BHP

# Assessment and development of erosion models for landform design at BHP legacy tailings storage facilities in Arizona, USA

Nathan Abramson [1], Jon D. Pelletier [1], Sriram Ananthanarayan[2], Satya Chataut[2], David Ludwick[3], Brian Ayres[2]

[1]Department of Geosciences, University of Arizona

[2]BHP, Technical Centre of Excellence and Legacy Assets

[3]SRK Consulting

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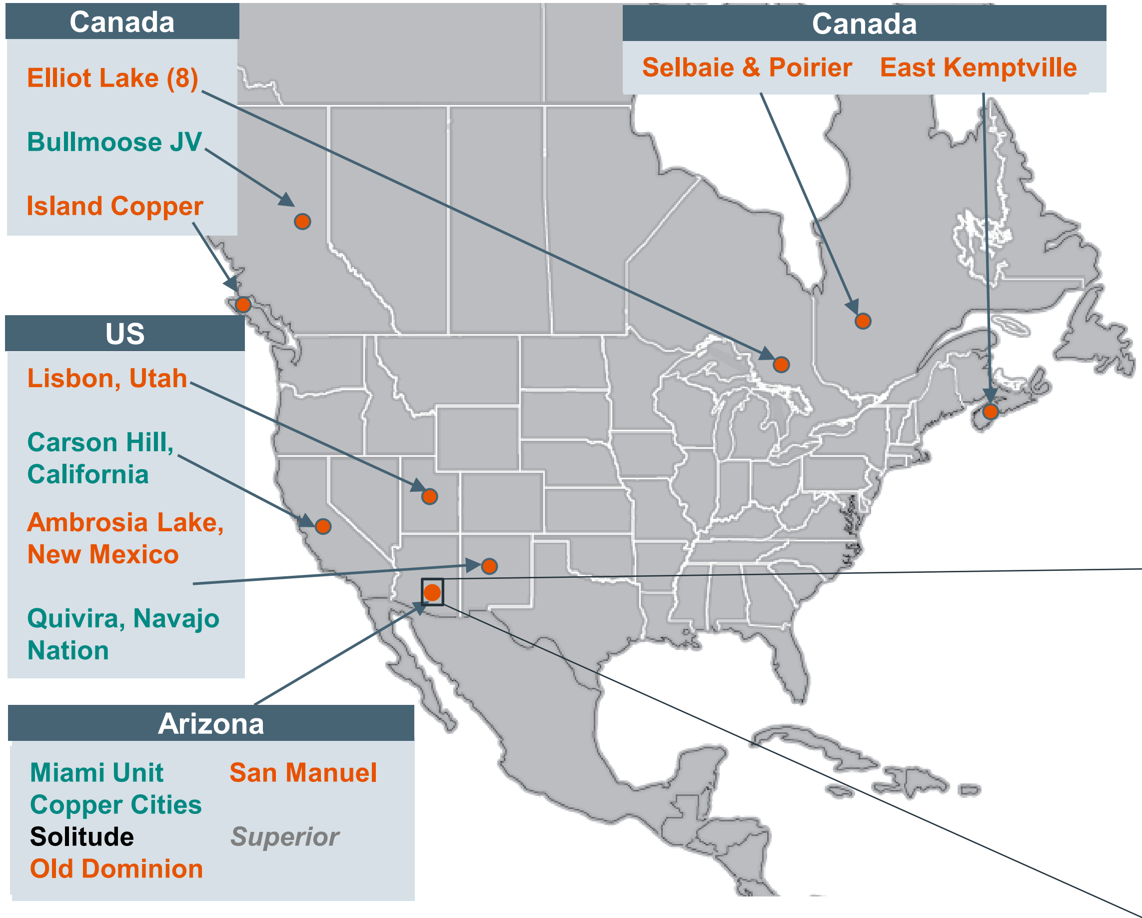
# Overview of BHP legacy sites in North America



**Canada**

**Elliot Lake (8)**

**Bullmoose JV**

**Island Copper**

**Canada**

**Selbaie & Poirier** **East Kemptville**

**US**

**Lisbon, Utah**

**Carson Hill, California**

**Ambrosia Lake, New Mexico**

**Quivira, Navajo Nation**

**Arizona**

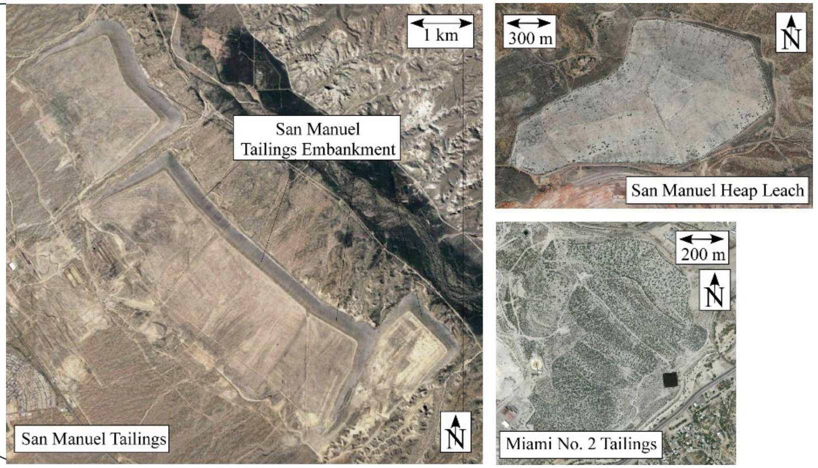
**Miami Unit**
**Copper Cities**
**Solitude**
**Old Dominion**
**San Manuel**
***Superior***

**Colour Legend:**

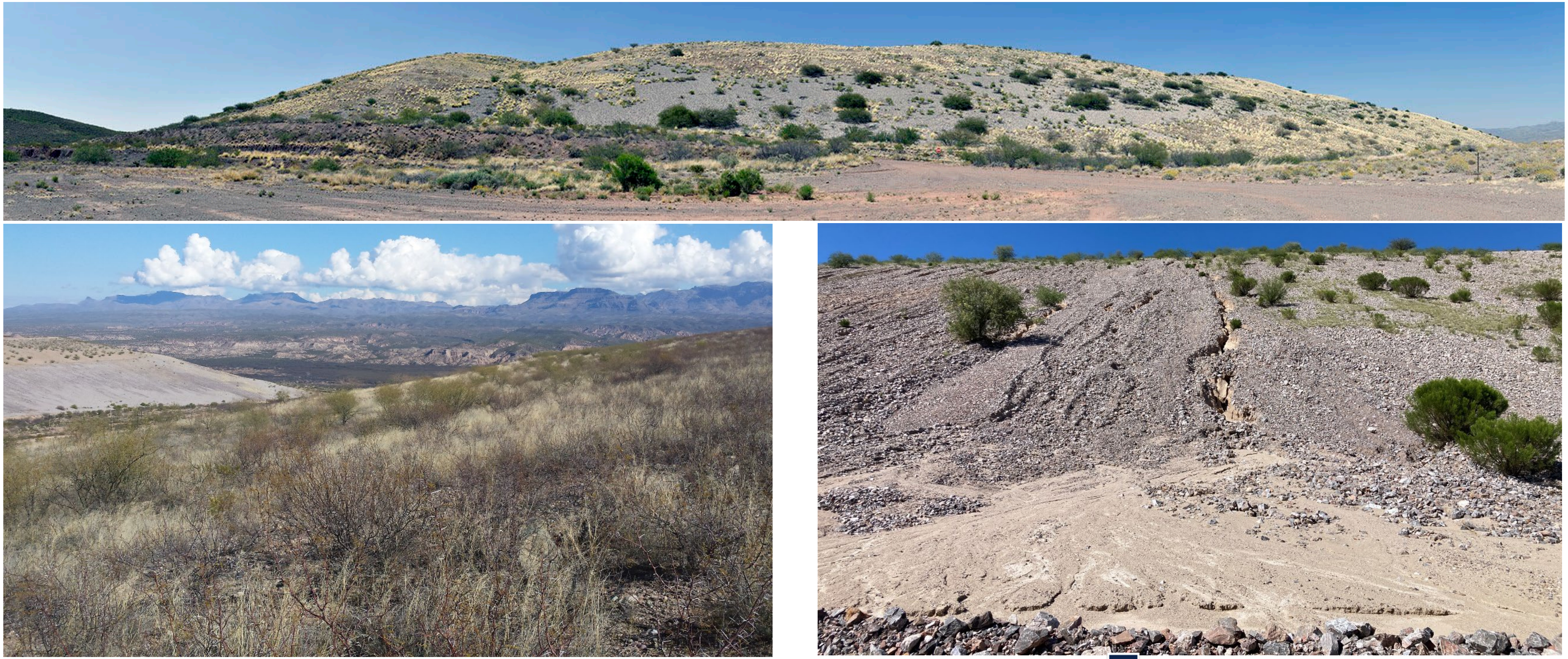
- **Pre-closure care & maintenance**
- **Care & maintenance, awaiting final closure** **Post-closure care & maintenance**
- **Closure execution liability**
- **Post-closure liability (not a site)**

- BHP manages 23 sites in various stages of closure in North America (primarily the result of liabilities acquired through mergers and acquisitions)
- About one-third of these sites are in Arizona, where challenges exist for mine site reclamation due to high-intensity rain events
- Some of these legacy assets in Arizona comprise inactive mine waste storage facilities with relatively steep (up to 2.5H:1V) and long (up to 350 m) slopes

**Study Sites**



# Mixed results in terms of erosional stability of reclaimed hillslopes in Arizona with rock armouring



# Need to better understand erosional performance of reclaimed mine hillslopes

**Reclaimed hillslopes that do not perform well are concerning due to:**

- Potential threat to downstream environment and population
- Potential for exposure of underlying tailings and/or unacceptable sedimentation of surface water courses
- Challenges for potential relinquishment of properties with hillslopes requiring frequent maintenance
- Increasing slope maintenance costs (>$250,000 USD/yr)

**BHP realized that more research was needed on hillslope erosion mitigation and subsequently entered a multi-year research program with the Department of Geosciences at the University of Arizona, which began in 2018**

# Assessment and development of erosion models

**Goals:**

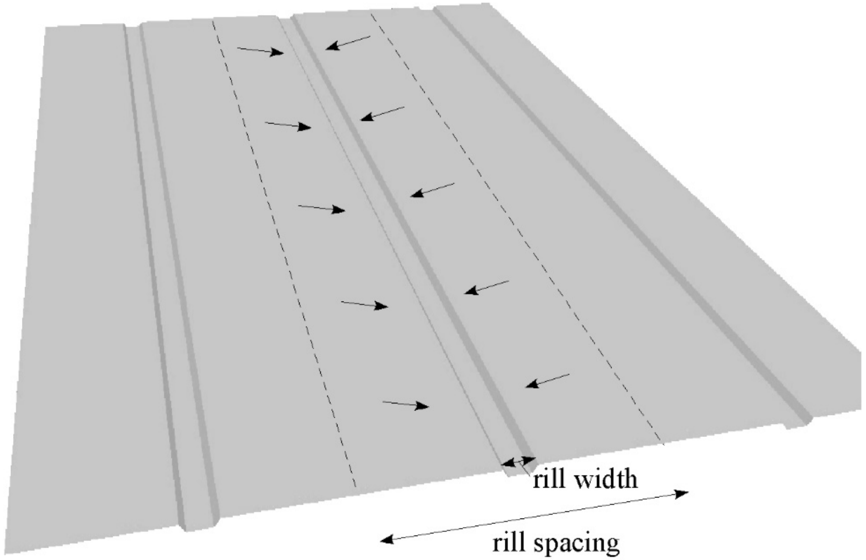
- Can erosion models successfully retrodict erosional patterns and depths for event-based timescales?
- Develop workflow to calibrate and validate models from site-specific event-based datasets
- Using modelling to better understand factors controlling erosion and apply lessons learned and new tools to future designs
- Application to long, steep, rock-armoured hillslopes in Southern Arizona

**Existing Models:**

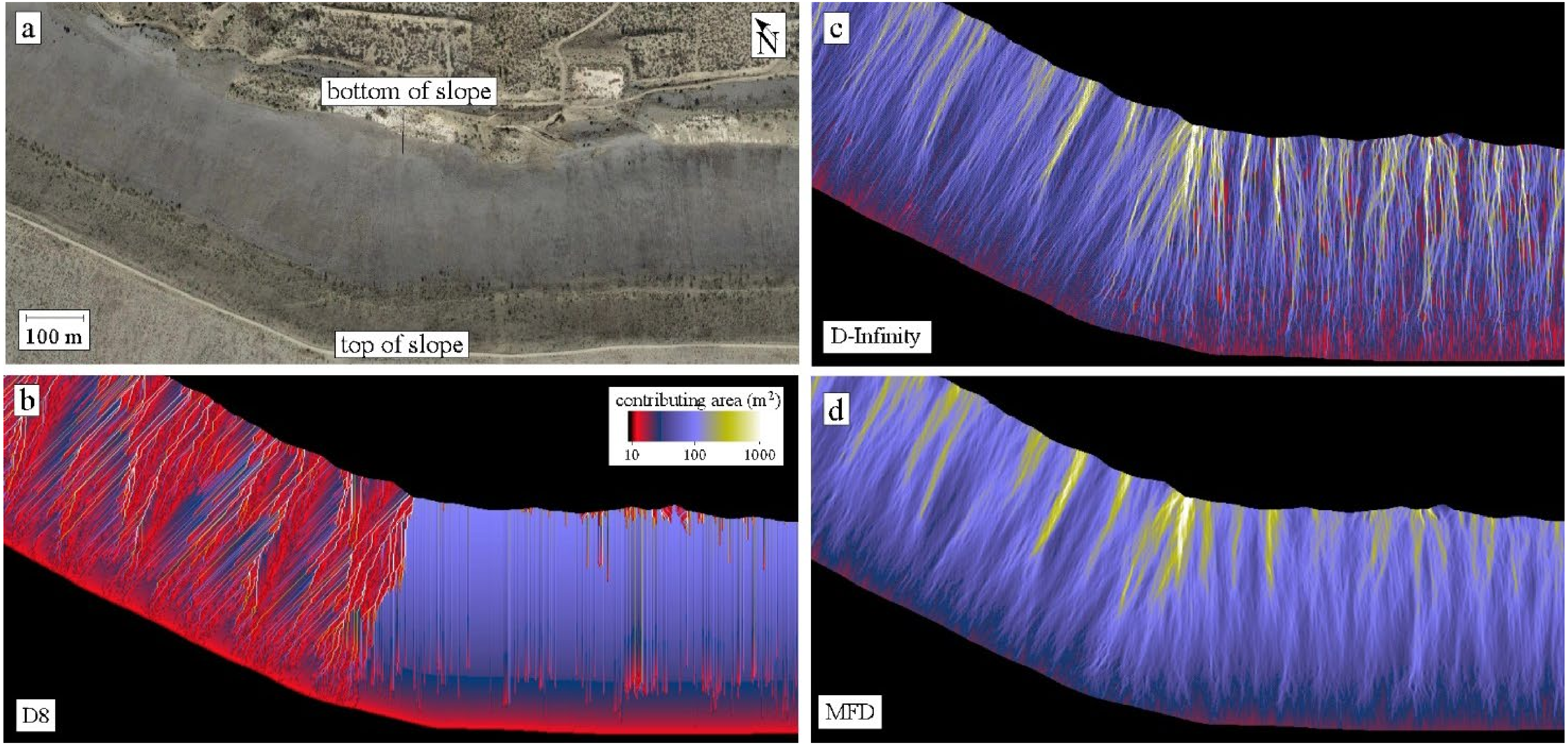
- **WEPP –** 1D model requiring rill spacing & width, slope length limitations
- **SIBERIA –** Flow routing algorithms, erosional patterns

**New Models:**

- **Rillgen2D** – reduced-complexity predictive model - alternative to WEPP
- **RITCH** – Rill-Interrill Transport and Conservation of mass optimized for Hillslopes - alternative to SIBERIA

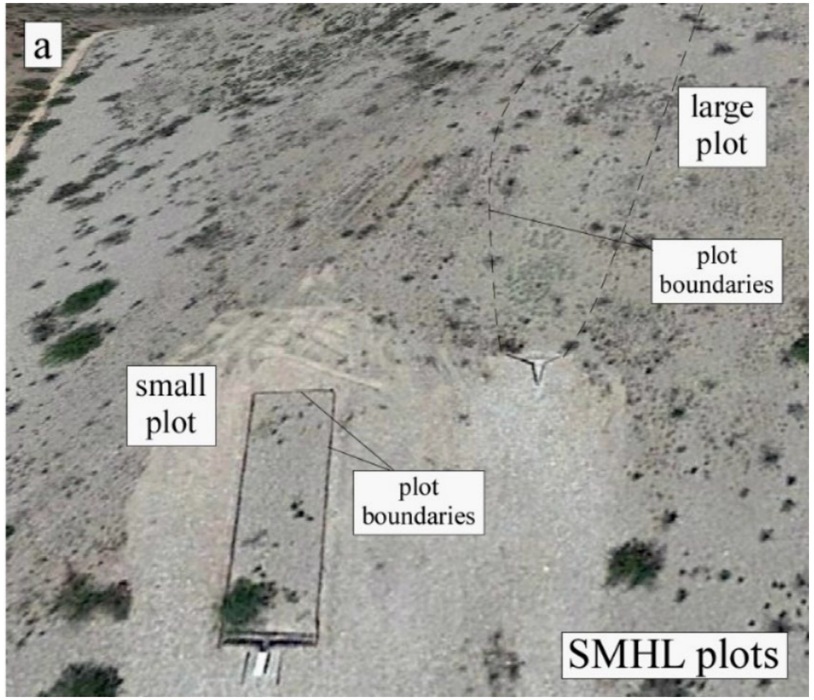


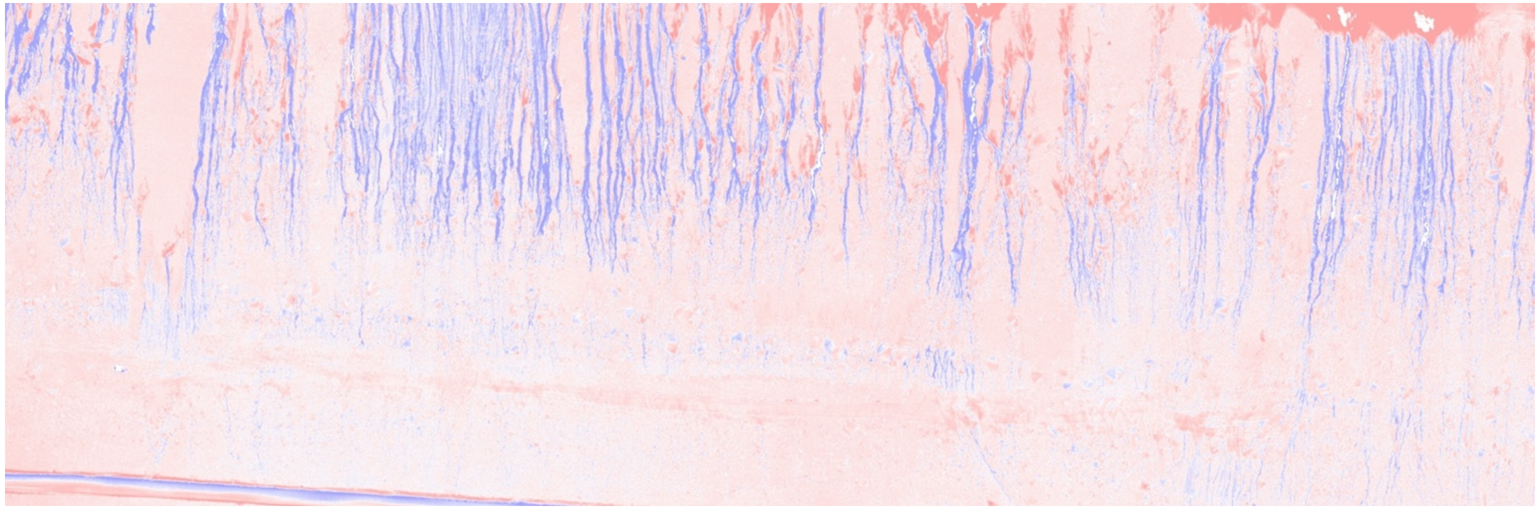
# Flow routing algorithms



Freeman (1991), Tarboton (1997)

# Methods



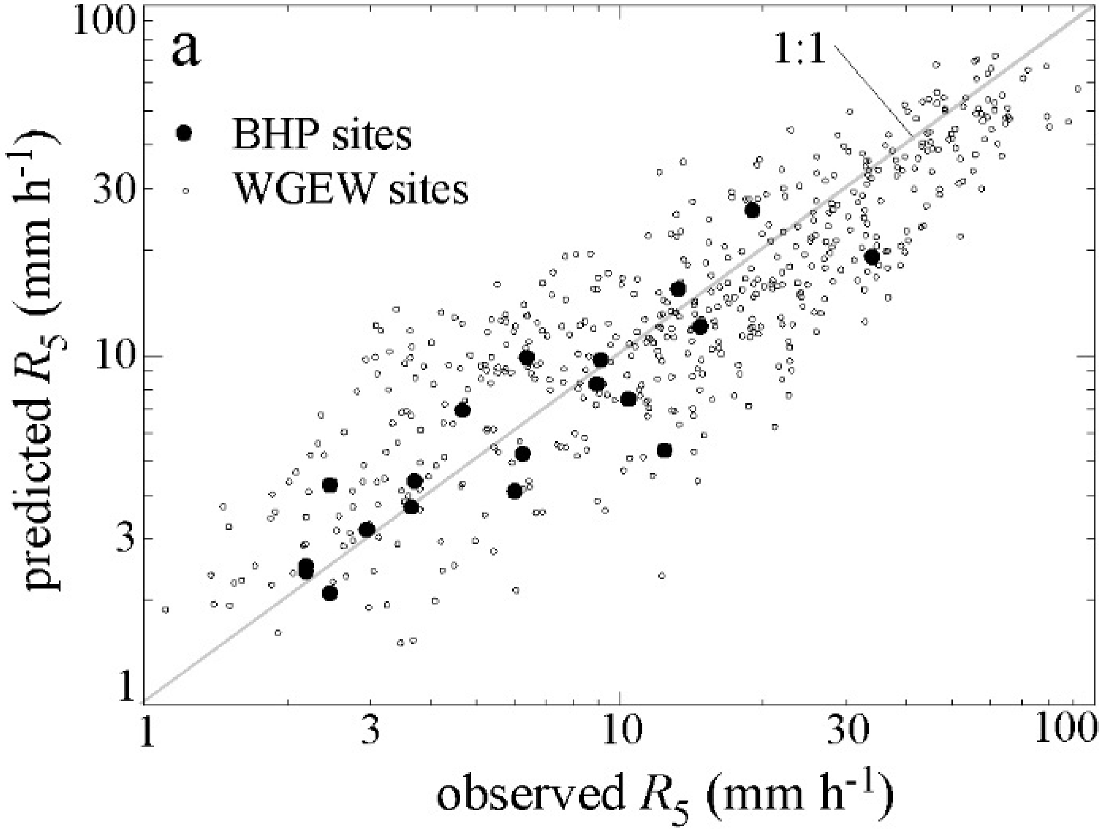


- Installation of monitoring plots for high-resolution rainfall, runoff, and SSC data
- Repeat photogrammetric drone surveys

# Rainfall-runoff model

- Develop model to produce timeseries of discharge and shear stress given input rainfall timeseries
- North American Monsoon short-duration high-intensity events associated with most all erosion at sites
- Multivariate regression of Area *(A)*, $I_5$, $I_{60}$

$$Q = R_5 A = 0.006 A^{0.88} I_5^{1.22} I_{60}^{0.91}$$



Goodrich et al. 2008 & Stone et al. 2008

# Rillgen2D

- Based on empirical equation developed using the Abt et al. (2013) dataset
- Predicts $q_c$ – unit discharge associated with rill development into the rock armor

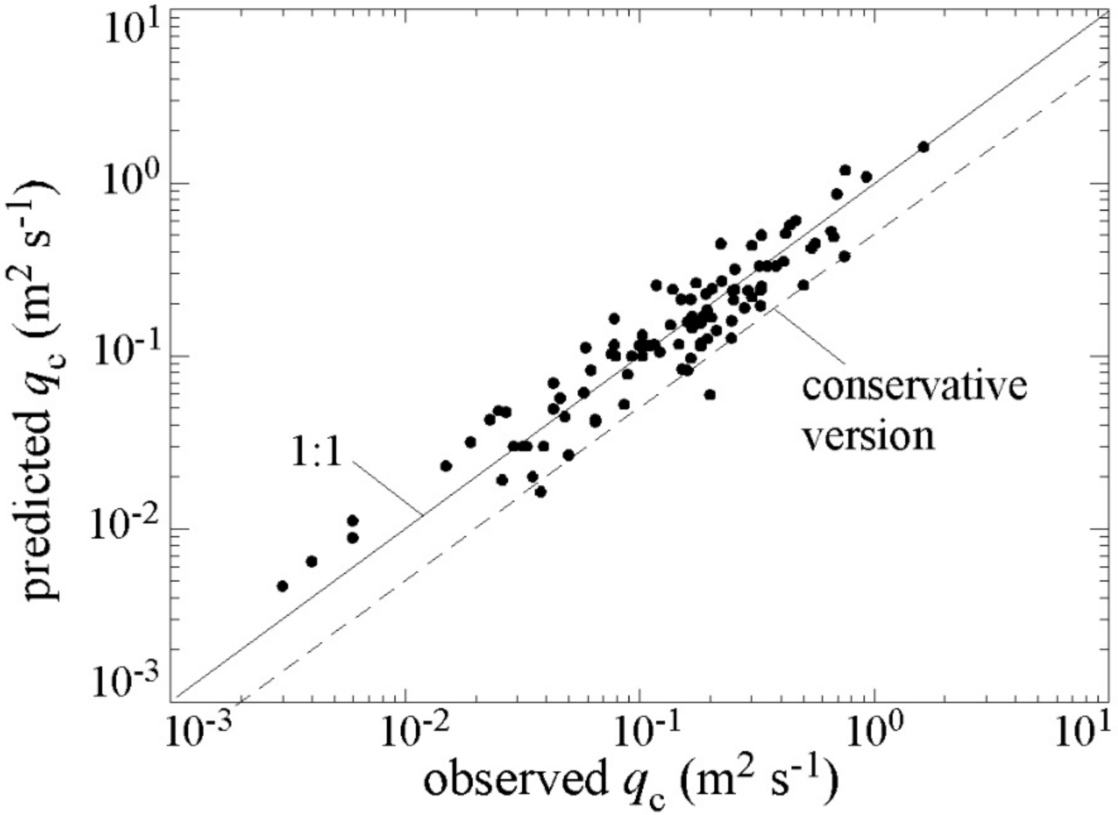
$$q_c = 1.3\left(\frac{\sin\theta}{\cos\theta\,\tan\phi - \sin\theta}\right)^{-0.86} d_{50}^{1.68}$$

- Evaluation of critical shear stress/peak shear stress

$$f = \tau_c/\tau$$

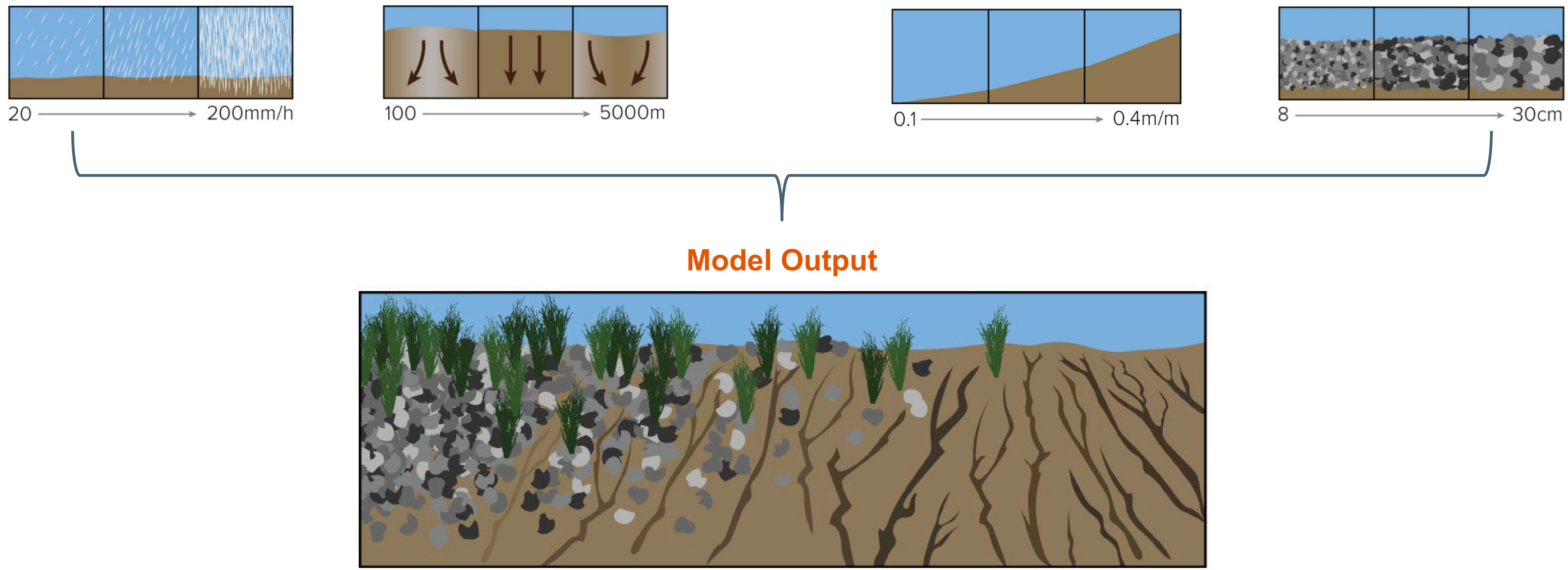
- Static and Dynamic mode

$$E = \begin{cases} K_r(\tau - \tau_c) & \text{if } \tau > \tau_c \\ 0 & \text{if } \tau \le \tau_c \end{cases}$$



Abt et al. 2013

# Rillgen2D



## Model Input

**Rainfall Intensity: $I_5$, $I_{60}$**

**Specific Contributing Area: $A$**

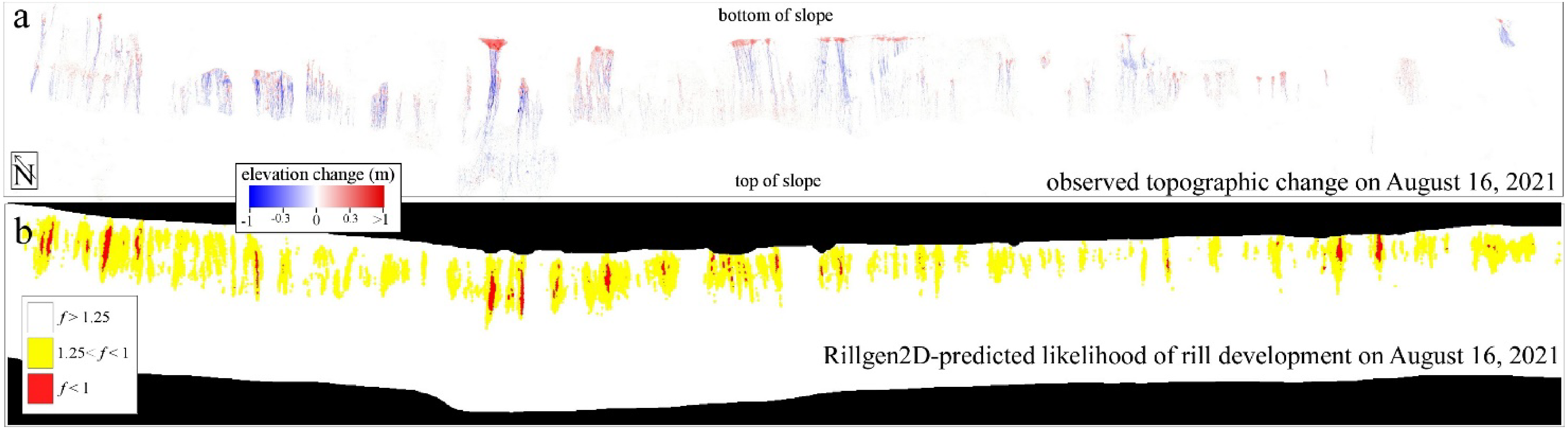
**Slope Gradient :$\theta$**

**Friction Angle:$\phi$**

**Particle Diameter: $d_{50}$**

## Model Output

# Rillgen2D static mode example results



Static Mode Inputs:

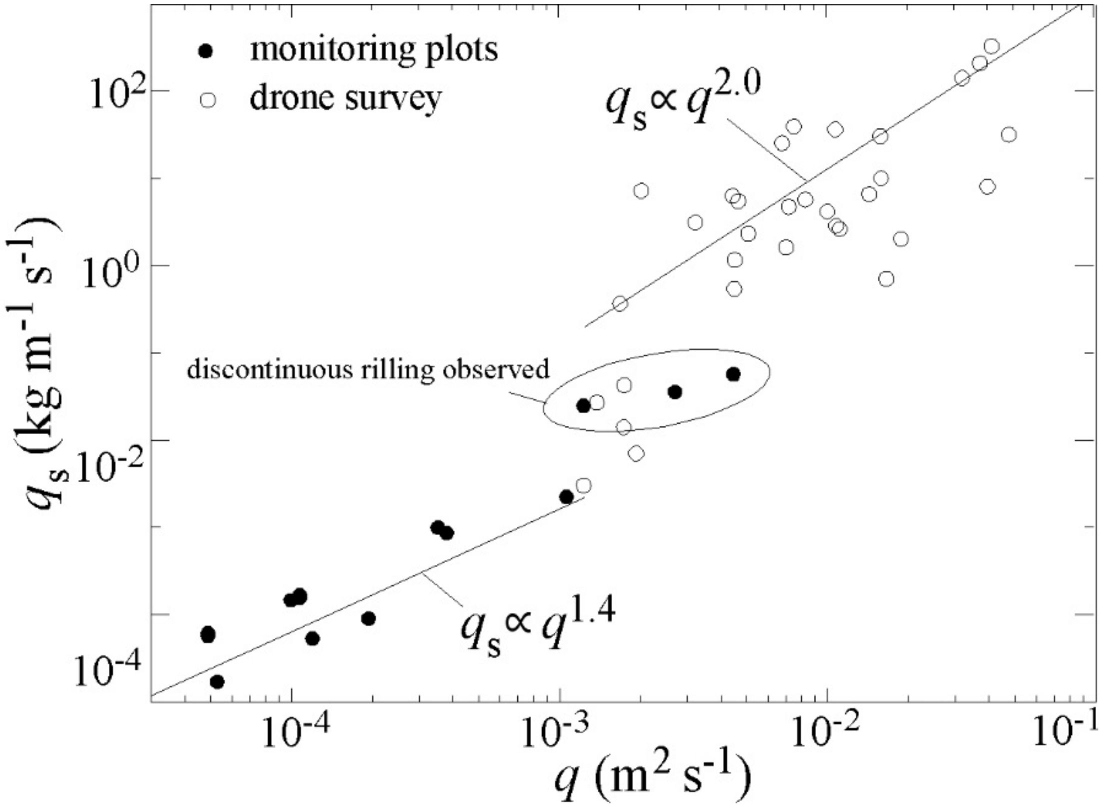
$d_{50}$ = 100 mm, $\phi$ = 32°, $I_5$ = 134 mm hr$^{-1}$, $I_{60}$ = 42 mm hr$^{-1}$

# RITCH

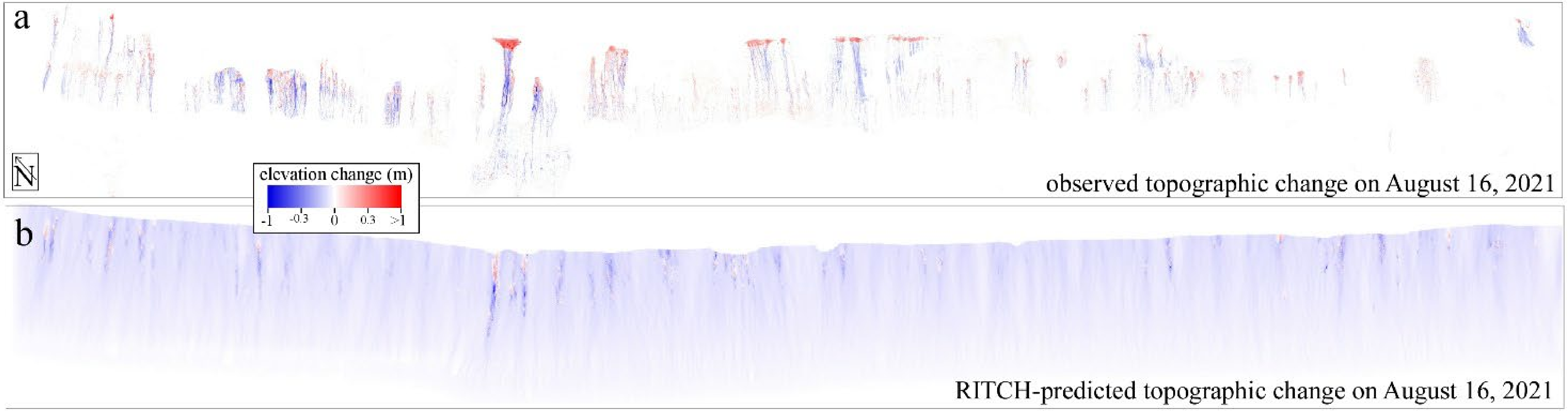
rill erosion

$$q_s = \begin{cases} -(\beta_1 q^{m_1} S^{n_1})\hat{s} & \text{if } q > q_c \\ -(\beta_0 q^{m_0} S^{n_1})\hat{s} & \text{if } q \le q_c \end{cases}$$

interrill erosion



# RITCH example results



# Future direction

- Need to apply models to broader range of climates, landforms and cover materials
- Collaborations needed – topography (alternative landform designs), cover characteristics (vegetated slopes, mixed covers), spatially distributed erosional patterns (i.e., repeat topographic surveys), high-resolution rainfall data
- Document and release for community use

Nathan Abramson

nabramso@arizona.edu

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