CHARACTERIZING DEBRIS FLOWS FOR DESIGN OF HAZARD MITIGATION

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DEBRIS

DEBRIS FLOW
IS A PART OF A CONTINUUM
(Stiny, 1910)

".. at a certain limit it has changed into a viscous mass consisting of water, soil, sand, gravel, rocks and wood mixed together, which flows like a lava into the valley".

- **Flood in a mountain torrent**
- **Debris flood**
- **Debris flow**

Definitions:

Debris flow

***is a very rapid to extremely rapid flow of saturated non-plastic debris** in a steep channel.*

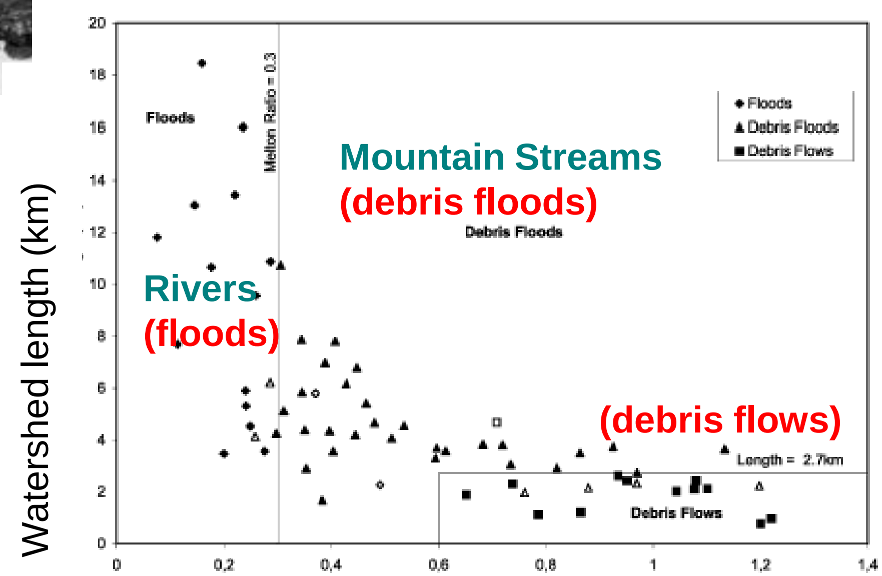
(Hungr et al., 2014)

Indicators of debris flow activity on a fan

LEVEE

LARGE CLAST

Debris flood *is a very rapid, surging flow of water, heavily charged with debris, in a steep channel.*



Melton Ratio: (watershed relief divided by the square root of watershed area (Wilford et al., 2004)

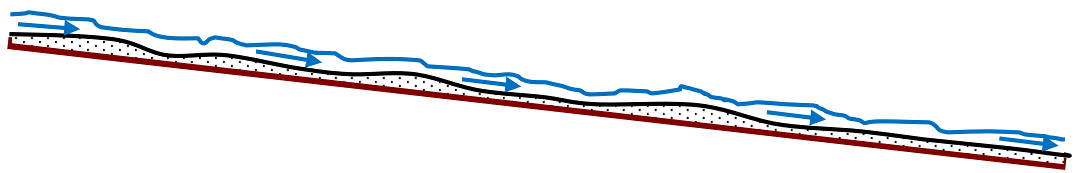
DEBRIS FLOOD

DEBRIS FLOW

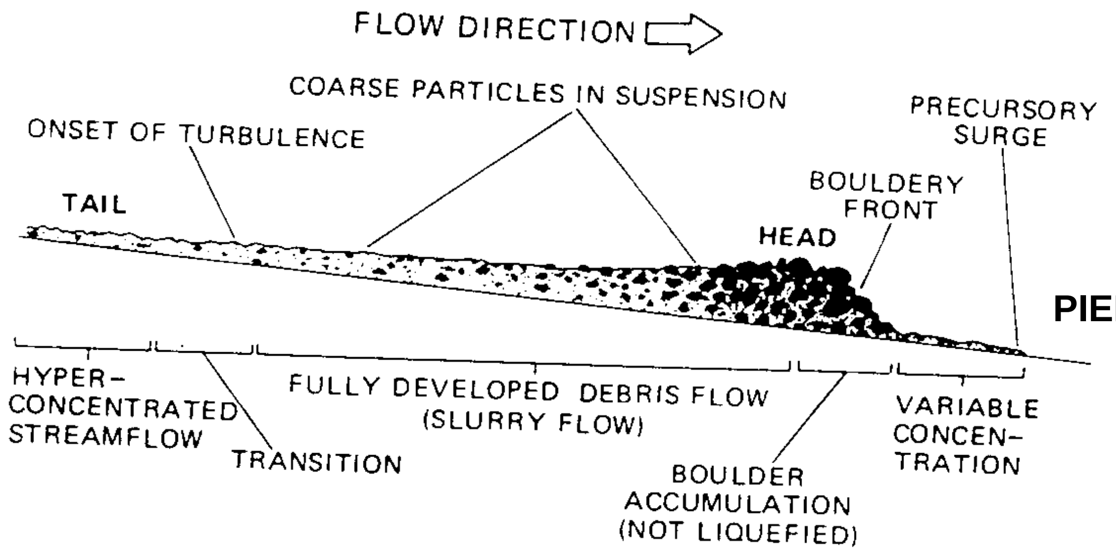
Kamikamihori Valley, courtesy Dr. H.Suwa

What is the most important difference? Concentration of solids?

DEBRIS FLOOD



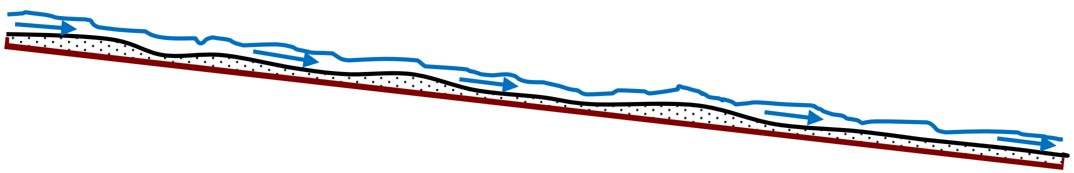
DEBRIS FLOW



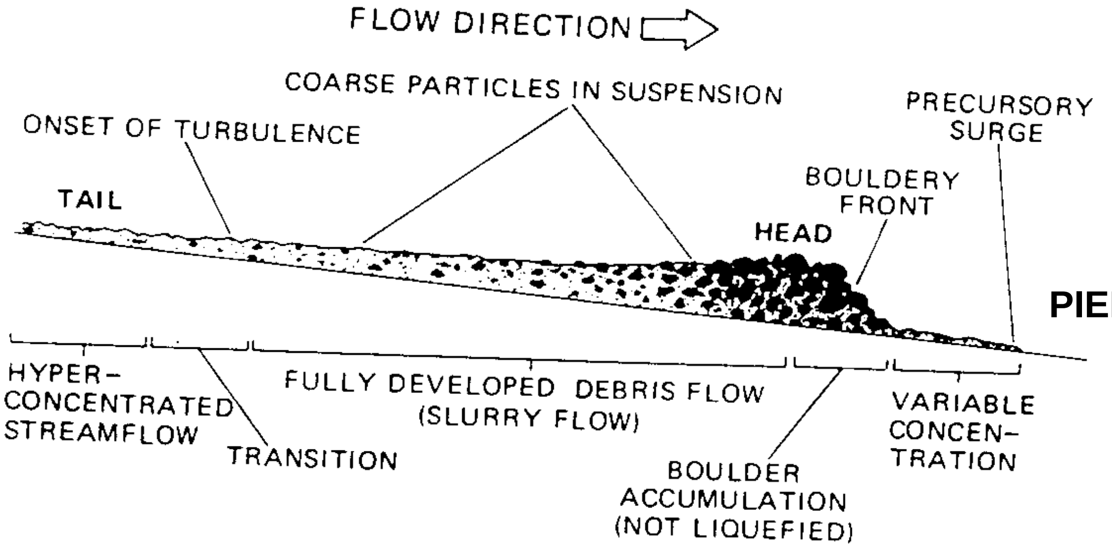
PIERSON, 1980

What is the most important difference?
Peak discharge (relative to flood) !

DEBRIS FLOOD, Q_p=~2 to 3 Q_f

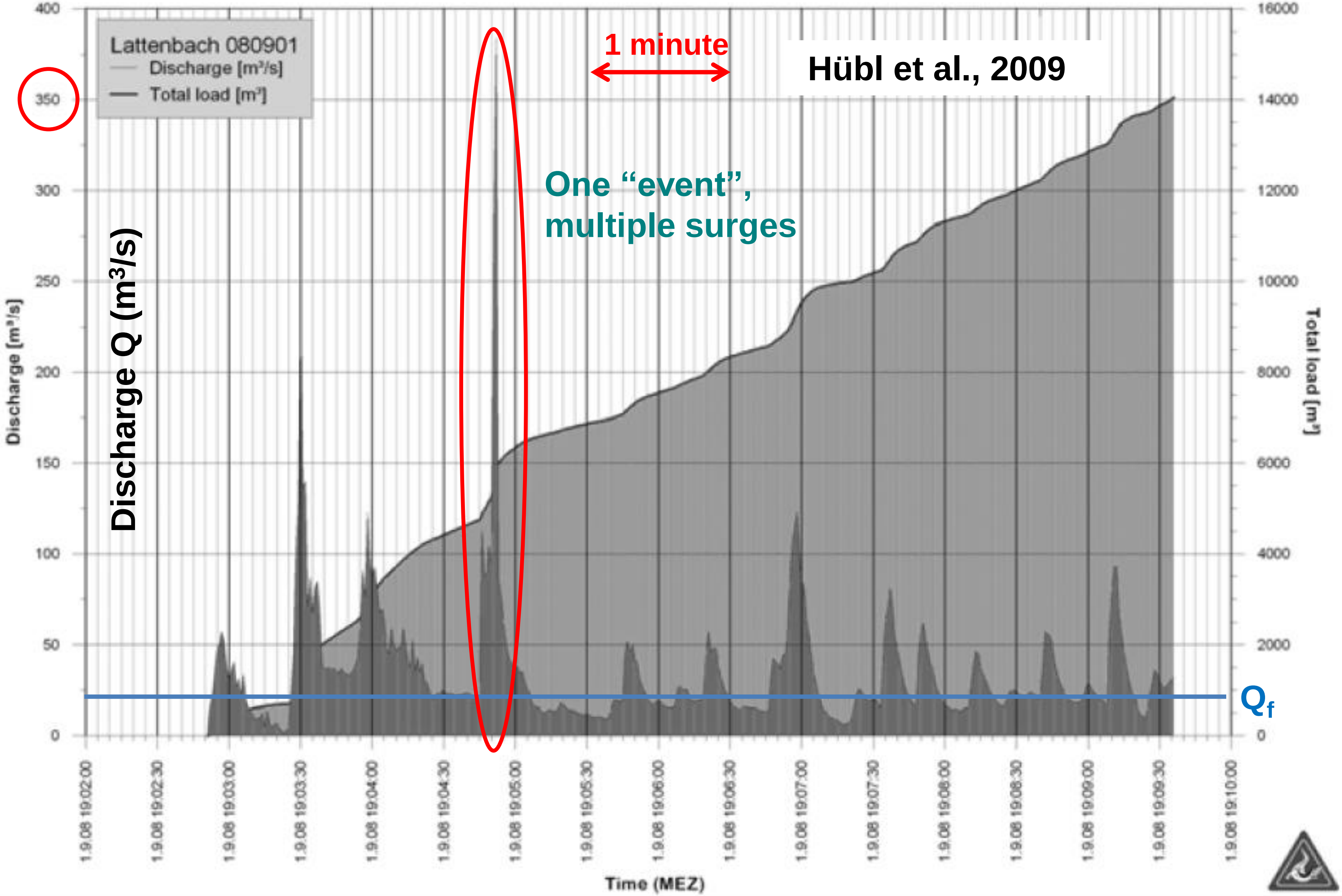


DEBRIS FLOW, Q_p=10 to 50+Q_f

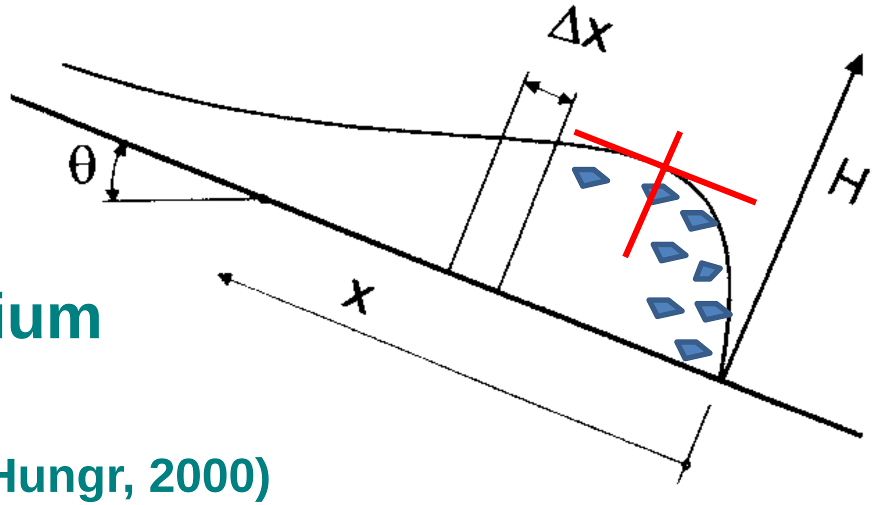


PIERSON, 1980

DEBRIS FLOW "EVENT"



Surge formation:



Reduce the moment equilibrium equation using the theory of uniformly-progressive flow (Hungr, 2000)

At steady state

(Constant velocity, acceleration=0):

$$\frac{dH}{dx} = S - S_f$$

S=slope; S_f=friction slope

Conclusion:
Surge building magnifies the peak discharge (“moving dam” effect)
depending on the boulder content of the surge

Another factor: Turbulence

Reynolds number depends on depth >> viscous flows develop turbulent fronts (Davies, 1986). Discharge magnification.

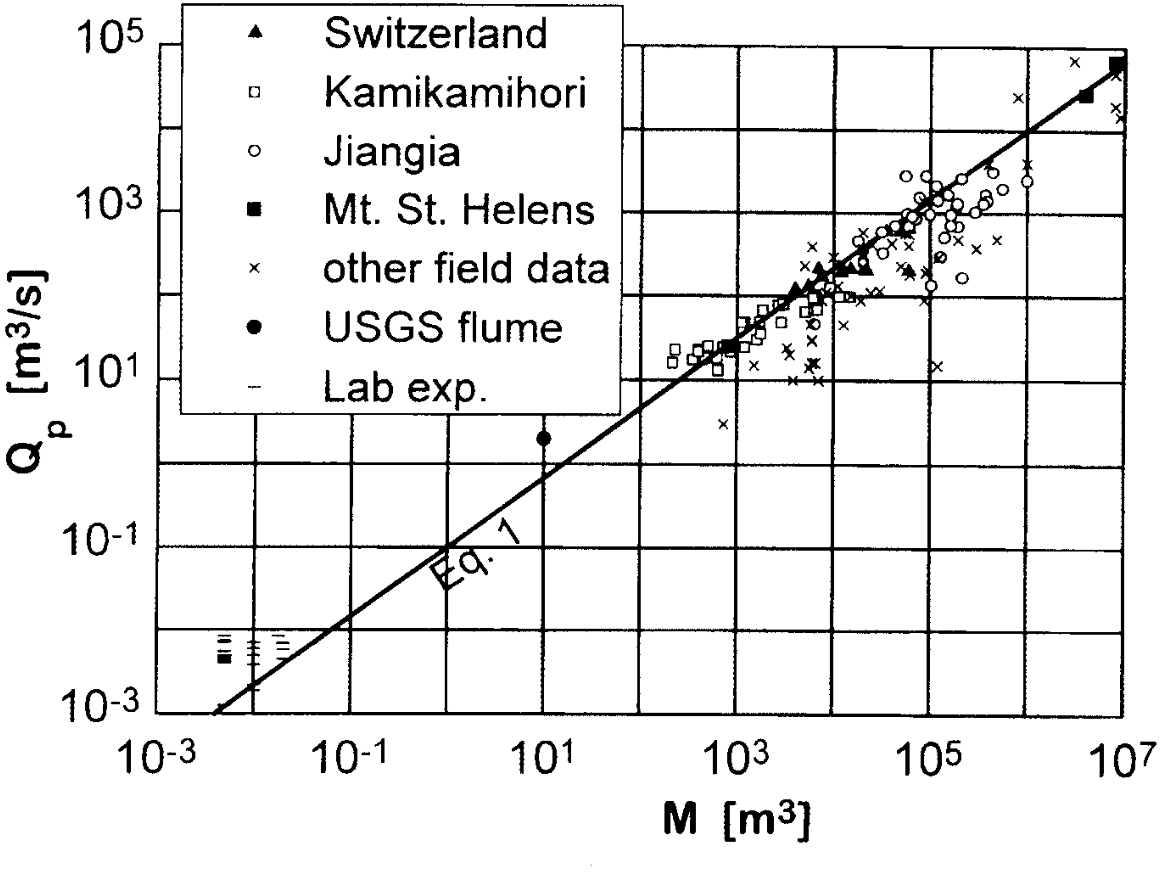
Capricorn Ck, British Columbia

Photo: K. Scott, USGS

How to estimate peak discharge? Empirical correlation with event magnitude

Rickenmann (1999)

Peak Discharge

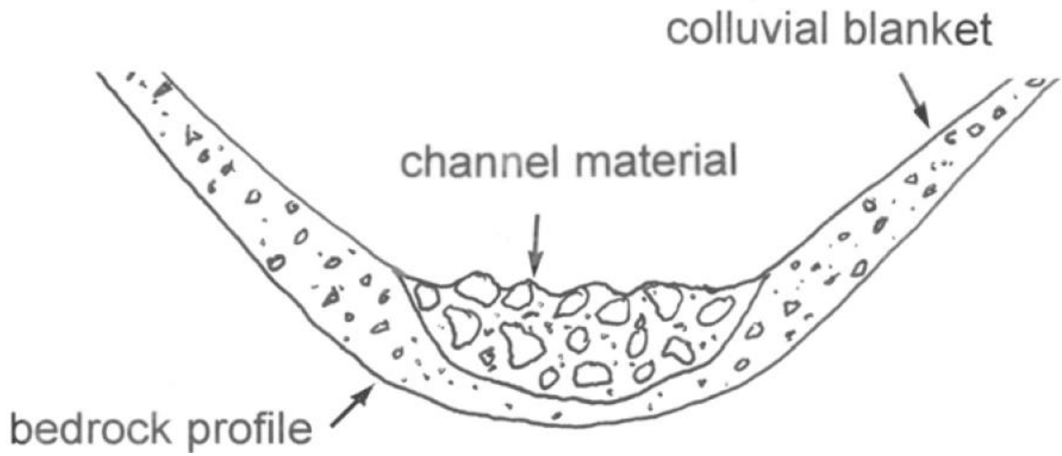


Event Magnitude

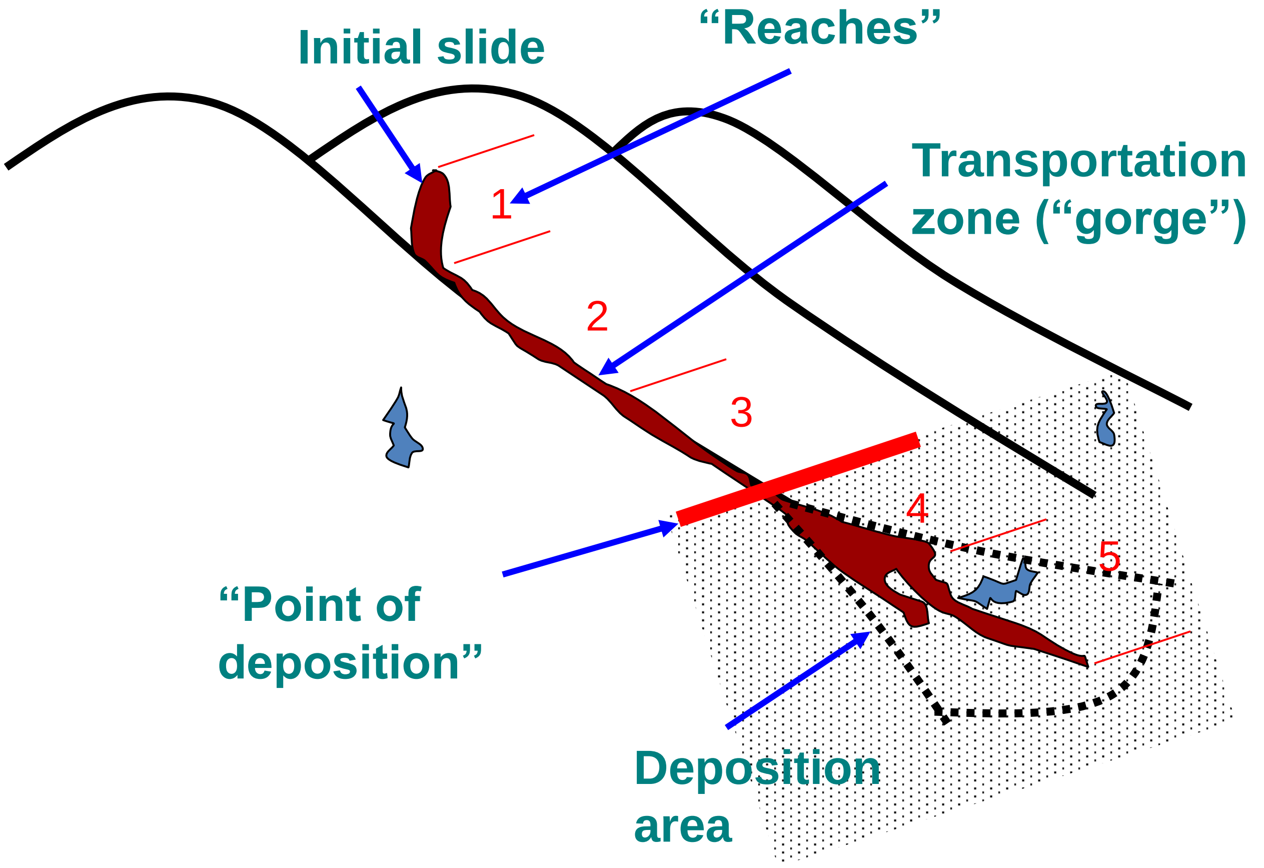
How to estimate Magnitude?
Yield rate (“Y”) concept

$$V = \sum L_i Y_i$$

Volume of an event depends on the length and condition of the contributing channel (e.g. Hungr et al., 1984)



Erosion/deposition boundary



Point of deposition (BC Coast):

10º to 14º - Unconfined channels)

8º to 12º (Confined channels)

Debris Yield Rates, British Columbia (Hungr et al., 1984)

Channel type	Gradient (deg)	Bed material	Side slopes	Stability condition*	Channel debris yield rate† (m^3/m)
A	20–35	Bedrock	Nonerodible	Stable, practically bare of soil cover	0–5
B	10–20	Thin debris or loose soil over bedrock	Nonerodible (bedrock)	Stable	5–10
C	10–20	Deep talus or moraine	Less than 5 m high	Stable	10–15
D	10–20	Deep talus or moraine	Talus, over 5 m high	Side slopes at repose	15–30
E	10–20	Deep talus or moraine	Talus, over 20 m high	Side slopes potentially unstable (landslide area)	Up to 200 (consider as point source)

*Prior to the expected debris torrent event.
†For drainage areas of 1–3 km^2. For other drainage areas use [2].

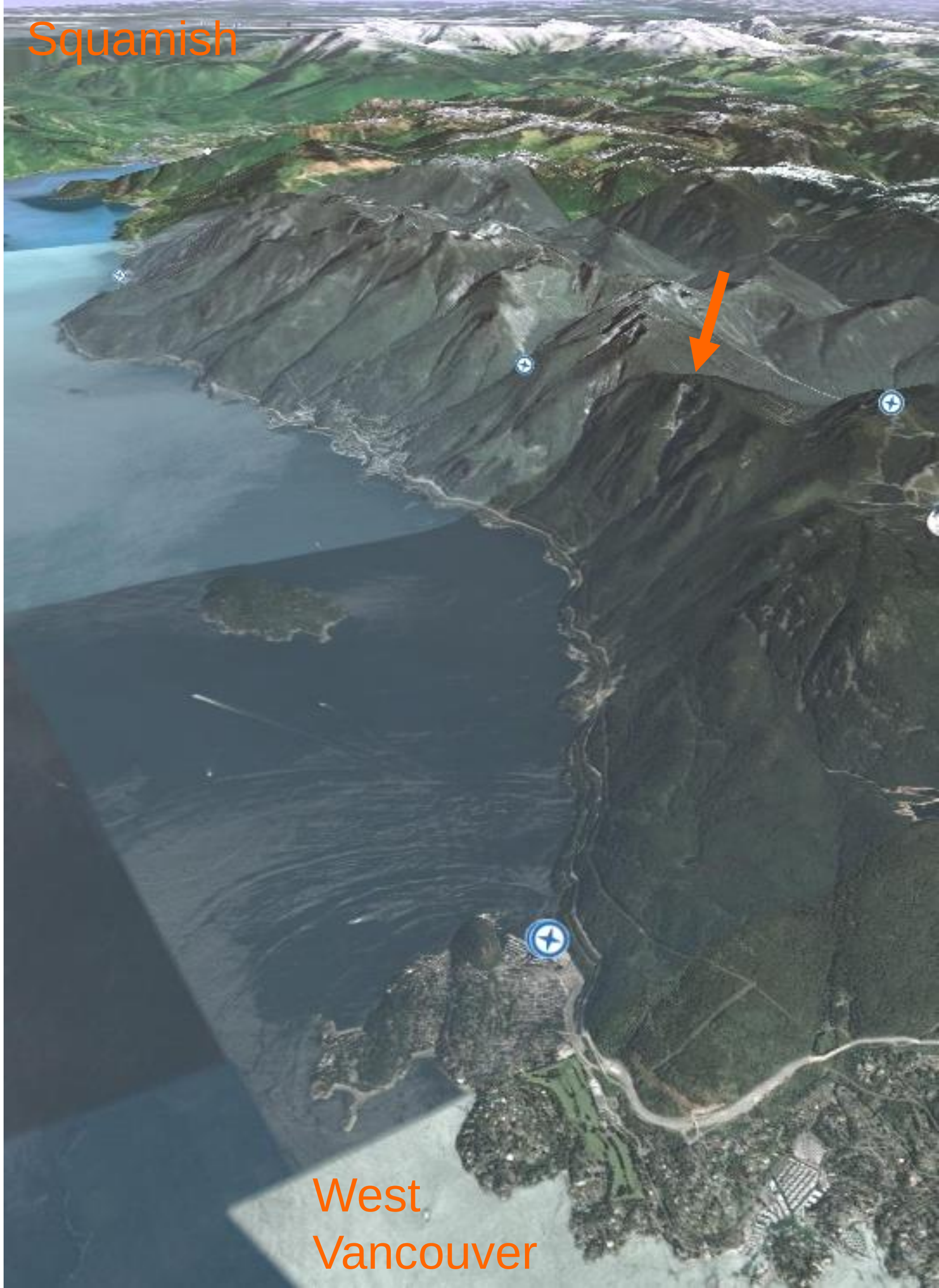
Factors controlling yield rate:

1) **Geology (material) of bed and banks**
2) **Slope angle**
3) **Confinement, stability of banks**

(for detailed discussion see Hungr et al., 2005)

Example:

Charles Creek British Columbia

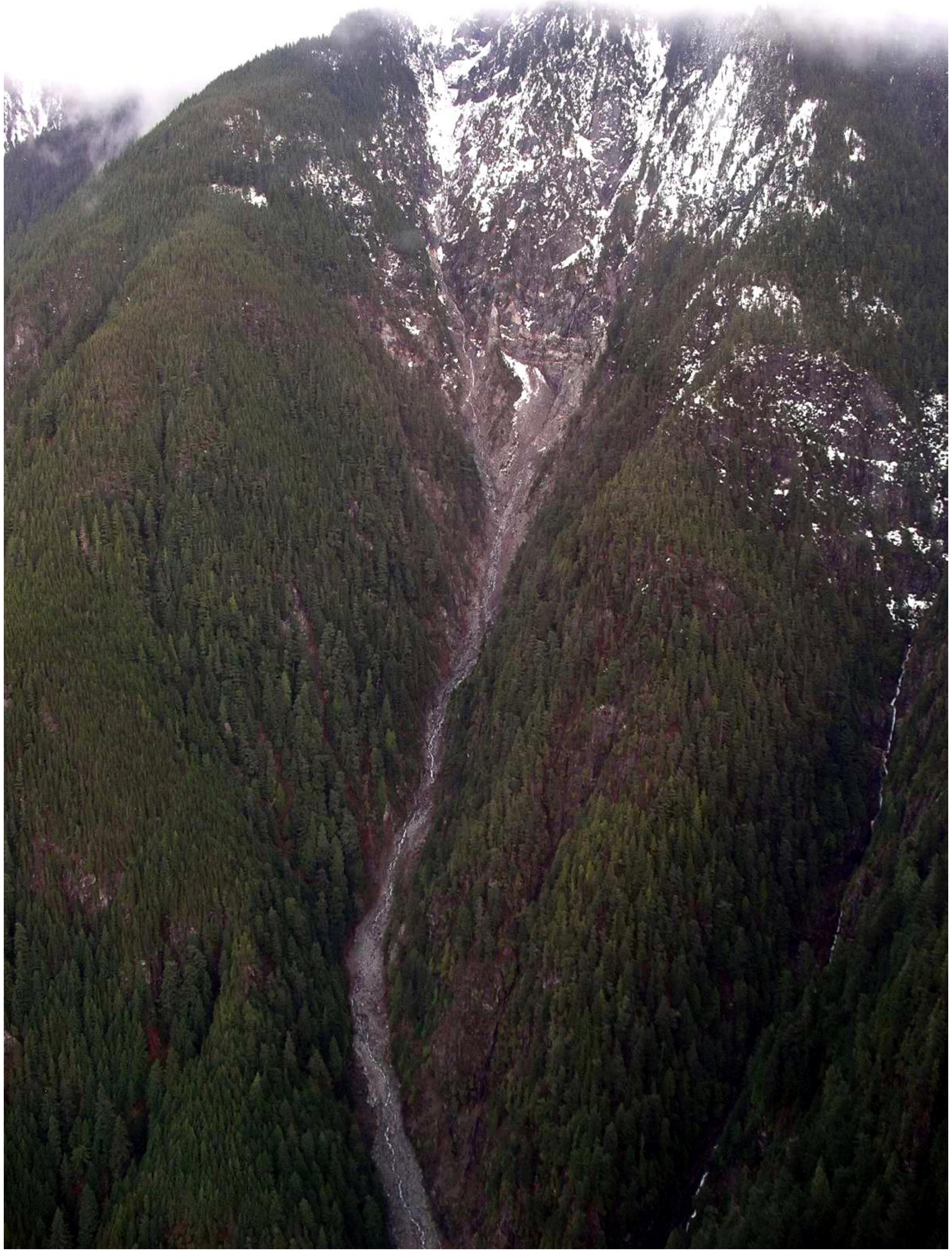


Charles Creek Drainage

Drainage area (A)	1.8 km^2
Main branch length	2550 m
Total length (both tributaries)	3526 m
Slope angle above fan (avg.)	27°
Drainage vertical relief (H)	1325 m
Subaerial fan area	0.045 km^2
Fan slope angle (avg.)	16°
Estimated 200 year flood	32 m^3/sec

Initiation zone

(rock falls)



Charles Creek debris

Charles Ck - Debris Flows – Dec 1981

Charles Ck - Debris Flows – Nov 1983

15 m

5 m^3/m

8 m^3/m

10 m^3/m

Channel types:

- Supply-controlled
- Transport-controlled

Inventory of erodible debris?

Yield Rate

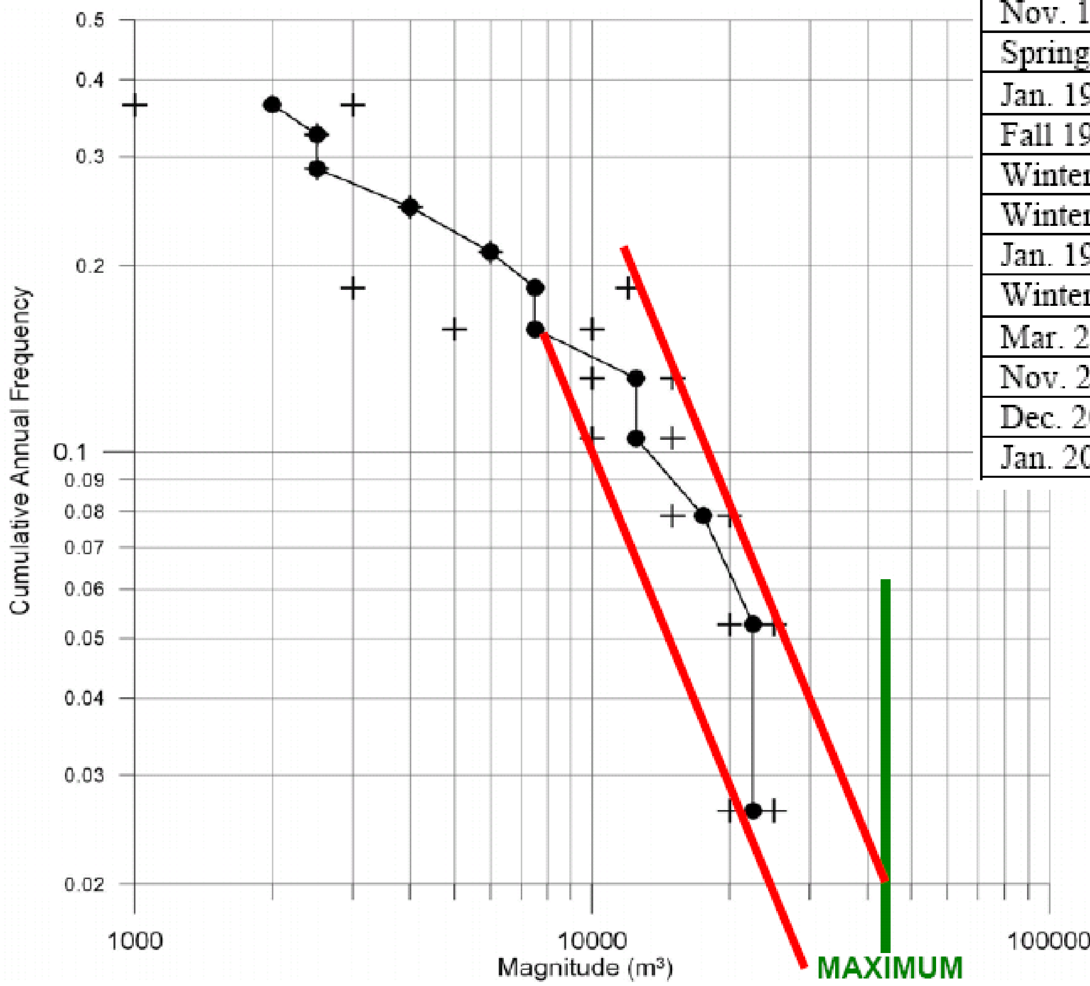
Estimated maximum debris flow magnitude

Sector	Elevation range	Length (m)	Description	Y (m^3/m)	Volume (m^3)	Comment
Main Branch						
1	120-190	100	Large boulders	10	1000	Ground
2	190-220	70	Debris	20	1400	Ground
3	220-260	65	Bedrock	5	325	Ground
4	260-360	215	Debris and rock	8	1720	Ground
5	360-400	165	Debris	15	2475	End ground traverse
6	400-450	230	Bedrock gorge	5	1150	Air
7	450-850	800	Talus deposits	20	16000	Air
8	850-1220	500	Bedrock	5	2500	Air
			Sub-Total		**26570**	**m^3**
Second Branch						
1	450-900	1000	Bedrock	5	5000	Air
Point sources total					10000	Subjective
			Total		**41570**	**m^3**

Maximum event volume (m^3)

Debris flow inventory

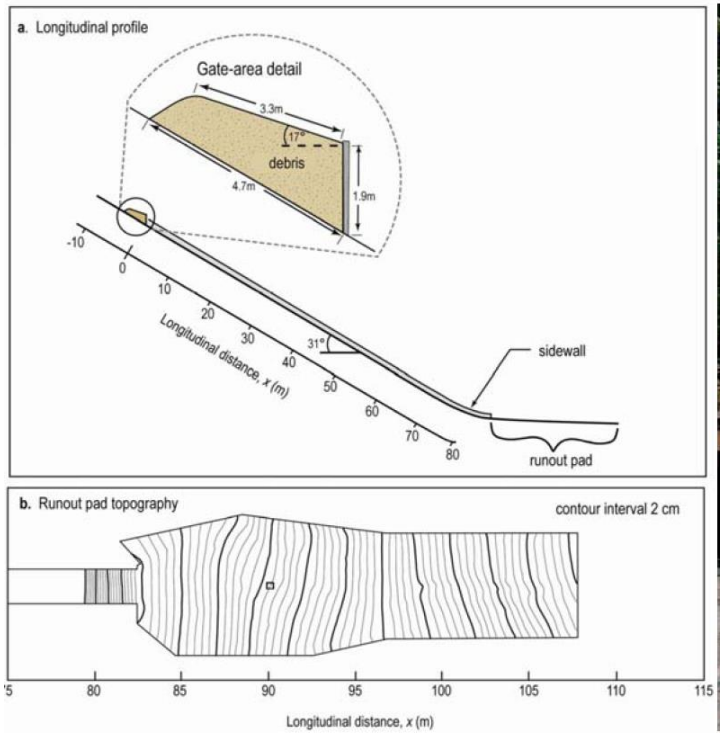
Date	Debris Volume (m^3)
Sep. 1969	20,000 to 25,000
Nov. 1972	5,000 to 10,000
Dec. 1981	10,000 to 15,000
Feb. 1983	3000 to 12,000
Nov. 1983	15,000 to 20,000
Spring 1990	2500
Jan. 1991	4000
Fall 1991	2500
Winter 1993/1994	1,000 to 3,000
Winter 1995/1996	1,000 to 3,000
Jan. 1998	6,000
Winter 1999/2000	1,000 to 3,000
Mar. 2005	1000 to 3000
Nov. 2006	20,000 to 25,000
Dec. 2007	10,000 to 15,000
Jan. 2008	1,000 to 2,000

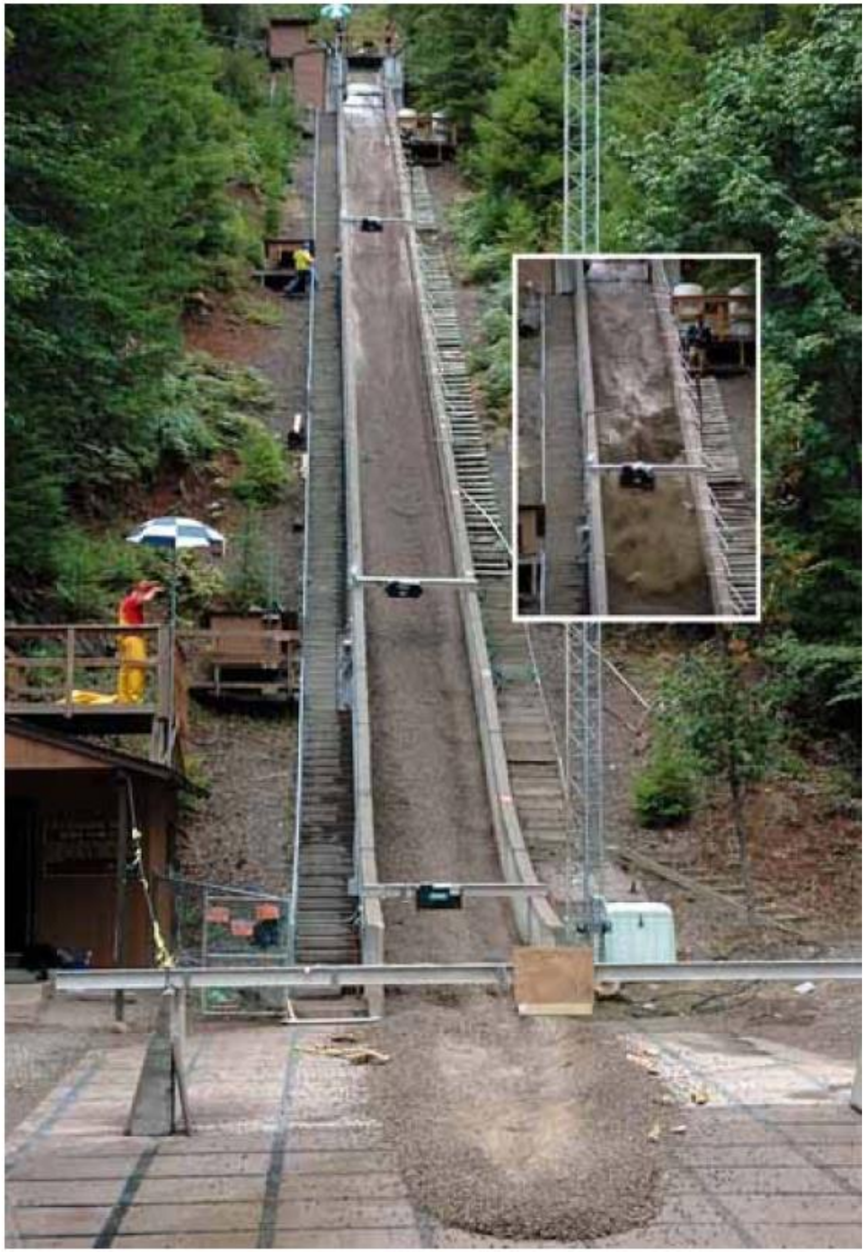


Cumulative Magnitude-Frequency (CMF) curve

Dynamic modelling:

The Perfect Debris Flow (Iverson, 2010)



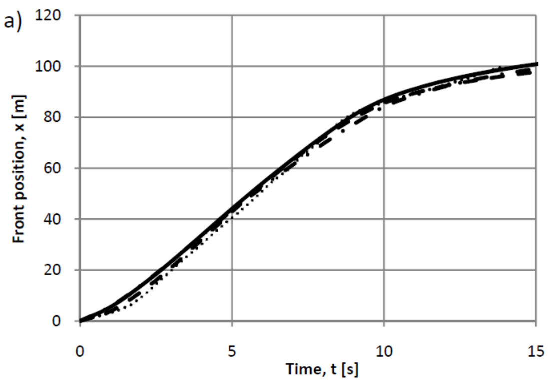


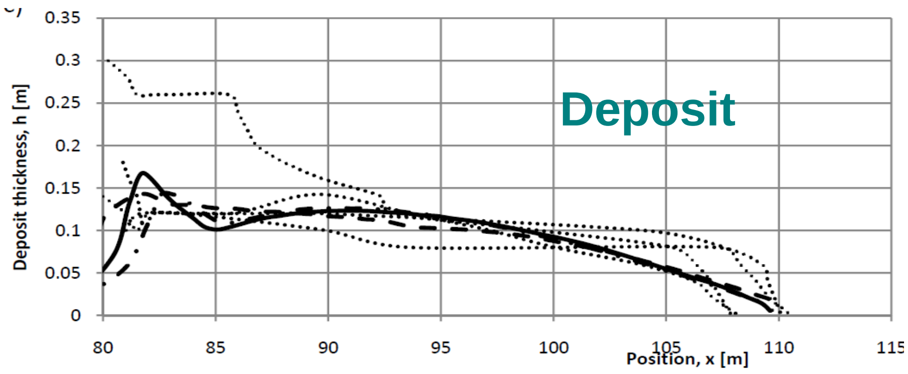
"Voellmy reology":
Resisting stress = frictional and turbulent term

$$T = f\sigma + \gamma \frac{V^2}{\xi}$$

V = mean velocity
σ = normal stress
ϒ = unit weight
F = friction coefficient

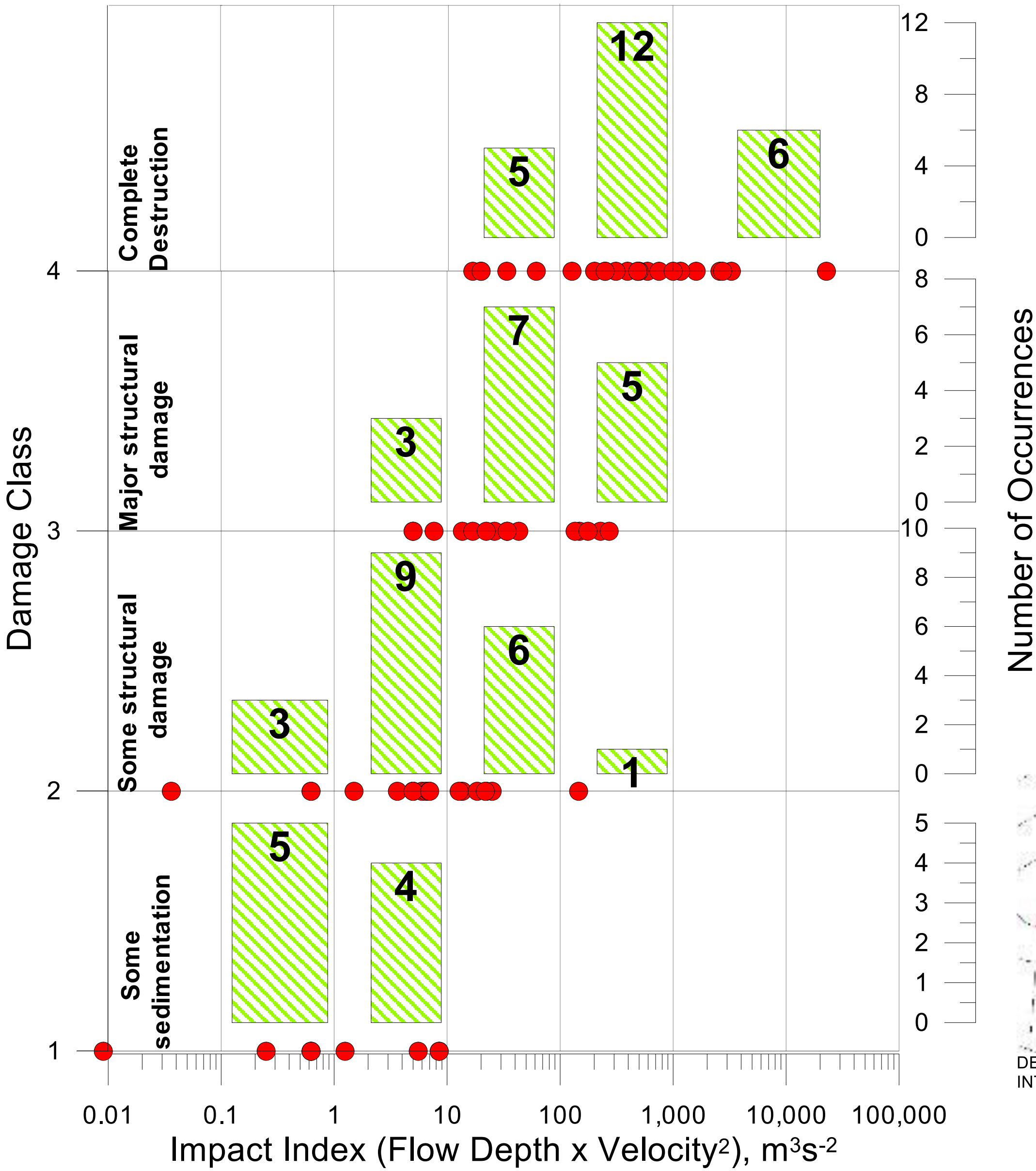
"Perfect debris flow:
by trial and error, f=0.06, ξ=600m/s^2





P. Fitze, 2011

Debris Flow Damage Relationship

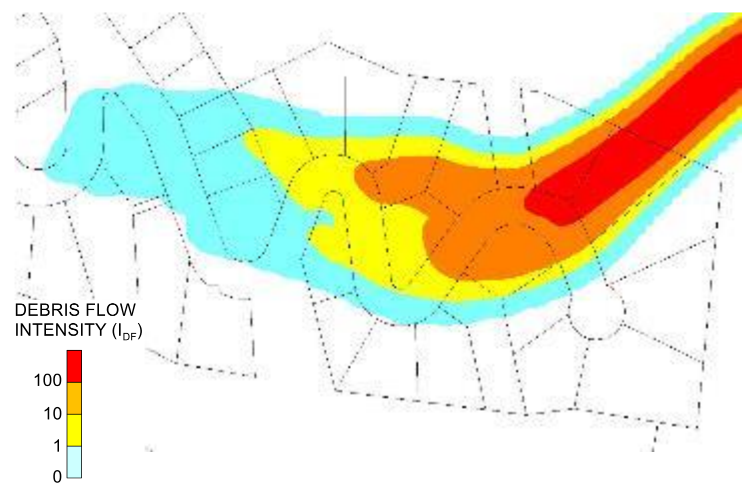


Jakob et al. (2011)

"Impact Index"

$$Ii_{df} = hv^2$$

h=flow depth
v=mean velocity



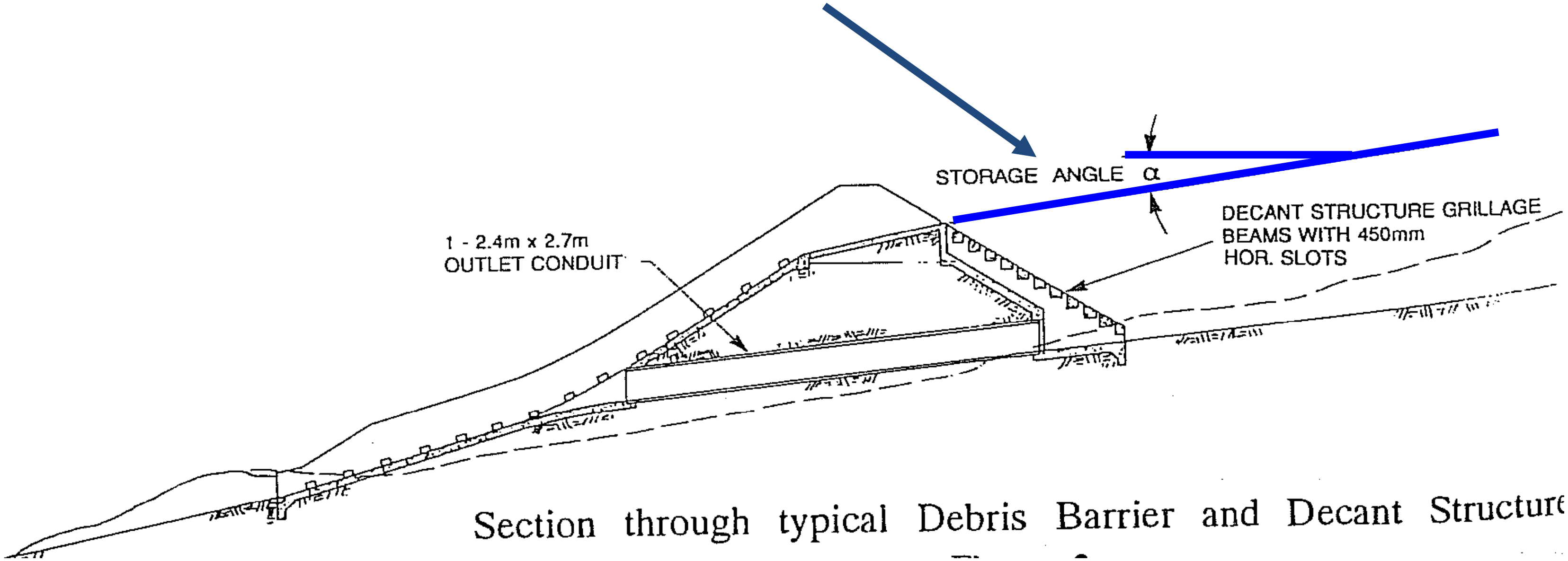
Protective measures:

Barriers and Basins

Charles Creek Barrier

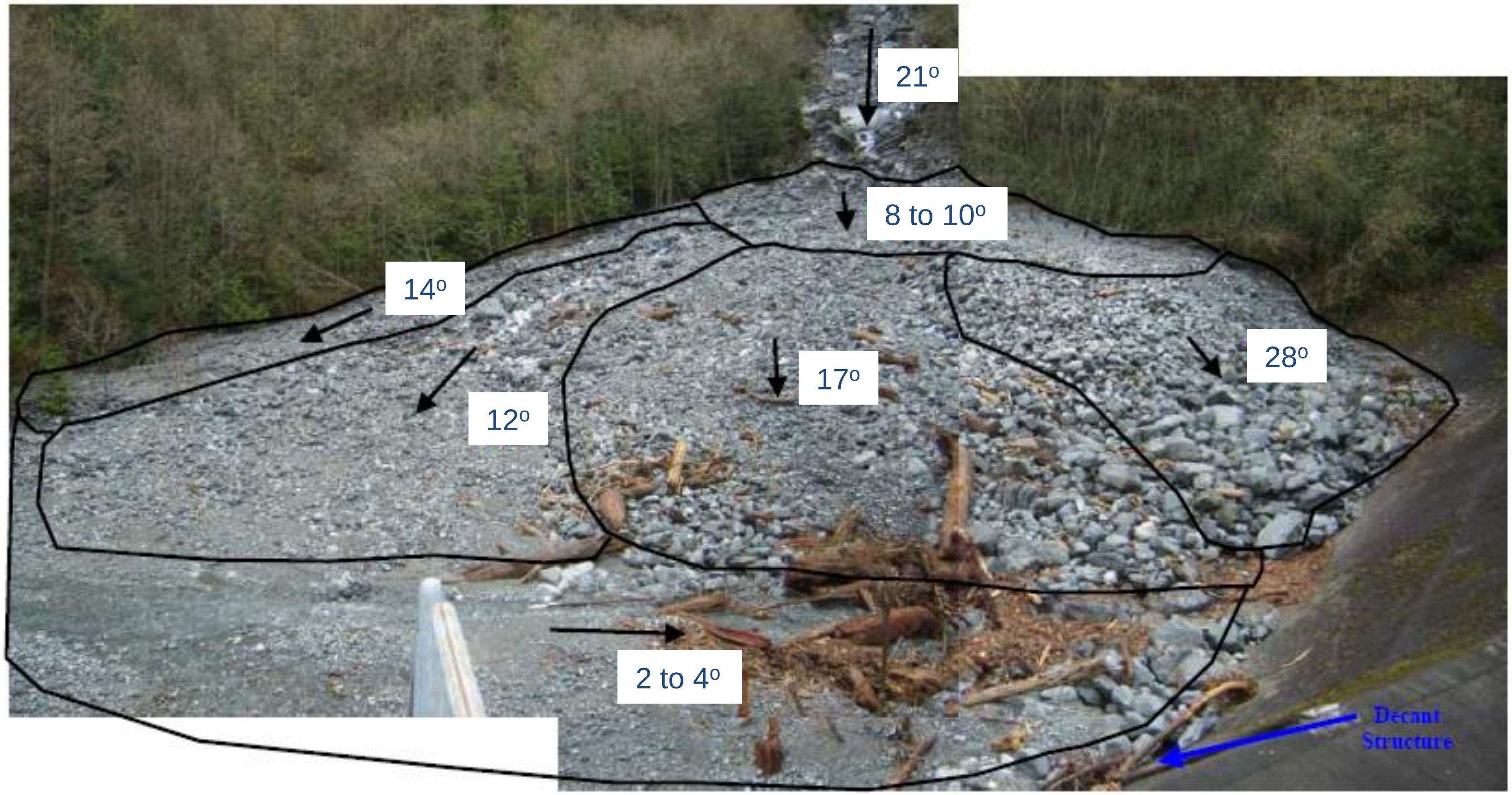
Charles Ck Barrier, “Storage Angle”

Design - 8°(half of original creek slope at basin)



Section through typical Debris Barrier and Decant Structure

Charles Ck – Storage Angles - Nov 2006



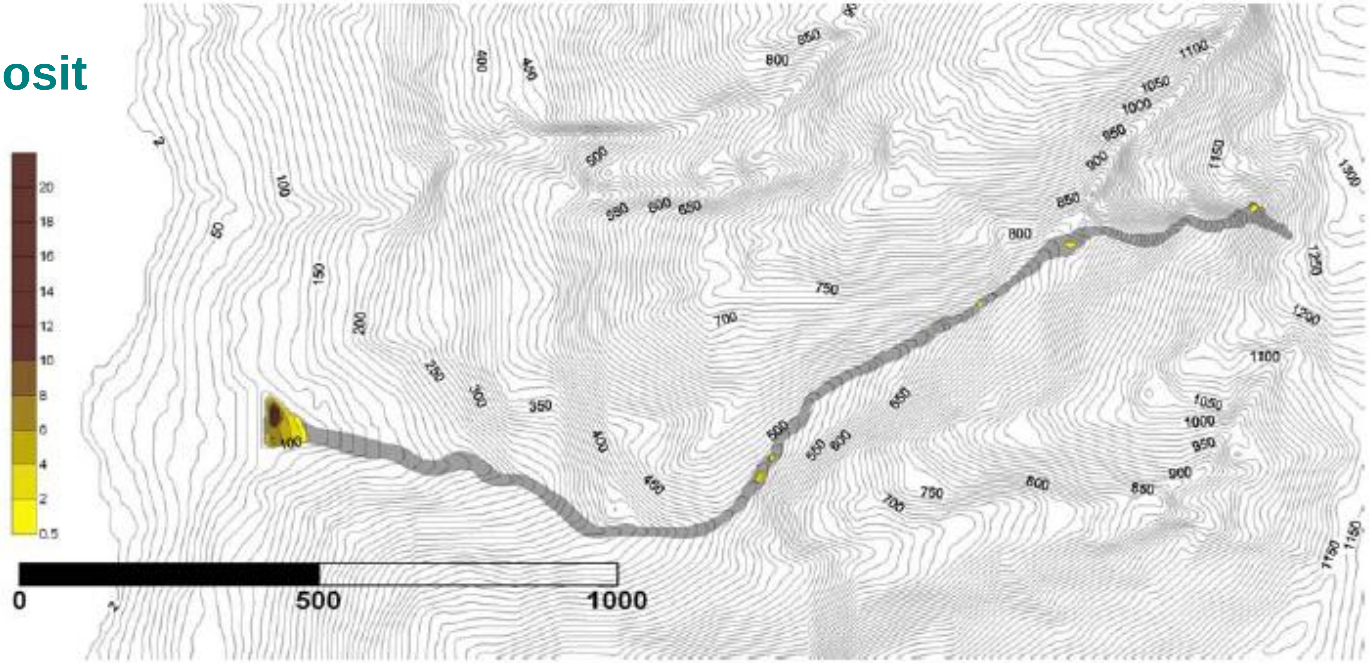
Charles Creek 2006 flow analysis

DAN 3D

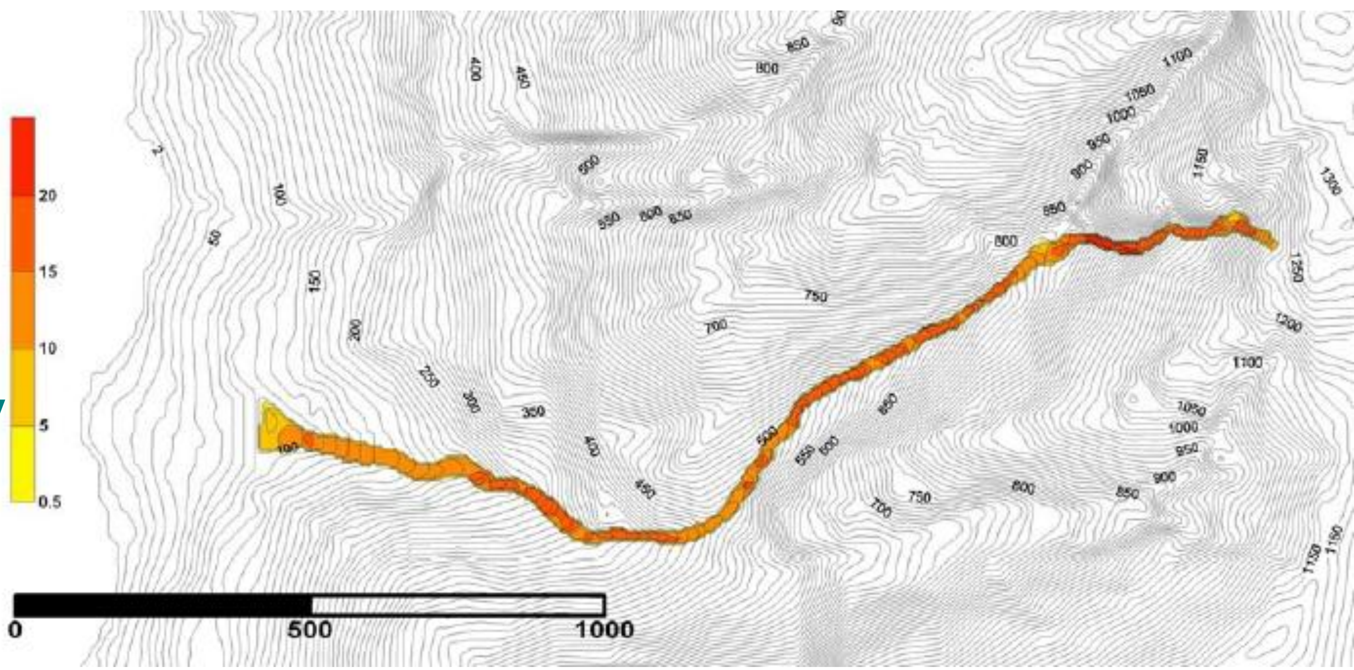
Voellmy

f=0.1, ksi=500 m/s^2

Deposit (m)

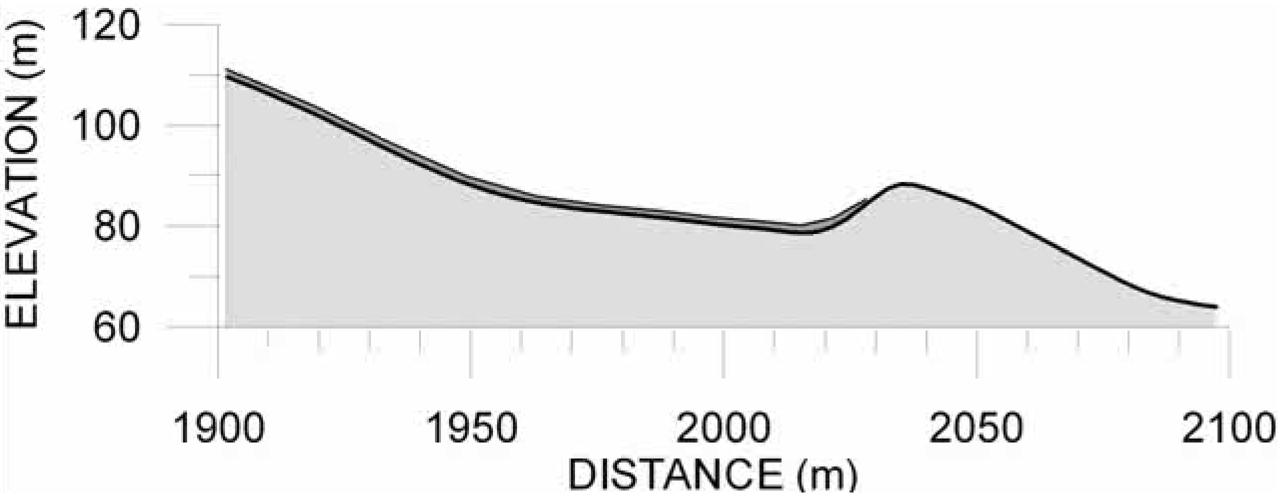


Max Velocity (m/s)



DAN analysis of basin filling

Voellmy, f=0.1, ksi=500 m/s²



A “shooting channel”, Savoy Alps. The bridge can be lifted at the time of danger

A lined channel designed for passage of debris flows on Alberta Creek, Lions’ Bay, British Columbia

Landslide Induced Debris Flows of August 2005 (Brienz) (Prof. S.Loew, ETH Zurich)

Initiation: a rockslide

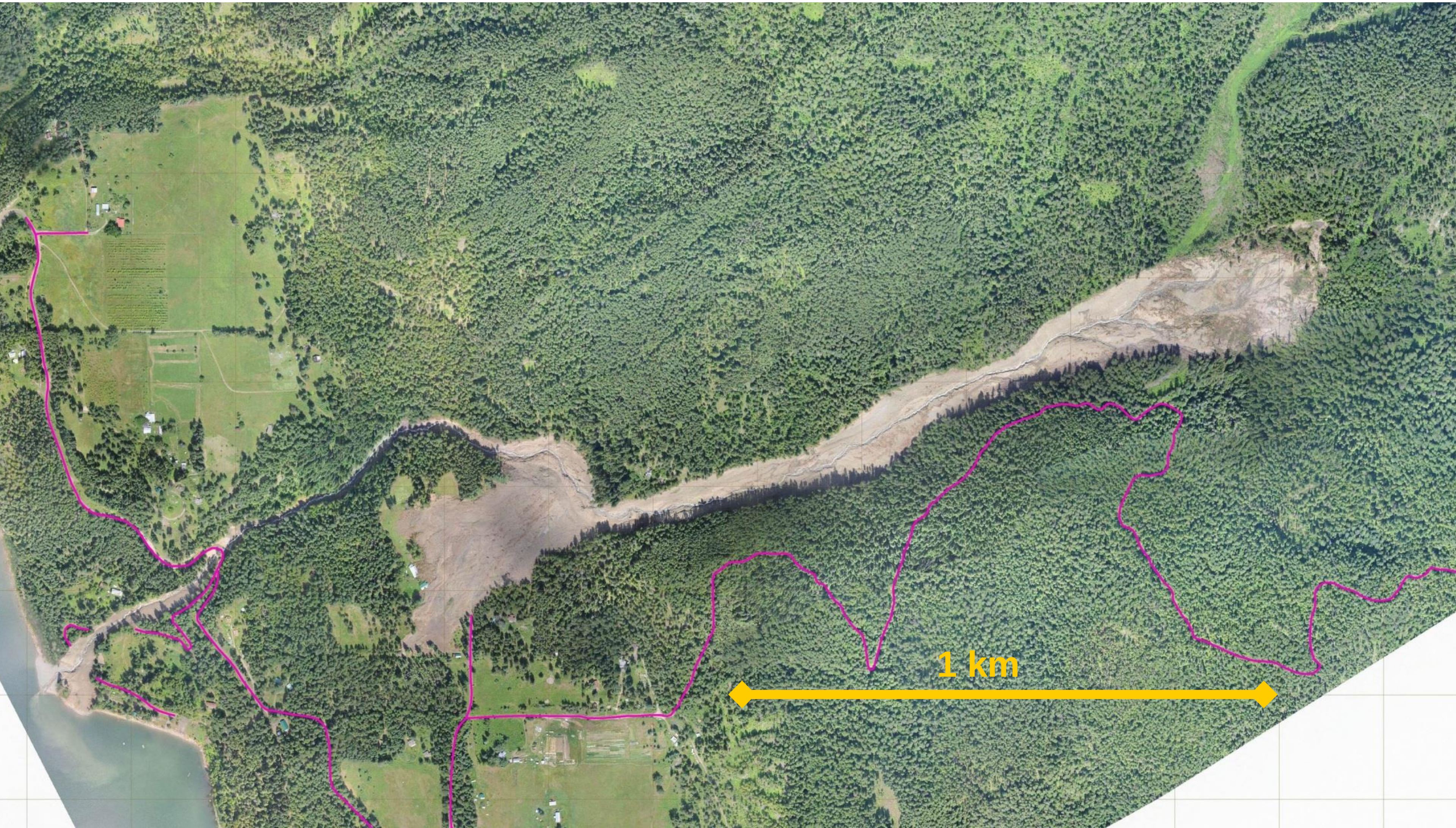
Another phenomenon: Debris Avalanche

Johnson's Landing, Kootenay Lake, 2004 image

Another phenomenon: Debris Avalanche

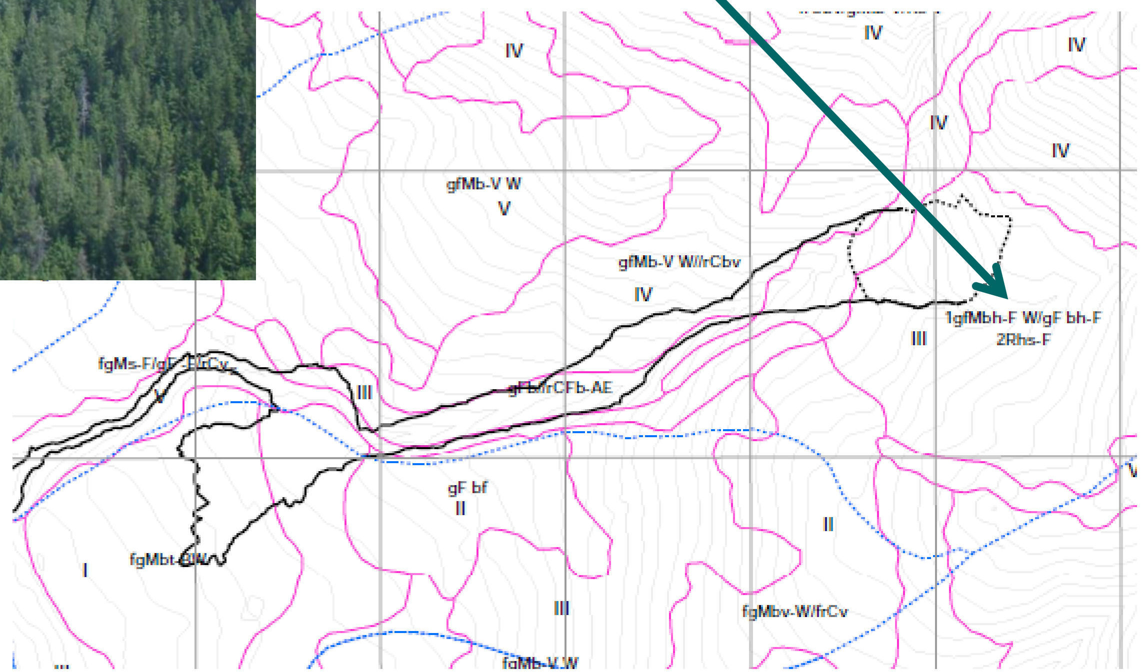
Johnson's Landing, Kootenay Lake, 2004 image

Johnson's Landing, British Columbia May, 2012



Pre-event geomorphological mapping:

Source area is situated in a geomorphological unit described as sandy moraine and glacio-fluvial soil (kame deposit) – Failing (i.e. in an unstable condition). Stability Class III (out of 5)



Deep-seated compound silt slide
320,000 m^3

1:500 year rain on snowmelt

Source volume: 320,000 m³

Minor soil entrainment, large quantities of timber debris

Flow velocity from eyewitness accounts: > 20 m/s

Channel overflow site **(Photo, Peter Jordan, BCF, Nelson)**

Channel overflow site (Photo, Peter Jordan, BCF, Nelson)

Deposit:

6 houses destroyed,
4 fatalities

This is the first landslide deposit on top of a glacio-fluvial terrace surface, over 9,000 years old!

Photo: Peter Jordan

Recommendations:

- Concentrate on site observations
- Carefully evaluate evidence on the fan
- Examine the initiation area
- Do not underestimate signs of instability
- Examine path
- Assess potential for entrainment
- Analysis: use a calibrated model
- Consider random factors (channel blockage?)
- Estimate the performance of protective measures under all possible scenarios

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THANK YOU

Expect the unexpected!