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Supplement of

Geologic and geomorphic controls on rockfall hazard: how well do past rockfalls predict future distributions?

Josh Borella et al.

Correspondence to: Josh Borella (josh@frontiersabroad.com)

Supplementary Information

3 Methods

Model Scenarios

RAMMS_1 (bare-earth CES model) utilized 7 individual release lines (CES-1 through CES-7). The release lines were drawn at the base of each field-identified CES detachment site and an individual drop height (z) was estimated. The drop heights for the CES detachment sites ranged from 3-15 m. To help constrain the range of potential boulder shapes released from each area, the detachment sites were recorded as occurring within volcanic breccia (VB) or coherent lava (CL) basalt. The total number of release points for RAMMS_1 was 56. The total number of simulated rocks was 1072 and represents the number of source points multiplied by the number of simulated rocks and number of random orientations (for boulder starting positions within source rock) (see S9-S15).

The RAMMS_2 (slope vegetation/prehistoric model) and RAMMS_3 (bare-earth modern hazard) model scenarios utilized the same 26 separate release lines (total combined line length=~3,895 m). Because we are uncertain from exactly which sections of the source cliffs the pre-CES boulders were released, the entire source cliff was delineated. RAMMS_2 release lines were used for the RAMMS_3 to provide a conservative (worst-case) scenario. The total number of release points for the RAMMS_2 and RAMMS_3 model scenarios was 567. The total number of simulated rocks was 22680 for each model scenario. An average drop height of 10 m was utilized above the release lines to insure realistic boulder kinetic energies, with the exception of the southernmost source outcrop (CES-7) where a release height of 3 m was inputted to reflect the smaller height of the source rock (see S18-S23).

Boulder Shape

Ten (10) individual boulders were created for RAMMS_1, while twenty (20) boulders were created for the RAMMS_2 and RAMMS_3 model scenarios. The following percentages were assigned for boulder shapes at Purau: 70% for equant, 15% for flat, 15% for long. For individual CES detachments (i.e. RAMMS_1) that were field-identified as occurring entirely within the coherent lava (CL) lithology, the shape distribution was modified to reflect the higher percentage of long and flat boulder morphologies and the following percentages were assigned: 40% for equant, 30% for flat, 30% for long.

The boulder sizes were chosen from a statistical analysis of the Purau pre-CES and CES boulder inventory, which includes volume estimated from axis proportions. We assumed a power-law distribution for the frequency-volume of simulated boulders, consistent with the mapped pre-CES and CES boulders at Purau. The simulated rockfall boulders range in size from 1.0 m^3 to 50 m^3. The following percentages were attributed to each boulder size range within RAMMS: 85% for 1-10 m^3; 15% for 10-100 m^3. Boulders sizes >100 m^3 are rare and were not included in the simulation. The relative proportions of volcanic breccia (2500 kg/m^3) and coherent lava (3000 kg/m^3) densities were applied.

5 Discussion

Interpretations of strong ground motion data

By assuming the shear velocity (V_s) of stratified basaltic lava and breccia at Rapaki and Purau sites to be ~ 2500 m/s (Christensen et al., 1980), we estimate f_n = ~5 − 6 Hz ($f_n = V_s/\lambda$). This V_s is likely an over estimate for the given sites as 2500 m/s corresponds to an effective confining pressure of 200 bar. On the other hand, if we use an average V_s30 value of 800 m/s applicable to Rapaki sites (e.g. Mackey and Quigley, 2014), we obtain f_n = ~2 Hz. Thus, it is safe to assume that f_n of these sites is less than 5 Hz.

Supplementary Data

Tables S1-S8 are found in the following Dryad repository - doi:10.5061/dryad.9km1t86

Table S1. Rapaki Pre-CES Rockfall Data
Table S2. Rapaki CES Rockfall Data
Table S3. Purau Pre-CES Rockfall Data
Table S4. Purau CES Rockfall Data
Table S5. Rapaki Pre-CES Runout Data
Table S6. Rapaki CES Runout Data
Table S7. Purau Pre-CES Domain Runout Data
Table S8. Purau CES Domain Runout Data

S9-S23. Rockfall simulation scenario logfiles for RAMMS_1, RAMMS_2, and RAMMS_3.

S24. Data fits for Purau runout distance.

S9. Rockfall simulation scenario logfile for RAMMS_1 CES_1

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************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_1_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_1_2019\

Simulation Started: Fri Mar 08 10:53:49 2019
Simulation Finished: Fri Mar 08 10:53:57 2019

Simulation Time (min): 0.1

Simulation Settings:
Nr_Source_Points: 3
Nr_Simulated_Rocks: 2
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 6)
Total_Nr_Simulations: 18

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.49 / 1.59 / 3.73
Velocities (m/s): 0.06 / 8.32 / 22.32
Kin. Energies (kJ): 0.01 / 964.74 / 7298.13
Rot. Velocities (rot s-1): 0.00 / 0.93 / 4.24
Average Slope (Degrees): 28.58 / 38.34 / 41.51

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_1_F.shp
Z-Offset: 15.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.12
 - Mean = 8.01
 - Max = 14.91
Rock Forms:
Real_Long_1.48_1.1m3(3000).pts
Real_Long_2.0_14.9m3(2500).pts
```

S10. Rockfall simulation scenario logfile for RAMMS_1 CES_2

```
**********************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_2_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_2_2019\

Simulation Started: Fri Mar 08 10:42:47 2019
Simulation Finished: Fri Mar 08 10:43:37 2019

Simulation Time (min): 0.8

Simulation Settings:
Nr_Source_Points: 6
Nr_Simulated_Rocks: 10
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 30)
Total_Nr_Simulations: 180

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.53 / 1.19 / 5.69
Velocities (m/s): 0.00 / 6.26 / 20.43
Kin. Energies (kJ): 0.00 / 374.61 / 14629.47
Rot. Velocities (rot s-1): 0.00 / 0.85 / 3.45
Average Slope (Degrees): 26.34 / 35.07 / 90.00

**********************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_2_F.shp
Z-Offset: 15.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.13
 - Mean = 8.84
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Long_2.0_17.8m3.pts
```

S11. Rockfall simulation scenario logfile for RAMMS_1 CES_3

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_3_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_3_2019\

Simulation Started: Fri Mar 08 10:32:28 2019
Simulation Finished: Fri Mar 08 10:33:25 2019

Simulation Time (min): 0.9

Simulation Settings:
Nr_Source_Points: 7
Nr_Simulated_Rocks: 10
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 30)
Total_Nr_Simulations: 210

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.52 / 1.31 / 5.48
Velocities (m/s): 0.01 / 7.78 / 25.36
Kin. Energies (kJ): 0.00 / 491.78 / 18487.71
Rot. Velocities (rot s-1): 0.00 / 0.94 / 3.93
Average Slope (Degrees): 30.05 / 35.85 / 51.42

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_3_F.shp
Z-Offset: 10.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.13
 - Mean = 8.84
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Long_2.0_17.8m3.pts
```

S12. Rockfall simulation scenario logfile for RAMMS_1 CES_4

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************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_4_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_4_2019\

Simulation Started: Fri Mar 08 10:26:31 2019
Simulation Finished: Fri Mar 08 10:27:05 2019

Simulation Time (min): 0.6

Simulation Settings:
Nr_Source_Points: 4
Nr_Simulated_Rocks: 10
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 30)
Total_Nr_Simulations: 120

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.53 / 1.48 / 7.33
Velocities (m/s): 0.00 / 11.88 / 29.83
Kin. Energies (kJ): 0.00 / 747.07 / 11670.40
Rot. Velocities (rot s-1): 0.00 / 1.68 / 5.59
Average Slope (Degrees): 26.33 / 33.91 / 65.35

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_4_F.shp
Z-Offset: 5.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.13
 - Mean = 8.84
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Long_2.0_17.8m3.pts
```

S13. Rockfall simulation scenario logfile for RAMMS_1 CES_5

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*************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_5_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_5_2019\

Simulation Started: Fri Mar 08 10:20:32 2019
Simulation Finished: Fri Mar 08 10:21:13 2019

Simulation Time (min): 0.7

Simulation Settings:
Nr_Source_Points: 5
Nr_Simulated_Rocks: 10
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 30)
Total_Nr_Simulations: 150

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.45 / 1.49 / 8.00
Velocities (m/s): 0.00 / 12.69 / 26.55
Kin. Energies (kJ): 0.00 / 486.66 / 2497.54
Rot. Velocities (rot s-1): 0.00 / 1.98 / 5.32
Average Slope (Degrees): 28.80 / 38.39 / 90.00

*************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_5_F.shp
Z-Offset: 5.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.02
 - Mean = 1.77
 - Max = 2.92
Rock Forms:
Real_Equant_1.25_1.5m3(3000).pts
Real_Equant_1.2_1.0m3(3000).pts
Real_Equant_1.4_1.3m3(3000).pts
Real_Equant_1.4_2.2m3(3000).pts
Real_Flat_1.77_1.2m3(3000).pts
Real_Flat_1.8_1.6m3(3000).pts
Real_Flat_2.35_2.5m3(3000).pts
Real_Long_1.48_1.9m3(3000).pts
Real_Long_2.0_1.4m3(3000).pts
Real_Long_2.0_2.9m3(3000).pts
```

S14. Rockfall simulation scenario logfile for RAMMS_1 CES_6

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_6_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_6_2019\

Simulation Started: Fri Mar 08 10:13:17 2019
Simulation Finished: Fri Mar 08 10:15:00 2019

Simulation Time (min): 1.7

Simulation Settings:
Nr_Source_Points: 13
Nr_Simulated_Rocks: 10
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 30)
Total_Nr_Simulations: 390

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.45 / 2.58 / 16.02
Velocities (m/s): 0.01 / 18.19 / 40.26
Kin. Energies (kJ): 0.00 / 3274.93 / 95261.15
Rot. Velocities (rot s-1): 0.00 / 2.54 / 7.61
Average Slope (Degrees): 28.34 / 35.17 / 80.14

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_6_F.shp
Z-Offset: 10.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.13
 - Mean = 8.84
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Long_2.0_17.8m3.pts
```

S15. Rockfall simulation scenario logfile for RAMMS_1 CES_7

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: CES_7_2019
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_7_2019\

Simulation Started: Fri Mar 08 09:57:18 2019
Simulation Finished: Fri Mar 08 09:58:59 2019

Simulation Time (min): 1.7

Simulation Settings:
Nr_Source_Points: 13
Nr_Simulated_Rocks: 10
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 30)
Total_Nr_Simulations: 390

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.52 / 1.10 / 3.65
Velocities (m/s): 0.00 / 8.16 / 20.55
Kin. Energies (kJ): 0.00 / 292.18 / 3110.81
Rot. Velocities (rot s-1): 0.00 / 1.16 / 3.91
Average Slope (Degrees): 16.58 / 24.30 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_7_RevisedFinal.shp
Z-Offset: 3.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.13
 - Mean = 8.84
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Long_2.0_17.8m3.pts
```

S16. Rockfall simulation scenario logfile for CES_7_CL_only

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.60

Scenario Name: CES_7_CL_Only
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_7_CL_Only\

Simulation Started: Mon Nov 13 12:40:26 2017
Simulation Finished: Mon Nov 13 12:41:43 2017

Simulation Time (min): 1.3

Simulation Settings:
Nr_Source_Points: 18
Nr_Simulated_Rocks: 8
Nr_Random_Orientations: 2
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 16)
Total_Nr_Simulations: 288

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.36 / 0.77 / 3.12
Velocities (m/s): 0.00 / 5.88 / 18.99
Kin. Energies (kJ): 0.00 / 80.04 / 603.95
Rot. Velocities (rot s-1): 0.00 / 0.99 / 4.12
Average Slope (Degrees): 22.30 / 38.28 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
Terrain_LoessandVolcanicColluvium_Final.shp:  Medium Hard
Terrain_VolcanicRock_Final.shp:  Extra Hard

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_7_F.shp
Z-Offset: 3.00 m

Rock:
Rock Density (kg/m3): 2700.00
Block Volumes (m3):
```

```
  - Min = 0.97
  - Mean = 1.00
  - Max = 1.02
Rock Forms:
Real_Flat_1.6_1.0m3.pts
Real_Flat_1.77_1.0m3.pts
Real_Flat_1.8_1.0m3.pts
Real_Flat_2.35_1.0m3.pts
Real_Long_1.2_1.0m3.pts
Real_Long_1.48_1.0m3.pts
Real_Long_1.5_1.0m3.pts
Real_Long_2.0_1.0m3.pts
```

S17. Rockfall simulation scenario logfile for CES_7_VB_only


```
*************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.60

Scenario Name: CES_7_VB_Only
Scenario Folder: C:\RAMMS\PurauRockfall\output\CES_7_VB_Only\

Simulation Started: Mon Nov 13 12:16:38 2017
Simulation Finished: Mon Nov 13 12:17:47 2017

Simulation Time (min): 1.2

Simulation Settings:
Nr_Source_Points: 18
Nr_Simulated_Rocks: 3
Nr_Random_Orientations: 5
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 15)
Total_Nr_Simulations: 270

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.44 / 0.90 / 3.32
Velocities (m/s): 0.01 / 8.50 / 20.07
Kin. Energies (kJ): 0.00 / 164.95 / 707.00
Rot. Velocities (rot s-1): 0.00 / 1.48 / 4.23
Average Slope (Degrees): 20.83 / 23.39 / 87.99

*************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
Terrain_LoessandVolcanicColluvium_Final.shp:  Medium Hard
Terrain_VolcanicRock_Final.shp:  Extra Hard

Release:
Type: Line
Line Shapefile: PurauRockfall\CES_7_F.shp
Z-Offset: 3.00 m

Rock:
Rock Density (kg/m3): 3000.00
```

```
Block Volumes (m3):
 - Min = 1.01
 - Mean = 1.01
 - Max = 1.02
Rock Forms:
Real_Equant_1.25_1.0m3.pts
Real_Equant_1.2_1.0m3.pts
Real_Equant_1.4_1.0m3.pts
```

S18. Rockfall simulation scenario logfile for RAMMS_3_ModernHazard_No South

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: ModernHazard_2019_NoSouth
Scenario Folder: C:\RAMMS\PurauRockfall\output\ModernHazard_2019_NoSouth\

Simulation Started: Mon Mar 11 17:19:27 2019
Simulation Finished: Mon Mar 11 19:44:56 2019

Simulation Time (min): 145.5

Simulation Settings:
Nr_Source_Points: 570
Nr_Simulated_Rocks: 20
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 60)
Total_Nr_Simulations: 34200

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.45 / 1.76 / 19.13
Velocities (m/s): 0.00 / 13.05 / 42.61
Kin. Energies (kJ): 0.00 / 1438.97 / 109452.22
Rot. Velocities (rot s-1): 0.00 / 1.84 / 8.01
Average Slope (Degrees): 20.90 / 33.48 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\ModernHazard_ReleaseLines_Final.shp
Z-Offset: 10.00 m

Rock:
```

```
Rock Density (kg/m3): 2700.00
Block Volumes (m3):
 - Min = 1.13
 - Mean = 6.27
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_1.5m3.pts
Real_Equant_1.25_14.7m3.pts
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.2m3(3000).pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_1.4m3(3000).pts
Real_Equant_1.2_1.8m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.6m3(3000).pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Equant_1.4_4.8m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Flat_1.8_2.6m3(3000).pts
Real_Long_1.2_2.9m3(3000).pts
Real_Long_2.0_17.8m3.pts
Real_Long_2.0_4.4m3(3000).pts
```

S19. Rockfall simulation scenario logfile for RAMMS_3_ModernHazard_South

```
***********************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: ModernHazard_2019_South
Scenario Folder: C:\RAMMS\PurauRockfall\output\ModernHazard_2019_South\

Simulation Started: Mon Mar 11 12:00:43 2019
Simulation Finished: Mon Mar 11 12:16:33 2019

Simulation Time (min): 15.8

Simulation Settings:
Nr_Source_Points: 57
Nr_Simulated_Rocks: 20
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 60)
Total_Nr_Simulations: 3420

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.49 / 1.08 / 4.57
Velocities (m/s): 0.00 / 7.14 / 21.40
Kin. Energies (kJ): 0.00 / 353.04 / 10059.03
Rot. Velocities (rot s-1): 0.00 / 1.02 / 4.56
Average Slope (Degrees): -90.00 / 24.09 / 90.00

***********************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Release:
Type: Line
Line Shapefile: PurauRockfall\ModernHazard_ReleaseLines_South_Final.shp
Z-Offset: 3.00 m

Rock:
Rock Density (kg/m3): 2700.00
```

```
Block Volumes (m3):
 - Min = 1.13
 - Mean = 6.27
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_1.5m3.pts
Real_Equant_1.25_14.7m3.pts
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.2m3(3000).pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_1.4m3(3000).pts
Real_Equant_1.2_1.8m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.6m3(3000).pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Equant_1.4_4.8m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Flat_1.8_2.6m3(3000).pts
Real_Long_1.2_2.9m3(3000).pts
Real_Long_2.0_17.8m3.pts
Real_Long_2.0_4.4m3(3000).pts
```

S20. Rockfall simulation scenario logfile for RAMMS_2_Prehistoric_No South_10k uniform vegetation

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: Prehistoric_2019_NoSouth_10k_Vegetation
Scenario Folder:
C:\RAMMS\PurauRockfall\output\Prehistoric_2019_NoSouth_10k_Vegetation\

Simulation Started: Tue Mar 12 14:35:06 2019
Simulation Finished: Tue Mar 12 17:52:59 2019

Simulation Time (min): 197.9

Simulation Settings:
Nr_Source_Points: 570
Nr_Simulated_Rocks: 20
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 60)
Total_Nr_Simulations: 34200

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.48 / 1.43 / 18.72
Velocities (m/s): 0.00 / 4.10 / 38.64
Kin. Energies (kJ): 0.00 / 687.52 / 103130.45
Rot. Velocities (rot s-1): 0.00 / 0.55 / 6.98
Average Slope (Degrees): 24.55 / 41.83 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Forest/Moor:
ForestDense_final.shp:  Dense Forest (50 m2/ha)
ForestMedium_final.shp:  Medium Forest (35 m2/ha)

Release:
```

```
Type: Line
Line Shapefile: PurauRockfall\Prehistoric_ReleaseLines_Final.shp
Z-Offset: 10.00 m

Rock:
Rock Density (kg/m3): 2700.00
Block Volumes (m3):
 - Min = 1.13
 - Mean = 6.27
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_1.5m3.pts
Real_Equant_1.25_14.7m3.pts
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.2m3(3000).pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_1.4m3(3000).pts
Real_Equant_1.2_1.8m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.6m3(3000).pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Equant_1.4_4.8m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Flat_1.8_2.6m3(3000).pts
Real_Long_1.2_2.9m3(3000).pts
Real_Long_2.0_17.8m3.pts
Real_Long_2.0_4.4m3(3000).pts
```

S21. Rockfall simulation scenario logfile for RAMMS_2_Prehistoric_No South

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: Prehistoric_2019_NoSouth
Scenario Folder: C:\RAMMS\PurauRockfall\output\Prehistoric_2019_NoSouth\

Simulation Started: Mon Mar 11 14:02:02 2019
Simulation Finished: Mon Mar 11 17:11:16 2019

Simulation Time (min): 189.2

Simulation Settings:
Nr_Source_Points: 570
Nr_Simulated_Rocks: 20
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 60)
Total_Nr_Simulations: 34200

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.48 / 1.46 / 16.71
Velocities (m/s): 0.00 / 5.71 / 39.65
Kin. Energies (kJ): 0.00 / 899.68 / 101926.38
Rot. Velocities (rot s-1): 0.00 / 0.77 / 6.80
Average Slope (Degrees): 23.84 / 38.79 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Forest/Moor:
ForestDense_final.shp:  Dense Forest (50 m2/ha)
ForestMedium_final.shp:  Medium Forest (35 m2/ha)

Release:
Type: Line
```

Line Shapefile: PurauRockfall\Prehistoric_ReleaseLines_Final.shp
Z-Offset: 10.00 m

Rock:
Rock Density (kg/m3): 2700.00
Block Volumes (m3):
 - Min = 1.13
 - Mean = 6.27
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_1.5m3.pts
Real_Equant_1.25_14.7m3.pts
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.2m3(3000).pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_1.4m3(3000).pts
Real_Equant_1.2_1.8m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.6m3(3000).pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Equant_1.4_4.8m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Flat_1.8_2.6m3(3000).pts
Real_Long_1.2_2.9m3(3000).pts
Real_Long_2.0_17.8m3.pts
Real_Long_2.0_4.4m3(3000).pts

S22. Rockfall simulation scenario logfile for RAMMS_2_Prehistoric_ South_10k uniform vegetation

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: Prehistoric_2019_South_10k_Vegetation
Scenario Folder:
C:\RAMMS\PurauRockfall\output\Prehistoric_2019_South_10k_Vegetation\

Simulation Started: Mon Mar 11 13:12:34 2019
Simulation Finished: Mon Mar 11 13:30:48 2019

Simulation Time (min): 18.2

Simulation Settings:
Nr_Source_Points: 57
Nr_Simulated_Rocks: 20
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 60)
Total_Nr_Simulations: 3420

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.50 / 1.16 / 3.84
Velocities (m/s): 0.00 / 1.88 / 10.39
Kin. Energies (kJ): 0.00 / 95.20 / 2762.00
Rot. Velocities (rot s-1): 0.00 / 0.26 / 1.31
Average Slope (Degrees): -90.00 / 41.50 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Forest/Moor:
ForestDense_final.shp:  Dense Forest (50 m2/ha)
ForestMedium_final.shp:  Dense Forest (50 m2/ha)

Release:
```

```
Type: Line
Line Shapefile: PurauRockfall\Prehistoric_SouthReleaseLines_Final.shp
Z-Offset: 3.00 m

Rock:
Rock Density (kg/m3): 2700.00
Block Volumes (m3):
 - Min = 1.13
 - Mean = 6.27
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_1.5m3.pts
Real_Equant_1.25_14.7m3.pts
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.2m3(3000).pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_1.4m3(3000).pts
Real_Equant_1.2_1.8m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.6m3(3000).pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Equant_1.4_4.8m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Flat_1.8_2.6m3(3000).pts
Real_Long_1.2_2.9m3(3000).pts
Real_Long_2.0_17.8m3.pts
Real_Long_2.0_4.4m3(3000).pts
```

S23. Rockfall simulation scenario logfile for RAMMS_2_Prehistoric_ South

```
************************************************************
RAMMS::ROCKFALL - Simulation Scenario Logfile

Version 1.6.61

Scenario Name: Prehistoric_2019_South
Scenario Folder: C:\RAMMS\PurauRockfall\output\Prehistoric_2019_South\

Simulation Started: Mon Mar 11 12:49:45 2019
Simulation Finished: Mon Mar 11 13:08:18 2019

Simulation Time (min): 18.6

Simulation Settings:
Nr_Source_Points: 57
Nr_Simulated_Rocks: 20
Nr_Random_Orientations: 3
Nr_Z-Offset_Iterations: 1
(Nr_Simulations_Per_Source_Point: 60)
Total_Nr_Simulations: 3420

Simulation Results:

(Min/Mean/Max Values)
Jumpheights (m): 0.42 / 1.06 / 3.87
Velocities (m/s): 0.00 / 2.62 / 13.91
Kin. Energies (kJ): 0.00 / 138.86 / 4493.12
Rot. Velocities (rot s-1): 0.00 / 0.39 / 1.55
Average Slope (Degrees): 2.99 / 28.65 / 90.00

************************************************************
Input Settings:

General:
Time Step (s): 0.010
Dump Step (s): 0.020
DEM File: PurauRockfall\PurauRockfall.xyz
DEM Resolution (m): 4.00
Calculation Domain: .\

Friction:
Overall Type: Medium
(Values have changed!)

Additional Friction Areas:
JWB_Volcanic_Rock_2019.shp:  Extra Hard
JWB_Loess_Volcanic_Colluvium_2019.shp:  Medium Hard
JWB_Valley_Terrain_2019.shp:  Extra Soft

Forest/Moor:
ForestDense_final.shp:  Dense Forest (50 m2/ha)
ForestMedium_final.shp:  Medium Forest (35 m2/ha)

Release:
Type: Line
Line Shapefile: PurauRockfall\Prehistoric_SouthReleaseLines_Final.shp
```

```
Z-Offset: 3.00 m

Rock:
Rock Density (kg/m3): 2700.00
Block Volumes (m3):
 - Min = 1.13
 - Mean = 6.27
 - Max = 50.43
Rock Forms:
Real_Equant_1.25_1.5m3.pts
Real_Equant_1.25_14.7m3.pts
Real_Equant_1.25_2.3m3.pts
Real_Equant_1.2_1.1m3.pts
Real_Equant_1.2_1.2m3(3000).pts
Real_Equant_1.2_1.3m3.pts
Real_Equant_1.2_1.4m3(3000).pts
Real_Equant_1.2_1.8m3.pts
Real_Equant_1.2_3.6m3.pts
Real_Equant_1.4_1.6m3(3000).pts
Real_Equant_1.4_1.7m3.pts
Real_Equant_1.4_1.9m3.pts
Real_Equant_1.4_2.0m3.pts
Real_Equant_1.4_4.8m3.pts
Real_Flat_1.77_50.4m3.pts
Real_Flat_1.77_6.0m3.pts
Real_Flat_1.8_2.6m3(3000).pts
Real_Long_1.2_2.9m3(3000).pts
Real_Long_2.0_17.8m3.pts
Real_Long_2.0_4.4m3(3000).pts
```

S24 Purau Rockfall Runout – Data Fit Results

CES D1 Polynomial

Equation $Y = -5.352366643 + 0.5828450158 * X - 0.0005711632991 * pow(X,2)$

Degree = 2
Number of data points used = 30
Average X = 119.626
Average Y = 47.7263

Coefficients:
Degree 0 = -5.352366643
Degree 1 = 0.5828450158
Degree 2 = -0.0005711632991

Degree: 0
Residual sum of squares = 71031.6
Coef of determination, R-squared = 0

Degree: 1
Residual sum of squares = 1225.85
Coef of determination, R-squared = 0.982742

Degree: 2
Residual sum of squares = 331.456
Coef of determination, R-squared = 0.995334

Pre-CES D1 Linear

Equation $Y = 0.4137619746 * X + 7.802815954$
Number of data points used = 17
Average X = 29.8612
Average Y = 20.1582
Residual sum of squares = 288.534
Regression sum of squares = 2483.05
Coef of determination, R-squared = 0.895896
Residual mean square, sigma-hat-sq'd = 19.2356

CES D2 Linear

Equation $Y = 0.7229916898 * X + 3.597202216$
Number of data points used = 2
Average X = 14.105
Average Y = 13.795
Residual sum of squares = 0

Regression sum of squares = 3.40605
Coef of determination, R-squared = 1
Residual mean square, sigma-hat-sq'd = 0

Pre-CES D2 Linear

Equation Y = 0.4826062189 * X + 11.73054364
Number of data points used = 39
Average X = 84.0121
Average Y = 52.2753
Residual sum of squares = 488.349
Regression sum of squares = 39016.4
Coef of determination, R-squared = 0.987638
Residual mean square, sigma-hat-sq'd = 13.1986

CES D3 Log

Equation Y = 112.0567131 * ln(X) - 402.7873441
Number of data points used = 41
Average ln(X) = 5.43171
Average Y = 205.872
Residual sum of squares = 568.485
Regression sum of squares = 37982.9
Coef of determination, R-squared = 0.985254
Residual mean square, sigma-hat-sq'd = 14.5765

Pre-CES D3 Log

Equation Y = 112.0310699 * ln(X) - 404.957145
Number of data points used = 97
Average ln(X) = 5.43007
Average Y = 203.379
Residual sum of squares = 2083.81
Regression sum of squares = 120505
Coef of determination, R-squared = 0.983002
Residual mean square, sigma-hat-sq'd = 21.9349

CES D4 Linear

Equation Y = 0.4222533788 * X + 39.52552325
Number of data points used = 36
Average X = 181.752
Average Y = 116.271
Residual sum of squares = 510.625
Regression sum of squares = 23377.1
Coef of determination, R-squared = 0.978624

Residual mean square, sigma-hat-sq'd = 15.0184

Pre-CES D4 Linear

Equation Y = 0.4401373207 * X + 34.8872446
Number of data points used = 9
Average X = 109.11
Average Y = 82.9106
Residual sum of squares = 183.023
Regression sum of squares = 5282.47
Coef of determination, R-squared = 0.966513
Residual mean square, sigma-hat-sq'd = 26.1461