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Lower Cherry Creek and Lower Ames Creek Watersheds

Dissolved Oxygen Study

by

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Waterbody Numbers:
WA-07-1062 (Cherry Creek) and WA-07-1066 (Ames Creek)

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Table of Contents

Page

List of Figures....5

List of Tables....6

Abstract....7

Acknowledgements....8

Introduction....9
- Cherry Creek....11
- Ames Creek....13
- Project Collaboration....15
- Project Goal....15
- Project Objectives....16
- Site Selection....16
- Water Quality Criteria and Aquatic Life....17

Methods....20
- Field Data Collection....20
- Data Preparation....21

Results and Discussion....22
- Data Quality Assurance....22
- Water Quality Criteria....24
  - Daily Minimum Dissolved Oxygen Concentrations....29
  - Snoqualmie River Streamflow Relationship to Dissolved Oxygen....32
- Lower Cherry Creek Watershed....34
- Lower Ames Creek Watershed....39
- Similar Studies....44
  - Effects of Waterway Maintenance....44
  - Nutrients....45
  - Groundwater....48
  - Groundwater Results from Previous Studies....49
- Future Projects....50

Conclusions....51

Recommendations....52

References....53

Appendices....55
- Appendix A. Tables....57
- Appendix B. Charts....61
- Appendix C. Glossary, Acronyms, and Abbreviations....68

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List of Figures

Page

Figure 1. Lower Cherry and Ames Creek subbasin study areas in the Snoqualmie River watershed, May – June 2011. 10
Figure 2. Lower Cherry Creek basin and water quality monitoring locations, May – June 2011. 12
Figure 3. Lower Ames Creek watershed and water quality monitoring locations, May – June 2011. 14
Figure 4. Time-series dissolved oxygen concentrations in lower the Cherry Creek watershed. 25
Figure 5. Time-series dissolved oxygen concentrations in the lower Ames Creek watershed. 26
Figure 6. Dissolved oxygen data distribution including maximum, minimum, mean, 90^{th} percentile, and 10^{th} percentile of all data recorded. 27
Figure 7. Daily minimum dissolved oxygen concentrations in the lower Cherry Creek watershed. 29
Figure 8. Daily minimum dissolved oxygen concentrations in the lower Ames Creek watershed. 30
Figure 9. Data distribution of the daily minimum dissolved oxygen including maximum, minimum, mean, 90^{th} percentile, and 10^{th} percentile. 31
Figure 10. Snoqualmie River discharge near Carnation from January through September 2011, provided by USGS. 32
Figure 11. Snoqualmie River discharge near Carnation, change in snow depth, and precipitation data during the study period, May – July 2011. 33
Figure 12. Daily minimum dissolved oxygen concentrations in Lateral A compared with instream staff gage heights. 35
Figure 13. Antecedent Precipitation Index (API) and daily minimum dissolved oxygen in Cherry Creek and Lateral A. 37
Figure 14. Soil percolation descriptive in the lower Cherry Creek watershed. 38
Figure 15. Snoqualmie River stage height (USGS gage station near Carnation (12149000)) and dissolved oxygen concentrations in Ames Creek at the upstream site (80^{th}) and the downstream site (100^{th}). 40
Figure 16. Antecedent Precipitation Index (API) and daily minimum dissolved oxygen in Ames Creek and the dredged and undredged agricultural waterways. 42
Figure 17. Soil percolation descriptive in the lower Ames Creek watershed. 43
Figure 18. Map of historical nutrient data collection stations by Wild Fish Conservancy and the Tulalip Tribes of Washington (2009). 47
Figure 19. Staff gage heights of Lateral A and nearby well depths. 49

List of Tables

Page

Table 1. Lower Cherry and Ames Creeks monitoring locations, May – June 2011.........16

Table 2. Washington State water quality criteria and aquatic life uses specific to each waterbody..18

Table 3. Summary of precision measurement quality objectives (MQO) for the multi-probe post-deployment calibration check. 22

Table 4. Percent of the time that water quality criteria were not met based on summarized daily data. 24

Table 5. Discharge measurements taken on the dredged and undredged waterways including upstream and downstream transects. 40

Table 6. Dissolved oxygen grab samples from the drain tiles that discharge to the dredged waterway of the Ames watershed. 41

Table 7. Ammonia-nitrogen concentration summary from previous studies in Cherry Creek and Ames Creek. 45

Table 8. Historical ammonia-nitrogen concentrations along Lateral A............................45

Abstract

Dissolved oxygen (DO) concentrations have frequently failed to meet Washington State water quality standards in the Snoqualmie River flood plain Agricultural Production District (APD) reaches of Cherry and Ames Creeks. However, Cherry and Ames Creeks are not on the federal Clean Water Act Section 303(d) list for DO because the data were yet to be verified for the most recent 2008 water quality assessment.

This study was conducted in order to: (1) characterize DO concentrations, (2) identify possible mechanisms that influence DO, and (3) provide information about the possibility of low DO coinciding with high groundwater-to-surface-water ratios during late spring following long periods of soil saturation. Study results will be used for future water quality improvement projects and help form a basis for continuing investigations. This report presents time-series (continuous) DO concentrations recorded from May through June 2011 in the lower Cherry and lower Ames Creek watersheds.

Based on study results, waterways of the lower Ames Creek and Cherry Creek watersheds did not meet Washington State quality criteria for DO. Sites with low stream velocities such as the recently dredged agricultural waterway had the highest DO range, and Lateral A showed erratic diurnal signatures often reaching DO concentrations of 0 mg/L. Sites with higher stream velocities such as Cherry and Ames Creeks showed a lower range of DO concentrations diurnally. Temperature did not appear to be the driving factor influencing DO fluctuations. Water column stratification and nearby ponds may have affected DO concentrations in Lateral A. Fluctuations of the Snoqualmie River streamflow may have affected its tributary DO concentrations.

Other studies suggest waterway dredging may influence DO concentrations initially as soils rebuild in the recently dredged waterways.

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Introduction

Dissolved oxygen (DO) concentrations have frequently failed to meet Washington State water quality standards in flood plain drainage channels of Cherry and Ames Creeks (Sargeant and Svrjcek, 2008; Wild Fish Conservancy, 2009). However, Cherry and Ames Creeks are not currently on the federal Clean Water Act Section 303(d) list for DO because the data were yet to be verified for the most recent 2008 water quality assessment.

Low DO conditions have been documented in Cherry and Ames Creeks during varying seasonal temperature and discharge conditions. Typically as stream temperatures drop in the fall and winter, DO concentrations will rise above the seasonal, summer low DO concentrations. However, DO levels remain low in the lower reaches of Ames Creek well into winter, and these impairments are even more prevalent in Cherry Creek (Kaje, 2009). Seasonal depletion of DO in the flood plain habitats of Cherry Valley is at times severe enough to kill fish or otherwise make those habitats inhospitable (Wild Fish Conservancy, 2009). Possible mechanisms that cause low DO concentrations in the lower Cherry and Ames watersheds include excessive nutrients or direct inputs of low-oxygen water such as groundwater and drain tile runoff (Kaje, 2009).

Figure 1 shows the study areas of Cherry and Ames Creeks along with the Snoqualmie River and its flood plain. DO concentrations were continuously monitored in these study areas from May - June 2011.

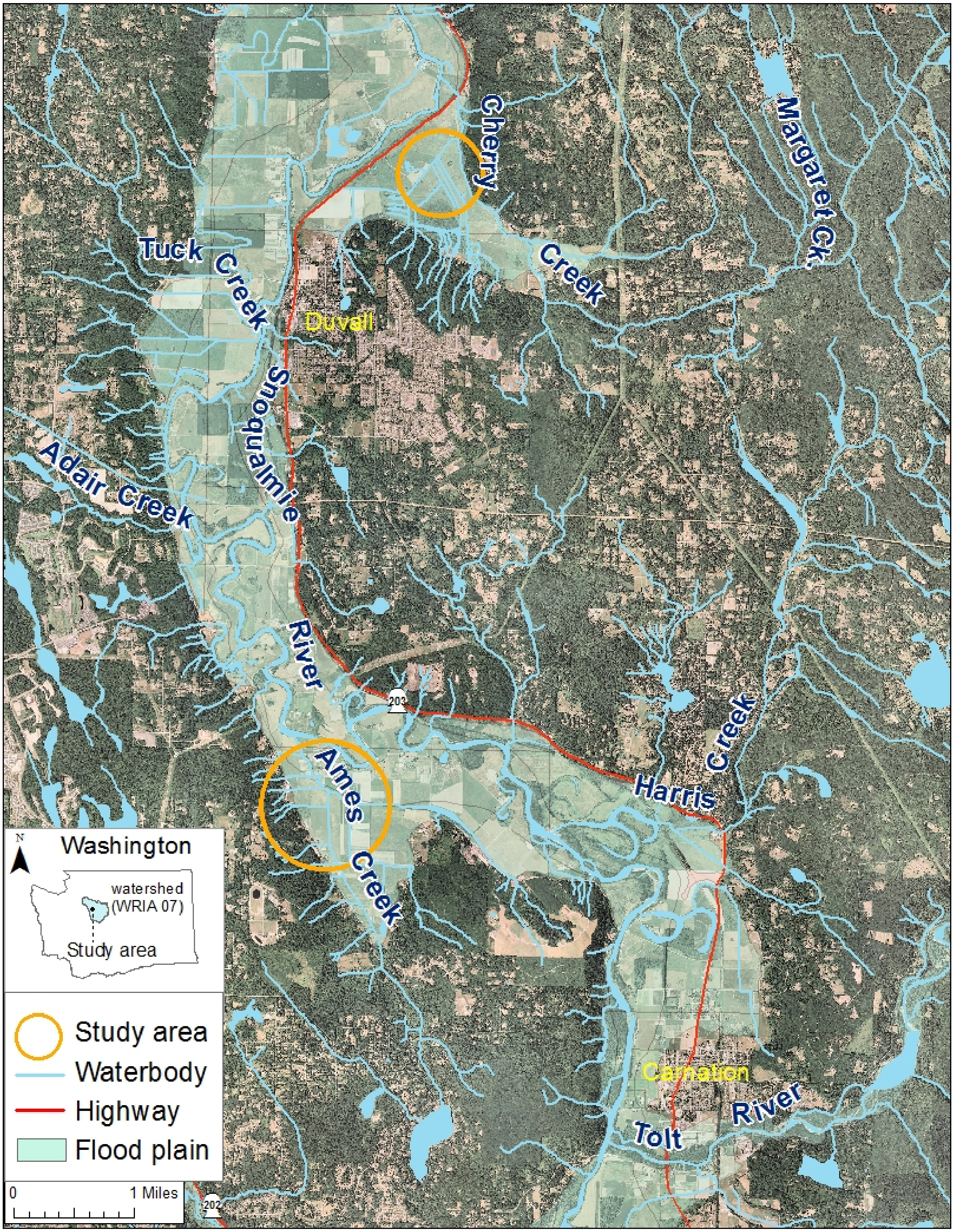

Figure 1. Lower Cherry and Ames Creek subbasin study areas in the Snoqualmie River watershed, May – June 2011.

Cherry Creek

The Cherry Creek watershed is 28.1 mi^2 (72.8 km^2) with its mainstem oriented east-to-west. It enters the Snoqualmie River at RM 6.7 downstream of Duvall (Figure 2). Land use in the watershed includes agriculture and wildlife area in the lower portion, rural residential, and forestry along the headwaters.

The Snoqualmie River 100-year flood plain extends approximately 2 miles into the Cherry Creek watershed (Figure 1). The Snoqualmie River floods the valley portion (Cherry Valley) of Cherry Creek during high-flow conditions (Kaje, 2009). This is one of the lowest points in the Snoqualmie River valley, so flooding is common from mid-November to April (WDFW, 2012). The lower 1.6 miles of Cherry Creek has a dike constructed along the left bank that primarily prevents backwater flooding of Cherry Valley from the Snoqualmie River (Harring, 2002).

Lateral A is a drainage channel that conveys tributary inflow and field drainage into Cherry Creek (Figure 2). All other drainage channels or laterals in the study area flow into Lateral A. Surface water discharge of Lateral A is regulated by a pump station at its confluence with Cherry Creek.

The lower reaches of the watershed are within a portion of the King County Snoqualmie River Agricultural Production District (APD). The Cherry Valley Farm is a dairy with less than 100 head of cattle; it borders Rasmussen Creek that flows into Cherry Creek via Lateral A (Figure 2). One pond near the dairy was historically used as a waste storage pond (Marsh, 2012).

The Cherry Valley Wildlife Unit area comprises most of the study area (Figure 2). The Cherry Valley Wildlife area is 386 acres, including about 100 acres of deciduous and coniferous forest (70 acres in swamp, 30 acres in uplands). The remainder is fields of primarily reed canary grass, 15 small man-made ponds (from 1/4 acre to two acres), and about two miles of hedgerows (WDFW, 2012). The ponds were constructed for waterfowl habitat and to enhance hunting opportunities (Peoples, 2012; Marsh, 2012).

Lake Margaret (53 acres) is a water supply for the lake area residents. Margaret Creek drains the lake and flows mostly through forested land with limited residential land use (Figure 1). The Margaret/Cherry Creek confluence is the approximate midway point on Cherry Creek from its mouth to headwaters (Kaje, 2009).

Instantaneous stream discharge of Cherry Creek was measured near the mouth at Highway 203 (Joy, 1994; Sargeant and Svrjcek, 2008; Stohr et al., 2011). Based on 14 measurements, the average discharge is 8.2 cubic feet per second (cfs) with a minimum of 2.8 cfs and a maximum of 31.9 cfs. The historical USGS Cherry Creek streamflow station (12150500) was in operation from July 1, 1945 to September 30, 1964. The average streamflow during this time was 58.3 cfs with a maximum of 550 cfs and a minimum of 2.2 cfs.

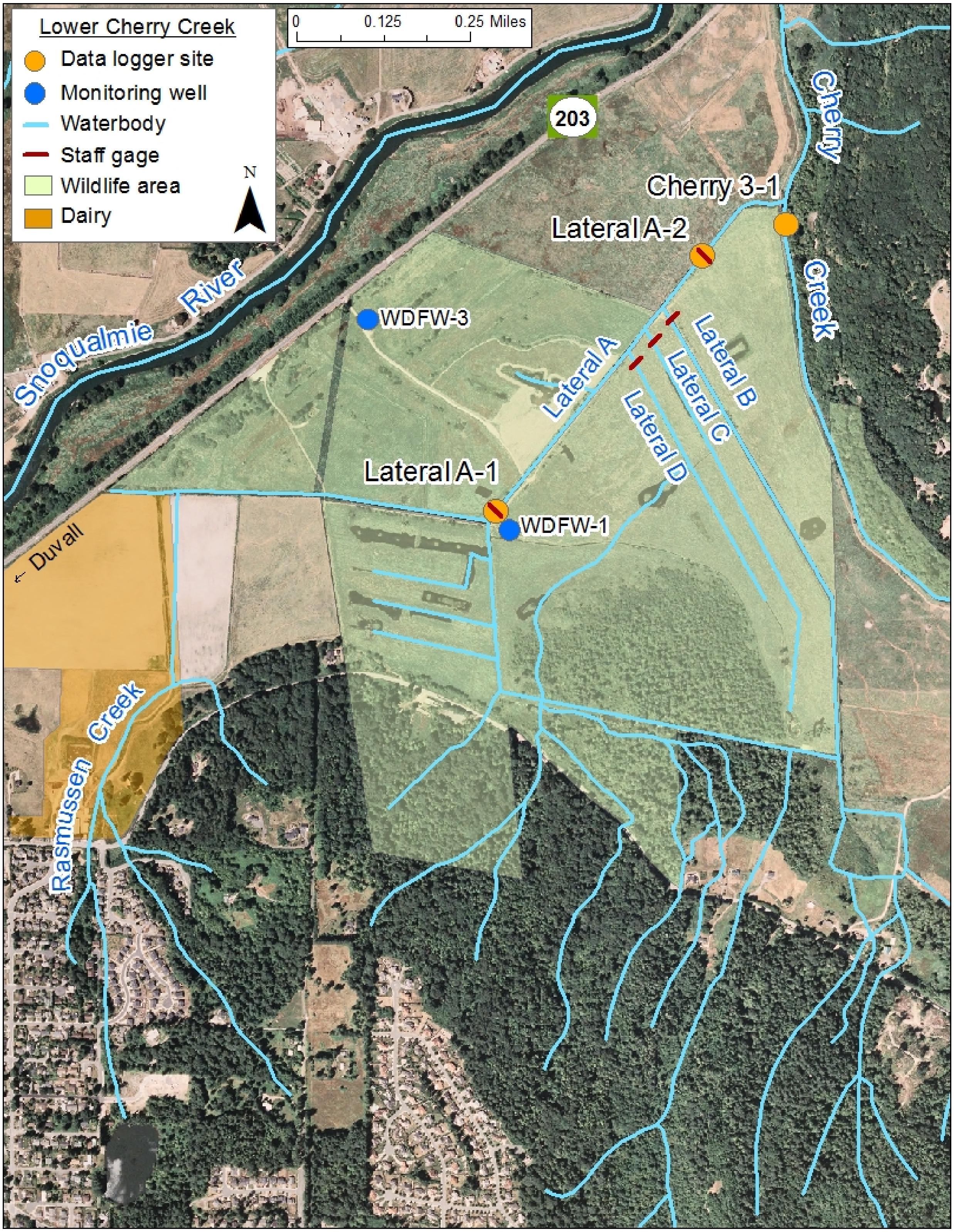

Figure 2. Lower Cherry Creek basin and water quality monitoring locations, May – June 2011.

Cherry Creek has an aquatic life use water quality designation of *core summer salmonid habitat* (WAC 173-201A- 602) because of the known presence of coho, chum, threatened Chinook, pink, threatened winter steelhead, and coastal Cutthroat (WDFW, 2007). Coho and winter steelhead spawn in the upper reaches of Cherry Creek. Chum, Chinook, and pink tend to spawn and rear in the lower portions of the subbasin. Among the lowland tributaries of the broader Snohomish Basin, Cherry Creek is thought to provide the highest potential to support Chinook salmon. However, habitat conditions would need to be improved substantially for Cherry Creek to meet its potential to support healthy Chinook populations (Kaje, 2009).

Lateral A and its tributaries are known to provide rearing habitat for Coho, cutthroat trout, and other native fishes, but few data are available to document summer low-flow water quality parameters that may preclude fish use or in fact contribute to fish mortality (WFC). The pump station on Lateral A hinders fish access to and from Cherry Creek (Harring, 2002).

Ames Creek

The Ames Creek (also known as Ames Lake Creek) watershed is 8.1 mi^2 (20.9 km^2) and primarily drains rural residential uplands before traversing a portion of the King County Snoqualmie River Agricultural Production District (APD) across the Snoqualmie River flood plain (Figure 1). Ames Creek enters the Snoqualmie River at RM 17 downstream of Carnation (Figure 3).

The upper reaches drain fairly steep topography before entering Ames Lake, which is 76 acres surrounded by homes and over 100 lots ranging in size from 1/3 acre to over 1 acre. From the outlet of the lake, Ames Creek continues north to the valley floor. Like many other tributaries in the APD, the flood plain portions of Ames Creek and its tributaries have been deepened and straightened over several decades to benefit agriculture along the valley floor.

Sikes Lake Creek is a key tributary that drains the northeast portion of the basin and Sikes Lake before joining the mainstem in the flood plain a short distance upstream from the confluence with the Snoqualmie River. As detailed in the Snoqualmie Watershed Water Quality Synthesis Report (Kaje, 2009), Sikes Lake Creek drainage differs from Ames Creek for some parameters. For example, King County data show DO impairments in Ames Creek, while Sikes Lake Creek DO levels meet water quality criteria (Kaje, 2009). Furthermore, data collected on Ames Creek at 80th Street suggest good DO levels when compared to data collected at 100th Street (Figure 3). Therefore, significant factors that cause low DO conditions appear to be introduced along the section of Ames Creek below 80th Street.

The Ames Creek flood plain is low lying and thus prone to flooding when the Snoqualmie River is running high. Even when the Snoqualmie River has not overtopped its banks, the water level in the river can be high enough to flood Ames Creek, beginning at the creek mouth and flooding back into the valley (Kaje, 2009). The majority of the APD within the Ames Creek basin is within the 100-year flood plain of the Snoqualmie River (Figure 1).

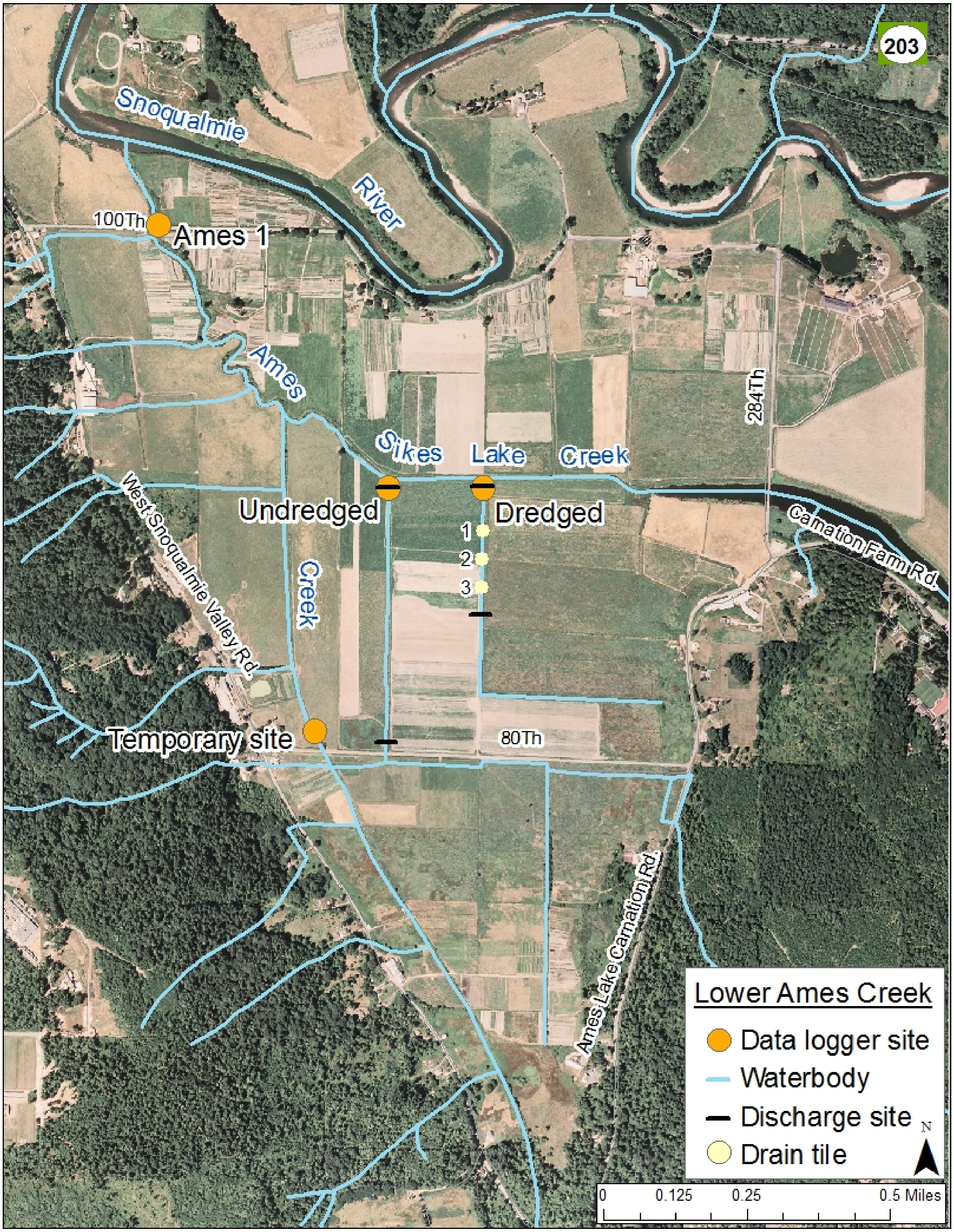

Figure 3. Lower Ames Creek watershed and water quality monitoring locations, May – June 2011.

Figure 3 shows sampling locations labeled *Dredged* and *Undredged*. These waterways enter Sikes Lake Creek before it flows into Ames Creek. The dredged waterway has been established for many years and was recently re-dredged in 2010 for maintenance, which was a year before field data collection for this study. Previously established drain tiles empty into the dredged waterway along its right bank. The undredged waterway was created many years ago. The exact date is not known. This waterway has not been dredged recently and has no known drain tiles that discharge to it.

Both private and commercial farms are located within the lower Ames Creek watershed. In 2011, Full Circle Farms completed a riparian restoration project along the dredged waterway by planting a variety of native vegetation. Small cattle farms are also within the watershed, primarily along the lower reaches of Ames Creek.

Instantaneous stream discharge of Ames Creek was measured near the mouth at 100th Street NE (Joy, 1994; Sargeant and Svrjcek, 2008; Stohr et al., 2011). Based on 21 measurements, the average discharge was 4.4 cubic feet per second (cfs) with a minimum of 3.1 cfs and a maximum of 11.3 cfs.

Ames Creek has an aquatic life use water quality designation of *salmonid spawning, rearing, and migration* (WAC 173-201A- 602) because of the known presence of coho, threatened Chinook, and threatened steelhead (WDFW, 2007, and Kaje, 2009). Chinook juveniles rear in the lower reaches, coho spawn and rear further up the watershed, and steelhead use is believed to fall somewhere in between Chinook and coho use (Kaje, 2009).

Project Collaboration

The Washington State Department of Ecology (Ecology), Wild Fish Conservancy (WFC), and King County collaborated to examine DO concentrations in the lower Cherry and Ames watersheds. All organizations agreed upon the study design and provided historical information about the study areas. Ecology and the WFC assisted each other with field data collection, data analysis, and report writing.

Ecology primarily took on the task of monitoring continuous DO conditions. WFC primarily took on the task of characterizing groundwater contributions to surface water drainage. King County advised all parties on the study design.

Project Goal

The study goal was to gain a more complete understanding of DO concentrations in the selected tributary subbasins of the Snoqualmie River valley flood plain including lower Cherry and Ames Creeks. Specifically, this study investigated if low DO conditions in surface water coincide with high groundwater/surface-water ratios during late spring following long periods of saturation in the Snoqualmie Valley flood plain. The study area included the lower reaches of Cherry Creek and Ames Creek and their contributing agricultural waterways. Study results may be used for future water quality improvement projects, forming a basis for continuing investigations.

Project Objectives

The project objective was to monitor springtime DO concentrations in selected agriculture waterway networks and identify potential contributing variables. Specific project objectives include:

- Provide information about the possibility of low DO coinciding with high groundwater-to-surface water ratios during late spring following long periods of soil saturation.
- Continuous monitoring of DO, temperature, pH, and conductivity at selected sites from May – June 2011.
- Compare continuous water quality data collected from recently dredged and undredged agricultural waterways.
- Locate tile drains and collect DO grab samples from the runoff.
- Compare time-series data results between the lower Cherry and Ames subbasins.
- Compare results to water quality criteria.
- Note fish presence and fish kills when apparent.
- Provide a data summary/analysis report for use by collaborators and other interested parties.

Site Selection

Six surface water monitoring locations were chosen in consultation with King County, Wild Fish Conservancy, and Ecology's Water Quality Program (Table 1).

Table 1. Lower Cherry and Ames Creeks monitoring locations, May – June 2011.

Site Name	Site Description	Latitude	Longitude
Cherry 3-1	Cherry Creek above Lateral A	47.76039	-121.95702
Lateral A-2	Cherry Valley Lateral A, below all other laterals	47.76005	-121.95960
Lateral A-1	Cherry Valley Lateral A, above other laterals	47.75451	-121.96597
Ames 1	Ames Creek at 100th below Sikes Lake Creek	47.68679	-121.98321
Dredged	Dredged waterway with drain tiles	47.68028	-121.97072
Undredged	Undredged waterway without drain tiles	47.68025	-121.97420

Latitude and Longitude coordinates derived from digital orthophotos, NAD 83 HARN datum.

Site selection was based on the following criteria and watershed characteristics:

- Sites located within the Snoqualmie River valley flood plain, within the Agricultural Production (ADP).
- Sites located in two different tributary subbasins to the Snoqualmie River that have similar soil properties, channelized drainage network, and land uses, including past and present agricultural practices.
- Presence of an agricultural waterway that was recently dredged for maintenance.
- Presence of an agricultural waterway that was not recently dredged.

Comparisons between the sites on Cherry and Ames Creeks were possible based on data collection results. Data results were used to compare the two sites on Lateral A and between the two sites within the lower Ames watershed including the dredged and undredged waterways. Data results from all sites were compared to the Washington State Water Quality Criteria.

Studies previously conducted in the Cherry and Ames watersheds, as well as the Snoqualmie River, were discussed in this report, including groundwater, nutrients, and streamflow. Other studies involving agricultural waterway maintenance, streambed soil structure, water quality, and biological activity were also presented. The reason for presenting the results from previous studies was to provide additional information about the study area.

Water Quality Criteria and Aquatic Life

The Snoqualmie River and its flood plain provides excellent wildlife habitat and is valued for recreation, aesthetics, agricultural production, and residential attractiveness. Many environmental studies have been conducted in the flood plain, but data gaps still remain. Low DO concentrations have been observed in flood plain reaches of Cherry Creek, Tuck Creek, Ames Creek, Patterson Creek, and Kimball Creek. However, the reasons for these depressed DO concentrations have not been identified.

Aquatic organisms are very sensitive to reductions in the level of DO in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. While direct mortality due to inadequate oxygen can occur, the state designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum DO concentrations, the water quality criteria are the lowest 1-day minimum oxygen concentrations that occur in a waterbody.

Table 2 shows water quality criteria applicable to the scope of this study within the Snoqualmie River watershed (WAC 173-201A). Aquatic life use designation includes *core summer salmonid habitat* criteria for Cherry Creek and *salmon spawning, and rearing migration* criteria for Ames/Sikes Creek.

Table 2. Washington State water quality criteria and aquatic life uses specific to each waterbody.
Adapted from WAC 173-201A including Table 602.

Aquatic Life Uses	Water Quality Criteria	Watershed Description
Core summer salmonid habitat. The key identifying characteristics of this use are summer (June 15 - September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids.	Temperature: (7-DADMax) 16°C Dissolved oxygen: (1-Dmin) 9.5 mg/L pH: pH shall be within the range of 6.5 to 8.5, with a human-caused variation within the above range of < 0.2 units	Cherry Creek watershed and its tributaries. Snoqualmie River and tributaries from and including Harris Creek to the west boundary of Twin Falls State Park on the South Fork (RM 9.1). Tributaries to all waters designated core summer salmonid habitat, or an Extraordinary primary contact for recreation. All lakes and all feeder streams to lakes, where reservoirs with a mean detention time > 15 days are treated as lakes for use designation. All surface waters not listed in Table 602 lying within National Forests, National Parks, or Wilderness Areas.
Salmonid spawning, rearing, and migration. The key identifying characteristic of this use is salmon or trout spawning and emergence that only occurs outside of the summer season (September 16 - June 14). Other common characteristic aquatic life uses for waters in this category include rearing and migration by salmonids.	Temperature: (7-DADMax) 17.5°C Dissolved oxygen: (1-Dmin) 8.0 mg/L pH: pH shall be within the range of 6.5 to 8.5, with a human-caused variation within the above range of < 0.5 units	Snoqualmie River from mouth to junction with Harris Creek (RM 21.3). All other surface waters.

7-DADMax is the 7 day rolling maximum average.
1-Dmin is the single day minimum.

Water quality criteria and aquatic life uses are designed to protect all natural biota living in our waters. The Snoqualmie River flood plain tributaries support life stages of many species of salmon, trout, whitefish, suckers, and more.

The wide range of plants, insects, and other organisms that live in the watersheds provide the underlying support for fish and other species. From the plant level with algae to zooplankton and macroinvertebrates, each organism is part of a properly functioning ecosystem. Sufficient DO concentrations, low water temperatures, proper nutrient levels, and adequate streamflows are all important to the good health of the animal species.

When a stream or river experiences pollution, native plants and bugs often fail to flourish and are replaced by non-native plants and bugs. Fish that have used those native species as food over their thousands of years in the stream often do not adjust to the new food sources and can suffer from a lack of nutrition. Malnourished fish do not compete as well and become more susceptible to predation. In extreme cases, young fish could die from malnutrition. Inappropriate oxygen, nutrient, or temperature levels can cause this problem. In addition, young fish that experience excessively high temperatures during rearing are more susceptible to diseases and can suffer developmental problems that can reduce their ability to spawn successfully in the future (Meyers et al., 1998).

Methods

Methods used for data collection and analysis are described in detail in the Quality Assurance (QA) Project Plan (Marsh and Kardouni, 2011). The QA Project Plan was published after data collection began. Additional unforeseen time was necessary to achieve consensus, development, and review. Involved organizations determined that immediate data collect was necessary in order to assess target conditions of extended groundwater saturation and spring run-off.

Following site establishment, equipment was successfully installed in the drainage ditch networks to monitor water quality during the antecedent spring conditions. However, when data collection commenced, the methods established to determine volume of groundwater contribution versus surface water run-off were not viable due to high sediment volumes and low flow velocities in the Ames Creek drainage network, and inability to establish cross-sections in the Cherry Valley drainage network due to depth and substrate composition. Stage gages were installed in the Cherry Valley system to relative changes in surface water levels in the ditches; however, these values do not provide a quantitative assessment of percent of groundwater contribution to the overall stage.

Field Data Collection

In summary, DO, temperature, pH, and conductivity were monitored providing a continuous (time series) data set. Data were logged every half hour. Calibration and deployment of Hydrolab® data loggers followed Ecology's Environmental Assessment Program standard operating procedure (SOP) EAP033 *Hydrolab DataSonde and MiniSonde Multiprobes* (Swanson, 2007). Data collection began during the first week of May 2011 and ended in the first week of July for most sites. Data collection began on the dredged and undredged sites (Table 1 and Figure 3) on May 20. The logging Hydrolab® was cleaned and the batteries refurbished. Often on a weekly basis the Hydrolabs® were entirely replaced with a recently calibrated instrument.

DO grab samples were collected for QA purposes at each monitoring site. DO grab samples were also collected on the drain tiles flowing into the dredged agricultural waterway of the Ames watershed (Figure 3). The drain tiles were located along the right bank of the recently dredged waterway. DO grab samples were collected and analyzed using SOP EAP023 *Collection and Analysis of Dissolved Oxygen (Winkler Method)* (Ward and Mathieu, 2011).

Instantaneous groundwater levels were measured on a weekly basis in the Cherry Creek watershed at two Washington State Department of Fish and Wildlife (WDFW) monitoring wells in the Cherry Valley Wildlife Unit (Figure 2). Surface water staff gages were installed and surface water levels were recorded at Lateral A, 1 and 2, and on Laterals B, C, and D during site visits (Figure 2). Streamflow was not assessed in Cherry Creek or Lateral A. Following inquiry, discharge rates of the pump station on Lateral A was also unknown.

Stream discharge was measured on a weekly basis along the dredged and undredged waterways (Figure 3). Stream discharge was also measured below the confluence of both agricultural waterways in the Ames watershed. However, these data were not considered usable, due to the high degree of error associated with the discharge measurement. Streamflow was not assessed on Ames Creek.

Data were temporarily collected on Ames Creek above the agricultural waterway confluence from May 10 through 20 (Figure 3). The 'Temporary site' near 80th Street was established when initial resources were available. Site selection changed over the course of the study to monitor the agricultural waterways. Therefore, the upstream site on Ames Creek needed to be abandoned. Data from the temporary Ames Creek site at 80th were compared to the downstream location at 100th in the 'Results and Discussion' section of this report.

The presence of fish was noted during this study; however, the fish were not identified by species. No fish kills were noticed over the course of field data collection.

Data Preparation

Recorded field data were entered in to Microsoft Excel spreadsheets, and an Access database (Microsoft, 2007). Data were checked for logging errors. Misrepresentative, erroneous, or missing data may be generated by the Hydrolab® either, drifting from calibration, going dry, buried in sediment, or replaced/serviced. Field observations, data charts, Winkler titrations, and Hydrolab® comparisons and calibrations, were all part of the data QA process.

To interpret DO patterns at the study sites, results were compared with Snoqualmie River discharge records, groundwater levels, staff gage levels, and climate data from two weather stations: Snohomish and 21 acres in Woodinville. The weather stations are operated by Washington State University (WSU) Agricultural Weather Network. Concurrent measurements of temperature, and historical water chemistry data were also compared to DO data.

The API can be used to estimate rainfall retention and release in natural watersheds (Kohler and Linsley, 1951). The API is a running sum of daily rainfall, calculated by adding each day's rainfall to a fraction 'K' of the previous day's API shown in the following equation:

$$I_t = I_0 K^t$$

I_0 is the initial value of the API, I_t is the reduced value after t days, and K is a constant recessive factor (K = 0.9 for this study). Average annual precipitation was used as the initial I_0 value, where I_0 = 0.2 inches based on the average precipitation from 2008 through 2011.

Results and Discussion

Data Quality Assurance

The measurement quality objectives (MQO) for the deployed Hydrolab® multi-probes are summarized in Table 3. Overall, the Hydrolab® data loggers operated with precision with the exception of specific conductance. Frequent cleaning, servicing, and calibration of the multi-probes increased the ability to log acceptable quality data.

Table 3. Summary of precision measurement quality objectives (MQO) for the multi-probe post-deployment calibration check.

Measured field parameter	Data qualifier and definition			Precision of data results		
	accept	estimate	reject	Average	Max	Min
Conductivity (uS/cm)	≤ ± 5%	> ± 5% and ≤ ± 10%	> ± 10%	-2.8%	56.7%	0.0%
Dissolved oxygen (% saturation)	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%	0.0%	12.0%	0.0%
pH (standard units)	≤ ± 0.25	> ± 0.25 and ≤ ± 0.5	> ± 0.5	0.02	1.58	0

Daily post-calibration check results compared to the MQOs are presented in Tables A-2, A-3, and A-4. Data qualifiers were used in order to characterize data usability. Data were either qualified as accepted, estimates, or rejected based on the MQO criteria. Specific conductivity data were often rejected and not used (Table A-2) because the calibration checks were not within the acceptable limits of the MQO. The Hydrolab® multi-probe in Ames Creek logged pH values that were rejected based on the MQO criteria (Table A-3). These data were adjusted as described in detail in this section of the report.

All Hydrolab® monitoring sites included a DO grab sample that was analyzed using the Winkler titration method (SM4500OC) described in Ecology's SOP manuals (Ward and Mathieu, 2011). The results from the DO titrations and Hydrolab® readings were compared using relative standard deviation (RSD). The MQO stated in the QA Project Plan (Marsh and Kardouni, 2011) recommends RSD values greater than 10% should be qualified. All acceptable DO QA data were within the 10% RSD MQO. The collective RPD between the Winkler QA and logged DO results was 2.75%. Logged DO data were not adjusted to Winkler titration results because the Measurement Quality Objective (MQO) was met.

In some instances, DO titration results were not used for the MQO assessment when (1) the water was notably stratified, (2) the probe was inaccessible, or (3) the water was highly turbid. Winkler DO QA results were not useable at times for the sites along Lateral A and the dredged waterway. In the cases mentioned below, the titration QA was considered misrepresentative and not used in the MQO evaluation.

- Lateral A-1 and A-2 was often stratified, made noticeable by comparing temperatures and DO concentrations at different depths. Collecting a clean representative DO grab sample near the DO probe was often not possible because the water was too deep or the bank was too steep for safe access.
- Upon site visit, the recently dredged waterway in the Ames watershed was often highly turbid, thus interfering with the Winkler titration. Furthermore, fine sediments were easily entrained from the soft channel bottom, given the shallow depths of the dredged waterway. The combination of turbid water, sediment entrainment, slow velocities, and shallow depths made it difficult to achieve a clean DO grab sample.

Lateral A is a tributary to Cherry Creek (Figure 2). Cherry Creek was only monitored upstream of the confluence with Lateral A. Therefore the effects of Lateral A DO concentrations on Cherry Creek are not captured in this study.

Deployed multi-probes (*Hydrolab®*) were replaced on an as-need basis for thorough cleaning and calibration at all but the Ames Creek site at 100th. The hydrolab in Ames Creek was cleaned at every site visit when the water was shallow enough for retrieval. The logger in Ames Creek showed pH drift; therefore, the data were adjusted (interpolated) using calibration results. Upon initial deployment the logged pH values were acceptable based on instrument calibration before deployment. Over the course of deployment, the instrument drifted 1.6 pH units above the calibration standard, evident in the final calibration check (Table A-3, #38). As a result, the pH values were adjusted using pH values from initial deployment to pH values of the retrieval using the linear interpolation function in Microsoft Excel. Similarly, pH data were adjusted for a 0.32 drift on Cherry Creek from 6/1/11 through 6/16/11 using pH values from initial deployment and a recently calibrated QA check probe.

Assessment of groundwater contributions to the drainage ditches proved to be difficult. The planned methodology was to measure volume along a longitudinal transect for each individual study ditch in effort to determine the increase due to groundwater contribution. This approach was flawed as it did not account for overland flow. In addition, field conditions prevented obtaining data using the acoustic Doppler velocimeter (ADV) to measure discharge.

In the lower Ames Creek watershed, the high sediment concentrations and low flow velocities prevented accurate discharge measurements. In the Cherry Valley drainage ditches, cross sections could not be established to obtain discharge measurements, due to depth and lack of accessibility, thus stage gages were installed as an alternative method of recording changes in surface water levels within the ditch network and along a longitudinal transect of Lateral A. However, the stage gages only provided relative depths and not actual changes in surface water elevations, due to the lack of bathymetric surface data. This method would have also failed to account for overland flow contributions.

Water Quality Criteria

Results show the Washington State water quality criteria were not met for all sites for at least two parameters (Table 4). The percentage of days when water quality did not meet criteria is calculated by the following equation:

$$\text{Did not meet criteria (\%)} = \frac{\text{Total number of days criteria not met}}{\text{Total number of days of data}}$$

All sites did not meet their respective one-day minimum DO water quality criteria. Sites on Cherry Creek, Lateral A-1, and A-2, did not meet the 9.5 mg/L criterion. Furthermore, Lateral A-2 did not meet the criterion on any day (100% of the time). Similarly, the dredged waterway site did not meet the 8 mg/L criterion on any day. The undredged waterway and Ames Creek also did not meet the 8 mg/L DO criterion on 79% and 29% of the days, respectively.

Table 4. Percent of the time that water quality criteria were not met based on summarized daily data.

Site ID	Did not meet criteria (%)			Water quality criteria		
	Dissolved oxygen	Temperature**	pH	Dissolved oxygen*	Temperature**	pH
Cherry 3-1	39	23	0	9.5 mg/L	16°C	6.5 – 8.5
Lateral A-2	100	41	66	9.5 mg/L	16°C	6.5 – 8.5
Lateral A-1	97	71	62	9.5 mg/L	16°C	6.5 – 8.5
Ames 1	29	3	12	8.0 mg/L	17.5°C	6.5 – 8.5
Dredged	100	84	94	8.0 mg/L	17.5°C	6.5 – 8.5
Undredged	79	0	18	8.0 mg/L	17.5°C	6.5 – 8.5

* Not to lower at any time
** 7-day average daily maximum temperature not to be exceeded

The 7-day rolling maximum average criteria for temperature were exceeded at all but the undredged waterway (Table 4). None of the Cherry Creek watershed sites met the 16°C 7-day average daily maximum criterion (Table 4). Ames Creek exceeded the 17.5°C temperature criterion only 3% of the time. However, the typical thermal critical period for temperature in western Washington was not surveyed during this study. In western Washington the thermal critical period is usually from mid-July through mid-August.

Cherry Creek had the only monitoring location where the pH water quality criteria were met. All other monitoring locations did not meet the pH criterion where pH was less than 6.5. Lateral A-1 did not meet the pH criteria on 62% of the monitoring days, and Lateral A-2 did not met the pH criteria on 66% of the monitoring days. Ames Creek and the undredged waterway exceeded the pH criteria on 12 and 18% of the monitoring days, respectively. The dredged waterway had the highest of all percentages of days not meeting the pH criteria at 94%.

Figures 4 and 5 show time-series DO concentrations plotted at half-hour intervals for all monitoring stations separated by watershed. DO means, maximum ranges, and percentiles for all data were different at each monitoring location (Figure 6).

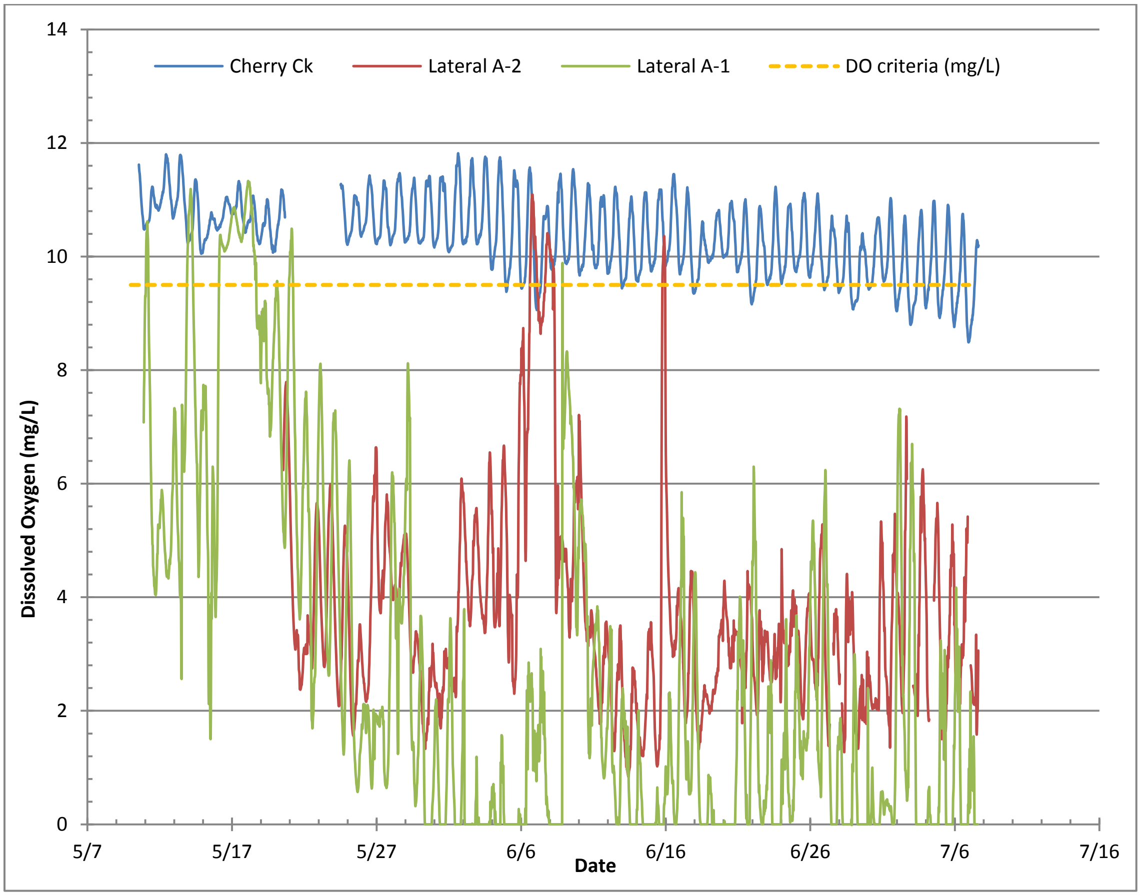

Figure 4. Time-series dissolved oxygen concentrations in lower the Cherry Creek watershed.

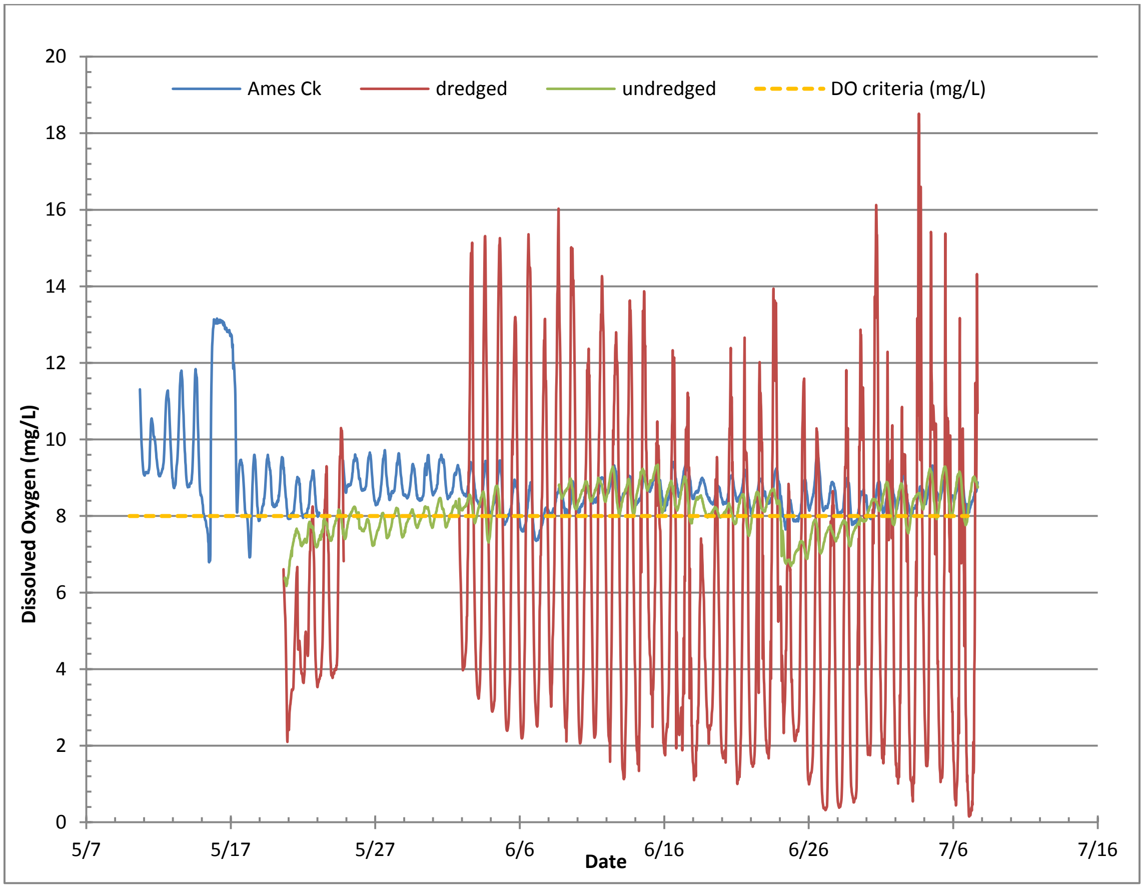

Figure 5. Time-series dissolved oxygen concentrations in the lower Ames Creek watershed.

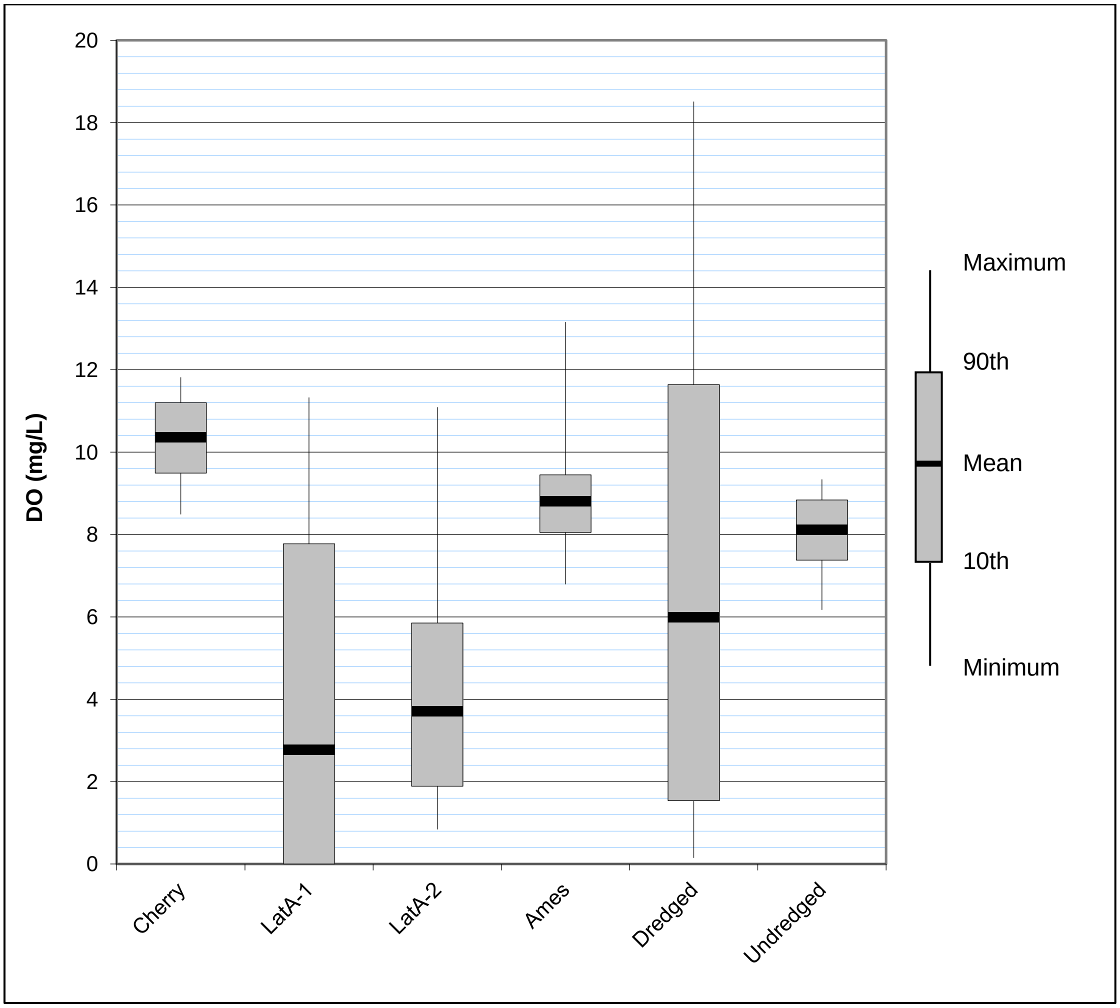

Figure 6. Dissolved oxygen data distribution including maximum, minimum, mean, 90th percentile, and 10th percentile of all data recorded.

Cherry Creek had a total maximum DO range of 3.3 mg/L that was lower than Lateral A-1 and A-2 with ranges of 11.3 and 10.3 mg/L respectively (Figure 6). Lateral A-1 had DO concentrations down to zero (Figure 4). Downstream of Lateral A-1 is Lateral A-2 where DO concentrations did not reach zero. DO concentrations in Cherry Creek fluctuated around a total average of 10.4 mg/L where Lateral A-1 and A-2 had much lower total averages of 2.9 and 3.8 mg/L respectively (Figure 6).

Ames Creek and the undredged waterway had total maximum DO ranges of 6.4 and 3.2 mg/L respectively and the dredged waterway had the highest total maximum range, compared to all other sites at 18.4 mg/L (Figure 5). DO concentrations in Ames Creek and the undredged waterway fluctuated around similar total averages of 8.8 and 8.1 mg/L, respectively, while the average DO concentrations in the dredged waterway was slightly lower at 6.0 mg/L.

A Mann-Whitney U-test showed that the distribution of DO concentrations were significantly different ($p<0.05$) between particular site comparisons. Comparisons include: Cherry Creek with Ames Creek, Undredged with Dredged, and along Lateral A (Lateral A-1 with Lateral A-2). The two sites on Lateral A were also analyzed for correlation using a linear regression. No correlation was found between Lateral A-1 and Lateral A-2.

Table A-1 in Appendix A shows the DO data distribution including the standard deviation (SD), mean, maximum, and minimum for all data. Appendix B, Figures B-1 through B-14, show individual DO charts for each site (including time-series, daily max, and daily min) and time-series charts comparing DO, temperature, pH, and conductivity.

Summarized data are available in table format in Ecology's Environmental Information Management (EIM) database. The user study ID code for this particular study in EIM is jkar0003, and the web site is www.ecy.wa.gov/eim.

Daily Minimum Dissolved Oxygen Concentrations

Daily minimum DO concentrations are shown in Figures 7 and 8 for each watershed. Distributions of daily minimum DO concentrations are presented in Figure 9.

The daily minimum DO levels in Cherry Creek gradually decreased from May to July (Figure 7). Daily minimum DO levels in Lateral A-2 did not rise above the 9.5 mg/L criterion. Daily minimum DO levels in Lateral A-1 showed a sharp increase and decline in mid-May and then eventually reached a concentration of zero.

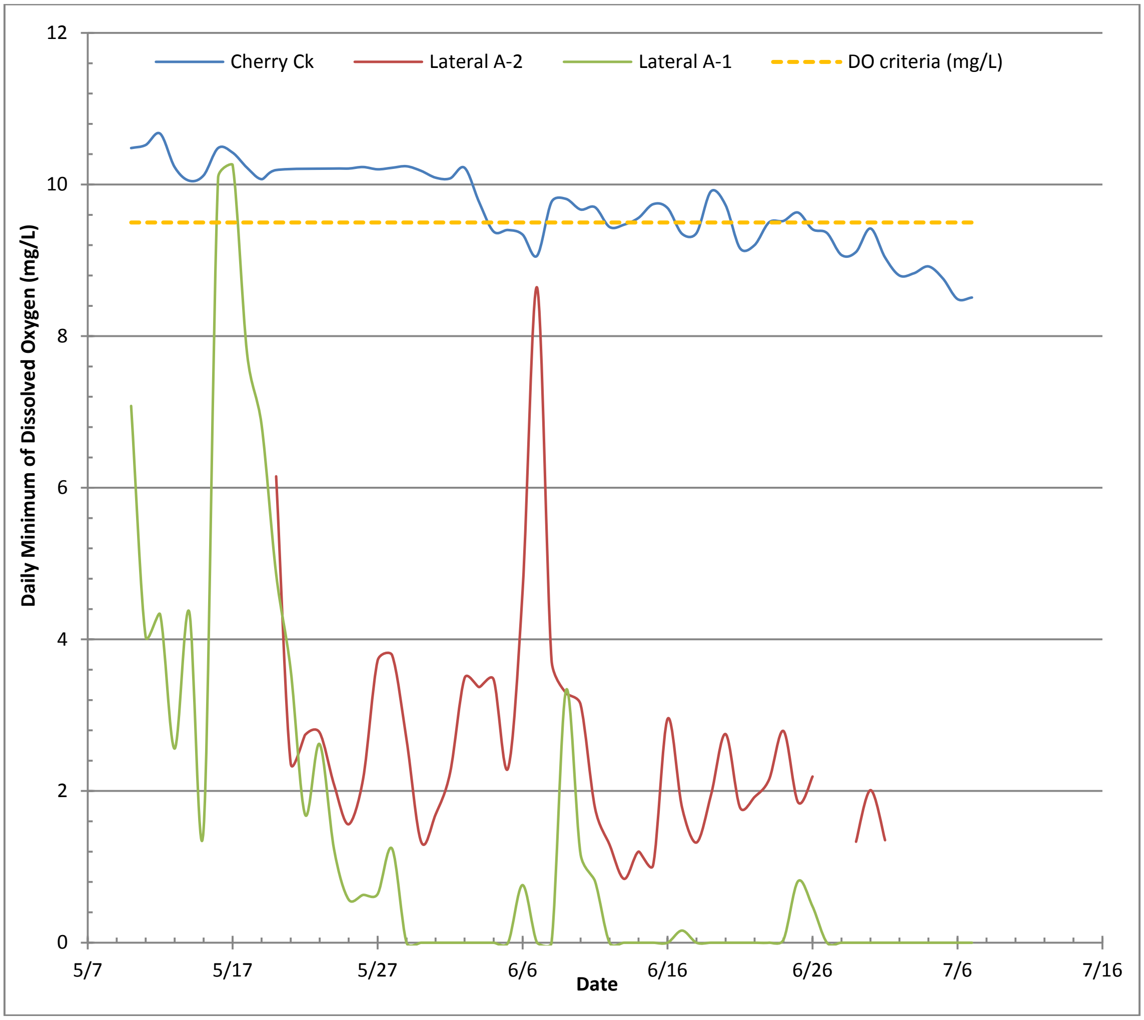

Figure 7. Daily minimum dissolved oxygen concentrations in the lower Cherry Creek watershed.

Both Ames Creek and the undredged waterway showed daily DO minimums that fluctuated near the 8 mg/L water quality criterion (Figure 8). However, the undredged waterway did not meet the DO water quality criterion more often than Ames Creek. The daily minimum DO concentrations of the dredged waterway did not rise above the 8 mg/L water quality criterion and had a decreasing trend from May to July.

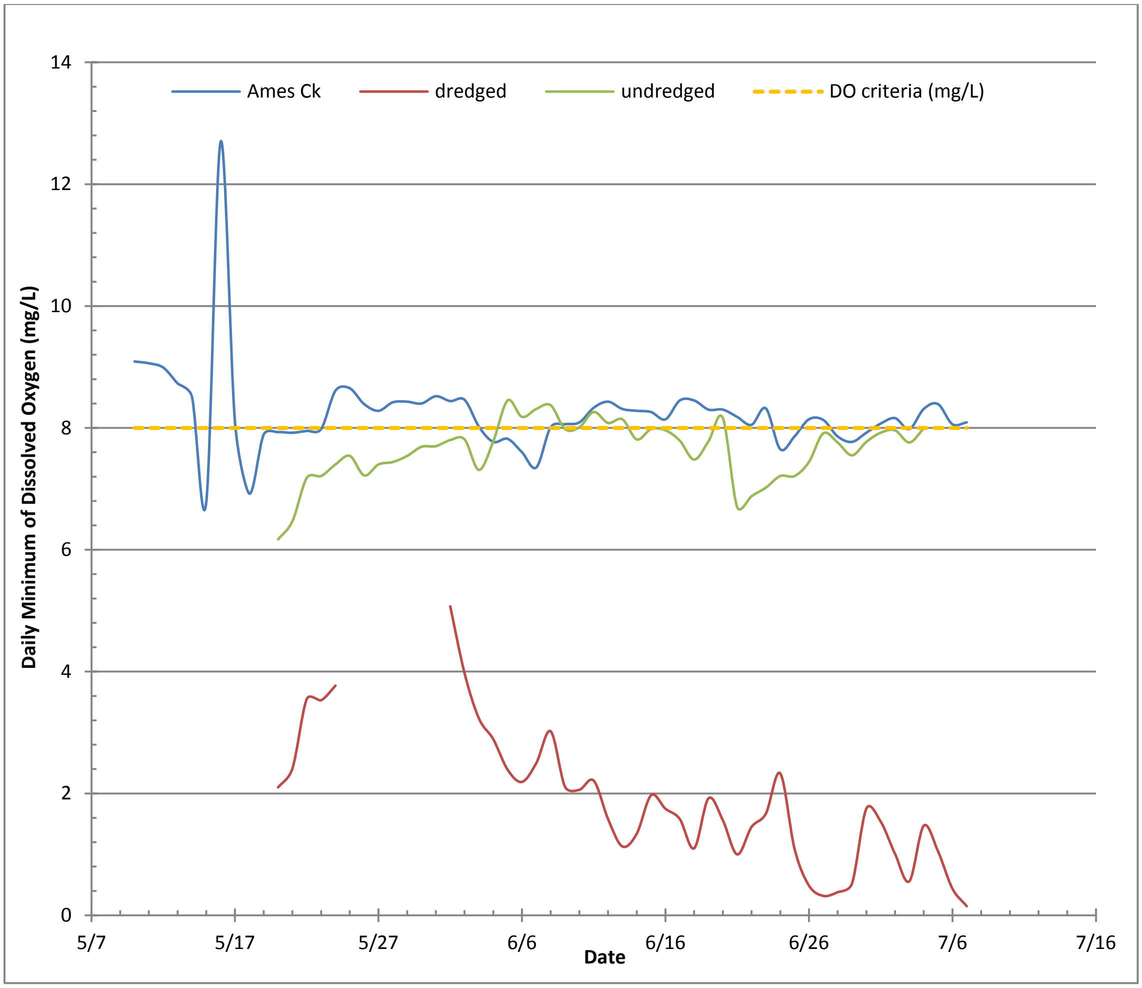

Figure 8. Daily minimum dissolved oxygen concentrations in the lower Ames Creek watershed.

Compared to all other monitoring locations, Lateral A-1 and the dredged waterway showed the lowest mean daily minimum DO levels (Figure 9). Cherry Creek and Ames Creek showed the highest mean daily minimum DO levels. The greatest distributions of minimum DO levels were observed in Lateral A-1 and the dredged waterway, while the lowest were observed in Ames Creek.

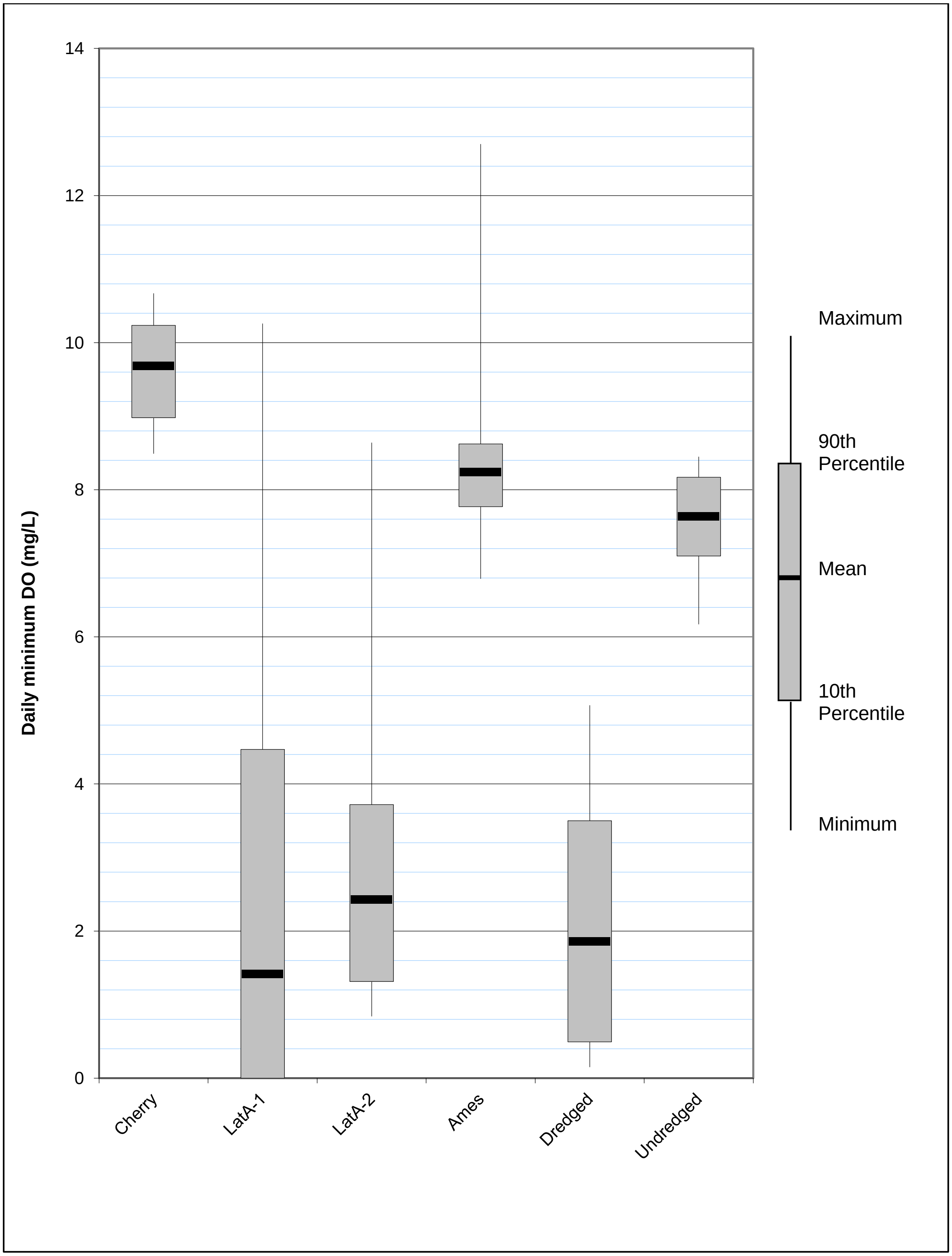

Figure 9. Data distribution of the daily minimum dissolved oxygen including maximum, minimum, mean, 90th percentile, and 10th percentile.

Snoqualmie River Streamflow Relationship to Dissolved Oxygen

Lateral A-1 showed a rapid increase and decline in daily minimum DO concentrations on two occasions: in mid-May and in early June (Figure 7). These spikes in DO levels occurred roughly from May 15 through May 17 and on June 8. Similarly, Lateral A-2 showed a rapid fluctuation in DO levels on June 6. Cherry Creek did not show a rapid change in DO levels of the same magnitude as the sites on Lateral A. Instead, Cherry Creek showed a slight increase and subsequent decrease in DO levels in mid-May. The opposite happened in early June, where the DO levels in Cherry Creek showed a slight decrease in DO levels followed by an increase. Similarly, Ames Creek also showed a rapid fluctuation in DO levels in mid-May and, like Cherry Creek, a subtle decrease in early June (Figure 8). There were no data in mid-May on the undredged and dredged waterways, and the early June event did not seem to be detected.

The reason for the rapid change in DO levels at some sites during mid-May and early June was not clear. However, it was likely that high discharge rates of the Snoqualmie River may have caused flooding that influenced the water quality at the monitoring stations. The Snoqualmie River USGS streamflow station near Carnation (12149000) showed an increased discharge in mid-May and another of smaller magnitude in early June (Figure 10). The timing of increased discharges of the Snoqualmie River coincided with the increased daily minimum DO levels along Lateral A and Ames Creek in mid-May. The slight increased discharge of the Snoqualmie River in early June coincided with increased DO levels in Lateral A and oppositely a slight decrease in DO levels in both Cherry and Ames Creeks.

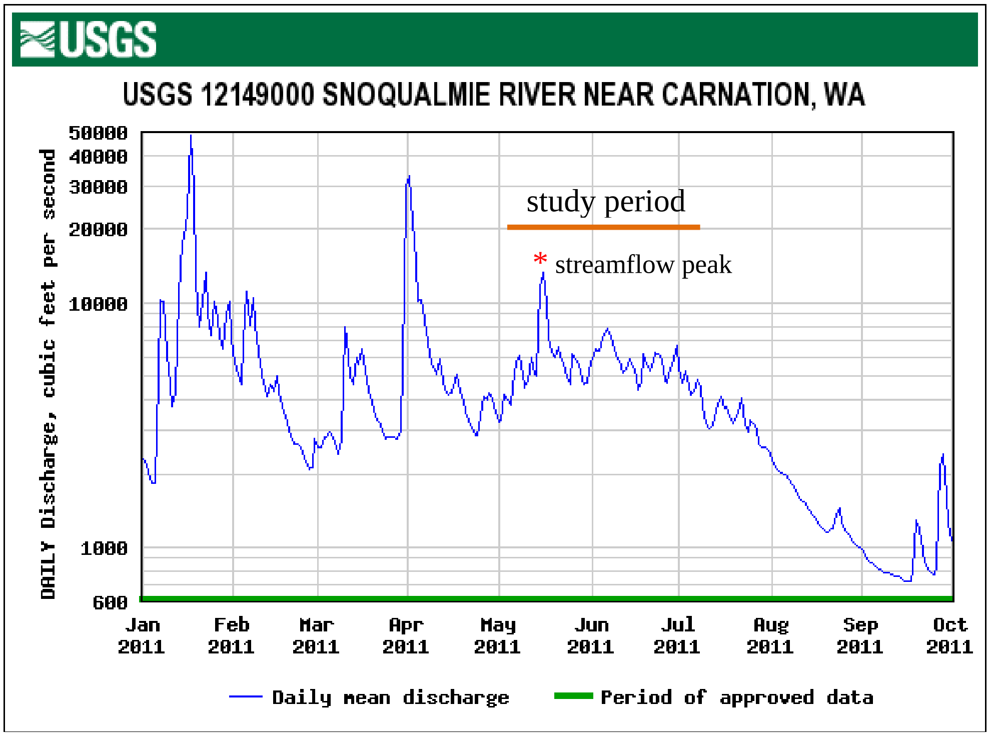

Figure 10. Snoqualmie River discharge near Carnation from January through September 2011, provided by USGS.

Stage height at the USGS gage station near Carnation (12149000) did not rise above flood stage (54 ft) from May through July 2011. During this time the stage height had a maximum of 52 ft on May 16, just to feet below flood stage. The USGS station at Duvall (12150400) has been established for flood monitoring purposes where the stage will begin working at 29 ft. May 16 showed a peak at 35 ft. The flood stage for this station has not been established.

Daily mean precipitation data from nearby WSU meteorological stations in Woodinville and Snohomish were averaged together and charted along with Snoqualmie River discharge and change in snow depth at Snoqualmie Pass (Figure 11). Snow depth data are provided by the National Weather and Climate Center Snotel meteorological station Olallie Meadows (672) with an elevation of 4,030 feet above sea level. The Snoqualmie River had a direct response to precipitation. Snow melt such as rain-on-snow could have also contributed to the rise in Snoqualmie River discharge in mid-May, where as much as 4 inches of snow melted in one day.

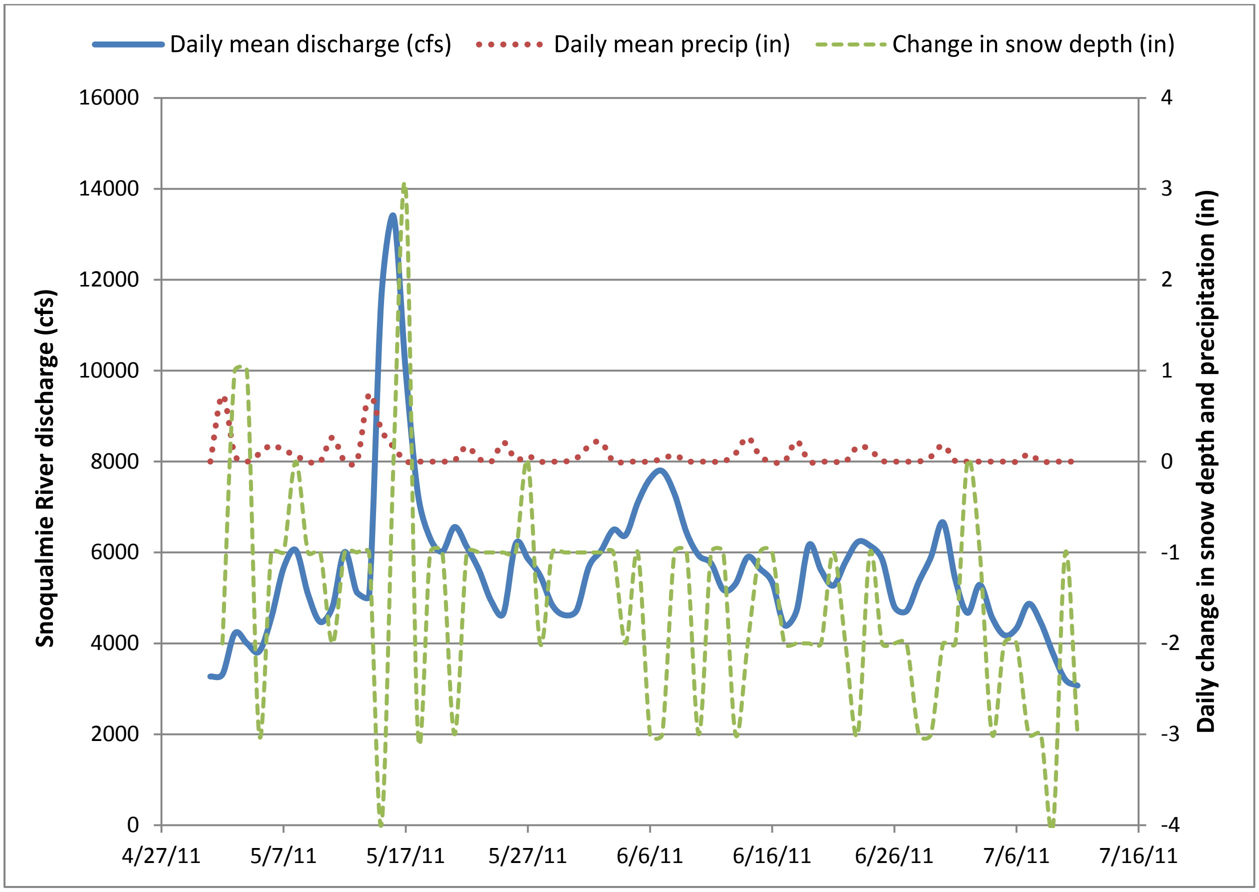

Figure 11. Snoqualmie River discharge near Carnation, change in snow depth, and precipitation data during the study period, May – July 2011.

Precipitation and snow melt increased the Snoqualmie River discharges (Figure 11). Under certain discharge conditions, the Snoqualmie River water level raised high enough to inundate its flood plain. The exact stage height of the Snoqualmie River that causes flooding in the lower reaches of the Cherry and Ames watersheds was not determined. However, there was evidence that suggests the possibility of Snoqualmie River flood waters raising the minimum DO concentrations of Ames Creek and Lateral A (Figures 7 and 8).

Lower Cherry Creek Watershed

The differences between data results and physical characteristics between sites along Lateral A were considered (see Figure 2 for site locations). Cherry Creek and Lateral A DO levels were compared with the antecedent precipitation index (API). Cherry Valley is known to flood frequently from late fall through late spring where estimated depths are much greater than presented here. Flood waters may have affected DO levels in both sites along Lateral A to varying degrees.

The storage and release cycle upstream of the pump station may have affected the water quality on Lateral A. Water quality may be influenced to a greater degree by the pump station operation at Lateral A-2 because it is closer to the pump than Lateral A-1. The pump station discharged water from Lateral A into Cherry Creek through several gates. Pump and gate operations were monitored once per week upon site visits. The pump station was in operation during each site visit; however, the rate of discharge was unknown. Streamflow and stream velocity data were not collected on Cherry Creek for this study. Historical instantaneous stream velocity data collected from June through October 2006 on Cherry Creek ranged from 0.20 – 1.27 ft/sec, with an average of 0.67 ft/sec (Stohr et al., 2011).

The sites along Lateral A had different water depths; however, the fluctuation ranges were similar. Lateral A-1 had an estimated maximum depth of 5.5 ft, with a minimum of 0.5 ft. Site Lateral A-2 had an estimated maximum depth of approximately 7 ft, with a minimum of 1.5 ft. The ranges of depths for Lateral A-1 and Lateral A-2 were similar at 5 ft and 5.5 ft, respectively. Hydrolab data logger depth varied according to water level but stayed within ½ a foot above the streambed during the lowest water depth levels. Due to relatively shallow waters, the data logger at Lateral A-1 spent more time closer to the streambed and closer to the surface than did the data logger at Lateral A-2.

Logging at varying depths in the water column may have produced different DO signals. The oxygen consumption of benthic organisms may have influenced DO concentrations to a greater degree at Lateral A-1 than at Lateral A-2. The Hydrolab® probes were often closer to the streambed at Lateral A-l than Lateral A-2, especially toward the end of the study. Furthermore, water volume increased from Lateral A-1 to A-2. The smaller, shallower waters passing through Lateral A-1 were more susceptible to temperature changes that have an influence on DO concentrations (Table A-1).

Ponds were also located upstream near the monitoring location of Lateral A-1 (Figure 2). Pond waters could be a source influencing the DO signal observed at Lateral A-1 and, to some degree, the site at Lateral A-2. Pond water possibly had a greater influence on the site Lateral A-1 than Lateral A-2, due to Lateral A-1 being in closer proximity to the ponds.

Waters from Laterals B, C, and D all passed through the site at Lateral A-2 (Figure 2). The water quality at Lateral A-1 was not influenced by Laterals B, C, and D, since it was upstream of these tributaries. These contributing laterals possibly influenced DO concentrations at Lateral A-2 since it is downstream of these tributaries.

Figure 12 shows daily minimum DO concentrations at Lateral A-1 and A-2 along with the spot check measurements of the staff gages at each site. Staff gage measurements seemed to loosely follow DO concentrations. Based on Figure 12, the DO levels along Lateral A may be affected by changes water depths. The mechanisms that affect DO concentrations as water levels change in Lateral A were not positively identified based on the results of this study. However, possible explanations may include, but are not limited to, the following: (1) a switch from surface water to sub-surface or groundwater as water levels dropped, (2) nearby ponds may have dominated the water quality of Lateral A as water levels dropped, (3) Snoqualmie River flood waters may have dominated water quality as water levels increased.

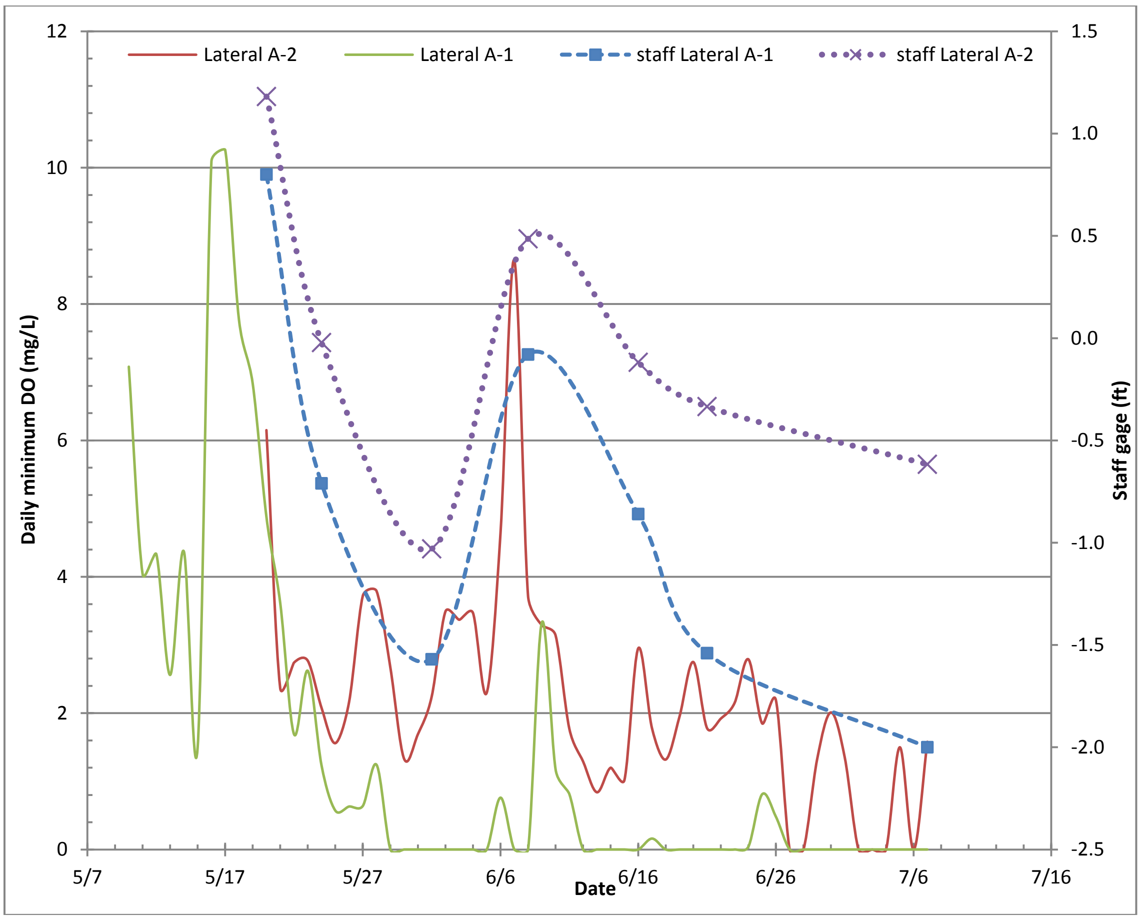

Figure 12. Daily minimum dissolved oxygen concentrations in Lateral A compared with instream staff gage heights.

The two monitoring locations along Lateral A often showed signs of stratification evident by incrementally lowering the field QA Hydrolab® to different depths and noting temperature, conductivity, pH, and DO readings. Unfortunately, these data were not recorded, but descriptions in the field note book mentioned this observed stratification. Temperatures and DO levels were higher near the surface and lower near the stream bottom. Stratification was more common during times of greater water depths and less common when the waters were shallower. The mechanisms that cause stratification were not positively identified. However, stratification may occur in slower moving to stagnant waterbodies.

DO percent saturation is the amount of oxygen dissolved in the water sample compared to the maximum amount that could be present at the same temperature and atmospheric pressure. Appendix B shows charts of DO percent saturation for Cherry Creek, Lateral A-1, and Lateral A-2 (Figure B-13). The percent saturation pattern followed a very similar to DO concentrations. Cherry Creek fluctuated between 86 and 117%, showing good water quality most of the time, even though it fell below the 9.5 mg/L DO criterion. Both sites on Lateral A showed that DO percent saturation fluctuated radically between 0 to 116% with seemingly no defined pattern. The monitoring sites on Lateral A were under-saturated most of the time, possibly indicating the potential for excessive biotic oxygen respiration.

Temperature, pressure, and dissolved solutes affect DO percent saturation. Relationships between temperature and DO were checked by comparing daily average maximum temperature with daily average minimum DO concentrations. Both sites on Lateral A showed no relationship between temperature and DO. In contrast, Cherry Creek showed a strong correlation between temperature and DO (r^2=0.97) using linear regression analysis. Water temperature had a greater effect on Cherry Creek than Lateral A, according to these results.

Lateral A showed an increase in DO concentrations three to four days after an increase in API (Figure 13). The DO minimum and average of Lateral A-1 had a positive correlation with API ($r^2 \approx 0.6$), although not very strong. Lateral A-1 is upstream of Lateral A-2 (Figure 2). A correlation was not indicated between Lateral A-2 and API. Cherry Creek had positive relationship between DO and API as well (DO minimum $r^2 \approx 0.5$, and DO maximum $r^2 \approx 0.6$) although not very strong. Precipitation runoff into the Cherry Creek watershed may have caused DO concentrations to temporarily increase; however, focused data collection will be necessary confirm this. For example localized meteorological stations in each watershed would produce more accurate precipitation information. Local precipitation information combined with time-series DO levels could be used to develop their relationship.

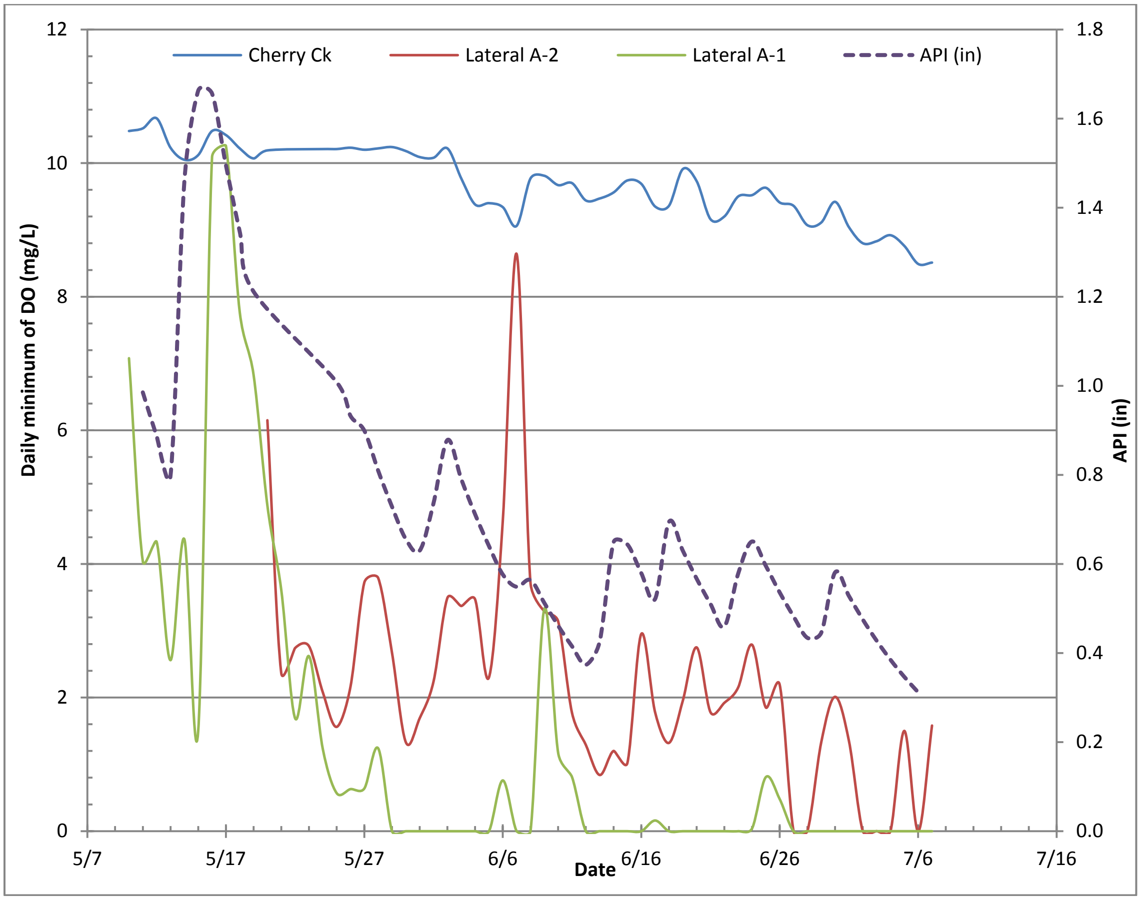

Figure 13. Antecedent Precipitation Index (API) and daily minimum dissolved oxygen in Cherry Creek and Lateral A.

API was also compared to the monitoring WDFW groundwater monitoring wells in Cherry Valley (Figure 2). Linear regression showed that a strong positive correlation existed between monitoring well WDFW-3 and API (r^2=0.95). However, a strong correlation was not detected between WDFW-1 and API (r^2=0.37). More data collection would be necessary in order to develop regression analysis more thoroughly.

Descriptive soil percolation rates in lower Cherry Valley are presented in Figure 14. Percolation rates are provided by Department of Natural Resources (DNR) from their Geographic Information System (GIS) database. The majority of the Cherry Creek study area showed slow to moderate soil percolation rates. Therefore, precipitation had the tendency to enter Lateral A and Cherry Creek by overland flow, instead of interflow through the soils.

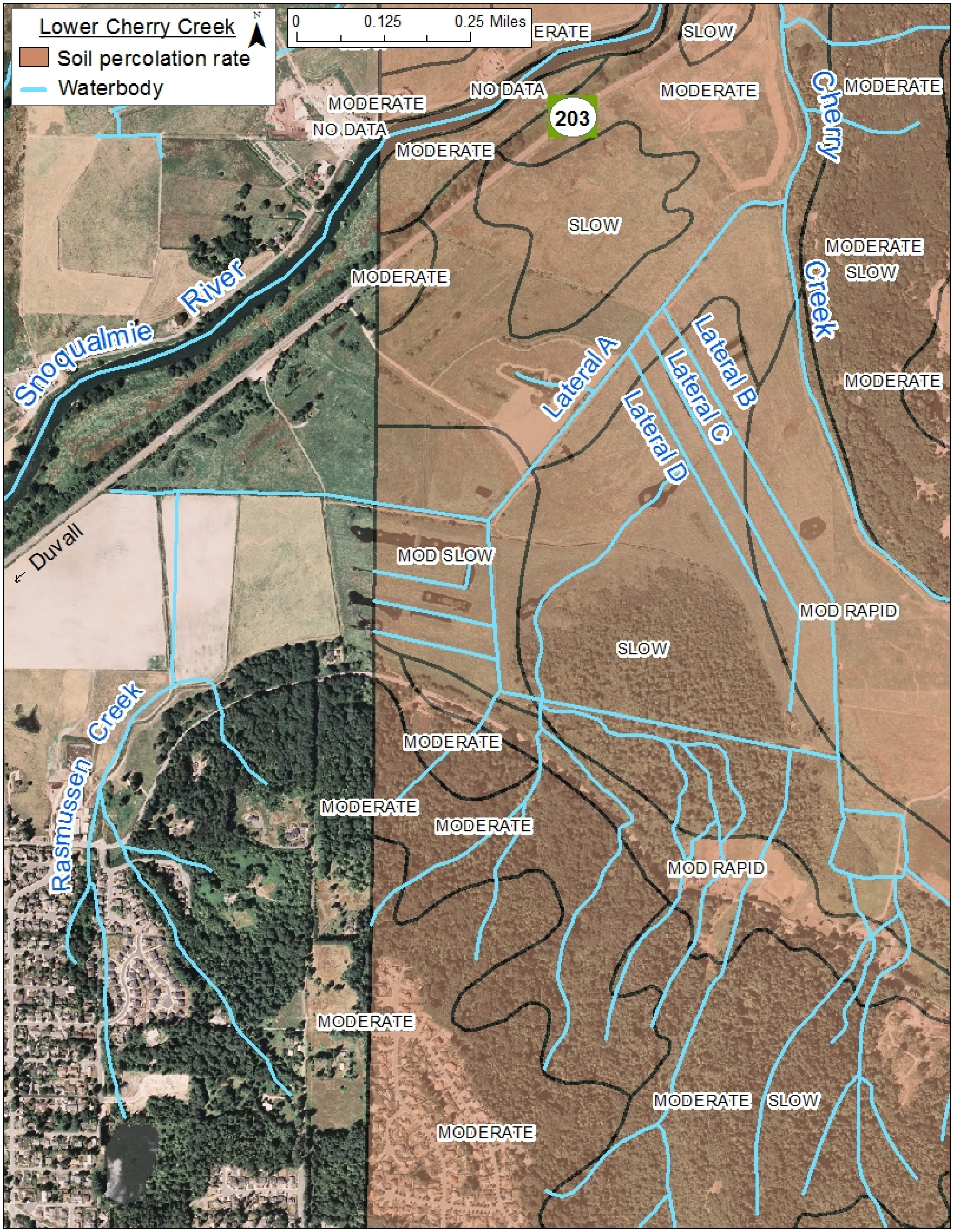

Figure 14. Soil percolation descriptive in the lower Cherry Creek watershed.

Lower Ames Creek Watershed

Ames Creek and the undredged waterway had similar DO characteristics, while the dredged waterway was different (Figures 5, 6, 8, and 9). Ames Creek was monitored below the confluence with the agricultural waterways. The magnitude of impact of water quality on Ames Creek from the agricultural waterways was not apparent from this study. Groundwater influences may have affected the DO levels in the lower Ames Creek watershed; however, study results did not yield sufficient information to address these possibilities. Over the course of field data collection, the adjacent agricultural fields along Ames Creek and the dredged and undredged waterways were being tilled and planted at various stages.

Data were temporarily collected on Ames Creek above the agricultural waterway confluence from May 10 through 20 (Figure 3). Ames Creek at the upstream site of 80th Street had higher average DO concentrations (10.4 mg/L) than the downstream site at 100th Street (9.7 mg/L). The DO minimums showed the same pattern where the upstream was 9.9 mg/L and the downstream was 8.6 mg/L. These data may reaffirm the suggested existence of a DO sink between 80th and 100th on Ames Creek (Kaje, 2009).

Ames Creek DO data from May 15 through 17 may have captured a Snoqualmie River backwater effect (Figure 15) or increased precipitation runoff (Figure 11). Figure 15 shows an unusual rise in DO levels at 100th Street that was not apparent at the monitoring location at 80th Street. When data from May 15 through 17 were not included for comparison, the average DO levels at 80th were higher than those at 100th, at 10.5 and 9.3 mg/L, respectively. The average minimum DO concentrations also followed this similar pattern, where the site at 80th had an average minimum DO concentration of 10.0 mg/L, and the site at 100th was 8.4 mg/L. Thus the suspected DO sink between 80th and 100th becomes more apparent when significant influences of the Snoqualmie River or increased precipitation runoff are not included in the data analysis.

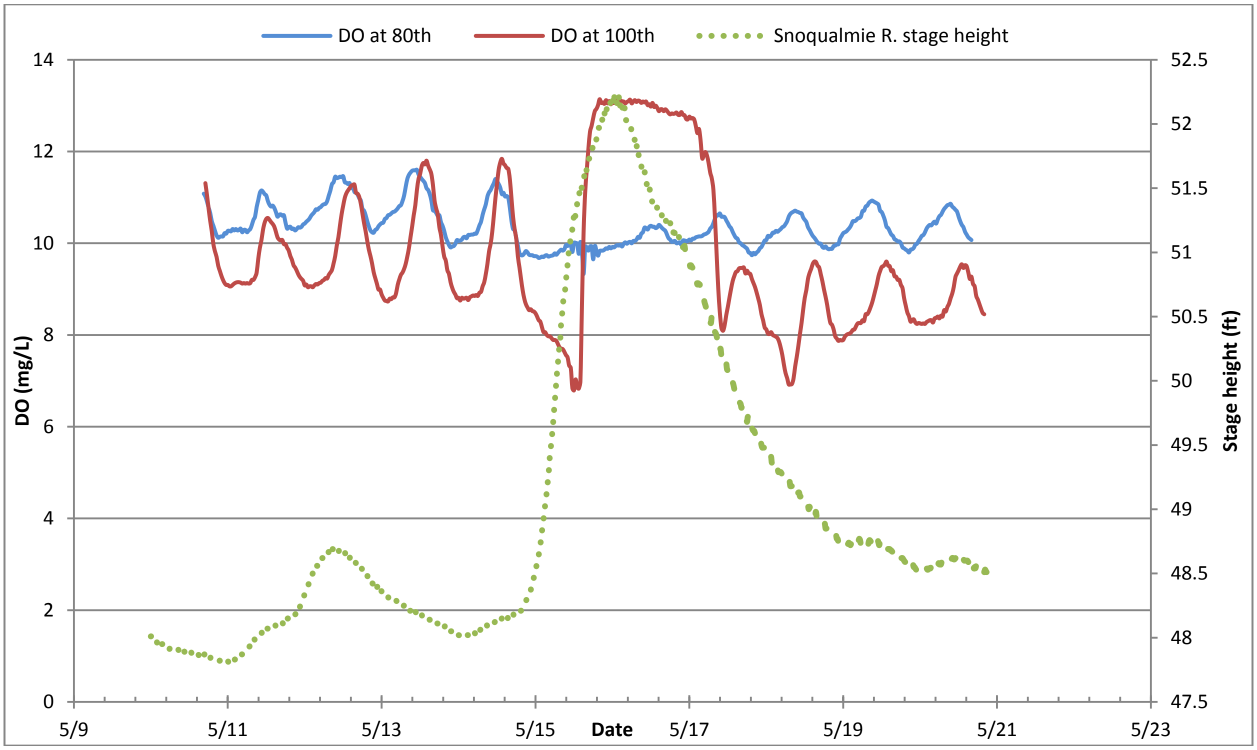

Figure 15. Snoqualmie River stage height (USGS gage station near Carnation (12149000)) and dissolved oxygen (DO) concentrations in Ames Creek at the upstream site (80th) and the downstream site (100th).

Instantaneous stream velocity data collected from June through October 2006 on Ames Creek ranged from 0.54 – 1.00 ft/sec, with an average of 0.67 ft/sec (Stohr et al., 2011). The dredged and undredged waterways were also assessed for streamflow over the course of this study; however, these data were not considered accurate, due to high degrees of uncertainty. Table 5 shows one set of streamflow measurements conducted in the dredged and undredged waterways. The velocities and discharges of the undredged waterway were greater than that of the dredged waterway.

Table 5. Discharge measurements taken on the dredged and undredged waterways including upstream and downstream transects.

Site	Date	Width	Area	Mean Depth	Mean Velocity	Total Discharge	Overall Discharge Uncertainty %
		(ft)	(ft^2)	(ft)	(ft/s)	(cfs)	(ISO)
Dredged, Upper	6/21/2011	2.00	0.462	0.231	0.1906	0.0881	13.3
Dredged, Lower	6/21/2011	6.80	2.57	0.378	0.0725	0.1863	8.5
Undredged, Upper	6/21/2011	5.10	1.595	0.313	0.793	1.2647	10.8
Undredged, Lower	6/21/2011	5.20	9.265	1.782	0.1873	1.7354	10.4

Low velocities (long residence times) can enhance local primary productivity rates, thus increasing diurnal fluctuation (Allan, 1995). Increased primary productivity in the slower moving waters of the dredged waterway may have been factors that led to a wide range of daily DO concentrations. However, there are no nutrient data and limited velocity measurements to confirm this possibility. Low DO concentrations occurred at night indicating biological respiration, and the high concentrations occurred in the afternoon indicating an increase in primary productivity (Figure 5). The higher stream velocities of Ames Creek and the undredged waterway tend to transport nutrients downstream before enhanced nutrient uptake occurs by autotrophs and microbes.

Based on aerial photos the dredged waterway had a different origin that the undredged waterway. The dredged waterway originates from the adjacent agricultural fields and hillside, primarily from the east. The undredged waterway originates from a wetland, agricultural fields, and hillsides south of 80th.

Drain tiles enter the dredged waterway from the right bank (in this case the eastern bank) upstream of the monitoring station (Figure 3). Three drain tiles had sufficient discharge to sample for DO and analyze using the Winkler method. Eventually only two drain tiles had sufficient discharge to sample during weekly site visits. DO concentrations in the drain tiles were low ranging from 0.8 – 4.1 mg/L with an average of 1.9 mg/L (Table 6). The drain tile closer to the monitoring site of the dredged waterway had a lower overall DO average (1.0 mg/L) than the drain tile near the upstream reach (2.6 mg/L). Drain tiles were not noticed entering the undredged waterway, where insufficient information was available to confirm their presence or absence.

Table 6. Dissolved oxygen (DO) grab samples from the drain tiles that discharge to the dredged waterway of the Ames watershed.

Sample collection date	Drain tile # and DO (mg/L)		
	1	2	3
6/1/11	1.05	2.65	3.8
6/8/11	1.2	no data	4.1
6/16/11	1.1		1.3
6/21/11	0.8		1.1

The effects of precipitation were compared to DO levels in Ames Creek and the agricultural waterways (Figure 16). Linear regression showed weak correlations between API and DO levels in the Ames Creek watershed. However, Figure 16 showed that API and the dredged waterway seemed to follow similar patterns.

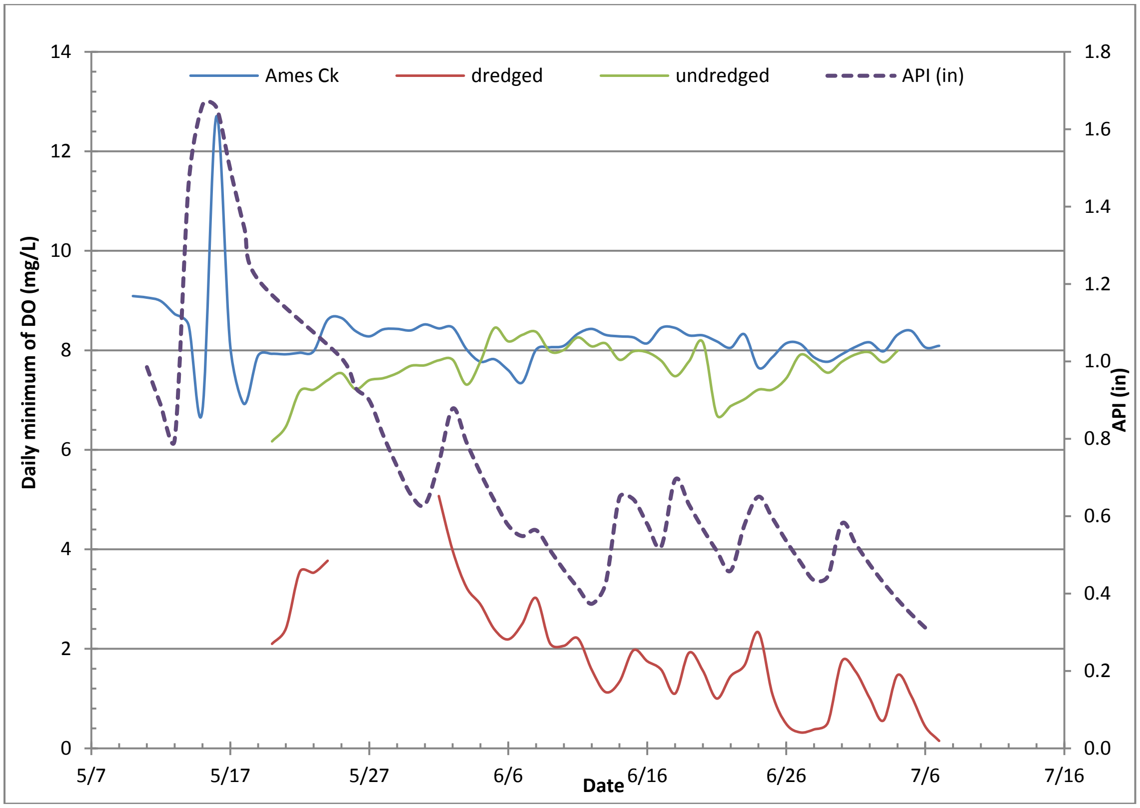

Figure 16. Antecedent Precipitation Index (API) and daily minimum dissolved oxygen (DO) in Ames Creek and the dredged and undredged agricultural waterways.

Descriptive soil percolation rates in the lower Ames Creek watershed are presented in Figure 17. Percolation descriptions are provided by Department of Natural Resources (DNR) from their Geographic Information System (GIS) database. The majority of the Ames Creek study area showed slow to moderate soil percolation rates. Therefore, precipitation had the tendency to enter nearby waterbodies by overland flow instead of interflow through the soils. The drain tiles that empty into the dredged waterway assist to increase the rate of water drainage from adjacent soils.

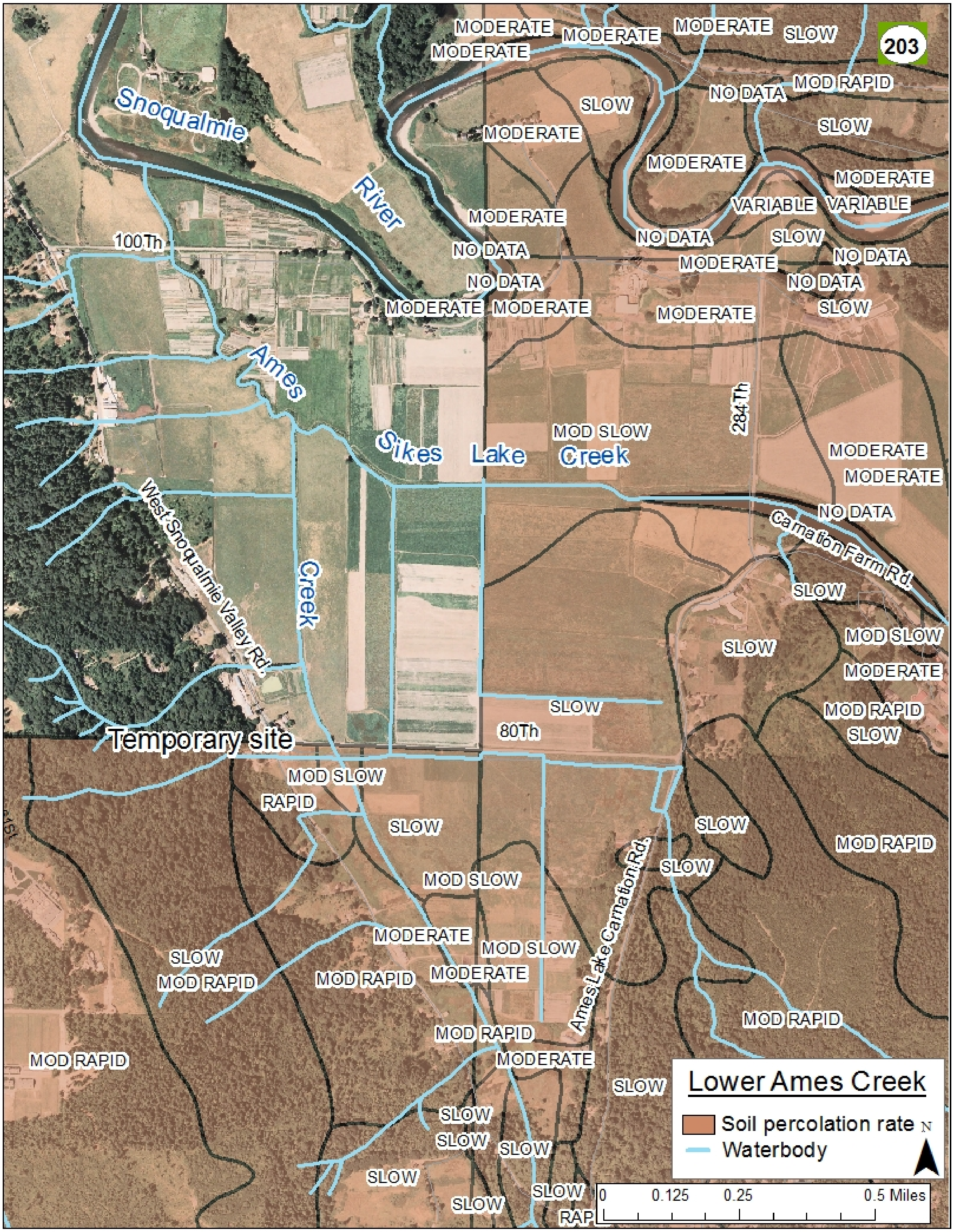

Figure 17. Soil percolation descriptive in the lower Ames Creek watershed.

Similar Studies

Results from similar studies are presented here in order to consider mechanisms that influence DO levels that were not assessed during this investigation.

Effects of Waterway Maintenance

A study conducted by Washington State University and the University of Washington (2008) monitored the effects of waterway dredging on water quality. The results of the study may help understand the water quality characteristics documented in the dredged site and may useful in determining the best management practices (BMP) for agricultural waterways. Dredging a waterway can significantly change its water quality. Contrary actions may occur post dredging, for instance increased sediment oxygen demand while average DO levels in the water column increase. Pertinent conclusions from that study are as follows:

- Sediment oxygen demand (SOD) was an integral part of the DO equation because DO depletion occurs when O_2 dependent micro-organisms and chemical processes decay organic sediments and vegetation at the sediment water column interface. This exhausts O_2 in the sediment and became a significant DO sink in the overlying water layers.
- Ditch maintenance altered DO considerably. There was a significant difference in DO between agricultural and non-agricultural waterways.
- Diel (daily) fluctuations in DO was more pronounced after dredging than before dredging, possibly due to increased sunlight availability to the waterway after dredging.
- Post-dredging DO concentrations were on average 3.4 mg/mL higher than pre-dredging.
- Chemical sediment oxygen demand (CSOD) had more effect on the total SOD than the biological component (BSOD), regardless of stream type and treatment. BSOD represented the biological oxidation of organic matter occurring in the aerobic portion of the sediment, while CSOD referred to the oxidation of reduced compounds diffusing upwards from deeper anaerobic soils.
- Pre-dredged SOD was lower than post-dredged channels.
- Elevated SOD in hand-cleaned channels were possibly due to organic matter remaining after treatment.
- Sandy substrate tended to have lower SOD. Fine sediments (silts, loams, organic debris) tended to have highest SOD.
- DO levels increased significantly following vegetation removal; however, SOD increased as well becoming a DO sink. This may be contrary; however, increased sunlight exposure post dredging may override SOD.

Soil organic matter accumulation in drainage ditch systems represents a significant contrast from most fluvial systems. Organic matter (OM) accumulation occurs under low-flow conditions, which prevents scouring and depresses decomposition rates under anaerobic conditions (Needelman et al., 2007).

Needelman (2007) suggests "soil-forming processes such as horizon formation, biogeochemical cycling, structure formation, and faunal activity may affect the environmental quality of a ditch and its role in mediating the quality of overlying waters… Management procedures that encourage ditch vegetation, such as targeted clean-outs and gradual inundation, may increase the stability and ecosystem services of ditch soils. Site assessment and modeling of ditches may be improved by integrating information about ditch soils".

Nutrients

Historical data showed that Ames Creek had an average ammonia-nitrogen (NH_4) concentration of 0.12 mg/L (Joy, 1994; Onwumere and Batts, 2004; Sargeant and Svrjcek, 2008). Cherry Creek had a relatively lower average concentration of 0.03 mg/L ammonia-nitrogen (Joy, 1994; Sargeant and Svrjcek, 2008). These data were collected as part of the same studies intermittently from 1989 to 2005 (summaries in Table 7). Agricultural practices were more predominate in the lower Ames Creek watershed than that of the lower Cherry Creek watershed. Agricultural practices are known to increase nutrient concentrations of receiving waterways.

Table 7. Ammonia-nitrogen concentration summary from previous studies in Cherry Creek and Ames Creek.

Stream name	Mean NH_4 (mg/L)	Max NH_4 (mg/L)	Min NH_4 (mg/L)
Cherry Creek	0.02	0.11	0.01
Ames Creek	0.12	0.33	0.02

Ames Creek nutrient data were collected at the same location where the monitoring for this study took place at 100th Street. The Cherry Creek data were collected at Highway 203 that is downstream of the monitoring location for this study where influences from Lateral A were captured. These results are in the EIM database (study IDs JJOY0001, and GONW0001) (Joy, 1994; Onwumere and Batts, 2004). Based on ammonia-nitrogen concentrations, the lower Ames Creek basin had a higher nitrogenous oxygen demand (BOD) than that of the lower Cherry Creek basin.

A previous study conducted in Cherry Valley showed that Lateral A had a high average ammonia-nitrogen concentration of 0.74 mg/L (Table 8) (WFC and Tulalip Tribes of Washington, 2009). The WFC and Tulalip Tribes collected data in the Cherry Valley flood plain including ammonia-nitrogen (Figure 18). Ammonia-nitrogen data were not available for the dredged and undredged waterways of the lower Ames Creek watershed.

Lateral A showed ammonia-nitrogen concentrations as high as 6.9 mg/L. From May through June 2009, weekly sampling showed an increase in ammonia-nitrogen concentrations in Lateral A (Table 8). In general, ammonia-nitrogen concentrations decreased from upstream to downstream in Lateral A on average of 3.1 mg/L (Figure 18). This suggests that Lateral A has a nutrient source that was utilized by autotrophs from upstream to downstream.

Table 8. Historical ammonia-nitrogen concentrations along Lateral A.

Ammonia-nitrogen, NH4 (mg/L)					Difference		
Date	CH2	CH8	CH7	CH13	CH7-CH2	CH13-CH7	CH13-CH2
8/14/2008	0.005	0.064	0.074		0.069		
8/21/2008	0.170	0.081	0.250		0.08		
9/4/2008	0.057	0.068	0.310		0.253		
9/19/2008	0.047	0.042	0.054		0.007		
10/16/2008	0.036	0.160	0.440		0.404		
11/20/2008	0.055	0.100	0.068		0.013		
1/27/2009	0.210	0.400	0.250		0.04		
3/17/2009	0.045	0.059	0.054		0.009		
5/12/2009	0.011	0.031	0.041	0.490	0.03	0.449	0.479
5/22/2009	0.049	0.048	0.098	0.320	0.049	0.222	0.271
5/28/2009	0.380	0.610	1.400	0.960	1.02	-0.44	0.58
6/4/2009	0.260	0.730	0.590	2.700	0.33	2.11	2.44
6/12/2009	0.140	0.510	5.200	6.600	5.06	1.4	6.46
6/22/2009	0.170	0.810	0.860	4.500	0.69	3.64	4.33
6/29/2009	0.082	0.190	0.920	6.900	0.838	5.98	6.818
Average difference					0.593	1.909	3.054

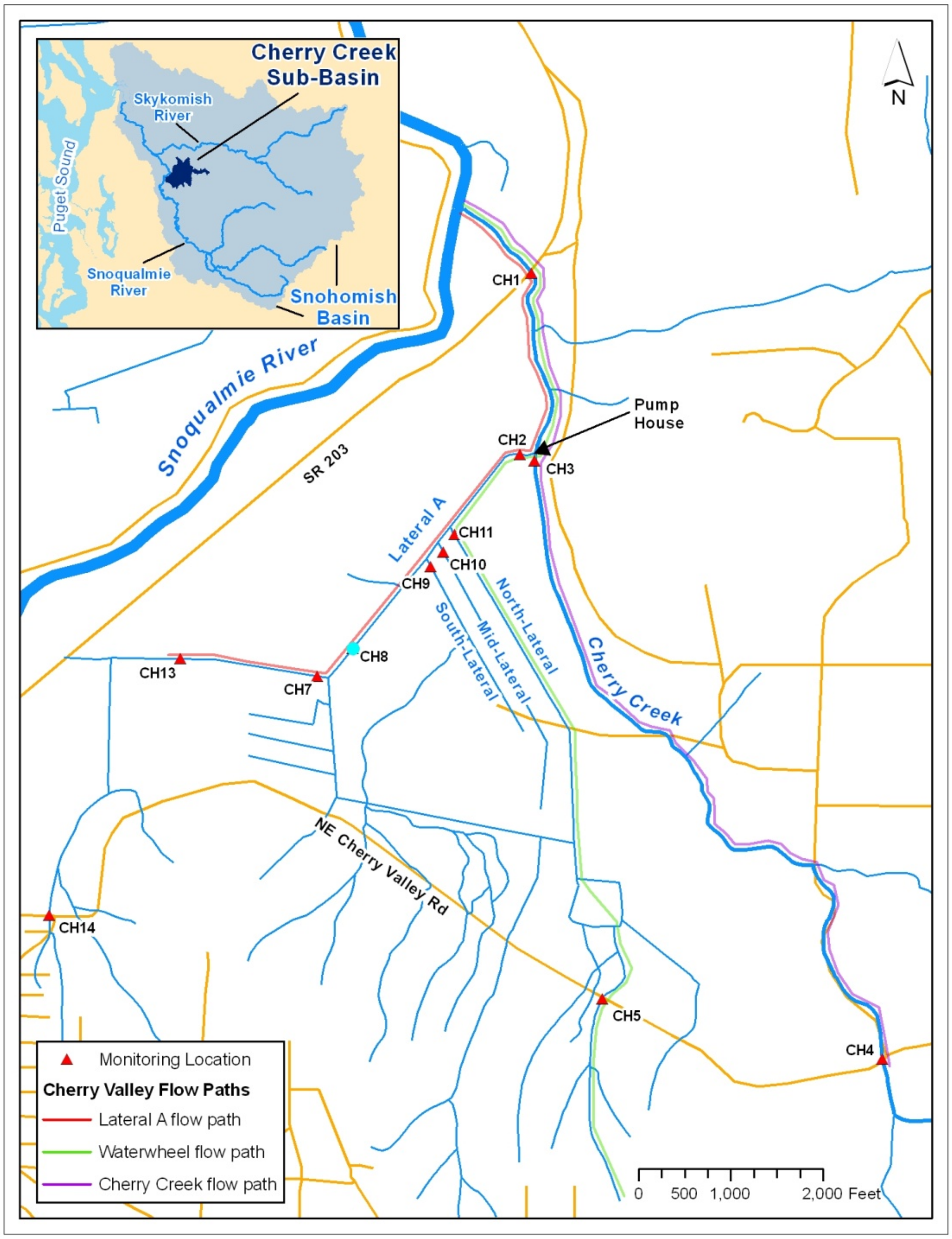

Figure 18. Map of historical nutrient data collection stations by Wild Fish Conservancy and the Tulalip Tribes of Washington (2009).

Ammonia-nitrogen includes the ionized form (ammonium, NH_4+) and the un-ionized form (ammonia, NH_3). Ammonium is produced when microorganisms break down organic nitrogen products such as urea and proteins. This decomposition occurs in both aerobic and anaerobic environments. In solution, ammonium is in chemical equilibrium with ammonia (EPA, 2009).

Generally, ammonia-nitrogen levels in flowing waters were low (less than 1.0 mg/L) because ammonium (NH_4+) is a preferred plant nutrient, as it is a form of nitrogen that is already reduced. Values greater than 1.0 mg/L are often indicative of anthropogenic pollution (WFC and Tulalip Tribes of Washington, 2009).

Lateral A may cause problems for fish. However, the toxicity is dependent upon the temperature and pH of the water. Ammonia exerts a direct oxygen demand on the receiving water, since DO is consumed as ammonia is oxidized. Moderate depressions of DO are associated with reduced aquatic species diversity, while more severe DO depressions can produce fish kills (EPA, 2009; McIsaac, 2003).

Wetlands have some capacity to remove nitrogen by microbial denitrification. Ammonia-nitrogen is converted by soil and aquatic bacteria to nitrate (NO_3^-). DO concentrations can be reduced when soils become saturated with NO_3^- due to these conversions and by microbial respiration. Wetlands can have high NO_3^-, and, in this case, the Snoqualmie River flood plain may often have wetland characteristics. The King County APD is often within the flood plain of the Snoqualmie River, where agricultural waterways have a tendency to contain high nitrates. This may be the case for the agricultural waterway in the Ames basin and Lateral A in the Cherry basin.

Nitrogen and phosphorus transport may be greatest as groundwater rises into the nutrient rich topsoil (Vadas et al., 2007). Nitrogen can move more readily in groundwater than phosphorous. High water table and excessive soil phosphorous concentrations mobilized phosphorous. Discharge of the high water table groundwater can be a significant contributor of nutrient loads in agricultural waterways.

Groundwater

The groundwater component of this study did not yield enough information to draw strong conclusions concerning its influence on surface water DO concentrations. One objective of this study was to provide information about the possibility of low DO coinciding with high groundwater-to-surface-water ratios during late spring, following long periods of soil saturation. We assumed spring conditions increased the magnitude and possibility for groundwater upwelling into surface water.

Figure 19 shows the staff gages of Lateral A and nearby monitoring well depths. The data were not normalized to a common point, and the depths of the monitoring wells were not known at this time. However, it is useful to see the relationship between surface water and groundwater. Well WDFW-1 was approximately 50 ft from the staff gage at Lateral A-1 (Figure 2). The staff gage at Lateral A-1 had a strong positive linear regression correlation with monitoring well WDFW-1 (r^2=0.91). Normalizing these data to one point, such as elevation, may be useful in determining the exact relationship between surface water and groundwater.

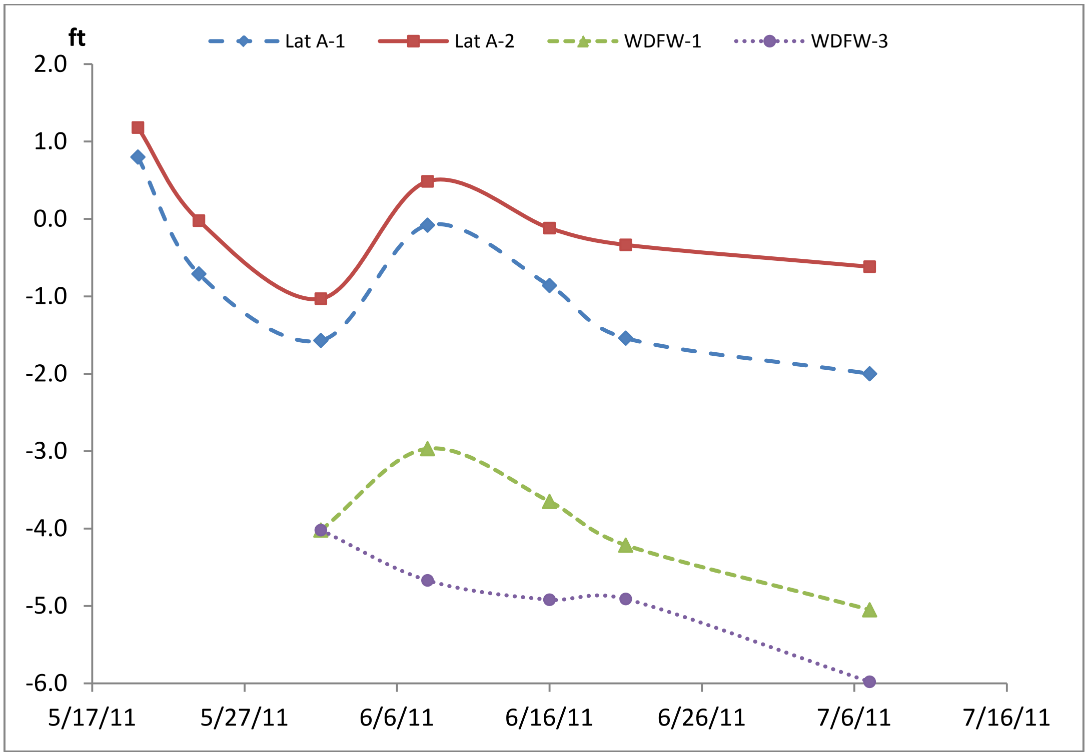

Figure 19. Staff gage heights of Lateral A and nearby well depths.

Monitoring well WDFW-3 was closer to the Snoqualmie River than Lateral A (Figure 2). It is possible that WDFW-3 was influenced by the Snoqualmie River more than WDFW-1, due to its close proximity. The two monitoring well depths showed no correlation with each other. More data are necessary in order to develop a possible relationship between the two monitoring wells in Cherry Valley.

Groundwater Results from Previous Studies

The following is a summary of groundwater conditions along the Snoqualmie River valley from previous studies (Turney et al., 1995; Stohr et al., 2011; Harring 2002; Joy, 1994). Baseflow conditions typically occur in late summer and early fall.

Groundwater upwelling (discharge) or downward movement (recharge) will vary from place to place along a streambed. In general, groundwater tends to percolate downward in reaches of high gradient and percolates upward at low gradients reaches (Allan, 1995). However, during periods of high saturation, such winter and spring, the water table will rise, increasing the tendency for groundwater upwelling.

A seepage study conducted in September 1991 showed the Snoqualmie watershed tributaries generally gained water as they flow downstream (Turney et al., 1995). The Snoqualmie River itself seemed to gain groundwater along its entire length, except for the reach from Carnation to Monroe, where it is a losing reach. Cherry and Ames Creeks are located along this reach. However, during wetter weather patterns, groundwater will discharge into surface water because regional water table levels rise. Furthermore, during significant rain events, interflow occurred where water entered the shallow water table and seeps directly into adjacent streams relatively quickly (Turney et al., 1995).

In 2006 Ecology conducted a Temperature Total Maximum Daily Load study (Stohr et al., 2011). The results were consistent with earlier groundwater studies reported in Turney et al. (1995) and Haring (2002). The Snoqualmie River system tends to gain groundwater along its length, except for the lower reach, below Carnation. However, groundwater condition and influence may differ from year to year. Joy (1994) found that the volume of groundwater inputs can change depending on whether the previous year had major valley flooding or not.

A Forward Looking Infra Red (FLIR) study was conducted on the Snoqualmie River in July 2006 during baseflow conditions (Stohr et al., 2011). FLIR is an aerial survey of surface water temperature. Cherry and Ames Creeks had lower stream temperatures than the Snoqualmie River. This may indicate possible groundwater contributions to Cherry and Ames Creeks during baseflow conditions. If groundwater upwelling occurs during baseflow conditions, it is likely to also occur during spring after extended periods of saturation.

Future Projects

The Wild Fish Conservancy (WFC) received funding to restore natural hydrologic function to a portion of the Cherry Valley drainage network (Glasgow, 2011). Lateral B, which is the historic channel for Waterwheel Creek, will be re-naturalized to a stream channel that will combine the flows from Laterals B, C, and D (Figure 2). WFC's Waterwheel Creek Restoration Project is designed to improve fish and wildlife habitat within the WDFW Cherry Valley Wildlife Area, while maintaining or improving drainage and other infrastructure for adjacent farmland and complementing other Wildlife Area uses. The project involves creating a new naturalized stream channel and riparian corridor for Waterwheel Creek.

Abandoning the drainage ditches and creating one larger, naturalized stream channel will improve water quality and dramatically increase the amount and quality of habitat available to fish. The new channel alignment will mimic the sinuosity and condition of the likely historical conditions and, to the extent possible, will restore natural features including beaver ponds. The project is the culmination of eight years of studies, planning, and coordination between Wild Fish Conservancy, WDFW, and Drainage District #7. Pending receipt of state and federal permits, construction will begin in July 2012. Results from the DO study provides baseline data for pre-restoration conditions and will provide a unique opportunity to compare pre- and post-restoration conditions.

Conclusions

Results of this spring 2011 lower Cherry Creek and lower Ames Creek watersheds study support the following conclusions:

- Waterways of the lower Cherry and Ames watersheds did not meet Washington State quality criteria for dissolved oxygen (DO).
- The dredged waterway and Lateral A exhibited extreme DO concentrations, showing wide ranges and often radical fluctuations.
- Steady free-flowing waterways tended to have typical DO characteristics, showing a small range in diurnal fluctuations. However, additional velocity data will be necessary to confirm this observation.
- Stratification may have affected DO concentrations in Lateral A of the Cherry Creek watershed.
- Lateral A reached DO concentrations as low as 0 mg/L.
- The impacts of groundwater on DO levels were inconclusive.
- The dredged and undredged agricultural waterways have different origins and streamflow characteristics, making direct comparisons difficult.
- The lower portions of the Cherry Creek and Ames Creek watersheds are in the flood plain of the Snoqualmie River, where higher discharges of the Snoqualmie River may have affected DO levels of these tributaries.
- Precipitation may have subtly increased DO concentrations of nearby receiving waterbodies in the Cherry Creek and Ames Creek watersheds.

Recommendations

Results of this spring 2011 lower Cherry Creek and lower Ames Creek watersheds study support the following recommendations:

- Use best management practices (BMPs) for land use to increase the chances of improving water quality.
- Follow-up studies, including nutrient, streamflow, and groundwater assessment, may assist in determining the factors that influence DO concentrations.
- The recently dredged agricultural waterway in the Ames Creek watershed should be monitored to assess the long-term effect of post-dredging.
- Lateral A and Cherry Creek, both upstream and downstream of their confluence, should be monitored as a follow-up in order to assess potential water quality effects from the Water Wheel project.
- Consider previous studies where DO characteristics may be driven by eutrophication, primary production, sediment oxygen demand (SOD), groundwater characteristics, and watershed management practices.

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Appendices

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Appendix A. Tables

Table A-1. Summary statistics for lower Cherry and Ames watersheds.

	Site ID					
	Cherry 3-1	Lateral A-2	Lateral A-1	Ames 1	Dredged	Undredged
Dissolved oxygen (mg/L)						
SD	0.65	1.90	3.22	0.93	3.89	0.56
Mean	10.37	3.75	2.91	8.81	5.99	8.11
Max	11.82	11.09	11.33	13.16	18.51	9.34
Min	8.49	0.84	0.00	6.79	0.15	6.17
Range	3.33	10.25	11.33	6.37	18.36	3.17
Dissolved oxygen % saturation						
SD	6.13	18.35	30.61	7.34	44.61	5.57
Mean	96.96	36.62	27.34	83.13	63.64	75.15
Max	117.17	111.88	115.81	115.48	207.74	87.26
Min	86.22	8.51	0.00	61.67	1.60	58.71
Range	30.95	103.37	115.81	53.82	206.14	28.55
Temperature (°C)						
SD	1.97	2.18	2.40	1.92	3.71	1.43
Mean	12.34	14.21	15.22	12.72	16.22	11.87
Max	19.53	22.15	24.41	17.65	27.23	16.97
Min	8.12	8.56	8.85	6.37	9.24	8.97
Range	11.41	13.59	15.56	11.28	17.99	8.00
pH						
SD	0.17	0.29	0.21	0.22	0.18	0.28
Mean	7.08	6.42	6.45	6.78	6.21	6.78
Max	7.54	7.45	7.79	7.16	7.11	7.25
Min	6.59	5.69	5.60	6.23	5.76	4.82
Range	0.95	1.76	2.19	0.93	1.35	2.43

SD = standard deviation

Table A-2. Multiprobe post-deployment calibration check and measurement quality objective (MQO) for specific conductance.

Post-check date	Hydrolab #	Conductivity 100uS standard		
		Hydrolab post-check value (before calibration)	Difference	Data qualifier conclusion
5/18/11	36	98.1	-1.9%	*accept*
5/31/11	39	96.4	-3.6%	*accept*
5/31/11	33	77.0	-23.0%	***reject***
5/31/11	36	100.0	0.0%	*accept*
6/7/11	41	156.7	56.7%	***reject***
6/7/11	37	143.9	43.9%	***reject***
6/7/11	18	84.3	-15.7%	***reject***
6/15/11	18	93.8	-6.2%	***estimate***
6/15/11	33	101.2	1.2%	*accept*
7/8/11	40	98.3	-1.7%	*accept*
7/8/11	41	67.0	-33.0%	***reject***
7/8/11	37	67.5	-32.5%	***reject***
7/8/11	38	97.5	-2.5%	*accept*
7/8/11	18	103.3	3.3%	*accept*
7/8/11	21	93.7	-6.3%	***estimate***
7/8/11	26	73.6	-26.4%	***reject***
7/8/11	33	99.8	-0.2%	*accept*

Conductivity post-calibration evaluation MQO criteria:

≤ ±5% = pass

> ±5% and ≤ ±10% = estimate

> ±10% = reject

Table A-3. Multiprobe post-deployment calibration check and measurement quality objective (MQO) for pH.

Post-check date	Hydrolab #	pH 7 standard			pH 10 standard			pH 4 standard		
		Hydrolab post-check value (before calibration)	Difference	Data qualifier	Hydrolab post-check value (before calibration)	Difference	Data qualifier	Hydrolab post-check value (before calibration)	Difference	Data qualifier
5/18/11	36	7.17	0.15	*accept*	9.85	-0.2	*accept*	3.91	-0.09	*accept*
5/31/11	39	7.12	0.12	*accept*	10	0	*accept*	3.95	-0.05	*accept*
5/31/11	33	6.99	-0.01	*accept*	9.95	-0.05	*accept*	3.91	-0.09	*accept*
5/31/11	36	6.88	-0.12	*accept*	9.98	-0.02	*accept*	3.95	-0.05	*accept*
6/7/11	41	6.9	-0.1	*accept*	10	0	*accept*	3.63	-0.37	***estimate***
6/7/11	37	6.95	-0.05	*accept*	9.94	-0.06	*accept*	3.85	-0.15	*accept*
6/7/11	18	7.1	0.1	*accept*	10.01	0.01	*accept*	3.93	-0.07	*accept*
6/15/11	18	7.04	0.04	*accept*	9.94	-0.06	*accept*	3.93	-0.07	*accept*
6/15/11	33	7.17	0.17	*accept*	9.85	-0.15	*accept*	3.91	-0.09	*accept*
7/8/11	40	6.99	-0.01	*accept*	no data			no data		
7/8/11	41	6.97	-0.03	*accept*						
7/8/11	37	6.91	-0.09	*accept*						
7/8/11	38	8.58	1.58	***reject***						
7/8/11	18	7.05	0.05	*accept*						
7/8/11	21	7.46	0.46	***estimate***						
7/8/11	26	7.03	0.03	*accept*						
7/8/11	33	6.98	-0.02	*accept*						

pH post-calibration evaluation MQO criteria:

≤ +0.25 = accept

> +0.25 and ≤ +0.5 = estimate

> +0.5 = reject

Table A-4. Multiprobe post-deployment calibration check and measurement quality objective (MQO) for dissolved oxygen (DO).

Post-check date	Hydrolab #	100% DO saturation standard		
		Hydrolab post-check value (before calibration)	Difference	Data qualifier conclusion
5/18/11	36	99.5%	-0.5%	*accept*
5/31/11	39	97.8%	-2.2%	*accept*
5/31/11	33	98.6%	-1.4%	*accept*
5/31/11	36	100.0%	0.0%	*accept*
6/7/11	41	112.0%	12.0%	***estimate***
6/7/11	37	98.5%	-1.5%	*accept*
6/7/11	18	95.1%	-4.9%	*accept*
6/15/11	18	99.5%	-0.5%	*accept*
6/15/11	33	100.5%	0.5%	*accept*
7/8/11	40	99.1%	-0.9%	*accept*
7/8/11	41	99.3%	-0.7%	*accept*
7/8/11	37	101.6%	1.6%	*accept*
7/8/11	38	98.5%	-1.5%	*accept*
7/8/11	18	101.6%	1.6%	*accept*
7/8/11	21	98.2%	-1.8%	*accept*
7/8/11	26	99.1%	-0.9%	*accept*
7/8/11	33	101.5%	1.5%	*accept*

Dissolved oxygen % saturation post-calibration evaluation MQO criteria:
≤ +5% = pass
> +5% and ≤ +15% = estimate
> +15% = reject

Appendix B. Charts

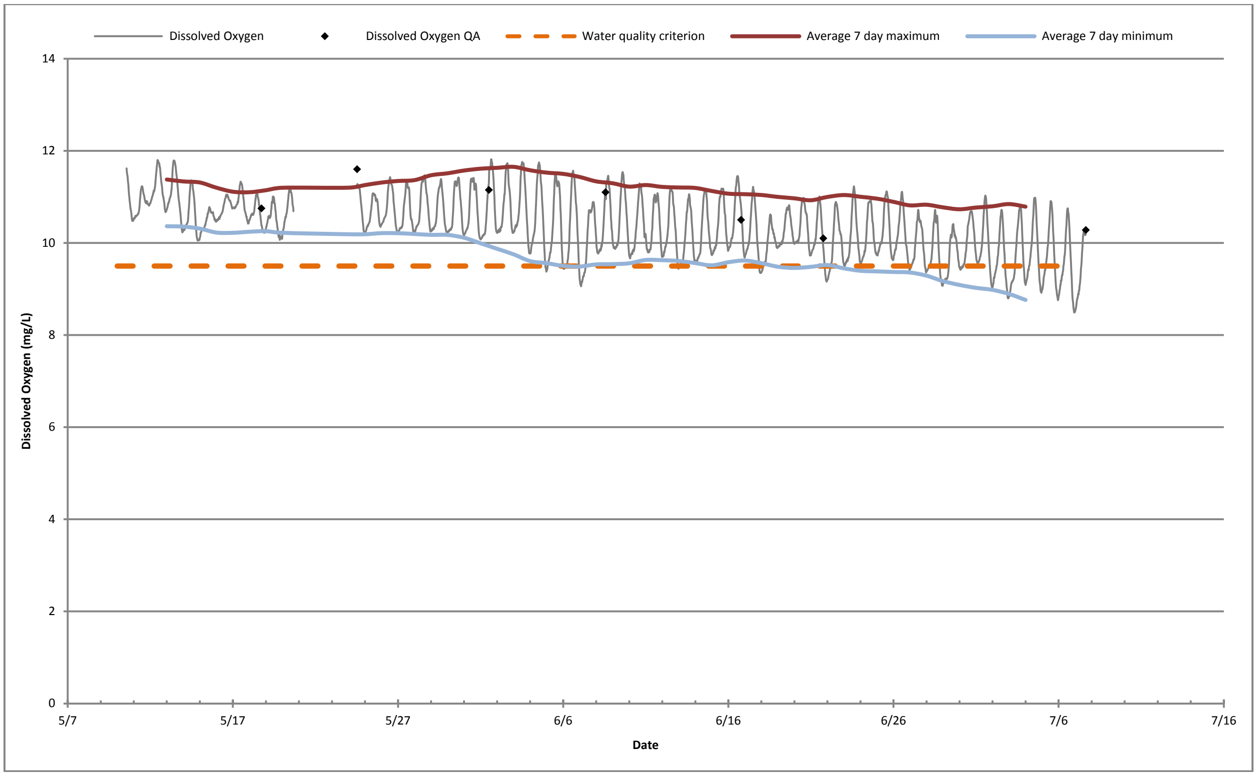

Figure B-1. Cherry Creek dissolved oxygen (DO).

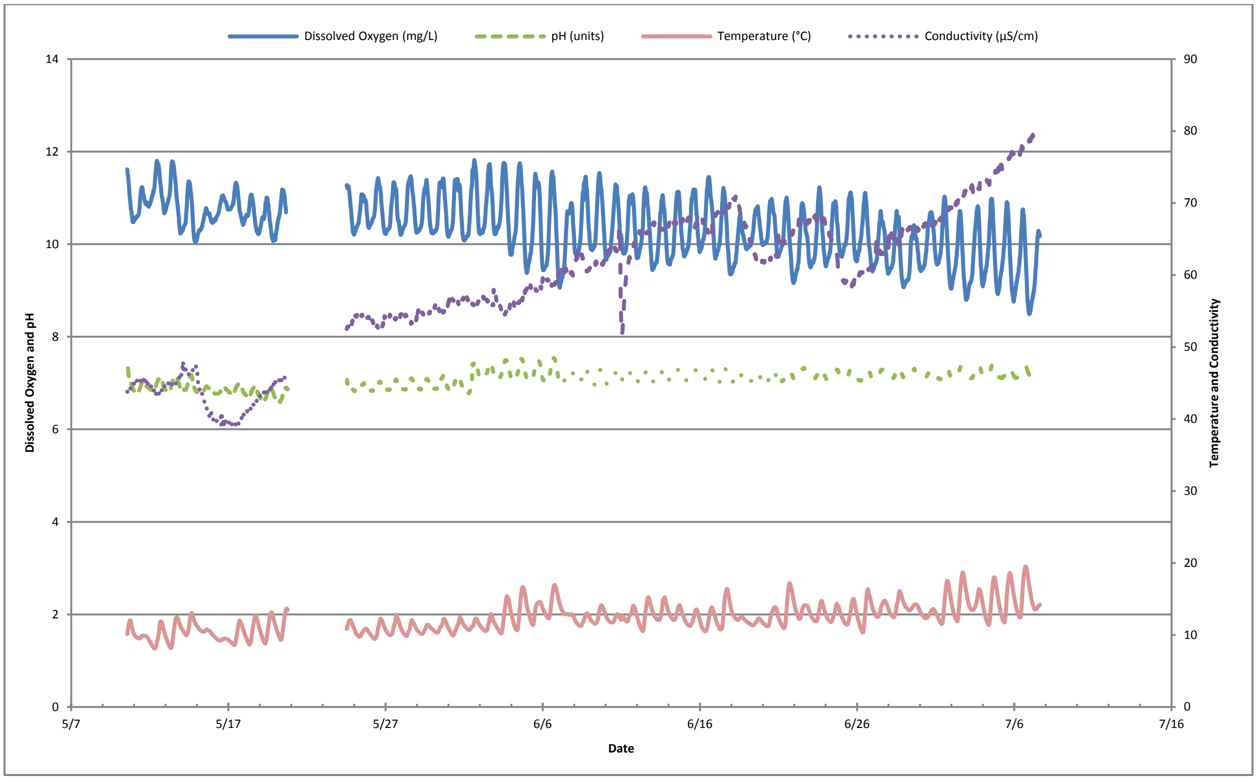

Figure B-2. Cherry Creek dissolved oxygen (DO), temperature, pH, and conductivity.

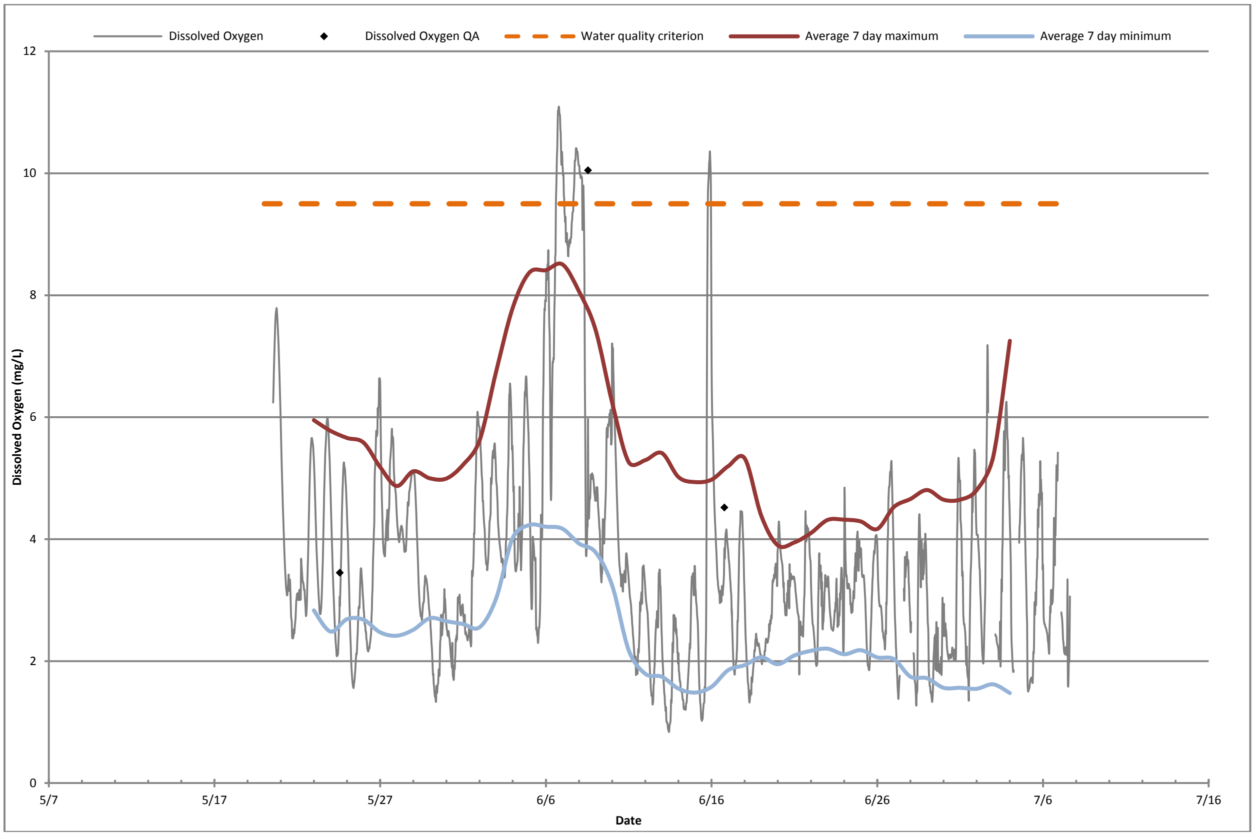

Figure B-3. Lateral A-2 dissolved oxygen (DO).

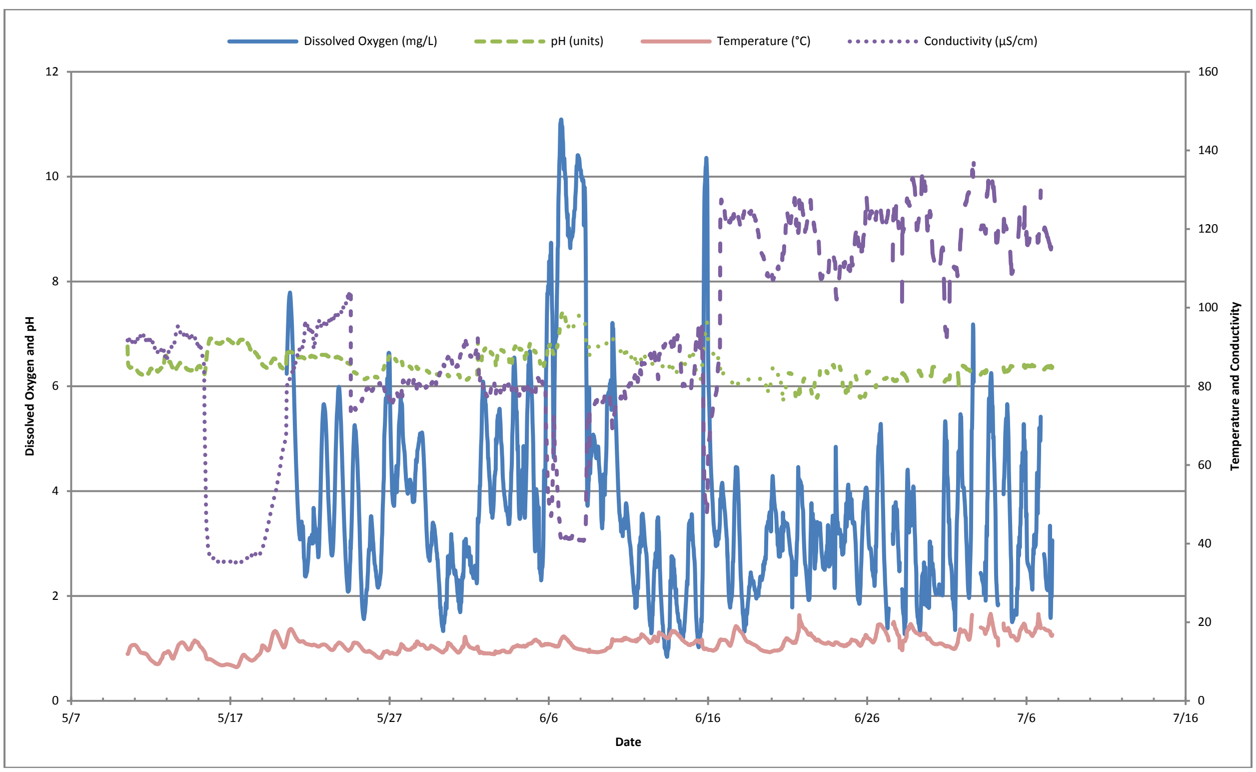

Figure B-4. Lateral A-2 dissolved oxygen (DO), temperature, pH, and conductivity.

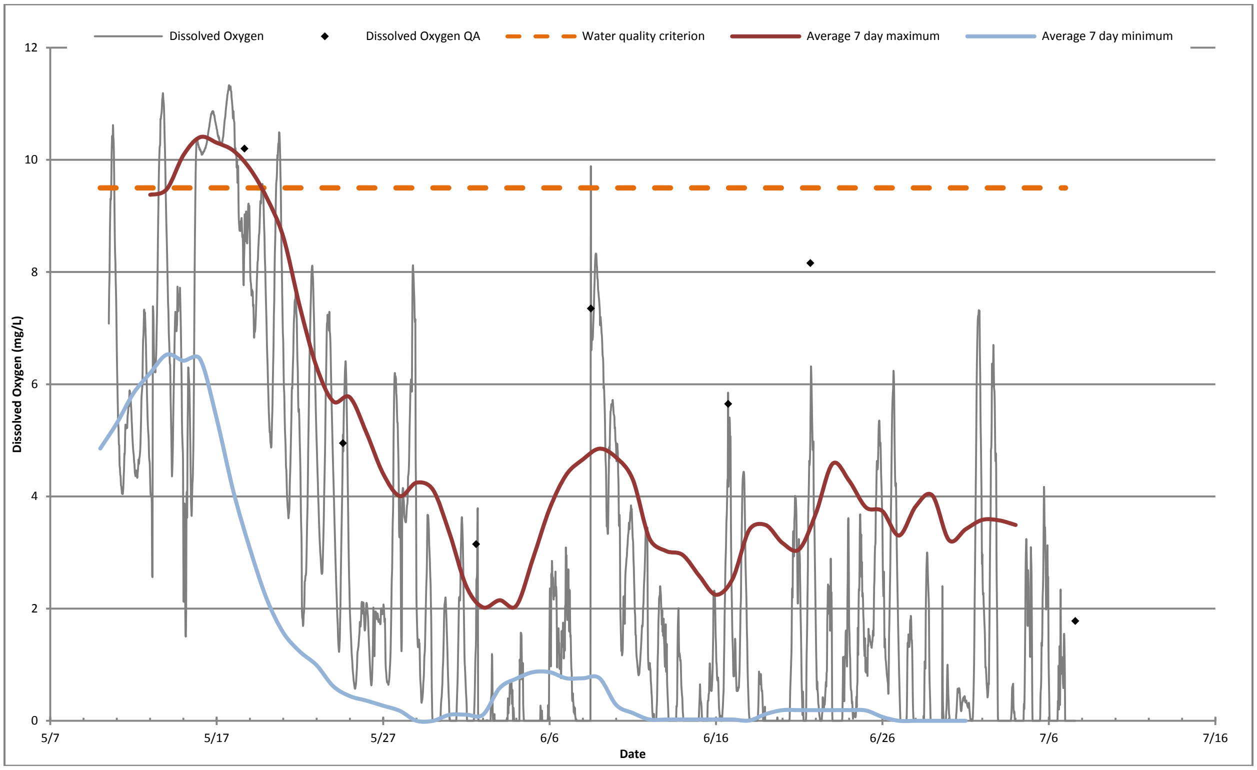

Figure B-5. Lateral A-1 dissolved oxygen (DO).

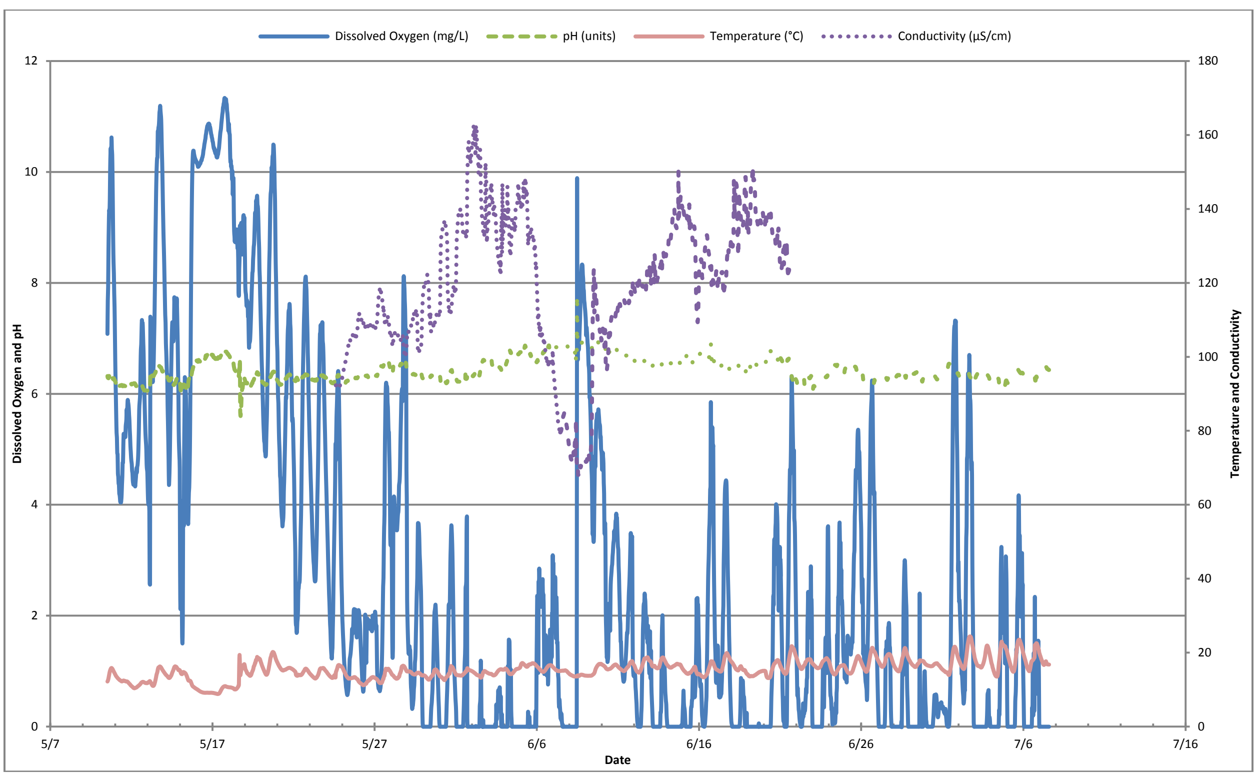

Figure B-6. Lateral A-1 dissolved oxygen (DO), temperature, pH, and conductivity.

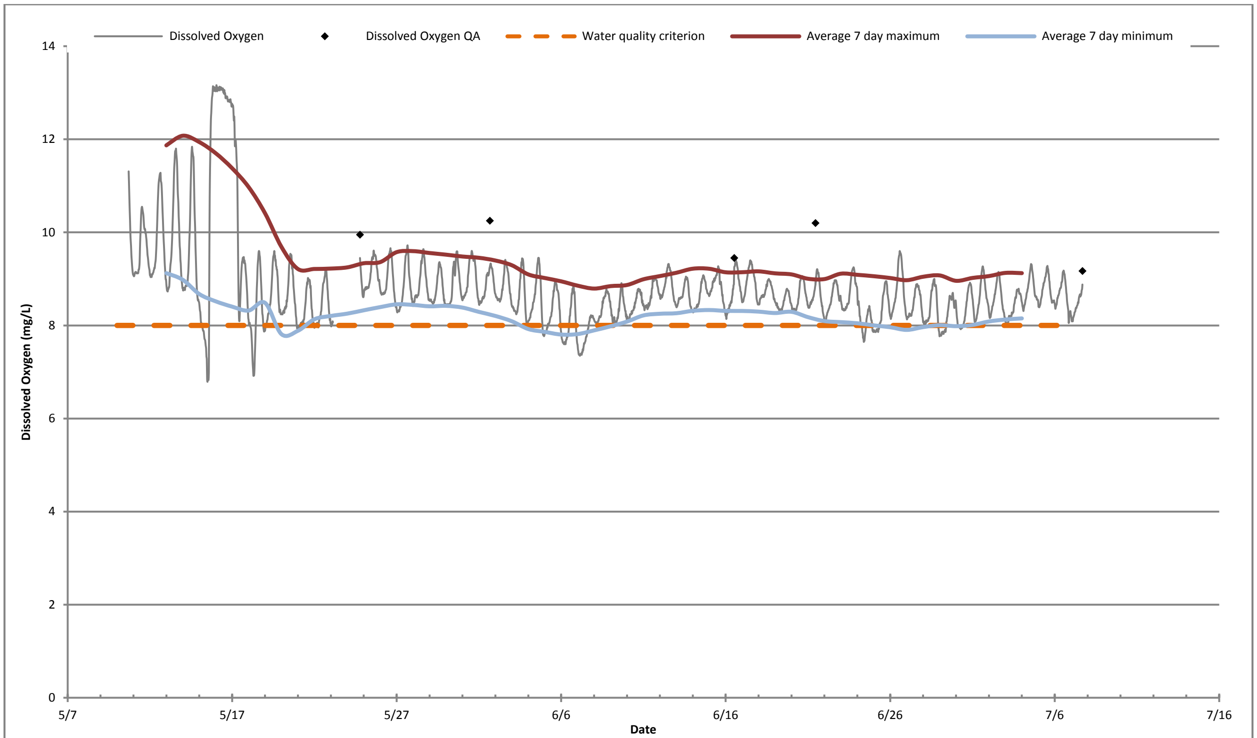

Figure B-7. Ames Creek at 100th dissolved oxygen (DO).

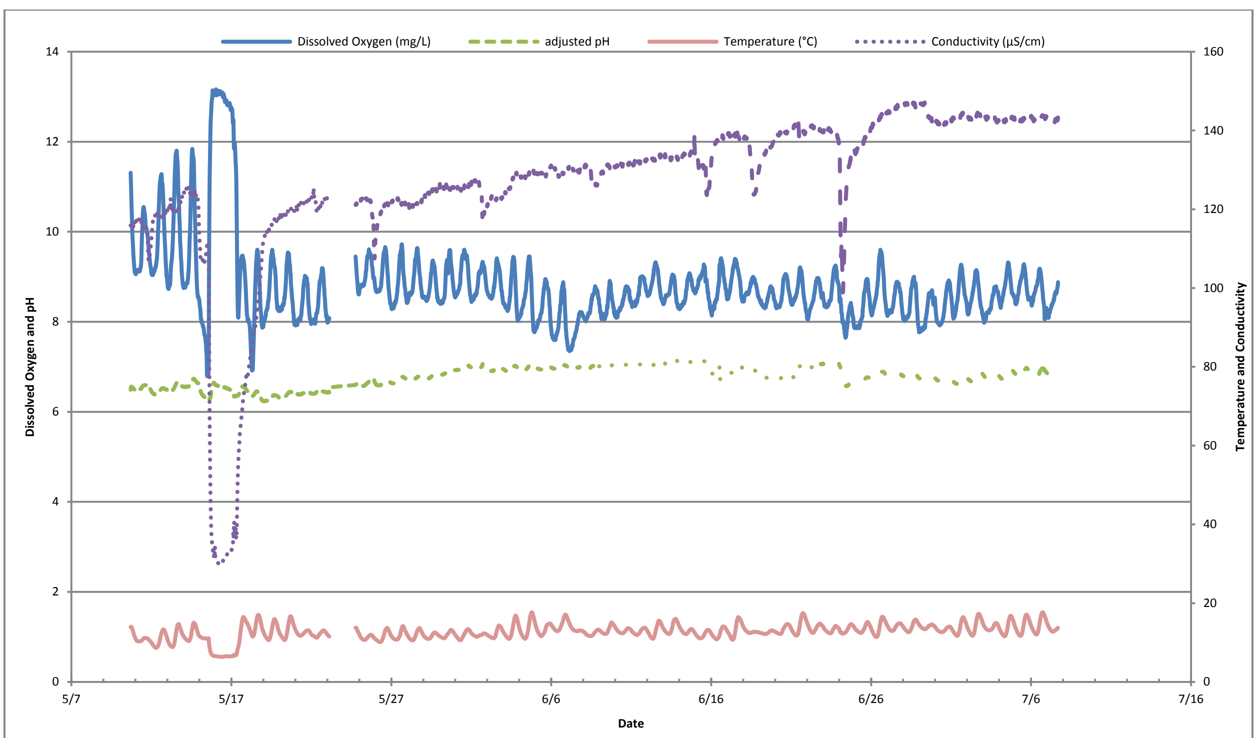

Figure B-8. Ames Creek at 100th dissolved oxygen (DO), temperature, pH, and conductivity.

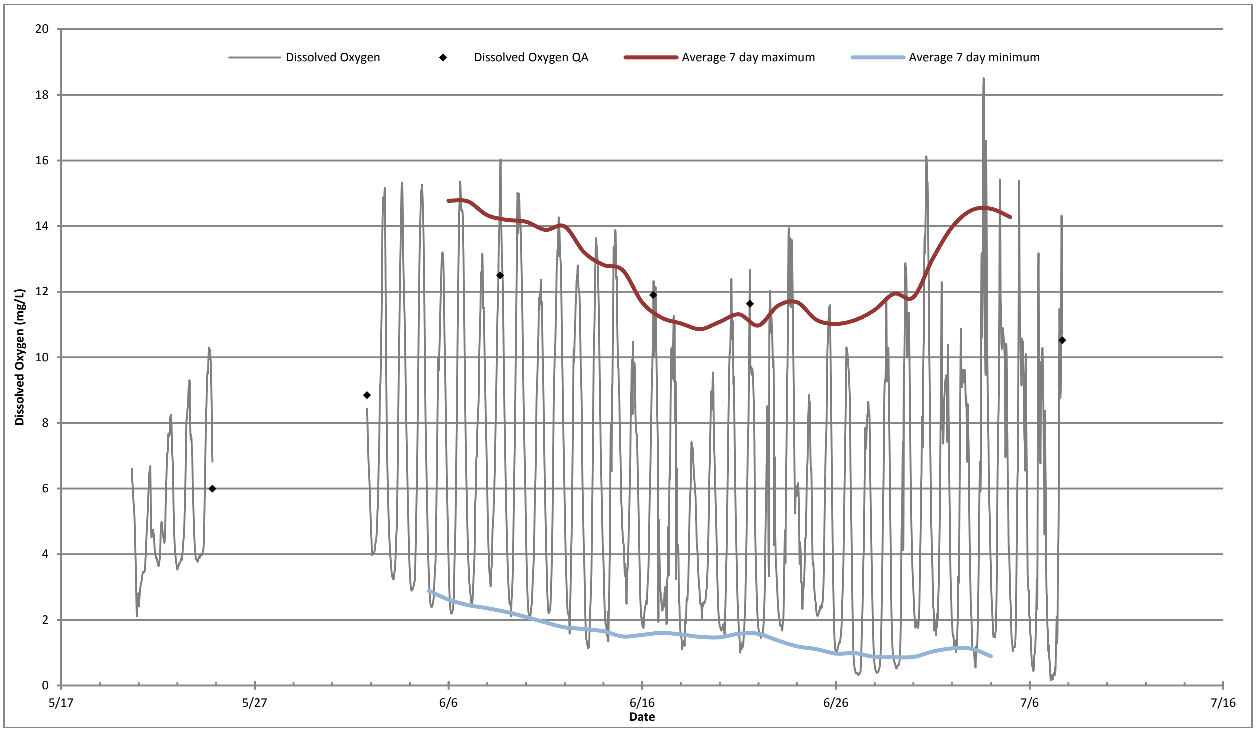

Figure B-9. Dredged waterway dissolved oxygen (DO).

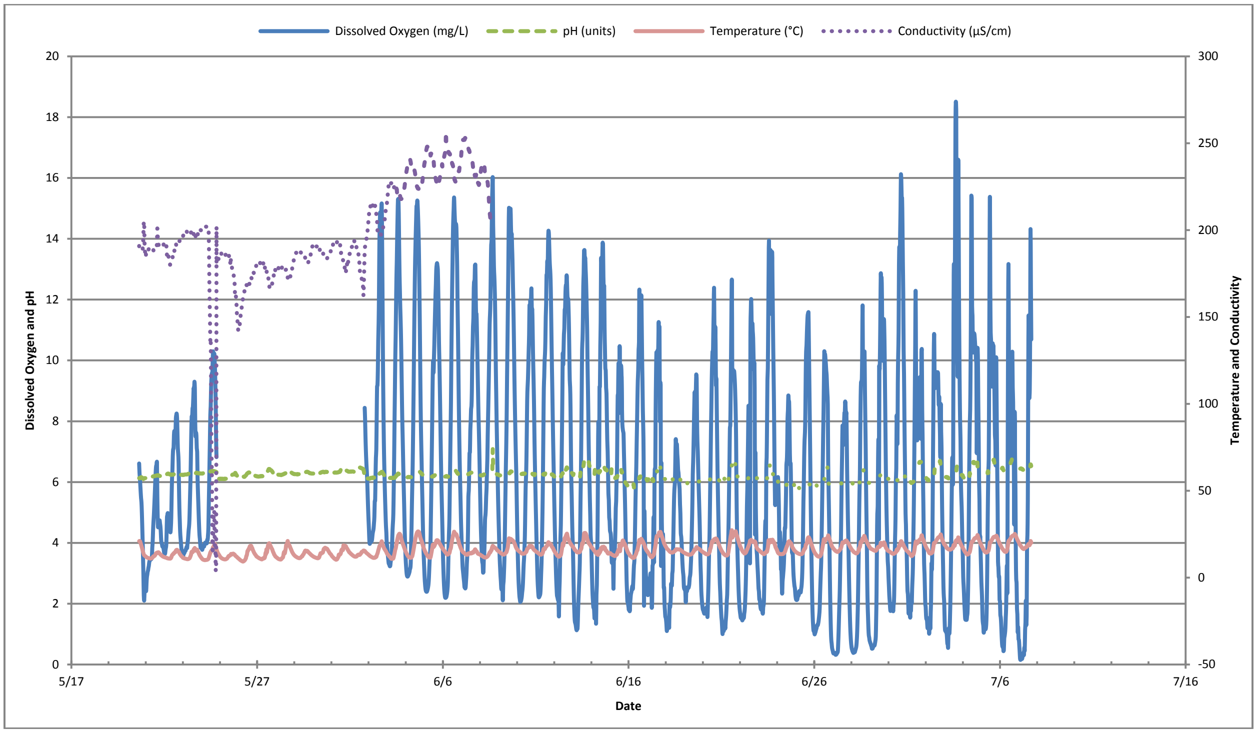

Figure B-10. Dredged waterway dissolved oxygen (DO), temperature, pH, and conductivity.

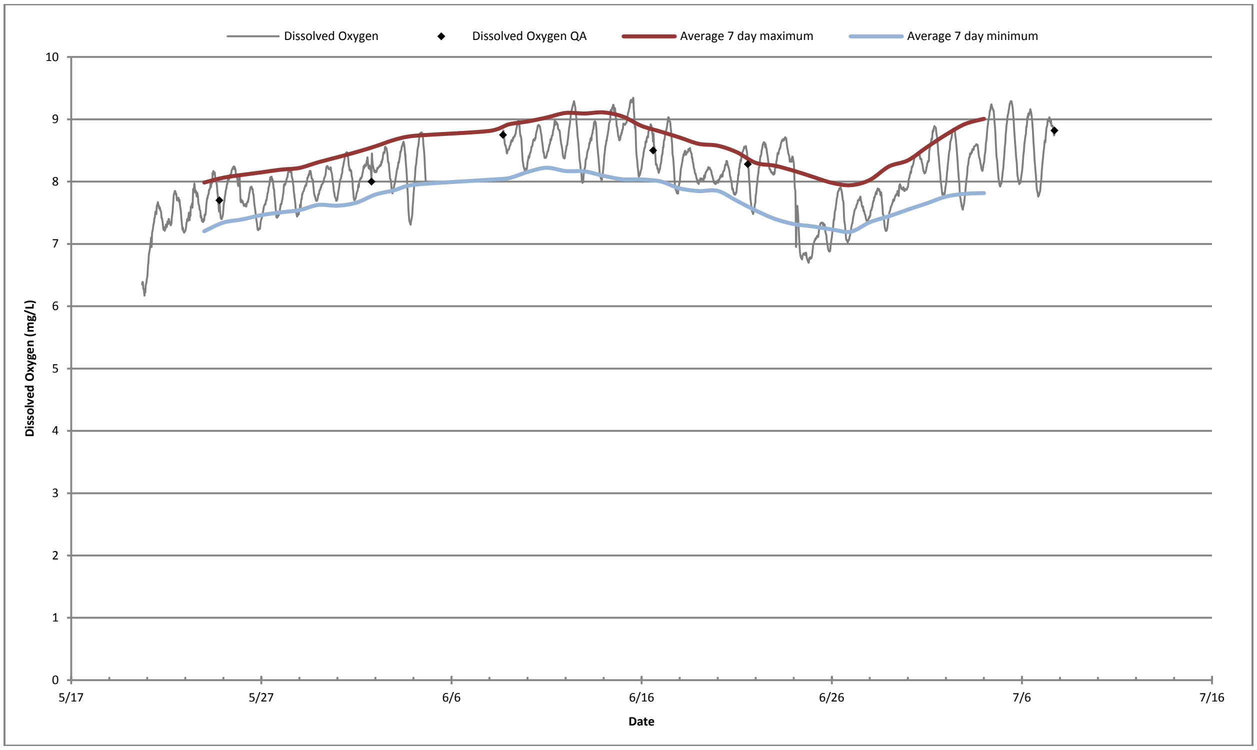

Figure B-11. Undredged waterway dissolved oxygen (DO).

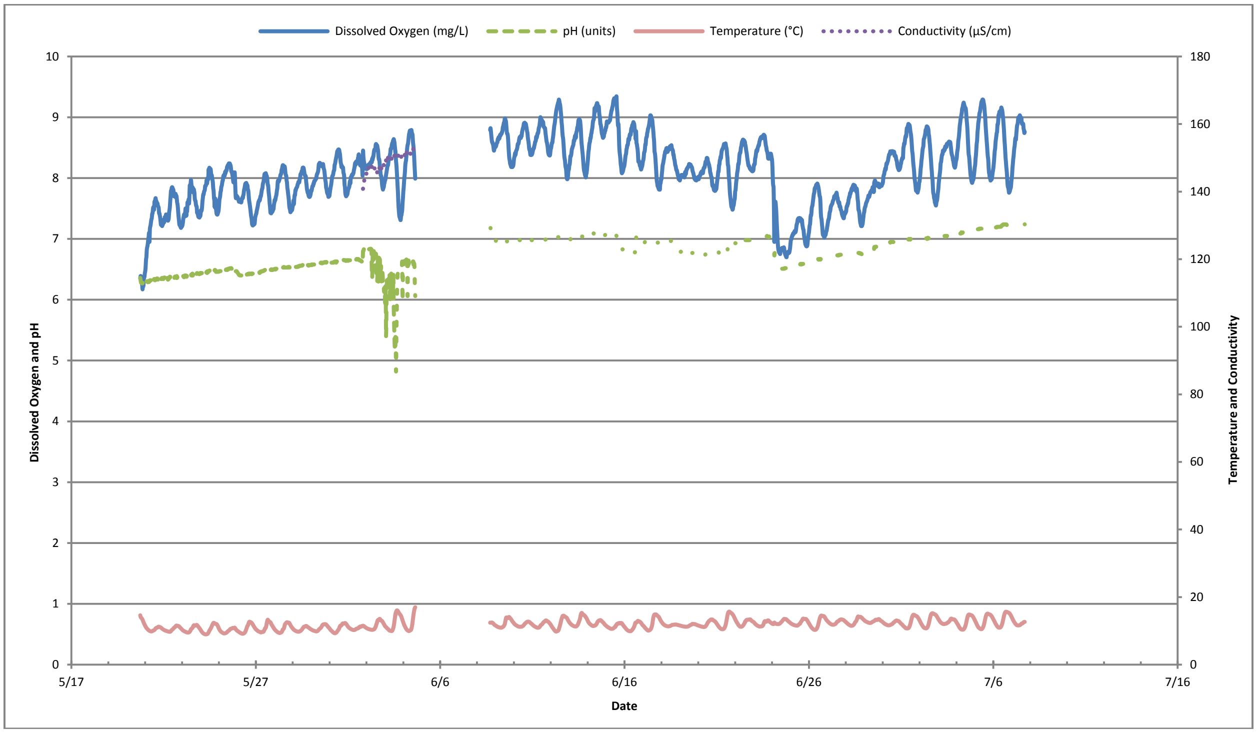

Figure B-12. Undredged waterway dissolved oxygen (DO), temperature, pH, and conductivity.

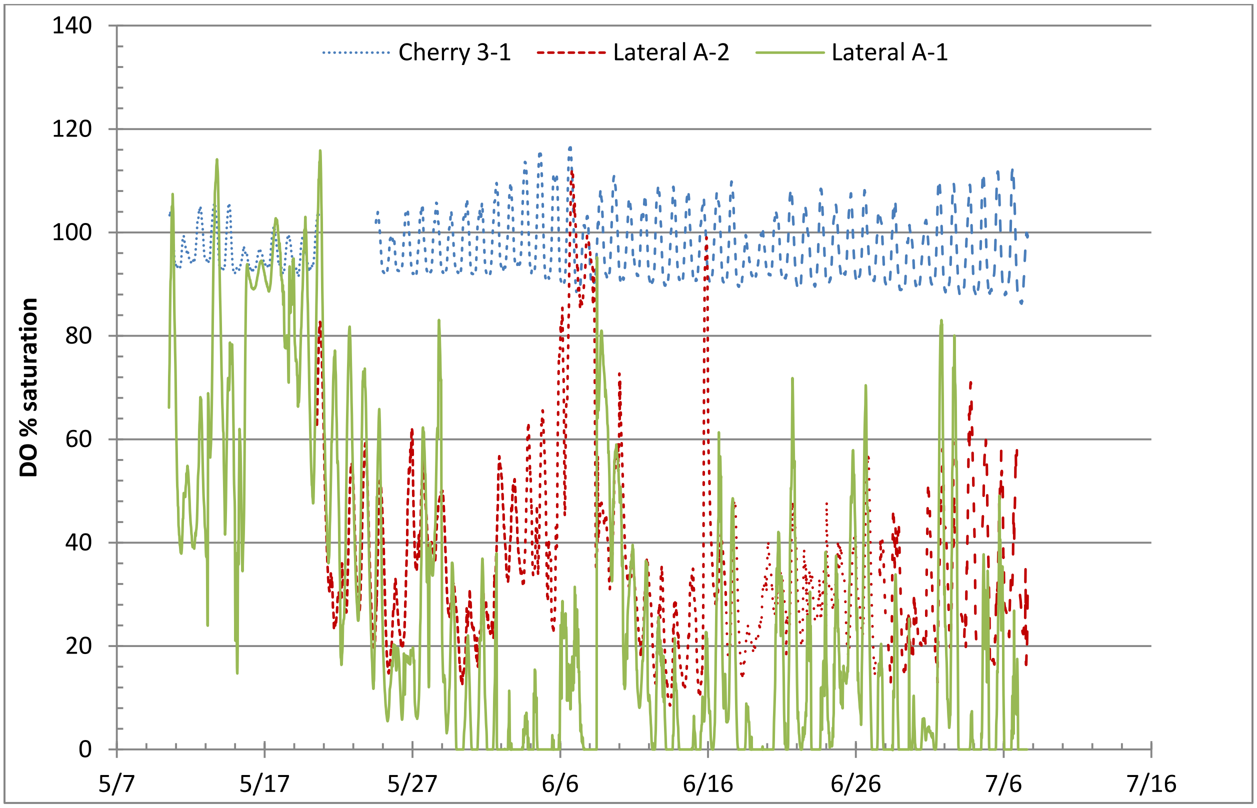

Figure B-13. Dissolved oxygen (DO) percent saturation for lower Cherry Creek and Lateral A.

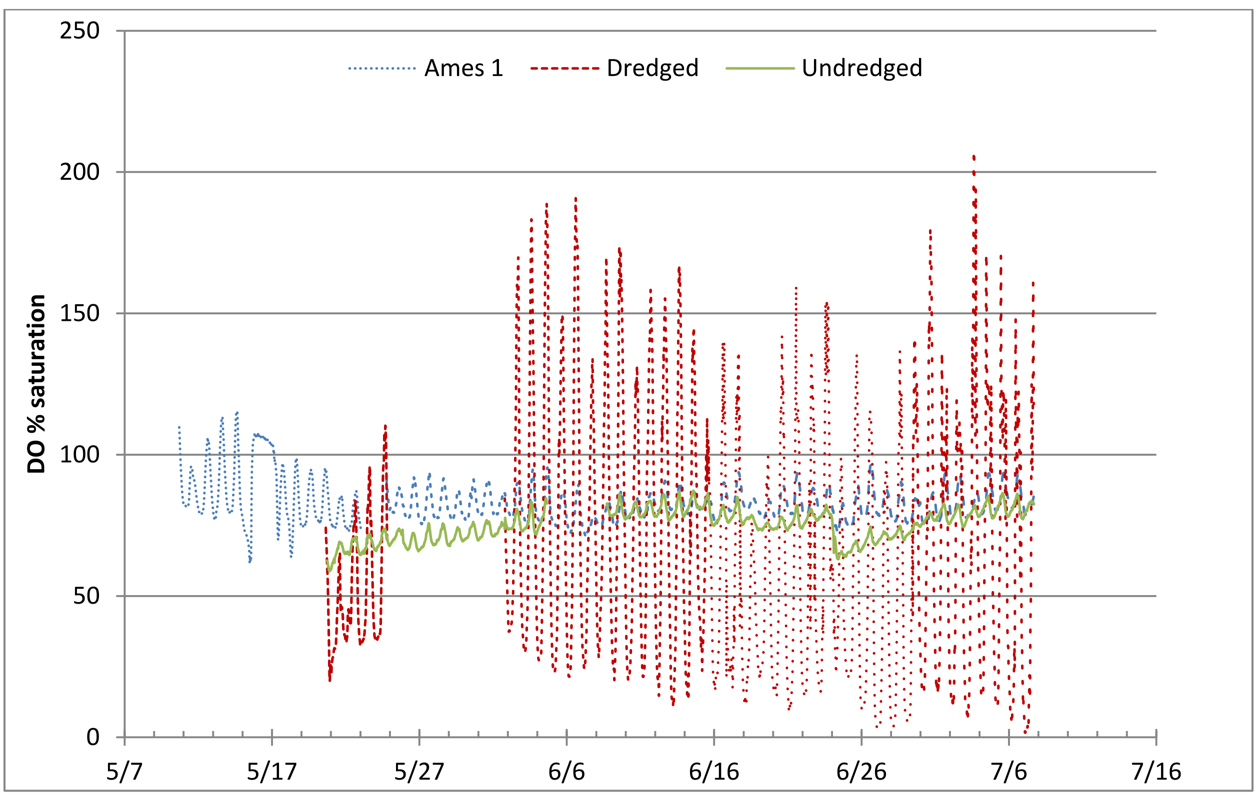

Figure B-14. Dissolved oxygen (DO) percent saturation for lower Ames Creek and the Dredged and Undredged waterways.

Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

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.

Diel: Of, or pertaining to, a 24-hour period.

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

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

10th percentile: A statistical number obtained from a distribution of a data set, above which 90% of the data exists and below which 10% of the data exists.

Acronyms and Abbreviations

BMP	Best management practices
DNR	Department of Natural Resources
DO	(See Glossary above)
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WFC	Wild Fish Conservancy
WSU	Washington State University

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
mg	milligrams
mg/L	milligrams per liter (parts per million)
uS/cm	microsiemens per centimeter, a unit of conductivity