DEPARTMENT OF ENVIRONMENTAL CONSERVATION
NONPOINT SOURCE POLLUTION PROGRAM
ACWA NPS WATER QUALITY GRANT

FY 2006
FINAL REPORT

PROJECT #: ACWA-06-09

Watershed Protection and Recovery for Duck Creek, Juneau, AK

July 2006

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Project Description and Purpose

The purpose of this monitoring effort was to characterize the water quality of Duck Creek in the Mendenhall Watershed (Figure 1), to compare the water quality to Alaska state standards, to evaluate the effects of urbanization in the watershed (e.g. road salt inputs), and to track water quality in Duck Creek above and below the wetlands that are currently being constructed. The stream corridor of Duck Creek has undergone extensive development but has also been the subject of broad restoration efforts, and it has been suffering from low flow levels, including complete drying out at lower sites, (likely due to uplift and urbanization) and declines in salmon usage. A suite of water quality parameters was collected at three representative sites on Duck Creek every two weeks from August 2005-June 2006. The data provide baseline water quality information as well as information that can be used to assess pre-established and ongoing restoration efforts on Duck Creek.

The specific goals of this project included:

- To document existing water quality conditions in Duck Creek and make comparisons to historic data
- To use water quality data for Duck Creek to differentiate natural versus anthropogenic inputs
- To assess the impacts of road salt on roads in the Mendenhall Valley on the water quality to Duck Creek
- To use water quality data for Duck Creek to aid in assessments of various restoration efforts both finished and underway on Duck Creek

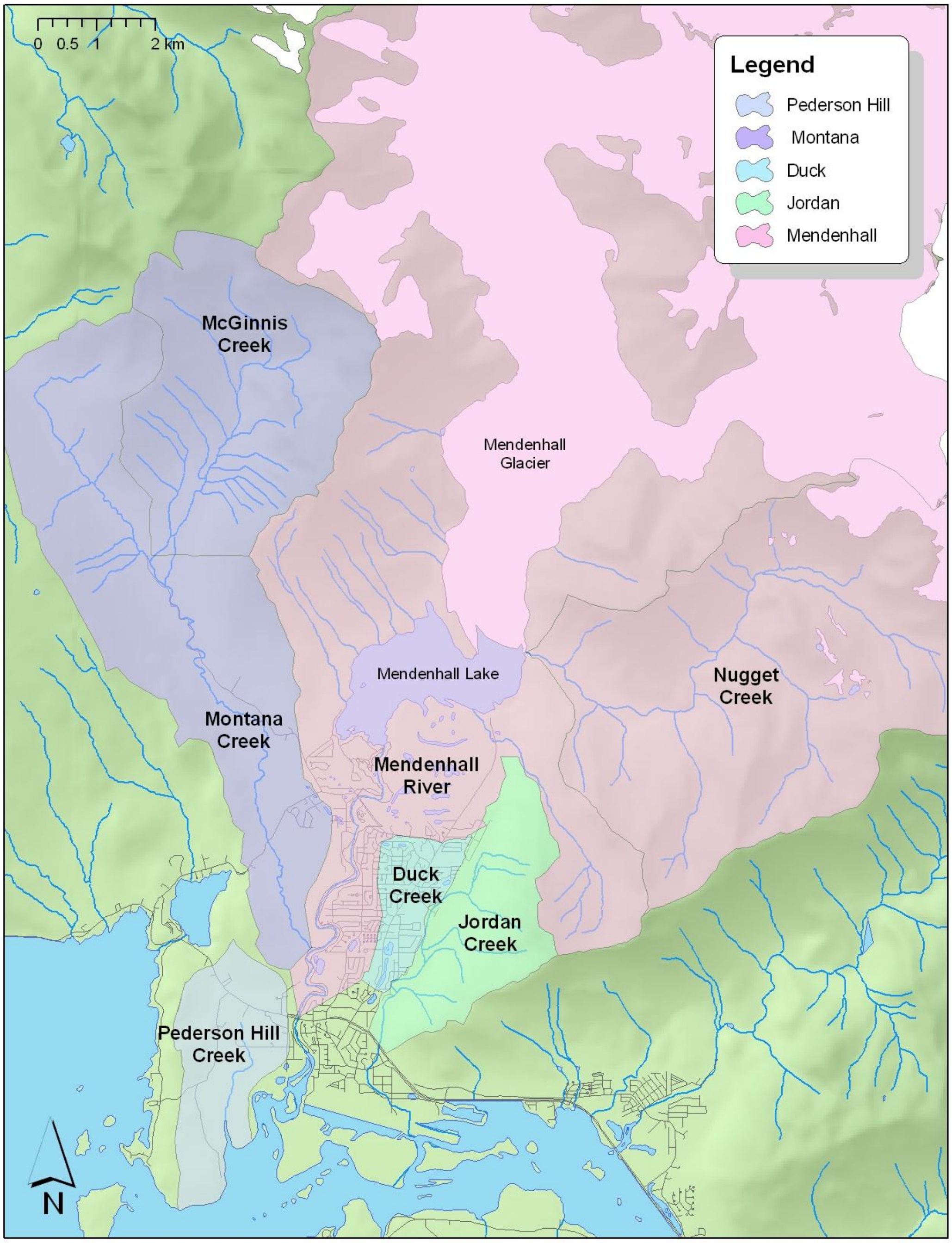

Figure 1: *Location of Duck Creek watershed and other watersheds in the Mendenhall Valley, Juneau.*

Research Design

The locations of the Duck Creek water quality monitoring sites were kept consistent with previous years' efforts, with three sites along the stream (Table 1, Figure 2). The Duck

Creek watershed is 1.3 square miles (above the former USGS gage site at Nancy Street) and includes areas of heavy suburban development as well as 2 acres of created wetland. Sample sites were chosen to identify source areas for aquatic pollution within the watershed and to monitor changes resulting from restoration efforts.

Table 1. *Stream sample locations along Duck Creek. Latitude and longitude coordinates were measured using GPS in April, 2006 and are reported in the North American Datum 1983.*

Site Code	Site Description	Latitude	Longitude
DC-A	Duck C @ Taku Blvd	58.39571273004	-134.56725198001
DC-B	Duck C @ Nancy Street bridge	58.37153233035	-134.58414436761
DC-B	Duck C @ Egan/Mendenhall Loop	58.36953035005	-134.58714014001

The sample sites on Duck Creek were selected to evaluate differently impacted areas of the watershed as well as ongoing remediation projects. DC-A (formerly called "DC3") is located farthest upstream on a severely impacted stretch of Duck Creek that has been subject to very limited attempts at remediation and is heavily impacted by groundwater intrusion and iron floc. DC-A will reflect conditions common to the impaired portions of Duck Creek. DC-B (formerly called "DC2") is located at the outflow of one of three fill ponds remaining after excavation in the 1960s; the Nancy Street Pond. Nancy Street Pond is downstream from the wetland created in 1998 by the Church of the Nazarene, and immediately downstream from the site currently undergoing remediation (filling of gravel pits, channel construction, and bank re-vegetation). DC-B will partially reflect changes in water quality resulting from the created wetland but these effects will be lessened due to groundwater intrusion at several locations on the fill pond. DC-C (formerly called "DC1") is located on a stretch of the stream that was subject to relocation during the construction of Egan Blvd and Mendenhall Loop Rd. Recent restoration efforts (2000) along the stretch of Duck Creek represented by DC-C include sediment removal (lowering the stream bottom) and streambed lining in an effort to minimize water loss during periods of low flow. However, water loss still occurs at this site as evidenced by the lack of data for this site during the summer months.

Stream sampling was conducted from July 2005 to June 2006. Samples were collected in the morning (between 8am and 1 pm) in the same sequence each time, in order to minimize compounding diel variations in water quality parameters. No operating stream gauge was available on Duck Creek, however streamflow was measured continuously on Jordan Creek by the USGS until January, 2006; and we manually gaged the discharge on both Duck Creek (at DC-B) and at a site on Jordan Creek on our water quality sampling dates beginning in January, 2006. Water quality data collected for Duck Creek during the project is shown in Appendix A of this report.

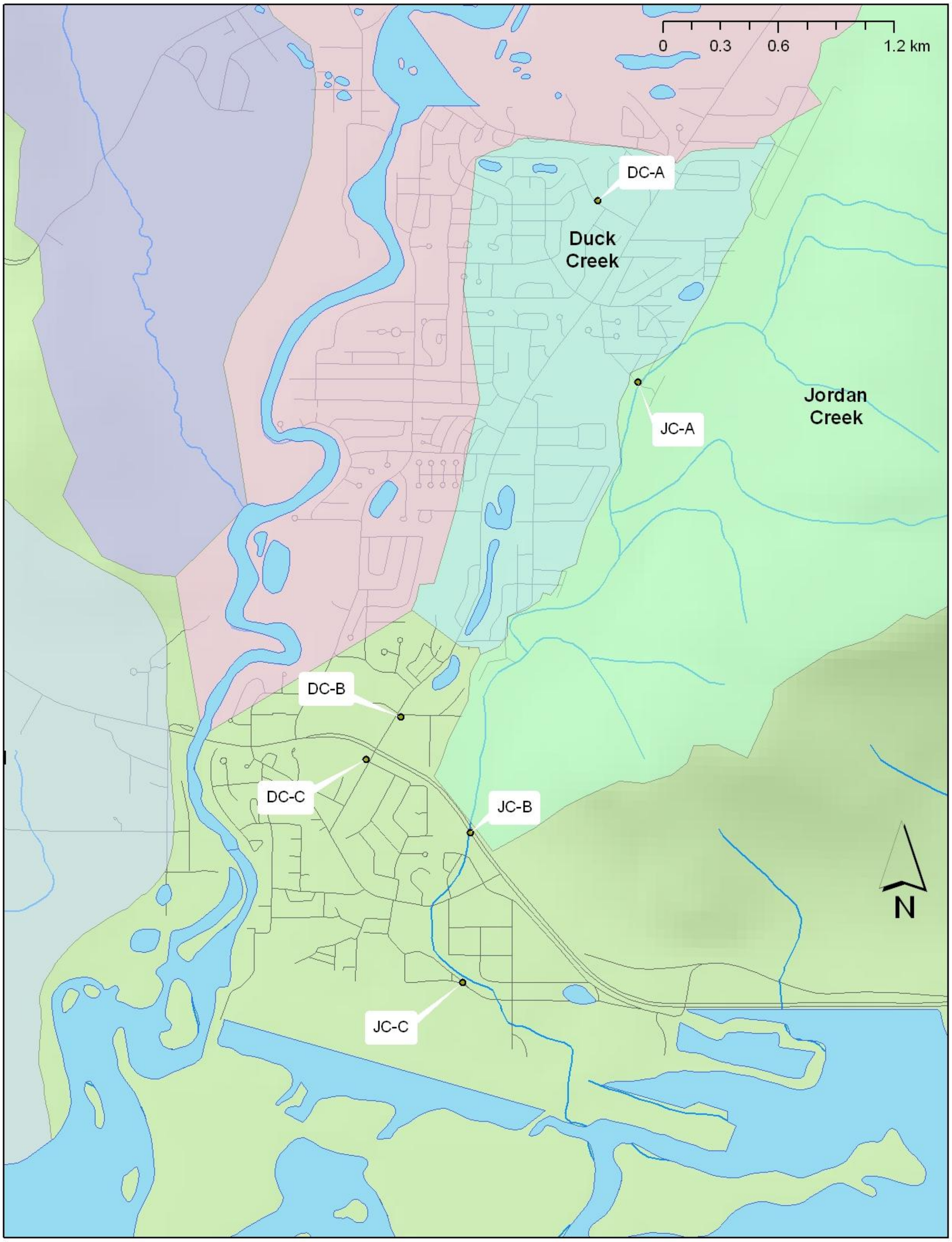

Figure 2. *Location of the Duck Creek study sites, DC-A, DC-B, and DC-C. (Duck Creek is not shown as a continuous stream channel on the GIS database.) Also shown are the study sites on the companion study on Jordan Creek (JC-A,B,C).*

Water quality parameters at the three sample sites were measured bi-monthly throughout the project period (except for one bi-monthly sample missed on 12/30/2005). Water temperature, conductivity, and pH were measured in the field using a YSI multi-probe unit. Dissolved oxygen was measured using a dedicated D.O. meter. Both meters were calibrated in the laboratory at the beginning of each sampling event. All in situ parameters were measured and recorded 3 times; averages of the triplicate values are presented in this report. Grab samples were also collected and returned to the UAS lab for analysis of turbidity, and total suspended sediment (TSS). Turbidity measurements for each event were bracketed by standard checks and were made within 6 hours of sample collection. TSS samples were obtained by weighing the mass of particulates retained on a glass microfiber filter following a vacuum driven filtration of at least 300 mL of sample. TSS filtrations were made within 48 hours of sample collection. Duplicate analyses were performed on 10% of samples to check for precision. Additional waters samples were taken in separate bottles in the field, filtered in the lab within 6 hours through 0.45 μm membrane filter into 125 mL polyethylene bottles, and frozen until analysis by Ion Chromatograph for cations and anions, as described below:

Analysis by Ion Chromatograph:

a) Anions. A 25 μL aliquot of the neutral sample was analyzed for chloride, nitrate, nitrite, sulfate and phosphate concentrations on a Dionex DX500 Ion Chromatography system with ion suppression and conductivity detection. The analytes were separated on an IonPac AS12 4 mm x 250 mm column preceded by an IonPac AG12 guard column using sodium carbonate (Na2CO3)/sodium hydrogen carbonate (NaHCO3) eluent at 1.5 mL min-1. Peaks were identified and quantified by comparison of retention times and peak areas with standards.

b) Cations. A 25 μL aliquot of the neutral sample was analyzed for sodium, potassium, ammonium magnesium and calcium concentrations on a Dionex DX500 Ion Chromatography system with ion suppression and conductivity detection. The analytes were separated on an IonPac CS12 4 mm x 250 mm column preceded by an IonPac AG12 guard column using sulfuric acid eluent (30 mM) at 1 mL min-1. Peaks were identified and quantified by comparison of retention times and peak areas with standards.

Water Quantity and Quality on Duck Creek

Water Quantity

Although continuous discharge data were unavailable for Duck Creek, examination of historic data at the site and on neighboring Jordan Creek, as well as field observations, indicates that Duck Creek is generally a flashy stream that responds to and recovers quickly from local precipitation events. There is little seasonal variation to the stream. In contrast to the Mendenhall River, whose flow is predictably maximal during summer glacial melting, Duck Creek discharge is a reflection of precipitation in the area (Figure

2). Therefore, flows are generally lowest and least flashy during the spring and early summer, and highest and flashiest during the fall and early winter.

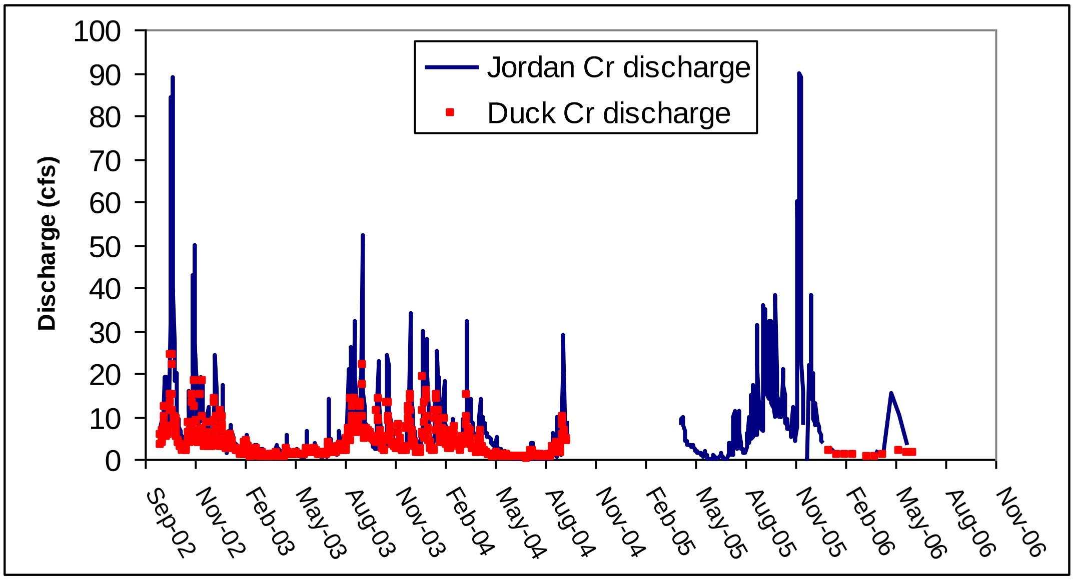

Figure 2. *Discharge on Duck and Jordan Creeks. Data based on USGS stream gage data, until January, 2006. (Data from September, 2005 on are provisional). Measurements since January 2006 are based on manually gaging using a pygmy flow meter.*

Water quantity was often higher at the upstream sites; DC-B and DC-A clearly had significant groundwater contributions that maintained consistent baseflows in the channel even during cold spells in the winter when air temperatures fell to as low as -15ºC (in March, 2006) (Figures 3a-c). DC-C site had no surface flow during portions of the late spring and summer (no flow on sampling dates between late February and late April, 2006) (Figure 3a). Loss of flow is an obvious major concern for salmonids attempting to utilize Duck Creek as habitat for rearing, spawning, and egg incubation. Discharge measurement made between January and June, 2006 never exceeded a meager 2.1 cfs (at site DC-2).

Figure 3a. *Site DC-C, showing no flow, on March 15, 2006 when air temperatures reached -15ºC in Juneau. No flow was observed at the site for 2 months, from late February to late April, 2006. During this no-flow period, the channel was either completely dry or contained small, stagnant ponds.*

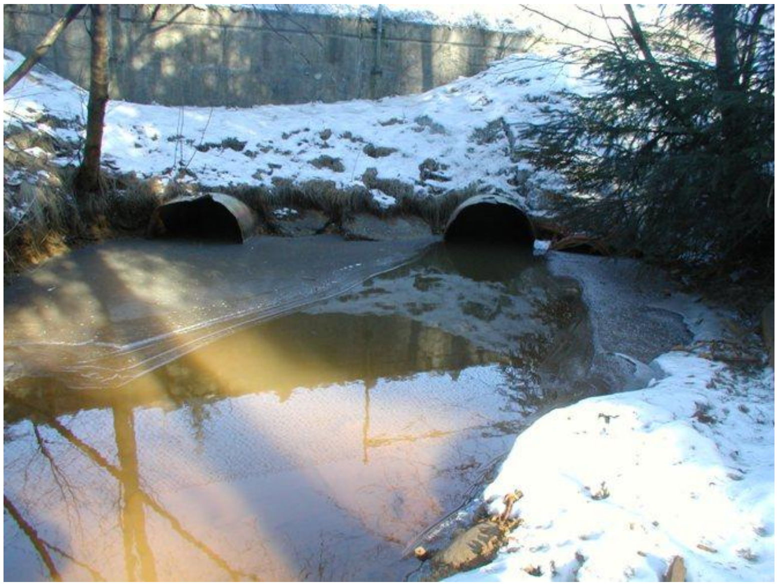

Figure 3b. *Site DC-B, showing unfrozen water, indicating strong groundwater inputs while the air temperature was as low as -15ºC in Juneau on 3/15/05. Water was present at the site on all sampling events.*

Figure 3c. *Site DC-A, showing largely unfrozen water (with a thin cover of ice), indicating strong groundwater inputs while the air temperature was as low as -15ºC in Juneau on 3/15/05. Water was present at the site on all sampling events. Also visible is the orange staining of the iron floc, which is particularly abundant at this upper site.*

Water Quality

The Duck Creek watershed has undergone extensive development. While small portions of the original upland forest and muskeg still remain, more than 90% of the watershed is developed with various structures and impermeable surfaces. Duck Creek is primarily groundwater fed and subject to iron floc formation originating from groundwater intrusion. The stream channel has been redirected multiple times. Four large ponds resulting from excavation for fill material in the 1960s and located upstream from sampling site DC-C have been and continue to be the focus of restoration efforts. One of these fill ponds (Church of the Nazarene) was converted into a wetland in 1998 and a second (Nancy Street Pond) was undergoing wetland conversion during the spring and summer of 2006 (during this project). Sampling site DC-B is located at the outlet of the Nancy Street Pond. Mean values for field parameters, turbidity, and TSS for the study period are presented in Table 2.

Table 2*: Mean values (standard deviation in parentheses) for water quality parameters during the period August, 2005 to June, 2006 at the 3 sites on Duck Creek.*

site	DO (mg/L)	Cond (μS/cm)	pH	Turb (NTU)	TSS (mg/L)	Temp (ºC)
DC-A	5.4 (2.4)	0.273 (0.105)	6.7 (0.2)	23.2 (19.7)	53.7 (176.0)	5.7 (2.4)
DC-C	8.3 (3.3)	0.196 (0.036)	6.9 (0.3)	13.9 (8.9)	6.8 (5.9)	7.7 (1.9)
DC-B	6.4 (2.0)	0.184 (0.045)	6.4 (0.2)	79.2 (150.5)	43.3 (88.2)	7.3 (4.8)

In general, water quality increased moving in a downstream direction (toward site DC-C), although the lower most site (DC-C), with the best water quality, experienced problems with in-stream flow.

Dissolved oxygen, conductivity, and pH

Dissolved oxygen increased from upstream to downstream (Table 2, Figure 4). At sites DC-B and DC-A, dissolved oxygen levels routinely fell below the State of Alaska water quality limit of 7.0 mg/L for the growth and propagation of fish, shellfish, and other aquatic life, and even below the water quality limit for waters not used by anadromous or resident fishes (5.0 mg/L) (DEC, 2006).

Dissolved oxygen (D.O.) has been previously identified as a parameter of concern on Duck Creek. Problems with D.O. levels meeting water quality standards exist at all three sites (Figure 4). Anaerobic groundwater from SE Alaska is typically high in dissolved ferrous iron and sulfide ion. These two species are unstable under surface conditions and quickly oxidize to ferric iron and sulfate ion, consuming significant amounts of oxygen in the process. Supporting this conclusion are the significantly higher conductivities measured at DC-A compared to the two other sites (Figure 5). Conductivity quantifies dissolved ions in the water column. The presence of the charged species, Fe^{2+} (ferrous iron), Fe^{3+} (ferric iron), S^{2-} (sulfide ion) and SO_4^{2-} (sulfate ion) is consistent with the higher conductivities measured at DC-A. Furthermore, increased acidity is a side-product of oxidation and will further increase conductivity. Time-dependent D.O. and conductivity are presented in Figures 3 and 4 for comparison.

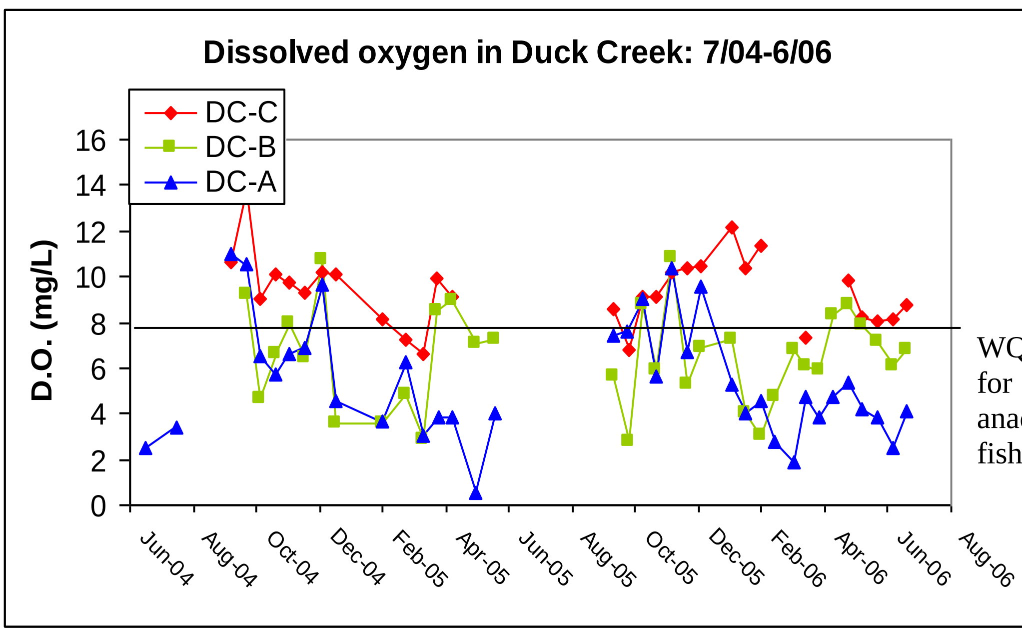

Figure 4. *Dissolved oxygen levels at the 3 sampling sites on Duck Creek. Graph includes data from year (2004-2005) prior to the current study year (2005-2006).*

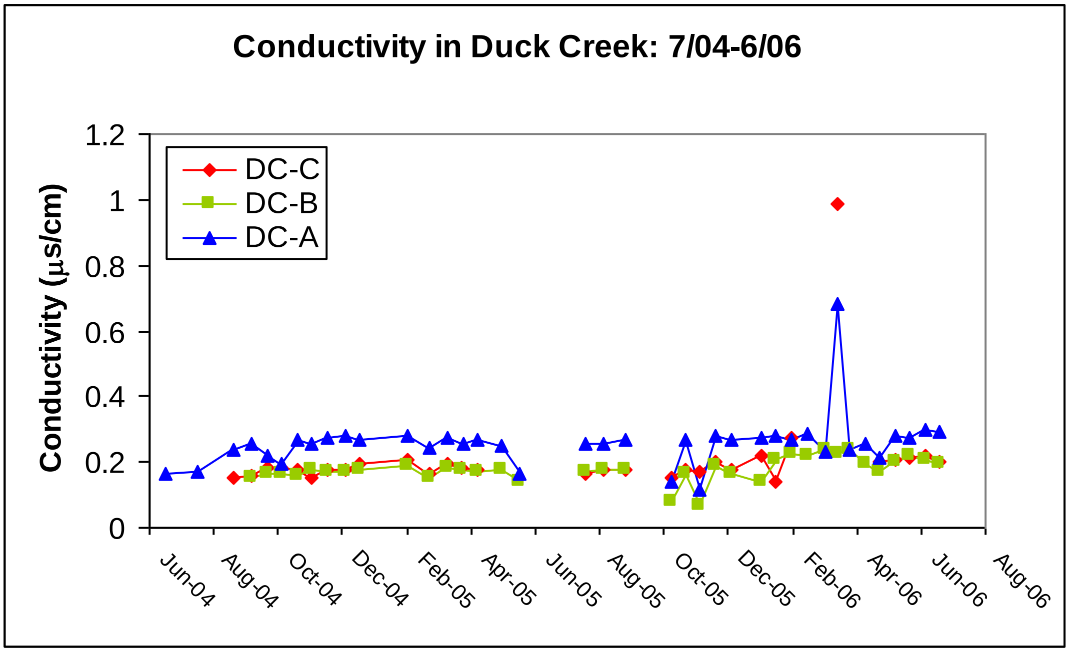

Figure 5. *Conductivity values at the 3 sampling sties on Duck Creek. Graph includes data from year (2004-2005) prior to the current study year (2005-2006). The high values at DC-C and DC-A occur with high chloride concentrations and may be indicative of road salt runoff.*

Values for pH showed significant scatter, ranging from 6.1 to 7.5 during the study period, which is generally consistent with values from the previous year (Figure 6). Lower pH values are likely caused by iron-rich groundwater intrusion, which becomes the dominant source of water during cold and dry climatic periods. pH values at DC-B routinely fell below the state water quality standard of 6.5 for the growth and propagation of fish, shellfish, and other aquatic life. At DC-A, pH values sometimes fell below the standard. The oxidation of reduced species prevalent in anaerobic groundwater produces significant acidity as a side-product (see D.O. discussion above for further details).

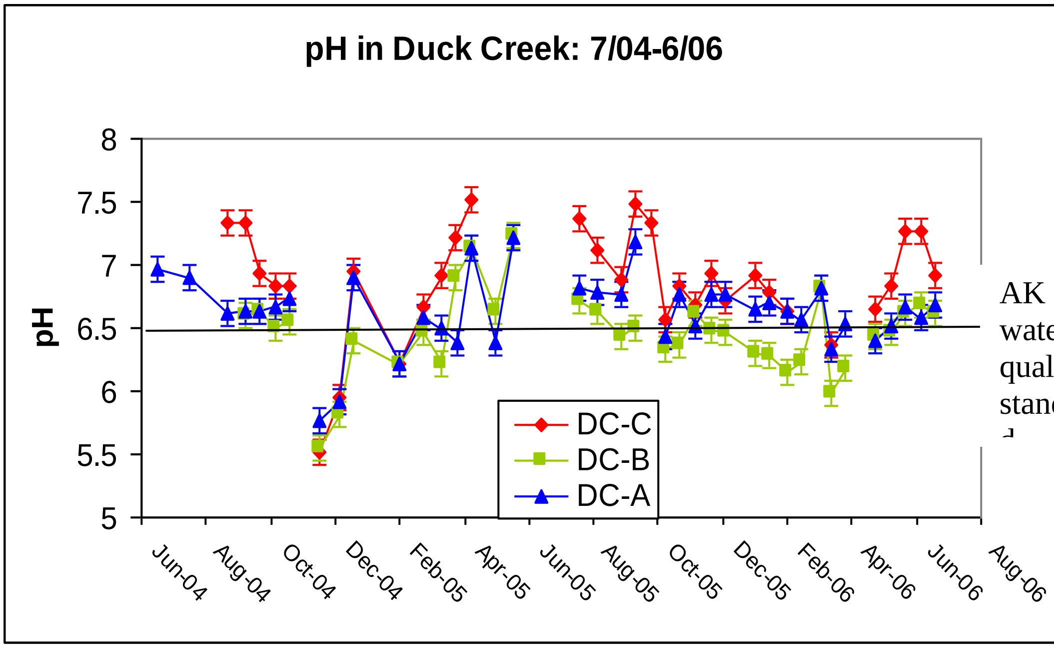

Figure 6. pH values at the 3 sampling sties on Duck Creek. Graph includes data from year (2004-2005) prior to the current study year (2005-2006). DC-C is least groundwater influenced and has the highest pH values.

It is important to note that stream pH variability on a diel scale can be substantial, with levels lowest during the nighttime; as a result, it is recommended that pH and D.O. levels are measured in the future both nocturnally and diurnally to better characterize the levels present in the stream during various parts of the day. Data from the mornings-only samplings (presented here) may not be accurate representation of daily average values. After the Nancy Street wetland area is constructed, the floodplain revegetated, and the channel constricted to a shallower and flowing conduit (rather than largely stagnant ponds) for the streamwater, it is likely that pH and dissolved oxygen levels at DC-B will rise. In the meantime, water quality at DC-B is degraded substantially.

Turbidity and Total Suspended Solids (TSS)

The state of Alaska water quality standards for turbidity dictate that to protect fish and wildlife, turbidity may not exceed 25 nephelometric turbidity units (NTUs) above natural background conditions. Turbidity is not a direct measurement of solids, but is related to the amount of suspended material in the water column because it is a measure of light attenuation due to absorption and reflection by solids. Turbidity can be expected to closely parallel total suspended solids (TSS). Depending on sampling date and location, Duck Creek water clarity varies significantly. Significant variation in turbidity and TSS values was observed within a single sampling location as well and this is most obvious at the site representing the unimproved section of Duck Creek, DC-A. Turbidity and TSS measurements at all three sites indicate persistent water quality problems on Duck Creek. Mean turbidity and TSS values were lowest at DC-C (Table 2), but were considerably high and in violation of the state water quality standards at DC-B and DC-A (Figure 7).

Mean turbidity values at DC-B are skewed due to the remarkably high value of 735 NTU found on 4/7/06, when immediately upstream, loose sediments were being dumped directly into Duck Creek as part of the wetlands construction project (Figures 9a and 9b). On this date, the TSS value jumped to 377 mg/L (Figure 8). These conditions were clearly violations of state standards; however, these conditions are expected to be temporary as long as construction of the wetlands continues upstream. The high TSS value collected on 6/16/06 at DC-A is likely an artifact of sampling error; the stream at DC-A did not appear particularly turbid on the date. Loose iron floc is highly abundant at the site, and the slightest physical disturbance of the streambed by the sampler can introduce large amount of floc into the sample bottle (Figure 10).

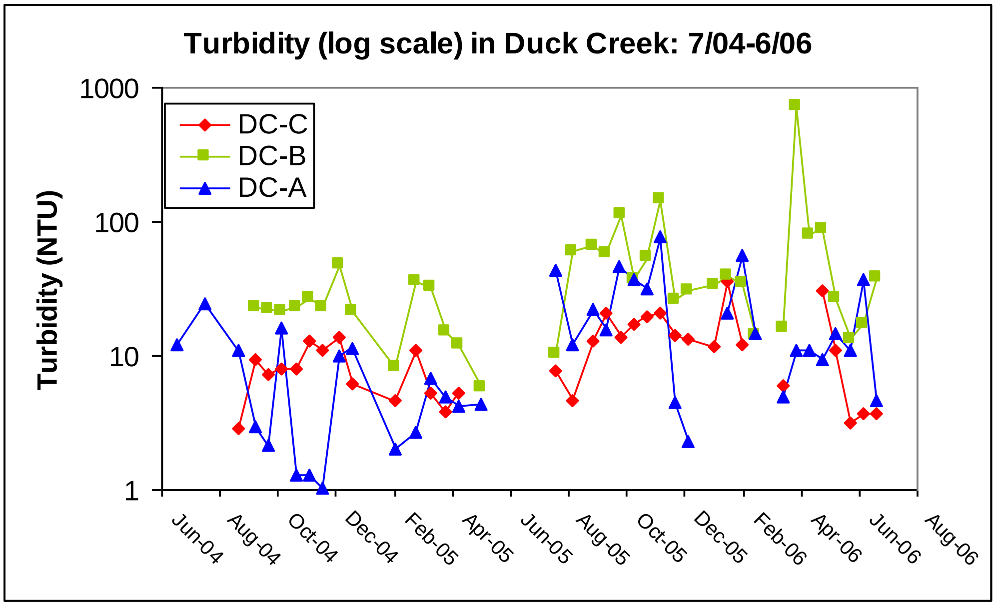

Figure 7. Turbidity (NTU) at the three Duck Creek sites. Note log scale.

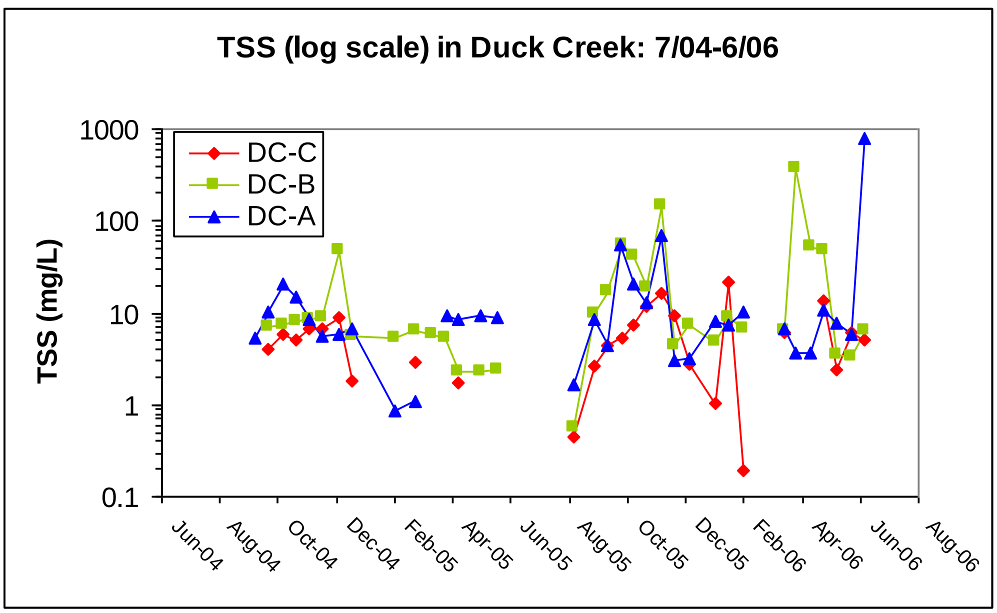

Figure 8. Total suspended solids (TSS, in mg/L) at the 3 Duck Creek sites. Note log scale.

Figure 9a. *Photo taken upstream of the Nancy Street bridge and site DC-B on 4/7/06, when sediment was being actively dumped into Duck Creek as part of the wetlands construction project. The activity greatly elevated turbidity and TSS levels downstream.*

Figure 9b. *Photo of sampling in situ water quality parameters in Duck Creek at site DC-B on 4/7/05 when active construction of the Nancy Street wetlands was underway immediately upstream of the site. Notice the extremely turbid coloration of the water.*

Figure 10. *Sampling at site DC-A in April, 2006. The thick coating of iron floc on the streambed is easily disturbed by any activity (including sampling) in the stream. Caution is taken to avoid introducing re-suspended floc into the turbidity and TSS sample bottles, but this is not always possible.*

Water temperature

Water temperature in Duck Creek shows strong seasonal variation, despite the flashy (event-controlled) discharge patterns on the stream. Figure 11 shows the temperature at the 3 Duck Creek sites compared to Juneau air temperature. Comparison of water temperature at the three locations along Duck Creek indicates that upstream site DC-A has generally lower summertime and warmer wintertime temperatures than does DC-C (Table 2),which is further indication of the groundwater upwelling at the sites because groundwater maintains a more stable temperature than does surface water. While residential dwellings surround site DC-A, the stream cover has remained intact and is less affected by higher summer temperatures and infiltration of direct sunlight. Higher temperatures at DC-B and DC-C are consistent with the more urbanized surroundings at these sites and lower proportional baseflow input. On some dates, temperatures observed at DC-B and DC-C exceed the 13^{o}C limit for egg and fry incubation and spawning, and the 15^{o}C limit for migration routes and rearing areas (DEC, 2006).

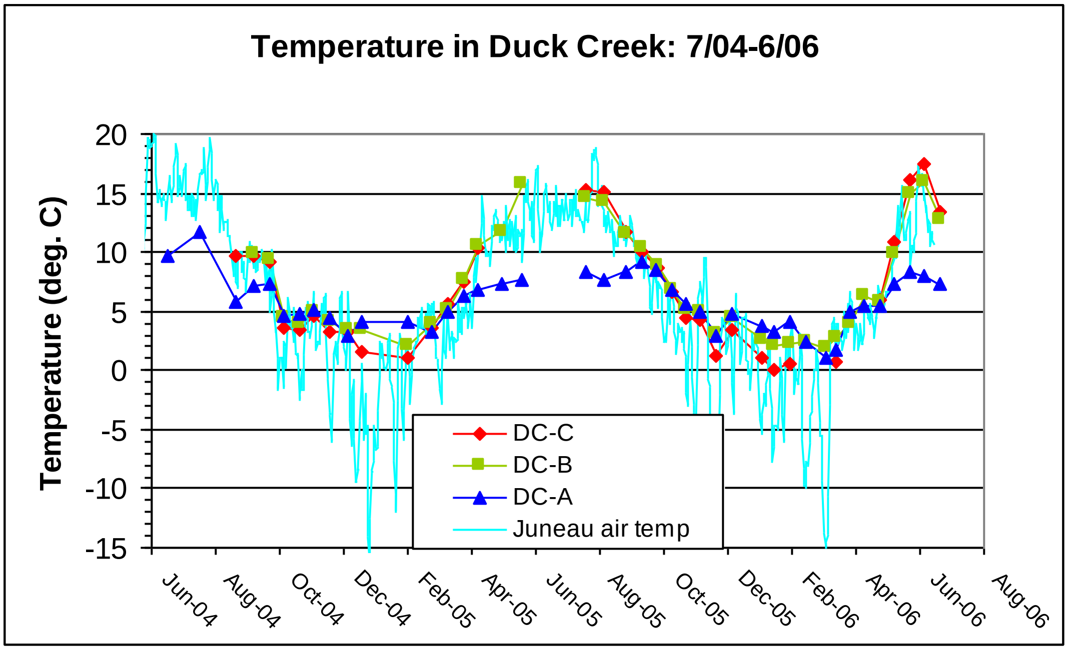

Figure 11*: Water temperature at the three sampling locations on Duck Creek, with Juneau airport air temperatures overlain to show the close relationship between air and water temperatures. Data shown include data collected in FY 05 as well as FY 04.*

Anions and cations

The extent to which the application of salts on roads in the Mendenhall valley may be affecting water quality was evaluated by examination of dissolved ion data (presented to Appendix B). Road salts used in the City and Borough of Juneau include NaCl, and $MgCl_2$; therefore Cl, Na, and Mg concentrations should be good indicators of the salting. During March, 2006, when air temperatures and water levels were extremely low (or stagnant in isolated pools, in the case of DC-C), some high levels of salt were found in the water samples (Figure 12). While Cl levels ranged between 5-12 mg/L during the fall and early winter, the concentration increased to 24.0 mg/L on 1/27/06; to 34.6 mg/L on 2/11/06; and on 3/25/06 shot up to 200 mg/L. The high value found in the 3/25/06 sample is currently being returned for laboratory analysis at a diluted level; its readback on the Ion Chromatograph was at the end of the calibration range of the instrument. The exact value of this concentration will be reported to the DEC when they become obtainable; in the meantime, the 200 mg/L should be treated as an approximate concentration level. The sample was clearly not contaminated because in situ conductivity measurements at this site also indicate a spike in value on this date (Figure 5). It is important to note the Duck Creek was not flowing at the site on this date; the sample was obtained from one of a series of stagnant, ice-covered small pools in the channel that likely formed as a result of recent rain. It appeared that the rain event was not sufficient to create in-stream flow at DC-A, but was sizable enough to wash out road salts into the channel and create a few small pools of water rich in road salt ions. The US Environmental Protection Agency sets the secondary maximum contamination level for chloride at 250 mg/L, the chronic freshwater criterion at 230 mg/L, and the acute freshwater criterion is 860 mg/L. Therefore, although Cl levels rose sharply, they did not exceed water quality standards, although the maximum concentration found (an approximate value) did approach the chronic freshwater standard.

Further evidence that Cl levels in the stream rose due to road salt is seen in the sodium data for DC-C (Figure 13). Concentrations of Na were between 3.8 and 5.5 in the summer and fall, but rose to 18 mg/L by 2/11/05 and jumped to 117 mg/L on 3/25/06. Mg concentrations on 3/25/05 were also approximately 4 times their fall and winter concentrations (Appendix B). There are no water quality standards for Na and Mg concentrations.

Other anions and cations measured indicated that F concentrations in Duck Creek are <0.2 mg/L; nitrate concentrations are <0.4 mg/L; sulfate concentrations were consistently between 2.8 and 5.7 mg/L; ammonium concentrations were <0.2 mg/L; potassium was consistently between 2.8-3.4 mg/L; magnesium levels were between 2.0-3.0 mg/L; and calcium was between 16.1-24.4 mg/L.

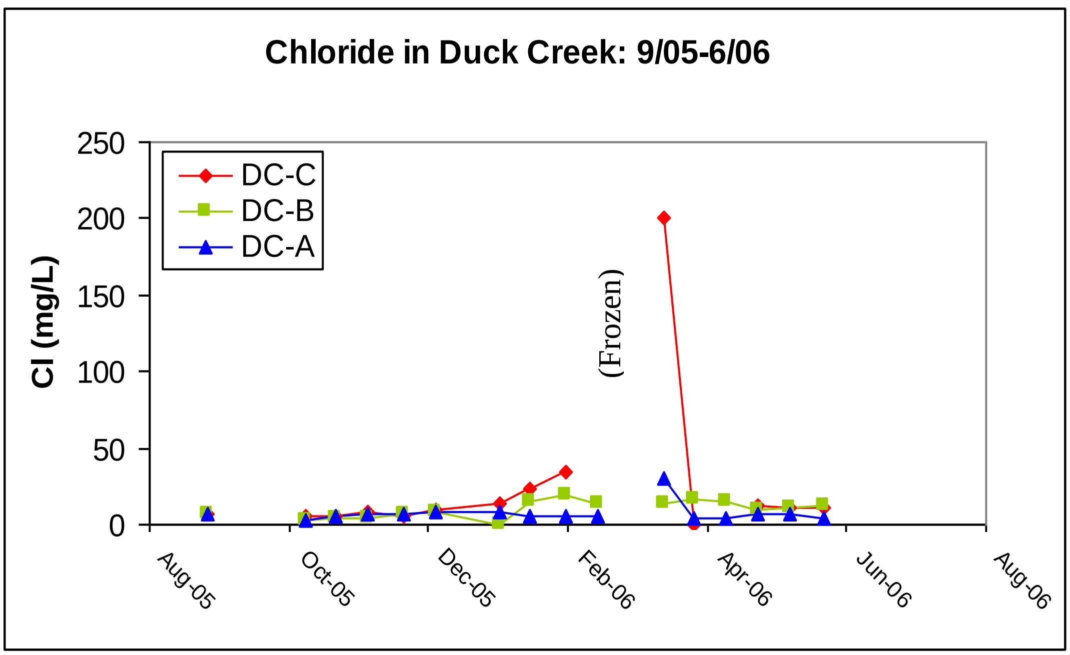

Figure 12. *Cl concentrations at the 3 Duck Creek sites. Notice the high concentration n at DC-C on March 25, 2005, which followed a dry spell in the creek and record low temperatures in Juneau that likely coincided with increased use of road salt in the valley. DC-C is the lowermost site of the 3, downstream of major roads and the Egan Drive-Mendenhall Loop Road Intersection. Na concentration patterns are nearly identical to Cl patterns; indicate a strong likelihood of NaCl salt inputs into the stream.*

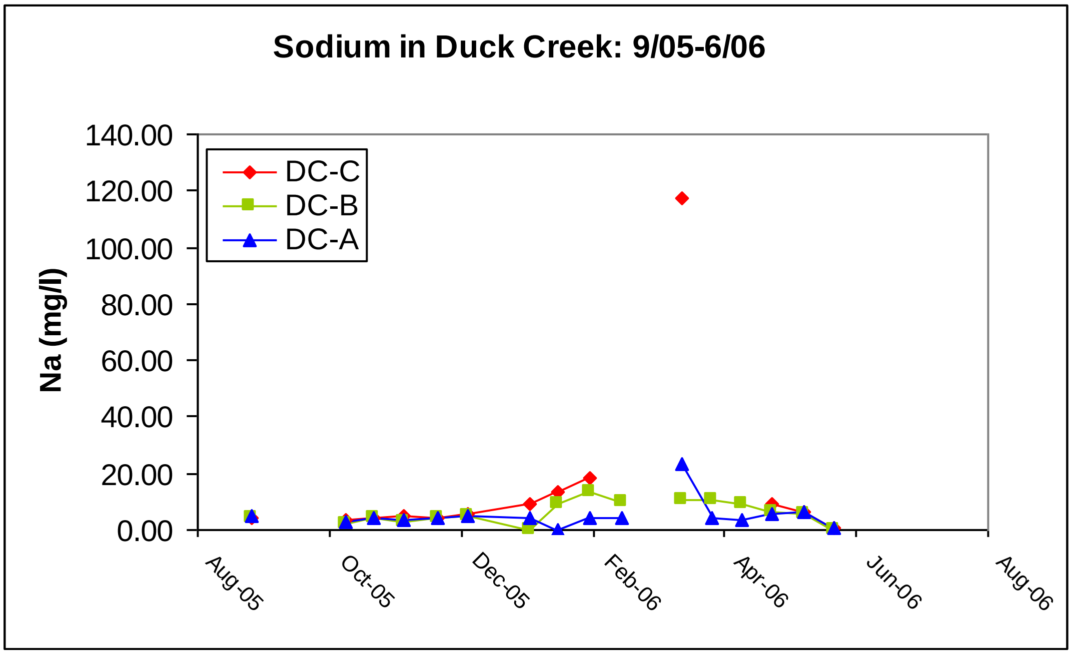

Figure 13. *Na concentrations at the 3 Duck Creek sites. Notice the high concentration at DC-C on March 25, 2005, which followed a dry spell in the creek and record low temperatures in Juneau that likely coincided with increased use of road salt in the valley. DC-C is the lowermost site of the 3, downstream of major roads and the Egan Drive-Mendenhall Loop Road Intersection. Na concentration patterns are nearly identical to Cl patterns; indicate a strong likelihood of NaCl salt inputs into the stream.*

Field audit by DEC

On March 7, 2006, Jim Gendron of the ADEC conducted a field audit of this project and found that with three exceptions, the sampling and analysis protocols for this project are being performed according to the quality assurance procedures and objectives that are listed in the QAPP (Gendron, 2006). The first exception was that site DC-A was in different location than shown on the site location map in the QAPP, and the audit requested that we submit a new map of the study sites with an explanation for why the site location was moved. Figure 2 in this report shows the correct location of site DC-A. To the best of our knowledge, the original map in the QAPP had the site location erroneously labeled; the site has not in fact been moved. The second exception cited in the field audit is that the new dissolved oxygen meter be intercalibrated using the Winkler titration method; this has been done and results are satisfactory. Finally, the audit recommended that we make note of the presence of any oil sheen in the streams, and as a result, we began to note this. The notation is shown in Appendix A.

Summary and conclusions

Duck Creek continues to suffer from low in-stream flow, except for during large precipitation events. Bimonthly discharge measurements between January and June, 2006, did not exceed 2.1 cfs. Dissolved oxygen levels continue to regularly fall below state standards for aquatic life. On some dates, temperatures observed at DC-B and DC-C exceed the 13^{o}C limit for egg and fry incubation and spawning, and the 15^{o}C limit for migration routes and rearing areas. pH values were centered near and at times below (especially at site DC-B) the state water quality standard of 6.5 for aquatic life, at least during the morning sampling events conducted for this study (variations in pH are expected based on time of day and amount of sunlight). Large amounts of iron floc were noted at all sites, with particularly high amounts at DC-A, where the streambed is thickly coated in floc that easily resuspend if disturbed. Construction of wetland habitat and channelization of the stream above Nancy Street (DC-B) is expected to improve fish and wildlife habitat, reduce turbidity and iron levels, and raise pH and D.O. in the future; however, short-term impacts of the construction included major surges in turbidity and TSS immediately downstream of the construction area. Salt application to roads in the Mendenhall Valley appears to have detectable impacts on Duck Creek, particularly at the lowermost site, where zero to low flows exacerbate the problem with low dilution potential. While the effects of salting included sharp rises in Na, Mg, and Cl levels in the stream, the concentrations of Cl (max. 200 mg/L) did not violate the EPA secondary drinking water standard (250 mg/L) nor the acute freshwater criterion (860 mg/L) but approached the chronic freshwater criterion (230 mg/L).

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Appendix A – Water quality data collected on Duck Creek during the period, August 2005 – July, 2006. Field parameters, TSS, turbidity, discharge, and oil sheen presence (Oil sheen notation began 4/7/06).

[a] Conductivity is temperature corrected and reported in mS/cm. n/a: data not available. bd: below detection limits.

Date	Time	Site	D.O. (% sat.)	D.O. (mg/L)	Temp. (°C)	Cond[a] (mS/cm)	pH	Turb (NTU)	TSS (mg/l)	Discharge (cfs)	Oil sheen?
8/2/2005	11:45	DC-A	(N/A)	(N/A)	8.3	0.254	6.8	43.3	(N/A)		
8/20/2005	12:50	DC-A	(N/A)	(N/A)	7.7	0.254	6.8	12.2	1.7		
9/10/2005	9:05	DC-A	(N/A)	(N/A)	8.3	0.266	6.8	22.1	8.3		
9/24/2005		DC-A	(N/A)	7.4	9.1	(N/A)	7.2	15.8	4.5		
10/7/2005		DC-A	(N/A)	7.6	8.5	(N/A)	(N/A)	46.0	55.2		
10/22/2005	9:40	DC-A	74.4	9.1	6.9	0.140	6.4	37.0	21.1		
11/4/2005	12:05	DC-A	44.4	5.6	5.6	0.266	6.8	31.6	13.1		
11/18/2005	12:25	DC-A	80.9	10.4	4.9	0.114	6.5	77.2	69.2		
12/3/2005	10:00	DC-A	50.5	6.7	3.0	0.281	6.8	4.5	3.1		
12/17/2005	11:15	DC-A	77.0	9.5	4.7	0.270	6.8	2.3	3.2		
1/14/2006	12:35	DC-A	39.6	5.3	3.7	0.275	6.7	41.7	8.2		
1/27/2006	13:15	DC-A	30.3	4.0	3.2	0.281	6.7	21.1	7.4		
2/11/2006	11:20	DC-A	34.8	4.6	4.1	0.270	6.6	55.4	10.2		
2/25/2006	11:20	DC-A	20.6	2.8	2.4	0.287	6.6	14.9	3.3		
3/15/2006	9:40	DC-A	11.9	1.9	1.1	0.234	6.8	(N/A)	N/A		
3/25/2006	10:10	DC-A	47.2	4.7	1.8	0.685	6.3	5.0	6.6		
4/7/06	10:45	DC-A	30.3	3.8	5.0	0.239	6.5	11.0	3.6		yes
4/21/2006	10:15	DC-A	37.0	4.7	5.4	0.258	(N/A)	11.1	3.7		yes
5/5/2006	10:30	DC-A	42.4	5.4	5.4	0.215	6.4	9.3	11.0		yes
5/19/2006	11:40	DC-A	34.6	4.2	7.4	0.280	6.5	14.5	7.8		yes
6/2/2006	12:26	DC-A	32.4	3.8	8.3	0.275	6.7	10.9	5.7		yes
6/16/2006	11:30	DC-A	21.8	2.5	8.0	0.300	6.6	37.4	777		yes
6/30/2006	11:40	DC-A	25.9	4.1	7.3	0.293	6.7	4.6	N/A		yes
8/2/2005	11:20	DC-B			14.6	0.169	6.7	10.4			
8/20/2005	12:35	DC-B			14.3	0.175	6.6	60.4	0.6		
9/10/2005	8:50	DC-B			11.5	0.176	6.4	66.2	9.7		
9/24/2005		DC-B		5.7	10.3		6.5	58.7	16.9		
10/9/2005		DC-B		2.7	8.8			112.0	54.9		
10/22/2005	9:20	DC-B	72.5	8.8	6.9	0.079	6.3	37.2	42.6		
11/4/2005	11:45	DC-B	45.9	5.9	5.1	0.167	6.4	54.3	18.5		
11/18/2005	12:00	DC-B	84.3	10.8	4.9	0.065	6.6	147.5	150		
12/3/2005	9:40	DC-B	39.7	5.3	3.1	0.186	6.5	26.5	4.4		
12/17/2005	10:55	DC-B	53.8	6.9	4.4	0.165	6.5	31.1	7.4		
1/14/2006	11:20	DC-B	54.0	7.3	2.6	0.142	6.3	33.6	4.9	1.70	
1/27/2006	11:35	DC-B	28.8	4.0	2.0	0.205	6.3	39.4	8.7	0.87	
2/11/2006	10:20	DC-B	22.0	3.0	2.3	0.226	6.1	35.0	6.7	1.08	
2/25/2006	9:35	DC-B	27.0	4.8	2.4	0.220	6.2	14.2	2.6	0.72	
3/15/2006	9:50	DC-B	48.9	6.8	1.9	0.235	6.8	N/A	N/A		
3/25/2006	9:55	DC-B	44.9	6.1	2.7	0.223	6.0	16.4	6.4	0.41	
4/7/06	9:20	DC-B	44.2	5.9	4.0	0.237	6.2	735.0	377	0.40	yes

4/21/2006	9:55	DC-B	67.2	8.3	6.3	0.197	N/A	80.3	52.7	0.72	No
5/5/2006	10:00	DC-B	70.3	8.8	5.9	0.169	6.4	88.5	48.9		No
5/19/2006	10:55	DC-B	69.7	7.9	9.9	0.200	6.5	27.1	3.5	1.82	No
6/2/2006	11:17	DC-B	70.9	7.1	15.0	0.219	6.6	13.5	3.3	1.40	No
6/16/2006	10:18	DC-B	61.3	6.1	15.9	0.210	6.7	17.4	6.5	1.53	No
6/30/2006	11:05	DC-B	63.6	6.8	12.8	0.192	6.6	38.1	N/A	2.14	No

8/2/2005	11:10	DC-C	(N/A)	(N/A)	15.3	0.167	7.4	7.8	(N/A)		
8/20/2005	12:35	DC-C	(N/A)	(N/A)	15.2	0.174	7.1	4.6	0.4		
9/10/2005	8:40	DC-C	(N/A)	(N/A)	11.6	0.177	6.9	12.8	2.7		
9/24/2005		DC-C	(N/A)	8.6	10.1	(N/A)	7.5	21.1	4.4		
10/9/2005		DC-C	(N/A)	6.8	8.6	(N/A)	7.3	13.7	5.3		
10/22/2005	9:10	DC-C	74.7	9.2	6.6	0.152	6.6	17.5	7.4		
11/4/2005	11:35	DC-C	71.1	9.2	4.5	0.178	6.8	19.4	12.0		
11/18/2005	11:50	DC-C	78.0	10.2	4.2	0.170	6.7	21.0	16.5		
12/3/2005	9:30	DC-C	72.8	10.3	1.2	0.200	6.9	14.0	9.1		
12/17/2005	10:44	DC-C	78.7	10.4	3.5	0.175	6.7	13.2	2.8		
1/14/2006	11:30	DC-C	85.4	12.1	1.1	0.219	6.9	11.9	1.0		
1/27/2006	11:20	DC-C	71.0	10.3	0.1	0.142	6.8	36.0	21.5		
2/11/2006	9:50	DC-C	79.0	11.4	0.5	0.272	6.6	12.1	0.2		
2/25/2006	9:20	DC-C	(No water- only broken-up ice)								
3/15/2006	9:45	DC-C	(No water)								
3/25/2006	9:15	DC-C	53.5	7.3	0.8	0.986	6.4	5.9	6.1		
4/7/06		DC-C	(No water)								
4/21/2006		DC-C	(No water)								
5/5/2006	9:45	DC-C	78.9	9.8	6.0	0.198	6.7	30.6	13.4		No
5/19/2006	10:45	DC-C	79.5	8.2	10.8	0.210	6.8	11.0	2.4		No
6/2/2006		DC-C	82.0	8.1	16.1	0.212	7.3	3.2	6.0		No
6/16/2006	10:00	DC-C	85.9	8.2	17.4	0.221	7.3	3.8	5.2		No
6/30/2006	10:50	DC-C	84.0	8.7	13.4	0.198	6.9	3.7	(N/A)		No

Appendix B. Water quality data collected on Duck Creek during the period, August 2005 – July, 2006. Anions and cation data.

Date	Time	Site	Cl (mg/L)	SO4 (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)
8/2/2005	11:45	DC-A			5.4	4.3	3.6	30.7
8/20/2005	12:50	DC-A			4.1	4.0	3.5	37.6
9/10/2005	9:05	DC-A	6.7	10.5	4.6	4.4	3.3	32.2
9/24/2005		DC-A						
10/7/2005		DC-A						
10/22/2005	9:40	DC-A	3.4	5.3	2.5	2.4	2.2	21.5
11/4/2005	12:05	DC-A	5.6	3.5	4.0	4.1	4.0	38.9
11/18/2005	12:25	DC-A	6.4	5.4	3.4	1.7	1.8	15.2
12/3/2005	10:00	DC-A	7.0	7.4	4.6	3.8	2.3	38.4
12/17/2005	11:15	DC-A	8.4	10.5	5.3	3.7	2.4	37.9
1/14/2006	12:35	DC-A	8.0	1.6	4.5	3.7	2.6	31.4
1/27/2006	13:15	DC-A	6.1	0.9	0.0	0.1		
2/11/2006	11:20	DC-A	5.9	0.8	4.1	3.5	2.8	36.0
2/25/2006	11:20	DC-A	5.9	0.9	4.3	3.5	3.3	36.7
3/15/2006	9:40	DC-A						
3/25/2006	10:10	DC-A	29.8	2.0	23.7	3.6	3.0	25.3
4/7/06	10:45	DC-A	3.9	1.5	4.2	3.1	2.8	29.3
4/21/2006	10:15	DC-A	4.0	1.5	3.8	3.3	3.0	33.2
5/5/2006	10:30	DC-A	6.7	1.6	5.6	2.5	2.2	26.2
5/19/2006	11:40	DC-A	7.3	1.6	6.7	3.6	3.3	33.1
6/2/2006	12:26	DC-A	4.5	1.1	0.5	1.0	0.4	6.5
6/16/2006	11:30	DC-A						
6/30/2006	11:40	DC-A						
8/2/2005	11:20	DC-B			4.7	3.0	2.1	18.6
8/20/2005	12:35	DC-B			4.9	3.5	2.5	24.8
9/10/2005	8:50	DC-B	6.6	4.4	4.4	3.3	2.0	21.0
9/24/2005		DC-B						
10/9/2005		DC-B						
10/22/2005	9:20	DC-B	2.5	1.7	2.0	1.4	1.1	8.2
11/4/2005	11:45	DC-B	4.0	1.8	4.0	3.3	2.9	24.6
11/18/2005	12:00	DC-B	4.7	4.6	2.8	1.2	1.2	9.0
12/3/2005	9:40	DC-B	6.4	4.8	4.4	2.9	1.3	22.7
12/17/2005	10:55	DC-B	7.8	4.5	5.1	2.6	1.3	20.2
1/14/2006	11:20	DC-B	0.3	0.0	0.0	0.1		
1/27/2006	11:35	DC-B	15.1	4.4	9.3	2.8	1.9	24.6
2/11/2006	10:20	DC-B	19.9	3.2	13.1	2.7	2.2	23.7
2/25/2006	9:35	DC-B	13.6	2.9	10.0	2.6	2.4	21.4
3/15/2006	9:50	DC-B						
3/25/2006	9:55	DC-B	14.3	2.1	10.6	2.6	2.2	18.1
4/7/06	9:20	DC-B	16.5	6.7	10.8	3.4	2.4	23.0
4/21/2006	9:55	DC-B	14.4	3.0	9.3	2.8	2.5	22.6
5/5/2006	10:00	DC-B	10.3	2.6	6.5	2.5	2.3	21.4
5/19/2006	10:55	DC-B	10.5	3.8	5.9	2.7	2.4	23.3

6/2/2006	11:17	DC-B	12.4	3.8	0.0				
6/16/2006	10:18	DC-B							
6/30/2006	11:05	DC-B							

8/2/2005	11:10	DC-C			4.7	2.8	2.1	16.2	
8/20/2005	12:35	DC-C			4.8	3.4	2.4	23.6	
9/10/2005	8:40	DC-C	6.28	5.7	4.3	3.4	2.0	24.4	
9/24/2005		DC-C							
10/9/2005		DC-C							
10/22/2005	9:10	DC-C	4.84	5.3	3.8	3.2	2.5	22.1	
11/4/2005	11:35	DC-C	5.07	5.7	4.1	3.4	3.0	25.8	
11/18/2005	11:50	DC-C	7.59	4.7	4.8	2.8	3.0	21.7	
12/3/2005	9:30	DC-C	6.17	6.3	4.5	3.3	1.4	27.1	
12/17/2005	10:44	DC-C	9.27	5.5	5.5	2.8	1.4	22.2	
1/14/2006	11:30	DC-C	13.81	4.9	8.9	3.2	1.9	23.3	
1/27/2006	11:20	DC-C	23.96	5.2	13.4	3.2	2.5	24.0	
2/11/2006	9:50	DC-C	34.60	5.7	18.4	3.1	2.9	24.4	
2/25/2006	9:20	DC-C							
3/15/2006	9:45	DC-C							
3/25/2006	9:15	DC-C	200	4.6	117	7.4	11.9	23.4	
4/7/06		DC-C							
4/21/2006		DC-C							
5/5/2006	9:45	DC-C	12.70	2.8	8.9	2.5	2.3	20.1	
5/19/2006	10:45	DC-C	11.32	4.1	6.3	2.8	2.5	23.5	
6/2/2006		DC-C	11.34	3.9	0.5	0.4	0.5	1.1	
6/16/2006	10:00	DC-C							
6/30/2006	10:50	DC-C							