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BankforNET v3.7.0
User Manual
2025

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Frontpage figure

Mödlingbach by Hinterbrühl, AT (photo: M. Schwarz)

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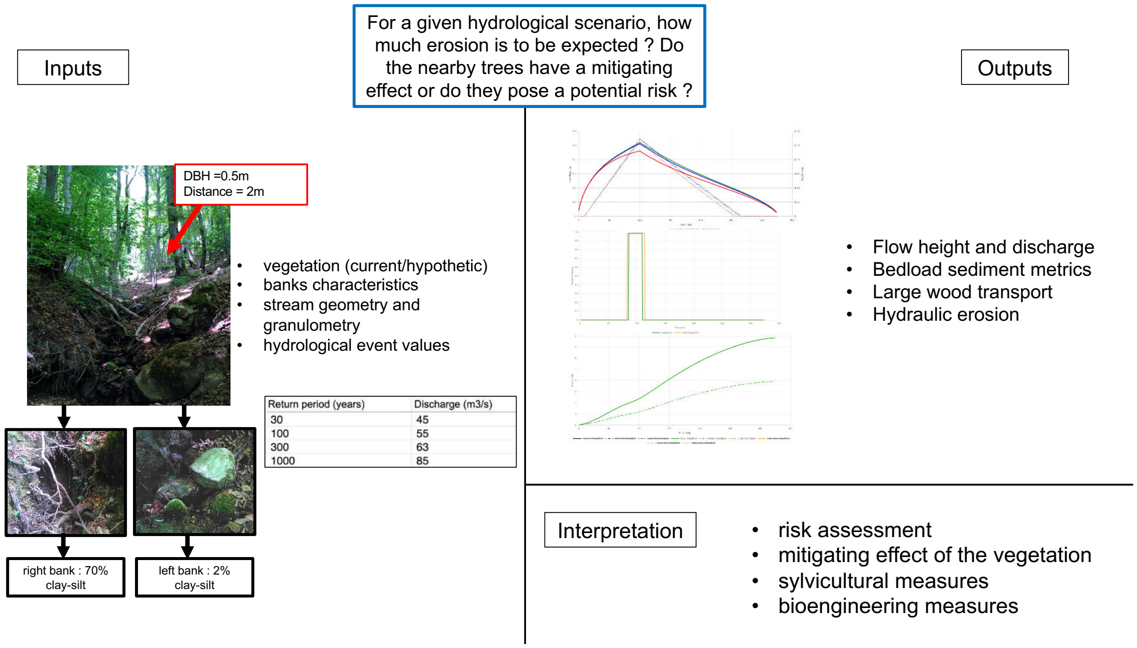
1 Introduction

BankforNET is an online tool that simulates hydraulic stream bank erosion that can be expected at a single section of a stream, in relation to the channel morphology, bank material, root distribution, and discharge scenario. Its aim is to support experts in the quantification of bank erosion hazards, sediment transport, and large wood recruitment. **BankforNET** is meant to be used as a quick quantitative support tool for decision makers in the field. Ultimately, the quantitative results can be applied as follow:

- Evaluation of hazards related to hydraulic stream bank erosion and/or large wood transport and/or bedload transport of sediments in a specific section of a stream
- Effects of different biological measures using three vegetation condition scenarios: current vegetation; no vegetation; ideal vegetation
- Quick assessment of measure effectiveness – technical or eco-engineering – or as support for calculations based on collected data (e.g., remote sensing or previous projects)
- Decisions regarding forest operations near streams

Figure 1 illustrates an example of the application of **BankforNET**, the necessary inputs, the outputs, and a possible interpretation of results. Further examples and details of applications of **BankforNET** and the interpretation of results are given at the end of this manual (see Section 10).



Return period (years)	Discharge (m3/s)
30	45
100	55
300	63
1000	85

Figure 1: Use of **`BankforNET`** applied to the Serine river, Switzerland, for different biological scenarios and rainfall rate return periods.

2 Features

BankforNET calculates bank erosion and sediment and large wood transport during a hydrological event at a specific cross section of a stream or river specified by the user. The hydrological event can be described by one of the following combinations

- Maximum discharge and duration,
- Catchment area and return period,
- Catchment area and discharge.

From this information, the model constructs a hydrograph (a graph of discharge or water flow rate as a function of time) and computes the erosion at the banks (inner and outer) and the sediment and the large wood transport in the channel cross section described by the user.

The distinguishing features of **BankforNET** are:

- Keeps track of the time evolution of the stream width and bank erosion during the hydrological event
- Updates the calculation of the channel geometry (width and flow height) at each time step during the hydrological event
- Performs calculations for three different scenarios: current vegetation, no vegetation, ideal vegetation
- Handles separate inputs and calculations for the inner and outer banks as it relates to sediment size distribution and vegetation
- Calculates critical shear stress using either: (i) randomly generated values of the mean sediment size distribution D_{50} (Brownlie model); (ii) three (lower, mean, and upper) sets of values for parameters of the Paphitis model that represents the 2.5 and 97.5 percentiles for the lower and upper bounds of the normally distributed parameter set; (iii) user defined values
- Incorporates the effect of roots on the critical shear stress via the estimation of the RVR (root volume ratio) using a calibration from [5]
- Uses a unique data set for root distribution as a function of depth for the tree species *Alnus incana* obtained from field measurements
- Computes sediment transport using a modified Stricker's coefficient based on data sets for mountain streams
- Combines fluvial bedload sediment transport and debris-flow transport at different spatial scales into a unified formulation for total sediment transport using a Weibull survival function

These features makes **BankforNET** a unique tool for estimating the erosion and the effects of vegetation (root reinforcement) on the stability of banks, as well as quantifying sediment and large wood transport during a hydrological event.

3 Framework

BankforNET is a one-dimensional, scenario-based, model to simulate hydraulic stream bank erosion considering the effects of root reinforced banks and randomness of the Shields entrainment parameter. **BankforNET** builds on the model published by [2]. The model uses the empirical excess shear stress equation, where the effects of roots are implemented by adapting the material dependent critical shear stress, τ_c, considering the root volume ratio (RVR). Different options are provided for the estimation of the Shields parameter. Sediment transport is based on a combination of debris-flow transport and fluvial transport, combined into a single estimate by an appropriate Weibull survival function transformation that depends on the mean slope of the channel at a larger (100 m) spatial scale. Wood transport is calculated using empirical relations. Stochastic calculations are performed for the sediment mean grain size distribution, D_{50}, to account for uncertainties in the value of this parameter. Figure 2 shows the overall framework of **BankforNET** with the model process, from the input data to the output of erosion, sediment, and wood transport estimates. Figure 3 illustrates the erosion calculation output of **BankforNET**.

The required input data consists of values on local channel geometry, soil description, bedload transport material, catchment area/discharge, as well as a vegetation description. The input data, short instructions for running **BankforNET**, and output data are described in detail in the following chapters.

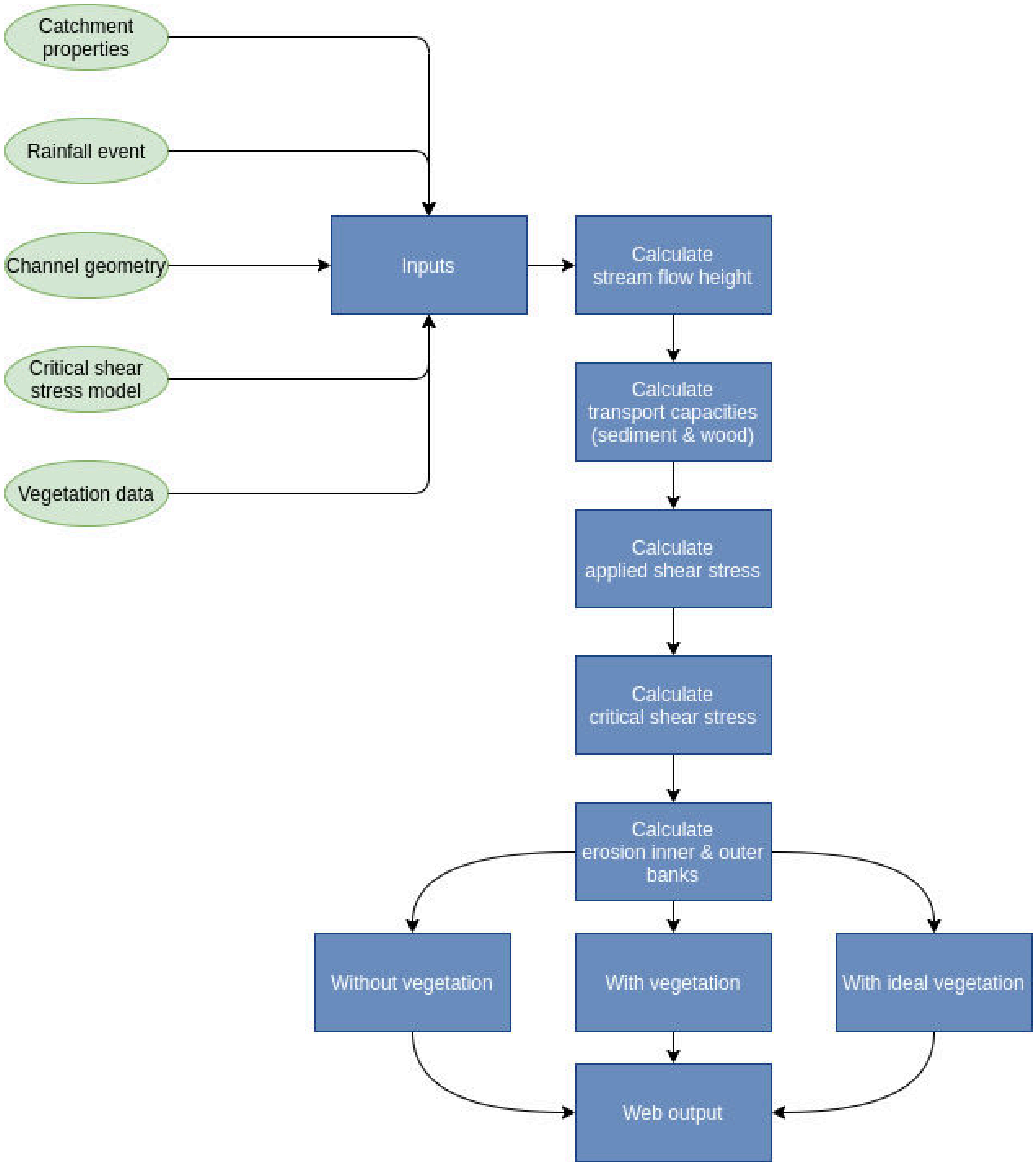


Figure 2: Modeling process framework of **BankforNET**.

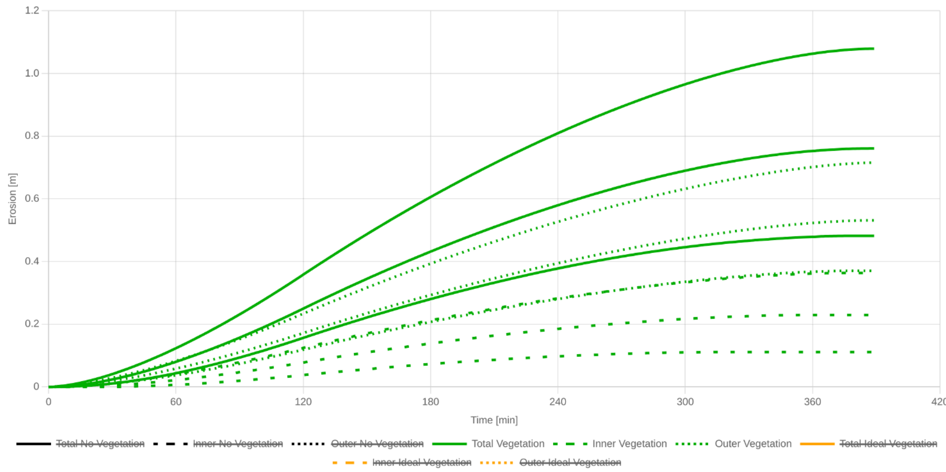


Figure 3: Web application output for the calculation of erosion with vegetation

4 Installation

BankforNET is a progressive web application (Progressive Web Apps! or PWA for short) that can be accessed using any web browser on a computer, a tablet, or a smart phone, by typing this address in the address bar: https://bankfornet.cosci-llc.com. At the time of publication of this User Manual, the version of **BankforNET** available is version 3.7.0. Reloading the Web page in your browser may be necessary to obtain the latest version of **BankforNET**.

Information on PWA can be obtained here: https://web.dev/learn/pwa/ A PWA can be accessed directly through a web browser or installed on your device for offline use, without requiring an external connection. **To access BankforNET in offline mode, BankforNET must be run at least once**.

Installation instructions may depend on your device and operating system, as well as the browser used. Detailed instructions for different platforms can be found in https://web.dev/learn/pwa/installation/ Instructions for Android and iOS and iPadOS are summarized below but may be different depending on your system.

4.1 Android installation

On Android devices, the PWA installation prompt differs by device and browser. In the Google Chrome browser:

1. Open the page of the **BankforNET** PWA
2. Click on the three vertical dots in the upper right of the page
3. Select **Add to Home Screen**.

4.2 iOS and iPadOS installation

On iOS and iPadOS, installation of the PWA can only be done with the Safari browser. Other browsers available in the App Store, such as Google Chrome, Firefox, Opera, or Microsoft Edge, cannot install a PWA on the home screen.

1. Open the Share menu, available at the bottom or top of the browser
2. Click **Add to Home Screen**
3. Confirm the name of the application; the name is user-editable
4. Click **Add**. On iOS and iPadOS, bookmarks to websites and PWAs look the same on the home screen.

5 User interface

BankforNET is a straight forward online web application tool that can be used on a computer or on a smartphone in the field. The user interface (UI) is the interface to interact with the application. By default, the UI starts in the *Basic* view mode. An *Advanced* mode is available by switching the toggle button in the upper left corner of the application. Figure 4 shows the UI in the default *Basic* configuration on the Chrome Web Browser.

The interface of both the *Basic* view and the *Advanced* view has four tabs located on the left side of the interface (see Figure 4) for the user to select models and values of input parameters and to visualize results:

- **Input**
- **Flow Height** (output)
- **Transport** (output)
- **Erosion** (output)

By default, the UI opens up on the **Input** tab. The other tabs display output results.

On the right side, there are two additional tabs:

- **Download**
- **User Manual**

The **Download** tab is to download results (together with data inputs) in the form of tables and graphs directly onto a computer or smartphone. In that way, **BankforNET** can be used as a digital protocol for field data collection and analysis. All inputs and results are downloaded to a zip file. The name of the zip file can be modified in the `Calculation Information` window at the bottom of the UI **Input** tab.

The **User Manual** is to download the User Manual in PDF format.

The `info` button, ⓘ in the upper right corner of the web application displays **BankforNET** version number, copyright information, and license agreement. Questions about the software can be sent to `software@cosci-llc.com`.

At the bottom of the application web page, the button **Calculate Erosion** launches the simulations.

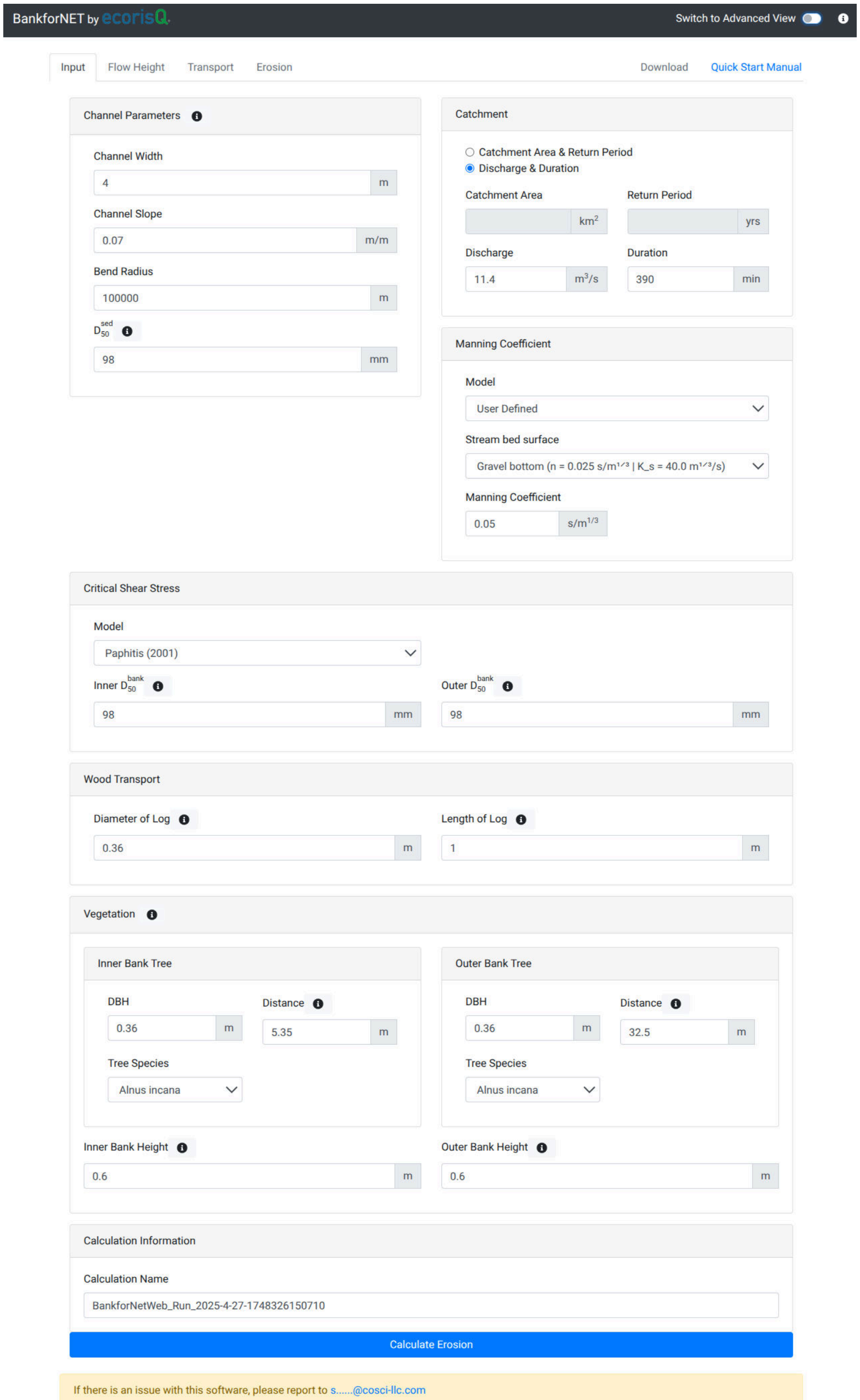


Figure 4: User interface in the default *Basic* mode using Google Chrome

6 Model inputs – *Basic* mode

In this section we describe the *Basic* mode interface. The *Advanced* mode is described in Section 7.

The **`Input`** tab is separated into several *windows* for different input parameter sets:

1. `Channel Parameters`
2. `Catchment`
3. `Critical Shear Stress`
4. `Wood Transport`
5. `Vegetation`
6. `Calculation Information`

Input parameters for each of these *windows* are described in details below.

6.1 Channel Parameters

- **Channel Width**: Total width of channel at cross-section of interest (m – meter)
- **Channel Slope**: Local slope gradient of the channel in the direction of the stream (m/m – meters per meters)
- **Bend Radius**: Radius of curvature of the stream, (m). The larger the number the more straight the section of the stream. By default, a value of 10^5 m represents a straight stream section
- D_{50}^{sed}: Mean sediment diameter of transported channel bed material (mm – millimiters)

Figure 5 shows the channel parameters in a drawing.

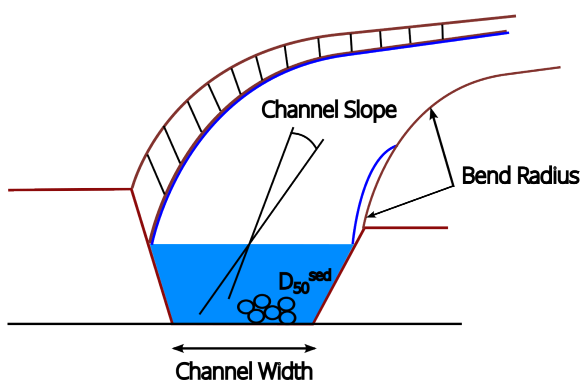


Figure 5: Channel parameters parameters for the *Basic* mode

6.2 Catchment

Two options are available for the hydrological scenario depending on the available information:

1. Catchment Area & Return Period
2. Discharge & Duration

Selecting one of these two options enables the user to enter the values of the parameters in the appropriate fields. The information is then used to calculate the water discharge in the stream as a function of time. If available, best results are obtained for known values of discharge (maximum value, in cubic meters per second) and duration (in minutes).

6.3 Manning coefficient

The channel roughness is calculated using Manning's coefficient and is used to compute the stream flow height. Two models are available to estimate Manning's coefficient:

1. User Defined
2. Rickenmann 1996

If Option 1, User Defined, is selected, several types of stream bed surfaces are available through a drop-down window. The type of surface and the associated value of the Manning coefficient are shown in Table 1 for different surfaces. In general, values range between 0.025 and 0.1 $m^{1/3}/s$. For natural mountain streams, a value of about 0.05 $m^{1/3}/s$) is commonly used. Figure 6 shows illustration of stream bed types and values of Strickler's coefficient for different water discharge.

Type of surface	**Manning** ($s\ m^{-1/3}$)	**Strickler** ($m^{1/3}\ s^{-1}$)
Gravel bottom	0.025 (0.02 – 0.03)	40
Mountain stream with rocky beds	0.045 (0.04 – 0.05)	22
Winding natural stream with weeds	0.035	28.5
Natural stream with little vegetation	0.025	40
Straight, unlined earth canal	0.020	50
Smoothed concrete	0.012	84

Table 1: Values for the Manning's and Strickler's coefficients for different types of stream bed surfaces

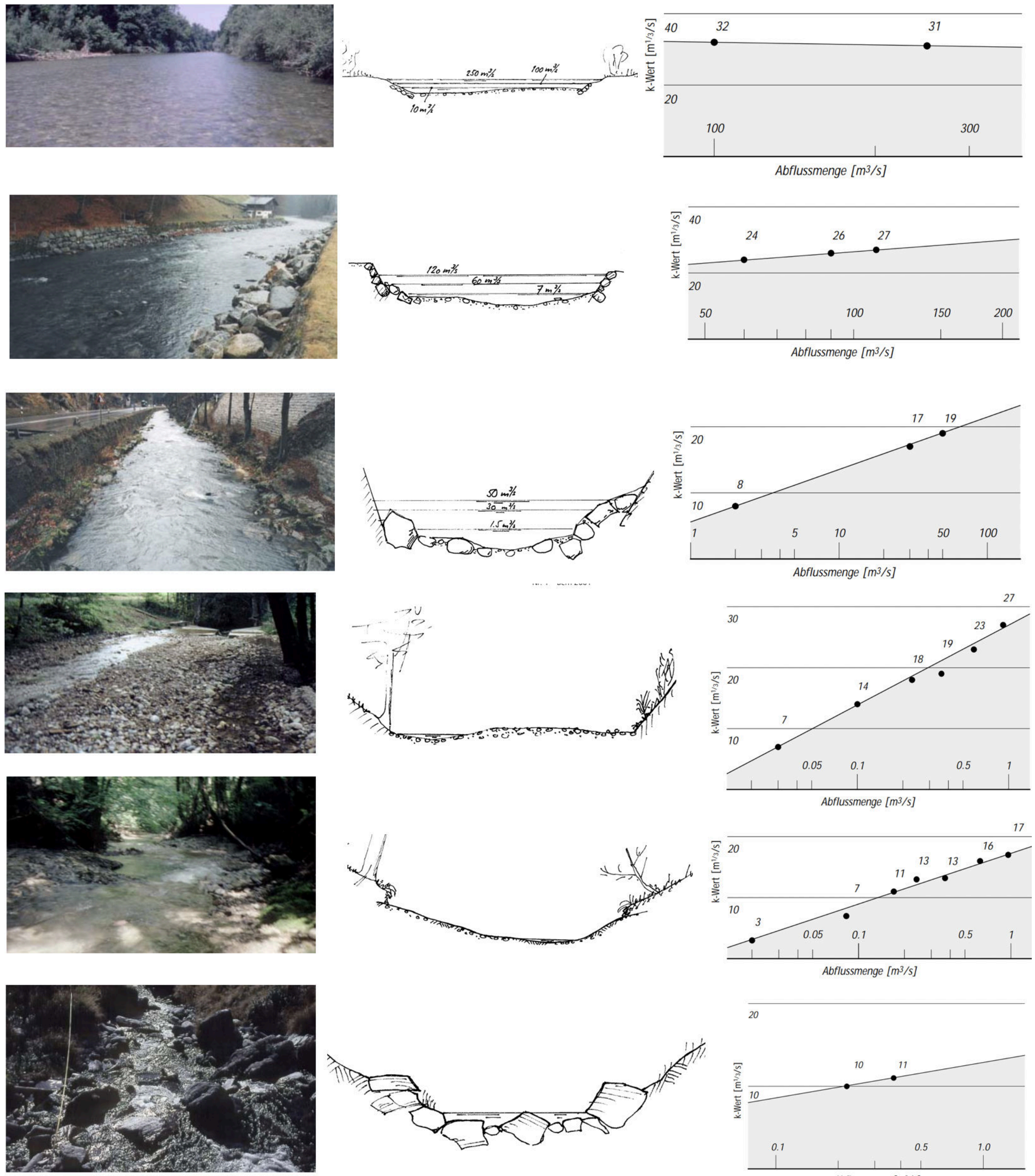


Figure 6: Illustration of values of Strickler's coefficient (1 over Manning) for different types of stream bed surfaces (Berichte des BWG, Serie Wasse – Rapport de l'OFEG, Série Eaux – Rapporti dell'UGAEG, Serie Acque, Nr. 1 – Bern, 2001). k-Wert is Strickler's coefficient; Abflussmenge is discharge.

If Option 2 is selected, the model of Rickenmann (1996) is used to compute the Manning coefficient based on the sediment size distribution parameter D_{90}^{sed} (the 90^{th} percentile used to represent the coarse fraction, i.e. 90% of the sediment is finer than D_{90}^{sed}), assumed in the *Basic* mode to be equal to 2.5 times the value of D_{50}^{sed}.

6.4 Critical Shear Stress

In the *Basic* mode, two options are available to compute the critical shear stress: the model of `Paphitis (2001)` and a `User Defined` option.

The model of Paphitis (2001) requires two inputs: the value of the mean bank sediment size diameter and the D_{50}^{bank} for the inner and outer banks. In this model three values of the Shields number are calculated using an empirical model that define three curves for a mean and an envelope for the threshold of critical condition for sediment transport as a function of the grain Reynolds number. These three Shields number are used to compute the critical shear stresses that correspond to the 5, 50, 95 percentiles and represent a kind of probabilistic or stochastic approach.

With Option 2, `User Defined`, the user can select for each bank, the value of the critical shear stress based on the percentage of Silt + Clay in the bank material.

6.5 Wood Transport

For **`BankforNET`** to assess the transport of wood by the stream for the given scenario, diameter (m) and length (m) of the log are needed. These values can refer to any piece of wood of interest. If the user is interested in assessing the transport of logs from felled trees in the stream due to bank erosion, it is necessary to estimate their lengths which can be significantly smaller than the height of the standing trees. Log length can be estimated based on the existing logs found in the stream (ideally of the same species). Alternatively, whilst it is not widely established or universally accepted as a standard in the scientific literature, the size of a log can be assessed in practice as equal to 1/5 of the length of the original tree height [7].

6.6 Vegetation (current)

In this window it is possible to set the properties of trees present on the inner and outer stream banks: one representative tree for each side of the stream must be defined. For each bank, the user must enter the DBH (diameter at breast height in meter) of the representative tree, its distance from the center of the stream (in meter) and select the tree species (as of **`BankforNET`** v3.7.0, only one tree species is available, *Alnus incana*). The DBH, the distance, and the tree species are used to compute the root distribution that's needed to calculate the influence of tree roots on hydraulic bank erosion (see Fig. 7).

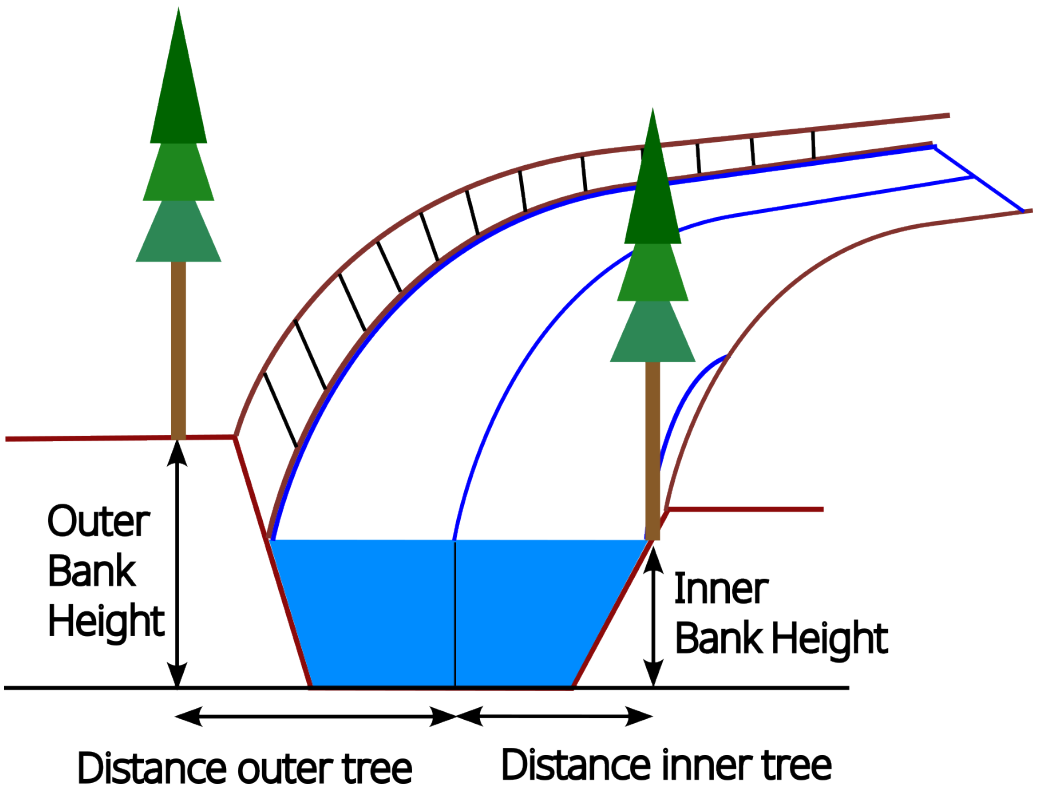


Figure 7: Illustration of trees on inner and outer banks of stream

6.7 Calculation Information

In this window, the user can enter a user-specified name for the zip file for download.

7 Model inputs – *Advanced* mode

As in the *Basic* view, the *Advanced* mode has the **`Input`** tab separated into several *windows* for different input parameter sets:

1. `Channel Parameters`
2. `Catchment`
3. `Critical Shear Stress`
4. `Wood Transport`
5. `Vegetation` – Identical to *Basic* view mode
6. `Ideal Vegetation`
7. `Calculation Information` – Identical to *Basic* view mode

The following subsections describe the all input data of the **`Input`** tab that appear in the different *windows*. When a *window* is unchanged from the *Basic* mode, we refer to the text in Section 6 on page 15.

7.1 Channel Parameters

We divide the `Channel Parameters` window into different subsection.

7.1.1 Channel geometry

The first set of input parameters is related to the channel geometry (see Figure 8):

- **Channel Width** Total width of channel at cross-section of interest (m – meter)
- **Channel Slope** Local slope gradient of the channel in the direction of the stream (m/m – meters per meters)
- **Mean Channel Inclination** Large scale slope gradient in the direction of the stream (100 meter scale) (m/m)
- **Inner Bank Slope** Slope angle measured from horizontal of the inner bank (degree)
- **Outer Bank Slope** Slope angle measured from horizontal of the outer bank (degree)
- **Bend Radius** Radius of curvature of the stream, (m). The larger the number the more straight the section of the stream. By default, a value of 10^5 [m] represents a straight stream section (m)

- **Inner Bank Height** Height of inner bank (m), defined as the vertical distance between the bed of the channel and the point where no vegetation can establish (m)
- **Outer Bank Height** Same as above for outer bank (m)

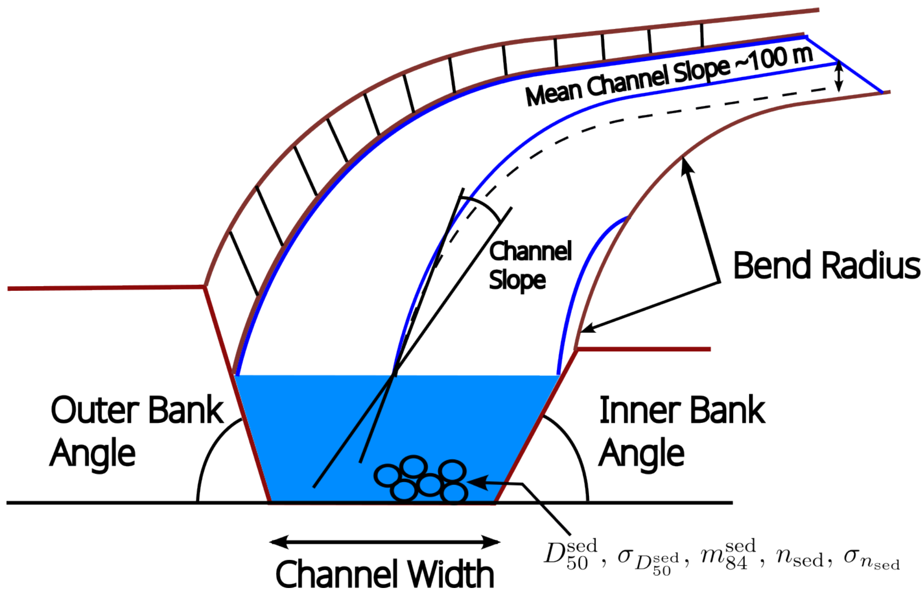


Figure 8: Channel Parameters parameters for the *Advanced* mode

7.1.2 Stream bed sediment material

- $D_{50}^{\rm sed}$ Mean sediment diameter of transported bedload material (mm – millimiters)
- $\sigma_{D_{50}}^{\rm sed}$ Standard deviation of mean sediment diameter of bed material (mm – millimiters)
- $m_{84}^{\rm sed}$ Multiplying factor to obtain $D_{84}^{\rm sed}$ from $D_{50}^{\rm sed}$, where $D_{84}^{\rm sed}$ is the $84^{\rm th}$ percentile used to represent the coarse fraction, i.e., 84% of the sediment is finer than $D_{84}^{\rm sed}$ (no units)
- $n_{\rm sed}$ Mean porosity of sediment material (no units)
- $\sigma_{n_{\rm sed}}$ Standard deviation of the mean porosity of sediment material (no units)

Grain size of bedload sediments, $D_{50}^{\rm sed}$, is used to calculate bed roughness. Figure 9 shows how to estimate the value of $D_{50}^{\rm sed}$ given a grain size distribution curve.

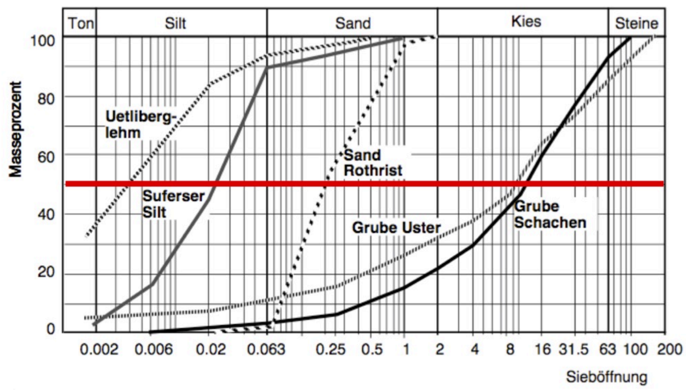


Figure 9: Graphical determination of the D_{50}^{sed} (red line) for five different grain size distributions.

7.2 Catchment

7.2.1 Hydrological scenarios

Three options for the hydrological scenario are available depending on the available information:

1. Catchment Area & Return Period
2. Discharge & Duration
3. Catchment Area & Discharge

In the *Advanced* mode, an additional option is available: Catchment Area & Discharge. As in the *Basic* mode, the user selects the appropriate option depending on available data and enters the values of the parameters in the input fields. As noted earlier, the input data is used to calculate the water discharge in the stream as a function of time and best results are obtained for known values of discharge (maximum value, in cubic meter per second) and duration (in minutes).

Also available in the *Advance* mode is a minimum value for the stream flow: Base Flow. This is used if the stream flow is significant before the hydrological event.

7.2.2 Hydrograph

We assume a triangular-shaped hydrograph with a rising and a falling limb. The timing of the peak discharge is calculated based on the value of the Hydrograph Ascending Factor. The duration of the rising limb of the hydrograph is equal to the total duration (either directly from the user input or calculated from the combination of Catchment Area/Return Period or Catchment Area/Discharge) divided by the Hydrograph Ascending Factor. A value of 2 means that the hydrograph rising limb is equal to the falling limb. A value around 3 is a good guess if no data is available. The default value is 3.25 in **BankforNET**.

7.2.3 Erosion coefficient

The Erosion Coefficient is used to calculate erosion based on the excess shear stress equation. The value of the coefficient can be changed if the user has performed a specific analysis for a particular case study. If no independent data and/or analysis is available, the default value of the erosion coefficient can be used. In **BankforNET** the default is 6.699×10^{-7} m Pa$^{-0.5}$ s^{-1}, a value obtained from the literature.

7.3 Manning Coefficient

In the *Advanced* mode, the user can specify the value of the multiplier m_{90}^{sed} for Rickenmann's 1996 model that is used to compute D_{90}^{secd} from D_{50}^{sed}.

If the User Defined option is selected, the user can modify the value of Manning's coefficient after selecting the stream bed surface.

7.4 Critical Shear Stress

In the *Advanced* mode, one additional option is available in addition to the `Paphitis (2001)` model and the `User Defined` option (see Section 6.4, page 18): the model of `Brownlie (1981)` With this model, the user must enter the values of the inner and outer banks D_{50}^{bank} as for the model of Paphitis (2001). In addition, the user must provide values for the standard deviation of D_{50}^{bank} for each bank or use the default values (10% of the mean).

7.5 Wood Transport

This process is identical to the one for the *Basic* mode described in Section 6.5 on page 18.

7.6 Vegetation (current)

This window is identical to the one for the *Basic* mode described in Section 6.6 on page 18.

7.7 Ideal Vegetation

In order to quantify how tree-roots influence hydraulic bank erosion at different stages of tree growth, it is possible to define future scenarios of tree dimensions that eventually may also represent *ideal* vegetation conditions. In the context of sustainable protection forest management, the *ideal* condition of the forest corresponds to the target conditions that are the best compromise for the optimization of the resilience, the resistance, and the delivery of ecosystem services of a forest in the long term. In **BankforNET** it is possible to define either a `Time Interval` for a future scenario, or a specific `Tree Size`. For the option `Time Interval`, this value is considered an indicative median value of the DBH annual increment of 4 mm based on the results of [1].

7.8 Calculation Information

This window is identical to the one for the *Basic* mode described in Section 6.7 on page 19.

8 Model outputs

BankforNET results are separated into three output tabs that become available once the **Calculate Erosion** button has been pressed and the calculations are over. The three output tabs are described in details below.

8.1 Flow Height tab

Flow height and bedload sediment flux: The graphic under the **Flow Height** tab (see illustration in Fig 10) shows the flow height in meter (left y axis) as a function of time. The height of water in the stream cross section is important to estimate the submerged zone during the event. Also shown in this graphic is the bedload sediment flux (Q_{sed}, dashed lines) at the stream cross section (volume of sediment per unit time in m^3/s, right y axis) as a function of time. These quantities, flow height and flux of bedload sediment, are computed for three cases: *No Vegetation* (black), *Vegetation* (orange), *Ideal Vegetation* (green). The *Ideal Vegetation* case only appears when using the *Advanced* mode.

Since hydraulic bank erosion depends on the presence of absence of roots, the flow height may be different for these different scenarios as vegetation directly affects the rate of bank erosion and thus the time evolution of the channel geometry — including the flow height — during the event. The same is true for the bedload transport: bedload transport is a function of the hydraulic radius which depends on the channel geometry.

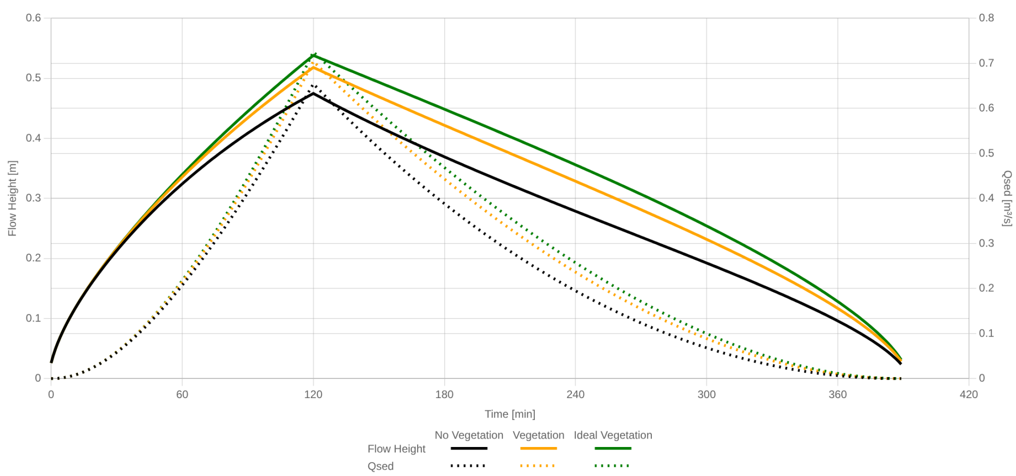


Figure 10: Flow height and bedload transport as a function of time for the three defined scenarios: *No Vegetation* (black), *Current Vegetation* (orange), and *Ideal vegetation* (green).

Flow Height Metrics: The table under this header (see Fig 11) shows the value of the *Maximum Water Discharge* obtained at the peak flow height (this is equal to the user input if *Discharge* was part of the input parameters in the `Catchment` window in the **Input** tab), the *Mean Flow Velocity at Peak Flow* based on the combined volumes of water and sediments, and the *Stream Power at Peak Flow* which depends on the maximum discharge as well as the channel slope.

	Values
Max Water Discharge (m^3/s)	14.00
Mean Flow Velocity at Peak Flow (m/s)	3.88
Stream Power at Peak Flow (W)	9604.19

Figure 11: Output table for flow height metrics

Sediment Metrics: The table under this header (see Figure 12) shows the *Total* (mean value) and *Minimum* and *Maximum* volume of sediments transported during the event. This includes both bedload transported sediment and debris-flow transported sediment. The latter is only significant for slopes greater than 20 degrees. The sediment volume outputs shown in this table can be used for hazard assessment and as a fist estimate for dimensioning technical protective measures (e.g., retention pond).

	No Vegetation	Vegetation	Ideal Vegetation
Total Sediment Volume (m^3)	2162.17	2227.58	2255.20
Minimum Total Sediment Volume (m^3)	2031.40	2101.67	2132.61
Maximum Total Sediment Volume (m^3)	2293.30	2354.13	2378.63

Figure 12: Output table for sediment metrics

8.2 Transport tab

The figure in the **Transport** tab shows the transport capacity of large wood, an index between 0 and 1, as a function of time. The large wood transport capacity is calculated based on two criteria:

1. Incipient transport condition calculated based on the DBH of the tree log and the stream flow height according to the model of Lange and Bezzola [3]
2. Transport probability calculated as the transport ratio (defined as the ratio between the outlet and inlet number of logs) based on empirical data as a function of the normalized log length ($L^* =$ Length of the log / Width of the channel) [6].

Figure 13 shows how the large wood transport probability changes as function of time during an event. The calculation of the transport capacity is based on an average of the logs of the inner and outer banks. The colors show the differences between the *Vegetation* (orange) and the *Ideal Vegetation* (green) scenarios. The *Ideal Vegetation* scenario only appears when using the *Advanced* mode.

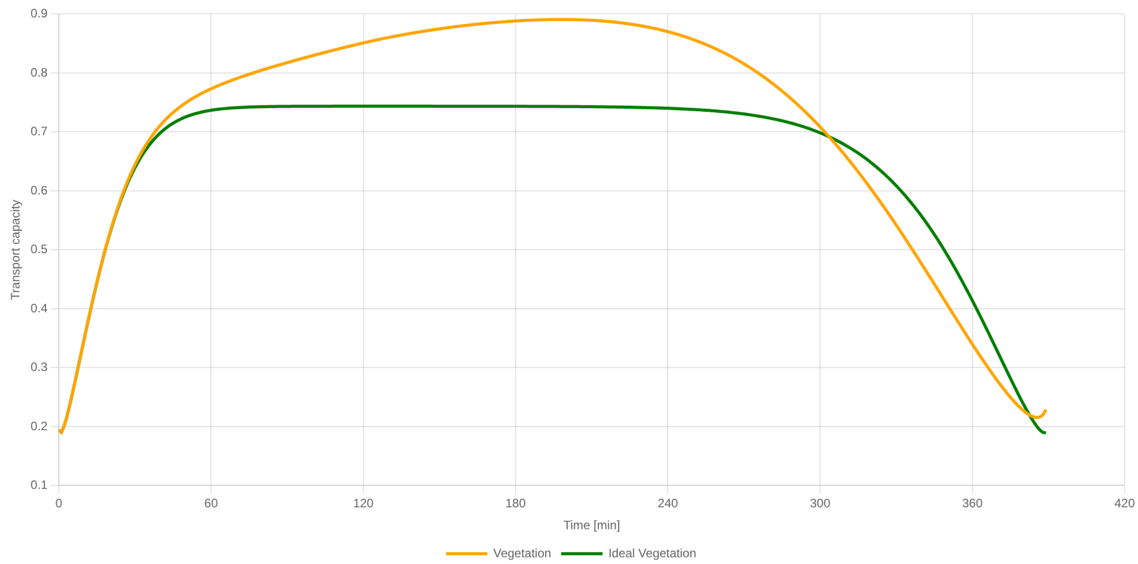


Figure 13: Example of the transport capacity in the **Transport** tab showing the time evolution of the transport capacity for the two vegetation scenarios: *Vegetation* (orange) and *Ideal Vegetation* (green).

8.3 Erosion tab

The **Erosion** tab shows the plot of the computed cumulative hydraulic bank erosion as a function of the time during the event (Fig. 14). Erosion is shown for the three scenarios: *No Vegetation* (black), *Vegetation* (orange), and *Ideal Vegetation* (green). The different types of *linestyles* show the total (continuous), inner bank (dashed), and outer bank (dotted) erosion. When the model of Paphitis (2001) is chosen for the critical shear stress, three lines are shown corresponding to the 5 (minimum), 50 (mean), 95 (maximum) percentile of the probability distribution of the critical shear stress. By clicking on the legend's description, the user can switch on and off curves for better visibility.

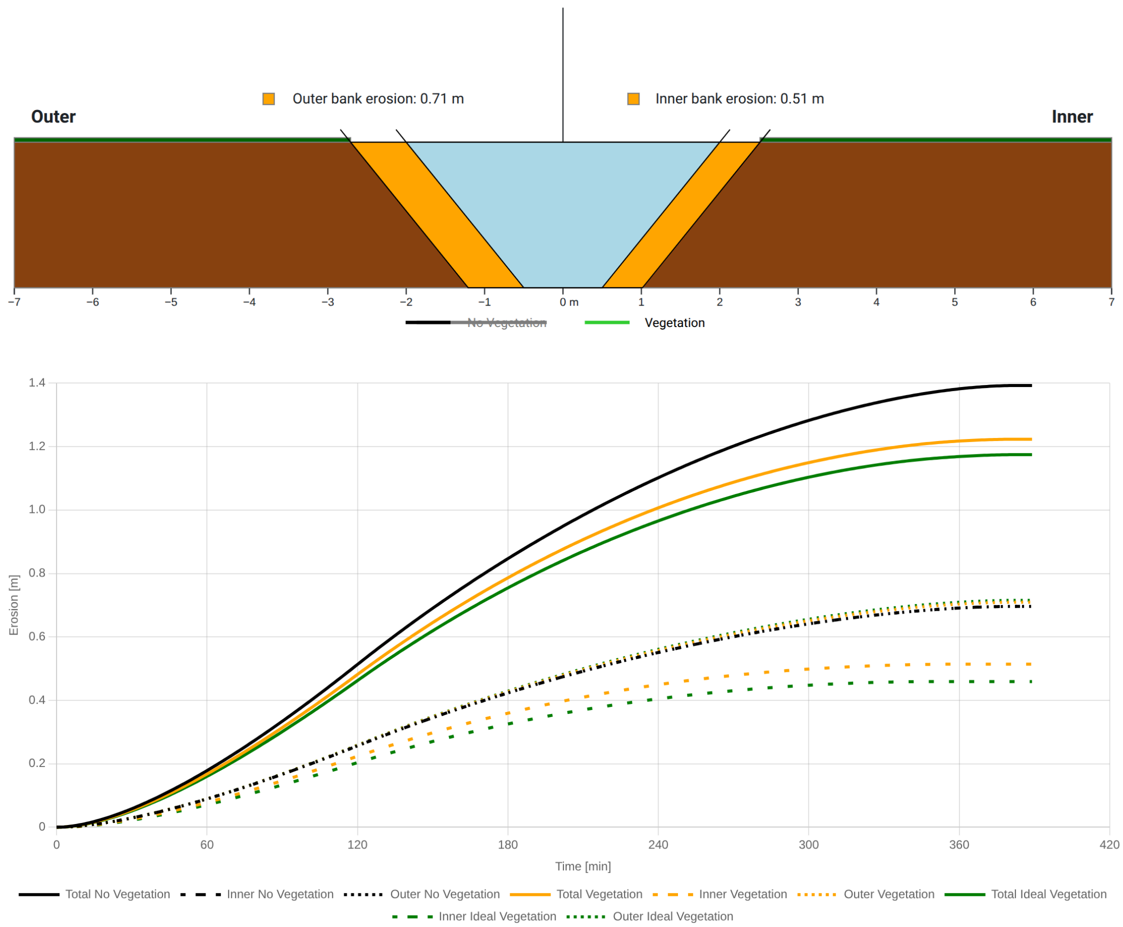


Figure 14: Example of output of **Erosion** tab. Top figure: Schematic of stream cross section showing stream in blue, banks in brown and bank erosion in orange. Diagram of stream width and inner and outer bank erosion is to scale. Bottom diagram: Total, inner and outer bank erosion as a function of time for the three scenarios: *No Vegetation* (black), *Vegetation* (orange), and *Ideal Vegetation* (green).

9 Field method to estimate input parameters

9.1 River bed granulometry

River bed granulometry is commonly assessed using the Wolman pebble count method (Wolman, 1954), where riverbed pebbles are randomly collected and measured. The median (D_{50}^{sed}) of these values is then calculated.

9.2 Banks characteristics

As for the riverbed, we use the median of the grain size (D_{50}^{bank}) for the banks granulometry. This value is commonly obtained by analyzing samples in a lab through a simplified sedimentation analysis. The inner and outer bank should be evaluated separately.

9.3 Vegetation parameters and wood transport

For **`BankforNET`** to assess large wood transport for a given scenario, the diameter (in meter) and length (in meter) of the log are needed. These values can refer to any piece of wood of interest. If the user is interested in assessing the transport of the log resulting from a tree that fell in the stream due to bank erosion during a specific scenario, it is necessary to estimate its size. The size of the log can be smaller than the tree that fell into the stream. The size of the log can be estimated based on either existing logs that can be found in the same stream (ideally for the same species), or, alternatively, assuming the length of the log is two-third the length of the tree it came from. While such an estimate is not widely established or universally accepted as a standard in the scientific literature, it is often used in practice. Alternatively, if the user is only interested in the general ability of the stream to transport wood, a log length of 1 meter with a log diameter of 0.1 m are recommended, as these values represent the minimum values for a piece of wood to be considered as having any influence on river processes.

10 Case studies

10.1 Hazard mapping due to bank erosion and quantification of effect of actual vegetation: La Morge stream, Canton of Valais, Switzerland

The stream La Morge flows near the village of Conthey, Canton of Valais, Switzerland. Downstream of a sediment and large woody debris retention basin, the watercourse enters a mildly meandering section, where the bend radius reaches minimum values of approximately 20 meters.

The primary question is: Does the development of meanders increases the risk (damage to the infrastructure) due to bank erosion hazards? If so, to what extent, and under which conditions? Additionally, how does the presence of riparian vegetation influence this process?

To assess the hazards related to bank erosion, the stream section with one of the most pronounced curvatures was selected for analysis (see Fig. 15). As an initial, rapid assessment, we use the basic version of **`BankforNET`** and consider a discharge event with a return period of 100 years. Fig. 16 shows the right bank of the stream.

Figure 15: Map showing the stream section selected for the analysis (`https://www.geo.admin.ch`). The red line shows the position of the chosen stream section on the map. The lower panel shows the extrapolated altitude from the digital terrain model along the section.

Figure 16: Pictures of the hydrographic right bank of the stream La Morge (downstream of the selected cross section).

10.1.1 Estimation of inputs parameters

The catchment area is about 77 km^2, with a maximum stream length of 23 km.

The water discharge for an event with a return period of 100 years is estimated to be 140 m^3 s^{-1}, with a duration to peak discharge of 90 minute ($= 0.0195 \times (23000^{0.77}) \times (0.15^{-0.385})$, Chow, 1964). The total duration of the discharge is estimated to be about 5 hours.

The width of the stream bed is 9 m (measured based on the digital elevation model). The channel slope is 0.01 (measured based on the digital elevation model). The bend radius (curvature) is 20 m.

The median size (diameter) of the sediment particle representative for 50% of the mass (D_{50}) that can be transported during an extreme water discharge is estimated to be ca. 50 mm.

For the calculation of the average water flow during the event we apply a Manning coefficient of 0.035 (which corresponds to a Strickler's value, K_s of 28.6). This value can be adapted depending on the scenario of discharge and the macro-roughness of the channel.

For the estimation of the critical shear stress of the bank material, it is necessary to determine the D_{50} of the sediment on both the inner and outer banks. In this case study, the same material is present on both sides, with D_{50} estimated at 10 mm (small gravel). The choice of the method of Paphitis [4] allows for a probabilistic estimation of the critical shear stress, providing values for the median, as well as the lower and upper 5-percentiles. In the case of cohesive material, it would be more appropriate to select a user-defined critical shear stress value.

Although wood transport capacity is not a central factor in this case study, representative log dimensions—accounting for the entrainment of riparian vegetation—are considered: log diameter = 0.15 m, log length = 2 m, taking into account the fragmentation effect during wood transport.

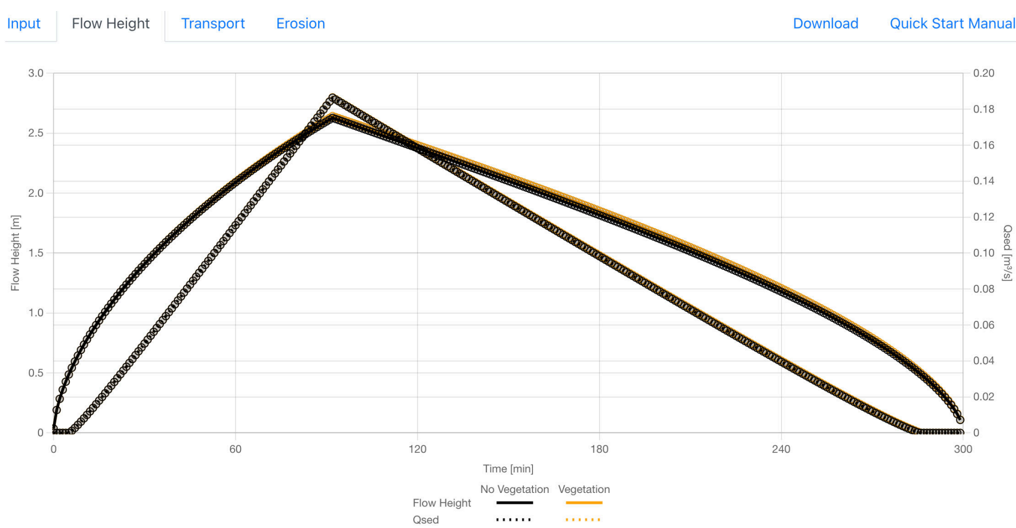
The effect of vegetation on bank stability is incorporated as an increase in critical shear stress, based on a

2D root distribution model (expressed as Root Area Ratio) of the existing vegetation [**perona2022tree**, 5]. For the outer bank in the selected section, the following parameters are used as representative of riparian vegetation: DBH = 0.15 m, distance to the channel centerline = 5 m (corresponding to 0.5 m from the bank toe), and elevation above the channel bed = 0.3 m.

At present, the selection of tree species is limited to *Alnus incana*, though ongoing research projects aim to expand the database to include additional species.

10.1.2 Results and interpretation

The tab **`Flow Height`** (Figure 17) shows the plot of the calculated flow height during the event. In this calculation the maximum flow height is about 2.5 m. This value considers the geometrical changes due to erosion during the event and the effect due to sediment transport. This result is important, especially during field survey, to have an idea of the hydraulic conditions during the water discharge event. In this case, we know that the water level stays lower than the maximum bank height. It is also possible to verify that an estimated average flow velocity of 4.34 m/s is a plausible estimation.



Flow Height Metrics

	Values
Max Water Discharge (m^3/s)	140.00
Mean Flow Velocity at Peak Flow (m/s)	4.34
Stream Power at Peak Flow (W)	13720.27

Figure 17: Results of the calculated flow conditions with **`BankforNET`**. The plot is selected to show the possible horizontal erosion on the outer bank, with (orange lines) and without (black lines) vegetation.

The **Erosion** tab summarizes the most important results for the calculation of bank erosion (Figure 18). The upper illustration shows the simplified geometry of the channel's cross section with the calculated horizontal erosion for the outer and inner banks. The plot below shows the calculated cumulative erosion. Clicking on the legend of the plot, it is possible to select detailed information for visualization. In this particular case, we are interested in analyzing the conditions of the outer bank, with or without vegetation. The results show that without vegetation erosion reaches values between 1.1 and 1.8 m (lower and upper percentile - black dashed lines), whereas with vegetation the erosion is reduced to 0.6 to 1.2 m (orange dashed lines). The shape of the curve shows the maximum effect of roots around a cumulated erosion of 0.5 m, that actually correspond to the distance of the tree from the toe of the bank. The effects of the roots yields a lower cumulated erosion.

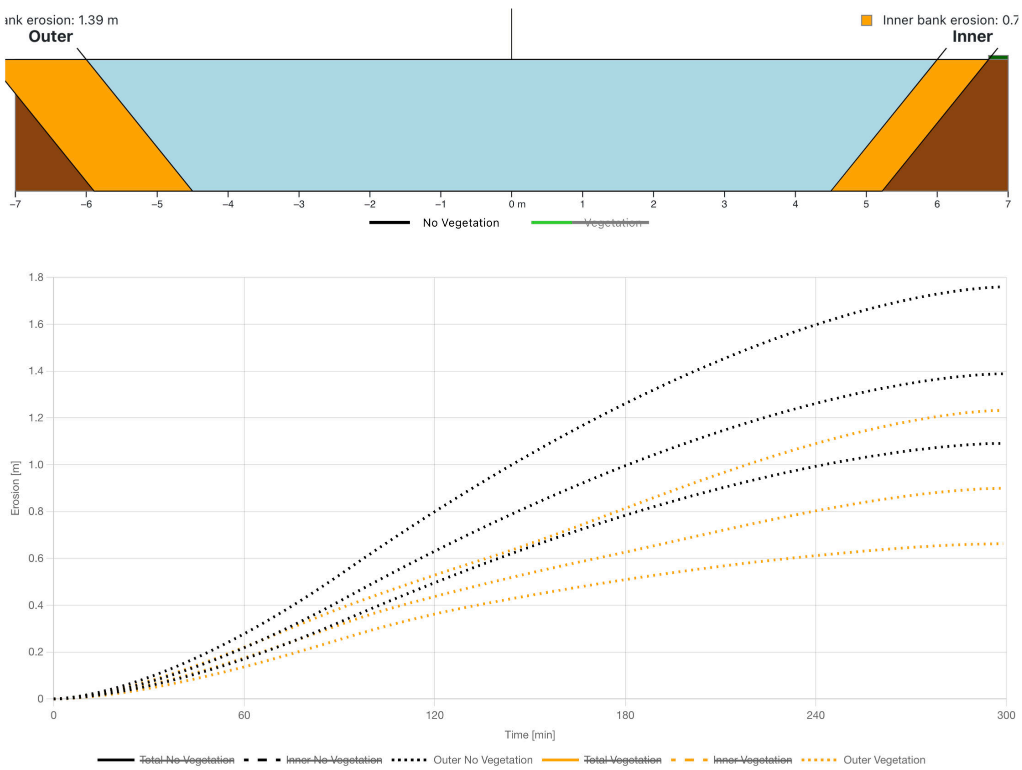


Figure 18: Results of the calculated erosion in **BankforNET**. The plot is selected to show the possible horizontal erosion on the outer bank, with (orange lines) and without (black lines) vegetation.

10.1.3 Conclusions

This preliminary assessment of bank erosion hazards suggests that, even during an extreme discharge event, the extent of hydraulic erosion on the outer bank remains limited (1–2 m) relative to the current channel geometry. Notably, there is approximately 10 m of buffer distance before any infrastructure could be affected.

However, it is important to highlight that the presence of riparian vegetation can significantly reduce erosion magnitude—by up to 30–40%. To further explore the conditions under which potential damage could occur (i.e., erosion exceeding 10 m), additional simulations should be conducted. In particular, the duration of the discharge event has a major influence on total erosion. For example, increasing the event duration from 300 to 1440 minutes (i.e., 24 hours—a still plausible scenario for this catchment) results in cumulative erosion of approximately 4–8 m on the outer bank.

If the D_{50} of the bank material is further reduced from 10 mm to 1 mm, the predicted erosion exceeds 10 m. Under both of these scenarios, the protective effect of vegetation is significantly diminished. This is because the tree(s) initially considered would likely be recruited (uprooted) during the event, and the remaining erosion is assumed to occur well below the root zone of the vegetation on the upper bank, leading to cantilever failure conditions.

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