# Temporal and Spatial Characteristics of Stream Temperature and Dissolved Oxygen in Mill Creek and Mullen Slough

Report Prepared for
King County

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## 1.0 Introduction

One of the most pressing environmental issues facing the Pacific Northwest is the recent listing of salmonid species under the Endangered Species Act. Wild Pacific Salmon have great cultural, economic, recreational and symbolic importance to the Puget Sound region. Due to federal regulations, responsibility for restoring, protecting and enhancing habitats for ESA listed species has partly fallen upon the state and local governments. Resource agencies and local governments are working to protect and restore physical, chemical and biological processes and habitats on which salmon depend. They also are working to protect and restore habitat connectivity and improve water quality and quantity conditions.

Water quality consists of a variety of components ranging from natural geological constituents to human created pollutants. Two of the most basic parameters for fish are temperature and oxygen. Acceptable ranges for temperature and oxygen vary by species and by life stage.

Stream and river temperatures are often related to air temperatures. In many situations, a strong linear relationship exists between air and river water temperatures. However departures from this linear relationship are common, as water rarely declines below 0ºC (Wetzel, 2001) and the high specific heat capacity of water means that it heats and cools more slowly than air does. The amount of oxygen a water body contains is determined by the gas absorbing capacity of the water. The concentration of dissolved oxygen in the water is affected by an array of factors including temperature, biological activity, turbulence and the atmospheric partial pressure of oxygen. Saturation refers to the largest amount of dissolved oxygen (DO) water of a specific temperature can contain. Increased water temperatures decrease the amount of DO that water can hold (Wetzel, 2001). In other words, the actual concentration in mg/l of DO at saturation is higher at lower water temperatures than it is at higher water temperatures even thought the saturation value may be the same.

Oxygen dissolved in water is essential to metabolism of all aerobic aquatic organisms. The rates of supply of dissolved oxygen from the atmosphere, photosynthetic inputs, and wind-wave action are counter-balanced by consumptive metabolism of biota and abiotic chemical reactions (Wetzel, 2001). Reduced levels of oxygen can stress fish and may cause potentially harmful responses. Fish may enter the upper water column seeking increased oxygen levels due to atmospheric gas exchanges (Suthers and Gee, 1986). This action puts them at greater risk of predation. Stressed fish are also at greater risk for disease (Groot and Margolis, 1995). Low dissolved oxygen is referred to as hypoxia; anoxia is the lack of dissolved oxygen. In aquatic systems, hypoxia represents conditions below 2 – 3 mg/L. For aquatic species, hypoxia can alter physical and morphological behaviors (Kushlan, 1974; Tramer, 1977). These alterations, along with hypoxia, can be deadly.

Dissolved oxygen levels in natural systems are dependent on physical, chemical and biological activities within the surface and subsurface zones. Subsurface zones include ground water and the hyporheic zone, which is the near surface interface between ground water and surface water. Ground water is often largely or completely devoid of oxygen as a result of chemical oxidations, bacterial respiration and organic matter decomposition that occur as water passes through soils toward stream channels (Mitsch and Gosselink, 2000). Groundwater influents, water emerging into the stream from groundwater sources, can be totally deoxygenated. As anoxic or oxygen-depleted water passes through hyporheic sediments, re-aeration occurs from the stream water allowing dissolved oxygen concentrations to increase (Malard and Hervant, 1999).

Biochemical oxygen demand (BOD) sampling is used to determine the relative oxygen requirements of polluted waters (APHA, 1999). BOD measures the amount of oxygen consumed by microorganisms in decomposing organic matter in stream water. Increasing the amount of in-stream organic matter can decrease oxygen concentrations in surface waters. Streams with a BOD of 2 mg/l or less are considered to be relatively clean (EEA 2003)

Because, temperature and dissolved oxygen are important water quality parameters necessary for maintaining healthy aquatic systems, federal and state agencies have established regulations requiring water bodies to meet certain water quality criteria. The existing state surface water quality standards separate the criteria into one-day limits that can be applied to streams and rivers.

The Washington State Department of Ecology (WSDOE) recently revised the class-based system for evaluating water quality standards to a use-base system. However, final approval from the U.S. EPA is still pending. The current classifications are Class AA-extraordinary; Class A-excellent; Class B -good and Class C-fair. The WSDOE designates the Green River watershed as Class AA above river mile 42.3, Class A between river mile 11 and 42.3 and Class B below river mile 11. The Mill Creek/Mullen Slough basins enter the Green River between river mile 11 and 42.3 and must meet Class A standards. Under the proposed use-based system they are Salmonid Noncore Spawning and Rearing Waters.

The class-based system uses a single daily maximum temperature criteria limit. The proposed use-based regulations assess water temperature as a 7-day average of the daily maximum temperatures (7-DADMax). Data collection and data analyses for this report used the class-based temperature system of one-day maximums < 18 C for Class A that were in effect during the sampling. The proposed use-based standard is a 7-day maximum average of < 17.5 C.

Both classification systems use a single daily dissolved oxygen minimum. The Washington State Department of Ecology (WSDOE) use-based criteria for dissolved oxygen conditions are specific to the life stage of the listed salmonids. Table 1 summarizes the acceptable one-day concentrations for salmonid spawning and rearing.

**TABLE 1. WSDOE WATER QUALITY STANDARDS**

| Class Based System WAC 127-201A | Dissolved Oxygen | Temperature |
|---|---|---|
| | One-Day Minimum | One-Day Maximum |
| Class AA Extraordinary | >9.5 mg/L | <16°C |
| Class A Excellent | >8.0 mg/L | <18°C |
| Class B Good | >6.5 mg/L | <21°C |
| Class C Fair | >4 mg/L | <22°C |
| | | |
| Proposed Use-Based Water Quality Standards WAC 173-201A | Dissolved Oxygen | Temperature |
| | One-Day Minimum | 7-Day Max average |
| Salmonid Core Spawning & Rearing Waters | 9.5 mg/L | 16°C |
| Salmonid Noncore Spawning & Rearing Waters | 8.0 mg/L | 17.5°C |
| Salmonid Rearing Only Waters | 6.5 mg/L | 17.5°C |
| Warm Water Fish Habitat | 6.5 mg/L | 18°C |

### 1.1 Objectives of Research

The King County Department of Natural Resources funded the Center for Water and Watershed Studies to monitor the duration and timing of dissolved oxygen levels in two streams within the floodplain of the lower Green River, assess the causes for observed spatial variation in DO levels, and determine the extent to which in-stream conditions do not meet state or federal standards for salmonid rearing and incubation as part of the Green-Duwamish action plan (see Kim 2003). The two study streams are Mill Creek, WRIA #09.0051, (also sometimes referred to as Hill Creek) and Mullen Slough (WRIA #09.0045). The Mill Creek/Mullen Slough basin include some of the most polluted streams in King County, according to the Green-Duwamish Watershed Non-point Action Plan (Metro, 1989).

The primary research goal is to investigate specific physical, biological and chemical parameters affecting the dissolved oxygen levels that influence salmonid habitat in the Mill Creek/Mullen Slough basin in King County WA. The emphasis is on summer conditions. This will be accomplished under three research objectives:

1. Characterize the temporal and spatial variation of dissolved oxygen and stream temperature levels in surface and subsurface waters in the Mill Creek/Mullen Slough basin.

2. Determine the primary causes of low DO conditions in the Mill Creek/Mullen Slough basin.

3. Estimate the duration and timing of DO conditions that are below proposed rearing and incubation standards.

As mentioned above, adequate environmental conditions, such as temperature and oxygen, are vital to the survival of salmonid species. Determining the spatial and temporal biogeochemical characteristics in the degraded portion of the watershed, particularly the lowest endpoint for salmonid survival, will aide in the assessment and management of the Green-Duwamish riverine system.

### 1.2 Study Area

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The Mill Creek/Mullen Slough basin (47º22'N, 122º15'W) is located in the lower Puget Sound region of Washington State within the Cities of Kent, Auburn and unincorporated King County. The Cities of Kent and Auburn were incorporated in the 1890s. Initially, agriculture, dairy farming and timber harvesting were the dominant industries within the Green River valley. Construction of transportation infrastructure including the Union Pacific and Burlington Northern Railroads in the early twentieth century, and several state and federal highways, as well as regional flood control facilities including Howard Hanson Dam built by the U.S. Army Corps of Engineers in 1964, and an extensive system of levees and revetments built by King County in the 1960s and 1970s, shifted the region's focus from an agricultural community to a rapidly urbanizing area. Subsequently many commercial, manufacturing and industrial businesses settled in the valley.

The basin contains 4 significant streams: Mill Creek (WRIA # 9.0051), Mullen Slough (WRIA # 9.0045), Midway Creek (WRIA # 9.0041) and Auburn Creek (WRIA # 9.0056). Mill Creek and Mullen Slough are the primary water courses in the basin and support several fish and wildlife species including salmonids, waterfowl, amphibians, beavers, freshwater otters and blue herons. The Mill Creek/Mullen Slough basin (Figure 1) is approximately 57 square kilometers (22 square miles). An estimated 7 square kilometers of the basin are wetlands. The channel slope for each drainage is approximately 0.1 to 0.2%. Thirty-one percent of the land use in the Mill Creek/Mullen Slough basin is mixed urban/low density, 29 percent is urban/high density, 21 percent of the basin is covered with herbaceous and scrub/shrub vegetation, and mixed forests cover 17 percent (Marshall & Associates, 2001).

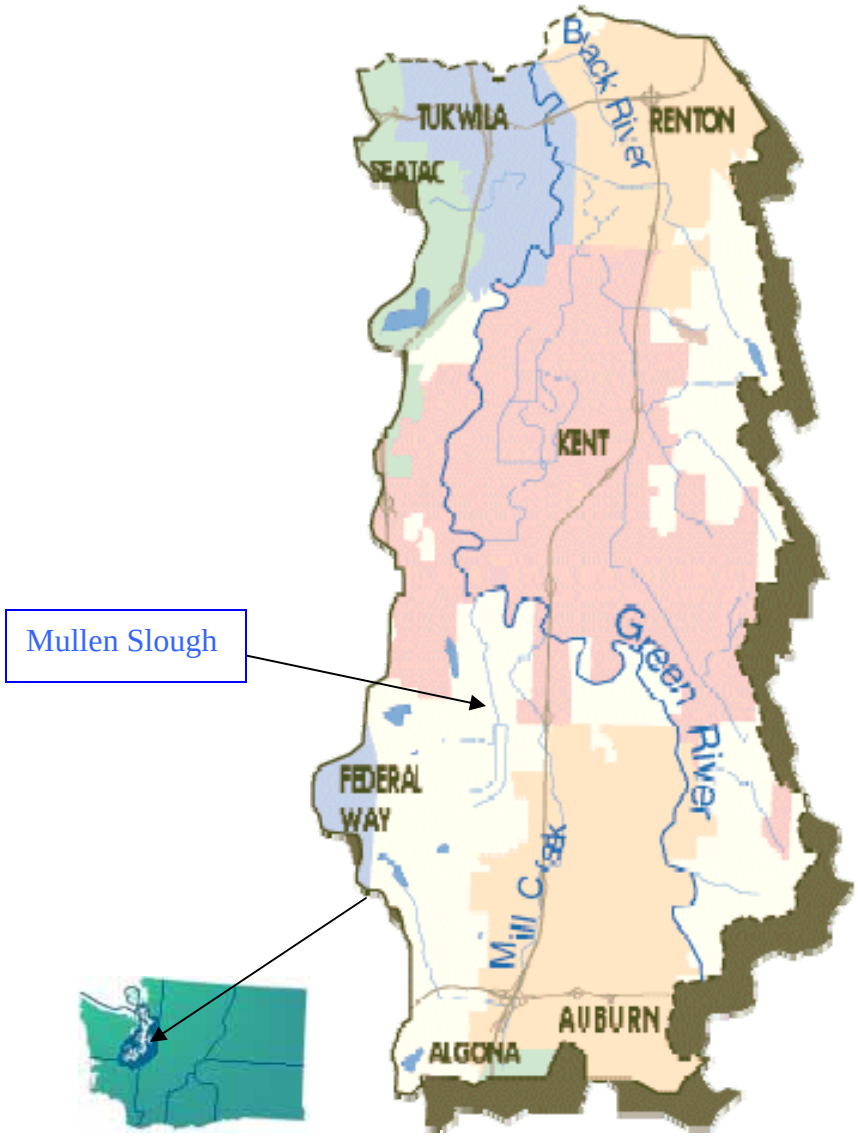



Figure 1. Map of lower portion of Green River watershed (KCDNR, 2004) showing Mill Creek and Mullen Slough

The lower Puget Sound climate is relatively mild with mean annual temperatures of 11.1ºC (51ºF) and annual precipitation, usually rainfall, of 995mm (39in) (NCDC, 2003). Soils in the Mill Creek/Mullen Slough basin belong to the Oridia-Seattle-Woodinville association. The description for each soil is very similar: somewhat poorly drained to very poorly drained, alluvial river valleys with organic materials (usually sedges and grasses). The majority of the soil types in the valley are Norma (sandy loam), Oridia (silt loam) or Snohomish (silt loam) soils (Snyder et al.., 1973), all of which are on the U.S. Natural Resource Conservation Service (NRCS) hydric soils list (http://www.wa.nrcs.usda.gov/technical/soils/hydric_lists/hydsoil-wa-633.pdf).

Within the Green River watershed, Mill Creek has the closest unobstructed access from Puget Sound available to spawning Coho and overwintering Chinook salmon. Upstream passage into Mullen Slough is unobstructed during high flow conditions, but is impaired to some extent at lower flows due to channelization of the lowermost segment of the stream a short distance upstream from the confluence with the Green River, where the stream gradient is relatively steep and the channel is lined with riprap. In addition, several studies indicate that existing water quality conditions within both water bodies are degraded (e.g., Minton et al., 1993; King County 2000).

### *1.21 Mill Creek*

Mill Creek originates from two source lakes (Lakes Dolloff and Geneva) located on a plateau west of the basin and drains an area of about 39.6 $km^2$ (15.3 $mi^2$) The creek flows east through Peasley Canyon and enters the valley near the intersection of Highways 18 and 167. The elevation of Mill Creek at Highways 18 and 167 is approximately 6.5 meters (21.3 feet) above mean sea level. Mill Creek enters the valley floor and connects with Algona tributary (WRIA # 9.0054). From the confluence, the two streams head north and, eventually, drain into the left bank of the Green River at about river kilometer (RKM) 38 (river mile RM 23.8) approximately 2.3 meters (7.5 feet) above mean sea level (Figure 2).

The upstream Mill Creek monitoring site at Park and Ride (P&R) site receives water from Peasley Canyon, a steep forested ravine with abundant canopy over the stream and cool water temperatures. The swampy area between P&R and 15th Street NW in the City of Auburn is densely covered with reed canary grass (*Phalaris arundinacea)*. This is a non-native, fast-growing, water-tolerant grass species that is widespread throughout the Mill Creek/Mullen Slough basin It commonly grows to heights in excess of two meters along stream banks, and can choke stream channels with its dense roots systems that can impede water movement. After the growing season, the grass growing in the stream dies back within the stream. Between 15th Street NW and the mouth, Mill Creek flows through wetlands, dairy farms, residential, industrial, and commercial areas.

Along Mill Creek (#9.0051) 15 sites (Table 2) were sampled at various times during the 2 years of sampling. The two most upstream monitoring stations (P&R and Algona) were accessed from the Washington Department of Transportation Park and Ride, on the Algona tributary and on Mill Creek as it flows between Highways 164 and 18. Figure 2 shows approximate locations on a general map of the area. Appendix A-1 has more detailed King County maps prepared by Todd Klinka of the north and south part of the Mill Creek/Mullen Slough basin with river miles marked. Miles are used in analyses and figures instead of kilometers in order to match the map units.

Table 2. Mill Creek site names, locations, WRIA numbers and description

| **Mill Creek** | | |
|---|---|---|
| **Site Name** | **River Mile** | **Location description** |
| Park & Ride (P&R) | 6.2 | #9.0051, most upstream sampling site |
| Algona | 0.05 | Tributary #9.0054 |
| Confluence | 6.1 | #9.0051 just downstream of where tributary #9.0054 enters |
| Hwy 164 & 18 | 6.0 | #9.0051 just North of Hwy 18 |
| Restoration | 5.6 | # 9.0051, on city of Auburn Property |
| Beaver | 5.4 | #9.0051, between tributaries 9.0051E and 9.0051GG |
| N 15th (w) | 4.5 | #9.0051, upstream of culvert running under North St. NW |
| N 15th (N) | 4.5 | #9.0051, downstream of culvert running under North 15th NW |
| Trib 51F | 0.05 | Tributary #9.0051F running parallel to 21st St. NW |
| M St | 4.05 | #9.0051 between M St and Hwy 167 |
| Emerald Downs | 3.5 | #9.0051 on north side of private access road west of Emerald Downs, near tributaries 9.0056CC and DD |
| Industrial Park | 2.85 | #9.0051 in a wetland north of 37th St and adjacent to Hwy 167 |
| Schuler Bridge | 1.8 | #9.0051, east of West valley Hwy and north of S. 277th St |
| Smith Bridge | 1.5 | #9.0051, at the bridge on West Valley Hwy across from Smith dairy |
| A315 | 0.3 | #9.0051, at King County monitoring station |

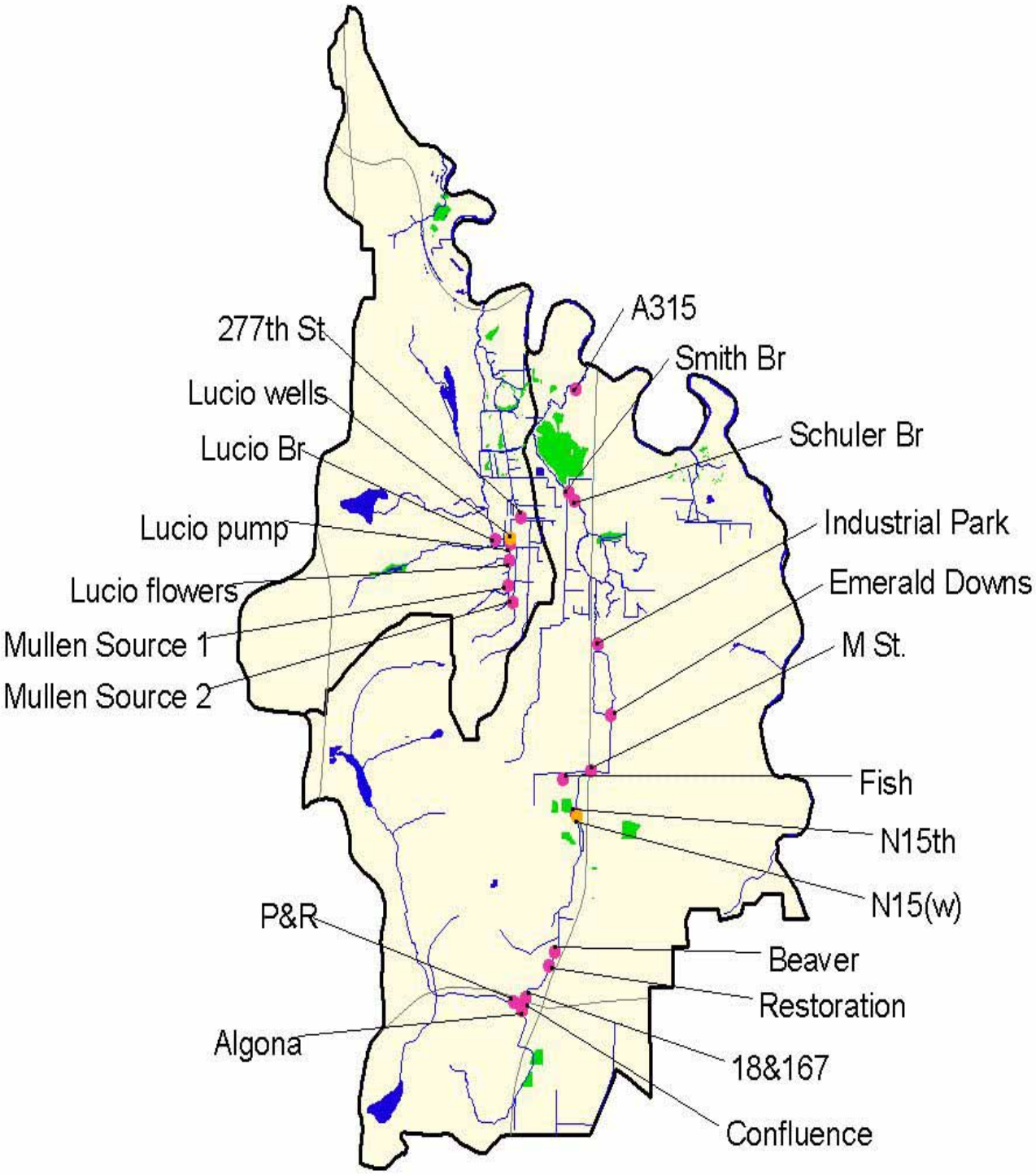



Figure 2. Monitoring locations along Mill Creek and Mullen Slough. Lucio Br. is the same as Source 3 (9.0049). Fish is the same as trib 51F.

### *1.22 Mullen Slough*

Mullen Slough drains an area of about 17.3 $km^2$ (6.7 $mi^2$). It originates from streams draining Bingaman Pond, Star Lake and Fenwick Lake situated in the uplands along the west side of the valley wall. These tributaries flow through steep forested ravines prior to reaching the valley floor. On the valley floor, Mullen Slough flows from south to north and is west of Mill Creek. Mullen Slough enters the valley floor along S. 287th Street at about 4.7 meters (15.4 feet) above mean sea level and flows into the left bank of the Green River at approximately RKM 34.8 (RM 21.6) (MCSAMP 2000).

A portion of the Mullen Slough basin is within the Lower Green River Agriculture Production District (APD) (MSCIPSP, 2001). Agricultural practices have created three drainage ditches that span the southern end of the basin that receive flow from WRIA #s 09.0045, 09.0047, 09.0048, and 09.0049. Eight sites (Table 3) were sampled along Mullen Slough and its tributaries and one in the mainstem of the Green River during the two years of the study. Lucio Boscolo graciously granted access to his property for this study. Many of the monitoring stations in Mullen Slough reference his name. Lucio flowers, Lucio pump and Lucio well are monitoring stations on the Boscolo property on stream 9.0048. Source 3 is a monitoring station on another tributary (9.0049) located west of Boscolo's driveway. 277th St monitoring station was located at a road crossing on the north side of 277th St. Mullen Mouth was a monitoring station located under SR 516 approximately 100 meters upstream of the Green River. Due to an on-going police investigation, we were unable to collect data on Mullen Slough below 277th Street for the 2003 summer field season. Monitoring sites in Mullen Slough are listed from upstream to downstream in Table 3.

Table 3. Mullen Slough sampling site names, locations, and WRIA numbers and descriptions

| **Mullen Slough** | **River Mile** | **WRIA # and Location description** |
|---|---|---|
| | | |
| Source 1 | 0.6 | Tributary #9.0047 |
| Source 2 | 0.6 | Tributary #9.0048 |
| Lucio Flower | 0.4 | Tributary #9.0048 |
| Lucio Pump | 0.3 | Tributary #9.0048 |
| Lucio Wells | 0.2 | Tributary #9.0048 |
| Source 3 | 0.35 | Tributary # 9.0049, west of Lucio Boscolo driveway |
| 277th St | 1.8 | Mainstem #9.0045 on the north side of S. 277th St. |
| Mullen Mouth | 0.05 | Mainstem #9.0045 under SR 516 |
| Green River | 22.6 | Mainstem of Lower Green River |

## 2.0 Methods

### 2.1 Dissolved Oxygen

### *2.11 Continuous monitoring*

Three Hydrolab Datasondes and five Hydrolab Recorders were used to make continuous measurements of dissolved oxygen, recorded as dissolved oxygen percentages and concentrations, at fifteen-minute intervals. These instruments have an accuracy of +/- 0.2 mg/L. Calibration was performed each time a data logger was removed from the stream for downloading data from it. During 2002, data were downloaded and loggers were calibrated every two to five weeks. During 2003, data were downloaded and the data loggers calibrated at two week intervals. The probe membranes were air calibrated between 99 – 100% saturation. If a probe was unable to hold calibration, the membrane was replaced. Recalibration was reattempted the following day, and, if successful, the unit was redeployed into the stream. However, it was discovered later that the Hydrolabs were deployed with the warm-up period disabled. Extensive discussions with Hach technical personnel left the question of data quality indeterminate. Without adequate warm-up time the DO reading does not have time to equilibrate. Readings may be higher or lower than actual DO concentrations, although there is a slightly higher likelihood that the readings may be artificially high. For this reason, 2003 DO values should be viewed as indicating spatial or temporal trends rather than absolute values. Some data loggers showed hourly drops in DO on some deployments. These sites are noted in the results section.

### *2.22 Data Collection*

**Year 2002**

During 2002, seven sites were selected for monitoring. Information provided in the Mill Creek Water Quality Management Plan (MCWQMP) and other historical data were consulted for guidance in determining site selection. Three sites were selected on Mill Creek, three sites on Mullen Slough and one location on the Green River WRIA # 9 (river mile 22.6, about 1 mile downstream of the mouth of Mullen Slough). During 2002, seven data loggers were deployed on August 13$^{th}$. Monitoring continued until November 10$^{th}$ at several, but not all, sites. The Green River site was monitored from September 3$^{rd}$ to September 17$^{th}$, 2002.

**Year 2003**

To better define temporal and spatial variations in DO, the number of monitored sites was increased for the summer 2003 collection period. Twenty sites (14 on Mill Creek and 6 on Mullen Slough) were selected for continuous and instantaneous monitoring within the Mill Creek/Mullen Slough basin. As in 2002, site selection was limited to street crossings

and properties for which access was permitted. The twenty sites are illustrated in Figure 2 and listed, along with river mile location, in Tables 2 and 3. During 2003, five data loggers were available and operational for deployment on June 20th, and all eight were available during mid- August. The data loggers were deployed on two-week rotations throughout the basin from approximately June 15th to September 16th.

### *2.23 Instantaneous DO measurements*

Grab samples for instantaneous DO measurements were taken at selected monitoring sites on July 7th, 8th, and 23rd, August 8th, and 19th, September 3rd and October 7th, 2003 to check data logger accuracy. The Winkler Titration Method and an YSI 95 model DO meter were used for instantaneous sampling to measure temperature and DO levels. The LaMotte 5860 field kit was used to perform titrations. These measurements were used to spot-check the accuracy of the hydrolab units. For the majority of each hydrolab deployment periods, the instrument was spot-checked at least once using a Winkler titration. A total of 38 successful Winkler titrations were conducted along Mill Creek and Mullen Slough.

## 2.3 Biochemical Oxygen Demand

### *2.31 Field collection*

BOD samples were collected by submersing 1 liter Nalgene ® bottles into the stream. The bottles were shaken to encourage air bubbles removal. The bottles were stored in a cooler with ice and taken to the UW Civil Engineering laboratory for analysis within four hours of collection. If samples were not immediately analyzed, they were placed in a 4ºC freezer.

### *2.32 Laboratory analysis*

Five-Day BOD tests were performed at the UW Civil Engineering Limnology lab following Method 5210 B as outlined by Standard Methods for Examination of Water and Wastewater (APHA, 1999). Samples were aerated for thirty minutes in glass beakers. After aeration, samples were diluted to 0%, 12.5% and 25% stream water. Using a YSI 5000 BOD probe, DO percentage, DO concentration (mg/l), and temperature were recorded before and after a five day incubation at 20ºC.

If a sample met the 2 mg/l depletion rate and the 1.0 mg/l residual, it was considered a viable test and BOD calculations were made. The equation to calculate BOD is

$$BOD_5, \text{ mg/L} = \frac{D_1 - D_2}{P} \qquad (1)$$

where $D_1$ is the DO of the diluted sample immediately after preparation (mg/L). $D_2$ is the DO of the diluted sample after 5-day incubation at 20ºC (mg/L). P is the decimal volumetric fraction of the sample used.

### *2.33 Data Collection*

Collections began August 8, 2003. Due to mechanical and human error, the BOD samples collected on August 8th, August 13th and August 20th, did not meet Standard Methods criteria (APHA, 1999), and thus these data were omitted from this report. BOD samples collected on September 9th, September 28th, October 3rd, and October 24th are included in this report.

### 2.4 Subsurface water monitoring

Subsurface water was monitored at two locations: a site on Mill Creek, and a site on Mullen Slough. Information collected during 2002 field season, and supported by historical evidence, suggested that the wetland (labeled as Wetland 5K on the SAMP study map) located between W. Main St. and 15th Street NW significantly influences the dissolved oxygen levels in Mill Creek. As a result, this wetland was selected for subsurface monitoring during summer 2003, at a site referred to as the N15 well site. It is an unknown distance upstream of the N15 stream sample sites Along Mullen Slough, the site selected to monitor subsurface DO levels is about 0.2 miles south of S. 277th Street on Source 2 (9.0048) about river mile 0.25, upstream of the Lucio well stream sample site.

At both locations, piezometers were installed along three transects. Piezometers consisted of one inch (2.54 cm) diameter Schedule 40 polyvinyl chloride (PVC) pipe cut into 139 cm lengths. Slot-shaped perforations formed using a 9/16th inch drill bit began 20 cm from the bottom of the pipe and continued to 50 centimeters from the bottom of the pipe. Piezometers were installed using a manual fence-post digger. Each transect had five or six piezometers; four of which were terrestrial and one or two of which were in-stream, as shown in figures 3 and 4. Terrestrial piezometers were installed 1m and 3 m from the stream. Transects were approximately 10 meters apart.

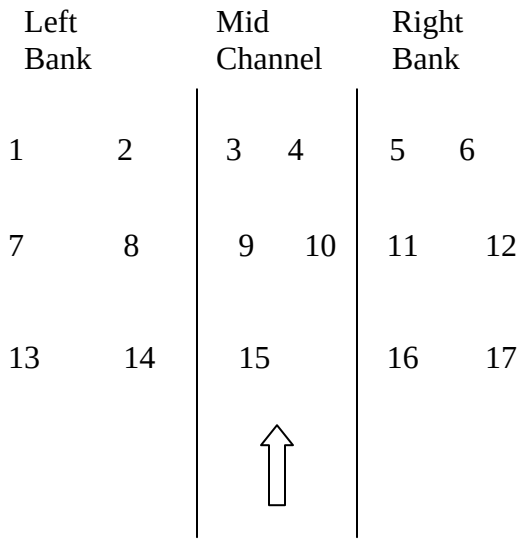



Figure 3. Piezometer placements at the N 15 site in Mill Creek.

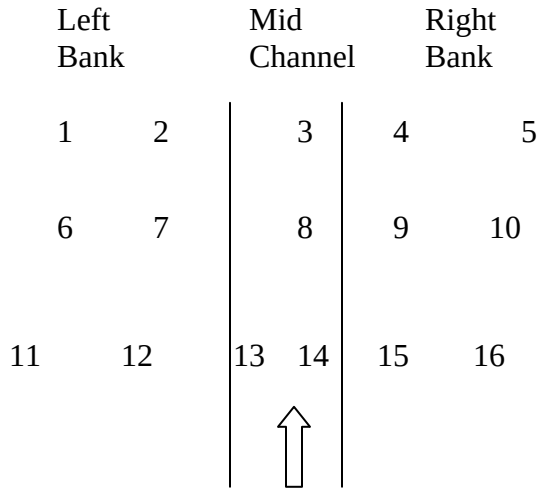



Figure 4. Piezometer placements at Lucio well site in Mullen Slough

Original soil was salvaged and used to backfill the holes once the piezometers were installed. The piezometers were allowed to settle for a week prior to beginning any data collection. Dissolved oxygen and temperature measurements were collected using the YSI 95 handheld meter before and after purging the piezometers. Water levels were measured using a metal carpenter's tape prior to clearing the piezometers.

### *2.41 Data Collection*

Measurements were taken at the Mill Creek piezometer site on July 24, August 7, August 19, September 2, October 3, and November 9, 2003. Measurements were taken at the Mullen Slough piezometer site (9.0048) on August 12, August 21, September 4, and October 4, 2003. Each sampling period included measurements of dissolved oxygen, temperature and water table depth. No analyses of water table depth were conducted.

## 2.5 Temperature

### *2.51 Air Temperature*

Daily summaries of air temperature from the NOAA National Climate Data Center (http://www.ncdc.noaa.gov/oa/climateresearch.html) for weather station 454169, Kent, Washington were compiled for the duration of the study period.

### *2.52 Water Temperature*

The Hydrolab Datasondes and Hydrolab Recorders measured temperature at fifteen-minute intervals.

## 2.6 Precipitation and Surface Water Monitoring

Precipitation and discharge summaries were provided by the King County Department of Natural Resources and Parks. A precipitation gage owned and operated by King County is located at Lake Dolloff, one of the two lakes that form the headwaters of Mill Creek. Another precipitation gage, owned and operated by King County Department of Natural Resources and Parks, is located at Star Lake, the source lake for Mullen Slough. Both gages are active and have been collecting precipitation data at 15-minute intervals since October 1, 1988.

A stream gaging station (MF-104, ~RM 6.15) owned and operated by King County on Mill Creek, between Peasley Canyon Road and SR-18, near the WSDOT Park & Ride on West Valley Highway (SR-181). Flow measurements have been collected at 15-minute intervals at this gage since February 1997. The data relevant to this study period were compiled and used to assess relationships between discharge and DO concentrations. Historic data from three inactive King County flow gages (41A, on Mill Creek at SR181 (~RM 0.3), 41B, on Mill Creek at 29$^{th}$ Ave NW (~RM 2.85), and 41C, Mill Creek at Peasley Canyon Road (~RM 6.25) were also evaluated to assess flow accumulation between the gages. About 1 year of stream gaging information is available for Mullen

Slough from late water year 1990 to end of water year 1991 but was not analyzed for this study.

## 3.0 Results and Discussion

### 3.1 Introduction

The climate conditions during the period of study are discussed prior to presenting the monitoring data for Mill Creek and Mullen Slough. The climate variables considered include relevant precipitation and discharge data for the period of study.

The monitoring results are presented in separate sections for Mill Creek and Mullen Slough. In each section, the results from the continuous monitoring using the hydrolabs, are presented separately from those collected at the instantaneous monitoring stations. The instantaneous monitoring included Winkler titrations, BOD analyses and subsurface water sampling. The continuous monitoring data collected by the data loggers were used to examine spatial variation of dissolved oxygen and temperature from upstream to downstream within each basin for each water body. These data are displayed as box plots and summarized in tables. The DO data were then analyzed with respect to water temperature and stream discharge.

The implications of these results are then discussed with respect to the state water quality standards (WAC 127-201A). For this portion of the analysis, the continuous monitoring data were summarized as the number of days the daily maximum temperature exceeded 18$^{o}$C, and the number of days that the minimum DO concentration was less than 8 mg/L for each site and sample period.

### 3.2 Climate Conditions during the Period of Study

#### *3.21 Air temperature*

Figure 5 compares the maximum daily air temperatures at Kent for the two sample years and for the 30-year average from 1974- 2003. Maximum temperatures were greater in 2003 than in 2002. Temperatures in both study years fluctuate as expected around the 30-year average.

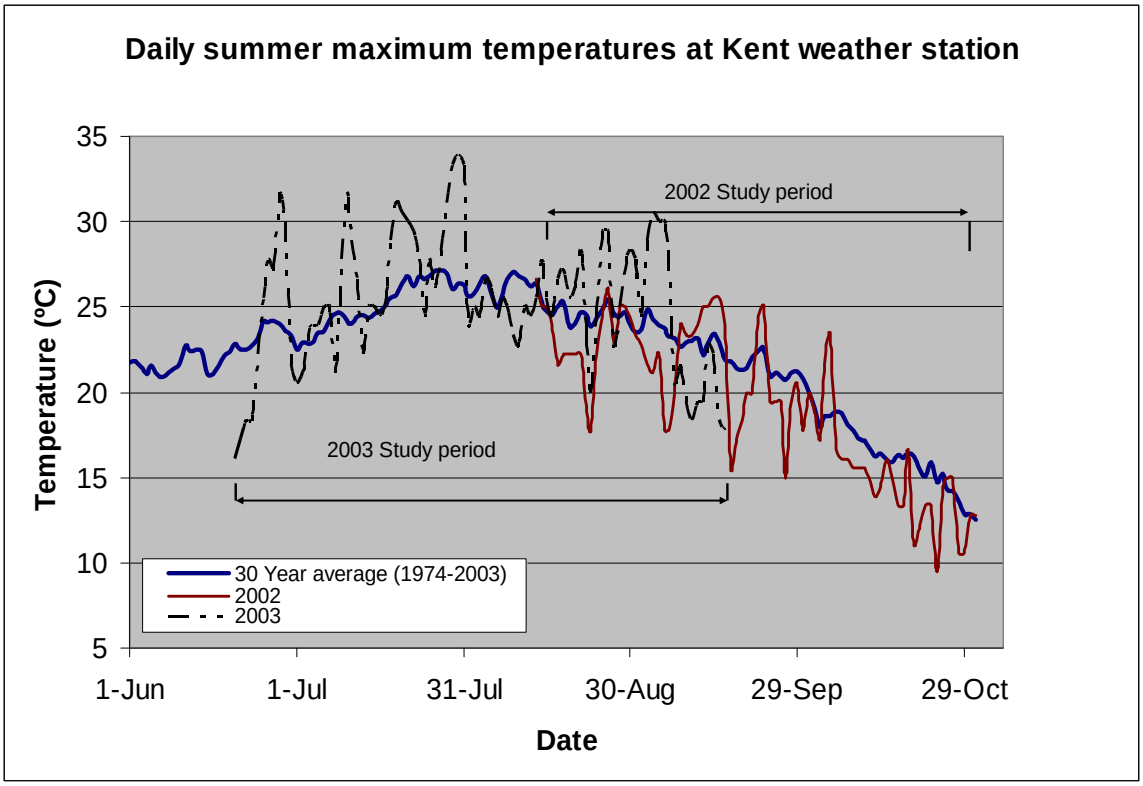



Figure 5. Comparison of daily maximum air temperatures during sample periods to average maximum temperatures.

### *3.22 Precipitation*

Rainfall data collected at the Lake Dolloff and Star Lake precipitation gages were highly correlated (r = 0.99). Because the Lake Dolloff rain gage is more closely related to the Mill Creek environment, analyses focused on the Lake Dolloff gage. The Lake Dolloff gage has been in place since 1988. The water year (Oct 1-Sept 30) annual average precipitation recorded at this location is 1011 mm (39.8 in). The total water year precipitation for 2002 and 2003 study years was 1011 mm (39.8 in) and 1034mm ( 40.7 in), respectively. Of more relevance to this study is summer precipitation (June 1-Sept 30). The average summer precipitation during the period of record is 112mm (4.39 in). During this study, summer precipitation was only 79 and 61 mm (3.12 and 2.41 in) in 2002 and 2003, respectively.

### *3.23 Discharge*

The only active gage available for use during this study was the gage near Peasley Canyon (MF-104), located on the east side of the intersection of West Valley Highway and State Highway 18, which was activated in late February 1997. Previously, from October 1988 to February 1992, Mill Creek had been gaged at upstream at station, 41C,

located at Peasley Canyon Road. The mean daily flow for the period of record at the two Peasley Canyon gages is 0.15 $m^3/s$ (5.2 $ft^3/s$) and 0.21 $m^3/s$ (7.4 $ft^3/s$) for 41C and MF104, respectively. Analysis of the summer flows shows that the record for MF104 is much more variable, and has a slightly higher base summer flow (0.051 $m^3/s$ (1.8 $ft^3/s$) vs. 0.026 $m^3/s$ (0.93 $ft^3/s$) than that recorded at the older 41C gage.

Using the inactive gages, 41B and 41C, a relationship was developed to estimate flow accumulation between the Peasley Canyon Road gage (41C) and the gage at 29th Ave NW (41B), which is located just north of the Emerald Downs Race Track. A polynomial equation was developed that predicted summer flow at 29th Ave NW, based on flow recorded at Peasley Canyon Road. The r-square for this equation is 0.89.

$$Q_{29th\ Ave\ NW} = 2.21*Q^2_{peasley} - 1.22*Q_{peasley} + 4.03 \qquad \text{where Q is in cfs} \qquad (2)$$

This boils down to an increase of about five $ft^3/s$ of flow at 29th Ave NW for every unit of flow at Peasley Canyon Road. If one assumes that the flow paths between these two gages have not changed much since 1992, then one can estimate flow at 29th Ave NW for the period of study based on the flow recorded at the MF-104 gage near Peasley Canyon.

During the summer of 2002, the average flow near Peasley Canyon was 0.024 $m^3/s$ (0.83 $ft^3/s$), with a median flow of 0.013 $m^3/s$ (0.47 $ft^3/s$). During summer of 2003, the average flow was 0.039 $m^3/s$ (1.37 $ft^3/s$) with a median flow of 0.032 $m^3/s$ (1.13 $ft^3/s$). In a typical summer, relatively high flows occur in June with flow volume dropping to minimum values sometime in July or August, depending on the summer rainfall pattern. The effect about 1 inch (2.54 cm) of rain during the last three days of June 2002 and again from July 2-7 in the headwaters is clearly shown in Figure 6. In 2003, moderate rainfall occurred on June 13 and 21.

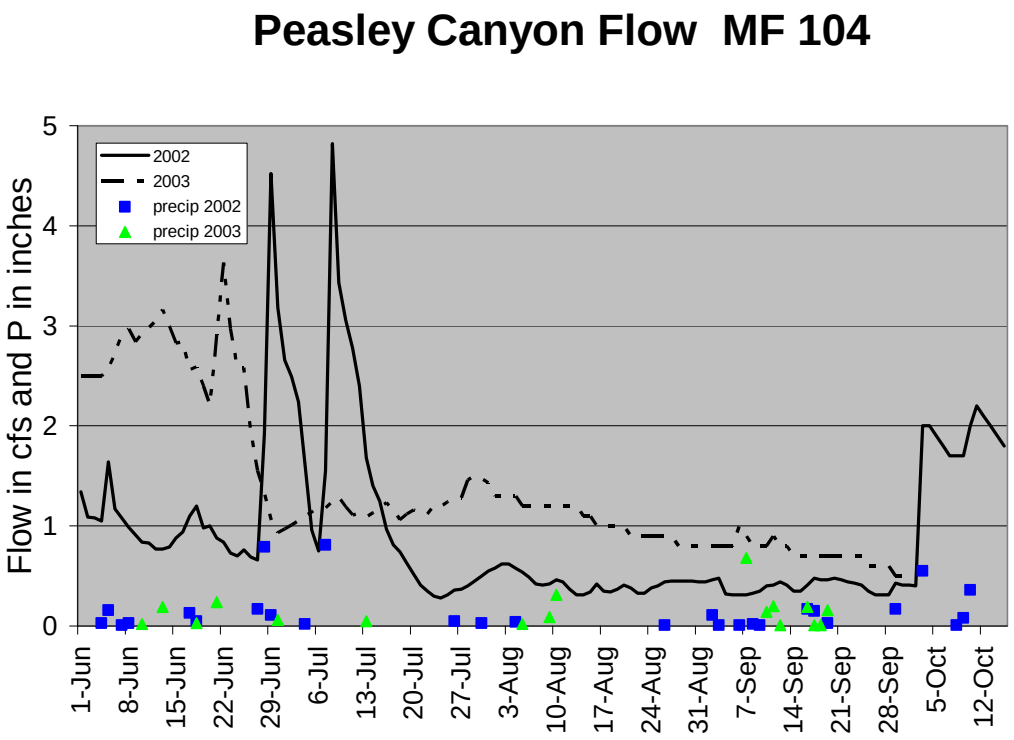



Figure 6. Flow pattern from summer 2002 and 2003 for gage MF-104 and precipitation at Lake Doloff.

### 3.3 Mill Creek

#### *3.31 Continuous monitoring*

Table 4 lists mean, median, maximum and minimum for the DO concentration, as well as the range and variance of these measurements. In Table 5, the mean, median, maximum and minimum temperatures recorded every 15 minutes by the Hydrolabs are given for each sampling period as well as the temperature range. Sites are listed from upstream to downstream and include sampling periods in 2002 and 2003. Because the one-week sample period occurred at different sites at different times of the year, these data are not combined by site, but are instead presented as relative temporal sample periods from upstream to downstream. Note that the statistics for 2002 are influenced by long sample periods that extended in November.

Table 4. Mill Creek Dissolved Oxygen (mg/l) - Summary Statistics. Data are clumped by temporal sampling periods and arranged from upstream to downstream stations. All sites are mainstem Mill Creek except Algona and 51F are tributaries. Shaded rows are deployments that exhibited erratic hourly values, usually a sharp drop in DO on the hour.

| Site | River Mile | Start Date | End Date | Sample Size | Mean | Variance | Median | Max | Min | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| P&R 2002 | 6.2 | 8/13/02 | 11/10/02 | 4647 | 9.19 | 1.39 | 9.12 | 12.70 | 5.81 | 6.89 |
| N15 2002 | 4.48 | 8/13/02 | 11/10/02 | 4692 | 0.88 | 0.68 | 0.48 | 6.58 | 0.38 | 6.20 |
| A315 2002 | 0.3 | 8/13/02 | 11/10/02 | 5029 | 9.14 | 1.77 | 9.27 | 12.16 | 6.68 | 5.48 |
| **June/July 2003** | | | | | | | | | | |
| Algona | 0.05 | 6/24/03 | 6/26/03 | 139 | 0.03 | 2.52E-05 | 0.03 | 0.04 | 0.03 | 0.01 |
| Restoration | 5.6 | 6/20/03 | 6/29/03 | 861 | 0.76 | 0.03 | 0.72 | 1.49 | 0.51 | 0.98 |
| N15 | 4.5 | 6/20/03 | 6/29/03 | 507 | 1.05 | 0.21 | 1.02 | 2.88 | 0.34 | 2.54 |
| Emerald Downs | 3.5 | 6/30/03 | 7/15/03 | 1411 | 0.80 | 0.04 | 0.79 | 1.31 | 0.31 | 1.00 |
| IP | 2.85 | 6/30/03 | 7/15/03 | 1413 | 1.86 | 0.23 | 1.86 | 3.19 | 0.62 | 2.57 |
| IP | 2.85 | 7/17/03 | 7/28/03 | 1023 | 6.26 | 3.85 | 5.32 | 10.28 | 3.16 | 7.12 |
| Smith Bridge | 1.5 | 6/30/03 | 7/7/03 | 639 | 6.68 | 3.74 | 6.22 | 9.87 | 4.23 | 5.64 |
| Smith Bridge* | 1.5 | 7/17/03 | 7/24/03 | 285* | 5.69 | 0.43 | 5.67 | 6.94 | 4.34 | 2.6 |
| A315 | 0.3 | 6/24/03 | 6/29/03 | 461 | 6.88 | 0.51 | 6.84 | 8.58 | 5.72 | 2.86 |
| **Aug 2003** | | | | | | | | | | |
| P&R | 6.2 | 8/14/03 | 8/28/03 | 1321 | 9.28 | 0.30 | 9.30 | 10.75 | 8.01 | 2.74 |
| Confluence | 6.1 | 7/31/03 | 8/09/03 | 906 | 1.69 | 1.62 | 1.22 | 6.8 | 0.38 | 6.42 |
| Hwy 167 | 6.0 | 8/14/03 | 8/28/03 | 1333 | 0.19 | 0.16 | 0.01 | 3.75 | 0 | 3.75 |
| Beaver | 5.4 | 7/31/03 | 8/11/03 | 1053 | 1.70 | 0.19 | 1.67 | 2.95 | 0.69 | 2.26 |
| N15 (w) | 4.5 | 7/31/03 | 8/8/03 | 1045 | 1.46 | 0.53 | 1.20 | 4.51 | 0.73 | 3.78 |
| Trib 51F | 0.05 | 8/14/03 | 8/28/03 | 1325 | 10.65 | 0.47 | 10.47 | 15.28 | 9.68 | 5.60 |
| M St. | 4.05 | 7/31/03 | 8/8/03 | | 3.56 | 1.28 | 3.75 | 8.00 | 0.70 | 7.30 |
| Schuler Br. | 1.8 | 8/14/03 | 8/28/03 | 1326 | 4.46 | 2.70 | 3.83 | 8.64 | 2.21 | 6.43 |
| **Sept 2003** | | | | | | | | | | |
| Restore | 5.6 | 9/2/03 | 9/15/03 | 1315 | 0.58 | 0.19 | 0.54 | 1.93 | 0 | 1.93 |
| Beaver | 5.4 | 9/2/03 | 9/16/03 | 1317 | 1.93 | 0.59 | 1.80 | 4.61 | 0.69 | 3.92 |
| N15(w) | 4.5 | 9/2/03 | 9/7/03 | 427 | 3.73 | 3.66 | 3.79 | 6.81 | 0.39 | 6.42 |
| M St | 4.05 | 9/2/03 | 9/16/03 | 1319 | 2.35 | 1.44 | 1.88 | 6.00 | 0.78 | 5.22 |
| IP | 2.85 | 9/3/03 | 9/16/03 | 1226 | 3.45 | 0.54 | 3.33 | 8.96 | 2.45 | 6.51 |
| | | | | | | | | | | |
| *data logger exposed to air 7/20-deleted data after 7/20 from analyses | | | | | | | | | | |

Table 5. Mill Creek Temperature $^{o}C$ - Summary Statistics. Data are clumped by temporal sampling periods and arranged from upstream to downstream stations. All sites are mainstem Mill Creek (#9.0051) except Algona (#9.0054) and Trib 51F (#9.0051F) which are tributaries.

| Site | River Mile | Start Date | End Date | Sample Size | Mean | Variance | Median | Max | Min | Temp Range |
|---|---|---|---|---|---|---|---|---|---|---|
| P&R 2002 | 6.2 | 8/13/02 | 11/10/02 | 4646 | 10.43 | 9.54 | 10.31 | 19.65 | 3.29 | 16.36 |
| N15 2002 | 4.48 | 8/13/02 | 11/10/02 | 4692 | 11.20 | 9.12 | 12.33 | 15.80 | 3.70 | 12.10 |
| A315 2002 | 0.3 | 8/13/02 | 11/10/02 | 5029 | 13.03 | 8.34 | 13.03 | 24.44 | 7.08 | 17.36 |
| **June/July 2003** | | | | | | | | | | |
| Algona | 0.05 | 6/24/03 | 6/26/03 | 139 | 15.55 | 0.54 | 15.71 | 16.63 | 14.28 | 2.35 |
| Restoration | 5.6 | 6/20/03 | 6/29/03 | 861 | 14.64 | 1.58 | 14.40 | 18.52 | 12.84 | 5.68 |
| N15 | 4.5 | 6/20/03 | 6/29/03 | 507 | 13.45 | 0.26 | 13.44 | 14.90 | 11.64 | 3.26 |
| Emerald Downs | 3.5 | 6/30/03 | 7/15/03 | 1411 | 15.60 | 0.65 | 15.66 | 17.50 | 13.63 | 3.87 |
| IP | 2.85 | 6/30/03 | 7/15/03 | 1413 | 13.70 | 0.33 | 13.72 | 15.00 | 12.37 | 2.63 |
| Smith Bridge | 1.5 | 6/30/03 | 7/7/03 | 639 | 16.22 | 4.35 | 15.97 | 20.32 | 12.69 | 7.63 |
| Smith Bridge* | 1.5 | 7/17/03 | 7/24/03 | 285* | 14.65 | 2.59 | 14.48 | 17.79 | 11.81 | 5.98 |
| A315 | 0.3 | 6/24/03 | 6/29/03 | 461 | 17.46 | 3.56 | 17.57 | 20.47 | 13.60 | 6.87 |
| **Aug 2003** | | | | | | | | | | |
| P&R | 6.2 | 8/14/03 | 8/28/03 | 1321 | 14.58 | 1.48 | 14.55 | 17.21 | 11.13 | 6.08 |
| Confluence | 6.1 | 7/31/03 | 8/9/03 | 905 | 15.31 | 0.43 | 15.28 | 17.17 | 14.18 | 2.99 |
| Hwy 167 | 6.0 | 8/14/03 | 8/28/03 | 1333 | 15.02 | 0.61 | 15.11 | 16.59 | 12.84 | 3.75 |
| Beaver | 5.4 | 7/31/03 | 8/11/03 | 1053 | 17.04 | 1.42 | 16.86 | 20.62 | 15.15 | 5.47 |
| N15 (w) | 4.5 | 7/31/03 | 8/8/03 | 1045 | 15.12 | 0.31 | 15.10 | 16.67 | 13.71 | 2.96 |
| Trib 51F | 0.05 | 8/14/03 | 8/28/03 | 1325 | 13.75 | 0.52 | 13.67 | 15.76 | 11.98 | 3.78 |
| M St. | 4.05 | 7/31/03 | 8/8/03 | 768 | 16.08 | 1.06 | 15.88 | 18.95 | 14.43 | 4.52 |
| Schuler Br. | 1.8 | 8/14/03 | 8/28/03 | 1326 | 17.15 | 3.90 | 16.92 | 21.41 | 12.74 | 8.67 |
| **Sept 2003** | | | | | | | | | | |
| Restore | 5.6 | 9/2/03 | 9/15/03 | 1315 | 14.75 | 1.86 | 14.80 | 17.79 | 12.11 | 5.68 |
| Beaver | 5.4 | 9/2/03 | 9/16/03 | 1317 | 15.24 | 1.58 | 15.36 | 17.45 | 12.51 | 4.94 |
| N15(w) | 4.5 | 9/2/03 | 9/7/03 | 427 | 14.85 | 0.50 | 14.73 | 16.47 | 12.98 | 3.49 |
| M St. | 4.05 | 9/2/03 | 9/16/03 | 1319 | 14.97 | 1.36 | 15.25 | 16.93 | 12.28 | 4.65 |
| IP | 2.85 | 9/3/03 | 9/16/03 | 1226 | 15.28 | 1.22 | 15.53 | 20.28 | 12.49 | 7.79 |
| | | | | | | | | | | |
| *data logger exposed to air 7/20- deleted data after 7/20 from analyses | | | | | | | | | | |

**Dissolved Oxygen**

Box plots in Figure 7 illustrate the distribution of dissolved oxygen levels for all sites and years from upstream to downstream. The only sites that consistently meet Class A state water standards are P&R (river mile 6.2) and tributary 51 F. Concentrations drop sharply at the Algona tributary junction. They remain well below the state water 8 mg/l until the tributary 51F junction. Tributary 51F has high levels of DO, and while

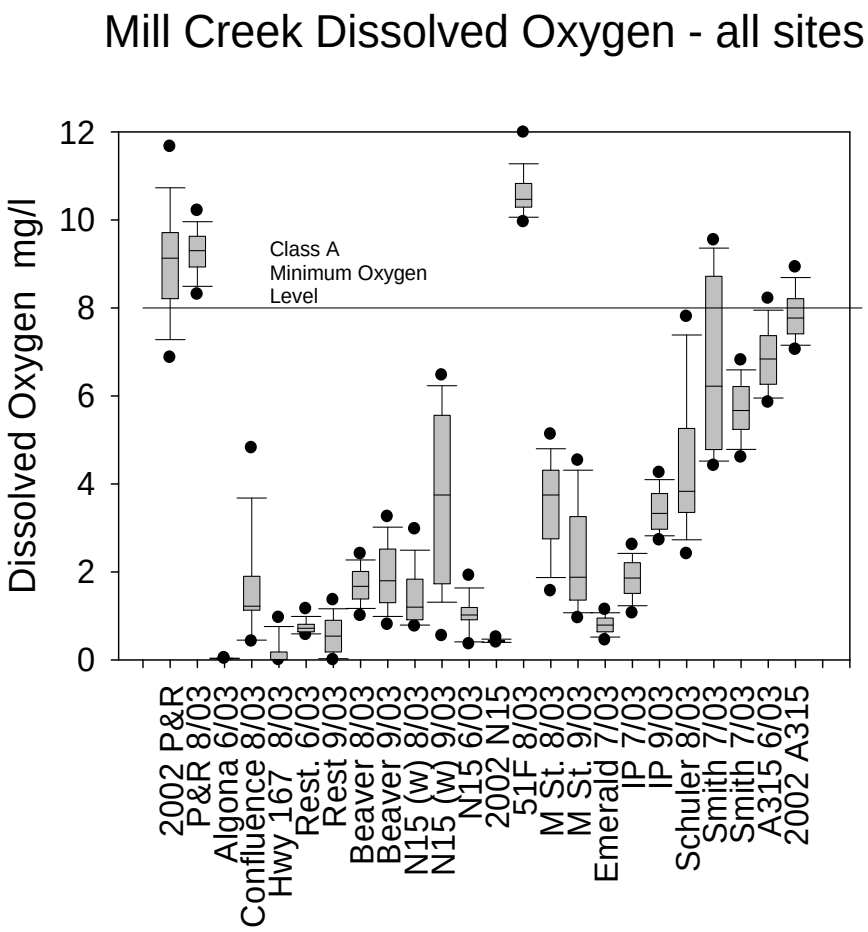
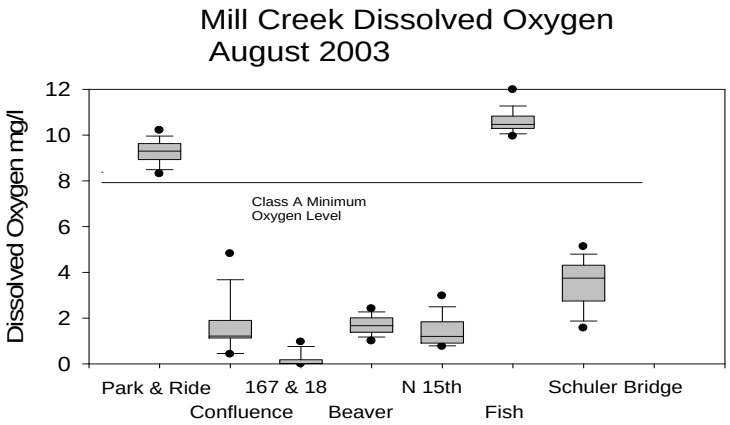



Figure 7. Box plots for all sites and sample dates in Mill Creek. Data shown for 2002 do not include October and November data. Box borders are 25th and 50th percentiles, interior line is median, whiskers are 10th and 90th percentiles, symbols are 5th and 95 percentiles.

flows from this tributary appear to increase DO somewhat downstream of its confluence with Mill Creek, downstream DO levels remain below 6 mg/L. DO levels begin to increase around river mile 1.5 (Smith Bridge) but do not ever consistently exceed 8 mg/l for the sites and time periods sampled in this study.

Additional analysis of specific sampling periods allows more detailed assessment of dissolved oxygen. Figure 8 illustrates the spatial variation in DO along Mill Creek for consistent sampling periods in 2003. The same trends show up in August and September 2003 as in the total data set. Oxygen levels < 8 mg/l are evident in all of Mill Creek except for the P&R site and the 51F tributary. Figure 9 looks at the 2002 data and shows how sites change monthly. P&R at river mile 6.2 shows a decrease in median DO in September, compared to August but also exhibits more variability. The N 15$^{th}$ site (river mile 4.48) shows a modest increase in DO concentration in October but levels are still well below 8 mg/l. The A315 site (river mile 0.3) shows DO levels increasing each month sampled from June to October. By September most values exceed 8 mg/l and all values exceed 8mg/l in October.



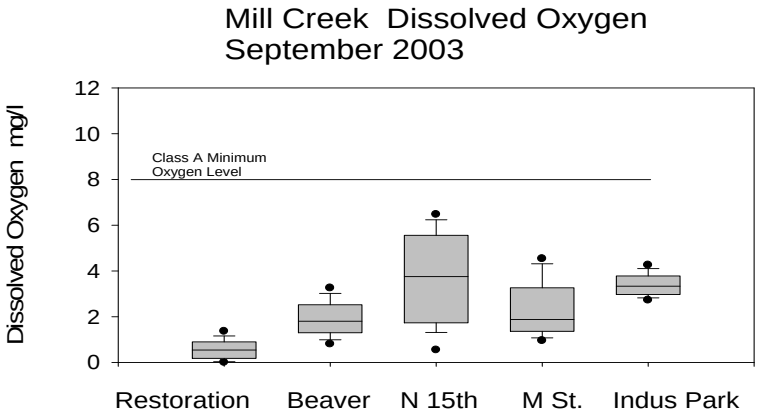




Figure 8. Box plots of Mill Creek dissolved oxygen concentration from upstream to downstream for consistent sampling times in August and September 2003. Box borders are 25$^{th}$ and 50$^{th}$ percentiles, interior line is median, whiskers are 10$^{th}$ and 90$^{th}$ percentiles, symbols are 5$^{th}$ and 95 percentiles.

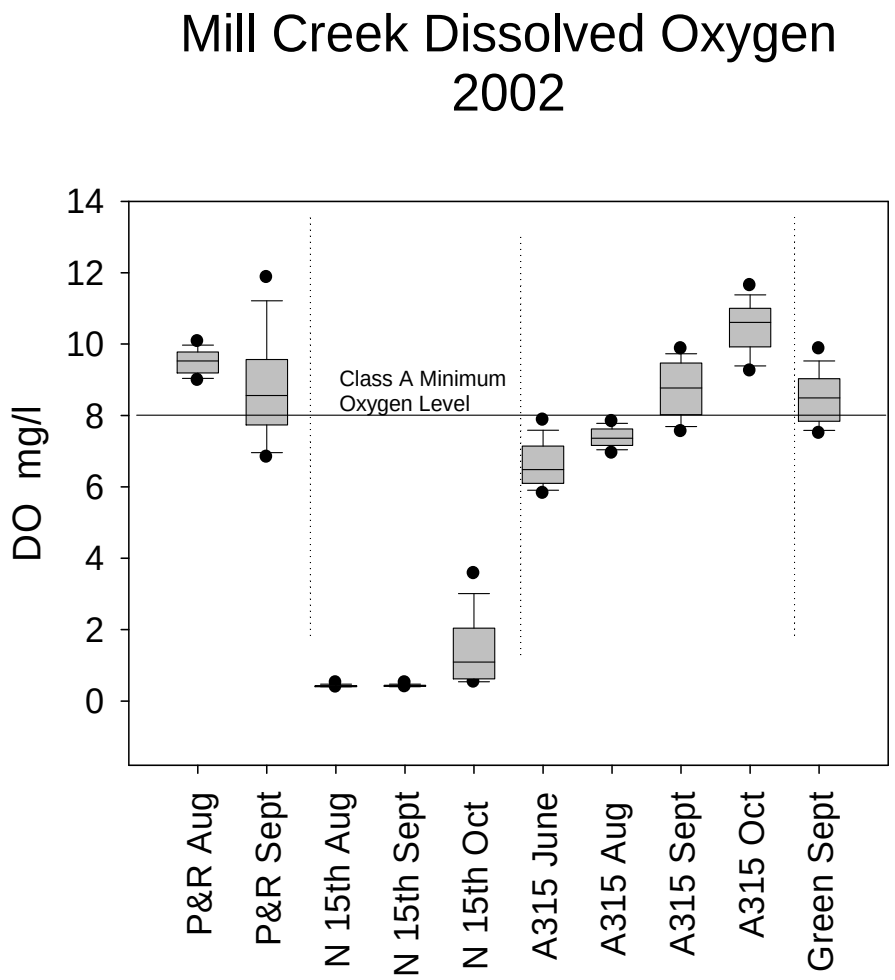



Figure 9. Mill Creek dissolved oxygen levels by month in 2002. Box borders are 25th and 50th percentiles, interior line is median, whiskers are 10th and 90th percentiles, symbols are 5th and 95 percentiles.

**Temperature**

Figure 10 illustrates the longitudinal spatial variation in temperature along Mill Creek. Temperature is relatively constant along the entire study area. Temperatures remain around 15°C with only a few sites exceeding 18 °C for a few samples. Some sites have greater temperature fluctuation such as IP in the late half of July, Smith Bridge and A315. The P&R and N15 sites that appear to have a wider range of temperatures were monitored for longer periods of time in 2002, but data in the box plots ends in mid-September in order to make comparisons easier. Even so, the 2002 data (P&R, N15, and A315) appear to be slightly cooler than other sites sampled in September 2003. Inspection of graphs of the 15-minute temperatures indicated that most sites have a noticeable daily cycle of temperature which accounts for much of the spread seen in the box plots. It is interesting to note that the August 2003 temperatures in tributary 51F, the

confluence of which is just upstream from RM 4.2 on Mill Creek at 21st Street are much cooler than the August sampling periods at sites immediately upstream and downstream from the confluence.

+

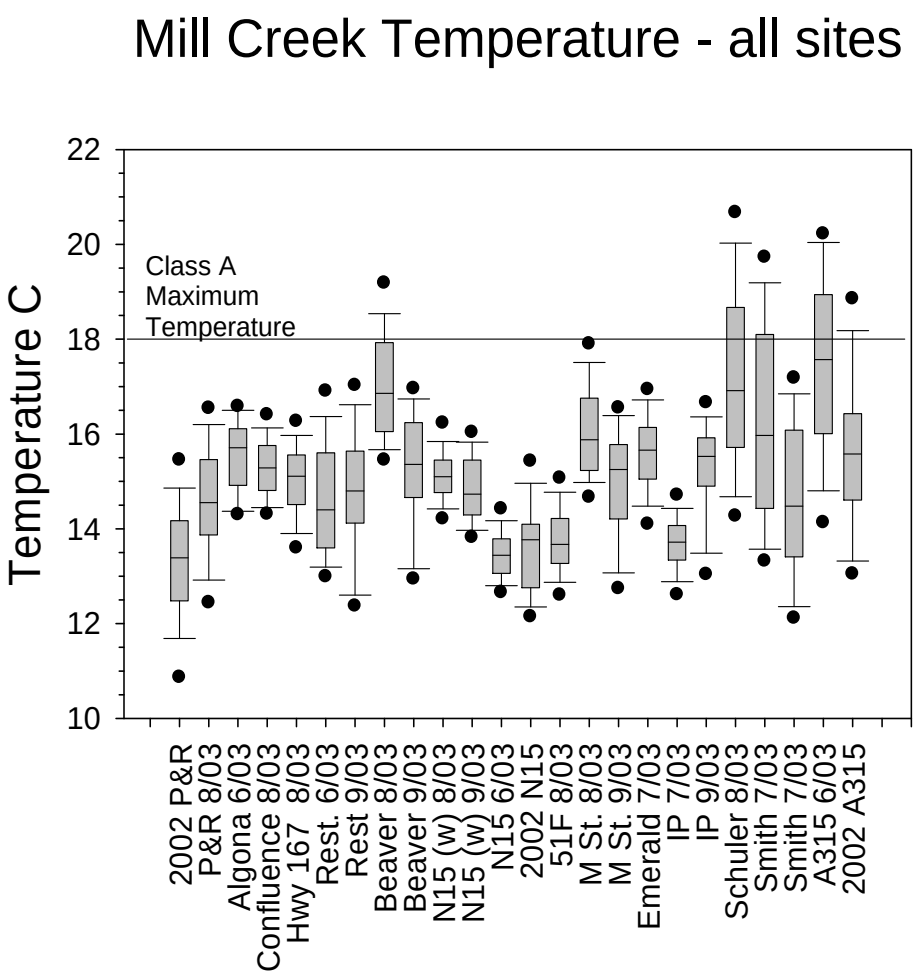



Figure 10: Box plot of Mill Creek water temperature from upstream to downstream. Box borders are 25th and 50th percentiles, interior line is median, whiskers are 10th and 90th percentiles, symbols are 5th and 95 percentiles. Data shown for 2002 do not include the October and November data

Figure 11 shows monthly decreases in temperature for the 2002 data. In June 2002, A315 water temperatures exceed 18 ˚C about half of the time. By August, A315 (river mile 0.3) temperatures are < 18 ˚C most of the time and by October, there are no recorded temperatures >18 ˚C. October water temperatures at both N 15th and A315 are much cooler than in September.

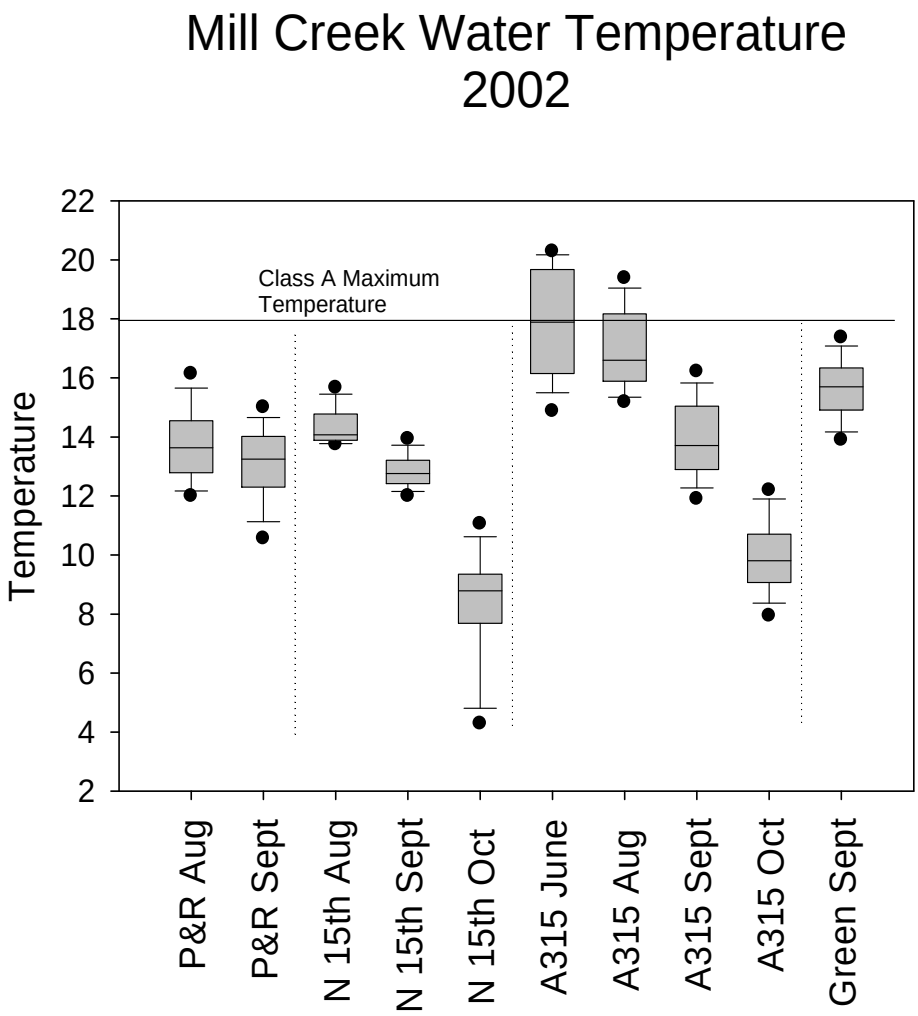



Figure 11: Box plot of Mill Creek water temperature for 2002 by month from upstream to downstream. Box borders are 25th and 50th percentiles, interior line is median, whiskers are 10th and 90th percentiles, symbols are 5th and 95 percentiles.

**DO and Temperature**

Daily average DO and water temperature are plotted in Figure 12. For sample sites with DO concentrations above 6 mg/L, the data are consistent with the expected inverse relationship between DO and water temperature. However, factors other than temperature clearly influence DO concentrations. Some DO concentrations are very low even at very cool temperatures. Analyses of percent saturation of DO at each site and sample period clearly indicated that low values of DO were not just an artifact of the inability of warm water to hold much DO. In sites with low values of DO (< 4 mg/l),

percent saturations levels were also very low, usually less than 50%. A strong relationship between water temperature and DO levels is seen at only three sites (Figure 12): P&R (river mile 6.2), Trib 51F which enters Mill Creek at RM 4.5 and A315 (river mile 0.3). These three sample sites also have the highest DO concentrations overall. At sites with consistently low DO levels, there is no apparent relationship between DO and water temperature. Thus it appears that where DO is a problem, factors other than temperature influence DO

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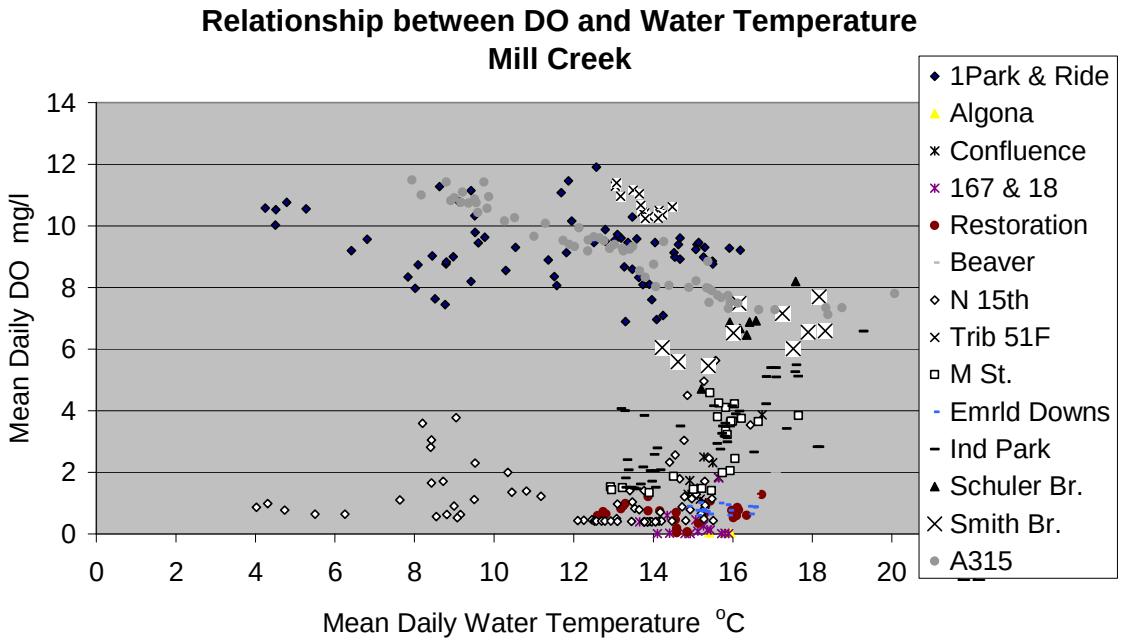


Figure 12. Mean daily dissolved oxygen and water temperature for Mill Creek

The relationship between water temperature and air temperature is shown in Figure 13. There is close correspondence between air and water temperatures at low air temperatures (< 5 ˚C), but as mean daily air temperatures increase, mean daily water temperatures begin to level off. Other factors influence water temperature including subsurface water inputs, tributary inputs or stratification in deep, slow-moving water.

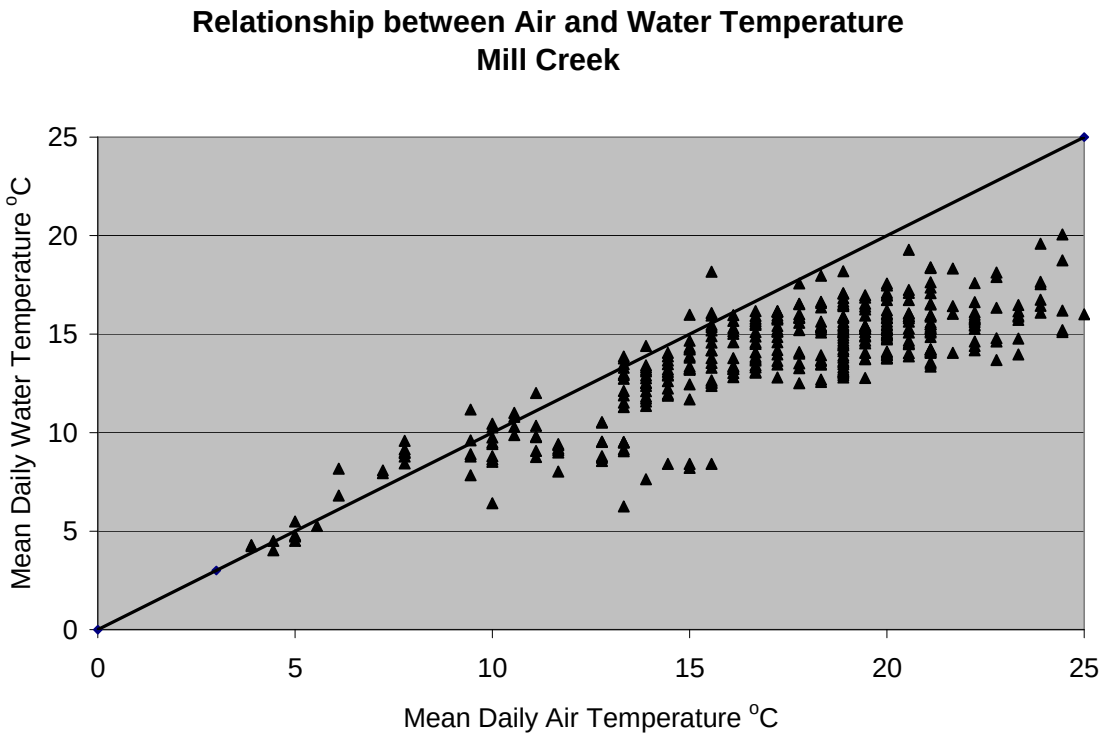


Figure 13. Mill Creek air temperature and water temperature with a one-to-one line.

**Dissolved Oxygen and Discharge**

Average daily DO concentrations were plotted with average daily discharge from the MF-104 gage operated by King County for the 2002 and 2003 summer period at all sites along Mill Creek (Figures 14 and 15). The fifteen-minute dissolved oxygen hydro lab data were summarized into daily averages because the only discharge data available were recorded as daily averages.

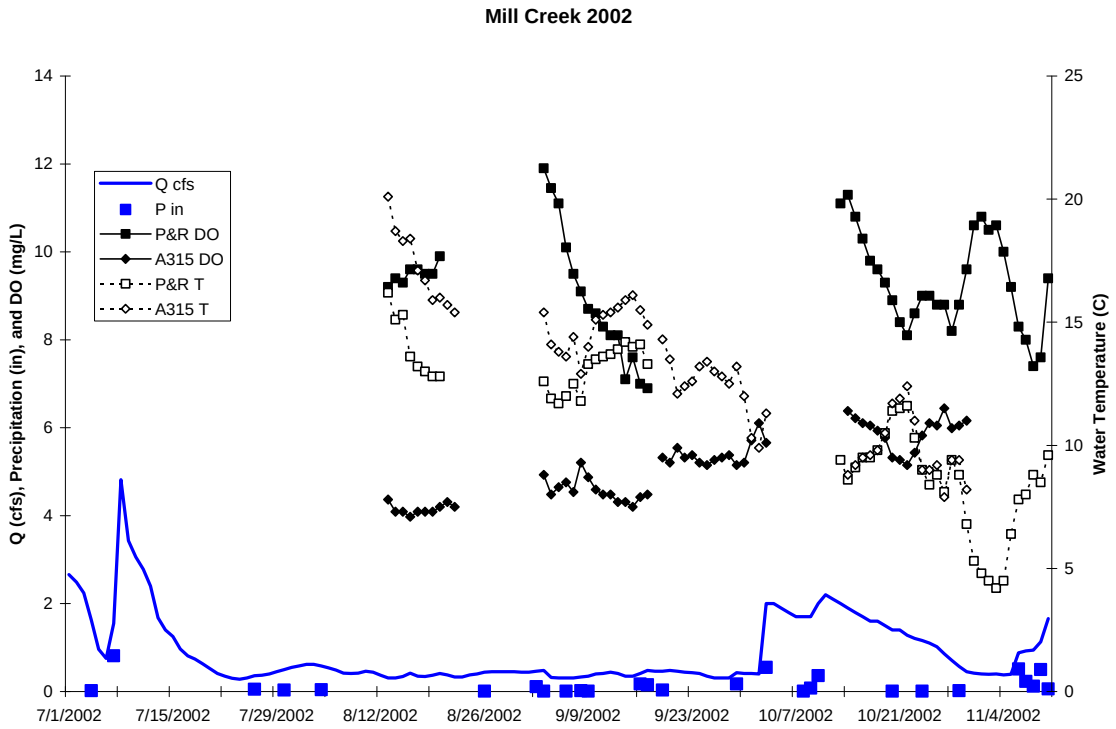


Figure 14. Dissolved oxygen, precipitation and discharge for 2002, Mill Creek.

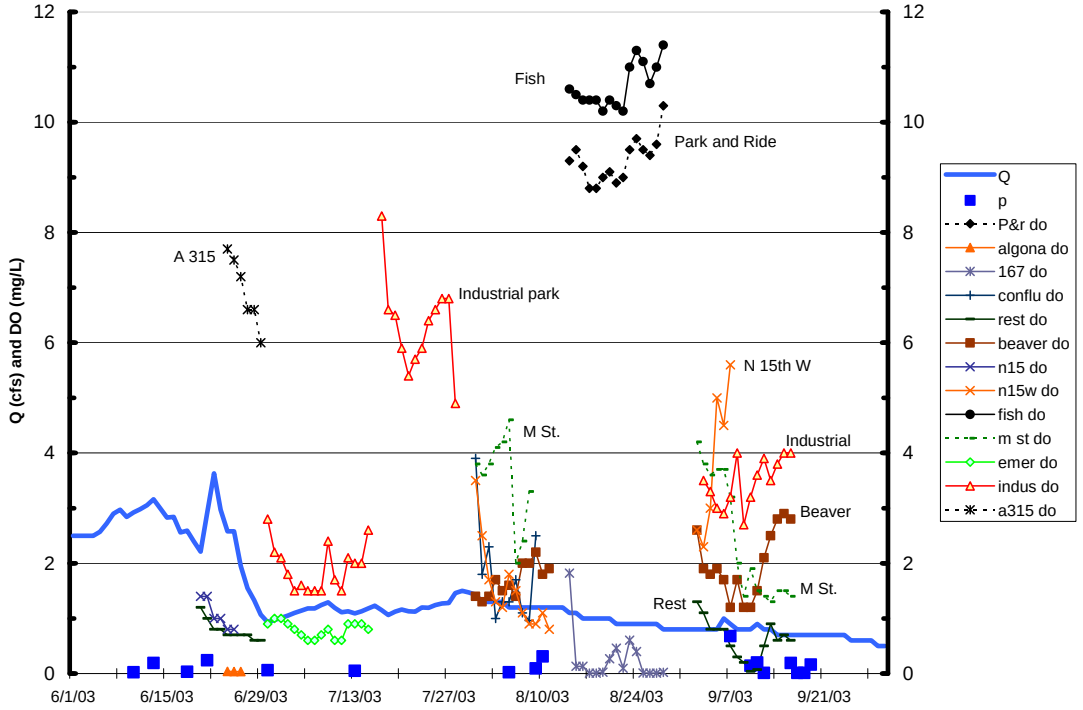


Figure 15. Dissolved oxygen, precipitation, temperature and discharge for 2003, Mill Creek.

There does not appear to be a consistent relationship between DO and discharge or precipitation in either 2002 or 2003. Discharge data from the MF104 gage near Peasley Canyon Road were used for all sampling locations along Mill Creek because this was the only active gage in the Mill Creek basin during this study period. Data from this gage can be considered to represent the driving hydrologic forces originating from the headwaters of Mill Creek, but do not reflect any substantial flows entering Mill Creek from ground water sources or tributaries along the study reach.

### *3.32 Instantaneous monitoring*

**Winkler Titrations**

In 2003, instantaneous data on DO concentrations were collected seven times from mid-June through mid-September at sites along Mill Creek and Mullen Slough. Assuming that the Winkler titration method is the most accurate, 0-intercept regressions were run comparing the Hydrolab data DO levels to those derived from the Winkler test. The Winkler DO levels were about 1.06 times higher than the Hydrolab DO levels (Figure 16, $r^2 = 0.69$) A comparison between the YSI 95 meter DO readings and the Hydrolab indicated that the YSI 95 values are almost 1.2 times higher than the Hydrolab DO levels ($r^2 = 0.83$). A comparison between the Winkler method and the YSI 95 meter indicated that YSI meter values are about 1.1 times .than the Winkler titrations ($r^2 = 0.88$)

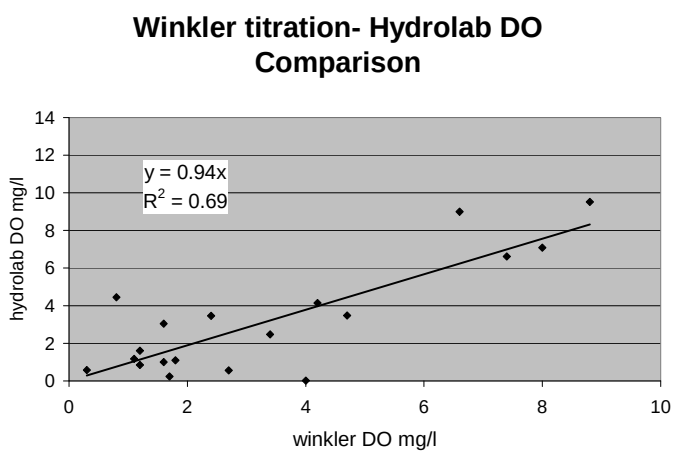


Figure 16. Relationship between DO levels using the Winkler titration method and those from the Hydrolab

**Biochemical Oxygen Demand**

Table 6 shows the results for the five-day incubation at 25$^{o}$C for samples taken along Mill Creek. The average BOD value for the Mill Creek sites was 3.53 mg/L. For the most part, these BOD levels are not indicative of high amounts of organic matter in the streams. The highest BOD measurements were observed at RM 0.05 (the Algona

tributary sampling site which enters Mill Creek at about RM 6.1) and RM 2.85 (the Industrial Park Way sampling site) on October 3, 2003 at 8.2 mg/L and 6.9 mg/L, respectively. At these two sites, the BOD levels indicate that bacterial decomposition of organic matter is occurring. Note that the BOD sampling was done late in the season (October) and it is unknown how these levels might compare to mid-summer levels.

**Table 6. Mill Creek Biochemical Oxygen Demand Five Day Incubation at 25C**

| Site | River Mile | Date | BOD mg/L |
|---|---|---|---|
| **Algona Trib #9.0054** | 0.05 | 9/9/2003 | 4.68 |
| **Algona Trib # 9.0054** | 0.05 | 10/3/2003 | 8.20 |
| **Confluence** | 6.1 | 10/3/2003 | 1.91 |
| **Confluence** | 6.1 | 10/3/2003 | 2.19 |
| **Hwy 167** | 6.0 | 10/3/2003 | 2.19 |
| **Restoration** | 5.6 | 10/3/2003 | 3.51 |
| **Restoration** | 5.6 | 10/3/2003 | 3.30 |
| **Beaver** | 5.4 | 9/9/2003 | 2.41 |
| **Beaver** | 5,4 | 10/3/2003 | 2.60 |
| **N15** | 4.5 | 9/28/2003 | 3.11 |
| **N15** | 4.5 | 10/3/2003 | 2.33 |
| **N15** | 4.5 | 10/3/2003 | 2.31 |
| **MSt** | 4.05 | 9/9/2003 | 2.95 |
| **M St** | 4.05 | 10/3/2003 | 3.64 |
| **Emerald Down** | 3.5 | 9/9/2003 | 4.28 |
| **IP** | 2.85 | 10/3/2003 | 6.90 |
| **Average** | | | 3.53 |

**Subsurface Water Monitoring**

Table 7 shows the mean, median, standard deviation, maximum, minimum, and range of temperature and DO levels from the piezometers near N15 along Mill Creek. There was no significant difference in temperature or dissolved oxygen between the initial sample time and the sample taking after clearing the piezometers. Values after clearing are used in the analyses. The mean DO concentration for all piezometers is 0.24 mg/L with a median value of 0.15 mg/L. Measured DO concentrations from piezometers in the stream channel fell in the same range as concentrations from the terrestrial piezometers. All DO concentrations were less that 1.10 mg/l. DO and temperature measurements were taken with the YSI meter. Exclusion of the October and November sample times to better match the stream studies shows little change in DO levels and only a slight increase in temperature. For comparison, the mean and median surface water temperature at the N15(w) stream site in August and September 2003 is 15.04 degrees ºC, about 1.7 ºC higher than the ground water temperature. The median and mean stream concentrations

for August and September are 2.12 mg/l and 1.43 mg/l, respectively compared to 0.22 mg/l and 0.12 mg/l in the ground water piezometers.

**Table 7. Mill Creek subsurface water dissolved oxygen measurements (mg/L) and temperature (C) at the N15 well site, near RM 4.5. Samples taken 7/24/03, 8/7/03, 8/19/03, 9/2/03, 10/3/03, 11/9/03**

| | N | Mean | Median | Std. Dev. | Maximum | Minimum | Range |
|---|---|---|---|---|---|---|---|
| **Transect 1** | | | | | | | |
| **DO** | 27 | 0.17 | 0.12 | 0.19 | 1.07 | 0.02 | 1.05 |
| **Temperature** | 27 | 13.31 | 13.30 | 1.22 | 16.00 | 10.60 | 5.40 |
| | | | | | | | |
| **Transect 2** | | | | | | | |
| **DO** | 31 | 0.27 | 0.18 | 0.24 | 1.04 | 0.09 | 0.95 |
| **Temperature** | 31 | 12.85 | 13.00 | 1.19 | 16.10 | 10.7 | 5.40 |
| | | | | | | | |
| **Transect 3** | | | | | | | |
| **DO** | 24 | 0.27 | 0.16 | 0.24 | 0.84 | 0.07 | 0.77 |
| **Temperature** | 24 | 12.70 | 12.75 | 1.15 | 16.10 | 10.40 | 5.70 |
| | | | | | | | |
| **All Piezometers** | | | | | | | |
| **DO** | 82 | 0.23 | 0.15 | 0.23 | 1.07 | 0.02 | 1.05 |
| **DO (Oct and Nov data deleted)** | 66 | (0.22) | (0.12) | (0.24) | (1.07) | (0.02) | (1.05) |
| **Temperature** | 82 | 12.96 | 12.9 | 1.20 | 16.10 | 10.40 | 5.70 |
| **Temperature (Oct and Nov data deleted)** | 66 | (13.34) | (13.10) | (0.90) | (16.10) | (12.1) | (4.0) |

### *3.33 State Water Quality Standards*

The number of days at each site that had a daily maximum temperature above state water quality standards for Class A streams (18$^{o}$C) is displayed from the most upstream sampling location at RM 6.2 (the P&R sampling site) to the most downstream sampling location RM 0.3 (the A315 sampling site) in Figure 17.

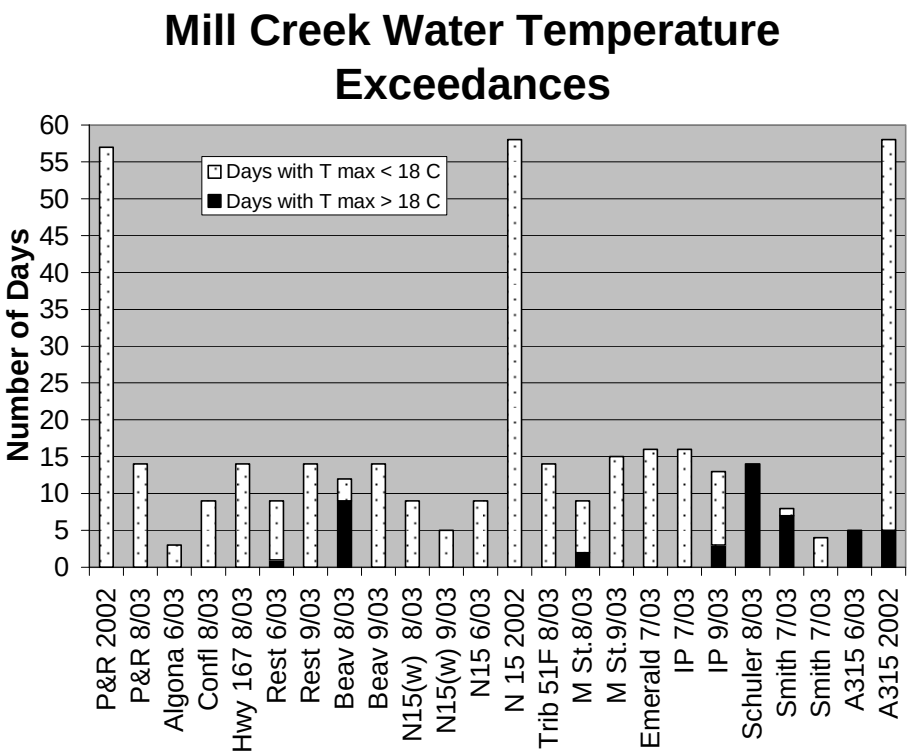


Figure 17. Number of days sampled with daily water temperature maximums above 18$^{o}$C from RM 6.2 (P&R) to RM 0.3 (A315).

Most sites exhibited no temperatures above 18 ˚C. For the sites and time periods sampled, more exceedances were seen below river mile 2.85 with only a few scattered exceedances between river mile 5.6 and 4.05. The sites with the highest percent of days with exceedances are from RM 2.85 (IP) to RM 0.3 (A315). The 2002 data for A315 show a low percentage of exceedances but the data set runs from August through November. Examination of the 2002 data collected at A315 (river mile 0.3) shows that the exceedances occurred in June and August 2002 (Figure 11). Overall, only 8 of the 24 possible site and date sampling periods had maximum temperatures that exceeded 18 ˚C.

Figure 18 shows the number of days that each site did not meet the state DO standards (> 8 mg/l) for Class A waters in both sampling years. Dissolved oxygen recorded at the majority of the sampling locations in Mill Creek during both sampling periods were below state water quality standards. P & R (8/03), river mile 6.2, and tributary 51F were the only monitoring locations where DO levels below 8.0 mg/l were not recorded. Dissolved oxygen levels exhibited varying amounts of daily temporal variation but were not extensively analyzed for this report. (See Travers 2006 for more information on daily variation.)

Examination of Figure 9 reveals that the P&R exceedances in 2002 all occurred in September. DO levels were all above 8 mg/l at P&R in Aug 2002. At A315 (river mile 0.3), Most of the exceedances occurred in June, There were only a few days in August when DO levels fell below 8 mg/l and none in October 2002.

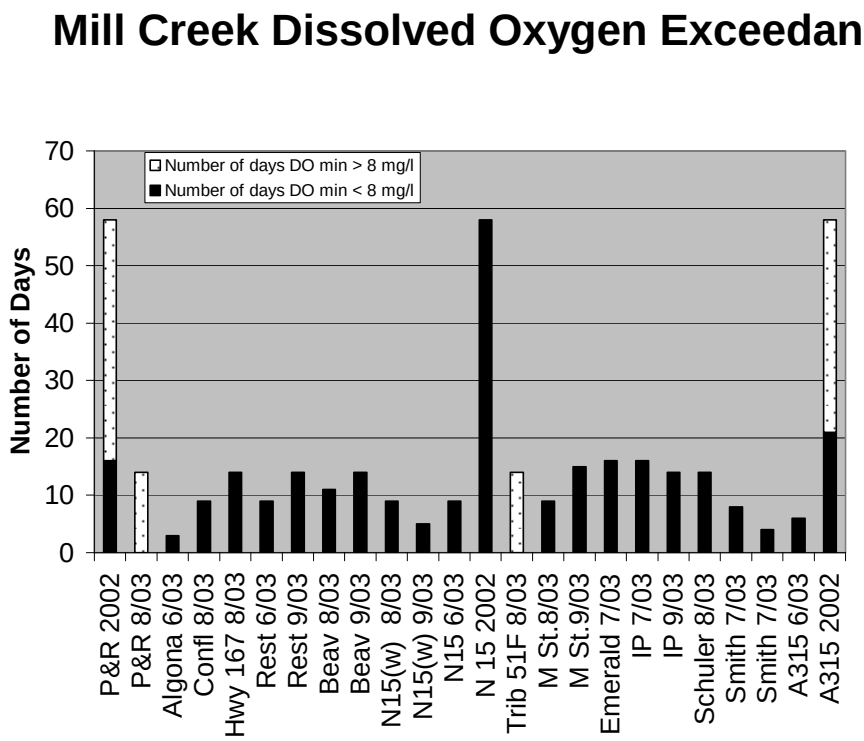


Figure 18. Number of days with one-day DO minimums below 8 mg/l of by site and sample period.

### 3.4 Mullen Slough

#### *3.41 Continuous dissolved oxygen and temperature monitoring*

In Table 8, the mean, median, maximum and minimum temperatures as well as the temperature range are presented for each sampling period. Sites are listed from upstream to downstream, and include sampling periods in 2002 and 2003. Table 9 shows the mean, median, maximum and minimum DO values, as well as the range and variance.

Because sampling was conducted over one-week periods at different sites at different times of the year, data are not combined by site, but instead are presented for individual sample periods, at stations listed upstream to downstream.

Table 8. Mullen Slough Temperature ( $^{o}$C) Summary Statistics. Data are clumped by temporal sampling periods and arranged from upstream to downstream stations. WRIA numbers are: Source 1 (#9.0047), Source 2 (#9.0048), Source 3 (#9.0049), Pump, Well and Flowers are on #9.0048, 277$^{th}$ is the start of #9.0045 which is the mainstem.

| Site | River Mile | Start Date | End Date | Sample Size | Mean | Variance | Median | Max | Min | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| **2002** | | | | | | | | | | |
| Source 2 | 0.6 | 9/03/02 | 9/17/02 | 1164 | 12.17 | 0.60 | 12.20 | 13.67 | 10.20 | 3.47 |
| Source 2 | 0.6 | 9/19/02 | 10/4/02 | 550 | 11.26 | 0.59 | 11.36 | 12.79 | 9.17 | 3.62 |
| 277th | 1.8 | 8/14/02 | 8/27/02 | 1250 | 14.48 | 0.66 | 14.45 | 16.81 | 12.83 | 3.98 |
| 277th | 1.8 | 9/03/02 | 9/17/02 | 1312 | 12.64 | 0.97 | 12.62 | 14.64 | 10.59 | 4.05 |
| 277th | 1.8 | 10/14/02 | 11/10/02 | 2588 | 7.19 | 6.54 | 7.82 | 11.62 | 1.76 | 9.86 |
| Mouth | 0.05 | 8/14/02 | 8/28/02 | 2488 | 15.30 | 0.66 | 15.12 | 17.11 | 13.78 | 3.33 |
| Mouth | 0.05 | 9/03/02 | 9/17/02 | 1320 | 13.09 | 1.04 | 13.10 | 14.58 | 11.05 | 3.53 |
| Green River | 22.6 | 9/03/02 | 9/17/02 | 1320 | 15.64 | 1.05 | 15.70 | 17.69 | 13.32 | 4.37 |
| **June/July 2003** | | | | | | | | | | |
| Source 2 | 0.6 | 6/30/03 | 7/15/03 | 1420 | 12.93 | 0.56 | 12.96 | 14.98 | 10.93 | 4.05 |
| Source 3. | 0.35 | 6/30/03 | 7/9/03 | 876 | 12.65 | 0.38 | 12.66 | 13.94 | 11.10 | 2.84 |
| Source 3. | 0.35 | 7/17/03 | 7/28/03 | 1032 | 14.83 | 2.48 | 14.67 | 18.34 | 11.72 | 6.62 |
| Lucio Pump | 0.3 | 7/17/03 | 7/20/03 | 285 | 14.66 | 2.59 | 14.48 | 17.79 | 11.81 | 5.98 |
| 277th | 1.8 | 6/20/03 | 6/29/03 | 864 | 13.59 | 1.46 | 13.21 | 16.13 | 11.81 | 4.32 |
| **Aug/Sept 2003** | | | | | | | | | | |
| Source 1 | 0.6 | 9/3/03 | 9/11/03 | 1227 | 12.68 | 0.92 | 12.93 | 14.65 | 10.15 | 4.50 |
| Lucio Flower | 0.4 | 8/14/03 | 8/20/03 | 539 | 14.52 | 1.08 | 14.37 | 16.52 | 11.76 | 4.76 |
| Lucio Well | 0.2 | 7/31/03 | 8/11/03 | 1055 | 14.47 | 1.22 | 14.33 | 17.42 | 12.30 | 5.12 |
| 277th | 1.8 | 9/3/03 | 9/16/03 | 1236 | 13.84 | 0.87 | 14.17 | 15.50 | 11.80 | 3.70 |

Dissolved Oxygen

Table 9. Mullen Slough Dissolved Oxygen Summary Statistics. Data are clumped by temporal sampling periods and arranged from upstream to downstream stations. WRIA numbers are: Source 1 (9.0047), Source 2 (9.0048), Source3 (9.0049), Pump, Well and Flowers are on 9.0048, 277th is the start of 9.0045 which is the mainstem. Shaded rows are deployments that exhibited erratic hourly values, usually a sharp drop in DO on the hour.

| Site | River Mile | Start Date | End Date | Sample Size | Mean | Variance | Median | Max | Min | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| **2002** | | | | | | | | | | |
| Source 2 | 0.6 | 9/3/02 | 9/17/02 | 1164 | 9.85 | 0.22 | 9.77 | 11.17 | 8.94 | 2.23 |
| Source 2 | 0.6 | 9/19/02 | 10/4/02 | 550 | 10.29 | 0.13 | 10.25 | 11.30 | 9.58 | 1.72 |
| 277th | 1.8 | 8/14/02 | 8/27/02 | 1250 | 0.51 | 0.06 | 0.41 | 1.55 | 0.33 | 1.22 |
| 277th | 1.8 | 9/3/02 | 9/17/02 | 1312 | 0.72 | 0.16 | 0.62 | 3.30 | 0.37 | 2.93 |
| 277th | 1.8 | 10/14/02 | 11/10/02 | 2588 | 3.51 | 2.64 | 2.99 | 7.34 | 1.13 | 6.21 |
| Mouth | 0.05 | 8/14/02 | 8/28/02 | 2488 | 6.10 | 0.76 | 6.12 | 6.65 | 4.72 | 1.93 |
| Mouth | 0.05 | 9/3/02 | 9/17/02 | 1320 | 7.32 | 0.33 | 7.27 | 8.34 | 5.76 | 2.58 |
| Green River | 22.6 | 9/3/02 | 9/17/02 | 1320 | 8.51 | 0.54 | 8.49 | 10.79 | 7.15 | 3.64 |
| **June/July 2003** | | | | | | | | | | |
| Source 2 | 0.6 | 6/30/03 | 7/15/03 | 1420 | 7.92 | 0.32 | 7.81 | 9.18 | 7.03 | 2.15 |
| Lucio Pump | 0.3 | 7/17/03 | 7/20/03 | 285 | 5.69 | 0.43 | 5.67 | 6.94 | 4.34 | 2.60 |
| Source 3. | 0.35 | 6/30/03 | 7/9/03 | 876 | 12.28 | 2.68 | 12.97 | 14.10 | 8.48 | 5.62 |
| Source 3. | 0.35 | 7/17/03 | 7/28/03 | 1032 | 6.56 | 0.43 | 6.58 | 8.25 | 4.85 | 3.40 |
| 277th | 1.8 | 6/20/03 | 6/29/03 | 864 | 0.83 | 0.18 | 0.73 | 2.13 | 0.23 | 1.90 |
| **Aug/Sept 2003** | | | | | | | | | | |
| Source 1 | 0.6 | 9/3/03 | 9/11/03 | 1227 | 8.67 | 0.56 | 8.75 | 9.97 | 6.43 | 3.54 |
| Lucio Flower | 0.4 | 8/14/03 | 8/20/03 | 539 | 7.63 | 1.12 | 7.92 | 9.26 | 4.06 | 5.20 |
| Lucio well | 0.2 | 7/31/03 | 8/11/03 | 1055 | 3.00 | 0.3 | 3.06 | 4.20 | 0.62 | 3.58 |
| 277th | 1.8 | 9/3/03 | 9/16/03 | 1236 | 0.80 | 0.01 | 0.77 | 2.37 | 0.72 | 1.65 |

Box plots of dissolved oxygen concentrations along Mullen Slough are presented in Figure 19. The site with the lowest concentration of DO is at river mile 1.8 (277th Street bridge) in the summer months, June through September, when DO levels less than 1mg/L were recorded. As in Mill Creek, DO was relatively high in the source flows (tributaries 0047, 0048 and 0049), and generally decreased downstream before increasing again near the mouth.

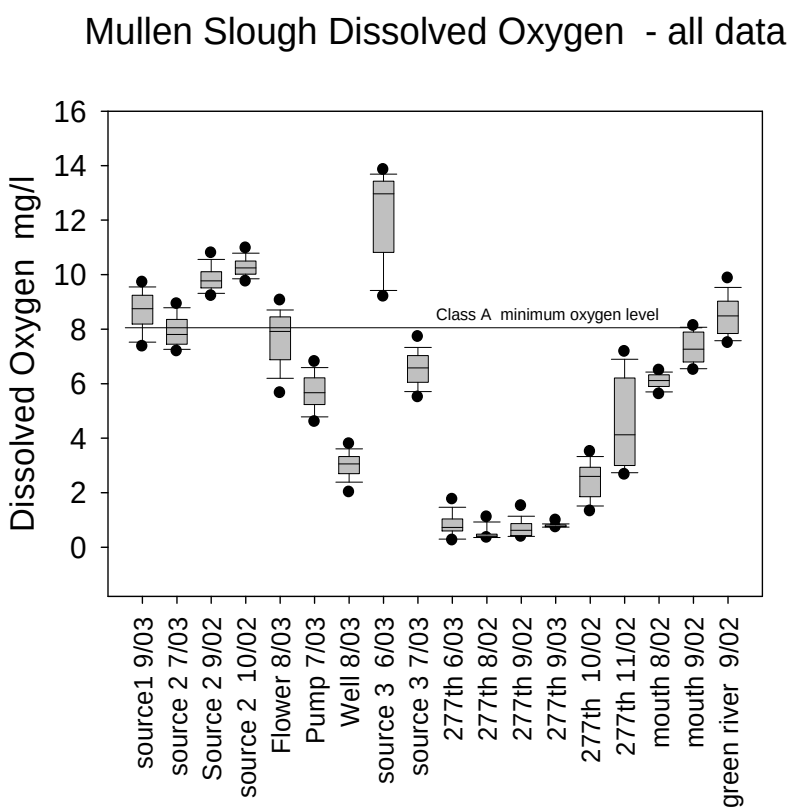


Figure 19. Dissolved oxygen concentration (15 minute values) from upstream Sources to downstream mouth of Mullen Slough. Box borders are 25$^{th}$ and 50$^{th}$ percentiles, interior line is median, whiskers are 10$^{th}$ and 90$^{th}$ percentiles, symbols are 5$^{th}$ and 95 percentiles

**Temperature**

The box plot in Figure 20 shows the distribution of water temperatures recorded in Mullen Sough. The site with the highest mean (15.3$^{o}$C), median (15.12$^{o}$C) and maximum (27.23$^{o}$C) water temperature was at river mile 0.05, (Mouth), near the confluence with the Green River, in August of 2002.

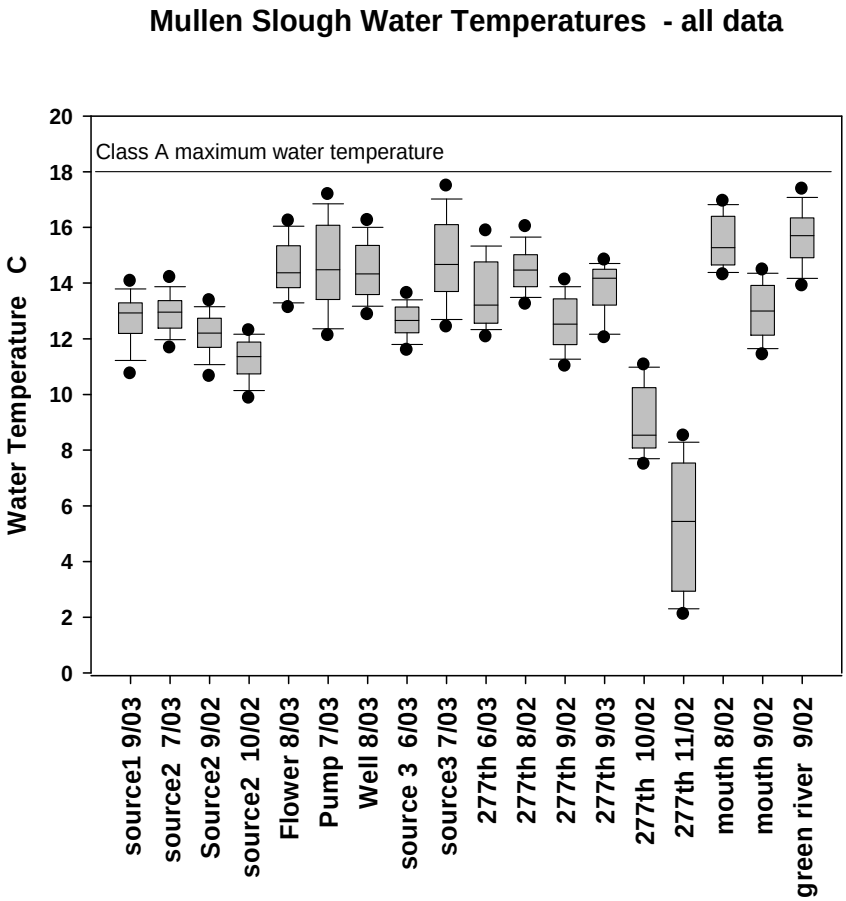


Figure 20. Box plot of water temperature (15 minute values) from upstream source to downstream mouth along Mullen Slough. Box borders are 25th and 50th percentiles, interior line is median, whiskers are 10th and 90th percentiles, symbols are 5th and 95 percentiles

.

**DO and Temperature**

Mean daily DO and temperature data (derived from the 15-minute Hydrolab data) were plotted for all Mullen Slough sample sites. Figure 21 shows the expected inverse relationship between water temperature and DO. However, one can see that for the same temperature range, there are areas where DO is high, medium and low, suggesting that factors other than temperature influence DO levels in Mullen Slough.

As was also seen in the Mill Creek data, there is a relationship between air and water temperature (Figure 22). As in Mill Creek, water temperature in Mullen Slough follows air temperature systematically at lower air temperatures, but begins to lag as air temperatures rise. Other factors that influence water temperature include groundwater inputs, tributary inputs or stratification in deep, slow-moving water.

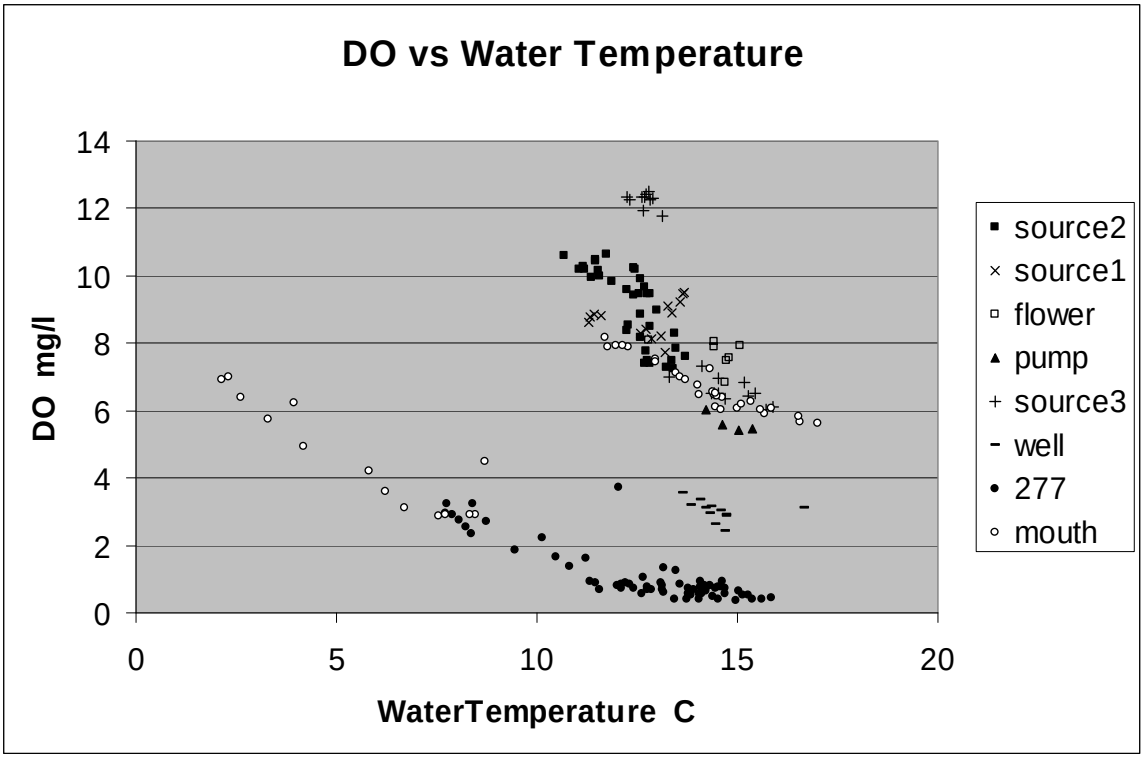


Figure 21. Dissolved oxygen and water temperature (daily means) for Mullen Slough for each sampling period at each site

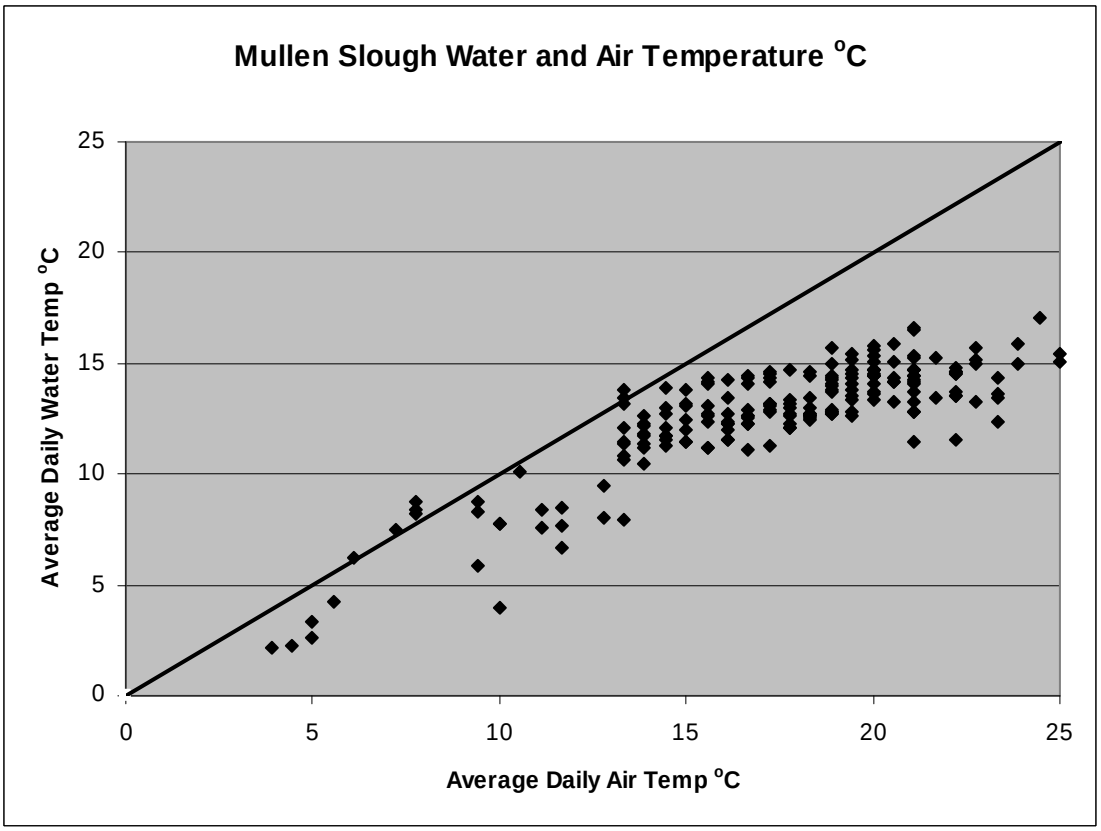


Figure 22. Mean daily water and air temperature in Mullen Slough.

#### DO and Discharge

Due to the lack of an active gage, discharge data for Mullen Slough were not available for the period of this study.

### *3.42 Instantaneous Monitoring*

#### Winkler Titrations

All comparisons between instantaneous DO levels and ;the recording data are shown in section 3.32 in the Mill Creek section. All the instantaneous data were combined as there was no need to look at the comparisons separately for each stream.

#### Biochemical Oxygen Demand

No usable results available.

#### Subsurface Water Monitoring

Table 10 shows the mean, median, standard deviation, maximum, minimum, and range of temperature and DO levels taken from the piezometers at Lucio well site along Mullen Slough. All of the piezometers showed very low levels (< 1 mg/L) of dissolved oxygen in the subsurface water.

**Table 10. Mullen Slough Piezometers. Dissolved Oxygen measurements (mg/L), Temperature (˚C) Samples taken 8/12/03, 8/21/03, 9/4/03, 10/4/03**

| | N | Mean | Median | Std. Dev | Maximum | Minimum | Range |
|---|---|---|---|---|---|---|---|
| Transect 1 | | | | | | | |
| DO | 13 | 0.14 | 0.13 | 0.06 | 0.33 | 0.09 | 0.24 |
| Temperature | 13 | 14.08 | 14.00 | 0.55 | 15.3 | 13.4 | 1.9 |
| | | | | | | | |
| Transect 2 | | | | | | | |
| DO | 13 | 0.27 | 0.18 | 0.23 | 0.8 | 0.1 | 0.7 |
| Temperature | 13 | 13.28 | 13.2 | 0.53 | 14.00 | 12.50 | 1.5 |
| | | | | | | | |
| Transect 3 | | | | | | | |
| DO | 13 | 0.15 | 0.14 | 0.07 | 0.38 | 0.1 | 0.28 |
| Temperature | 13 | 14.40 | 14.3 | 0.79 | 15.7 | 13.3 | 2.4 |
| | | | | | | | |
| All Piezometers | | | | | | | |
| | | | | | | | |
| DO | 39 | 0.19 | 0.14 | 0.15 | 0.80 | 0.09 | 0.71 |
| Temperature | 39 | 13.92 | 13.90 | 0.78 | 15.7 | 12.5 | 3.2 |

### *3.43 State Water Quality Standards*

Figure 23 displays the number of days that each site exceeded the state water quality standard for temperature (18$^{o}$C), displayed from the most upstream sampling location to the mouth of Mullen Slough. Only Source 3 (2 days out of 12) had maximum stream temperatures exceed 18$^{o}$C. Figure 24 displays the number of days that minimum DO levels were less than 8.0 mg/l. Only a few sites and sample periods had any days when daily DO levels remained above 8 mg/l. Source 2 (9.0048) at river mile 0.6 had all daily minimum levels > 8.0 mg/l in the September to October sample period but only 3 out of 16 days with levels > 8.0 mg/l in July 2003. Source 3 (9.0049) met state standards in late June/early July 2003, but not during the later sampling period in July 2003.

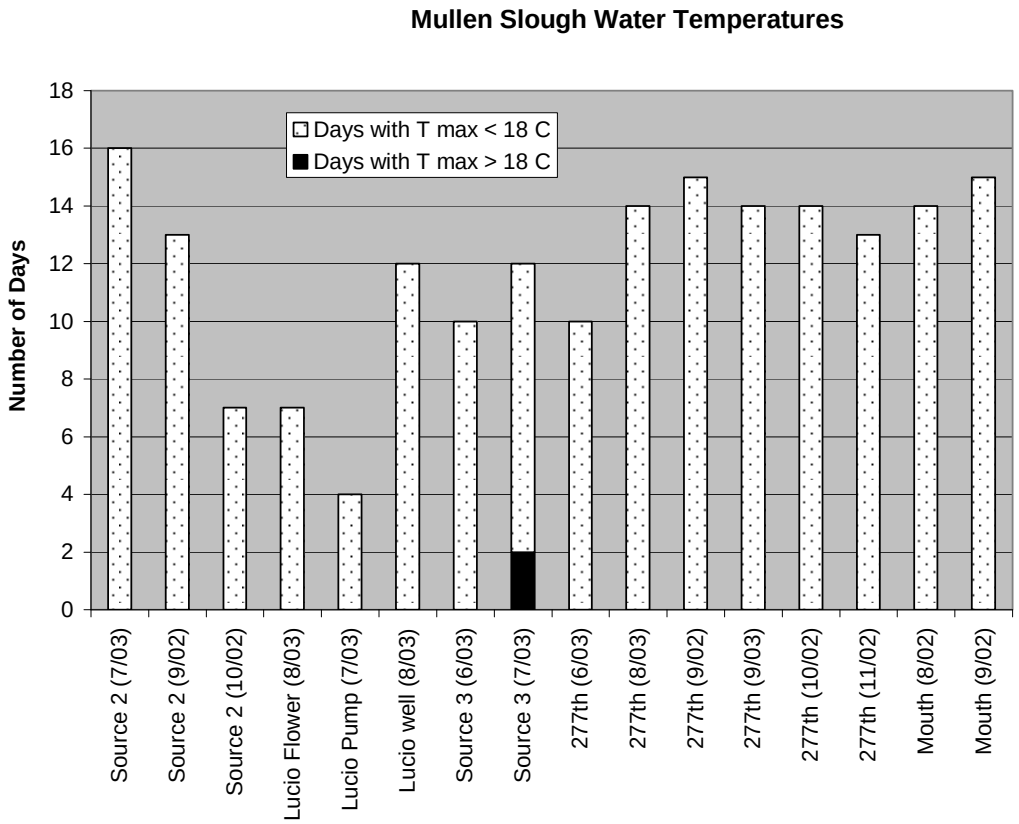


Figure 23. Number of days with maximum water temperature above 18$^{o}$C along Mullen Slough from upstream Source to downstream Mouth.

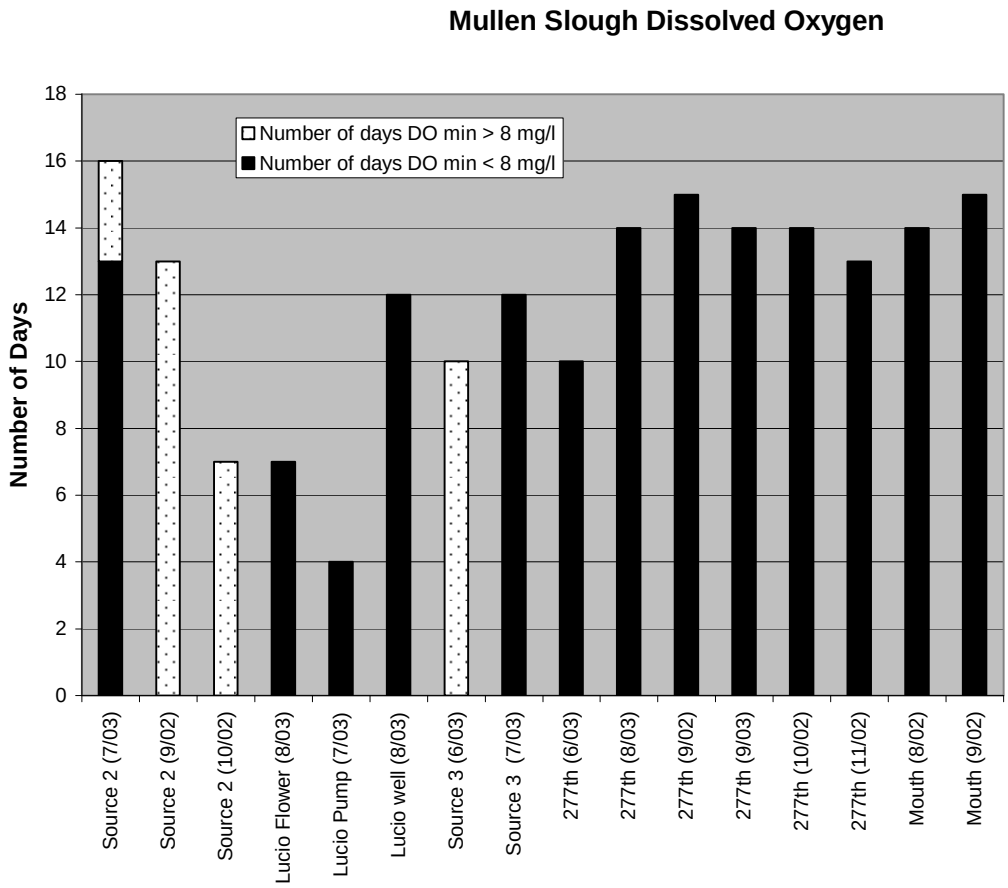


Figure 24. Number of days with minimum DO below 8 mg/l.

## 4.0 Conclusions

### 4.1 Mill Creek

The lack of a consistent relationship between water temperature and DO indicates that other factors besides water temperature likely influence the observed DO levels in Mill Creek. Analyses of inactive gage records indicated that summer flows increase about 5-fold between the well-oxygenated water at river mile 6.2 (the P& R sampling site) and the hypoxic water just north of Emerald Downs (the inactive gage) near river mile 3.5. The two tributaries, Algona (# 9.0054), which enters Mill Creek at about river mile 6.1, and tributary 51F, which joins Mill Creek at river mile 4.5 exhibit opposite characteristics. Algona Creek is relatively warm and hypoxic; 51F, is cool and well-oxygenated. Algona Creek enters Mill Creek through an algae-coated culvert. Tributary 51F enters Mill Creek in a 'natural' channel, typically has more flow than Algona Creek, and fish fry are seen in the vicinity.

A simple mass balance using equation 2, that was developed to estimate flow at river mile 3.5 (near Emerald Downs), can be used to estimate DO levels in that area. Assuming most of the flow entering the stream between river mile 6.2 and 3.5 is hypoxic (~2 mg/l), a rough estimate of DO concentration can be computed using mass-balance principles to yield the following mass balance equation:

$$DO_{29th} = \frac{(Q_{peasley} * DO_{peasley}) + (Q_{29th} * DO_{29th})}{Q_{peasley} + Q_{29th}}$$

$$DO_{29th} = \frac{(1\ cfs * 9\ mg/L) + ((5.01*1)\ cfs * 2\ mg/L)}{1\ cfs + 5.01\ cfs} = 3.2\ mg/L\ DO$$

Without additional information on discharge sources, it appears that much of the flow accumulation in the valley floor reach of Mill Creek comes from groundwater, which is very low in DO. If most of the water increase is due to poorly oxygenated ground water (mean piezometer DO was < 0.2 mg/l) , the estimated DO levels at 29$^{th}$ would be 1.6 mg/L. The average of the samples collected at Emerald Downs (river mile 32.) is 0.8 mg/l in June 2003. The combination of low DO inflow from ground water and moderate to high BOD likely combine to produce the low DO concentrations observed throughout the valley floor reach of Mill Creek. SOD may also remove oxygen but a pilot study on SOD was inconclusive and highlighted collection and analysis problems.

The DO measurements taken at the majority of the Mill Creek sampling locations during most of the sampling periods along Mill Creek were below state water quality standards

for DO. In addition, the valley floor reach of Mill Creek was the area were DO concentrations were least correlated with water temperatures. Laboratory analysis measured BOD levels at these sites in excess of 2 mg/L, and sometimes as high as 8 mg/L. These BOD measurements suggest that eutrophic conditions at these sites likely influence the concentration of DO in the stream.

Water temperatures in Mill Creek did not exceed the Class A state standard of 18 ˚C at most of the sites. Three sites occasionally exceeded 18 ˚C, but not for extensive periods of time. If most of the flow accumulation is from subsurface flows, which piezometer data indicated are cooler than the stream temperatures, the subsurface water may be helping keep the shallow, slow-moving stream relatively cool. Median piezometer water temperatures were < 13 ˚C. Water temperature does not appear to be a primary factor in low DO levels in Mill Creek.

An unexplored incidental finding relates to the influence of rainfall on dissolved oxygen. Anecdotal observations of 15-minute traces of DO in Mill Creek show what appear to be spikes in DO that coincide with precipitation events. On several occasions, DO increases of 2 mg/l or more occurred during the same time period as moderate to large precipitation events.

### 4.2 Mullen Slough

In Mullen Slough, most sites showed the expected inverse relationship between water temperature and dissolved oxygen concentrations, at least part of the time. Dissolved oxygen concentrations in Mullen slough were somewhat higher than those in Mill Creek. Only at river mile 1.8, which is the start of the mainstem where Tributaries 47 and 48 join, is dissolved oxygen at hypoxic levels. Source 2 (Trib 48) shows a sharp drop in DO concentration from river mile 0.6 to 0.2. The piezometer water concentrations near river mile 0.2 average < 0.2 mg/l. One possible explanation for the drop in DO along tributary 48 is the influx of ground water that is practically anoxic. There were no valid samples of BOD from Mullen Slough.

Water temperatures almost never exceeded the state water quality standard in Mullen Slough. The only site that ever got warmer than 18 ˚C was Source 3 (tributary 0049) for a brief period on 2 days in July 2003. At 277$^{th}$ St. (river mile 1.8) on Mullen Slough, dissolved oxygen levels increased in October and November coincident with sharp drops in water temperature. Even is DO is partly limited in Mullen Slough by water temperature, many sample periods still did not meet Class A standards even as streams cooled in the Fall. However, more temperature and DO data would need to be collected in Mullen Slough to firmly support this conclusion. Because surface discharge, groundwater influx, and BOD measurements were not made in the Mullen Slough basin, no conclusions can be drawn regarding the influence of these factors on DO in Mullen Slough.

### 4.3 Other Riverine Swamp Studies

An extensive literature review uncovered very few studies on streams that flow through wetlands. Most studies in the PNW on stream temperature have focused on forested lands and do not apply to lowland, unforested, streams. Prior to the start of this study, King County looked for a reference stream that would be appropriate for comparison with the Mill Creek/Mullen Slough basin, but none were identified. The few studies that were found are discussed below.

Other studies (e.g., those conducted by Sabo et al., 1999a; 1999b) have noted a relationship between water temperature, DO and discharge. Maximum variance in values across their site, located in Louisiana, was highest when temperature exceeded the median air temperature and stream discharge was less than the median discharge. Areas with no visible flow turbulence had highly variable chemical values and consistently lower DO values. These workers also noted that habitat variation in the riverine swamps where their sampling sites were located depended on how surface and ground water was exchanged within the floodplain, and how biological activity altered water chemistry, e.g. photosynthesis and respiration. Traditional physical hydraulic models may not be effective in predicting habitat conditions in riverine swamps. Discharge interacts with temperature to affect water chemistry by controlling the amount of suspended material and the amount of time and the rate at which organisms can metabolize organic matter. The DO values reported in the studies cited above ranged from 0.05 to 13.05 mg/l, and 0.6 to 142.4 % concentrations. These values are comparable to those measured in the present Mill Creek/Mullen Slough study, in which DO values ranged between 0 and 15 mg/L). The hydrology of the Louisiana swamp studied by Sabo et al. (1999a, 1999b) had been altered but was not influenced by agriculture, urbanization, or industrial land uses. These researchers hypothesized that the spatial and temporal variations in DO at their site were related to spatial differences in water flow paths.

Although there are indications that urbanization and agriculture affect the DO at certain locations along Mill Creek and Mullen Slough, (e.g., at the Lucio, Emerald Downs and Algona tributary sites) there is no clear evidence of the extent to which DO is influenced by land use versus the natural characteristics of riverine swamps.

## 5.0 Future Recommendations

The difference between the air and water temperature could be used to determine the temperature buffering capacity of the stream at each sampling location. This analysis could be conducted if 15-minute air temperature data were collected for the Mill Creek/Mullen Slough basin. Determining the buffering capacity of these streams may help indicate where groundwater inputs are located, and the extent to which such additions influence water temperatures and DO.

Width and depth measurements should be made at each site at comparable times during the study periods reported here in order to investigate the possible effects of channel

geometry on the hypoxic and anoxic factors observed during the present study (See Nurnberg 2002).

In addition, the, survey data collected at the same groundwater monitoring well sites used in the present study would allow use of the groundwater analysis program “Surfer” (Golden Software) to determine isopleths of water flow direction, and DO levels at each of the well sites.

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## Appendix A-1