Post-earthquake debris flows: addressing resilience during disaster recovery

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OUTLINE

Introduction

Post-earthquake Reconstruction and debris flows

Debris flow mitigation system: design and implementation

Debris flow mitigation system: performance

Concluding Remarks

INTRODUCTION

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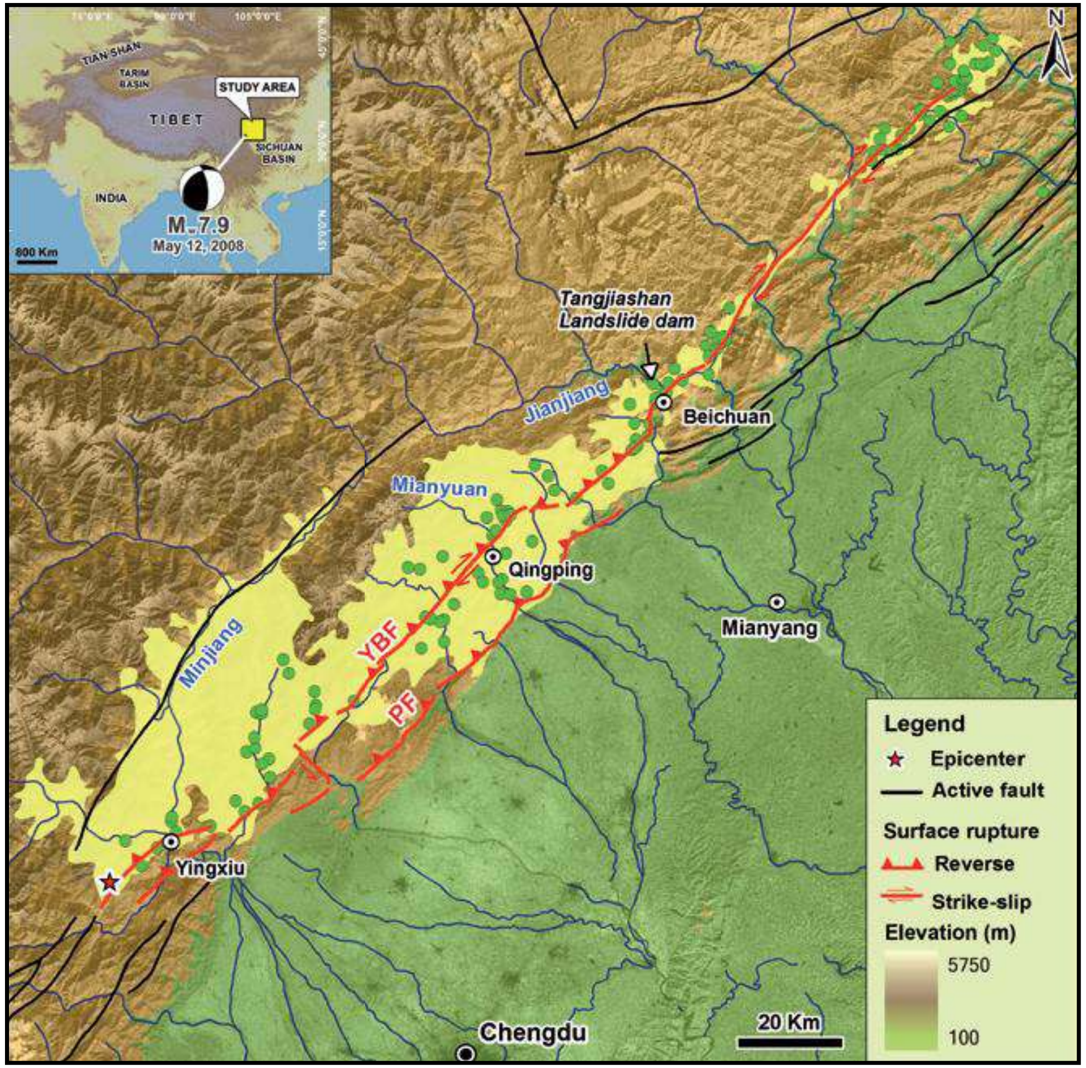


[Fan & Huang 2013]

7.9
Magnitude

May 12, 2008
Local time

87,587 (18,392 missing)
Number of people killed

370,000
Number of injured/permanently disabled

4,800,000
Number of people left homeless

51 counties
Extreme severe damage or severe damage

300,000 km^2
Area of impact

132,000 km^2
Requires reconstruction

$191,913 million
Estimated direct loss at time of event

$137.5 billion
Cost for rebuild and reconstruction

60,000
Number of quake triggered geohazards

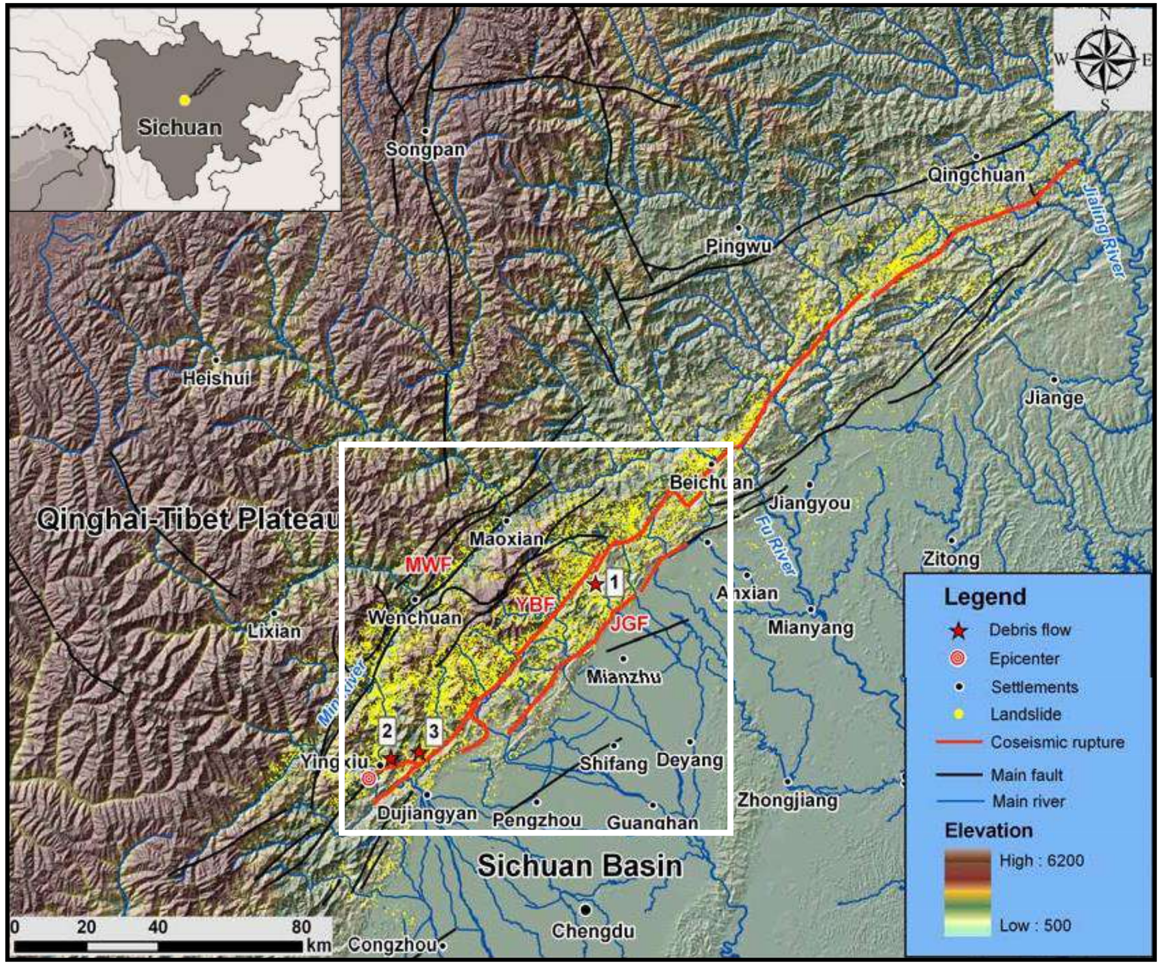
1,200
Number of local communities under direct impact of geohazards

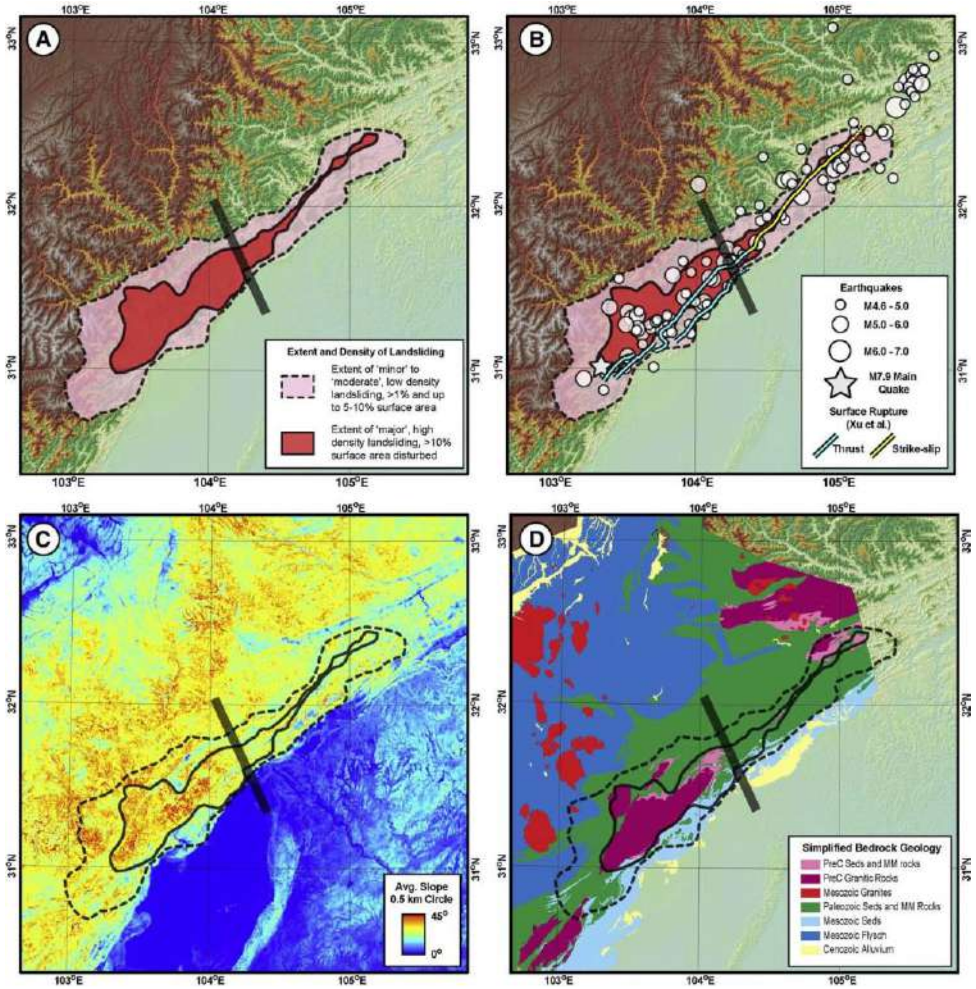
30
Extremely large-scale landslides (Estimated Vol. > 10 million m^3)

30,000
Number of people killed or missing due to geohazards

INTRODUCTION

- Coseismic landslides: 43,843 (Huang & Li, 2009) and 60,100 (Gorum et al. 2011)
- High landslide density within the Pengguan massif (southwest) with stronger motion and higher slope gradient (28 – 36°)





[Ouimet 2010]

THE 2008 WENCHUAN EARTHQUAKE: YINGXIU TOWN

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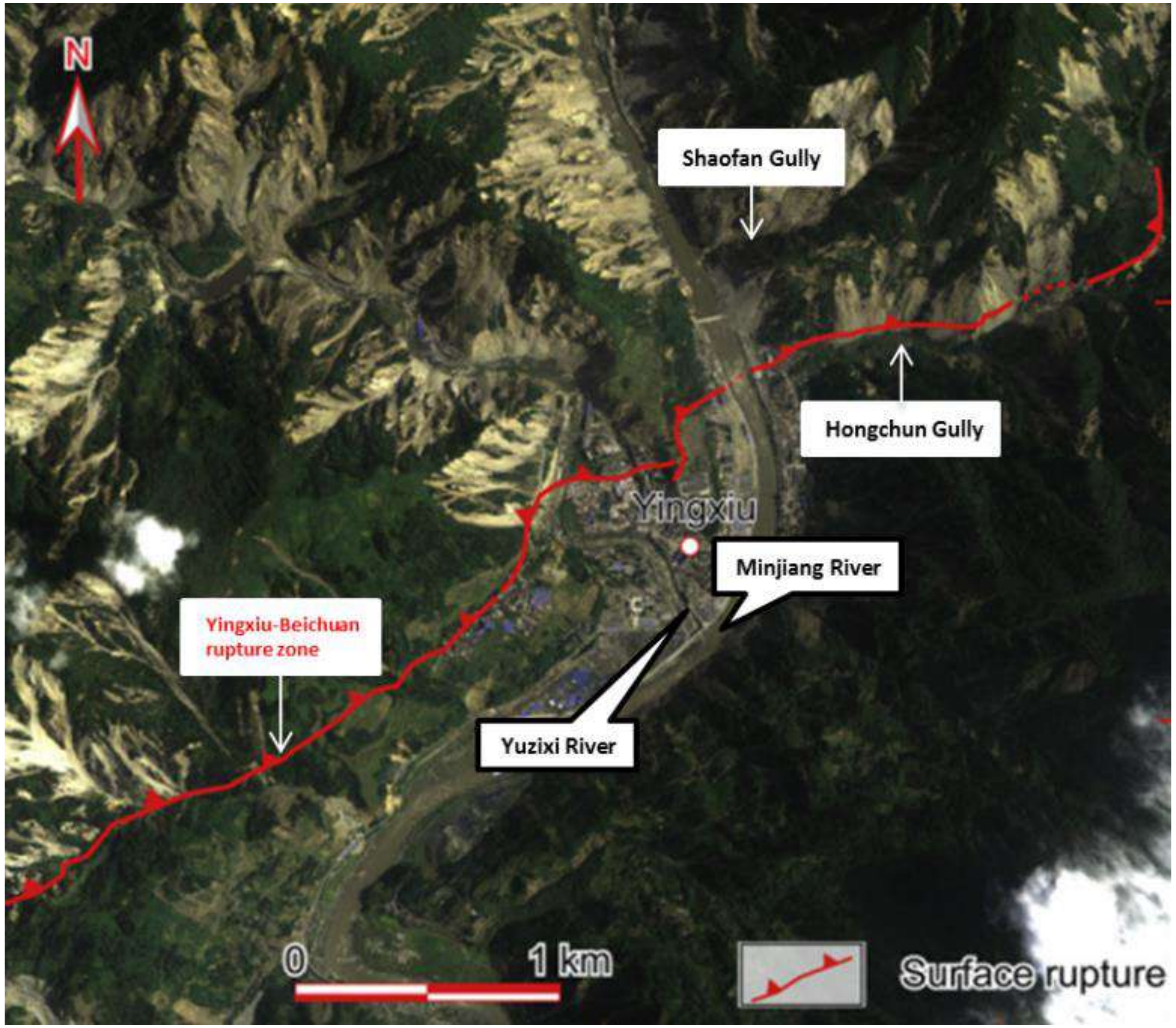

THE 2008 WENCHUAN EARTHQUAKE: YINGXIU TOWN

[credit: SKLGP)]

THE 2008 WENCHUAN EARTHQUAKE: YINGXIU TOWN

March 28, 2011

Reconstruction in Yingxiu
(Photo taken in May 12, 2010 facing west)

Reconstruction in town center of Yingxiu
(Photo taken in April 10, 2011 facing west)

[credit: SKLGP)]

POST-EARTHQUAKE DEBRIS FLOWS: YINGXIU TOWN

[credit: SKLGP)]

Impacts on reconstructed communities (on-site reconstruction) by urban flood due to upstream debris flows
[Huang & Li 2014]

Post-earthquake debris flows in Yingxiu

- May 17, 2008
- July 23, 2009
- May 29, 2010
- August 12-14, 2010: multiple debris flows – direct impact to reconstruction site.
- July 4, 2011
- August 21, 2011
- April 30, 2012
- August 18, 2012
- July 9, 2013: Niujuan gully debris flow – direct impact to reconstruction site.
- June 29, 2014

THE 2008 WENCHUAN EARTHQUAKE: OLD BEICHUAN TOWN

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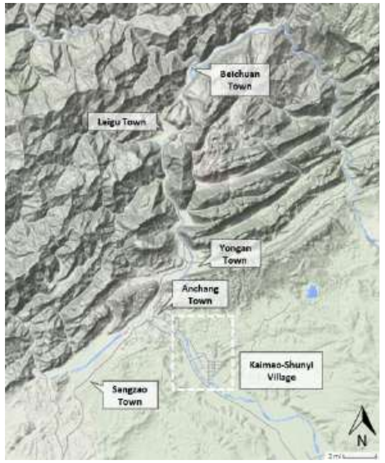
[after Fu *et al.* 2011]

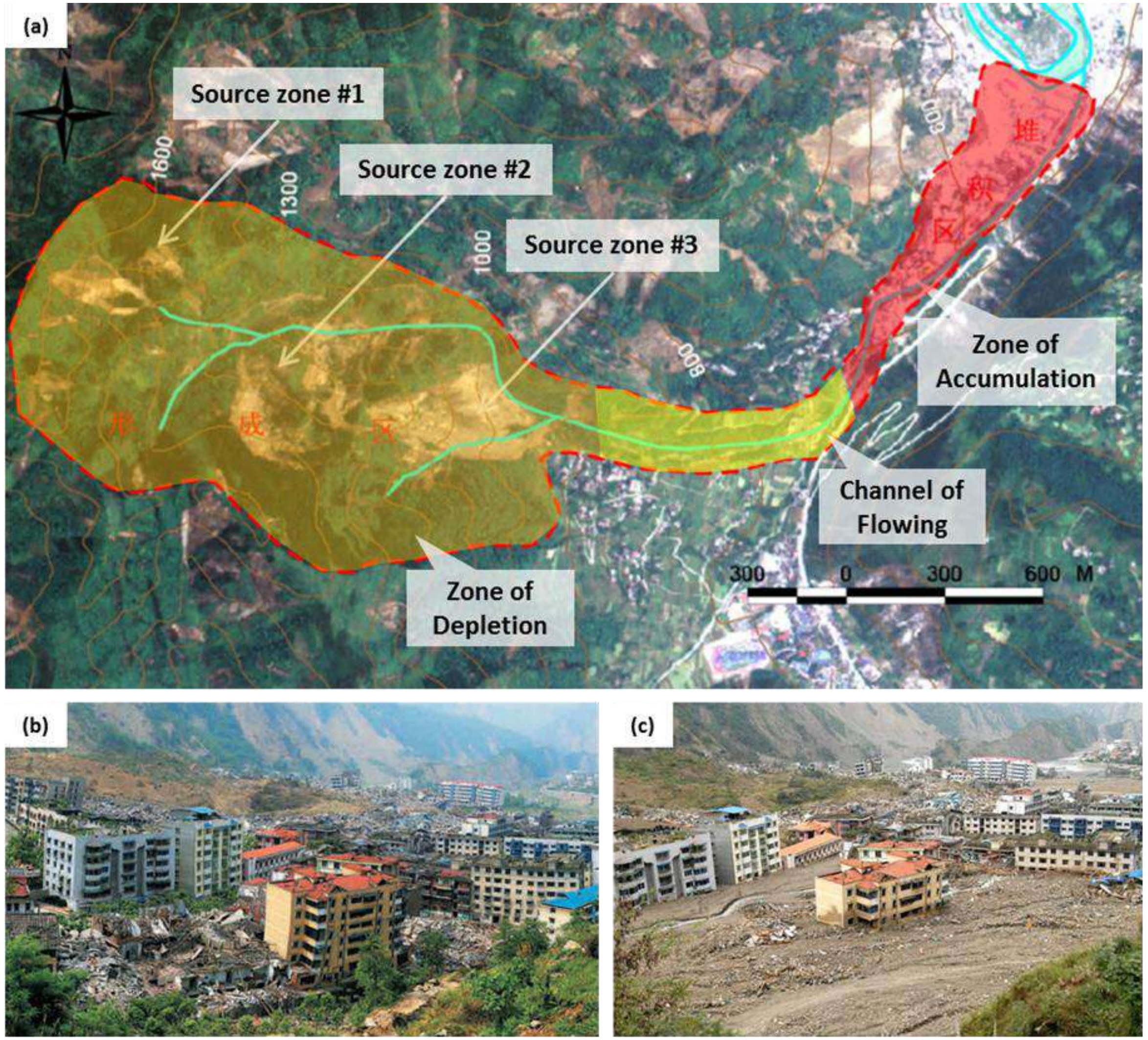
THE 2008 WENCHUAN EARTHQUAKE: OLD BEICHUAN TOWN

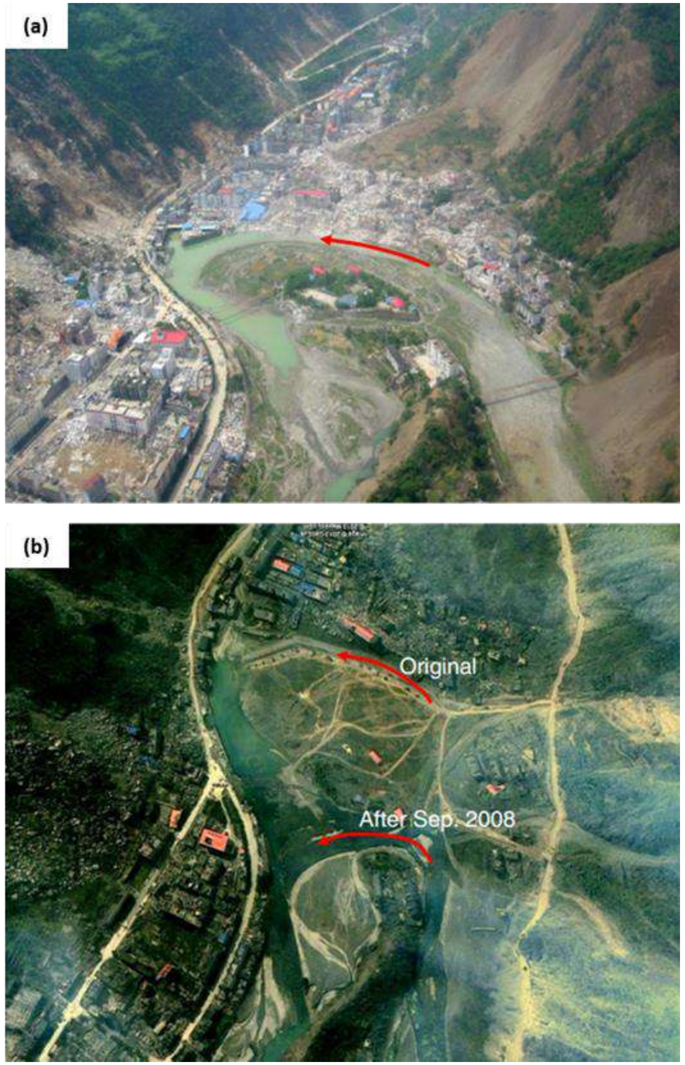
[credit: SKLGP)]



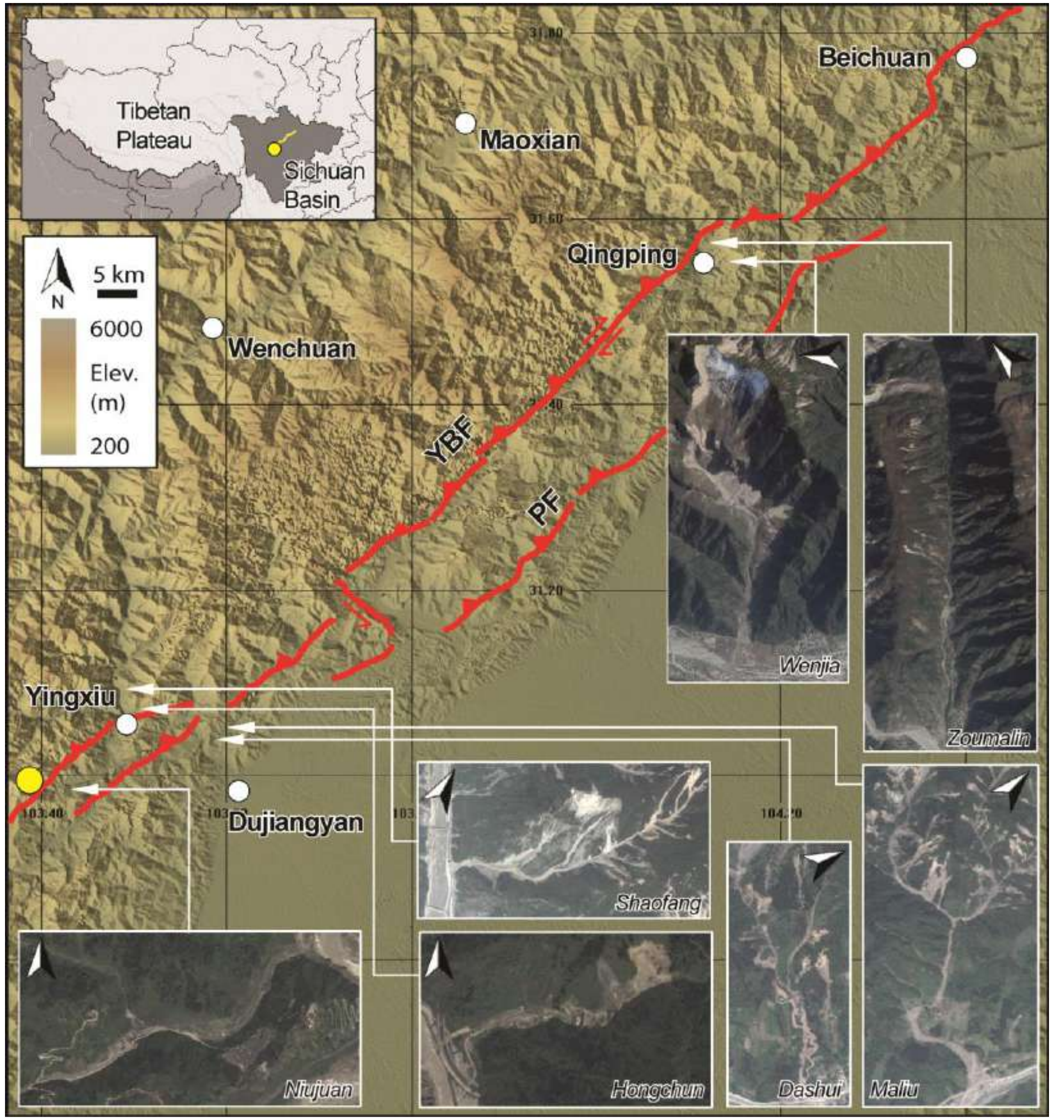
[Liu 2019]

THE 2008 WENCHUAN EARTHQUAKE: OLD BEICHUAN TOWN





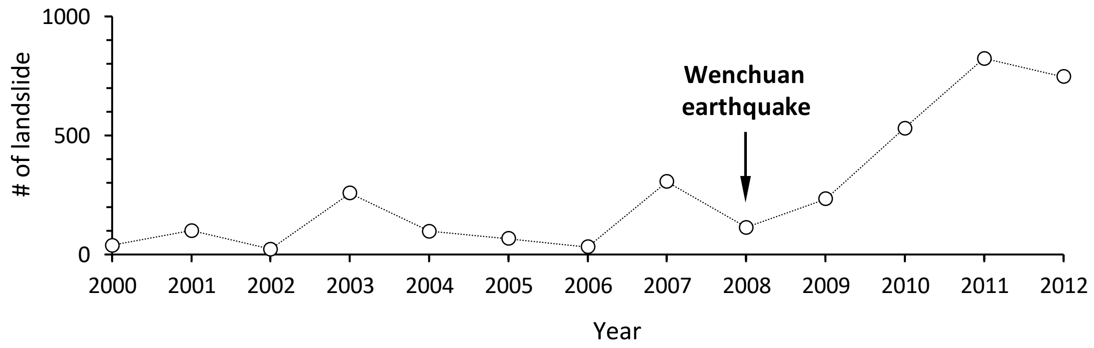
POST-EARTHQUAKE DEBRIS FLOWS



[Liu *et al*. 2019]

- Pre-earthquake debris flows: 758 (2003 – 2007)
- Post-earthquake debris flows: 2,333 (2008 – 2012)
- 6 large-scale group debris flow events after Wenchuan earthquake

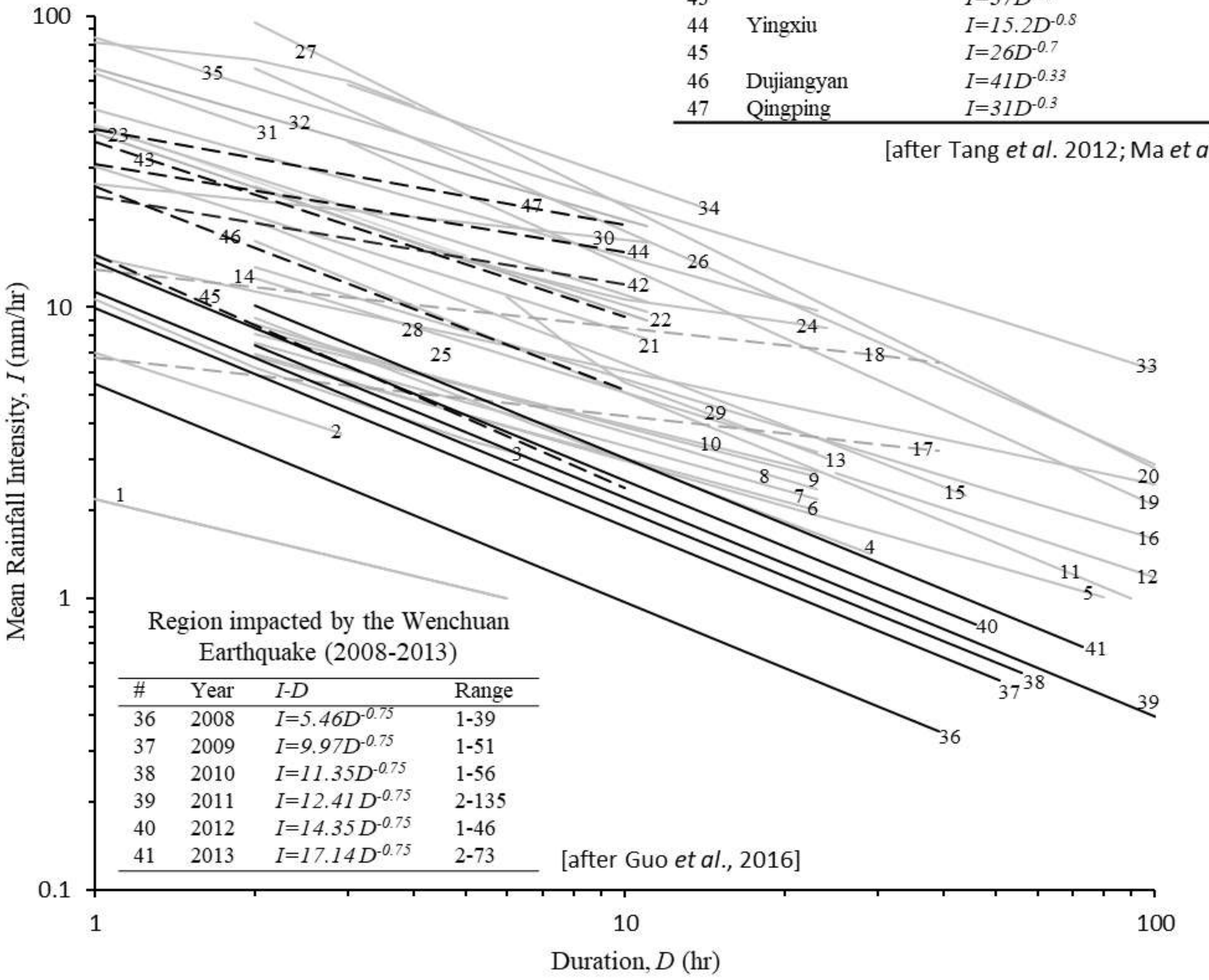
Place and name	Time	Remarks
Beichuan County	Sept 28 2008	72 debris flows occurred simultaneously
Gaochuan, Anxian County	July 18 2009	10 debris flows occurred in the Gaochuan in Jushui River basin (max. vol. ~3×10^5 m^3)
Qingping, Mianzhu County	August 13 2010	20 gullies from Qingping to Yibadao segments of Mianyuan River (total vol. ~10×10^6 m^3)
Yingxiu, Wenchuan County	August 13 2010	21 gullies (total vol. ~2×10^6 m^3). Largest event: Hongchun gully debris flow (max. vol. ~7.5×10^5 m^3).
Longchi, Dujiangyan	August 13 2010	44 gullies (total vol. ~3×10^6 m^3)
Pengzhou	August 18 2012	12 gullies (total vol. ~6×10^5 m^3)
Mingjiang river	July 8-10 2013	25 gullies along Mingjiang river. The largest one was Qipangou gully debris flow (max. vol. ~8.5×10^5 m^3).



DEBRIS FLOWS RAINFALL THRESHOLDS

#	Watershed	*I-D* threshold	Range
42	Beichuan	$I=24D^{-0.3}$	1-10*
43		$I=37D^{-0.6}$	
44	Yingxiu	$I=15.2D^{-0.8}$	
45		$I=26D^{-0.7}$	
46	Dujiangyan	$I=41D^{-0.33}$	
47	Qingping	$I=31D^{-0.3}$	

[after Tang *et al.* 2012; Ma *et al.* 2017]



Region impacted by the Wenchuan Earthquake (2008-2013)

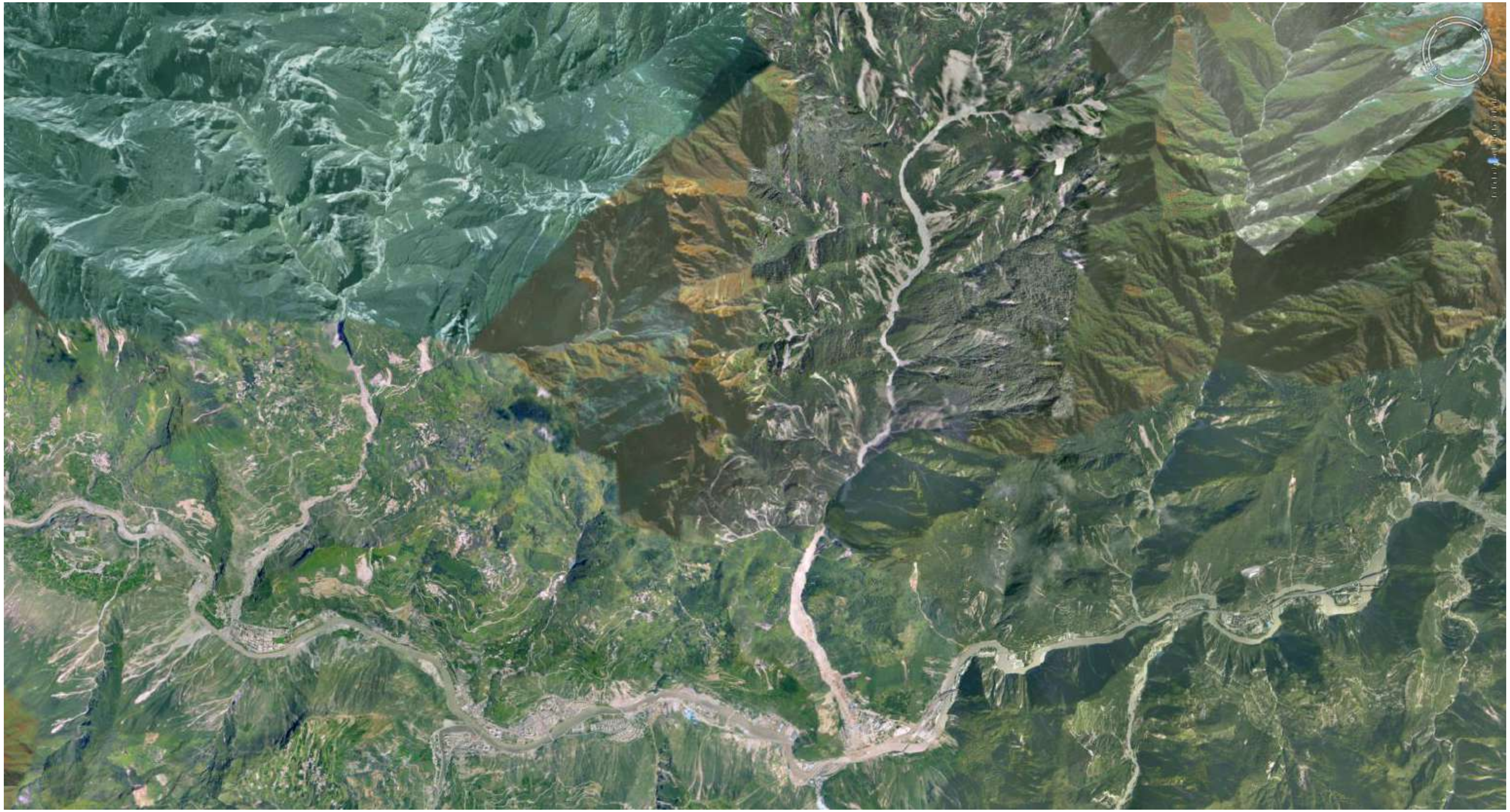
#	Year	*I-D*	Range
36	2008	$I=5.46D^{-0.75}$	1-39
37	2009	$I=9.97D^{-0.75}$	1-51
38	2010	$I=11.35D^{-0.75}$	1-56
39	2011	$I=12.41D^{-0.75}$	2-135
40	2012	$I=14.35D^{-0.75}$	1-46
41	2013	$I=17.14D^{-0.75}$	2-73

[after Guo *et al.*, 2016]

#	Area	*I-D* threshold	Range	Reference
1	Global	$I=2.2D^{-0.44}$	0.1-1000	(Guzzetti et al. 2008)
2		$I=7.0D^{-6.00}$	0.1-3	(Cannon and Gartner 2005)
3	CA, USA	$I=1.7+9D^{-1.00}$	1-6.5	(Wieczorek 1987)
4	Italy	$I=15D^{-7.00*}$	1-30	(Marchi et al. 2002)
5	OR, USA	$I=9.9D^{-0.52*}$	1-170	(Montgomery et al. 2000)
6	Piedmont, Italy	$I=9.521D^{-0.4955}$	1-24	(Bolley and Oliaro 1999;
7		$I=10.67D^{-0.5043}$		Calcaterra et al. 2000;
8		$I=12.649D^{-0.5324}$		Guzzetti et al. 2007)
9		$I=11.698D^{-0.4783}$		
10		$I=11.0D^{-0.4459}$		
11		$I=28.1D^{-0.74*}$		
12	Japan	$I=1.35+55D^{-1.0*}$	0.7-40	(Hong et al. 2005)
13	USA	$I=2.5+300D^{-2.0}$	5.5-24	(Cannon and Ellen 1985)
14	Piedmont, Italy	$I=18.675D^{-0.565}$	1-24	(Ceriani et al. 1992;
15	Switzerland	$I=32D^{-0.70*}$	1-25	Zimmermann 1997;
16	Italy	$I=20.1D^{-0.55*}$	1-1000	Guzzetti et al. 2007)
17	Central Taiwan	$I=6.7D^{-0.2}$	-	(Jan and Chen 2005;
18		$I=13.5D^{-0.2}$	-	Chen 2011)
19	Puerto Rico	$I=91.46D^{-0.82}$	2-312	(Larsen and Simon 1993)
20	Global	$I=14.82D^{-0.39}$	0.167-500	(Caine 1980)
21		$I=30.53D^{-0.57}$	0.5-12	(Jibson 1989)
22	Japan	$I=39.71D^{-0.62}$	0.5-12	
23	CA, USA	$I=35.23D^{-0.54}$	3-12	
24		$I=6.9+38D^{-1.0}$	2-24	
25	China	$I=49.11-6.81D^{1.0}$	1-5	
26	Campania, Italy	$I=176.4D^{-0.90}$	0.1-1000	
27	Taiwan	$I=115.47D^{-0.8}$	1-400	(Chen et al. 2005)
28	Hong Kong	$I=41.83D^{-0.58}$	0.5-12	(Jibson 1989)
29	Italy	$I=47.742D^{-0.507}$	0.1-24	(Paronuzzi et al. 1998)
30	CA, USA	$I=26.51D^{-0.19}$	0.5-12	(Jibson 1989)
31	Brazil	$I=63.38-22.19D^{1.0}$	0.5-2	
32	Puerto Rico	$I=66.18D^{-0.52}$	0.5-12	
33	Portugal	$I=84.3D^{-0.57*}$	0.1-2000	(Jan and Chen 2005)
34	USA	$I=116.48D^{-0.63}$	2-16	(Wieczorek et al. 2000)
35	Indonesia	$I=92.06-10.68D^{1.0}$	2-4	(Jibson 1989)

Note: *Applicable to all types of landslide.

DEBRIS FLOWS MITIGATION: INTERCEPT



[credit: SKLGP]

DEBRIS FLOWS MITIGATION: INTERCEPT

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DEBRIS FLOWS MITIGATION: INTERCEPT

DEBRIS FLOWS: WENJIA GULLY

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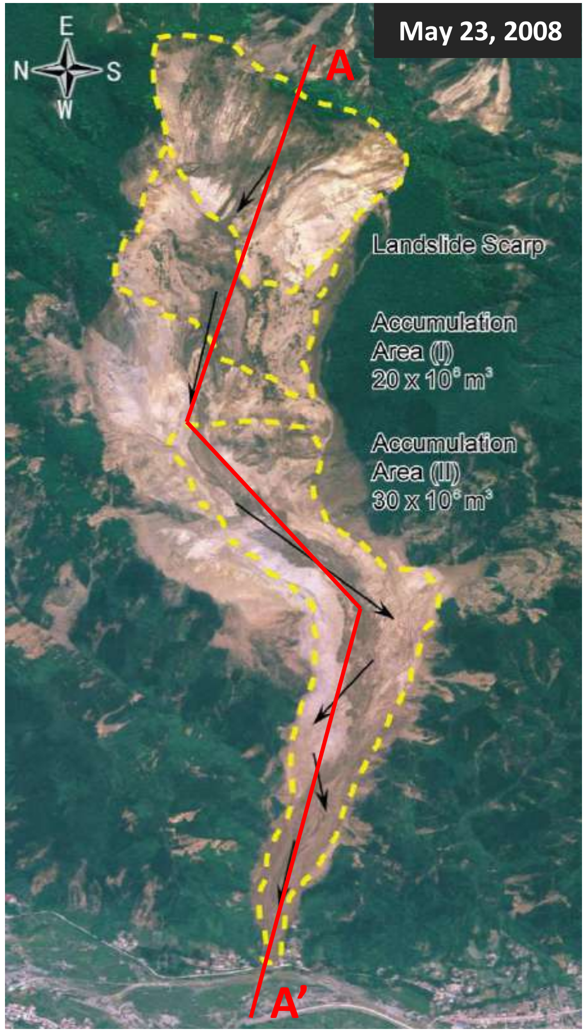
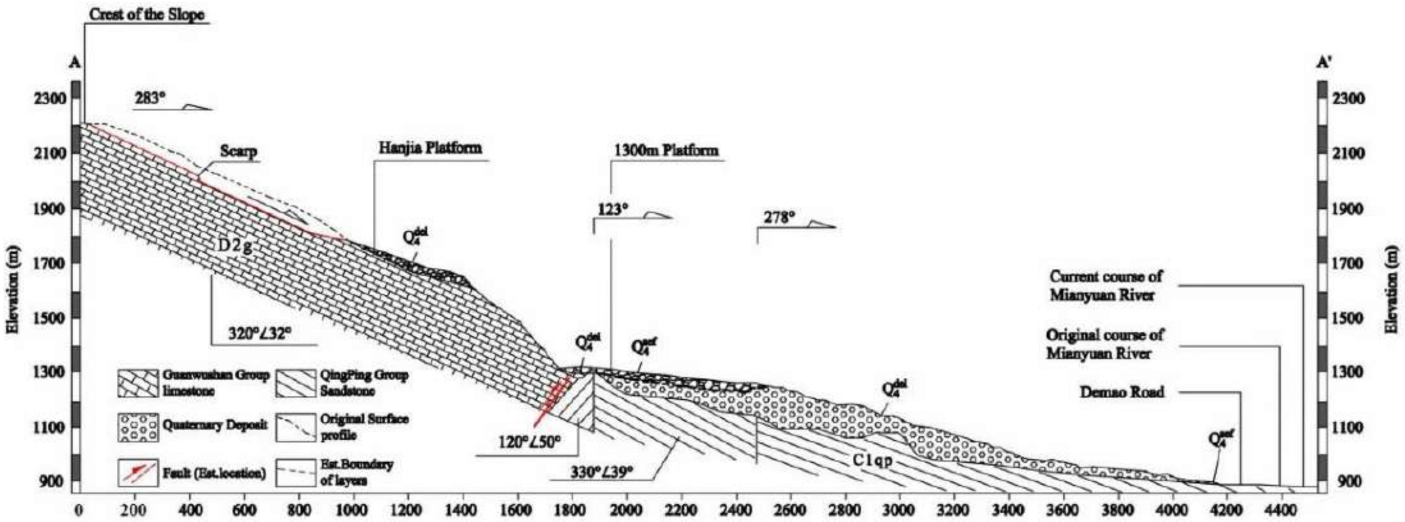
Co-Seismic Landslide (May 12, 2008)

Vol: 50 million m^3

(Approx. 30×10^6 m^3 in Area II)





[Liu *et al.* 2017]

DEBRIS FLOWS: WENJIA GULLY

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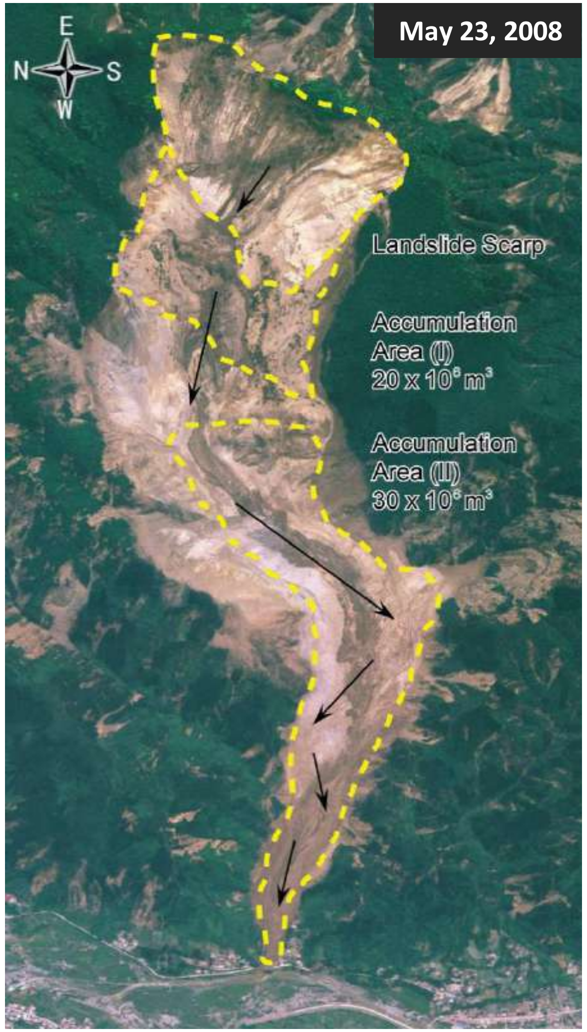


First Major Debris Flow (Sept 24, 2008)

Vol: 0.5 million m^3
(1% of the deposit in the gully)

Conventional Debris Flow Mitigation System Failure

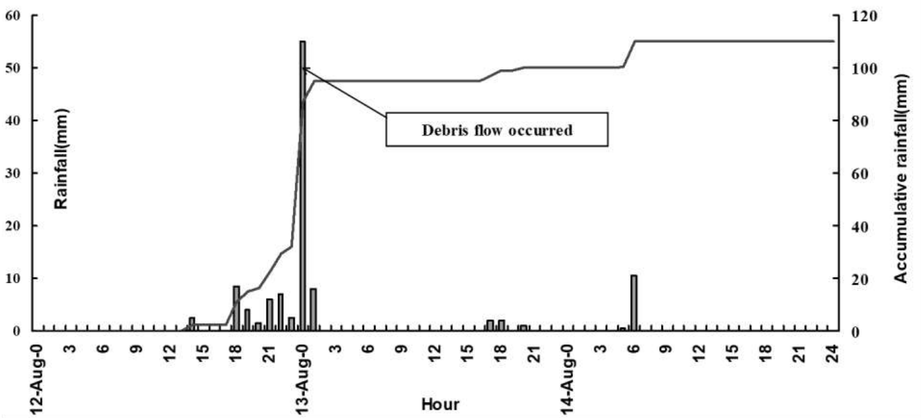
53 small sectional barriers;
18 small check dams;
1 diversion dike & 1 drainage channel;
1 large check dam (length 215 m & height 8 m);
Numerous localized retaining structures

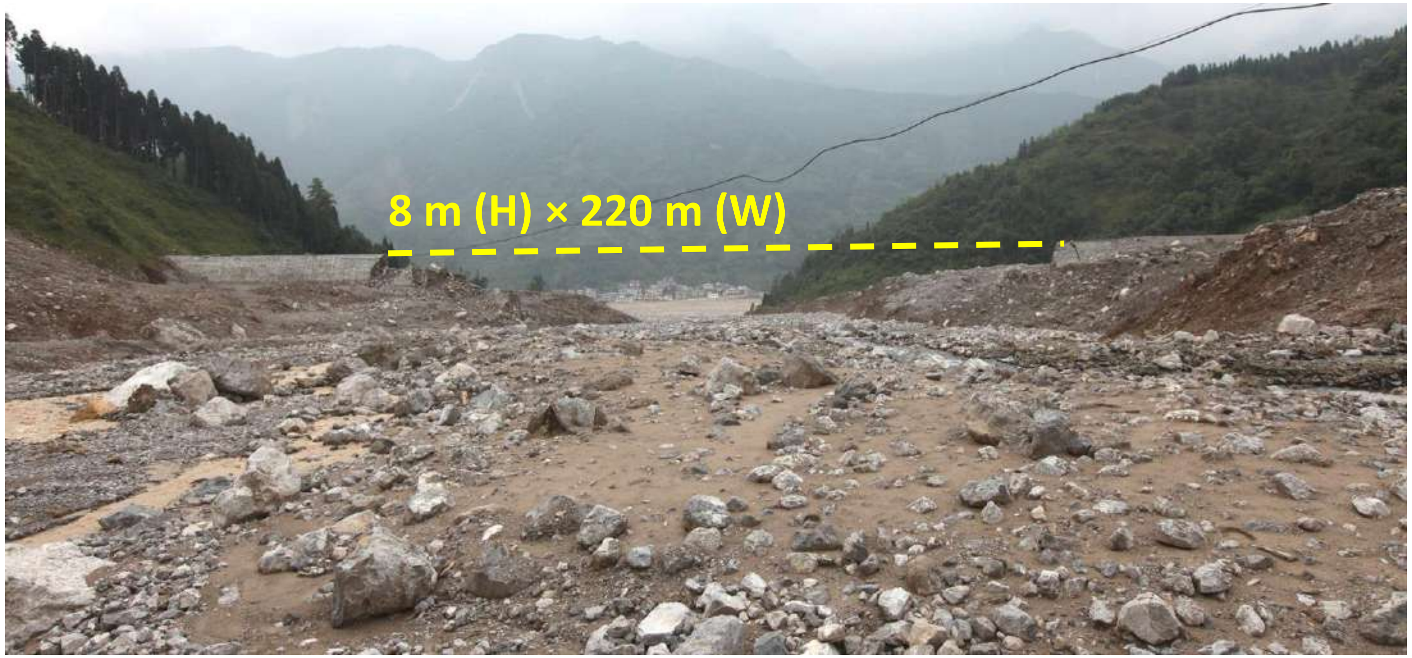
Debris Flow (Aug 13, 2010)

Vol: 4.5 million m^3
(7 fatalities, 39 injuries, and 497 buried houses)

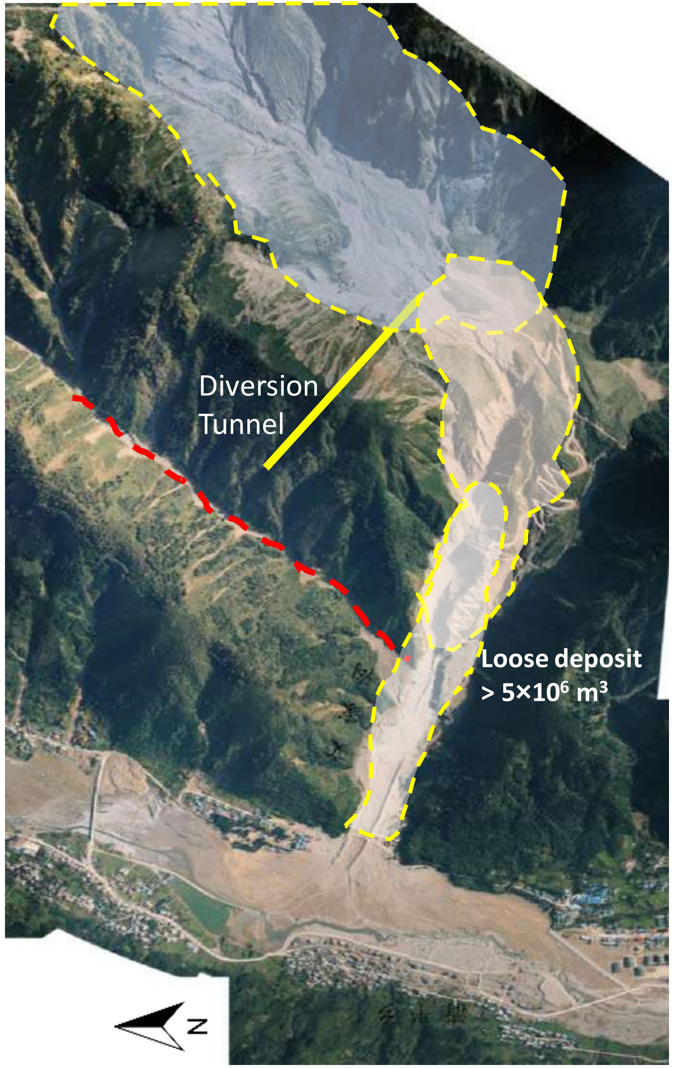
[Liu *et al.* 2017]

DEBRIS FLOWS: WENJIA GULLY





DEBRIS FLOW MITIGATION SYSTEMS: WENJIA GULLY

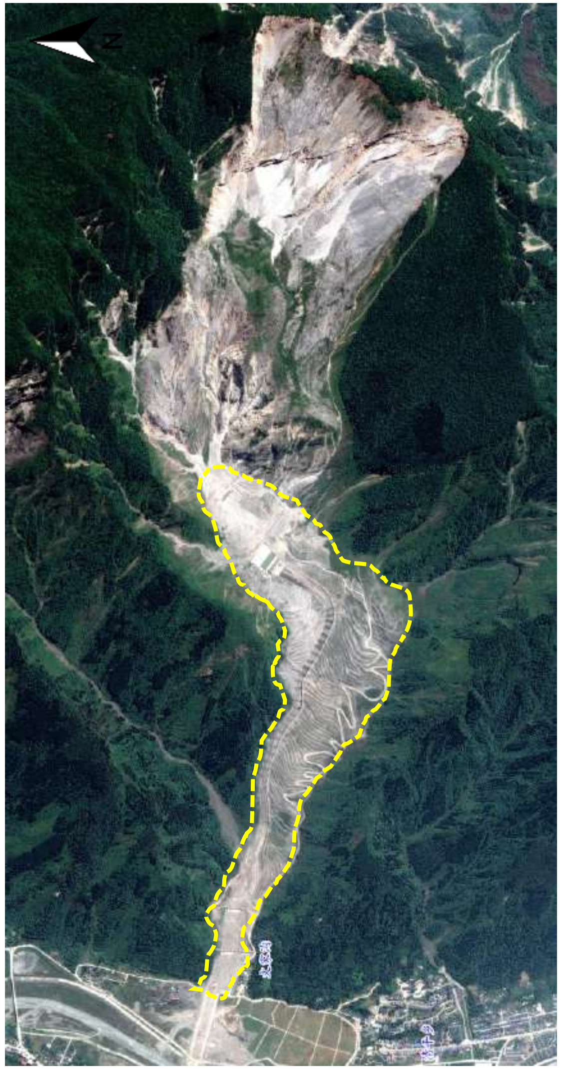


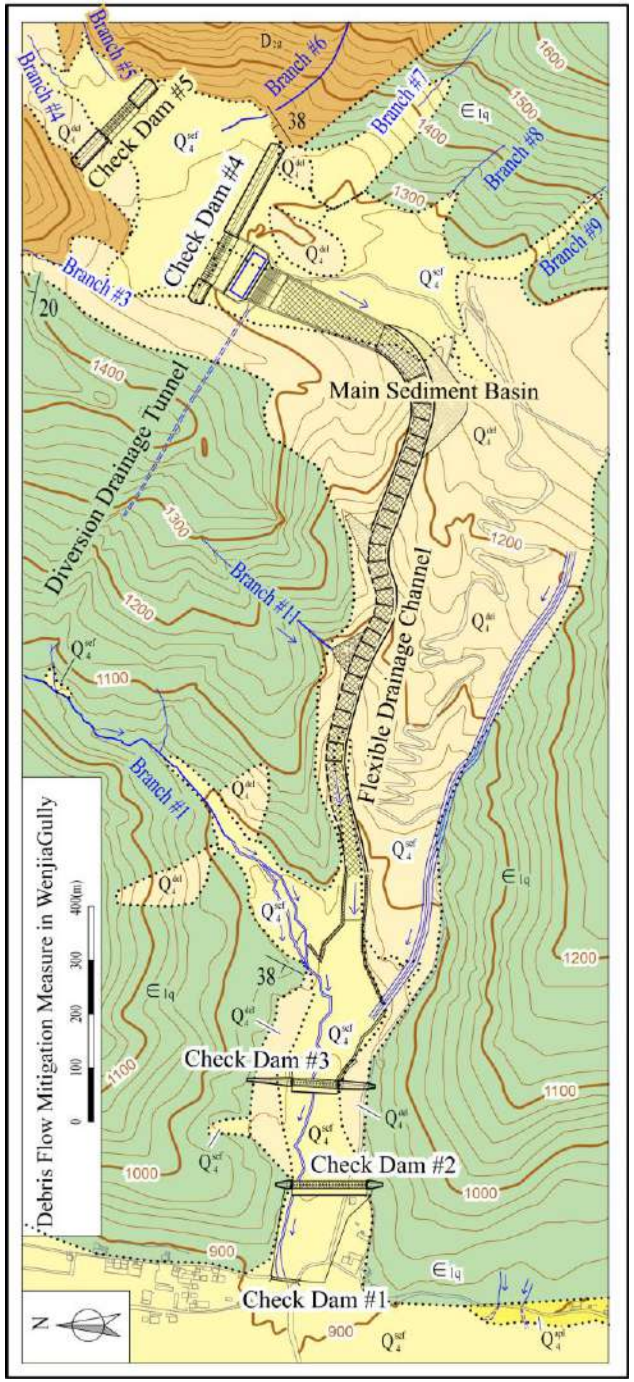
Key mitigation elements:

Water control
Water-sediment segregation system (upstream)

Sediment control
Stabilization of the loose sediment as the source material for debris flows (upstream & mid-stream)

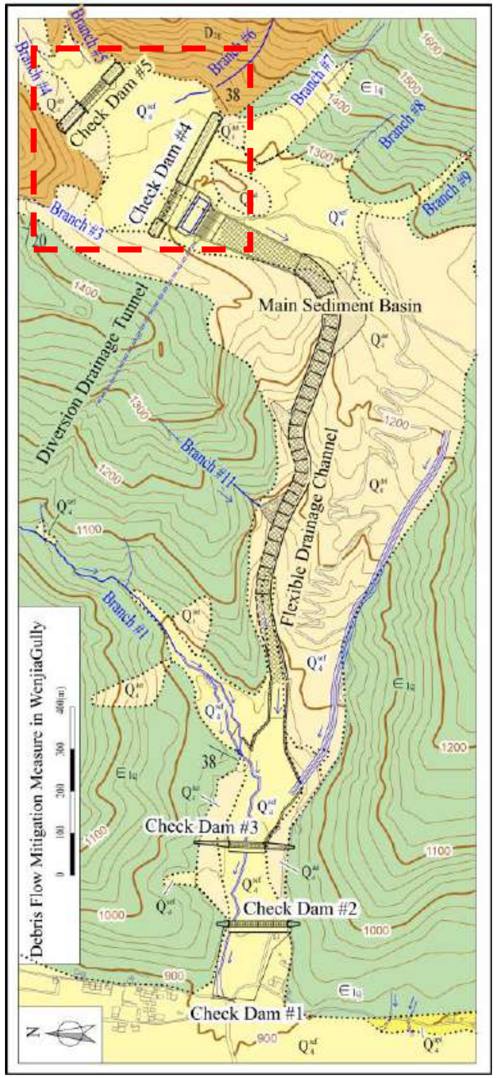
Erosion control
Prevention of the channelized erosion



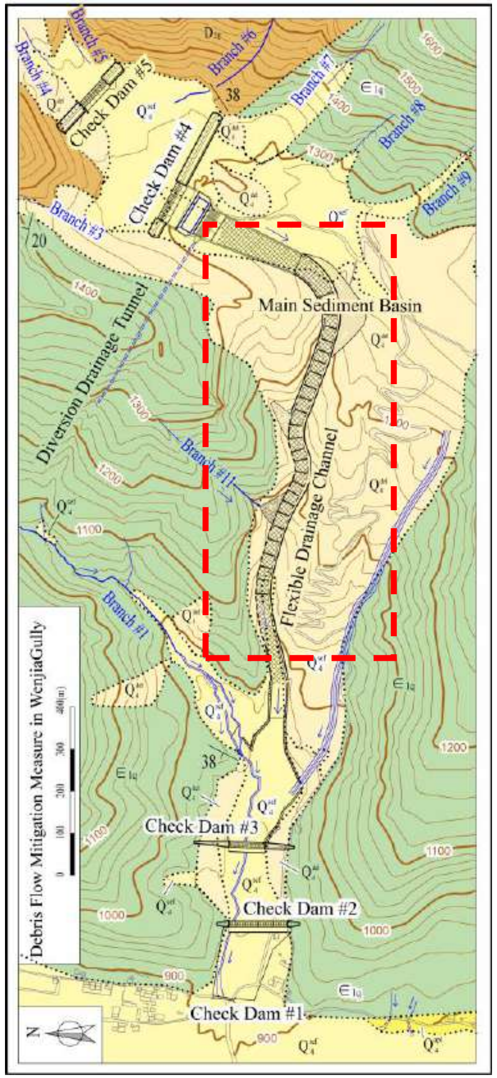


[Liu *et al.* 2017]

DEBRIS FLOW MITIGATION SYSTEMS: WENJIA GULLY

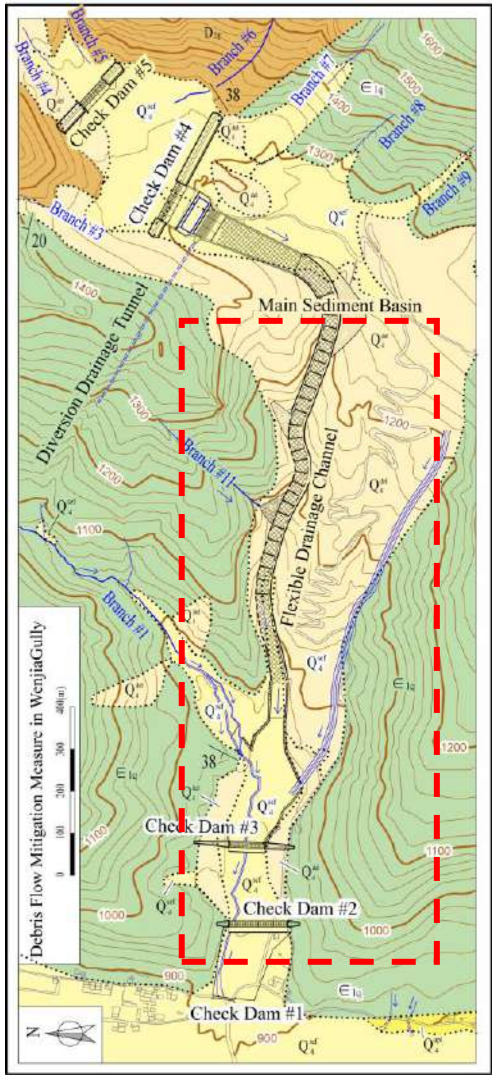


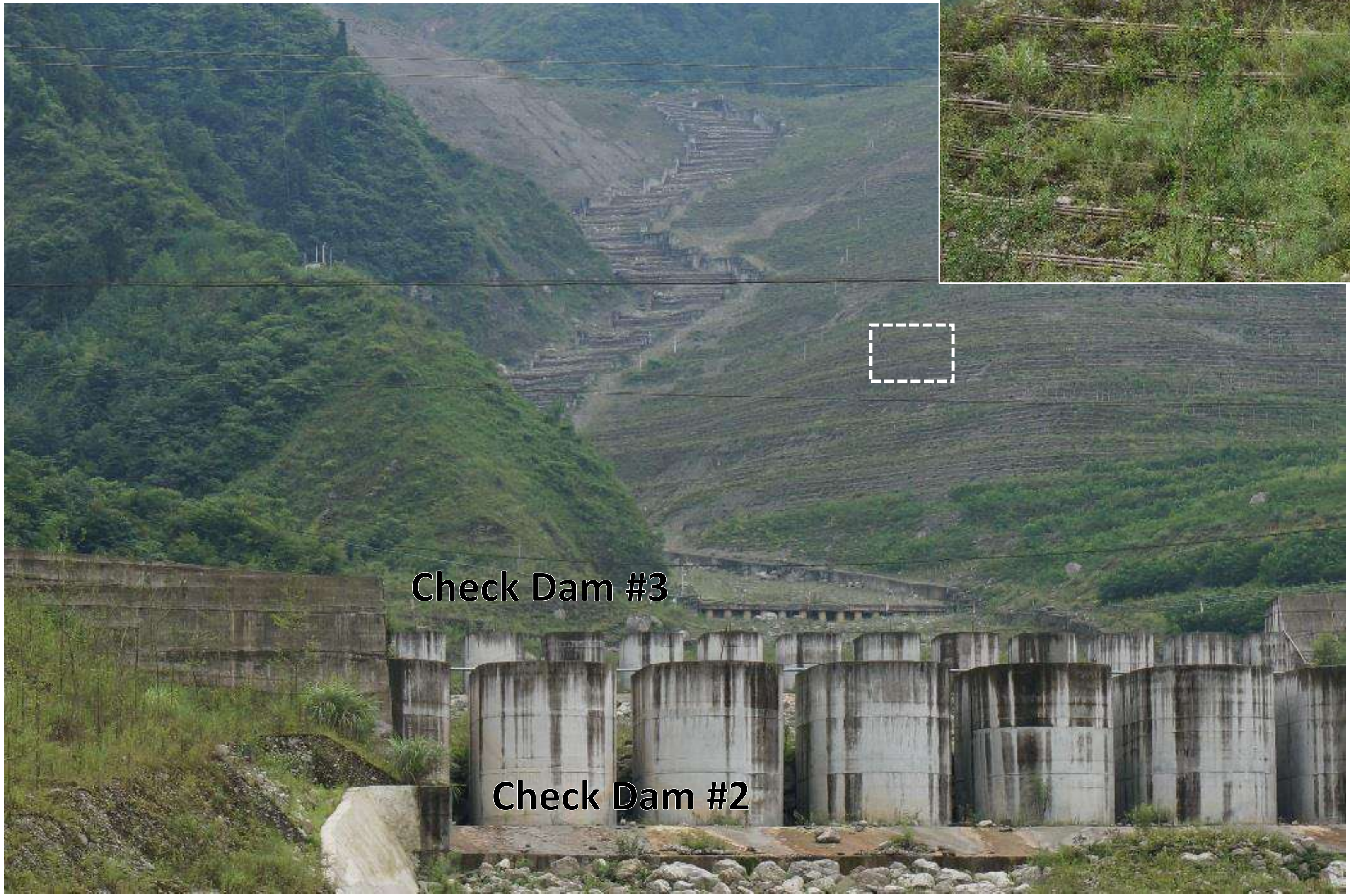
DEBRIS FLOW MITIGATION SYSTEMS: WENJIA GULLY

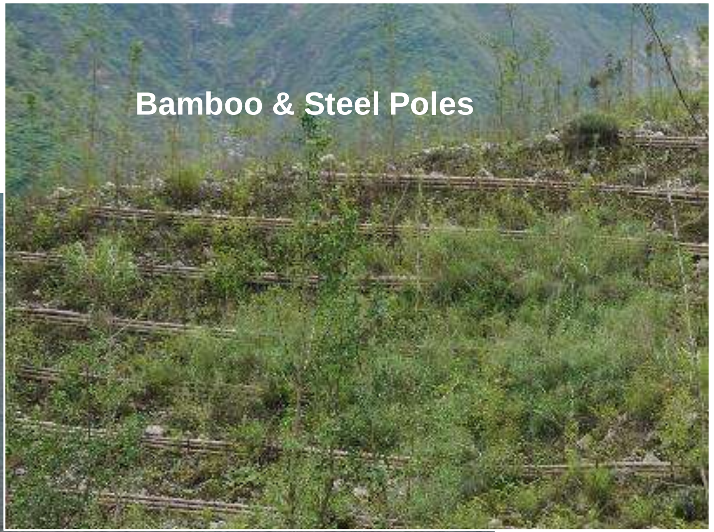


Eroded debris flow diversion channel (Xiaogangjian gully)

DEBRIS FLOW MITIGATION SYSTEMS: WENJIA GULLY







WENJIA GULLY MITIGATION SYSTEM: PERFORMANCE

Debris flows occurred on August 14 and 17, 2012

- Total volume: 78,000 m^3
- Overflow at Check Dam #5 and filled the sediment basin of Check Dam #4
- Depth of water in tunnel: 1.2 m with peak flow discharge of 49.1 m^3/s, mobilized the loose deposit in downstream branch and damaged Check Dam #1
- Did not cause any damage to the downstream community

WENJIA GULLY MITIGATION SYSTEM: PERFORMANCE

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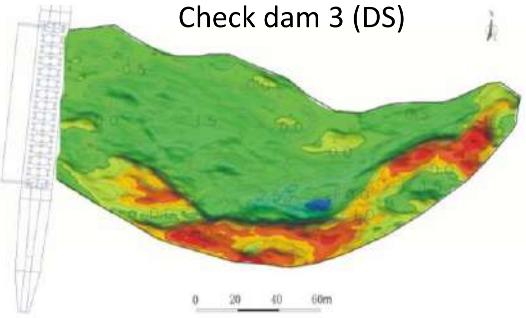

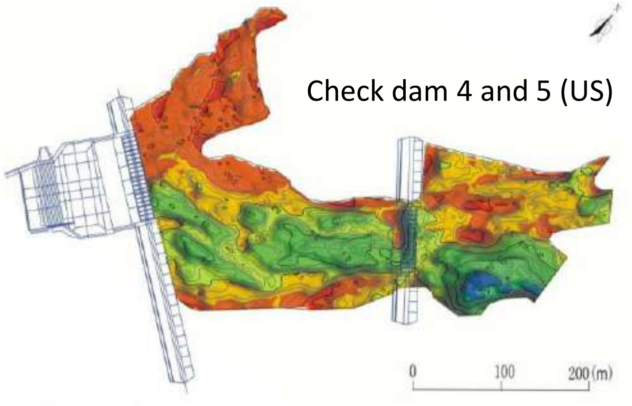

Debris flow occurred on July 8, 2013

- Total vol: 344,000 m^3
- Buried Check Dam #5
- Filled Check Dam #4 basin & damaged left flank of the dam
- Mobilized the loose deposit in downstream branch
- Did not cause any damage to the downstream community

WENJIA GULLY MITIGATION SYSTEM: PERFORMANCE

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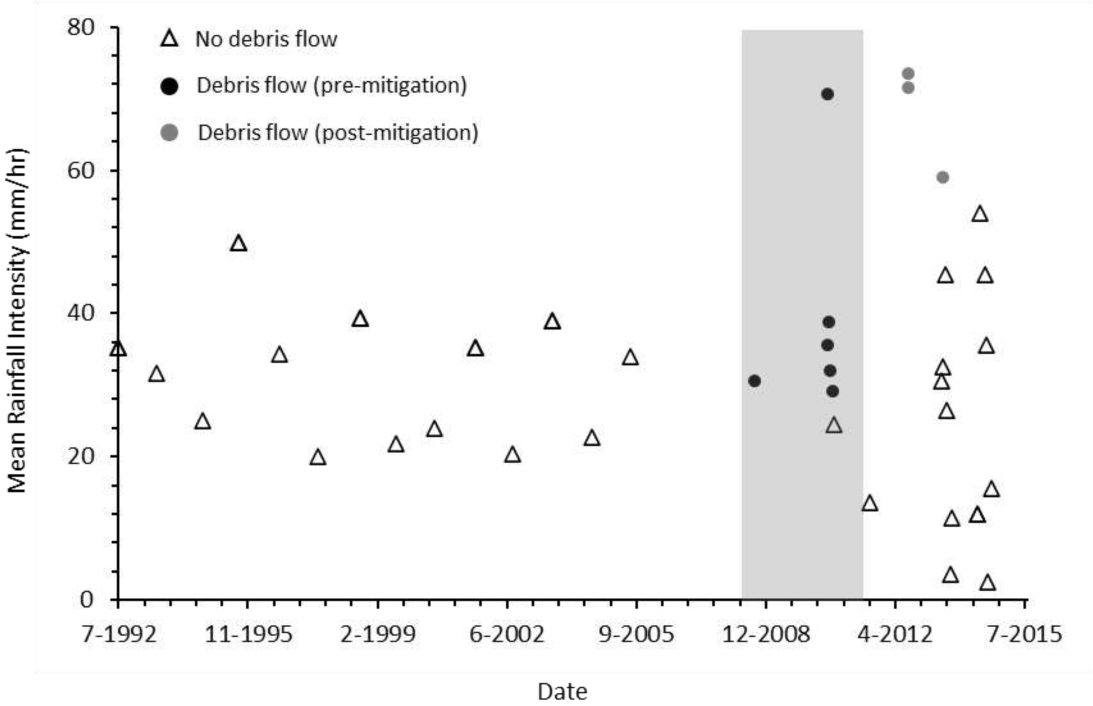
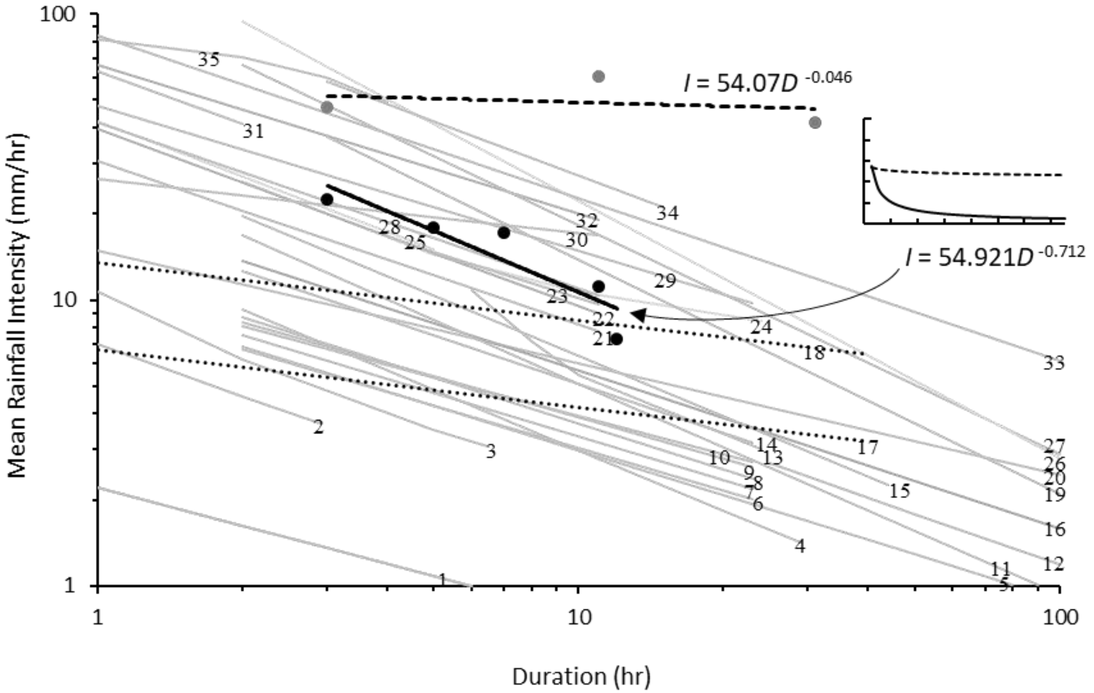
- No debris flows in Wenjia gully before the earthquake.
- Pre-mitigation rainfall intensity decreases with increasing duration.
- Post-mitigation rainfall intensity remains almost unchanged with increasing duration (antecedent water content seems no longer important).
- The debris flow susceptibility reduced to the pre-earthquake level after implementing new mitigation system.
- No standard quantitative assessment on debris flow mitigation system at site, watershed, regional, or national scale are adopted.





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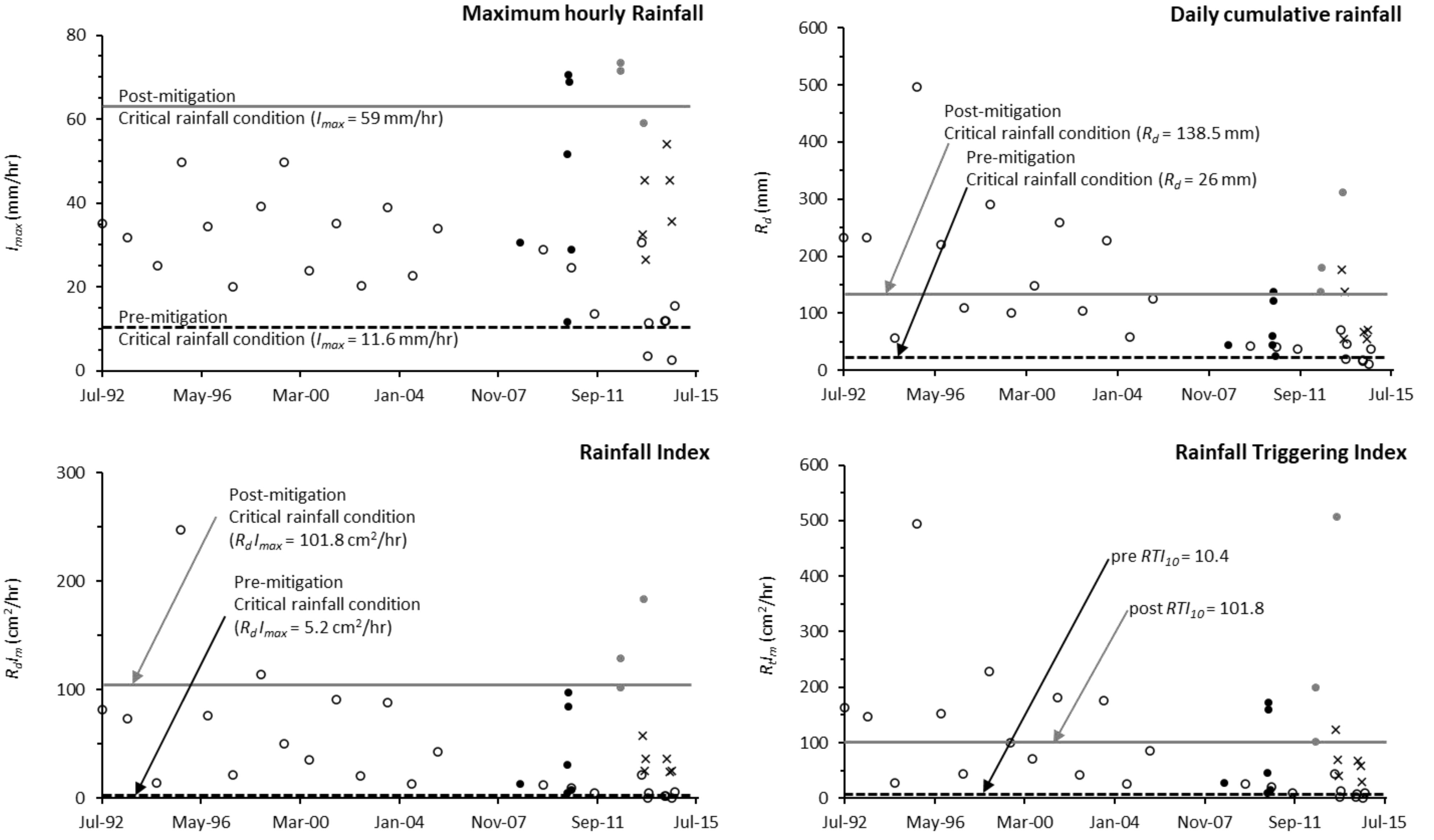

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DEBRIS FLOW MITIGATION SYSTEMS: PERFORMANCE

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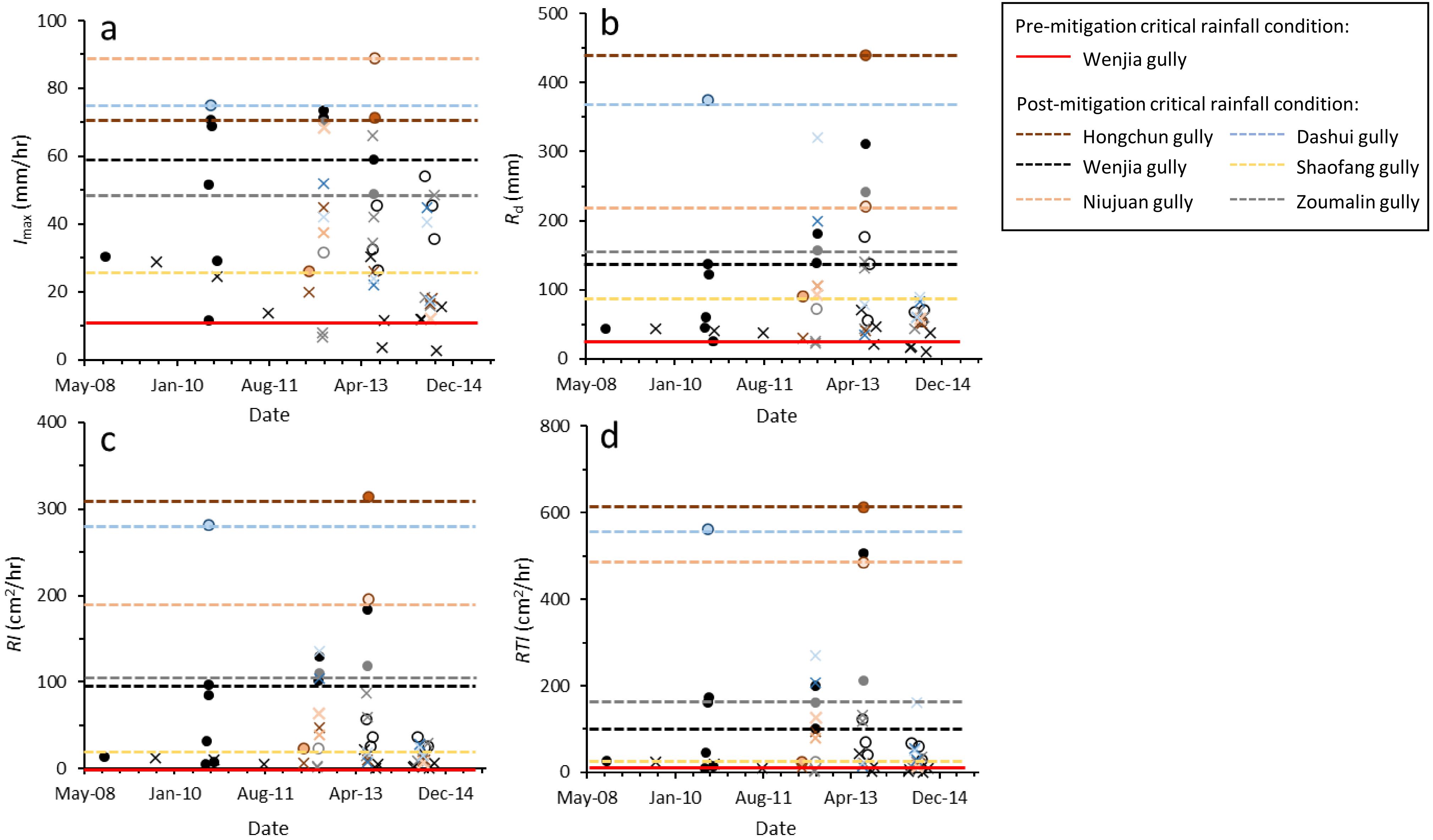

CONCLUDING REMARKS

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- The regional debris flow susceptibility in Wenchuan has increased significantly since the earthquake.
- The debris flow after the Wenchuan earthquake represents the typical cascading impacts associated with a major earthquake.
- Debris flow would continue to cause disruption to the downstream community for a long period of time if mitigation system were not implemented.
- The design of the Wenjia gully mitigation system can serve as a path forward under the challenges of climate change and the increasing extreme weather events;
- An effective large-scale debris flow mitigation system relies on the understanding of the area as well as the creativity of utilizing the nature of the area as the basis of the design.
- Mitigation system design mentality: confronting nature vs. working with nature

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