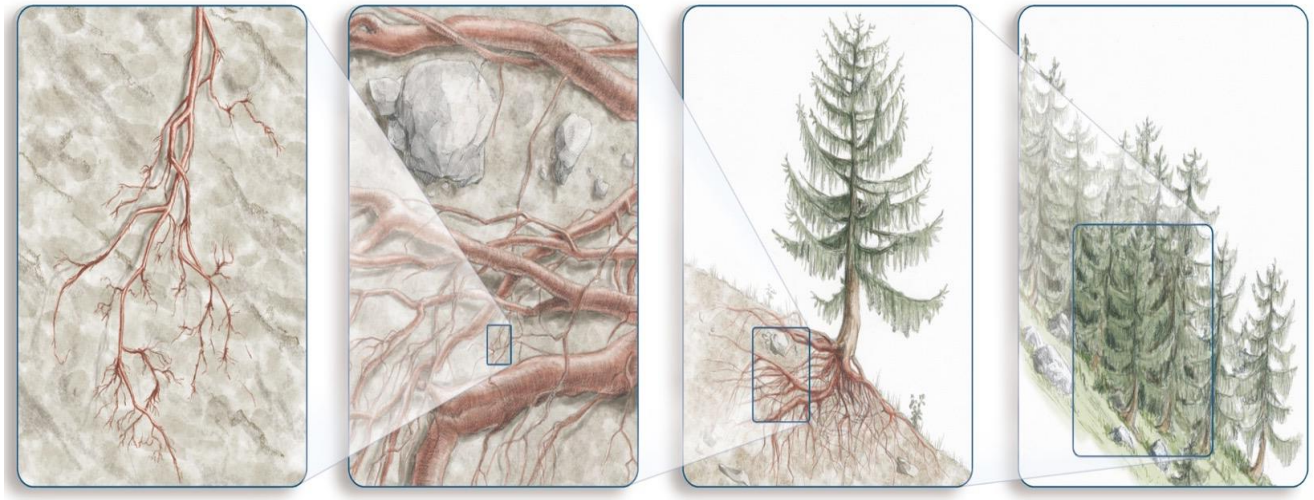
Berner Fachhochschule

ecorisQ
INTERNATIONAL ASSOCIATION FOR NATURAL HAZARD RISK MANAGEMENT



# Quantifizierung und Implementierung der Wurzelverstärkung in Hangstabilitätsmodellen

Schwarz M.

Schwägalp, 24.10.2019

Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften HAFL

# Inhalt

Berner Fachhochschule

Was ist die Bedeutung der Wurzelverstärkung?

Welchen sind die Mechanismen der Wurzelverstärkung?

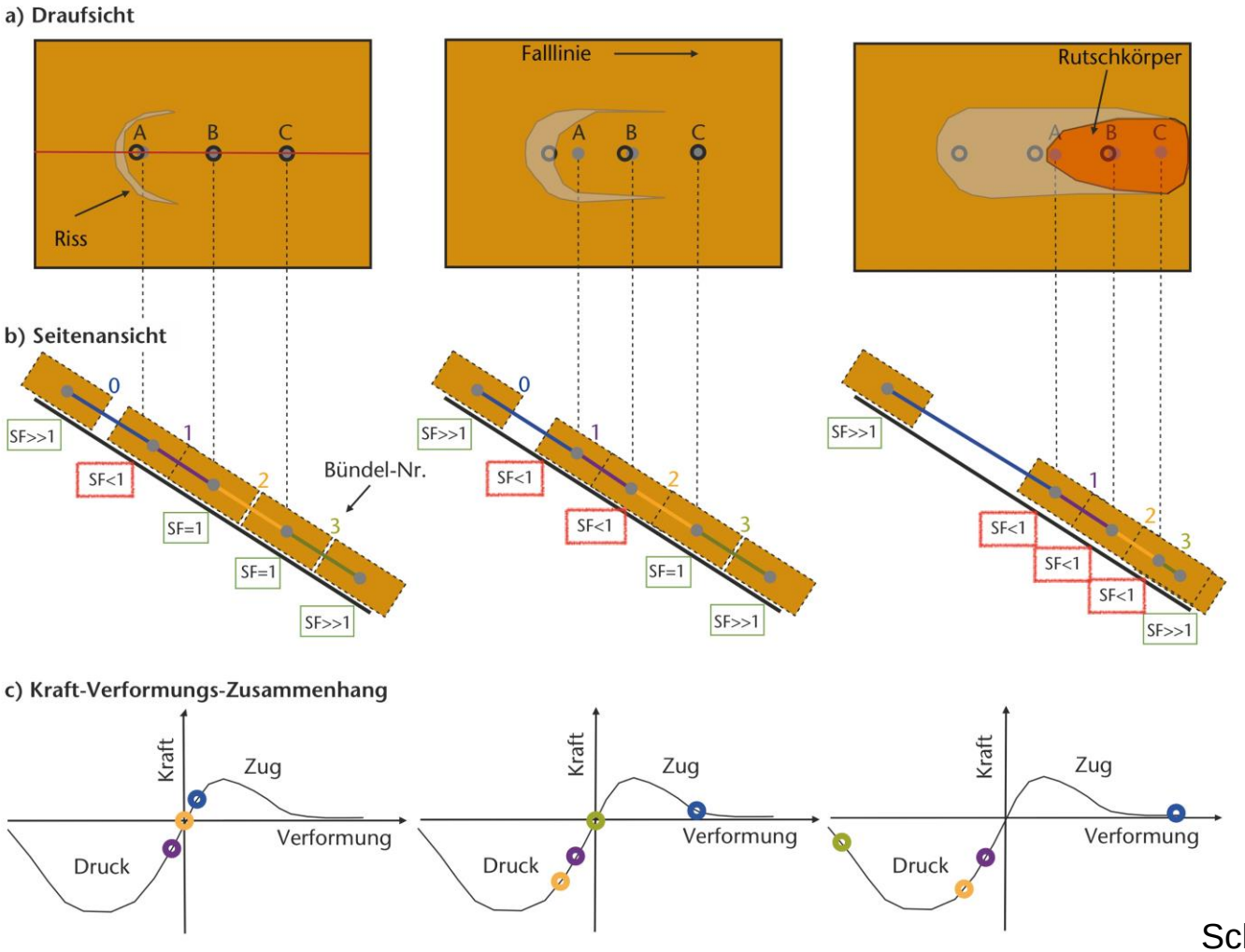
Wie kann man die Wurzelverstärkung quantifizieren?

Wie kann man die Wurzelverstärkung in Hangstabilitätsmodelle implementieren?

Photo: Dr. C. Phillips

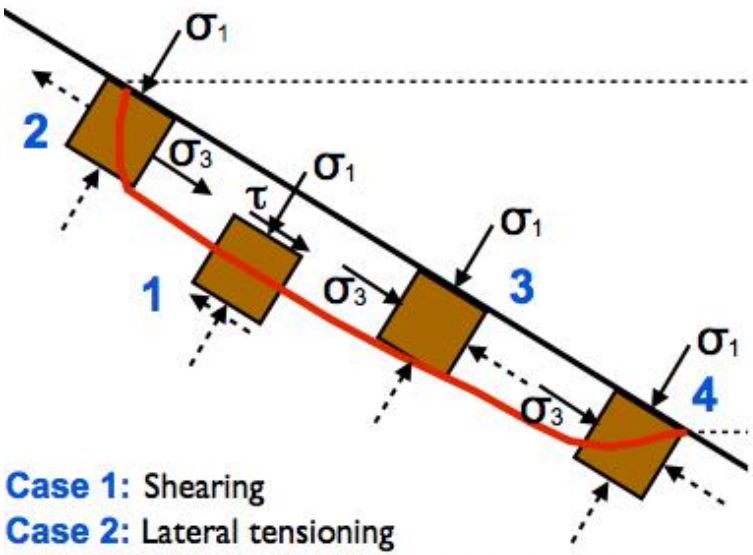
Experiment of the IGT Group of the ETHZ, Prof. S.Springman; TRAMM Project

# Mechanismen der Wurzelverstärkung

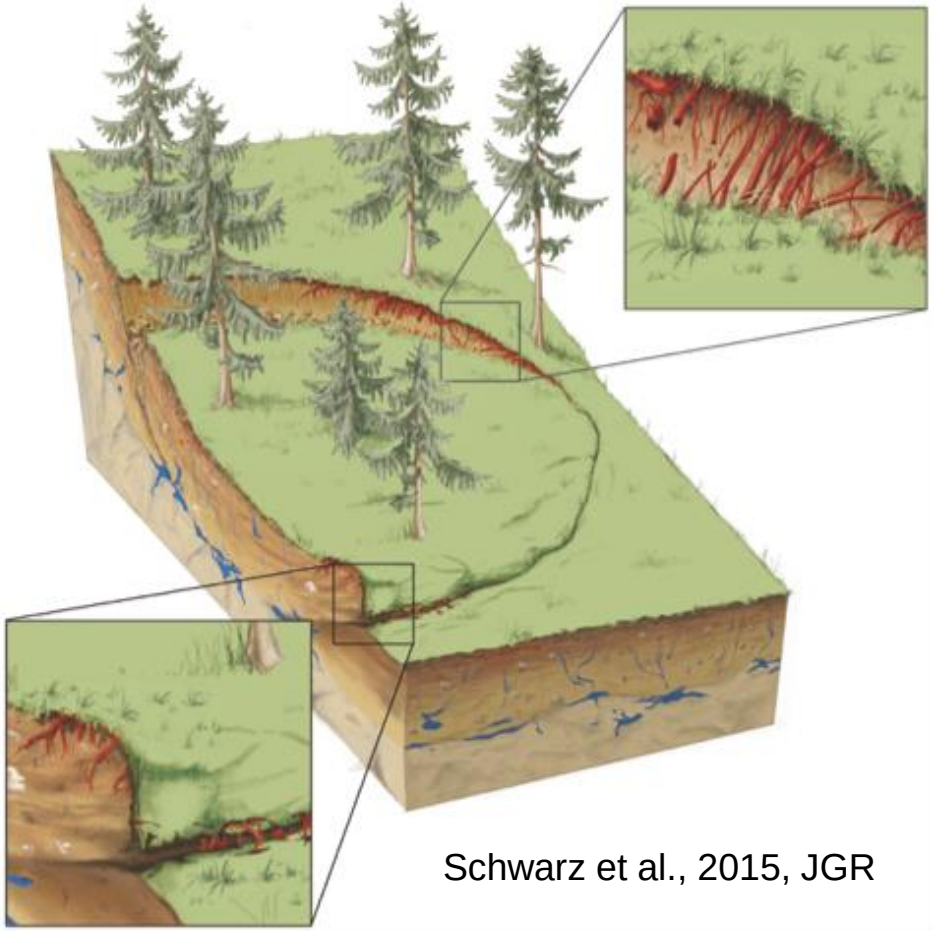



Schwarz, 2019, SZF

# Mechanismen der Wurzelverstärkung



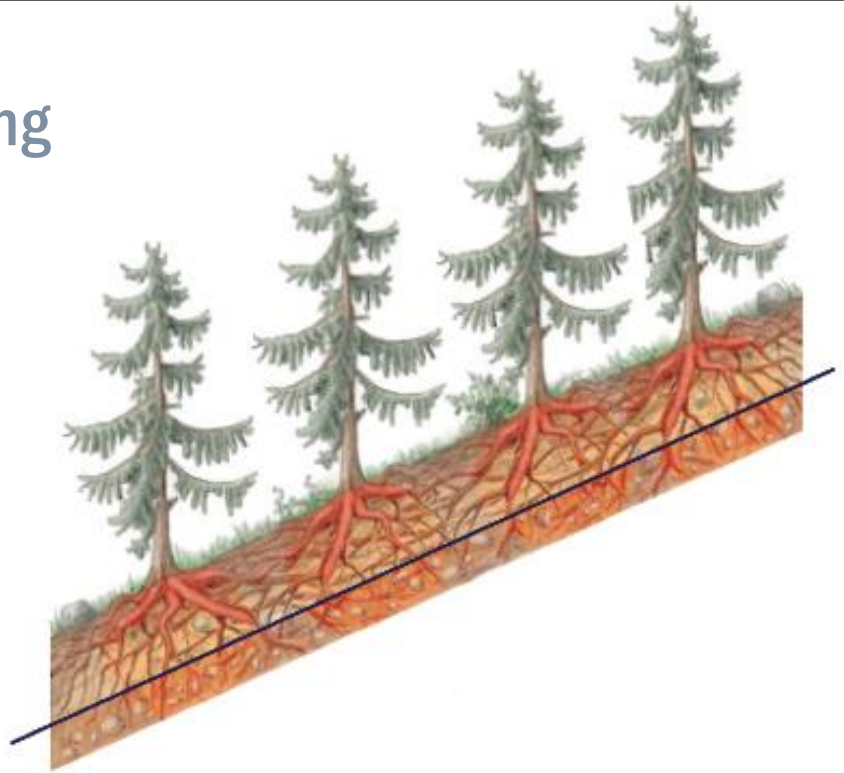

**Case 1:** Shearing
**Case 2:** Lateral tensioning
**Case 3:** Lateral compression before failure
**Case 4:** Lateral compression after failure



Schwarz et al., 2015, JGR

# Mechanismen der Wurzelverstärkung

1. Auf die Scherfläche. “Basale Wurzelverstärkung”. (seit 1977).



0.5 m

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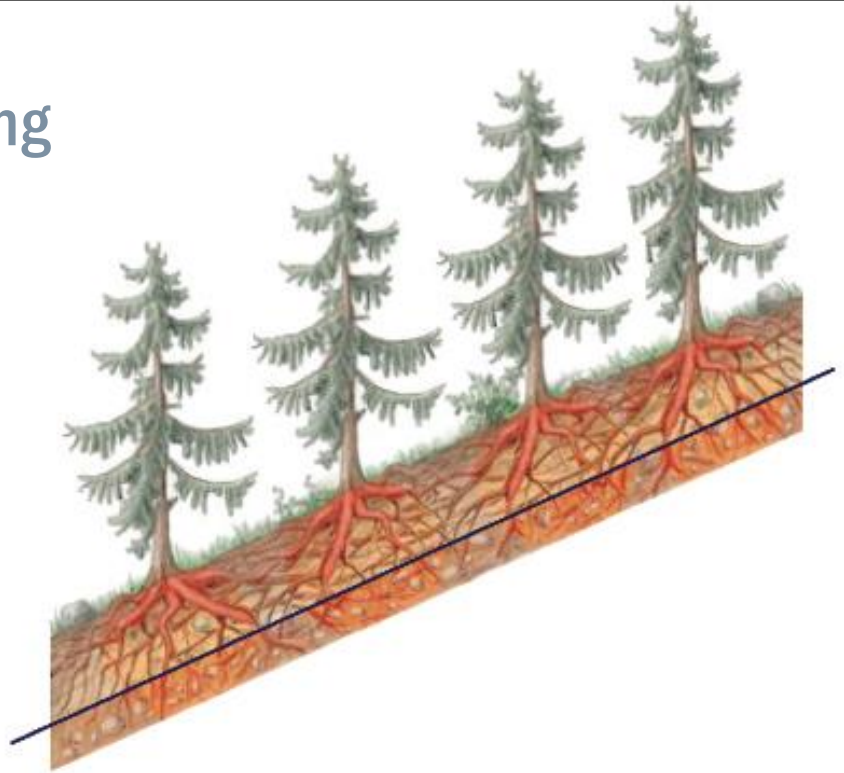
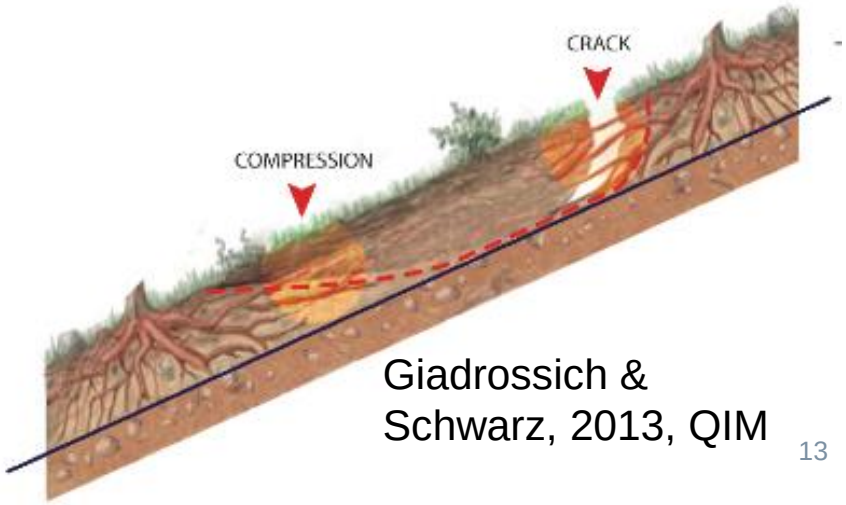
Fachhochschule

# Mechanismen der Wurzelverstärkung

1. Auf die Scherfläche. “Basale Wurzelverstärkung”. (seit 1977).



3. **Laterale Wurzelverstärkung** (since 2001)




Giadrossich & Schwarz, 2013, QIM

# Mechanismen der Wurzelverstärkung

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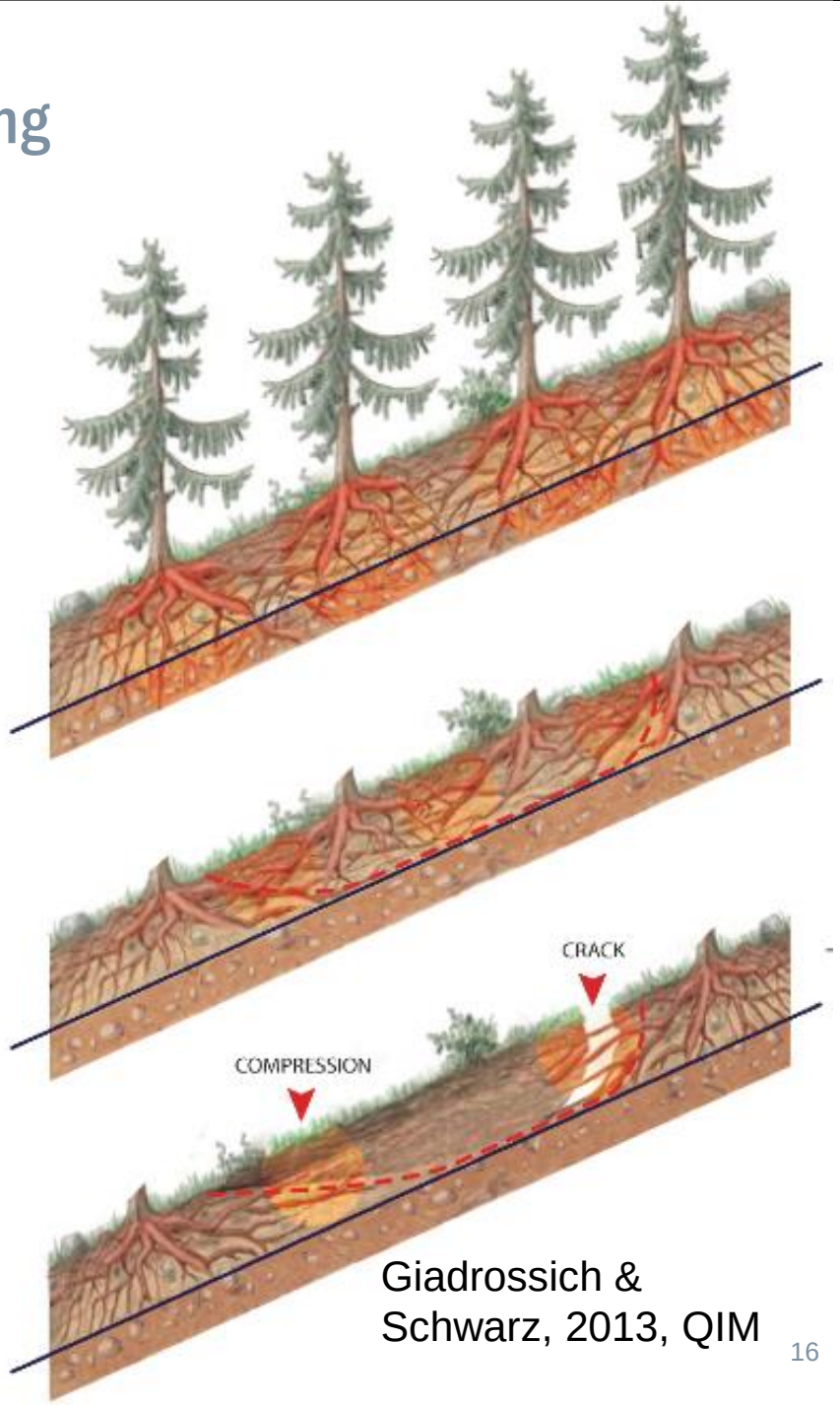
# Mechanismen der Wurzelverstärkung

1. Auf die Scherfläche. “Basale Wurzelverstärkung”. (seit 1977).

2. Erhöhung Steifigkeit und passiver Erddruck (seit 2011)

3. **Laterale Wurzelverstärkung (since 2001)**




Giadrossich & Schwarz, 2013, QIM

# Quantifizierung der Wurzelverstärkung: Was brauchen wir?

1. Kraft

2. Verformung

3. Art von Belastung (Zug, Druck, Scherung)

# Quantifizierung der Wurzelverstärkung: Aufskalierung

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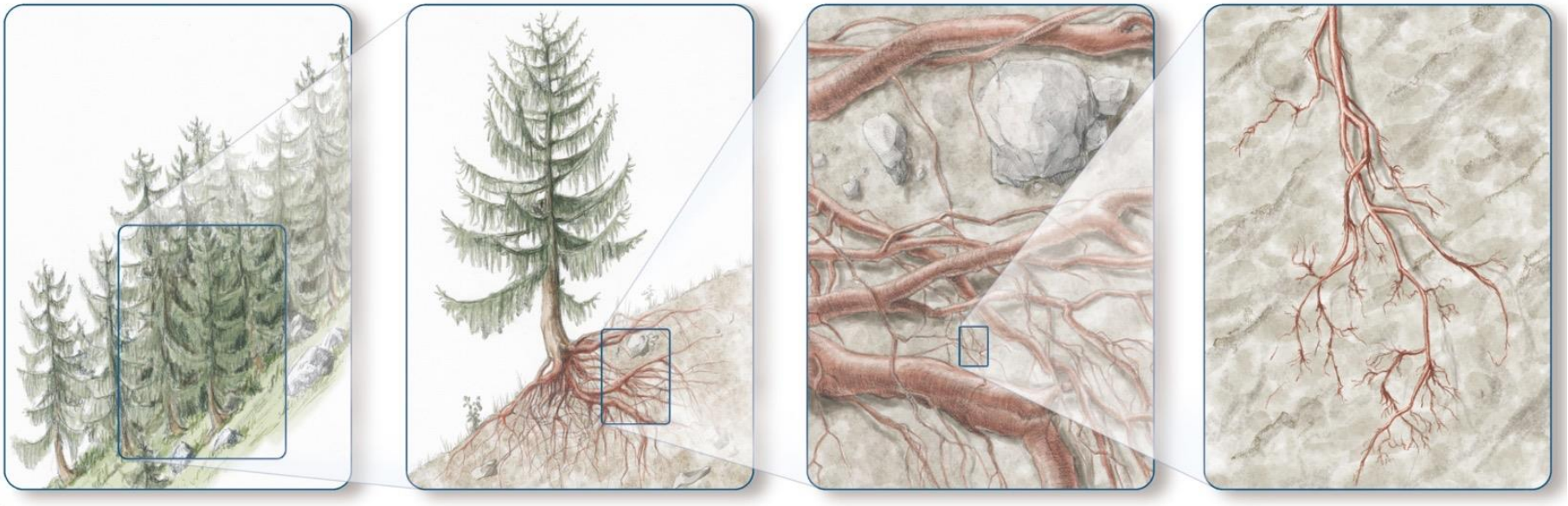
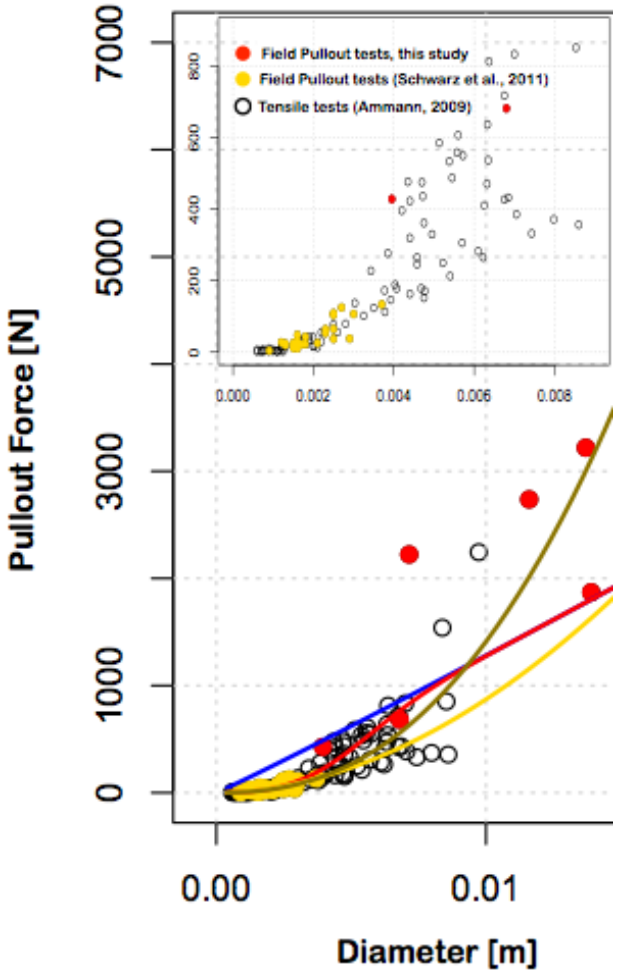
*Schwarz et al., 2010, ESPL*



RBMw

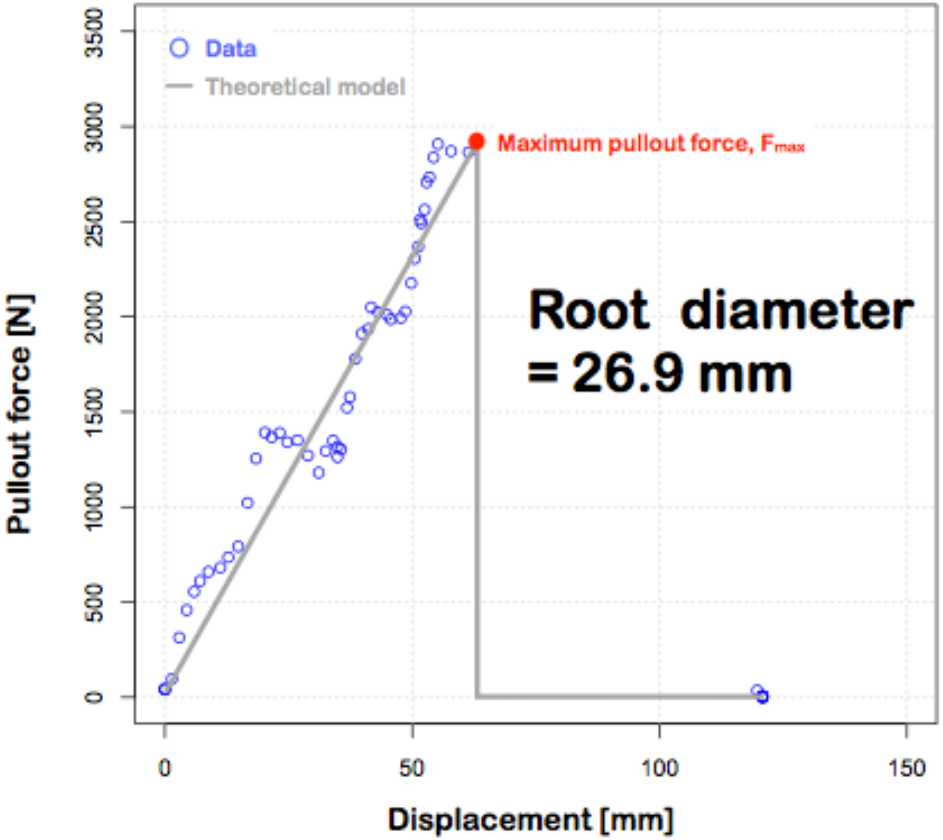
0.5 m

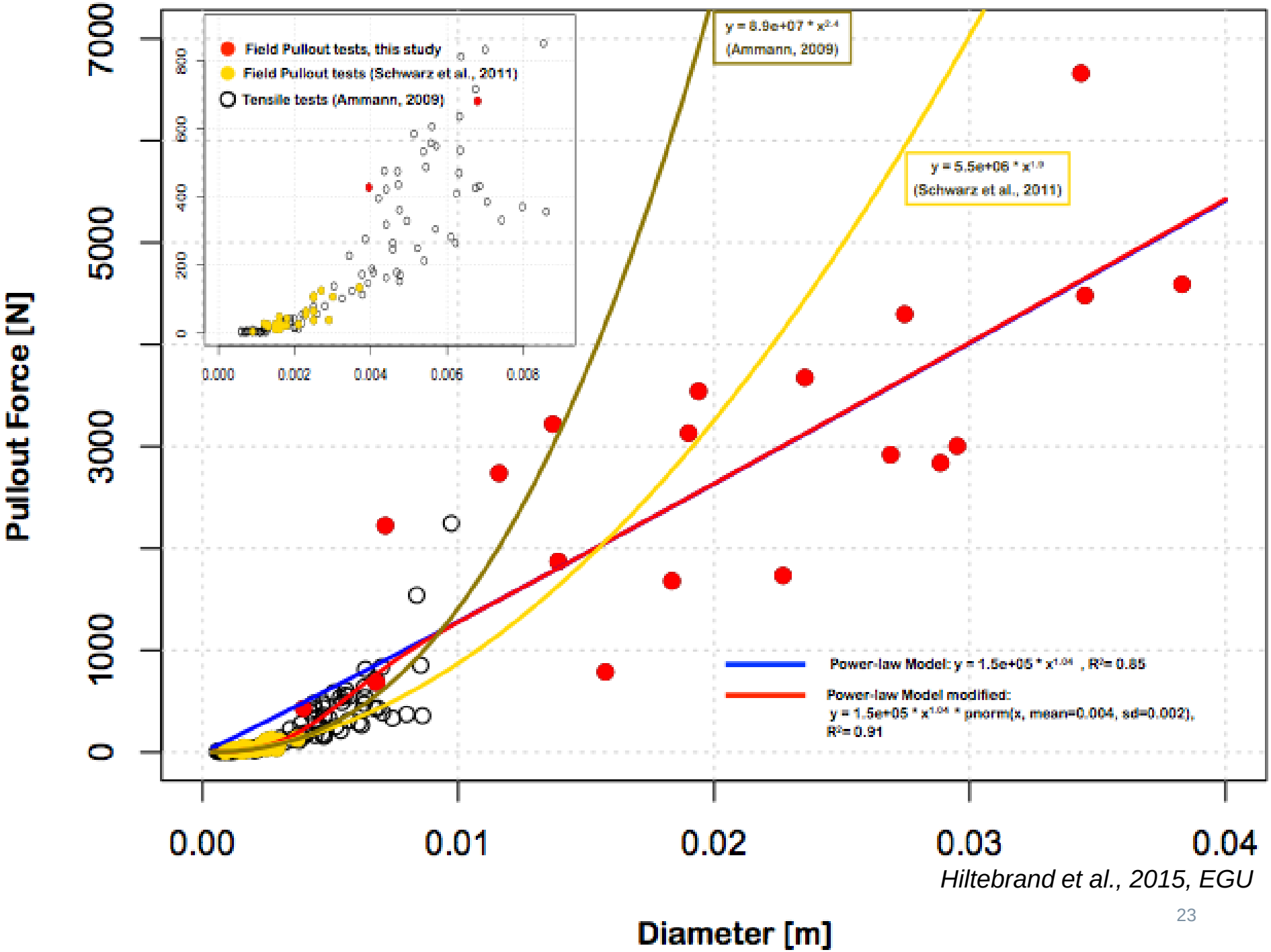
# Quantifizierung der Wurzelverstärkung: Einzeln Wurzel




?

3
2
1

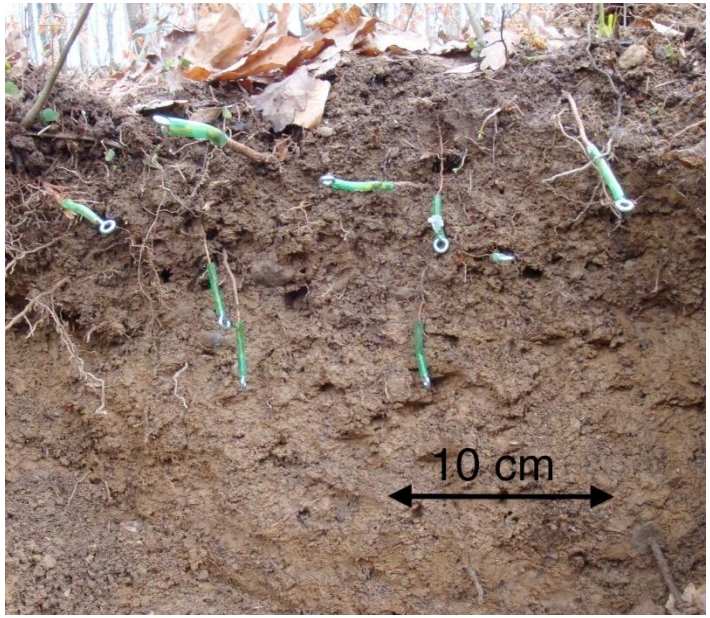

Data
Theoretical model
Maximum pullout force, $F_{max}$
Root diameter
= 26.9 mm
Pullout force [N]
0
500
1000
1500
2000
2500
3000
3500
0
50
100
150
Displacement [mm]

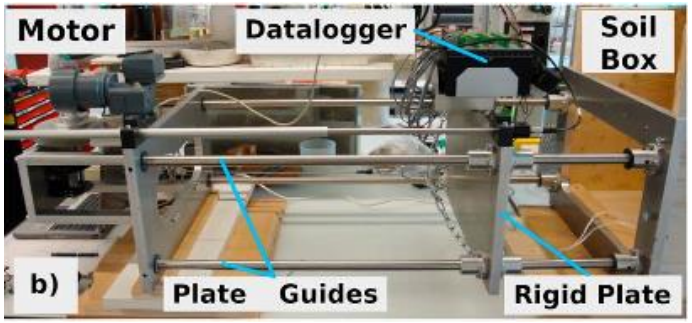



*Hiltebrand et al., 2015, EGU*

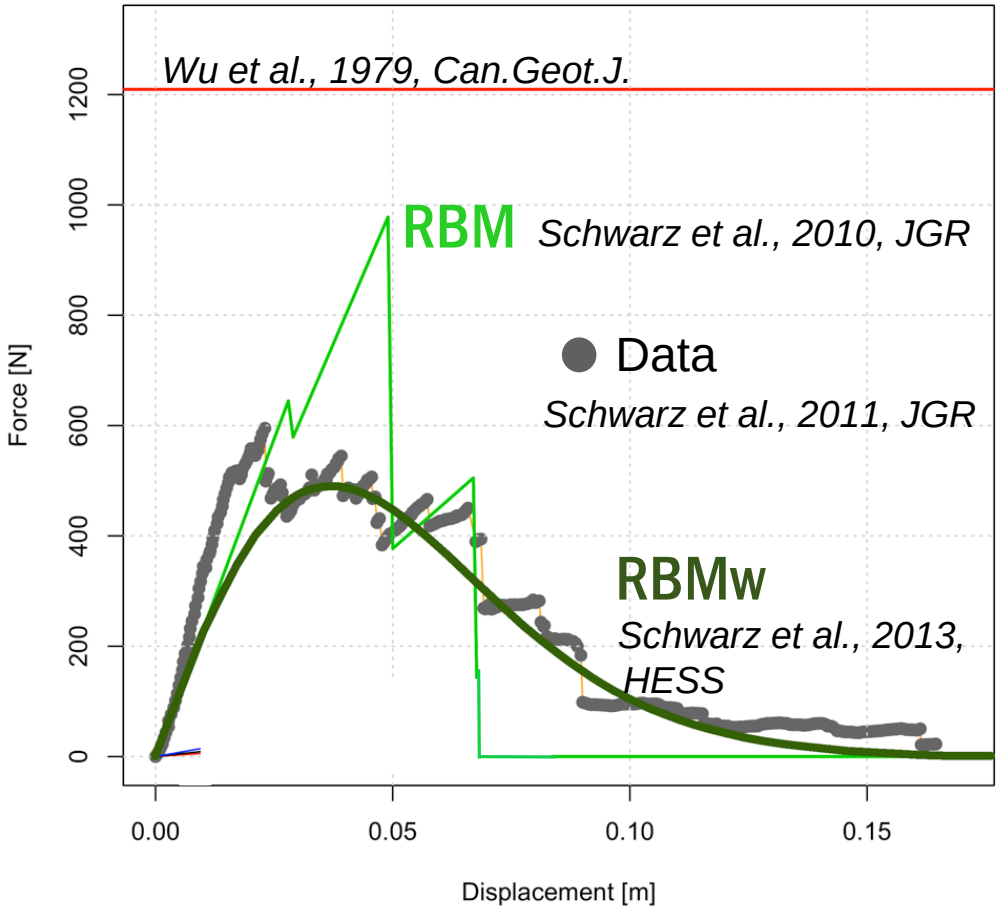
# Quantifizierung der Wurzelverstärkung, Zug: Bündel von Wurzeln - RBMw

Berner Fachhochschule



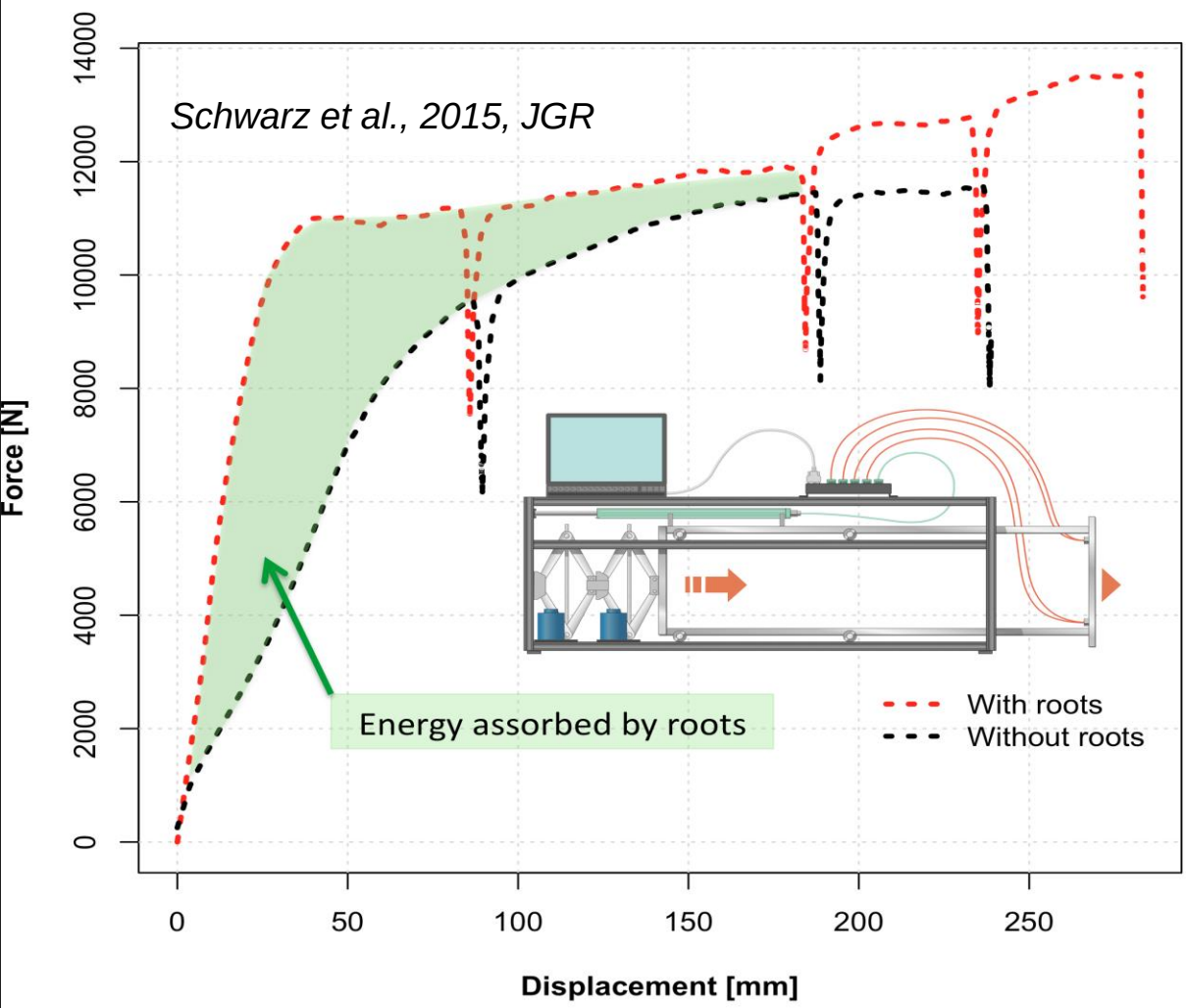




www.ecorisq.org/openFTP/Schwarz.zip

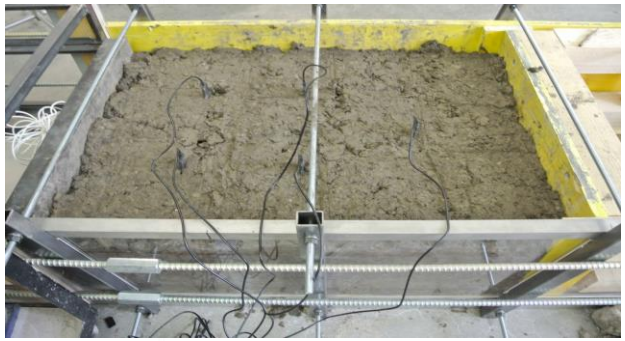


# Quantifizierung der Wurzelverstärkung, Druck: Bündel von Wurzeln - RBMw

Berner Fachhochschule



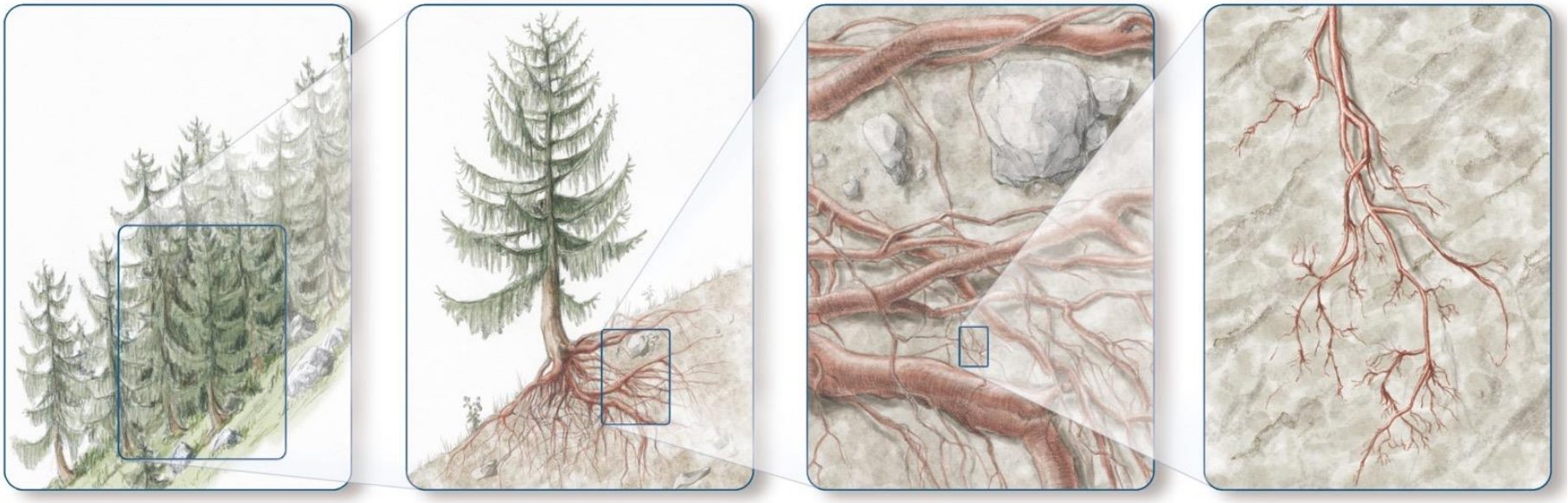
*Detail of compressed rooted soil*



*Box used for the lab. experiments*

# Quantifizierung der Wurzelverstärkung: Aufskalierung

*Schwarz et al., 2010, ESPL*

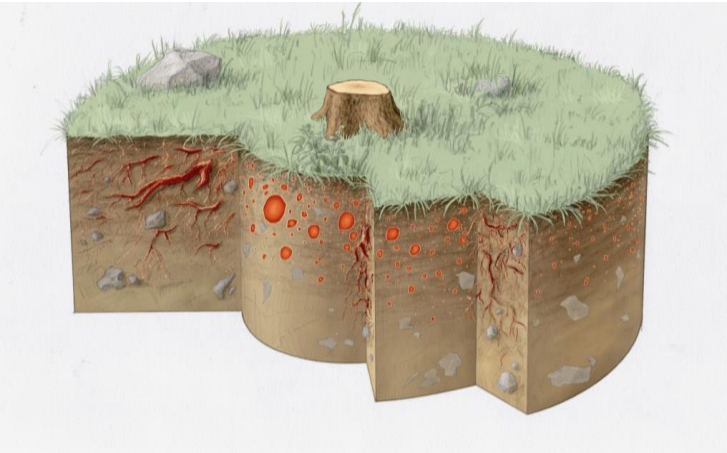


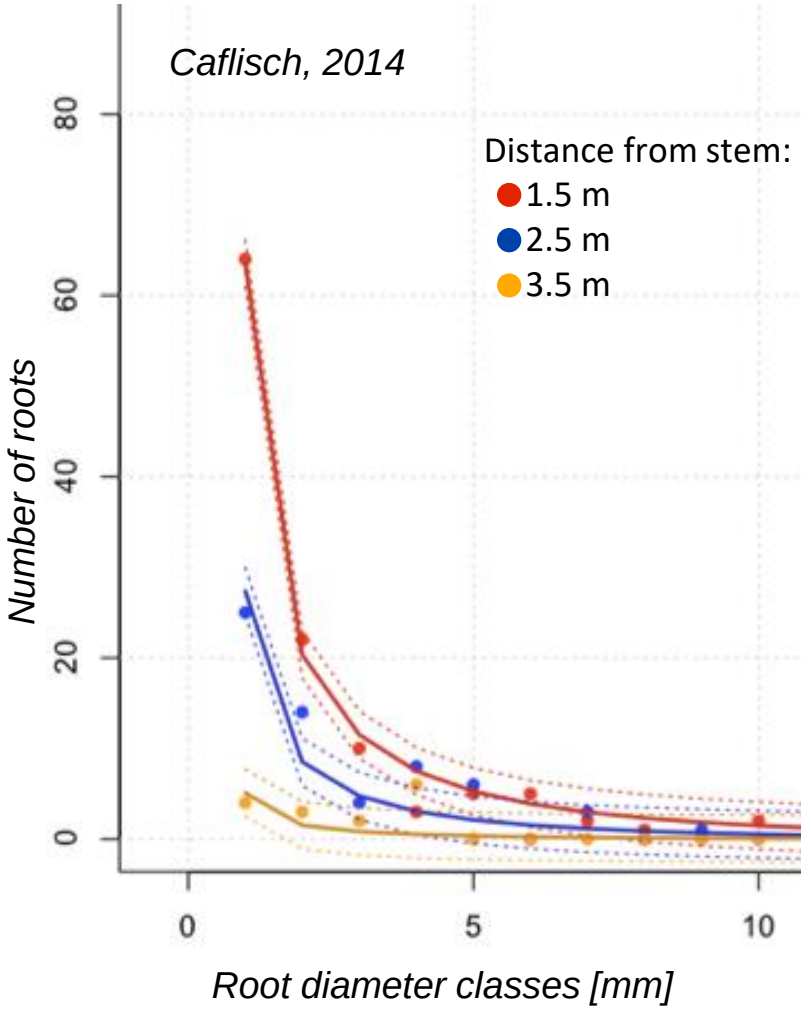
Root Distribution Model

RBMw

# Quantifizierung der Wurzelverstärkung: Wurzelverteilung

*Schwarz et al., 2010, ESPL*





*Betula pendula*

*Ailanthus altissima*

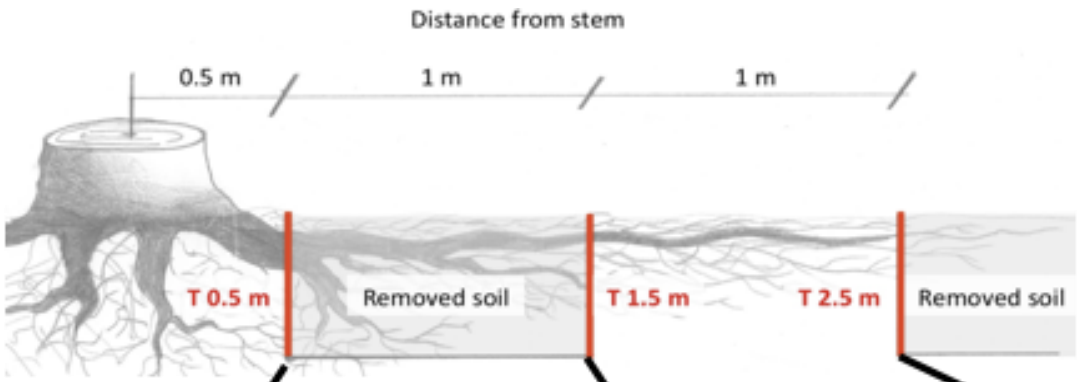
Castanea sativa

*Quercus pubescens*

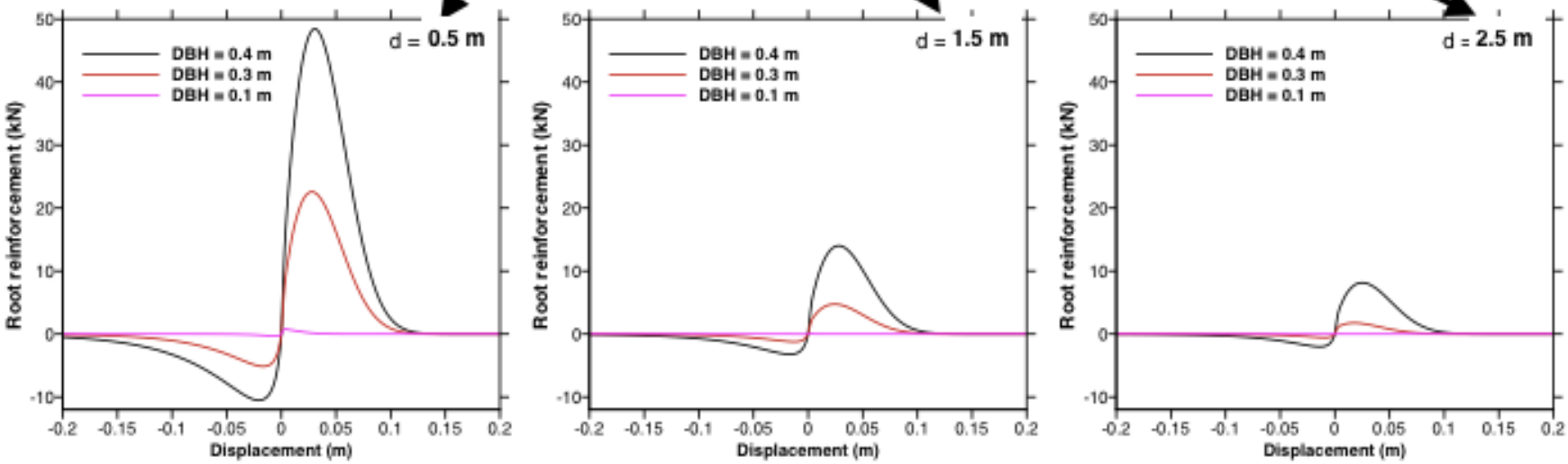
*Trachycarpus fortunei*

# Quantifizierung der Wurzelverstärkung: Wurzelverteilung

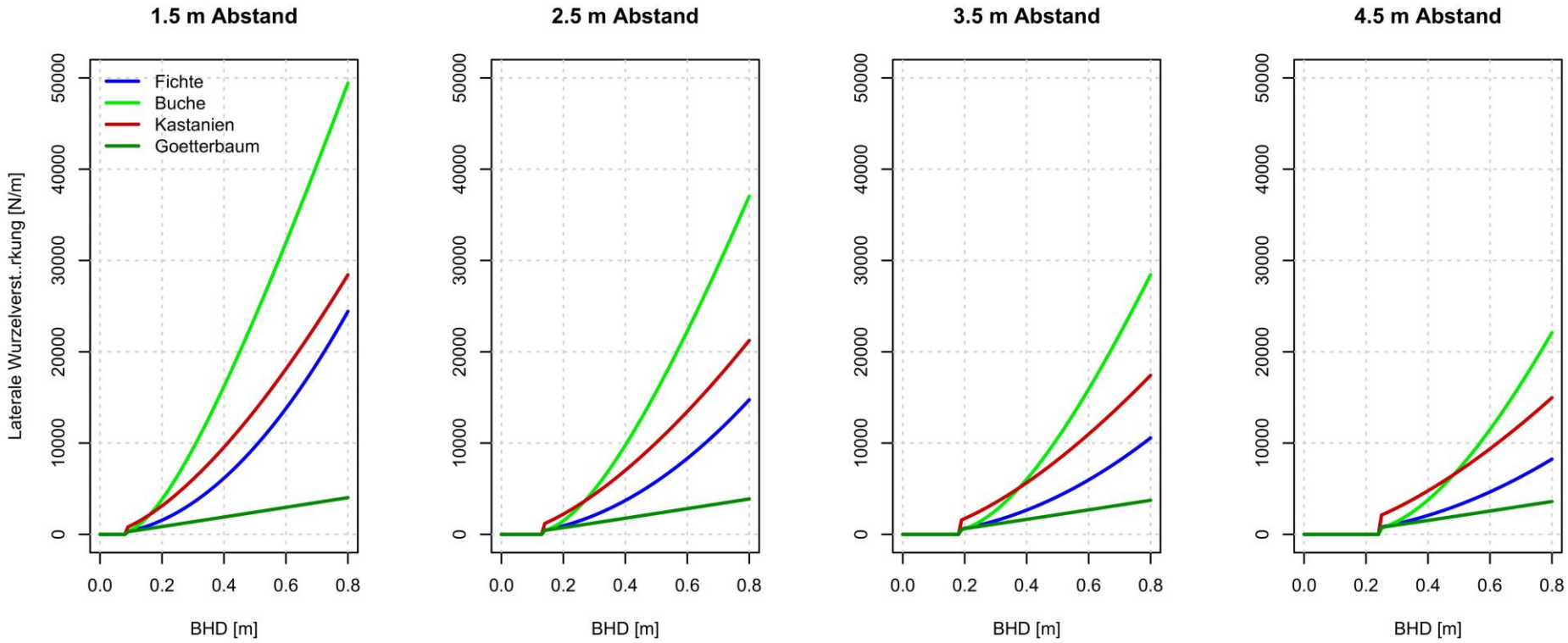
Berner Fachhochschule




*Dazio et al., 2018, Forest Ecol. Manag.*

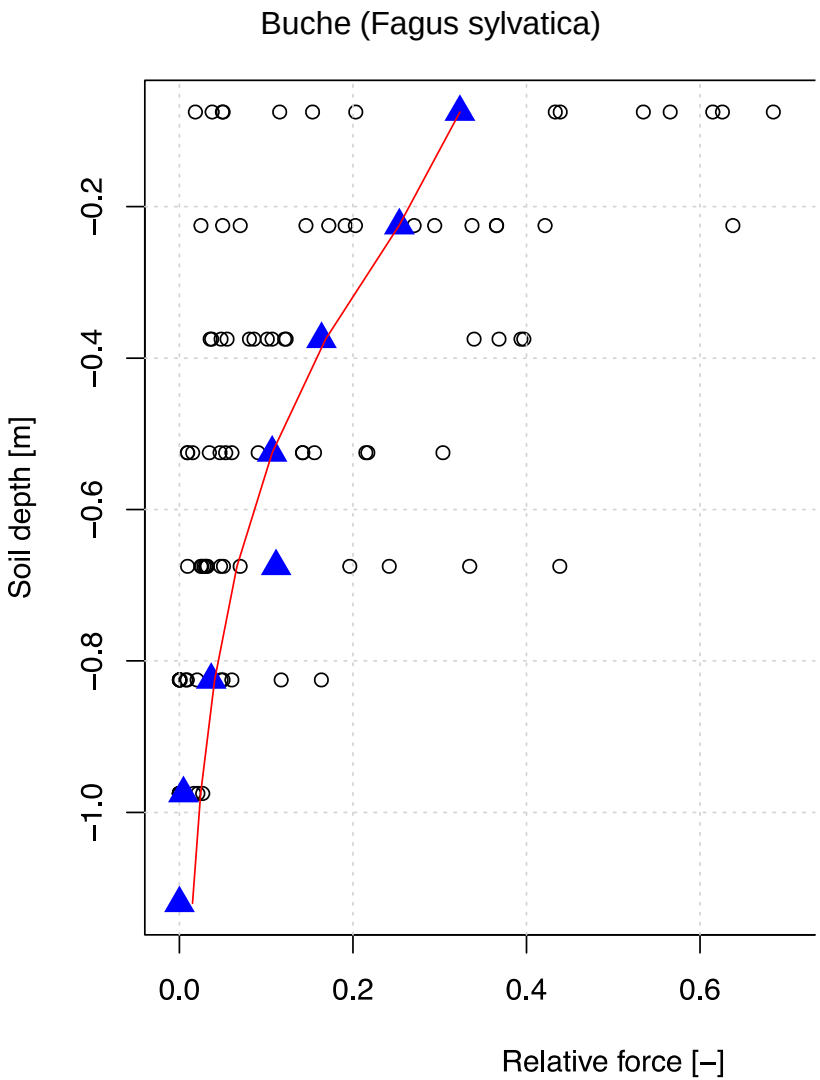


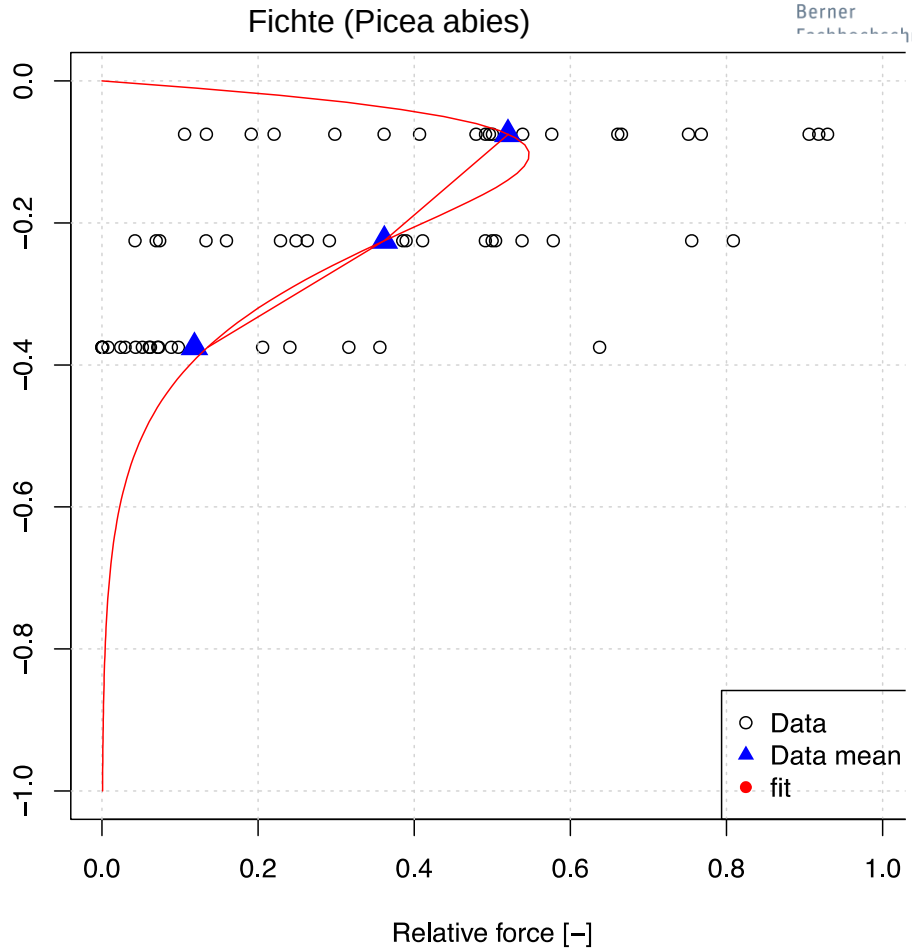
# Quantifizierung der Wurzelverstärkung: Vergleich Baumarten




*Schwarz et al., 2019, FAN Agenda*

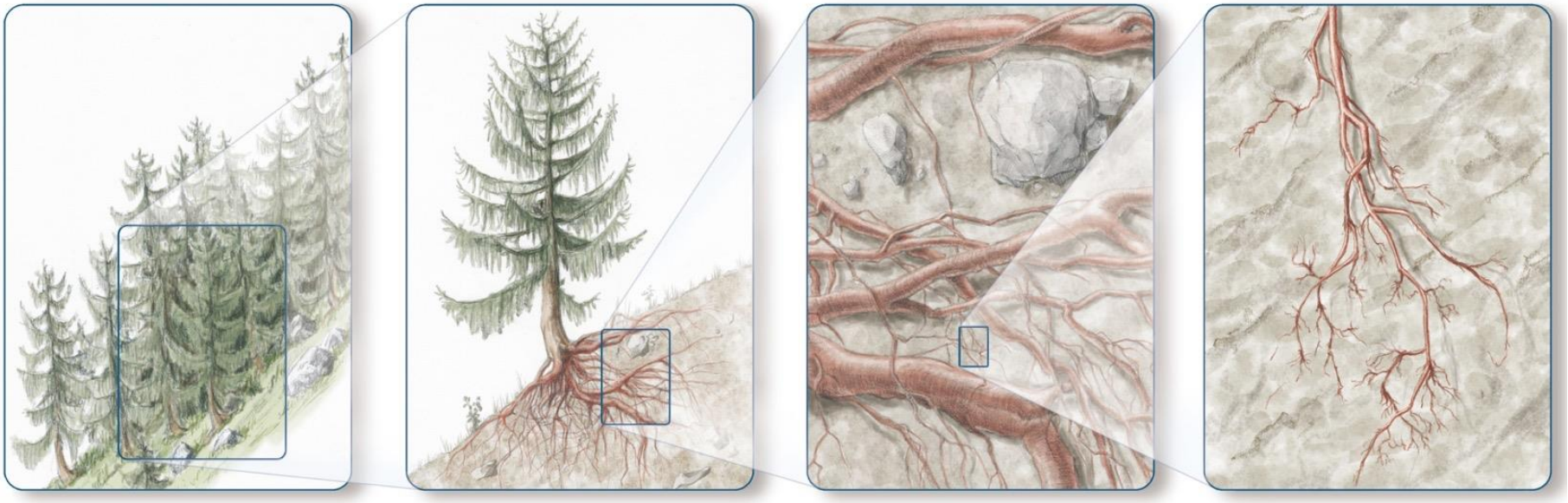
# Quantifizierung der Wurzelverstärkung: Vergleich Baumarten



# Quantifizierung der Wurzelverstärkung: Aufskalierung

*Schwarz et al., 2010, ESPL*



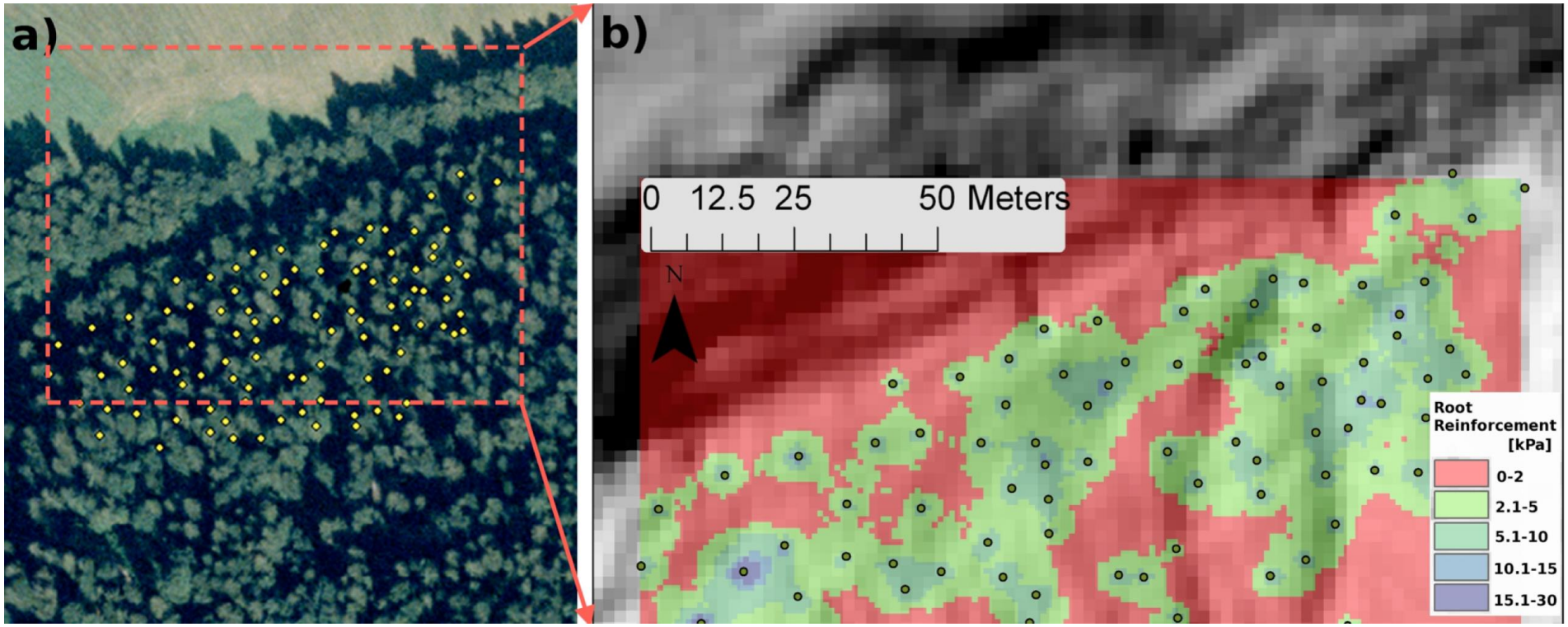
Remote Sensing

Root Distribution Model

RBMw

# Quantifizierung der Wurzelverstärkung: Räumliche Verteilung der Wurzelverstärkung

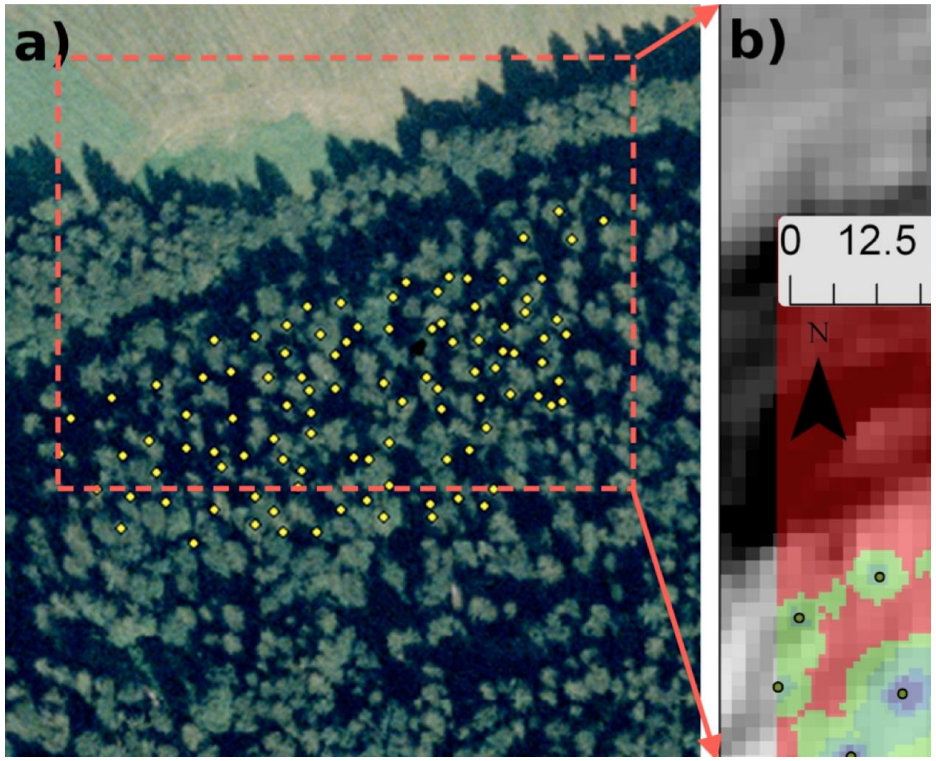
Berner Fachhochschule




*Schwarz et al., 2012, Geosciences*

*Steinmösli, Emmental, CH*

# Quantifizierung der Wurzelverstärl
# Räumliche Verteilung der Wurzelv




*Steinmösli, Emmental, CH*

**FINT – Find Individual Trees**

User manual

ecorisQ.
International association for natural hazard risk management
www.ecorisq.org

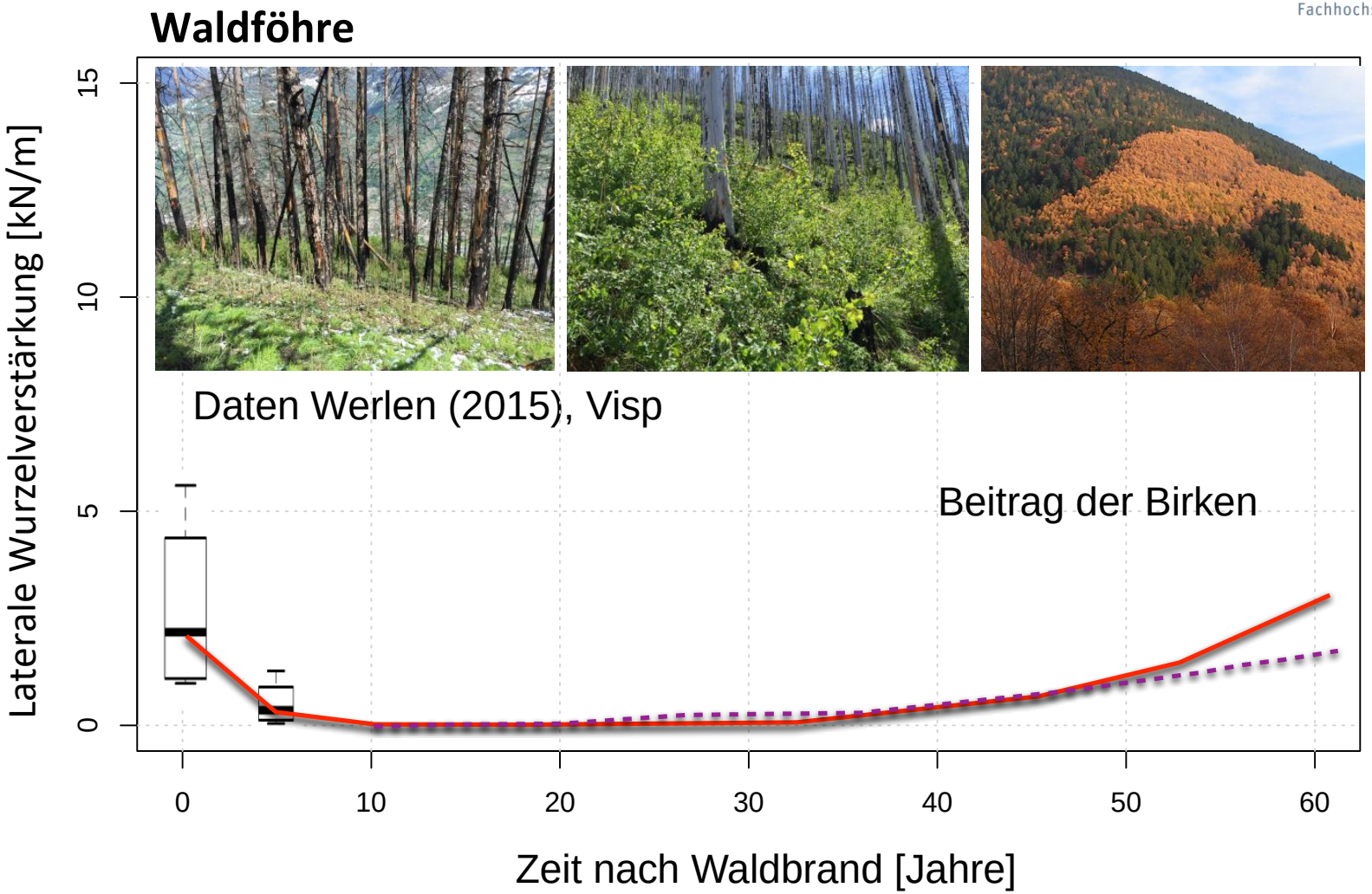
# Quantifizierung der Wurzelverstärkung: Zeitliche Entwicklung der Wurzelverstärkung

Berner Fachhochschule

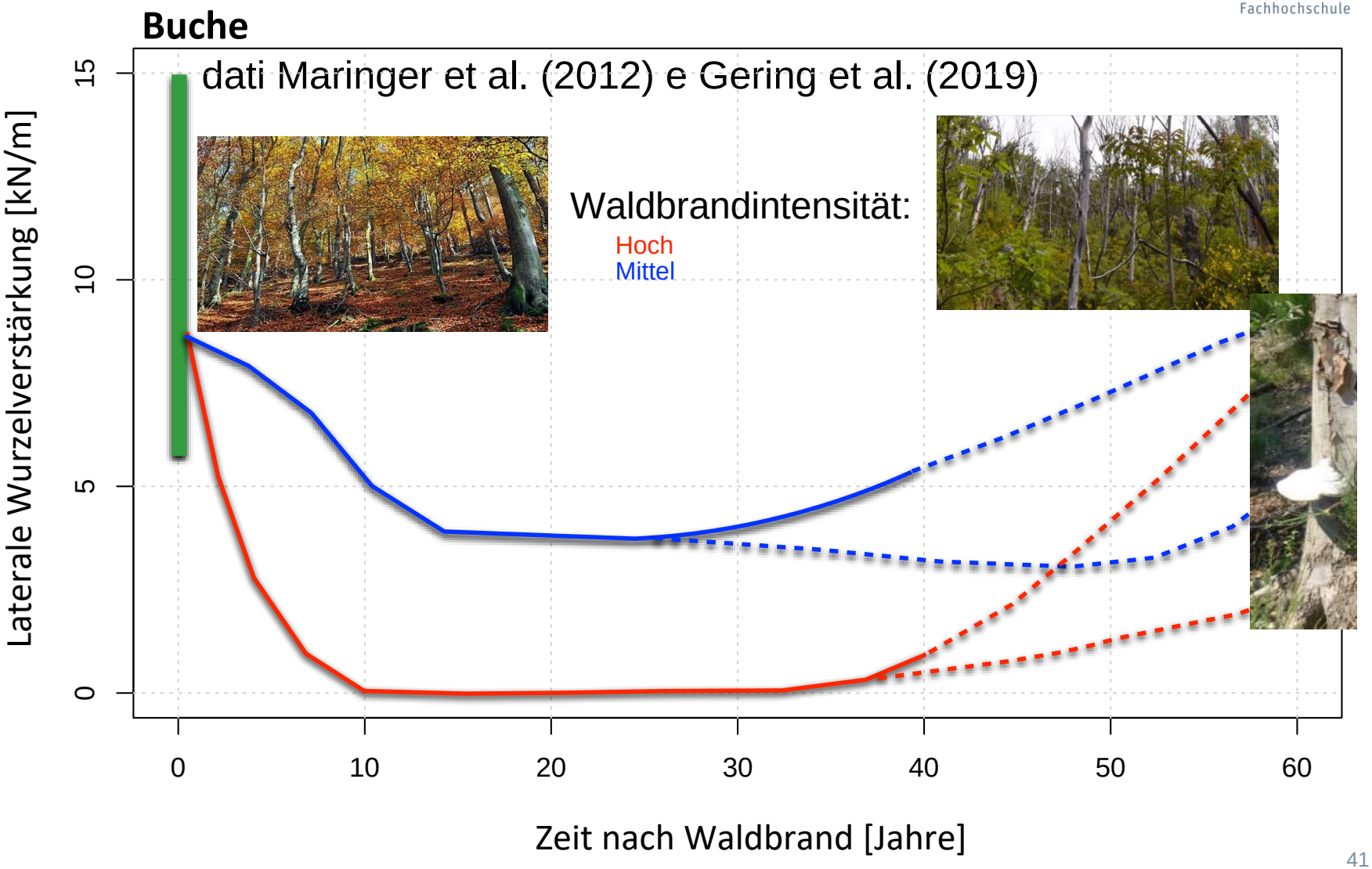
2013

2015

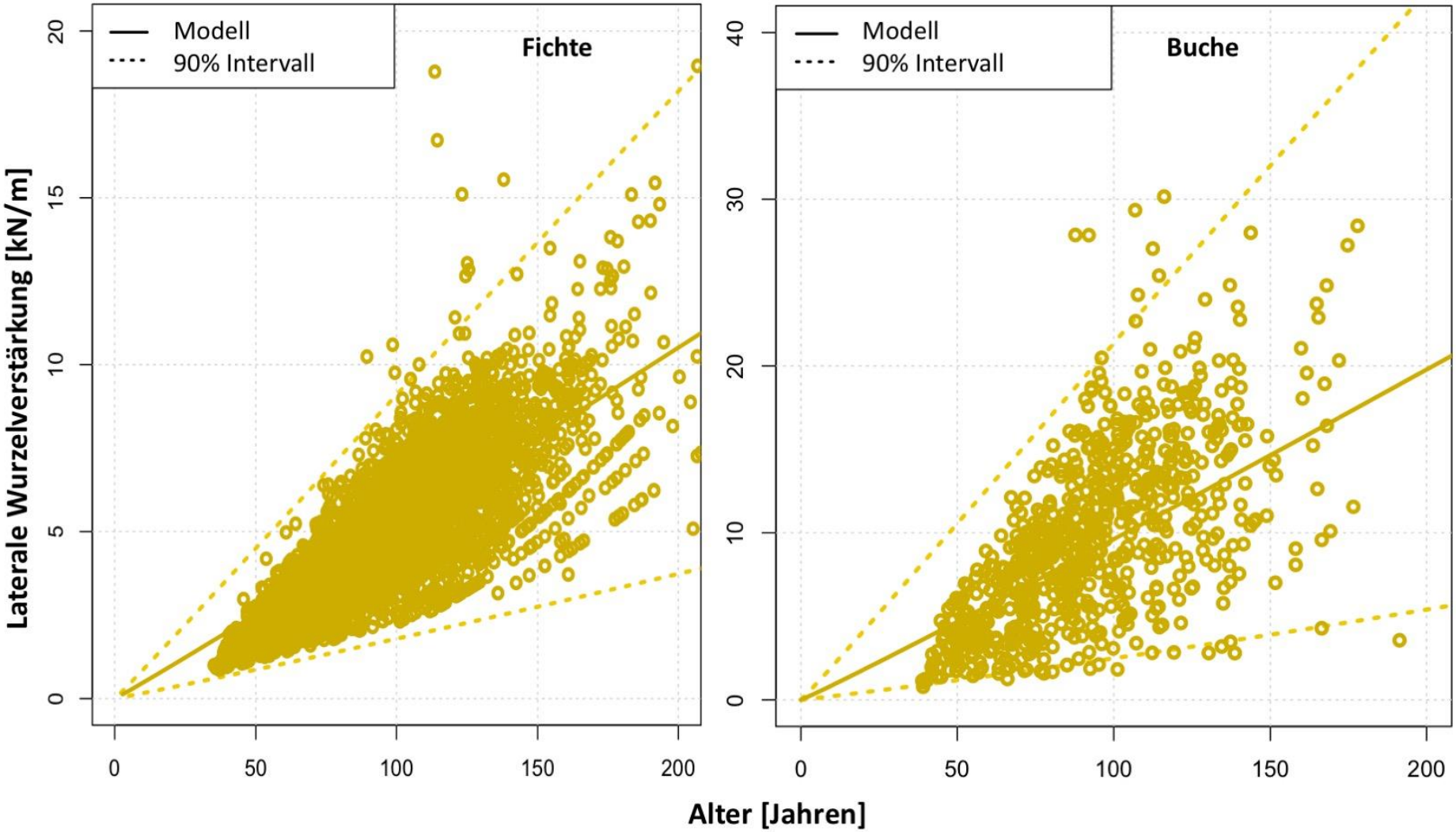
# Quantifizierung der Wurzelverstärkung: Zeitliche Entwicklung der Wurzelverstärkung



# Quantifizierung der Wurzelverstärkung: Zeitliche Entwicklung der Wurzelverstärkung



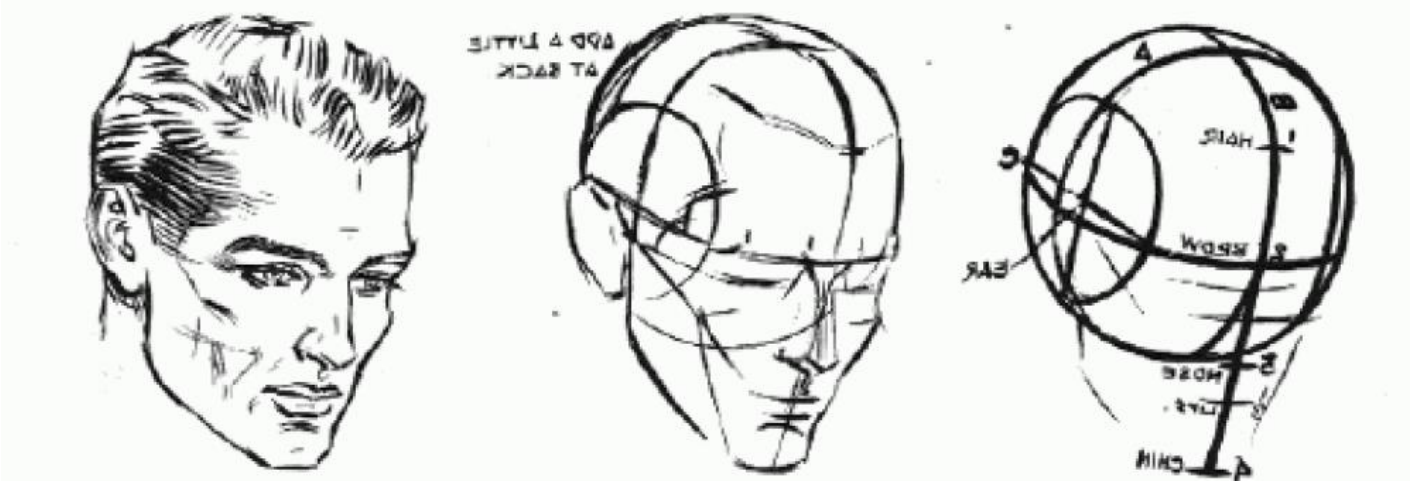
# Quantifizierung der Wurzelverstärkung: Zeitliche Entwicklung der Wurzelverstärkung



Wie viel stabilisiert dieser Wald? Und wo?

# Implementierung der Wurzelverstärkung in Hangstabilitätsmodelle: **simplify**!

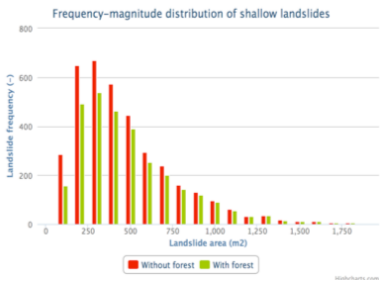
The more you need/**want to simplify**, **the greater your need to understand** which of the components you can legitimately simplify or discount!



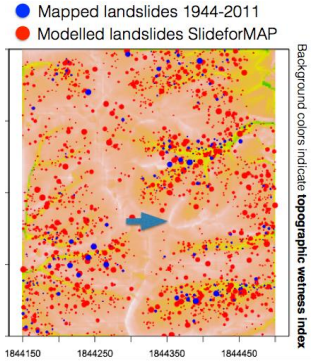
# Implementierung der Wurzelverstärkung in Hangstabilitätsmodelle

Berner Fachhochschule

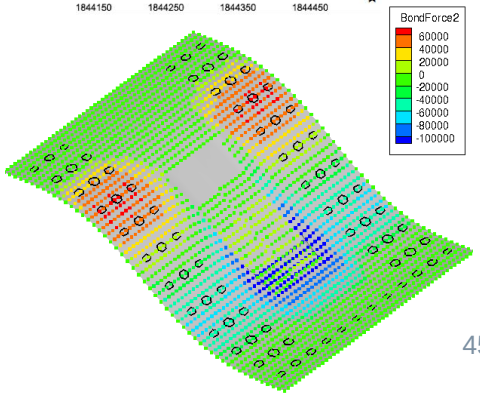
- **“Feld” Werkzeug** (**Slidefor.NET**): Anwendung für einer Hang. Wenige Minuten Auffand. Für erste Schätzung.




- **Regionale Skala** (**SlideforMAP**): ca. 1 Tag computation + Feldarbeit. Für Hinweiskarte Schutzwald und Priorisierung in Schutzwaldpflege.

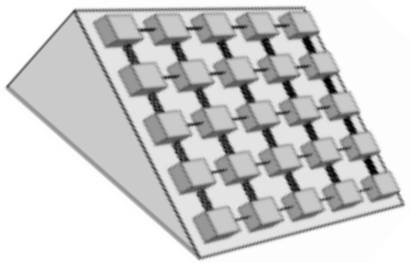


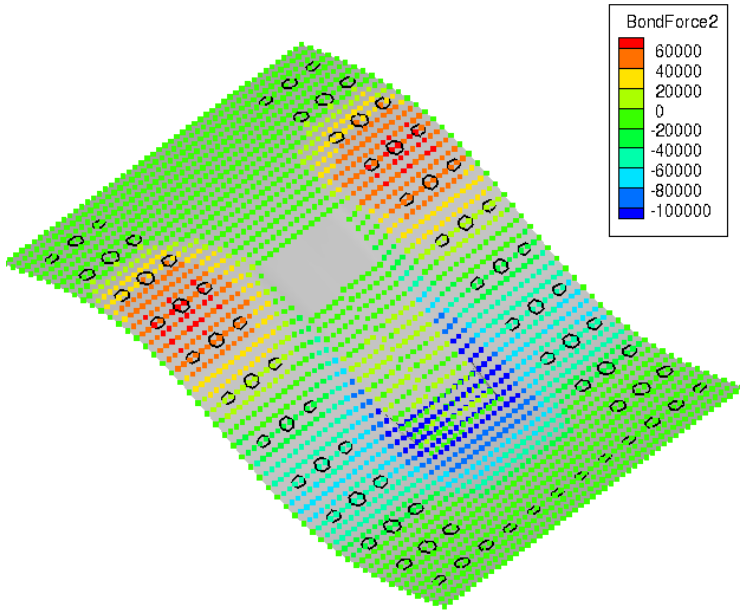

- **Hangskala** (**SOSlope**): ca. 1 Tag computation + Feldarbeit. Für Risiko-basierte Analyse, Planung waldbauliche Massnahmen.



# SOSlope

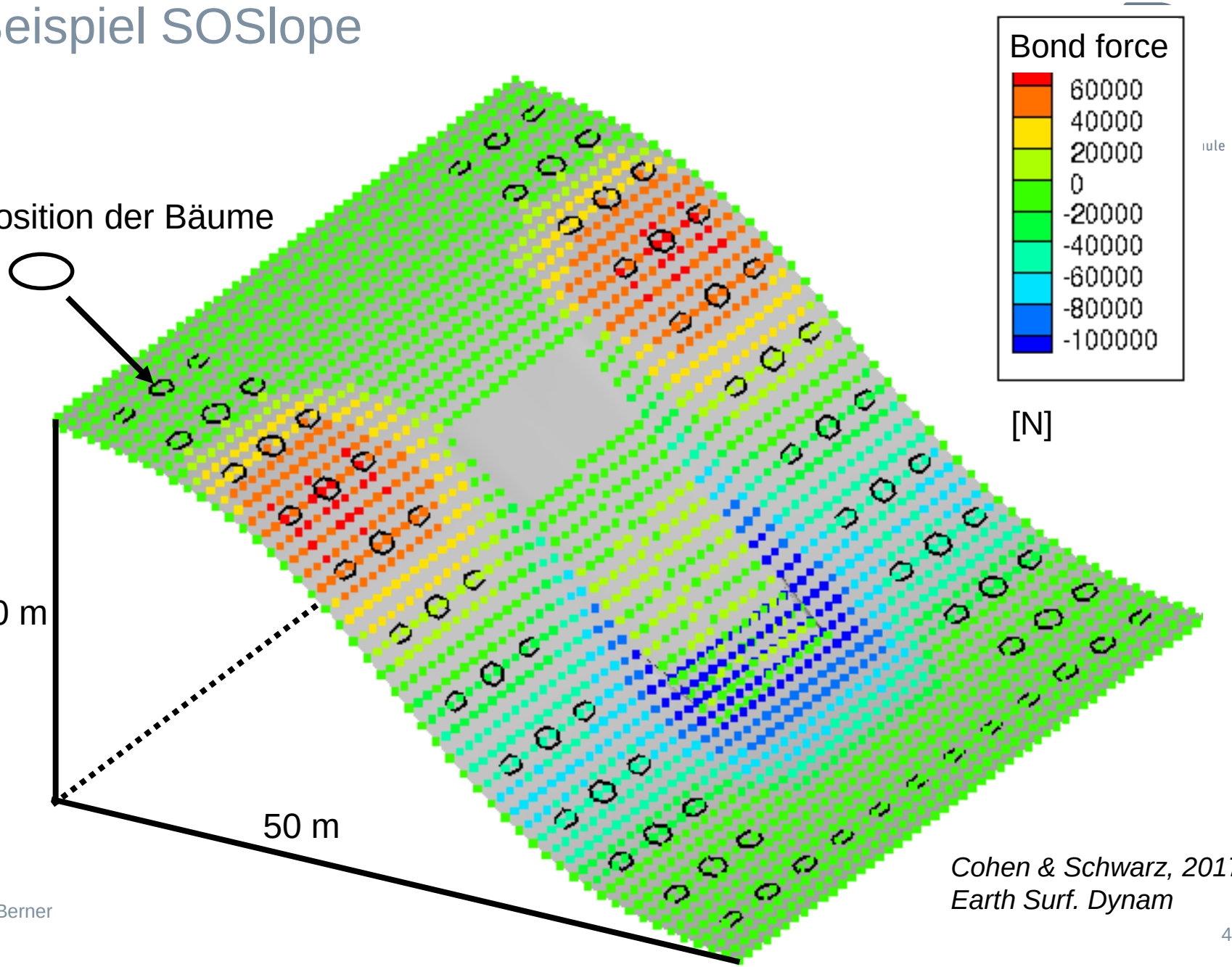
*Cohen & Schwarz, 2017, Earth Surf. Dynam*





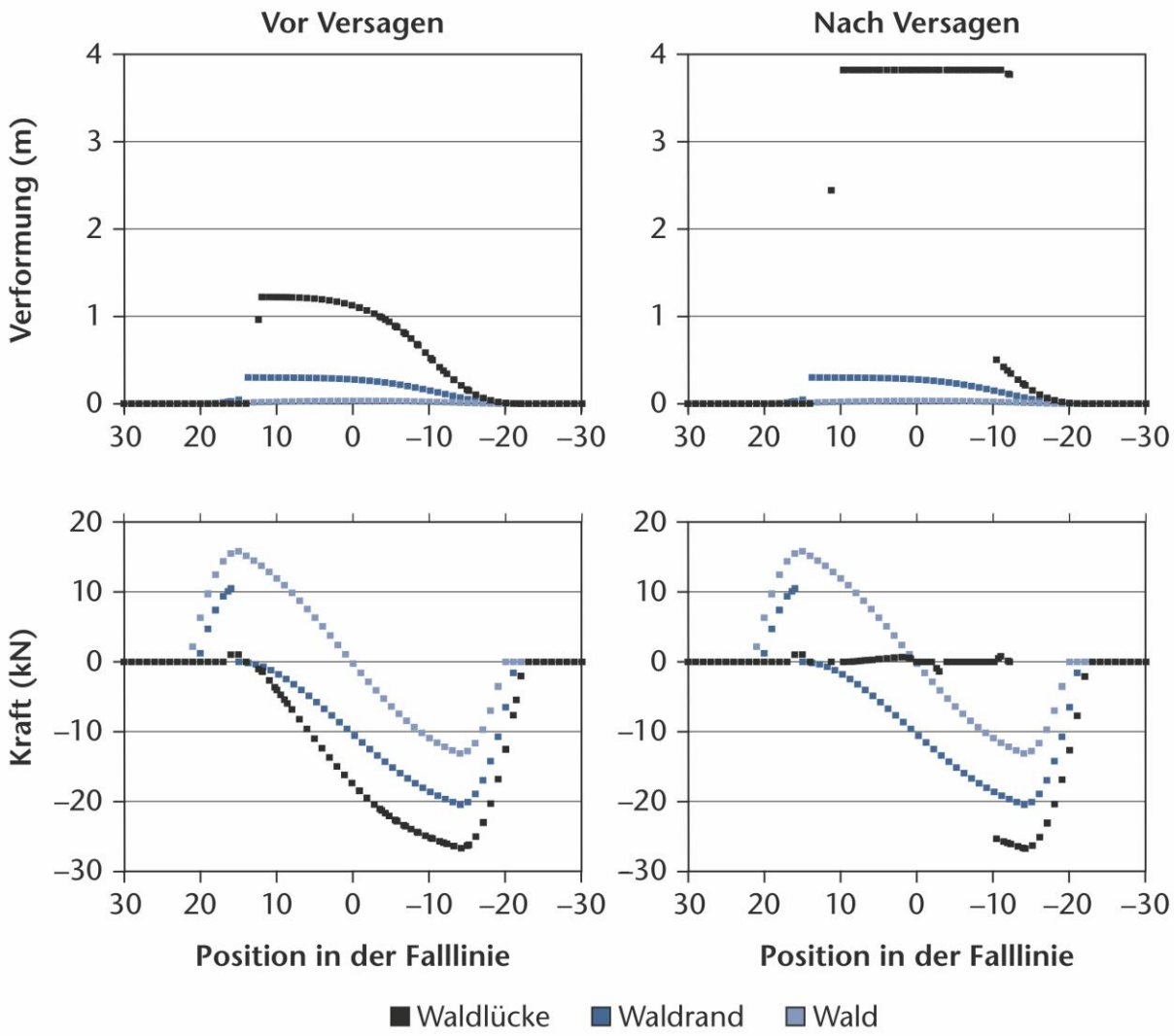

- **Feder-Block Modell**
- **Laterale und Basale Wurzelverstärkung**
- **Ungesättigte Bodenmechanik**
- **Hydrologische Modellierung (dual Porosity)**

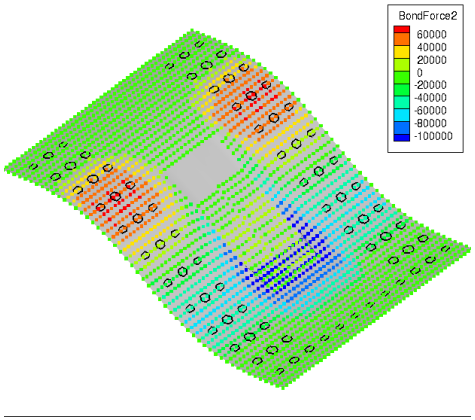
# Beispiel SOSlope



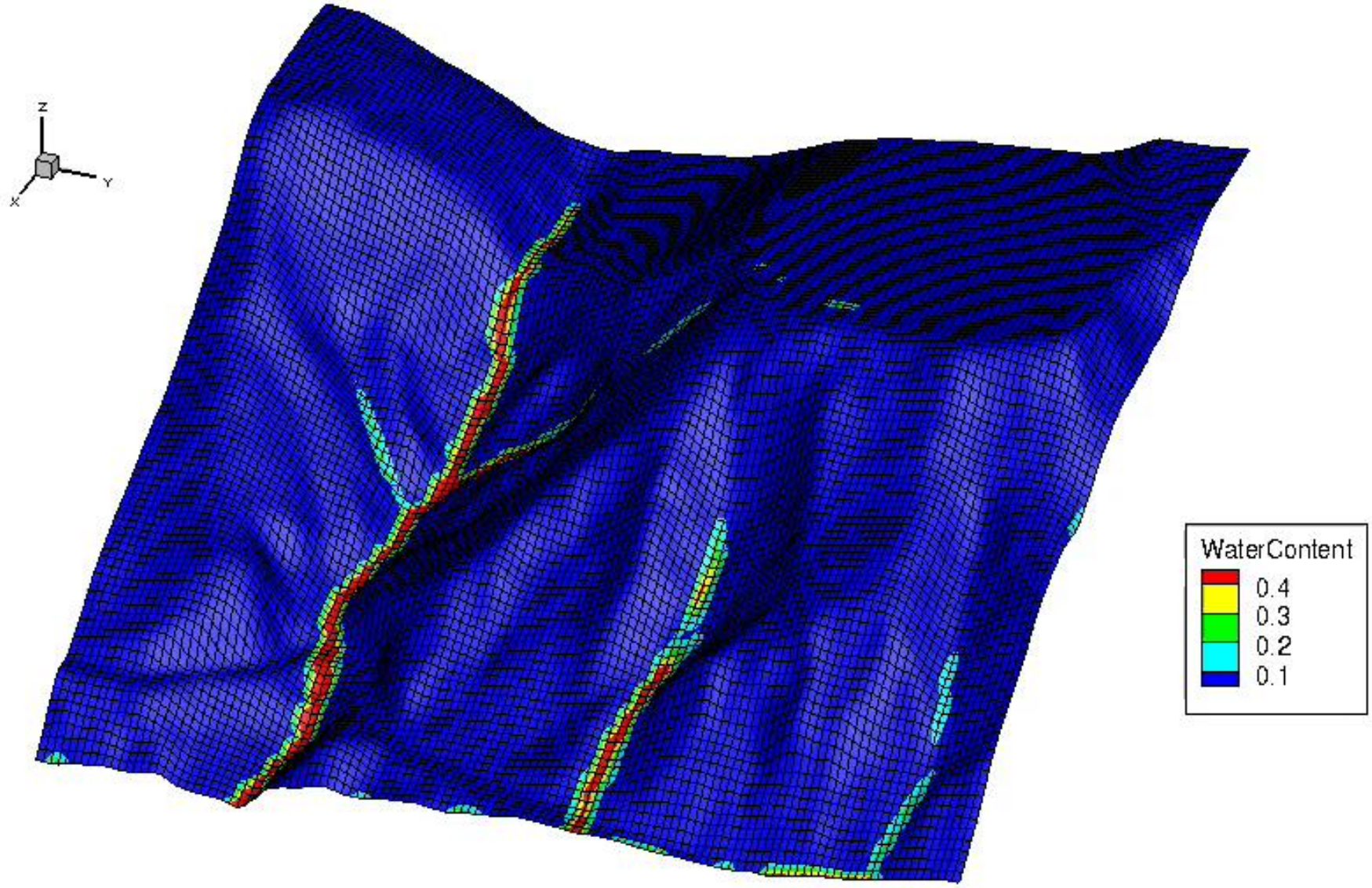

*Cohen & Schwarz, 2017, Earth Surf. Dynam*

# Beispiel SOSlope: Aktivierung Wurzelverstärkung



# SOSlope: Hydrologie



# Beispiel SOSlope: Protect-Bio

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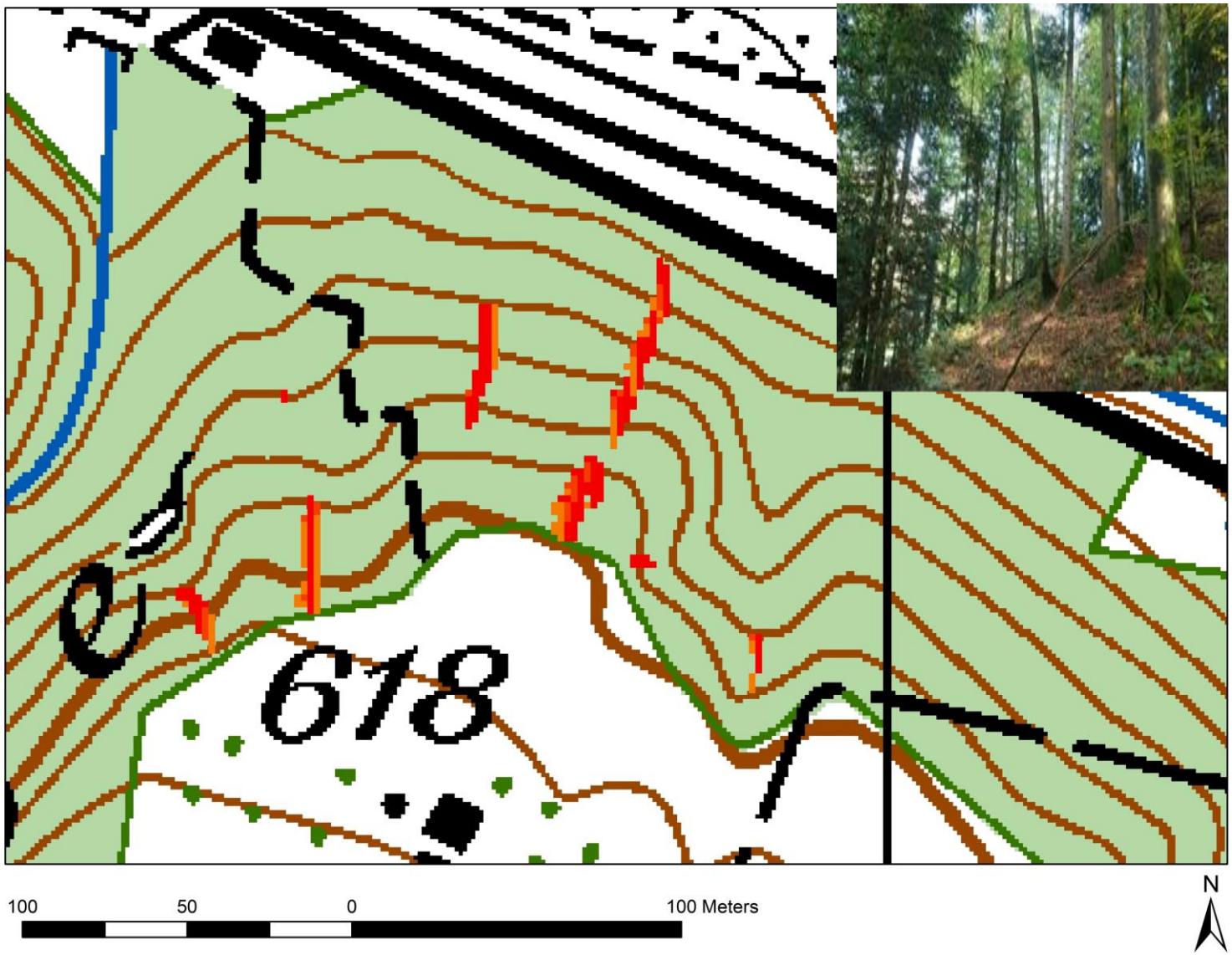
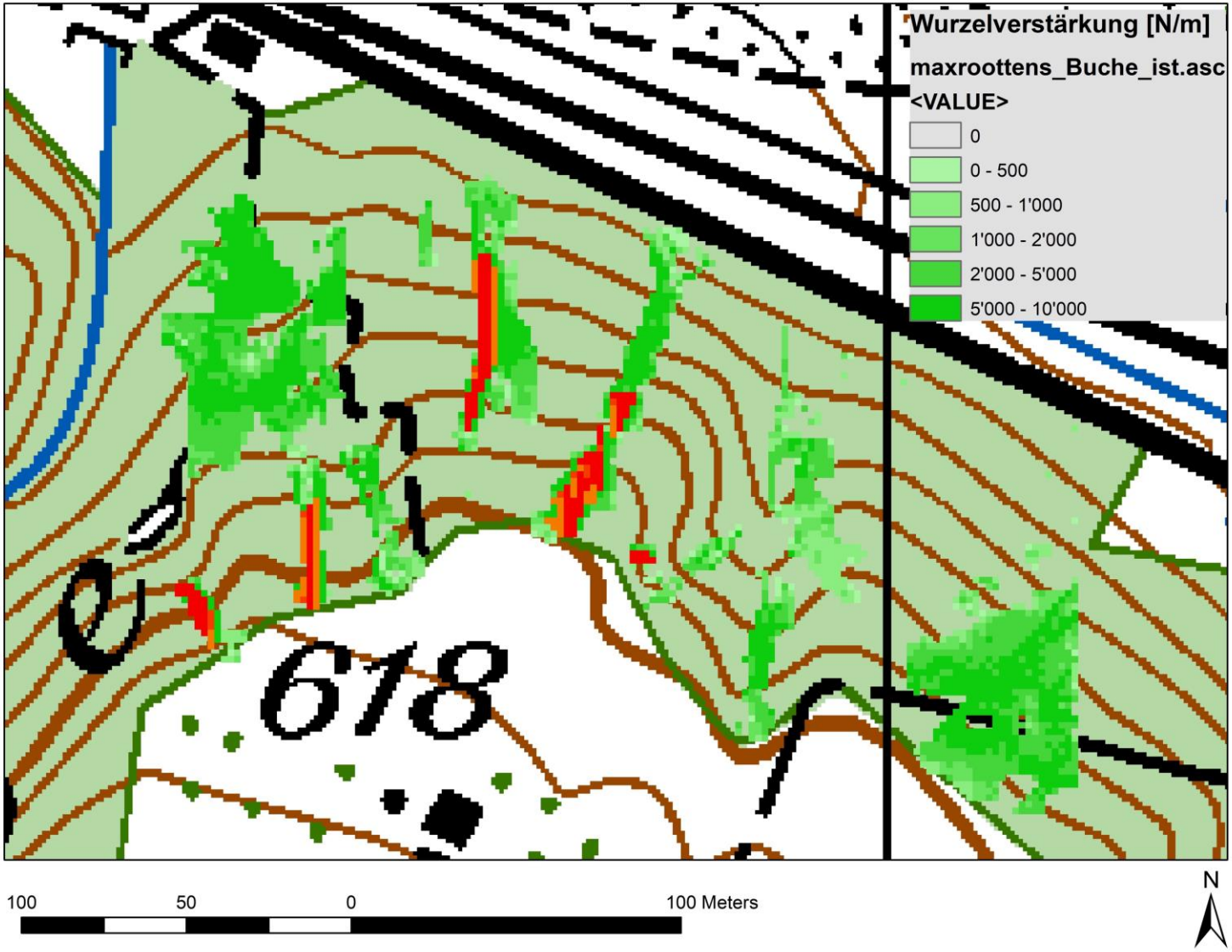
# Beispiel SOSlope: Protect-Bio

SOSlope, 100J, mit Wald, IST (Fichte)



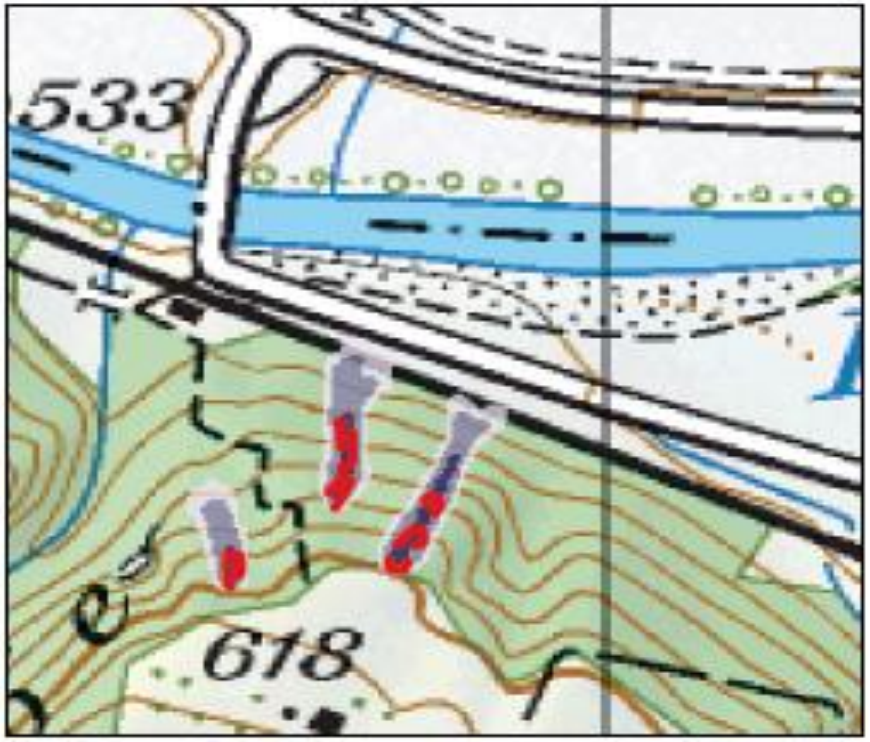
# Beispiel SOSlope: Protect-Bio

SOSlope, 100J, mit Wald, IST (Buche), aktivierte Wurzelverstärkung

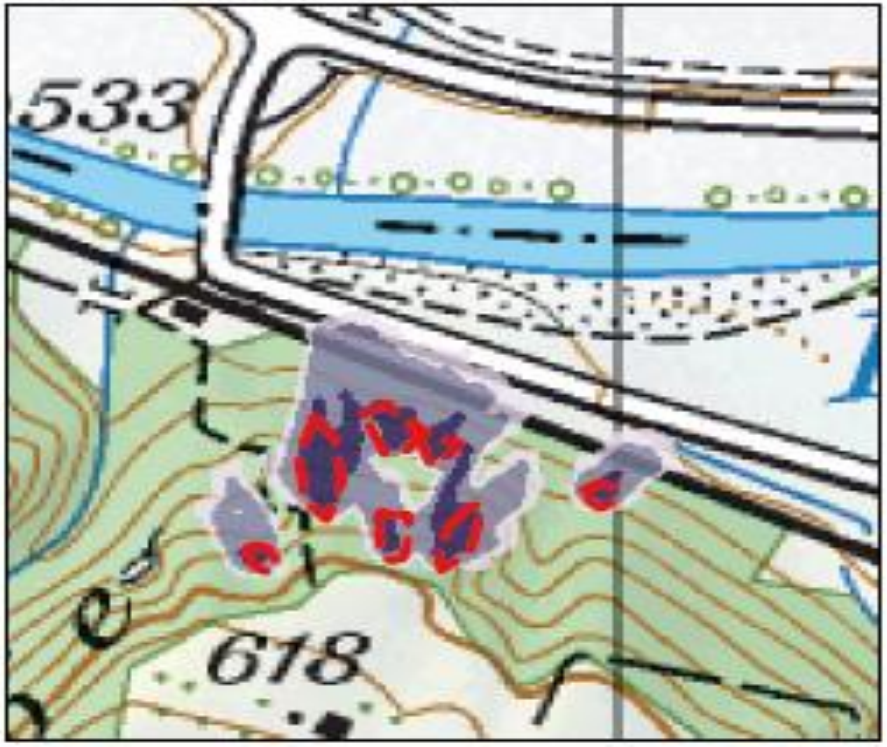


# Beispiel SOSlope: Protect-Bio

Langnauerwald - 30J (Mit Wald - Ist-Zustand)




Langnauerwald - 30J (ohne Wald)



# Beispiel SOSlope: Protect-Bio

Berner Fachhochschule

| Langnauerwald | Vor Massnahme | Nach Massnahme (mit Waldszenarien) | | |
|---|---|---|---|---|
| | ohne Wald | Buche minimal (NaiS) | Buche ideal (NaiS) | Wald Istzustand |
| **Risiko** | 207‘561 CHF/a | 207‘561 CHF/a | 160‘436 CHF/a | 104‘739 CHF/a |
| **Risikoreduktion** | - | 0 CHF/a | 47‘125 CHF/a | 102‘822 CHF/a |
| **Nutzen/Kosten-Verhältnis** | - | 0 | 22.1 | 48.6 |

# Beispiel SOSlope: Biologischer Objektschutz

Berner Fachhochschule

Agenda FAN 2/2017

## Beurteilung der Wirkung biologischer Objektschutz-Massnahmen: Anwendungsbeispiel des Modells SOSlope

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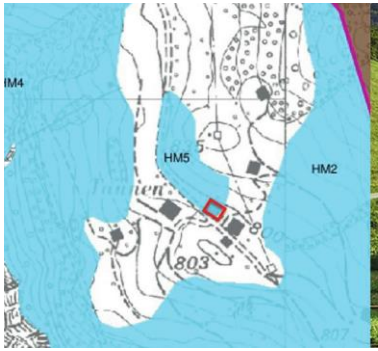

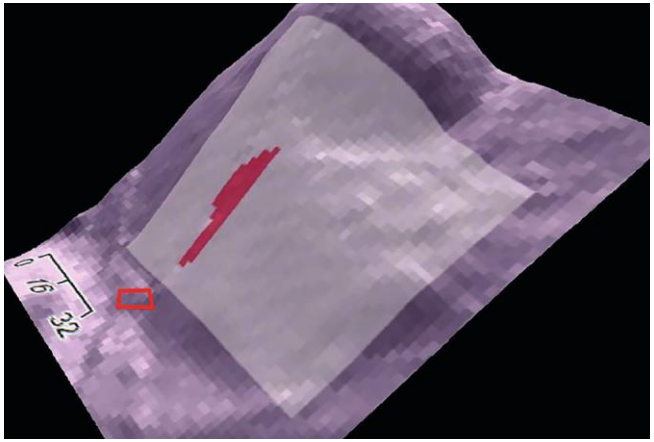

Berner Fachhochschule

**5th International Conference on Soil-, Bio- and Eco-Engineering in 2020: SBEE2020**
**Bern, Switzerland**
**13-19 June 2020**

Institution: Bern University of Applied Sciences,
Address: Länggasse 85, 3052 Zollikofen, Bern, Switzerland
www.hafl.bfh.ch

# Übung

## Wurzelverstärkung

# Schätzen sie die laterale Wurzelverstärkung!

Berner Fachhochschule

# Schätzen sie die laterale Wurzelverstärkung!

Berner Fachhochschule

# Schätzen sie die laterale Wurzelverstärkung!

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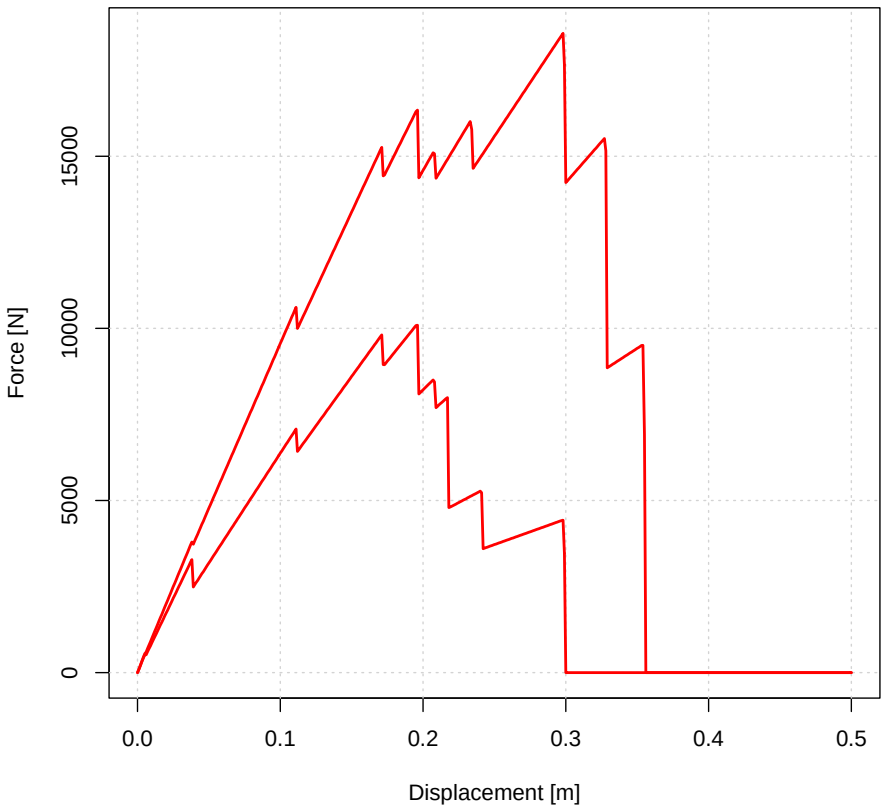
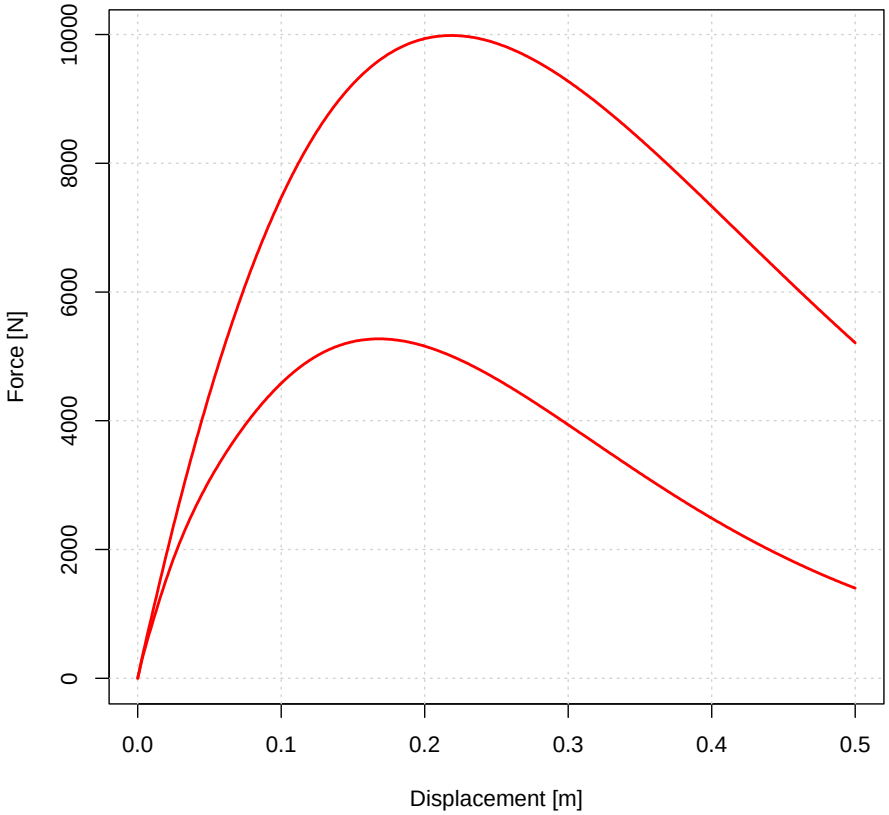
- 500 N/m
- 5 kN/m
- 10 kN/m

# Schätzen sie die laterale Wurzelverstärkung!




*Berechnete Kraft-Dehnung Diagramme der laterale Wurzelverstärkung von 2 Bodenprofile in der Kontrolle. Links: ohne Weibull Ansatz. Rechts: mit Weibull Ansatz.*

# Wie viel stabilisiert 10 kN/m laterale Wurzelverstärkung?

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Eine Gefahrenbeurteilung ergibt eine Gefährdung durch eine flachgründige Rutschung. Es ist gefragt die Rolle der Wurzelverstärkung zu quantifizieren.

<u>Eingangsparameter</u> <u>Rutschung</u>

| | | |
|---|---|---|
| Fläche **A** bei Annahme 1 | = 100 | [$m^2$] |
| Mächtigkeit **t** | = 1 | [m] |
| Form der Rutschung | = Kreisförmig | |
| Hangneigung **m** | = 29 | [°] |
| Kohäsion **c** | = 0 | [kPa] |
| Scherwinkel **φ** | = 30 | [°] |

Wassersättigung Bodenprofil

Treibende Kraft **Gpar** = ***761 kN*** [-]

# Wie viel stabilisiert 10 kN/m laterale Wurzelverstärkung?

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- 5 %
- 20 %
- 50 %

# Wie viel stabilisiert 10 kN/m laterale Wurzelverstärkung?

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| SZENARIO | 10J | 30J | 100J |
|---|---|---|---|
| Porenwasserdruckkraft [kN] | 0 | 11.2 | 112.2 |
| Normal Kraft [kN] | 1372.8 | 1374.1 | 1385.6 |
| Treibende Kraft [kN] | 760.9 | 761.7 | 768.1 |
| Scherwiderstandskraft [kN] | 792.6 | 786.9 | 735.2 |
| Laterale Wurzelverstärkung [kN/m] | 10 | 10 | 10 |
| Totale laterale Wurzelverstärkung [kN] (1/2 Umfang) | 177.2 | 177.2 | 177.2 |
| % Wurzelverstärkung/tot. Wiederstandskraft [%] | 22.4 | 22.5 | 24.1 |
| SF mit wald | 1.27 | 1.26 | 1.18 |
| SF ohne wald | 1.04 | 1.03 | 0.96 |

# Übung

SlideforNET

## BECOME A MEMBER

The core of ecorisQ is made of its members. By joining ecorisQ you will expand your professional network and profit from transparent tools in the field of natural hazard risks. Being an ecorisQ member demonstrates that you are willing to increase the transparancy and reproducibility of natural hazard analyses and that you promote sustainable protection against natural hazards.

Benefits of membership

Who can become a member?

Membership fee

How to apply?

# Landslide and forests

*Created on Sunday, 26 January 2014 22:50*

Scientific evidence that forests have a stabilising effect on slopes that are prone to shallow landsliding has been increasing over the last 20 years. Lateral reinforcement by tree roots seems to be the crucial factor here. To facilitate the quantification of the possible stabilising effect of a forest, ecorisQ, in collaboration with Massimiliano Scharz from the Bern University of Applied Sciences developed a rapid assessment tool called SlideforNET, which can be used online for free. Please have a try and if considered appropriate send us your feedback.

# Implementierung der Wurzelverstärkung in Hangstabilitätsmodelle: SlideforNET

Schwarz et al., 2010, Ecol. Eng.

$$SF = \frac{A \quad {}_{bas.} + F_{lat.veg.}}{F_{par.}}$$

$$F_{lat.veg.} = \frac{\text{lateral_Area}}{2} c_{lat} \quad [\text{kN}]$$

$$F_{par.} = [(Ah)\varepsilon g \sin\beta] + (Am_{veg.} g \sin\beta) \quad [\text{kN}]$$

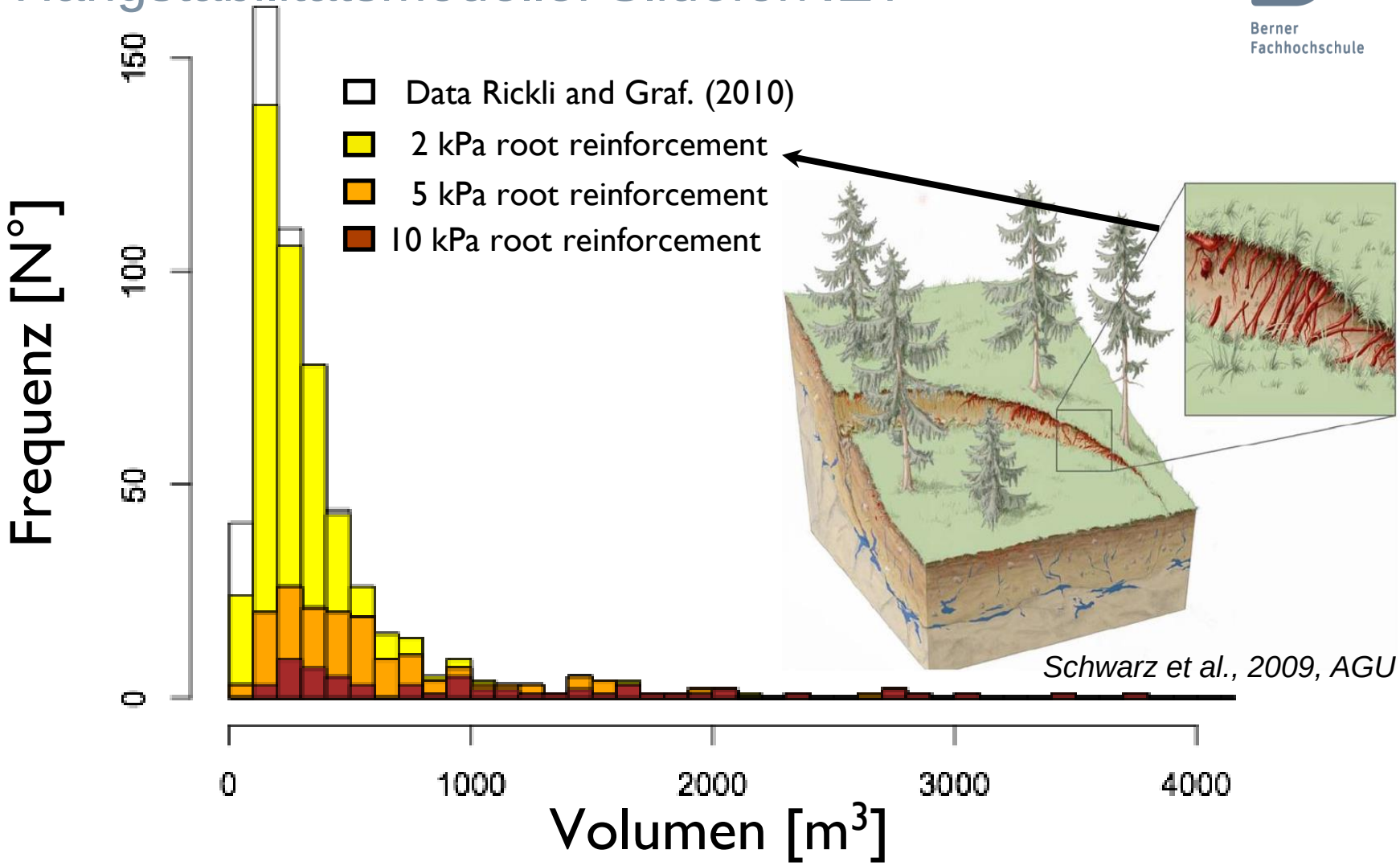
$${}_{bas.} = c + \quad {}^{*} \tan \quad {}' \quad [\text{kPa}]$$

$$c = c_s + c_{bas.veg.} \quad [\text{kPa}]$$

Gesättigte Bedingungen

- = total normal stress [kPa]
- $u$ = pore water pressure [kPa]
- $'$ = residual friction angle [°]
- $A$ = basal area [m$^2$]
- $h$ = soil depth [m], perpendicular to the slope
- $\varepsilon$ = soil bulk density [t/m$^3$]
- $\beta$ = slope angle [°]
- $m_{veg.}$ = weight of vegetation cover [t/m$^2$]
- $c_s$ = residual soil cohesion [kPa]
- $c_{lat.\ veg.}$ = lateral root reinforcement [kPa]
- $c_{bas.\ veg.}$ = basal root reinforcement [kPa]
- $g$ = gravitational acceleration [m/s$^2$]

# Implementierung der Wurzelverstärkung in Hangstabilitätsmodelle: SlideforNET



# SlideforNET: Assumptions

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**Slope characteristics**

| | | |
|---|---|---|
| Mean gradient of the slope | 25 | ° |
| Estimated depth of the slide plane | 2 | m |
| Friction angle of the soil | 28 | ° |
| Soil cohesion | 0.5 | kPa |
| Safety Factor (SF) | 1 | - |

**Forest characteristics**

| | | |
|---|---|---|
| Mean stand density | 350 | $ha^{-1}$ |
| Mean diameter at breast height (DBH) | 39 | cm |
| Occurrence of dominant tree species: | | |
| - Norway spruce (*Picea abies*) | 80 | % |
| - Silver fir (*Abies alba*) | 20 | % |
| - European beech (*Fagus sylvatica*) | 0 | % |
| - Other broadleaved species | 0 | % |
| - Other coniferous species | 0 | % |

- Landslide shapes are elliptical with a fixed length/width ratio.
- The dimensions of potential landslides in an area are characterized by a specific frequency-magnitude distribution.
- The hydrological worse case scenario is considered, assuming it to correspond to the full saturation of soil profile.
- Only minimum lateral root reinforcement (between trees) contribute to landslide stability.
- Only lateral root reinforcement under tension on the upper half of the lateral landslide surface contribute stability (compression on the bottom part is activated not at the same time).
- Basal root reinforcement is function of soil depth and minimum lateral root reinforcement.

1930
1933
1953
1983
2010

# SlideforNET: Beispiel waldbau.Massnahmen

Berner Fachhochschule

**Fragestellung:**
- Ist die Schutzwirkung des Waldes relevant in diesem Standort?
- Kann ich die Shutzwirkung steuern mit waldbauliche massnahmen?

Vorgehen

- Analyse Fallstudie mit SlideforNet: http://www.ecorisq.org/slidefor-net-en

- Mit SlideforNet berechnen sie die “ist Zustand” Szenario in Sinn von Schutzwaldwirkung und Rutschgefahr (sieht Plot Frequenz-Rutschfläche) mit der gegebenen Unterlagen.

- Auf Grund die Standort Angabe berechnen sie die Schutzwirkung eine minimale und optimale NaiS-Profil.

# SlideforNET: Beispiel waldbau.Massnahmen

## “Honegg” bei Schangnau

**Depth failure surface:** **1.5 m**

***Slope inclination:*** **25°**

**Soil type: clayed sandy soil ( √=25 c=0.5)**

***Actual species composition:*** **Bu 0%, Ta 30%, Fi 70%;**

**Mininal profile for Swiss Guidelines:**

**Bu 30-80%,**

**Ta 20-60%,**

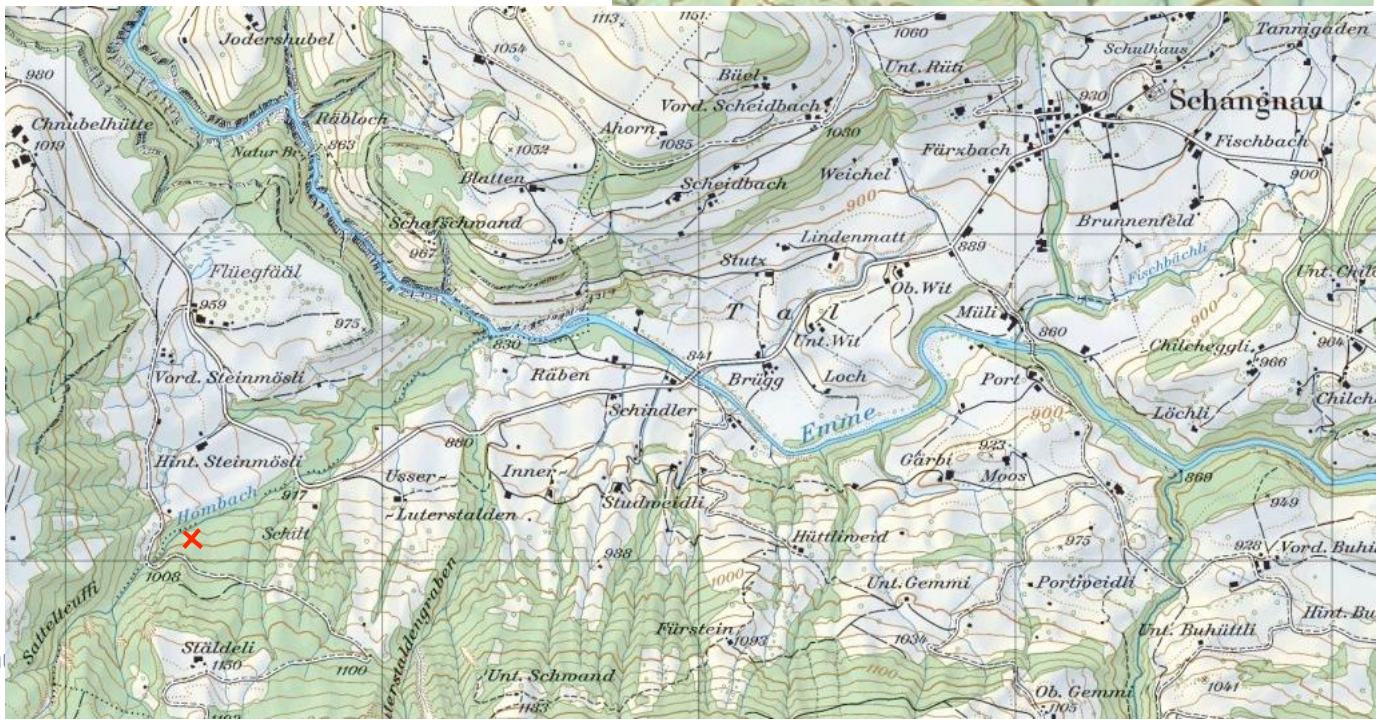
**Fi 0-30%;**

***Number of stems per hectar:***

**350/ha;**

***Mean BHD:***

**38.91 cm;**



# SlideforNET: Beispiel waldbau.Massnahmen

**Slope characteristics**

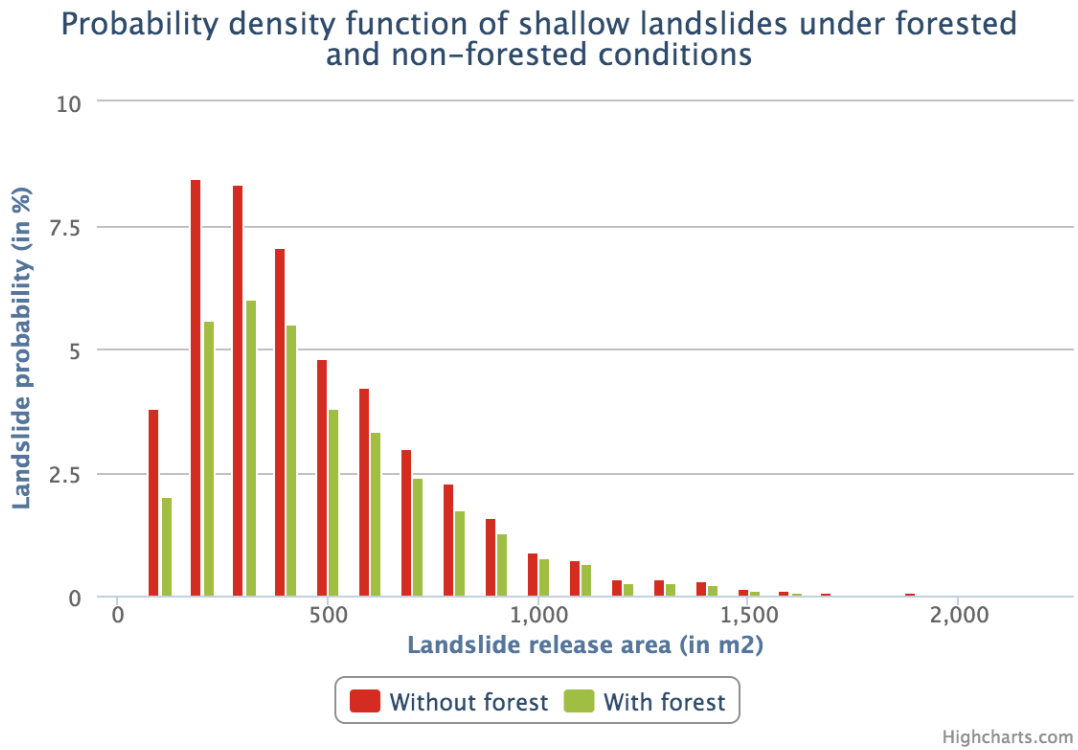
| | | |
|---|---|---|
| Mean gradient of the slope | 25 | ° |
| Estimated depth of the slide plane | 1.5 | m |
| Effective friction angle of the soil | 25 | ° |
| Effective soil cohesion | 0.5 | kPa |
| Safety Factor (SF) | 1 | - |

**Forest characteristics**

| | | |
|---|---|---|
| Mean stand density | 350 | /ha |
| Mean diameter at breast height (DBH) | 38.91 | cm |
| Occurrence of dominant tree species: | | |
| - Norway spruce (*Picea abies*) | 70 | % |
| - Silver fir (*Abies alba*) | 30 | % |
| - European beech (*Fagus sylvatica*) | 0 | % |
| - Other broadleaved species | 0 | % |
| - Other coniferous species | 0 | % |

- Without forest: 47 %
- With the above-defined forest: 34 %

**2. Current degree of protection: 25 - 50 %**




**Data used for the calculation:**

- Safety Factor (SF) of slopes at the point of failure (critical) = 1
- Lateral reinforcement by tree roots = 5 kN/m
- Average basal reinforcement by tree roots = 0.1 kPa
- Weight of the forest vegetation = 0.04 t/m (on average ±2 cm of soil)

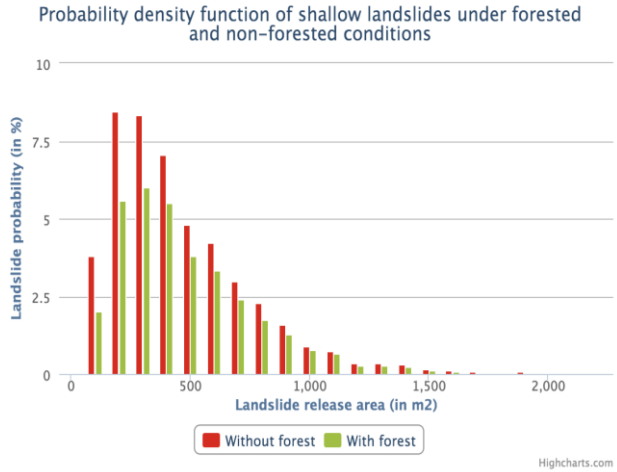
**Slope characteristics**

| | | |
|---|---|---|
| Mean gradient of the slope | 25 | ° |
| Estimated depth of the slide plane | 1.5 | m |
| Friction angle of the soil | 25 | ° |
| Soil cohesion | 0.5 | kPa |
| Safety Factor (SF) | 1 | - |

**Forest characteristics**

| | | |
|---|---|---|
| Mean stand density | 350 | $ha^{-1}$ |
| Mean diameter at breast height (DBH) | 38.91 | cm |
| Occurrence of dominant tree species: | | |
| - Norway spruce (*Picea abies*) | 70 | % |
| - Silver fir (*Abies alba*) | 30 | % |
| - European beech (*Fagus sylvatica*) | 0 | % |
| - Other broadleaved species | 0 | % |
| - Other coniferous species | 0 | % |

**2. Current degree of protectio 25 - 50 %**




**Data used for the calculation:**

- Safety Factor (SF) of slopes at the [illegible] (critical) = 1
- Lateral reinforcement by tree roo = 5 kN/m
- Average basal reinforcement by tree [illegible] kPa
- Weight of the forest vegetation = 0.04 t/m (on average ±2 cm of soil)

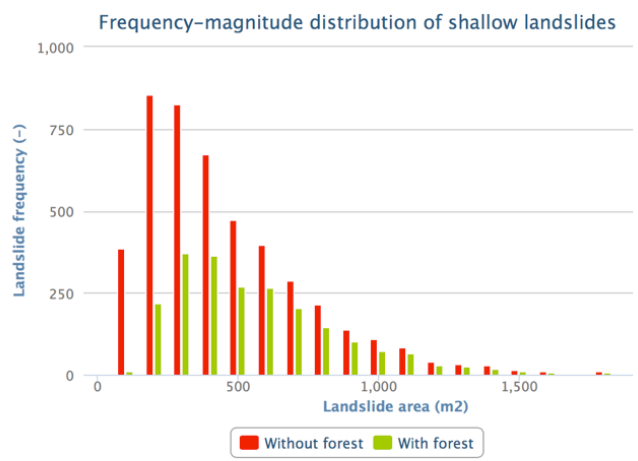
**Slope characteristics**

| | | |
|---|---|---|
| Mean gradient of the slope | 25 | ° |
| Estimated depth of the slide plane | 1.5 | m |
| Friction angle of the soil | 25 | ° |
| Soil cohesion | 0.5 | kPa |
| Safety Factor (SF) | 1 | - |

**Forest characteristics**

| | | |
|---|---|---|
| Mean stand density | 350 | $ha^{-1}$ |
| Mean diameter at breast height (DBH) | 38.91 | cm |
| Occurrence of dominant tree species: | | |
| - Norway spruce (*Picea abies*) | 0 | % |
| - Silver fir (*Abies alba*) | 40 | % |
| - European beech (*Fagus sylvatica*) | 60 | % |
| - Other broadleaved species | [illegible] | % |
| - Other coniferous species | 0 | % |

**1. Current degree of protectio 50 - 75 %**




**Data used for the calculation:**

Safety Factor (SF) of slopes at the p[illegible]ure (critical) = 1
Lateral reinforcement by tree roo = 15 kPa
Weight of the forest vegetation = 0.0[illegible] (on average ±3 cm of soil)

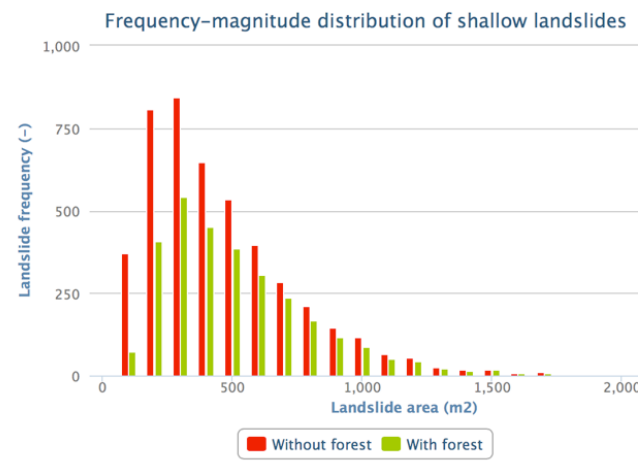
**Slope characteristics**

| | | |
|---|---|---|
| Mean gradient of the slope | 25 | ° |
| Estimated depth of the slide plane | 1.5 | m |
| Friction angle of the soil | 25 | ° |
| Soil cohesion | 0.5 | kPa |
| Safety Factor (SF) | 1 | - |

**Forest characteristics**

| | | |
|---|---|---|
| Mean stand density | 70 | $ha^{-1}$ |
| Mean diameter at breast height (DBH) | 38.91 | cm |
| Occurrence of dominant tree species: | | |
| - Norway spruce (*Picea abies*) | 0 | % |
| - Silver fir (*Abies alba*) | 40 | % |
| - European beech (*Fagus sylvatica*) | 60 | % |
| - Other broadleaved species | 0 | % |
| - Other coniferous species | 0 | % |

**1. Current degree of protectio 25 - 50 %**




**Data used for the calculation:**

Safety Factor (SF) of slopes at the p[illegible]ure (critical) = 1
Lateral reinforcement by tree roo = 10 kPa
Weight of the forest vegetation = 0.0[illegible] (on average ±1 cm of soil)

Val Caruga, TI

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# Quantifizierung der Wurzelverstärkung: Einzeln Wurzel

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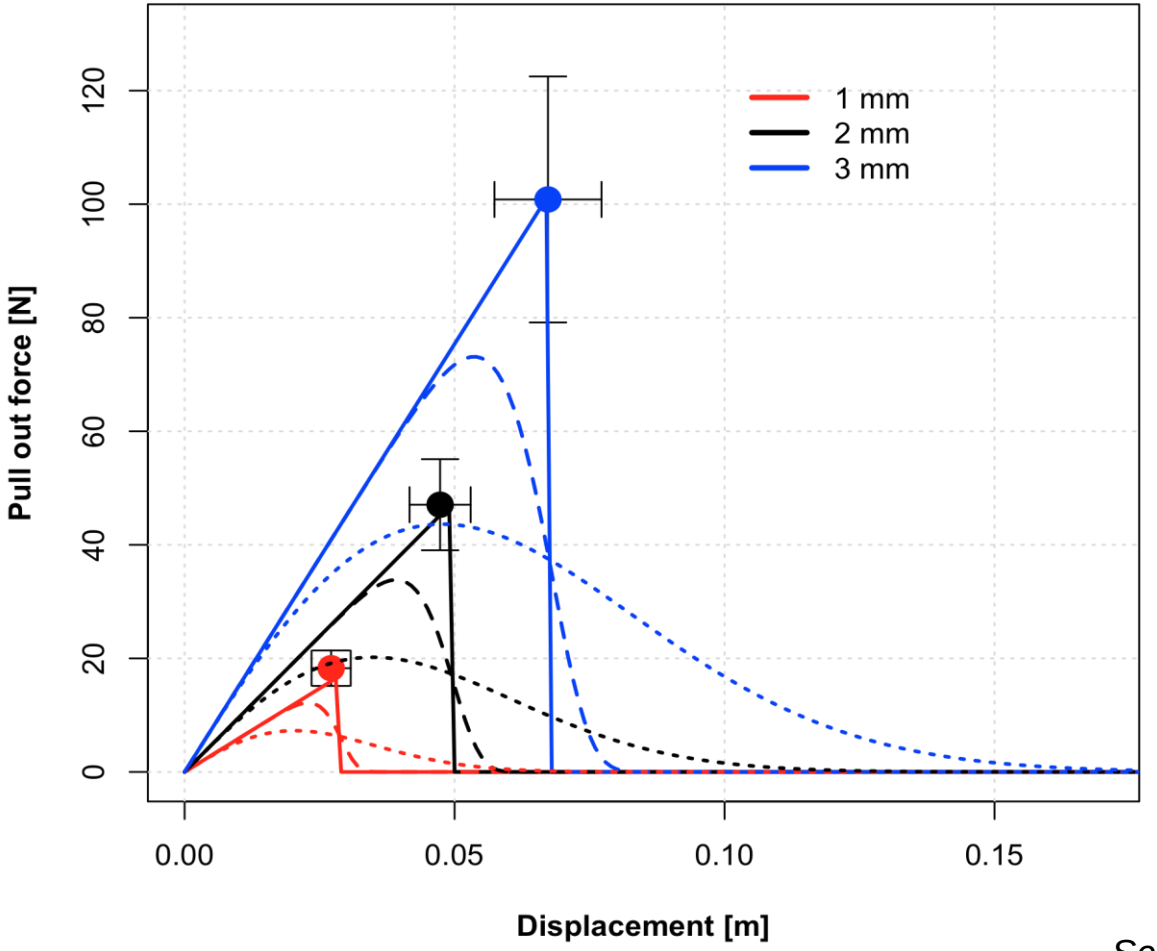
**Faktoren:**

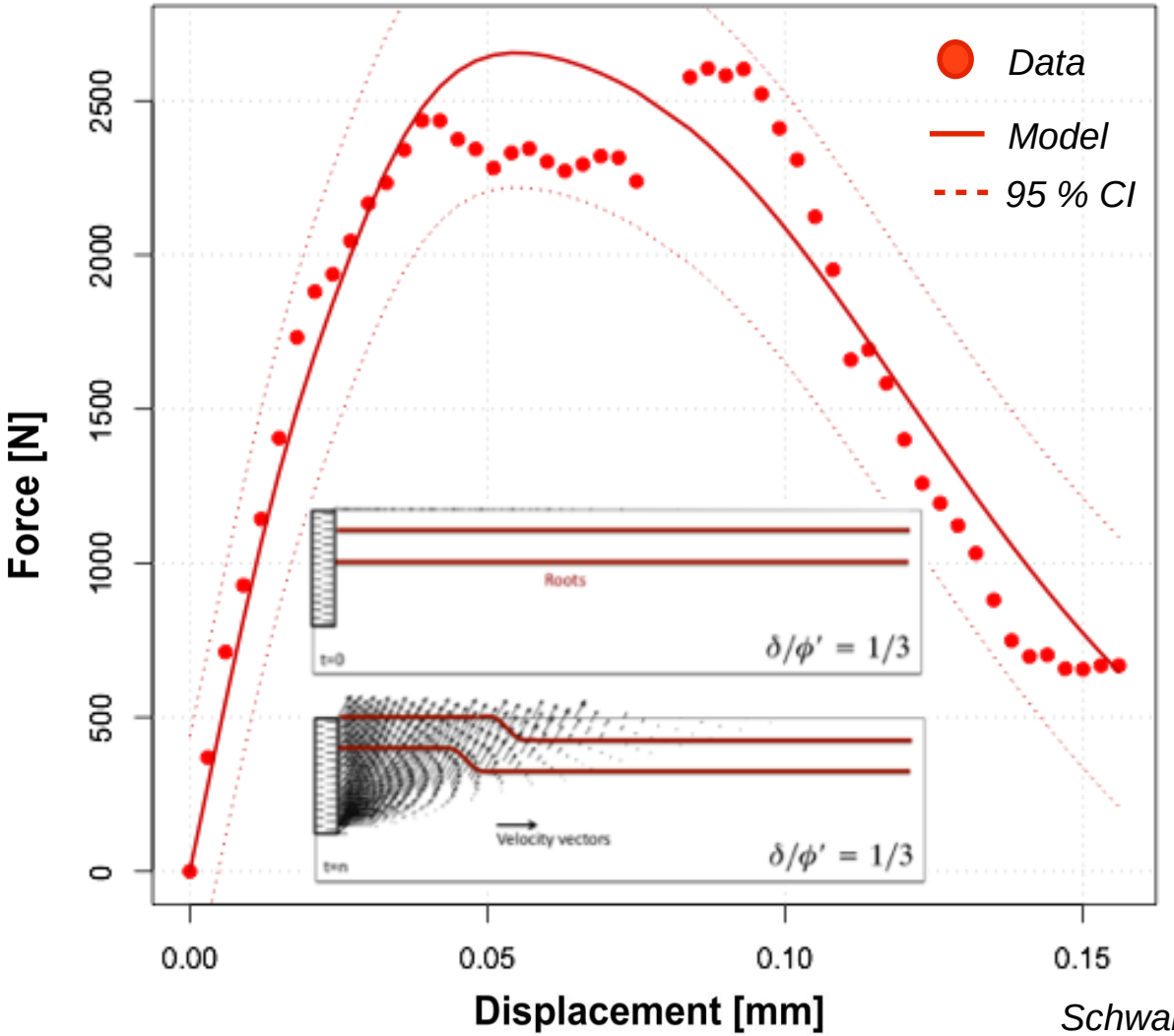
1. Baumart
2. Geometrie der Wurzel
3. Bodenbedingungen (Wassergehalt, Skelett, ..)
4. Elastizitätsmodul
5. Tortuosität
6. Richtung
7. ...

# The “Root Bundle Model - RBMw”: Calculation of root reinforcement



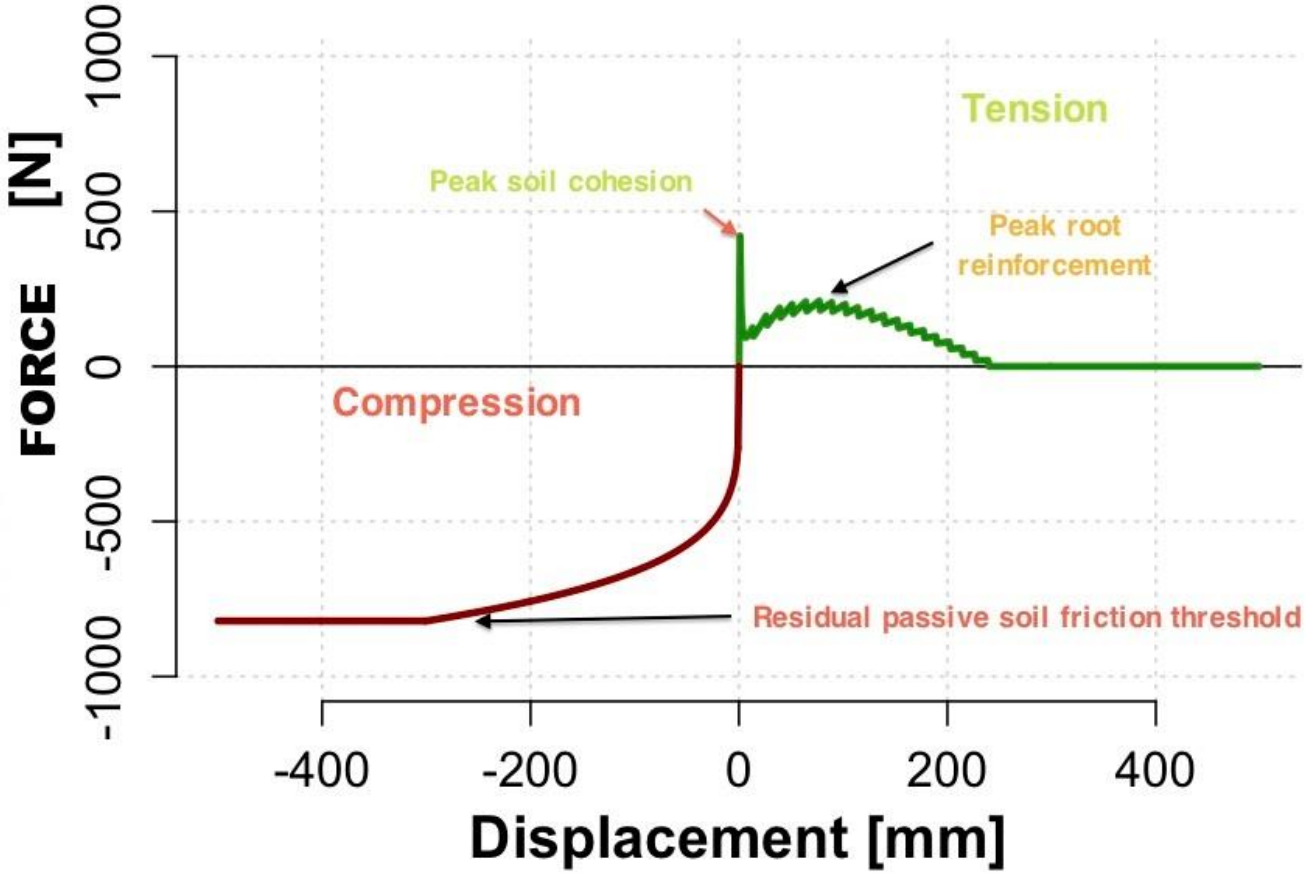

*Schwarz et al., 2013, HESSD*

# *Root reinforcement under compression*




*Schwarz et al., 2015, JGR*

# Quantifizierung der Wurzelverstärkung, Druck: Bündel von Wurzeln - RBMw



SOSlope

ecorisQ

About SOSlope

DEM /Users/monterosa2/Documents/Work/SHL/Projects/2017_SBB_ProtectBIO/Daten/Gambarongo/Fill_dhm_2m_gamba_small.asc Browse

TWI /Users/monterosa2/Documents/Work/SHL/Projects/2017_SBB_ProtectBIO/Daten/Gambarongo/TWI_gamba_small.asc Browse

Soil type User defined

Cohesion 0.50 kPa Friction angle 34 ° Density 1570 kg/m³ Porosity 0.45

Initial water content 0.35 m³/m³ van Genuchten parameters: α 0.10 kPa⁻¹ n 3.00

Hydrology

Rainfall event: intensity 80.00 mm/hr, duration 1.00 hr, centennial rainfall intensity (1 hr) 80.00 mm/hr

Fixed saturation: 0.00 m

Use trees

File Browse

Uniform stand 850 trees/ha, DBH 40 cm

Random stand 750 trees/ha, DBH 40 cm, DBH std dev 5 cm

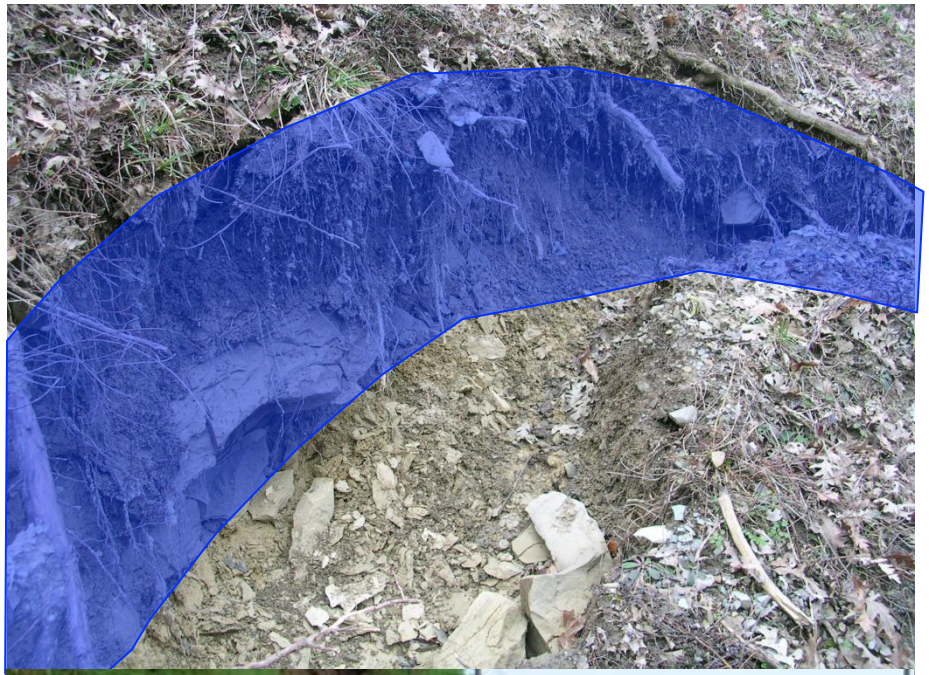
Specie Castanea sativa M (Chestnut)

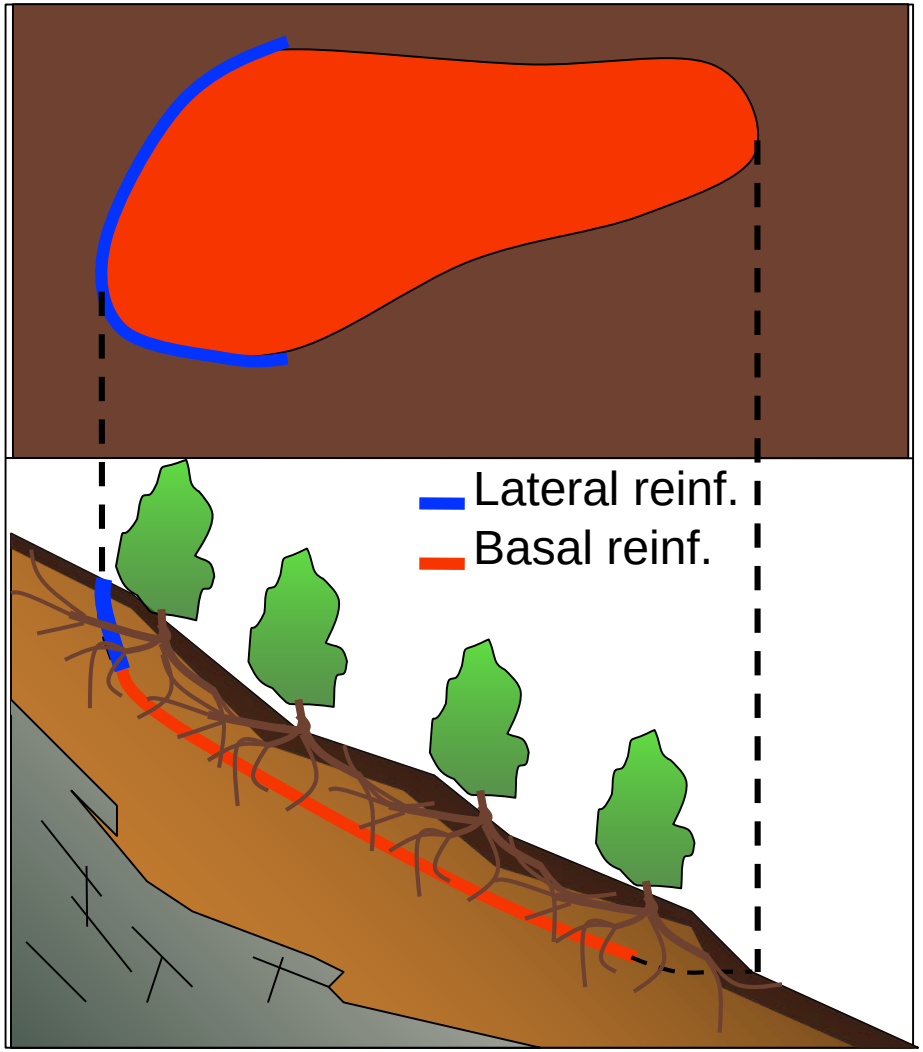
Print probe at x = 500 m, y = 400 m

```
>>> Load step 60. Time = 1.000000 hours  Rainfall rate = 80.000000 mm/hr  Rainfall cumul = 80.000000 mm
Move # 9010  Max moves = 15717  Max displ = 1.999718  Min SF = 1.000025 => Slope is stable
##############################################################################
TOTAL LANDSLIDE AREA = 36594.111397 m^2 (62.747105 %)
##############################################################################
Results written to MyProject
End program SOSlope
```

Done! Run Stop

# Implementierung der Wurzelverstärkung in Hangstabilitätsmodelle: SlideforNET






Schwarz et al., 2010, Ecol. Eng.

# Workflow for SlideforNET

Berner Fachhochschule

## INPUTS

In the field:
- Measure of **Slope Inclination**
- Estimation of **soil class** (USCS)-> friction angle and cohesion
- Estimation **depth** of the potential failure surface

- Measure or estimation of **mean tree DBH** and **stems density** (Stems per hectare)
- Estimation of **species composition**

SlideforNET

## OUTPUTS

- **Level of protection** based on the difference between the sum of landslides volume mobilized with and without the effect of root reinforcement.

- **Frequency-Magnitude distribution of shallow landslides** with or without the effect of root reinforcement (red-green histogram)

- **Estimated basal and lateral root reinforcement**.

- Calculation of the **effect of vegetation weight surcharge** on slope stability.