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

Total Maximum Daily Load (TMDL) for Turbidity 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 (EPA) is establishing a Total Maximum Daily Load (TMDL) that will significantly reduce the presence of high turbidity in Duck Creek to comply with the designated use in Alaska's water quality standards.

Signed this _17th_____ day of _December_, 1999.

________/s/____________
Randall F. Smith
Director
Office of Water

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

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December 17, 1999

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Turbidity

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TMDL AT A GLANCE:

Water Quality-limited?	Yes
Hydrologic Unit Code:	19010301
Standard of Concern:	Turbidity
Designated Use Affected:	Drinking water and agriculture, primary and secondary contact recreation, propagation of fish and aquatic life.
Environmental Indicator:	Turbidity/Total suspended solids (TSS)/suspended sediment concentration (SSC)
Major Source(s):	Urban runoff and highway maintenance practices
Loading Capacity:	Monthly loading capacities
Wasteload Allocation:	No point sources; wasteload allocation set to zero
Load Allocation:	Monthly load allocations
Margin of Safety:	Explicit MOS of 5 percent and conservative analysis assumptions

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, fecal coliform, and turbidity (ADEC, 1998). Although TMDLs will ultimately be developed for each of the pollutants, this document addresses only the turbidity impairment to the creek. (Turbidity occurs when sediment is suspended in the water.) 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 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) drinking water and agriculture, (2) primary and secondary contact recreation, and (3) propagation of fish and aquatic life (Alaska Administrative Code [AAC] § 18.70.020).

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 turbidity and suspended sediment impairment observed in Duck Creek is attributable to both watershed loadings of sediment and in-stream alterations. The stream channel has been modified extensively over time by relocating the channel, gravel mining, buildings and roads located too close to the streambank, and road crossings. Several large borrow pits and dredge ponds characterize the East Fork. The creek typically has an orange color because of iron floc. The iron floc forms mats on the streambed and stream surface. Habitat impairment in Duck Creek results to a great extent from obstructions to fish passage, removal of riparian (stream-side) vegetation, and reduced streamflow. Fish passage is hindered by improperly sized and located culverts, which impede fish movement and can result in increased mortality. Culverts also affect Duck Creek when their upstream ends are perched higher than the streambed, creating a small dam and reservoir, which reduces water velocity and prevents sediment from moving downstream. This changes the shape of the stream channel. Riparian vegetation helps maintain a healthy stream ecosystem by providing energy and structural woody debris to the stream, removing nutrients from overland and subsurface flow before they reach the stream, and

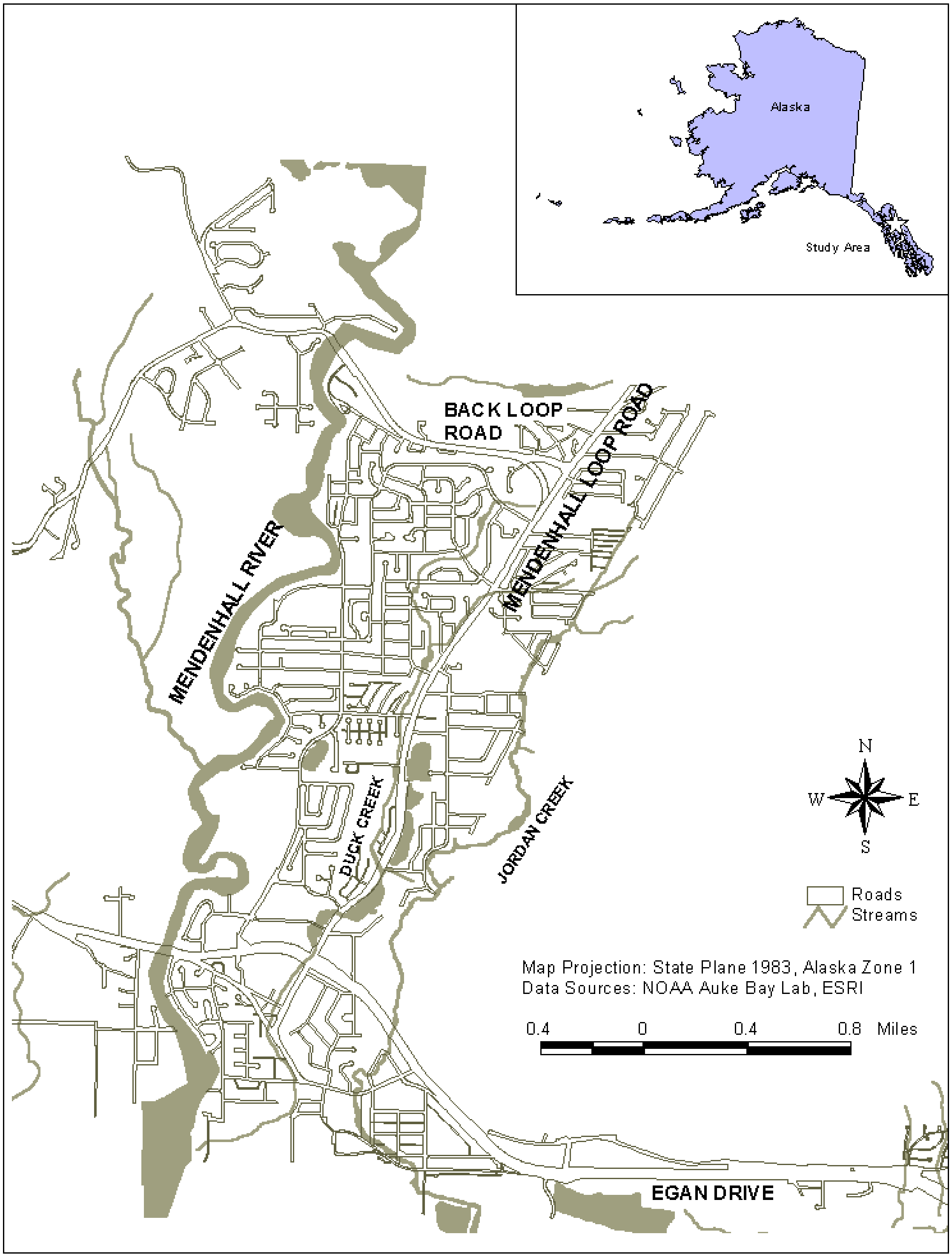

Figure 1: Location of the Duck Creek watershed

regulating streamflow. The removal of riparian vegetation eliminates these beneficial functions and can lead to habitat degradation. Streamflow alterations such as ditching, channel relocation, and collecting stormwater and diverting it outside of the Duck Creek watershed have also contributed to habitat impairment in Duck Creek. Combined with highly permeable reaches of streambed where the creek may drain through the bottom of the stream, 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

The Duck Creek watershed consists of approximately 1,080 acres, 36 percent of which is covered with 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, commercial, or industrial 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 and industrial (282 acres), and recreation and wetland (175 acres.)

Climate

Historical climate data are available from the Juneau International Airport (Station number 504100), adjacent to the lower reach of Duck Creek. The temperature ranges from a normal daily minimum temperature of 19 ^{o}F in January and 48 ^{o}F in July to a normal daily maximum temperature of 29 ^{o}F in January and 64 ^{o}F 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 and is characterized by frequent cycles of freezing and melting. 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 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. The most stringent of the standards, with respect to turbidity, is for water supply.

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

Applicable Water Quality Criteria and Numeric Target
Tables 1 and 2 present Alaska's applicable numeric and narrative state water quality criteria for Duck Creek's designated uses for turbidity and sediment. Because Alaska's water quality standards do not establish specific numeric criteria for turbidity, a site-specific target has been established using the median value of turbidity data collected at Taku Boulevard as part of the Alaska Water Watch Program. Taku Boulevard is the most upstream sampling station in Duck Creek and is located near the edge of the developed portion of the watershed; it is also strongly influenced by groundwater recharge. Consequently, this station is assumed to reflect natural baseline turbidity values for the creek. The median value of the turbidity data was selected instead of the mean because a few of the data points were significantly higher than most of the data points. Turbidity from a comparable nearby stream had extremely low (<1.0 nephelometric turbidity units, or NTU) turbidity, which indicates the high measurements at Taku may be influenced by other factors. Thus the median value at Taku is more likely to capture the baseline turbidity value for Duck Creek.

Turbidity measurements made as part of the Alaska Water Watch program at the Taku Boulevard station between January 1992 and July 1993 range from 0.62 NTU to 20.6 NTU with a median value of 4.4 NTU. Alaska's applicable water quality criterion for turbidity states that it:

> *May not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than a 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 25 NTU.*

Therefore, the water quality target for turbidity (ADEC, 18 AAC 70.020(b)) used in this Duck Creek TMDL is 4.4 NTU + 5 NTU, or 9.4 NTU.

Because the problems associated with excessive turbidity are linked to sediment loading from watershed sources, the sediment criteria were also considered for use as an indicator for this TMDL. However, because of the lack of available data to characterize streambed sediment characteristics, the turbidity criterion listed above was selected as the most appropriate numeric target for the TMDL.

Table 1: Applicable Alaska state turbidity water quality criteria.

Designated Use	Turbidity
Drinking Water	≤ 5 NTU above natural conditions when the natural turbidity ≤ 50 NTU
	≤ 10% increase in turbidity (not to exceed a maximum increase of 25 NTU) when the natural turbidity > 50 NTU
Agriculture	May not cause detrimental effects on indicated use
Primary Contact Recreation	≤ 5 NTU above natural conditions when the natural turbidity ≤ 50 NTU
	≤ 10% increase in turbidity (not to exceed a maximum increase of 15 NTU) when the natural turbidity > 50 NTU
Secondary Contact Recreation	≤ 10 NTU above natural conditions when the natural turbidity ≤ 50 NTU
	≤ 20% increase in turbidity (not to exceed a maximum increase of 15 NTU) when the natural turbidity > 50 NTU
Propagation of Aquatic Life and Wildlife	May not exceed 25 NTU above natural conditions

Table 2: Applicable Alaska state sediment water quality criteria.

Designated Use	Sediment
Drinking Water	No measurable increase in concentration of settleable solids above natural conditions, as measured by the volumetric Imhoff cone method.
Agriculture	For sprinkler irrigation, water must be free of particles of 0.074 mm or coarser. For irrigation or water spreading, may not exceed 200 mg/L for an extended period of time.
Primary Contact Recreation	No measurable increase in concentration of settleable solids above natural conditions, as measured by the volumetric Imhoff cone method.
Secondary Contact Recreation	May not pose hazards to incidental human contact or cause interference with the use.
Propagation of Aquatic Life and Wildlife	The percent accumulation of fine sediment in the range of 0.1 mm to 0.4 mm in the gravel bed of waters used by anadromous or resident fish for spawning may not be increased more than 5 percent by weight above natural conditions. In no case may the 0.1 mm to 0.4 mm fine sediment range in those gravel beds exceed a maximum of 30 percent by weight.

Turbidity is an optical measure of water related to light transmission and is a measure of the total amount of light-scattering particles in a water sample. It does not lend itself to developing a loading capacity and load allocations to different sources. Other measures of sediment in a stream, such as TSS (total suspended solids) and SSC (suspended sediment concentration) serve better in establishing targets. TSS refers to solids that are not in true solution and can be removed by filtration. Such suspended solids usually contribute directly to turbidity. SSC consists of very fine soil particles that remain in suspension in water for a considerable period of time without contact with the bottom. Such material differs from TSS in that TSS also includes organic particles while SSC accounts for only mineral particles.

Because turbidity does not work well as the basis for calculating a target loading capacity, a turbidity TMDL normally uses TSS to establish the target. If TSS data are not available, SSC may be used. Local TSS (or SSC) data provide a measure of the amount of sediment suspended in the stream at a given moment in time. The data can be used to develop a statistical relationship between turbidity and either TSS or SSC. This relationship should be based on local data because it can vary significantly from stream to stream.

Because of various data limitations for Duck Creek, this TMDL could not establish a relationship between turbidity and TSS or SSC using local data. Furthermore, little TSS data were available. Thus this TMDL relies primarily on turbidity and SSC data from Duck Creek and is supplemented by established relationships from relevant literature.

In reviewing literature for relationships between turbidity, TSS and/or SSC in Alaska, one pertinent study was found. This study, Lloyd et al. (1987), developed a relationship between turbidity and SSC in non-glacial streams in interior Alaska. For lack of better information, this estimate is used in this TMDL. Still, it does not address the relationship between TSS and SSC data for Duck Creek.

Usually the relationship between TSS and SSC also is developed statistically using local data. A 1:1 ratio of TSS to SSC indicates that organic inputs are insignificant relative to the overall sediment load. Organic inputs in Duck Creek include leaf litter from shrubs and trees, waste from ducks and other animals, and iron oxidizing bacteria. It is possible that organic inputs could be significant. However, based on discussions with ADEC staff, and in light of the lack of data to support the selection of a particular ratio, this TMDL assumes a 1:1 ratio between TSS and SSC. While this relationship may underestimate the amount of sediment in Duck Creek, the five percent margin of safety and other conservative assumptions should be adequate to compensate.

Critical Conditions

Many species are potentially affected by turbidity and the accumulation of fine sediment, and selection of an indicator species is frequently done 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 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 flow (Lorenz, 1998). Once the salmon have migrated to their natal stream, the female digs a nest, called a redd, and deposits eggs that are fertilized with sperm by the male. 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 may 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 impaired status of the waters of Duck Creek affect the life cycle of coho salmon at three critical periods. First, adult salmon entering the creek to spawn during periods of high runoff are likely to encounter high levels of turbidity and suspended sediment. Cordone and Kelley (1961) have found that migrating salmonids avoid waters with high silt loads or cease migration when such loads are unavoidable. This first critical period takes place between July and November (Figure 2). Second, to survive, salmon eggs must be deposited in porous substrate that allows a constant exchange of cool water supplying dissolved oxygen and removing wastes. The cementing action of too much sand or silt in the substrate makes it difficult for adults to excavate redds, can limit intragravel flow, and can trap emerging fry. Sedimentation from urban development has heavily impacted spawning habitat in Duck Creek, where up to 30 percent more fine sediments are present than in either Steep Creek or Jordan Creek (Koski and Lorenz, 1999). As a result of sedimentation and low dissolved oxygen levels, egg to fry survival of coho salmon in the creek is close to zero, and nearly all coho rearing in Duck Creek migrated there from outside the watershed (Lorenz, 1998). The critical period for this life cycle stage is from hatching to fry emergence, which takes place between January and May (Figure 2). The third critical period in the coho salmon life cycle is the migration of smolt to sea. Because of inadequate flow in the lower reaches of Duck Creek during spring months (April to June), 66 percent of the smolt that migrate from the creek each year require assistance getting to sea (they are carried in buckets) and 25 percent die (Koski and Lorenz, 1999). This final critical period is attributable more to the disruption of flow in the creek than to excessive turbidity. As a result, the critical periods in the coho life cycle that are susceptible to turbidity impairments are from July to November and from January to May (Figure 2).

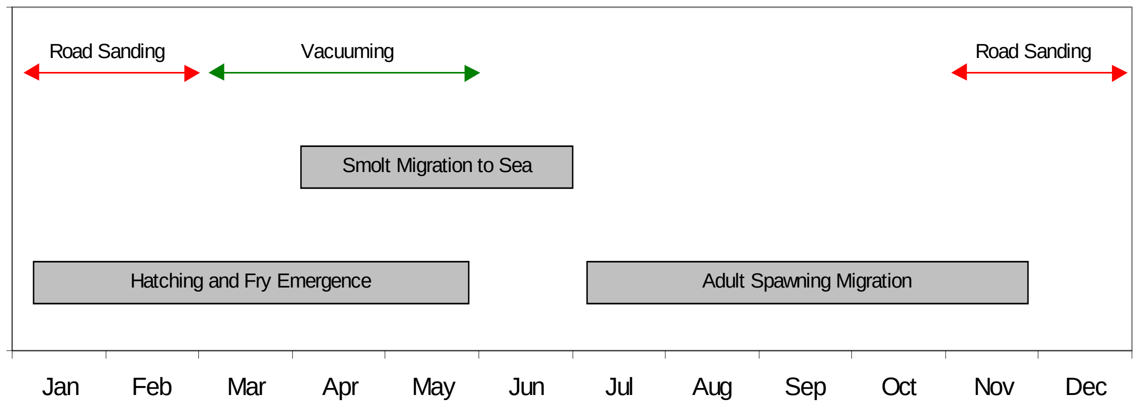

Figure 2. Winter road maintenance activities and critical periods for the salmon fishery

Water Quality Analysis

Water Quality Data

The data available for assessing the condition of Duck Creek, as well as for establishing a scientifically based desired in-stream condition, are described in this section. In general, the data available for the development of a turbidity TMDL for Duck Creek are characterized by spatially and temporally periodic water quality samples collected and analyzed for various pollutants, including turbidity, TSS, and SSC. Because the better data sets measured SSC, these data are being used as a surrogate measure for turbidity based on a relationship presented in Lloyd et. al. (1987) for several Alaskan streams. In some cases, the quality of the Duck Creek data has been questioned by the laboratory or 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 turbidity TMDL were reviewed and are summarized in this section.

<u>1992-1993 Alaska Water Watch-Water Quality Monitoring in Duck Creek:</u>
During 1992 and 1993, local students from Juneau Youth Services, Miller House, collected water quality samples at nine sites in Duck Creek. The geographic locations of the stations within Duck Creek are referenced by street names and are presented in Figure 3. Parameters measured include water temperature, DO, pH, turbidity, specific conductivity, alkalinity, and fecal coliform bacteria. Table 3 summarizes turbidity measurements taken at all nine sites. The turbidity data collected at these sites did not have any corresponding flow, TSS, or SSC data, and the period of record did not have temporal overlap with the flow data collected at the Nancy Street U.S. Geological Survey (USGS) gaging station.

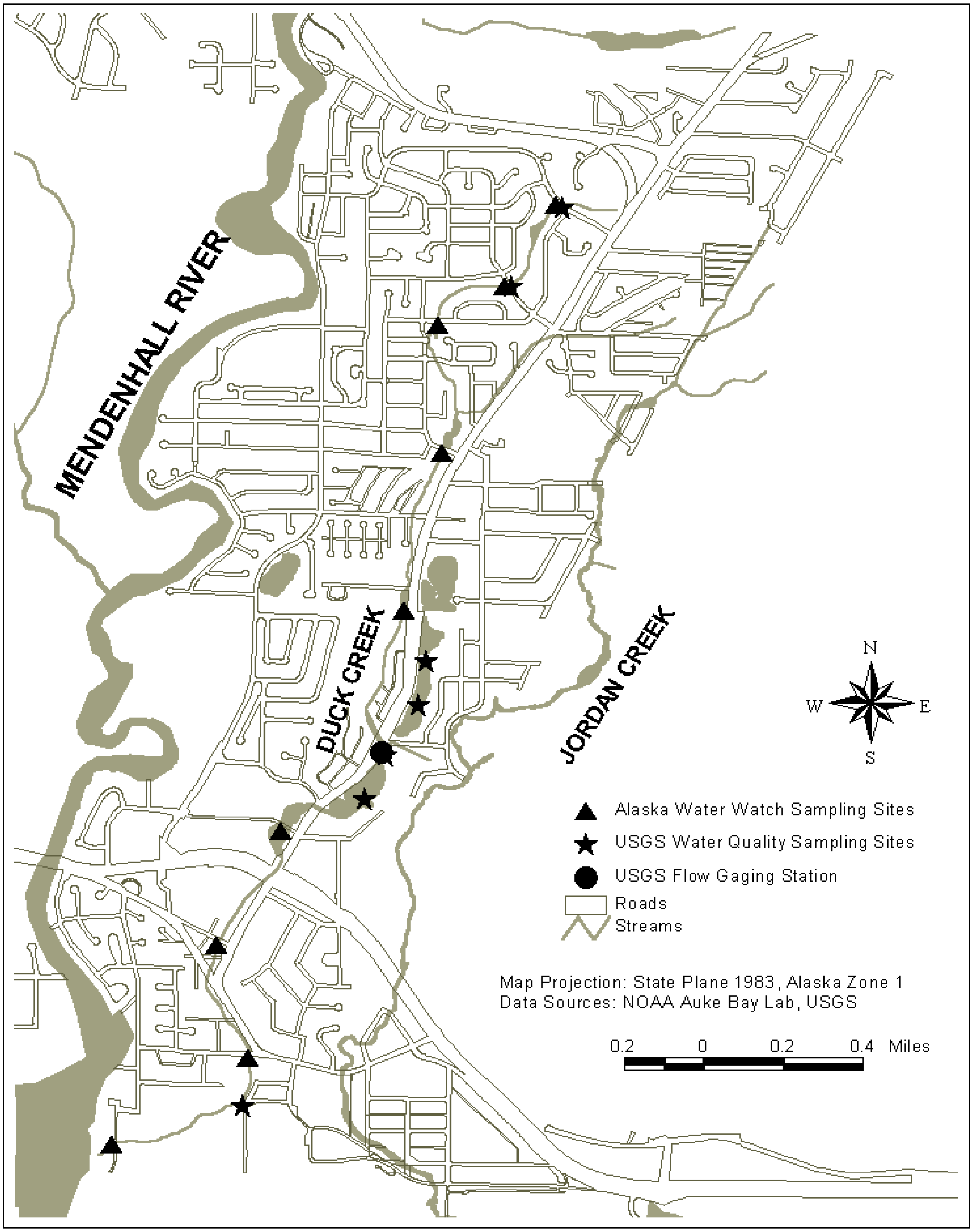

Figure 3. Location of sampling stations in Duck Creek.

Table 3. Summary of turbidity data for Alaska Water Watch Sites (1/7/1992 to 7/13/1993)

Turbidity (NTU)	Number of Obs.	Median Value	Mean Value	Maximum Value	Minimum Value	Standard Deviation
Site 1: Taku	14	4.35	6.69	20.6	0.67	6.61
Site 2: Mendenhall	10	6.85	8.75	23	1.45	7.01
Site 3: Aspen	15	12.9	18.7	50.5	2.5	17.0
Site 4: McGinnis	15	14.3	17.5	62.3	1	14.8
Site 5: Kodzoff	13	11	14.9	45	1.3	14.0
Site 6: Mendenhall Mall	13	17.4	16.9	30.1	4.3	6.29
Site 7: Del Rae	10	12.6	16.5	57.5	1.9	15.5
Site 8: Berners	13	12.77	16.8	40	7.57	10.7
Site 9: Radcliff	8	14	24.8	67.4	5.39	23.7

1994-1998 USGS Water Quality Sampling and Flow Gage Monitoring

Daily streamflow has been measured since December 1993 at a USGS gaging station (15053200) located downstream of Nancy Street in the Duck Creek watershed (Figure 3). 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. Table 4 shows annual and monthly average flows and precipitation for 1994 to 1998.

Peak monthly discharges and precipitation in the watershed occur on average during the months of September and October (Table 4). This represents the period of maximum runoff and increased nonpoint source pollutant loading from areas in the Duck Creek watershed. In addition to peak flow, low flow periods in the watershed are critical when they coincide with the fish migration or spawning seasons.

Table 4. Streamflow data from USGS gaging station at Nancy Street (15053200) and precipitation from NCDC Juneau International Airport Station (504100) from 1994 to 1998.

Annual Average Flow[a]											
							1994	**1995**	**1996**	**1997**	**1998**
Annual mean flow in cfs							3.87	2.65	3.67	3.85	3.75
Annual runoff in acre-feet/year							2,800	1,920	2,660	2,790	2,710
Monthly Average Flow for 1994-1998 (cfs)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.70	2.30	2.52	2.76	2.49	2.00	2.76	3.61	6.72	7.52	3.92	4.31
Annual Average Precipitation[a]											
							1994	1995	1996	1997	1998
Annual mean precipitation in inches/year							68.89	46.35	60.45	74.62	53.20
Annual precipitation in acre-feet/year							6,200	4,170	5,440	6,720	4,790
Monthly Average Precipitation for 1994-1998 (inches/month)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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] Data summarized by calendar year.

In addition to streamflow, USGS also monitors water quality at seven stations in the Duck Creek watershed (Figure 3). SSC was measured at only two locations, and turbidity and TSS were not measured at any of the sites. A summary of the water quality data for SSC at these stations is presented in Table 5.

Table 5: SSC at USGS water quality monitoring stations in the Duck Creek watershed.

Station ID	Station Location	No. of Obs.	Avg. Value (mg/L)[a]	Max	Min	Std. Dev.	Years Covered
15053170	Duck C at Taku Blvd nr Auke Bay AK	7	18	70	1	24	1994, 1996
15053200	Duck C Bl Nancy St nr Auke Bay AK	14	11	19	5	4.4	1994, 1996-98

[a] Samples evaporated at 110 ^{o}C.

Several other data sets were reviewed (see Appendix A) and were not used in this TMDL for turbidity in Duck Creek.

Pollutant Sources

An assessment of potential sediment sources is needed to evaluate the type, magnitude, timing, and location of sediment loading to Duck Creek. A number of factors were considered in conducting the source assessment, including identifying the various types of sources (e.g., point, nonpoint, background), 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. The evaluation of loadings is often performed 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. The selection of an appropriate method for determining sediment loads to Duck Creek was based on the availability of monitoring data and the management objectives under consideration in the DCMP.

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 within the Duck Creek watershed.

Nonpoint and Natural Sources

The 1998 Alaska § 303(d) list identifies the primary sources of impairment as urban runoff and runoff from winter road maintenance. For each of these nonpoint sources, an estimate of the sediment load has been developed for comparison with the in-stream loading capacity calculated for Duck Creek.

In addition to sediment and other solids that are delivered to a stream from watershed sources, a certain amount of sediment originates and is transported and stored within a stream system as part of its normal functioning. The natural ability of the stream system to manage these materials becomes taxed as the magnitude of the sources increases or the hydrologic capacity of the stream to assimilate the loadings becomes impaired. Several nonpoint watershed sources have been identified in the Duck Creek watershed. It has been observed, and is evident in the impairment to Duck Creek, that the loading from watershed sources has exceeded the system's ability to function properly. While watershed sources clearly contribute to the turbidity and sediment impairment to Duck Creek, in-stream sources also contribute to this impairment and must be considered in development of the TMDL. Bedload transport and streambank erosion were considered as in-stream sources, but no data were found for either source. However, because Duck Creek is a low gradient stream, bedload transport and stream bank erosion are considered relatively insignificant sources of sediment. The in-stream source of primary concern is groundwater-discharged iron that precipitates as iron floc which is then available for resuspension. Other possible in-stream sources that could contribute to turbidity include leaf detritus and organic enrichment from wildlife (e.g., ducks).

Although the nature of the sources and the limited amount of data available do not allow the development of an exact estimate of sediment available for delivery to the creek, the analysis presented here does provide an indication of the relative contribution of major pollutant sources and the gross watershed reductions needed to attain water quality standards. The watershed loading was estimated in two ways: (1) by calculating the in-stream sediment load based on available SSC data and (2) by calculating watershed loads using information on land uses. The loading analysis conducted using in-stream measurements of SSC provides an estimate of the existing sediment load, accounting for various in-stream processes (e.g., transport, deposition) that affect the fate of sediment delivered to the stream from the watershed. However, the in-stream analysis does not provide any insight into the relative contributions from sources within the watershed. An analysis of land use-based loadings was conducted to determine these relative contributions. The combination of in-stream sediment loads and land use-specific sediment loads generated from both of these analyses provides the basis for the load reduction assumptions and calculations presented in this report.

Analysis of In-stream Data

Instream SSC and flow values were used to estimate instream sediment loads in Duck Creek. However, the available data on in-stream SSC in Duck Creek are very limited. Data are completely lacking for flows below 5 cfs, which account for almost 80 percent of the flow observations from 1994 to 1998. As a result, the following approach was taken. Flow observations were grouped into three categories–less than 5 cfs, between 5 and 15 cfs, and 15 cfs and greater–and a SSC was applied to each flow category. The categories were chosen by examining the flow distribution of the 14 available SSC observations: seven of those observations were collected at flows above 15 cfs, seven were collected at flows between 5 and 15 cfs, and no observations were available for flows below 5 cfs. The maximum observed SSC was applied to each category, resulting in 12 mg/L SSC for flows less than 15 cfs and 19 mg/L SSC for flows greater than 15 cfs. Given the lack of SSC observations at flows below 5 cfs, a concentration of 12 mg/L SSC at low flows was assumed, providing a margin of safety for the load estimated at these flows. Table 6 summarizes the selected flow categories and their corresponding SSCs.

Table 6: Flow categories and SSC used to determine existing suspended sediment loads.

Flow category	Frequency of Flow Occurrence	Number of SSC Observations	Maximum SSC
Less than 5 cfs	78%	0	12 mg/L[a]
Between 5 and 15 cfs	21%	7	12 mg/L
Greater than 15 cfs	1%	7	19 mg/L

[a] Conservative assumption based on data at higher flows.

These flow categories were selected with the goal of developing a daily suspended sediment loading record for 1994 through 1998 by applying the appropriate concentration to the daily flow record at Nancy Street (USGS Station number 15053200.) Inspection of the data presented in Table 6, however, indicated that a continuous five year daily sediment loading record would be developed based on 14 SSC observations at flows representing only 21 percent of the observed flow range. Instead, EPA selected an alternate approach, to estimate the suspended solids loading to Duck Creek based on watershed processes.

Iron in Groundwater Entering Duck Creek

Iron concentrations vary along the length of Duck Creek and violate Alaska's state standards at several locations. Elevated iron concentrations can affect turbidity and streambed sediment, both of which in turn affect aquatic life in Duck Creek. Iron can also rob a stream of dissolved oxygen. It may be having such an affect on Duck Creek, as the water quality violation most often cited in Duck Creek is the exceedance of the water quality standard for dissolved oxygen (Koski and Lorenz, 1999).

Iron enters Duck Creek through groundwater at various locations along the creek. The iron is picked up by groundwater as it travels through the marine sediments underlying portions of the Duck Creek watershed (Stahl, 1999). The iron in these marine sediments commonly exists 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 red staining of the water and streambed and by the formation of iron-floc (Koski and Lorenz, 1999, Stahl, 1999, Lorenz, 1998).

Iron in groundwater is primarily found in the soluble (ferrous) form due to the low levels of oxygen (Stahl, 1999). This soluble iron is environmentally important because it can easily move through the groundwater and be transported 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). The floc covers the stream substrate causing sedimentation and a red staining effect (Lorenz, 1998).

The sources, fate, and transport of iron in Duck Creek are important to the turbidity TMDL because iron floc has been identified as one of the major sources of fines in the creek (Koski and Lorenz, 1999). These fine particles, which also include various mineral soils and organic matter, cause impairments by clogging of spawning gravels, filling pools, and potentially transporting toxic pollutants. A study conducted in Duck Creek between Mendenhall Mall Road and Taku Boulevard found that the substrate contained high levels of fine sediment and high concentrations of iron floc. The iron floc, as well as the fine sediment, present in the stream bottom can easily be resuspended during periods of increased flow velocity (e.g., storm events or snow melt), movement by wildlife, or other activity, which can result in increased turbidity. Although it is likely that iron floc contributes to the turbidity impairment of Duck Creek, the extent and magnitude of this contribution is unknown.

Lacking data that characterize the spatial and temporal trends of iron concentrations in the creek, the contribution of iron floc to turbidity could not be quantified for this TMDL. Instead, the TMDL identifies, using the best available data, the locations where iron floc problems have been observed but not necessarily measured.

At some locations within the creek (i.e. below Nancy Street) the water has been observed to appear orange due to suspended iron floc (Beilharz 1998). The stream reaches with the heaviest inflow of groundwater with high concentrations of dissolved iron are the areas where there have been excavations of the channel or ponds. These excavations often exposed the underlying floodplain and glaciomarine deposits.

The highest concentrations of dissolved iron are at seeps along the streambank before it is converted to floc. This is the case above Taku Boulevard, below Berners Avenue, and in the East Fork ponds. The sites with the highest iron levels in the water are Taku Boulevard (10 mg/L), Mendenhall Mall Road (9.5 mg/L), and 200 feet below Berners Avenue (9 mg/L). Iron concentrations decrease as the stream size increases, down to Berner's Avenue, where concentrations begin to increase again. The upper watershed tends to have very high concentrations of dissolved iron at the groundwater discharge sites.

Watershed-Based Loading Estimate

The primary source of sediment to Duck Creek is urban runoff (Koski and Lorenz, 1999). The quality of urban runoff is greatly affected by land use practices within the watershed and the proximity of these land uses to the waterbody. To develop the loading estimate for urban runoff in the Duck Creek watershed, the watershed land uses were taken from the DCMP and grouped into the following land use categories: (1) residential, (2) commercial/industrial, (3) transportation, and (4) recreation and wetlands (Lorenz, 1998). The information presented by the DCMP (Lorenz, 1998) provides general land uses for the Duck Creek watershed and does not include the spatial distribution of the land uses or the overall areas for each. The land use areas presented in Table 7 were estimated based on the general descriptions provided by the DCMP (Lorenz, 1998).

The table also includes information from Bannerman et al. (1983, 1993) used to develop the sediment loading estimates. Bannerman has conducted extensive research into the contaminants found in urban stormwater runoff from various source areas in several Wisconsin watersheds. The two papers cited in this study (Bannerman et al., 1983 and 1993) provide land use-specific estimates of sediment in runoff, measured as TSS concentrations in mg/L. As discussed previously in the Applicable Water Quality Criteria section, TSS is one measure of the amount of sediment in the stream. It is a more complete measure of suspended particles in runoff than SSC, since TSS includes organic matter. Thus this TMDL uses TSS estimates to evaluate the impacts of runoff from the various sources of sediment, and for the loading capacity and allocations. In-stream data from Duck Creek, which is primarily available as SSC, is translated into TSS measurements.

Table 7. Land use distribution in the Duck Creek watershed and typical concentrations of TSS in runoff.

Land Use	Area (acres)[a]	TSS Concentration (mg/L)
Residential	540	199[b]
Commercial/Industrial	282	107[b]
Transportation	83	535[b]
Recreation/Wetland	175	195[c]

[a] Estimated from Koski and Lorenz, 1998.
[b] Estimated from Bannerman et al., 1993.
[c] Estimated from Bannerman et al., 1983.

Table 8 presents monthly suspended solids loading estimates calculated for the land use categories within the Duck Creek watershed. These values were calculated by determining a runoff coefficient for each land use based on its estimated percent impervious area. The runoff coefficient determined for each land use was then applied to the average monthly precipitation from 1994 to 1998 to obtain the volume of runoff by land use type. The TSS concentrations in Table 7 were then applied to the runoff volume to calculate the monthly TSS load from each land use type. The values in Table 8 represent an estimate of the baseline suspended solids loadings for each category and do not account for winter road sanding activities.

An additional load representing the contribution of winter road sanding operations was calculated for the transportation land use category. The following section presents the methodology used to estimate sediment loading from winter road sanding operations for the transportation land use.

<u>Winter Road Maintenance Load Estimate</u>

Another major source of sediment to Duck Creek is the application of sand to road surfaces, which generally occurs from November through February (ADOT&PF, 1999.) The volume of sand applied and the location of sand applications–primarily on two major roads (one of which runs along the stream for most of its length), at intersections near the stream and areas with numerous stream crossings, and at snow dumps–facilitate the transfer of sediment to the stream. As a result, a higher proportion of the road maintenance sediment load estimate is expected to be delivered to the stream than of the estimated loads from other land uses.

Table 8. Monthly average available TSS (tons) from urban runoff.

Month	**Residential**	**Commercial/ Industrial**	**Transportation**	**Recreation/ Wetland**
January	4.6	2.0	1.1	0.2
February	6.7	2.9	1.6	0.3
March	5.9	2.6	1.4	0.3
April	4.3	1.9	1.0	0.2
May	4.0	1.7	1.0	0.2
June	4.9	2.1	1.2	0.2
July	7.6	3.3	1.8	0.3
August	7.4	3.2	1.8	0.3
September	12.2	5.3	2.9	0.5
October	11.6	5.0	2.7	0.5
November	6.0	2.6	1.4	0.3
December	9.7	4.2	2.3	0.4
Total Annual	**84.8**	**36.6**	**20.1**	**3.6**

Sand and gravel are applied to roads by the Alaska Department of Transportation and Public Facilities (ADOT&PF) and the City and Borough of Juneau (CBJ) during the months of November, December, January, and February. The amount of sand and gravel applied in the watershed was estimated to demonstrate the potential magnitude of this source. The estimate was developed using an application rate of 1.0 yd^3 per lane-mile based on information provided by ADOT&PF (1999) and CBJ (1999), and obtained through personal communication with Carl Schrader (ADEC, September 22, 1999), and represents the high end of the range of application rates.

ADOT&PF applies sand to two major sections of road in the Duck Creek watershed: the intersection of Egan Drive and Mendenhall Loop Road, and the section of Old Glacier Highway from Berners Avenue to Egan Drive. The estimate for the sand and gravel applied to these areas by ADOT&PF is as follows:

Egan Drive/Mendenhall Loop Road Intersection:

Road miles treated x lanes x applications x volume of material per lane-mile x density of material applied
(0.3 miles) x (4 lanes) x (48 applications) x (1 yd^3 per lane-mile) x (1.3 tons per yd^3) = 75 tons

Old Glacier Highway from Berners Avenue to Egan Drive:

Road miles treated x lanes x applications x volume of material per lane-mile x density of material applied
(0.5 miles) x (2 lanes) x (32 applications) x (1 yd^3 per lane-mile) x (1.3 tons per yd^3) = 42 tons

The total material applied by ADOT&PF is therefore 117 tons per year.

In addition to the state's maintenance of the main roads, the CBJ provides maintenance services to secondary roads. It is estimated that the city applies approximately 13 tons of sand and gravel per season to secondary roads and side streets. This yields a total Duck Creek watershed (state and city maintenance) sand and gravel application of 130 tons per year. This value represents a conservative estimate (more likely to overestimate than to underestimate) of the total material applied to roads within the Duck Creek watershed. Only a portion of this material is likely to be delivered to the creek and to contribute to turbidity problems.

The material applied by both agencies is a mix of sand and gravel. It is important to characterize the material used because the size of the particles affects both the potential for delivery to the stream and the potential to contribute to the in-stream turbidity problem. The material applied by ADOT&PF is dominated by sand, since the application of large amounts of gravel on major roadways would be likely to damage vehicles traveling at high speeds. The ADOT&PF material consists of 15% gravel (4.75 mm to 9.5 mm), 83% sand (0.075 mm to 4.75 mm) and 2% silt and clay (less than 0.075 mm) (ADOT&PF, 1999). Because the city maintains secondary roads, it is able to apply material containing a higher proportion of gravel than sand. The CBJ material consists of 40% gravel (4.75 mm to 9.5 mm), 50% coarse sand (2.37 mm to 4.75 mm), 9.5% fine sand (0.075 mm to 2.37 mm) and 0.5% silt and clay (less than 0.075 mm) (CBJ, 1999).

In order to assess the potential impact of the particles described above on turbidity in Duck Creek, a distinction must be made between particles small enough to be suspended and thus to contribute to turbidity, and larger particles that will settle out of the water column under normal flow conditions. According to Dunne et al. (1978), particles smaller than 0.5 mm in diameter will remain suspended in flowing waters. The distributions provided by ADOT&PF and CBJ were broken out into the following particle size classes using linear interpolation: gravel (4.75 mm to 9.5 mm), coarse sand (0.5 mm to 4.75 mm), fine sand (0.075 mm to 0.5 mm), and silt and clay (less than 0.075 mm). Only the fine sand and silt and clay size classes are likely to contribute to in-stream turbidity under normal flow conditions. Particles in the coarse sand class could, however, become suspended during high flow conditions. These particles also contribute to the habitat impairment in Duck Creek by making redd excavation more difficult, limiting intragravel flow, and trapping emerging fry. As a result, the coarse sand, fine sand, and silt and clay particle classes all have the potential to impact turbidity and habitat quality in Duck Creek. Table 9 presents the particle size distributions and masses of road sanding material applied to roads in the watershed.

Table 9. Particle size distributions of material applied to roads by ADOT&PF and CBJ.

Particle Class	Size Range (mm)	ADOT&PF (%)	ADOT&PF (tons)	CBJ (%)	CBJ (tons)	Total (tons)
Gravel	4.75 - 9.5	15.0%	17.6	40.0%	5.2	22.8
Coarse Sand	0.5 - 4.75	75.5%	88.3	57.7%	7.5	95.8
Fine Sand	0.075 - 0.5	7.5%	8.8	1.8%	0.2	9.1
Silt and Clay	< 0.075	2.0%	2.3	0.5%	0.1	2.4
All	0 - 9.5	100.0%	117.0	100.0%	13.0	130.0

The total sand, silt and clay applied in the watershed is therefore estimated as 107 tons. It was assumed that material in each particle class could be pulverized by vehicular traffic and transported as smaller particles. It was assumed that 20 percent of each particle class applied by ADOT&PF and 10 percent of each particle class applied by CBJ is ground into the next smaller particle class. A higher percentage of ADOT&PF material is assumed to be pulverized due to greater vehicular traffic on the main roads maintained by ADOT&PF than on the secondary roads maintained by CBJ. The particle size distributions of material after pulverization are presented in Table 10 and bring the total amount of sand, silt and clay applied to the roadways to 111 tons.

Table 10. Particle size distributions of material applied to roads after pulverization.

Particle Class	Size Range (mm)	ADOT&PF (%)	ADOT&PF (tons)	CBJ (%)	CBJ (tons)	Total (tons)
Gravel	4.75 - 9.5	12.0%	14.0	36.0%	4.7	18.7
Coarse Sand	0.5 - 4.75	63.4%	74.1	56.0%	7.3	81.4
Fine Sand	0.075 - 0.5	21.1%	24.7	7.4%	1.0	25.7
Silt and Clay	< 0.075	3.5%	4.1	0.7%	0.1	4.2
All	0 - 9.5	100.0%	117.0	100.0%	13.0	130.0

Once this material is applied to roadways, practices associated with road maintenance can influence its delivery to Duck Creek. Snow dumps, the practice of plowing snow from roadways to centralized storage sites, can provide a chronic source of sediment, particularly when they are located in close proximity to the creek. When located near the creek, snow dumps act as low discharge point sources, delivering sediment directly to the stream through snowmelt. Information on the amount of snow and the sand content in the snow dumps located in the Duck Creek watershed was not available, but it is known that snow dumps are only employed by CBJ and not by ADOT&PF. It was assumed that 10 percent of the available material (1.3 tons) is stored in snow dumps close enough to Duck Creek to be directly delivered to it during the spring snowmelt, and that 0.8 tons of that material has the potential to contribute to turbidity. As they melt, snow dumps are assumed to deliver an estimated monthly load of 0.3 tons of sand, silt and clay to Duck Creek during the months of March, April and May.

Other practices that result in the direct delivery of sand, silt and clay to Duck Creek include the plowing of snow directly into the stream and vehicular sidecast. Although it is assumed that the practice of plowing snow directly into the stream does not occur throughout the watershed, an estimate of sediment loading was developed. An analysis of road-stream crossings in the watershed revealed that approximately one percent of the total road surface area is located within ten feet of Duck Creek. As a result, it was assumed that one percent of the road sanding material is delivered to Duck Creek by vehicular sidecast, while four percent is delivered by plowing, for a total of five percent delivered directly to the stream. The loading estimate from this source is 6.5 tons, 5.6 tons of which is sand, silt and clay. The load is assumed to be delivered from December through February, for a monthly load of 1.9 tons of fine sand, silt and clay in each of these months.

A portion of the remaining 122 tons (total material applied [130 tons] minus material in snow dumps [1.3 tons] and material delivered to the creek by sidecast and plowing [6.5 tons]) is vacuumed up each spring by ADOT&PF and CBJ. Street cleaning is estimated to remove 32.5 tons of the material applied by ADOT&PF and 6.5 tons of the material applied by the CBJ, and is completed by the end of May each year. The remaining 83 tons of material are assumed to be available for transport to the stream during runoff events throughout the year. Table 11 contains a summary of the fate of road sanding material applied withing the Duck Creek Watershed by ADOT&PF and CBJ.

Table 11. Fate of road sanding material applied by ADOT&PF and CBJ.

	ADOT&PF (tons)		CBJ (tons)		Total (tons)	
Activity	**Gravel**	**Sand, Silt, Clay**	**Gravel**	**Sand, Silt, Clay**	**Gravel**	**Sand, Silt, Clay**
Material Applied	17.6	99.5	5.2	7.8	22.8	107.3
After Pulverization	14.0	103.0	4.7	8.3	18.7	111.3
Snow Dumps	0.0	0.0	0.5	0.8	0.5	0.8
Plowing and Sidecast	0.7	5.2	0.2	0.4	0.9	5.6
Material Vacuumed	3.9	28.6	2.3	4.2	6.2	32.8
Remaining Material	9.4	69.2	1.6	2.9	11.1	72.1

The material from snow dumps, plowing and sidecast, and remaining after vacuuming is assumed to be available for delivery to Duck Creek. The monthly sediment loads available for delivery to Duck Creek from winter road maintenance activities are presented in Table 12, and from all land uses are presented in Table 13. The loads in Table 13 are the same as those presented in Table 8, with the addition of a winter road maintenance load for transportation. The loads associated with winter road maintenance are assumed to be delivered between November and May.

Table 12. Monthly sediment loads available for delivery to Duck Creek from winter road maintenance activities.

Month	Snow Dumps[a]	Plowing and Sidecast[a]	Remaining Material[a]	Total[a]
January	0.0	1.9	8.0	9.9
February	0.0	1.9	11.7	13.5
March	0.3	0.0	10.4	10.7
April	0.3	0.0	7.6	7.8
May	0.3	0.0	7.0	7.3
June	0.0	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0
September	0.0	0.0	0.0	0.0
October	0.0	0.0	0.0	0.0
November	0.0	0.0	10.6	10.6
December	0.0	1.9	16.9	18.8
Total Annual	**0.8**	**5.6**	**72.1**	**78.5**

[a] Columns may not add due to rounding error.

Table 13. Monthly sediment loads available for delivery to Duck Creek from all land uses including winter road maintenance.

Month	Residential	Commercial/ Industrial	Transporta-tion	Winter Road Maintenance	Recreation/ Wetland
January	4.6	2.0	1.1	9.9	0.2
February	6.7	2.9	1.6	13.5	0.3
March	5.9	2.6	1.4	10.7	0.3
April	4.3	1.9	1.0	7.8	0.2
May	4.0	1.7	1.0	7.3	0.2
June	4.9	2.1	1.2	0.0	0.2
July	7.6	3.3	1.8	0.0	0.3
August	7.4	3.2	1.8	0.0	0.3
September	12.2	5.3	2.9	0.0	0.5
October	11.6	5.0	2.7	0.0	0.5
November	6.0	2.6	1.4	10.6	0.3
December	9.7	4.2	2.3	18.8	0.4
Total Annual	**84.8**	**36.6**	**20.1**	**78.5**	**3.6**

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 turbidity TMDL for Duck Creek, the following core set of principles was identified and applied:

(1) The TMDL 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
- Portions of the scientific analysis used have been successfully applied in other Alaska TMDLs (e.g., Lemon Creek, Vanderbilt Creek)

(2) The TMDLs must use the best available data.
- All available data within the watershed were reviewed and used in the analysis when possible or appropriate.
- Data from nearby unimpaired watersheds were reviewed and incorporated into the analysis when appropriate (e.g. Peterson Creek, Steep Creek.)

(3) Models should be applied only where appropriate.

- – Simple spreadsheet analysis and empirical relationships were used for the estimation of sediment loads.
- – Available data and the nature of the pollutant did not support the use of watershed or water quality models.

(4) Methods should be clear and as simple as possible to facilitate explanation to stakeholders.

- – All methods used in the analysis are described in detail, along with all major assumptions.
- – The TMDL document has been presented in a format that allows for review and understanding by a wide range of audiences, including the public and interested stakeholders.

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

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 sediment loadings and still support designated uses. For this TMDL, several assumptions were made, including the following:

(1) Duck Creek has a natural background turbidity of 4.4 NTU.
(2) A turbidity of 4.4 NTU + 5 NTU = 9.4 NTU corresponds to a suspended sediment concentration of 9.1 mg/L (Turbidity [NTU] = 1.103*[SSC (mg/L)]$^{0.968}$ from Lloyd et al., 1987.)

The first assumption was made based on discussions with ADEC and EPA staff and review of data from the Alaska Water Watch Taku Boulevard sampling station. Taku Boulevard is the most upstream sampling station in Duck Creek and is located near the edge of the developed portion of the watershed. It is also strongly influenced by groundwater recharge. Consequently, this station is assumed to reflect natural baseline turbidity values for the creek. Turbidity measurements made as part of the Alaska Water Watch program at the Taku Boulevard station between January 1992 and July 1993 range from 0.67 NTU to 20.6 NTU, with a median value of 4.4 NTU. Some USGS water quality sampling of SSC at Taku Boulevard has also been done, but these samples are heavily biased toward storm events and therefore were not considered to reflect the natural baseline condition of the creek. As a result, the Alaska Water Watch data were used to establish the background turbidity level in Duck Creek.

The second assumption provides a quantitative measure for the calculation of a sediment loading capacity for Duck Creek. Turbidity cannot be used directly to calculate pollutant loads and loading allocations, as discussed above in the section on applicable water quality standards.

Assuming that a turbidity of 9.4 NTU (4.4 NTU background + 5 NTU maximum increase) corresponds to a SSC of 9.1 mg/L allows the establishment of a quantitative sediment loading capacity. Studies indicate that the ratio of SSC to turbidity can vary significantly from site to site (Waters, 1995). Simultaneous turbidity and SSC measurements were not available for Duck Creek, and as a result the SSC-to-turbidity relationship calculated for five interior Alaskan streams by Lloyd et al. (1987) was adopted for use in Duck Creek. The desired in-stream turbidity values were based on the applicable water quality standard, which states that turbidity "*may not exceed 5 nephelometric turbidity units (NTU) above natural conditions when the natural turbidity is 50 NTU or less*...."

Although the 9.4 NTU target applies throughout the year, the loading capacity was developed on a monthly basis to reflect different flow regimes and the critical periods for the salmon fishery supported by Duck Creek. The loading capacity was calculated for each month by applying a maximum allowable SSC of 9.1 mg/L to the daily flow record at the USGS station located at Nancy Street, summing the daily loads by month, and calculating the average monthly load for the period of record (1994 to 1998). Table 14 presents the loading capacity for Duck Creek at the Nancy Street gaging station.

Table 14: Monthly sediment loading capacity for Duck Creek at Nancy Street (1994 to 1998).

Month	Average Flow (cfs)[a]	In-Stream Sediment Loading Capacity (tons)[b]
January [c]	1.70	1.29
February [c]	2.30	1.59
March [c]	2.52	1.91
April [c]	2.76	2.03
May [c]	2.49	1.89
June	2.00	1.48
July [d]	2.76	2.10
August [d]	3.61	2.74
September [d]	6.72	4.95
October [d]	7.52	5.72
November [d]	3.92	2.89
December	4.31	3.28
Annual Total	**3.55**	**31.9**

[a] Based on flow data from January 1994 to December 1998.
[b] Calculated using the maximum allowable SSC concentration of 9.1 mg/L and the daily flow record at Nancy Street from January 1994 to December 1998.
[c] Corresponds to critical period for coho egg and alevin development in Duck Creek.
[d] Corresponds to critical period for adult coho migration in Duck Creek.

It is estimated that 75% 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. 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). This analysis assumes that flow is conserved from Nancy Street to the mouth of the creek at Radcliff Road. Therefore, loads calculated based on data available at the Nancy Street station are assumed to be representative of the entire watershed.

Load Allocation

The Pollutant Sources section of this TMDL outlines the significant sources of sediment responsible for the observed in-stream turbidity impairment. The loading values presented for urban runoff and road maintenance represent the pool of available sediment and do not correspond to actual sediment delivered to the creek. Sediment delivery is a function of many factors, including proximity of the source to the creek, the method of transport (direct deposit versus runoff-driven), and the type of source. Estimating sediment delivery is difficult because few models are able to accurately simulate watershed loading of sediment and in-stream processes. Instead, sediment delivery was estimated using information on each source and several conservative assumptions. The methodology used to estimate sediment delivery for each of the major sources is presented below.

Sediment Delivery from Road Maintenance

Based on the analysis presented in the Pollutant Sources section, the total sediment load available for transport to Duck Creek is 98.7 tons. Although the estimated load is based in part on the sand and gravel amounts applied to roads in the Duck Creek watershed from the months of November to February, the effects of these road applications will be observed as late as May (when vacuuming is completed) and will be greatest during periods of high rainfall and runoff. In addition, the baseline transportation load presented in Table 8 is generated and available for transport throughout the year. Therefore, the total available load (98.7 tons) was apportioned as monthly loads based on the runoff characteristics identified from the watershed precipitation record. Table 13 in the Pollutant Sources section presents the total sediment available for delivery to the stream based on the runoff analysis. Table 15 presents sediment delivery for all land uses based on an assumed delivery ratio of 50 percent for transportation and 27 percent for all other land uses. The sediment delivery from a watershed the size of Duck Creek is estimated at 27 percent (USDA, 1973). However, a delivery ratio of 27 percent was not considered appropriate for the load generated from roads, which are characterized by very high percent impervious area and close proximity to streams. Therefore, 50 percent was considered appropriate for this land use. The sand, silt and clay loads from snow dumps, plowing and vehicle sidecast, totaling 6.4 tons, are assumed to be delivered directly to the creek from December to May, and thus have a delivery ratio of 100 percent.

Sediment Delivery from Urban Runoff

Potential sediment loads from urban runoff are presented in Table 8 of the Pollutant Sources section. The loads presented in the table for residential, commercial/industrial, and recreation land uses were developed using literature-based TSS concentrations that were applied to runoff from the watershed. The runoff was estimated by using the percent impervious for each land use and calculating the runoff coefficient using the Simple Method approach (USEPA, 1997). The sediment delivery was estimated to be 27 percent based on values presented by USDA (1973).

Table 15. Sediment load (tons) delivered to Duck Creek.

Month	Residential[a]	Commercial /Industrial[a]	Transporta-tion[b]	Winter Road Maintenance[c]	Recreation/ Wetland[a]	Total Load
January	1.2	0.5	0.5	5.9	0.1	8.2
February	1.8	0.8	0.8	7.7	0.1	11.1
March	1.6	0.7	0.7	5.5	0.1	8.5
April	1.2	0.5	0.5	4.1	0.1	6.3
May	1.1	0.5	0.5	3.8	0.1	5.8
June	1.3	0.6	0.6	0.0	0.1	2.5
July	2.1	0.9	0.9	0.0	0.1	3.9
August	2.0	0.9	0.9	0.0	0.1	3.8
September	3.3	1.4	1.4	0.0	0.1	6.3
October	3.1	1.4	1.4	0.0	0.1	6.0
November	1.6	0.7	0.7	5.3	0.1	8.4
December	2.6	1.1	1.1	10.3	0.1	15.3
Annual	**22.9**	**9.9**	**10.1**	**42.5**	**1.0**	**86.3**

[a] Load delivered to stream calculated by applying a delivery ratio of 0.27 to monthly loadings presented in Table 13.
[b] Load delivered to stream calculated by applying a delivery ratio of 0.50 to monthly loadings presented in Table 13.
[c] Load delivered to stream calculated by applying a delivery ratio of 1.00 to the load from snow dumps, sidecast and plowing and 0.50 to the remaining portion of the loadings presented in Table 13.

Load Allocations

A TMDL must express a relationship between the in-stream target (water quality standard) and the proposed reduction in source loads. Many methods for estimating this relationship have been demonstrated. For this TMDL it was decided to assume a direct relationship between the estimated sediment loadings and the existing in-stream turbidity values. For example, it was assumed that a 10 percent reduction in sediment loadings would result in a corresponding 10 percent reduction in in-stream turbidity levels. This relatively simple approach is discussed in EPA's Protocol for Developing Sediment TMDLs (USEPA, 1999) and was determined to be the most appropriate given the available monitoring data and the commitment to implementation of BMPs and other restoration activities. The monthly load reductions required to attain the water quality standard are presented in Table 16. The load allocation (Table 16) is based on the relationship between the targets identified in the in-stream analysis (summarized in Table 14) and the watershed analysis (summarized in Table 15). They are presented as gross allotments based on the availability of data–this approach is recognized as a valid method (40 CFR 130.2(g).)

Table 16: Monthly suspended sediment load reductions required in Duck Creek.

Month	Existing Watershed Suspended Sediment Load (tons)[a]	In-Stream Sediment Loading Capacity (tons)[b]	Percent Reduction Needed in Watershed Load	Explicit Margin of Safety (5%)	Loading Allocation
January	8.2	1.3	84%	5%	0.9
February	11.1	1.6	86%	5%	1.0
March	8.5	1.9	78%	5%	1.5
April	6.3	2.0	68%	5%	1.7
May	5.8	1.9	68%	5%	1.6
June	2.5	1.5	42%	5%	1.3
July	3.9	2.1	46%	5%	1.9
August	3.8	2.7	28%	5%	2.6
September	6.3	5.0	22%	5%	4.6
October	6.0	5.7	4%	5%	5.4
November	8.4	2.9	66%	5%	2.5
December	15.3	3.3	79%	5%	2.5
Total Annual	**86.3**	**31.9**	**63%**	**5%**	**27.6**

[a] Existing load based on analysis of watershed loading sources–values are repeated from Table 15.
[b] Monthly loading capacity based on analysis of in-stream data–values are repeated from Table 14.

Wasteload Allocation

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

Margin of Safety

This section addresses the incorporation of a margin of safety (MOS) in 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.

Assumptions are often used in TMDL analyses when data are lacking or limited. The assumptions, although necessary for the analyses, can lead to uncertainty, depending on the information used as the basis for the assumption. For instance, where the analysis is based on an adequate understanding of watershed processes and is backed up by reliable data, the uncertainty can be reflected in the use of an explicit margin of safety. In contrast, when data are lacking, TMDL analyses often rely on the use of conservative assumptions that recognize the gaps in information.

The draft Duck Creek TMDL for turbidity included the use of several conservative assumptions in the analysis. However, based on comments received and a review of the assumptions used in the draft TMDL, the final TMDL added an explicit five percent margin of safety. In addition to the explicit MOS, the TMDL still relies on the use of conservative assumptions where data are lacking (e.g., the establishment of the water quality target for turbidity). The conservative assumptions made were related to both the estimation of the existing loading and the selection of a water quality target for the TMDL, and include the following

1. *The use of the median of the turbidity observations at Taku Boulevard to establish the baseline turbidity for Duck Creek:* the median of the turbidity observations at Taku Boulevard is 4.4 NTU, which is substantially lower than the average value of 6.7 NTU. Using a lower turbidity value to establish the background turbidity in the creek represents a conservative approach because it means that the load reductions required to meet the turbidity standard are more likely to be overestimates than underestimates.
2. *The use of a winter road sand application rate at the upper end of the range:* use of the upper end of the application range in estimating the amount of sand applied for winter road maintenance helps ensure that load reductions specified in the TMDL result in attainment of the TMDL, even in years requiring increased sand applications.

Seasonal Variation

It is difficult to predict and estimate the annual and seasonal variation in the delivery of sediment to stream systems. Delivery occurs on an annual basis but is typically driven by wet-weather events. The consideration of seasonal variation was an important component of the Duck Creek TMDL because of the critical time period associated with the fishery. The critical period for the fishery varies 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 the adult spawning migration is from July to November. To account for differences in sediment loading throughout the year, as well as to incorporate the important fishery-related critical periods, the TMDL was established with monthly allocations of sediment to Duck Creek. The TMDL will therefore be sensitive to periods of low flow when less sediment load would be needed to cause a violation of the turbidity standard. Figure 4 presents a graphical summary of how variations in monthly flow and sediment load coincide with the critical periods for the fishery and road sanding.

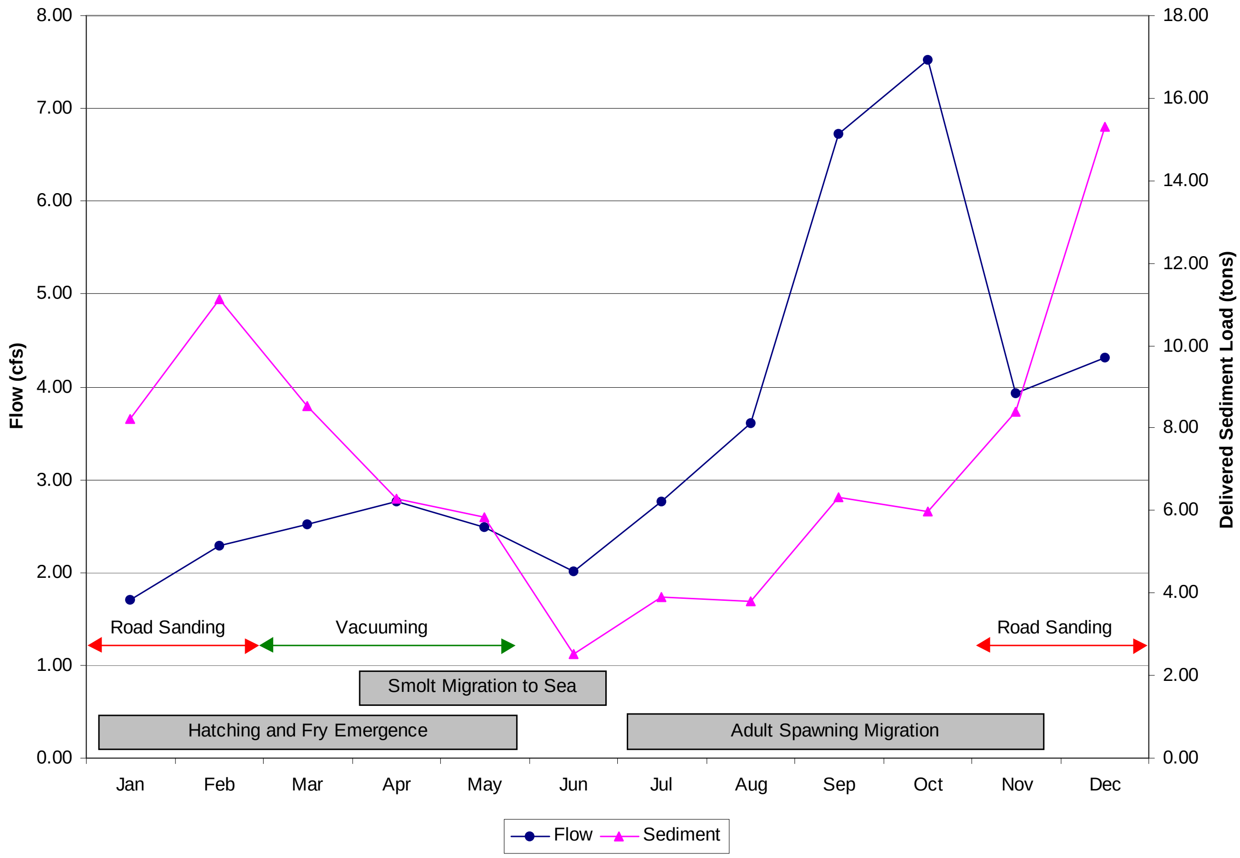

Figure 4. Summary of variations in monthly flow and existing watershed sediment load, winter road maintenance activities, and critical periods for the salmon fishery

Monitoring

Sediment-related impacts on designated uses are often difficult to characterize. For this reason, sediment-related TMDLs are 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 Duck Creek Watershed is part of the larger Mendenhall Valley Watershed, which includes Jordan Creek, a similar stream that is impaired for sediment (as well as dissolved oxygen, and debris). TMDLs are scheduled to be developed for Jordan Creek over the next few years. Monitoring to track the recovery of Duck Creek and to refine the TMDL for turbidity, as well as TMDLs for dissolved oxygen, metals, fecal coliform and debris (under development) should be conducted on a watershed scale that will include Jordan Creek. Monitoring on the larger watershed scale will facilitate parallel development and monitoring of TMDLs for both creeks in the watershed.

The past and current monitoring activities in the Duck Creek watershed are outlined in the water quality analysis section of this TMDL, Appendix A, and in the DCMP. It is anticipated that water quality and flow monitoring will continue at the USGS flow gaging stations in the the Mendenhall Valley Watershed including Duck Creek and Jordan Creek. The monitoring data collected at these sites will provide data that:

- Verify the SSC-to-turbidity sediment relationship assumed in the TMDL.
- Indicate improvements in water quality and flow.
- Verify the natural background conditions in the watershed.

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 be coordinated and a comprehensive Mendenhall Valley Watershed Monitoring Plan developed. This monitoring plan should provide for long-term monitoring at key locations and should address all water quality parameters of concern for Duck and Jordan Creeks including turbidity, sediment, dissolved oxygen, and flow.

The focus of the monitoring programs could be on the assessment of in-stream conditions (i.e., turbidity, SSC, percent fines in sediments, macroinvertebrates), and assessment of BMP effectiveness and implementation. The in-stream monitoring will provide information on in-stream improvements and show long-term trends. The BMP implementation monitoring would ensure that identified management actions (such as specific BMPs or resource restoration or enhancement projects) are undertaken. Implementation monitoring is often cited as the most cost-effective of the monitoring types because it provides information on whether BMPs are being installed or implemented as intended. BMP effectiveness monitoring is used to assess whether the source controls had the desired effect. Specific projects that potentially affect water quality conditions should be monitored to determine their immediate on-site effects.

Although it is not feasible to develop a detailed monitoring plan at this time, it is expected that upon TMDL adoption, participating parties will develop a cost-effective monitoring plan for the Mendenhall Valley watershed.

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 projects and pollution control throughout the watershed.

Public attitude and perception toward the importance of Duck Creek are already changing as a result of the work done by the DCAG and other community organizations. Public awareness of the impacts of habitat loss on small streams such as Duck Creek has immeasurable value in protecting and restoring salmonid habitat.

Education

Watershed education that includes discussions of the importance of environmental safeguards to protect salmon streams such as Duck Creek could help the community better understand requirements for stream protection and help foster a sense of ownership and a demand for stricter enforcement.

Management

Most of the impairment to Duck Creek is from urban runoff and development that does not include appropriate environmental safeguards. Many source control practices (BMPs) are available to help limit polluted runoff entering the stream. For example, altered practices on snow dumps and additional swales where road runoff enters creeks are management practices that could significantly reduce turbidity and sediment in Duck Creek. The selection and implementation of BMPs 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.

A comprehensive stormwater management program for the Mendenhall Valley watershed should be implemented to assure that polluted runoff is adequately treated so that water quality standards are met where stormwater enters Duck Creek and other streams and lakes within the watershed.

The attainment of the water quality standard for turbidity will require implementation of BMPs that will ultimately achieve the load reductions presented in this TMDL report. There are a number of BMPs, used singly or in combination, that have demonstrated pollutant removal efficiencies within the range identified as necessary for meeting water quality standards in Duck Creek. Possible BMPs include vegetated filter strips, grassed swales, porous pavement, concrete grid pavement, filtration basins and sand filters, and water quality inlets (USEPA 1993). The implementation of the Duck Creek turbidity TMDL will likely consist of implementing one or more of the described management practices appropriate to the source, location, and climate. Table 17 below lists the advantages, disadvantages, and the average removal efficiency rate of TSS associated with each management practice.

Table 17. Possible BMPs for TSS Removal (USEPA 1993).

BMP	Advantages	Disadvantages	Average TSS Removal Efficiency (%)
Vegetated Filter Strip	• Low maintenance requirements • Can be used as runoff conveyance system to provide pretreatment • Can reduce particulate pollutant levels when runoff velocity is low to moderate	• Often concentrates water, which significantly reduces effectiveness • Ability to remove soluble pollutants highly variable • Limited feasibility in highly urbanized areas where runoff velocities are high.	90
Grass Swale	• Requires minimal land area • Can be used as runoff conveyance system to provide pretreatment • Can provide runoff control to replace curb and gutter in residential subdivisions and highway medians	• Low pollutant removal rates • Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients	60
Porous Pavement	• Provides water quality control without additional consumption of land • Provides peak flow control • High removal rates for sediment, nutrients, organic matter, and trace metals	• Requires regular maintenance • Possible risk of contaminating groundwater • Only feasible where soil is permeable, there is sufficient depth to rock and water table, and there are gentle slopes	90

BMP	Advantages	Disadvantages	Average TSS Removal Efficiency (%)
Concrete Grid Pavement	• Provides peak flow control • Provides groundwater recharge • Provides water quality control without additional consumption of land	• Requires regular maintenance • Not suitable for areas with high traffic volume • Possible risk of contaminating groundwater	90
Sand Filter/ Filtration Basin	• Ability to accommodate medium-size development (3-80 acres) • Provides peak volume control	• Requires pretreatment of storm water through sedimentation to prevent filter media from prematurely clogging	80
Water Quality Inlets Catch Basins	• Provide high degree of removal efficiencies for larger particles and debris as pretreatment • Require minimal land area	• Not feasible for drainage area greater than 1acre • Marginal removal of small particles, heavy metals and organic pollutants	35
Water Quality Inlet Catch Basins with Sand Filter	• Provide high removal efficiencies of particulates • Require minimal land area • Flexibility to retrofit existing small drainage areas	• Not feasible for drainage area greater than 5 acres • Only feasible for areas that are stabilized and highly impervious • Not effective as water quality control for intense storms	80
Water Quality Inlet Oil/Grit Separator	• Captures coarse-grained sediments and some hydrocarbons • Requires minimal land area • Flexibility to retrofit existing small drainage areas and applicable to most urban areas	• Not feasible for drainage area greater than 1acre • Minimal nutrient and organic matter removal • Not effective as water quality control for intense storms	15

Although it was not possible to quantify the contribution of iron floc to turbidity in Duck Creek with the available data, it is generally acknowledged that iron floc can contribute to turbidity problems. Several methods were proposed in the DCMP to reduce dissolved iron in Duck Creek (Koski and Lorenz, 1999), which would in turn reduce the iron floc that contributes to sedimentation and turbidity. The proposed restoration methods for controlling iron (Koski and Lorenz, 1999) include the following:

- cap source areas with organic fill

- plant riparian/aquatic plants
- aerate the water
- increase the volume of the flow.

Capping the source areas with organic fill would involve placing fill in seep areas along the mainstem and in ponds upstream of Taku Boulevard and downstream of Berners Avenue in order to precipitate or bind the dissolved iron as it enters the stream. Aquatic vegetation can then be planted on the fill material. Plants are able to oxidize Fe^{2+} to Fe^{3+} in their roots (Stahl, 1999). Fe^{3+} can then precipitate out of solution as an oxide or carbonate. It is common to find plant roots covered by iron oxide plaque in wetland soils. This iron is believed to be chemically stable. The second option of planting riparian or aquatic vegetation in areas of high iron concentrations may also help in reducing iron entering the stream by the means just stated above. The third option for iron reduction is aeration. Aeration of the water can be done mechanically at the sources of dissolved iron or a gallery of aeration pipes can be constructed (Koski and Lorenz, 1999). The final restoration option is to increase the volume of flow in Duck Creek. This would dilute the dissolved iron and flush the floc.

The DCMP recommended the third alternative (aeration) because it is a proven method, requires the least amount of maintenance, and is the easiest to install and operate (Koski and Lorenz, 1999). Since the iron floc problem occurs only in areas of groundwater discharge, any iron conversion treatments must be implemented in the immediate vicinity of the inflowing water (Beilharz, 1998).

Restoration

Environmental standards and the substantial loss of aquatic resources in the watershed will require not only that development policies be changed and BMPs applied, but also 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. 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.

Appendix A. Other Data Reviewed in Developing the Duck Creek TMDL for Turbidity

Several data sets were reviewed that were not used in developing the TMDL for turbidity in Duck Creek. They are summarized below.

University of Alaska Rapid Bioassessment of Macroinvertebrate Populations in Duck Creek
Four sites in Duck Creek and two sites in Jordan Creek were sampled in June 1994 for macroinvertebrates. Bioassessment metrics (EPT/TOT, DOMTAX, and FBI[1]) were used to calculate the overall macroinvertebrate population "health." Survey results indicated a severely impaired stream system. No data on streambed condition or water quality were presented with the macroinvertebrate assessment that would allow correlation to sediment. As a result, the rapid bioassessment data were not used in this TMDL analysis.

National Marine Fisheries Service 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 conductance, salinity, dissolved oxygen, redox[2], and water level. No TSS, SSC or turbidity data were collected. As a result, the NMFS data were not used in this TMDL analysis.

1994-1995 Alaska Department of Environmental Conservation Water Quality Screening Survey
During 1994 and 1995, the Alaska Department of Environmental Conservation (ADEC) performed four water quality sampling surveys of from three to six monitoring sites. Surveys were conducted in October 1994 and February, April, and May 1995. The Juneau Environmental Assessment Laboratory (JEAL) analyzed samples for total dissolved and total suspended solids (TDS and TSS), biological and chemical oxygen demand (BOD and COD), and nitrate and nitrite (NO_3 and NO_2), among other parameters. Raw data from the surveys are presented in Appendix C of the DCMP (Lorenz, 1998). It is difficult to determine the spatial coverage or specific geographic origin of most of the data presented in the ADEC surveys. Therefore, the results presented from the ADEC data might not reflect water quality conditions specific to Duck Creek since the data may have been obtained from other waterbodies in the Mendenhall Valley area. In addition, quality assurance problems were identified in the data reviewed. As a result, the ADEC data were not used in this TMDL analysis.

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[1]EPT/TOT is the ratio of Ephemeroptera, Plecoptera and Tricoptera to the total number of individuals sampled. DOMTAX is the percent of the population that is made up of the dominant taxa. FBI (Family Biotic Index) is the average of tolerance values of all arthropod families in a sample.

[2]Oxidation is a process in which a molecule or ion loses electrons. Reduction is a process by which electrons are gained. A measurement of the potential for these processes to occur is called redox potential (reduction-oxidation potential).

Appendix B. Average monthly discharge, existing in-stream load, and loading capacity for Duck Creek

The values presented in the table below were calculated using the daily flow record at the USGS flow gaging station at Nancy Street, assumed suspended sediment concentrations (SSC) of 12 mg/L for flows below 15 cfs and 19 mg/L for flows above 15 cfs (for the existing load), and an in-stream standard SSC of 9.1 mg/L (for the loading capacity). The daily loads were then summed by month.

Date	Average Discharge (cfs)	Existing Load (tons/month)	Loading Capacity (tons/month)
1994.01	2.95	2.96	2.25
1994.02	1.61	1.46	1.10
1994.03	5.08	5.10	3.86
1994.04	4.26	4.14	3.14
1994.05	3.51	3.52	2.67
1994.06	1.83	1.78	1.35
1994.07	2.23	2.23	1.69
1994.08	1.31	1.31	0.99
1994.09	6.11	6.86	4.50
1994.10	8.58	9.32	6.53
1994.11	5.16	5.01	3.80
1994.12	3.69	3.70	2.81
1995.01	1.04	1.04	0.79
1995.02	1.65	1.50	1.13
1995.03	0.94	0.95	0.72
1995.04	1.84	1.79	1.35
1995.05	1.85	1.85	1.40
1995.06	1.78	1.73	1.31
1995.07	1.75	1.75	1.33
1995.08	4.55	4.57	3.46
1995.09	6.20	7.19	4.57
1995.10	5.85	5.87	4.45
1995.11	2.36	2.29	1.74
1995.12	1.95	1.96	1.48

Date	Average Discharge (cfs)	Existing Load (tons/month)	Loading Capacity (tons/month)
1996.01	1.70	1.71	1.30
1996.02	3.46	3.25	2.46
1996.03	3.59	3.60	2.73
1996.04	1.68	1.63	1.24
1996.05	1.60	1.61	1.22
1996.06	2.11	2.05	1.56
1996.07	3.25	3.55	2.47
1996.08	4.68	5.04	3.56
1996.09	10.27	12.39	7.56
1996.10	5.83	5.85	4.43
1996.11	3.07	2.98	2.26
1996.12	2.80	2.80	2.13
1997.01	0.85	0.86	0.65
1997.02	3.55	3.52	2.44
1997.03	1.76	1.76	1.34
1997.04	3.59	3.83	2.64
1997.05	3.18	3.19	2.42
1997.06	3.09	3.00	2.28
1997.07	4.23	4.24	3.22
1997.08	3.93	3.95	2.99
1997.09	3.81	3.70	2.80
1997.10	5.29	5.31	4.03
1997.11	4.83	4.69	3.56
1997.12	8.06	8.73	6.13

Date	Average Discharge (cfs)	Existing Load (tons/month)	Loading Capacity (tons/month)
1998.01	1.94	1.95	1.48
1998.02	1.18	1.07	0.81
1998.03	1.21	1.22	0.92
1998.04	2.43	2.36	1.79
1998.05	2.29	2.30	1.74
1998.06	1.20	1.17	0.89
1998.07	2.35	2.36	1.79
1998.08	3.56	3.58	2.71
1998.09	7.23	7.02	5.32
1998.10	12.05	14.81	9.17
1998.11	4.20	4.08	3.09
1998.12	5.07	5.39	3.86
Jan Avg	1.70	1.70	1.29
Feb Avg	2.29	2.16	1.59
Mar Avg	2.52	2.52	1.91
Apr Avg	2.76	2.75	2.03
May Avg	2.49	2.50	1.89
Jun Avg	2.00	1.95	1.48
Jul Avg	2.76	2.83	2.10
Aug Avg	3.61	3.69	2.74
Sep Avg	6.72	7.43	4.95
Oct Avg	7.52	8.23	5.72
Nov Avg	3.92	3.81	2.89
Dec Avg	4.31	4.52	3.28
Annual	**3.55**	**44.08**	**31.89**

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