Landslide dam susceptibility in the Austrian Alps inferred from modelled landslides, potential valley damming and lake formation

EGU 2020 presentation

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What are landslide dams?

Landslide dams

Landslides deposited in the river bed, damming the river flow and forming a (temporal) lake.

Figure 1: Landslide of Creux-du-Van dams the Val-de-Travers. (a) Landslide begins. (b) Landslide dams the river, sedimentation. (c) Dam break or overtopping. [From Matthey, 1971.]

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Landslide dams

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Figure 2: A view of the Leader dam in New Zealand, triggered by the 14 November 2016 Kaikoura earthquake. The dam has been incised by the river. 03.01.2019
Modeling approach
Modeling approach
Input data

Simple input data.

Figure 3: Workflow

Our landslide model relies on topographical data only.
Modeling approach
Determination of landslide release areas

Figure 3: Workflow

Figure 4: The probability density of the landslides corresponds to a power-law distribution [from Hergarten, 2012].

**Methodology**

**Landslide simulation**

**Figure 3: Workflow**

1. **Input data**
   - Literature data
   - 10m DEM of the Austrian Alps
   - Tectonical map (Bousquet et al., 2012)

2. **Landslide release area determination code (Hergarten, 2012)**
   - Slope thresholds: stable < 45°, 78.7° < unstable
   - Code applied homogeneously from tile area
   - Output: Landslide release area and thickness

3. **Landslide simulation with Gerris (Popinet, 2003)**
   - Voellmy rheology: \( \xi = 150 \, \text{m.s}^{-2} \), \( \mu = 0.12 \)
   - Discard landslide deposits outside Austria
   - Output: DEM after landsliding

4. **Landslide dam geomorphometrics**
   - Landslide deposits: - volume \( V_{dep} \), - maximum height \( H_{dep} \)
   - Dammed lake: - volume \( V_{lake} \), - maximum depth \( H_{lake} \)
   - Catchment area \( A_b \), Channel slope \( S \)

5. **Comparison**

- Cut into 13 parts
- Fill, compute accumulation and gradient with Topotoolbox
- Only take landslide volumes > \( 10^5 \) m³
- NaN values are transformed into 0s
- Cut smaller parts for simulation in Gerris
- Fill the DEM with GRASS GIS

**Figure 5:** Landslide modeled with Gerris (Popinet, 2003), a depth-averaged flow solver.

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Methodology
Geomorphometric parameters

100 landslide dams as preliminary results. 1000 intended.

Common geomorphometric parameters:
- Landslide volume
- Lake volume
- Dam volume & height

→ Definition not straightforward

Figure 3: Workflow
First results
Observations:

- Linear correlation between landslide and lake volume
- Values are shifted to the left in comparison with literature data

→ Investigate the shift in our values by looking at the dam height (which is not directly measurable).

Figure 6: Our landslide dammed lake values.
First results – Comparison with literature

Proxies for dam height $H_{dam}$

$H_{dam}$: Dam height
$H_{lake}$: Maximum depth of the lake
$H_{dep}$: Maximum height of the landslide deposits.

Legend:
- Green: Valley flanks
- Brown: Landslide release area
- White: Landslide deposits
- Yellow: Fluvial sediments
- Blue: Water body (river or lake)

Figure 7: Measurement of heights in cross and longitudinal sections.

**Heights relationship:**

\[ H_{lake} \leq H_{dam} \leq H_{dep} \]
First results – Comparison with literature
Relation of $H_{dep}$ and $H_{lake}$ with $V_{landslide}$ and $V_{lake}$

Figure 8: Decomposition of the relation with the dam height proxies: the landslide deposits height $H_{dep}$ and the lake depth $H_{lake}$.

$H_{lake}$ and $H_{dep}$ values are clearly separated...
First results – Comparison with literature
Relation of $H_{\text{dep}}$ and $H_{\text{lake}}$ with $V_{\text{landslide}}$ and $V_{\text{lake}}$

Figure 9: Decomposition of the relation with the dam height proxies: the landslide deposits height $H_{\text{dep}}$ and the lake depth $H_{\text{lake}}$.

...and values with high $H_{\text{lake}}/H_{\text{dep}}$ tend close to the literature.
First results - Comparison with literature
Landslide and lake volumes

Observations:
- Linear correlation between landslide and lake volume
- Values are shifted to the left in comparison with literature data
- Gradient of the $H_{lake}/H_{dep}$ ratio.
- Values closer to literature when $H_{lake}/H_{dep}$ is closer to 1.

Figure 10: Our landslide dammed lake values.
First results – Comparison with literature

Conclusions

1. $H_{dep}$ fits $V_{landslide}$ very well, like $H_{lake}$ with $V_{lake}$.

2. Landslide dam literature tend to record the most exceptional landslide dams. We modeled damming and non-damming landslides. We get similar results when $H_{lake}/H_{dep}$ ratio $\approx 1$.

There is a need for:

- **3D** geomorphometric parameters of landslide dams.
- **well-defined on-field procedure** for the assessment of the landslide dam geomorphometric parameters (e.g. dam height).
Link to tectonic units
Link to tectonic units
Area, landslide numbers & densities

**Figure 11:** Area, landslide number and density for 3 tectonic units.

**Grauwackenzone:** Low landslide density

**Gentle slopes** → lower than the stability threshold (e.g. 45°)

**Figure 12:** Slope vs elevation [From Robl et al., 2015].

Link to tectonic units
Area, landslide numbers & densities

Figure 11: Area, landslide number and density for 3 tectonic units.

Figure 13: Slope vs elevation [From Robl et al., 2015].

Tirolian Nappes: High landslide density
Steep slopes → higher than the unstability threshold (e.g. 78.7°)

Link to tectonic units
Landslide & lake volumes, height ratios

Observations:

- $H_{lake} / H_{dep}$ ratio mostly correlated to lake volume
- $H_{lake} / H_{dep}$ ratio and lake volume varies depending on tectonic unit, for similar landslide volumes
- Probable influence of topography

Figure 14: Mean deposits and lake volumes, ratio $H_{lake} / H_{dep}$. 
### Link to tectonic units

**Landslide & lake volumes, height ratios**

**Figure 14:** Mean deposits and lake volumes, ratio $H_{\text{lake}}/H_{\text{dep}}$.

**Figure 15:** Slope vs elevation [From Robl et al., 2015].

**Grauwackenzone:** Low $H_{\text{lake}}/H_{\text{dep}}$ ratio

- Gently dipping valley flanks $\rightarrow$
- Landslide masses deposit close to valley flanks

**Large valley floors** $\rightarrow$ Harder to dam
Link to tectonic units
Landslide & lake volumes, height ratios

Figure 14: Mean deposits and lake volumes, ratio $H_{lake}/H_{dep}$.

Figure 16: Slope vs elevation [From Robl et al., 2015].

**Bavarian Nappes:** High $H_{lake}/H_{dep}$ ratio

Steep valley flanks $\rightarrow$ Landslide masses reach the river bed

V-type of valleys $\rightarrow$ Easier to dam
Conclusion

- There is a correlation between landslide and lake volumes.
- The modeled landslide dams with high $H_{lake}/H_{dep}$ ratio are closer to literature values.
- Tectonic units present different $H_{lake}/H_{dep}$ ratios and lake volumes for similar landslide volumes.

Future possible work:

- Investigate the variability of the $H_{lake}/H_{dep}$ ratio, and look for a relation with the slope, the topography.
- Try measuring the $H_{lake}$ and $H_{dep}$ of a substantial amount of real-world landslide dammed lakes.
Looking for a post-doc in 2021

Let’s chat!

NH3.1: Tuesday May 5, from 14:00 to 18:00

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