Public Review Draft....August 15, 2000

United States
Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

Total Maximum Daily Load (TMDL) for Dissolved Oxygen and Iron in the Waters of Duck Creek in Mendenhall Valley, Alaska

In compliance with the provisions of the Clean Water Act, 33 U.S.C. §1251 et seq., as amended by the Water Quality Act of 1987, Public Law 100-4, the Environmental Protection Agency is establishing a Total Maximum Daily Load (TMDL) that will result in an increase in dissolved oxygen and a decrease in elevated iron in Duck Creek to comply with the designated use in Alaska's water quality standards.

This TMDL will become effective immediately. Subsequent actions must be consistent with this TMDL.

Signed this ___________ day of ___________, 2000.

____
Randall F. Smith
Director
Office of Water

United States
Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

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Dissolved Oxygen and Iron

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TMDL AT A GLANCE:

Water Quality-limited?	Yes
Hydrologic Unit Code:	19010301
Criteria of Concern:	Dissolved oxygen and iron
Designated Uses Affected:	Water supply, water recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife
Environmental Indicators:	Dissolved oxygen monitoring and mats of iron floc
Major Source(s):	Groundwater and dissolved ferrous iron from glaciomarine sediments
Loading Capacity:	0.23 tons/yr iron
Wasteload Allocation:	No point sources; wasteload allocation set to zero
Load Allocation:	0.23 tons/yr iron
Margin of Safety:	Implicit MOS included through conservative assumptions

Executive Summary

Duck Creek is listed on the 1998 303(d) list of impaired waters in Alaska for metals (iron) and low dissolved oxygen. The primary source of iron in the creek is groundwater inflow. Much of the Mendenhall Valley is underlain by iron-rich glaciomarine deposits. As the watershed has become more developed, channel modifications and land disturbances near the creek have removed the thick layer of peat that previously filtered out much of the iron. The primary cause of low dissolved oxygen in Duck Creek is the increased influx of iron, which becomes oxidized and forms iron floc when the groundwater flows into the creek. As a result, the dissolved oxygen and iron impairments are related, and reductions in the inflow of iron to the creek will result in attainment of the dissolved oxygen criteria. The water quality standard for dissolved oxygen and the oxygen demand exerted by dissolved iron set the loading capacity for iron at 1.36 tons/yr to protect designated uses. It is recommended that proposed flow augmentation and streambed lining projects be carried out in order to reduce the inflow of iron to the creek and to increase turbulence and aeration in the creek.

Overview

Section 303(d)(1)(C) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 CFR Part 130) require the establishment of a Total Maximum Daily Load (TMDL) for the achievement of state water quality standards when a waterbody is water quality-limited. A TMDL identifies the degree of pollution control needed to maintain compliance with standards and includes an appropriate margin of safety. The focus of the TMDL is reduction of pollutant inputs to a level (or "load") that fully supports the designated uses of a given waterbody. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices and/or effluent limits and monitoring required through National Pollutant Discharge Elimination System (NPDES) permits.

The state of Alaska identified Duck Creek as being water quality-limited because of low dissolved oxygen, excess debris, metals (iron), fecal coliform, and turbidity (ADEC, 1998). The TMDL for turbidity was completed in December of 1999 (USEPA, 1999). TMDLs for debris and fecal coliform are currently under development. This document addresses only the dissolved oxygen and iron impairments to the creek.

General Background

Duck Creek is located near Juneau, Alaska, in the Mendenhall Valley, a watershed that drains several streams into one of only a few major estuarine wetlands in Southeast Alaska (Figure 1). The Duck Creek watershed drains runoff and groundwater primarily from the floor of this large glacial valley. Duck Creek is a small stream of just over 3 miles in length that flows south through the middle of the heavily populated valley and enters the Mendenhall River and wetlands directly upstream of the Juneau International Airport runway. The creek is an anadromous fish stream (Alaska Department of Fish and Game Catalog No. 111-59-10500-2002) that historically supported runs of coho, pink, chum, and sockeye salmon. Based on descriptions from early residents, the creek originally had numerous beaver ponds and clear water that flowed year-round. Currently, the creek varies from about 5 to 15 feet in width and from a few inches to several feet in depth. Duck Creek has two main tributaries–East Fork and El Camino.

The Duck Creek Advisory Group (DCAG), which was formed to coordinate, plan, initiate, and carry out activities to restore water quality and anadromous fish habitat, has drafted the Duck Creek Watershed Management Plan (DCMP). The DCMP states that urban runoff and current land use management practices are the two key problems leading to the water quality impairment of Duck Creek (Koski and Lorenz, 1999). Designated uses for Duck Creek include (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife (Alaska Administrative Code [AAC] § 18.70.020).

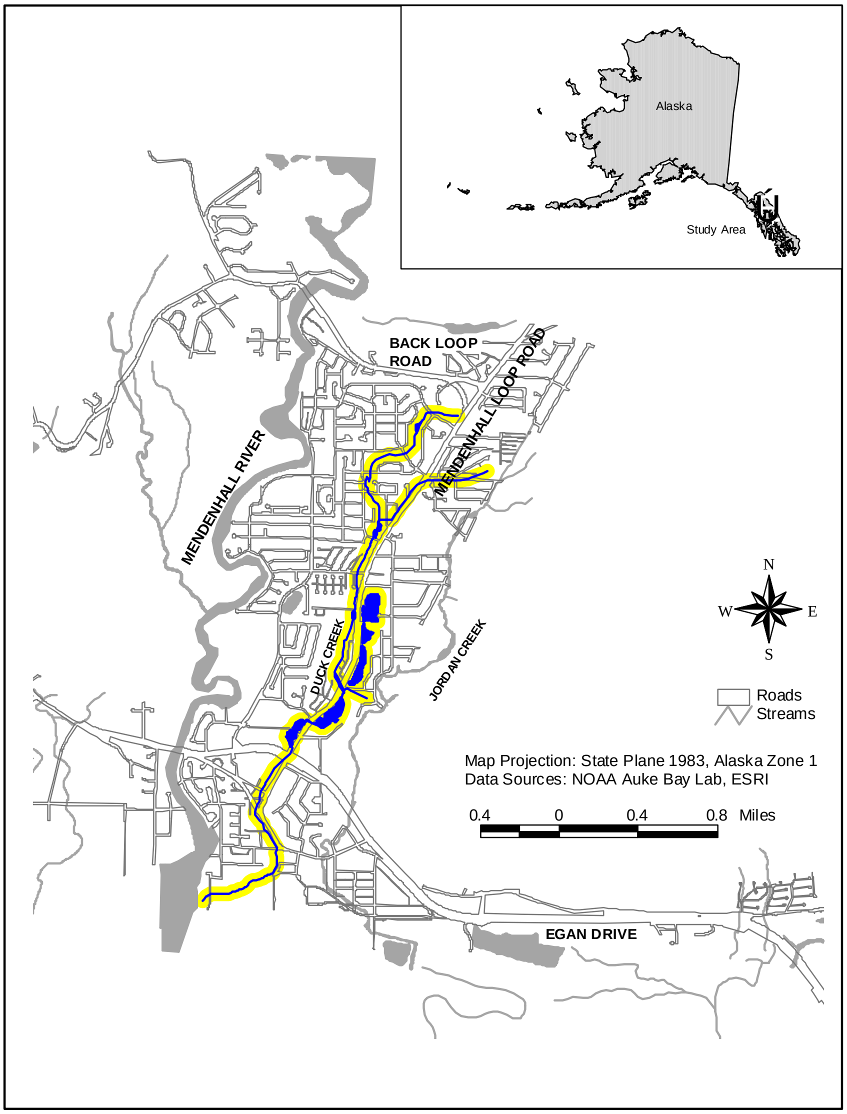

Figure 1. Location of Duck Creek

Dissolved oxygen is vital to fish, shellfish and other aquatic life living in a given waterbody. These organisms respire using the oxygen dissolved in water and are essentially suffocated when there is not enough oxygen available. The dissolved oxygen (DO) levels observed in Duck Creek are below the minimum level required by the criteria for the growth and propagation of fish, shellfish, other aquatic life, and wildlife. Low DO is frequently caused by excess nutrients, which can consume oxygen as they are chemically transformed or can cause algal blooms which then die-off and consume oxygen as they decompose. However, the nutrient observations available for Duck Creek do not indicate that these processes are contributing significantly to the DO impairment. Rather, the DO impairment is for the most part attributable to groundwater inflow, iron in the groundwater, and in-stream alterations. Groundwater is typically lower in DO than surface waters. Measurements taken in 1997 by the USGS at two wells showed values below 2 mg/L (Stahl, 1999). As a result, when the groundwater flows into a stream, a depression in DO is usually observed near the location of the inflow. As the water flows downstream from a groundwater inflow, it is aerated and the DO level increases.

In the Mendenhall Valley, the contribution of low DO from groundwater is compounded by the high dissolved iron content of the groundwater. Much of the valley is underlain by glaciomarine deposits that are high in iron. As the groundwater flows through these deposits, it picks up iron which can ultimately be delivered to surface waters. When this dissolved iron in groundwater is exposed to the air, it is oxidized, consuming oxygen and forming iron floc. The inflow of iron-rich groundwater has been substantially increased by the channel modifications that have taken place in Duck Creek. The stream channel has been modified extensively over time by channel relocation, gravel mining, streambank encroachment, and road crossings. Several large borrow pits and dredge ponds characterize the East Fork. The creek typically has an orange color at several locations caused by mats of iron floc on the streambed and stream surface. Because the iron and DO impairments in Duck Creek are related, this TMDL addresses these two impairments together. Channel and streamflow alterations also contributed to habitat impairment in Duck Creek. Combined with highly permeable reaches of streambed, these alterations have led to significantly reduced flow, and in some cases to the complete absence of flow, during the critical salmon smolt migration.

Land Use

Thirty-six percent of the 1,080-acre Duck Creek watershed is covered by impervious surfaces such as roofs, roads, and parking lots (Lorenz, 1998). The remainder is a mix of cultivated landscaping, nonvegetated athletic fields, natural vegetation, and wetlands. Nearly half of the watershed provides space for residential housing, yards, and driveways. Most of the housing is single-family construction. Another third of the watershed is used for transportation or commercial interests. Based on this land use distribution, the Duck Creek watershed was divided into the following land use categories and areas: residential (540 acres), transportation and utilities (83 acres), commercial (282 acres), and recreation and wetland (175 acres.) Table 1 summarizes the land use distribution.

Table 1. Land use distribution in the Duck Creek watershed

Land Use	**Area (acres)**[a]
Residential	540
Transportation	83
Commercial	282
Recreation/Wetland	175
Total	**1,080**

[a] Estimated from land uses and information presented in Lorenz, 1998.

Climate

Historical climate data are available from the Juneau International Airport (Station 504100), adjacent to the lower reach of Duck Creek. The temperature ranges from a normal daily minimum temperature of 19 EF (-7.2 EC) in January and 48 EF (8.9 EC) in July to a normal daily maximum temperature of 29 EF (-1.7 EC) in January and 64 EF (18 EC) in July. Rainfall averages 54 inches per year, ranging from less than 3 inches per month to well over 7 inches per month. Snowfall averages 99 inches per year, ranging from 0 to 26 inches per month. Wind averages about 8 mph daily (NOAA National Climate Data Center).

Applicable Water Quality Standards

TMDLs are developed to meet applicable water quality standards. These standards may include numeric water quality standards, narrative standards for the support of designated uses, and other associated indicators of support of beneficial uses. The numeric target identifies the specific goals or endpoints for the TMDL that equate to attainment of the water quality standard. The numeric target may be equivalent to a numeric water quality standard where one exists, or it may represent a quantitative interpretation of a narrative standard. This section reviews the applicable water quality standards and identifies an appropriate numeric indicator and an associated numeric target level for the calculation of the TMDL.

Designated Uses

Designated uses for Alaska's waters are established by regulation and are specified in the State of Alaska Water Quality Standards (18 AAC 70). For fresh waters of the state, these designated uses include (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife. Duck Creek only partially supports these designated uses.

Parameters of Concern

The Alaska 1998 § 303(d) list of impaired waters identified Duck Creek as water quality-limited because of dissolved oxygen, debris, metals (iron), fecal coliform bacteria, and turbidity. This TMDL addresses only the dissolved oxygen and iron impairments to the creek.

Applicable Water Quality Criteria and Numeric Target

The most stringent of Alaska's water quality standards with respect to dissolved oxygen (DO) is for the growth and propagation of fish, shellfish, other aquatic life and wildlife. The applicable standard states that:

> *D.O. must be greater than 7 mg/L in waters used by anadromous and resident fish. In no case may D.O. be less than 5 mg/L to a depth of 20 cm in the interstitial waters of gravel used by anadromous or resident fish for spawning. For waters not used by anadromous or resident fish, D.O. must be greater than or equal to 5 mg/L. In no case may D.O. be greater than 17 mg/L. The concentration of D.O. may not exceed 110% of saturation at any point of sample collection. (18 AAC 70 (1)(C))*

The water column DO criteria in Duck Creek, which has historically supported salmon runs, is therefore 7 mg/L. DO values as low as 0.61 mg/L have been observed in the creek.

Duck Creek is also listed for dissolved iron. The iron and DO impairments in Duck Creek are thought to be related because dissolved iron is a source of oxygen demand. The iron criteria in Alaska's water quality standards is the EPA Drinking Water Standard of 0.3 mg/L (EPA, 1996).

Critical Conditions

The criterion of concern for DO in Duck Creek is related to the growth and propagation of fish, shellfish, other aquatic life, and wildlife. Many species are potentially affected by low DO, and an indicator species is frequently selected to facilitate the assessment of overall habitat quality for fish and wildlife. Coho salmon have been selected as an indicator species in Duck Creek, where the coho run has declined from about 500 in the 1960s to less than 20 in 1998 (Koski and Lorenz, 1999). Coho are highly migratory at each stage of their life history and are dependent on good habitat conditions in their migration corridors (e.g., lack of physical obstruction; adequate water depth, water velocity, water quality, and cover.) Small streams such as Duck Creek (total drainage area of 1,080 acres) are particularly important to coho salmon, providing nearly 90 percent of their spawning and rearing habitat. In Alaska, nearly all coho are wild fish that spend about 2 years in fresh water followed by about 16 months at sea before returning to reproduce in natal streams (Lorenz, 1998).

Coho salmon enter spawning streams from July to November, usually during periods of high runoff (Lorenz, 1998). Once the salmon have migrated to their natal stream, the female digs a nest, called a redd, and deposits eggs that the male fertilizes with sperm. The eggs develop during the winter and hatch in early spring; the larvae, called alevins, remain in the gravel utilizing the egg yolk until they emerge as fry in May or June. During the fall, juvenile coho can travel miles before locating off-channel habitat, where they pass the winter free of floods. After one or two rearing years, juvenile coho migrate to the sea as smolt in the spring. Time at sea varies, with some males (called jacks) maturing and returning after only 6 months at sea at a length of about 12 inches, while most fish stay 18 months before returning as full-size adults.

The entire freshwater portion of the coho salmon life cycle takes place in Duck Creek. As a result, the DO impairment to the creek has the potential to affect adults migrating upstream to spawn, eggs and alevins developing in the stream gravel, and juveniles during their rearing years. Adult salmon returning to breed encounter pools with low DO and could experience physiological stress and fail to successfully reach the breeding grounds. This physiological stress might also impact the quality of the eggs produced once breeding begins. Insufficient oxygen in the water column, combined with siltation of the stream bottom by sediment and iron floc, reduces the DO content of the interstitial waters of gravel used for spawning, potentially leading to higher alevin mortality and the emergence of weaker fry. The emergent fry would already be stressed and subject to higher mortality as they encounter low DO during their migration to sea. According to Lorenz (1998), egg-to-fry survival of coho salmon in the creek is close to zero as a result of sedimentation and low DO levels, and nearly all coho rearing in Duck Creek migrated there from outside the watershed.

Water Quality Analysis

Water Quality Data

The data available for assessing the condition of Duck Creek with respect to DO and iron are described in this section. In general, a good amount of data is available for flow, precipitation, DO, temperature, pH, and conductivity. Data on iron and other potential sources of oxygen demand such as 5-day biochemical oxygen demand (BOD_5) and nutrients are extremely limited. In some cases the quality of the data has been questioned by the responsible agency or the temporal coverage of the data is not adequate for certain analyses. However, TMDL guidance (USEPA, 1991) provides that TMDLs should be developed using the best available information, especially when nonpoint sources are the primary concern. Therefore, as part of the Duck Creek watershed characterization process, all data available to support the DO and iron TMDLs were reviewed and are summarized in this section.

1994-1998 U.S. Geological Survey Streamflow Monitoring

Daily streamflow has been measured since December 1993 at a United States Geological Survey (USGS) gaging station (15053200) located downstream of Nancy Street in the Duck Creek watershed (Figure 2). The DCMP (Lorenz, 1998) indicates that flow at the gaging station represents discharges from approximately 75 percent of the watershed (approximately 810 acres). It is estimated that approximately 46 percent of the total precipitation that falls in the Duck Creek watershed is transported into the stream through overland runoff (Lorenz, 1998). The remaining 54 percent is believed to enter Duck Creek as groundwater or through sewer systems. Because flow in Duck Creek is heavily influenced by groundwater, there is a substantial lag between precipitation events and peak flow stages. Duck Creek has been observed to peak approximately 24 hours after the neighboring Jordan Creek. Annual and monthly average flows and precipitation for 1994 to 1998 are presented in Appendix B, Table B-1.

Peak monthly discharges and precipitation in the watershed occur on average during the months of September and October. This represents the period of maximum runoff and increased nonpoint source pollutant loading from areas in the Duck Creek watershed. Periods of low flow are also critical to water quality in Duck Creek because this is when the impact of groundwater inflow is at its peak. Groundwater inflow remains relatively constant over the course of the year, but it makes up a larger percentage of total streamflow at lower flows when the contributions from precipitation and runoff are at their lowest. As a result, groundwater conditions can dominate in-stream water quality when groundwater is the main contributor to streamflow.

1997 USDA Forest Service Iron Sampling

In the United States Department of Agriculture Forest Service's *Duck Creek Hydrology Baseline Conditions* report, the stream reaches with the heaviest inflow of groundwater with high concentrations of dissolved iron were found to be those areas where the channel or ponds had been mechanically deepened into the underlying floodplain and glaciomarine deposits (Beilharz, 1998). The stream is underlain by three types of material: alluvial outwash composed mainly of gravel, floodplain deposits of silt and organic soils, and glaciomarine sediments composed of gravel, sand, silt, and dense clay. Natural and human stream channel realignment has resulted in sections of the stream bottom intercepting each of these layers. The majority of the streambed consists of floodplain deposits of silt and organic soils. Where alluvial outwash is the predominant streambed material, the stream experiences significant flow losses, especially in the vicinity of Del Rae Street. Where the stream channel intersects the glaciomarine sediments, the groundwater has high iron concentrations. The iron in groundwater is in a reduced state and oxidizes when it flows into the stream and comes into contact with higher DO levels, forming iron floc. A single groundwater seepage observation was collected at each of 11 sites in June 1997. This set of observations showed dissolved iron concentrations as high as 10 mg/L (the data are presented in Appendix B, Table B-2).

The 1997 USDA Forest Service iron sampling data were used to identify three distinct locations where iron-rich groundwater is seeping into the stream and to estimate the typical dissolved iron concentration in groundwater at these inflow locations. These locations are Taku Boulevard, below Berners Avenue, and the dredge ponds on the East Fork.

1996 U.S. Geological Survey Water Quality Monitoring

A limited amount of water quality data was available from the USGS, with one sample collected at each of four sites (Appendix B, Table B-3). The collection sites are in close proximity to the locations of high iron groundwater inflow. The observed nutrient concentrations from USGS shown in Table B-3 are all low (NO_2 < 0.01 mg/L, NO_x < 0.23 mg/L, NH_3 < 0.285 mg/L and TKN < 0.37 mg/L), suggesting that the high iron concentrations at these locations represent the majority of the in-stream oxygen demand. The observed DO concentrations are consistent with

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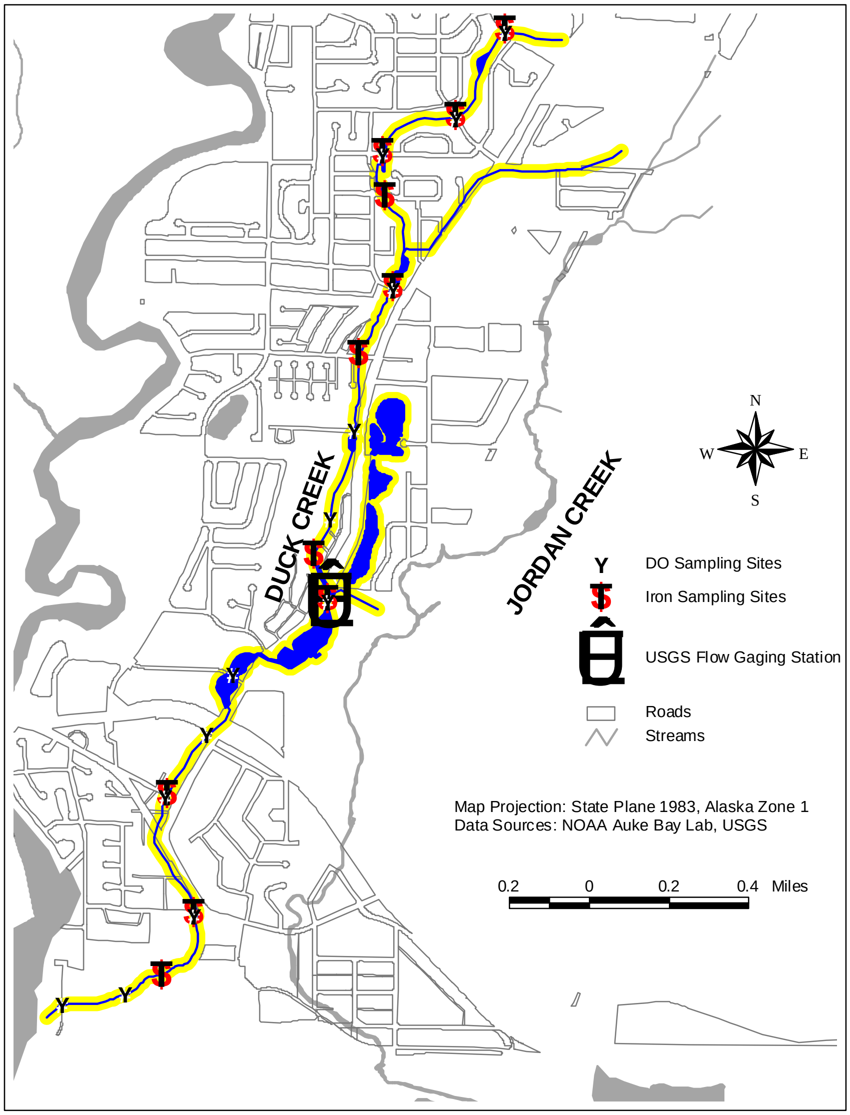

Figure 2. DO, iron and streamflow sampling locations in Duck Creek

ata presented below, were used to support the assumption that nutrients are not contributing significantly to the DO impairment to Duck Creek.

1994-1995 Alaska Department of Environmental Conservation Water Quality Monitoring

The Alaska Department of Environmental Conservation (ADEC) collected water quality samples on three dates. These samples were tested for various organic chemicals, nitrate, nitrite, BOD_5, and chemical oxygen demand (COD). Samples were collected at five sites, Taku Boulevard, Airport Boulevard, Dredge Lake, Stump Pond, and Rainbow Road. Dredge Lake is above Taku Boulevard and may serve as a headwater for Duck Creek. Based on street maps and various names for the station, Rainbow Road may be Rainbow Row, which drains into the East Fork. The exact location of Stump Pond is not known, but it is suspected to be on the East Fork. The data collected by ADEC are spatially scattered to such an extent that only a general pattern of water quality can be determined and are presented in Appendix B, Table B-4. However, the low nutrient and BOD values observed (on average, NO_2 = 0.3 mg/L, NO_3 = 0.3 mg/L, BOD_5 = 2.2 mg/L and COD = 16 mg/L) support the assumption that nutrients are not contributing significantly to the DO impairment to Duck Creek.

1997 and 1999 Groundwater Monitoring

Groundwater inflow typically has low levels of pollutants and reflects background or unimpacted conditions. Two groundwater monitoring wells were found in the USGS data with one reading at each well. Information describing the well locations was not available. DO was below 2 mg/L and iron was above 10 mg/L for both of these wells (Appendix B, Table B-5). Several groundwater wells have been placed in the Duck Creek watershed. In an unpublished report by Dr. Randy Stahl at the University of Alaska Southeast, monitoring results from these wells were summarized (Stahl, 1999). Three of the wells were sampled in 1999. Well 3, located near Cessna Drive, has been impacted by construction and is not being monitored. Well 4 is located south of Berners Avenue. Both wells 3 and 4 were located near the stream and were observed to go dry when the stream went dry, suggesting that they were influenced by in-stream conditions and are not a good reflection of groundwater conditions. Well 17 is located at El Camino Street and is near a pool and the East Fork. The three iron readings for Well 17 are 8 mg/L or higher. In Beilharz (1998), high iron readings were linked to discharge from the glaciomarine sediments, which suggests that Well 17 might be in the glaciomarine soils, and not representative of background conditions. Dissolved iron and DO readings for these wells are presented in Appendix B, Table B-5.

1992-1993 Alaska Water Watch Water Quality Monitoring

During 1992 and 1993, local students from Juneau Youth Services, Miller House, collected water quality samples at nine sites in Duck Creek as part of the Alaska Water Watch (AWW) program. The geographic locations of the stations in Duck Creek are referenced by street names and are presented in Figure 2. Parameters measured include water temperature, DO, pH, turbidity, specific conductivity, alkalinity, and fecal coliform bacteria. The in-stream data collected at these sites did not have any corresponding flow, and the period of record did not have temporal overlap with the flow data collected at the Nancy Street USGS gaging station. The DO data available for 18 sampling events between 1992 and 1993 were included in the data analysis.

1994-1997 National Marine Fisheries Service and Alaska Water Watch Water Quality Sampling

The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) has conducted both continuous and periodic water quality sampling of Duck Creek using portable Hydrolab electronic sensors. Measurements were taken of temperature, pH, specific conductivity, salinity, DO, redox, and water level. These data have temporal overlap with the USGS flow record and constitute the bulk of the available DO data. Data were collected at 25 sites along the main stem and 5 sites on the East Fork. Data were available for 47 sampling events between 1994 and 1997.

Because many stations were not sampled on a regular basis, long-term DO trends could be determined for only 13 sites along the main stem of Duck Creek. Table B-6 in Appendix B summarizes the AWW and NMFS DO data at the 13 sites used to develop this TMDL. The complete list of DO monitoring stations is presented in Appendix A.

Analysis of DO, Temperature, and pH Data

The available in-stream measurements were combined by parameter and station to evaluate trends and possible exceedances of the water quality standards. The data that overlap the flow record were also used in determining relationships with flow. Not all stations were sampled on each sampling date, with the number of observations varying between 14 and 61 readings per station from 1992 to 1997. The location and distance upstream from the mouth for each station was estimated with the best available maps and data. Some stations had several names, and all distances were rounded to the nearest 5 meters.

Dissolved Oxygen

Dissolved oxygen readings were available on 63 dates. Many stations were not sampled on a regular basis. Long-term trends were determined for 13 sites along the main stem of Duck Creek (Table B-6). Figure 3 shows a summary of the DO monitoring data for 1997. As shown in the figure, the average DO is relatively low near Taku Boulevard (just above 7 mg/L) and recovers downstream (nearly 10 mg/L) until Nancy Street, where the East Fork joins the main stem and DO drops to 6.5 mg/L. The DO recovers again below Nancy Street (between 8 and 9 mg/L) until the vicinity of Berners Avenue, where it again drops below 8 mg/L. From below Berners Avenue to the mouth of the stream, DO improves again, reaching 12 mg/L near the mouth. The iron concentrations from June 1997, also plotted in Figure 3, show a co-occurrence of increased iron concentrations with decreased DO concentrations. Figure 4 shows the maximum, minimum, and mean DO concentrations for all sample dates (1992 to 1997). The same DO concentration trend is observed for 1992 to 1997 as for 1997 alone, with depressions in DO at Taku Boulevard, Nancy Street, and Berners Avenue. Figure 5 presents pairwise comparisons of DO at adjacent stations. In all but two cases, there appears to be a strong correlation between the DO at each station and the DO at the station immediately upstream, suggesting that conditions immediately upstream are the major determinant of downstream conditions. Where a tributary enters the stream (Nancy Street) or there is groundwater seepage from the glaciomarine sediments (Berners Avenue) , the correlation is not as pronounced, which is to be expected as a new flow source with different water quality is added at those points.

As part of the analysis, the DO readings were compared to the criterion of 7 mg/L. Table 7 summarizes the data for the 13 stations used, including the number and percent of samples that do not meet the criterion. This exceedance analysis shows the same pattern of DO depression and improvement from Taku Boulevard to Nancy Street, from Nancy Street to Berners Avenue, and from Berners Avenue to the mouth of the creek. In each case, as shown in Figures 3 and 4, the DO depression coincides with an elevated iron concentration from groundwater inflow.

Temperature

In general, low DO concentrations occur at lower flows and higher water temperatures. The saturated DO concentration increases with decreasing temperature, and multiple-year plots of DO versus temperature should show this relationship. The monitoring data were analyzed to see if the DO-temperature relationship in Duck Creek followed these trends. Figures 6 and 7 show the correlation of temperature with month and with flow. These figures show that virtually any combination of streamflow and in-stream temperature is possible, but that the overall seasonal patterns of temperature do hold, with maximum water temperatures occurring in June through August and minimum temperatures occurring in January and February. For the period between 1992 and 1997, the maximum temperatures varied between 10 EC at Taku Boulevard and 22.3 EC at McGinnis Street. The minimum temperatures generally ranged between 0 EC and -1 EC. The DO in Duck Creek is generally below 80 percent of saturation.

pH

On 58 dates, pH readings were taken from as few as 3 stations and as many as 27 stations. On 19 of these dates, the difference between the minimum and maximum pH in the creek exceeded 1 pH unit. When the pH does not significantly differ over the length of the stream, stream chemistry remains relatively constant, and comparisons between stations are simplified. This condition was assumed in developing the simplified model. When the pH does significantly differ, a greater portion of the oxygen deficit might be due to chemical speciation and equilibrium processes and not the decay and reaeration process. Comparing the pH values for each month shows a pattern similar to that of the temperature analysis, with the maximum pH readings generally occurring from June to August.

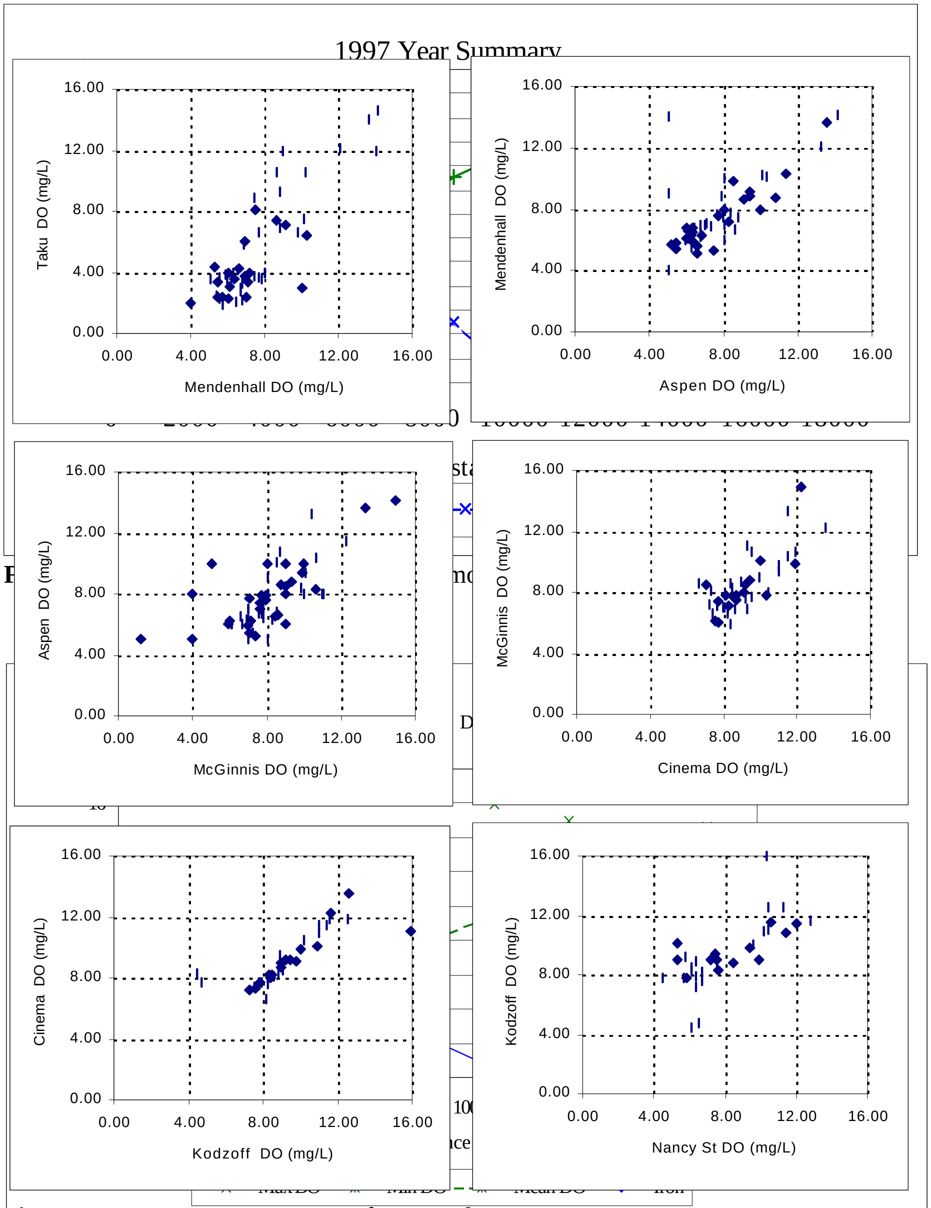

Figure 5.a. Pairwise comparison of DO at adjacent monitoring stations

Figure 4. 1992-1997 dissolved oxygen monitoring data for Duck Creek

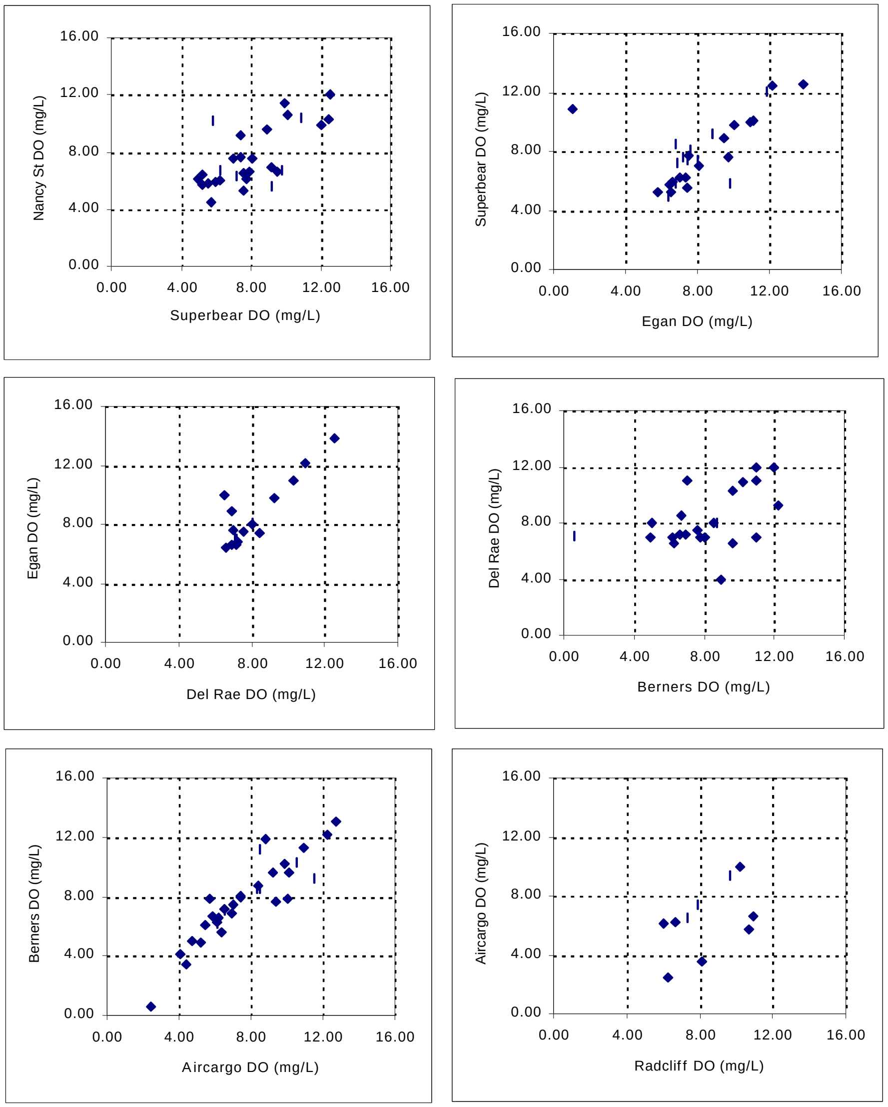

Figure 5.b. Pairwise comparison of DO at adjacent monitoring stations *(continued)*

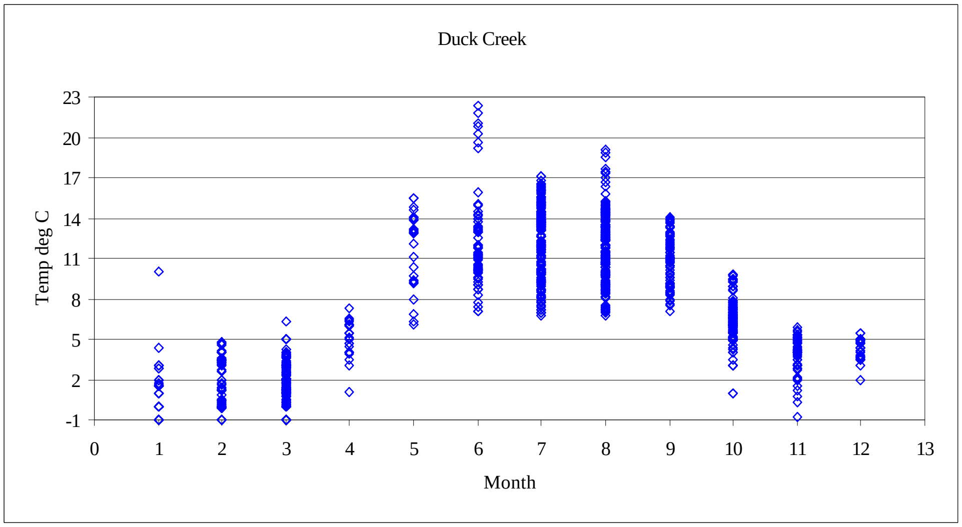

Figure 6. Temperature observations by month in Duck Creek

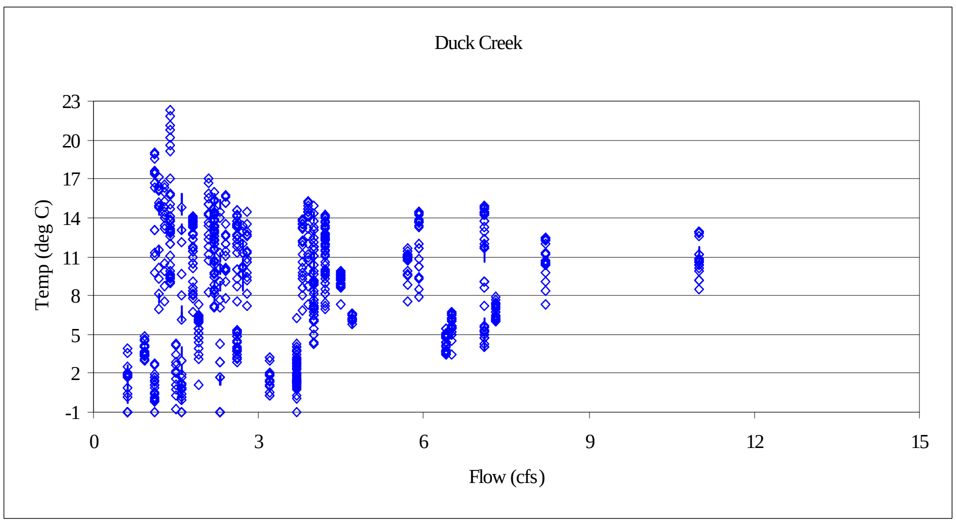

Figure 7. Temperature versus flow in Duck Creek

Pollutant Sources

An assessment of potential sources oxygen demand is needed to evaluate the type, magnitude, timing, and location of the oxygen demand loading to Duck Creek. The source assessment includes identification of the various types of sources (e.g., point, nonpoint, background), determination of the relative location and magnitude of loads from the sources, and the transport mechanisms of concern. Of particular concern is what loading processes cause the impairment. Loadings are often evaluated using a variety of tools, including existing monitoring information, aerial photography analysis, simple calculations, spreadsheet analysis using empirical methods, and a range of computer models.

Point Sources

No point sources are specified in the DCAG reports (Lorenz, 1998; Koski and Lorenz, 1999). A search of EPA's Permit Compliance System identified no point sources in the Duck Creek watershed. National pollutant discharge elimination system (NPDES) permits are required for stormwater discharges in cities of 100,000 or more. Because Juneau is smaller than this, no stormwater permit is required, and stormwater is treated like a nonpoint source of pollution in this TMDL.

Nonpoint and Natural Sources

Organic Material

The decay of organic compounds and the conversion of ammonia to nitrite and nitrate consume DO. Limited in-stream data are available for nitrogen concentrations and BOD_5 (Tables B-3 and B-4). The available samples did not exceed 0.3 mg/L for ammonia and nitrite, and 3.1 mg/L for BOD_5. Possible nonpoint sources for these compounds include waste deposition throughout the watershed by wildlife and pets, leaves or other organic material deposited in the stream, and stormwater runoff. The observed concentrations do not present a significant source of oxygen demand in Duck Creek. Using typical decay rates (USEPA, 1985), no reaeration, and the same velocity and distance as were used in the simplified model used to develop this TMDL, the oxygen demand for the BOD_5 and ammonia at Taku Boulevard is estimated to be 0.5 mg/L. The modeled oxygen demand for 10 mg/L of iron is about 8 mg/L, and the low groundwater DO creates a 6.5 mg/L oxygen demand. As a result, it should be possible to attain the water quality standard by controlling the inflow of iron-rich and oxygen-poor groundwater to the creek and through flow augmentation.

Organic chemicals can also contribute to DO problems. Deicing agents like ethylene glycol and propylene glycol are found in automotive antifreeze and have a high chemical oxygen demand (COD). Runoff from urban areas can result in these chemicals reaching the stream. Samples from October 1994 ranged between 8 mg/L and 23 mg/L COD, while the February 1995 samples ranged from 5 mg/L to 45 mg/L. Samples in May 1995 measured CODs between 9 mg/L and 12 mg/L, suggesting the February sample might have been an isolated event or an event associated with the deicing activity as suggested. Because the laboratory COD measurement uses strong oxidative reagents, it is likely to reflect a much stronger oxygen demand than would occur in-stream. In addition, the primary means of transport of these chemicals to the stream is through stormwater runoff, which tends to be highly oxygenated. The relationship between laboratory and in-stream COD is not well documented in the literature, and there is no readily available model that simulates COD. As a result, the impact of the COD values presented in Table B-4 were included in the 0.5 mg/L impact estimated for nitrogenous and BOD decay.

Iron

Iron concentrations vary along the length of Duck Creek and approach 10 mg/L at several locations. Elevated iron concentrations can form iron floc and affect streambed aeration, which in turn affects aquatic life in Duck Creek. As the iron oxidizes, an iron floc forms and settles on the stream bottom, filling interstitial spaces in the gravel. The floc limits the aeration of the interstitial water and traps organic sediments that require DO to decompose. This decomposition can create an oxygen demand and cause low interstitial DO where the in-stream iron concentrations and associated floc formation are highest. Because no data are available on interstitial DO levels in Duck Creek, this TMDL addresses only the water column DO impairment. However, it is anticipated that reducing iron and increasing water column DO will also improve interstitial DO.

Iron can also deplete DO in the water column. Iron enters Duck Creek through groundwater at several locations along the creek. The iron is picked up by the groundwater as it travels through the glaciomarine sediments underlying portions of the Duck Creek watershed (Stahl, 1999). The iron in these marine sediments commonly is present as pyrite (FeS_2) in the +2 oxidation state (Stahl, 1999). The locations where groundwater high in iron discharges into the creek are distinguished by orange staining of the water and streambed and by the formation of iron floc (Koski and Lorenz, 1999, Stahl, 1999, Lorenz, 1998).

Iron in marine sediments is primarily found in the reduced (ferrous) form because of the low levels of oxygen (Stahl, 1999). This soluble iron is environmentally important because it can easily move through the groundwater and be discharged to surface waters. When exposed to oxygen, the iron is oxidized to the +3 oxidation state (ferric iron) and forms insoluble ferric oxides or hydroxides (Viswanathan and Boettcher, 1991), which precipitate out of the water column as iron floc (Lorenz, 1998). As the floc settles out of the water column, it builds up on the stream substrate, causing a red staining effect (Lorenz, 1998).

The sources, fate, and transport of iron in Duck Creek are important to the DO TMDL because the formation of iron floc consumes oxygen. Iron floc has also been identified as a potentially significant source of fines in the creek (Koski and Lorenz, 1999), as well as a source of DO depletion (Beilharz, 1998). A study conducted in Duck Creek between Taku and Mendenhall Boulevards found that the substrate contained high levels of fine sediment and high concentrations of iron floc (Lorenz, 1998). The iron floc and fine sediment present in the stream bottom can easily be resuspended during periods of increased flow velocity (e.g., storm events or snowmelt), movement by wildlife, or other in-stream activity. The turbidity impairment to Duck Creek was addressed in the turbidity TMDL (USEPA, 1999).

The available iron data provide a general overview of the spatial pattern of iron along the length of Duck Creek (Table B-2). Increased iron concentrations are seen at Taku Boulevard, Nancy Street (below the confluence of the East Fork), and below Berners Avenue. All three are believed to be locations where iron-rich groundwater is seeping into the stream (Beilharz, 1998). The flows and in-stream DO values corresponding to these iron concentrations were not available. A more complete characterization of the distribution of iron concentrations would involve additional sampling above Nancy Street on both the main stem and East Fork, and at least one site downstream of Berners Avenue, preferably Air Cargo. Sampling at various dates and flows would help clarify the observed spatial pattern and would provide some insight into any temporal patterns that might exist. Using the best available data, this TMDL identifies the locations where elevated iron concentrations have been observed (Taku Boulevard, East Fork and Berners Avenue) and explores management options to reduce their impacts. This assumes that iron floc and floc transport will be affected to a similar extent as dissolved iron.

At some locations in the creek (below Nancy Street), the water has appeared orange due to suspended iron floc (Beilharz, 1998). The three stream reaches with the heaviest inflow of groundwater containing high concentrations of dissolved iron coincide with locations where there have been modifications to the channel or excavations of ponds. These excavations often exposed the underlying sediments and glaciomarine deposits.

Analytical Approach

Development of TMDLs requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. In identifying the technical approach for development of the DO and iron TMDLs for Duck Creek, the following core set of principles was identified and applied:

- The TMDLs must be based on scientific analysis and reasonable and acceptable assumptions. All major assumptions have been made based on available data and in consultation with local agency staff.
- The TMDLs must use the best available data. All available data in the watershed were reviewed and were used in the analysis when possible or appropriate.
- Watershed-scale models should be applied only where appropriate and when sufficient data are available. A simplified modeling approach based on empirical relationships was used for the estimation of the iron and DO concentrations in Duck Creek. Available data and the complex chemistry of iron oxidation did not support the use of watershed or water quality models.
- Methods should be clear and as simple as possible to facilitate explanation to stakeholders. All methods and major assumptions used in the analysis are described, with additional detail

provided in the appendices. The TMDL document has been presented in a format accessible by a wide range of audiences, including the public and interested stakeholders.

The analytical approach used to estimate the loading capacity, existing loads, and load allocations presented below relies on the above principles and provides a TMDL calculation that uses the best available information to represent watershed and in-stream processes.

Simplified Model Development

The limited data available on nutrients, BOD and COD (Tables B-3 and B-4), and the negative correlation of iron and DO concentrations (Figure 3) suggest that the dominant oxygen-consuming process in Duck Creek is iron oxidation. As a result, the approach taken in the simplified model analysis focused on iron concentration as a predictor of in-stream DO. This assumption should be verified as additional water quality monitoring data are collected.

Estimation of Flow

The flow pattern in Duck Creek is complex and varies along the length of the stream, but continuous flow observations are available only at Nancy Street. A method was therefore devised to estimate flows at locations of interest along Duck Creek using information from the *Duck Creek Hydrology Baseline Conditions* report. The flow estimation method, presented in detail in Appendix C, was used to estimate the flow at four of the eight stream segments simulated: Aspen Avenue, Duran Street, McGinnis Drive, and below Kodzoff Acres.

Interaction of Iron and DO

Iron and DO losses due to oxidation and floc formation, as well as DO increases due to in-stream aeration, were calculated for each stream segment. For example, a stream segment starting with an iron concentration of 6 mg/L and a DO of 8 mg/L will experience floc formation and settling, resulting in a decrease of iron to 5.2 mg/L and a decrease of DO to 7.4 mg/L. These concentrations are then further changed due to groundwater inflow. The groundwater, which is assigned an iron concentration in each segment based on the information in Table B-2, will increase or decrease the in-stream iron concentration. In this example we will assume a groundwater iron concentration of 5 mg/L, which is lower than the in-stream iron concentration and will therefore dilute it. The groundwater DO of 2 mg/L is also lower than the in-stream DO concentration, so the in-stream DO would also be decreased. The initial conditions for the next segment downstream will therefore be 5 mg/L of iron and 7 mg/L of DO. The details of the equations used to calculate iron and DO in each stream segment are presented in Appendix D.

The simplified model was calibrated using data from August 1995 and validated using data from August 1997 (see Figures D-1 and D-2). It was then used to simulate the stream conditions for June 15, 1997, and the mean flow for June 1997 (Figure 8). These dates were chosen because they most closely match the conditions when the groundwater seepage data were collected (Table

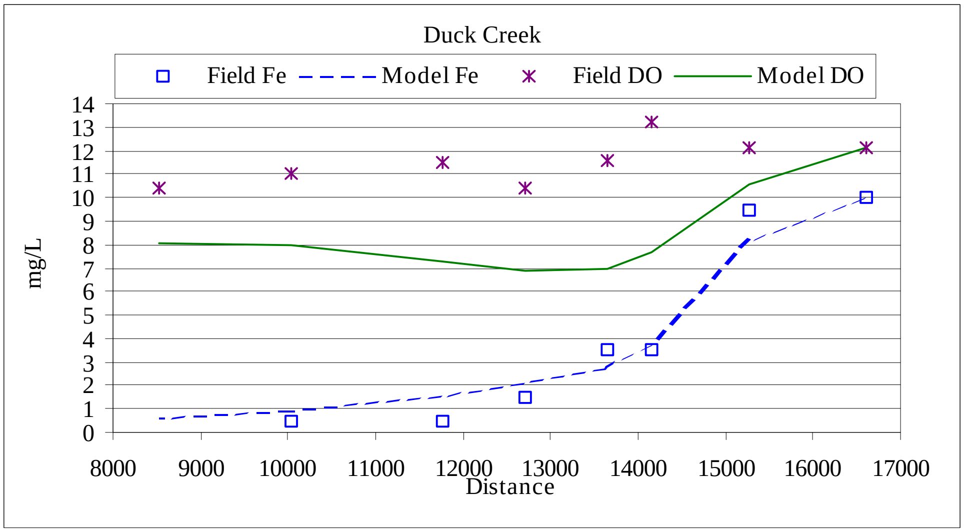

Figure 8. Validation of simplified model simulation for June 1997

B-2). For both June predictions, the simplified model analysis shows poor agreement with the stream conditions, which frequently exceeded saturated conditions. The predictions did capture the overall pattern of the June 15 DO measurements, with DO values underestimated by approximately 3 mg/L (see Figure 8). A DO prediction that matches the trend of observed data but is shifted up or down usually indicates a discrepancy in the starting values or the sampling equipment calibration. When compared to the mean DO concentration for 1997, the predicted DO values were within 1 standard deviation for all but one site. The predicted values are deemed to be sufficiently accurate given the limited amount of iron data available because they capture the relative pattern of the iron and DO dynamics well.

Loading Capacity

One of the essential components of a TMDL is identifying and representing the relationship between the desired condition of the stream (expressed as the water quality standard) and pollutant loadings. Once this relationship has been established, it is possible to determine the capacity of the waterbody to assimilate iron loadings and still maintain acceptable DO levels.

It is estimated that 75 percent of the watershed (810 acres) drains to the USGS gaging station at Nancy Street. Duck Creek currently experiences flow losses in the reach downstream of the Nancy Street station, to the point that flow is entirely absent from this reach during certain parts of the year. This analysis assumes that flow is conserved from Nancy Street to the mouth of the creek at Radcliff Road. Although flow conservation does not represent current conditions, it was necessary to assume that no reaches of the creek went dry in order to simulate iron and DO dynamics in the creek. It is not possible to model water quality during zero flow events. Several management options have been proposed to restore flow in this reach, including lining the streambed to prevent flow losses to groundwater and flow augmentation (Koski and Lorenz, 1999).

It is also assumed that the iron and DO concentrations in the East Fork and Berners Avenue seepage are equal to the concentrations at Taku Boulevard. Table B-2 shows that the iron concentrations at Berners and Taku are nearly equivalent (9 mg/L and 10 mg/L, respectively.) No iron measurements are available for the East Fork. The iron and DO concentrations in the creek in proximity to groundwater seepage are therefore assumed to be 10 mg/L and 2 mg/L, respectively. The DO and iron concentrations of the groundwater inflow at Taku Boulevard are also assumed to be constant year-round. Sufficient data are not available to suggest that the quality of the groundwater varies seasonally (the data in Table B-2 were collected in June 1997, the USGS groundwater monitoring wells in Table B-5 were sampled in September, 1997, and Well 17, also in Table B-5, was sampled four times over a six week period in the spring of 1999.) While the high iron content of groundwater is a natural condition in the Mendenhall Valley, the inflow of iron to Duck Creek has been increased by stream modifications, including dredging, that have intercepted the glaciomarine sediment layer.

Were sufficient flow records and monitoring data available, the loading analysis would be based on a statistical low flow analysis using long-term average concentrations. The limited flow record is, however, not sufficient to perform a low flow analysis. The loading analysis was therefore done at several flow conditions determined based on the flow percentiles calculated from December 1993 to September 1999 flow record. Based on this flow record, the 10^{th} percentile flow, or flow that is exceeded 90 percent of the time, is 1.0 cfs, whereas the 50^{th} percentile flow, or mean flow, is 2.4 cfs.

Using the 50^{th} percentile flow, an in-stream iron concentration of 10 mg/L, and an upstream DO of 7 mg/L, the simplified model analysis predicted DO in the stream segment between Aspen Avenue and Stephen Richards Memorial Drive would be below the water quality criterion of 7 mg/L. Decreasing both the groundwater and headwater iron concentration to 0 mg/L still resulted in an exceedance of the DO standard at Duran Street, indicating a portion of the stream between Aspen Avenue and McGinnis Drive would be below the criterion. Due to the current stream hydraulics, reductions in iron concentration alone are not sufficient to prevent DO exceedances at mean flow.

Using the 10^{th} percentile flow and an upstream DO of 7 mg/L, an iron concentration of 10 mg/L still results in DO problems. A reduction to 0.3 mg/L of iron, however, resulted in no exceedance of the DO criterion. It appears that the reaeration rate is sufficient at this low flow to replenish the DO in the correspondingly small volume of water.

Flow augmentation and channel lining are among the many options presented in the *Duck Creek Baseline Hydrology Conditions* report (Beilharz, 1998) to compensate for the loss of water below Nancy Street. The 10^{th} percentile and 50^{th} percentile analyses described above also were run with an additional 3 cfs of flow, bringing the mean flow to 5.63 cfs and the 10^{th} percentile flow to 3.76 cfs. Using the augmented flows, an iron concentration of 0.3 mg/L, and a headwater DO of 7 mg/L, the model showed no DO exceedances, with the lowest predicted DO occurring at the headwaters.

When flow augmentation alone (no iron reduction) was simulated, multiple sites showed predicted DO concentrations between 7.0 and 7.1 mg/L. The accuracy of this simplified model analysis is estimated at 0.1 mg/L. To ensure that the DO standard is being met, additional reductions in the iron reaching the stream are required. Reductions in the iron concentration will increase in-stream DO and reduce aesthetic concerns of color and floc formation.

The loading capacity (LC) for iron in Duck Creek is the total amount of iron that the stream can assimilate without exceeding the DO standard of 7 mg/L. The LC can be calculated as the maximum allowable concentrations of iron multiplied by the flow at Nancy St. Evaluating this formula at the critical low flow (10^{th} percentile) condition leads to the following loading capacities for iron in Duck Creek:

1. Under existing flow conditions: LC = 0.3 mg/L * 0.76 cfs = 0.23 tons/yr

2. With a flow augmentation of 3 cfs: LC = 0.3 mg/L * 3.76 cfs = 1.13 tons/yr

The loading capacity for iron in Duck Creek is therefore 0.23 tons/yr under current flow conditions. Should the flow be augmented by 3 cfs, the loading capacity would be increased to 1.13 tons/yr.

Wasteload Allocation

Because no point sources contribute to the iron and DO impairment in Duck Creek, the wasteload allocation was set to zero.

Load Allocation

As discussed earlier, the delivery and deposition to Duck Creek via storm water runoff may exert an oxygen demand, but that demand is significantly less than the impact of the in-stream iron. The allocation for the organic material has been set at zero for this TMDL because the sources can not be reasonably estimated.

Because there are no point sources and iron is assumed to be the only significant source of oxygen demand, the load allocation (LA) for iron is set equal to the loading capacity (LC). The existing load (EL) is calculated by multiplying the current concentration of iron by the existing flow. The current concentration of iron in groundwater inflow is assumed to be 10 mg/L. The existing load is therefore 6.79 tons/yr, corresponding to a load reduction of 6.56 tons/yr (97 percent). With a flow augmentation of 3 cfs, a similar reduction in the iron concentration of groundwater inflow is required in order to meet the water quality standard. In summary:

1. Under existing flow conditions:
   LA = LC = 0.3 mg/L * 0.76 cfs = 0.23 tons/yr
   EL = 10 mg/L * 0.76 cfs = 6.79 tons/yr
   Load Reduction = EL - LA = 6.56 tons/yr (97%)

2. With a flow augmentation of 3 cfs:
   LA = LC = 0.3 mg/L * 3.76 cfs = 1.13 tons/yr
   EL = 10 mg/L * 3.76 cfs = 33.6 tons/yr
   Load Reduction = EL - LA = 32.5 tons/yr (97%)

The allocation is partially controlled by the current flow dynamics. Of the flow regimes in Table C-1, the highest ratio of Taku Boulevard to Nancy Street is for a flow of 0.76 cfs, with the Taku Boulevard flow being 16 percent of the Nancy Street flow. Assuming a linear increase in flow in the downstream direction, the minimum flow percentage needed to prevent DO exceedances is 25 percent at Taku Boulevard. Stream flow improvements could significantly alter the allocations. When the culverts and stream gradient have been corrected, the TMDL should be revised to reflect these changes.

Margin of Safety

This section addresses the incorporation of a margin of safety (MOS) into the TMDL analysis. The MOS accounts for any uncertainty or lack of knowledge concerning the relationship between pollutant loading and water quality. The MOS can be implicit (e.g., incorporated into the TMDL analysis through conservative assumptions) or explicit (e.g., expressed in the TMDL as a portion of the loadings) or a combination of both.

The MOS was included in this TMDL implicitly through a series of conservative assumptions related to both the estimation of the existing loading and the water quality target for the TMDL. The conservative assumptions include the following:

- The assumption of an iron concentration of 10 mg/L at Taku Boulevard for all flows: 10 mg/L is the maximum observed in-stream concentration. Using this value represents a conservative assumption because it is likely that it overestimates the contribution of iron to Duck Creek. The monthly distribution of flows presented in Table B-1 shows that June is the month with the lowest flow. At low flow, groundwater contributes a larger proportion of in-stream flow and is more likely to dominate in-stream water quality. The in-stream iron measurements measured by USFS were made in June of 1997, and are therefore likely to reflect the maximum concentration of in-stream iron.
- The use of a low gradient and wide channel cross section for all stream segments: a steeper stream segment would have a faster flushing rate, whereas wider stream segments or

segments with backwater pools would have a longer retention rate with a higher oxygen deficit. For calibration, the channel varied based on the flow, but the allocation was performed assuming a 3.2 foot width for all flows.

- The use of a simple model to simulate the uptake of iron: chemical equilibrium and speciation changes with changes in pH and temperature. Many equilibrium reactions are not first-order so the use of a first-order model could overestimate the uptake of iron and overpredict the oxygen demand. The temperature correction of the settling and decay rates is also a conservative assumption, which would tend to slow the decay rate, extending the length of stream with high iron concentrations.

Seasonal Variation

It is difficult to predict and estimate the annual and seasonal variation in the delivery of iron to and the consumption of oxygen in stream systems. Delivery occurs throughout the year, but can also be increased by wet-weather events. The consideration of seasonal variation is an important component of the Duck Creek TMDL because of the critical time periods associated with the fishery. These critical periods vary depending on the life stage being considered. The critical period for hatching and fry emergence is from January to May, whereas the critical period for adult spawning migration is from July to November. The TMDL was established with annual allocations of iron to Duck Creek, but the analysis focused on periods of low flow, when the groundwater inflow is more likely to dominate in-stream chemistry. The TMDL is therefore sensitive to periods of low flow when exceedances of the DO standard are most likely to occur.

Monitoring

The impacts of dissolved iron and other oxygen-demanding substances on designated uses are difficult to characterize in Duck Creek. For this reason, this TMDL is likely to have significant uncertainty associated with selection of numeric targets representative of the desired in-stream condition and estimates of source loadings and waterbody assimilative capacity. Recognizing this inherent uncertainty, EPA has encouraged the development of TMDLs using available information and data with the expectation that a commitment to additional monitoring will accompany the TMDL (USEPA, 1991). This approach allows proceeding with source controls while additional monitoring data are collected to provide a basis for reviewing the success of the TMDL. This approach enables stakeholders to move forward with resource protection based on existing data and less rigorous analysis.

The past and current monitoring activities in the Duck Creek watershed are outlined in the water quality analysis section of this TMDL (and in the DCMP). Although the future status of these monitoring programs is uncertain, it is anticipated that water quality and flow monitoring will continue at the USGS sampling stations in the watershed. The monitoring data collected at these sites will provide data that

- Verify the assumption that nutrients and BOD are not significant sources of oxygen demand compared to iron.
- Assess improvements in water quality.
- Establish the background condition of Duck Creek and its groundwater inflows. This TMDL assumed Tables B-3 and B-4 concentrations as background.

In addition to continued collection of data at the USGS stations, water quality monitoring by other involved state and federal agencies (e.g., ADEC, NMFS) and volunteer groups (such as DCAG) should continue in a coordinated manner.

The focus of the monitoring programs should be on the assessment of stormwater as a COD source, assessment of in-stream conditions (iron and DO concentrations, nutrients, BOD, COD) and assessment of the impacts on water quality of the planned flow augmentation and channel improvements. The monitoring will provide information on in-stream improvements and show long-term trends. Implementation monitoring is often cited as the most cost-effective of the monitoring types because it provides information on whether restoration efforts are having the desired effect on water quality. Specific projects that potentially affect water quality conditions should be monitored to determine their immediate on-site effects.

Possible Future Actions

Public Participation

The DCAG was formed in 1993 to coordinate, plan, initiate, and carry out activities to restore water quality and anadromous fish habitat in Duck Creek and its freshwater and estuarine wetlands. The DCAG provides education and facilitates work with the City and Borough of Juneau, state and federal agencies, private businesses, conservation organizations, and homeowners in the design of restoration and pollution control projects throughout the watershed. The MWP coordinates restoration projects, public education and outreach, and volunteer activities. Public attitudes and perceptions toward the importance of Duck Creek are already changing as a result of the work done by the DCAG, MWP, and other community organizations, and it is hoped that these organizations will continue their efforts in the future.

Education

Watershed education that includes discussions of regulations and ordinances could help the community better understand requirements for stream protection and help foster a sense of ownership. Land disturbances associated with development have had a wide variety of impacts, including the increased inflow of dissolved iron to the creek.

Restoration

Environmental standards and the substantial loss of aquatic resources in the watershed will require that significant restoration be done. The process of restoring the watershed can and should be used to achieve community objectives beyond compliance with environmental standards. The DCAG has identified two areas in which restoration efforts should be focused – water quality and fish habitat. It recommends that water quality restoration efforts should concentrate on the creation of wetlands to treat storm water, the development of riparian greenbelts to serve as stream buffers, and the reduction of dissolved iron levels in the stream. Specific alternatives proposed for the control of dissolved iron include capping source areas with organic fill, planting riparian and aquatic vegetation, aerating the water, and increasing the volume of flow (DCMP, 1999). Fish habitat restoration efforts should focus on the restoration of stream hydrology, including reduced flooding and increased streamflow, and improved stream crossings.

A number of demonstration projects have already been completed, including several improved stream crossings, better snow management, revegetation, sediment removal and channel reconfiguration, and wetland creation. Planned projects include additional stream crossing improvements, wetland creation and riparian zone revegetation, control of dissolved iron, streamflow restoration, streambed lining or sealing, fine sediment removal, and public access and education. The selection and implementation of restoration projects should be balanced with residents' concerns regarding drainage and flood control, while focusing on storm water treatment and wetland management. Education and stricter enforcement of existing regulations will help curtail the latter two causes of impairment.

Public Comments

This proposed TMDL is open for public comment from August 15, 2000 to September 15, 2000. People wishing to comment on the proposed TMDL should do so in writing by the close of the public comment period, September 15, 2000. All comments should include the name, address, and telephone number of the commenter and a concise statement of the comment and the relevant facts upon which it is based. Written comments must be postmarked by the close of the comment period and sent to Randall F. Smith, Director, Office of Water, USEPA Region 10, 1200 Sixth Avenue, Seattle, WA 98101. Comments may be faxed to EPA at (206) 553-0165 and e-mailed to carlin.jayne@epa.gov by the close of the public comment period.

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Appendix A: Complete List of Dissolved Oxygen Monitoring Stations

Monitoring Station	Distance Upstream (ft)	Parameters Sampled	Used in Analysis?	Notes
Dredge Lake	N/A	Coliform	No	Above watershed
Taku Blvd	16,600	DO, Coliform	Yes	
Mendenhall Blvd	15,275	DO	Yes	
Aspen Av	14,145	DO	Yes	
Duran St	13,650	DO	Yes	
McGinnis Dr	12,710	DO	Yes	
Stephen Richards Memorial Dr	11,775	DO	Yes	
Glacier Valley School	11,500	DO	No	Drains to East Fork, Rainbow Rd
Cinema Dr	10,975	DO	Yes	
Kodzoff North	10,600	DO	Yes	
Lakeside Condos	10,575	DO	No	Drains to East Fork
Kodzoff South	10,035	DO	Yes	
Nazerene Pond	9,995	DO	No	
Nancy above East Fork	8,645	DO	No	Samples limit to 1995
Nancy Pond 1	8,620	DO	No	On East Fork
Nancy Pond 2	8,590	DO	No	On East Fork, Stump Lake?
Nancy St	8,520	DO	Yes	At USGS Gage
James Blvd	7,170	DO	Yes	
Tesoro Ditch	7,000	DO	Yes	
Pumphouse	6,800	DO	Yes	
Superbear Pond	6,290	DO	Yes	
Egan Dr	5,490	DO	Yes	
Del Rae Rd	4,370	DO	Yes	
Glacier Hwy	4,150	DO	No	Not enough samples
F.A.A.	3,900	DO	Yes	
Valley Restaurant	3,600	DO	Yes	
Valley Paint	3,300	DO	Yes	

Monitoring Station	Distance Upstream (ft)	Parameters Sampled	Used in Analysis?	Notes
Professional Plaza	3,000	DO	Yes	
Berners Av	2,701	DO	Yes	
Air Cargo	2,040	DO	Yes	
Airport Blvd	1,050	DO, Coliform	Yes	
Radcliff Rd	0	DO	Yes	

Appendix B: Water Quality and Flow Monitoring Data

1994-1998 U.S. Geological Survey Streamflow Monitoring

Table B-1. Streamflow data from USGS gaging station at Nancy Street (15053200) and precipitation from NCDC Juneau International Airport Station (504100) from 1994 to 1998

Year[a]			1994		1995		1996		1997		1998	
Annual mean flow (cfs)			3.87		2.65		3.67		3.85		3.75	
Annual runoff (acre-feet/yr)			2,800		1,920		2,660		2,790		2,710	
Annual precipitation (in/yr)			68.89		46.35		60.45		74.62		53.20	
Annual precipitation (acre-feet/yr)			6,200		4,170		5,440		6,720		4,790	
Month[b]	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Flow (cfs)	1.70	2.30	2.52	2.76	2.49	2.00	2.76	3.61	6.72	7.52	3.92	4.31
Precipitation (in/month)	3.27	4.77	4.25	3.10	2.86	3.50	5.43	5.27	8.74	8.27	4.32	6.92

[a] Annual values are summarized by calendar year.
[b] Monthly values are averages for 1994 to 1998.

1997 USDA Forest Service Iron Sampling

Table B-2. Iron in groundwater seepage along Duck Creek (June 1997)

Street Crossing	Total Iron (mg/L)	Temperature (EC)
Taku Blvd	10	4.2
Mendenhall Blvd	9.5	7.4
Aspen Av	3.5	9.1
Duran St	3.5	9.8
McGinnis Dr	1.5	13.4
Stephen Richards Memorial Dr	0.5	13.8
Below Kodzoff Acres (Kodzoff South)	0.5	15.7
Nancy St (below confluence of East Fork)	2.5	16.9
Del Rae Rd	1	15.6
Berners Av	5	10
200 feet below Berners Av	9	6.6

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

1996 U.S. Geological Survey Water Quality Monitoring

Table B-3. USGS water quality monitoring data

Site	Date	NO_2 (mg/L)	NO_x (mg/L)	NH_3 (mg/L)	TKN (mg/L)	DO (mg/L)
Taku Blvd	8/26/96	<0.01	0.116	0.14	<0.20	4.1
Mendenhall Blvd	8/26/96	<0.01	0.23	0.118	<0.20	6.1
East Fork	9/2/96	<0.01	<0.05	0.044	<0.20	4.6
Cessna Dr	9/2/96	<0.01	<0.05	0.285	0.37	3

1994-1995 Alaska Department of Environmental Conservation Water Quality Monitoring

Table B-4. ADEC water quality monitoring data

Site	Date	NO_2 (mg/L)	NO_3 (mg/L)	BOD_5 (mg/L)	COD (mg/L)
Taku Blvd	10/10/94	3	0.35	<2	14.75
	2/10/95	<0.04	<0.11	3.1	28.06
	5/1/95	<0.04	0.68	3	11.79
Airport Blvd	10/10/94	0.1	0.23	<2	8.85
	2/10/95	<0.04	0.22	<2	5.26
Dredge Lake	10/10/94	0.07	0.02	<2	20.65
	2/10/95	<0.04	<0.11	<2	45.59
	5/1/95	<0.04	0.72	<2	12.23
Rainbow Road	10/10/94	0.84	0.53	<2	22.62
	2/10/95	<0.04	0.38	2	–
	5/1/95	<0.04	1	<2	10.47
Stump Pond	10/10/94	0.05	0.06	<2	2.55
	2/10/95	<0.04	<0.11	2.1	24.55
	5/1/95	<0.04	0.71	<2	9.15

1997 and 1999 Groundwater Monitoring

Table B-5. Groundwater monitoring for DO and iron

Site	Date	DO (mg/L)	Iron (mg/L)
USGS 582147134351401	9/5/97	0.50	19.4
USGS 582322134341001	9/3/97	1.80	12.2
Well 3 (near Cessna Dr)	4/7/99	4.00	0.6
	4/21/99	7.50	0.2
Well 4 (south of Berners Av)	5/26/99	3.30	0.64
	6/9/99	4.90	-
Well 17 (at El Camino St)	4/21/99	1.30	19.8
	5/5/99	1.20	21
	5/26/99	0.40	8
	6/9/99	1.40	-
Average		**2.63**	**8.18**

1994-1997 National Marine Fisheries Service and Alaska Water Watch Water Quality Sampling

Table B-6. Summary of DO monitoring data used in TMDL development

Site	Distance Upstream (ft)	No. of Obs.	Mean	Max	Min	No. of Ex-ceedances	Percent Ex-ceedances
Taku Blvd	16,600	61	5.13	14.60	1.83	48	79%
Mendenhall Blvd	15,275	55	7.58	14.12	4.00	30	55%
Aspen Av	14,145	61	7.72	14.12	5.00	29	48%
McGinnis Dr	12,710	63	8.15	14.94	1.20	17	27%
Cinema Dr	10,975	46	9.07	13.51	6.61	1	2%
Kodzoff Acres	10,600	49	9.55	15.95	4.43	2	4%
Nancy St	8,520	45	7.77	12.77	4.47	20	44%
Superbear Pond	6,290	44	8.36	14.00	3.00	14	32%
Egan Dr	5,490	41	8.43	13.85	1.07	10	24%
Del Rae Rd	4,370	27	8.32	12.54	4.00	9	33%
Berners Av	2,700	48	8.09	13.06	0.61	16	33%

Site	Distance Upstream (ft)	No. of Obs.	Mean	Max	Min	No. of Exceedances	Percent Exceedances
Air Cargo	2,040	38	7.38	13.43	1.08	19	50%
Radcliff Rd	0	19	9.00	14.00	3.00	5	26%

Appendix C: Flow Estimation Method

In the Duck Creek Hydrology Baseline Conditions report (Beilharz, 1998), flows were measured and reported at six locations for six flow regimes varying from low to high flows, and the percentage of total flow that would occur in stream segments was estimated based on the 25-year return interval. The streamflow percentages can be used in flow interpolation for the simplified model segments. Table C-1 lists the six flow regimes, and Table C-2 lists the estimated percentage of flow in each of the stream segments.

Table C-1. Flow measurements in Duck Creek under six different flow regimes

Location	Low Flow		ø		High Flow	
	3/5/96	5/31/95	4/3/95	8/16/95	8/28/96	9/11/95
Taku Blvd	0.12	0.15	0.13	0.28	0.64	1.03
Mendenhall Blvd	0.34	0.76	0.81	1.15	1.70	2.70
Stephen Richards Memorial Dr	0.35	1.72	1.85	3.37	5.75	14.60
Nancy St	0.76	2.63	3.26	6.77	12.60	25.20
Del Rae Rd	0.00	0.18	1.49	5.44	14.50	22.50
Berners Av	0.00	0.00	0.00	3.36	12.10	25.20

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

Table C-2. Estimated streamflow percentages in Duck Creek

Stream Reach	Percentage of Total Flow
Taku Blvd to Mendenhall Blvd	26%
Mendenhall Blvd to Aspen Av	30%
Thunder Mt. Rd to El Camino St	15%
El Camino St to Nancy St	82%
“East Fork” channel	16%
Nancy St to Egan Way	92%
Egan Way to Glacier Hwy	96%
Glacier Hwy to Mendenhall River	100%

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

Although derived for higher streamflows (25-year return interval flows), the percentages of total flow for Nancy Street before and after the East Fork were assumed valid for all flow levels. These are the best available data for estimating the variation in flow along Duck Creek. The simplified model simulation of Duck Creek was limited to the portion between Taku Boulevard and Nancy Street prior to the East Fork confluence, which covers three of the six flow sites in Table C-1 and 49 percent of Duck Creek. The flow in the model for Nancy Street above the confluence with the East Fork was calculated using a ratio of the appropriate percentages in Table C-2.

Model Final Flow = 0.82 * Gage Flow / 0.92

For stream locations not found in Table C-2, the flows were interpolated assuming a uniform variation in flow per meter of stream length. The USGS topographic maps show no tributaries to Duck Creek except at Nancy Street. The incremental increases in flow from location to location moving downstream were therefore assumed to come from groundwater. Groundwater inflows between the sites were assumed to have a DO of 2 mg/L based on the groundwater monitoring shown in Table B-5. An iron concentration of 10 mg/L was assumed in groundwater inflows at the three locations where the glaciomarine sediments have been exposed (Taku Boulevard, the East Fork, and below Berners Avenue). Groundwater inflows at all other points along the stream were assumed to have an iron concentration of 0.3 mg/L based on the water quality standard and data contained in an unpublished report by Dr. Randy Stahl at the University of Alaska Southeast. Table C-3 shows several channel cross sections that were proposed in the hydrologic baseline report (Beilharz, 1998). The channel width and velocity for the model were chosen from Cases 1, 2, and 3 based on which discharge was closest flow to the modeled flow.

Table C-3. Channel characteristics at various discharge levels

Discharge (cfs)	2	5	10
Channel Width (ft)	1.5	3.2	7.15
Flow Velocity	1.17	1.3	1.43
Water Depth (ft)	0.8	0.8	0.8
Stream Roughness	0.035	0.035	0.035
Stream Slope	0.002	0.002	0.002
Sideslopes	2:1	2:1	2:1

Source: *Duck Creek Hydrology Baseline Conditions* (Beilharz, 1998).

Appendix D: Simplified model Analysis of Iron and DO Dynamics

Iron Dynamics

The simplified model assumes that the assimilation of iron through oxidation and floc settling follows a first-order decay rate with stream reaeration. The Streeter-Phelps equation (Chapra, 1997) presented below was used to simulate iron dynamics.

$L = L_0 \exp(-K_{r*}x/u)$

where: L = iron concentration leaving a given stream segment
L_0 = iron concentration entering a given stream segment
$K_r = K_d$ (decay) + K_s (settling) rates
x = length of stream segment
u = flow velocity

A longer stream segment will lose more iron than a shorter segment. Similarly, a segment with a slower flow velocity will lose iron more quickly than a faster-flowing segment. And increased settling and decay rates will lead to faster decreases in iron concentration.

Dissolved Oxygen Dynamics

The simulation of DO dynamics is based on the oxygen deficit, which is the difference between saturation and actual conditons. The following equation was used to calculate DO at saturation:

$D = DO_{sat}$ -model segment DO

$DO_{sat} = \exp(-139.34+1.57E5/T -6.64E7/T^2 +1.24E10/T^3 -8.62E11/T^4)$ (Chapra, 1997)

where: T is temperature in degrees Kelvin, or 273.15 + T EC

The following equation was used to simulate DO dynamics:

$D = D_0 \exp(-K_{a*}x/u) + [K_{d*}L_0/(K_a-K_r)]*[\exp(-K_{r*}x/u) - \exp(-k_{a*}x/u)]$ (Chapra, 1997)

where: D = DO deficit leaving a given segment
D_0 = DO deficit entering a given segment
K_a = reaeration rate
L_0 = iron concentration entering a given stream segment
$K_r = K_d$ (decay) + K_s (settling) rates
x = length of stream segment
u = flow velocity

Similarly to the dynamics of the iron loss equation, a longer distance, slower flow velocity, increased iron floc settling rate, or increased iron decay rate would increase the oxygen deficit, as would a lower reaeration rate.

Reaction rates were adjusted for temperature using the following equation:

$K_T = K_{20} * 2^{(T-20)}$ where: 2 = 1.024 for reaeration and 1.047 for decay and settling.

Simplified model Calibration and Validation

The simplified model was calibrated using the flow, temperatures, and DO readings from August 18, 1995. The flows for each stream segment were calculated using the 4.2 cfs flow at the Nancy Street USGS flow gage and the flow ratios from August 16, 1995, in Table C-1. The estimated iron concentration at Taku Boulevard from June 1997 (Table 5) was used as L_0 and the measured DO reading as D_0. The decay, settling, and reaeration rates were adjusted to obtain a good comparison between the model predictions and field conditions. Figure D-1 shows the iron and DO fit for the calibration. Initial reaeration rates calculated using formulae by Churchill and O'Connor Dobbins overestimated the DO, so the rate was manually adjusted to obtain a good fit. The simplified model was validated using the data for August 15, 1997, and changing the temperatures, flows, and starting DO. A reasonable fit was obtained for these data, as shown in Figure D-2. All of the formulae used are available in Chapra (1997).

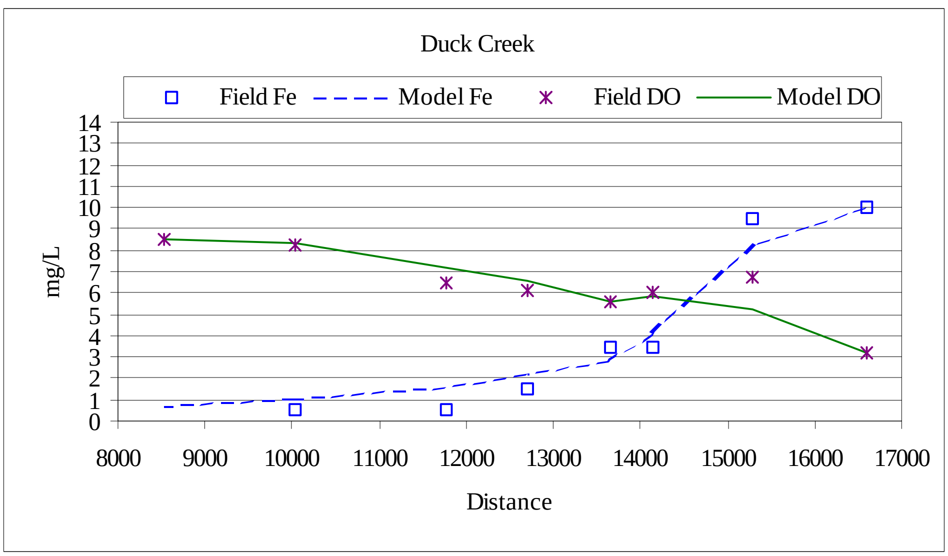

Figure D-1. Calibration of simplified model simulation of iron and DO

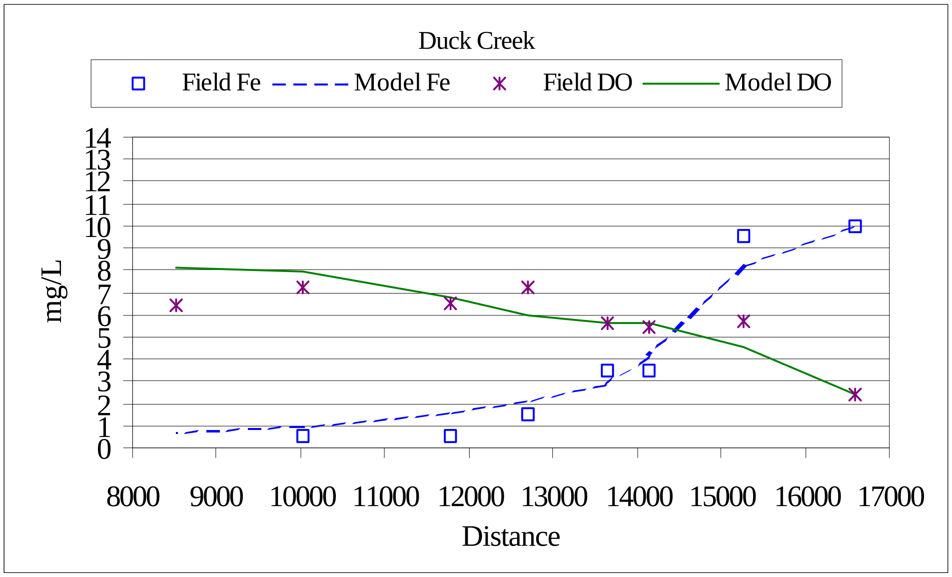

Figure D-2. Validation of simplified model simulation of iron and DO for August 1997