GRANITE CREEK TMDL AND RECOVERY STRATEGY:

REVIEW AND CUMULATIVE ANALYSIS OF WATER QUALITY DATA, SEDIMENT LOAD REDUCTIONS, AND VALIDATION OF TMDL ASSUMPTIONS

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June 2007

ACKNOWLEDGMENTS

Special thanks go to the contributors, reviewers and participants in this review and cumulative analysis of Granite Creek water quality data collected since 2002 and the validation of assumptions used in TMDL development. Mark Buggins, Rich Riggs, Marlene Campbell, Bob Reid and Brian Bergman of the City and Borough of Sitka provided substantive guidance, comments or recommendations on draft versions of this document and recovery aspects in general. Laura Eldred of the Alaska Department of Environmental Conservation provided encouragement and valuable technical support for this project over five years. The staff of the Juneau USGS office provided helpful insight and recommendations on log-log transformation of historical discharge and sediment data for improved plotting of results. Bob Reid is thanked for his active participation over five years in collecting weekly staff gage elevation data and monthly TSS and turbidity data from Granite Creek that were central to this analysis. Brian Bergman of CBS was responsible for installing, maintaining and overseeing many of the stormwater improvements in the Granite Creek watershed since 2002. Carl Schrader of the Alaska Department of Natural Resources provided suggestions on working up and plotting water quality trend data and ideas on revisiting TMDLs after many years of implementation.

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Funding for this project was provided by the Alaska Department of Environmental Conservation and the Environmental Protection Agency through an ACWA community water quality grant awarded under Section 319 of the Clean Water Act. Matching funds were provided by the City and Borough of Sitka.

GRANITE CREEK TMDL AND RECOVERY STRATEGY: REVIEW AND CUMULATIVE ANALYSIS OF WATER QUALITY DATA, SEDIMENT LOAD REDUCTIONS, AND VALIDATION OF ASSUMPTIONS USED IN TMDL DEVELOPMENT

Introduction

The "*Granite Creek Watershed Recovery Strategy and Total Maximum Daily Load (TMDL) for Sediment and Turbidity*" was completed in June 2002 and approved by the Department of Environmental Conservation (ADEC) and Environmental Protection Agency (EPA) in September 2002. Development of the TDML and Action Plan relied on the best available information at the time to describe critical creek processes and to calculate sediment loads and prescriptions. These included estimates of average monthly flow, average monthly TSS concentrations, the empirical relationship between turbidity and total suspended solids (TSS), the relationship of TSS to average monthly flows, and existing in-stream sediment loads and loading capacity using historical water quality data.

Given that complete information is rarely, if ever, available at the time of TMDL development, it is accepted that a variety of assumptions need to be made in order to complete the TMDL. These assumptions must be reasonable and based on accepted scientific analysis.

Task 7 and 8 of the approved FY07 workplan call for a cumulative analysis of water quality data collected since October 2002 and a review and analysis of the original assumptions, respectively.

Task 7 reads:

> "*Provide cumulative analysis of turbidity and sediment (TSS) data collected to date and calculate actual sediment load reductions achieved through implementing the Watershed Recovery Strategy*"
>
> *Description: This task will calculate current monthly sediment loads (tons/month) using all available water quality information and the stage-discharge curve completed for the creek. The existing monthly sediment loads will be compared to monthly sediment loads calculated in 2002 for the TMDL and quantify sediment load reductions over the four years.*

Task 8 of the workplan is very closely related to Task 7 and addresses several assumptions central to developing the original TMDL. Task 8 reads:

> "*Validate assumptions made during TMDL development concerning flow-sediment relationships, the TSS to turbidity ratio, and Granite Creek's monthly and annual sediment load allocation*"

*Description: This task is closely linked to Task 7, and is also listed as an ACWA Priority Action for FY07. TMDLs are developed using best available information. Key assumptions were made in the Granite Creek TMDL development regarding average monthly flows, the relationship of flow rate to sediment loads, the relationship of TSS to turbidity determined through regression analysis of simultaneous data sets, and the calculation of monthly sediments loads. The following equation was used in 2002 to quantify the relationship between turbidity and TSS: TSS (mg/l) = [1.075 *(turbidity in NTUs)] –1.681. Considerable new TSS and turbidity data exist. Data collected since 2002, including the USGS-completed stage discharge curve for Granite Creek, will be reviewed and analyzed against the original assumptions and any major differences noted. The Contractor who prepared the TMDL will complete the analysis and products listed below. This task analyzes key assumptions, but does not rewrite the TMDL."*

This report addresses both tasks. It describes the analytical process and approach used in reviewing water quality data collected since 2002, examines assumptions and mathematical relationships, and includes tables and figures of five years of water quality information. It also compares water quality data with the original TMDL assumptions. *The report is not a rewrite of the TMDL, rather, an analysis of information collected over five years in the context of examining the original assumptions.* A "Lessons Learned" section is included. Conclusions and recommendations are made at the end of the report.

<u>The Stepwise Process Used in the Cumulative Analysis of Water Quality Data</u>

A listing of sequential steps that needed to occur was prepared to guide the data analysis. Essential variables, parameters and relationships that needed examination were identified and key assumptions noted from the original TMDL. Data analysis focused on the monitoring results from Station GC1, the watershed integrator station at the Halibut Point Road bridge site. This station is the location of a USGS staff gage and the site of monthly monitoring of TSS and turbidity concentrations.

In addition, comprehensive monitoring data collected throughout the watershed by the project consultant from 2002 through 2006 were used to address time series of events over three day periods, and confirm source contributions of sediment within the watershed. These results are discussed in the section *<u>Watershed Water Quality Data Analysis and Source Contributions.</u>*

The steps in the analysis included:

- Tabulate the relationship of turbidity, TSS and discharge (flow) rate using all simultaneously-collected data sets from October 2002 through January 2007.

- Complete a new linear regression analysis on all simultaneously-collected TSS and turbidity data sets and generate a new "y = mx + b" equation representing that relationship.

- Calculate the average background turbidity level from 2002 through 2006 for comparison with the original background turbidity value used in the TMDL.

- Prepare new estimates of average monthly flows for January through December based on four years of data. This involves converting each of 208 stream staff gage elevation measurements to a discharge rate (cfs) using the USGS-derived Stage Discharge Curve for Granite Creek. Prepare a table of all discharge (cfs) data collected from October 2002 through January 2007, including average monthly flow calculations, maximum and minimum flows and number of flow observations.

- Calculate average monthly TSS concentrations (for January through December) correlated to average monthly flows using four years of water quality data collected over a range of flow conditions. Tabulate Granite Creek TSS concentrations, by month, measured from October 2002 through January 2007.

- Calculate annual sediment loads by year (2002, 2003, 2004, 2005 and 2006) to show trends in sediment load reductions (in tons/year) over time.

- Graph TSS and turbidity concentrations from October 2002 through 2006

The results of data analysis above were then used to prepare two major tables for comparing the original and revised sediment load estimates:

1. Annual and monthly suspended sediment (TSS) loading capacity for Granite Creek
2. Annual and monthly existing in-stream suspended sediment loads in Granite Creek

These two tables were required elements of the original TMDL in 2002, guiding subsequent calculations of load reductions and load allocations central to the TMDL. The newly generated tables allow for a side-by-side comparison of loads with the 2002 values.

<u>Review and Validation of Key Assumptions used in the Development of the Granite Creek TMDL</u>

Essential to developing the Granite Creek TMDL in 2002 were assumptions about key processes and relationships. The TMDL often involves extrapolation of data from other similar watersheds, coupled with site-specific data and an understanding of watershed processes.

A TMDL is a prescriptive tool and must be based on reasonable and acceptable assumptions and accepted scientific analysis. Such was the case in the review and approval of the Granite Creek TMDL. Assumptions were made in 2002 based on the best available water quality and stream flow data and in full consultation with CBS staff, USGS and Forest Service hydrologists, and ADEC and ADF&G water quality and fisheries specialists.

A TMDL must rely on the best available information at the time of its drafting. In 2002, Granite Creek lacked water quality data for several months of the year, particularly during winter and early summer months. Only a few stream flow measurements were available. All available TSS and turbidity data for the Granite Creek watershed were reviewed and used in the analysis. By necessity, USGS stream flow data from the nearby, continuously gaged, Indian River watershed were extrapolated from to estimate average monthly flows for Granite Creek.

Developing the Granite Creek TMDL required making several assumptions and estimates of key parameters based on best available information. These included calculating average monthly flows, the TSS-to-turbidity correlation, background turbidity concentrations, the flow-to-sediment relationship, and average monthly TSS concentrations. Margin of Safety (MOS) assumptions were also made. These assumptions and estimates were necessary to calculate the prescriptive requirements of a TMDL, including load capacity, existing in-stream loads, and subsequent sediment load reductions and allocations.

Each of these major parameters is discussed below, including an assessment of their relative validity in 2007 based on the water quality results of four years of post-TMDL implementation monitoring at Granite Creek.

1. Average monthly flows

Average monthly flow is a significant and essential variable in calculating loading capacity and in-stream sediment load.

During TMDL development in 2002, Granite Creek did not have a continuous flow meter or staff gage to provide instantaneous, daily, or monthly stream flow data. Therefore, monthly average flows for Granite Creek were estimated using the following method.

Flow (cfs) measurements at Granite Creek were made on three intervals to capture a range of high and low flow events: October 15, October 17 and November 20, 2001. Measured flows ranged from 12.8 cfs to 186 cfs. For each date and time, measured flow was compared to the corresponding flow for that date and time for Indian River in the Sitka area. The USGS maintained flow records at 15 minute intervals at Indian River and these tables were used to develop a ratio of Granite Creek flow to Indian River flow for any given time.

The three simultaneous flow measurements taken at both creeks showed a ratio of Granite Creek flow/Indian River flow of 16.28%, 24.67%, and 28.0%, with a mean of 22.8%. Using this ratio, the published average monthly flows for Indian River covering the period of USGS record (October 1998 to September 2000) were multiplied by .228 to estimate the corresponding average monthly flow for Granite Creek for January through December.

The USGS installed a permanent stream staff gage on Granite Creek in November 2002. Roughly 208 stream gage height readings and 11 actual stream flow measurements were taken on Granite Creek from October 2002 through January 2007. The 208 gage height readings were converted to flow rates (cfs) using the stage discharge curve and tables completed by the USGS in June 2005 (see Appendix). *Table 1* summarizes creek discharge rates by month and year, and includes average monthly flow calculations along with maximum and minimum flows.

While many of the gage height readings from 2002 through 2006 was taken on a random schedule, attempts were also made by CBS and project staff to take gage height measurements, and corresponding TSS and turbidity measurements, during heavy rain and swollen stream conditions. This lead to several very high flow data points, including a recorded 1390 cfs discharge event in November 2005 and 1070 cfs in December 2004. Absent a flow-weighted approach, such episodic storm events tend to bias (increase) average monthly flow calculations. Since the same average monthly flow value is used for calculating both Loading Capacity (LC) and Existing In-Stream Flows, both these load estimates will be affected equally. However, the calculation of the average monthly TSS concentration using TSS data from such high flow events, creates a significant “high bias”, given the relatively few TSS samples (roughly 3 to 8) collected during each month. *Table 2* summarizes the Granite Creek TSS concentrations, by month, at Station GC1, from October 2002 through January 2007.

This cumulative analysis suggests that the original 2002 estimates of average monthly flows underestimated flows for several months, and overestimated flows in other months. This is not unexpected, given the available data in 2002. It is worth noting that the USGS protocol for calculating average monthly flow requires a discharge measurement every day of the month, for all months of the year. This was not possible on Granite Creek as no continuous recording gage exists, as it currently does for Starrigavin Creek or, historically, for Indian River. Neither was it practical to read staff gage heights on a daily basis at Granite Creek. Relying on a roughly weekly gage height measurement schedule provided approximately 50 discharge readings each year and totaled 208 over the four-year period. Average monthly discharge flow estimates – while still below the USGS standard of daily flow measurements- are certainly more accurate than those used in 2002.

2. Background concentrations of TSS and turbidity

A sufficient turbidity database existed in 2002 for the upper reaches of Granite Creek (unaffected segments of the North and South tributaries) to establish natural background conditions for turbidity. Historical data from 1996 to 2002 were analyzed. A mean natural turbidity value of 1.64 NTU was calculated using all available data.

A comprehensive review of data collected from 2002 through 2006 reaffirmed this value. Forty (40) background /natural condition turbidity samples were collected during that time. *Table 3* summarizes those data from the watershed control stations and calculates the mean (average) turbidity value over that period. The only deviation from a normal condition/background level occurs during severe rainstorms, where high flows erode stream banks in upper portions of the creek tributaries, causing episodic, short-term elevations of background levels. For example, a background turbidity of 14.8 NTUs was recorded during a very heavy rainstorm on October 16, 2002.

A mean background turbidity concentration of 1.77 NTUs was calculated from the 40 data points from October 2002 through October 2006. This validates the accuracy of the original 2002 estimate of 1.64 NTU. Therefore, no changes were necessary in sediment background loads used in the Load Capacity calculation in *Table 5*.

3. TSS-to-turbidity relationship

Alaska water quality standards limit allowable turbidity to 5 NTUs above natural conditions to protect the drinking water use - the "default" designated use for Granite Creek. The turbidity criterion for the aquatic life use category may not exceed 25 NTUs above natural conditions.

The following assumptions were made in 2002:

1. Granite Creek has a natural background turbidity of *1.64 NTU*.
2. A turbidity of 1.64 NTU + 5 NTU = *6.64 NTU* as the target turbidity water quality standard

Another important conversion was necessary to allow for a quantitative calculation of sediment loading capacity for Granite Creek. The majority of water quality data collected from Granite Creek through 2002 was turbidity. Turbidity is an optical property and is a measure of the amount of light-scattering particles in the water. However, loading capacities are most often expressed as a mass per unit time. Not being a measure of the weight of particles in water, turbidity cannot be used *directly* to calculate pollutant loads (in tons of sediment) or load allocations. The TMDL required conversion of turbidity values to an equivalent TSS value to estimate sediment loads gravimetrically (by weight, in tons). Total suspended solids (TSS) was selected to represent sediment loads in Granite Creek.

Therefore, defining the mathematical relationship between TSS and turbidity through simultaneous measurements was a central focus of water quality monitoring in October and November 2001. Over 16 TSS grab samples were collected from various stations in the watershed and analyzed for the development of a regression equation. Turbidity was measured simultaneously on-site at each station using a Hach 2100P portable turbidimeter.

GRANITE CREEK, ALASKA

Table 1. Granite Creek discharge rates, in cubic feet per second (cfs), October 2002 through January 2007 [1], with average monthly flow calculations[2]

.

YR	*JAN*	*FEB*	MA	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*		*NOV*	*DEC*	*Notes*
2002										51.4*	3.3* 12.8 10.7 137 347	3.8 11.9* 10.2	
2003	46.4 6.3* 4.3 30.0* 33.9	15.9 4.3 5.5	30.0 13.4 3.3 7.3 3.8 3.3 3.5 12.2	3.8 3.6 4.0 4.9* 3.6 6.0	2.6 33.9 4.3 3.1	2.0 24.4* 6.7 8.1	5.2 2.6 5.7 3.1	8.1 2.3 15.3 4.0	85.7 19.8 19.0 161 17.4	24.4 84.6* 10.2	5.2 8.4 863 8.4 85.7	3.1 3.0 16.7 70.0 3.1	
2004	1.8 8.4 18.2 30.0 2.4	1.8 126 62.8 10.2	2.3 80.1 50.1 14.6 3.6 10.2	9.7 9.7 12.2 3.1 41.3	6.0 3.1 3.1 3.9	2.2 1.7 1.5 1.4	1.7 1.2	4.0 1.9 1.7 1.5 3.1	2.5 11.2 4.0 35.2 5.64* 90.2*	10.7 31.6 12.3	39.7 21.5 4.5 67.6 26.5	1070 9.7 16.7 38.1	
2005	4.7 44.6 242 15.3 52.0	7.0 15.3 31.2	115 11.7 5.5 18.2	12.2 4.9 13.4	4.3 3.5 3.5 3.0 2.9	6.3*	3.8 4.0 3.8	6.3 6.3 3.0 60.5 161 165 390 94.6	259 22.5	38.1 36.7 12.2 10.2 14.0	12.8 6.0 253 282 1390 12.8	5.7 191 10.2 33.9	
2006	44.6 7.7 23.4 5.7	17.4 58.3 20.7	3.8 4.9	15.3	85.7 26.5 24.4	94.6 11.2 7.7 26.5 24.4	13.4 5.7 14.6 16.7 46.4	31.2 62.8 182 126 20.7 115 31.2	542 15.9 26.5 21.5 5.7 130 115	62.8 488 80.1 94.6 72.4	26.5 24.4 26.5 26.5 21.5 16.7	169 48.2 50.1 9.3	Nov and Dec 2006 hts/flows are estimates read from a damaged (bent) staff gage

[1] Stream staff gage heights were converted to flow rates (cfs) using the USGS-derived stage discharge curve for Granite Creek. Eleven direct flow measurements were taken. All measurements were taken at Station GC1.

[2] All flows are given equal weight in calculating average monthly flows for a given month over the four+ year period. Dates and a complete record of staff gage heights are found in the comprehensive water quality database maintained for Granite Creek and reported annually to ADEC.

* indicates a direct flow measurement completed by USGS or USFS hydrologists.

2007	6.0 38.1 313												
 Total Mean Max Min # obs	***JAN*** 979 **44.5** 313 1.8 22	***FEB*** 376 **29.0** 126 1.8 13	***MAR*** 397 **19.8** 115 3.3 20	***APR*** 148 **9.9** 41.3 3.1 15	***MAY*** 214 **13.4** 85.7 2.6 16	***JUN*** 217 **15.5** 94.6 1.4 14	***JUL*** 128 **9.1** 46.4 1.2 14	***AUG*** 1498 **62.4** 390 1.5 24	***SEP*** 1590 **79.5** 542 2.5 20	***OCT*** 1134 **66.7** 488 10.2 17	***NOV*** 3740 **138** 1390 3.3 27	***DEC*** 1774 **88.7** 1070 3.1 20	**Average (mean) monthly flows** are used to calculate load capacity & existing sediment loads

Table 2. Granite Creek Total Suspended Solids (TSS) concentrations (mg/l), by month, at Station GC1, October 2002 through January 2007.[3]

JAN	*FEB*										
0.05 0.2 17.6* 4 Monthly Mean TSS: (mg/l)[4] 1.42 (5.46 w/all)	6 3.4 4.8 4.73	0.75 1.5 0.1 0.3 0.1** 0.1** 0.48	0.8 0.1 0.7 0.4 0.1** 0.42	0.2 0.1 0.7 6.4 1.70** 1.43** 1.76	1.7 0.1 0.9 0.8 0.88	0.5 0.7 0.6	0.9 0.03 14* 7.3 2.74 (5.56 w/all)	8.2 3.3 13* 14* 5.0** 5.50 (8.70 w/all)	47* 1.9 0.2 2.2 0.7 0.3 13 0.9 7.8 0.1** 0.1** 5.78** 3.00 (6.67 w/all)	0.4 11.1 0.6 15* 3.6 3.93 (6.14 w/all)	2 1.8 123* 2.7 3 2.38 w/o high

** TSS concentration derived from turbidity value using linear regression equation

[3] Note: While most simultaneous TSS and turbidity samples at GC1 were collected on a random monthly schedule by CBS staff, others were deliberately collected during extreme storm events to determine “worst case” flows and sediment transport. During these episodic events, stream bank erosion contributed a significant proportion of sediment transport in comparison to sediment from gravel operations. Operators typically do not blast or move earth and gravel during heavy rains per CBS lease stipulation. For this reason, those high TSS values marked above with an asterisk (*) were considered storm-related anomalies, i.e. not representative of typical sediment transport, and were not included in the calculation of average TSS concentration for that month.

[4] For statistical reasons, the average monthly TSS concentrations generated from the logarithmic TSS-flow regression equation on page 9 were used in calculating monthly load capacity in in-stream sediment loads, rather than the monthly means values shown here.

Table 3. Background turbidity values measured at Granite Creek control stations[5], October 2002 through October 2006.

Date	North Fork control station	GC4 control station
2002 October 16-17, 2002	1.36	14.8
2003 March 19-20, 2003 September 23-25, 2003	1.28 2.18	0.63, 0.45, 1.00, 0.95, 1.46 6.04, 6.62
2004 *April 7-8, 2004* June 16, 2004 October 5-7, 2004	1.34, 1.33, 0.95 0.91, 0.70 1.44, 2.53	0.6, 0.47 0.19 1.43, 2.43
2005 *May 11-13, 2005* October 26, 2005	1.07, 2.04 1.48	2.00 1.10, 0.44
2006 *April 18-20, 2006* *October 24-26, 2006*	1.63, 1.12, 0.62 0.93, 1.48, 0.84, 1.55	0.44, 1.54 0.51, 0.77
Average [Turbidity] NTUs Combined station average turbidity using all 40 background measurements from both reference stations	1.34 NTU 1.77 NTUs[6]	2.19 NTU

[5] See approved QAPP for a description of Granite Creek permanent monitoring stations and control sites.
[6] A natural background value of 1.64 NTUs was used in the original TMDL, showing good comparison.

In 2002, regression analysis was completed on the data sets to establish the TSS-turbidity relationship. Sixteen data sets were plotted. The following equation described the relationship between TSS and turbidity in the 2002 TMDL:

$$\text{TSS (mg/l)} = [1.075\ (\text{turbidity in NTUs})] - 1.681$$

The correlation coefficient for the data was a highly significant 0.9676.

Validating this relationship was an important objective in implementing the TMDL from 2002 to the present. Cumulative analysis was completed on 52 *simultaneously-collected* TSS and turbidity data sets from October 2002 through January 2007. *Table 4* summarizes these data. A new linear regression analysis was completed on the data collected from 2002 through early 2007. The following equation was generated:

$$\text{TSS (mg/l)} = [1.2204\ (\text{turbidity in NTUs})] - 2.934$$

The correlation coefficient for the new cumulative analysis is a highly significant 0.9780.

Importantly, the new equation yields TSS values that deviate from the original equation by only 2% to 12% over the range of normally encountered turbidity levels. For example, using the original equation, a turbidity concentration of 10 NTUs represented a TSS equivalent of 9.07 mg/l. Using the new equation, a 10 NTU turbidity level equates to a TSS level of 9.27 mg/l, a 2% change from the original estimate. At 30 NTUs, the comparison is 33.68 mg/l and 30.57 mg/l, respectively, a 12% change from the original estimate. The new allowable target TSS concentration (equivalent to 6.64 NTUs) is 5.17 mg/l, compared to the 5.46 mg/l limit derived in 2002.

The bottom line is that the original regression equation was valid and acceptably accurate as confirmed from subsequent analysis of 52 data sets from 2002 through early 2007. The new equation, however, should be used for further analysis since it is based on a much larger number of data points and, hence, is expected to be more accurate.

Confirming the close relationship between turbidity and TSS provides several benefits. First, water quality sampling could potentially rely on turbidity measurements alone, or a reduced number of TSS samples, in calculating TSS with a reasonable amount of accuracy. This is both cost-effective and provides real-time information without the need to await the results of laboratory analysis. Secondly, turbidity concentrations are more easily estimated and understood by gravel operators and other lease operators in conducting visual self-monitoring of the effects of their operations on water quality.

4. Average monthly TSS concentration

As discussed previously, the calculation of the average monthly TSS concentration using TSS data from very high – and unweighted - flow events, creates a significant “high bias”, given the relatively few TSS samples (roughly 3 to 8) collected during each month.

Average monthly TSS concentrations, by month, were first calculated using the mean concentration for that particular month for samples collected from October 2002 through January 2007. Two calculations were made: one including all TSS data; and a second which threw out TSS data collected during episodic flow events considered anomalously high. These later TSS values are noted with a single asterisk in *Table 2.* The number of samples for each month over that period varied from two (July) to eleven (October). This distribution shows that relatively more samples were collected during high flow months (September through December) than during lower flow months. This was by design, in order to capture high flow and high TSS conditions to establish episodic, worst case conditions.

For this reason, and in an effort to flow-weight the turbidity data over four years, the regression equation on the relationship of TSS to flow rate (see page 9) was used to calculate average monthly TSS concentrations for a given average monthly flow rate. It is a statistically stronger approach than using *Table 2* values alone, by relying on over 50 data sets and avoiding any bias by not throwing out any high TSS values. Therefore, the equation was used in lieu of *Table 2* in calculating average monthly TSS concentrations.

5. Sediment-to-flow relationship

Of key importance in estimating monthly loading capacity and in-stream sediment loads in Granite Creek is creating a statistical model of the TSS-flow relationship. In 2002, data were insufficient to support a statistically significant regression equation. This was particularly true for higher flow-higher TSS conditions. However, some data were available to bracket high and low flow ranges and associated sediment concentrations. Direct TSS-flow data sets existed for flows less than 23 cfs and for flows of 186 cfs. Turbidity data existed for flows between this range, but no direct TSS measurements. The TSS concentration for intermediate flows was estimated based on a combination of historical turbidity data, rough estimates of flow rates, the statistically-supportable conversion of turbidity- to-TSS, and best professional judgement based on several years of monitoring operations in the watershed. This initial approach was consistent with EPA's guidance that allows for the use of best available information in developing TMDLs.

Based on the above information, the following relationship of flow rate-to-TSS was used in the 2002 TMDL to estimate monthly existing in-stream sediment loads in Granite Creek.

< 15 cfs = 1.0 mg/liter average monthly TSS concentration
15-35 cfs = 5.0 mg/liter average monthly TSS "
35-50 cfs = 8.0 mg/liter average monthly TSS "
>50 cfs = 10.0 mg/liter TSS average monthly TSS "

The cumulative analysis of TSS and flow data collected from October 2002 through January 2007 suggest that the above relationship is not entirely accurate for Granite Creek. While TSS concentrations for flows below 15 cfs appear accurate on analysis of

Table 4. Relationship of Total Suspended Solids (TSS), turbidity, and flow rates at Station GC1, Granite Creek, Alaska, from October 2002 to January 2007. [7] [8]

Date[9]	**TSS (mg/l)**	**Mean turbidity (NTU)**	**Turbidity Replicates (NTU)**	*Flow rate* **(cfs)**	**USGS staff gage height (ft)**	**Comments and notes**
10/16/2002	47	44.8	45.2, 44.5			USGS installed permanent stream staff gage on November 8, 2002
10/17/02	1.9	5.44	5.85, 5.02	51.3 *		
11/08/02	0.4	2.57	2.54, 2.6	3.4 *	18.92	
11/16/02	11.1	17.4	17.8, 17	137	19.82	
12/11/02				11.9 *	19.18	
12/31/02	2	3.63	3.61, 3.66	10.2	19.14	
1/10/2003	0.05	0.54	0.6, 0.53	6.4 *	19.04	
3/1/03	0.75	2.88	2.86, 2.9	30.0 *	19.39	
3/18/03	0.3	2.79	2.72, 2.85	7.3	19.07	
4/16/03	0.8	4.00	4.19, 3.81	4.89 *	18.95	
5/22/03	0.2	0.44	0.45, 0.43	3.1	18.90	
6/19/03	1.7	2.52	2.38, 2.65	28.3 *	19.36	
8/11/03	0.9	0.92	0.89, 0.94	2.3	18.83	
9/25/03	8.2	3.44	3.85, 3.02			
10/04/03				84.6 *	19.66	
10/30/03	0.2	0.87	0.89, 0.86	10.2	19.14	
12/16/03	1.8	7.28	7.08, 7.49	16.7	19.25	
1/29/2004	0.2	0.58	0.61, 0.55	2.4	18.84	
2/8/04	6	6.81	7.42, 6.19	126	19.79	
3/8/04	1.5	3.22	3.35, 3.09	50.1	19.52	
4/7/04	0.1	1.70	1.78, 1.62	9.7	19.13	
5/17/04	0.1	0.51	0.52, 0.50	3.1	18.90	
6/16/04	0.1	0.49	0.48, 0.49	1.7	18.76	Second highest flow measured at Granite Creek on 12/2/04. TSS max of 123 mg/l. Highest recorded flow was on 11/22/05.
8/12/04	0.03	0.38	0.38, 0.39	1.7	18.77	
9/08/04				5.64 *	18.90	
9/21/04	3.3	4.62	4.83, 4.40	90.2*	19.61	
10/05/04	2.2	6.45	6.84, 6.05	31.6	19.39	
11/04/04	0.6	1.50	1.52, 1.47	21.5	19.31	
12/02/04	123	95.0	94.1, 95.9	1070	20.90	
1/17/2005	17.6	19.9	21.1, 18.7	242	20.05	USGS completed Stage Discharge
2/24/05	3.4	9.12	8.99, 9.25	15.3	19.23	

7 Flow rates are derived from staff gage height readings converted using the USGS Stage discharge curve (SDC) unless otherwise noted.
* indicates actual flow measurements taken by USGS or USFS hydrologists for use in developing the stage discharge curve for Granite Creek

2 Table 4 includes only those dates where simulataneous TSS and turbidity measurements were taken at GC1. Turbidity alone was collected at GC1 on several other dates and results are included in supporting tables.

4/4/05 5/25/05 6/14/05 7/13/05 8/18/05 9/19/05 10/13/05 10/26/05 11/17/05 11/21//05 12/22/05	0.7 0.7 0.9 0.5 14 13 0.7 0.3 15.0 3.6 2.7	1.74 1.29 --- 1.46 8.11 16.2 1.91 2.09 19.4 3.41 5.78	1.75, 1.74 1.26, 1.33 --- 1.44, 1.48 7.7, 8.52 16.0, 16.4 1.89, 1.93 1.43, 2.75 19.2, 19.6 3.49, 3.33 5.74, 5.82	12.2 2.9 6.3 * 4.0 60.5 259 36.7 12.2 253 282 33.9	19.18 18.88 19.04 18.95 19.57 20.08 19.44 19.18 20.07 20.12 19.42	Curve (SDC) in June 2005 based on 11 actual flow measurements covering a range of flow rates.
1/9/2006 2/7/06 3/29/06 4/18/06 5/17/06 6/26/06 7/25/06 8/18/06 9/1/06 10/04/06 10/24/06 10/25/06 12/18/06	2.9 4.8 0.1 0.4 6.4 0.8 0.7 7.3 14 13 0.9 7.8 3	9.39 9.90 0.48 3.23 8.55 1.34 1.15 9.97 13.5 12.6 3.05 20.2 4.66	9.42, 9.36 9.86, 9.94 0.47, 0.50 2.41, 4.05 8.47, 8.63 1.28, 1.41 1.13, 1.17 10.1, 9.83 13.5, 13.6 13.2, 12.1 3.16, 2.92 18.8, 21.5 4.69, 4.63	44.6 58.3 4.9 15.3 85.7 24.4 16.7 126 542 80.1 94.6 9.3	19.49 19.56 18.99 19.23 19.67 19.34 19.25 19.79 20.46 19.65 19.70 19.12	Staff gage damaged 9/25/06 during high flow. Gage partially restored; USGS to resurvey in early 2007
1/15/2007	4	4.87	4.94, 4.80	38.1	19.45	

2002-2006 data, the 2002 estimated TSS concentrations for flow ranges above 15 cfs appear to overestimate actual sediment loads. This is discussed below.

Analysis of data from fall 2002 through early 2007

From October 2002 through January 2007, 50 sets of simultaneous TSS-flow measurements (flow rates converted from gage height elevations) were collected. These data have allowed for developing a Granite Creek sediment-rating curve from actual stream data. Given the unique environmental characteristics of each stream, the slope and characteristics of a sediment-rating curve typically apply only to that stream. The relationship is exponential. Sediment loads tend to increase as a square of flow.

The most common statistical method of analyzing sediment – discharge data is a power function (regression analysis) that relates TSS to flow rate. Typically, a common logarithmic transformation of both TSS and discharge data is done prior to analysis. Logarithmic transformation makes it easier to evaluate the relationship between two variables by linearizing the relationship, normalizing distribution of highly skewed data, and stabilizing variance. By transforming both variables, the log-log association becomes linear when plotted. The USGS used this identical method to plot Granite Creek gage height data and discharge data on a log–log scale, generating the stage-discharge curve for Granite Creek in 2005.

The standard relationship between variables in a sediment-rating curve is:

$$Q_s = aQ^b$$

Where Q_s is sediment concentration (mg/l), Q^b is the discharge in cubic feet per second, and a and b are empirical constants. b generally varies between 1.5 and 2.5. The relationship suggests that sediment loads generally tend to increase exponentially with increases in stream flow. This is the case for Granite Creek.

Table 4 includes all simultaneous TSS and flow data collected over the project. Common (base 10) logarithmic transformation was completed on all the data sets for Granite Creek listed in the table. The transformed data were then run through linear regression analysis. The following equation was developed for the relationship of TSS and discharge rate in Granite Creek:

$$\log(\text{TSS (mg/l)}) = 0.92489 * \log(\text{flow (cfs)}) - 1.1521$$

This equation represents the standard regression: $y = mx + b$

The "y" variable is TSS and the "x" variable is flow rate. The slope is "m', or 0.92489. The "b" intercept on the graph is – 1.1521. The correlation coefficient (r^2) is 0.85351. The mean of all TSS measurements was 1.30 mg/l and the mean of all discharge rates is 23.48 cfs.

Average monthly flows listed in column 2 of *Table 5* were converted to common logarithmic values and a logarithmic value for TSS was generated for that particular month using the above equation. The antilogarithm was then calculated from this value to yield the TSS concentration corresponding to the average monthly flow. This calculation was completed for all months, January through December, for all years combined.

For example, January has an estimated average monthly flow of 44.5 cfs, based on the average of five measurements over the period 2002 through early 2007. Log transformation of 44.5 gives a value of 1.648. Using the above equation, (0.92489)(1.648) - 1.1521 = 0.372. The antilogarithm of 0.372 is 2.36 mg/l TSS. This represents the calculated average monthly TSS concentration for January for the period 2002 through early 2007.

Using the logarithmic equation above, the average monthly TSS concentrations calculated for each month are:

January: 2.36 mg/l	July: 0.54 mg/l
February: 1.60 mg/l	August: 3.22 mg/l
March: 1.12 mg	September: 4.03 mg/l
April: 0.59 mg/l	October: 3.43 mg/l
May: 0.78 mg/l	November: 6.71 mg/l
June: 0.89 mg/l	December: 4.46 mg/l

Existing in-stream sediment loads *(Table 6)* for each month are then calculated by the following equation:

> Average monthly flow (cfs) * 0.0027 * average TSS concentration (mg/l) correlated to that monthly flow rate * number of days in the month = tons of sediment (TSS) for that month

Comparing against actual data collected over four years, the equation is a good predictive tool for estimating TSS concentrations from flow data.

The alternative method of estimating average TSS concentration for each month is to average the TSS measurements taken for that month from October 2002 through January 2007 (*see Table 2*). This is problematic for two reasons. One is that one high reading can significantly skew the data. For months with few TSS samples, such as July with only two measurements from 2002-2006, this can cause significant “high bias”. The second problem is that some TSS samples were collected without a corresponding flow rate. As mentioned above, logarithmic transformation evens out such extremes (low and high) and normalizes the distribution.

For these reasons, all average monthly TSS concentrations were developed from the logarithmic regression equation that was based on 50 data sets (49 degrees of freedom) and is statistically defensible.

6. Loading Capacity (LC)

A necessary element of the TMDL is identifying the relationship between the *allowable or desired* condition of Granite Creek (expressed as the water quality standard) and the *actual, or existing,* condition for sediment and turbidity loading. This relationship determines the degree to which Granite Creek meets or exceeds its assimilative capacity for sediment.

The allowable sediment load, or loading capacity, defines the upper limit for sediment loads while still meeting water quality standards and supporting fisheries, recreation and other protected uses of the creek.

Monthly sediment (TSS) loading capacity for Granite Creek, which includes the natural sediment load, is summarized in *Table 5*. Load capacity varies as a function of average monthly flow. The monthly load capacities set the "ceiling" for allowable sediment inputs to the creek from all sediment sources in the watershed. For the original TMDL, the annual loading capacity for Granite Creek was estimated at 122.00 tons of TSS. The natural background sediment load in Granite Creek was estimated at 22.63 tons of TSS. Natural background loads are included as part of the calculated loading capacity of Granite Creek. These values are fixed and all load reductions/allocations are designed to meet these target values.

In order to recognize seasonal flow regimes, the seasonality of some operations in the watershed, and critical periods for salmon and recreational resources in Granite Creek, monthly sediment loading capacities were calculated.

An analysis of all water quality data collected from 2002 through 2006 suggests a revision of loading capacity (tons/year) is warranted. The allowable target TSS value was reduced slightly from of 5.46 mg/l to 5.17 mg/l to reflect the results of the new TSS-to-turbidity regression equation (see Section 3 discussion above on the TSS: turbidity relationship). More important, however, is that *estimates of average monthly flows have increased significantly*, thereby increasing load capacity estimates for Granite Creek. Both the original 2002 and revised load capacity values are shown in *Table 5* for comparison. The revised annual sediment loading capacity is estimated at **224.86 tons/year** as compared to the 2002 estimate of **122 tons/year**. This increase is due almost entirely to the higher average monthly flow values documented from 2002 through 2006.

7. Existing in-stream sediment loads

Average monthly existing in-stream sediment loads (tons) for Granite Creek are calculated by multiplying the estimated average monthly Q (flow) in cfs by the average monthly TSS concentration (mg/l). This number is multiplied by 0.0027 to convert the result to tons/day. The resulting number is *tons/day* of TSS. Tons/day is multiplied by the number of days in the respective month to yield *tons TSS/month*.

Using January as an example, the initial 2002 estimate of existing in-stream TSS load for that month was calculated as:

*20.98cfs * 5.0 mg/liter TSS * 0.0027 * 31 days in the month = 8.78 tons TSS*

Using the newly derived TSS-flow regression equation described on page 9, January would have a sediment load of:

*44.5 cfs * 2.36 mg/liter TSS * 0.0027 * 31 days in the month = 8.79 tons TSS*

Each month was calculated this way. All months were summed to provide an annual in-stream sediment load of **187.06 tons** of TSS in Granite Creek generated from all land use sources.

Table 6 summarizes the revised estimates of existing in-stream suspended sediment loads by month and includes the original 2002 TMDL values in (parentheses) for easy comparison.

Comparing month-by-month, the newly estimated in-stream loads *exceed* the 2002 TMDL estimates for five months (February, March, August, November, December) and are *lower* than the 2002 estimates for five months (April – July and October). The original TMDL estimates and the new 2007 estimates are almost identical for January and September.

An estimated 81.9% of the annual total load occurs from September through December and 58% of the annual load is represented by two months, November and December. Flows from January through July contribute relatively little sediment to Granite Creek's annual sediment load budget.

The existing in-stream sediment load exceeds the loading capacity of Granite Creek only during the month of November. This could be an aberration as November had several extremely high flows that skewed the calculation of average monthly flow shown in *Table 1*. The estimated average monthly flow for November was 138 cfs, far exceeding that of any other month. In any case, continuing to diligently follow the Recovery Strategy BMPs and a program of routine monitoring should adequately address any exceedances.

The 2002 TMDL estimated annual in-stream load was 140.85 tons. The revised annual existing in-stream sediment load is 187.06 tons. The 2002 estimated Loading Capacity (LC) for Granite Creek was 122.00 tons. The revised Loading Capacity is estimated at 244.86 tons.

This suggests that significant sediment load reductions have occurred in Granite Creek during the period 2002 through early 2007, that monthly load capacity exceeds existing in-stream loads for most months of the year, and therefore, new sediment load allocations can be safely reserved for future sources in the watershed.

Table 5. Monthly Suspended Sediment Loading Capacity (LC) for Granite Creek, showing both revised sediment loads and original 2002 TMDL load estimates in ( ).

Month	**Average Monthly Flow (cfs)[10] Revised (Original)**	**Natural Background Load (tons)[11]**	**Loading Capacity TSS (tons)[12] Revised (Original)**
January	44.5 (20.98)	1.86	19.26 (9.59)
February	29.0 (6.06)	0.56	11.33 (2.50)
March	19.8 (9.37)	0.93	8.57 (4.28)
April	9.9 (18.40)	1.50	4.15 (8.14)
May	13.4 (24.17)	2.17	5.80 (11.05)
June	15.5 (23.94)	1.80	6.49 (10.59)
July	9.1 (14.84)	1.24	3.94 (6.78)
August	62.4 (12.11)	0.93	27.00 (5.53)
September	79.5 (38.30)	3.00	33.29 (16.94)
October	66.7 (53.58)	4.34	28.86 (24.49)
November	138 (13.70)	1.20	57.79 (6.06)
December	88.7 (35.11)	3.10	38.38 (16.05)
Annual Total		**22.63 tons**	**244.86 tons (122.00[13])**

[10] Average monthly flows are calculated in Table 1. Original 2002 estimates are shown in (parentheses).
[11] Natural background sediment loads used in the original 2002 TMDL remain accurate and unchanged based on five years of water quality data collection.

[12] Monthly load capacity based on analysis of in-stream data. Includes natural background sediment load. Calculated as: (Monthly Q (cfs)) * (5.17 mg/liter TSS) * (0.0027) * (# days in month). The following regression equation developed from 50 simultaneous data sets was used to calculate the revised allowable TSS concentration:

$$TSS\ (mg/l) = 1.2204\ (\text{turbidity in NTUs}) - 2.934$$

[13]Load capacity (tons) includes the allowable sum of existing loads, future loads (LA/WLAs) and any explicit MOS.

Table 6. Monthly existing (in-stream) suspended sediment loads in Granite Creek, comparing 2007 calculations with original 2002 TMDL estimates in ( ).

Month	**Average Monthly Flow (cfs) Revised (Original)**	**Existing In-Stream Suspended Sediment (TSS) Load (tons)[14] Revised (Original)**
January	44.5 (20.98)	8.79 (8.78)
February	29.0 (6.06)	3.51 (0.46)
March	19.8 (9.37)	1.86 (0.78)
April	9.9 (18.40)	0.47 (10.43)
May	13.4 (24.17)	0.87 (14.16)
June	15.5 (23.94)	1.12 (9.70)
July	9.1 (14.84)	0.41 (1.24)
August	62.4 (12.11)	16.82 (1.01)
September	79.5 (38.30)	25.95 (24.82)
October	66.7 (53.58)	19.15 (44.85)
November	138 [15](13.70)	75.00 (31.11)
December	88.7 (35.11)	33.11 (23.51)
Annual Total		**187.06 tons (140.85 tons)**

[14] Tons of TSS/month = monthly average Q (cfs) * average TSS (mg/l) concentration corresponding to the average monthly flow (see text on using the TSS-flow regression equation) * 0.0027 * # of days in the month.

[15] November average includes 2 of the 3 highest flow rates recorded at Granite Creek from October 2002 through January 2007. Throwing out one or both of these flows from the average would result in a significantly lower existing in-stream load estimate for November. They are both left in here to provide a conservative worst case scenario.

Since significantly higher average monthly flow rates were used in the 2007 calculations, this suggests that the decrease in annual sediment loads for Granite Creek compared to 2002 is due to a lower average TSS concentration in the creek.

8. Margin of Safety (MOS)

EPA regulations require 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 load allocations and water quality. EPA guidance specifically allows the option of including the MOS in the TMDL analysis either *implicitly* through conservative assumptions or *explicitly* as a stand-alone portion of the total load allocation. An implicit MOS must be supported by a discussion of the conservative assumptions used and how they adequately account for uncertainties.

A MOS for Granite Creek was included implicitly in the original TMDL source load calculations through a series of conservative assumptions. This approach was approved in 2002. These assumptions remain valid in 2007.

The major contributions of sediment to Granite Creek are typically episodic and variable during the year rather than continuous, and are typically tied to heavy rainfall, truck traffic, and reduced settling pond retention times during rainy periods. Episodic events increase the average monthly flow and average TSS concentrations used to estimate in-stream sediment loads. As stated earlier, monitoring often targeted high flow events to establish episodic conditions. This tends to statistically overestimate actual sediment loadings in cases where relatively few measurements exist. This is inherently a conservative approach to calculating in-stream sediment loads and provides the required "built in" margin of safety pending acquisition of more complete long-term monitoring data. Therefore, an implicit margin of safety remains justified.

Annual Sediment Load Reductions Since 2002

It is not a simple task to compare in-stream sediment loads for each year from 2002 through 2006 because Granite Creek lacks a continuous flow gage and daily samples of TSS and turbidity that would allow easy calculation of daily, monthly and annual sediment loads. Faced with weekly discharge estimates and monthly TSS and turbidity sampling from 2002 through early 2007, a number of assumptions were required to calculate annual sediment loads and allow for comparison with load capacity *(Table 5)* and combined year in-stream sediment loads *(Table 6).*

The method selected for calculating sediment loads for each year from 2002 through 2006 involved the following approach.

- Summing all average monthly flows for January through December found in *Table 5* and *Table 6* and dividing by 12 to generate *an average annual flow rate for all years combined* of 48.04 cfs.

- Multiplying the average annual flow rate (48.04 cfs) by the average TSS concentration for all samples collected *for that particular year* taken from *Table 4,* and then multiplying the result by the conversion factor 0.0027 and 365 days to yield annual in-stream sediment load in tons/year for that particular year. Two anomalously high TSS values (out of the total of 52) were associated with major storm events and were not included in the calculations to avoid skewing the annual average. These occurred on October 16, 2002 and December 2, 2004. CBS staff deliberately sampled during these storm events to document a "worst case" scenario for sediment loads, i.e. they were not random sampling events.

The calculated annual in-stream sediment loads from 2002 through 2006 are:

2002 (partial year, October 15 through December 31): 3.85 mg/l * 48.04 cfs * 0.0027 * 90 days = 44.94 tons sediment projected to over *240 tons for the full year*

2003: 1.49 mg/l * 48.04 cfs * 0.0027 * 365 days = *70.54 tons sediment for the year*

2004: 1.42 mg/l * 48.04 cfs * 0.0027 * 365 days = *67.23 tons sediment for the year*

2005: 4.63 mg/l * 48.04 cfs * 0.0027 * 365 days = *219.20 tons sediment for the year*

2006: 4.01 mg/l * 48.04 cfs * 0.0027 * 365 days = *189.95 tons sediment for the year*

All annual sediment load estimates from 2003 through 2006 are below the allowable loading capacity of 244.86 tons/year. Initial decreases seen in late 2002, 2003 and 2004 coincided with the installation of multiple settling ponds, newly-installed buffer protections, and a variety of sediment control BMPs first implemented beginning in fall 2002.

The relatively higher stream sediment loads occurring in 2005 and 2006 coincided with increased gravel extraction at the CBS and Tisher pit sites, coupled with a commensurate increase in truck traffic and road runoff to the creek. Additionally, some very high flows and TSS measurements were recorded during those years in an effort to document the TSS-to- flow relationship, both of which increase the average flow rate and the average concentrations of sediment (TSS) used in the calculations. These factors elevated estimated annual sediment loads. The elevated levels most likely include sediment from stream bank erosion, and not operational inputs, as operators often stop work during such events. Indeed, operators are required to cease blasting and earthmoving during very heavy rains per CBS lease stipulation. It is also true that sampling during those years was not totally random, and very high flow events and corresponding TSS concentrations were measured to document worst case conditions.

For comparison with the values above, if the two highest TSS values are thrown out for each of the years 2005 and 2006, the following annual in-stream loads are calculated:

2005: 3.68 mg/l * 48.04 cfs ***** 0.0027 * 365 days = 174.22 tons sediment for the year

2006: 3.19 mg/l * 48.04 cfs ***** 0.0027 * 365 days = 151.03 tons sediment for the year

In both cases, annual existing in-stream sediment loads are below the allowable loading capacity of 244.86 tons.

<u>*Load Allocations, Load Reductions and Provision for Future Growth*</u>

Since 2002, a decline in sediment input to Granite Creek has occurred. This is the direct result of the successful implementation of the Recovery Strategy and its range of stormwater runoff and other controls. Construction of multiple settling ponds in series, routine cleaning of ponds, establishment and protection of vegetated riparian buffers along tributaries to Granite Creek, placement of physical barriers to limit encroachment on stream banks, road grading and maintenance, operator education and improved awareness, pre-construction design modifications, and routine water quality monitoring have been key BMPs and actions contributing to the decline in sediment loads.

Load reductions are defined as the reductions in sediment source loads needed so that the total sediment load to Granite Creek is less than or equal to the allowable load capacity of the creek. Monthly load reductions represent the difference between the existing in-stream load and the loading capacity for that particular month.

Tables 5 and 6 summarize the current monthly loading capacity and existing in-stream sediment loads for Granite Creek. Target load reductions prescribed in the 2002 TMDL have largely been met on an annual basis. Monthly anomalies do exist.

Since the estimated annual loading capacity for Granite Creek (244.86 tons sediment/yr) exceeds the estimated annual existing in-stream sediment load (187.06 tons/yr), no load reductions are necessary on an annual basis. For 11 of the 12 months, existing in-stream loads are less than the loading capacity for that particular month. November represents the only anomaly, where an estimated existing in-stream load of 75.00 tons sediment exceeded the calculated allowable load capacity of 57.79 tons of sediment. This suggests periodic exceedances of the water quality standards for turbidity and sediment during November. December is also a month of interest.

Therefore, a new load reduction of 17.21 tons is prescribed for November. This represents a revised *load allocation (LA)* for November of:

> $LA_{November}$ = 75.00 tons (existing load) - 17.21 tons (load reduction) = 57.79 tons sediment

Several factors may explain November's relatively high sediment loads. Two of the three highest recorded flows at Granite Creek (863 cfs and a peak of 1390 cfs) occurred during November. These data significantly increased the calculation of average monthly flow and existing in-stream sediment loads.

Given that Granite Creek remains compliant with the 2002 TMDL-prescribed load reductions and allocations on an *annual* basis, no action other than continuing to follow and adjust the BMPs and the Action Plan are warranted. Particular attention will be placed on minimizing road runoff from September through November. The City and Borough of Sitka is currently negotiating with a lease operator to pave the portion of Granite Creek Road leading to the lease area (projected to occur in June 2007) and the newly aligned access road through the leases. Both these actions would significantly reduce road runoff and sediment contributions to the creek during the rainy fall period. Road runoff has been found to be a very significant sediment source during such times.

A Margin of Safety (MOS) load allocation of 0 tons is budgeted, identical to the approach taken in developing the TMDL in 2002, given that the MOS is implicit and included in conservative assumptions. ADEC and EPA accepted an implicit MOS in approving the TMDL in 2002.

Future growth allocations for sediment from nonpoint sources and point sources is determined through this equation:

> Load capacity (tons/yr) – total existing sources (tons/yr) – margin of safety (tons/yr) = future growth allocation (tons/yr)

Plugging in the annual values from *Tables 5 and 6* results in the following:

> 244.86 tons/yr – 187.06 tons/yr – 0 tons/yr = 57.80 tons sediment/yr reserved for future point and nonpoint sources

This is a greater future growth load allocation than calculated in the original TMDL. In the 2002 TMDL, future source load allocation was limited to a maximum of 22.25 tons sediment/year.

Future growth at Granite Creek will include residential housing, a Class III landfill and biosolids disposal, continuing organic waste overburden disposal, asphalt plant relocation, benchroad construction, and expanded gravel extraction.

Watershed Water Quality Data Analysis and Source Contributions

Whereas Station GC1 integrates the effects of all stormwater runoff events at the mouth of the creek, the permanent monitoring station network established throughout the watershed allows for discriminating sources, background concentrations and the relative significance of individual sources to overall water quality. This results in targeting BMPs and adjustments to specific operations to solve any problems.

Granite Creek is affected by a variety of nonpoint sources, principally gravel mining and road runoff. Existing in-stream loads shown in *Table 6* integrate all source contributions.

While it is beyond the scope of this analysis to recalculate source-specific sediment loads, a number of conclusions can be made regarding the relative significance of source contributions of sediment from 2002 through 2006.

The permanent watershed-wide water quality monitoring network was established in 2002 and approved in the Granite Creek QAPP. The station network included Station GC1 (integrator at Halibut Point Road bridge), GC 2 (North Fork below gravel operations), GC3 (South Fork below gravel operations), GC4 (South Fork control above gravel operations), and North Fork control (unaffected by lease operations). Additionally, multiple settling pond sampling stations, and opportunistic road ditch/pond and culvert discharges along Granite Creek Road have been routinely monitored since October 2002.

1. Summary results of watershed data analysis

Turbidity and TSS data collected throughout the watershed since 2002 have verified a reduction in sediment loads to Granite Creek. Road runoff continues to be a major contributor of sediment when coupled with high truck traffic and rainy conditions. Roadside detention basins and vegetated ditches help to treat and reduce pulses in sediment runoff. With few exceptions, the CBS settling pond series/network constructed in July 2001 has proven very effective and has demonstrated sufficient residence time to collect and treat sediment and turbidity from lease operations at the city pit. These are engineered, large, deep ponds. On rare occasions during heavy rain events, residence times are not entirely adequate for the smaller series of ponds at the Dormand McGraw lease site and the Tisher pit floor area. Even in these worst case events, insufficient residence times and overflows typically occur for relatively few days of the year. Nonetheless, they should be addressed. Efforts are being taken to increase the volume of these smaller ponds to promote improved treatment and to utilize vegetated swales to further treat runoff before it enters the creek. As shallow bedrock may limit deepening the Tisher ponds, resizing to increase the area of the ponds holds more promise for increasing volume and retention times. Reducing run-on to the pit floor will also help address retention time problems.

Protecting, maintaining and enhancing the vegetated riparian buffers along the tributaries has been a very effective stormwater control BMP, both in reducing direct bank encroachment and treating/filtering sediment runoff. The purchase of the hydroseeder in FY07 will provide the means to further enhance grass growth and natural filtration (swales) as a stormwater treatment tool.

For detailed watershed water quality monitoring results, the reader is referred to the annual and quarterly reports submitted to ADEC from 2002 through 2007.

2. Source contributions and environmental audits

The 2002 TMDL estimated the percentage of total existing in-stream sediment load contributed by each source as:

Industrial: 65.17%
Overburden waste disposal site: 5.41
Road runoff and grading: 4.45%
Residential/light commercial: 6.08
Recreation areas: 17.32%
Winter road sanding and maintenance: 1.55%

Over the last five years, water quality monitoring has documented the relative importance of source contributions of sediment to Granite Creek. They have changed considerably from the 2002 estimated percentages. The dispersed permanent monitoring stations allow for segregating out individual sources of sediment on a real-time basis. Additionally, project consultant field trips typically occurred for three days, allowing for the capture of a time series of runoff effects over that period. This information provided hard data on the relative efficiency of settling ponds, their optimal residence times for treating sediment and turbidity-laden stormwater runoff, system stressors, recovery times, and real-time responses to rain, road traffic and other operational events.

On an annual basis, industrial inputs from gravel mining operations and associated pond effluents remain the most significant single source, although considerably reduced from the initial 65% estimate. These inputs affect both the North and South Forks of Granite Creek. A second major contributor of sediment is road runoff during heavy rains, particularly when rains coincide with extensive truck traffic along the road system. At such times, road runoff is often documented to be the major contributing sediment source to the lower segment of the North Fork and the main stem of Granite Creek. The upper North Fork and entire South Fork are more affected by gravel operations than road runoff above the point where the two forks merge to form the mainstem of Granite Creek. In direct response to these water quality results over several years, roadside drainage channels were seeded, check dams installed, bank breakouts repaired, several new roadside detention ponds constructed, collection drains and culverts installed, and road grading practices modified to collect and treat road runoff to Granite Creek. These improvements continue to be refined today.

In FY05, annual environmental audits of Granite Creek lease operations were included as a workplan task. These audits itemized the degree of compliance with both CBS lease stipulations and TMDL and water quality prescriptions. Audits are completed twice each year, once in the fall and again the following spring. The CBS Director of Public Works uses the results of the audits to direct removal of unauthorized solid waste, negotiate stormwater improvements on-site, and correct inadequacies in stormwater collection and treatment. Audits also play a role in providing information to the CBS Planning Department on the sensitivity of particular areas to new developments planned for the watershed. Linking the Granite Creek Master Plan – administered by the Planning

Department – to the TMDL – administered by the Public Works Department - is an ongoing objective, with an improved process for interdepartmental coordination and review of proposals now put in place.

Several new developments are planned for the watershed. Building lots will soon be cleared and a few residential homes are planned along lower Granite Creek. A Class III inert solid waste landfill has been permitted for the Tisher quarry area, plus disposal of biosolids at the old CBS overburden disposal site beginning in May 2007. A bench road above the quarry site is being considered. A new access road to a demolition waste storage area above the CBS pit run site was constructed in 2006. All must be planned and operated in full compliance with the TMDL and Action Plan BMPs. Regular audits will help ensure this result is achieved.

"Lessons Learned" from TMDL Implementation: Conclusions and Recommendations

The Granite Creek TMDL and Watershed Recovery Strategy are well regarded and helped to serve as a "blueprint" for a number of subsequent TMDLs developed since 2002. At the time of its development, the importance of the Implementation Strategy and Action Plan were emphasized by CBS, its project contractor and ADEC. This is reflected in the document's title: "Granite Creek Watershed Recovery Strategy and Action Plan and a Total Maximum Daily Load (TMDL) for Sediment and Turbidity ".

The intended emphasis is first on implementing the Recovery Strategy to solve problems. While prescriptive TMDLs and load reductions are required in EPA regulations as a benchmark for evaluating success, the process of solving problems towards meeting the load prescriptions is invariably the most challenging and important aspect of the process. This is the case with Granite Creek.

TMDLs are developed using best available information. Sometimes, relatively little information is available. A number of findings - or "lessons" - are apparent in this cumulative analysis of water quality data. These may be useful to others when reexamination of assumptions and loads is called for in other approved TMDLs developed for Alaskan waterbodies.

- Virtually any TMDL reexamined five years after development will show that some original assumptions were either too conservative or too liberal, or a combination of both. This is a function of better understanding watershed processes after many years of data collection.
- Verifying sediment load reductions is important. It is possible to compare pre-TMDL sediment loads with 2006 loads and show rough trends from 2002 through 2006. Plotting TSS and turbidity concentrations over several years also provides valuable real-time information on the degree of compliance with water quality standards and the sediment Load Capacity (LC) for Granite Creek.
- Protocols for reexamining TMDL assumptions and load calculations several years after they are approved – and periodically updating the TMDL - are not well defined.

There appears little benefit in formally amending the original TMDL, as new information collected in the future, as well as new activities occurring annually in the watershed, will undoubtedly alter it further. Rather, the process and assumptions used should be reviewed and reported, and perhaps including the results of the analysis as a supplement or addendum to the original TMDL.

- The Implementation Plan, *aka* Action Plan, would benefit from periodic updates to refine needed tasks and BMPs. The same could apply to updating the watershed description to address new sources and activities in the Granite Creek watershed since 2002.
- Semi-annual audits have been a useful, formal tool to document compliance of lease operations with municipal lease agreements and the TMDL and should be continued.
- Diligence in carefully tracking and monitoring new developments from the planning stage through the operation phase should continue to ensure the Master Plan and permitted land use activities address and conform to the TMDL.
- The “bottom line” should continue to be confirming compliance with water quality standards from all operations and making scheduled adjustments to the Implementation Plan to further refine and improve pollution control BMPs.

Perhaps the most important question to answer with the cumulative analysis is whether the TMDL and Recovery Strategy have worked to reduce sediment loads over time since 2002 and prior years. The answer is yes.

SALIENT POINTS

1. Existing in-stream sediment loads were reduced significantly in 2003 and 2004 compared with 2002, with more modest reductions calculated for 2005 and 2006.

2. Water quality standards are being met the vast majority of time.

3. In-stream sediment loads are below the annual allowable loading capacity for the creek. Combined-year analysis suggests that November’s in-stream sediment load exceeds November’s monthly loading capacity, with several fall months close to the monthly loading capacity.

4. The 2002 TMDL estimated annual in-stream TSS load was 140.85 tons/yr. The revised annual existing in-stream sediment (TSS) load is 187.06 tons/yr. The 2002 estimated Loading Capacity (LC) for Granite Creek was 122.00 tons TSS/yr. The revised Loading Capacity is estimated at 244.86 tons TSS/yr. Load allocation reserved for future point and non-point sources is calculated as 244.86 tons/yr– 187.06 tons/yr = 57.80 tons TSS/yr.

5. An estimated 81.9% of the annual total sediment load in Granite Creek occurs from September through December, with 58% of the annual load contributed during two months, November and December. Flows from January through July contribute relatively little sediment to Granite Creek’s annual sediment budget.

6. Roads can be a significant source of turbid runoff for short periods of time, coinciding with heavy rain and a high level of truck traffic.

7. The structural BMPs (settling ponds, riparian buffers, roadside channel modifications, etc) are working effectively to control turbidity and sediment runoff.

8. Well-constructed, properly sized, and maintained settling ponds are very effective and operate well during heavy rain events. Smaller ponds not linked in a series are less effective and provide less residence time for treatment, particularly during heavy rains.

9. Episodic rainstorm/rain events still contribute sediments to the creek, as smaller pond capacity is overwhelmed, road runoff is significant and stream banks erode.

10. Annual sediment loads are estimates and will continue to be revised as more monitoring and stream flow data become available.

11. Data collection targeting high flow events skews the data set, most likely causing an overestimate of sediment loads, as compared to strictly random sampling. This effect was statistically moderated somewhat with the 208 discharge measurements and the 52 simultaneous stream flow and TSS data sets collected from 2002 through 2006.

12. This cumulative analysis suggests that the original 2002 estimates of average monthly flows underestimated flows for several months, and overestimated flows in other months. Additionally, five years of data collection suggest the original TSS-to-flow relationship used in the TMDL is not entirely accurate for Granite Creek. A new regression equation is now generated to more accurately define this relationship.

13. Establishing the statistical relationship between turbidity and TSS over five years provides several benefits. First, water quality sampling could potentially rely on turbidity measurements alone, or a reduced number of TSS samples, in estimating TSS with a reasonable amount of accuracy. This is both cost-effective and provides real-time information without the need to await the results of laboratory analysis. Secondly, turbidity concentrations are more easily estimated and understood by gravel operators and other lease operators in conducting visual self-monitoring of the effects of their operations on water quality.

14. The heart of the Granite Creek TMDL remains the Implementation Plan. It is recommended that the focus continue to be on the Recovery Strategy and implementing the BMPS and water quality monitoring in the Action Plan**,** rather than focusing strictly on sediment load prescriptions. Carrying out effective stormwater controls and other BMPs for new developments to ensure minimum sediment runoff to Granite Creek will pay large dividends. Periodically updating the Action Plan and watershed description to keep them current is recommended.