The importance of inter-flood periods on alluvial fan morphology, hazards and reworking

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Abstract

On steep alluvial fans, debris floods happen rarely but are often catastrophic. Debris floods and their associated hazards are well documented, but the time between flood events has generally been considered a period of 'dormancy', and thus ignored. Here, we present results from a series of four alluvial fan experiments in which we examine the inter-flood period processes and their influence at both event and fan evolution timescales. We built each fan from the same number of debris floods, and the same volume of sediment, but varied the duration of the inter-flood period. This duration had a fundamental influence on fan morphology: in particular fan slope and fan area varied between the experiments. In addition, longer inter-flood periods led to increased flow channelization and channel incision near the fan apex. Our findings challenge the notion that inter-flood periods on steep alluvial fans may be considered dormant. Moreover, the results suggest that longer inter-flood periods may act to contain subsequent debris flood events, shift the locus of debris flood hazard, and reduce their severity.

The importance of secondary processes on alluvial fan morphology, hazards and reworking

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Post-event downcutting at Turbid Creek, BC Sept 24, 2019. Photo by author.

The processes occurring between processes delivering material to the fan (primary processes) may be referred to as secondary processes.

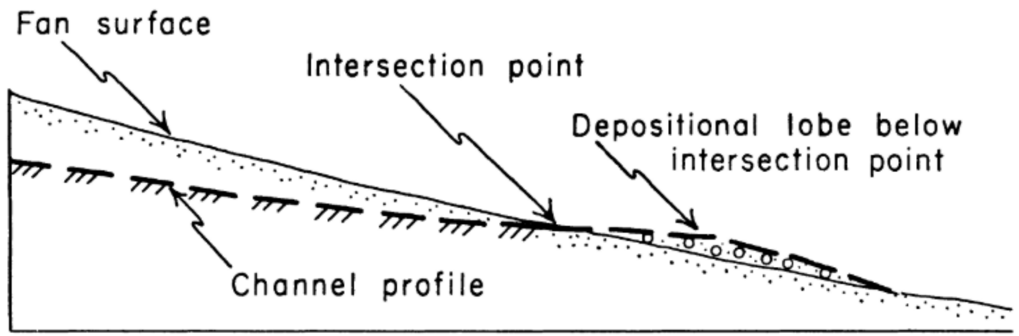
Primary processes

Three Sisters Creek during 20 June 2013.
Photos: M. Jakob. (Church and Jakob, 2020)

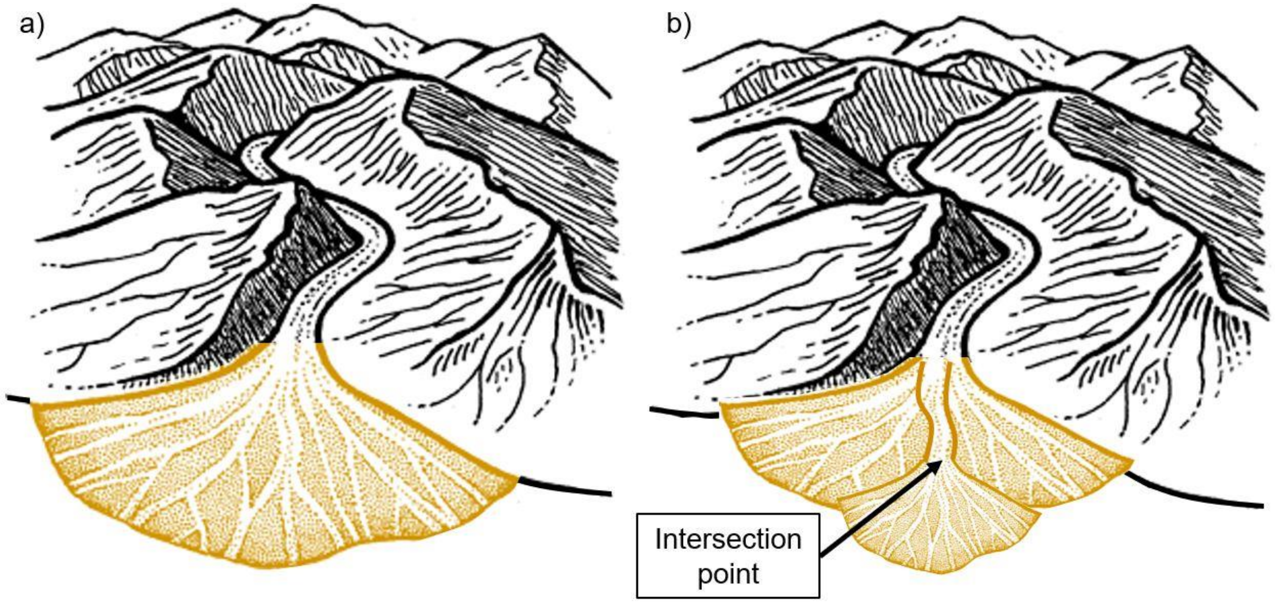
Secondary processes

Post-event downcutting at Turbid Creek, BC Sept 24, 2019. Photo by author.

Secondary processes re-mobilize and rework sediment previously deposited on the fan.



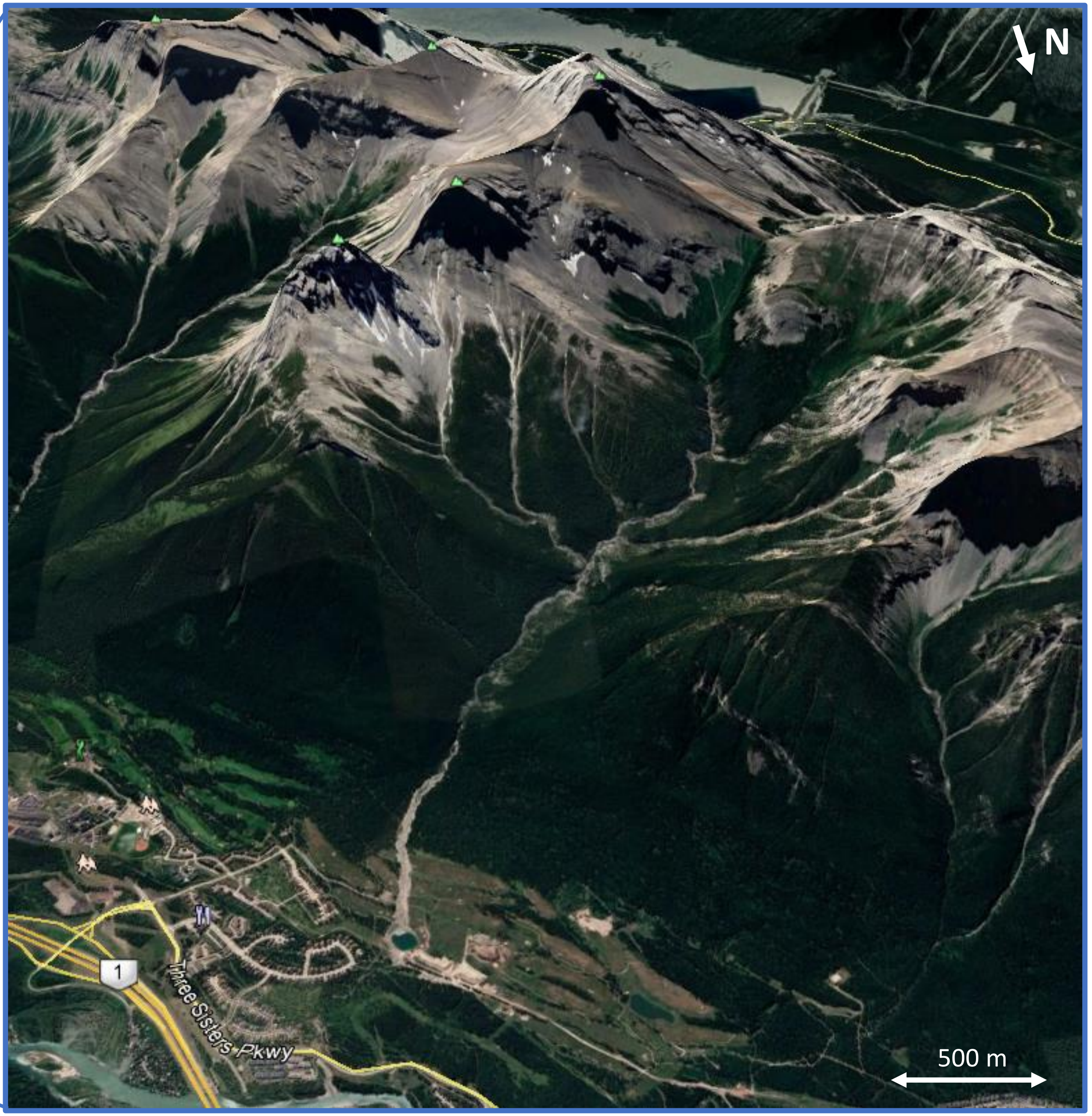
(Hooke, 1967)



- Channel incision/ entrenchment
- Terracing
- Channel bed armouring
- Sediment redistribution
- Down-fan migration of the intersection point

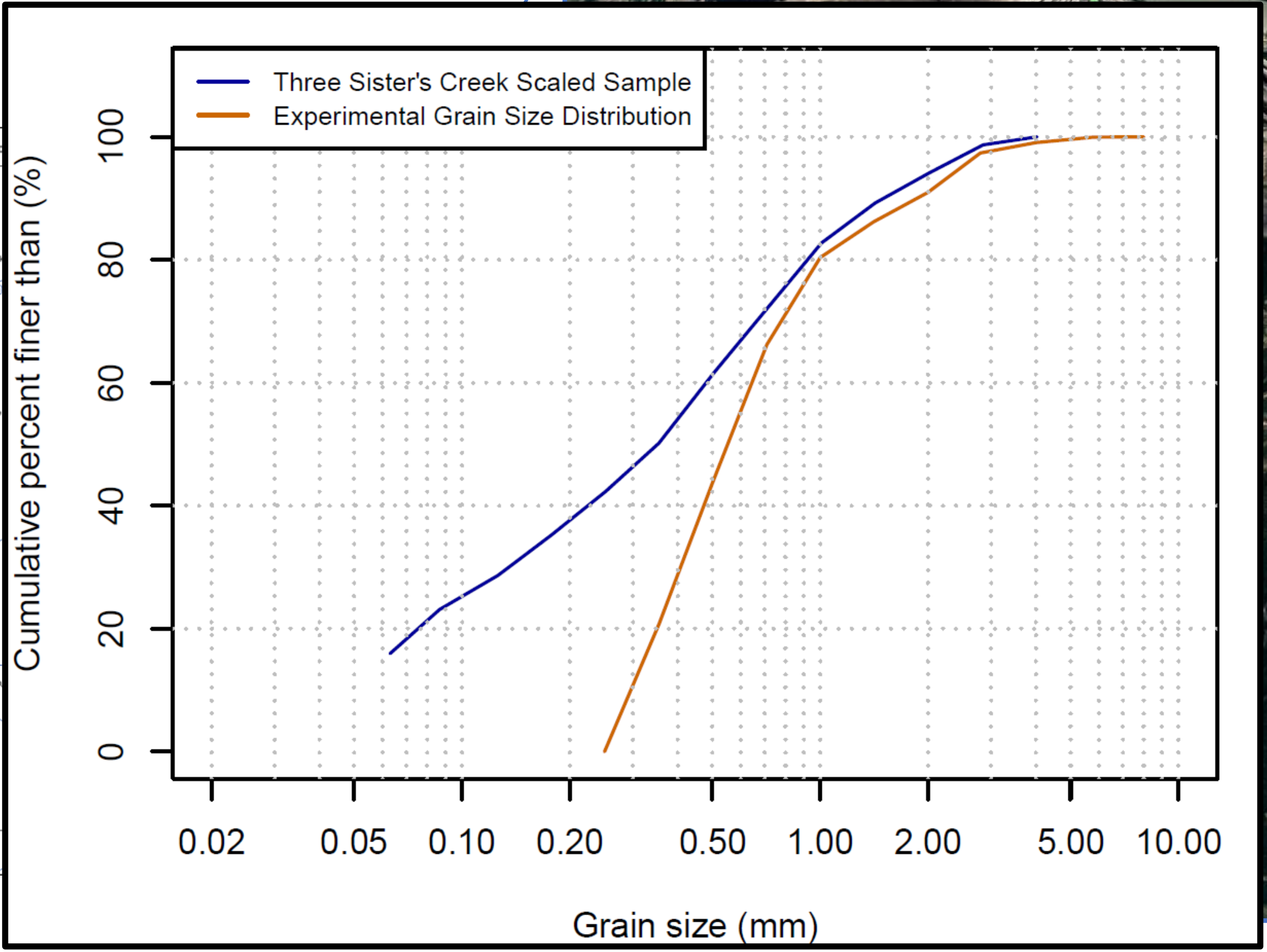
Three Sisters Creek, AB

Source: https://d-maps.com



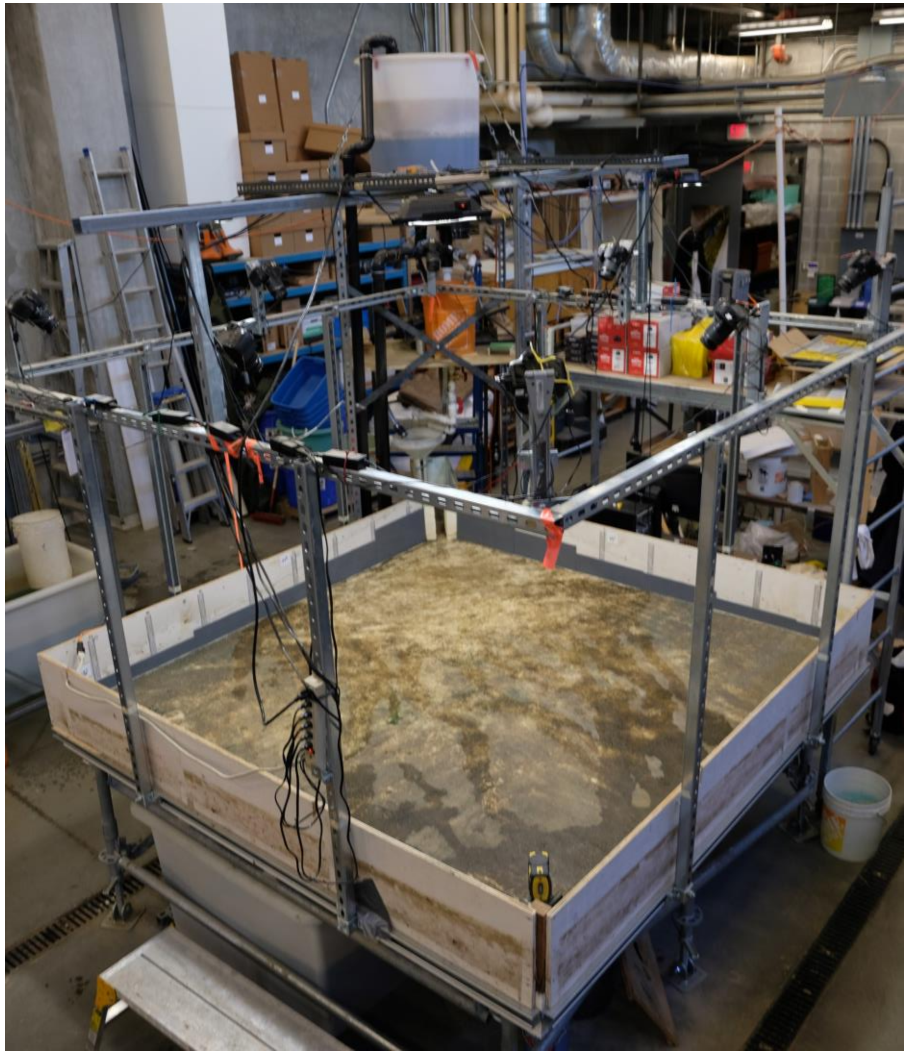
Source: Google Earth (2018)

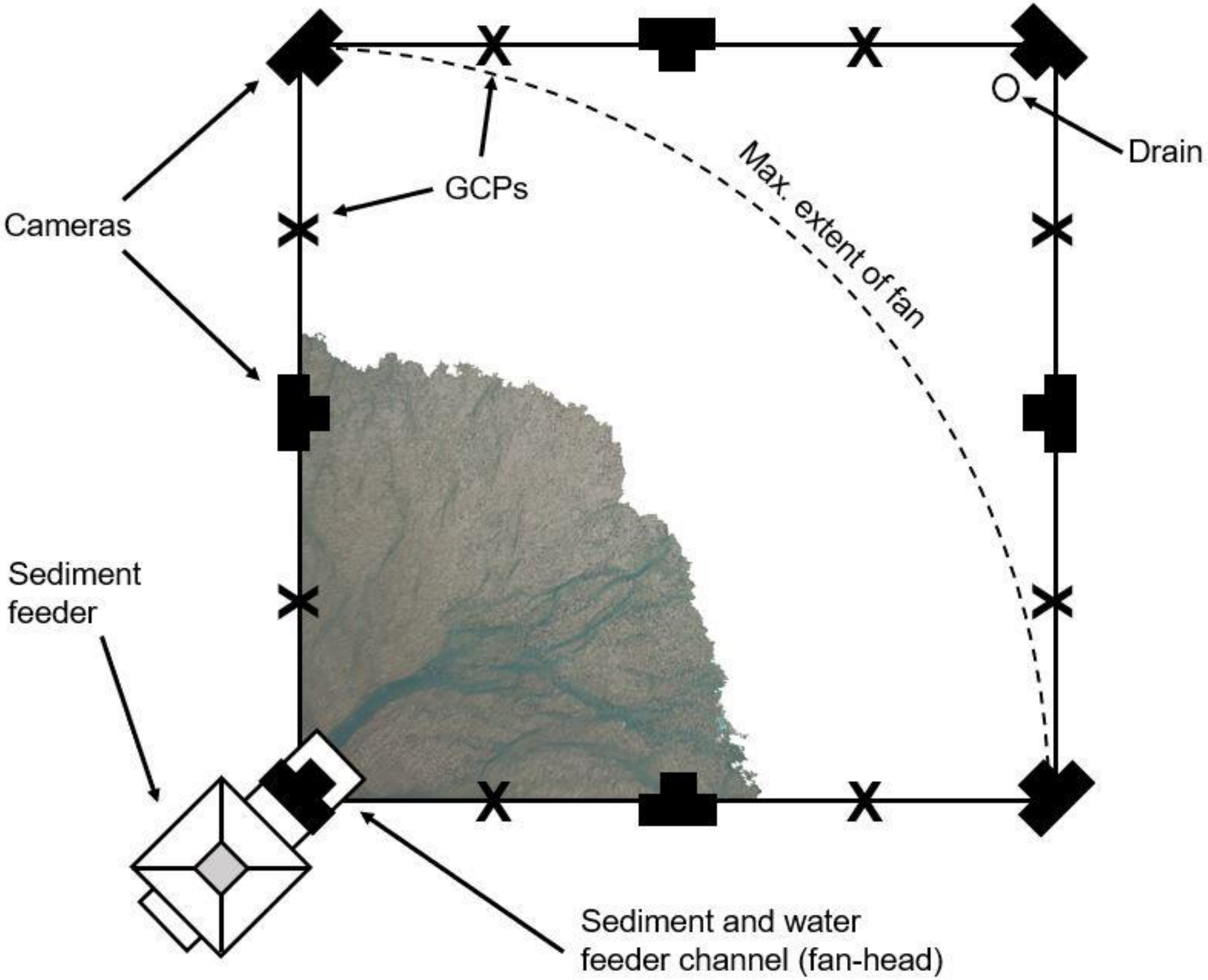
Three Sisters Creek, AB



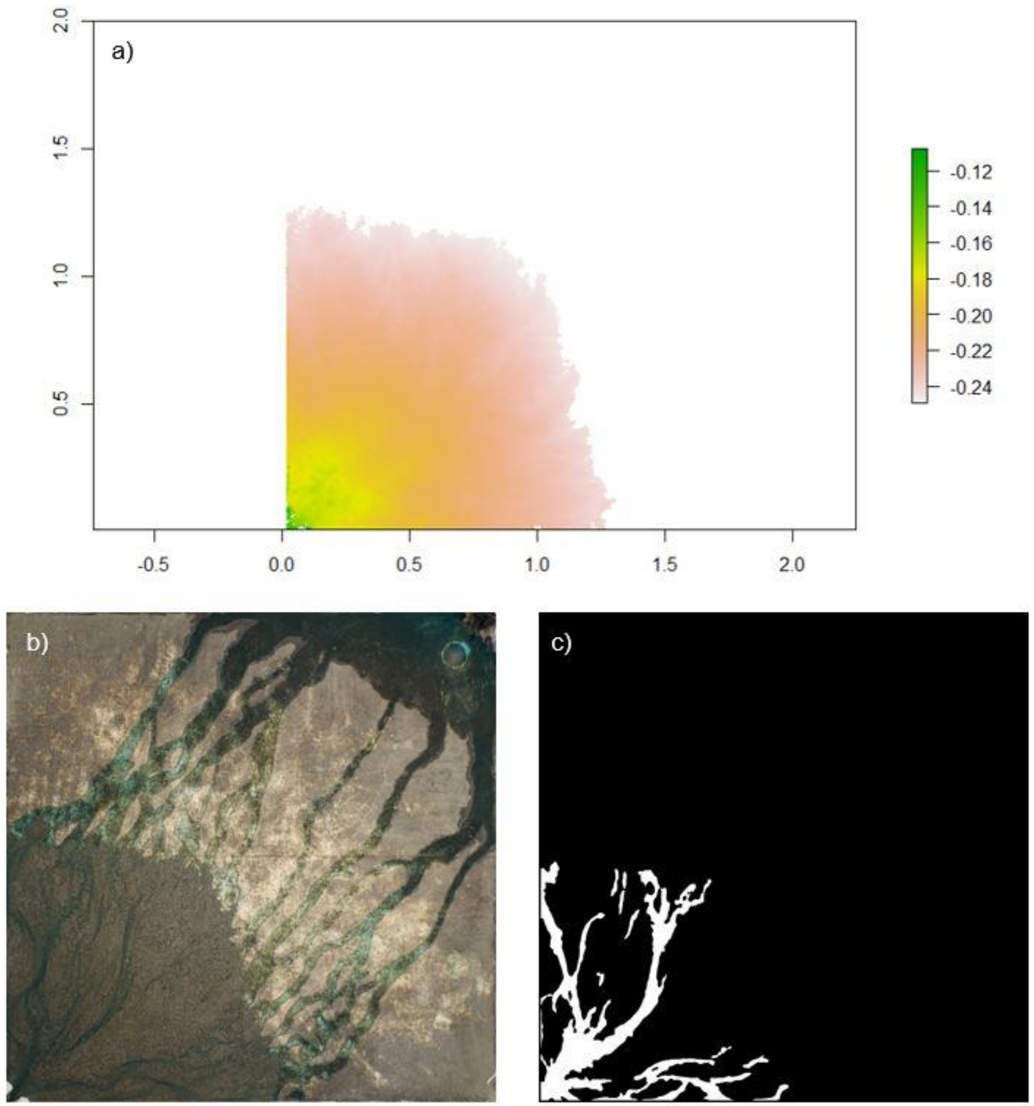
Source: Google Earth (2018)

A stream table was used to replicate alluvial fans generated under debris flood conditions.





Photographic data were collected at 1 minute intervals and used to generate DEMs, orthomosaics and binary channel maps.



Phase 1: Fan Formation

Experiment #	Primary Process			Secondary Process			Total Est. Experiment Duration (hours)
	Discharge (mL/s)	Sediment Feed (g/s)	Duration (mins)	Discharge (mL/s)	Sediment Feed (g/s)	Duration (mins)	
1	100	10	5	50	0	5	4
2	100	10	5	50	0	10	6
3	100	10	5	50	0	20	10
4	100	10	5	50	0	40	18

Notes:

- Each line represents a distinct experiment and alluvial fan.
- Experiments were run until a total of 72 kg of sediment had been input into the fan.
- The total length of the experiments varied based on the duration of secondary processes.

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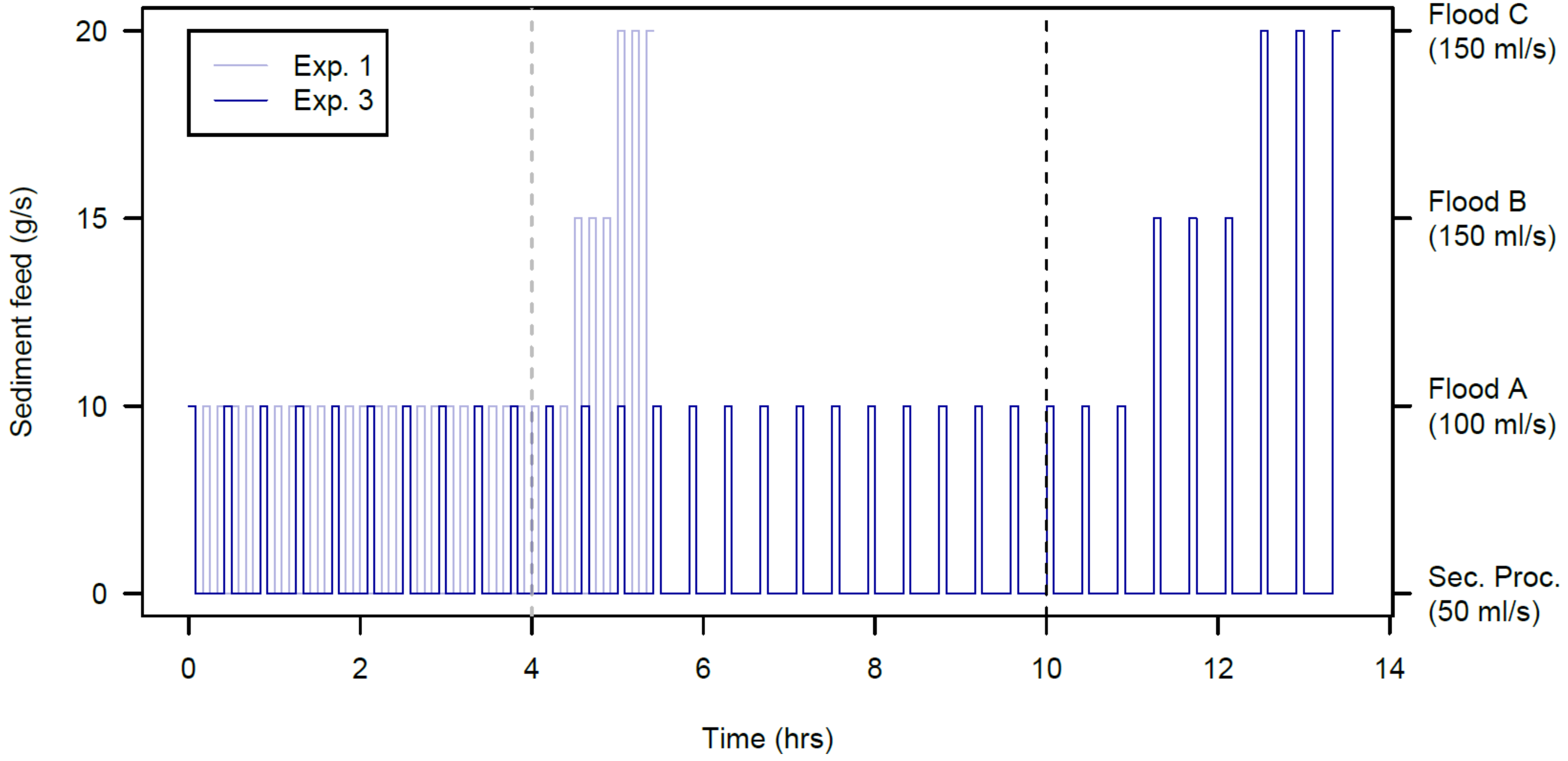
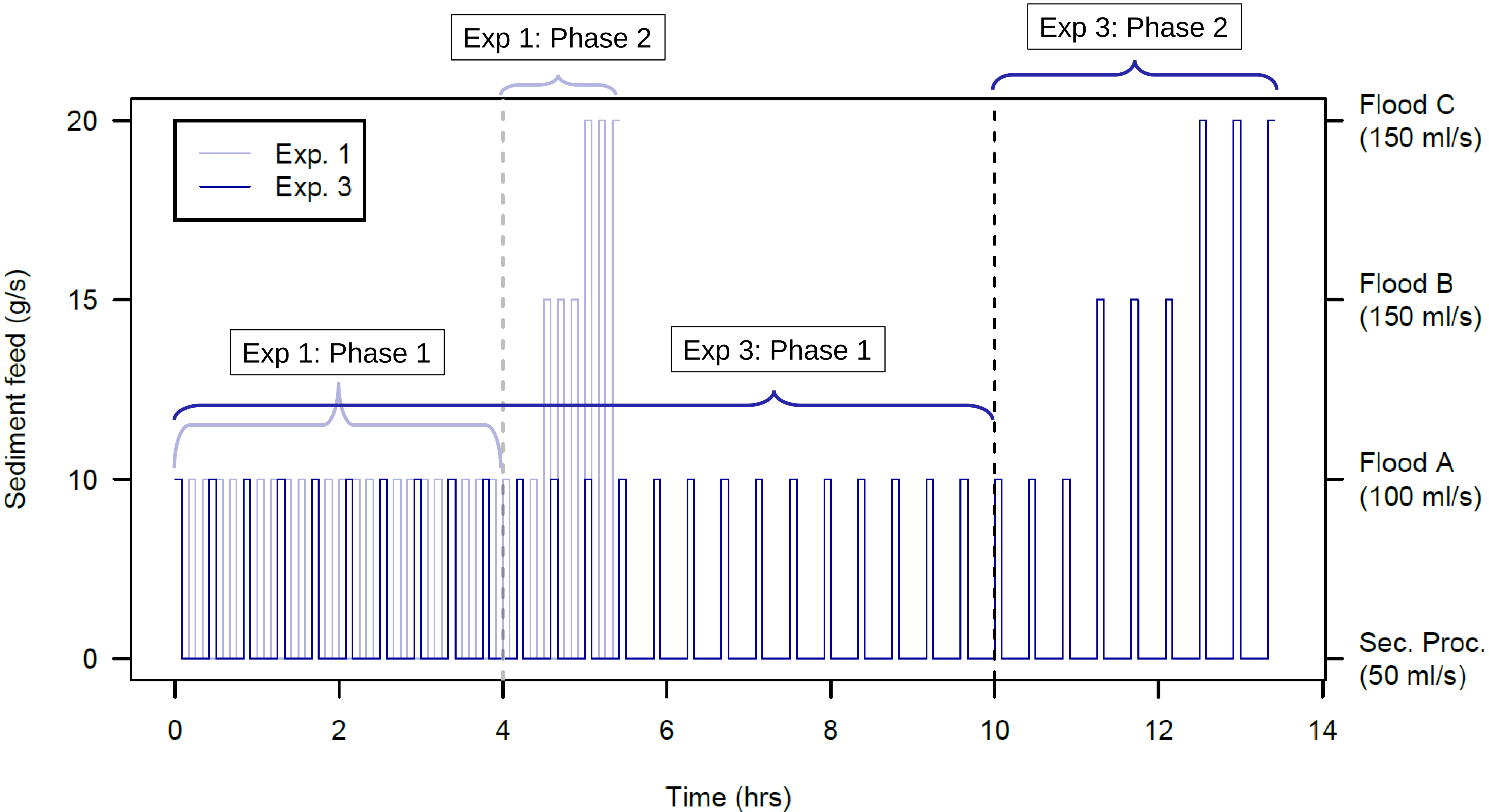
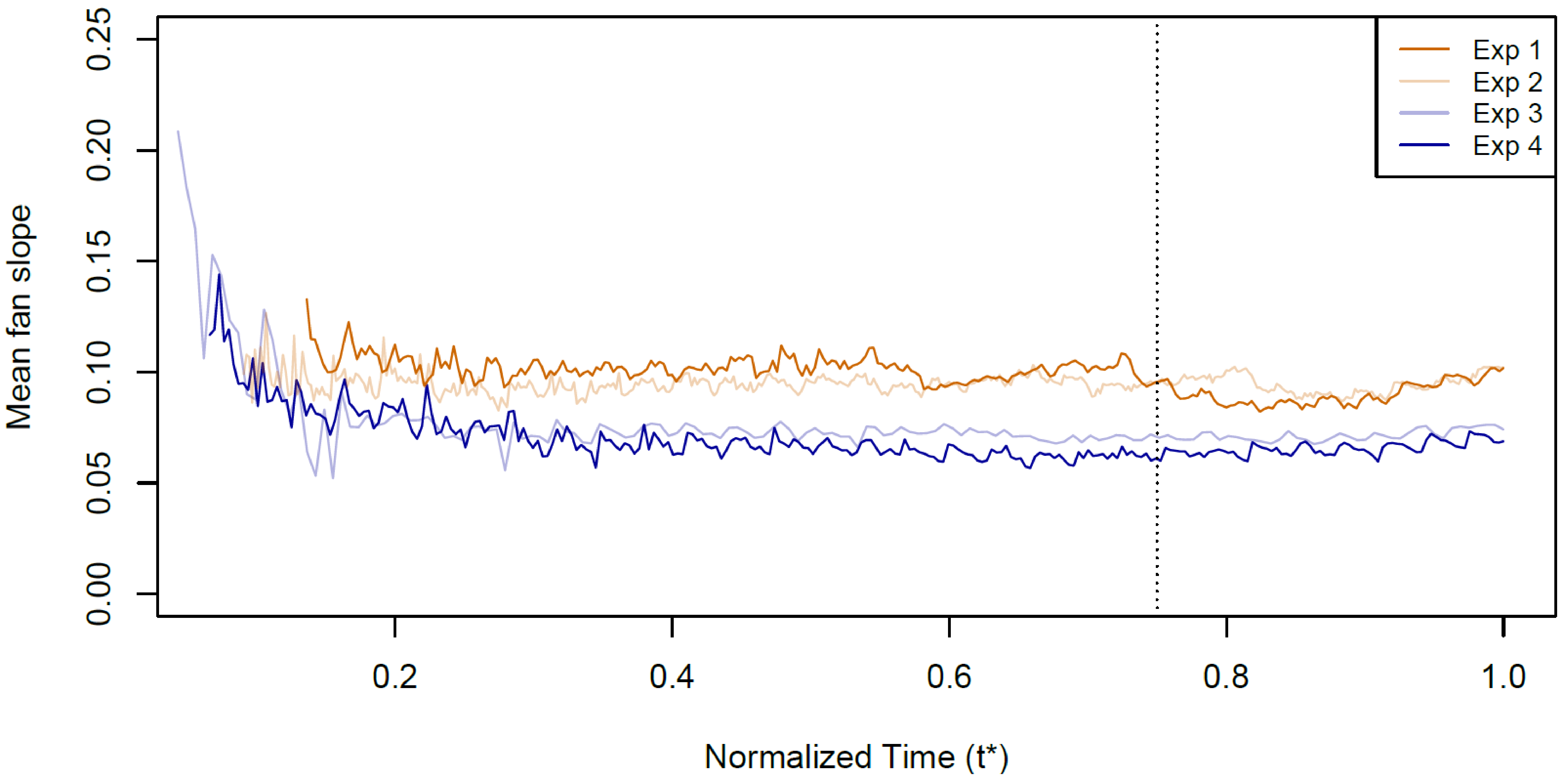
- The total length of the experiments varied based on the duration of secondary processes.

Phase 2: Fan Flooding

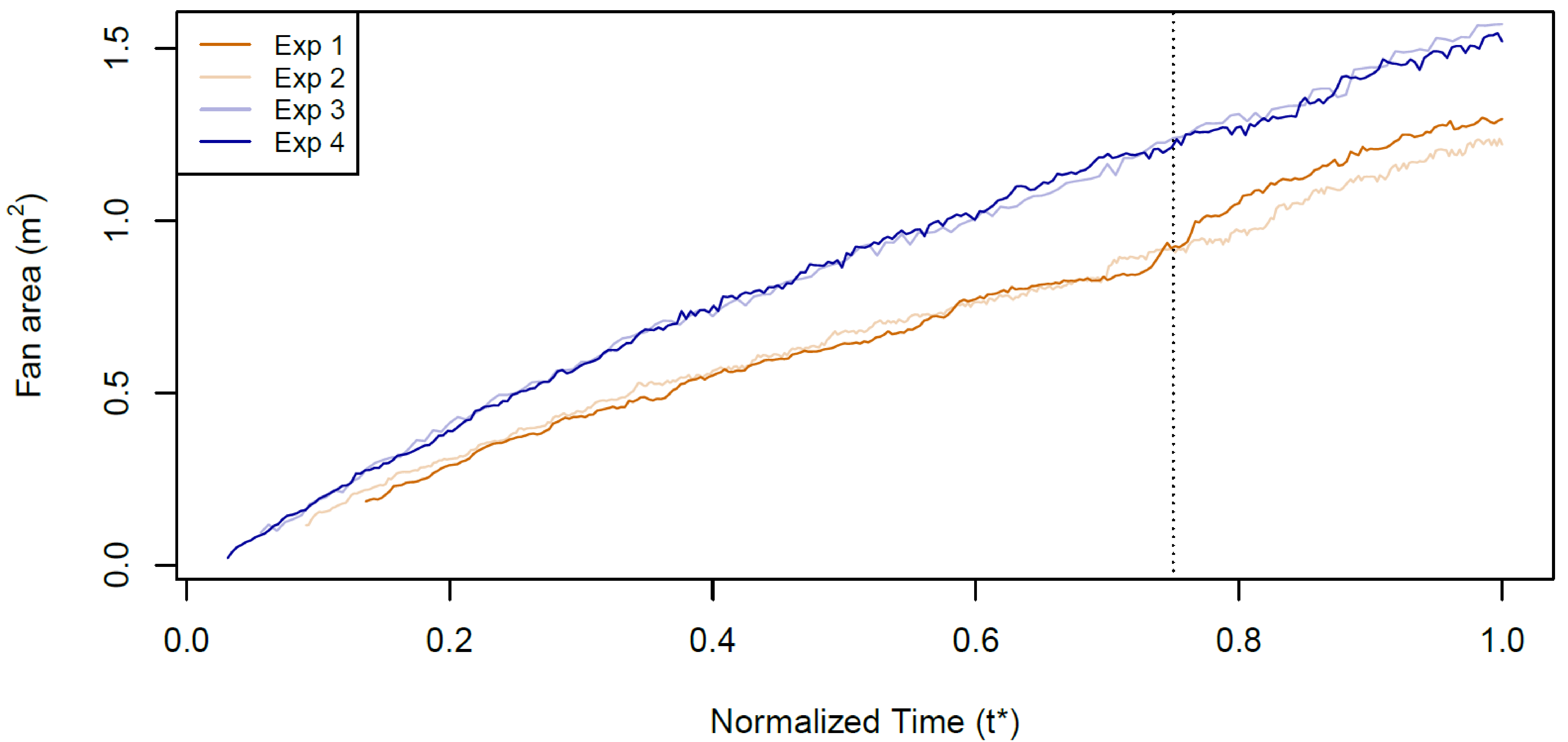
Flood Name	Discharge (mL/s)	Sediment Feed (g/s)	Duration (mins)	No. of Repeats
A	100	10	5	3
B	150	15	5	3
C	150	20	5	3



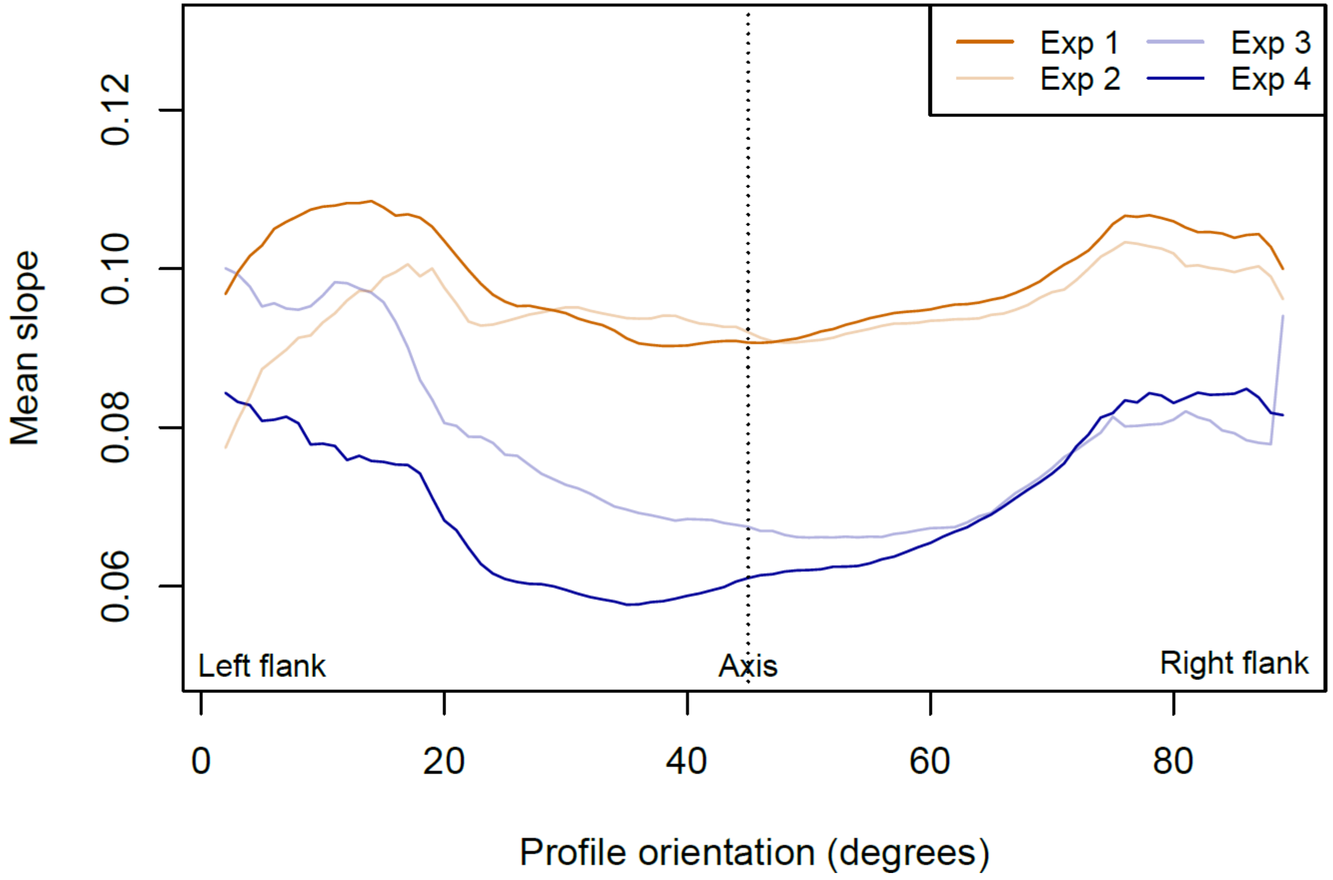

Exp 1: Phase 2
Exp 3: Phase 2
Exp. 1
Exp. 3
Exp 1: Phase 1
Exp 3: Phase 1
Flood C
(150 ml/s)
Flood B
(150 ml/s)
Flood A
(100 ml/s)
Sec. Proc.
(50 ml/s)
Sediment feed (g/s)
20
15
10
0
0
2
4
6
8
10
12
14
Time (hrs)

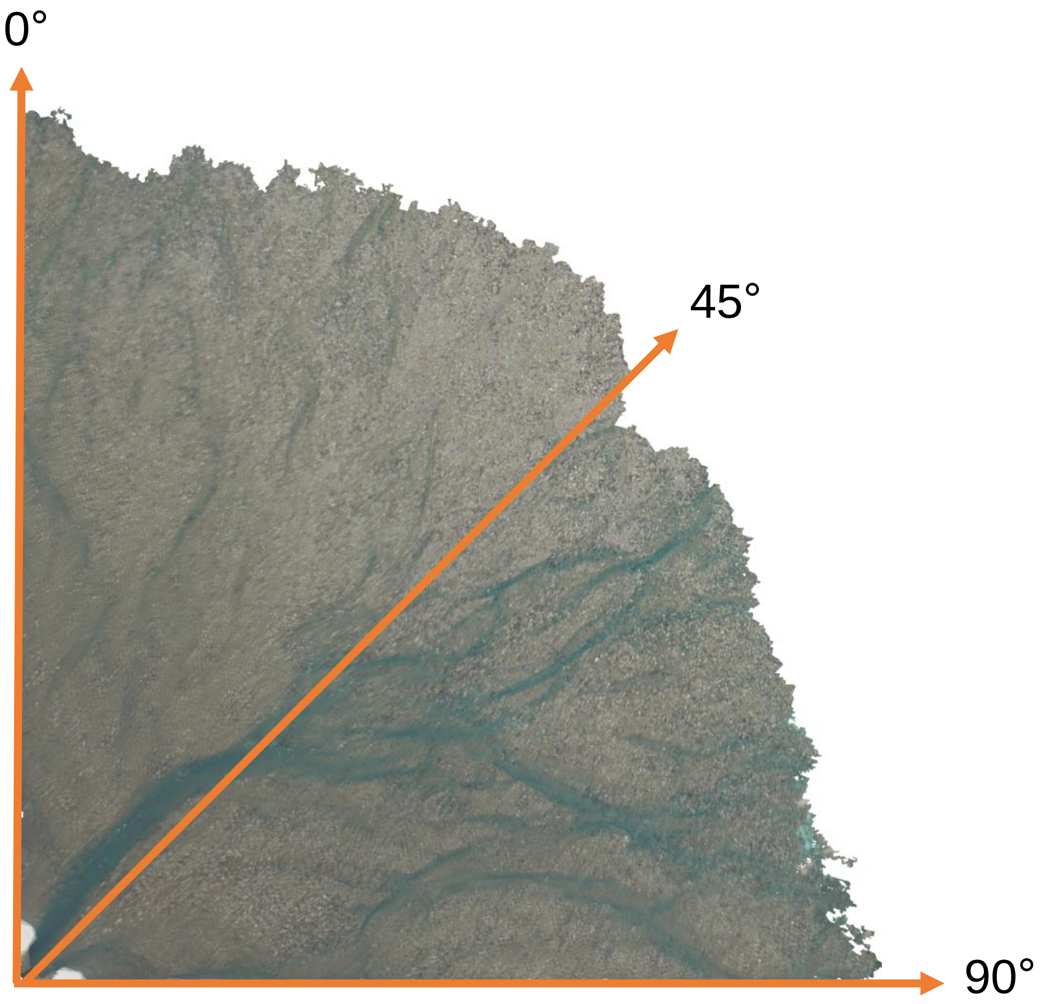


Exp 1
Exp 2
Exp 3
Exp 4
Mean fan slope
0.00
0.05
0.10
0.15
0.20
0.25
0.2
0.4
0.6
0.8
1.0
Normalized Time (t*)

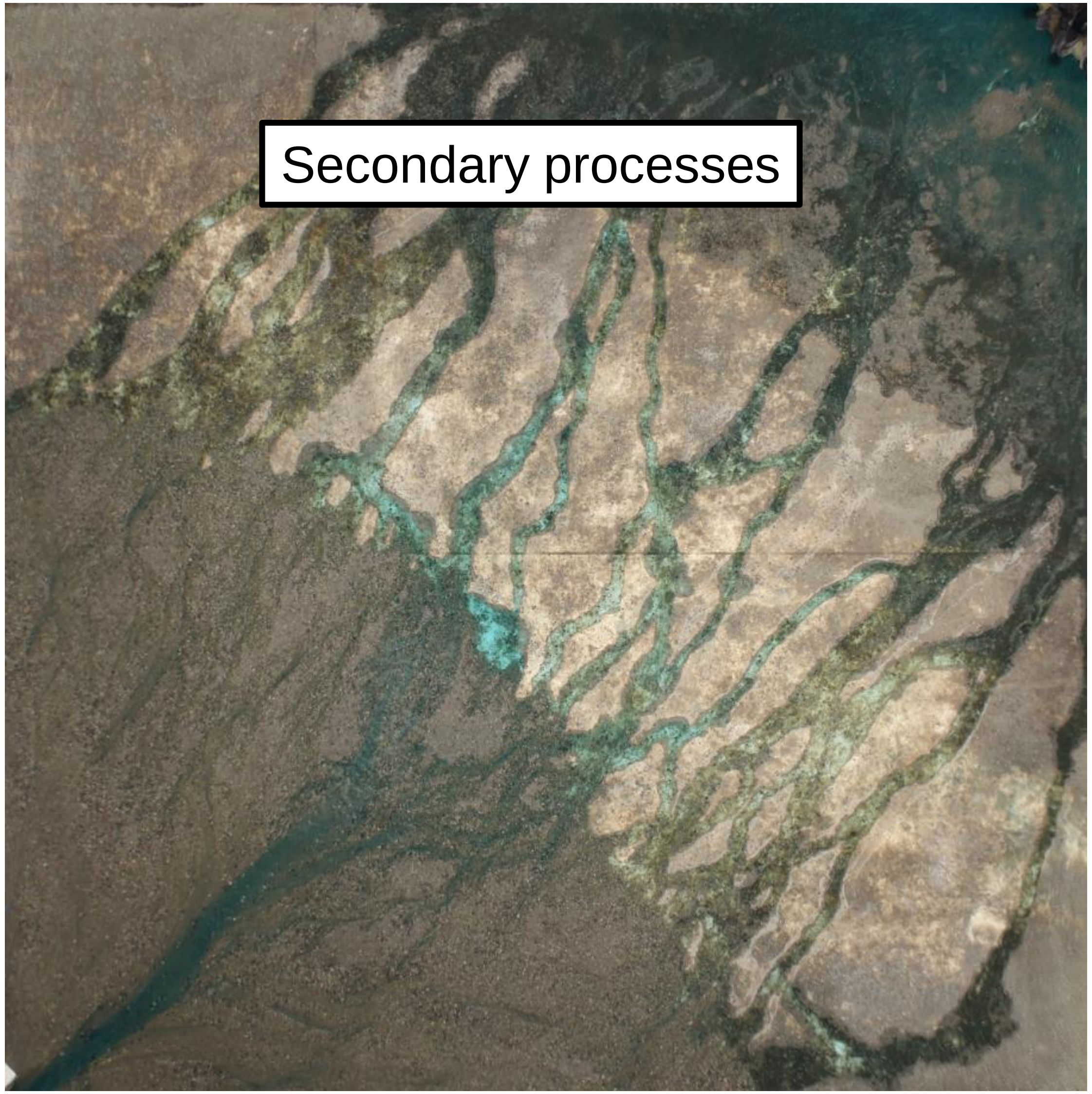

Exp 1
Exp 2
Exp 3
Exp 4
Fan area (m2)
0.0
0.5
1.0
1.5
0.0
0.2
0.4
0.6
0.8
1.0
Normalized Time (t*)

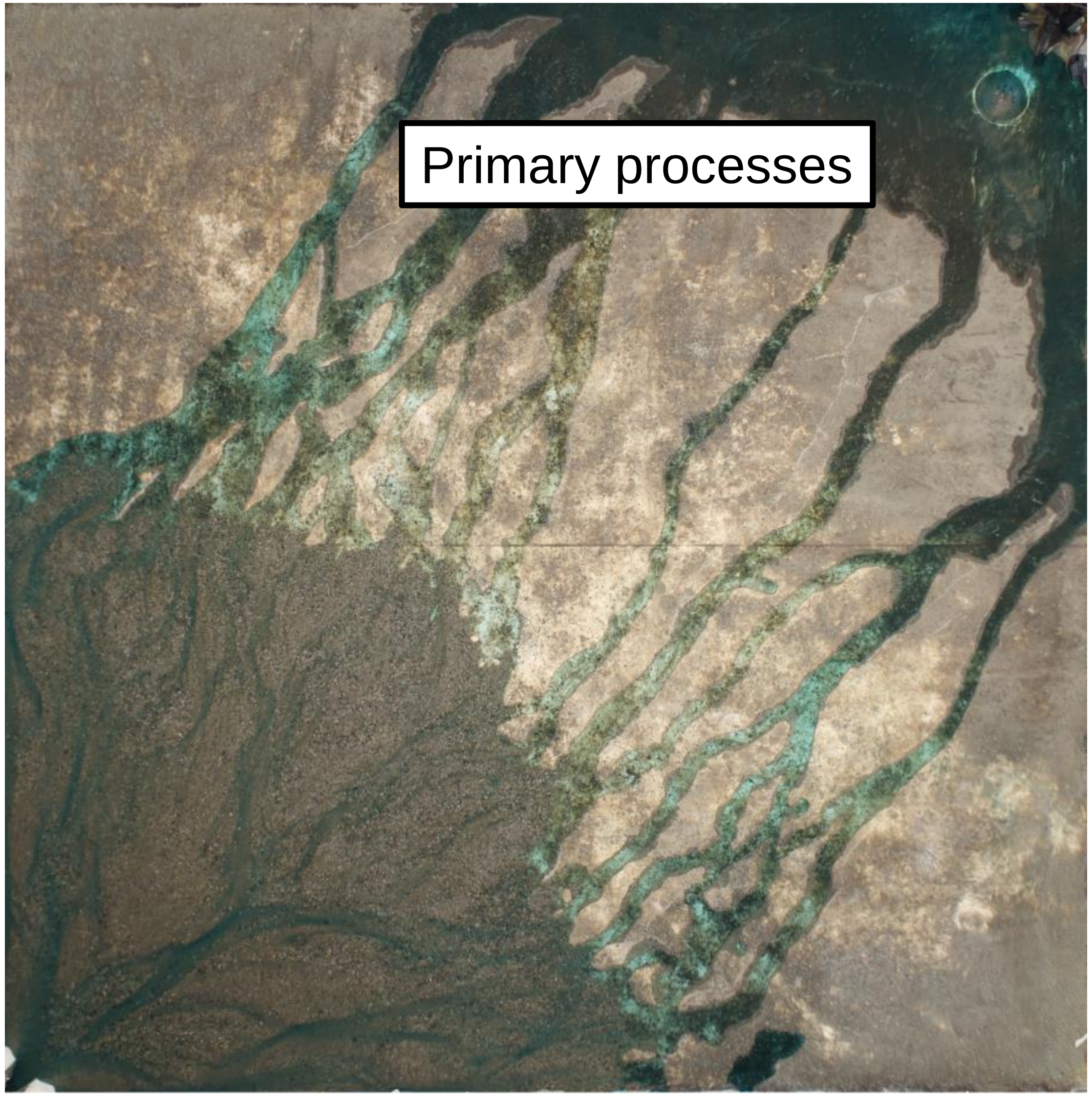
Fan gradient was lowest adjacent to the fan axis, and highest near the fan flanks.



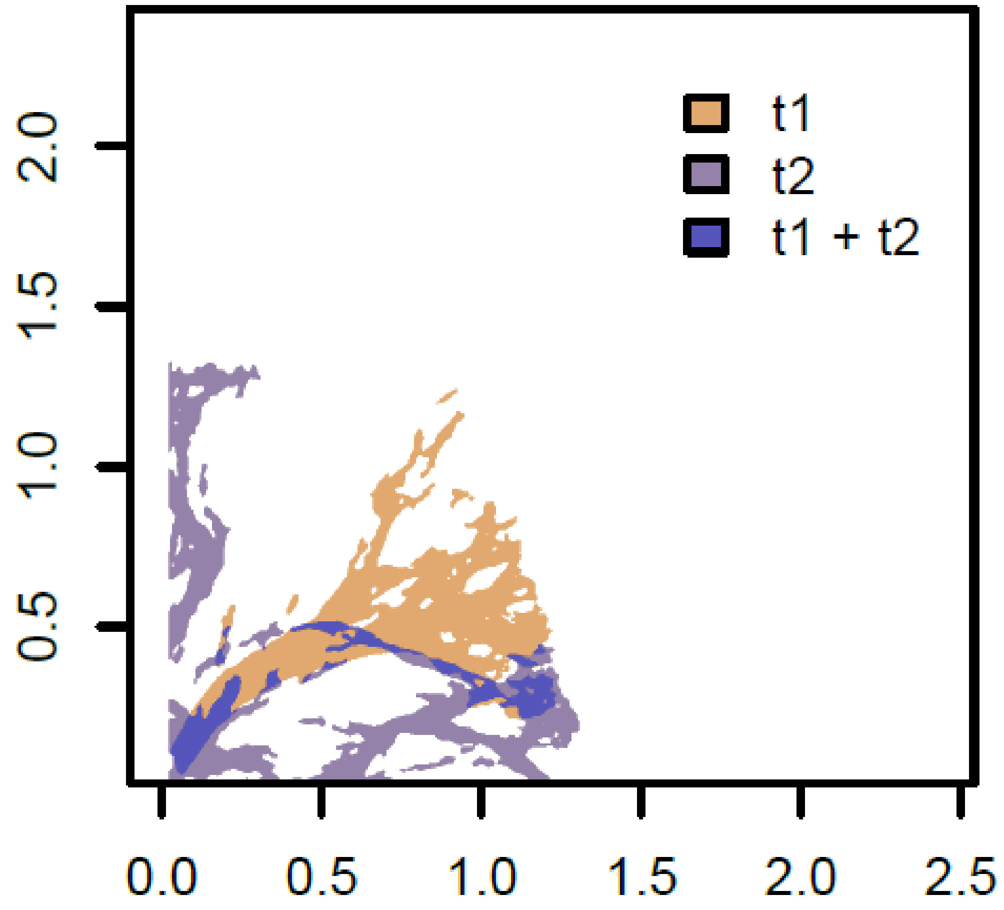


Secondary processes tended to produce a single centralized channel, while primary processes resulted in bifurcated flow.





Experiments with longer secondary processes had fewer avulsions and the first avulsion occurred later in the flood period.



Exp. #	Total Avulsion Count	Avg. Avulsion Timing (mins)
1	20	2.6
2	18	2.7
3	15	3.1
4	12	3.4

T_A indicates that the decrease in avulsion frequency from Experiment 1 to 4 cannot be explained entirely by increasing fan radius.

$$T_A(t) = \frac{hwr(t)}{Q_s}$$

Channel dimensions

Predicted avulsion frequency

Sediment feed rate

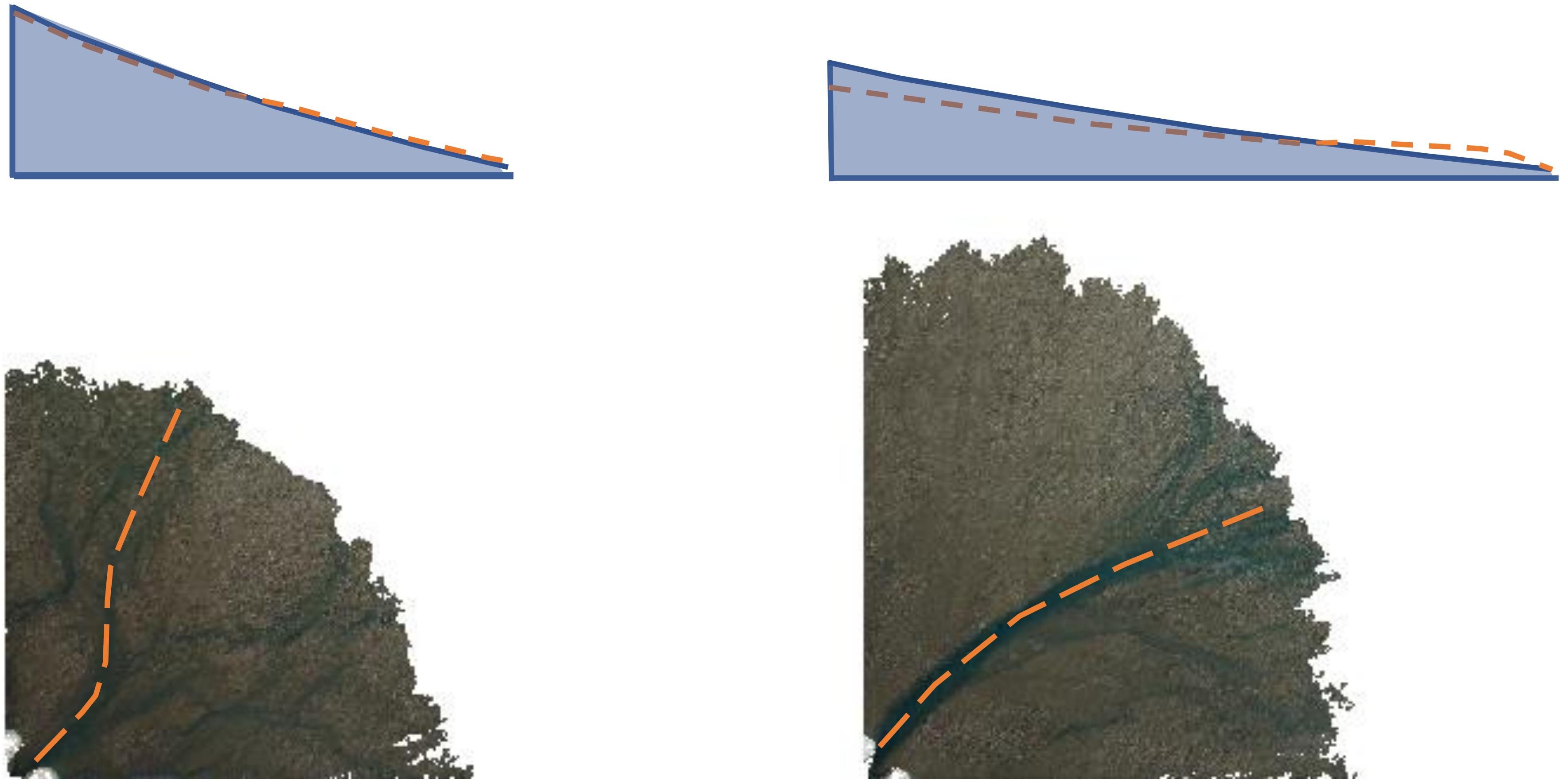
Exp. #	Total Avulsion Count	Predicted Avulsion Count (T_A)	Percent Change
1	20	18	+ 10%
2	18	18	0%
3	15	16	- 7%
4	12	16	- 33%

From Reitz et al. (2010)

Increasing duration of secondary processes

Primary fan channel cross-section

Fan top-down view



Experiment 1 (3 h 30 min)

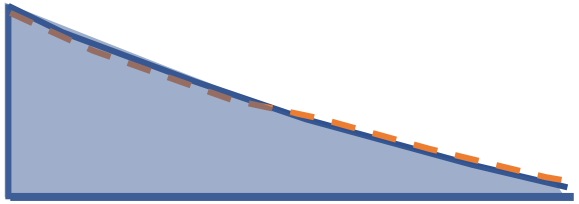
Experiment 4 (16 h 25 min)

Climate Change Impacts:

Increased frequency and
magnitude of rainfall events

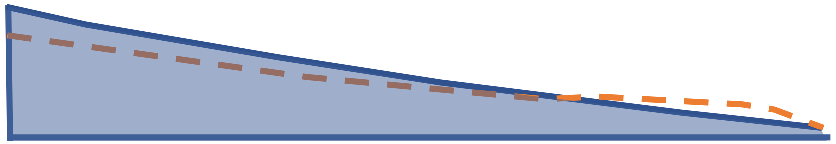
Sediment unlimited catchment

More debris laden flows
Shorter secondary process periods



Sediment limited catchment

More clearwater flows
Additional secondary processes



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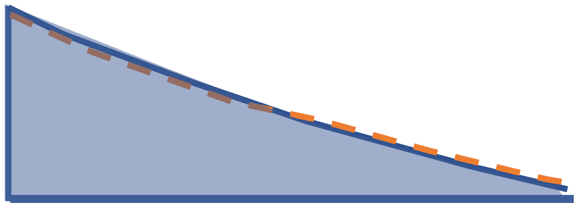

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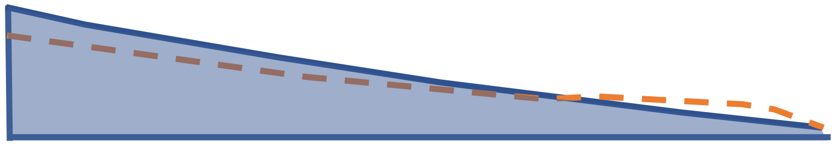

These results highlight the importance of secondary processes in determining pre-flood conditions.

My experiments used constant flow during flooding; if you want to dig into how variable flood discharge impacts alluvial fans, check out:

Floods on alluvial fans: implications for fan hazards, morphology and reworking

by Anya Leenman EP038-0005