APPENDIX D

Geomorphic Analysis Information

Table D-1. Summary Table of Sediment Yield from Goodell Creek (Syvitski et al. 2005)

Basin	Basin area (km^2)	Total Annual average sediment input (tons/year)	Total Annual average sediment input (cy/year)	Total Annual average bedload flux (tons/year)	Total Annual average bedload flux (cy/year)
Goodell to Landslide	86.53	142,300	109,500	21,400	16,500
Goodell Basin	99.05	197,500	152,000	29,700	22,800
Lower Goodell Only	12.52	55,200	42,500	8,300	6,300

Table D-2. Goodell Creek Alluvial Fan (Basin to Landslide), Skagit River watershed.
Sediment Yield Calculations from Syvitski et al. 2003, 2005 **** ONLY EDIT YELLOW CELLS ****

Updated 06/12/14 by: CMA
Checked 06/12/14 by: JP

Input dry density: 1.3 tons/cy
Input bedload fraction: 0.15
Mass conversion: 907.1858189 kg/ton (note 1 US ton is 2000lb, and 1 kg is 2.20462 lb)

Table 2. Regression coefficients for $\hat{Q}_s = \alpha_3 A^{\alpha_4} R^{-\alpha_5} e^{kT}$

Global Sector	α_3	α_4	α_5	k
Polar (T<0 deg C)	0.00002	0.50	1.50	0.1
Temperate (Lat>30N, T>0 deg C)	0.000061	0.55	1.12	0.07
Tropics (Lat 0 to 30 deg N)	0.31	0.40	0.66	-0.1
Tropics (Lat 0 to 30 deg s)	0.57	0.50	0.37	-0.1
Temperate (Lat>30S, T>0 deg C)	0.0013	0.43	0.96	0.0

Copy and paste site-specific regression coefficients below.

Global Sector	α_3	α_4	α_5	k
Temperate (Lat>30N, T>0 deg C)	0.000061	0.55	1.12	0.07

Table 2. *Regression coefficients on* $\overline{Q_s} = \alpha_3 A^{\alpha_4} R^{\alpha_5} e^{kT}$.

Global Sector	α_3	α_4	α_5	k	R^2
Polar (T<0°C)	$2\ 10^{-5}$	0.50	1.50	0.1	0.76
Temperate N (Lat >30°N, T>0°C)	$6.1\ 10^{-4}$	0.55	1.12	0.07	0.63
Tropics N (Lat 0 to 30°N)	0.31	0.40	0.66	−0.1	0.58
Tropics S (Lat 0 to 30°S)	0.57	0.50	0.37	−0.1	0.67
Temperate S (Lat >30°S, T>0°C)	$1.3\ 10^{-3}$	0.43	0.96	0	0.54

T = the average temperature (°C) across A drainage basin area (km²); R = maximum relief from sea level to the mountain top (m); Q_s = long term sediment load (kg/s).

Estimate Annual Average Sediment Flux

Basin	*Basin relief (m)*	*Size of drainage basin (km²)*	*Average basin temperature (deg C)*	*Total average annual sediment input (kg/s)*	*Total average annual sediment input (tons/year)*	*Sediment flux from basin (tons/km²/year)*	*Bedload flux from basin (tons/year)*	*Bedload flux from basin (cy/year)*
Goodell to Landslide	2249	86.53	0.23	4.092	**142,252**	1,644	21,338	16,414

Lapse Rate Calculation (Syvitski et al., 2003)

Latitude	Lapse Rate (°C/km)
48.687	7.435369127

$$L(x) = (a_0 x^2 + a_1)\{1 - a_2 \exp[-(x/a_3)^2]\}$$
(modified quadratic) (5)

Average Temperature Calculation (Syvitski et al., 2005)

Average Annual Temperature at basin mouth (F) T_{0m}	Average Annual Temperature at basin mouth (C) T_{0m}	Area-weighted basin elevation (m) H	Area-weighted basin elevation (km)	Average Basin Temperature (°C) T
49.61	9.783333333	1,285	1.29	0.228884005

$$T(x,\theta,H) = T_{0m}(x,\theta) - [L(x)H]$$

Assumptions
Base temperature from Newhalem Western Regional Climate Center website
Define relief as the local relief: difference between the maximum elevation in the watershed minus the pour point elevation at the mouth
Mass conversion:

Guidlines for estimating percent bedload
1) Global Average

Table 1
Global estimates of the flux of sediment from land to the ocean (after Syvitski, 2003)

Transport mechanism	Global flux GT/year	Estimate grade	Reference
Rivers: suspended load	18	B*	Milliman and Syvitski, 1992
bed load	2	B*	Milliman and Syvitski, 1992
dissolved load	5	B*	Summerfield and Hulton, 1994
Glaciers, sea ice, icebergs	2	C	Hay, 1994
Wind	0.7	C	Garrels and Mackenzie, 1971
Coastal erosion	0.4	D	Hay, 1994

Mechanism	Global flux (GT/yr)	fraction of total	fraction of total excluding dissolved
Suspended load	18	0.72	0.90
Bedload	2	0.08	0.10
Dissolved load	5	0.20	
Total load	25		

2) Mountain Rivers

Quaternary Research 68 (2007) 111–120

Bedload-to-suspended load ratio and rapid bedrock incision from Himalayan landslide-dam lake record

Beth Pratt-Sitaula [a,*], Michelle Garde [a,b], Douglas W. Burbank [a], Michael Oskin [c], Arjun Heimsath [d], Emmanuel Gabet [e]

Mechanism	Relative volume	fraction of total
Suspended load	2	0.67
Bedload	1	0.33
Total load	3	

Abstract

About 5400 cal yr BP, a large landslide formed a >400-m-tall dam in the upper Marsyandi River, central Nepal. The resulting lacustrine and deltaic deposits stretched >7 km upstream, reaching a thickness of 120 m. ^{14}C dating of 7 wood fragments reveals that the aggradation and subsequent incision occurred remarkably quickly (~500 yr). Reconstructed volumes of lacustrine (~0.16 km³) and deltaic (~0.09 km³) deposits indicate a bedload-to-suspended load ratio of 1:2, considerably higher than the ≤1:10 that is commonly assumed. At the downstream end of the landslide dam, the river incised a new channel through ≥70 m of Greater Himalayan gneiss, requiring a minimum bedrock incision rate of 13 mm/yr over last 5400 yr. The majority of incision presumably occurred over a fraction of this time, suggesting much higher rates. The high bedload ratio from such an energetic mountain river is a particularly significant addition to our knowledge of sediment flux in orogenic environments.
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Table D-3. Goodell Creek Alluvial Fan (Entire Basin), Skagit River watershed.
Sediment Yield Calculations from Syvitski et al. 2003, 2005 **** ONLY EDIT YELLOW CELLS ****

Updated 06/12/14 by: CMA
Checked 06/12/14 by: JP

Input dry density: 1.3 tons/cy
Input bedload fraction: 0.15
Mass conversion: 907.1858189 kg/ton (note 1 US ton is 2000lb, and 1 kg is 2.20462 lb)

Table 2. Regression coefficients for $\bar{Q}_s = \alpha_3 A^{\alpha_4} R^{\alpha_5} e^{k\bar{T}}$

Global Sector	α_3	α_4	α_5	k
Polar (T<0 deg C)	0.00002	0.50	1.50	0.1
Temperate (Lat>30N, T>0 deg C)	0.000061	0.55	1.12	0.07
Tropics (Lat 0 to 30 deg N)	0.31	0.40	0.66	-0.1
Tropics (Lat 0 to 30 deg s)	0.57	0.50	0.37	-0.1
Temperate (Lat>30S, T>0 deg C)	0.0013	0.43	0.96	0.0

Copy and paste site-specific regression coefficients below.

Global Sector	α_3	α_4	α_5	k
Temperate (Lat>30N, T>0 deg C)	0.000061	0.55	1.12	0.07

Table 2. *Regression coefficients on* $\overline{Q_s} = \alpha_3 A^{\alpha_4} R^{\alpha_5} e^{k\bar{T}}$.

Global Sector	α_3	α_4	α_5	k	R^2
Polar (T<0°C)	$2\ 10^{-5}$	0.50	1.50	0.1	0.76
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Temperate S (Lat >30°S, T>0°C)	$1.3\ 10^{-3}$	0.43	0.96	0	0.54

T = the average temperature (°C) across A drainage basin area (km²); R = maximum relief from sea level to the mountain top (m); Q_s = long term sediment load (kg/s).

Estimate Annual Average Sediment Flux

Basin	*Basin relief (m)*	*Size of drainage basin (km²)*	*Average basin temperature (deg C)*	*Total average annual sediment input (kg/s)*	*Total average annual sediment input (tons/year)*	*Sediment flux from basin (tons/km²/year)*	*Bedload flux from basin (tons/year)*	*Bedload flux from basin (cy/year)*
Entire Goodell	2380	99.04720434	2.94	5.68	**197,416**	1,993	29,612	22,779

Lapse Rate Calculation (Syvitski et al., 2003)

Latitude	Lapse Rate (°C/km)
48.687	7.435369127

$$L(x) = (a_0x^2 + a_1)\{1 - a_2\exp[-(x/a_3)^2]\}$$
(modified quadratic) (5)

Average Temperature Calculation (Syvitski et al., 2005)

Average Annual Temperature at basin mouth (F) T_{0m}	Average Annual Temperature at basin mouth (C) T_{0m}	Area-weighted basin elevation (m) H	Area-weighted basin elevation (km)	Average Basin Temperature (°C) T
49.61	9.783333333	920	0.92	2.942793736

$$T(x,0,H) = T_{0m}(x,0) - [L(x)H]$$

Assumptions
Base temperature from Newhalem Western Regional Climate Center website
Define relief as the local relief: difference between the maximum elevation in the watershed minus the pour point elevation at the mouth
Mass conversion:

Guidlines for estimating percent bedload
1) Global Average

Table 1
Global estimates of the flux of sediment from land to the ocean (after Syvitski, 2003)

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Rivers: suspended load	18	B+	Milliman and Syvitski, 1992
bed load	2	B-	Milliman and Syvitski, 1992
dissolved load	5	B+	Summerfield and Hulton, 1994
Glaciers, sea ice, icebergs	2	C	Hay, 1994
Wind	0.7	C	Garrels and Mackenzie, 1971
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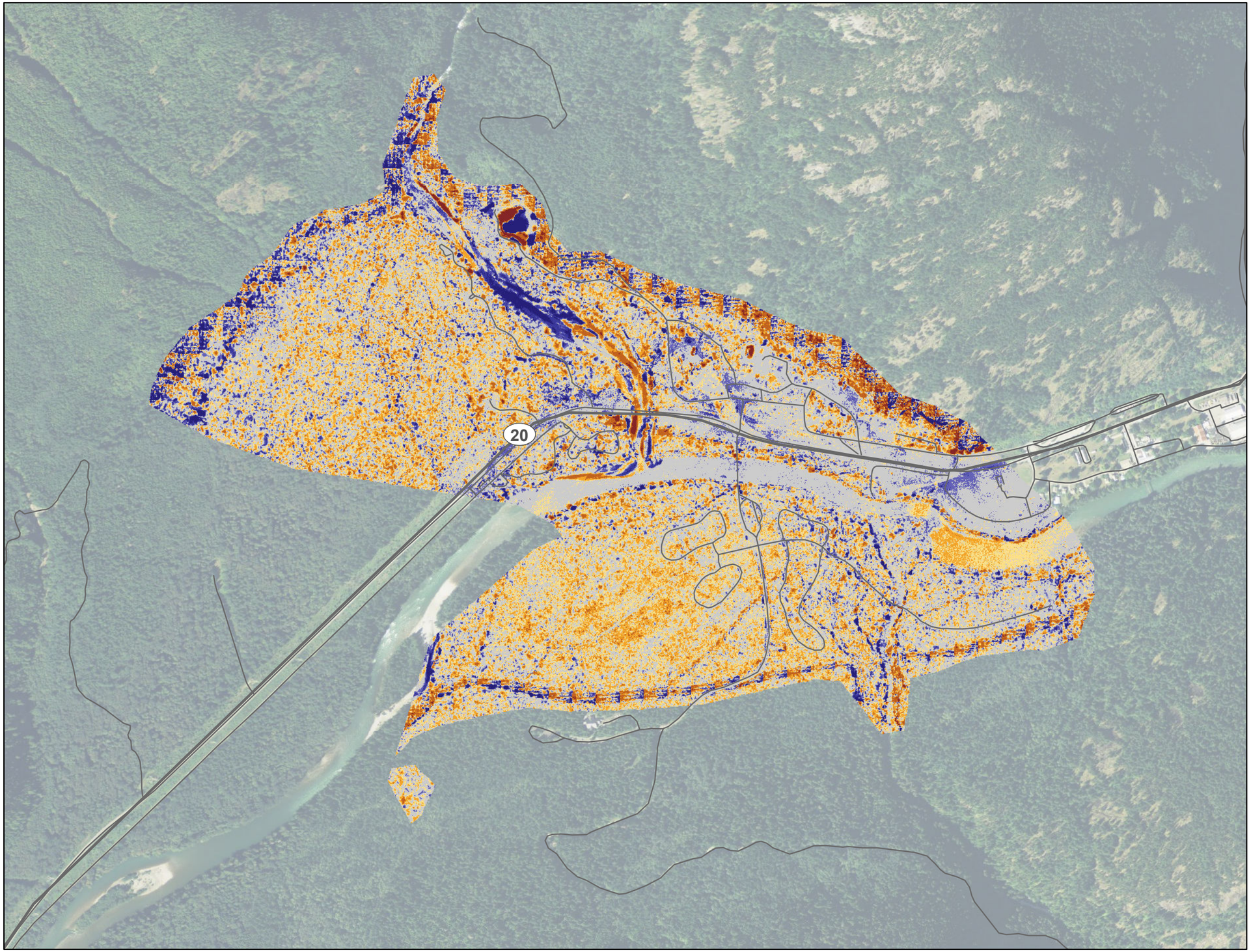


Figure D-1. Comparison of 2009 (NPS) minus 2006 (PSLC) lidar data for the Goodell Creek alluvial fan project area.

Legend

Highway

Road

2009 minus 2006

<VALUE>

- < -5
- -5 to -2
- -2 to -1
- -1 to -0.5
- -0.5 to 0.5
- 0.5 to 1
- 1 to 2
- > 2

N

0 450 900 1,800 ft

HERRERA

PSLC, Lidar (2006); USDA, Aerial (2013)

Table D-4. Summary of Aggradation Volume Assumptions for No-Action Alternative.

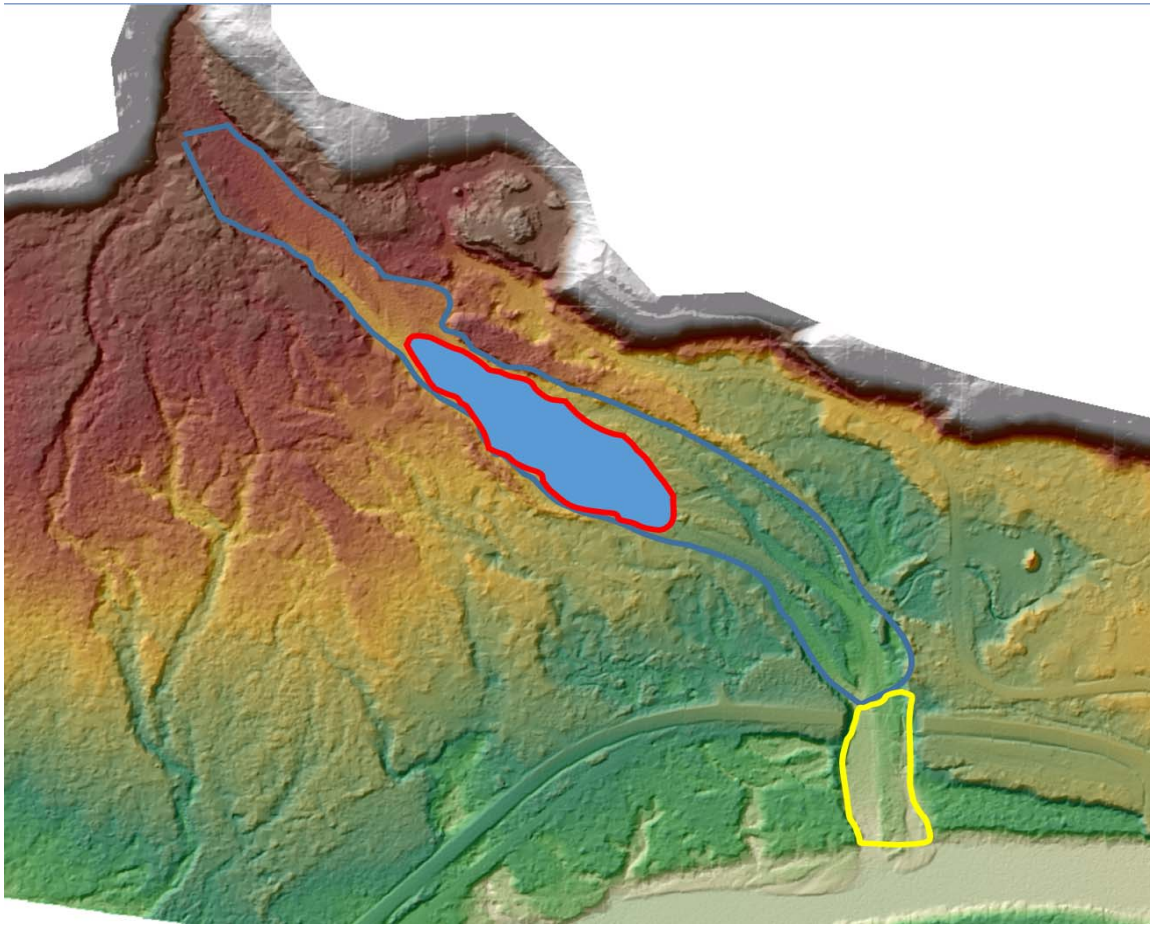
5 ft aggradation 255690 sf = 47350 cy
3 ft aggradation 421121 sf = 46791 cy
1 ft aggradation 95535 sf = 3538 cy

Total volume = 97679 cy

Location	Area (sf)	Depth (ft)	Volume (cf)	Volume (CY)
Red	255,690	5	1,278,450	47,350
Blue	421,121	3	1,263,363	46,791
Yellow	95,535	1	95,535	3,538
Sum	772,346		2,637,348	97,680

Lake Storage filled b/t 2003 and 2014	250,000	CY
Bedload influx to Lake	25,000	CY/Year
Landslide-derived aggradation	5,333	CY/Year
10 years of aggradation to FAN in future	303,333	CY/Year

Sediment wave seen in lidar on fan between 2006 and 2009 = 16,000 CY
(this is really coarse, cobble +)

Current sediment volume stored in lake = 250,000 CY (bedload only)

Remaining sediment storage in/above lake = 120,000 CY (bedload nly)