

Effects of agricultural drainage ditch maintenance on water temperature
in the Snoqualmie River valley, Washington State

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Abstract

Water temperature profoundly affects the health of freshwater ecosystems and is an increasing water quality concern in the Pacific Northwest, where warm stream temperatures can threaten the survival and growth of already endangered salmonid species. Agricultural drainage ditches exist to improve drainage off fields but are also used by endangered salmon. Maintenance of these waterways is regulated by the Washington Department of Fish and Wildlife because it may affect fish survival and habitat, but the impacts are not well studied. This study examines the effect of maintenance (dredging sediment and reed canary grass then planting a buffer of native riparian plants) on water temperature in 9 drainage ditches between July and early October 2011. Weekly and continuous water temperature measurements were collected in the Snoqualmie Agricultural Production Districts in Washington and were analyzed for the 7-day average of the daily maximum temperature, water temperature sensitivity to air temperature, and heating from upstream to downstream. Vegetation above and within the waterway was measured to examine canopy effects on water temperature and reed canary grass presence. Maintenance appears to have the greatest influence on water temperature immediately after it is performed, likely because maintenance removes all vegetative cover and exposes waterways. Canopy coverage over previously maintained ditches did not show a relationship with maximum water temperatures, but it did appear to reduce reed canary grass presence. The primary source of the water (valley wall-based seep, shallow groundwater interception, oxbow lake, or surface tributary) appears to have a significant influence on water temperatures for these agricultural drainage ditches, perhaps more so than maintenance activities over time.

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1. Introduction

Water temperature profoundly affects the health of freshwater ecosystems and is of increasing water quality concern in the Pacific Northwest, where warm stream temperatures can threaten the lives and growth of already endangered salmonid species. Wild salmon species have declined in the Pacific Northwest due to a variety of factors including dam construction, altered hydrology and temperature regimes, increased land development and urbanization within salmon habitat, and ocean and climatic factors (Richter and Kolmes 2005). Three salmonid species in the Puget Sound region, *Oncorhynchus tshawytscha* (chinook), *Oncorhynchus kisutch* (coho), and *Oncorhynchus mykiss* (steelhead), are currently listed for protection under the Endangered Species Act.

Waterways within the Snoqualmie River valley serve many purposes, from potential salmon habitat to improved drainage from farms that produce crops for Seattle-area residents. River and tributary temperatures in the Snoqualmie River watershed have exceeded Washington State standards for core summer salmonid habitat, salmonid spawning, rearing and migration, and char spawning and rearing at various locations since 1991 (Svrjcek et al. 2011). The Washington State Department of Ecology water quality improvement report suggests four primary ways to maintain or decrease water temperatures or temperature Total Maximum Daily Load (TMDL) in the Snoqualmie River: 1) control wastewater treatment plant discharges, 2) improve riparian shading, 3) control water being withdrawn from the system, and 4) improve instream habitat. The Department of Ecology determined that increased riparian shading along the main stem and tributaries is a priority in reducing water temperature.

1.1 Fish and agriculture in the Snoqualmie River valley floodplain

The Snoqualmie River lowland floodplain and tributaries are of specific importance to salmon habitat because Snoqualmie Falls, located just upstream of the town of Snoqualmie, is a natural barrier to fish passage. Thus, the tributaries below the waterfall are used by both resident and anadromous salmon species for not only rearing but also spawning where the habitat is suitable (Collins and Sheikh 2002). The anadromous salmonid species known to use the Snoqualmie River include the endangered chinook, coho, and steelhead, in addition to *Oncorhynchus keta* (chum), *Oncorhynchus gorbuscha* (pink), and *Oncorhynchus clarkii clarkia* (coastal cutthroat trout). Other species known to use the river below Snoqualmie Falls include *Oncorhynchus mykiss* (rainbow trout), *Oncorhynchus clarkia* (cutthroat trout), and *Prosopium williamsoni* (mountain whitefish) (Collins and Sheikh 2002). Many non-profit organizations and public agencies in the Pacific Northwest work to restore habitat for these salmonid species, which are culturally and ecologically important. King County established long-term recovery goals for Chinook salmon in each of its four Watershed Resource Inventory Areas (WRIAs), which includes the Snoqualmie River watershed. Recovery in 2010 was only at 7% of the 2055-targeted goal (Gelb 2009).

US Army Corps of Engineers field reports indicate that in 1870 the Snoqualmie River valley was undeveloped consisting of 4500 ha (11,120 acres) of floodplain forest and 2000 ha (4,942 acres) of wetlands. In the early 1900s, landowners dug ditches in wetlands and modified and straightened tributaries of the Snoqualmie River to drain lands and render them suitable for farming. By 1990, agriculture dominated (77%) the floodplain with only 15% still in wetlands and the remainder in rural development (Collins et al. 2003).

Much of the land adjacent to the main stem of the Snoqualmie River from Fall City to the northern border of King County is currently zoned for agriculture by King County, and is divided into the South and North Snoqualmie Agricultural Production Districts (APDs) (Figure 1).

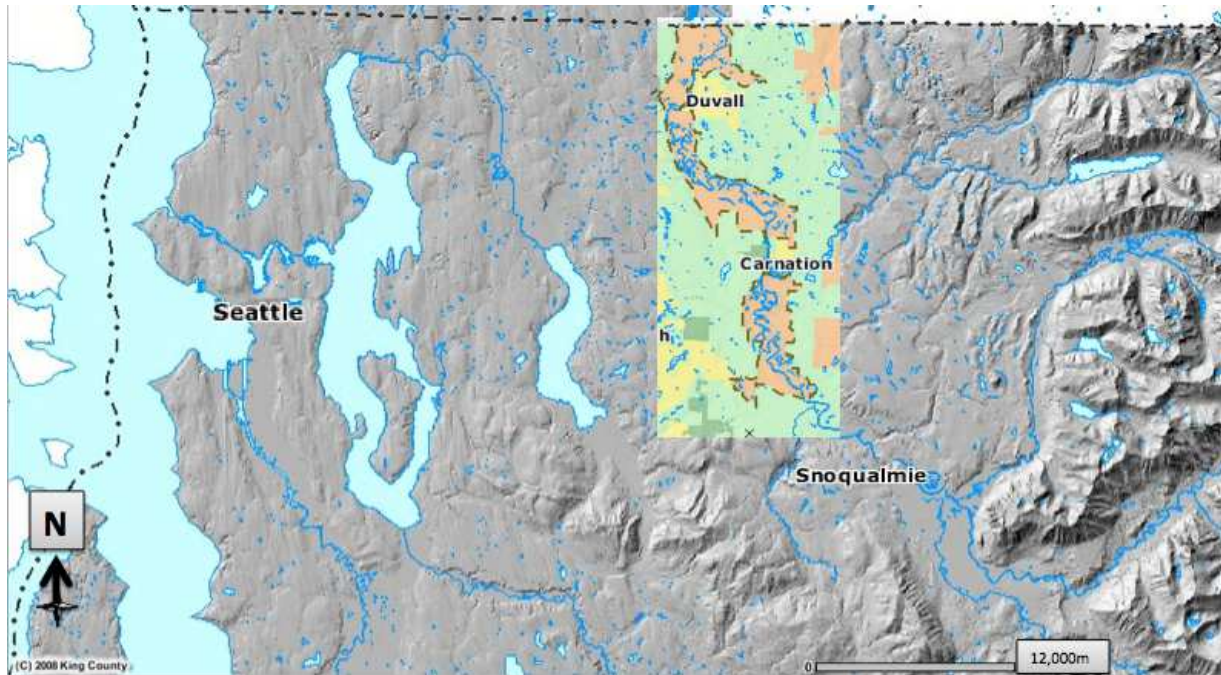


Figure 1: Hydrological and topographic map of the greater Seattle area showing the Snoqualmie River that drains north through the Snoqualmie Agricultural Production Districts (APDs). Brown dotted lines border APDs, which are divided at Carnation (King County iMap 2013).

The Snoqualmie APDs total 5,892 ha (14,560 acres), and the primary land uses are livestock/forage (33%), other (13%), forest/upland (12%), and market crops (11%). In 2009, the market crop acreage in the Snoqualmie APDs was more than half of all market crop acreage in all King County APDs (King County 2009). These crops are major contributors to the 39 farmers markets in the Seattle area, which had sales between \$20 and \$30 million in 2009 (King County 2010). Farms in King County are relatively small-scale, with the average farm size at 11.3 ha (28 acres) in 2007 (King County 2009). Many landowners maintain and construct ditches to help drain fields to increase productivity on these small acreages.

1.2 Efforts to serve the needs of both fish and agriculture

Local agencies and organizations including King County and the King Conservation District are trying to find ways to encourage farmers to increase riparian shading along their drainage ditches in ways that meet the needs of both fish and farmers in the Snoqualmie River valley. From 1998 until 2010, King County Water and Land Resources Division supported farmers by performing technical assessments, paying for permits, and filling out paperwork for waterway maintenance through the Agricultural Drainage Assistance Program (ADAP). Prior to ADAP, landowners needed to obtain multiple permits from different agencies to maintain their waterways to ensure that agricultural ditch construction and maintenance was performed in a manner that did not degrade water quality and salmon habitat. Now, if landowners develop a farm plan with the King Conservation District that includes planting native riparian vegetation after dredging sediment and removing reed canary grass (“maintenance”), they only need to obtain a single Hydraulic Project Approval (HPA) permit, signed by the Director of the Washington State Department of Fish and Wildlife (WDFW). Even with assistance from ADAP, drainage ditch maintenance can be costly and time consuming. Costs range from around \$1,000 to \$44,000 per 305 to 914 meters (1,000 to 3,000 feet) of ditch, which includes preparing the ditch for dredging, dredging, mitigation planting, and plants (Sleight 2012 personal communication). HPA permits require a minimum of one and a half months to process once submitted, reducing landowners’ flexibility to perform maintenance (Benedict 2012 personal communication).

King County ADAP would like to transfer primary responsibility for maintenance to private landowners due to budget and time limitations. The County partnered with agricultural landowners, WDFW, the Department of Ecology, the Farm Bureau, the Tulalip and Snoqualmie

tribes, the King Conservation District, and other parties through the ADAP Committee to determine a way to transfer responsibility to landowners while still addressing water quality concerns. ADAP is working to streamline the processes of obtaining permits for landowners.

As a part of the streamlining efforts, King County classified every waterway in its Agricultural Production Districts by its degree of modification (artificial, modified, natural) and probability of salmonid presence (low, medium, high) (Lucchetti and Higgins 2010). Best management practices for riparian planting after ditch maintenance are based on how waterways are classified under this system, with the intent to direct more efforts towards natural streams with high salmon presence. For example, waterways with the highest probability of salmon use have the widest recommended riparian buffers, at 3-4 rows of plants on either side of the bank (Benedict 2012).

The King Conservation District, Washington State Department of Ecology, and King County have invested multiple years and funds into water quality monitoring of agricultural drainage ditches. A recent project between the King Conservation District and Washington State University (WSU) Extension provided data on the effects of shade and buffer widths on ditches in Whatcom County (Benedict and Shaw 2012). In 2012, ADAP and WSU Extension partnered to write the “Manual of Best Management Practices for Maintenance of Agricultural Waterways in King County.” This manual describes the best management practices that were developed in consultation with WDFW, Department of Ecology, and King County’s Department of Development and Environmental Services, farmers, King Conservation District, tribes, and other groups. The best management practices range from methods to block fish from a ditch during construction, to control erosion, and to re-vegetate a waterway. The recommended best

management practices may be updated as further research provides insights on their effectiveness at achieving water quality goals.

1.3 Objective and Research Questions

This study, in partnership with the King Conservation District, aims to provide insight regarding the effects of agricultural drainage ditch maintenance on stream water temperature over time.

Although the King Conservation District has monitored water quality in agricultural ditches for a few years, the effects of maintenance on water temperature have not been scientifically analyzed.

This research provides scientific insight into how maintenance influences water quality, and how effective the associated best management practices for maintenance are at achieving water quality goals. The King Conservation District may use this information to help inform or refine best management practices and for communicating the effects of maintenance to other agencies, organizations, and landowners. Maintenance specifically refers to dredging sediment and reed canary grass and then planting native riparian vegetation along the banks of an agricultural drainage ditch.

This study primarily addresses the following questions.

- 1) What is the influence of maintenance on the summer 7-day average of the daily maximum temperatures?
- 2) What is the influence of maintenance on the sensitivity of water temperature to air temperature?
- 3) What is the influence of maintenance on how ditch waters heat up over a day?
- 4) How is canopy cover above the waterway related to reed canary grass presence in the water?

2. Literature Review

2.1 Influences on water temperature in streams from source to mouth

Water temperature is a function of both heat and water volume; it is proportional to the amount of heat energy divided by the water volume (Poole and Berman 2001). Heat exchange is important both at the air-water interface, but also at the water-streambed interface, where exchanges with groundwater inputs occur through hyporheic exchange (Arrigoni et al. 2008, Webb et al. 2008). There are many natural factors that influence stream water temperature and seasonal and daily variations, including distance from the source of the stream, type of source, topographic shade, stream orientation, upland shading, riparian vegetation, precipitation, air temperature, flow and discharge, wind speed, solar angle, cloud cover, relative humidity, groundwater temperature and hyporheic exchange, tributary temperatures and flow, and bankfull width and depth (Caissie et al. 1998, Poole and Berman 2001). Climate variables, morphological characteristics of the stream, exchange with groundwater sources, and riparian shading tend to be the most influential. However, human management of streams can also influence stream temperature and temperature variations by altering the heat budget of a stream through heat fluxes and water volume (Poole and Berman 2001).

As streams flow from the headwaters to the mouth, temperatures transition from being driven by the source to being driven by air temperatures (Borman and Larson 2003, Moore et al. 2005).

Water originating from springs tends to have relatively constant temperatures, which become more variable downstream as they are influenced by other inputs of water and meteorological factors (Sand-Jensen and Pedersen 2005). Mean daily water temperature tends to increase downstream, and tends to increase more in small, shallow streams than in large rivers. Variation

between daily minimums and maximums also tends to increase downstream, with the most variation occurring in wide and shallow waterways that are less dominated by groundwater and most exposed to meteorological conditions. However, as rivers gain more depth and volume downstream, temperature variation tends to decrease (Caissie et al. 1998).

2.2. Water temperature in small floodplain streams

Temperature in small floodplain streams tends to be most influenced by solar radiation when there is no riparian canopy, and tends to have a strong relationship with air temperature (Blann et al. 2002, Caissie et al. 1998, Mohseni et al. 2002, Morrill et al. 2005, Sand-Jensen and Pedersen 2005, Sahoo et al. 2009). Thus, stream water temperature regression models often rely on air temperature to predict water temperature (Blann et al. 2002, Caissie et al. 1998, Mohseni et al. 2002, Morrill et al. 2005, Sahoo et al. 2009). Specifically, daily maximum water temperature has been found to have a strong relationship with daily maximum air temperature (Chenard and Caissie 2008, Sahoo et al. 2009). Additionally, lowland streams that are wider and shallower are influenced more by solar radiation and heat exchange with the air than are deeper and narrower waterways (Blann et al. 2002, Poole and Berman 2001). Discharge can be a predictor of water temperature as well, especially for streams with low discharge. Using linear regression models, Neumann et al. (2003) and Moore et al. (2005) found the most significant predictors of daily maximum stream temperatures to be maximum daily air temperature and average daily discharge. Finally, over the course of a day, waterways with lower flows warm more rapidly than those with higher flows (Neumann et al. 2003).

2.3 Effects of canopy cover on water temperature in small floodplain waterways

Many researchers have explored the effects of altered canopy cover due to logging activities on water temperature in mountainous streams in the Pacific Northwest, as much of the available spawning and rearing habitat for salmon is in mountainous areas (Janisch et al. 2012, Pollock et al. 2009, Poole and Berman 2001). There is less peer-reviewed literature on the effects of riparian shading on small floodplain streams in the Pacific Northwest.

In general, canopy cover over waterways modifies solar radiation reaching the water and affects other meteorological factors that may influence water temperature, such as air temperature.

Riparian shade over a waterway has been shown to decrease daily water temperature maximums, increase daily minimums, decrease daily means, and reduce variation between maximums and means during the summer (Malcolm et al. 2008, Moore et al. 2005, Sand-Jensen and Pedersen 2005).

The effect of riparian shading on water temperatures has been shown to be greatest during summer months, and on waterways with higher width: depth ratios (Blann et al. 2002, Malcolm et al. 2008). In a study of agricultural streams in southeastern Minnesota, Blann et al. (2002) found water temperature means and maximums were more sensitive to the width: depth ratio than to percent shade, when discharge was constant. However, at higher width: depth ratios, shade was more effective at moderating water temperatures. Thus, lowland waterways that have higher width: depth ratios may have higher maximum temperatures, but they also may be more responsive to riparian shading, holding all else constant.

2.4 Influence of canopy cover on reed canary grass (*Phalaris arundinacea*) survival in water

Invasive plants, especially reed canary grass, commonly line agricultural waterways in King County, limiting growth of native riparian species. In the past, reed canary grass was planted in many areas to provide forage for farm animals, although now it is considered a nuisance and has displaced native wetland species with widespread invasions found in many regions including the northwestern US (Perry et al. 2004, WSU 2011). Reed canary grass thrives along unshaded ditches. Reed canary grass does not grow well under a dense canopy cover, and has lower above- and below-ground biomass in densely vegetated areas (Lindig-Cisneros and Zedler 2002, Maurer and Zedler 2002, Morrison and Molofsky 1998). Under 65% canopy cover, reed canary grass can still survive at optimal levels, but 85% canopy cover for at least 28 days can decrease its above ground biomass by 97% (Maurer and Zedler 2002). Similarly, another study found that reed canary grass biomass is most decreased under a canopy cover greater than 80% (Morrison and Molofsky 1998). In terms of germination, reed canary grass has high rates under white light (81.5%) but does not germinate well under far-red light (15.8%), which is the type of light prevalent in dense canopies (Lindig-Cisneros and Zedler 2002). Thus, both reed canary grass biomass and germination are decreased under full canopies.

3. Methods

3.1 Study Sites and Experimental Design

Water temperature and other water quality measurements were studied in the Ames Creek area in the North Snoqualmie APD, in one ditch near Duvall, and another in the South Snoqualmie APD (Figures 2, 3, and 4).

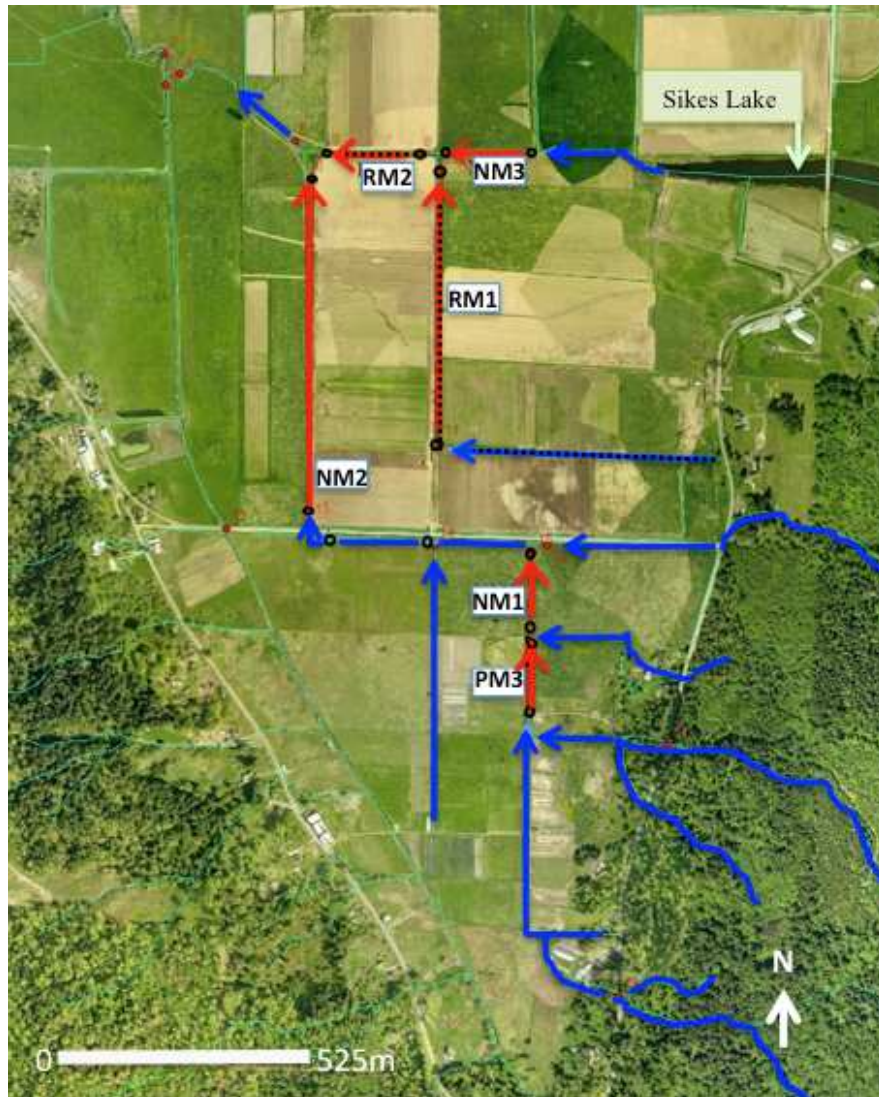


Figure 2: Ames creek study area in the Snoqualmie Agricultural Production District shows sampled ditch reaches (red) and unsampled waterways (blue) with arrows indicating flow direction. Ditches include RM1, RM2, PM3, NM2, and NM3. Black dots indicate sites sampled in 2011 during this study, red dots indicate sites sampled in 2010 by King County and the King Conservation District. Dotted black lines indicate ditch reaches that were maintained in 2010. Map is modified from a map of 2010 monitoring locations (Richter et al. 2010).

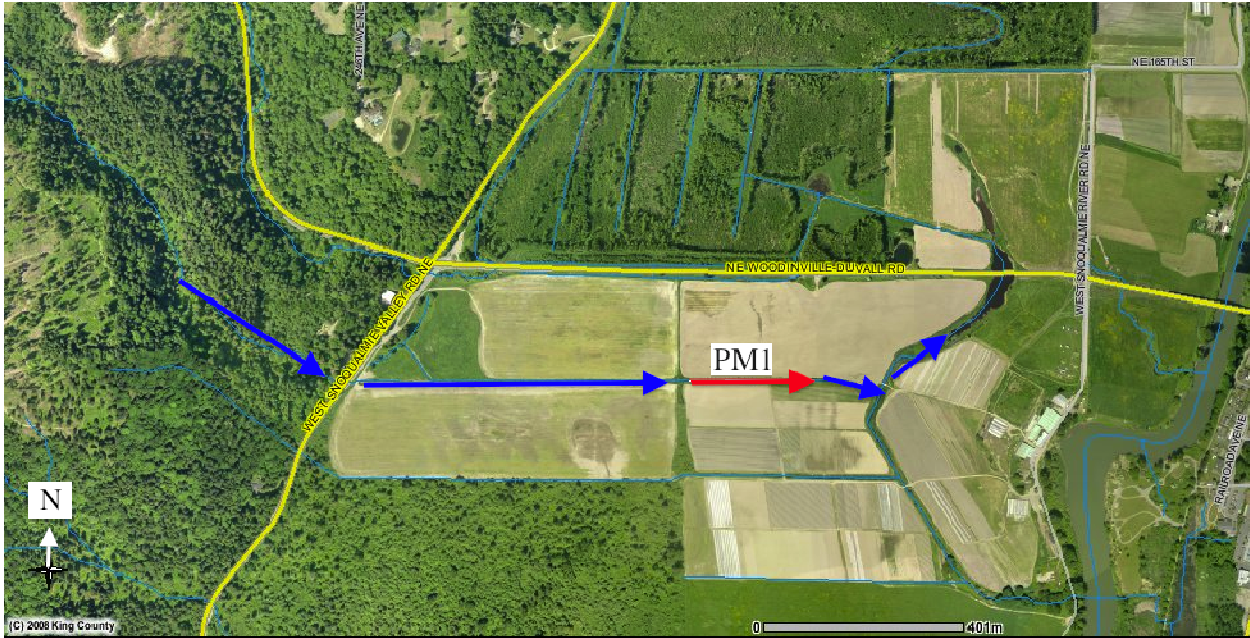


Figure 3: Study site on HerbCo International farm (PM1) in the North Snoqualmie Agricultural Production District shows sampled ditch reach (red) and remaining waterways (blue) with an arrow indicating flow direction towards the Snoqualmie River (King County iMap 2013).

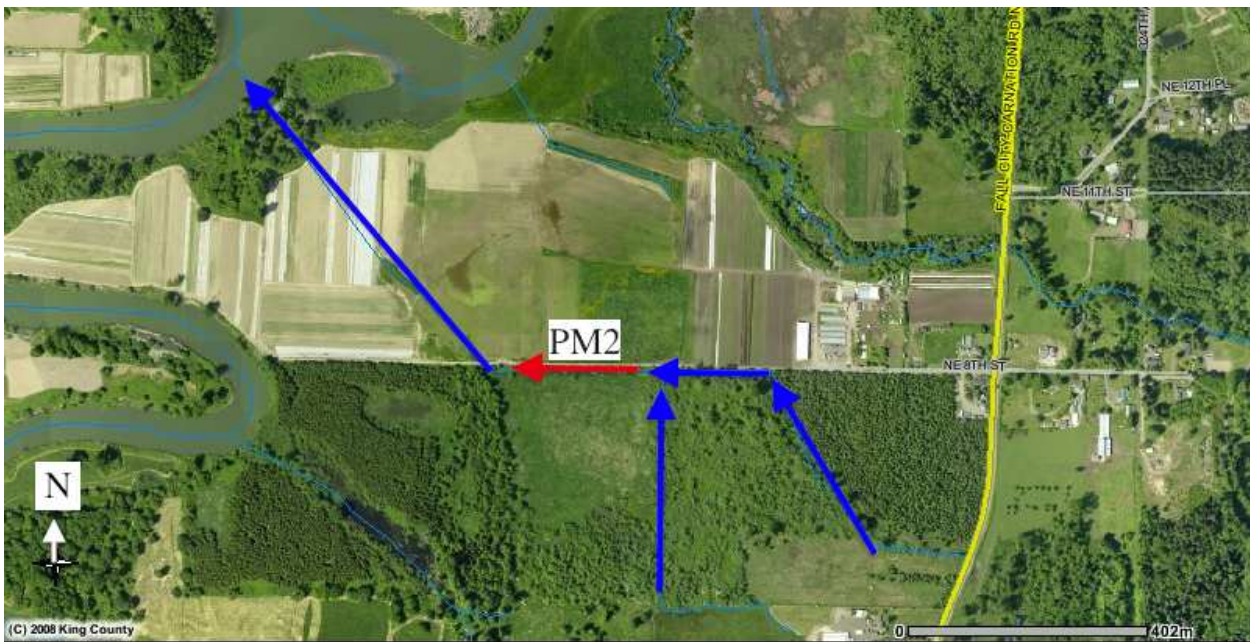


Figure 4: Study site on Full Circle farm (PM2) in the South Snoqualmie Agricultural Production District shows sampled ditch reach (red) and remaining waterways (blue) with an arrow indicating flow direction towards the Snoqualmie River (King County iMap 2013).

The main stem of the Snoqualmie River runs through these APDs (Figure 1). The Ames Creek area historically was a scrub-shrub wetland and was completely cleared for agriculture by 1936

(Collins and Sheikh 2002). The “lake fed” ditches in this study are fed by Sikes Lake, an oxbow lake (Figure 2) (Collins and Sheikh 2002).

Every ditch monitored is classified as having a “high” probability of salmonid use, and “modified” from its natural meander by King County’s proposed waterway classification (Appendix 1), except for RM2, which is classified as “low modified.” “High” means the waterway is either known to have high salmon use (more than or equal to 0.2 salmonids per linear foot), or the characteristics of the waterway are suitable for salmon use, as compared to “moderate” and “low.” “Modified” is defined as “historically natural waterways that have been diverted, dredged, straightened, or diked,” as compared to the “natural” and “artificial” waterways (Lucchetti and Higgins 2010).

Table 1 provides information on the ditches sampled in this study. To assess effects of maintenance over time, ditches are organized into three categories:

- 1) Recently Maintained (RM), which have no vegetative cover and were dredged in September 2010 and planted in March 2011 (n=2)
- 2) Previously Maintained (PM), which have a developing native species riparian canopy and were maintained five or more years ago (n=3), and
- 3) Not Maintained (NM), which are surrounded by a reed canary grass monoculture and have no recorded maintenance (n=3)

Table 1: General information on ditches sampled in this study (King County 2011).

Ditch	Primary source of water	Year maintained	Approximate reach length sampled (m)	Catchment size (hectares)	Probability of salmonid use
RM1	Valley wall-based seepage (suspected)	2010	560	No record, but no upstream catchment	high
RM2	Sikes Lake	2010	210	No record	high
PM1	Surface tributary	Late 1990s & understory planting in 2007	150	182	high
PM2	Shallow groundwater interception	2003	200	No record	low
PM3	Surface tributary (suspected)	2006	220	No record	high
NM1	Surface tributary	n/a	180	282	high
NM2	Surface tributary	n/a	690	330+	high
NM3	Sikes Lake	n/a	180	No record	high

Water quality data were collected between July 17th and October 10th, 2011 at upstream and downstream sites for eight agricultural drainage ditches and one road ditch. Vegetation data were collected at four random points along each ditch. The upstream and downstream sampling locations were along straight reaches, at least 7.6 meters in from the end of a property line or turn in the ditch. As this research was conducted on private land, landowners had to volunteer their ditches to be studied. The King Conservation District contacted landowners, and most landowners were willing to participate in the study. All ditches monitored for water temperature were adjacent to organic fruit and vegetable and/or flower fields, with the exception of the Not Maintained 1 ditch, which is on fallow land dominated by reed canary grass.

3.2 Field Methods

Although temperature is the focus of this report, additional parameters such as dissolved oxygen, conductivity, discharge, suspended sediment, and the wetted width to water depth ratio were measured in this study and are reported in the Appendices (4, 5, 6, 7, 10, 11). All water quality parameters were sampled at upstream and downstream points along each ditch, and methods are described below.

3.2.1 Water and air sampling

Instantaneous temperature, dissolved oxygen, discharge, and suspended sediment measurements were taken approximately once a week. Temperature and dissolved oxygen were measured with a *YSI Model 85: Handheld Oxygen, Conductivity, Salinity, and Temperature System (YSI Model 85)*, which was calibrated for dissolved oxygen on July 16, 2011 and August 22, 2011 using the Winkler titration method with a LaMotte Direct Reading Titrator test kit. Each measurement was taken between 8-13 cm below the surface of the water in the center of the waterway, with the probe facing upstream. Discharge was measured with a *Marsh-McBirney* velocity meter, although the float method was also used for a few measurements on July 17th. Depth was measured from the top of the sediment to the surface of the water. Suspended sediment was measured by collecting a 250 ml water sample from the center of each ditch measurement point 2.54 cm below the surface. The suspended sediment samples were placed in aluminum trays weighed then dried in an oven at 105°C until evaporated, and then reweighed for grams of suspended solids. Floating sticks and macrophytes were not included in these measurements.

Two Hobo® data loggers were deployed at each site to help control for variation among individual monitoring devices and battery failure. The devices were attached via zip ties to bricks, and placed in the center of the waterway so they would not become covered in sediment or float away. The bricks were connected to fishing line or cords and attached to a flagged wooden stake along the bank of the ditch, to help prevent losses and to easily locate the devices. Every 30 minutes Hobo Pendant® or TidbiT® v2 Water Temperature Data Loggers recorded water temperature. Measurements were downloaded and checked on August 23rd using Onset Hoboware Data Logger software to ensure devices were operating correctly.

Instantaneous air temperature was measured approximately once a week at each site with the *YSI Model 85* by holding the probe 1 meter above the ground adjacent to the waterway, facing the ground.

In 2010, the King Conservation District deployed Hobo® data loggers to collect instantaneous water temperature every 15 minutes. Maximum daily water temperature measurements were calculated from these data to compare 2010 and 2011 maximum temperatures for the same sites. A day is defined as midnight to midnight (PDT) for daily temperature in this study.

Daily maximum air temperature for summer months of 2010 and 2011 were downloaded from the National Weather Service Seattle-Tacoma International Airport location (SeaTac) for use in the analysis (National Weather Service 2013).

3.2.2 Vegetation Transects

Vegetation was measured along and within the waterways and adjacent riparian buffers once for each ditch between June and September, 2011. Within the waterway, percent canopy cover was recorded, as well as reed canary grass and other green vegetation under or on the surface of the water. Within the buffers, ground cover and canopy cover percentages were estimated, and species diversity was recorded.

Each ditch was divided into four blocks, and locations within each block were randomly assigned for vegetation transects. At each random location a transect was performed perpendicular to the waterway, which covered vegetation within the waterway and generally covered the entire vegetative buffer (6.85 meters on either side of the waterway). Every vegetation species covering 5% or more of approximately each meter (0.9 meters) along the transect was recorded for its percent cover and species name. For example, one “ground cover” meter might be recorded as: reed canary grass 70%, *Rubus laciniatus* (evergreen blackberry) 10%, bare ground (15%), and *Rosa nutkana* (nootka rose) 5%. The plants categorized as canopy cover include *Salix sitchensis* (sitka willow), *Salix lasiandra* (pacific willow), *Sambucus racemosa* (elderberry), and *Cornus sericea* (red osier dogwood). Reed canary grass and evergreen blackberry were categorized as ground cover species. All species recorded for each ditch are reported in Appendix 2.

Canopy cover was ocularly estimated by percentage and then divided into three categories: “low” (0-40% amount of estimated canopy cover), “medium” (40-80%), and “high” (80-100%). Photo samples of each maintenance category are shown in Figures 5-7.



Figure 5: Sample photos of recently maintained ditches (RM1 left, RM2 right).



Figure 6: Sample photos of not maintained ditches (NM1 left NM3 right). The photos face directly up the waterways, which are obscured by reed canary grass.



Figure 7: Sample photos of previously maintained ditches (PM2 left, PM3 right)

3.3 Data Analysis

3.3.1 7-Day Running Average of the Daily Maximum Temperature Calculations

Daily maximum water temperatures were calculated from the continuous temperature measurements to derive the 7-day running average of the daily maximum temperatures (7-DADMax) using Microsoft Excel. The temperature standards for salmonid species are set as the 7-DADMax by the Department of Ecology as authorized by the US Environmental Protection Agency (EPA) under Section 510 of the Clean Water Act. The 7-DADMax is calculated by taking the average of the day's maximum temperature and the daily maximum temperature 3 days before and 3 days after. This value is used in determining a stream's habitability for fish, as it is assumed that fish can move and adjust to avoid high temperatures on a single day, but have greater threats to spawning, rearing, and migration when high maximum temperatures persist for a week. Data for these calculations are taken from downstream sampling points for all ditches except NM2 due to battery failure of downstream data loggers on August 24.

3.3.2 Statistical Analysis

Simple linear regressions were used to examine the sensitivity of water temperature to air temperature using SPSS Statistics (SPSS). Thermal sensitivity is the slope of the relationship between water and air temperature, and can help estimate and predict how sensitive stream water temperatures are to changing and warming air temperatures (Kelleher et al. 2012). Significance is assumed for all tests when $p \leq 0.05$.

Simple linear regressions of the daily maximum water temperature (dependent) and the daily maximum SeaTac air temperature (independent) were performed using SPSS. For each

regression model, the residuals were graphed to check for problems with heteroskedasticity. A multiple linear regression was performed with instantaneous water temperature as the dependent variable, and instantaneous air temperature, instantaneous discharge, instantaneous wetted width, dummy variables for each type of maintenance (recent, previous, not) and dummy variables for each primary source of water (shallow groundwater interception, valley wall-based seep, surface tributary, lake) as the independent variables. SPSS was used to check for problems with multicollinearity and heteroskedasticity.

A two-sided test of the difference between two population regression coefficients was performed for the recently maintained and not maintained lake-fed ditches in 2011 (Zar 2009). A two-sided t-test was performed on the conductivities for ditches with different sources of water. A two-sided t-test was performed on the 7-DADMax temperatures for PM1, PM2, and PM3. A two-sided t-test was performed on the air temperatures for 2010 and 2011 for the seven days after maintenance.

3.3.3 Hysteresis curves

Water temperatures for upstream sampling points were plotted against water temperatures for the downstream sampling points, for water temperature measurements taken every 30 minutes over the course of 24 hours. July 30th was a date chosen using a random number table to examine sample patterns of warming and cooling over the course of a day for each ditch.

4. Results

4.1 Influence of maintenance on summer 7-DADMax water temperatures

Water 7-DADMax temperatures in both of the recently maintained ditches are more variable and higher than all other ditches except the not maintained lake ditch (Figure 8). The previously maintained groundwater-fed ditch (PM2) has the coolest median 7-DADMax temperatures. Interestingly, the recently maintained groundwater ditch (RM1) does not have similarly cool temperatures, even though it is fed by groundwater. However, the sources of groundwater differ, with RM1 originating from a valley wall-based seep, and PM2 originating from a shallow groundwater interception. Even before maintenance in 2010, RM1 had warmer temperatures than PM2. The 7-DADMax lake-fed ditch temperatures are similar before maintenance in 2010 (Appendix 3) and during the summer of 2011. The primary source of the ditch water is color coded for the remaining figures.

The Department of Ecology regulatory limit for the highest 7-DADMax for core summer salmonid habitat is 16°C, while the highest 7-DADMax for salmon spawning, rearing and migration is 17.5°C (Washington State Department of Ecology 2008). The EPA reports that lethal temperatures for juvenile salmon are a constant 23-26°C at a 1-week exposure (EPA 2003). All four of the surface water-fed ditches meet standards for summer habitat, spawning, rearing, and migration for salmonid species. The recently maintained and lake-fed not maintained ditches exceed these standards.

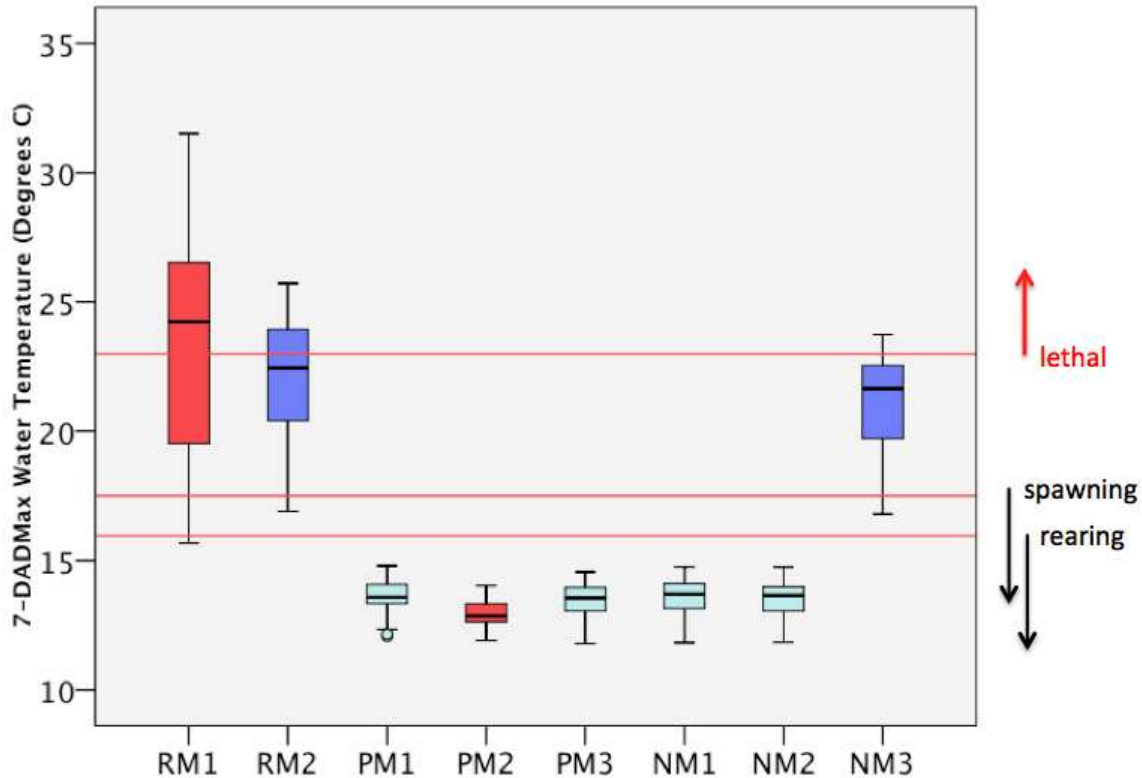


Figure 8: Box plot of the 7-day running average of the daily maximum temperatures for the downstream sample points in recently maintained (RM), previously maintained (PM), and not maintained ditches (NM) between July 30-October 2, 2011. Primarily groundwater-fed ditches are red, primarily lake-fed ditches are dark blue, and primarily surface water-fed ditches are pale turquoise. Red lines indicate Ecology's standards. Box borders are the 25th and 75th percentiles, interior line is the median, and whiskers are the minimum and maximum values that are not statistically significant outliers. The small circle is an outlier.

When canopy cover is compared with maximum water temperatures (Figure 9) there does not appear to be a relationship between vegetation and maximum water temperatures. For example, for the ditches with canopy cover, PM2 has the coolest 7-DADMax temperatures and lowest canopy cover, followed by PM3, which has the most canopy cover, and then PM1, which has the warmest 7-DADMax temperatures and middle amount of canopy cover.

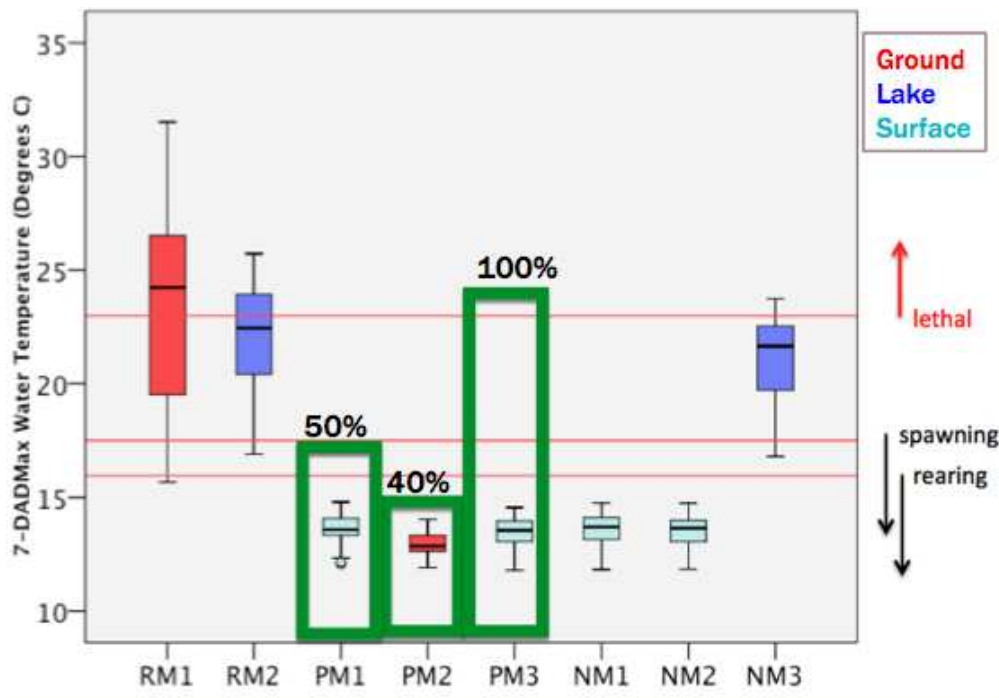


Figure 9: Box plot of the 7-day running average of the daily maximum temperatures for the downstream sample points in recently maintained (RM), previously maintained (PM), and not maintained ditches (NM) between July 30-October 2, 2011 with green bar graphs showing estimated percent canopy cover. Red lines indicate Ecology's standards. Box borders are the 25th and 75th percentiles, interior line is the median, and whiskers are the minimum and maximum values that are not outliers.

RM1 and RM2 were maintained between September 6th and 23rd 2010. 7-DADMax water temperatures were significantly higher immediately after maintenance in 2010 compared to the same dates in 2011 for the recently maintained ditches (Figure 10, Appendix 8). However, the 7-DADMax of the surface-water ditch temperatures between 2010 and 2011 are not significantly different. Additionally, the 7-day running average of the daily air temperatures in 2010 and 2011 are also not significantly different.

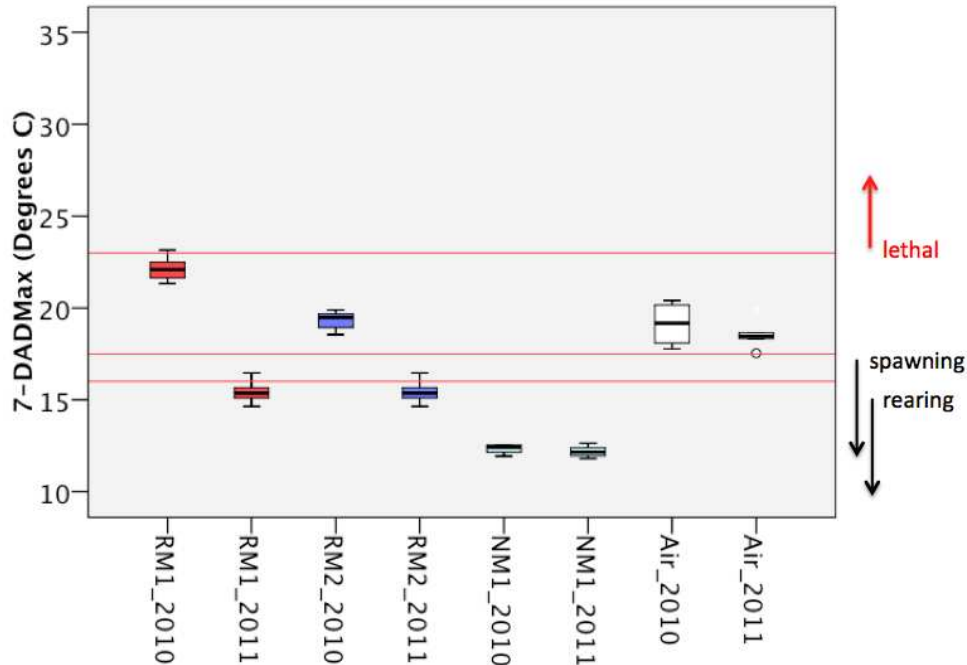


Figure 10: Comparison of the 7-day running average of the daily maximum temperatures for three ditch water temperatures with air temperature from the SeaTac weather station from September 27th to October 2th in 2010 and 2011. Primarily groundwater-fed ditches are red, primarily lake-fed ditches are dark blue, primarily surface water-fed ditches are pale blue, and air temperatures are white. The bottom red line indicates Ecology’s upper limit for salmon rearing, the middle red line is the upper limit for salmon spawning, and the upper red line is the lower limit for lethal temperatures. Box borders are the 25th and 75th percentiles, interior line is the median, and whiskers are the minimum and maximum values that are not statistically significant outliers. Small circle is an outlier. Water measurements are from downstream sampling points, except for RM1, where the 2010 and 2011 measurements are taken from the upstream sampling point because 2010 downstream data loggers were lost. However, the RM1 upstream sampling point is approximately 500 meters downstream of recent maintenance (Figure 1).

4.2 Influence of maintenance on the sensitivity of water temperature to air temperature

The maximum air temperature coefficient, or slope, represents the “sensitivity” of water temperature to air temperature. The immediate influence of maintenance on water temperatures can be examined by comparing the sensitivity of daily maximum water temperatures to daily maximum air temperatures directly after maintenance in 2010. Both before and after maintenance in 2010, water temperature has a statistically significant positive relationship with air temperature (Table 2). Immediately after maintenance, the slope of this relationship increases,

indicating that after maintenance water temperature is more sensitive to air temperature for both the lake-fed and groundwater-fed ditches (Figure 11).

Table 2: Simple linear regression outputs of the sensitivity of water temperature to air temperature before and after maintenance in 2010.

Ditch Before or After Maintenance 2010	Y-intercept (standard error)	Max air temp coefficient (standard error)	Adjusted R ²	Degrees of freedom
RM1 Before	8.34* (1.31)	0.39* (.05)	0.54	45
RM1 After	6.35* (2.96)	0.80* (.17)	0.49	23
RM2 Before	14.26* (1.03)	0.33* (.04)	0.58	45
RM2 After	6.78* (1.91)	0.61* (.11)	0.58	23

* Indicates statistical significance

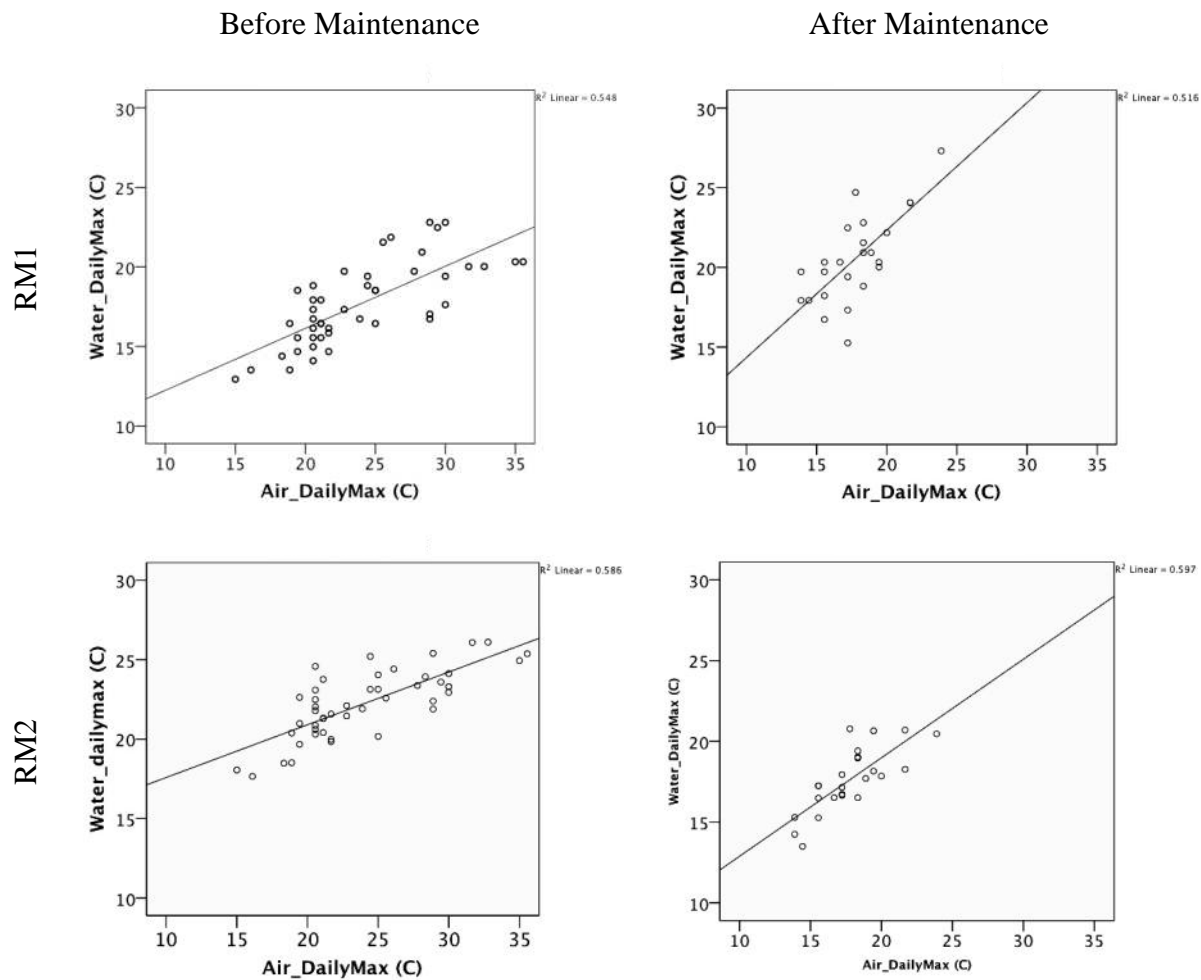


Figure 11: 2010 Daily maximum air temperatures plotted against daily maximum water temperatures for RM2 and RM1 immediately before (July 23 to September 6, 2010) and immediately after maintenance (September 24 to October 17, 2010).

In 2011, approximately one year after maintenance, the recently maintained ditches are more sensitive to air temperature than all other ditches except for the not maintained lake-fed ditch (NM3). In 2011 the ditches that show the greatest sensitivity to air temperatures are the same as the ditches with the warmest 7-DADMax water temperatures (Figures 8 and 12). Interestingly, both lake-fed ditches, NM3 and RM2, do not have statistically different sensitivities to air temperature. All surface water-fed ditches have similar sensitivities to air temperature. The valley wall-based seep recently maintained (RM1) ditch is the most sensitive to air temperature, while the shallow groundwater interception-fed previously maintained (PM2) ditch is the least sensitive to the maximum air temperatures (Figure 12 and Table 3). Kelleher et al. (2012) also found that small groundwater-fed stream waters tended to have lower sensitivities to air temperature. None of the linear regression models had problems with heteroskedasticity; errors appear to be randomly distributed for these models.

Water temperature is significantly related to air temperature for all ditches in this study. Additionally, instantaneous air temperatures were found to have a positive relationship with instantaneous water temperature (Appendix 12). A multiple linear regression analysis found that instantaneous air temperature and the source of the water were the only significant predictors of instantaneous ditch water temperature for this study (Appendix 12).

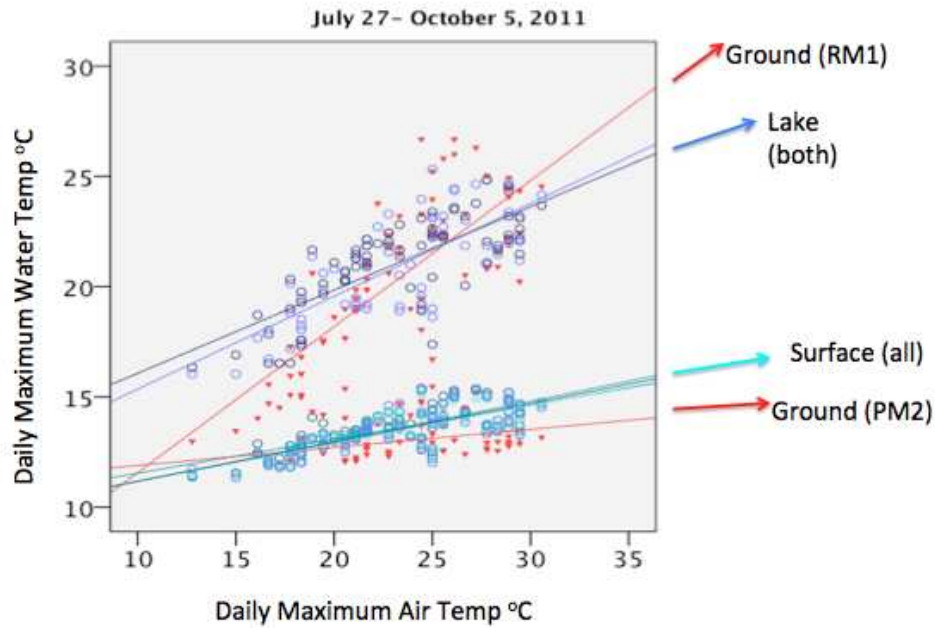


Figure 12: The sensitivity of daily maximum water temperature to daily maximum air temperature for all ditches between July 25 and October 5, 2011.

Table 3: Simple linear regression outputs of the sensitivity of daily maximum water temperature to daily maximum air temperature for all ditches in 2011.

Ditch in 2011 (Primary Source)	Y-intercept (standard error)	Max air temp coefficient (standard error)	Adjusted R ²	Degrees of freedom
RM1 (Ground)	4.94* (1.51)	0.66* (0.06)	0.60	70
RM2 (Lake)	11.14* (1.02)	0.42* (0.04)	0.57	70
PM1 (Surface)	9.99* (0.45)	0.16* (0.02)	0.48	70
PM2 (Ground)	11.07* (0.53)	0.08* (0.02)	0.15	70
PM3 (Surface)	9.46* (0.37)	0.17* (0.02)	0.63	70
NM1 (Surface)	9.36* (0.39)	0.18* (0.02)	0.63	70
NM2 (Surface)	9.41* (0.42)	0.18* (0.02)	0.58	70
NM3 (Lake)	12.30* (0.92)	0.38* (0.04)	0.57	70

* Significant

4.3 Influence of maintenance on ditch water heating from upstream to downstream

Heating patterns for ditch reaches over the course of a day are compared through scatter plots of upstream and downstream temperatures for a ditch reach, or hysteresis curves. Figure 13 shows hysteresis curves for all ditches for a randomly sampled day, July 30th, 2011. The recently maintained ditches, RM1 and RM2 experience more heating over the course of a day than any other ditches. RM1 experiences the most heating over the course of a day, with rapid heating occurring during the middle of the day (left side of hysteresis curve, also see Appendix 9). Maximum water temperatures for RM1 reach above 30°C for the downstream sampling point, and minimum water temperatures for both upstream and downstream points reach 16°C around 6:30 am after nighttime cooling.

RM1 may experience the most heating between upstream and downstream sampling points likely because it has low discharge and no canopy cover. Waterways with low discharge tend to be more responsive to air temperatures when air heats during the day (Mohenski et al. 1998).

RM1 may experience the most heating also because it is one of the longest reaches measured (560m). However, PM2 is the longest reach measured (690m), and does not experience the large range of heating that RM1 does. Additionally, RM2 (210m) experiences the second largest amount of heating over the course of a day. This is likely due to RM2's lack of canopy, as it is a similar length to other reaches measured. The not maintained lake-fed ditch (NM3) directly upstream (220m) does not experience heating differences between upstream and downstream sampling points. Although heating tends to naturally occur between upstream and downstream points, previously and not maintained ditches between 150m and 690m show little if any differences in upstream and downstream sampling points, as seen by the close fit of these

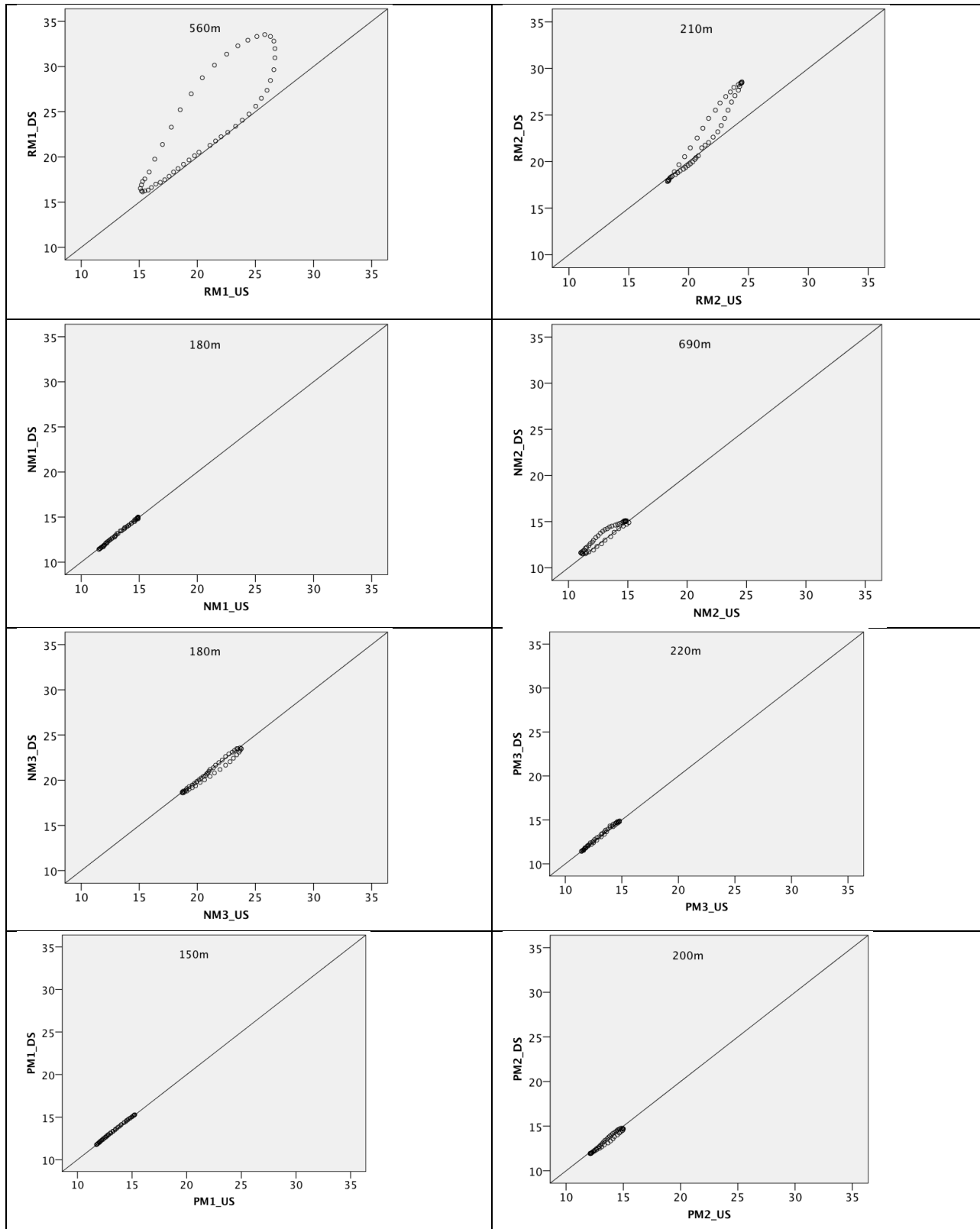


Figure 13: Water temperature hysteresis curves for all ditch reaches, with points every 30 minutes from midnight to midnight on July 30th. Upstream water temperature (°C) is on the x-axis (US), and downstream water temperature (°C) is on the y-axis (DS) for all graphs.

hysteresis curves to a 1:1 line. The SeaTac weather station for this day recorded 26°C maximum, 13°C minimum, and 20°C mean air temperatures.

4.4 Influence of canopy cover on reed canary grass presence within the waterway

Ditches that have no canopy cover above the waterway had a range in amount of reed canary grass within the waterway from below 20% to above 80% (Figure 14). For the three ditches that do have canopy cover above the waterway, there appears to be a relationship between canopy cover and reed canary grass, with more canopy cover associated with less reed canary grass.

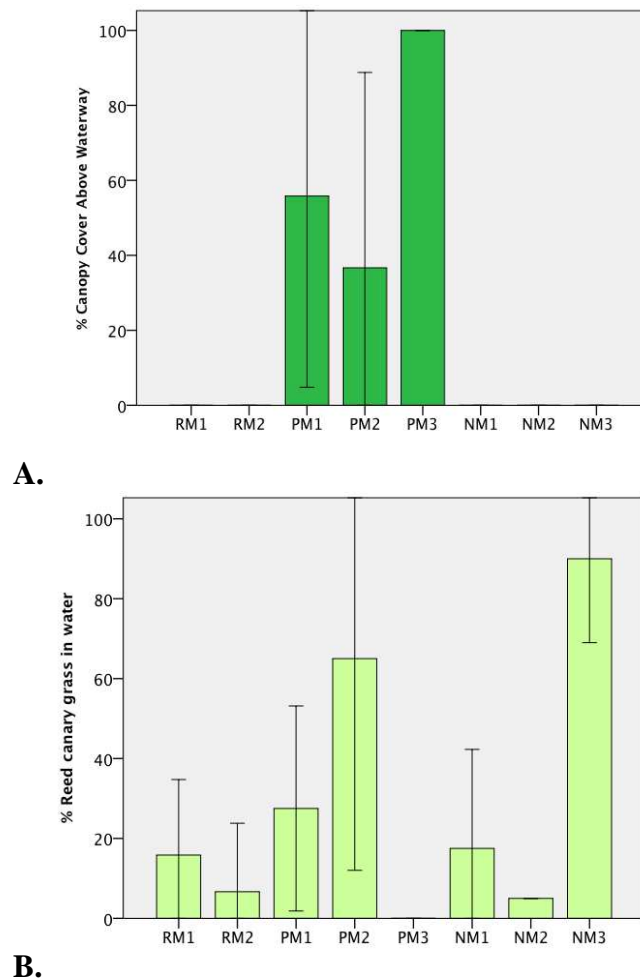


Figure 14: Percent canopy cover above the waterway (A), and percent reed canary grass within the waterway (B) for ditches in the study. Error bars represent 95% confidence intervals.

The only ditch that does not have reed canary grass within the waterway (PM3) has a nearly 100% canopy cover directly above the waterway. However, PM1 and PM2 have more reed canary grass within the waterway than any of the other ditches except NM3, suggesting that native canopy cover of 60% or less does not necessarily reduce reed canary grass growth in the waterway.

5. Discussion

Although results provide some insights regarding the immediate effects of maintenance, the effects of maintenance over time is difficult to evaluate because results suggest that the effects of the primary source of ditch water play an important role in ditch water temperatures.

Recently maintained ditch (RM1, RM2) temperatures exceeded Department of Ecology standards for salmonid core summer habitat, rearing, spawning, and migration, and also experienced the greatest amount of heating between upstream and downstream sampling points. RM1 and RM2 in addition to the not maintained lake-fed ditch (NM3) waters were most sensitive to air temperatures, suggesting these waters were more likely to exceed standards on warmer days. RM1 had the highest median 7-DADMax temperatures (above 23°C), and the lake-fed ditches RM2 and NM3 also had high median 7-DADMax temperatures (above 21°C). All previously maintained and surface water-fed not maintained ditches had lower 7-DADMax median temperatures (below 15°C).

5.1 Influence of maintenance and a groundwater source on ditch water temperature

Although groundwater has often been found to be cooler than stream water during the summer (Arrigoni et al. 2008), this study suggests that the inputs of groundwater within these historical wetlands may be either warmer or cooler than nearby surface water.

Of all the studied ditches, RM1, originating from a valley wall-based seep, was the most sensitive to air temperature, experienced the most warming between upstream and downstream points, and has significantly warmer 7-DADMax temperatures than the other groundwater-fed ditch (PM2) and the surface water-fed ditches in 2011. Groundwater can either heat or cool

waterways (Arrigoni et al. 2008), and the groundwater seeping into RM1 is likely already warm. Summer temperatures before maintenance in 2010 had a median of 17.5°C (Appendix 3). However, the low discharge (Appendix 4) and exposure to solar radiation and air temperature after maintenance may have resulted in the even higher temperatures found immediately after maintenance in 2010 and during the 2011 summer. Waterways with lower discharge and more surface area exposed to the air have been found by others to be more sensitive to atmospheric heating (Neumann et al. 2003, Mohensi et al. 2002, Janisch et al. 2012).

Although the previously maintained groundwater-fed ditch (PM2) also had low discharge, it had a canopy cover of about 40% above the waterway. PM2 was not sensitive to air temperature, and had the lowest median maximum temperatures of all ditches. This suggests that canopy cover may contribute to reduced water temperature maximums and sensitivity to air temperature for PM2. However, these cooler temperatures are also likely due to the shallow groundwater interception source, which may inherently have cooler temperatures. Kelleher et al. (2012) also found that canopy cover and groundwater inputs contribute to lowered water temperature sensitivity to air temperature for small streams.

5.2 Influence of maintenance and the lake source on ditch water temperature

For the recently maintained lake-fed ditch (RM2), about a year after maintenance the source of water influences the sensitivity to air temperature more than maintenance of the ditch. However, a year after maintenance RM2 has slightly warmer 7-DADMax temperatures and experiences more rapid and increased heating between upstream and downstream reaches than the not maintained lake-fed ditch (PM3). This suggests that the RM2 experiences more heating during

the day because it is exposed, compared to the PM3, which is surrounded by reed canary grass, although inputs from incoming RM1 also likely influence the warmer 7-DADMax temperatures. Immediately after maintenance in 2010, sensitivity to air temperature increases and the 7-DADMax temperatures are significantly higher than for this same period in 2011, holding air temperature constant. This suggests that maintenance may contribute to increased sensitivity to air temperature and increased 7-DADMax temperatures in at least the first seven days after maintenance.

5.3 Influence of maintenance and the surface source on ditch water temperature

The primarily surface water fed ditches (PM1, PM3, NM1, NM2) have similar 7-DADMax temperatures, sensitivity to air temperature, and heating patterns between upstream and downstream reaches, even though riparian canopy cover differs due to whether the ditches were previously maintained or not, and reach length varies. The waterways of surface water-fed ditches NM1 and NM2 are surrounded by reed canary grass, PM3 has a dense riparian cover, and PM1 has a developing riparian canopy with some reed canary grass growing within. Both PM3 and NM1 do not warm between the upstream and downstream sampling points of the reach. This may be because reed canary grass provides a buffer in terms of water temperature, or the reach may not be long enough to experience warming. PM3, NM1, and NM2 are all part of the same waterway, which also likely explains the similarities in maximum temperatures, sensitivities to air temperature, and heating patterns. The reaches measured may not be long enough to see a difference due to vegetation, or reed canary grass may act as a canopy in buffering temperatures.

5.4 Immediate influence of maintenance on ditch water temperature

Similarly to the recently maintained lake-fed ditch, the recently maintained groundwater-fed ditch waters had higher sensitivities and 7-DADMax temperatures immediately after maintenance, controlling for air temperature. This suggests that in the days immediately after maintenance, maintenance may lead to increased sensitivity and higher 7-DADMax water temperatures in ditches. This could be because after removing reed canary grass, the waterways were fully exposed to solar radiation, whereas before maintenance reed canary grass provides some canopy cover. However, reed canary grass canopy cover was not recorded for this study. Other studies suggest that grassed buffers may be able to provide shade and buffer mean water temperatures just as well as wooded vegetation, for waterways with low width to depth ratios (Blann et al. 2002). The NM1 ditch water, surrounded by reed canary grass, does not warm between the upstream and downstream points. The NM2 and NM3 ditches surrounded by reed canary grass do warm as they flow downstream, but these reaches are longer than NM1 and temperatures tend to increase as they head downstream holding other factors constant. Future studies should measure the canopy of reed canary grass over waterways to better understand its potential impact on shading and buffering for not maintained ditches.

5.5 Potential influence of canopy cover and groundwater exchange on water temperature

Some parameters that might show relationships with water temperatures did not appear to do so among all ditches. There is no clear relationship between canopy cover above the waterway and maximum water temperatures for the surface water-fed and lake-fed ditch reaches in 2011. However, by examining only groundwater-fed ditches, canopy cover may have an influence on decreased temperatures. By examining only lake-fed ditches, reed canary grass cover may have

an influence on heating from upstream to downstream sampling points. Discharge and the width to depth ratio additionally do not appear to have a relationship with maximum water temperature for the set of all ditches (Appendices 4 and 5). Variables such as the primary source of the water may be more important in determining daily maximum temperatures in this data set.

Other studies examining the influence of riparian canopy cover and riparian buffers on maximum water temperatures have mixed findings. For example, Whitney (2000) results suggest that 7-DADMax summer stream temperatures increase as percent canopy cover decreases. Pollock et al. (2009) also found average daily maximum stream temperature to have a positive relationship with the amount of riparian buffer cleared for forest harvest. However, Janisch et al. (2012) found that although the surface area of waterways and the amount of fine textured sediment both had significant positive relationships with maximum daily water temperatures, canopy cover did not. An unpublished study of lowland agricultural streams in Skagit County, Washington with similarly low flows and a similar range of canopy cover (0-90%), found that riparian canopy cover provided a decent explanation for the differences in maximum water temperature offsets from air temperature (R^2 of 0.39), while discharge and drainage area had no relationship with maximum temperature offsets (Stoll and Monohan 2004).

Not many studies have examined the influence of riparian canopy cover on waterways with different sources. However, Rayne et al. (2008) found that reduced riparian shade due to forest harvest had a greater influence on increasing daily maximum temperatures for headwater streams (up to 8°C) that had a surface water source as compared to headwater streams with a wetland source (up to 1-2°C). As the ditches in this study are located in a historic wetland, future research

could examine if riparian shade is more or less effective for ditches with wetland groundwater seep compared to surface tributary sources, if all else is held constant.

Although not measured in this study, hyporheic and groundwater exchange can help keep water temperatures cool (Moore et al. 2005, Story et al. 2003). In addition to riparian shading, the Department of Ecology also recommends increasing channel complexity and increasing and protecting groundwater exchange to reduce water temperatures in the Snoqualmie River watershed (Svrjcek et al. 2011). Instantaneous conductivity measurements from 2011 are very low for all ditches, suggesting there is very limited hyporheic and groundwater exchange (Appendix 6). Field observations for RM1, RM2, and PM2 ditches noted fine sediments on the channel bed, up to one to two feet deep in the recently maintained groundwater-fed ditch. Fine sediments along streambeds may inhibit hyporheic exchange, limiting the potential for cooler groundwater to buffer stream temperatures. Future studies should take ditch streambed sediment samples in addition to conductivity measurements to better explore potential hyporheic inputs and the groundwater buffering capacity of different reaches. Additionally, it may be useful to measure at multiple places along a reach to see if there is thermal heterogeneity within a ditch. Cooler water pockets from hyporheic exchange within warm waterways may provide thermal refugia for fish (Moore et al. 2005).

5.6 Relationship of canopy cover and reed canary grass within the waterway

The only waterway with no reed canary grass had approximately 100% canopy cover. At least 80 or 85% canopy cover has been described as the minimum needed to reduce reed canary grass biomass (Morrison and Molofsky 1998, Maurer and Zedler 2002). Additionally, deeper ditches

may prevent reed canary grass from growing directly in the waterway because reed canary grass biomass decreases under inundated conditions (Maurer and Zedler 2002). In this study, NM2 had the highest discharge, deepest waterway, and least reed canary grass growing within the waterway, although reed canary grass grew along the banks and covered the waterway. Prolonged inundation has been shown to decrease reed canary grass aboveground biomass by 73% (Maurer and Zedler 2002). Narrower and deeper channels may thus potentially help limit reed canary grass growth within the waterway by flooding the grass. Narrower channels also are more likely to be effectively shaded with small riparian plants and trees than wider channels that have more surface area (Poole and Berman 2001, Arrigoni et al. 2008). Holding other factors constant, narrower and deeper ditches may possibly drain fields more quickly by channeling surface water and by lowering the water table.

The type of vegetation surrounding the waterway, whether reed canary grass or native riparian canopy cover, does not appear to have an effect on water temperatures for this study. However, this does not necessarily mean that reed canary grass is an equivalent replacement for native riparian canopy cover. Species diversity decreases in riparian zones colonized by reed canary grass, and reed canary grass produces a large amount of litter compared to native grasses and woodland species (Xiong and Nilsson 1999). Litter decomposition and respiration from reed canary grass need oxygen, and could reduce dissolved oxygen levels in waterways at night when plants are not photosynthesizing. As low dissolved oxygen can lead to direct fish mortality, this water quality parameter should be measured continuously to better understand the full effects of reed canary grass in agricultural waterways.

5.7 Management considerations

Maintenance appears to increase 7-DADMax temperatures, water temperature sensitivity to air temperature initially, and the amount of heating that ditch water experiences from upstream to downstream. Best management practices for maintenance could consider methods to mitigate these initial potential increases in water temperatures by limiting the initial exposure to solar radiation. For example, creating shade through shade screens or weed fabric may help buffer water temperatures and limit reed canary grass growth initially. These methods were used for Tuck Creek restoration efforts, just north of PM1, and resulted in decreased heating and decreased maximum water temperatures on days with high air temperatures. However, shade cloth may interfere with beneficial vegetative growth, depending on how it is installed (Eastman 2006).

The effects of maintenance may vary ditch by ditch, and may become less pronounced over time. Riparian vegetation restoration might be more effective at lowering water temperature maximums and sensitivities to air temperatures for some ditches more than others, due to the primary source of the water and physical parameters such as the width to depth ratio. This may be especially true for ditches that are not fed by lakes, and for wider and shallower ditches with lower discharge. Using the results of this study and future recommended studies, managers could consider prioritizing restoration resources for ditches that would receive the most benefits from canopy cover to help lower water temperatures in the Snoqualmie River valley.

Additionally, King County's proposed agricultural waterway classification system might consider further classifying waterways based on source, as ditches that drain groundwater from

fields and surface tributaries running through floodplains appear to have significantly different characteristics, which may respond in different ways to maintenance.

5.8 Limitations of the study

This study has a very small sample size, and sites were not randomly assigned. Comparisons between recently maintained (n=2), previously maintained (n=3), and not maintained (n=3), provide rough insight into the effects of maintenance over time, but no statistically significant conclusions can be drawn on these effects. The study sites were located on private property, which meant that “treatments” of maintenance could not be randomly assigned. Landowner willingness to participate in the study was required, which limited the sample size. The different primary sources of water, from valley wall-based seepage, to shallow groundwater interception, to an oxbow lake and surface tributaries, ideally would be controlled for but were not due to the small sample size. There were no recently maintained surface water-fed ditches in this study; while the potential effects of recent maintenance were studied for ditches originating from a valley wall-based groundwater seep and an oxbow lake, the potential effects of recent maintenance could not be examined for surface water-fed ditches. Additionally, many reaches were part of the same ditch and directly fed into each other, which increased the challenge of isolating the effects of maintenance on these ditch water temperatures.

Finally, there are limitations of the field methods and there was potential for human error while taking measurements. Some data loggers were found to have sunk into sediment between sampling dates, which appeared to lower maximum temperatures and reduce the amplitude of diurnal fluctuations from continuous temperature sampling. Canopy cover was estimated by eye,

and although two people came to consensus on the estimated percent of cover for each sampling point, there is room here for human error.

5.9 Directions for future study

Future studies could control for the source of the ditch water by:

- Including more than one recently maintained, previously maintained, and not maintained ditch for each primary source of water within the study, or by
- Focusing on either 1) primarily groundwater-fed ditches or 2) primarily surface water tributary-fed ditches, to have a better sense of maintenance on these two common types of agricultural ditches in the Snoqualmie APDs, and by
- Collecting data from more independent ditches that are not part of the same waterway.

It is also recommended that future studies examine:

- The effects of reed canary grass on water temperature and dissolved oxygen,
- Continuous dissolved oxygen to better assess habitat for salmonid species, and
- Ditch reaches of similar lengths and orientations when studying heating in ditches to help control for the natural heating that tends to occur over longer reaches.

To better understand the effects of maintenance over time, the recently maintained ditches in this study could be monitored in the future. However, monitoring should not only be done on these two ditches, as controls are needed. Most importantly, future studies on water temperature in drainage ditches should control for the primary source of ditch water.

6. Conclusions

The small sample size of this study suggests that recent maintenance contributes to increased summer maximum water temperatures, increased sensitivity of water temperature to air temperature, and increased heating along the ditch reach over the course of a day, at least after one year. However, the primary source of the ditch water, which appears to be related to discharge in this study, has an influence on ditch water temperatures, despite maintenance.

The primary source of drainage ditches, whether a surface-water tributary, valley wall-based groundwater seep, shallow groundwater interception, or an oxbow lake, had an influence on maximum water temperatures and the sensitivity of water temperature to air temperature. Ditch waters fed primarily from groundwater seeps from the hillside or shallow groundwater interceptions within the floodplain are likely to have lower flows than surface tributaries flowing off the hillsides. The low flows of the recently maintained groundwater-fed ditch, coupled with the lack of any vegetative cover, likely contributed to this ditch's high maximum temperatures. For the lake-fed ditches, maintenance appeared to contribute to increased heating of the water downstream, although maintenance did not appear to have much influence on maximum water temperatures or the sensitivity of water temperature to air temperature after a year. Surface water-fed ditches surrounded by reed canary grass or by native riparian canopy had similarly low maximum temperatures (7-DADMax below 15°C), and experienced limited if any heating from upstream to downstream over the course of a day. Future studies should examine a larger sample size and should control for the primary source of the ditch water.

References

- Arrigoni, A.S., Poole, G.C., Mertes, L.A.K., O'Daniel, S.J., Woessner, W.W., Thomas, S.A., 2008, Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stream channels, *Water Resources Research*, 44, 1-13.
- Benedict, C., 2012, Manual of best management practices for maintenance of agricultural waterways in King County, Washington State University.
- Benedict, C., and Shaw, J., 2012, Agricultural waterway buffer study, Whatcom County, Washington, Washington State University.
- Benedict, Christopher, 5 April 2012, Personal communication.
- Blann, K., Nerbonne, J.F., Vondracek, B., 2002, Relationship of riparian buffer type to water temperature in the driftless area ecoregion of Minnesota, *North American Journal of Fisheries Management*, 22, 441-451.
- Borman, M.M., and Larson, L.L., 2003, A case study of river temperature response to agricultural land use and environmental thermal patterns, *Journal of Soil and Water Conservation*, 58, 8-12.
- Caissie, D., 2006, The thermal regime of rivers: a review, *Freshwater Biology*, 51, 1389-1406.
- Caissie, D., Nassir, E., Andre S., 1998, Stochastic modelling of water temperatures in a small stream using air to water relations, *Canadian Journal of Civil Engineering*, 25, 250-260.
- Chenard, J-F., Caissie, D., 2008, Stream temperature modelling using artificial neural networks: application on Catamaran Brook, New Brunswick, Canada, *Hydrological Processes*, 22, 3361-3372.
- Collins, B.D., Montgomery, D.R., and Sheikh, A.J., 2003, Chapter 4: Reconstructing the historical riverine landscape of the Puget Lowland, *Restoration of Puget Sound Rivers*, University of Washington Press.
- Collins, B.D., Sheikh, A.J., February 2002, Mapping historical conditions in the Snoqualmie River valley (RM 0- RM 40) Report for King County Department of Natural Resources, University of Washington Department of Earth and Space Sciences.
- Eastman, D., 2006, Tuck Creek water temperature monitoring project, Snoqualmie River basin, King County Department of Natural Resources and Parks, Water and Land Resources Division.
- Environmental Protection Agency (EPA), 2003, EPA Region 10 guidance for Pacific Northwest State and Tribal temperature water quality standards, EPA 910-B-03-002, Region 10 Office of Water, Seattle, WA.

Gelb, Richard, King County aquatic biota indicators, 2009, Accessed 12 May 2012, <http://your.kingcounty.gov/dnrp/measures/indicators/ae-aquatic-biota.aspx>

Janisch, J.E., Wondzell, S.M., Ehinger, W.J., 2012, Headwater stream temperature: Interpreting response after logging, with and without riparian buffers, Washington, USA, *Forest Ecology and Management*, 270, 302-313.

King County, March 2006, Department of Natural Resources and Parks Water and Land Resources Division, Tolt River Natural Area Site Management Guidelines.

King County, December 2009, Department of Natural Resources and Parks, Farms Report: Future of Agriculture, Realize Meaningful Solutions.

King County, February 2010, Department of Natural Resources and Parks, Land and Water Division, King County Farmers Market Report, <http://your.kingcounty.gov/dnrp/library/water-and-land/agriculture/farmers-markets/farmers-market-report-final.pdf>

King County, 2011, King County Agricultural Drainage Assistance Program, Projects and Mitigation Document, King County Staff.

King County, 2013, King County iMAP: Interactive mapping tool, Accessed May 2013, <http://www.kingcounty.gov/operations/GIS/Maps/iMAP.aspx>

Kelleher, C., Wagener, T., Gooseff, M., McGlynn, B., McGuire, K., Marshall, L., 2012, Investigating controls on the thermal sensitivity of Pennsylvania streams, *Hydrological Processes*, 26, 771-785.

Lindig-Cisneros R., Zedler J., 2002, Relationships between canopy complexity and germination microsites for *Phalaris arundinacea* L, *Oecologia*, 133, 159-167.

Lucchetti G., Higgins, K., 2010, A salmon-based classification to guide fish protection measures for agricultural waterways maintenance Draft, King County Department of Natural Resources and Parks.

Malcolm, I.A., Soulsby, C, Hannah, D.M., Bacon, P.J., Youngson, A.F., Tetzlaff, D., 2008, The influence of riparian woodland on stream temperatures: implications for the performance of juvenile salmonids, *Hydrological Processes*, 22, 968-979.

Maurer D., Zedler J., 2002, Differential invasion of a wetland grass explained by tests of nutrients and light availability on establishment and clonal growth, *Oecologia*, 131, 279-288.

Mohseni O., Stefan H., Erickson T., 1998, A nonlinear regression model for weekly stream temperatures, *Water Resources Research*, 34, 2685 – 2692.

- Mohseni O., Erickson T., Stefan H., 2002, Upper bounds for stream temperatures in the contiguous United States, American Society of Civil Engineers, Journal of Environmental Engineering, 128, 4–11.
- Monaghan, J., 2010, Map of Ames Creek area monitoring locations.
- Moore, R.D., Sutherland, P., Gomi, T., Dhakal, A., 2005, Thermal regime of a headwater stream within a clear-cut, coastal British Columbia, Canada, Hydrological Processes, 19, 2591-2608.
- Morrill, J., Bales, R., Conklin, M., 2005, Estimating stream temperature from air temperature: Implications for future water quality, Journal of Environmental Engineering, 131, 139-146.
- Morrison S., Molofsky J., 1998, Effects of genotypes, soil moisture, and competition on the growth of an invasive grass, *Phalaris arundinacea* (reed canary grass), Canadian Journal of Botany, 76, 1939-1946.
- National Weather Service, 2013, SeaTac daily maximum temperatures, July-October 2010 and 2011, Seattle-Tacoma International Airport, Accessed 5 March 2013, <http://www.nws.noaa.gov/climate/index.php?wfo=sew>
- Neumann, D., Rajagopalan, B., Zagona, E., 2003, Regression model for daily maximum stream temperature, Journal of Environmental Engineering, 129, 667–674.
- Newcombe, P., Jensen, J., 1996, Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact, North American Journal of Fisheries Management, 16, 693-727.
- Perry, L. G., S. M. Galatowitsch, C. J. Rosen, 2004, Competitive control of invasive vegetation: a native wetland sedge suppresses *Phalaris arundinacea* in carbon-enriched soil, Journal of Applied Ecology, 41, 151-162.
- Pollock, M.M., Beechie, T.J., Liermann, M., Bigley, R., 2009, Stream temperature relationships to forest harvest in western Washington, Journal of the American Water Resources Association, 45, 141-156.
- Poole, G.C., and Berman, C.H., 2001, An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation, Environmental Management, 27, 787-802.
- Rayne, S., Henderson G., Gill, P., Forest, K., 2008, Riparian forest harvesting effects on maximum water temperatures in wetland-sourced headwater streams from the Nicola River watershed, British Columbia, Canada, Water Resources Management, 22, 565-578.
- Richter A., Kolmes, S.A., 2005, Maximum temperature limits for chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest, Reviews in Fisheries Science, 13, 23-49.

Richter, K.O., Dunnahoe, M., Lucchetti, G., 2010, Water temperatures of creeks and agricultural ditches and their potential use by salmon and trout, Draft report, King Conservation District and King County, Accessed May 2011.

Rowe, M., Essig, D., Jessup, B., June 2003, Guide to selection of sediment targets for use in Idaho TMDLs, Idaho Department of Environmental Quality, http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/sediment/upload/2004_08_17_criteria_sediment_appendix5.pdf

Sahoo, G.B., Schladow, S.G., Reuter, J.E., 2009, Forecasting stream water temperature using regression analysis, artificial neural network, and chaotic non-linear dynamic models, *Journal of Hydrology*, 378, 325-342.

Sand-Jensen, K., Pedersen, N.L., 2005, Differences in temperature, organic carbon and oxygen consumption among lowland streams, *Freshwater Biology*, 50, 1927-1937.

Sleight, Brian, 1 May 2012, King County Agricultural Drainage Assistance Program Manager, Personal communication.

Stoll, K., Monohan, C., 2004, Effects of external drivers on lowland agricultural stream temperature, University of Washington Department of Civil and Environmental Engineering and the College of Forest Resources.

Story, A., Moore, R.D., Macdonald, J.S., 2003, Stream temperatures in two shaded reaches below cutblocks and logging roads: downstream cooling linked to subsurface hydrology, *Canadian Journal of Forest Research*, 33, 1383-1396.

Svrjcek., R., Stohr, A., Kardouni, J., June 2011, Snoqualmie River basin temperature total maximum daily load: Water quality improvement report and implementation plan, Washington State Department of Ecology, Ecology 11-10-041.

Washington State Department of Ecology, 2008, Surface water quality standards: Supplemental aquatic life temperature criteria information, Accessed 6/5/13, <http://www.ecy.wa.gov/programs/wq/swqs/AquaticLifeTempSupp.html#timeframes>

Webb, B.W., Hannah, D.M., Moore, R.D., Brown, L.E., Nobilis, F., 2008, Recent advances in stream and river temperature research, *Hydrological Processes*, 22, 902-918.

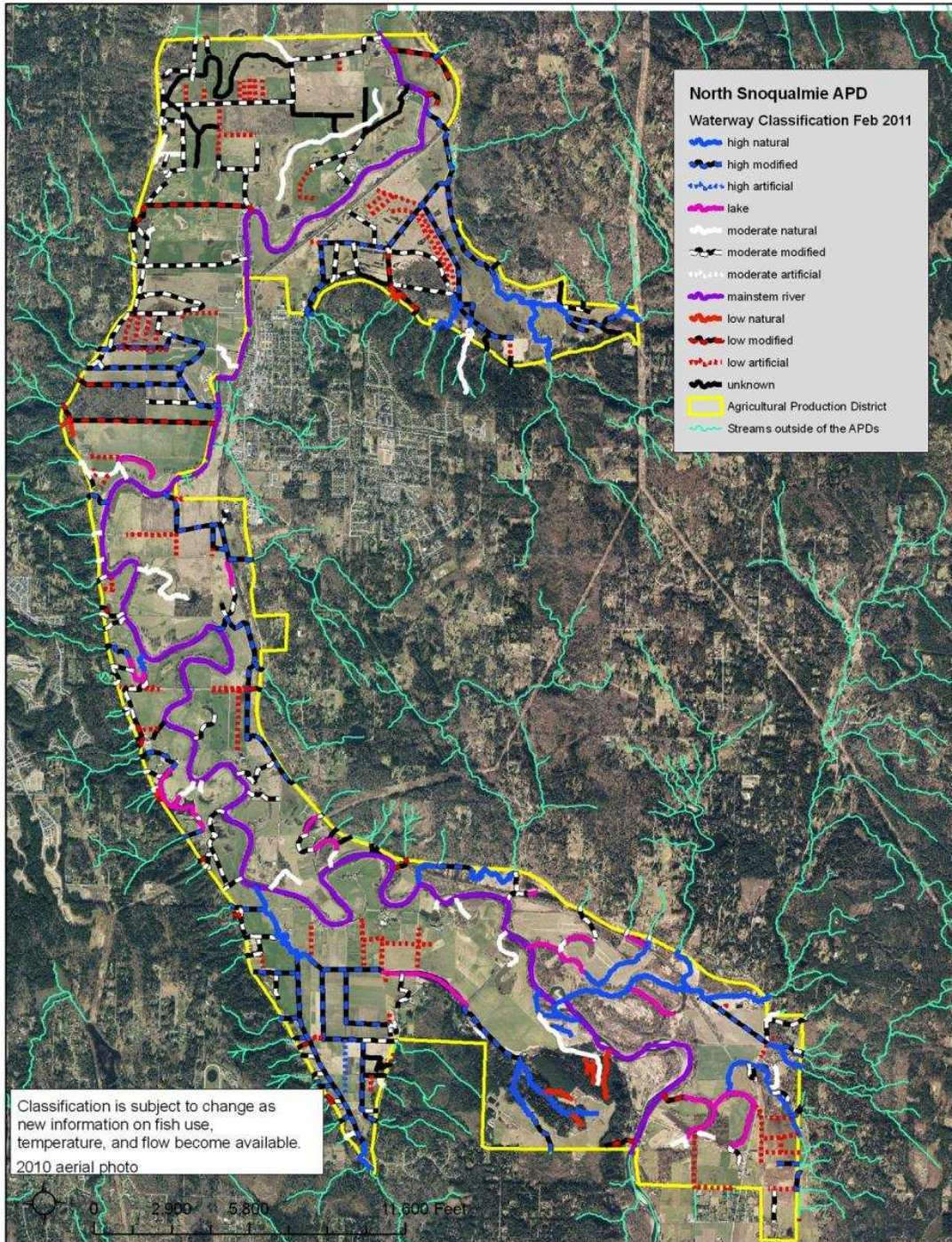
Whitney, L., 2000, Grande Ronde section 319 national monitoring program project: Temperature monitoring summary report 1993-1998, Oregon Department of Environmental Quality.

WSU Whatcom County Extension. Integrated pest management for blueberries: Reed canary grass (*Phalaris arundinacea* L.), Accessed 17 May 2011, http://whatcom.wsu.edu/ag/comhort/nooksack/ipmweb/blue/reed_canary_grass.html.

Xiong, J., Nilsson, C., 1999, The effects of plant litter on vegetation: a meta-analysis, *Journal of Ecology*, 87, 984-994.

Zar, Jerrold H., 2009, *Biostatistical Analysis* (5th edition).

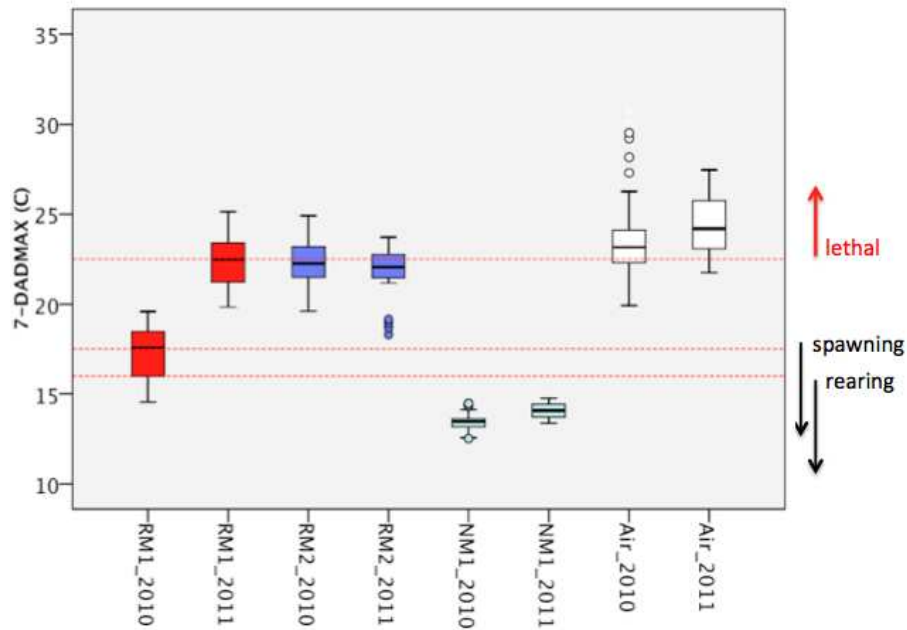
Appendices



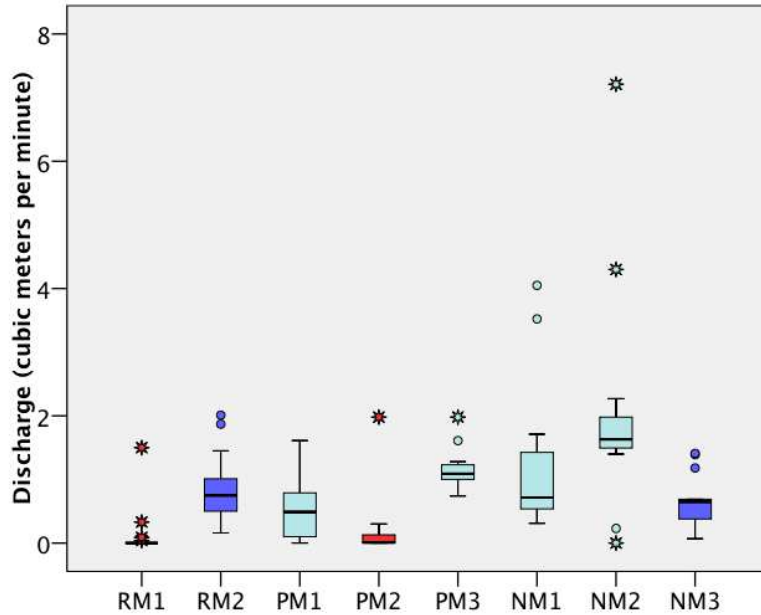
Appendix 1: Map of the North Snoqualmie Agricultural Production District showing proposed classification system of agricultural waterways (Lucchetti and Higgins 2010). Ditches monitored in this study are “high modified,” indicated by blue and black dotted lines.

Appendix 2: Lists of vegetation found adjacent to previously maintained ditches (both ground species and canopy species) and adjacent to recently maintained ditches (planted March 2011). Woody debris, black weed plastic, and vegetative litter are also reported.

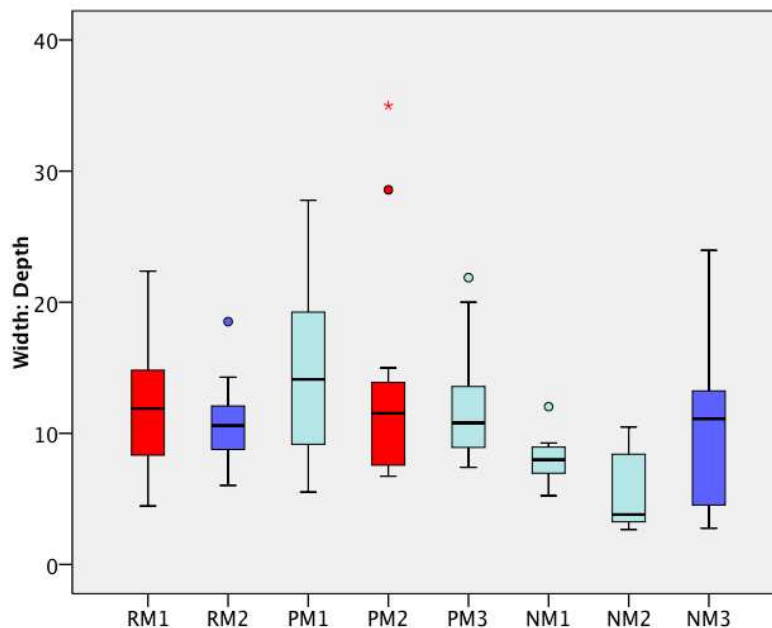
<p>PM1 <u>Ground</u> Reed canary grass (<i>Phalaris arundinacea</i>) Medium woody debris (5-10cm diameter) Buttercup (<i>Ranunculus repens</i>) <u>Canopy</u> Sitka willow (<i>Salix sitchensis</i>) Red osier dogwood (<i>Cornus sericea</i>) Pacific willow (<i>Salix lasiandra</i>)</p> <p>PM2 <u>Ground</u> Morning glory (<i>Convolvulus arvensis</i>) Reed canary grass (<i>Phalaris arundinacea</i>) Snowberry (<i>Symphoricarpos albus</i>) Nootka rose (<i>Rosa nutkana</i>) Evergreen blackberry (<i>Rubus laciniatus</i>) Reed canary grass litter Medium Woody debris (5-10cm diameter) Fine woody debris (0.6-2.4cm diameter) <u>Canopy</u> Sitka willow (<i>Salix sitchensis</i>) Red osier dogwood (<i>Cornus sericea</i>) Pacific willow (<i>Salix lasiandra</i>)</p> <p>PM3 <u>Ground</u> Evergreen blackberry (<i>Rubus laciniatus</i>) Buttercup (<i>Ranunculus repens</i>) Reed canary grass <i>Phalaris arundinacea</i> Himalyaan blackberry (<i>Rubus discolor</i>) Lady fern (<i>Athyrium felix-femina</i>) Snowberry (<i>Symphoricarpos albus</i>) Nettle (<i>Urtica dioica</i>) Moss (unknown) Leaf litter (miscellaneous) Fine woody debris (0.6-2.4cm diameter) Medium woody debris (5-10cm diameter) Large woody debris (over 10cm diameter) <u>Canopy</u> Elderberry (<i>Sambucus racemosa</i>) Pacific willow (<i>Salix lasiandra</i>) Sitka willow (<i>Salix sitchensis</i>)</p>	<p>RM1 <u>Starts planted March 2011</u> Alder (<i>Alnus rubra</i>) Reed canary grass (<i>Phalaris arundinacea</i>) Buttercup (<i>Ranunculus repens</i>) Hazelnut (<i>Corylus rostrata</i>) Snowberry (<i>Symphori-carposalbus</i>) Salmon berry (<i>Rubus spectabilis</i>) Red osier dogwood (<i>Cornus sericea</i>) Vine maple (<i>Acer circinatum</i>) Sitka willow (<i>Salix sitchensis</i>) Pacific Ninebark (<i>Physocarpus capitatus</i>) Black plastic Pigweed (<i>Amaranthus palmeri</i>) Red Clover (<i>Trifolium pratense</i>) Lamb's-quarters (<i>Chenopodium album</i>) Plant litter (miscellaneous)</p> <p>RM2 <u>Starts planted March 2011</u> Reed canary grass (<i>Phalaris arundinacea</i>) Serviceberry (<i>Amelanchier alnifolia</i>) Hazelnut (<i>Corylus rostrata</i>) Nootka rose (<i>Rosa nutkana</i>) Morning glory (<i>Convolvulus arvensis</i>) Evergreen blackberry (<i>Vaccinium ovatum</i>) Alder (<i>Alnus rubra</i>) Bitter cherry (<i>Prunus emarginata</i>) Crab apple (<i>Malus fusca</i>) Vine maple (<i>Acer circinatum</i>) Pacific willow (<i>Salix lasiandra</i>) Red osier dogwood (<i>Cornus sericea</i>) Sitka willow (<i>Salix sitchensis</i>) Sitka spruce (<i>Picea sitchensis</i>) Black plastic Farm weeds (unknown) Large woody debris (7m long, 1.2m in diameter at one end and .3m in diameter at the other end)</p>
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Appendix 3: Comparison of the 7-day running average of the daily maximum temperatures for three ditch water temperatures with air temperature from the SeaTac weather station from July 30th to September 2nd in 2010 and 2011. Primarily groundwater-fed ditches are red, primarily lake-fed ditches are dark blue, and primarily surface water-fed ditches are pale blue. The bottom red line indicates Ecology's upper limit for salmon rearing, the middle red line is the upper limit for salmon spawning, and the upper red line is the lower limit for lethal temperatures. Box borders are the 25th and 75th percentiles, interior line is the median, whiskers are the minimum and maximum values that are not statistically significant outliers, and small circles are outliers. Water measurements are from downstream sampling points, except for RM1, where the 2010 and 2011 measurements are taken from the upstream sampling point because 2010 downstream data loggers were lost. However, the RM1 upstream sampling point is downstream of approximately 500 meters of recent maintenance.



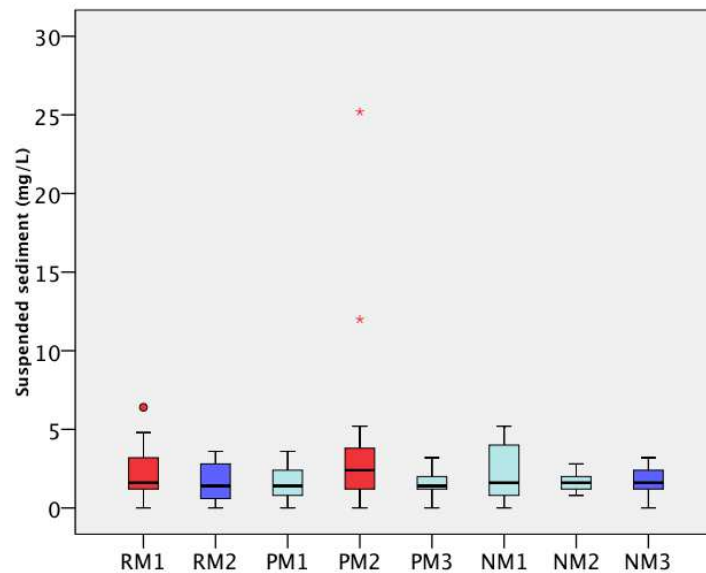
Appendix 4: Box plot of the discharge for all ditches. Primarily groundwater-fed ditches are red, primarily lake-fed ditches are dark blue, and primarily surface water-fed ditches are pale blue. Box borders are the 25th and 75th percentiles, interior line is the median, and whiskers are the minimum and maximum values that are not statistically significant outliers. Small circles are outliers, and stars are extreme values.



Appendix 5: Box plot of the wetted width to water depth ratio for all ditches. Primarily groundwater-fed ditches are red, primarily lake-fed ditches are dark blue, and primarily surface water-fed ditches are pale blue. Box borders are the 25th and 75th percentiles, interior line is the median, and whiskers are the minimum and maximum values that are not statistically significant outliers. Small circles are outliers, and stars are extreme values.

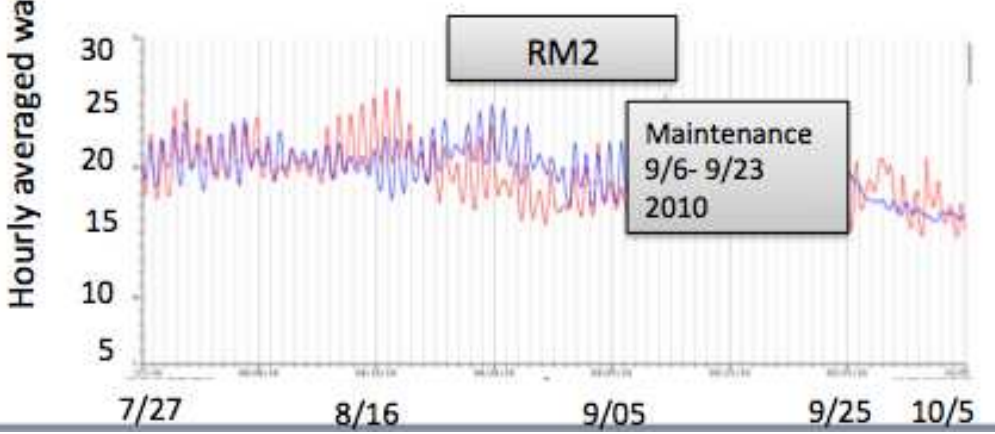
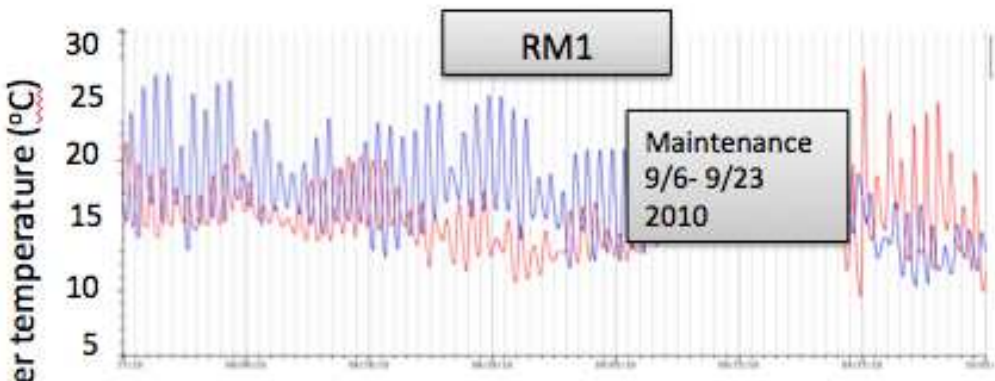
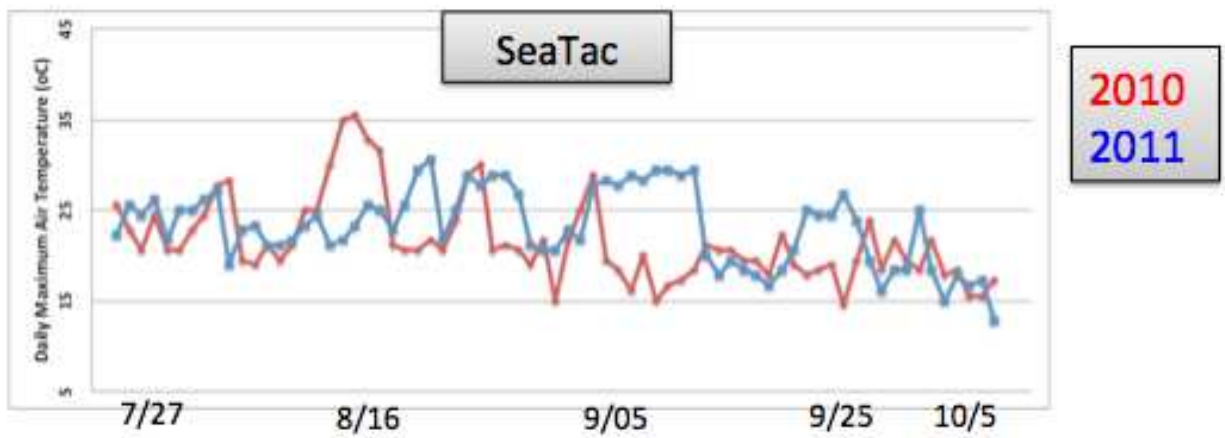
Appendix 6: Conductivity in decisiemens per meter (dS/m) means and standard deviations for ditches divided by primary source. All values are very similar, and are very low. The very low concentrations of ions in these ditch waters indicate that the waters are very poor conductors of electricity. Conductivity can be used to estimate how much groundwater is moving through soils, and low conductivities suggest there are very low inputs of groundwater exchange through the soil within the ditch.

Ditches and sample size	Means (dS/m)	Standard deviation
Groundwater-fed (n=42)	0.10	0.03
Lake-fed (n=40)	0.14	0.02
Surface water-fed (n=97)	0.10	0.02

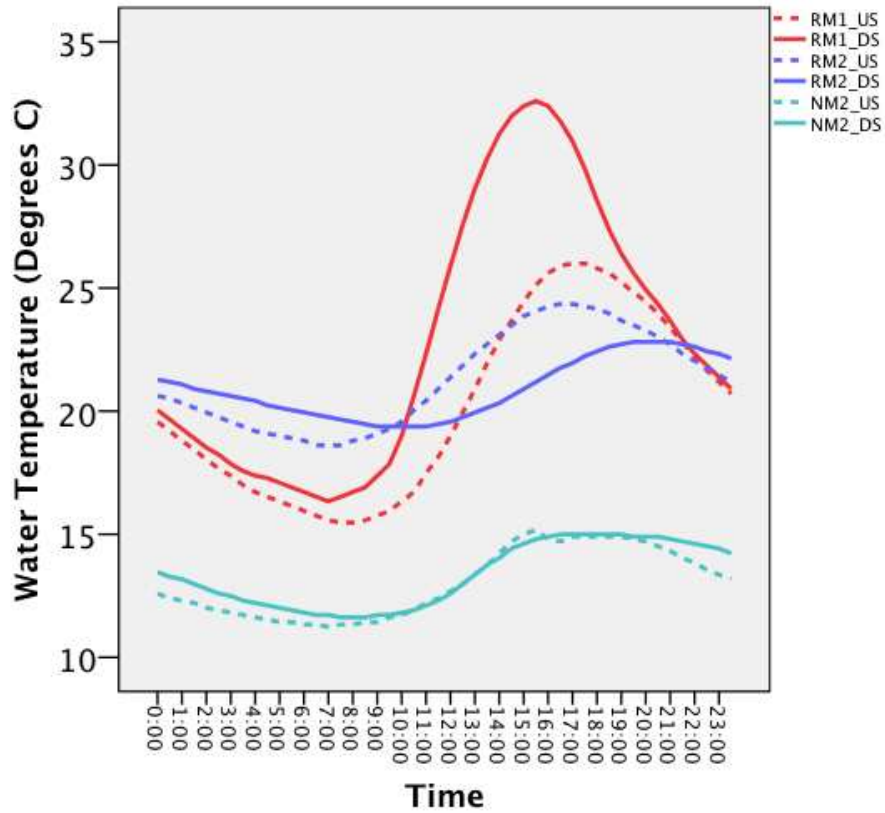


Appendix 7: Box plot of the suspended sediment concentrations. Box borders are the 25th and 75th percentiles, interior line is the median, and whiskers are the minimum and maximum values. Small circles are outliers, and stars are extreme values.

Ecology does not have a standard value for suspended sediments, which is a direct measure of the amount of sediment in the water column. However, samples of suspended sediment in all ditches are below instantaneous levels of concern for juvenile and adult salmon (Newcombe and Jensen 1996, Rowe et al. 2003). Ecology does have standards for turbidity, which are set from baseline conditions, for which there are no records for these ditches.



Appendix 8: Daily maximum air temperatures from the SeaTac weather station and hourly averaged water temperatures in the recently maintained ditches between July 27th and October 5th for 2010 and 2011. Maintenance occurred between September 6th and 23rd, 2010.



Appendix 9: Heating and cooling patterns over the course of 24 hours for three sample ditches, RM1, RM2, and NM2 on a random day chosen, August 3rd. Dotted lines indicating upstream sampling points (US) and solid lines indicating downstream sampling points (DS). RM2_DS was likely sunk into sediment on this day.

Appendix 10: Table of instantaneous data collected in 2011 for upstream and downstream sampling points along each ditch reach. Cells left blank have no recorded data.

Ditch & up or down stream sample point	Date in 2011	Time of day	Water Temp (°C)	Dissolved oxygen (mg/L)	Conductivity (dS/m)	Discharge (m ³ /min)	Suspended sediment (mg/L)
NM1 DS	6-Oct	11:40	11	8.59	0.09	1.710	2.4
NM1 DS	21-Sep	13:00	12.3	9.1	0.10	0.601	2
NM1 DS	15-Sep	12:30	12.3	8.9	0.10	0.618	1.2
NM1 DS	9-Sep	12:35	12.9	8.51	0.11	3.523	4.4
NM1 DS	31-Aug	12:30	12.1	8.87	0.11	0.397	0
NM1 DS	23-Aug	13:06	13.8	8.85	0.11		4.4
NM1 DS	16-Aug	13:00	12.9	3.62	0.10	0.477	1.2
NM1 DS	7-Aug	13:35	13.8	7.14	0.14	0.598	5.2
NM1 DS	2-Aug	13:50	13.6	8.98	0.14		4
NM1 DS	26-Jul	13:10	12.7	8.4	0.10		
NM1 DS	17-Jul	15:20	12.5	8.8		0.31	0
NM1 US	6-Oct	11:50	11	8.71	0.13	1.32	4
NM1 US	21-Sep	13:10	12.3	9.35	0.10	1.53	1.2
NM1 US	15-Sep	12:40	12.2	9.12	0.10	0.76	1.2
NM1 US	9-Sep	13:00	13.1	8.7	0.11	4.05	0.4
NM1 US	31-Aug	12:50	12.1	8.71	0.11	0.98	2.8
NM1 US	23-Aug	13:00	13.3	9.22	0.14		0
NM1 US	16-Aug	14:00	13.3	3.48	0.10	0.67	0.4
NM1 US	7-Aug	13:25	13.7	7.01	0.11	1.27	1.2
NM1 US	2-Aug	14:15	13.6	9.02	0.14		5.2
NM1 US	26-Jul	13:15	12.5	9.04	0.10		
NM1 US	17-Jul	14:40	12.4	9.3		0.40	2
NM2 DS	10/5/11	10:30	11.1	7.86	0.10	4.30	2
NM2 DS	21-Sep	10:45	11.6	9.06	0.10	1.81	0.8
NM2 DS	15-Sep	10:20	12.2	8.46	0.11	1.63	1.2
NM2 DS	9-Sep	11:00	12.4	8.48	0.11	1.54	2.4
NM2 DS	31-Aug	11:10	12.2	8.43	0.11	1.60	0.8
NM2 DS	23-Aug	11:00	13.5	8.59	0.12		2.4
NM2 DS	16-Aug	11:20	11.7	3.73	0.11	1.48	1.6
NM2 DS	7-Aug	12:00	13	8.14	0.11	2.15	1.6
NM2 DS	2-Aug	12:00	12.4	8.74	0.11		0.8
NM2 DS	26-Jul	11:50	12.6	8.52	0.11	0.23	
NM2 US	6-Oct	9:45	11.1	8.12	0.10	7.21	2
NM2 US	21-Sep	12:15	12.3	9.21	0.10	2.27	1.2
NM2 US	15-Sep	10:00	11.9	8.84	0.11	1.40	1.2
NM2 US	9-Sep	11:30	12.3	8.82	0.11	1.51	2.8

Appendix 10: (Continued) Table of instantaneous data collected in 2011 for upstream and downstream sampling points along each ditch reach. Cells left blank have no recorded data.

Ditch & up or down stream sample point	Date in 2011	Time of day	Water Temp (°C)	Dissolved oxygen (mg/L)	Conductivity (dS/m)	Discharge (m ³ /min)	Suspended sediment (mg/L)
NM2 US	31-Aug	11:45	11.9	8.92	0.11	1.63	1.6
NM2 US	23-Aug	11:25	13.2	9.15	0.12		1.6
NM2 US	16-Aug	11:40	12.3	3.74	0.11	1.81	1.2
NM2 US	2-Aug	12:30	12.4	9.3	0.11		1.2
NM2 US	26-Jul	12:50	12.6	9.2	0.14		
NM3 DS	7-Oct	10:50	14.5	4.84	0.14	1.41	3.2
NM3 DS	21-Sep	9:45	17.2	4.76	0.15	0.12	0.4
NM3 DS	15-Sep	11:15	18.5	2.95	0.20	0.45	1.2
NM3 DS	9-Sep	10:00	18.6	4.12	0.15	0.64	2.4
NM3 DS	31-Aug	10:10	18.7	3.7	0.15	0.69	2.4
NM3 DS	23-Aug	10:13	21	3.49	0.15		1.6
NM3 DS	16-Aug	10:00	18.2	2.26	0.14	0.67	0
NM3 DS	7-Aug	11:05	20	4.86	0.15	0.28	3.2
NM3 DS	2-Aug	10:30	20	4.15	0.10		1.2
NM3 DS	26-Jul	10:50	19.7	3.86	0.14		
NM3 US	7-Oct	11:15	14.5	4.6	0.14	1.39	2.4
NM3 US	21-Sep	10:10	17.4	4.57	0.20	0.68	1.2
NM3 US	15-Sep	11:30	18.6	2.69	0.20	0.59	0
NM3 US	9-Sep	10:10	18.9	3.83	0.15	0.07	2.4
NM3 US	31-Aug	10:20	18.9	3.45	0.08	0.66	2.4
NM3 US	23-Aug	10:00	21.1	3.65	0.15		1.6
NM3 US	16-Aug	10:15	18.6	2.37	0.14	1.18	1.2
NM3 US	7-Aug	10:50	20.2	4.5	0.14	0.38	2.8
NM3 US	2-Aug	10:45	20.3	4.01	0.15		1.6
NM3 US	26-Jul	10:30	19.8	3.96	0.14		
PM1 DS	6-Oct	8:45	10.6	8.34	0.06	1.61	0
PM1 DS	21-Sep	8:50	11.6	8.68	0.04	0.00	2.4
PM1 DS	15-Sep	8:45	12.6	8.04	0.09	0.20	0.8
PM1 DS	9-Sep	9:00	11.9	8.01	0.09	0.00	0.8
PM1 DS	31-Aug	14:30	12.7	8.72	0.11	0.84	3.2
PM1 DS	23-Aug	14:00	14.4	8.33	0.11		0.8
PM1 DS	16-Aug	15:00	13.6	3.28	0.11	0.41	2.4
PM1 DS	7-Aug	15:25	13.8	5.95	0.11	0.87	2
PM1 DS	3-Aug	11:30	13.1	9.34	0.09		2.4

Appendix 10: (Continued) Table of instantaneous data collected in 2011 for upstream and downstream sampling points along each ditch reach. Cells left blank have no recorded data.

Ditch & up or down stream sample point	Date in 2011	Time of day	Water Temp (°C)	Dissolved oxygen (mg/L)	Conductivity (dS/m)	Discharge (m ³ /min)	Suspended sediment (mg/L)
PM1 DS	26-Jul	14:40	12.7	9.49	0.08		
PM1 US	6-Oct	9:00	10.7	8.97	0.08	1.29	1.6
PM1 US	21-Sep	9:00	11.5	8.98	0.08	0.00	0
PM1 US	15-Sep	9:00	12.3	9.07	0.04	0.53	0.4
PM1 US	9-Sep	8:30	11.8	8.51	0.09	0.00	0.4
PM1 US	31-Aug	14:15	12.7	9.07	0.09	0.49	2.4
PM1 US	23-Aug	13:45	14.5	8.62	0.09		1.2
PM1 US	16-Aug	14:45	13.8	3.34	0.00	0.69	1.2
PM1 US	7-Aug	15:15	13.7	6.56	0.11	0.74	2
PM1 US	3-Aug	11:00	13.1	10.92	0.08		3.6
PM1 US	26-Jul	14:25	12.7	9.45	0.09	0.24	
PM2 DS	10-Oct	8:30	11	4.95	0.09	0.17	
PM2 DS	21-Sep	15:00	13.4	3.85	0.00	0.30	2.4
PM2 DS	15-Sep	14:45	12.4	3.34	0.10	0.01	0.4
PM2 DS	9-Sep	15:00	13.9	3.41	0.10	0.02	2.8
PM2 DS	31-Aug	9:00	11.2	2.66	0.10	0.01	4.4
PM2 DS	23-Aug	8:45	12.9	2.68	0.05		5.2
PM2 DS	16-Aug	8:15	10.6	1.83	0.09	0.04	0.8
PM2 DS	7-Aug	9:50	11.5	4.97	0.10	0.00	12
PM2 DS	2-Aug	9:15	11.6	3.76	0.10		25.2
PM2 DS	26-Jul	16:05	13.1	5.81	0.10	0.00	
PM2 US	10-Oct	8:45	11.6	4.3	0.10	1.98	
PM2 US	21-Sep	15:15	13.7	3.93	0.10	0.26	2.4
PM2 US	15-Sep	15:00	12.2	3.22	0.10	0.00	1.6
PM2 US	9-Sep	15:15	13.3	3.01	0.13	0.00	
PM2 US	31-Aug	8:45	12.2	2.95	0.10	0.16	0.8
PM2 US	23-Aug	8:20	12.3	2.72	0.11		2.4
PM2 US	16-Aug	8:00	11.3	1.46	0.10	0.10	0
PM2 US	7-Aug	9:40	12.4	3.92	0.12	0.00	2.8
PM2 US	2-Aug	8:50	11.9	2.87	0.11	0.00	3.2
PM2 US	26-Jul	15:50	13	7.78	0.10	0.07	
PM3 DS	10/6/11	11:00	11.1	8.54	0.10	1.61	1.6
PM3 DS	21-Sep	13:40	12.3	9.26	0.10	0.99	2.4
PM3 DS	15-Sep	12:55	12.2	9.28	0.10	0.74	1.6
PM3 DS	9-Sep	13:15	13.1	8.71	0.11	1.07	1.2
PM3 DS	31-Aug	13:10	12.1	8.99	0.11	1.23	2.4

Appendix 10: (Continued) Table of instantaneous data collected in 2011 for upstream and downstream sampling points along each ditch reach. Cells left blank have no recorded data.

Ditch & up or down stream sample point	Date in 2011	Time of day	Water Temp (°C)	Dissolved oxygen (mg/L)	Conductivity (dS/m)	Discharge (m ³ /min)	Suspended sediment (mg/L)
PM3 DS	23-Aug	12:45	13.6	8.9	0.10		2
PM3 DS	16-Aug	13:45	13.1	3.44	0.10	1.28	1.6
PM3 DS	2-Aug	14:25	13.8	8.8	0.11		3.2
PM3 DS	26-Jul	13:20	12.4	9.37	0.10		
PM3 DS	17-Jul	14:10	12.2	9.17			2
PM3 US	7-Aug	13:10	13.6	7.6	0.11	1.11	2
PM3 US	6-Oct	12:20	11.1	8.25	0.10	1.98	0.4
PM3 US	21-Sep	13:50	12.3	9.02	0.10	1.15	1.2
PM3 US	15-Sep	13:05	12.1	9.17	0.10	1.06	0.4
PM3 US	9-Sep	13:30	13.1	8.4	0.11	1.15	0
PM3 US	31-Aug	13:25	12	8.45	0.11	1.00	1.2
PM3 US	23-Aug	12:30	13.3	8.75	0.11		0.8
PM3 US	16-Aug	13:30	13.2	3.75	0.10	1.06	1.2
PM3 US	7-Aug	13:55	14	7.03	0.14	.79	3.2
PM3 US	2-Aug	14:40	13.7	8.7	0.11		1.2
PM3 US	26-Jul	13:30	12.4	9.14	0.13		
PM3 US	17-Jul	13:20	12.2	9.16			1.2
RM1 DS	7-Oct	11:30	12.5	6.96	0.08	0.04	2
RM1 DS	21-Sep	11:05	16.2	6.7	0.10	0.00	2.4
RM1 DS	15-Sep	11:40	16.5	5.1	0.00	0.09	1.2
RM1 DS	9-Sep	9:43	16.4	5.94	0.12	0.00	1.6
RM1 DS	31-Aug	9:50	16.4	6.23	0.12	0.00	1.2
RM1 DS	23-Aug	9:45	19.5	4.75	0.06		1.2
RM1 DS	16-Aug	9:40	16.1	2.45	0.12	0.00	0.4
RM1 DS	7-Aug	10:40	21.1	7.17	0.13	0.00	1.6
RM1 DS	2-Aug	10:20	19.5	9.9	0.00		3.2
RM1 DS	26-Jul	11:10	18.2	8.7	0.13		
RM1 DS	17-Jul	11:45	18.2	8.9		0.00	0.4
RM1 US	7-Oct	12:00	12.1	8.05	0.10	0.33	0.8
RM1 US	21-Sep	11:40	14.9	7.06	0.10	0.00	1.6
RM1 US	15-Sep	12:00	15.3	2.89	0.10	0.00	2.4
RM1 US	9-Sep	9:30	14.5	5.51	0.12	0.00	1.6
RM1 US	31-Aug	9:35	15	4.21	0.12	0.00	3.2
RM1 US	23-Aug	9:25	17.3	3.53	0.13		4
RM1 US	16-Aug	9:20	13.8	2.42	0.12	0.00	0

Appendix 10: (Continued) Table of instantaneous data collected in 2011 for upstream and downstream sampling points along each ditch reach. Cells left blank have no recorded data.

Ditch & up or down stream sample point	Date in 2011	Time of day	Water Temp (°C)	Dissolved oxygen (mg/L)	Conductivity (dS/m)	Discharge (m ³ /min)	Suspended sediment (mg/L)
RM1 US	7-Aug	14:45	13.2	6.02	0.12	1.50	1.6
RM1 US	7-Aug	10:25	17.5	6.8	0.14	0.00	6.4
RM1 US	2-Aug	10:00	16.2	6.57	0.10		4.8
RM1 US	17-Jul	11:00	16.1	7.35		0.00	3.2
RM2 DS	6-Oct	10:45	14.2	4.95	0.13	0.95	
RM2 DS	21-Sep	10:35	17.5	8.04	0.10	0.72	0.4
RM2 DS	15-Sep	10:30	18.1	5.32	0.15	0.47	0.4
RM2 DS	9-Sep	10:50	19.8	9.17	0.15	0.34	1.6
RM2 DS	31-Aug	10:50	18.5	7.35	0.14	1.87	3.2
RM2 DS	23-Aug	10:45	21.5	8.95	0.15		1.2
RM2 DS	16-Aug	11:00	20.7	3.14	0.14	1.07	0.4
RM2 DS	7-Aug	11:45	22.2	8.49	0.14	0.83	2.8
RM2 DS	2-Aug	11:40	21.1	10.3	0.14		
RM2 DS	26-Jul	11:30	19.4	8.56	0.14		
RM2 US	6-Oct	11:00	14.3	4.48	0.14	1.45	2.8
RM2 US	21-Sep	10:20	17.3	5.19	0.10	0.16	1.2
RM2 US	15-Sep	11:00	18.3	4.01	0.15	0.53	0
RM2 US	9-Sep	10:30	18.9	5	0.15	0.71	0.8
RM2 US	31-Aug	11:20	18.4	4.23	0.15	2.01	3.6
RM2 US	23-Aug	10:30	21	4.68	0.15		3.6
RM2 US	16-Aug	10:30	18.6	2.85	0.14	0.33	1.6
RM2 US	7-Aug	11:30	20.6	6.07	0.15	0.86	2.4
RM2 US	2-Aug	11:00	20.4	5.89	0.15		0.8
RM2 US	26-Jul	9:50	19.5	4.6	0.14	0.75	

Appendix 11: 7-DADMax summary data for each ditch and for SeaTac air temperature between July 30 and October 2, 2011. Data are taken from downstream sampling points for all ditches except NM2 because the downstream data loggers for NM2 ran out of batteries by August 24.

Date	RM1	RM2	PM1	PM2	PM3	NM1	NM2	NM3	Air
07/30/11	31.15	25.51	14.71	14.03	14.41	14.54	14.48	22.54	24.29
07/31/11	31.5	25.15	14.75	13.92	14.52	14.67	14.67	22.76	24.84
08/01/11	31.48	24.75	14.78	14.03	14.56	14.76	14.75	22.98	25.08
08/02/11	29.84	24.12	14.76	13.97	14.28	14.45	14.43	22.77	24.29
08/03/11	29.08	23.11	14.56	13.65	14.19	14.35	14.37	22.61	23.81
08/04/11	29.51	22.68	14.59	13.59	14.26	14.42	14.5	22.74	24.05
08/05/11	28.27	21.94	14.49	13.33	14.11	14.28	14.35	22.61	23.49
08/06/11	27.14	21.72	14.36	13.22	13.94	14.1	14.2	22.42	22.94
08/07/11	25.81	21.39	14.04	13.12	13.71	13.87	13.94	22.12	22.3
08/08/11	24.94	21.06	13.72	13.05	13.53	13.67	13.72	21.81	21.75
08/09/11	25.84	20.87	13.69	13.12	13.65	13.83	13.89	21.84	22.54
08/10/11	25.05	20.74	13.71	13.24	13.49	13.67	13.67	21.62	22.3
08/11/11	24.21	20.53	13.57	13.22	13.37	13.56	13.53	21.35	22.06
08/12/11	24.63	20.44	13.58	13.39	13.41	13.59	13.56	21.34	22.38
08/13/11	25.5	21.19	13.68	13.45	13.56	13.72	13.67	21.49	23.02
08/14/11	26.12	21.91	13.76	13.46	13.64	13.79	13.72	21.61	23.49
08/15/11	26.04	22.44	13.71	13.14	13.63	13.75	13.69	21.66	23.41
08/16/11	25.77	22.97	13.63	12.81	13.6	13.71	13.64	21.73	23.57
08/17/11	26.59	23.64	13.71	12.77	13.79	13.91	13.87	22.05	24.76
08/18/11	27.29	24.45	13.85	12.82	13.98	14.08	13.98	22.44	26.03
08/19/11	26.7	24.74	13.99	12.71	13.96	14.07	13.97	22.55	25.79
08/20/11	26.29	24.56	14	12.73	13.94	14.11	14	22.7	25.71
08/21/11	26.46	24.62	14.11	12.77	14.08	14.26	14.15	23.01	26.27
08/22/11	27	24.87	14.34	12.84	14.27	14.46	14.35	23.4	26.98
08/23/11	27.36	25.12	14.58	12.9	14.43	14.64	14.53	23.72	27.46
08/24/11	27.43	25.53	14.72	12.86	14.48	14.68	14.53	23.73	27.38
08/25/11	27.31	25.72	14.73	12.75	14.42	14.63	14.49	23.66	26.83
08/26/11	27.17	25.65	14.8	12.66	14.39	14.58	14.43	23.6	26.75
08/27/11	26.52	25.26	14.67	12.59	14.26	14.42	14.3	23.21	26.11
08/28/11	25.18	24.58	14.42	12.49	13.95	14.12	13.97	22.64	24.92
08/29/11	24.33	24.25	14.06	12.4	13.71	13.86	13.69	22.21	24.21
08/30/11	23.69	23.94	13.74	12.35	13.5	13.64	13.46	21.72	23.17
08/31/11	23.11	23.31	13.51	12.33	13.34	13.47	13.31	21.42	23.02
09/01/11	22.65	22.79	13.34	12.35	13.23	13.38	13.2	21.23	23.25
09/02/11	23.13	23.03	13.33	12.43	13.28	13.45	13.28	21.28	24.21
09/03/11	23.63	23.36	13.34	12.54	13.39	13.54	13.39	21.51	25.4
09/04/11	24.32	23.73	13.43	12.66	13.56	13.71	13.6	21.71	26.51
09/05/11	24.13	23.59	13.48	12.74	13.57	13.74	13.63	21.65	27.46

Appendix 11: 7-DADMax summary data for each ditch and for SeaTac air temperature between July 30 and October 2, 2011. Data are taken from downstream sampling points for all ditches except NM2 because the downstream data loggers for NM2 ran out of batteries by August 24.

Date	RM1	RM2	PM1	PM2	PM3	NM1	NM2	NM3	Air
09/06/11	24.24	23.58	13.46	12.83	13.64	13.82	13.72	21.8	28.57
09/07/11	24.23	23.55	13.52	12.92	13.72	13.9	13.82	21.95	28.73
09/08/11	24.31	23.62	13.59	13.03	13.82	14	13.93	22.06	28.89
09/09/11	23.71	23.35	13.67	13.07	13.75	13.91	13.83	21.92	27.78
09/10/11	22.92	22.86	13.62	13.01	13.57	13.75	13.65	21.64	26.19
09/11/11	22.17	22.41	13.49	12.93	13.42	13.58	13.47	21.42	24.92
09/12/11	21.58	21.94	13.41	12.85	13.32	13.47	13.36	21.17	23.33
09/13/11	20.69	21.31	13.23	12.69	13.1	13.23	13.09	20.73	21.67
09/14/11	19.53	20.56	13	12.48	12.81	12.91	12.74	20.11	19.92
09/15/11	18.62	19.92	12.65	12.35	12.63	12.7	12.54	19.64	18.33
09/16/11	18.7	19.79	12.54	12.51	12.62	12.69	12.54	19.51	18.41
09/17/11	18.92	19.73	12.59	12.63	12.62	12.68	12.52	19.53	19.44
09/18/11	18.92	19.61	12.53	12.8	12.64	12.68	12.51	19.35	20.16
09/19/11	19.09	19.69	12.54	13.04	12.7	12.75	12.59	19.27	21.03
09/20/11	19.35	20.04	12.65	13.38	12.91	12.98	12.81	19.42	22.3
09/21/11	19.87	20.41	13.06	13.73	13.06	13.14	12.99	19.72	23.33
09/22/11	20.02	20.56	13.25	13.98	13.12	13.21	13.06	19.77	23.49
09/23/11	19.47	20.09	13.38	13.75	13.02	13.12	12.99	19.55	22.86
09/24/11	18.98	19.85	13.43	13.73	13.05	13.14	13.08	19.15	21.9
09/25/11	18.7	19.7	13.54	13.54	12.99	13.09	13.05	18.96	21.03
09/26/11	18.43	19.45	13.47	13.33	12.87	12.95	12.9	18.7	21.11
09/27/11	17.8	18.79	13.14	12.97	12.59	12.65	12.63	18.32	19.92
09/28/11	17.04	18.1	12.85	12.58	12.34	12.4	12.37	17.88	18.65
09/29/11	16.48	17.6	12.48	12.26	12.14	12.18	12.16	17.43	18.41
09/30/11	16.26	17.53	12.34	12.18	12.07	12.11	12.1	17.12	18.49
10/01/11	16	17.27	12.15	12.01	11.92	11.96	11.93	16.97	18.33
10/02/11	15.68	16.9	12.07	11.9	11.78	11.82	11.83	16.79	17.54

Appendix 12: Multiple linear regression analysis to determine the relative influence of maintenance and the primary source of ditch water on instantaneous water temperatures

Three multiple linear regression models were performed on all data for 2011 to examine which variables provided the best explanation for the variance in drainage ditch water temperature for this study. The dependent variable was instantaneous water temperature ($^{\circ}\text{C}$) for all models. Independent variables for the first model (Model 1) were instantaneous air temperature ($^{\circ}\text{C}$), instantaneous wetted width (meters), and instantaneous discharge (m^3/min). Model 2 additionally included dummy variables for recent maintenance, previous maintenance, and no maintenance. Model 3 also included dummy variables for the primary source of the ditch water (surface, lake, shallow groundwater interception, and valley wall-based seep). T-tests were performed on each independent variable to determine which variables were significant predictors of instantaneous maximum water temperature.

Although all models are significant, the best model is Model 3, which includes all variables. Model 3 explains the variation in instantaneous water temperatures well (adjusted $R^2 = 0.86$), compared to Model 2 (adjusted $R^2 = 0.49$), and Model 1 (adjusted R^2 of 0.31). Including the source of the water greatly improves the ability of the model to explain differences in instantaneous water temperature.

Appendix 12: Outputs of three multiple linear regression models to determine the relative influence of various independent variables on instantaneous water temperature for ditches studied between July 17th and October 10th, 2011.

	Model 1	Model 2	Model 3
Independent variable	B (std error)	B (std error)	B (std error)
(Constant)	**7.54 (1.43)	**9.45 (1.35)	**8.90 (0.75)
Wetted Width (m)	**0.56 (0.10)	**0.36 (0.10)	0.01 (0.06)
Discharge (m ³ /min)	*-1.44 (0.67)	** -1.72 (0.63)	-0.32 (0.36)
Air (°C)	**0.18 (0.07)	**0.18 (0.057)	**0.19 (0.03)
Recently Maintained	-	** -1.92 (0.49)	-0.23 (0.44)
Previously Maintained	-	1.08 (0.62)	0.18 (0.31)
Lake source	-	-	**5.63 (0.40)
Shallow groundwater interception source	-	-	0.06 (0.37)
Valley wall-based seep source	-	-	**3.36 (0.63)
R Square	0.52	0.33	0.88
Adjusted R Square	0.49	0.31	0.86
Degrees of freedom	F(3,80)	F(5,78)	F(8,75)
F score	**13.40	**16.75	**67.01
Dependent Variable: Instantaneous Water Temperature (°C)			
*p<0.05, **p<0.01			

Model 3 suggests that the main predictors of instantaneous water temperature for the ditches in this study are instantaneous air temperature, whether or not a ditch is from the lake source (includes RM2 and NM3), and whether or not the ditch is the valley wall-based seep ditch (RM1). Discharge and the wetted width of the ditch are not significant predictors of

instantaneous water temperature when the sources of the water are included as independent variables. Maintenance is also not a significant predictor of instantaneous water temperature in Model 3. However, recent maintenance is a significant predictor of water temperature for Model 2, suggesting that recent maintenance and the source of the water are somewhat correlated within the model. Still, this is not a significant problem; the model was tested for problems with multicollinearity and heteroskedasticity and none were found.

This analysis suggests that air temperature and the primary source of the ditch water are significant predictors of instantaneous water temperature, while maintenance is less important. Thus, this multiple linear regression supports other findings that in order to better understand the effects of maintenance, studies should control for the source of the water.