# ARCHIBALD DETERMINATION OF RUNOFF PATHS FOR PARTICLE SIMULATIONS

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**Abstract**

For advanced geotechnical assessment of slope stability and sediment transport using particle simulations, preparing input data in the required formats is essential. Accurate evaluation relies on the input data quality, a precise cleaned digital terrain model creation and the subsequent determination of runoff paths. This article compares runoff paths generated by the custom module – SurfaceFlow with those produced by commonly used software tools across selected sites.

**Keywords**

Slope stability, digital terrain, runoff lines, particle simulations, erosion

# 1 INTRODUCTION

Slope failures and landslides remain a highly relevant topic. The field of research focuses both on the faster and more accurate identification of at-risk areas and on the development of descriptions and models of material movement occurring during landslides. Advanced geotechnical assessments of slope stability and transported sediments (materials) rely on particle-based simulations. However, these simulations require high-quality input data, such as digital terrain models (DTM), flow path determination, and other essential parameters. Computational demands increase significantly as data quality improves and assessments expand to larger areas.

It is crucial to pay close attention to the techniques employed to achieve reliable results, as they have a fundamental impact on the outcomes.

- Digital Terrain Model creation

Various combinations of surveying techniques are used to create a DTM, including ground-based methods (total stations, GNSS, and levelling instruments), aerial techniques (photogrammetry, LIDAR, and drone scanning), and others. These techniques are often combined due to specific requirements to generate the desired point network (regular, triangular, etc.). Different applications require varying levels of DTM accuracy, yet no standardized methodology currently exists for assessing sufficient precision [1]. DTM smoothing is frequently applied, which can significantly influence the results., It has been found that smoothing can affect the length and sinuosity of surface runoff paths which arekey parameters for subsequent analyses [2] for the identification of erosion paths.

- Runoff paths estimation

Runoff lines are most commonly identified for hydrological purposes, such as comprehensive water management planning or assessing the risk and extent of soil erosion on agricultural land. Surface runoff is closely linked to geotechnical analyses focusing on the slope stability and the volume of transported material. Consequently, coupled models of surface and subsurface water movement are increasingly used to improve the simulation of surface runoff dynamics [3]. Problematic slopes are being studied in relation to these models, such as those affected by wildfires, where rapid sediment displacement is expected [4]. Karst areas also significantly influence sediment transport due to the concentrated flow during heavy rainfall which leads to severe soil erosion [5].

- Particle simulations

Particle simulations in geotechnics enable detailed modelling of processes such as sedimentation, erosion, and soil movement, which are crucial for managing risks associated with geological phenomena. These simulations are based on various approaches, including the law of mass conservation, incorporating both flow direction and runoff

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length and data on the volume and velocity of transported material [6]. Runoff models can also be based on the Saint-Venant equations, accounting for water accumulation on the soil surface, infiltration, and subsurface water movement [7]. To achieve a more accurate representation of the interaction between sliding masses and terrain, numerical models such as the Material Point Method are employed [8]. The primary objective is to leverage computational power efficiently to provide fast and reliable simulations.

This article specifically examines the determination of runoff lines for geotechnical applications using the custom Archibald software. Existing, widely used methods are primarily designed for hydrological purposes and are not fully sufficient for geotechnical applications. Runoff lines generated by the custom SurfaceFlow module are compared with those produced by commonly used hydrological software tools across three selected locations to assess their effectiveness.

# 2 METHODOLOGY

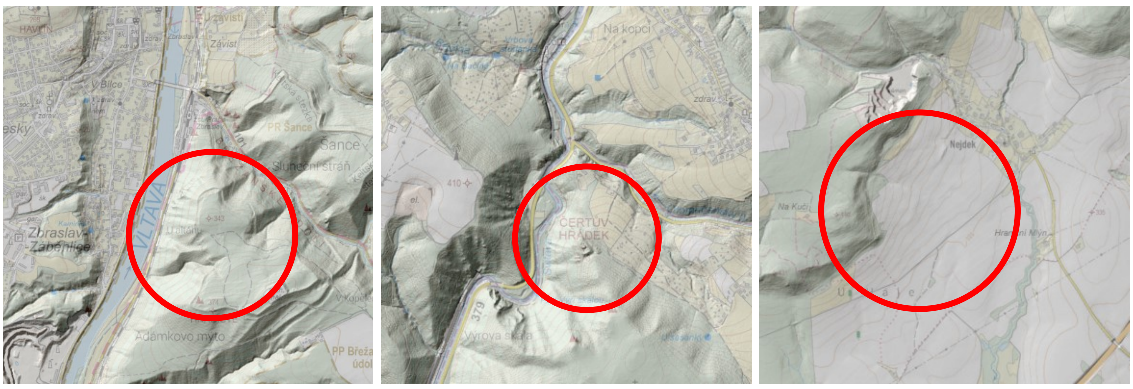
This chapter introduces:

- Description of the areas of interest,
- Digital terrain model,
- Determination and comparison of runoff lines.

## Description of the areas of interest

Three locations in the Czech Republic were selected for the purposes of this study, each representing a different type of geotechnical challenge:

- **Zbraslav** – A forested slope intersected by a railway corridor, experiencing recurring mudflows during heavy rainfall (Fig. 1a)
- **Olomučany** – A combination of open terrain (fields, meadows) and steep forested slopes (Fig. 1b).
- **Nejdek near Hranice** – An area with documented slope deformations caused by intense precipitation or snowmelt, transitioning into a flat river valley (Fig. 1c) [9].




1a Zbraslav 1b Olomučany 1c Nejdek u Hranic

Legend: ◯ exclusive area of study

Fig. 1 Selected case studies [10], [11].

## Digital terrain model

A high-quality DTM is essential for obtaining precise results from simulations. When point clouds (e.g., obtained from terrestrial scanning) include vegetation cover, it is necessary to digitally remove this vegetation. An algorithm was developed for this purpose within one of the modules of the Archibald application [12].

Publicly available elevation data for the Czech Republic, provided by the State Administration of Land Surveying and Cadastre (ČÚZK), were used to create the DTM [11] in this study. These datasets were already vegetation-

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free and were directly used for the creation of the DTM. Unstructured, unclassified point clouds [11] were transformed into an organized square grid. The analysis was conducted on DTMs with various raster resolutions. A 2×2 m grid was selected as the optimal resolution for representing all selected locations.

### Determination and comparison of runoff lines

Runoff lines were also determined using the widely used QGIS software for the comparison with the developed SurfaceFlow module.

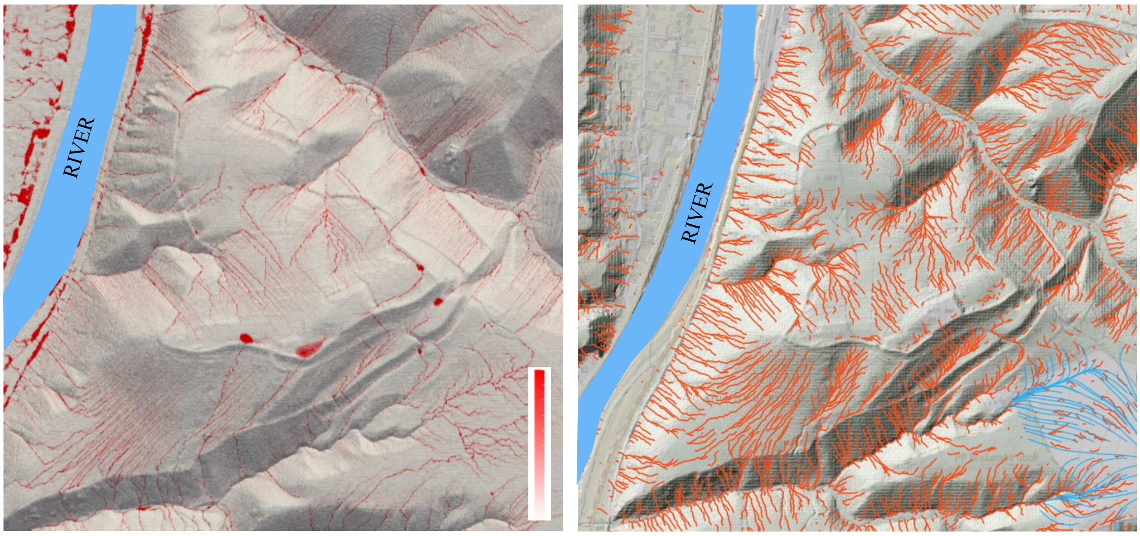
In QGIS, the D8 algorithm was employed for generating runoff lines. This algorithm calculates the flow direction based on the steepest descent among the eight neighbouring cells of the raster. The D8 algorithm is widely used in hydrological models due to its implementation simplicity and well-defined flow direction. However, it may underestimate the branching of streams.

The SurfaceFlow module was designed to allow more detailed modelling of runoff lines, considering hydrological processes. The algorithm always selects the lowest point in the surrounding area of the raster, while also being able to identify and assess water accumulation points. If no runoff occurs in a specific area, the model simulates the gradual filling of depressions and their subsequent overflow.

The resulting runoff lines were compared between the different methods. The analyses included assessing the continuity of the lines, the ability of the models to capture main runoff lines, and the identification of local accumulation areas. The study focused on the extent to which each method accurately reflects the real morphological conditions and examined the differences in the connectivity and precision of the runoff lines.

# 3 RESULTS

For each location, the results are presented in pairs, with the first output generated by the **SurfaceFlow** module (Fig. 2a, Fig. 3a, Fig. 4a). The second output is obtained using **QGIS b** [13], and if **KAPKY** [14] data are available, they are also included as supplementary results (Fig. 2b, Fig. 3b, Fig. 4b).




2a SurfaceFlow 2b QGIS/KAPKY

Legend of runoff lines: — SurfaceFlow, — QGIS, — KAPKY

Fig. 2 Zbraslav – comparison of runoff ratios.

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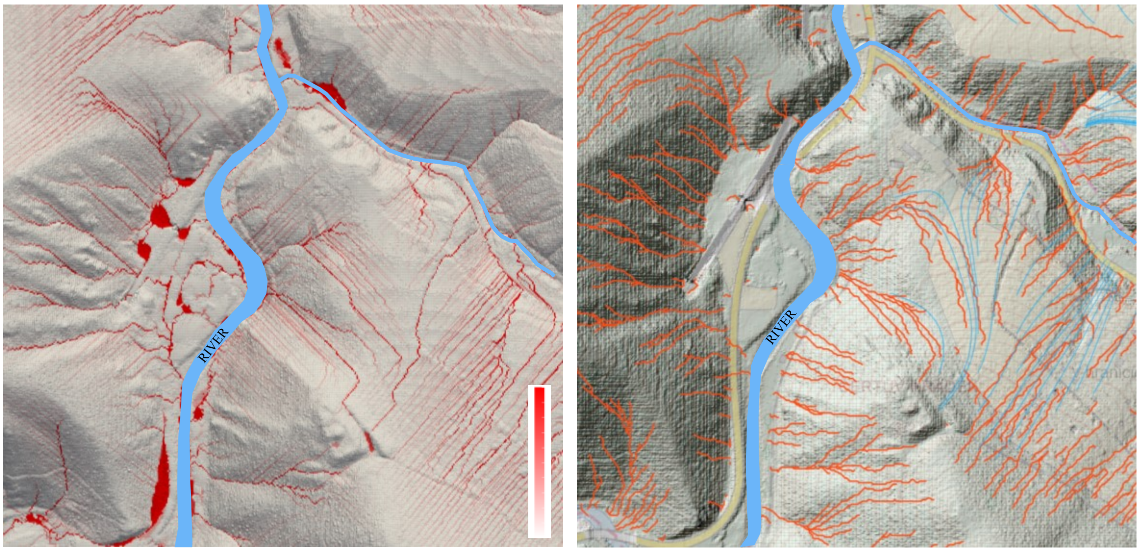
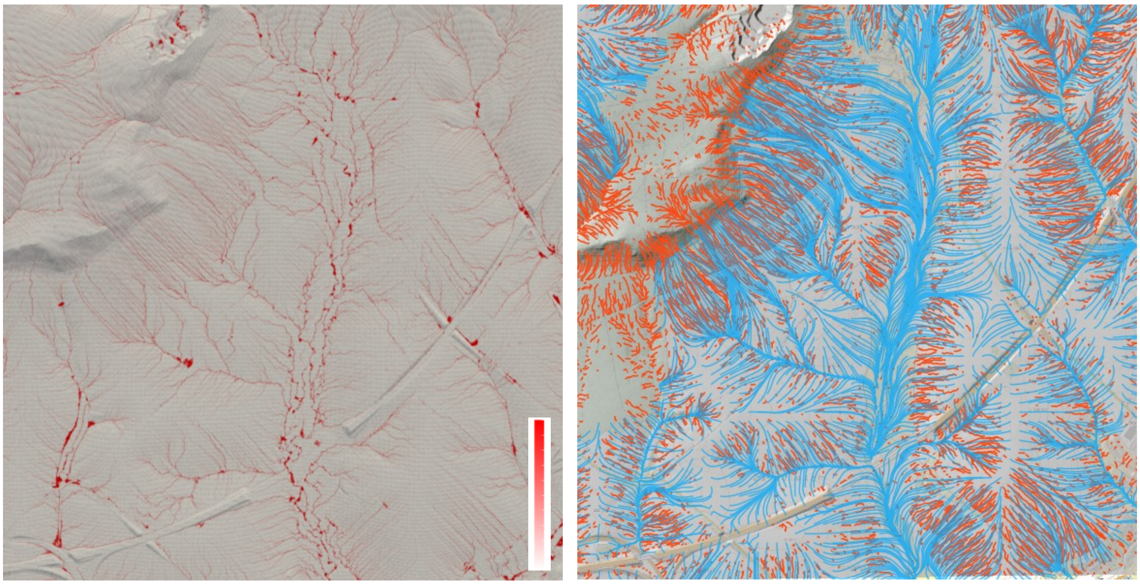



3a SurfaceFlow 3b QGIS/KAPKY

Legend of runoff lines: — SurfaceFlow, — QGIS, — KAPKY

Fig. 3 Olomučany – comparison of runoff ratios.



4a SurfaceFlow 4b QGIS/KAPKY

Legend of runoff lines: — SurfaceFlow, — QGIS, — KAPKY

Fig. 4 Nejdek – comparison of runoff ratios.

# 4 DISCUSSION

The image pairs display the resulting runoff lines for each location:

- **Zbraslav** –The SurfaceFlow method demonstrates a superior ability to assess flat areas at the summit of slopes, which allows for more accurate identification of water accumulation zones (see Fig. 2a).
- **Olomučany** – Fig. 3a and Fig. 3b reveal consistency in identifying the main runoff lines. In Fig. 3b, the KAPKY method aligns with the established runoff lines, but the smoother continuity does not

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always accurately follow the locations of erosion channels, which are critical for evaluating erosion processes. Conversely, Fig. 3a provides better continuity between runoff lines, making it more suitable for surface runoff prediction.

- **Nejdek near Hranice** – A comparison of Fig. 4a and Fig. 4b shows that the SurfaceFlow method excels in capturing runoff in valley areas, maintaining continuity between lines and accurately identifying local water accumulation points. The QGIS method only assesses segments of the flow, while the KAPKY layer is heavily influenced by human adjustments, reducing its reliability.

The comparison of runoff lines generated by the SurfaceFlow module and commonly used hydrological tools in QGIS demonstrates small deviations in the positioning of the runoff lines when using the same DTM. These differences are primarily caused by the algorithmic approach to determining flow direction and the use of different interpolation methods. SurfaceFlow could achieve even more refined lines by modifying the algorithm, particularly by incorporating a drainage line to identify the lowest point.

The accuracy of the outputs is influenced both by the chosen algorithm and by the quality of the input data and their preprocessing. Unlike some studies that rely on highly detailed DTMs (e.g., based on LIDAR data), this study shows that even publicly available data can yield sufficiently accurate results when appropriate methodological adjustments are made.

In this study, analyses were conducted at several DTM resolutions, a key factor influencing the results. It was found that excessive smoothing of the terrain could lead to an underestimation of runoff lines, which may significantly impact the accuracy of predictions regarding erosion processes and sedimentation.

One of the limitations of this study is the lack of direct validation of the modelled runoff lines with real-world field observations. To ensure greater reliability of the results, future research should include comparisons of the modelled runoff lines with data obtained during intense precipitation events. This would allow for the validation of the flow path algorithm, particularly in complex areas (e.g., plateaus, and local depressions).

# 5 CONCLUSION

This paper introduced the **SurfaceFlow** module, which builds on the previously developed Archibald modules and expands the possibilities for data processing in subsequent particle simulations. The results of the runoff paths analyses enable the identification of key routes for potential soil movement, contributing to a better understanding of flow behaviour in landslides. The key findings include:

- The resolution of the Digital Terrain Model (DTM) affects the accuracy of the results – excessive smoothing of the terrain may not always be beneficial and depends on the specific phenomenon being observed.
- The developed module effectively builds on the previous DTM module and allows the direct use of runoff lines in particle simulations.
- The identified runoff lines generally match those from the QGIS application; however, for more advanced validation, real-world observations during rainfall events in the studied area should be carried out.
- SurfaceFlow better preserves the continuity of runoff lines, especially in areas with complex terrain morphology, such as valleys or regions with local depressions.
- The module allows users to define the significance of runoff lines, providing flexibility in the analysis of hydrological and geomorphological processes.
- A key advantage is the integration of the entire process into a single application, ensuring compatibility of outputs and simplifying subsequent geotechnical analyses.

Accurate flow path analysis is crucial for erosion analysis and slope stability, particularly in landslide-prone areas. The study confirmed that the developed module is a reliable tool for simulating hydrological processes in geotechnical applications. Future research will focus on particle simulations to determine the amount of transported material, based on the DTM and established runoff lines.

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