REPORT

Applied Avalanche Research in Norway

RESEARCH PLAN 2023–2025

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NORWEGIAN GEOTECHNICAL INSTITUTE
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Client:	NVE – Norwegian Directorate of Water Resources and Energy
Client contact person:	Odd Are Jensen
Contract reference:	Tildelingsbrev

for NGI

Project manager:	Kjersti G Gisnås
Prepared by:	Callum Tregaskis, Christian Jaedicke, Peter Gauer, Kjersti G Gisnås, Kate Robinson, Dieter Issler, Sean Salazar, Hervé Vicari, Regula Frauenfelder
Reviewed by:	Christian Jaedicke and Kjersti G Gisnås

NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Main office
PO Box 3930 Ullevaal St.
NO-0806 Oslo
Norway

Trondheim office
PO Box 5687 Torgarden
NO-7485 Trondheim
Norway

T 22 02 30 00
NGI@ngi.no

BIC NO. DNBANOKK
IBAN NO26 5096 05 01281
ORGANISATION NO.
958 254 318MVA

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1 Introduction

Snow avalanches are a frequent and significant natural hazard in Norway. Each year, avalanche events result in fatalities, evacuations, interruptions, and damage to infrastructure networks such as roads, railways, and electrical transmission lines. This combines to a substantial impact on the livelihoods of the people living and working in mountainous areas or also along the fjords in Norway. Persistent avalanche hazard in steep terrain is a major factor considered during land-use planning and development. During the snow season, variations in the avalanche danger identified in regional and site-specific bulletins influence the operation of the transportation networks and the safety of workers in these areas.

Applied research on avalanches and their societal impacts has been conducted at the Norwegian Geotechnical Institute (NGI) since 1973. The year 2023 will mark the 50 years anniversary of this research project. The research has been funded in part by an annual grant from the Norwegian parliament administered by the Norwegian Water Resources and Energy Directorate (NVE). Recent research activities have improved our understanding of avalanche formation, movement and impacts from avalanches. For example, enhanced knowledge of the individual processes leading to avalanche initiation, avalanche dynamics and avalanche impacts have been applied to develop tools for prediction of avalanche events, runout distance and impact pressures. While much has been accomplished within the avalanche research community in recent years, many key questions remain. Research in this area becomes increasingly important as a changing climate will vary the frequency and behaviour of avalanche events. In addition, the transfer of resent research outcomes into common practise is an ongoing challenge which needs continuous attention.

This project plan will:

- Present the research goals for the 2023–2025 period.
- Outline the project organisation.
- Present the work-package structure and specific research tasks to be undertaken by the applied avalanche research group at NGI over the next three years.

2 Project Goals

Modern avalanche research covers a wide scope of research topics across many different scientific disciplines. This includes, for example, the monitoring of avalanche events at the regional scale via satellite data, modelling of fracture mechanics and analysing the psychology of decision practices in dangerous terrain. These different aspects of avalanche research are studied using a wide variety of approaches by specialized research groups worldwide.

The applied avalanche research team at NGI has traditionally concentrated on the topics of:

1. Avalanche dynamics
2. Avalanche release
3. Forecasting
4. Mitigation
5. Hazard zoning

The aim of the applied avalanche research group is to support the Norwegian society and conduct leading research projects to further the understanding of avalanche processes in both Norway and abroad. Also, we aim to convert the latest research results into daily practice.

The full-scale test site Ryggfonn and the research station Fonnbu are fundamental infrastructure for our field-based research. In recent years we have developed a strong focus on modelling, analysis and mapping to upscale field observations and achieve our societal mandate.

The overarching research goals for the period 2023–2025 are to

- Integrate avalanche research in other major national research projects,
- To this means, unite national and international resources for the best use of the Ryggfonn and Fonnbu research facilities,
- Contribute to the development of national best-practice for hazard assessment.

The societal goals are:

- To enable communal and private land-use developments and simultaneously to keep the societal and private risk to an acceptable level,
- To provide means for cost-effectiveness studies of mitigation measures.

3 Project Organization

3.1 Project leadership and project participants

3.1.1 Steering group

The project is supervised by a steering committee, which follows the project and supports the project leadership during the project period. The steering group consists of the project leader, the head of the section for "Snow Avalanches and Rock Falls" (Heidi Hefre), the market-area director (Dominik Lang) and the NVE program responsible (Odd Are Jensen). The steering group will meet every six months.

3.1.2 Reference group

The task of the reference group is to position the avalanche research within a national and international context, to give advice and direction on research topics and to support cooperation between the projects and other research groups. The reference group consists of snow and avalanche experts from national and international organisations.

We aim to form a group of 6-8 members, minimum two of which will be from national institutions and, if possible, two–four from international institutions, and will consist of scientists and practitioners. The reference group will be confirmed at the beginning of 2023.

3.1.3 Post-doctoral researcher

A post-doctoral researcher will continue to work on the project for a minimum of one year. We will consider the possibility to look for further candidates that could work on a task specified in this proposal, or on topics in keeping with their own unique research interests/specialities if it aligns with other activities.

3.2 Field resources

For the understanding and quantification of avalanche processes, full-scale experiments on avalanche release, movement and effects are needed. There are two full-scale experimental sites for research on avalanches with size 3 or larger world-wide, one of which is the Norwegian test site at Ryggfonn in the Strynefjell mountains. The test site is supplemented by the nearby Fonnbu research station. Significant results have been obtained from field research at these two facilities. Therefore, one of the essential components of the project is the continued operation and the necessary maintenance of these two unique and valuable research facilities, but also to prepare them for new questions at the same time.

Ryggfonn and Fonnbu will continue to be administrated separately as "Research Infrastructure Resources" (RIR) for all costs, both incurred expenses and hours, that are needed to maintain and modernise the infrastructure. The RIR costs will be invoiced to the project. Hours spent on conducting research and investments in new instrumentation will be accounted for directly in the research project.

In this way we will 1) gain a better overview of the actual costs of maintaining the research infrastructure resources, 2) subsidize the operational costs by renting out the facilities to other projects, institutions in Norway and visiting researchers, and 3) improve management of necessary upgrades and investments. This will also ensure a better continuity in the experiments that are required for avalanche research.

3.3 Research ideas and suggestions

To ensure wide acceptance and research goals and activities focused on pressing societal needs, ideas and suggestions for research were collected from the wider avalanche community in Norway. Sources for input were taken from:

- Internal discussions of the needs of avalanche consultancy undertaken at the NGI.
- A stakeholder seminar run by NGI, with contributions from the avalanche community in Norway including NVE, forecasters, researchers, rescue

organisations and consultants. All participants were invited to provide suggestions for research activities.
- Members of the Norwegian Avalanche Association (Norskred), who were invited to provide suggestions for the research activities.
- Feedback and discussion with the international research community, undertaken to identify cutting-edge goals and targets in avalanche research.

This preparational work resulted in a significant number of valuable ideas that were all considered for their potential to become a part of this research plan.

3.4 Work packages and tasks

The research activities are organised into four work packages (WP0–WP3), each with specific tasks. This research plan provides an overview of the objectives for each work package. Work package descriptions purposely allow for some flexibility in order to adapt the project in new directions if required or to pursue novel ideas as research progresses. For example, if one work package bears important new knowledge that calls for dissemination, it will be possible to allocate additional resources to the work package to publish the results. Significant avalanche events, or the possibility to conduct several experiments in Ryggfonn will be prioritised. Keeping a flexible project plan will allow us to embrace full experimental efforts at the site as soon as, and whenever, field conditions are identified as being favourable to carrying out experiments.

3.5 Research infrastructure and sensor technology

Research infrastructure and sensor technology is not an end in itself, but a means of developing research ideas, verifying and quantifying research results. To this end, the research infrastructure must be maintained, and the sensor technology adapted to new circumstances.

3.6 National collaboration

Avalanche research covers a wide field of expertise and involves different stakeholders from road authorities to land-use managers. We aim for increased interaction with different Norwegian stakeholders to adjust the research to their needs. We will be open to the following three types of collaboration:

- Research collaboration with:
    - Companies and start-ups that require avalanche and snow research for developing new products and services,
    - Universities and other research institutes that can contribute with expertise and students,
    - Public agencies such as the Norwegian Public Roads Administration or NVE,
    - Important end-users such as Statnett and Statkraft.
- Dissemination and discussion partners:
    - Presentations and discussion at the biannual Nordisk Snøskred-konferanse,

  - Some of the research results will contribute to NVE's guides for hazard mapping and mitigation measures.
  - Organisations such as Norskred,
  - Local and national media,
  - Scientific research community,
  - Affected communities and counties,
  - Other organisations that have an interest in avalanche research.
- Supporting partners:
  - We will invite selected companies and organisations to support avalanche research with rebates, financial participation or in-kind contributions.

3.7 International collaboration

Due to the specialized nature of most research groups, international exchange of experiences, results and opinions is essential for progress in avalanche research. Currently, NGI maintains an extensive international network and is active in initiatives to increase the cooperation with colleagues in Iceland, Austria, Switzerland and Japan. We will increase international collaboration in the coming project period by:

- Contributing to international meetings and conferences, including the European Geosciences Union (EGU) and the International Snow Science Workshop (ISSW),
- Exchange of researchers with BFW in Austria, NIED in Japan and possibly further institutions,
- Prioritizing joint scientific publications with international and domestic colleagues.
- Revitalize the Circum-Arctic Slushflow Network (CASN), which is a working group for scientists and practitioners with an interest in slushflows.

3.8 Teaching and education

In Norway, there is a demand for avalanche expertise in the public, private and education sectors. Currently, most education focusses on the planning and safety during recreation in the avalanche terrain. Few opportunities are available to learn about the technical aspects of avalanches. For example, courses that teach the basics of snow and avalanche physics are uncommon, despite the knowledge being essential to training the next generation of avalanche experts. NGI promotes and supports such courses in cooperation with Norwegian educational institutions. We teach avalanche science at the University Centre in Svalbard (UNIS, three weeks in two courses), the University of Oslo (UiO, adjunct professor Regula Frauenfelder), University of Tromsø (UiT, adjunct professor Christian Jaedicke) and national geohazard course etc. In addition, we will contribute with our expertise and results in the education and supervision of MSc and PhD students e.g., through the RNC project GEOMME in collaboration with Japanese and South Korean institutions.

4 Project Leadership Structure

The project will be allocated in the NGI section "Snow Avalanches and Rockfall" with the section leader Heidi Hefre as the principal responsible. The project leader will be Kjersti Gisnås, assisted by Callum Tregaskis. The three work packages each have a distinct leader to overview the scientific work and progress:

WP1: Kjersti Gisnås
WP2: Peter Gauer
WP3: Kate Robinson

All three WP leaders have substantial experience from research in the AARN project and are experienced project leaders. Each WP will be awarded an annual budget to fulfil the appointed tasks. Alongside this, task leaders will be designated who will be responsible for specific research targets. All work packages will have defined topics, deliverables and deadlines which the project and WP leader will check and follow up on. The WP leaders will report budget and progress to the project leader every two months.

The Research Infrastructure Resources (RIR) of Ryggfonn and Fonnbu will continue to be led by Peter Gauer, assisted by Sunniva Skuset and Anders Kleiven.

5 WP 0 – Management and Dissemination

WP0 will focus on project management and dissemination and is the formal administration of the project and the reporting to NVE, the steering group and the reference group. All reports will be presented in English to increase the accessibility of the research results. To ensure dissemination to Norwegian stakeholders, we will additionally present major findings and results in Norwegian on the project website and during national seminars and conferences. This will help to maintain and further develop a Norwegian vocabulary of avalanche- and snow-related terms.

Tasks **Working Period**

T0.1 Project administration **2023–2025**

Focus on project management, budget administration and resource allocation. Meetings with WP leaders every three months. External contact and reporting to NVE, organisation of seminars etc.

T0.2 Internal communication and group collaboration **2023–2025**

The AARN team will commit to internal seminars – twice per year – to update the members of the working groups on progress. Official meeting minutes will be taken. NVE and the reference group will be invited to these seminars and presentations will be shared for feedback. We will also have regular content seminars with short presentations with relevant group members to discuss progress and planning.

T0.3 Steering committee and reference group 2023–2025

The project steering committee will meet every six months to discuss recent progress and provide feedback and questions on the work packages. Progress will be summarized through the shared presentations and discussed at a meeting which will be called by the project leader at NGI.

The reference group will meet annually. We will include at least two international representatives, if possible. A kick-off meeting will be planned in the first half of 2023 and a final assembly and public seminar will take place in autumn 2025.

T0.4 Reporting 2023–2025

We propose three levels of progress reporting:

- Brief biannual progress reports in January and July of each year, in advance of the steering committee meetings.
- The annual progress report in July will provide a summary of activities and results during the previous year. This will include a list of publications, dissemination efforts and educational activities.
- A final project report will be delivered at the end of 2025.

T0.5 Conferences and publications 2023–2025

Support (direct costs and hours) for the participation in relevant national and international meetings and conferences as well as financial support to cover publication fees. Additional support from internal and NFR mobility funds and publication funds will be applied for, where applicable.

T0.6 Dissemination 2023–2025

WP0 will coordinate dissemination activities, including:

- Presentations at seminars and conferences within Norway. Previously NGI has contributed in events such as the Nordisk snøskredkonferanse and NVE's fagdag. Activities such as this will ensure that Norwegian stakeholders are informed of the research results.
- The project members will present in Norskred seminars, avalunsj. We will supply several presentations on current research and informative / educational topics per year.
- Reports and Technical notes will be published on the project website and made available for all in a timely fashion.
- Presentation at major international conferences. We will select the most relevant conferences and symposia each year and send delegates who will give talks or present posters. Among these meetings may be the following:
    - International Snow Science Workshops (USA) 2023 & (Norway) 2024
    - Nordisk snøskredkonferanse (Norway) 2023 & 2025
    - EGU (Vienna) 2024 & 2025
    - INTERPRAEVENT (Taiwan) 2023

- Publication in peer-reviewed journals.
- Contributions to education by involvement in university courses and advising MSc students.
- Final seminar in autumn 2025. We will invite interested parties from across the Norwegian spectrum of avalanche workers.

In addition, we will explore ways of communicating avalanche science and its practical applications to non-scientific audiences.

T0.7 Project plan 2026–2028 2025

The new project plan for the subsequent three-year period will be developed in autumn 2025 and will be based on the results from the current period as well as relevant developments in national and international research.

Table 1 Timeline and deliverables in WP0

D0.01	Progress report month 6	2023-07
D0.02	Progress report month 12	2024-01
D0.03	Progress report month 18	2024-07
D0.04	Progress report month 24	2025-01
D0.05	Progress report month 30	2025-07
D0.06	Final report for three-year period 2023–2025	2026-01
D0.07	Final assembly and public seminar	2025-11
D0.08	Project plan 2026-2028	2025-12

6 WP 1 – Avalanche Formation and Release

Work package 1 is to be led by Dr. Kjersti Gisnås and is divided into three interlinked main tasks.

6.1 Variable size of release areas and release masses

For the simulation of avalanches, numerous input parameters must be determined by experts. With complex topographies, it can be very difficult to determine the location and size of a release area for certain scenarios/probabilities. Tools that can support the expert by the process of the delineation of release areas and that providing corresponding initial masse for the simulation can help to harmonize the process.

We will use field observations from Norway and Switzerland in combination with results from recent studies on fracture mechanics, the spatial variability of weak layer distribution and geostatistical modelling to address the variability of snow depth, stability, and the extent of release areas to achieve a probability distribution function for release of a given snow mass.

T1.1 Literature review of models for release area delineation 2023

Search and review relevant literature and recent studies to access and validate different approaches for release area delineation and spatial and temporal distribution of snow in steep terrain. The outcome will be a literature review that can be used in a future publication and report.

T1.2 Collection of data for statistical analysis 2023–2024

Collect data from partners and colleagues on the release volume of natural and artificially triggered avalanches (e.g. Ryggfonn, Grasdalen, Vallée de la Sionne, other data sources in Norway). Additional data such as detailed digital elevation models (DEMs) and weather and climate information will be collected and stored in a database for geostatistical modelling.

T1.3 Snow distribution probability maps 2023–2024

The previously published Winstral sheltering index in combination with wind data will be used to produce maps that present the probability for accumulating above-average snow amounts in the terrain. The maps will be validated using field surveys and remote sensing tools for selected slopes, where high resolution data of snow heights and weather data are available (T1.2).

T1.4 Delimitation of release areas of variable size 2024

Conceptual approaches for variable release sizes are described in e.g., Bühler, et. al. (2013), Veitinger (2015), Bühler, et. al. (2018), or in 20200017-03-TN. These approaches will be evaluated and if necessary improved. Release area size and snowpack properties are not independent and need to be seen in a combined process. A final approach will be implemented in the existing NAKSIN methodology for identification of release areas and will be used as a starting point for further development for a model for release area delineation accounting for snow drift (T1.3) forest effects 6.2 and release probability (6.3). Data collected in T1.2 will be used for model validation.

6.2 Forest effects on snowpack properties

Forest plays a major role on the release probability of snow avalanches. This is due to several reasons:

- Reduced, slower and more heterogeneous snow loading
- Changes in snow properties due to radiation effects
- Anchoring of the snowpack
- Change in wind effects

T1.5 Modelling Forest effect on snowpack 2023–2025

To quantify the forest effect on the release probability, we need to better account the effect of trees on the snow cover with regards to snowpack stability. In this task we aim to make a first step towards usable procedures to run snowpack models accounting for the forest effects for estimating release probabilities. The procedure will include running SNOWPACK and/or Crocus under Norwegian conditions, include the effect of adjusted snow loading and wind, possibly combined with a separate radiation model for forest.

6.3 Probabilistic release models including topography, climate and forest effects

First versions of a simple probabilistic release model accounting for slope, climatic factors (derived from SeNorge data) and forest effects (based on SR16 data) have been developed at NGI in the previous years.

T1.6 Calibration of probabilistic release models 2023–2024

However, further work on calibration against avalanche paths with well-known history is needed, as well as inclusion of wind drift effects on the used climate parameters, Results from 6.1 will be important.

T1.7 Forest effects on avalanche release probability 2024–2025

In this task forest effects will further be seen in connection to release area size and loading intensities and their influence on release probability. Results from 6.1 and 6.2 will be important.

Table 2 Timeline and deliverables in WP1

D1.01	Literature review: Methodologies for release area delineation	2023
D1.02	Report: Validation database for release area size and volumes	2024
D1.03	Publication: Snow drifting probability maps for Norway	2024
D1.04	Map: national map of snow distribution probability	2025
D1.04	Report/publication: About methodologies for delineation of release areas of variable size	2024
D1.05	Report: Procedure for modelling forest effects on the snowpack under Norwegian conditions	2025
D1.06	Report: suggested methodology for release probability for NVEs guidelines for avalanche assessments	2025

7 WP 2 – Avalanche Dynamics

Work package 2 is to be led by Dr. Peter Gauer and is divided into two main tasks.

7.1 Evaluation of experimentation on avalanches

A continuation of full-scale experiments at Ryggfonn to further improve our understanding of avalanche dynamics is planned. Major research questions involve:

- Probability of avalanche release as a function of the environmental conditions,

- Effect of snowpack properties on avalanche flow (flow regimes and entrainment/deposition),
- Flow-regime dependence of avalanche impact forces,
- Effect of the avalanche catching dam in the runout area.

T2.1 Full-scale experiments and data analysis 2023–2025

Continuation of the regular full-scale experiments at Ryggfonn and data collection. Here, the ongoing snow monitoring and planned snow-cover modelling at the Fonnbu station and Grasdalen is highly important, because they allow to quantify the snow properties along the Ryggfonn path, and hence quantification the influence of snowpack condition on avalanche dynamics.

Obtained test results are checked, analyzed and archived in a form suitable for further use in the research. Which aspects of data are analyzed in detail largely depends on the data quality and the characteristics of the triggered avalanche.

Data analysis also includes the cross-comparison of the data obtained at Ryggfonn with suitable data from other full-scale or laboratory experiments. This cross-comparison between different avalanche paths (test sites) and experiments is necessary to uncover scaling relations, e.g., due to different drop heights or due to differences in the steepness of the paths.

T2.2 Small-scale experiments 2023–2025

In addition, dedicated experiments on small avalanches, with a particular focus on measuring flow basal stresses (also within the snow cover) and differentiating erosion vs. entrainment (erosion columns + particle tracking device à la BFW) are considered.

7.2 Avalanche dynamics

The model development in this project period will focus on validation of avalanche models developed over the past years (MoT-Voellmy and MoT-Vollemy-PSA), documentation and making the models available. We will also continue development of a dynamical model with improved representation of avalanche speed. By including additional considerations for varying topography, curvature effects, forest effects, the erosion, entrainment and deposition of material, and phase-change, the models developed here are of direct relevance for hazard zoning and modelling of snow avalanches in mountainous areas. The overall plan for development and publication of models for the next 3 years are provided in Figure 1.

Status and plans for model development

Observations from Ryggfonn, and other large-scale avalanche test sites, have indicated that the velocity measurements are not always adequately captured by widely used rheological models, such as the Voellmy-Salm approach used in RAMMS::Avalanche, MoT-Voellmy and other avalanche software available for consultancy. The reason for the discrepancy is that the drag term in the Voellmy–Salm model increases with the square of velocity, which severely limits the velocity that an avalanche can attain. This is especially critical in designing mitigation measures like dams where the effectiveness and economic impact are directly linked to the pressures the measure has to account for. To make progress on this front, we need to look to the physics controlling the granular behaviour of dry-snow avalanche flow but not compromise on the benefits of such methodologies, for instance, the ability to model avalanches at a large-scale without detrimental computation time to complete avalanche simulations and that the model usage be accessible for avalanche consultants and scientists alike.

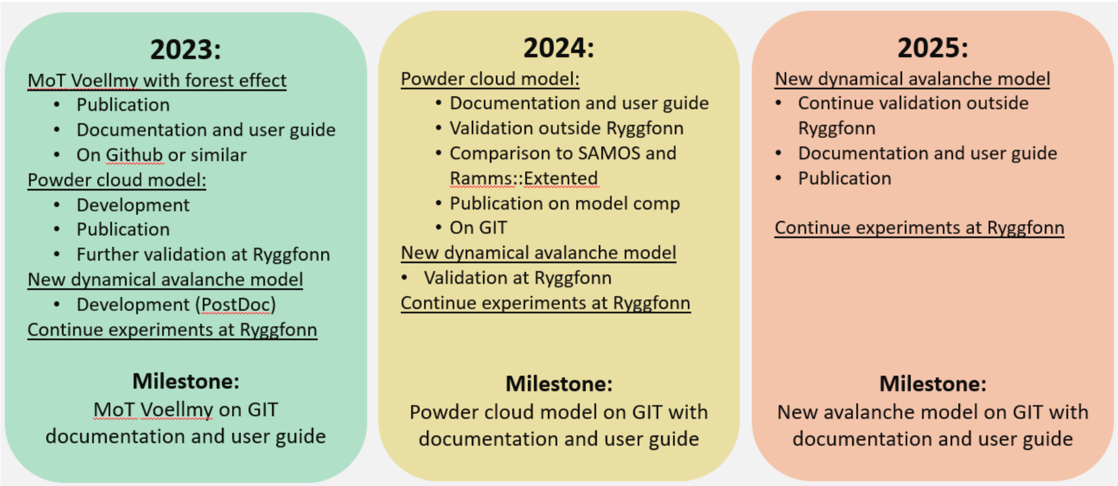

Figure 1: Progress plan and milestones for model development for the AARN project period 2023-2025.

Recent advances in the continuum modelling of granular materials have led to significant development of rheological models, such as the μ(I)-rheology, where μ is the internal friction and I is the inertial number. The rheology introduces more physical granular behaviour by coupling the shear-rate and the granular temperature of the flow. This introduces to a model the desired behaviour of granular flows (of which snow avalanches are an example) as observed in experiments, namely that there is a sub-linear increase of frictional drag with velocity (or, more precisely, the shear rate) for dense granular flow. By utilising such a rheology in a depth-averaged setting, it is possible to maintain computational efficiency at geophysical scale whilst including a more sophisticated, and realistic, frictional behaviour of the avalanche.

Over this project period we will continue to develop an avalanche model to better represent powder-snow avalanches for use in consultancy. To validate such a model we will compare between experimental measurements from the Ryggfonn test site in Norway, commonly used models utilising the Voellmy-Salm framework, and the prototype depth-averaged μ(I) avalanche model, developed in the project, parameterised for snow avalanches. A key advantage of such an approach is that with further developments extending the applicable range of the rheology into regions of rapid collisional flow, phase change effects for more dilute flow can be captured. Due to this, such extended rheologies may now be applicable to dry fluidised snow avalanches, which exhibit a phase change between dilute collisional flow and a more dense granular core. It is also possible to link the material properties of the snowpack and the parameters in the friction law, allowing an avenue for material effects to be included in such models.

The four central shortcomings of presently used avalanche flow models are (1) use of a calibration that underestimates avalanche speed, (2) neglect of entrainment and deposition, (3) the absence of flow-regime transitions, in particular (4) the formation of a powder-snow cloud. The development of avalanche models at NGI has aimed to improve on each of these fronts. NGI's code MoT-Voellmy resembles RAMMS: :AVALANCHE but features a physically consistent entrainment module. This code has also been further developed over the past project period to include the effect of forest in the run-out. Also developed recently is the MoT-Voellmy PSA (Powder Snow Avalanche) model which adds entrainment and deposition effects to a two-layer density-varying avalanche model in order to extend the MoT-Voellmy approach to also include a powder snow cloud.

T2.3 Model testing and workflow integration 2023

We will calibrate the model using both runout and speed measurements as well as estimated snow strength, mainly using data from Ryggfonn, thus addressing issues 1 and 2. MoT-PSA extends MoT-Voellmy with a dynamical powder-snow cloud to estimate the reach and damage potential of mixed avalanches. The new model will be tested extensively and practical procedures for determining the additional input parameters elaborated to approach a solution to issue 4.

T2.4 Development of a new dynamical model 2023–2025

Issue 3 is complex and will be studied from different sides. To obtain a testable and practical model, we will implement a depth-averaged $\mu(I)$ avalanche model and parametrise for snow avalanches utilising Ryggfonn data. To include fluidization due to pore-air expulsion from the compressed snow-cover, a mechanism proposed earlier in AARN, we will explore the potential of very recent extensions of the $\mu(I)$-rheology to model the density variation and transition to a fluidized flow regime. The objective is to find approximate parameterizations of the effective rheology of the flowing snow (including variable density) and of the entrainment/deposition rate under different conditions, so that they can be used in simpler and more efficient depth-averaged models.

Table 3 Timeline and deliverables in WP2.

D2.01	Summary of experimental results at Ryggfonn 2023	2023
D2.02	Summary of experimental results at Ryggfonn 2024	2024
D2.03	Summary of experimental results at Ryggfonn 2025	2025
D2.04	MoT-Voellmy with forest effects: documentation for published code on Github or similar platform:	2023
D2.05	MoT-Voellmy with forest effects: publication with recommendations for parameter choice in Voellmy-type models with entrainment giving realistic speeds	2023
D2.06	MoT-Voellmy PSA: Publication with recommendations for simulation of mixed dry-snow avalanches.	2023
D2.07	MoT-Voellmy PSA: Documentation for published code on Github or similar.	2024
D2.08	Report / paper on simulating real avalanches with an extended μ(I) rheology to include fluidization effects based on pore air expulsion	2024
D2.10	New dynamical avalanche model: Documentation for published code on Github or similar: New dynamical model	2025

8 WP 3 – Avalanche Interaction

Work package 3 is to be led by Kate Robinson and is divided into three main topics with seven tasks.

8.1 Vulnerability

T3.1 Vulnerability of people in buildings impacted by avalanches 2023

A dataset containing information from Norwegian avalanches impacting buildings with people inside was developed in the previous project period, and a vulnerability curve showing probability of survival for the people in the buildings was developed based on the degree of damage to the building. Additional parameters such as time of event will be added to the database to better quantify the uncertainty in the vulnerability curve. In addition, data from significant events in other countries will be considered, both as a part of the analysis and as validation.

T3.2 Vulnerability of buildings impacted by avalanches 2023–2024

Numerical modelling will be used to create a vulnerability curve for typical Norwegian wood-frame buildings impacted by avalanches, linking avalanche pressure to degree of damage. Combining the vulnerability of people in the buildings and the buildings themselves will result in a vulnerability for people inside of buildings impacted by an avalanche. The deliverable once this task is complete will be a vulnerability curve linking avalanche pressure to probability of survival for people inside buildings hit by avalanches.

A long-term goal is to complete small-scale testing of avalanche impact on buildings. This will be investigated in this research period, and if promising, could be implemented at Grasdalen in the future.

T3.3 Quantitative risk assessment 2025

A final task incorporating the results from vulnerability studies is developing a framework for quantitative risk assessment for snow avalanches. The framework will include the results from the vulnerability studies in T3.1 and T3.2 as quantitative inputs to the risk assessment. This work is proposed completed in collaboration with other ongoing research projects at NGI.

8.2 Mitigation measure design and implementation

Physical mitigation measures are used to reduce the release probability of an avalanche or minimize the runout or destructive effects of an avalanche. It is planned to investigate the impact pressures on objects using depth-averaged models, with the potential of testing other (eg. 3D) models in the future.

T3.4 Impact pressures on objects 2024–2025

This research area involves using a model to compute impact forces on objects. Depth averaged models may be used to provide an approximation for this, however, more sophisticated approaches in 3D (e.g., through use of Material Point Methods (MPM) or Smoothed Particle Hydrodynamics (SPH) numerical methods) may be used for specific cases, although this is not planned for this project period. This is relevant for designing mitigation measures like dams but can also be applied to calculating pressures on other infrastructure objects impacted by avalanches or surges/large mixed fronts.

8.3 Avalanche event documentation and reporting

T3.5 Investigation of avalanche and slush flow events 2023–2025

Reporting of avalanche (including slush flow) events is invaluable for collecting data for use in future research. Time will be used to document relevant information for noteworthy Norwegian avalanche events and update the avalanche database. Particular attention will, in light of the first two research topics in WP3, be focused on avalanche–structure interaction, and avalanche–forest interaction. Information on the avalanches will be obtained through site visits and interaction with locals. Existing recommendations for observations and reporting will be updated and explained to team members and made easily transferrable to the existing Norwegian avalanche database.

There is currently a revision underway of the existing national landslide and avalanche inventory, administered by NVE. NGI has been and wishes to continue providing suggestions and feedback on the proposed revision from both a research and consulting perspective.

Table 4 Timeline and deliverables in WP3

D3.01	Paper on vulnerability of persons inside of buildings hit by avalanches	2023
D3.02	Paper on vulnerability of buildings impacted by avalanches	2024–2025
D3.03	Framework for Quantitative Risk Assessment, applicable to avalanches	2025
D3.04	Initial guidelines for impact pressures on objects from depth-averaged numerical modelling	2024–2025
D3.05	Reports on significant avalanche and slushflow events during the project period, uploaded to the national landslide and avalanche inventory	2023–2025

9 Research Infrastructure Resources (RIR) and Sensor Technology

9.1 Full-scale avalanche test-site Ryggfonn

A main challenge for avalanche research is to obtain a comprehensive understanding of the different flow regimes (dense, fluidized or suspension flow) and of the involved physical processes. A combination of different measurements and observations is desirable to gain a broad and consistent picture of the avalanche flow. The complexity and variety of avalanche motion requires a combination of small-scale experiments (detailed investigations, statistics), large-scale tests (detailed investigation), and field observations (diversity, statistics). Cross-comparison between different avalanche paths (test sites) is necessary to uncover scaling relations, i.e., to identify differences in avalanche behaviour arising from variations in total length or slope along avalanche paths.

Field observations and full-scale tests under controlled conditions are still necessary for the mentioned reasons and as a basis for statistical analysis. But also, to gain new insight through more recent sensor technologies.

T RIR.1 Full-scale avalanche test-site Ryggfonn 2023–2025

The task RIR 'Full-scale avalanche test-site Ryggfonn' includes the operation and maintenance of the test site, as well as measurement campaigns at Ryggfonn every year (which are largely dependent on the weather and snow conditions).

The avalanche experiments need to be seen in close connection with the snow monitoring at the Fonnbu station.

A continued upgrade of the Ryggfonn avalanche full-scale research site will ensure that the facility can provide up-to-date data needed for the development of a thorough understanding of avalanche dynamics.

The following instrumental updates / additions will be discussed and evaluated with the intention of implementing them within the coming period (see also 9.3):

- Infrared/RGB camera
- Infra-sound sensors system as redundant measuring system for the characterization of flow behaviour and the interaction with the dam.
- Prototype for avalanche obstacle / building interaction
- Field shear test device with measurement of pore pressures

Avalanche experiments

The weather and snow-cover development in Grasdalen is continuously monitored with weather stations and video cameras at different locations, to recognize promising situations in advance. The experiments will follow the same script as in the past, guaranteeing a high standard of safety and maximum information gain from successful releases.

The experiments in Ryggfonn are also open to other institutions that wish to collaborate with NGI on snow avalanche dynamics. Currently, the Norwegian Public Roads Administration (NPRA) and the BFW are partners in the experiments. NPRA is particularly interested in pressure conditions and the danger to cars behind a terrain trap (dam) or depressions, while BFW contributes through speed measurements with its Doppler radar.

Representatives from BFW Innsbruck and SVV are invited to participate in the campaigns, other interested parties can also apply to join.

Major research questions involve:

- Avalanche release
- Probability of natural release depending on the environmental conditions
- Avalanche flow depending on the snowpack properties
- Avalanche impact forces
- Effect of the avalanche catching dam in the run-out area.

9.2 Research station in Fonnbu

The RIR Fonnbu is a unique platform for research in the Norwegian alpine environment. While the station has been used intensively for snow and avalanche research, its use for other research fields such as mountain ecology and geological processes could be of interest. Fonnbu offers all facilities for this kind of research and will be available for research projects, courses and other research and education-related activities.

T RIR.2 Operation and maintenance of Fonnbu 2023–2025

The task RIR Fonnbu includes the operation and maintenance of the research station. A new weather station was established in 2019 and we will work to improve the accessibility of the data for the meteorological institute and the general public.

9.3 Remote sensing

T RIR.3 Further development of remote sensing activities 2023–2025

This task supports the integration of sensing (observations and validation activities) with the prioritized activities in the work packages. Planned and proposed activities include implementation of the following technologies at Strynefjellet with analysis conducted in appropriate work packages:

- Thermal infrared camera installation at Ryggfonn for remote observations in winter conditions.
- Infra-sound at Rv15 to detect avalanche releases (NPRA project, task execution conditioned that NPRA can grant access to infra-sound data)
- Infra-sound sensing to improve means of quantifying the flow behaviour of avalanches and the interaction and energy dissipation at the dam.
- Distributed acoustic sensing (DAS) for avalanche detection.

Additionally, synergy with planned activities within GEOSFAIR (Geohazard Survey from Air; Innovation Project for the Public Sector, 2021-2024) will be considered. Examples related to, e.g., repetitive snow surface observations with drone-borne lidar from January to March to study snowpack evolution.

Table 5 Timeline and deliverables for Research Infrastructure Resources (RIR)

D RIR.1	Avalanche experiments in Ryggfonn. Annual operation and maintenance of the test site. Feasible upgrades of instrumentation.	2023-12
D RIR.2		2024-12
D RIR.3		2025-12
D RIR.4	Annual operation and maintenance of the research station Fonnbu.	2022–2025

10 Budget

Annual fixed costs in kNOK:

- Ryggfonn maintenance and upgrade 500
- Post-doctoral fellow 1,000
- Ryggfonn field campaign(s) 500

The remaining annual budget of approximately 2,000 kNOK will be allocated at the beginning of each project year based on task progress, available personnel resources and possible new opportunities that have arisen since the completion of the present document.

A central way of communicating our research results to colleagues around the world is through papers in peer-reviewed journals. Part of the funds allocated to this project will be used to support the writing of high-quality papers. Additional funding will be made available from NGI's general research budget on request.

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OSLO
TRONDHEIM
HOUSTON
PERTH

NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Main office
PO Box 3930 Ullevaal St.
NO-0806 Oslo
Norway

Trondheim office
PO Box 5687 Torgarden
NO-7485 Trondheim
Norway

T (+47)22 02 30 00
NGI@ngi.no

BIC NO. DNBANOKK
IBAN NO26 5096 0501 281
ORGANISATION NO.
958 254 318MVA

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