Hydroclimatic Controls over High Arctic Suspended Sediment Transport

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Introduction: Suspended sediment is seen as a sensitive indicator of localized environmental change (Hodgkins et al. 2003), and through linkages with the near-shore marine environment can be an important measure of climate impact in the arctic. Land surfaces may be subject to disturbance through changes in precipitation and thermal regimes due to erosion and permafrost degradation. Although sediment transport in arctic environments is important, available data is limited. This study reports preliminary results from two seasons of research from Cape Bounty, Melville Island, Nunavut.

Objectives:

The primary objective of this study is to monitor suspended sediment transport throughout the melt season and examine the supply through:

- Temporal and spatial trends in transport
- Sediment transport in response to snowmelt and precipitation
- Analysis of effective grain size during the season

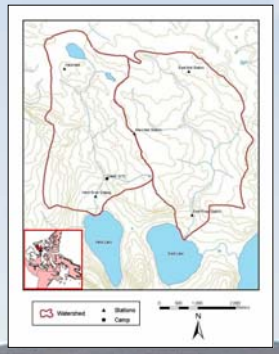

Figure 1. Cape Bounty, Melville Island, Nunavut. Research has taken place in both the East and West catchments. This study focuses on the west catchment. Fluvial data was collected from the West River station.

Study Site: Cape Bounty is located on the south-central coast of Melville Island, Nunavut (74°52' N, 109 °32' W). The watershed of West River lies in south-facing catchment and drains into West Lake (unofficial names) whose outlet leads into Viscount Melville Sound (Figure 1). The catchment is underlain by weathered quartzose sandstone and minor siltstone and shale. Glacial and marine deposits compose the surficial sediment. The river flows through a moss and wet sedge-rich valley flanked by sparsely-vegetated, dry plateaus (<125 m a.s.l...) (Figure 2). Snow blankets the valley and concentrates in channels.

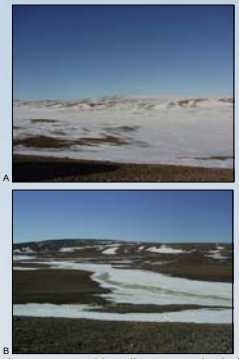

Figure 2. Snow is concentrated in valleys, comprised of mosses and wet sedges. Plateaus are sparsely vegetated lack snow cover due to wind erosion. A) June 6, 2004 (20 days prior to flow), B) June 8, 2005 (flow has commenced).

Results and Discussion

Meteorology: In 2004 and 2005 the average June temperatures recorded at the west catchment meteorological station were -0.1 °C and 2.0 °C, respectively. The snow water equivalence in 2004 and 2005 differ substantially at 82 mm and 55 mm (Table 1).

	2004	2005
Average June Temp (°C)	-0.1	2
SWE (mm)	82	55
Discharge (mm)	101	68

Table 1. Average, minimum and maximum temperatures and snow water equivalence from 2004 and 2005

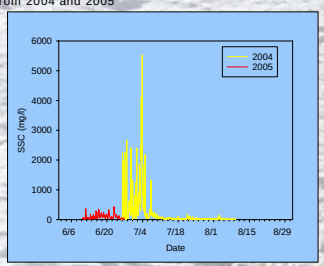

Figure 3. Suspended sediment records for 2004 and 2005 melt seasons. Note the substantially different magnitudes and general patterns in sediment delivery over the seasons.

Suspended Sediment Concentration and Discharge: In 2004 (SWE 82 mm) a maximum discharge of 1.6 m^3s^{-1} was recorded and coincides with an SSC of 626 mgl^{-1} on June 28 (Figures 3, 4) The maximum SSC (5526 mgl^{-1}) occurred five days later with a discharge of 1.02 m^3s^{-1} (Figures 3, 4). Figure 3 illustrates that the magnitude of the suspended sediment concentration (SSC) was considerably higher in 2004 and was sustained for a substantially longer period. In 2005 (SWE 55 mm) the nival freshet occurred nearly one month earlier than in 2004. Peak recorded discharge was 0.9 m^3s^{-1} on June 11 and did not coincide with the maximum recorded SSC of 461 mgl^{-1}, which occurred during an initial pulse on June 8 (Figures 3, 4).

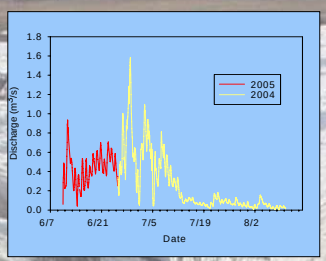

Figure 4. 2004 and 2005 discharge records. Note the different magnitude and timing between seasons.

Cumulative Suspended Sediment: West River delivered ~410 Mg of sediment to West Lake in 2004 and ~ 62 Mg in 2005 (Figure 5). The substantially higher sediment yield in 2004 is attributed in part to the greater amount of snowpack, sediment storage in the catchment and channel dynamics including channel ice and snow and thermal erosion (Costard et al. 2003, McCann et al. 1972). It is possible that 2004 represents an anomalous year. However, warming climate may change the snowpack regime considerably and result in persistent high yield years in the future (Przybylak, 2002; Ye and Mather, 1997).

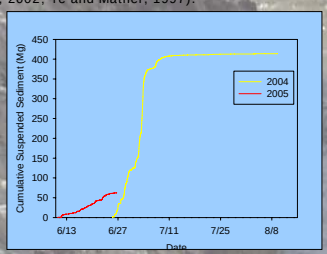

Figure 5. Cumulative suspended sediment in West River over the 2004 and 2005 field seasons. Note the substantial difference in magnitude and timing of the yield in subsequent seasons.

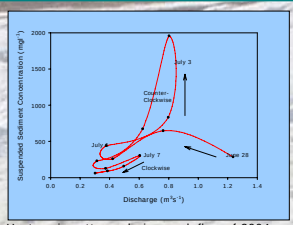

Figure 6. Hysteresis patterns during peak flow of 2004 melt season. Note the change from a clockwise pattern, to a counter-clockwise pattern, indicating that sediment is less available later in the melt season.

Hysteresis: In 2004 clockwise hysteresis relationship is evident followed by a counter-clockwise relationship suggesting that sediment comes from in-channel sources initially and extra-channel sources later in the melt season (Figure 6) (Nistor and Church, 2004; Williams, 1989). It is likely that the channel and a substantial portion of the sources adjacent to the channel are armoured by snow and ice early in the melt and only become available following the major discharge event.

In 2005 two instances of clockwise hysteresis are apparent during the nival freshet, which were much more subdued than 2004. This indicates that the limited amount of sediment was transported from sources close to or within the channel (Figure 7) (Williams, 1989).

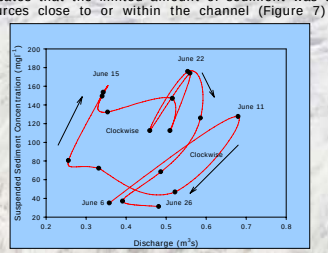

Figure 7. Hysteresis relationships during the melt season of 2005. Clockwise and counter-clockwise relationships are evident suggesting a shift in sediment sources during the peak melt period

Future Study: In an attempt to characterize spatial and temporal variation in sediment transport and sediment mobilizing processes, transmissivity (a measure of suspended load) has been collected in 3 locations in the catchment in 2005 and will be collected in 2006, augmented by discharge data from these locations (Figure 8.) A turbidity sensor will be installed at the West River station in order to obtain an uninterrupted record of suspended load.

Figure 8. Site of tributary suspended sediment and discharge monitoring.

Conclusion: This study has shown that small high arctic rivers are capable of delivering a substantial amount of sediment to the near-shore marine environment in a short period of time. This study has shown that sediment yields are related to snow water equivalency more strongly than to temperature, suggesting that snow plays an important role in the disruption and erosion of land surfaces. Potential shifts in the winter precipitation regime of the arctic may therefore have implications for sediment delivery to coastal environments. Further research is necessary to establish a more definitive relationship between snowpack and sediment transport.

Implications for Arcticnet IRIS Development:

- **Short-lived pulses during the nival freshet deliver the majority of seasonal sediment.**
  - ✓Aquatic ecological systems establishing early in the season may be impacted by increased turbidity
- **High suspended sediment yields have been shown to be associated with high SWE**
  - ✓Projected climate warming may increase winter precipitation, increasing the magnitude and duration of the nival freshet and the seasonal sediment yield (Figure 9)

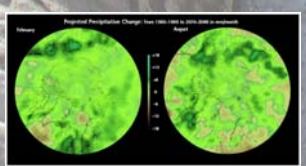

Figure 9. Projected precipitation change (mm per month) from 1990s to 2090s calculated from ACIA models (ACIA, 2004).

- **Suspended sediment concentrations appear to be primarily associated with water availability rather than melt intensity**
  - ✓This study has shown that snowpack is a dominant determinant of suspended sediment yield.
  - ✓Projected temperature increases may have an impact on the degradation of localized ground ice.
  - ✓Melting ground ice can act as a constant contributor of fine-grained sediment and have implications for the aquatic environment through prolonged and increased turbidity, particularly after the nival freshet (Figure 10).

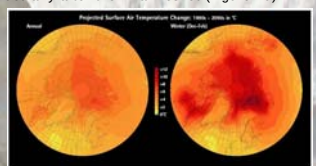

Figure 10. Projected temperature change from the 1990s to the 2090s based on ACIA climate models (lower emissions scenario) (ACIA, 2004).

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