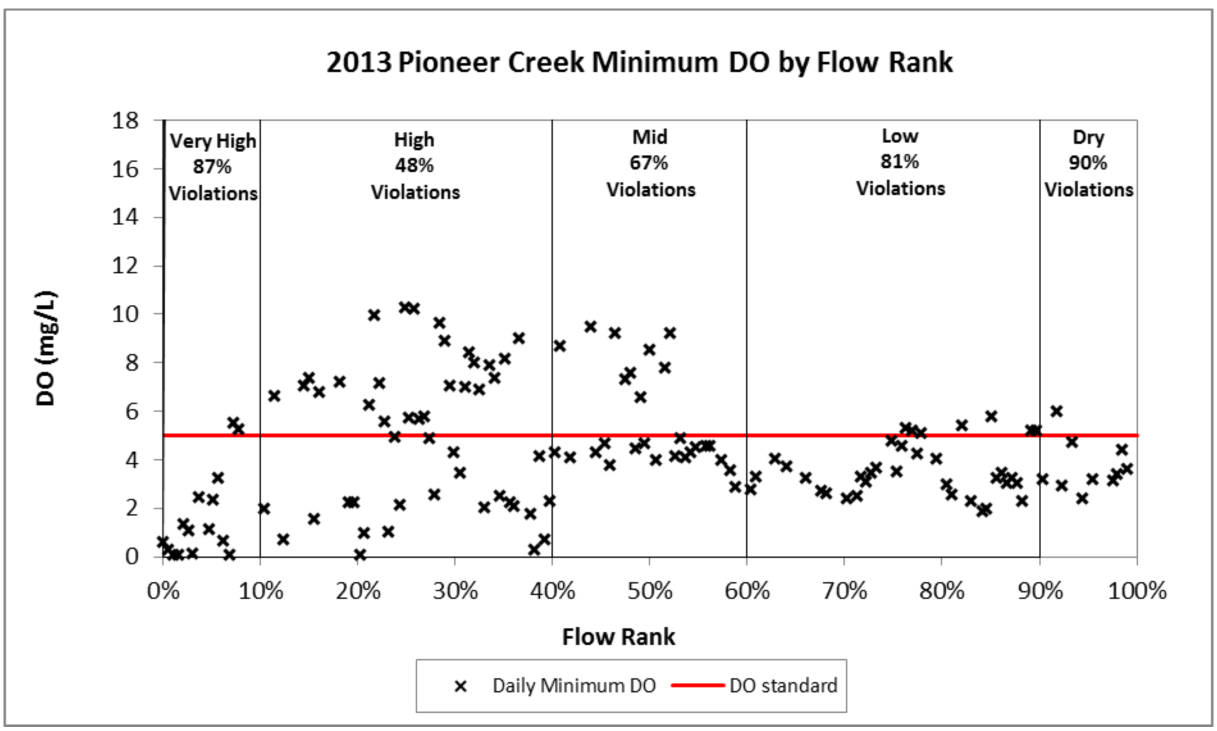

Figure 2-10. Pioneer Creek (PC2.60) 2013 daily minimum DO from data sonde deployment.

3.0 WATER QUALITY PARAMETERS AFFECTING DO

Daily dissolved oxygen swings are affected by biological activities such as photosynthesis and respiration by algae and submerged vegetation. Stream DO, however, can also be affected by water column and/or sediment oxygen consumption that occurs through the breakdown of organic compounds. Loading of organic matter to streams can come from both natural (plant and leaf debris, in-situ primary production) and anthropogenic (wastewater effluent, animal feces) sources. Biochemical oxygen demand (BOD) from the breakdown of organic compounds can be measured directly through laboratory incubation (typically 5-days). The nitrogen component of BOD can also be measured directly through lab incubations, or estimated by measuring nitrogen-series parameters within the system. This section provides an analysis of the water quality parameters that may be affecting DO conditions in the Pioneer Creek impaired reach.

3.1 BIOCHEMICAL OXYGEN DEMAND

5-day BOD sampling in Pioneer Creek is limited to 30 samples at PC2.60 and only 5 samples at 6.55 from 2010-2013. Results indicate BOD_5 was typically below detection limit (<2.0 mg/L) at both sites, with maximum levels reaching only 2.0 mg/L at PC2.60 and 2.3 mg/L at PC6.55 (Figures 3-1 through 3-4). These values are low and are within the typical range (1.5 – 3.2 mg/L) for streams in the North Central Hardwood Forest ecoregion. MPCA's Nutrient Criteria Development for Rivers in the Central Region suggest BOD_5 levels greater than 2.0 mg/L indicate potential eutrophication and impacts to biologic communities (MPCA, 2013). To date, there has only been one BOD_5 measurement greater than 2.0 mg/L. This sample was collected at PC6.55 in August, 2010 during low flow conditions. Since there are no industrial or wastewater treatment facilities in the Pioneer Creek watershed, elevated levels of BOD_5 likely come from algae loading from Lake Independence or the large in-channel wetland complex.

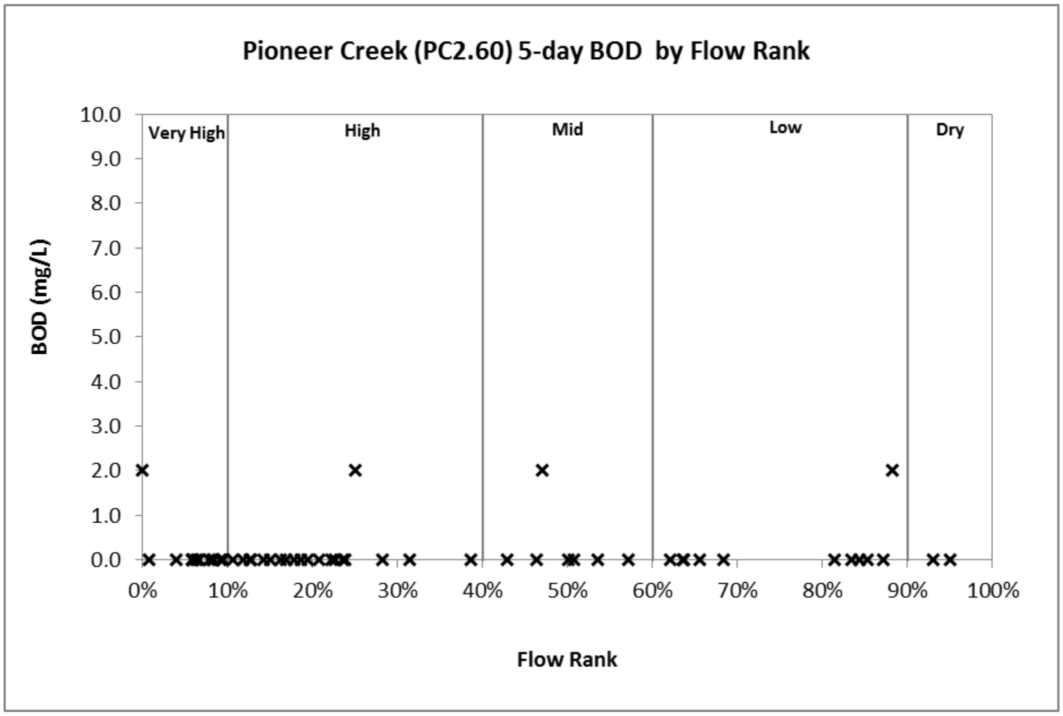

Figure 3-1. PC2.60 5-day BOD by flow condition.
Note: Samples below detection limit (<2.0 mg/L) are shown on the figure as 0.0 mg/L.

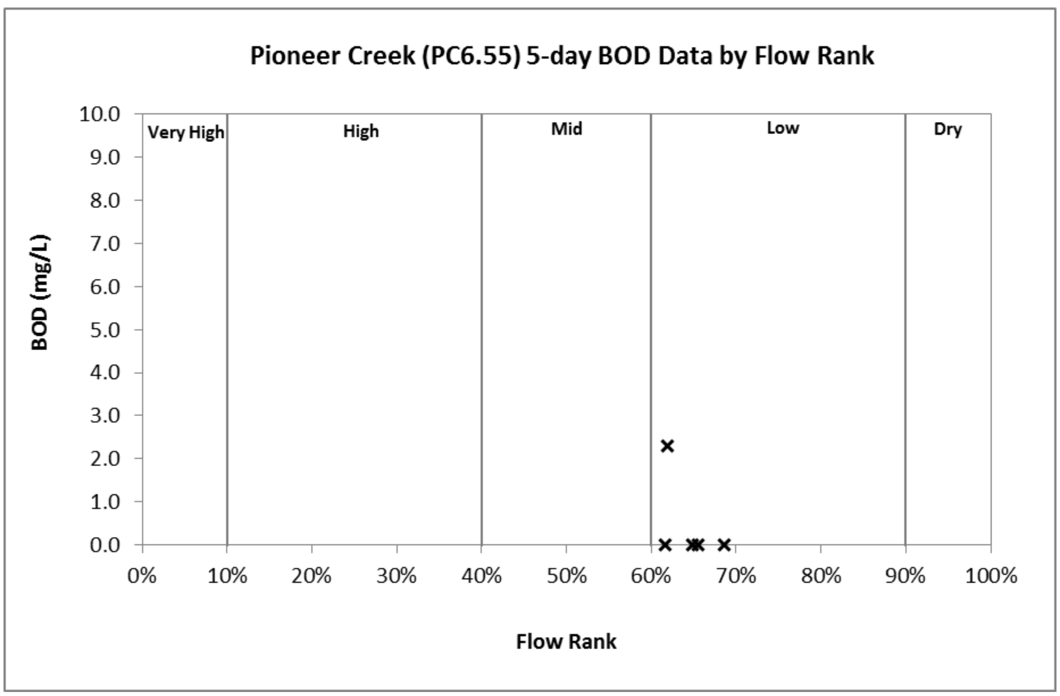

Figure 3-2. PC6.55 5-day BOD data by month.
Note: Samples below detection limit (<2.0 mg/L) are shown on the figure as 0.0 mg/L.

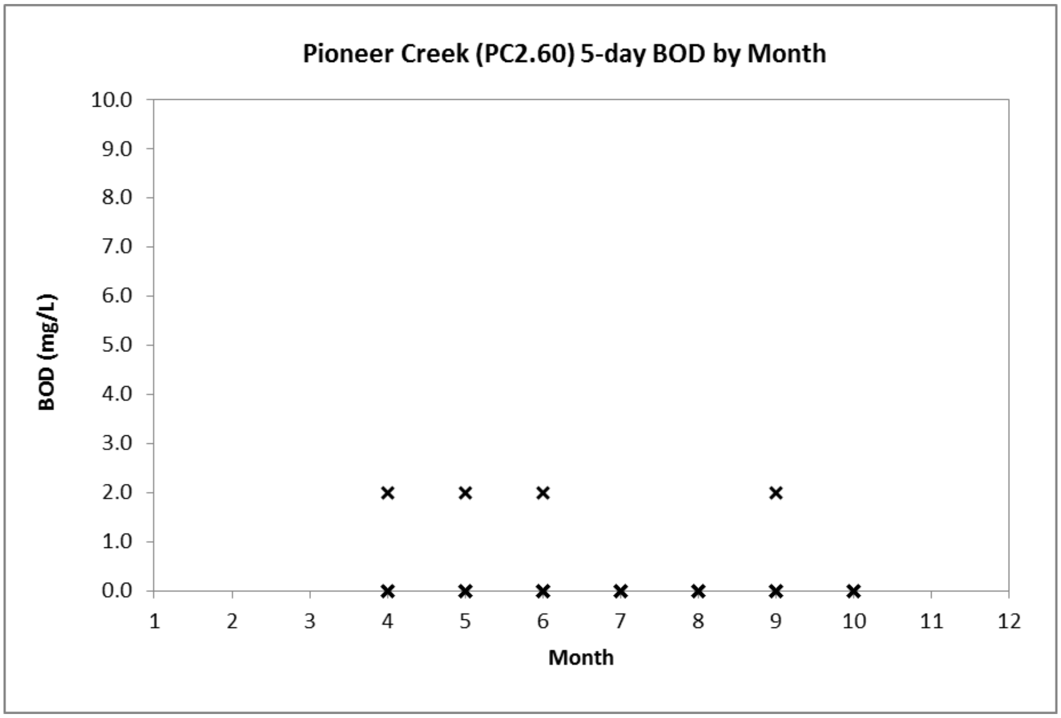

Figure 3-3. PC2.60 5-day BOD data by month.
Note: Samples below detection limit (<2.0 mg/L) are shown on the figure as 0.0 mg/L.

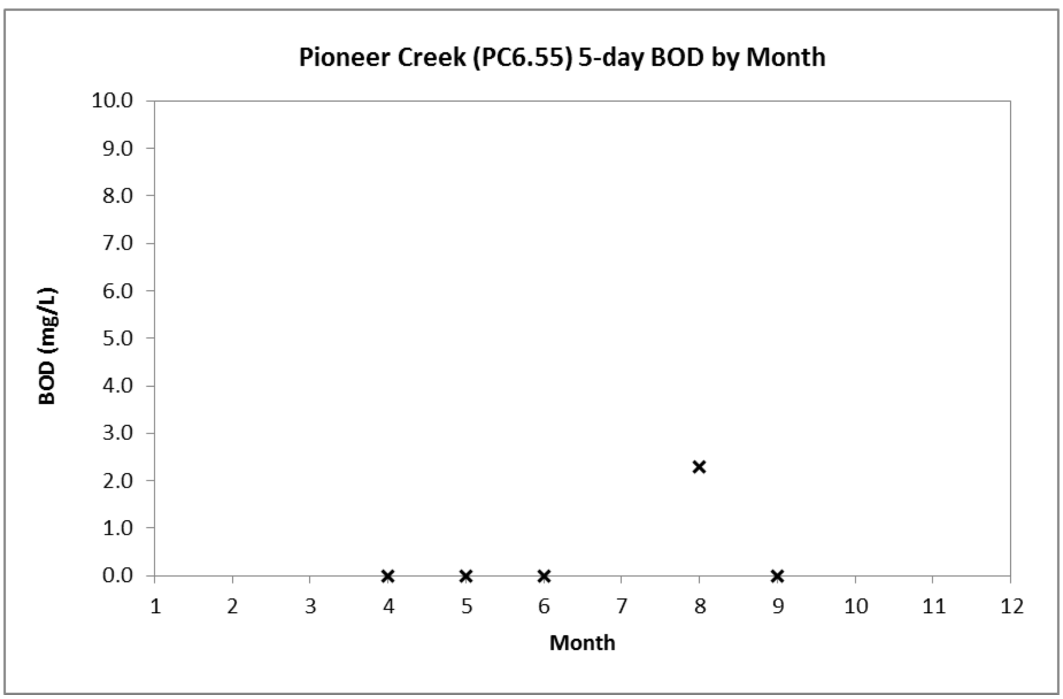

Figure 3-4. PC6.55 5-day BOD data by month.
Note: Samples below detection limit (<2.0 mg/L) are shown on the figure as 0.0 mg/L.

3.2 NITROGEN

Total nitrogen (TN) is the sum of organic nitrogen (ON), ammonia (NH_3) and ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-). Of the nitrogen components, NH_3 and NH_4^+ break down quickly in natural systems and are rapidly converted to nitrate by nitrifying bacteria, a process which consumes oxygen. TN data has been collected at both Pioneer Creek sampling stations since 2009. Ammonia-N (NH_3 + NH_4^+-N) data were collected at PC2.60 from 2010-2013. Ammonia-N data has not been collected at PC6.55. Total nitrogen concentrations at PC2.60 and PC6.55 ranged from 0.61-3.98 mg/L and 0.56-2.41 mg/L, respectively. Overall, TN concentrations were slightly higher at PC2.60 than PC6.55, which indicates TN loading downstream of PC6.55 and the large in-channel wetland complex. Ammonia-N concentrations from PC2.60 were below detection limit (<0.050 mg/L) for 36 of the 38 samples collected, suggesting almost all of the nitrogen in Pioneer Creek is some combination of ON and NO_3^--N+NO_2^--N. Total nitrogen is typically highest in Pioneer Creek during April, July and August and during higher flow conditions (Figures 3-5 through 3-8).

TN concentrations from 2009-2013 for Lake Independence, the headwaters of the Pioneer Creek impaired reach, ranged from 0.64-2.09 mg/L and were within the range observed at PC6.55 (Figures 3-6 and 3-8). Total nitrogen concentrations for two other lakes in the Pioneer Creek watershed, Lake Irene and Robina Lake, ranged from 1.35-3.30 mg/L and 1.10-4.40 mg/L, respectively. Lake Irene is a shallow lake that drains a small area of the impaired reach watershed just south of Pioneer Creek and Highway 12. Outflow from Lake Irene enters Pioneer Creek downstream of PC6.55 near river mile 6.0. Robina Lake is a shallow lake located along Highway 12 near Delano, MN and drains approximately 1,600 acres of land north of Pioneer Creek. Outflow from Robina Lake enters a county ditch near Highway 12 where it travels approximately 2.5 miles before discharging to Pioneer Creek upstream of PC2.60 near river mile 3.2. In general, these lakes likely contribute TN and other nutrients to Pioneer Creek, especially during high flow conditions when lake levels are high and the lakes are discharging. Total nitrogen concentrations in Lake Irene and Robina Lake are slightly higher than those measured at PC2.60 during summer low-flow conditions when primary production in the lakes are high and they are likely not discharging (Figures 3-5 and 3-7).

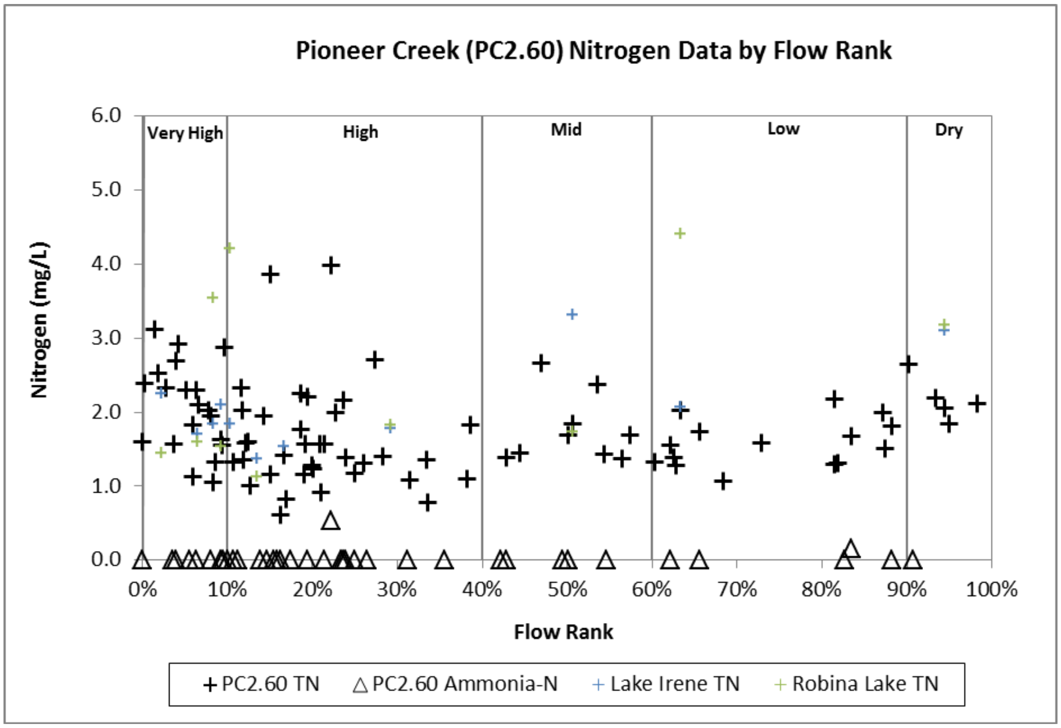

Figure 3-5. PC2.60, Lake Irene and Robina Lake total nitrogen and ammonia-N data by flow condition.
Note: Samples below detection limit (<0.050 mg/L) are shown on the figure as 0.0 mg/L.

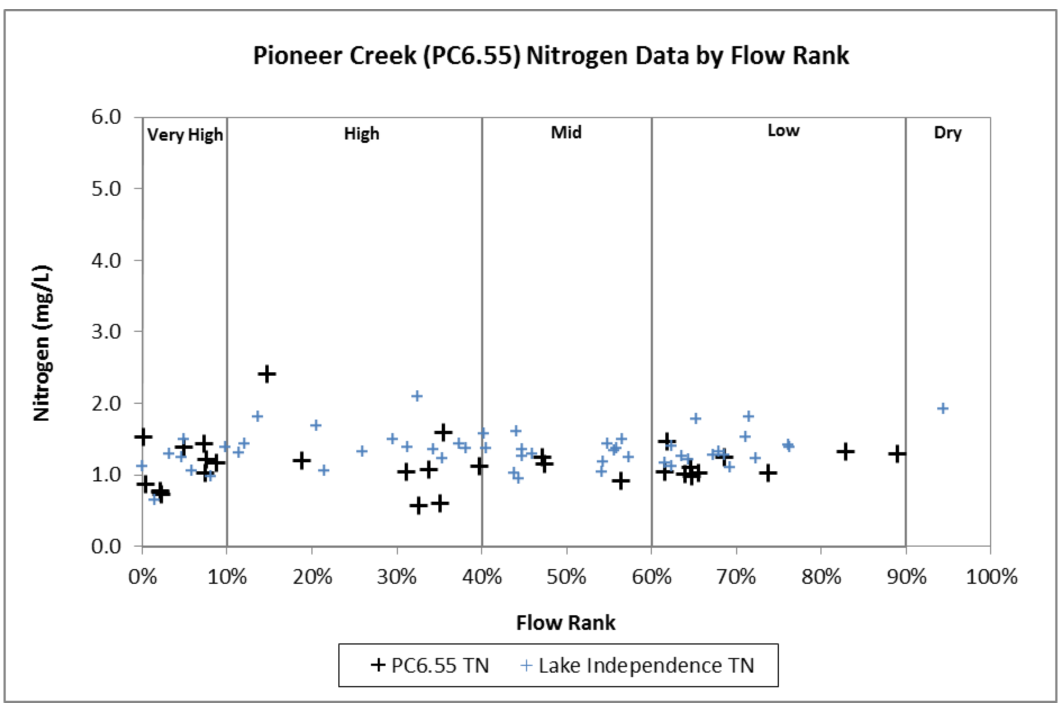

Figure 3-6. PC6.55 and Lake Independence total nitrogen data by flow condition.

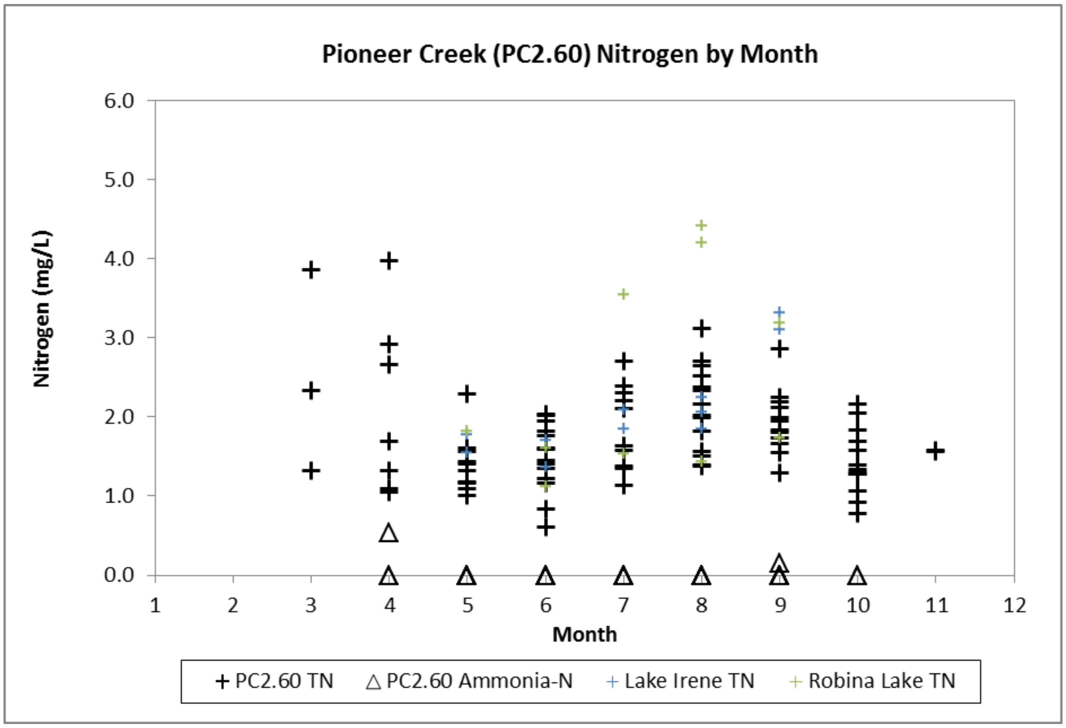

Figure 3-7. PC2.60, Lake Irene and Robina Lake total nitrogen and ammonia-N data by month.
Note: Samples below detection limit (<0.050 mg/L) are shown on the figure as 0.0 mg/L.

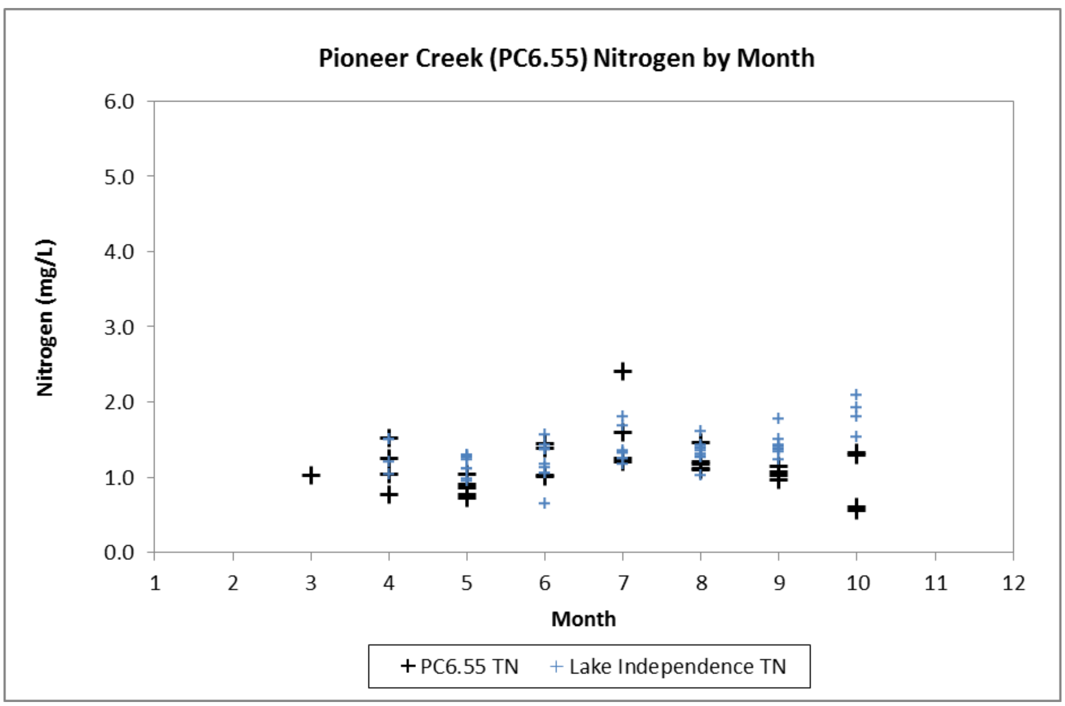

Figure 3-8. PC6.55 and Lake Independence total nitrogen data by month.

3.3 PHOSPHORUS

High nutrient concentrations, particularly phosphorus, can accelerate eutrophication, thus increasing diurnal DO concentration swings and biochemical oxygen demand (BOD) after the organic matter dies off. Total phosphorus was measured at both Pioneer Creek sampling stations from 2009-2013 (Figures 3-9 through 3-12). TP concentrations ranged from 48-818 µg/L at PC2.60 and 16-296 µg/L at PC 6.55. Total phosphorus was consistently higher at PC2.60 compared to PC6.55 which suggests TP loading to Pioneer Creek downstream of the wetland complex. PC2.60 TP concentrations were high for streams and often exceeded the100 µg/L proposed central region river/stream eutrophication standard (MPCA, 2013). Orthophosphate concentrations at PC2.60 were also high and accounted for, on average, about 52% of the total phosphorus in the stream. Orthophosphate concentrations were lower at PC6.55, but accounted for a slightly higher fraction (64%) of the TP compared to PC2.60. High orthophosphate levels in streams indicate loading from illicit point sources (e.g. failing septic systems), agricultural runoff, or internal loading from channel/wetland sediment that is exposed to anoxic conditions. At PC2.60, TP and orthophosphate concentrations were highest during the very high, high and dry flow conditions suggesting phosphorus loading to Pioneer Creek may be a combination of all the previously mentioned sources.

2009-2013 TP concentrations for Lake Independence ranged from 23-120 µg/L with annual summer (June – September) averages ranging from 46-59 µg/L. These TP levels exceed state standards for deep (40 µg/L) lakes in the NCHF Forest Ecoregion and suggest a significant amount of TP and algae is discharged to the headwaters of Pioneer Creek during the summer months. However, TP and orthophosphate concentrations are typically higher at PC6.55 compared to Lake Independence which indicates additional phosphorus inputs downstream of the lake's outlet (Figures 3-10 and 3-12). Total phosphorus concentrations for Lake Irene and Robina Lake, range from 57-391 µg/L and 29-340, respectively. These lakes likely contribute phosphorus and other nutrients to Pioneer Creek, especially during high flow conditions when lake levels are high and discharging. In general, TP and orthophosphate concentrations in Lake Irene and Robina Lake are slightly lower than those measured at PC2.60 (Figures 3-9 and 3-11) suggesting Pioneer Creek phosphorus levels are driven more by in-stream and watershed sources than discharge from these lakes.

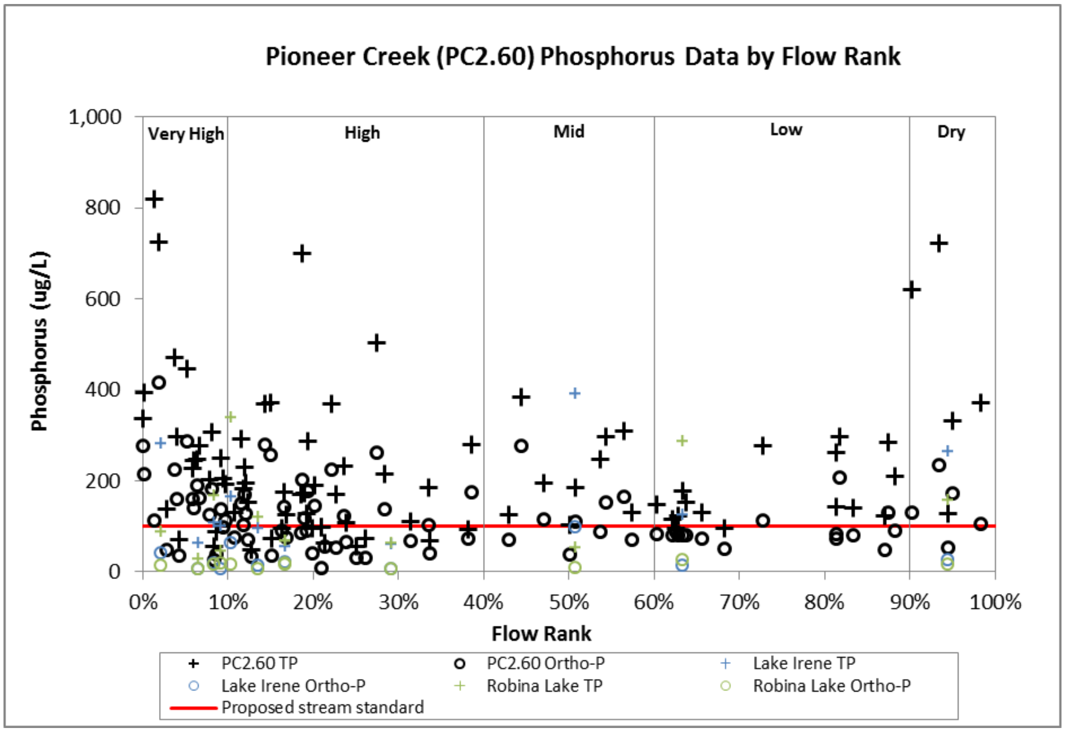

Figure 3-9. PC2.60, Lake Irene and Robina Lake TP and orthophosphate data by flow condition.

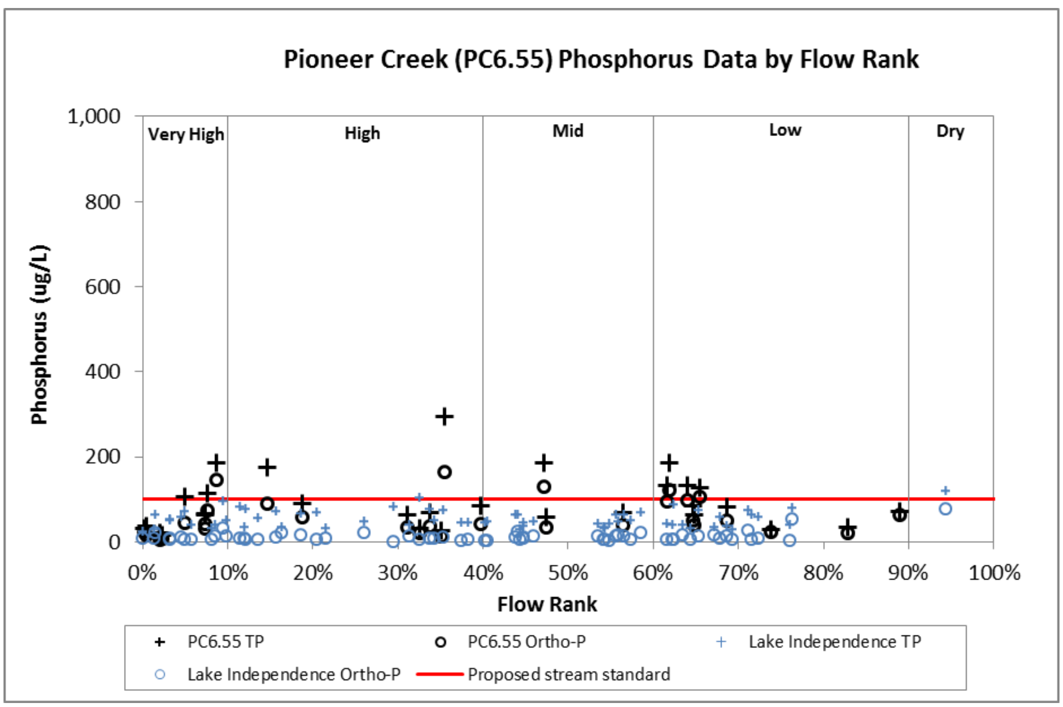

Figure 3-10. PC6.55 and Lake Independence TP and orthophosphate data by flow condition.

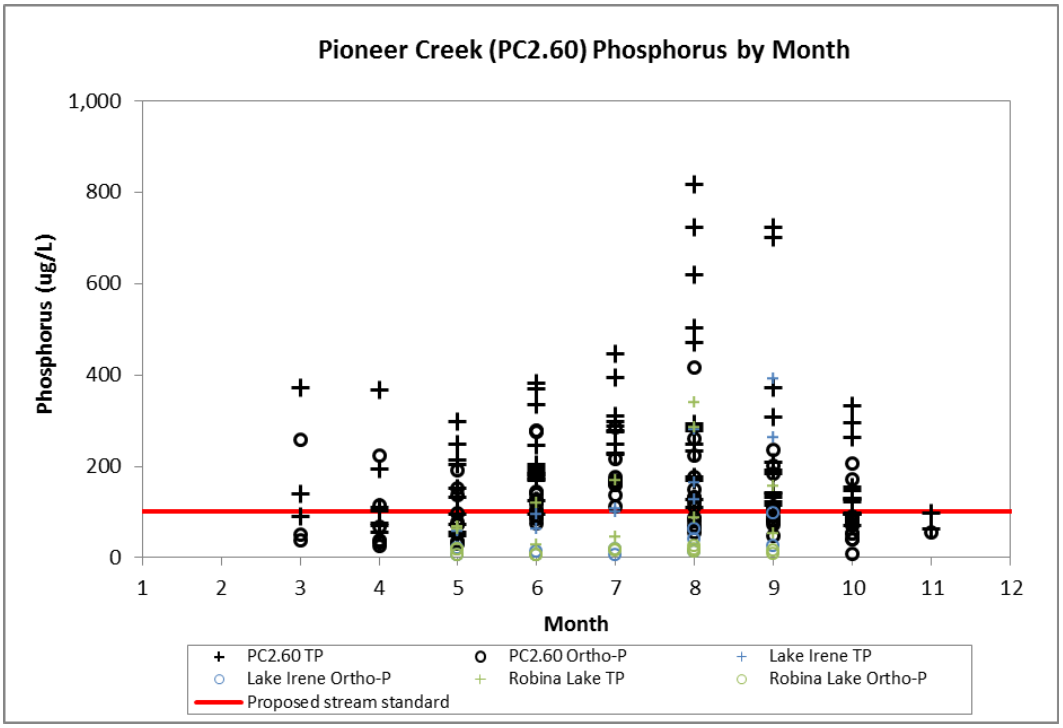

Figure 3-11. PC2.60, Lake Irene and Robina Lake TP and orthophosphate data by month.

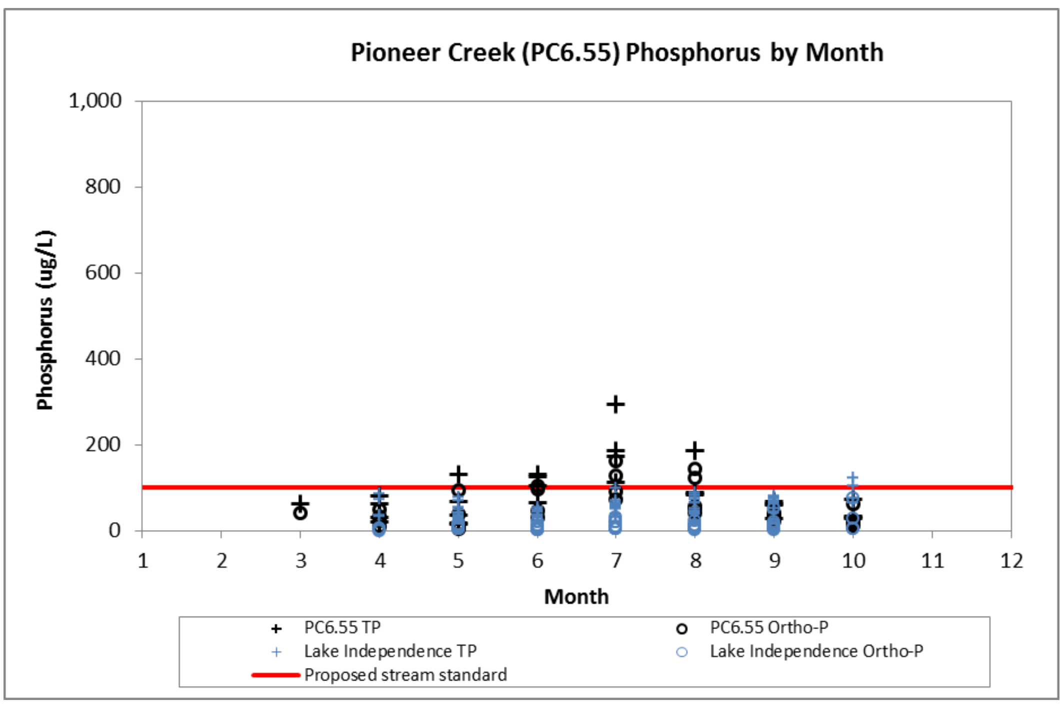

Figure 3-12. PC6.55 and Lake Independence TP and orthophosphate data by month.

3.4 CHLOROPHYLL-A

Chlorophyll-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since chlorophyll-*a* is an inexpensive and simple measurement, it is often used to evaluate algal abundance. Chlorophyll-*a* measurements are often paired with TP and transparency to assess trophic status in lakes and streams. Fifteen chlorophyll-*a* samples were collected at PC2.60 in 2013 and concentrations ranged from below detection limit (<5 µg/L) to 20 µg/L (Figures 3-13 and 3-14). It should be pointed out that 10 of the 13 samples collected in 2013 were below detection limit and no samples exceeded the MPCA's 20 µg/L chlorophyll-*a* target for rivers/streams in Minnesota's central region according to the MPCA's Nutrient Criteria Development for Rivers (MPCA, 2013). All five chlorophyll-*a* samples that were above detection limit were collected in April and May during higher flow conditions when lakes and wetlands were likely discharging to the creek.

Chlorophyll-*a* concentrations for Lake Independence from 2009-2013 ranged from 4-99 µg/L with annual summer (June – September) averages ranging from 18-38 µg/L. These chlorophyll-*a* levels exceed state standards for deep (14 µg/L) lakes in the NCHF Ecoregion and suggest a significant amount of algae is discharged to the headwaters of Pioneer Creek during the summer months. During low-flow conditions most of the algae that enters Pioneer Creek dies and/or settles out near the creek's headwaters or in the wetland complex. Chlorophyll-*a* concentrations are typically below detection limit at PC2.60 which is approximately 6.1 miles downstream of the lake. Chlorophyll-*a* concentrations for Lake Irene and Robina Lake, range from 10-174 µg/L and 5-233, respectively. Chlorophyll-*a* measured in these lakes were consistently above levels measured at PC2.60 during all months and flow conditions suggesting little algae is discharged from these lakes or it settles/dies off before reaching the PC2.60.

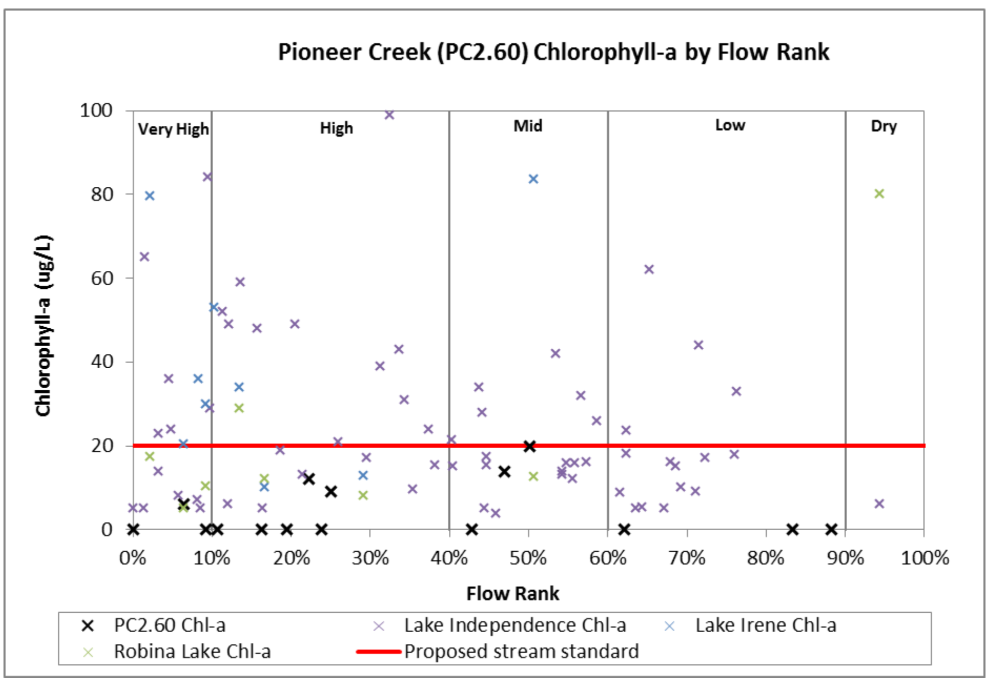

Figure 3-13. PC2.60, Lake Independence, Lake Irene and Robina Lake chlorophyll-a data by flow condition.
Note: Samples below detection limit (<5 µg/L) are shown on the figure as 0 µg/L.

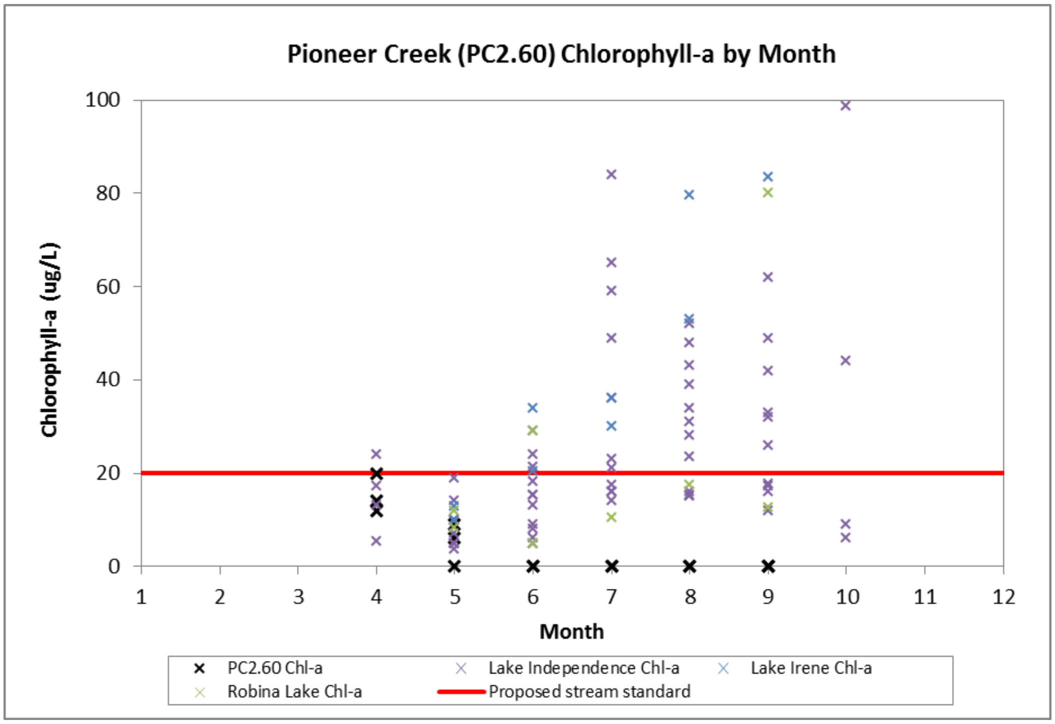

Figure 3-14. PC2.60, Lake Independence, Lake Irene and Robina Lake chlorophyll-a data by month.
Note: Samples below detection limit (<5 µg/L) are shown on the figure as 0 µg/L.

3.5 TEMPERATURE

Temperature also has a significant effect on stream DO concentrations. Dissolved oxygen solubility in water is temperature-dependent in that cold water holds more DO than warmer water. Summer water temperatures for the Pioneer Creek impaired reach occasionally exceed the upper end of typical NCHF streams (2-21°C) during the summer months (June-August; Figure 3-15 and 3-16).

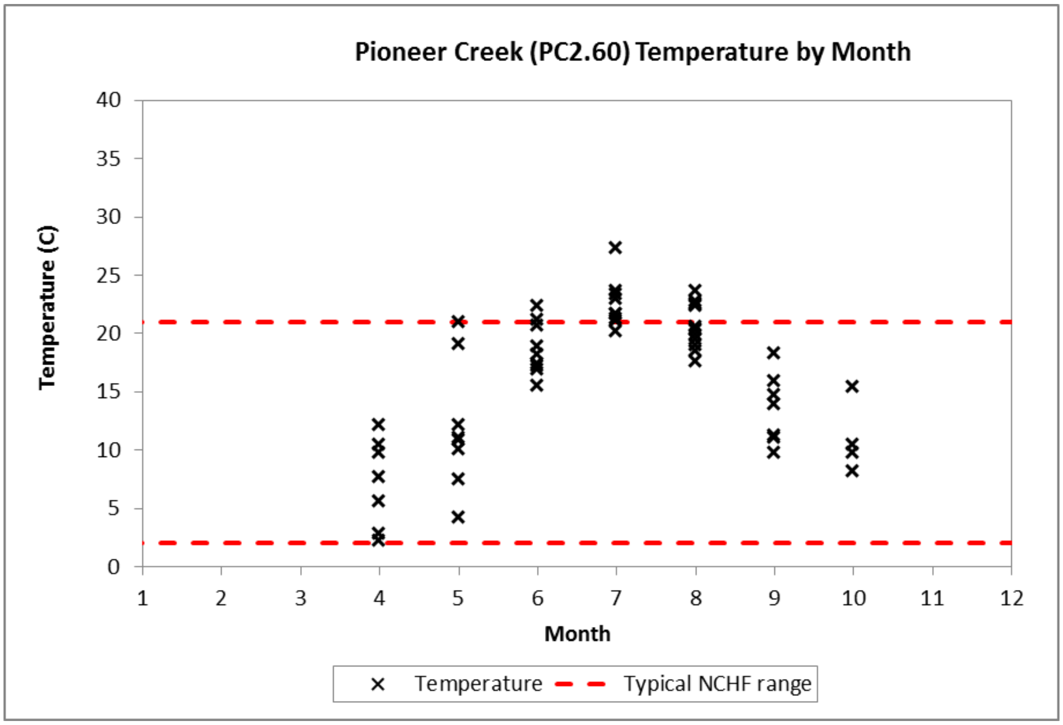

Figure 3-15. PC2.60 temperature data by month.

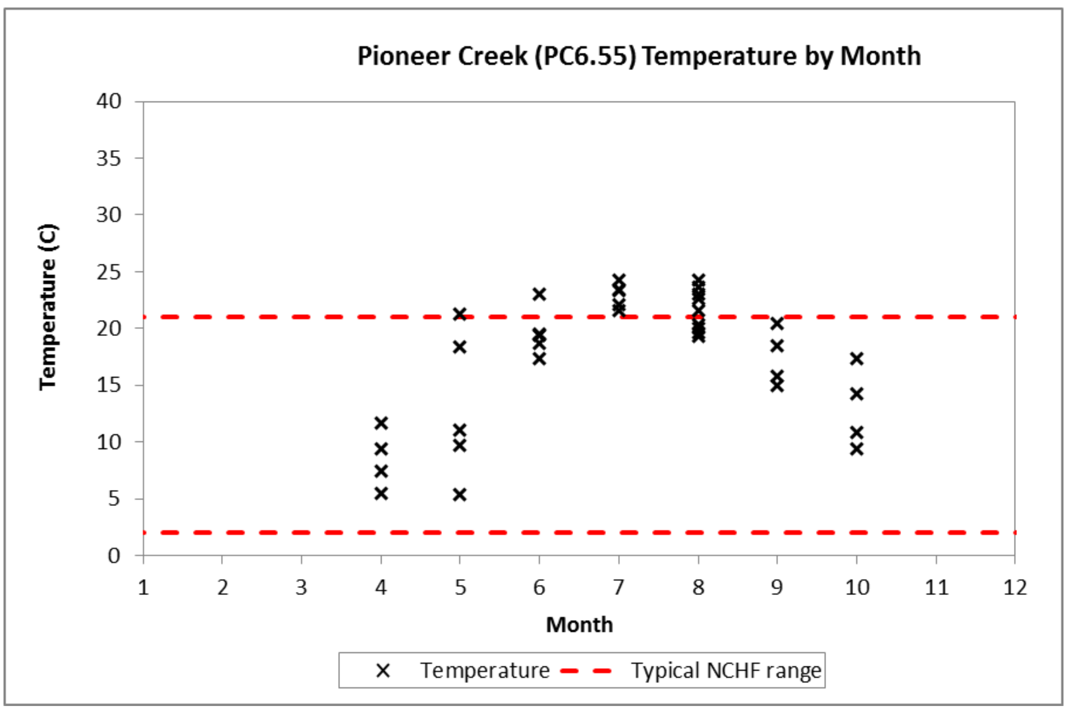

Figure 3-16. PC6.55 temperature data by month.

4.0 CONCLUSIONS

Pioneer Creek DO measurements indicate violations occur throughout all summer months regardless of time of day or flow condition. Dissolved Oxygen was consistently lower at station PC6.55, which is at the downstream end of a large in-channel wetland complex located between the outlet of Lake Independence and County Road 90. This wetland complex appears to be a major driver of low DO in Pioneer Creek through SOD, low velocity and low reaeration rates. Pollutant loading to Pioneer Creek from Lake Independence is occasionally high, but does not appear to be the primary driver of low DO in the impaired reach.

There are a number of factors that may be affecting DO and nutrient dynamics in Pioneer Creek including:

1. Low velocity and reaeration, and high levels of SOD throughout the large in-stream wetland complex between Lake Independence and County Road 90 appear to be the biggest drivers of low DO in Pioneer Creek. Dissolved oxygen levels are higher at PC2.60 compared to PC6.55 indicating tributary DO and/or reaeration improves downstream of the large wetland complex.

2. Outflow from Lake Independence likely plays a role in the DO dynamics in the wetland complex near the headwaters of the impaired reach. Lake Independence is impaired for nutrients and discharges high concentrations of phosphorus, nitrogen, BOD and algae (chlorophyll-*a*) to the headwaters of Pioneer Creek near Independence Road.

3. Two other nutrient impaired lakes, Lake Irene and Robina Lake, are located in the Pioneer Creek DO impaired reach watershed. These lakes have significantly smaller watersheds compared to Lake Independence and discharge to the impaired reach downstream of the wetland complex (PC6.55). These lakes do not appear to be a significant driver of low DO in Pioneer Creek but likely discharge elevated levels of phosphorus, nitrogen, chlorophyll-*a* and BOD to the creek, particularly during high flow conditions.

5.0 REFERENCES

Minnesota Pollution Control Agency (MPCA). 2013. Minnesota Nutrient Criteria Development for Rivers (Draft). http://www.pca.state.mn.us/index.php/view-document.html?gid=14947

Wenck Associates, Inc.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, MN 55359-0249

800-472-2232
(763) 479-4200
Fax (763) 479-4242
wenckmp@wenck.com
www.wenck.com

TECHNICAL MEMORANDUM

TO: Pioneer- Sarah Creek Watershed Management Organization
Minnesota Pollution Control Agency

FROM: Jeff Strom and Diane Spector

DATE: April 2015

SUBJECT: Pioneer Creek Synoptic Survey Methods and Results

1.0 PURPOSE

This technical memorandum summarizes the data collection methods and results for the August 14, 2013 Pioneer Creek synoptic survey. This survey was conducted to obtain the data needed to construct and calibrate a River and Stream Water Quality Model (QUAL2K) to address the Pioneer Creek dissolved oxygen (DO) impairment.

1.1 Study Area Locations

The synoptic survey covered the Pioneer Creek DO impaired reach from the outlet of Lake Independence at Independence Road to the south line of T118 R24W S30 in Independence, MN (AUID 07010205-653). To better understand conditions in Pioneer Creek, monitoring and modeling were extended further downstream into AUID 07010205-654. The impaired reach is considered a beneficial Class 2B warm water stream that spans a total of 7.09 river miles. Monitoring locations were distributed relatively evenly throughout the stream. All sampling stations referred to in this memo are shown in Figure 1-1 and described in Table 1-1.

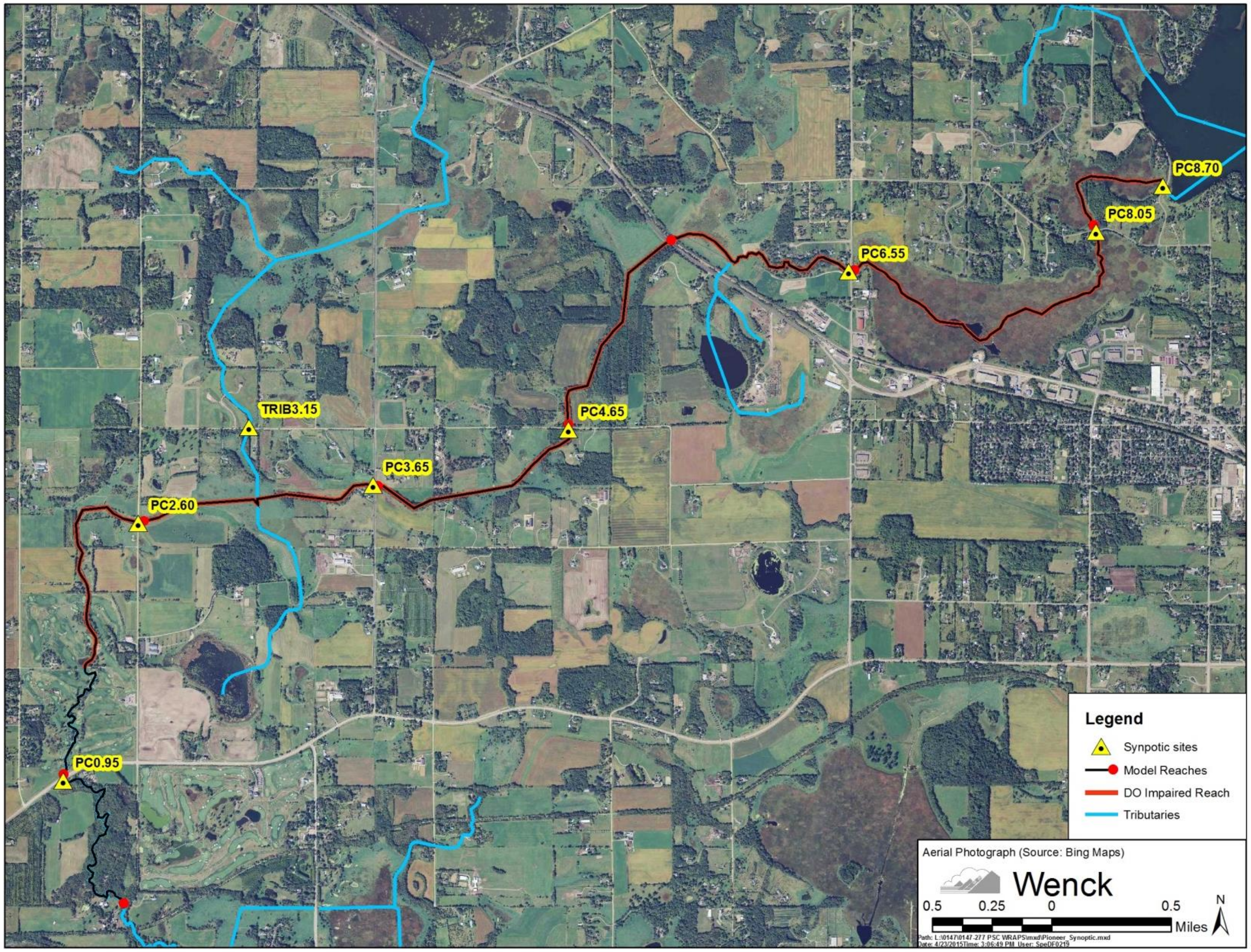

Figure 1-1. Pioneer Creek DO impaired reach and synoptic survey sampling locations.

Table 1-1. Pioneer Creek synoptic survey monitoring locations.

Station ID	EQuIS ID	Description	River Mile	WQ/Flow Monitoring	Continuous DO	Dye Injection	Dye Monitoring
PC0.95	S007-701	Pioneer Creek at Watertown Road	0.95	Yes	No	No	Yes
PC2.60	S005-811	Pioneer Creek at Copeland Road	2.60	Yes	Yes	No	No
PC3.65	S007-706	Pioneer Creek at County Road 92	3.65	Yes	No	Yes	Yes
PC4.65	S007-707	Pioneer Creek at Pioneer Creek Road	4.65	No	No	No	No
PC6.55	S006-370	Pioneer Creek at County Road 90	6.55	Yes	No	Yes	Yes
PC8.05	S007-702	Pioneer Creek at Pagenkopf Road	8.05	Yes	No	Yes	Yes
PC8.70	S007-703	Pioneer Creek at Independence Road	8.70	Yes	No	Yes	No
TRIB3.15	S007-704	Tributary to Pioneer Creek at Pioneer Creek Rd		No	No	No	No

1.2 Dye Study

Dye travel through the impaired reach was measured in four sub-reaches: PC8.70 to PC8.05, PC8.05 to PC6.55, PC6.55 to PC3.65, and PC3.65 to PC0.95. A slug of a tracer (Rhodamine WT dye) was injected at the four sites indicated in Table 1-1 and Figure 1-1. Water samples were collected to measure dye concentrations using ISCO automatic samplers. The ISCO samplers were programmed and left running until it was determined the dye cloud passed. Dye concentrations were measured using an Aquafluor handheld fluorometer.

Figures 1-2 through 1-5 are time series concentration plots for each dye study sub-reach. Estimated travel time for each sub-reach was based on timing of the concentration peak (Table 1-2). Dye did not pass through sub-reach 2 (PC8.05 to PC6.55) likely due to significant mixing and dilution through this reach. It is assumed residence time in this reach is long since this reach flows through a large wetland complex located north of Highway 12 in Maple Plain/Independence. Average velocities in sub-reaches 1, 3 and 4 ranged from 0.06-0.40 feet per second during the synoptic survey. Sub-reach 1 had the longest travel time and lowest average velocity. Sub-reach 1 displayed a lower dye peak concentration and longer tail compared to sub-reaches 3 and 4, indicating a long residence time and significant mixing throughout the reach. Sub-reach 1 also flows through a large wetland complex located at the outlet of Lake Independence.

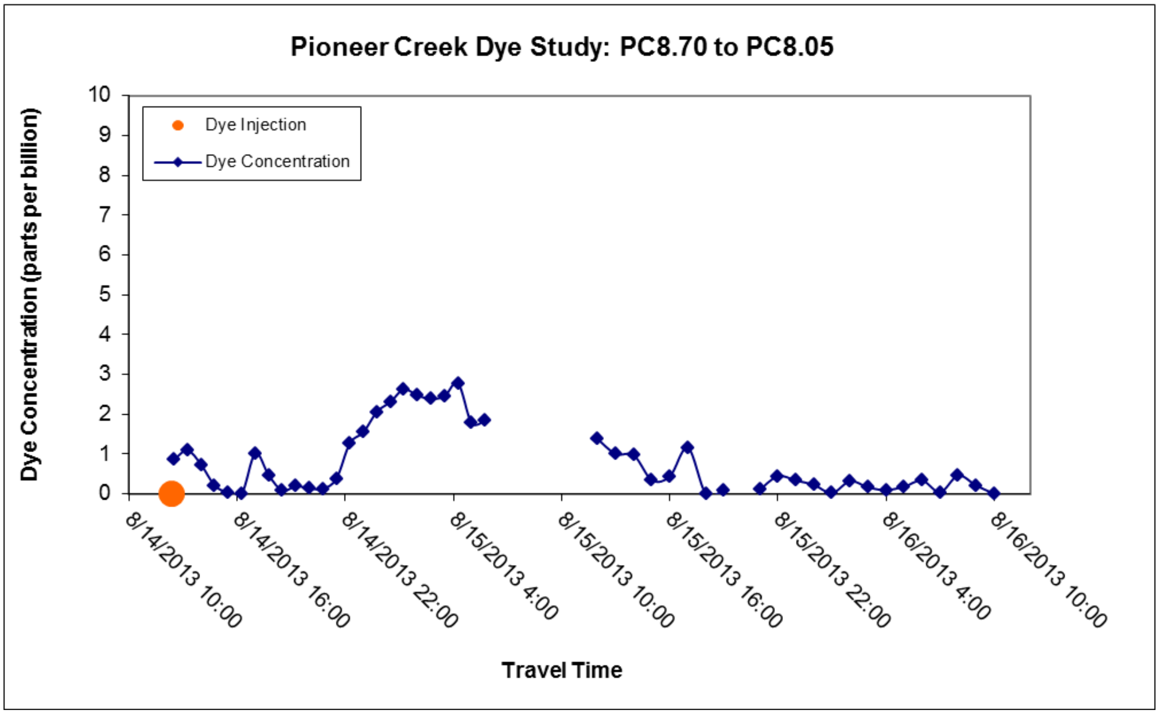

Figure 1-2.Sub-reach 1 dye study measurements.

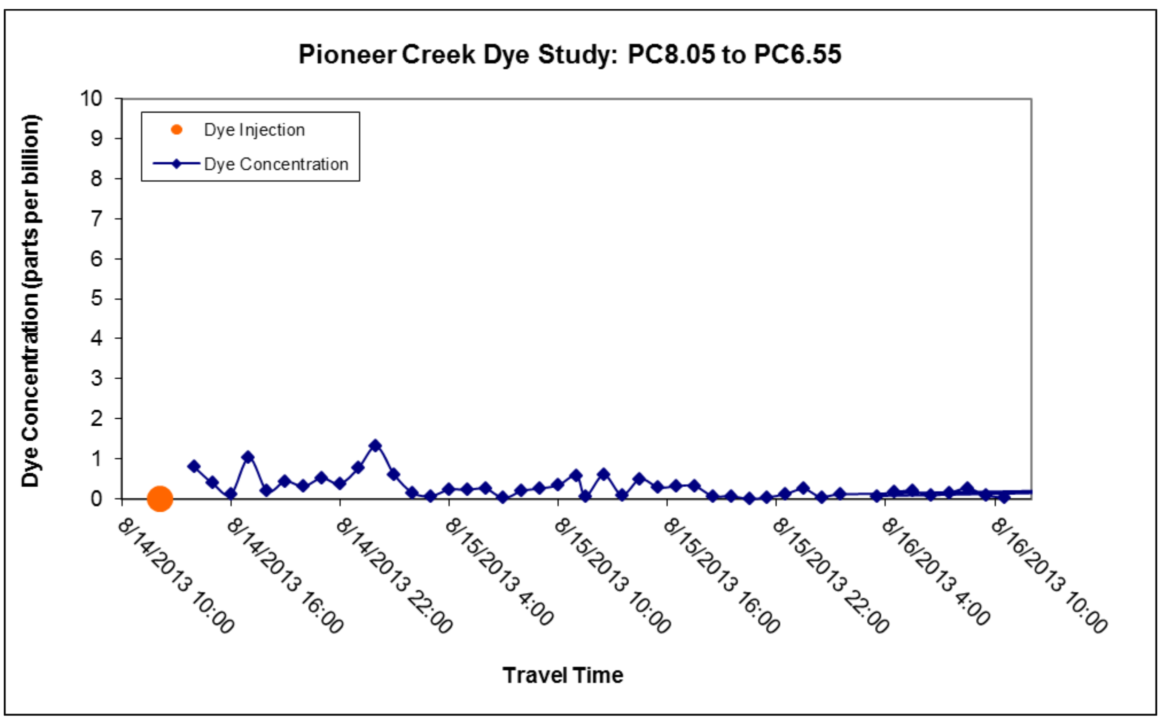

Figure 1-3. Sub-reach 2 dye study measurements.

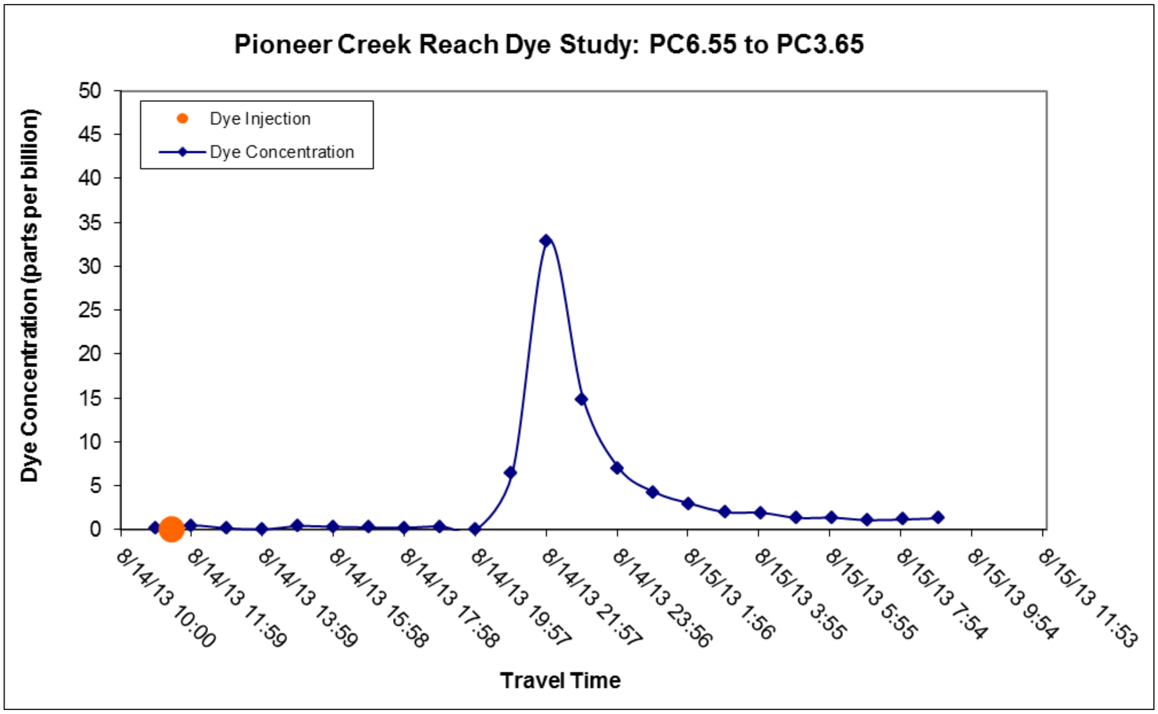

Figure 1-4. Sub-reach 3 dye study measurements.

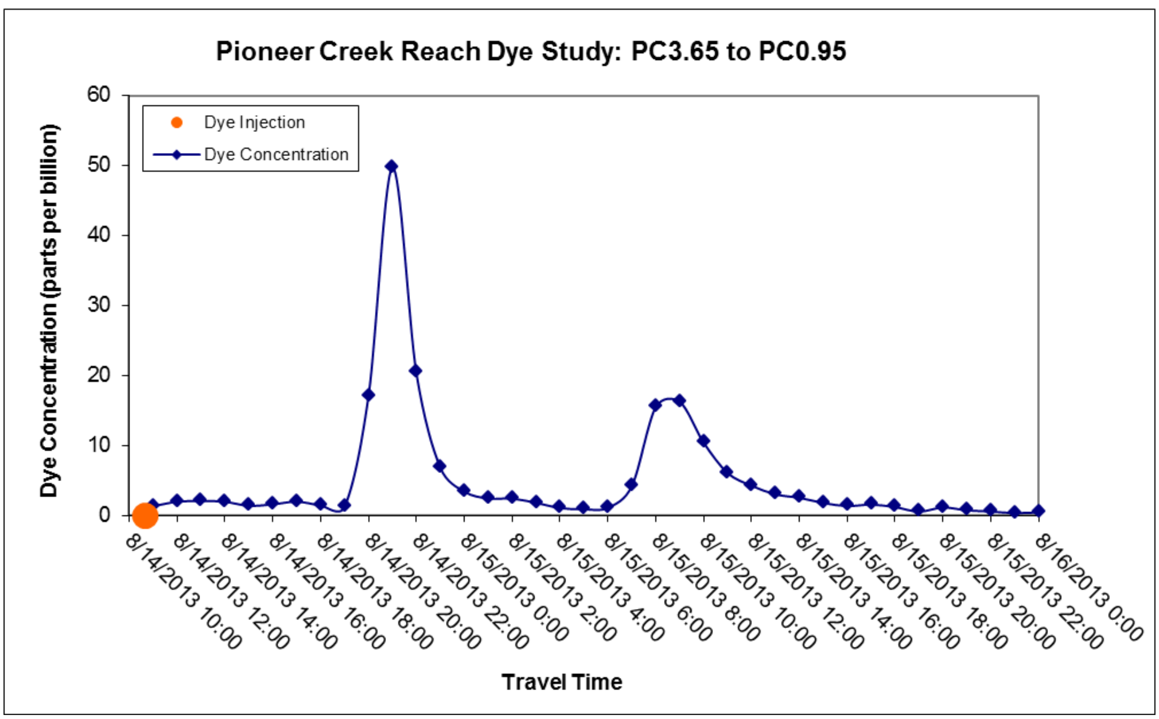

Figure 1-5. Sub-reach 4 dye study measurements.

Table 1-2. August 14 dye study estimated travel times.

Sub Reach	Description	Reach Length (miles)	Injection Time	Dye Peak Time	Reach Flow (cfs)	Estimated Travel Time (hrs)	Average Velocity (ft/s)
1	PC8.70 to PC8.05	0.65	8/14 12:20	8/15 4:15	3.83 (PC8.70) 5.70 (PC8.05)	15:55	0.06
2	PC8.05 to PC6.55	1.50	8/14 12:05	Could not measure	5.70 (PC8.05) 7.05 (PC6.55)	Could not measure	Could not measure
3	PC6.55 to PC3.65	2.90	8/14 11:25	8/14 22:00	7.05 (PC6.55) 7.49 (PC4.65) 8.10 (PC3.65)	10:35	0.40
4	PC3.65 to PC0.95	2.70	8/14 10:40	8/14 21:00	8.10 (PC3.65) 7.97 (PC0.95)	10:20	0.38

Note: Travel times estimated by calculating the time between upstream injection and peak concentration measured downstream.

1.3 Flow Gauging

Flow gauging was conducted at each water quality and dye monitoring station during the August 2013 synoptic survey. Flow was recorded using a SonTek Flow Tracker handheld digital velocity meters with an accuracy of 0.001 cubic feet per second (cfs). Velocity measurements were taken at 60 percent of the total depth. Horizontal spacing of velocity measurements was set so less than 10 percent of total discharge is accounted for by any single velocity measurement.

Results from all stream flow measurements during the August survey are illustrated in Figure 1-6 and summarized in Table 1-3. The flow data shows Pioneer Creek is a gaining stream between PC8.70 and PC0.95. No rainfall was recorded in the week leading up to the start of this survey (8/8 – 8/14).

Table 1-3. Gauged flow measurements during the August 14, 2013 synoptic survey.

Station	River Mile	Flow (cfs)	Average Velocity (ft/s)	Average Depth (ft)	Channel Width (ft)
PC0.95	0.95	7.97	0.37	1.86	11.6
PC3.65	3.65	8.10	0.42	1.50	13.0
PC4.65	4.65	7.49	0.46	1.08	15.0
PC6.55	6.55	7.05	0.27	1.18	22.0
PC8.05	8.05	5.70	0.31	2.32	8.0
PC8.70	8.70	3.83	0.05	3.30	25.0
TRIB3.15		0.12	0.29	0.21	2.0

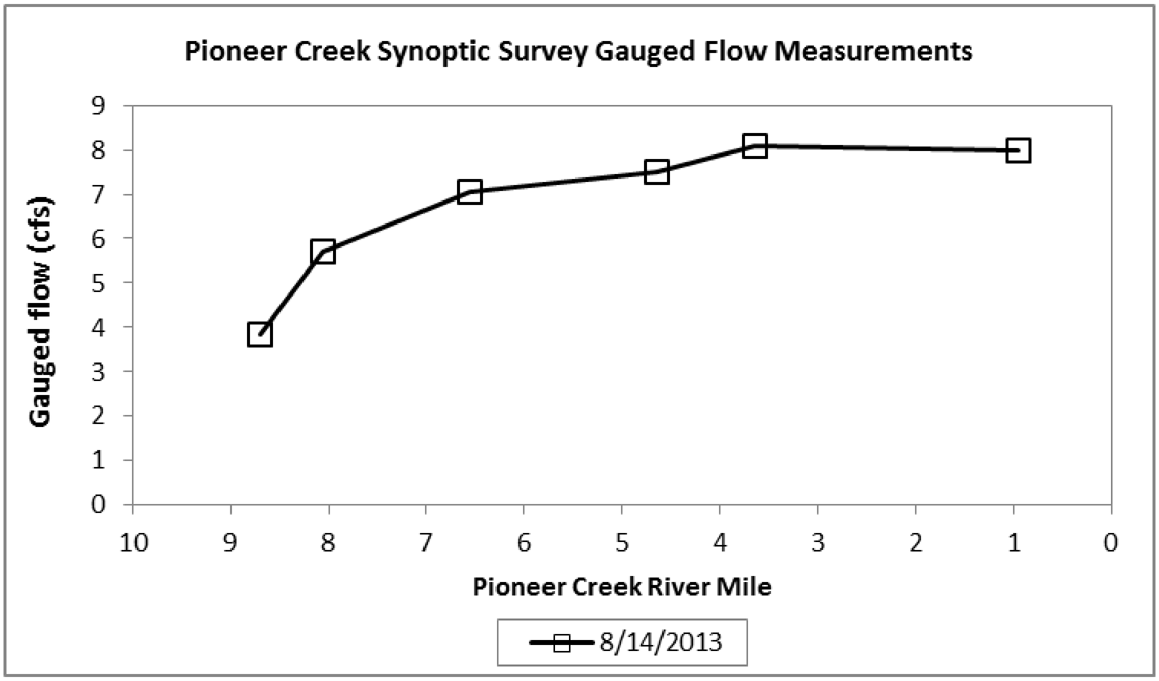

Figure 1-6. Gauged flow measurements during the August 14, 2013 synoptic survey.

1.4 Water Quality Sampling

Water quality data were collected at eight main-stem and tributary sites (Figure 1-1 and Table 1-1) during the August synoptic survey. One water sample (grab) was collected at four stations on 8/14/2013 and preserved for lab analysis through the Metropolitan Council Environmental Services laboratory and Instrumental Research, Inc. Samples were analyzed for the following parameters: total Kjeldahl nitrogen (TKN), ammonia-N (NH_3-N), nitrate+nitrite-N (NO_3^- +NO_2^--N), 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), ultimate biochemical oxygen demand (BOD_U), total phosphorus (TP), ortho-phosphorus (Ortho-P) and chlorophyll-*a*. Data sondes were used in the field to collect the following water quality parameters at the eight main-stem and tributary sites: temperature, conductivity, pH, oxidation reduction potential (ORP), and dissolved oxygen (DO). Transparency measurements were also recorded at each water quality station using a 100 centimeter transparency tube.

Lab and field water quality results are summarized in Table 1-4 and illustrated in Figures 1-7 through 1-11. TKN, BOD_U, chlorophyll-*a*, total suspended solids (TSS) and volatile suspended solids (VSS) are all higher at the upstream station (PC8.70) compared to downstream stations. Station PC8.70 is driven by outflow from Lake Independence, a eutrophic lake with high algae growth during the summer months. Total phosphorus and ortho-phosphorus were increasingly higher at the downstream stations indicating loading from the large wetland complex upstream of PC6.55 and several small tributaries downstream of PC6.55.

Table 1-4. August 14, 2013 synoptic survey water quality results.

Parameter	PC8.70	PC8.05	PC6.55	PC4.65	PC3.65	PC2.60	PC0.95	TRIB3.15
Temperature (Celsius)	23.06	20.34	19.66	18.02	17.65	17.69	18.02	14.37
Sp. Conductivity (µmhos/cm)	375	390	390	387	389	401	402	619
DO (mg/L) grab Time	7.39 7:11	0.59 7:17	1.47 7:24	6.20 7:36	7.24 7:43	6.71 8:02	7.71 8:10	6.06 7:54
pH	8.23	7.13	6.94	7.29	7.46	7.42	7.52	7.44
ORP (mV)	161	117	109	121	123	129	131	137
Total Phosphorus (µg/L)	26	--	42	--	57	--	80	--
Orthophosphate (µg/L)	7	--	22	--	45	--	67	--
TKN (mg/L)	1.60	--	1.10	--	1.02	--	1.20	--
Ammonia-N (mg/L)	<0.05	--	<0.05	--	<0.05	--	<0.05	--
Nitrate+Nitrite-N (mg/L)	<0.05	--	<0.05	--	<0.05	--	0.06	--
5-day CBOD (mg/L)	1.2	--	1.2	--	5.3	--	2.0	--
Ultimate BOD (mg/L)	15.6	--	6.6	--	9.8	--	12.4	--
Chlorophyll-*a* (ug/L)	33.1	--	3.7	--	1.1	--	1.2	--
Transparency (cm)	75	--	>100	--	79	--	>100	--
Total Suspended Solids (mg/L)	7.6	--	3.2	--	4.0	--	4.8	--
Volatile Suspended Solids (mg/L)	6.8	--	2.4	--	2.4	--	2.4	--

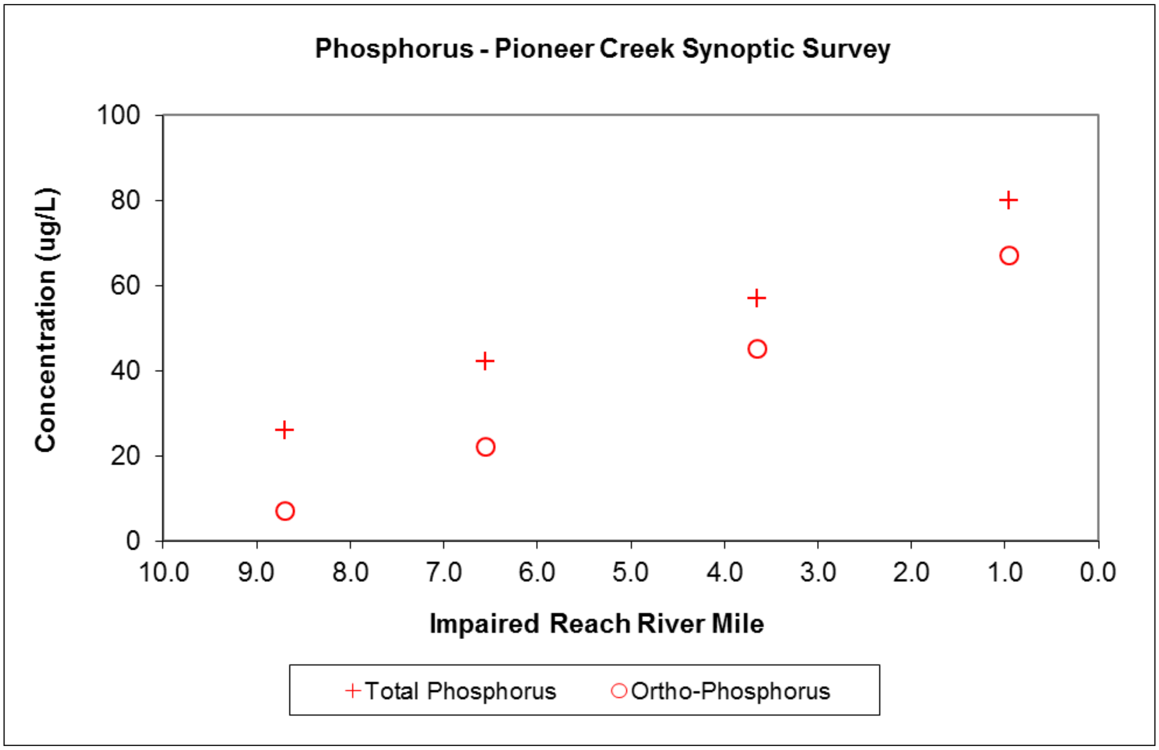

Figure 1-7. Pioneer Creek main-stem synoptic survey phosphorus sampling results.

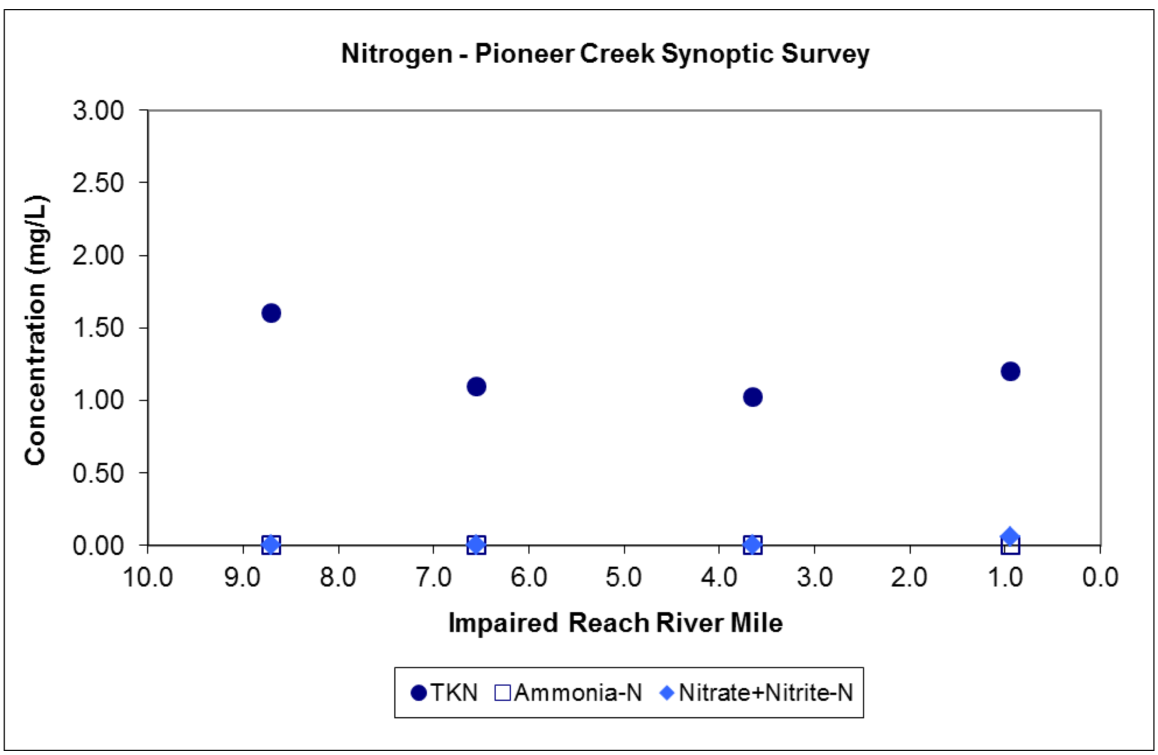

Figure 1-8. Pioneer Creek main-stem synoptic survey nitrogen sampling results.

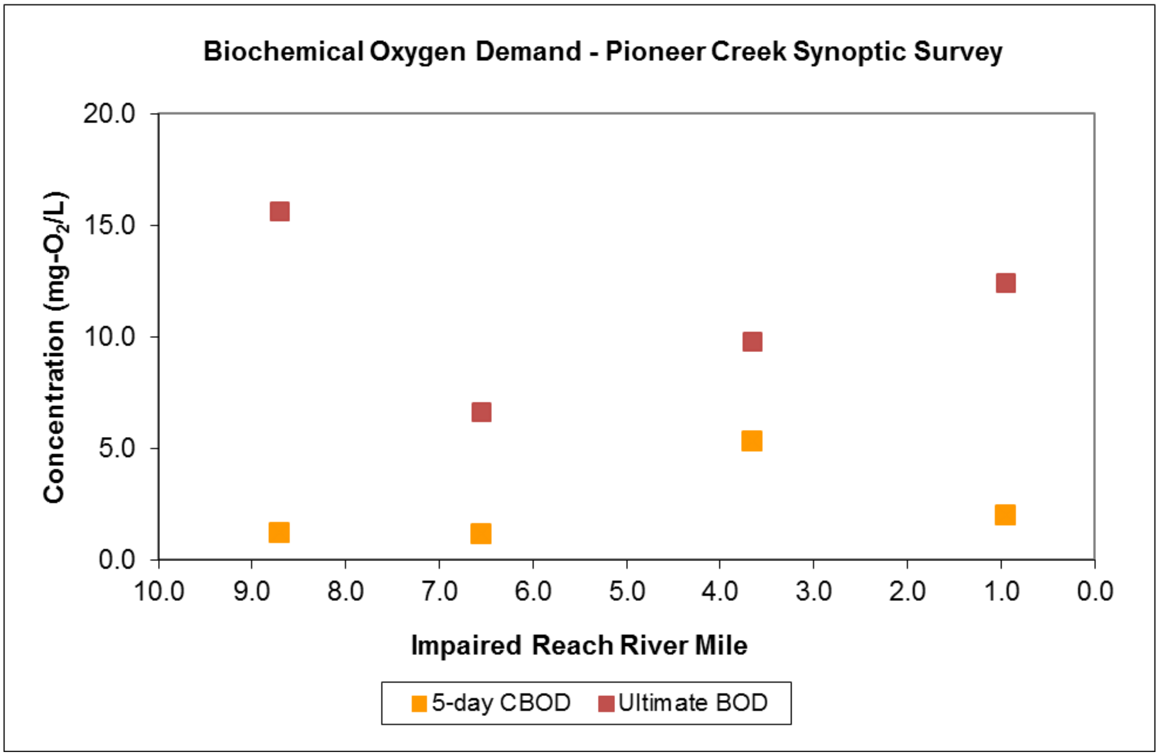

Figure 1-9. Pioneer Creek main-stem synoptic survey $CBOD_5$ and BOD_U sampling results.

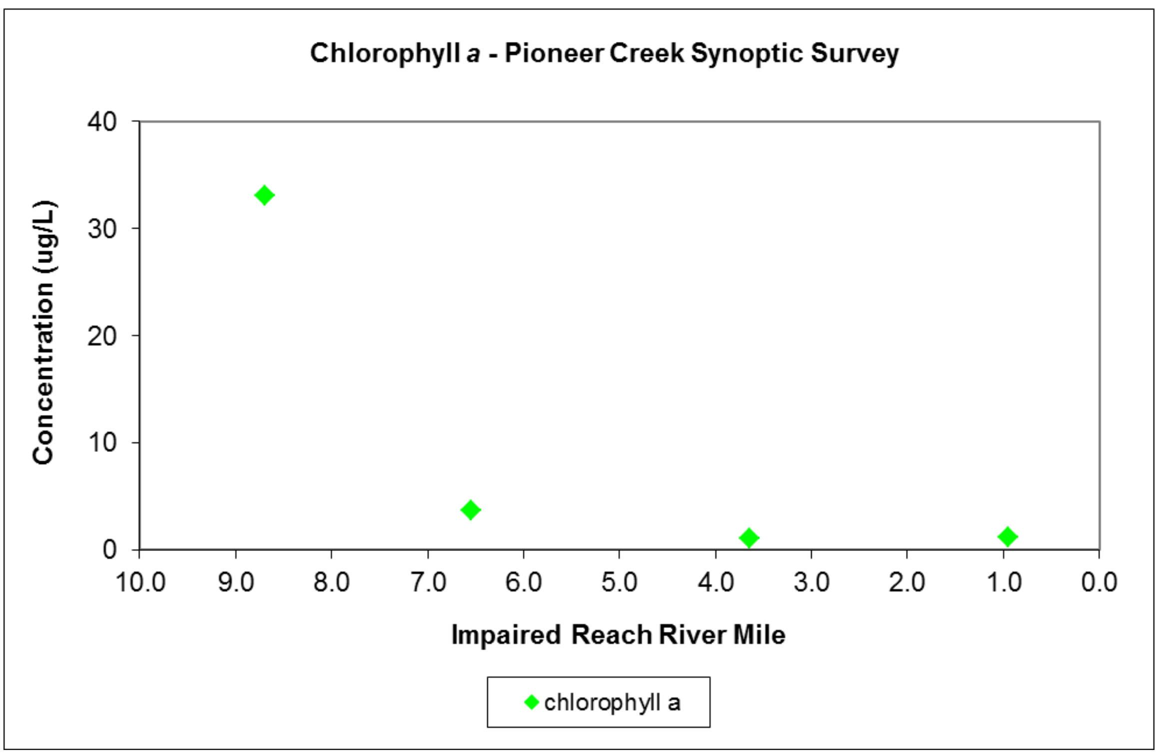

Figure 1-10. Pioneer Creek main-stem synoptic survey chlorophyll-*a* results.

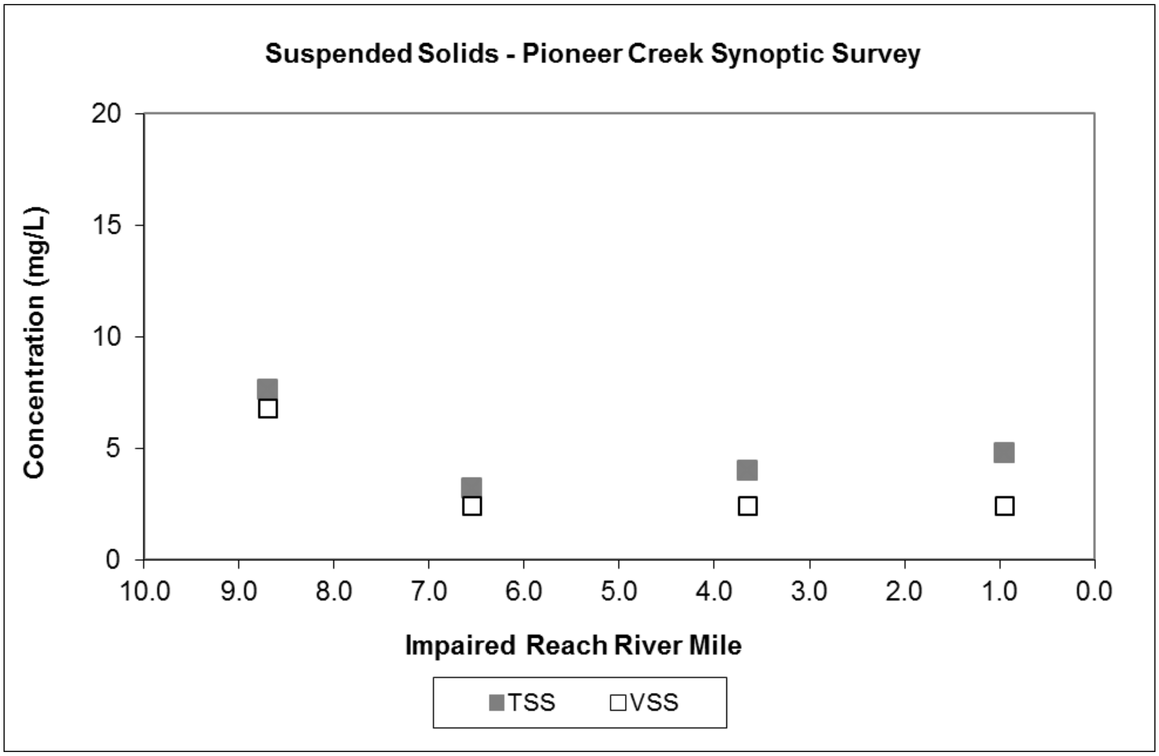

Figure 1-11. Pioneer Creek main-stem synoptic survey TSS and VSS sampling results.

1.5 Longitudinal DO Profile

Results of three early morning (pre 9:00 am) DO longitudinal profiles are shown in Figure 1-12. These profiles show a sharp decrease in DO immediately downstream of Lake Independence as the creek flows through a large wetland complex between stations PC8.77 and PC6.55. However, DO quickly rebounds and increases downstream of the wetland complexes between stations PC6.55 and PC0.95. It should be noted that DO violations were widespread during the July 12th 2013 early morning survey as all stations recorded DO well below the 5.0 mg/L standard. During the August 13-14 surveys, only monitoring stations in or downstream of the wetland complex (PC8.05 and PC6.55) had early morning DO concentrations below the 5.0 mg/L standard.

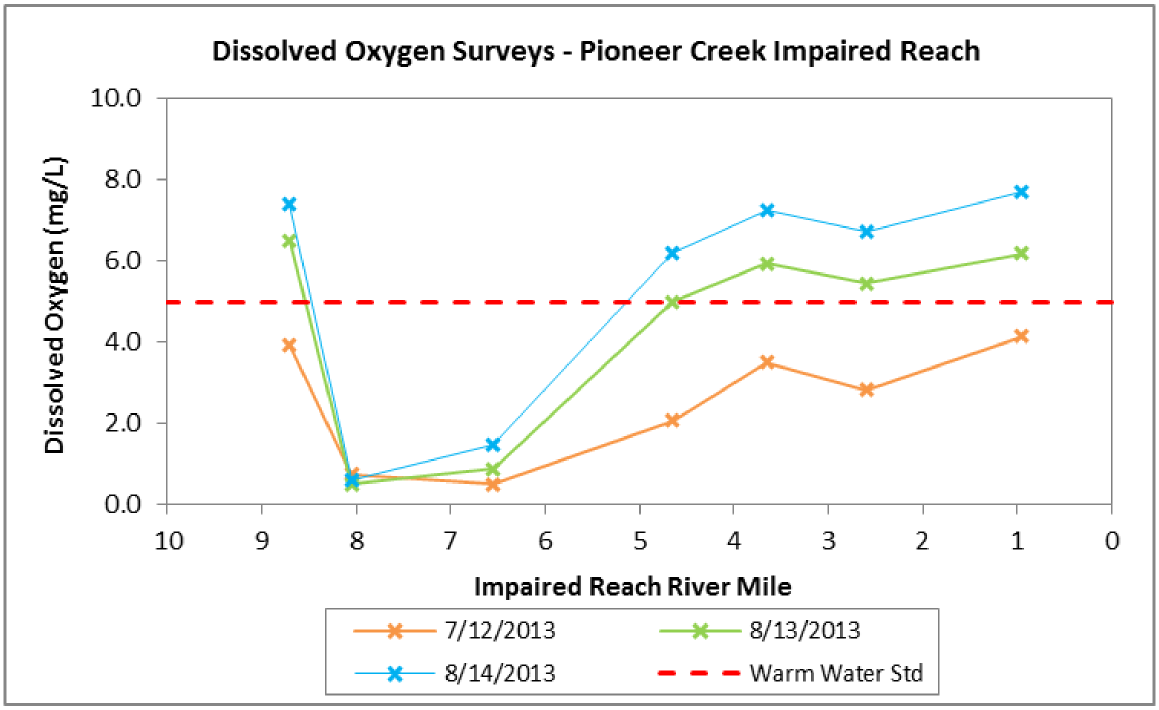

Figure 1-12. Pioneer Creek early morning DO longitudinal profiles measured before and during the August 2013 synoptic survey.

Wenck Associates, Inc.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, MN 55359-0249

800-472-2232
(763) 479-4200
Fax (763) 479-4242
wenckmp@wenck.com
www.wenck.com

TECHNICAL MEMORANDUM

TO: Pioneer- Sarah Creek Watershed Management Organization
Minnesota Pollution Control Agency

FROM: Jeff Strom, Erik Megow and Diane Spector

DATE: April 2015

SUBJECT: Pioneer Creek QUAL2K Modeling Methods and Results

Wenck Associates, Inc. has developed and calibrated a low-flow QUAL2K model for Pioneer Creek reach AUID 070010205-653 from the outlet of Lake Independence to the south line of T118 R24W S30 in Independence, MN. This reach is expected to be listed on the 2016 303(d) list of impaired waters for dissolved oxygen (DO). The purpose of this technical memorandum is to describe the methods and assumptions used to create and calibrate the QUAL2K model.

1.0 INTRODUCTION

1.1 Model Selection

The U.S. EPA River and Stream Water Quality Model (QUAL2K) version 7 is a modernized version of the QUAL2E model developed by Dr. Steven Chapra with Tufts University and Greg Pelletier with Washington State. It was selected to analyze Pioneer Creek because it is a relatively simple surface water quality model that can be used during steady-state conditions to model nutrient, algal and DO dynamics.

1.2 General Overview of the Model

The model was built using late summer synoptic survey data collected on August 14th, 2013. Stream locations and physical features were built in to the model first before proceeding to hydraulic calibration. Once tributary and diffuse inflow (groundwater) were quantified and incorporated into the model, the temperature and conductivity were calibrated to synoptic survey data by adjusting stream shading and groundwater input parameters. Then, chlorophyll-*a* (phytoplankton production), nutrients (phosphorus and nitrogen components), and carbonaceous biochemical oxygen demand (CBOD) were calibrated by adjusting tributary contributions and/or kinetic coefficients within the range of published values. Finally, bottom algae coverage was adjusted for each reach to match observed DO data.

2.0 MODEL SETUP AND INPUTS

The QUAL2K model covers the main stem of Pioneer Creek from the outlet of Lake Independence to the end of the next downstream, unimpaired reach (AUID 070010205-654) north of Ox Yoke Lake. This stretch of Pioneer Creek, explicitly modeled, represents approximately 8.8 river miles and was represented in the model as eight individual reaches. The start of each reach correlates with a monitoring station location, road crossing, or physical change in stream morphology (Tables 2.1 and 2.2, Figure 2.1).

These final "modeled" channel slopes were adjusted and are different than those measured during the channel survey. The surveyed slopes did not work well in the model and grossly under-estimated travel time and over-estimated observed velocities in the field. The slope was used as a calibration adjustment to accurately model hydraulics and match observed data on travel time and velocity.

Table 1.1. Model reach characteristics.

Reach	Description	Upstream River Mile	Downstream River Mile	Reach Length (miles)	Channel Slope[1] (ft/ft)
1	Lake Independence (PC8.8) to Pagenkopf Rd (PC8.1)	8.8	8.1	0.7	0.00003
2	Pagenkopf Rd (PC8.1) to CR 90 (PC6.6)	8.1	6.6	1.5	0.00001
3	CR 90 (PC6.6) to HWY 12 (PC5.6)	6.6	5.6	1.0	0.01000
4	HWY 12 (PC5.6) to Pioneer Creek Road (PC4.7)	5.6	4.7	0.9	0.00900
5	Pioneer Creek Road (PC4.7) to CR 92 (PC3.6)	4.7	3.6	1.1	0.00050
6	CR 92 (PC3.6) to Copeland Road (PC2.6)	3.6	2.6	1.0	0.00050
7	Copeland Road (PC2.6) to CR 26 (PC1.0)	2.6	1.0	1.6	0.00050
8	CR 26 (PC1.0) to End of Impaired Reach (PC0.0)	1.0	0.0	1.0	0.00050

[1]The channel slopes listed in Table 2.1 are the modeled channel slopes for each reach.

Table 1.2. Monitoring locations and available data.

Reach	Monitoring Location ID	Description	Data Collected
HW	PC8.70	Pioneer Creek at Lake Independence (HW)	Q, Grab, Field
1	PC8.05	Pioneer Creek at Pagenkopf Road	Q, Field
2	PC6.55	Pioneer Creek at CR 90	Q, Grab, Field
4	PC4.65	Pioneer Creek at Pioneer Creek Road	Q, Field
5	PC3.65	Pioneer Creek at CR 92	Q, ToT, Grab, Field
6	PC2.60	Pioneer Creek at Copeland Road	Field
7	PC0.95	Pioneer Creek at CR 6	Q, ToT, Grab, Field

Q = Gaged flow.
ToT = Time of travel determined from dye study.
Grab = Water quality grab sample collected and lab analyzed for standard pollutants: total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_2-N), 5-day carbonaceous biological oxygen demand ($CBOD_5$) and ultimate biochemical oxygen demand (BOD_u), total phosphorus (TP), ortho-phosphorus (soluble reactive phosphorus), total organic carbon (TOC), and chlorophyll-*a*.
Field = In-field measurement of temperature, conductivity, pH, and dissolved oxygen (DO).

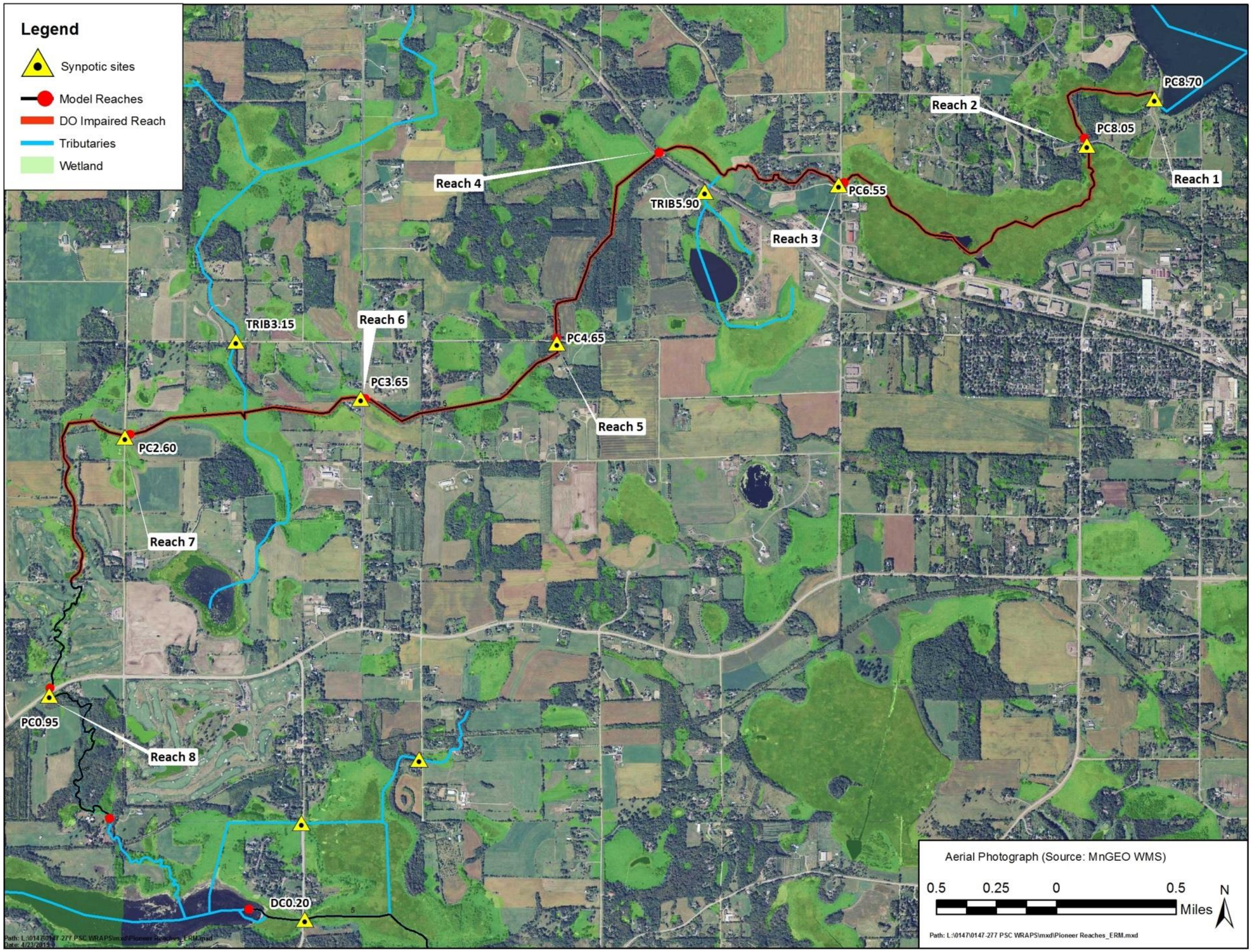

Figure 1.1. Pioneer Creek monitoring stations and modeled reaches.

2.1 Channel Slope

Reaeration in QUAL2K may be prescribed by the user or calculated using one of eight hydraulic-based reaeration formulas built into the model. The Tsivoglou-Neal reaeration model was selected for Unnamed River because it performs well in predicting reaeration in low-flow and low gradient rivers/streams (Tsivoglou and Neal, 1976; Thomann and Mueller, 1987). This model calculates reaeration using stream velocity. Modeled channel slopes were assigned based on data from an elevation survey conducted by Wenck in the fall of 2013. However, applying the surveyed channel slopes greatly underestimated observed travel times and over-estimated field velocity measurements. Therefore, modeled channel slopes had to be adjusted downward to meet the observed measurements. It is believed the final channel slope adjustments more accurately reflect the average slope of each reach. These slopes were verified using MN LiDAR, air photos, wetland locations, and general field observations (Table 2.1).

2.2 Weather and Physical Processes

Hourly weather measurements of temperature, cloud conditions, relative humidity and wind speed were downloaded for a long-term Minneapolis weather station from Minnesota's Automated Surface Observing Systems (ASOS) website. Channel coverage, canopy and shading were set based on inspection of recent air photographs in GIS.

2.3 Headwaters

The headwater of the Pioneer Creek impaired reach is Lake Independence. During the synoptic survey, headwater station PC8.70 had measurable flow (3.83 cfs), and all water quality data collected at this station on August 14^{th} was used to represent the upstream boundary condition/headwater in the model. Three field measurements from Station PC8.70 (EQuIS S007-703) on August 14, 2013 were used to model DO, temperature, conductivity, and pH. The field measurements were taken at 7:38 and 11:00, and 16:50 and therefore represented the range of headwater DO observed throughout the day. These field samples were supplemented by a water quality grab sample that was used to model headwater chemistry.

2.4 Carbonaceous Biochemical Oxygen Demand (CBOD)

QUAL2K calculates nitrogenous oxygen demand separate from carbonaceous biochemical oxygen demand (CBOD). To do this, QUAL2K requires individual inputs of CBOD and organic nitrogen plus ammonia-nitrogen (TKN – reduced nitrogen). Ultimate BOD (BOD_u), not $CBOD_u$ was analyzed during the Pioneer Creek synoptic survey. BOD_u is a measure of the total oxygen consumed by bacteria from the decomposition of organic matter. Laboratory methods for $CBOD_u$ analysis require addition of a chemical that inhibits nitrogen bacteria. Thus, $CBOD_u$ only measures oxidation of the carbon fraction of organic matter. For the Pioneer Creek QUAL2K model, $CBOD_u$ was estimated by subtracting the oxygen equivalents (4.57 mg O_2 per mg nitrogen) of the reduced nitrogen in the sample according to the following equation (Thomann et al., 1987; Chapra et al., 2007):

$$CBOD_u = BOD_u - (4.57*TKN)$$

3.0 HYDRAULIC CALIBRATION

Manning's Equation was used to model the hydraulics of Pioneer Creek. The model assumes steady flow conditions in each reach and uses the following Manning's Equation to model the flow in each reach:

$$Q = \frac{S_0^{1/2}}{n} \cdot \frac{A_c^{5/3}}{P^{2/3}},$$

Where Q is the flow, S_0 is the bottom slope, n is the Manning roughness coefficient, A_c is the cross-sectional area, and P is the wetted perimeter.

For the QUAL2K model, the necessary inputs for Manning's equation are side slopes (z_1 and z_2), bottom width (W_b), channel slope (S_0), and roughness coefficient (n). The side slopes and width are used to calculate the wetted perimeter (P) and cross-sectional area (A_c) in the equation above.

Reach channel slopes, side slopes and bottom widths are shown in Table 3.1. The bottom width and side slopes were calculated by approximating a trapezoidal channel to match cross-section survey data from one location within each reach. Final channel slopes were determined by calibrating to synoptic survey travel time and velocity measurements.

Table 3.1 Manning formula inputs and assumptions

Reach	*n*	W_0 (ft)	Channel Slope (ft/ft)	Side Slope (Z_1)	Side Slope (Z_2)
1	0.080[1]	65.6	0.00003	1.29	0.29
2	0.080	14.8	0.00001	1.87	2.33
3	0.080	11.0	0.01000	7.14	7.86
4	0.080	11.0	0.00900	7.14	7.86
5	0.080	6.6	0.00050	2.50	1.67
6	0.080	6.6	0.00050	1.82	0.91
7	0.080	6.6	0.00050	0.74	0.90
8	0.080	6.6	0.00050	1.00	2.80

[1]Roughness is assumed based on literature values (Mays, 2005)

3.1 Flow and Travel Time Calibration

Gauged flow data for Pioneer Creek was collected on August 14, 2013 at six sites along the impaired reach. The measured flows are listed in Table 3.2.

Table 3.2 Pioneer Creek gauged flow data from August 14, 2013

Site	Timestamp	Flow (cfs)	Flow (m^3/s)
PC8.70	12:15	3.83	0.108
PC8.05	11:50	5.70	0.144
PC6.55	11:00	7.05	0.200
PC4.65	14:33	7.49	0.212
PC3.65	10:20	8.10	0.228
PC0.95	9:30	7.97	0.225
TRIB3.15	10:00	0.12	0.003

Incremental increases in flow between gauging stations were built into the model as diffuse sources and/or point sources where appropriate. Diffuse sources were modeled as groundwater, while point sources were modeled as tributaries.

Groundwater was estimated using 32 inches of annual rainfall and based on a unit-area hydrograph for each reach. Based on literature values, an estimated 2.2% of rainfall over each reaches watershed area is delivered to the stream as groundwater (Baker et al, 1979). Table 3.3 lists the estimated groundwater entering each reach.

Table 3.3 Pioneer Creek estimated groundwater as diffuse flow for each modeled reach.

Reach	Watershed Area (ac)	Groundwater Inflows			
		Inch/yr	Acre-feet/yr	Inflow (CFS)	Inflow (m^3/s)
1	255	0.7	15	0.021	0.0006
2	1370	0.7	80	0.110	0.0031
3	1487	0.7	87	0.120	0.0034
4	416	0.7	24	0.034	0.0009
5	551	0.7	32	0.044	0.0013
6	4609	0.7	269	0.371	0.0105
7	630	0.7	37	0.051	0.0014
8	470	0.7	27	0.038	0.0011

After groundwater sources were calculated and incorporated into the model, additional increases in flow between gauging stations was modeled as tributaries at locations determined through aerial imagery. Table 3.4 lists the modeled inflows, both tributary (point sources) and groundwater (diffuse sources) for each reach.

Table 3.4 Pioneer Creek modeled tributary (point source) and groundwater (diffuse source) inflows

Reach	Groundwater Inflow (m^3/s)	Tributary Inflow (m^3/s)	Tributary Location
1	0.0006	0.0345	RM 8.3
2	0.0031	0.0529	RM 7.3
3	0.0034	0.0000	None
4	0.0009	0.0081	RM 5.4
5	0.0013	0.0030	RM 4.4
6	0.0105	0.0000	None
7	0.0014	0.0000	None
8	0.0011	0.0000	None

The model was deemed calibrated for total flow once the headwater, tributaries and the groundwater diffuse source inflow were built in to the model (Figure 3.1.).

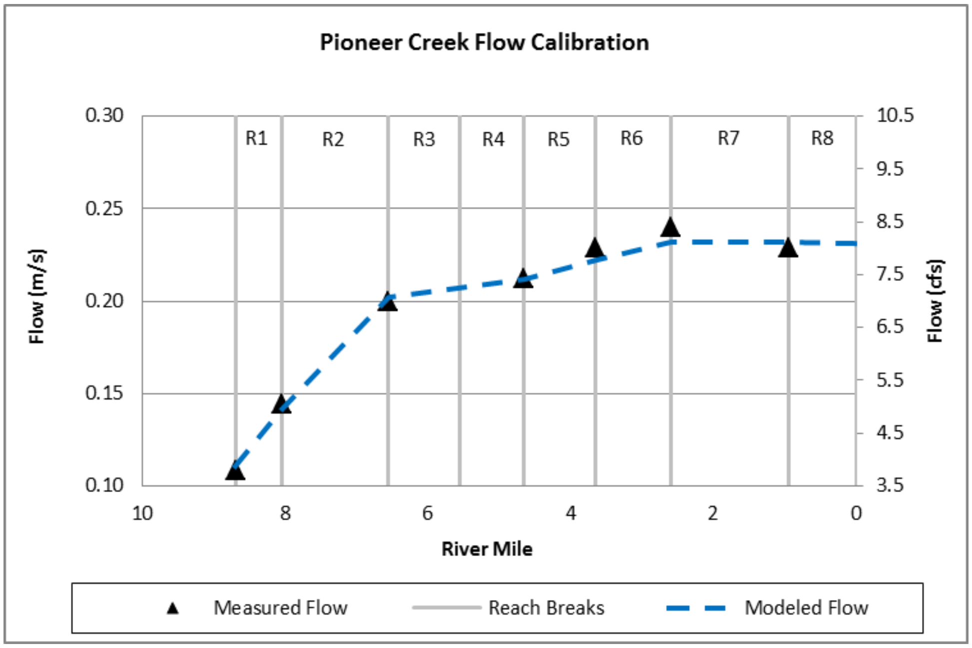

Figure 1.2. Pioneer Creek QUAL2K flow calibration with headwater, tributary and groundwater diffuse inflows.

Model-predicted travel time throughout the impaired reach matched observed travel time data once the tributary and diffuse sources were properly incorporated into the model (Figure 3.2). Manning's inputs, specifically channel slope and width, were calibrated based on MN LiDAR, air photos, travel time and average reach velocity observations.

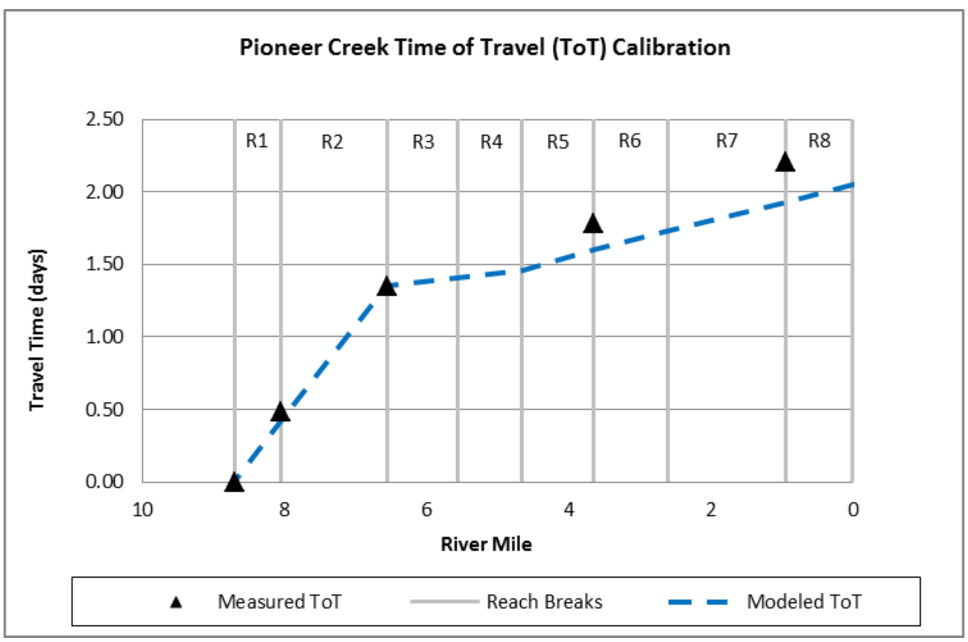

Figure 1.3. Pioneer Creek QUAL2K travel time calibration.

4.0 WATER QUALITY CALIBRATION

All headwater and tributary water quality model inputs were derived from data collected during the August 14th, 2013 synoptic survey. Groundwater diffuse source water quality parameters were estimated based on literature values and calibration to in-stream water quality data. The QUAL2K model was set up to model flow, travel time, depth, temperature, conductivity, pH, DO, organic nitrogen (ON), ammonia nitrogen (NH_4-N), nitrate/nitrite nitrogen (NO_2/ NO_3-N), CBOD, sediment oxygen demand (SOD), organic and inorganic phosphorus, and chlorophyll-*a*. All model changes to global and reach specific kinetic rates as well as the groundwater diffuse source settings are discussed in this section.

4.1 General Kinetic Rates

Eleven kinetic rates were considered during water quality calibration to meet longitudinal changes in the observed data. Organic-N, inorganic-P, and organic-P settling velocities were the only kinetic rates adjusted from default rates. All kinetic rate adjustments were within the range of published values (Table 4.1).

Table 1.3. Pioneer Creek QUAL2K kinetic rates adjustments.

Rate	Calibrated Rate	Default Rate	Literature Range	Citation/Study Area
Reaeration (day^{-1})	1.5 – 10 (model calculated)	Tsivoglou and Neal, 1976		
CBOD oxidation rate (day^{-1})	0.20	0.20	0.02 – 0.60 0.56 – 3.37	Bowie et al., 1985, Table 3-17 p152 Kansas (6 rivers) Michigan (3 rivers) reported by Bansal, 1975
Inorganic-P Settling Velocity (m/d)	0.00	0.01	Influenced by the amount of particulate organic matter and its size, shape and density and velocity of stream	
Organic-N Hydrolysis (day^{-1})	0.05	0.05	0.02 – 0.10 0.03 – 0.20	Bowie et al., 1985, Table 5-3 p259 Scavia, 1980 Di Toro & Matystik, 1980
Nitrification (day^{-1})	0.20	0.20	0.09 – 0.20	Thomann et al., 1982; Di Toro et al., 1980
Organic-N Settling Velocity (m/d)	0.01	0.05	Influenced by the amount of particulate organic matter and its size, shape and density and velocity of stream	
Organic-P Hydrolysis (day^{-1})	0.05	0.05	0.02 – 0.80	Bowie et al., 1985, Table 5-5 p266 Jorgenson, 1976 Bowie et al., 1980
Organic-P Settling Velocity (m/d)	0.1	2.0	Influenced by the amount of particulate organic matter and its size, shape and density and velocity of stream	
Sediment Inorganic-P Flux (mg P/m^2/d)	20	Model Calculated	9.6-95	Filos and Swanson, 1975
Sediment NH4 Flux (mg N/m^2/d)	Model Calculated	Model Calculated	20-325	Thomann and Mueller, 1987
Phytoplankton Settling (m/d)	0.25	0.25	0 – 2	Bowie et al., 1985, Table 6-19 p352 Chen & Orlob, 1975 and Smith, 1978

4.2 Diffuse Groundwater Quality Inputs

Diffuse groundwater inputs were assigned typical groundwater quality values for the Franconia aquifer (CFRN) based on MPCA's 1999 baseline groundwater report (MPCA, 1999). Organic nitrogen and $CBOD_u$ diffuse inputs had to be assumed as these parameters were not monitored during the MPCA's 1999 study. Table 4.2 lists the values used for modeling groundwater quality parameters.

Table 1.4. Groundwater parameter model assumptions and literature values.

Parameter	Modeled Value	Groundwater Literature Values[1]	Notes
Temp (C)	10.3	9.1 – 11.5	Used mean groundwater value for Franconia aquifer (MPCA 1999)
Sp. Cond (µmhos/cm)	718	421 - 951	Used mean groundwater value for Franconia aquifer (MPCA 1999)
pH	7.39	6.92 – 7.96	Used mean groundwater value for Franconia aquifer (MPCA 1999)
DO	0.3	0.30 – 5.78	Used median groundwater value for Franconia aquifer (MPCA, 1999)
Organic- N (µg/L)	500	NA	Calibrated adjustment to in-stream conditions (no published data available)
Nitrate+Nitrite-N (µg/L)	500	<500 – 6,900	Used median groundwater value for Franconia aquifer (MPCA 1999)
Organic-P (µg/L)	48	19 - 293	Used mean groundwater value for Franconia aquifer (MPCA 1999)
Inorganic-P (µg/L)	25	<20 – 630	Used mean groundwater value for Franconia aquifer (MPCA 1999)
$CBOD_u$ (mg O_2/L)	0	NA	Calibrated adjustment to in-stream conditions (no published data available)

[1] Typical groundwater quality literature values for the Franconia aquifer (MPCA, 1999)

4.3 Tributary Water Quality Inputs

Tributary (point source) water quality values were modeled using the average values measured along the main-stem during the August 14, 2013 longitudinal sampling. If needed, the average values were then adjusted within the range of typical Minnesota water quality conditions for the North Central Hardwood Forest ecoregion values to better match main-stem water quality results. Table 4.3 summarizes the modeled water quality parameters for each tributary.

Table 4.3. Tributary parameter model assumptions and literature values.

Parameter	In-stream Values		Tributaries				Justification
	Range[1]	Average	RM 8.3	RM 7.3	RM 5.4	RM 4.4	
Temp (C)	23.1 - 17.7	19.2	20.3	20.3	20.3	20.3	Adjusted within MPCA typical stream values; 2-21°C
Specific Conductance (µmhos/cm)	300 - 402	384	384	384	384	384	Adjusted within main-stem values
CBOD (mg/L)	8.3 - 1.6	5.48	3.2	3.2	3.2	3.2	Adjusted within main-stem or MPCA typical stream values; 1.5 – 3.2 mg/L
DO (mg/L)	12.02 - 0.59	6.32	5.0	5.0	5.0	5.0	Adjusted within main-stem values
Organic- N (µg/L)	1337 - 987	1135	1135	1135	1135	1337	Adjusted within main-stem values
Nitrate+Nitrite-N (µg/L)	60.0-0.0	15.0	15.0	15.0	15.0	60.0	Adjusted within main-stem values
Ammonia-N (µg/L)	0.0	0.0	0.0	0.0	0.0	0.0	Adjusted within main-stem values
Organic-P (µg/L)	16.0 - 0.0	9.8	100.0	10.0	10.0	10.0	Adjusted within main-stem values and within MPCA typical stream values for TP; 60 - 150
Inorganic-P (µg/L)	67.0 - 7.0	35.3	5.0	5.0	35.0	35.0	Adjusted within main-stem values
pH	8.2 - 6.9	7.4	7.0	7.0	7.0	7.0	Adjusted within main-stem values

[1]These values represent the maximum and minimum values measured along the main stem

4.4 Final Water Quality Calibration

CBOD, chlorophyll-*a* and all forms of nitrogen and phosphorus were deemed calibrated after diffuse source water quality parameters and kinetic rates were properly incorporated and adjusted within the model. The model performed well in predicting monitored concentrations of the primary water quality parameters that affect DO.

5.0 DISSOLVED OXYGEN CALIBRATION

5.1 Diurnal Dissolved Oxygen Calibration

The Pioneer Creek QUAL2K model applies half-saturation formulations defining the relationship of light penetration through the water column and effects on algae and photosynthesis. It was assumed that water column algae is accurately depicted in the model since modeled chlorophyll-*a* concentrations closely match observed values throughout the impaired reach during the synoptic survey. However, early model runs did not accurately predict daily minimum and maximum DO observations suggesting there was in-situ primary production (photosynthesis and respiration) not accounted for or under-represented. QUAL2K has a bottom algae component that simulates photosynthesis and nutrient uptake of any non-suspended algae and/or plants. In the Pioneer Creek model, the bottom algae channel coverage was adjusted by reach to match observed swings in the DO data observed throughout the August 14, 2013 synoptic survey (Table 5.1). It is assumed that this bottom algae component represents all elements of primary production (attached algae, submerged macrophytes, rooted aquatic vegetation) that could not be measured or quantified in the field.

Last, sediment oxygen demand (SOD) was incorporated in the model. SOD is calculated in QUAL2K based on the delivery and breakdown of particulate organic matter from the water column. Currently, the model does not have a macrophyte or riparian vegetation SOD component, nor does it incorporate any upland sediment transported and deposited during non-steady state conditions such as storm events. The model does allow the user to prescribe SOD to specific reaches that is added to the model predicted rate to account for SOD outside the modeling framework. SOD in streams varies depending on sediment type but is typically between 0.05 (mineral soils) and 2.00 (estuarine mud) g O_2/m^2/day (Thomann and Mueller, 1987). After the inclusion of bottom algae coverage, the model predicted DO concentrations were still slightly higher than observed in the upstream portion of Pioneer Creek (reaches 1-6). Therefore, sediment oxygen demand (SOD) was assigned to the upstream portions within typical literature ranges (Table 5.1).

Table 1.5. Reach specific SOD and bottom algae coverage

Reach	SOD (g O_2/m^2/day)	Bottom Algae Coverage (%)	Notes
1	2.0	0	Slow moving, wide reach with backwater pools and wetlands.
2	2.0	25	Slow moving reach through large wetland system
3	1.0	25	
4	1.0	15	
5	1.0	10	
6	1.0	10	Slow moving reach through wetland
7	0.0	25	Pioneer Creek Golf Course reach
8	0.0	35	Windsong Farm Golf Club reach

5.2 Final Dissolved Oxygen Calibration

Figure 5.1 shows the model-predicted and observed DO for the Pioneer Creek QUAL2K calibrated model run. Field DO grabs were measured three times at each of the seven sites in the early morning, midday, and afternoon on August 14th using a hand-held YSI. These three measurements aimed to capture the diurnal pattern of DO at each site (Table 5.2).

Table 1.2. Longitudinal DO data for August 14, 2013

Location	Monitored DO Concentrations (mg/L)		
	Morning (7:11-8:10)	Mid-day (9:30-11:00)	Afternoon (16:00-16:50)
PC0.95	7.71	8.59	12.02
PC2.60	6.71	6.71	9.20
PC3.65	7.24	8.01	8.94
PC4.65	6.20	No data	8.80
PC6.55	1.47	2.62	3.80
PC8.05	0.59	No data	1.05
PC8.70	7.39	6.47	8.05

The model performed well in predicting monitored DO concentrations (black squares) and diurnal patterns (daily minimum and maximum, shown in plots as blue dashed lines) at the seven monitoring stations with DO measurements. The model and data show that the DO drops drastically in wetland reaches 1 and 2, and then increases above the 5.0 mg/L standard as stream velocity, flow, and channel slopes begin to increase in reach 3. DO remained above the standard throughout reaches 4-8.

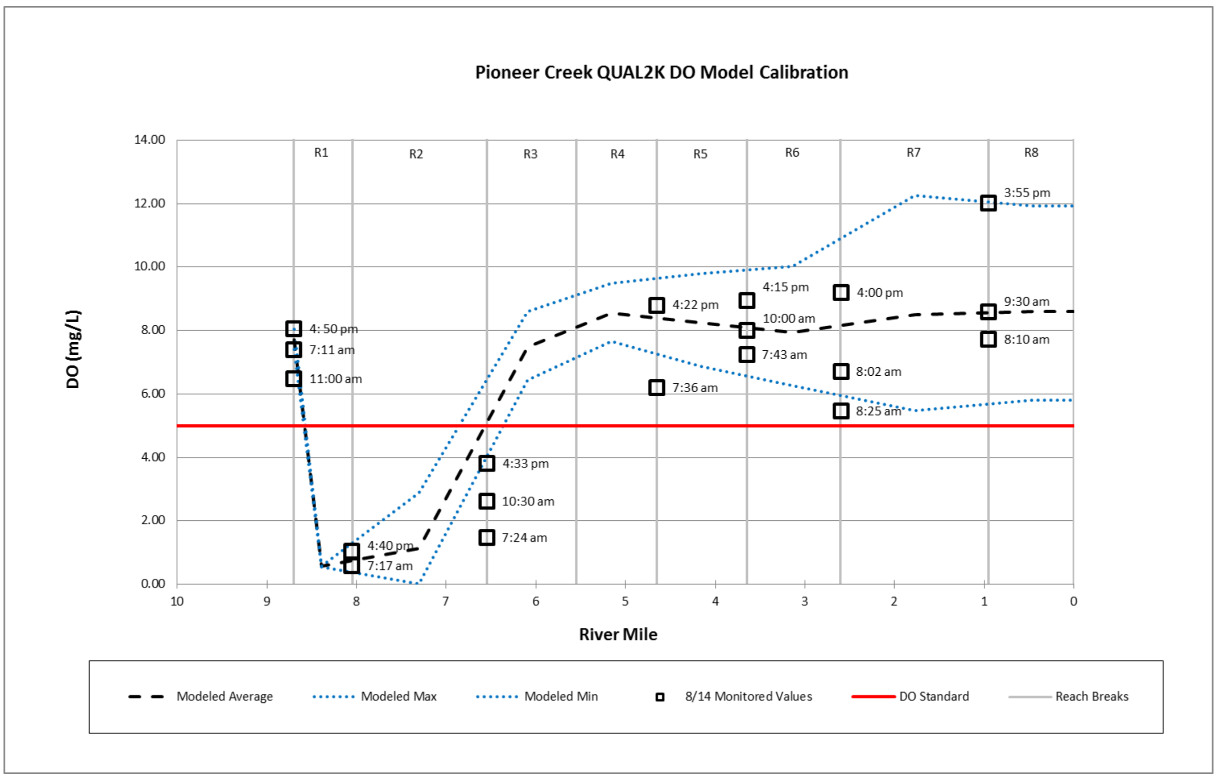

Figure 1.4. DO longitudinal profile for the Pioneer Creek QUAL2K calibrated model run.

6.0 SENSITIVITY ANALYSIS

To evaluate the sensitivity of model predicted DO to changes in model variables, seven kinetic rates (Table 6.1), two reach specific rates (Table 6.2), and channel slopes (Table 6.3) were removed or adjusted by specific percentages. The following tables summarize the affect these changes have on the average model-predicted DO concentration for the entire modeled stretch of Pioneer Creek. Results show DO throughout the system is not sensitive to kinetic rates and only slightly sensitive to the reaeration rate, bottom algae and channel slope adjustments. This exercise suggests that DO levels below the 5.0 mg/L standard observed in reaches 1-3 during the synoptic survey are most affected by reaeration and SOD.

Table 1.6. DO sensitivity to kinetic rates.

Kinetic rate	+25%	-25%	Default
Organic-N Settling (m/d)	-0.5%	-0.5%	-1.2%
Organic-P Settling (m/d)	0.0%	0.0%	0.0%
Inorganic-P Settling (m/d)	0.0%	0.0%	0.0%

Table 1.7. DO sensitivity to reach rates.

Action	DO Sensitivity
Remove all bottom algae coverage	-11.4%
Remove prescribed SOD in all reaches	8.7%
Remove all SOD by setting SOD channel coverage to 0%	18.3%

Table 1.8. DO sensitivity to channel slope.

Channel Slope	DO Sensitivity
Increased by 25 percent	1.5%
Decreased by 25 percent	-2.4%

7.0 REFERENCES

Bansal, M.K., 1975. Deoxygenation in Natural Systems. Water Resources Bulletin 11: 491-504.

Bowie, G.L., C.W. Chen, and D.H. Dykstra. 1980. Lake Ontario Ecological Modeling, Phase III. Tetra Tech, Inc., Lafayette, California. For National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

Bowie, G.L., et al., 1985. « Rates, constants and kinetic formulations in surface water quality modeling (2nd Edition.)" USEPA

Chapra, S.C., Pelletier, G.J. and H. Tao. 2007. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.07: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Chen, C.W. and G.T. Orlob. 1975. Ecological simulation for aquatic environments. Systems Analysis and Simulation in Ecology, Volume 3. Academic Press, New York, New York. pp. 476-588.

Di Toro, D.M. and W.F. Matystik, Jr. 1980. Mathematical Models of Water Quality in Large Lakes. PartII: Lake Erie. U.S. Environmental Protection Agency, Ecological Research Series. EPA-600/3-3-80-065.

Jorgensen, S.E.. 1976. A Eutrophication Model for a Lake. Ecol. Modeling, 2: 147-165.

Minnesota Pollution Control Agency. 1999. Baseline Water Quality of Minnesota's Principal Aquifers – Region 6, Twin Cities Metropolitan Area. http://www.pca.state.mn.us/index.php/view- document.html?gid=6296

Olsen, B. 2011. Groundwater – Surface Water Interactions Along the Vermillion River. Dakota County Water Resources Deprtment.

Scavia, D. 1980. An Ecological Model of Lake Ontario. Ecol. Modeling, 8: 49-78.

Smith, D.J. 1978. Water quality for river-reservoir systems. Resource Management Associates, Inc., Lafayette, California. For U.S. Army Corps of Engineers, Hydrologic Engineer Center, Davis, California.

Thormann, R.V. and J.J. Fitzpatrick. 1982. Calibration and Verification of a Mathematical Model of the Eutrophication of the Potomac Estuary. Government of the District of Columbia, Washington, D.C.

Thomann, R. V., Mueller, J. A., 1987. "Principles of Surface Water Quality Modeling and Control." Harper Collins Publishers Inc.

Tsivoglou, E.C., and Neal, L.A. 1976. “Tracer Measurement of Reaeration. III. Predicting the Reaeration Capacity of Inland Streams.” Journal of the Water Pollution Control Federation, 48(12): 2669-2689.