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

FY 2003
FINAL REPORT

PROJECT #: NP-03-R02

Lemon Creek Natural Sediment Assessment

November 2003

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Executive Summary

A paired watershed study was conducted from May 2002 through June 2003 to ascertain the roles of glacier processes on watershed sediment discharge. Lemon Creek, an actively glaciated watershed, and Gold Creek, unglaciated, were used in this study. Some specific event-based effects of the glacier were identified but in general not as pronounced as anticipated, perhaps due to the unseasonably warm winter during the study period and probably also due to landslide activity in both watersheds that added unexpected variability to the data. Overall the glaciated system produced an order of magnitude more sediment over the course of the year than the unglaciated watershed. This study concludes that in systems substantially influenced by glacier and mass wasting processes, the traditional TSS-Q (total suspended sediment-stream discharge) relationship is not particularly meaningful because some of the most pronounced sediment events are associated with processes that are not well correlated with stream discharge. At the time of this report, analysis of the collected data is continuing in order to identify additional insights into the erosion processes in Lemon and Gold Creeks.

Project Description and Purpose

The purpose of this study was to demonstrate that fluctuations in suspended sediment concentration (SSC) in Lemon Creek were dependent upon active glacial processes, such as supra-glacial lake drainage. Preliminary investigations suggest that the glacier has a larger impact on sediment loads than on flow, thus, the findings from this project are intended to illustrate the need for revising the TMDL/BMP strategies for Lemon Creek in ways that are consistent with the basin's geophysical processes. The project was designed to determine the magnitude, timing, and intra-annual frequency of the glacially controlled sediment fluctuations. A paired watershed approach was used in measuring SSC and discharge from Lemon Creek, a glaciated catchment and Gold Creek, which is not glaciated. This project will also contribute to a larger USGS project to monitor Lemon Creek discharge and sediment.

The specific goals of this project included:

- Defining natural sediment concentrations and fluctuation with respect to seasonal discharge variability and active glacial processes.
- Determining the relative amounts of natural sediment contribution vs. anthropogenic sediment pollutant along Lemon Creek.
- Recommending TMDL revisions or, possibly, removing Lemon Creek from the impaired waterbody list (with respect to sediment) if most of the sediment is indeed attributable to natural glacial processes.

Research Design

This project uses a paired watershed approach, comparing discharge and sediment fluxes from two watersheds that are similar in all aspects but one in order to isolate the role of the unique feature. The watersheds chosen for this study were Lemon and Gold Creeks, which have similar sizes,12.1 and 9.8 square miles (at gauging stations 70002 and 70018), respectively, and similar topographies, and aspects, and, due to their close

proximity to each other, similar weather patterns (Fig.1). The unique difference between the watersheds is a glacier in the headwaters of the Lemon Creek watershed. We monitored discharge and SSC fluctuation in both Lemon Creek (glacially influenced) and Gold Creek (unglaciated control). This project collected a year's worth of data (5/2002 – 5/2003) to account for seasonal variations in glaciological, hydrometeorological, biological, and land use controls.

Discharge measurement and sediment sampling was be automated at three sites: two on Lemon Creek (one below the glacier terminus, one downstream-- near the industrial park), and one on Gold Creek (unglaicated control), a similar, though non-glaciated watershed located two miles southeast of Lemon Creek watershed. USGS discharge gauging stations on Lemon Creek and Gold Creek served as two of the sample sites. The third sample site was a discontinued USGS station, re-occupied by UAS in June 2001, near the Lemon Creek correctional facility, approximately 1 mi. upstream from the creek mouth. Samples were stored and analyzed for suspended sediment concentrations (SSC) at the Juneau AK-DEC/UAS laboratory.

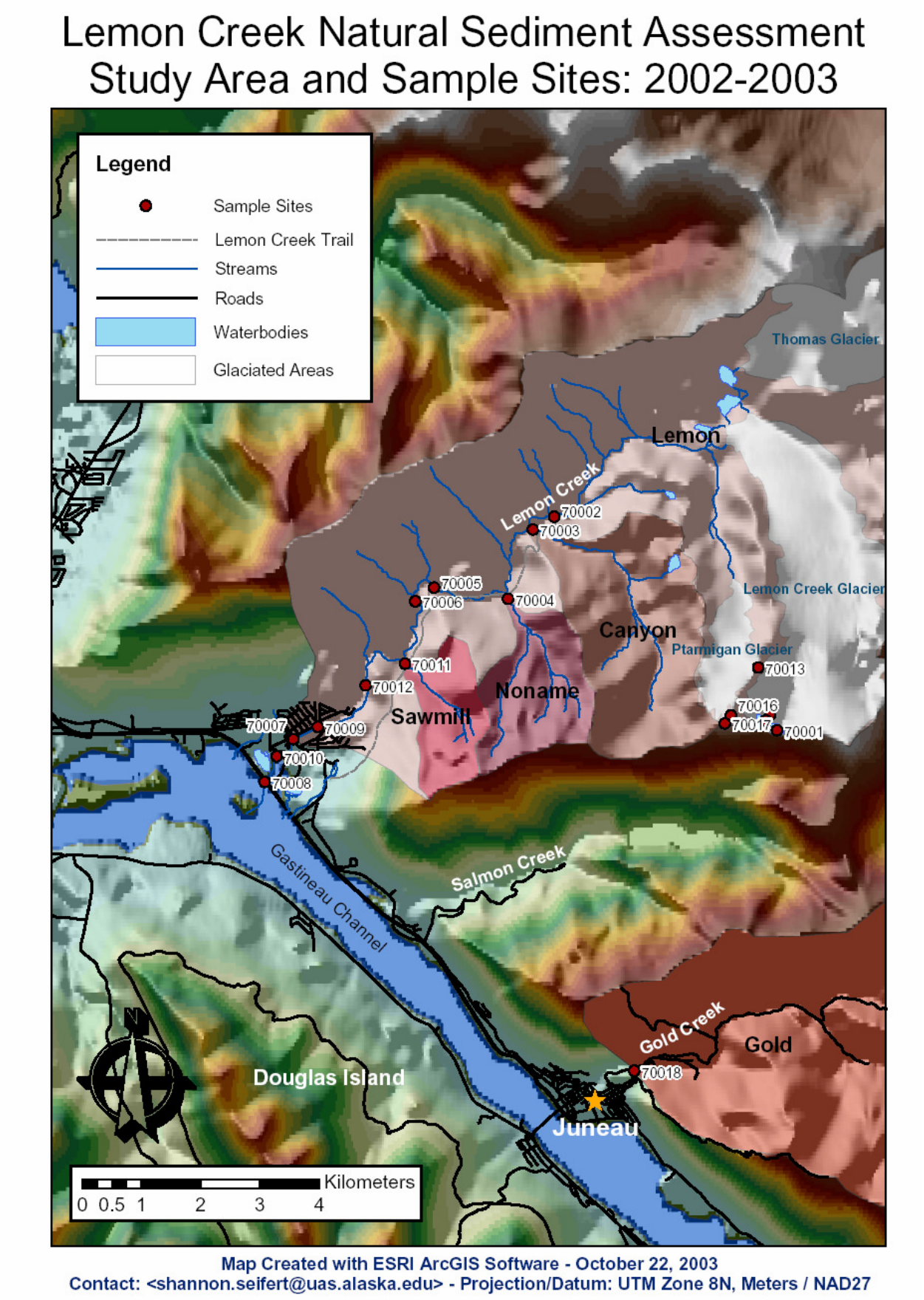

Figure 1. Map of the Lemon Creek and Gold Creek watersheds.

A submersible pressure transducer, coupled with a bathymetric survey, was placed in the supra-glacial lake on Lemon Glaciers from July through October 2002 to estimate timing of glacial outbursts, which occur regularly in this system. Additional observations of glacial activity and measurements of local meteorology on Lemon Glacier from July through September 2002 provided additional information for estimating glacial hydrological activity.

We originally proposed sediment-"fingerprinting" analyses, to be conducted at the ADEC under the direction of Alan Love using an Inductively Coupled Plasma Mass Spectrometer (ICPMS) but due to State budgetary decisions, the lab was closed before this analysis was complete. Thus, at the time of this report we still have not been able to complete this aspect of the project but we anticipate eventually completing the "fingerprinting"as soon as we can get access to a different ICPMS.

A project database has been created at UAS and all data relevant to the USGS has been submitted for the USGS national data archive system. All data were geo-referenced using the UAS Environmental Science Program's (ENVS) mapping-grade GPS, and may be accessed through GINA (www.uas.alaska.edu/spatialdata). Project research papers for publication in refereed journals are in preparation.

Hydrological Controls on Lemon Creek

Figure 2 shows the daily discharge from Lemon and Gold Creeks and relevant meteorological data. The stream discharges diverge during the summer months and generally converge again in the winter (with the exception of the event marked with an "**X**"). This is expected because during the summer Lemon Creek is recharged by glacial melt water and Gold Creek is not and in the winter both systems are essentially frozen. The generally decreasing low-flows in Gold Creek between June and August reflect the disappearance of the watershed's annual snowpack.

The stars in Fig. 2 indicate times when we were able to verify that the supra-glacial lakes on Lemon Glacier, Lakes Linda and Lynn, had drained, i.e., periods of glacial outburst. It is interesting that the outbursts do not constitute the high peak flows in Lemon Cr. The July outburst corresponded to the 7th highest peak flow for the period and the August outburst was 4th. There are probably smaller outburst events that we were unable to verify but it is unlikely that that the largest peak flows are associated with glacial outbursts.

Both systems respond to rain events although in the summer Lemon Creeks response is somewhat exaggerated by snowmelt from rain-on-snow and enhanced longwave radiation from the associated cloud cover. The glacial outbursts appear to be triggered by rain events although the actual mechanism controlling them is not identified yet.

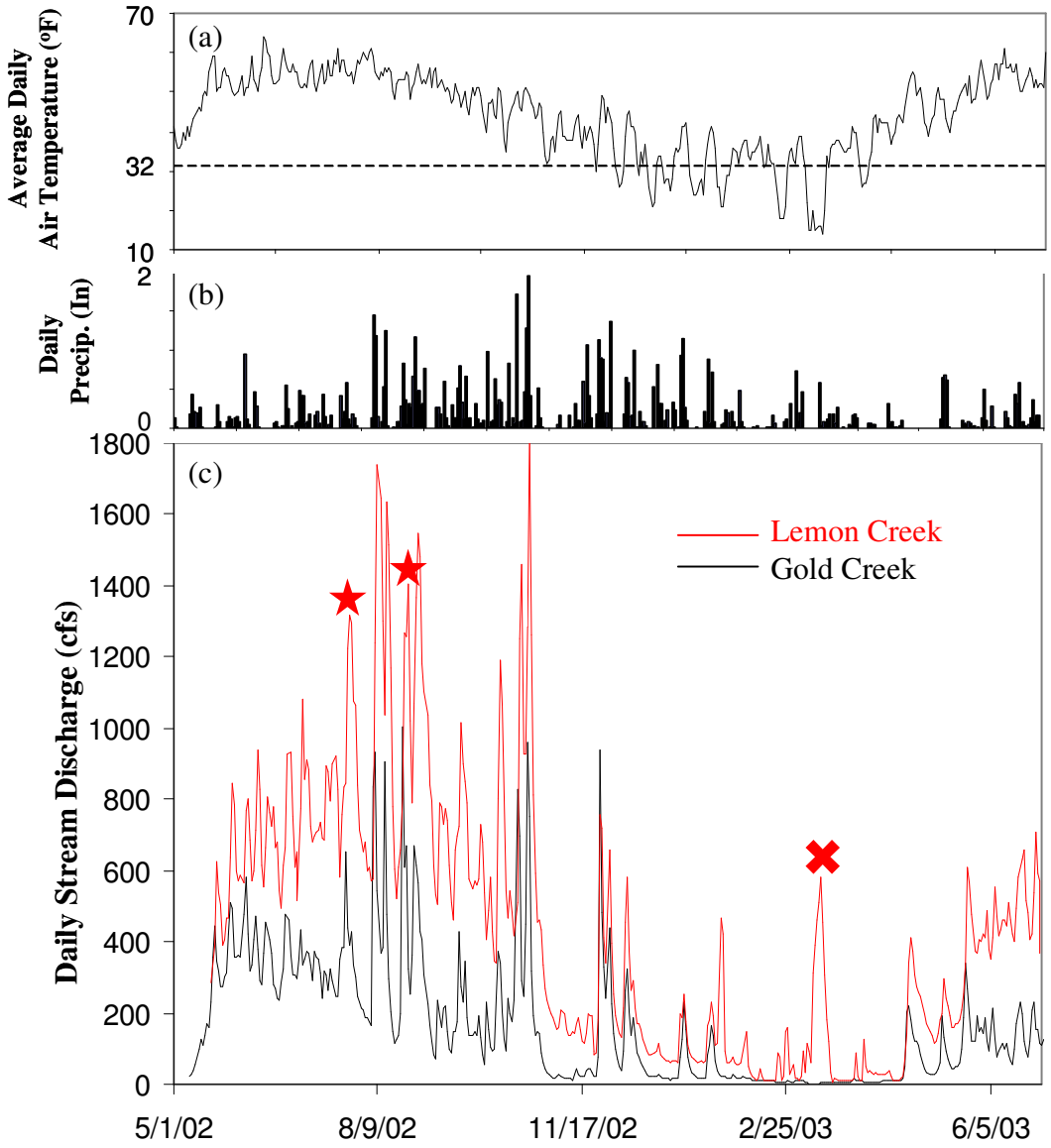

Figure 2. Daily (a) air temperature, (b) precipitation, and (c) discharge for Lemon Creek (red line) and Gold Creek (black line) for the period May 2002 through June 2003. The stars in (c) indicate verified glacial-lake outbursts and the "**X**" indicates an unexpected discharge event that looks like a glacial-lake outburst. Meteorological data are from the USWS Juneau Airport weather station.

The event identified with an "**X**" is unique and mysterious. It corresponds to an extreme low flow period in Gold Creek and the year's coldest air temperatures. One possible explanation is that the unusually prolonged February melt period preceding this event filled the Lakes Linda and Lynn and they subsequently drained. The study year, 2002-2003, had an unusually warm winter with only 7 or 8 short, punctuated periods of subfreezing temperatures (Fig 2a), and there is evidence of glacial melt water contributions to Lemon Creek into December and January (Fig. 2c).

Identifying Glacial Sediment Contributions

Figure 3 shows the time series of daily sediment discharges from Lemon and Gold Creeks. It is obvious the Lemon Creek has a generally higher sediment load probably because of the basins ongoing glacial activity as well as its recent history of relatively extensive glaciation, i.e., the landscape, especially the river valley, is relatively unconsolidated from the recent glacial advance and retreat. Note that no adjustment has been made to the data in Fig. 3 to account for different basin sizes. Lemon Creek's annual sediment discharge was 135,000 T/yr and Gold Creek's sediment load was only 22,000 T/yr (adjusted for basin size, 19,000 T/yr unadjusted). For both watersheds, sediment discharge was highest in the summer. Lemon Creek showed somewhat less annual variability, probably because the unseasonably warm winter prolonged glacial sediment contributions to the stream. Unlike discharge, the identified outburst events constitute 2 of the 4 highest observed sediment peaks in the record. The mystery event noted with the "**X**" in Figs. 2 and 3 was not a particularly high annual sediment event but was extremely high for the winter period.

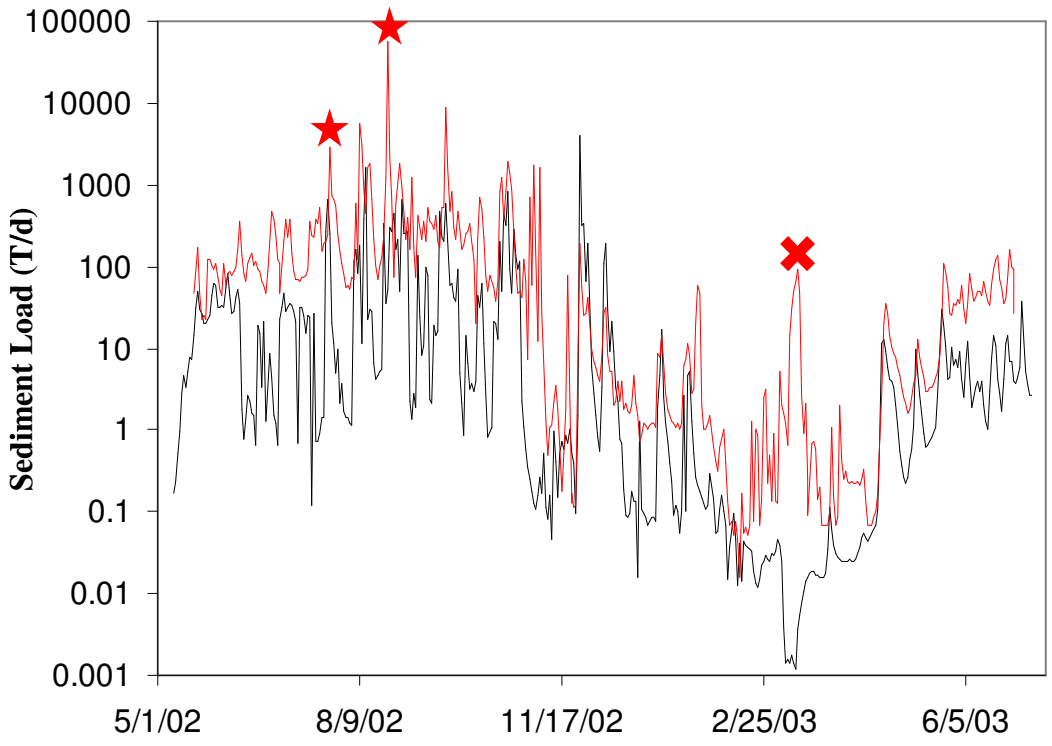

Figure 3. The daily sediment discharges from Lemon Creek (red) and Gold Creek (black) from 5/2002 through 6/2003. The stars and "**X**" correspond to the same events indicated in Fig. 2.

Some of the mismatched sediment spikes between the two basins are probably the result of mass wasting events, the timing of which would not necessarily be well matched between the two systems. Some Lemon Creek "high sediment loads" may also be from localized gravel mining just up stream of the sampling point but this cannot be confirmed until we finish the sediment "fingerprinting" analysis.

The reason the sediment peaks are uniquely high for the outburst events is illustrated in Fig. 4, which shows flow and SSC for a short period in 2001. Notice that the outburst discharge peak is similar in magnitude to the other, non-outburst peak, shown in the figure. The SSC values, however, rise dramatically in response to the outburst event, probably due to sediment discharged from under the glacier.

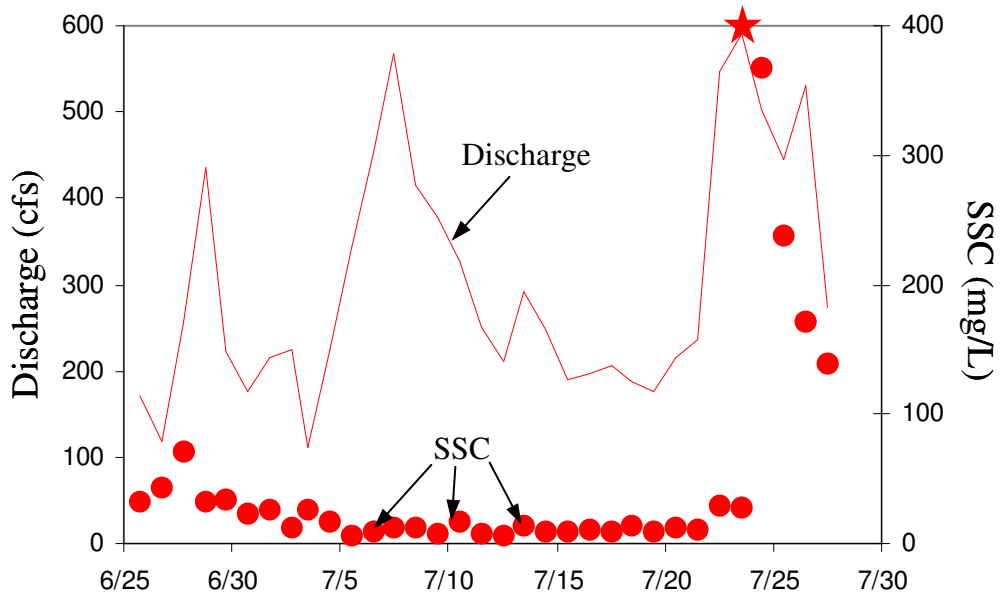

Figure 4. An example of an outburst discharge (line) and SSC (circles) from 2001 showing that outburst discharge peaks (marked with a star) are similar in magnitude to other non-outburst events (the other flow peaks shown in figure) but the sediment signal is much more pronounced.

Figure 5a shows the total sediment load (TSS)-discharge (Q) relationship for Lemon and Gold Creeks. Surprisingly, both systems have similar relationships; the equations for the trend lines in Fig. 5a are:

Lemon Creek: $TSS = 0.0003Q^{1.98}$ ($R^2 = 0.86$)
Gold Creek: $TSS = 0.0006Q^{1.88}$ ($R^2 = 0.85$)

The large degree of positive variability, i.e., data above the trend lines, for both systems around 100-600 cfs is probably due to the influences of mass wasting. The reasons for negative deviations from the trend line in this range of discharge are less obvious, perhaps they represent punctuated snowmelt events when the potential sediments sources remained largely frozen. The very tight relationship for Gold Creek at low flows is common among systems where the primary source of sediment is restricted to the streambed. Notice that Lemon Creek has no similarly tight, or low variability segments in its data (Fig. 5a), suggesting that landslides and glacial erosion processes, which are not strongly related to watershed hydrology, play larger roles in the basin-wide sediment load than they do for Gold Creek.

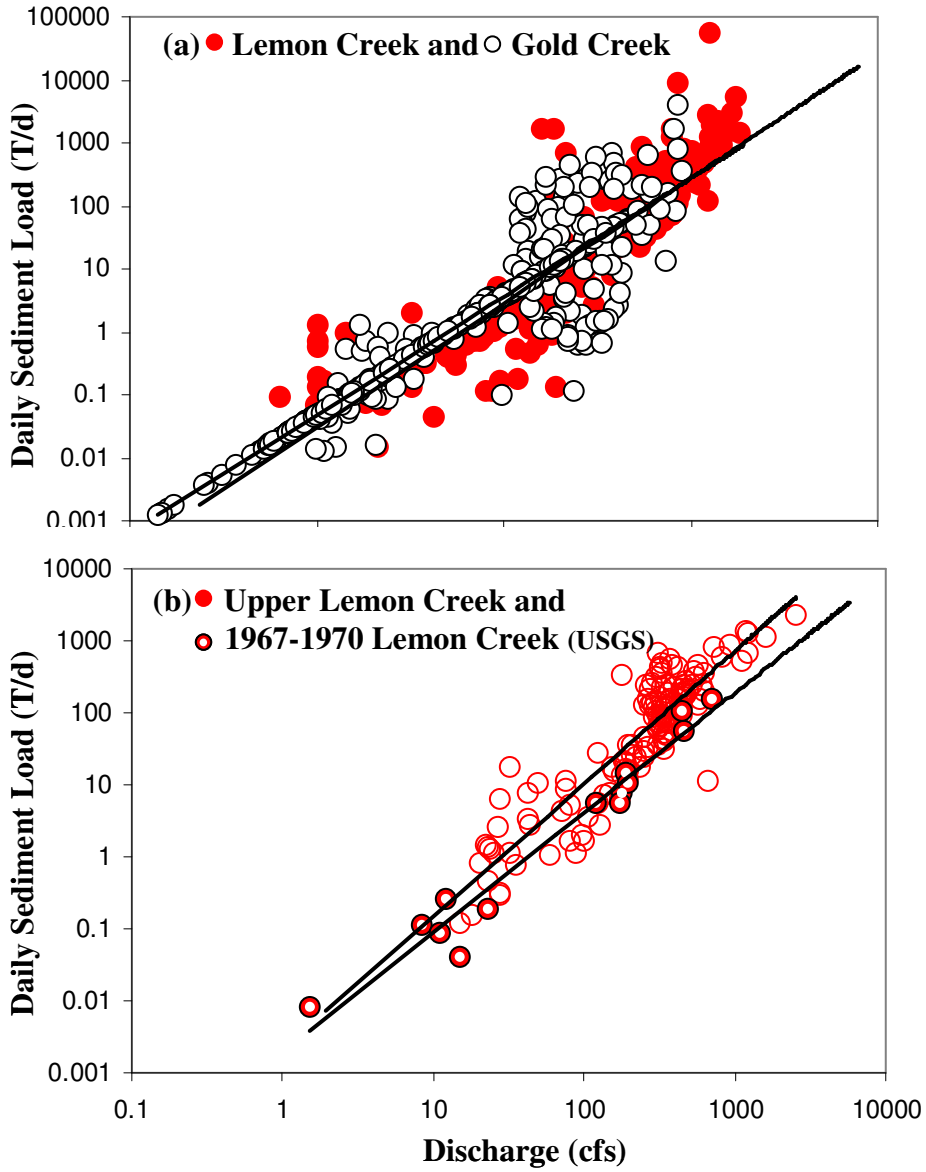

Figure 5. The Daily Sediment load vs. Discharge relationships for (a) Lemon and Gold Creeks and (b) Upper Lemon just below the glacier terminus and Lemon Creek based on 13 measurements made between 1967 and 1970 by the USGS. The symbology used in these figures is explained in the graphs.

Figure 5b shows the TSS-Q relationships for upper Lemon Creek measured just below the glacier terminus and for the Lemon Creek outlet based on a small set of data collected between 1967 and 1970. The upper Lemon Creek relationship is similar that for lower Lemon Creek but the previous, 1967-1970 relationship is somewhat different, the equations for the trend lines in Fig. 5a are:

Upper Lemon Creek: $TSS = 0.002Q^{1.85}$ ($R^2 = 0.81$)
1967-1970 Lemon Creek: $TSS = 0.002Q^{1.66}$ ($R^2 = 0.96$)

Because the glacier is such a major source of sediment to Lemon Creek, it follows that the trends at the glacier terminus and at the watershed outlet should be similar. It is not completely clear why the older Lemon Creek relationship is so different (differences in the exponents best express the relationship differences) but presumably this is a result of climate changes which have lead to more active glacial activity and perhaps more severe weather.

Conclusions

This study found that glacial processes play an important role in determining watershed sediment loads and that the glacial contributions are not necessarily well correlated to discharge. Thus the common TSS-Q relationships used to describe watershed sediment output from watersheds where the main sources of sediment are the streambed and overland flow induced erosion does not work as well in glacial systems. The differences between Lemon Creek (glaciated) and Gold Creek (un-glaciated) were less pronounced than expected because of (A) the unusually warm winter during the study period and (B) landslides also play important sediment-load roles in both systems and, like glacial processes, are not necessarily well correlated with stream discharge. In other words, it was difficult to distinguish TSS-Q anomalies associated with landslides and glacial outburst events. Further analysis of the data, especially glacial lake level and sediment "fingerprinting" data, should provide additional insights into these two different processes.

This study also showed that climate change may be having substantial effects on the sediment and streamwater discharges in Lemon Creek. We did not anticipate this finding but are planning to investigate this possibility over the next year.