AdaptaN II - Integrated approaches of the Moravian-Silesian Region landscape to climate change adaptation.

Report NIBIO activities – Part 2: Modeling effectiveness of measures.

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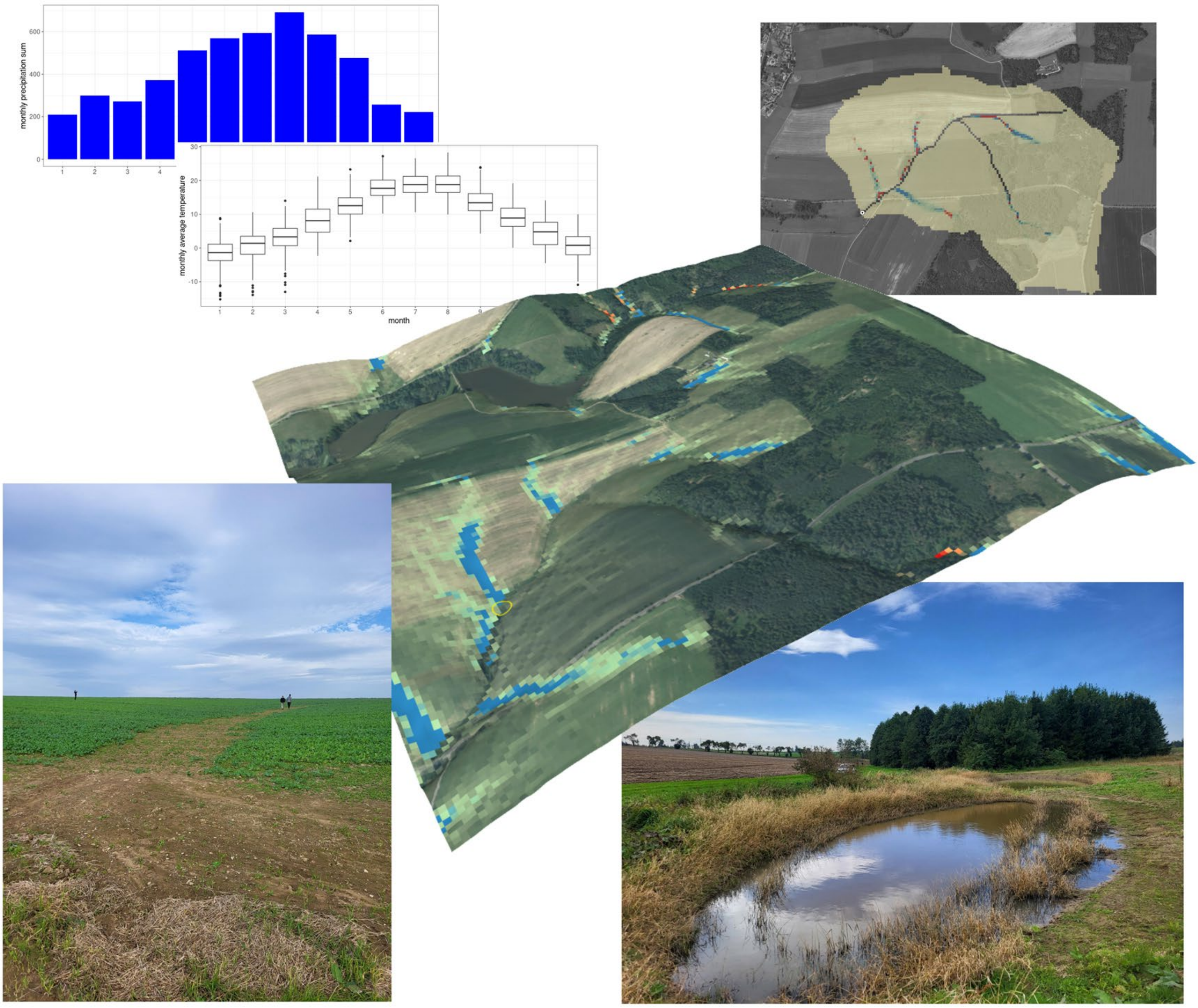

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Divisjon for Miljø og Naturressurser

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SAMMENDRAG/SUMMARY:

Rapporten gir en oversikt over NIBIO sine aktiviteter i AdaptaN II prosjektet gjennomført i samarbeid med tsjekkiske partnere. NIBIO har bidratt med vurdering av erosjonsrisiko og modellering av erosjonstiltak for klimatilpasning på jordbruksarealer for et nedbørfelt i Větřkovice i Moravian – Silesian Region i Tsjekkia. Delrapport 1 gir en oversikt over aktuelle erosjonstiltak i bruk i Norge samt regelverk, støtteordninger og subsidier for miljøtiltak. Delrapport 2 gir en oversikt over viktige faktorer ved vurdering av erosjonsrisiko og resultat fra modellering av utvalgte erosjonstiltak, spesielt vegetasjonssoner og grasdekte vannveier for studieområdet i Tsjekkia.

The report gives an overview of NIBIO activities in the AdaptaN II project and cooperation with the Czech partners. NIBIO has contributed with evaluating erosion risk, modelling of erosion and measures to reduce erosion for the Větřkovice cadastrial area in the Moravian – Silesian Region. Report- Part 1 presents an overview of the erosion measures used in Norway and overview of regulations and support systems for such measures. This report- Part 2 gives an overview of the work with evaluation of the erosion risk factors and modelling of erosion measures for the study area in Czech Republic. It includes identifying crucial factors for erosion in the landscape and modelling effects of selected adaptation measures like buffer zones and grassed waterways.

NIBIO
NORSK INSTITUTT FOR
BIOØKONOMI

LAND/COUNTRY:	Czech Republic
STED/LOKALITET:	Větřkovice cadastral area

APPROVED	PROJECT LEADER
Anja C. Winger	Lillian Øygarden
ANJA C.WINGER	LILLIAN ØYGARDEN

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Content

Preface

The report gives an overview of NIBIO's activities in the project: AdaptaN II- Integrated approaches of the Moravian-Silesian Region landscape to climate change adaptation. The AdaptaN II project is funded by the Financial Mechanism within the Norway Grants Programme (2014- 2021), grant call 4A Bergen. Project registration number 320- 4200006. The project period has been July 2021- April 2024.

In the project NIBIO has cooperated with partners from Czech Republic under the leadership of professor Miroslav Dumbrovsky at Brno University of Technology. Assistant professor Veronika Sobotkova at Brno University of Technology has been the contact person for the administrative matters during the project period, including reporting and organizing joint project meetings.

During the project period, the project teams from NIBIO and Czech partners have visited each others institutes and field locations for experiments. Joint exursions of the project teams into different landscapes in the two countries have documented differences in topography, soils and agricultural practices and environmental influence. It has also given opportunity to discuss and compare efficient environmental measures to reduce runoff and erosion from agricultural areas. During these meetings there has been knowledge sharing of working methods, field experiments and modelling. These excursions and meetings are documented on the webpages for the project.

NIBIO has contributed with two reports in the project:

AdaptaN II- Integrated approaches of the Moravian-Silesian Region landscape to climate change adaptation:

Report -Part 1 gives an overview of erosion measures used in Norway and overview of regulations and support systems for such measures.

Report -Part 2 gives an overview over modelling for the Větřkovice cadastrial area in Moravian Silesian region. It includes identifying crucial factors for erosion in the landscape and modelling effects of selected adaptation measures like buffer zones and grassed waterways.

Dominika Krzeminska, Robert Barneveld and Lillian Øygarden have been the core team from NIBIO. We have also had valuable contributions from collegues giving presentations at AdaptaN II project meetings at NIBIO.

Marie- Cecile Gruselle has contributed to collect information from available reports about agricultural measures used in Norway and finalizing the reports. Csilla Farkas has contributed with information about NIBIO modelling activities and models being used in ongoing projects. Anja C. Winger has read the reports for quality check.

From the administration in NIBIO we have got a lot of assistance from Susanna Pedersen, Anne Kallum and Hanne Sørli with follow up contracts and documents for the reporting periods during the project.

Lillian Øygarden

Project leader

Ås 24.04 2024

1 Background and introduction

1.1 Background

The AdaptaN II project is funded by the Norwegian Financial Mechanism within the Norway Grants Programme (2014 - 2021), grant call 4A Bergen. Project registration number 320 - 4200006.
Project period: July 2021- April 2024. The project builds on the previous, successfully evaluated project AdaptaN I, which was performed in the period 2015-2016 and was financially supported by the EEA mechanism Norwegian Funds.

Project webpage: https://adaptan2.eu/o-projektu

NIBIO -webpage: https://nibio.no/en/projects/adaptan-ii.integrated-approaches-of-the-moravian-silesian-region-landscape-to-climate-change-adaptation

The aim of the project is to support the implementation of selected nature-friendly adaptation and mitigation measures in the Moravian-Silesian region in Czech Republic.
The Moravian-Silesian Region (MSR) was the first region in the Czech Republic to develop "Adaptation Strategy of the Region for the Impacts of Climate Change. The project will support next phases of implementation and realization of adaptation measures in MSR, will elaborate the whole implementation process of adaptation for free landscape and suburban zones as a model for other Czech regions. It will apply integrated approaches according to the National Action Plan for Climate Change and it will contribute to the implementation of 7 measures according to the MSR Adaptation Strategy.

The main goal of the project is professional support for implementation of the "Adaptation strategy of the Moravian-Silesian region against impacts of climate change." As such, the project is supporting the goals of regional, national and European strategies for adaptation to climate change by addressing protection against drought and erosion, reduction of material runoff, improving water retention and the green infrastructure of the landscape.

The sub goals of the project are:

- Model example of methods and course of implementation nature-related adaptation measures in rural and suburban areas within the Region and target user groups, including promotion.
- Locational targeting of measures for relevant and vulnerable areas.
- Demonstration of measures in pilot areas using integrated approach.

Project partners:
Project leader of AdaptaN- II has been Professor Miroslav Dumbrovsky at Brno University of Technology. Overview of the project partners;

- Brno University of Technology, Faculty of Civil Engineering, Institute of Landscape Water Hydrology,
- T.G. Masaryk Water Institute
- ARVEN-Academy of Rural Development, registered association
- Slovak University of Agriculture in Nitra
- NIBIO-Norwegian Institute of Bioeconomy Research

Detailed description of partners at: https://adaptan2.eu/o-projektu

1.2 NIBIO's contributions

NIBIO has been involved in several project activities. The main contributions:

- Modeling erosion risk at the catchment level and effectiveness of implemented (and/or potential) measures → as contribution to:
    - **Indicator 8:** Infiltration belt alongside water courses to reduce contamination by erosion runoff-buffer zones.
    - **Indicator 24:** Application of methods to identify factors in terms of erosion intensity and runoff ratio in the non-vegetation period and proposal of adaptation measures.
- Overview of measures, rules, subsidy schemes in Norway→ as contribution to indicator 8 and indicator 24 (see description above) as well as in combination with contributions and input to **Indicator 25** (described below).

NIBIO main activities have been performed in the catchment of Větřkovice cadastral area (about 10 km^2). In this study area the Norwegian team has worked with erosion and drainage conditions and measures to reduce erosion and nutrient fluxes from the areas by:

- Applying methods and modelling for identifying and optimization of crucial factors in terms of erosion and drainage condition in non- vegetated period (wintertime).
- Proposal of adaptation measures including reduction of substance efflux, with regards to hydropedologic and climate conditions within the pilot area (including map of locations).
- Proposal for the location and establishment of protective grass belts- buffer zones along watercourses in the pilot area (including map).

The project also includes a comparative study **(indicator 25)** for the Cizina River catchment where the methods and approaches for integrated landscape protection used by the Norwegian (from Větřkovice), Slovakian and Czech partner will be compared. The study will include transfer of examples of good practice and model demonstrations.

In addition to the modelling work at catchment scale and evaluating measures NIBIO has been involved in:

- Establishment of network, scientific cooperation and exchange of knowledge between NIBIO and Czech partners. This has included scientific joint meetings and excursions to landscapes and monitoring stations areas both in Norway and Czech study area. This activity has been reported on the project's webpages.

- Information about the AdaptaN- II project and about the EEA mechanism Norwegian Funds, the Norwegian Financial Mechanism within the Norway Grants Programme (2014 - 2021), grant call 4A Bergen. The information activities include the AdaptaN II project webpage at the NIBIO -webpage: https://nibio.no/en/projects/adaptan-ii.integrated-approaches-of-the-moravian-silesian-region-landscape-to-climate-change-adaptation. It has also been produced a poster about the project and Czech and Norwegian activities. This, along with other information material from the project, is available on the webpage.

1.3 Activities and indicators

ADAPTAN II – Integrated approaches of the Moravian-Silesian Region landscape to climate change adaptation

Stage 01: Territorial study to implement adaptation measures close to nature in the territory of the Moravian-Silesian Region.

Substage 07: Preparation and implementation of model demonstration projects of adaptation measures in the catchment area and floodplains with a focus on reducing unwanted substance flows and water contamination.

Activity 07-21: Various ways of using protective grass belt- "buffer zones" along water course to reduce water contamination by erosion runoff in the pilot area (Větřkovice).

Indicator 8: Infiltration belts alongside water courses to reduce contamination by erosion runoff-buffer zones.

Outcome: Proposing the location and establishment of protective grass belts, buffer zones along the watercourse in the pilot area. NIBIO Report- Part 2 (details given below).

Activity 07-22: Modeling of erosion processes for the identification of decisive factors in terms of the intensity of erosion and runoff conditions in the off-vegetation period.

Indicator 24: Application of methods for the identification of decisive factors in terms of the intensity of erosion and runoff conditions in the off-vegetation period and the design of adaptation measures. Proposal of adaptation measures including reduction of substance efflux with regard to hydropedologic and climatic conditions within the pilot area.

Outcome: NIBIO Report- Part 1 (mitigation, indicator 24) and NIBIO Report -Part 2 (modelling, indicator 8 and indicator 24):

AdaptaN II - Integrated approaches of the Moravian Silesian region landscape to climate change adaptation.

Report NIBIO activities - Part 1: Mitigation measures. Dominika Krzeminska, Robert Barneveld, Lillian Øygarden.

Report NIBIO activities - Part 2: Modeling effectiveness of measures. Robert Barneveld, Dominika Krzeminska, Lillian Øygarden.

The Programme: *„Environment, Ecosystem and Climate Change" financed from Norway Grants 2014–2021.*

Call for proposals *„Bergen" on the implementation of selected nature related adaptation and mitigation measures, Call No.: Call-4A*

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Partners:

April 2024

More information – Czech website:

- Státní fond životního prostředí ČR: www.sfzp.cz/norskefondy
- Ministerstvo financí České republiky: www.norskefondy.cz
- Fondy EHP a Norska: https://eeagrants.org/.

More information – English website:

- State Environmental Fund of the Czech Republic: https://www.sfzp.cz/en/norway-grants/
- Ministry of finance of the Czech Republic: https://www.eeagrants.cz/en/
- EEA and Norway Grants: https://eeagrants.org/

2 Modeling the efficiency of the measures

Many approaches can be taken to assess the efficiency of soil and water conservation measures and their optimal placement. These can be categorized broadly into those that are based on historical information and those that build on process understanding. Usually, some kind of modelling is involved in these assessments. Models can therefore be both **empirical** or **process based,** but are often a combination of both.

2.1 Empirical models in erosion studies

The most used empirical approach for erosion modelling is the family of erosion models that builds on the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978). Predicted erosion rates in the USLE method are the product of the five factors that drive the erosion process, and one that reduces it, so that:

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where E is the annual erosion rate (kg ha^{-1} y^{-1}), R the rainfall erosivity, K soil erodibility, L and S the slope inclination and length factors, C the cropping factor and P a factor to reflect the implementation of soil conservation measures. The values of the individual factors are traditionally derived based on measurements of soil loss from standardised runoff plots. Due to the historical background of the model (the USDA developed it to counteract the effects of the Dust Bowl), many of the available values for the five factors are representative for North America.

USLE-based methods focus on erosion rates and do not account for transport and deposition of eroded particles at the scale of the landscape. When (part of) the objective of soil conservation measures is the prevention of sediment reaching surface waters, erosion rates alone are not sufficient. The transport of sediment is dynamic in space and time and is not easily determined from static factors like those in the USLE. In addition, total loads per time period are not always the main concern when off-site effects of erosion are assessed. Peak concentrations can sometimes be much more relevant because of their detrimental effect on water biota.

The accuracy of local implementations of empirical models like the USLE depends on the reliability and representativeness of the measurements that form the basis for the models' parameters. When these measurements are not available, not reliable or not representative for the myriad combinations of physical, climatic and agronomic circumstances, process-based models can be an alternative.

2.2 Process-based and hybrid models

In the absence of local, empirical data, erosion studies for the assessment of the optimal placement and choice of measures can be carried out by means of process-based models. In these models, the (statistical) inductive element is replaced by a deductive approach. Such models depart from general principles and undisputed physical laws that describe spatial elements and process. The erosion, transport and deposition process is then represented by the parameters and equations that describe these elements and processes.

Examples of process-based models are Erosion3D (Von Werner, 2003) and the Limburg Soil Erosion Model (LISEM, De Roo et al., 1996). A common trait of this type of models is their computational intensity. This is because of their spatial concretisation and the explicitness of the mathematical sub-process descriptions. Process based models often represent a spatial domain as a series of raster grids, each with a certain property (terrain, soil physical properties, etc.). Sub-processes that are explicitly simulated in these models are infiltration, the degradation of soil moisture content, overland flow, particle detachment and transport. Subsidiary processes like groundwater level development, plant growth and the subsequent effect on soil moisture content are often included. This computational intensity renders these models little useful for the simulation of erosion and particle transport at the larger spatio-temporal scales.

Hybrid models use quasi-empirical shortcuts to represent sub-processes without explicit mathematical representation. An example of such a simplified approach is the use of exponential decay functions to represent the recession curves of soil moisture content in dry periods, as opposed to numerical solvers for the Darcy or Green-Ampt equations. Another simplification is the use of mass balance-based methods instead of hydraulics-based methods for mass (water and sediment) transport through a catchment.

Hybrid models lack the sophistication and some of the precision that process based models have. Models like LISEM can be run with small time steps, in the order of magnitude of minutes, while hybrid models often have larger time steps. The advantage of the use of hybrid models is their reduced demand for computational capacity and the fact that they are less input-data demanding.

PESERA (Pan-European Soil Erosion Risk Assessment; Kirkby et al., 2008) is a hybrid model that was used for Norway's national soil erosion risk map (see Section 3.2). The core of the model is a monthly soil water balance that predicts the amount of monthly overland flow for a certain location (soil and climate). On the positive side of the balance are rainfall and snowmelt, on the negative side evapotranspiration, seepage and runoff. Storage in the soil and on the surface are the dynamic balance elements. Once the monthly runoff is calculated, the model calculates the associated erosion risk as a function of that runoff, the slope inclination and the soil erodibility. Erodibility is calculated by means of pedo-transfer functions that utilize the information that is readily available in the national soil map (texture fractions, organic matter content).

Another such hybrid model is the Morgan, Morgan and Finney model (MMF), originally defined in 1984 (Morgan et al., 1984), redeveloped in 2001 (Morgan et al., 2001). The model is process based, because it differentiates between the water and sediment phases in the erosion process. In its original definition however, it relied heavily on empirical relations between soil type and management and the generation of overland flow. The model is, however, spatially explicit and can typically run on raster grids with cell size in the order of magnitude of meters. The advantage of the original definition of the model over USLE-based methods is the model's ability to simulate particle transport and deposition in addition to particle detachment.

2.3 Examples of Models used in NIBIO

Recently NIBIO lunched the '**Environmental Modeling and Measures' thematic website**[1]**.** There one can find the overview of models used by NIBIO to account for the mitigation measures effect(s) at different scales. It is very important to stress that a lot here depends on parametrisation of the measures and their potential effects. To account for measures in modeling approaches, their

[1] https://www.nibio.no/en/subjects/environment/environmental-modelling-and-measures?locationfilter=true

parametrisation is a key. It can be very intuitive in some cases; in others it may need serious adaptation in model setups.

When looking at the models overview one can see that field/crop management measures and some structural/design measures can be directly implemented in several models (e.g SWAP), by using/adopting specific parameters. In addition, there are options to account for both in-field and out-field mitigation measures and estimate the effects of such measures indirectly, using expert judgments and specific parameterization (INCA, PERSiST, SWAP, AGRICAT).

In case of majority of structural/design measures, such as constructed wetlands, grassed waterways etc, only spatially distributed models (LISEM, SWAT+ etc.) have the capacity to directly incorporate them in the model.

The complexity of models and parametrization of measures to be accounted for in the modeling differs a lot depending on the purpose of the model use. Below we describe two of the used models in NIBIO both in the process of planning the mitigation measures in the catchment and to assess the effectiveness of existing measures: AGRICAT and MMF. These two were chosen to show, in a bit more detail, the two different modeling approaches.

2.3.1 AgriCat

The Agricat 2 model (Kværnø *et al.*, 2014) is a catchment scale, empirical model that can be used to calculate the loss of soil and phosphorus from agricultural land. The model can be run for different operating systems and different combinations of measures. The model has been developed by NIBIO, and it has been used in several projects where the results are used by the public administration to support the planning and selection of measures.

Agricat 2 consist of a set of empirical equations and coefficients based on measured data from national and international studies. Soil loss is based on erosion risk calculated originally for spring cereals with autumn ploughing (representing one of the "worst-case scenario"). The next steps for introducing mitigation measures are:

- to convert to soil loss at the given combination of crops and tillage by multiplying with crop and tillage specific management factors – for field/crop management measures (Table 2.1).
- To adjust the soil losses from areas that drain to grass-covered buffer zones or constructed wetlands through calculation of their retention effect (Fig. 2.1).

Table 2.1. Examples of management factors for soil loss via surface runoff for four erosion risks classes (see AdaptaN II report – Part1: Mitigation measures, section 3.2) (after Kværnø et al. 2014).

Erosion risk class (soil loss kg/daa/year) (class#)				
Crop & tillage	25 (#1)	125 (#2)	500 (#3)	1500 (#4)
Autumn cereals with autumn ploughing	1.20	1.20	1.20	1.20
Potatoes, root vegetables	1.20	1.20	1.20	1.20
Spring cereals with autumn ploughing	1.00	1.00	1.00	1.00
Spring cereals with autumn harrowing	1.00	0.66	0.46	0.34
Spring cereals with reduced tillage (stubbles)/ Spring cereals with direct sowing	0.49	0.27	0.16	0.11
Grass (meadow, pasture)	0.21	0.09	0.04	0.02

**1 daa = 0.1 ha.*

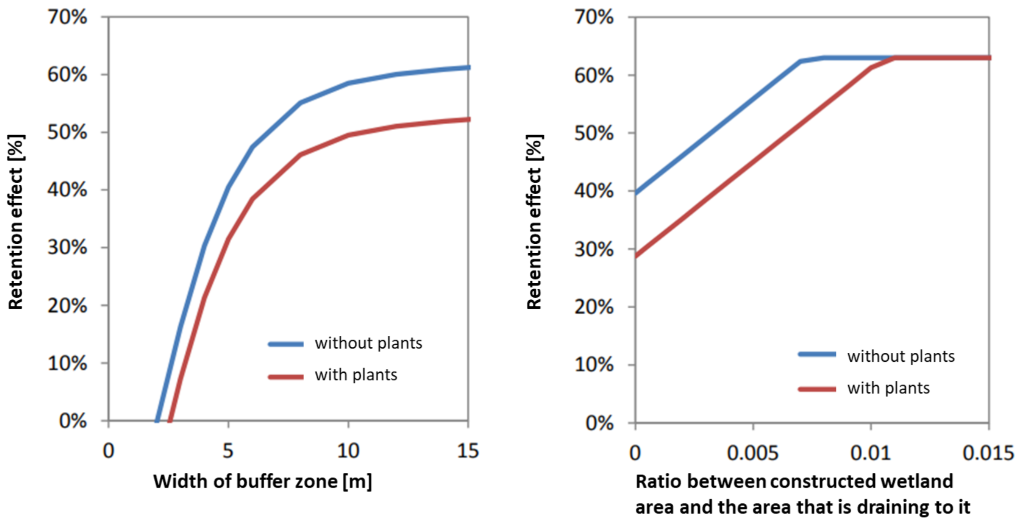


Figure 2.1. Relationships that are based to calculate the retention effect of (left) buffer zones and (right) constructed wetlands (after Kværnø et al. 2014).

NOTE: both management factors and functions for retention effect of buffer zones and constructed wetlands can be modified according to availability of data.

2.3.2 Morgan, Morgan and Finney model (MMF)

NIBIO has worked with versions of the MMF model since 2013. MMF is a flexible method and due to its modular nature (water and sediment), it can be simplified and/or improved for any of the phases in the erosion process. NIBIO's current version can best be described as having a hydrological core (the layered soil water content model) for the estimation of daily overland flow rates, with optional modular extensions. The modular extensions currently tested include the simulation of interflow and fluctuating groundwater levels, a lake and reservoir routine, and an erosion and deposition module. The model is adapted to Scandinavian conditions, mainly through the inclusion of a snow accumulation and melt model, and the parameterisation that is built on the Norwegian national soil database (agricultural soils only).

3 Modelling erosion and measures in Větřkovice municipality

3.1 Background

An implementation of NIBIO's version of the MMF erosion model (Morgan, Morgan and Finney) was developed for an area in Větřkovice in the Moravian-Silesian region in the northeastern Czech Republic. The goal of the exercise was (1) the assessment of how certain factors would affect the accumulation of sediment in the existing sedimentation/retention pond, and (2) the comparison of the efficiency of buffer zones and grassed waterways. Agronomic measures like reduced tillage could not be simulated without an empirical basis for the assumed reduction in erodibility and sediment transport capacity.

The spatial domain of the simulation is represented by a raster grid with a 10 by 10 m cell size. The total area for the simulations was approximately 26 km² (Fig. 3.5) and the period for which the scenarios were calculated consisted of the eight years from 2015 to 2022, with daily time steps.

Figure 3.1. Photo mix from the Větřkovice catchment, focusing on the area selected for the modelling (see Fig 3.5) (*Photos: R. Barneveld*).

Photos in the Figure 3.1 give an overview of the modelling domain. Indicated in Figure 3.5 are a V-notch weir where discharge is monitored and mixed sediment samples are taken. The sedimentation pond, situated approximately 400 upstream of the V-notch weir, is also indicated on the map in Figure 3.5.

3.2 Model description

The Norwegian adaptation of the model is based on the following principles.

- It utilises any available input data sources.
- It simulates surface runoff, particle detachment and transport rates separately.
- It simulates these processes in a high spatial resolution, so that gully erosion risk zones can be identified, and
- It is not too computationally intensive to be unpractical for large areas and/or long time series.

Surface runoff, the main driver behind the erosion process, is a function of weather conditions and the soil pore space available for infiltration. Precipitation and snowmelt become runoff if either the infiltration capacity is exceeded, or the maximum storage capacity. In Norway, the most erosive periods in the year coincide with the seasons with the highest overall soil moisture content. Even low intensity rainfall can lead to runoff in these periods. Soil moisture is therefore of pivotal importance for a simulation of the erosion process that is representative for the various conditions of Norwegian agricultural soils.

The positive elements of the soil water balance are rainfall, snowmelt and surface run-on from upstream raster cells. Evapotranspiration, infiltration and seepage and runoff to lower neighbouring cells are the negative elements. Daily snow water equivalent (SWE) values are estimated by:

$T < 0°$ SWE increases with daily precipitation

$T > 0°$ SWE decreases by $1.2 \cdot T^{1.4}$

where T is the daily average temperature (°C). Daily potential evapotranspiration (ET_{POT}) is estimated by:

$$ET_{POT} = 2 \cdot \cos((T/9)-2) + 0.75$$

If ET_{POT} is less than the available moisture in the top soil, the actual evapotranspiration is equal to the potential. If larger, soil moisture content is reduced by the potentially evaporated moisture.

Infiltration of precipitation and melting snow will limit the available pore volume in the top layer. Any surplus will be assumed to be runoff. If the moisture content exceeds the daily pore volume, the soil water is assumed to be drained through tile drainage (on drained soils). Runoff is generated after the potential storage at the soil surface (surface depression storage, SDS) is filled up. For agriculture, maximum SDS values ranges between 10 and 20 mm. When the water balance surplus is larger than the SDS, a raster cell will start to generate runoff.

Flow routing in the model is accounted by means of a multiple flow direction algorithm. Here, flow is directed to all neighbouring cells that are lower, by ratio of the slope inclination to the source cell. The advantage of this method is that converging and diverging flow patterns can be modelled and this is important for the identification of deposition zones in the landscape.

Particle detachment is a function of the daily runoff and direct impact of precipitation. It is estimated by:

$$E_{runoff} = 1/(\theta_t - \theta_{2.0})^{0,1} \cdot k \cdot q^{1,6} \cdot S^{0,3}$$

where q is the daily runoff (mm), k is the erodibility of Figure 3.2 (kg m^{-1} d^{-1} mm^{-1}) and S the local slope inclination (m/m). The term ($\theta_t - \theta_{2.0}$) denotes the difference between the actual (t) and saturated moisture content (pF=20) and accounts for a decrease in resistance to detachment under wet conditions. Detachment from raindrop impact is calculated as:

$$E_{rain} = k \cdot KE$$

where KE a measure of the kinetic energy of the rainfall, calculated by:

$$KE = P\,(8{\cdot}95 + 8{\cdot}44 \log_{10} I)$$

where P is the daily precipitation (mm) and I a typical value for continental European circumstances(10 mm $hour^{-1}$). Transport capacity, given a certain daily runoff (kg m^{-2} d^{-1}) is given by:

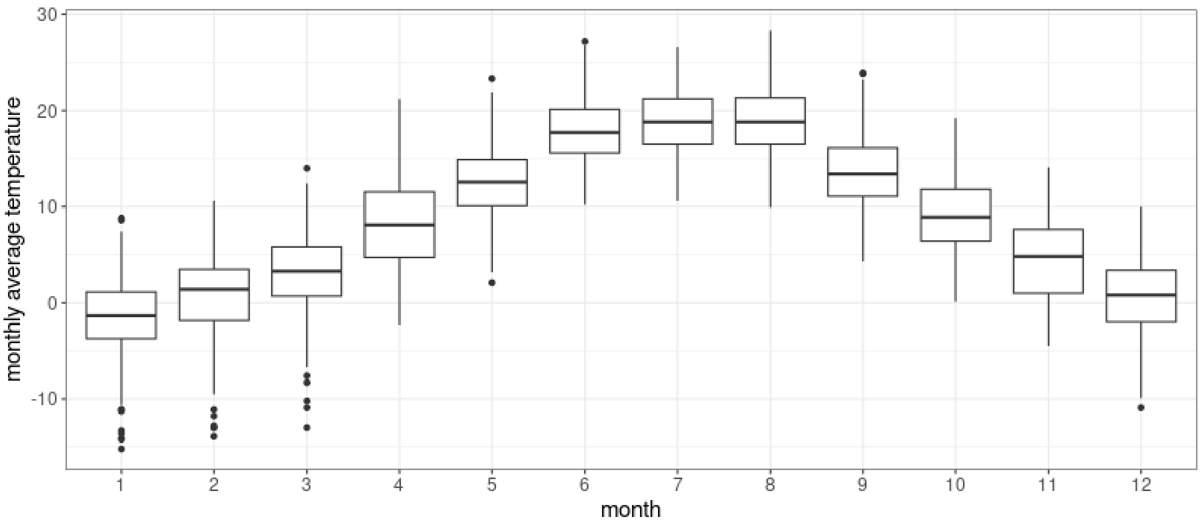
$$TC = q^2 \cdot S^{1,5} \cdot n^{-0,6}$$

where n is Manning's roughness coefficient. Roughness reduces over time in the model as a function of erosion and runoff.
If the transport capacity is higher than the particle detachment on any given timestep, deposition occurs and otherwise soil is lost.

3.3 Input data

Brno University of Technology provided the required input data for the model run:

- Weather data were provided as daily averages for temperature (˚C) and day sums for precipitation (mm), for the period 1961 to 2022. Simulations of erosion and soil loss were carried out for the period between 2015 and 2022 (see Fig.3.2.).
- Land cover, classified as urban, grass, arable land and forested, was provided as the vector data depicted in Figure 3.4. For the model run, a summer cereal crop with autumn tillage was assumed for all arable land. In practice, maize is a dominant culture in the area.
- Soil erodibility was provided as a function of soil type; the data are shown in Figure 3.3
- Water dischare measurements, from V-notch weir and water quality data.
- Elevation data were provided (DMT 4th generation) and resampled from 5 x 5 m to 10 x 10 m to increase computational efficiency.



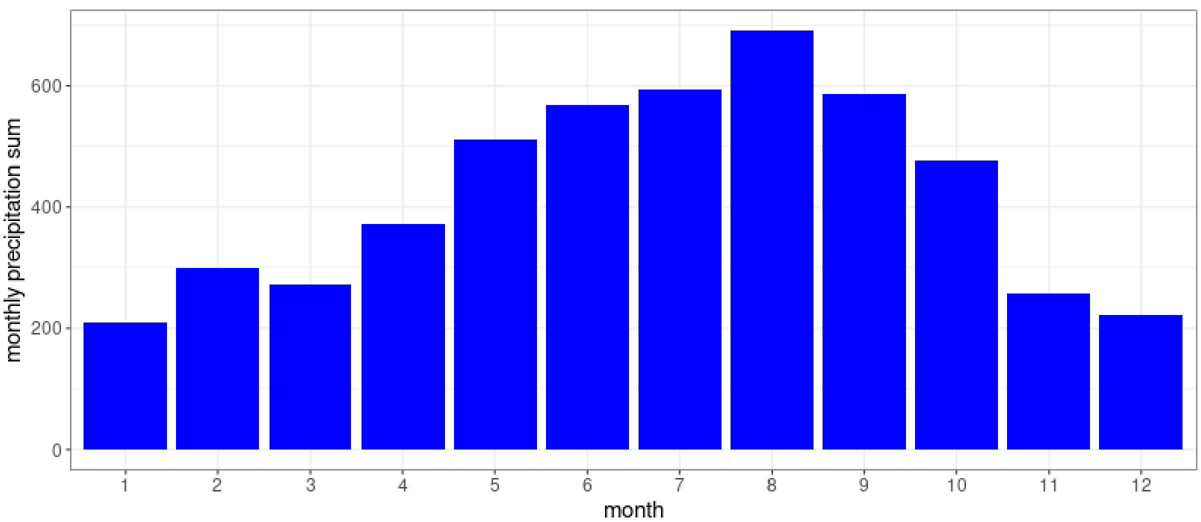


Figure 3.2. Monthly weather characteristics for the period 2015-2022; (upper figure) monthly average temperature C°, (lower figure) monthly precipitation (mm).

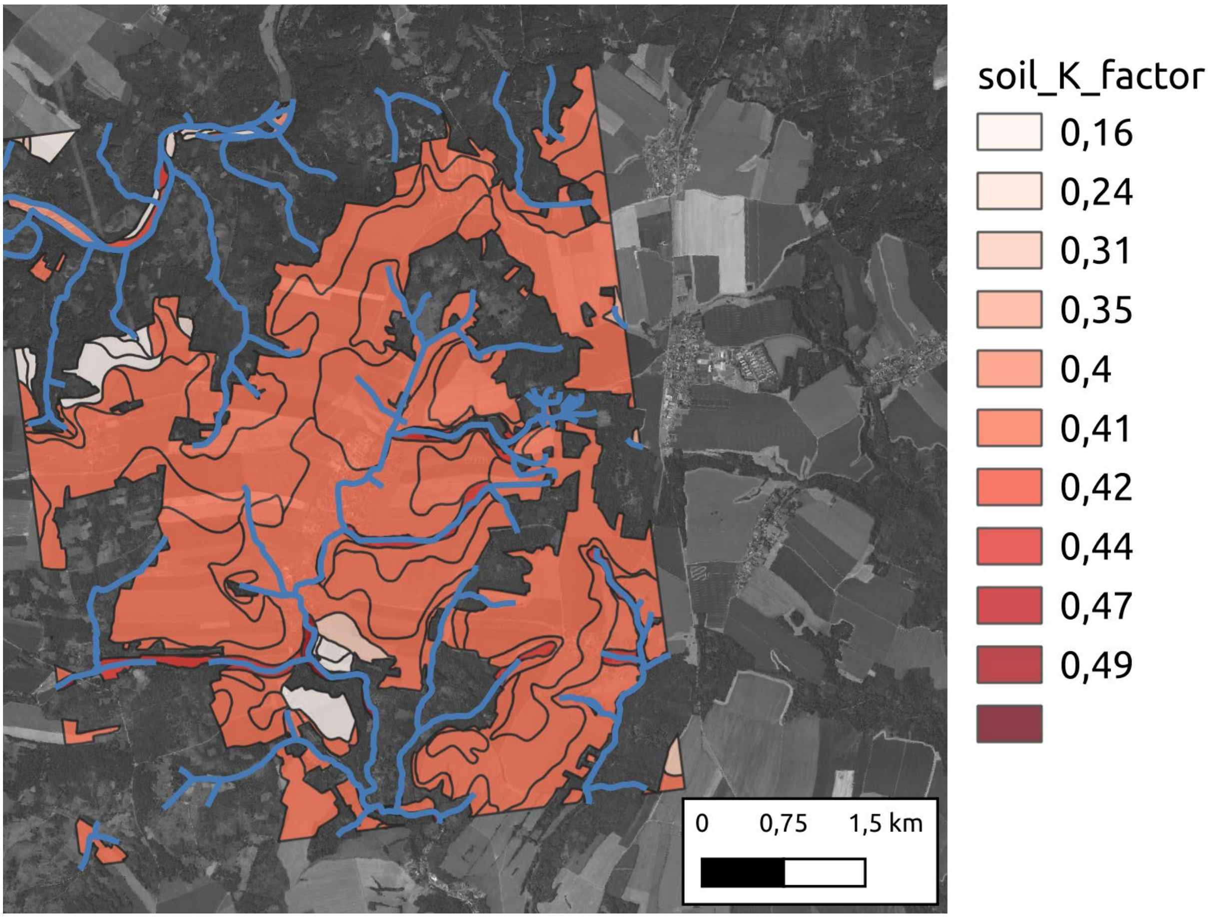


Figure 3.3. Soil erodibility values (source: from Brno Univ. of Technology)

Soil physical parameters (natural drainage rate, bulk density and effective hydrological depth) were estimated based on the given erodibility values, provided by the project partner.

Daily weather data were also provided by the project partner (temperature and precipitation).

Elevation data were provided as well (DMT 4th generation) and resampled from 5 x 5 m to 10 x 10 m to increase computational efficiency.

The choice for a detailed look at the catchment upstream of the sedimentation pond (Fig. 3.5) was inspired by the field visit to the study area in October 2023.

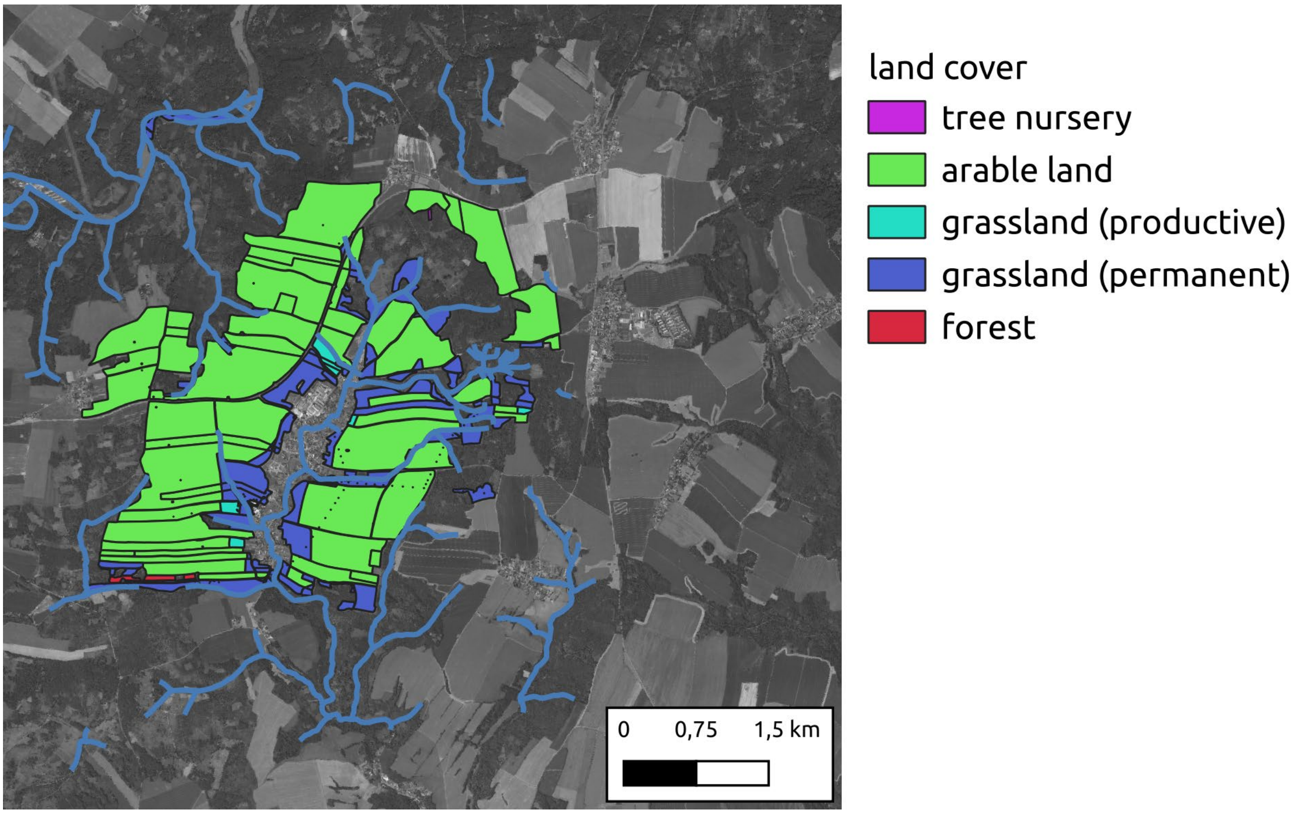


Figure 3.4. Land use in the study area (source: from Brno Univ. of Technology).

3.4 Scenarios

Initially, three scenarios were assessed with the model: (1) baseline (no measures), (2) buffer zones along all streams, and (3) grassed waterways in areas that are prone to gully erosion. The measures were parameterised conservatively, in order to retain the focus on the comparative aspect of the study (realistic absolute values for erosion and deposition were not the primary objective). Due to NIBIO's limited knowledge of the area, the effects of the conservation measures on runoff and infiltration had to be restricted to a minimum. Parameterisation for conservation efficiency was finally carried out by reducing the particle detachment E_{runoff} and transport capacity TC (both a function of daily runoff) by 50%. This is a 'rule of thumb' number that can be considered appropriate for the indicative nature of the study (Zhang et al., 2010).

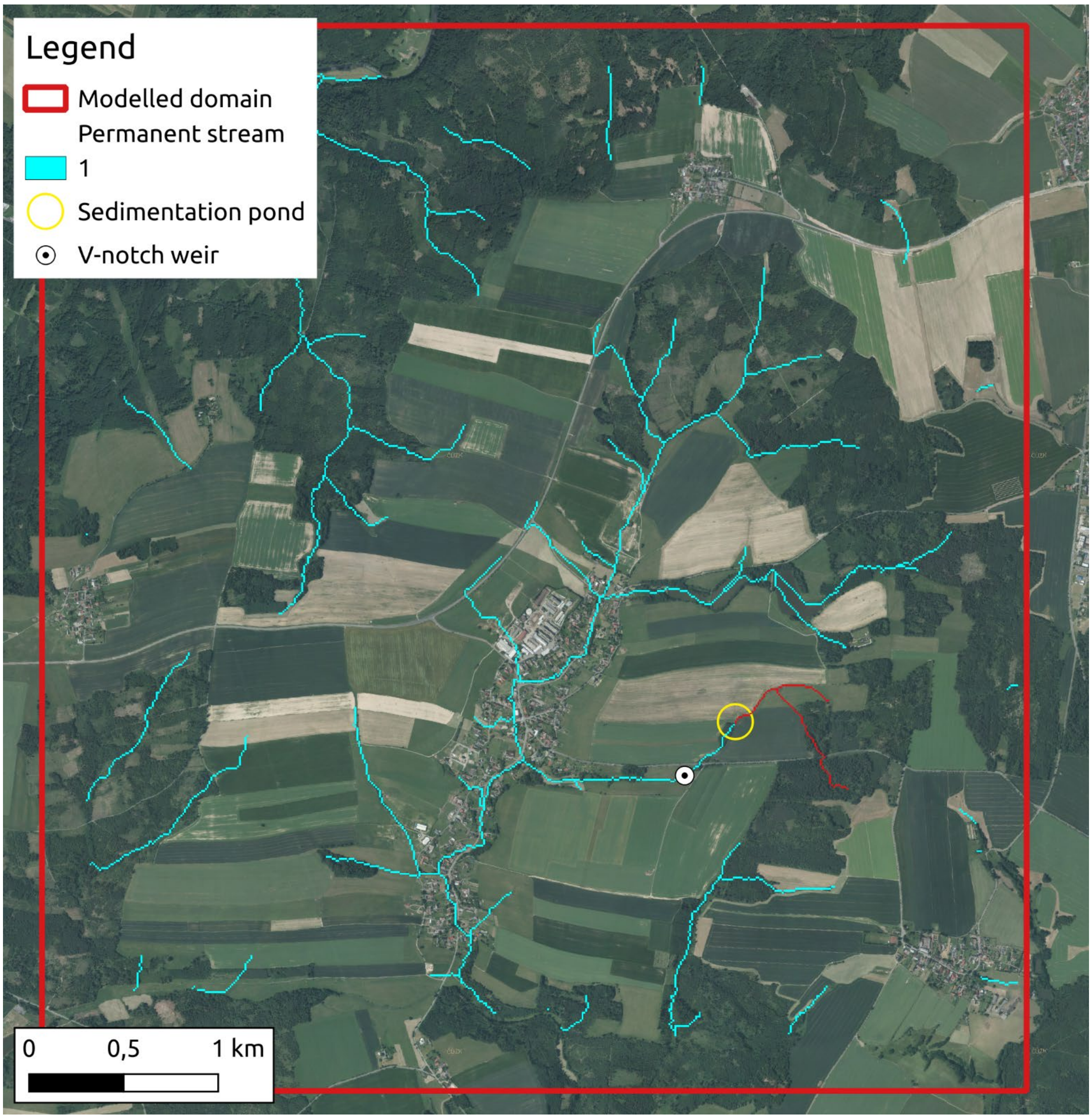


Figure 3.5. Overview of the simulated area in Větřkovice municipality. The part of the stream network upstream of the sedimentation pond is indicated in red. NOTE: white point indicates location of the V-notch weir and the yellow circle indicate location of the sedimentation pond.

Figure 3.6 shows the potential placement of the grassed waterways and buffer zones, according to the principles mentioned in *section 3.3 in AdaptaN II report – Part1: Mitigation measures*. Due to the raster cell size of 10 x 10 m, the buffer zones in the model simulation represent a 10m (one cell) width at both sides of the streams. Similarly, grassed waterways are one to two (10 to 20m) wide in the simulation. These values are somewhat higher than the values typically used in Norway, but not unrealistic in any given terrain.

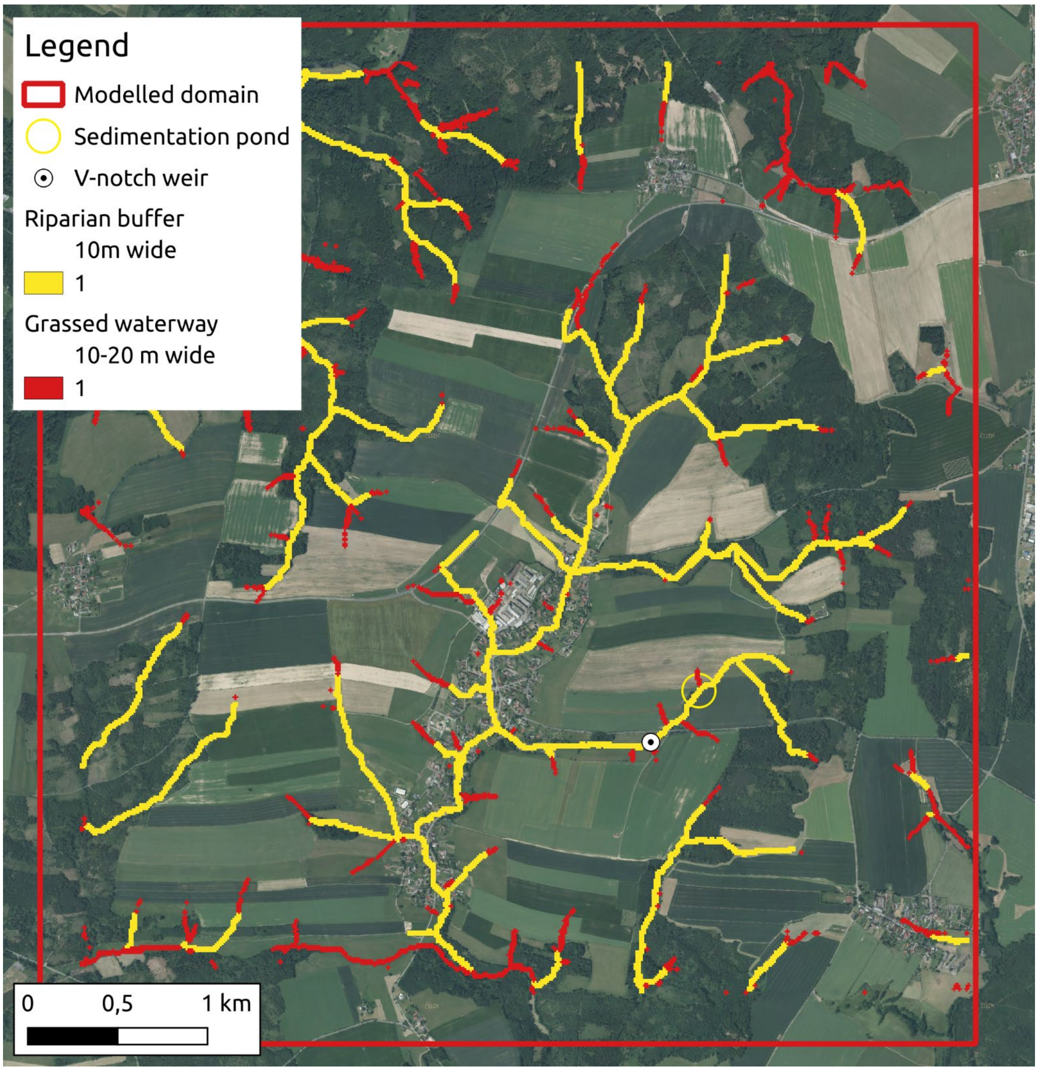


Fig. 3.6. Placement of buffer zones (yellow) and grassed waterways (red) in the landscape of Větřkovice municipality. NOTE: white point indicates location of the V-notch weir and the yellow circle indicate location of the sedimentation pond.

3.5 Results

The results of the baseline scenario - without any implemented soil conservation measures - indicate an average annual rate of sediment delivery to the stream that leads to the sedimentation pond of 10.26 tonne ha^{-1} year^{-1}. This average, however, is dominated by the value generated for the year 2020, which was exceptionally wet. In this year, the precipitation totaled almost 900 mm, in a period during which the average annual sum is approximately 600 mm. Soil erosion rates in the months June-July and October-November were particularly aggravated in comparison to the other simulated years (Fig. 3.7). The Figure also shows the correlation between increased average soil moisture content and increased erosion rates.

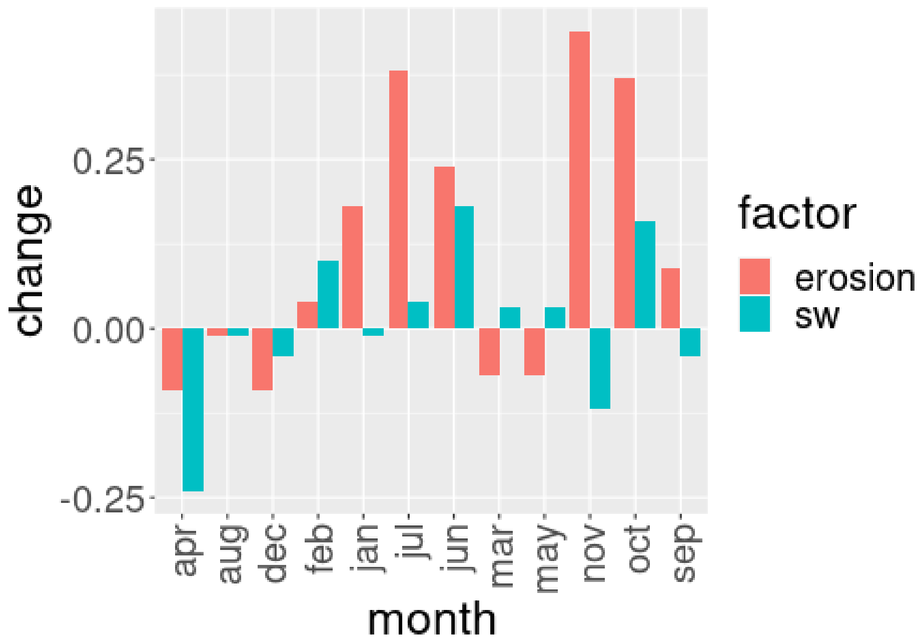


Figure 3.7. Comparative erosion rates (red) and soil moisture (blue) content levels for the erosive year 2020 (difference relative to the overall simulation period).

Soil loss rates, calculated as the net annual sum of particle detachment and deposition (kg m^{-1}) for a typical year (2021, in the case of the study area) are depicted in Figure 3.8.

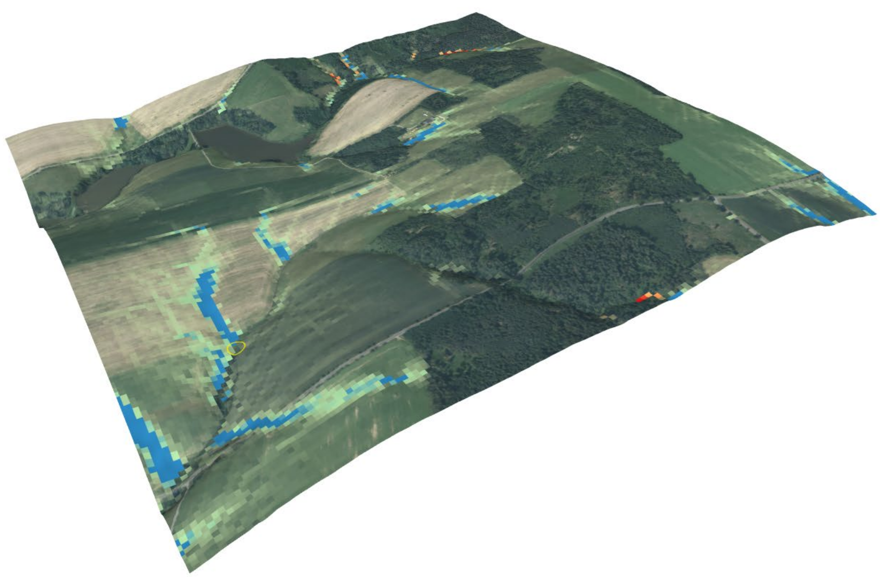


Figure 3.8. Example output from the model: blue tones indicate net soil loss values for the catchment area of the upper sedimentation pond in the case study area. The orange and red pixels in the upper, forested, part of the catchment indicate net deposition.

the overview map of Figure 3.8 confirms the intuitive notion that the highest erosion and soil loss rates occur in the talwegs in the landscape. Sediment source areas are connected to the hillslope in locations where talwegs meet the riparian zone. Consequently, making these to high erosion risk areas and indicating potential location of mitigation measures.

Soil loss in the area in the simulated period was concentrated in the months March to (early) May, and August to October. The reason for this is twofold:

- the spring period is characterised by poor soil cover (the scenario assumes autumn tillage, meaning bare soil in spring). This is also the period when the winter precipitation, accumulated as snow, is released during intensive snow melting intervals.
- autumn erosion can be attibuted to a combination of high average soil moisture conditions and steady, wet weather conditions. This was especially so in the year 2020, when little erosion occured in spring, but the rates in autumn were extremely high.

This discharge and erosion rate patterns are also very typical in Norwegian catchment, see *section 3.1 in AdaptaN II report – Part 1: Mitigation measures*. Erosion during autumn period is also dependent of timing of tillage related to the occurrence of precipitation events.

Figure 3.9 shows the daily rates of soil loss to the sedimentation pond for the three scenarios.

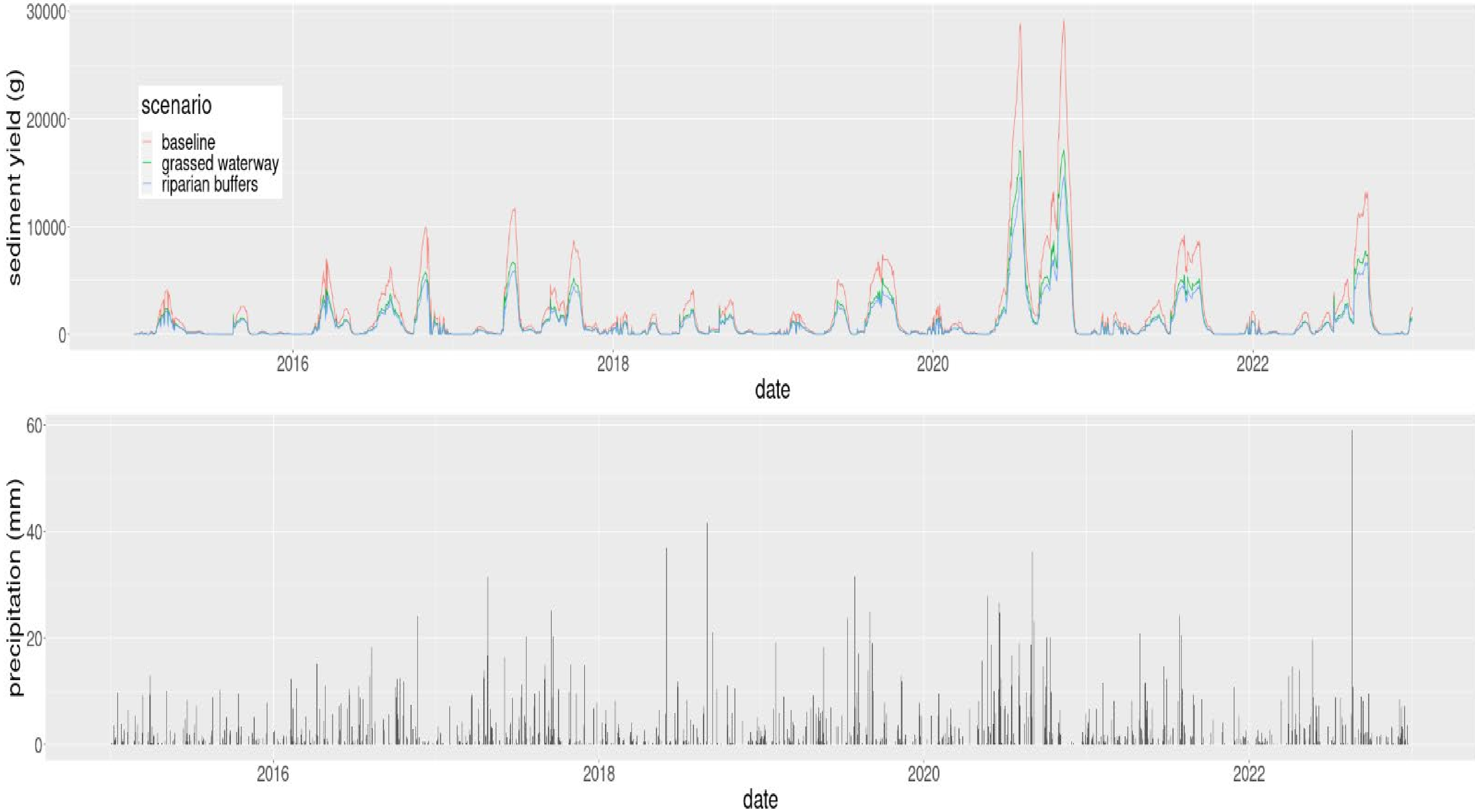


Figure 3.9. Daily soil loss (gram) to the stream for three scenarios (upper) and daily precipitation (mm) (lower) for the period 2015-2022.

The annual values for the 3 scenarios are given in table 5.1.

Table 5.1. Annual soil loss for the three scenarios (tonne ha⁻¹).

Year	Baseline (no measures)	Grassed waterways	Buffer zones
2015	2.89	1.73	1.60
2016	9.81	5.94	5.22
2017	10.23	6.16	5.40
2018	3.78	2.25	2.08
2019	8.27	5.00	4.41
2020	28.74	17.69	14.81
2021	9.25	5.60	4.89
2022	9.15	5.59	4.83
Average 2015 -2022	10.26	6.24	5.40

The year 2020 was an exceptionally erosive year according to the simulations. The soil loss values for this year can be explained by the high daily runoff volumes to the stream. In the model, this was the result of high daily precipitation values in periods with high antecedent soil moisture conditions. Total annual sediment delivery rates to the sedimentation pond are approximately 70m^3 (assuming a sedimentation rate of 0.25 for all combined particle size fractions). This value is likely to be less in reality, and the overestimation can be explained due to the absence of transport equations in the implementation of the MMF model for Větřkovice.

Reductions of annual soil loss were calculated for the two scenarios with soil conservation measures. The reductions, as a ratio of the soil loss for the baseline scenario, are given in Table 5.2.

Table 5.2. Reductions of annual soil loss calculated for the two scenarios: (1) grassed waterways and (2) buffer zones, expressed in a ratio of the soil loss for the baseline scenario.

Year	Grassed waterways	Buffer zones
2015	0.40	0.45
2016	0.40	0.47
2017	0.40	0.47
2018	0.40	0.45
2019	0.40	0.47
2020	0.38	0.48
2021	0.39	0.47
2022	0.39	0.47
Average	0.40	0.47

It can be observed that both measures have a significant effect on the amount of sediment that has to be buffered by the sedimentation pond. Buffer zones appear to have the greatest overall effect, with an average efficiency of 47% for the area of interest. Grassed waterways reduce the amount of soil particles delivered to the stream network by 40%. It should be noted that the area that is taken up by grassed waterways is a much less than that of the area taken up by riparian buffers. In the study area, buffer zones take up 4.7 % of the entire area, while the projected grassed waterways take up 2.9%. When the spatial resolution and raster cell size of the model configuration are considered, the area that is actually required for the grassed waterways is likely to be less than 1.5% of the total area.

Likely reasons for this difference in percent reduction per used area, is that much of the erosion in the area is concentrated in the talwegs where the grassed waterways are placed. In addition, grassed waterways reduce the sediment connectivity of the upstream area, partially de-coupling areas that would otherwise have contributed significantly to annual sediment loads in the stream network.

3.6 Conclusions and recommendations

The indicative modeling exercise for part of Větřkovice catchment gave several interesting results and they indicate main potential challenges in the area:

- The erosion risk distribution is directly connected to the topography. More specifically, it indicates the high erosion and soil loss rates are situated in the talwegs in the landscape. This result is a natural combination of soil erodibility, k_{soil}, (Fig 3.3) and topography (DEM).
- There are two periods with high soil losses: spring and autumn. These periods can be directly connected to the snow melting (spring) and highly intensive precipitation in combination with limited vegetation cover (autumn). Exceptional years, however, show high erosion rates outside of these periods.
- Scenario results indicates that grassed waterways and buffer zones can be seen as effective mitigation measures in the area. This is not surprising as there two measures are especially dedicated to address a problem in the locations with high erosion risk (like talwegs in the landscape or areas along the streams receiving most of the surface runoff from the surroundings field).
- Moreover, it should be noted that grassed waterways seem to have bigger effect than buffer zones. Again, this is in agreement with what one could conclude when looking at the results from the base line scenario (Fig 3.6), indicating that the highest soil losses are associated with local talwegs. Grassed waterways are the most space-efficient way of reducing erosion rates.

Based on the results of modeling exercise presented here and on our experience from other Norwegians studies we can further formulate following suggestions/recommendation points:

- When the erosion risk is associated with the 'out of growing season' implementation of management measures should be prioritized. Measures to consider are:
    - Reduced tillage – meaning not tillage in autumn/leaving stubbles over the wintertime. This will affect both erosion in the field and in the talwegs.
    - Cover crops - as undersown crop or after main crop to protect for erosion and nutrient losses.
    - "Breaking down" long slopes
- Exceptionally wet conditions can occur throughout the year and the simulations have shown that the erosion rates in these periods can occur outside of the growing season. Structural measures are therefore of pivotal importance for an integrated soil conservation strategy.
- Possibility for structural/design measures should be assessed based on the terrain characteristics:
    - Grassed waterways – providing permanent vegetation in the talwegs, especially the once that are discharging to close vicinity if surface waters.
    - Grass covered buffer zones – an efficient way of reducing sediment delivery to surface waters. Here additional analysis can be made to estimate recommended width of buffer zones, for example wider buffer zones in the areas of concentrated surface flow and narrower areas where there is limited surface runoff towards the streams.
    - Retention ponds/constructed wetland – we know that there is already a series of retention/sedimentation pond in the area, which is for sure very good strategy. The

need for more or bigger ponds can be assessed. It could be also interesting to elaborate what could be more effective – one bigger pond or series of smaller ponds.

All these possible mitigation measures could be first in the more detailed modeling exercise taking into account all available data from the area, like soil physical and hydrological characteristic, crop management practices, timing of tillage and sowing, drainage system etc.

Process based models can assess comparative efficiency ratios and address spatial aspect of soil conservation measure planning.

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NIBIO
NORSK INSTITUTT FOR
BIOØKONOMI

Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter.

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