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„Effects of vegetated riparian buffer strips on lateral sediment input to agricultural river systems and the role of human-made linear flow paths in the Fugnitz catchment, Lower Austria"

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Author's declaration

Herewith I confirm that this thesis was written by me. I did not use any sources besides those cited as reference. Furthermore, this thesis was not submitted prior to this as an examination paper in any form. This thesis is identical with the version evaluated by the advisor.

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Abstract

Heavily intensified soil erosion by cultivation of arable land is a main contributor to the chemical pollution of freshwater ecosystems. High loads of fine sediment are transported to the channel via overland flow pathways, furthermore man-made linear flow pathways can drain substantial parts of a catchment. Vegetated buffer strips (VBS) between arable fields and the river channel are a common mitigation measure, since they are considered to be highly effective in removing suspended solids, nutrients and pesticides from runoff by trapping sediment and consequently reducing sediment connectivity. The role of human-made linear flow paths in delivering sediment to streams is often overlooked. This study investigates the effectiveness of existing vegetated buffer strips and the role of anthropogenic flow paths in terms of sediment connectivity and fine sediment input in the agricultural intensively used Fugnitz catchment in Lower Austria.

Vegetated buffer strips alongside permanent streams are eligible for subsidy in Austria, but not continuously present along the Fugnitz and its tributaries. In order to assess the effectiveness of the existing buffer strips, the volume of the buffered sediment was measured in the field after heavy rainfall events. Afterwards the respective runoff and erosion events as well as the sediment yield rates were modelled using the Water Erosion Prediction Project (WEPP). The resulting sediment yield rates of the model were compared to the event-based in situ data. Concerning the role of man-made linear flow paths, the connectivity between these and the actual permanent streams was investigated in the field by mapping and later modeling the entry-points of the man-made flow paths into the river channel system.

All investigated VBS showed signs of sediment overflow after a heavy rainfall event. The trapping efficiencies for the investigated rainfall event were between 12 and 32%, showing that the width of the buffers is insufficient for the amount of eroded sediment coming from the fields. Several entry points of the anthropogenic drainage network into the river channel were found. Major areas of the catchment drain through those drainage channels. Therefore, human-made flow paths need to be included in sustainable management plans.

Zusammenfassung

Durch die Bewirtschaftung von Ackerland kommt es zu einer erhöhten Bodenabtragsrate. Diese trägt maßgeblich zur chemischen Verunreinigung von Fließgewässern bei. Große Mengen an Feinsediment werden über oberirdische Fließwege in die anliegenden Wasserwege transportiert. Künstlich angelegte Drainagegräben entwässern große Teile der hydrologischen Einzugsgebiete, werden jedoch bisher in Studien zur Sedimentkonnektivität häufig übersehen. Mit Vegetation bedeckte Gewässerrandstreifen werden oftmals als eine effektive Maßnahme gegen Feinsedimenteintrag von Ackerflächen erachtet.

Diese Arbeit untersucht die Effektivität der vorhandenen Gewässerrandstreifen und die Rolle anthropogener Fließwege in Bezug auf Sedimentkonnektivität und Feinsedimenteintrag in Fließgewässersysteme im landwirtschaftlich intensiv genutzten Einzugsgebiet der Fugnitz in Niederösterreich. Gewässerrandstreifen werden in Österreich gefördert, sind entlang der Fugnitz jedoch nur sehr begrenzt vorhanden. Um die Effektivität der vorhandenen Gewässerrandstreifen festzustellen, wurde das Volumen des aufgefangenen Sediments nach Starkregenereignissen gemessen. Danach wurden die Erosionsereignisse der untersuchten Hänge unter Verwendung des Water Erosion Prediction Project modelliert (WEPP). Die modellierten Sedimentraten wurden dann mit den In-situ-Daten verglichen, um die Genauigkeit des Models zu überprüfen und die Effektivität der Buffer zu berechnen. Um die Rolle künstlicher linearer Fließwege im Kontext von Sedimenttransport zu untersuchen, wurde die Konnektivität zwischen diesen und dem Fluss vor Ort durch Kartierung und später durch Modellierung untersucht.

Alle untersuchten Gewässerrandstreifen zeigten nach einem Starkregenereignis Anzeichen eines Sedimentüberlaufs. Es wurden nur 12 - 32% des erodierten Sediments abgefangen, was auf die unzureichende Breite der Streifen zurückzuführen ist. Es wurden mehrere Verbindungspunkte der anthropogenen Fließwege ins Flussnetzwerk gefunden. Durch diese entwässern große Bereiche des Einzugsgebiets, weshalb sie bei der Erstellung von nachhaltigen Managementplänen einbezogen werden sollten.

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1 Introduction

Soil erosion is the removal of surface material by water, wind, or tillage (Zuazo et al., 2011; Breburda & Richter, 1998; Kirkby, 1980). For almost a century it is known to be the biggest threat to soil quality and soil ecosystem services (FAO, 2019). Despite the extension of efforts in research and management, soil erosion is a growing problem in many regions of the world (Zuazo et al., 2011). With the increase of the global population, the pressure on usable agricultural land is rising and the reduction of arable land due to soil erosion intensifies this pressure (A. Parsons, 2019). The acceleration of soil erosion is caused by human activity and land-use change (Borrelli et al., 2017), which not only leads to the stated problem of food supply, but also to environmental issues. Apart from soil health, the pollution of water bodies states the greatest environmental problem of soil erosion in agriculturally used areas. The use of fertilizers and the release of materials from livestock build substantial sources of river ecosystem contamination. In 2000 the National Water Quality Inventory of the US stated, that agricultural lands are the leading source of pollutants to river systems. (Miller & Miller, 2007) Eroded soil particles are transported from the agricultural fields into the river channel network. This causes sedimentation that reduces the water storage capacity in downstream reservoirs and raises water turbidity and pesticide runoff (Chiu et al., 2007). Therefore, the off-site effects of soil erosion are not only ecologically critical but can also have negative effects on infrastructure (Hewett et al., 2018).

The first step to improve the economic and ecologic problems caused by soil erosion is to protect the soil from erosion (Pimentel et al., 1995). There are different approaches to prevent on-site effects of soil erosion on agricultural fields that have proven to be effective in multiple studies. They involve different tillage techniques, cropping, and crop rotations (Bucur et al., 2007; Zuazo et al., 2011). To prevent the off-site effects of soil erosion, the installation of buffer strips with perennial grass vegetation between agricultural fields and water bodies has shown to be efficient. They prevent eroded sediment from entering the river system and therefore minimize the risk of sedimentation and water pollution downstream. (Jankauskas et al., 2004; M. Nearing et al., 2005) An essential part of sustainable catchment management is the prevention of the off-site effects of soil erosion (Mekonnen et al., 2014; Ghafari et al., 2017).

High loads of fine sediments are transported to the channel via overland flow pathways (Croke et al., 2005). Human-made linear flow pathways can drain substantial parts of a catchment (Hösl et al., 2012), further affecting connectivity relationships in a catchment (Nicoll & Brierley, 2018). Nevertheless, anthropogenic ditches and their role in sediment transport remain understudied (Prosser et al., 2020).

The Fugnitz River in the north of Lower Austria is a 29.7 km long stream with a catchment area of 138.4 km (Poeppl et al., 2012). On Austrian territory, the Fugnitz is the main tributary of the Thaya, the bordering river between Austria and the Czech Republic, where the Thayatal National Park is located. The Fugnitz catchment is characterized by intensive agricultural land use. The official land use data show that 56 % of the catchment are agricultural areas. Recent studies on river ecosystem condition state, that the Fugnitz is in a poor to moderate ecological state, besides other factors, being caused by high phosphorus concentrations caused by lateral sediment-associated input from arable fields (fig. 1.1) (Scheder & Gumpinger, 2014; Akbari, 2019). Vegetated buffer strips alongside permanent streams are eligible for subsidy in Austria, but not continuously present along the Fugnitz and its tributaries. Anthropogenic drainage ditches can be found along most of the streets in the catchment and along the slope foot of agricultural fields.

Figure 1.1: Outlet of the Fugnitz entering the Thaya at Hardegg (Lazarek 2009).

Motivated by the local problems and the research gaps mentioned above, the following research questions were formulated:

1. *Do vegetated buffer strips in the Fugnitz catchment prevent eroded agricultural fine sediment from reaching the river systems?*
    a) *What is the role of the rainfall event magnitude?*
    b) *How do the field characteristics (e.g., topography, crop cover) influence sediment transport?*
    c) *How does the vegetation structure of the buffer strip influence its buffer capacity throughout the season?*
2. *Is the installation of buffer strips a suitable management tool to effectively prevent lateral fine sediment input to streams?*

3. *What is the role of human-made linear flow paths in terms of sediment input into the Fugnitz and its tributaries?*

4. *What are the options for improvement for the management of lateral sediment input measures in the Fugnitz catchment?*

The first two research questions focus on the efficiency of the present vegetated buffer strips along the Fugnitz catchment. The third research question tackles the lack of knowledge of human-made linear flow paths and their role in sediment transport. The fourth research question aims to sum up the results of the first three research questions and translate them into recommendations for local conservation management.

In order to understand the processes and terms of the research objectives in this study, chapter 2 provides a general theoretical overview of soil erosion, connectivity, and vegetated buffer strips. Chapter 3 describes the study area (Fugnitz catchment) in detail, including all relevant physiographic features. Chapter 4 will introduce the methods used in this research. Afterward, the results will be summarized in chapter 5. The results will be discussed, and the research questions answered in chapter 6. Chapter 7 provides a short and comprehensive conclusion of this thesis.

2 Theory

This chapter will provide relevant theoretic background for this study. It includes the principles of soil erosion, soil erosion in the context of human cultivation, soil erosion management with a focus on vegetated buffer strips, and catchment connectivity. It will give an overview of the basics and also the state of the art of the different topics in order to provide a general understanding of the processes that are relevant for this study.

2.1 Soil erosion

Soil erosion is defined as »the net long-term balance of all processes that detach soil and move it from its original location«(FAO, 2019). The detachment of surface material is caused by wind or water, though water erosion is the most destructive erosion type (Zuazo et al., 2011). The following chapter has the objective to explain the involved processes and their physical properties in order to gain a better understanding of the mechanisms that are essential for this study. It will focus on water-driven surface erosion and the role of human activity due to its mentioned general importance and its relevance in the study area.

2.1.1 Causes & effects of soil erosion

Soil erosion, in general, is a natural phenomenon that shapes the landscape, but it has been increased due to human activity. The erosion by water occurs in three steps: detachment, transport, and deposition (see fig.2.1). Flowing water, falling raindrops, or freezing and thawing cause the detachment of soil particles in the topsoil. The detached soil particles get transported by floating, dragging, rolling, or splashing and deposited at places with a low relief energy. The processes of splashing and deposition cause the plugging of soil pores, which leads to the development of a soil crust once the soil dries. The soil crust intensifies the runoff, which leads to an acceleration of the erosion process. (Zuazo et al., 2011)

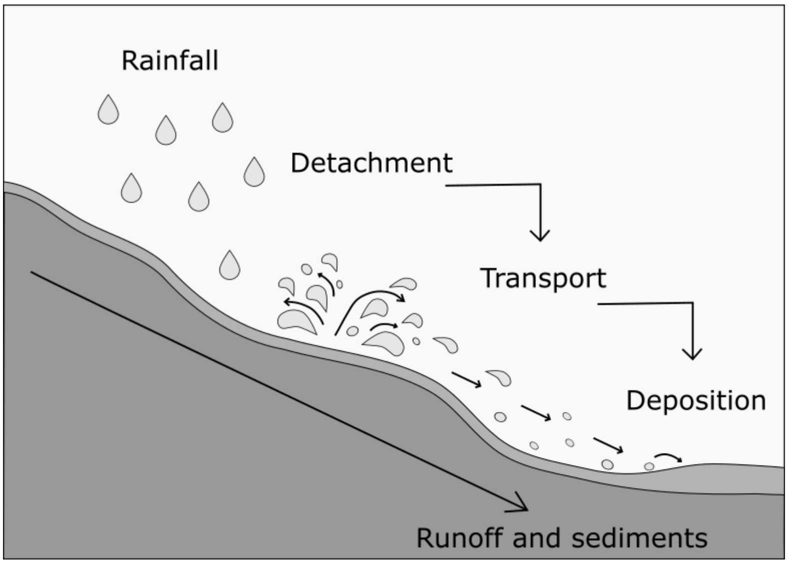


Figure 2.1: Mechanics of water erosion (based on (Zuazo et al., 2011).

The process of soil erosion is determined by several factors that affect if and how fast the soil will erode.

Rain is the most critical force for water erosion processes since it detaches soil particles and forms surface runoff (Ballabio et al., 2017). Raindrops break down soil aggregates and make the material easy to be transported by runoff. During high-intensity thunderstorms, this runoff as a result of raindrop splash is usually the greatest form of soil movement. (Zuazo et al., 2011) Therefore the **rainfall erosivity**, which is the relationship between rainfall and sediment yield, is one of the most important factors when dealing with soil erosion processes. It is calculated by multiplying the total storm kinetic energy from a series of single storm events with the measured maximum 30-minute rainfall intensity (Wischmeier & Smith, 1978). So precipitation is a primary factor for the process of soil erosion. Many studies show that there is a distinct correlation between rainfall intensity and water-driven erosion (Critchley et al., 2013). Therefore, precipitation is the most important climate variable in the context of soil erosion (Pruski & Nearing, 2002).

Depending on its properties, soils have different propensities to erode. This **soil erodibility** is a key factor for soil erosion processes, but it is difficult to access. In general, silty soils tend to erode faster, while soils with a high content of clay are the least erosive soils. Therefore loess (wind-blown silt) is referred to as the most erosive soil worldwide. (Zuazo et al., 2011) The soil erodibility factor (K) represents the average soil response to rainstorms on a long-term basis (Borselli et al., 2012). For a particular soil, it is the average soil loss per unit of the erosion index (R) from a standard plot (Mitchell & Bubenzer, 1980). Soil erodibility can be evaluated by simulation experiments with rainfall, wind-tunnels, scouring, and plots or by measuring physiochemical soil properties. It is also influenced by biotic factors, mainly human activities, which lead to limitations in soil erodibility research. For soil-erosion-prediction-models, a constant erodibility value for a given soil type is used, based on the soil-erodibility nomograph, which has first been published in the 1970s. (Zuazo et al., 2011)

The **topography** of a slope is an important factor in relation to soil erosion and surface runoff. The degree and the length of a slope are affecting the sediment yield significantly. Due to the increase in volume and velocity of the surface runoff, soil erosion can be expected to increase with steepness and length of the slope. (Zuazo et al., 2011) The slope angle is an important factor governing the severity of erosion. If the slope angle steepens, more soil is splashed downslope. Also, the increase in slope length increases the severity of erosion. The form of the slope determines the distribution of erosion and its form. (Evans, 1980) The topography of a slope is also of interest in managing practices like contouring and terracing. (Zuazo et al., 2011)

Another important factor that influences soil erosion is vegetation. Water-driven erosion is a result of rain dropping on the soil surface or the flow of surface runoff. Therefore, the erosion of soil decreases in areas with vegetation cover. (Roose et al., 1996) Plant cover increases the water infiltration into the soil and reduces water runoff (Zuazo et al., 2011). Additionally, plants stabilize the soil by fixing it with their roots (De Baets et al., 2008). Due to these beneficial effects, implementing vegetation is essential in soil conservation planning. Since the vegetation cover is immensely driven by anthropogenic land use, soil erosion is especially severe in the context of human cultivation (see ch.2.1.3).

2.1.2 Types of water-driven soil erosion

As stated before, the detachment of soil particles by a raindrop is the initial stage of the soil erosion process. This part of the process is called splash erosion and is followed by short-distance transport of the detached particles. Therefore, splash erosion is the first erosion that occurs when a rainfall event happens. (Angulo-Martinez et al., 2012) A study by Ryżak et al. (2015) showed that soil particles can be displaced up to 1.5 m vertically and in combination with wind and slope transported over 5m horizontally (see fig. 2.2) (Erpul et al., 2009).

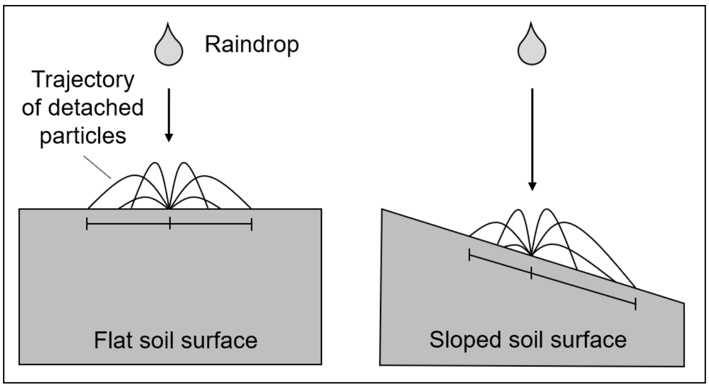


Figure 2.2: Splash effect on flat and soil surfaces (based on Fernández-Raga et al.).

When splash erosion occurs on bare soil surfaces, it can lead to compaction and crusting through blockage of pores and thereby increase the bulk density of the soil (Terry & Shakesby, 1993).

The two major components of soil erosion on a hillslope are interrill and rill erosion (Zhang et al., 2014). **Interrill or sheet erosion** is described as the removal of a uniform layer of soil triggered by splash erosion (Auerswald et al., 2006). The main force of interrill erosion is shallow overland flow (see fig. 2.3) (Morgan, 2006). Splash erosion is described as the initial stage of interrill erosion. During rainfall events, both types usually co-occur and cause 70% of eroded material. (Blanco & Lal, 2008) The interrill erosion rate increases gradually with increasing runoff, but it is less visible than rill erosion (Zhang et al., 2014).

Figure 2.3: Sheet erosion and deposition in the Fugnitz catchment near Rassingdorf (Photo: Humer 2018).

Rill erosion describes the formation of small channels under the action of small intermittent watercourses, both only several centimeters deep (see. fig. 2.4) (Auerswald et al., 2006). When the surface flow exceeds a certain threshold of soil resistance, the surface flow breaks into erosion rills (Moss et al., 1982). Rills are the main transport network on hillslopes during erosion periods (Shen et al., 2015). Rills are, therefore, an important geomorphological feature because they transport materials supplied by interrill erosion (Bewket & Sterk, 2003).

Interrill and rill erosion mostly occur simultaneously (Blanco & Lal, 2008). Depending on the physiographic setting, rill networks can establish differing complexity (Mancilla et al., 2005). A developed rill network causes increased runoff connectivity and a concentration of flow and, therefore, faster erosion rates (Moreno-de Las Heras et al., 2011; Blanco & Lal, 2008). As time goes by, the drainage area tends to fill more completely (Shen et al., 2015). The width-to-depth ratio is a quantitative measurement of rill erosion, as well as space-filling tendencies of the networks (Raff et al., 2004). Rill erosion forms are often distinguished between main rills and secondary rills. Main rills transport most of the surface runoff and sediment, while secondary channels are smaller and transport less surface runoff or dissipate before reaching the outlet. Those secondary channels are often ignored when investigating rill erosion. (Mancilla et al., 2005) Shen et al. (2015) state that the neglect of secondary rills in soil erosion studies leads to the exclusion of an essential part of the rill network.

Figure 2.4: Rill erosion and surface crusting in the Fugnitz catchment (Photo: Eberhard 2018).

A large fraction of eroded soil is redistributed and delivered to the river channel network through gully erosion (Martınez-Casasnovas et al., 2002). When runoff water accumulates in narrow channels and often reappears, the soil is removed from the narrow channel to considerable depths. This process is called **gully erosion**. (Poesen, 1993) Permanent gullies can reach from 0.5 m up to 25-30 m in depth, which impacts agricultural land because the channels are too deep to be easily machined with farm tillage equipment (see. fig. 2.5) (America, 2001). Therefore, gully erosion is stated as the main factor of land degradation by erosion and leads to irretrievable loss of arable land and a highly damaged landscape (Ries, 2011).

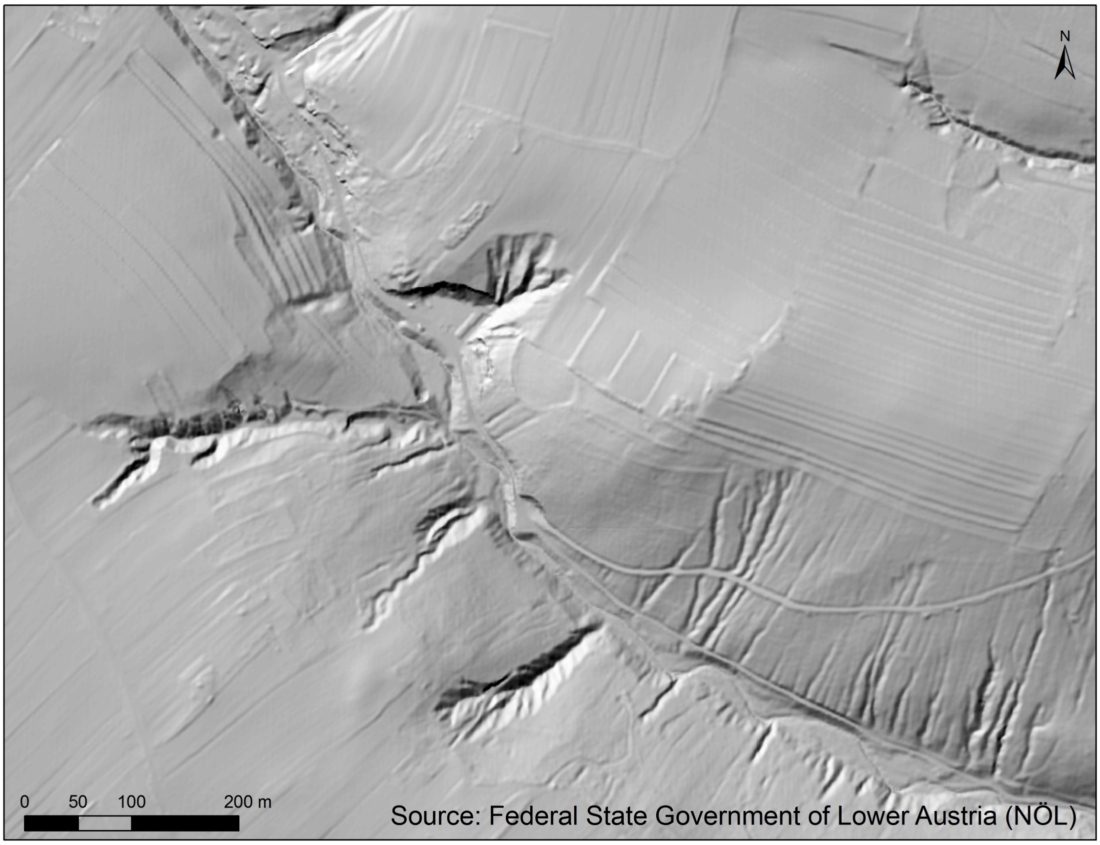


Figure 2.5: Gully erosion in the downstream area of the Fugnitz, clearly recognizable on the hillshade.

Ephemeral gullies are defined as a form of erosion that has a larger concentrated flow than rill erosion but is less than a classical gully erosion (Foster, 1986). The Soil Science Society of America (2001) defines ephemeral gullies as »small channels eroded by concentrated overland flow that can be easily filled by normal tillage, only to form again in the same location by additional runoff events«. They occur along concentrated flow zones in natural drainage lines or along with linear landscape elements like drill lines or access roads (Poesen, 1993). To distinguish between ephemeral gullies and rills, Poesen (1993) defined a square foot criterion, that is specified by a critical cross-sectional area of 929 cm^2. Brice (1966) introduced a criterion that incorporates a minimum width of 0.3 m and a minimum depths of 0.6 m. As to the upper limit of gullies, there is no existing definition, this is why Poesen et al. (2006) conclude that the boundary between an ephemeral gully and a large gully is »very vague«.

2.1.3 Soil erosion in the context of human cultivation

The presence, respectively, the density of the vegetation cover is the factor in the erosion process that determines its severity. Thus the removal, decrease, and change of vegetation cover by human activity, especially in the context of cultivation (e.g., overgrazing, cropping, and deforestation), causes soil erosion. (Zuazo et al., 2011) Therefore, the type of crop and its density changes the intensity of soil loss on the hillslope. Haselberger (2017) stated that the average annual hillslope soil loss of maize is more than five times higher than that of wheat. Howden et al. (2007) recommend to »maintain crop cover during periods of high risk so as to reduce raindrop damage on the soil surface and allow for water to infiltrate«.

Tillage erosion is a major process in intensive agriculture and mainly controlled by the topography (Van Oost et al., 2003). Soil loss and the redistribution of soil on slopes follow characteristic patterns. Soil loss can be observed on convexities, while soil aggradation is the dominant pattern on concavities. (Govers et al., 1994) Quine et al. (1997) stated that arable soils show annual erosion rates of more than 20 t/ha. The occurrence of soil loss or soil aggradation is proportional to the change in the slope gradient (Govers et al., 1994). The tillage erosivity does not only depend on tillage speed and depth but on tillage direction (Heckrath et al., 2006). The displacement of soil by tillage is a process that is characterized by a vector of soil movement in tillage direction or perpendicular to it. This vector is affected by the slope gradient and the complexity of the topography. (De Alba, 2001). A study by Heckrath et al. (2006) showed that tillage direction has a significant effect on soil redistribution and that the least erosive tillage direction is at $45°C$ to the gradient turning soil upslope.

The transport of sediment downslope and into the watercourses can result in sedimentation (Morgan, 2005). **Sedimentation** can reduce the water storage capacity in downstream reservoirs and increases the water turbidity and pesticide runoff (Chiu et al., 2007). As a result, pollution affects water bodies and therefore influences riverine habitats and sensitive ecological processes (Rodrigues & Silva, 2012). The amount of eroded sediment does not have to be high to cause significant pollution. Therefore, the pollution of water bodies through soil erosion is a primary driver for soil conservation today. Another effect of soil erosion can be the flooding of downstream areas due to increased runoff. (Zuazo et al., 2011) The implications of soil erosion on agricultural areas can be divided into **on-site and off-site effects** (see fig. 2.6). (Zuazo et al., 2011) The main on-site effects of soil erosion in agricultural landscapes are soil degradation, the reduction of soil aggreagate stability by tillage, the increase of bulk density through compaction and crusting, and the depletion of nutrient and carbon content by fertilization (Morgan, 2005). The major off-site effects are related to the transport of eroded sediment and nutrient into the river channel network and the concomitant ecological consequences (Walling, 2003). Figure 2.6 shows the major on- and off-site effects of soil erosion in agricultural areas.

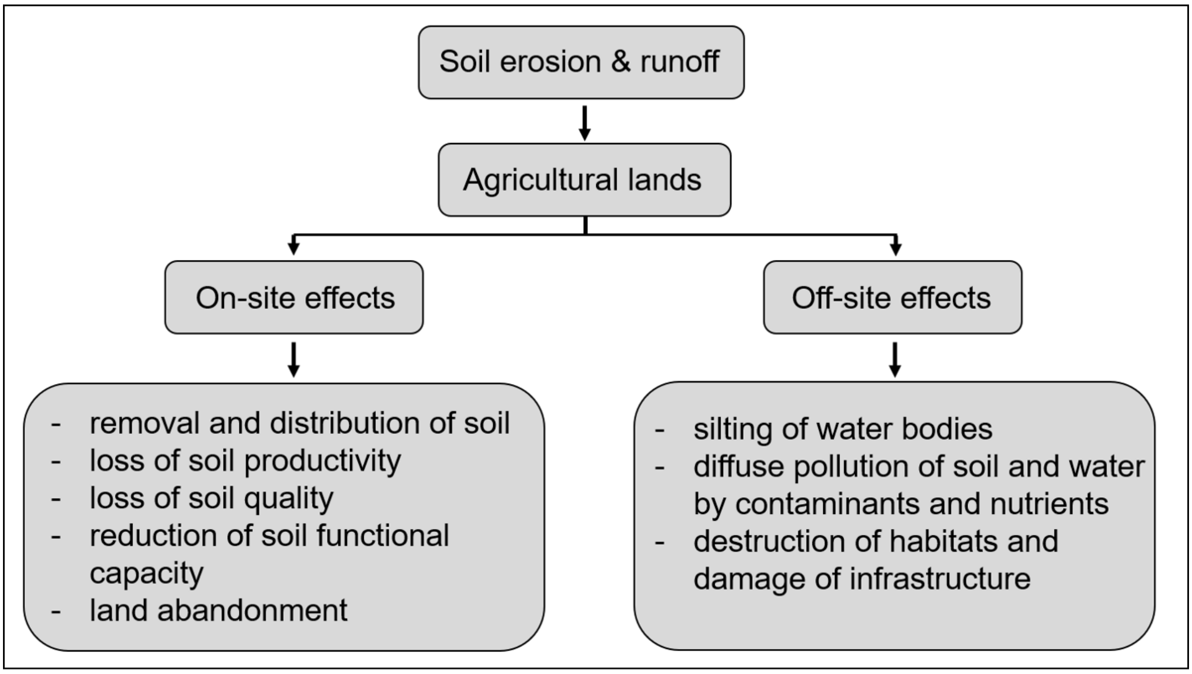


Figure 2.6: On- and off-site events of soil erosion on agricultral lands (based on Zuazo et al. 2011).

2.1.4 Management of soil erosion

When anthropogenic influences on soil, vegetation, or climate conditions increase erosion rates to a rate that exceeds their natural variability, it is called accelerated soil erosion (Webb et al., 2014). This accelerated erosion takes place when talking about soil erosion in the context of human cultivation. Most research and soil conservation measures are carried out on agricultural landscapes due to their economic importance (Zuazo et al., 2011). When managing soil erosion, it is important to consider both on- and off-site effects in order to get a working integrated and holistic management. On- and off-site effects need different measures in different locations (Ghafari et al., 2017). Suitable and appropriate management techniques are essential and can only be achieved with site-specific mitigation strategies (Fryirs et al., 2007). Therefore, management decisions should not only be based on soil loss rates but also on sedimentation rates of the local water bodies (Ghafari et al., 2017). There are a variety of approaches to soil conservation that showed to be effective in different studies. A lot of measures involve tillage techniques and cropping. Most of the measures that can be taken for sloping arable land are inexpensive and effective (Bucur et al., 2007). Crop rotations that involve row crops (e.g., maize) and grain crops (e.g., wheat) instead of continuous row crops can reduce soil losses by 30 % (Zuazo et al., 2011). The practice of strip cropping across the slope instead of up-downslope cropping can reduce soil loss by 50 % (Stone & Moore, 1997). Perennial grass species can prevent soil erosion and buffer eroded sediment in the upland regions to minimize the risk of sedimentation and water pollution downstream (Jankauskas et al., 2004; M. Nearing et al., 2005). Due to the importance of this study, the conversation measurement of vegetated buffer strips will be presented in detail in chapter 2.3.

2.1.5 Soil erosion modeling

To understand erosion patterns, observe trends, and get an idea about potential landscape change in the past and in the future, soil erosion models are used (Millington, 1986). When working with models, it is important to understand that they are always just a simplification of reality. Nevertheless, they are a major and necessary tool to visualize, quantify, and understand processes. In the context of soil erosion, they can help to identify essential values like soil loss and evaluate possible management strategies and conservation measures (Haiyan & Liying, 2017).
The models translate environmental processes and forms into mathematical equations (Hutton, 2012). Soil erosion models that are used for planning conservation measures can be divided into empirical and processed-based models. (M. A. Nearing, 2013) The first model for the effects of soil erosion was the **Universal Soil Loss Equation (USLE)** by Wischmeier and Smith (1965, 1978). It was based on a large database with statistical data of more than 10.000 plot-years of data from natural runoff plots all over the United States (M. A. Nearing, 2013). It is the most used processed-based prediction tool worldwide, because if its simplicity

(Bagarello et al., 2017). It is based on the Wischmeier equation (Wischmeier & Smith, 1978):

$$\mathbf{A = R \text{ x } K \text{ x } L \text{ x } S \text{ x } C \text{ x } P}$$

A is the annual average soil loss over a given area. R is the rainfall erosivity, K the soil erodibility, L the slope-length factor, S is the slope-steepness factor, C the cropping factor, and P is the conservation-practices factor. Not all complex processes and factors of soil erosion that were also described in this chapter are included in the USLE, for example, the physical aspects of rills and gullies. Therefore, the model is limited and cannot be used for all conditions and scales. (Blanco & Lal, 2008) Physically-based models are used to simulated complex landscape processes (e.g., soil erosion) (Gregory & Goudie, 2001), and physical principles like the USLE are often the basis for the building of those models. Also, the WEPP (Water Erosion Prediction Project) model used in this study is process-based and partly built on the USLE. A description of the WEPP model will be given in chapter 4.1. Physically-based models have their strength in their descriptive depth (Mulligan & Wainwright, 2013). Still, their requirement of large and complex input data can be problematic and limiting since they are often not available or difficult to gather (Nachtergaele et al., 2001). Another issue of physical-based models is their low ability to predict and their differing results from observations made in the field (Mulligan & Wainwright, 2013). Empirical models, on the other hand, have their strength in making statistical predictions (Eslamian, 2014). They use information about past events (e.g., heavy rainfall, debris flow) and empirically predict future occurrences (Cannon et al., 2003). Laws that are based on empirical simulations do not explain the mechanisms of the underlying processes (Beven, 2002).

2.2 Sediment connectivity

Geomorphic processes are shaped by the landscape setting. Spatial relationships determine patterns and the fluxes of water and sediment. These fluxes influence biophysical processes that affect habitats of flora and fauna and biogeochemical functions. (Brierley et al., 2006) Understanding these processes, links, and dependencies in a landscape is the research subject of earth scientists. The concept of **connectivity** is used to describe and quantify the fluxes of sediment and water and their influences on different scales (A. J. Parsons et al., 2015). Connectivity and scales are linked because water and sediment transfer change with the scale (Cammeraat, 2002).

Hydrological connectivity describes the relations between runoff and sediment sources within a catchment. It can be divided into direct connectivity via channels and gullies, and diffuse connectivity, where runoff reaches streams via overland pathways (Croke et al., 2005). Hooke (2003) showed that sediment transport into river channels depends on the internal connectivity of different units within the catchment. There are different steps that water and sediment can go through when being transported. From source to sink, water and sediment can either be stored or released with temporal variations. This is called catchment cascade. (Fryirs et al., 2007)

Hydrological and erosional connectivity is naturally driven by the local geology, geomorphological processes, climate and biota (Keesstra et al., 2018). The worlds surface is under immense influence of human actions, leading to altered landscapes and water courses and therefore greatly affect connectivity (Hawtree et al., 2015; Poeppl et al., 2015). Apart from the already mentioned influences of agricultural land use, deforestation and the resulting increase of runoff (Zhao et al., 2016) and man-made structures can be named as the most affecting anthropogenic actions on vertical and lateral connectivity (K. Fryirs, 2013; Cao et al., 2015). To understand the connection of sediment pathways, the catchment has to be fractioned in smaller units. Otherwise, problems related to sediment pathways can not be tackled effectively by conservation measures. The catchment level analyzes river systems from source to sink and thus in a more global manner. (Bentley Sr et al., 2016) This thesis investigates sediment flow and connectivity on a hillslope and subcatchment scale in order to derive recommendations for management that can improve the situation of the whole catchment (see fig. 2.7). Connectivity is a useful concept to understand, measure, and model water and sediment fluxes in catchment systems and makes it understandable for landowners and policymakers (Keesstra et al., 2018).

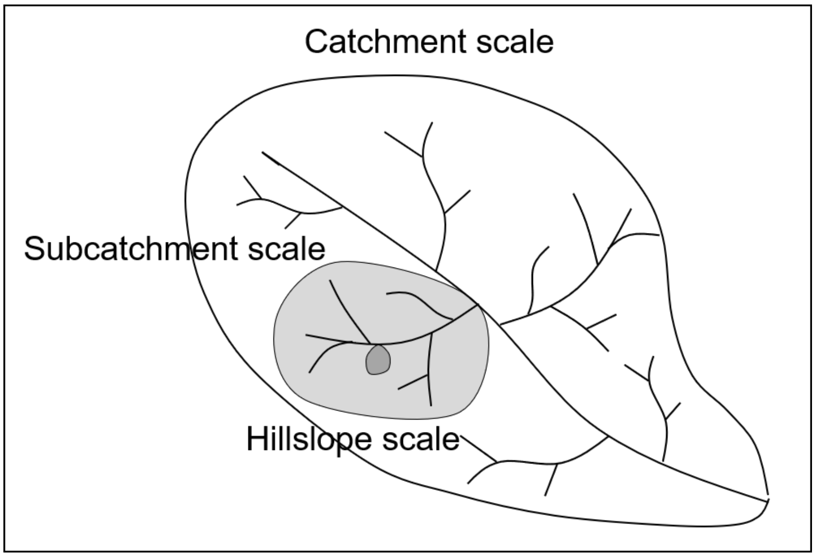


Figure 2.7: Different scales within a catchment (based on Keesstra et al., 2018).

2.3 Vegetated buffer strips

The use of plant covers to control water erosion is a common mitigation strategy. Vegetation protects the soil surface by intercepting runoff and hindering clogging by raindrops. The relationship between vegetation and erosion rates is complex. On a long-term time scale vegetation influences the fluxes of water. The installation of plant-cover strips showed to be effective in controlling soil erosion and runoff on sloping lands with agricultural land use. (Zuazo et al., 2011) In this study, the focus lies on vegetated buffer strips at the foot of

slopes bordering agricultural fields. For this purpose, a vegetated buffer strip (or "buffer", or "VBS") is defined as a section of land with grasses or broad-leaved trees and shrubs that separates an agriculturally used slope from aquatic habitat (in this case streams)(fig.2.8).
Vegetated buffers are usually used as measurement against the off-site effects of soil erosion since they hinder detached sediment from entering waterways. (Gene et al., 2019) The runoff with the detached sediment gets transported via overland flow into the buffer. In the buffer, the water infiltrates (Barfield et al., 1998). The process of infiltration in the VBS is considered the most important in order to reduce the sediment flow from agricultural fields (Grismer, 2006). The root zone has a relatively high porosity, which increases the rate of infiltration deep into the soil (fig.2.8) (Barfield et al., 1998). Pesticides and nutrients get degraded by the soil microbial community after the infiltration (Bradford et al., 2013). Studies showed that infiltration leads to the sorption of pesticides residues on soil particles, which can reduce the number of pesticide residues in the runoff by 47 – 100 % (Moore et al., 2001; Otto et al., 2012). Therefore, buffers work effectively in sequestering significant amounts of phosphorus and nitrate from entering water bodies (Janssen et al., 2018).
VBS also trap sediment physically by slowing down the runoff, causing the sediment to deposit (Prosser et al., 2020). Different studies state different trapping rates, ranging from 41 – 100 % of inputs (Coyne et al., 1995; Daniels & Gilliam, 1996). Besides the positive effects of VBS in preventing off-site effects of soil erosion, they also provide habitat for wildlife and pollinators (Smith et al., 2008). That leads to positive effects not only for the ecosystem but also for farmers. VBS are important habitat for birds that help controlling crop pests (Jobin et al., 2001), and native pollutants increase crop pollination and crop yield (Wratten et al., 2012).
Gene et al. (2019) divide vegetated buffer strips into permanent and temporary types. Temporary buffers are defined as areas that are left untreated by farmers, and size and location can vary individually. These temporary buffers are often "spray buffers" and include

areas of the field where no pesticides are applied and that depend on the type of crop that is planted. Buffers with permanent vegetation can also vary but have the intention to increase the water quality for the long term. In agricultural areas, permanent buffers can exist as within-field buffers or as edge-of-field buffers. Buffers that are located at the end of the field can have different vegetation covers. They can have riparian forests with trees and shrubs, they can be "eco-buffers" that are created and where native trees and shrubs are planted in the most effective way, or grass filter strips. The effects of VBS are also of interest in the context of sediment connectivity. Buffer strips decrease the lateral sediment connectivity between valley floor zone and the riparian zone (Poeppl et al., 2012).

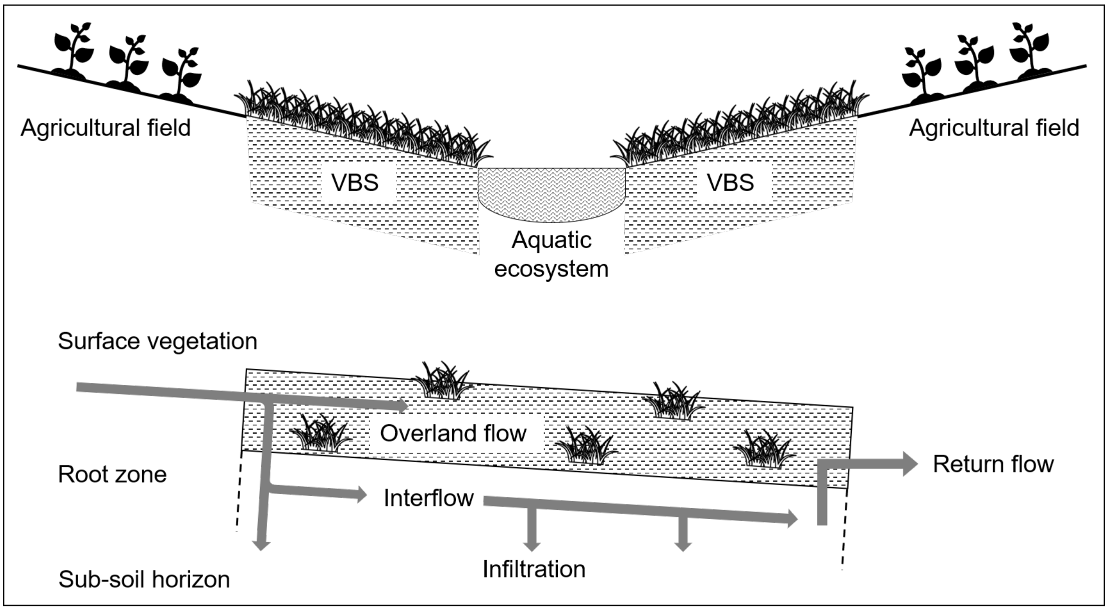


Figure 2.8: Top: Diagram illustrating areas (dotted) within an agriculture landscape that would be described as vegetated buffer strips (based on Gene et al. (2019)). Bottom: Water flow through vegetated buffers (based on Grismer (2006)).

The efficiency of a VBS to hinder sediment from entering waterways highly depends on its width (X. Liu et al., 2008). Since most buffers are implemented on private owned farmland, the width of the buffers is important to the farmers as well. Every square meter of a buffer means a loss of farming area. (Gene et al., 2019) The Austrian Agri-environmental

Programme (ÖPUL) recommends a minimum buffer strip width of 12 m. The funding for VBS only becomes effective along declared water bodies, with the recommended width of at least 12 m, without the use of fertilization and crop protection and with annual maintenance. Is the VBS located on acreage, the farmer gets funding of 450 per hectare (ÖPUL, 2015).

3 Study area

The Fugnitz catchment has a total area of 138.4 km^2 and is located in the Waldviertel region in the North of Lower Austria. The main stem has a length of 29.7 km, the total permanent channel network of the catchment amounts around 135 km. On Austrian territory, the Fugnitz is the main tributary of the Thaya River. It drains into the Thaya near the city of Hardegg, directly at the border to the Czech Republic. (Poeppl et al., 2012) The mean discharge at the outlet is around 0.5 m^3/s (Scheder & Gumpinger, 2014). Poeppl et al. (2015) define the Fugnitz as a »mixed-loaded single-threated perennial wadable stream«.

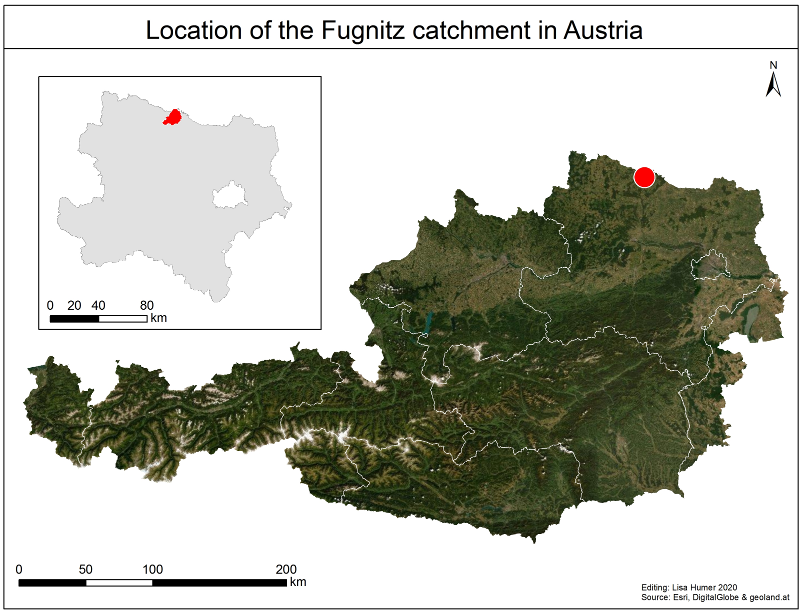


Figure 3.1: Location of the Fugnitz catchment in Lower Austria.

3.1 Climate

A humid, temperate climate characterizes the catchment. It has a mean annual temperature of $8.3°C$ and an annual precipitation rate of around 550 mm. (Poeppl et al., 2012) The region is influenced by two different climates, the warm and dry Pannonian climate from the south-east and the cool and moist Atlantic climate from the north-east (Grulich, 1997). Due to that, the region is exposed to wind circulations that lead to cooler temperatures compared to bordering areas (Fischer, 1994). The Fugnitz catchment is located in the east of the Waldviertel region, at the direct border to the Weinviertel region. Therefore the influence of the Pannonian climate is more dominant. The precipitation maxima are measured between April and September with the highest values in the summer from June to August. In Winter, monthly temperatures average below $0°C$ (December to March). (Haselberger, 2017) Snowmelt leads to increased runoff in spring. The last major flood event with a magnitude of a 100-year flood happened in June 2006, caused by a local thunderstorm cell (Poeppl et al., 2015).

3.2 Geology & Topography

The study area is located at the eastern part of the Bohemian Massif, the oldest mountain range in Austria. The catchment is situated in the Moravikum. The bedrock is the Thaya-Batholith, which consists of crystalline mica granite and mica shale. It is a plutonic complex that arose in the Cadomian orogeny during the Proterozoic. Loess layers from the Pleistocene (silt, fine sand) largely overlie this formation, while in some places, Tertiary silts, clays, and sand (brackish-maritime) are present (Roetzel & Fuchs, n.d.). The Fugnitz catchment is characterized by easily erodible sediments in its upper reaches and solid bedrock and steeper parts towards its outlet (Haselberger, 2017).

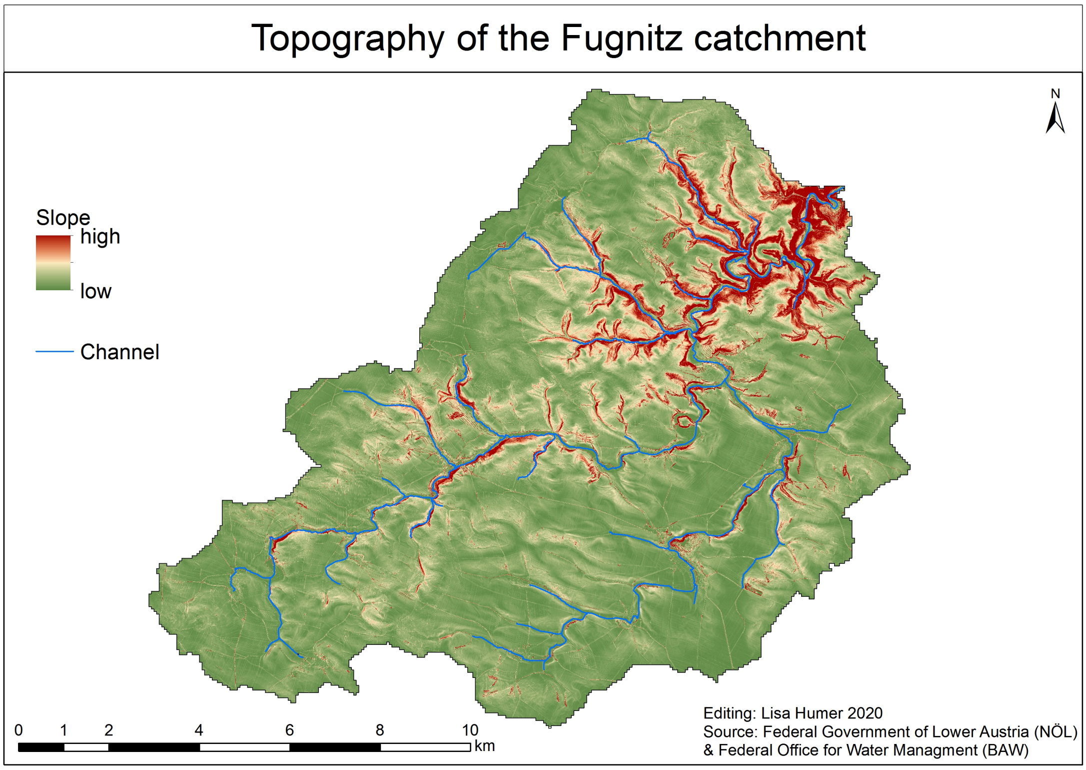


Figure 3.2: Topography of the Fugnitz catchment.

The source of the Fugnitz is located in the catchments southwest, and it drains into the Thaya River in the north-east. The upper parts of the river are characterized by a relatively flat landscape with low slope angles, low river gradients, and no bedrock steps. Towards the confluence with the Thaya River, the slope angles are comparatively steeper, the valleys are V-shaped, and bedrock steps occur. (Poeppl et al., 2015) The elevation ranges between 286 m and 540 m a.s.l. throughout the catchment. It features an average slope angle of 2.6° and maximum slope angles up to 32°. (Poeppl, 2010) The topography of a catchment is crucial to understand the prevalent cascading processes of the sediment (K. Fryirs & Gore, 2013). As a result of the vertical incision processes, the lower reaches of the Fugnitz catchment are prone to mass movement processes that tend to bring sediments into the channel system (Poeppl et al., 2015). The upper reaches with a lower relief energy are affected by water-induced soil erosion, that transports fine-grained sediment via overland flow paths into the channel system

(Poeppl et al., 2012). Besides these natural characteristics of the catchment, anthropogenic structures like various old fish dams and weirs can be found along the Fugnitz. Poeppl et al. (2015) describe these features as the leading contemporary driver of river evolution.

3.3 Soils

The underlying bedrock formations of the Fugnitz catchment are the crystalline rocks of the Bohemian Massif. The soils that originate from these crystalline rocks are mainly gleyic podzolic soils on the lower slopes and valleys and acid cambisols on the upper slopes. On the plateaus in the south and south-eastern parts of the catchment, brown podzolic soils are characteristic. (Strebl & Gerzabek, 1997) Figure 3.3 shows the proportion of clay in the topmost soil layer of the Fugnitz catchment. In the areas with agricultural land use, the proportion of clay is mainly over 20%. Phosphorus adsorbs to clay minerals and gets transported via soil erosion into water bodies (Dorioz, 2018).

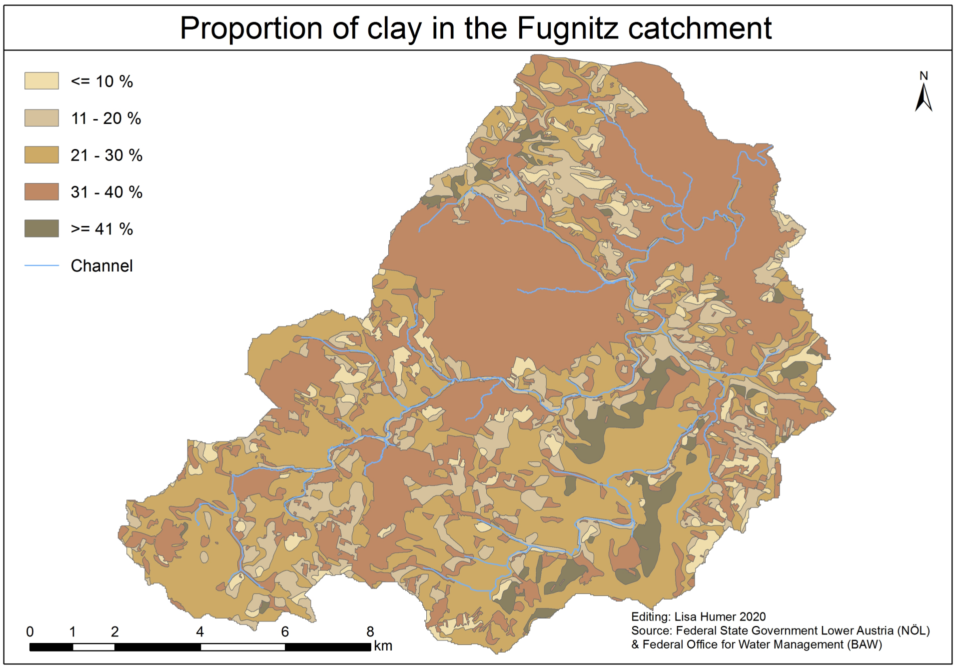


Figure 3.3: Poportion of clay in the Fugnitz catchment.

3.4 Land use & Management

The Fugnitz catchment is characterized by intensive agricultural land use. The official land use data show that 56 % of the catchment are agricultural areas, 34 % are forests and woodland, 7 % grassland, and 3 % are occupied by residential structures and traffic (see fig.3.4).

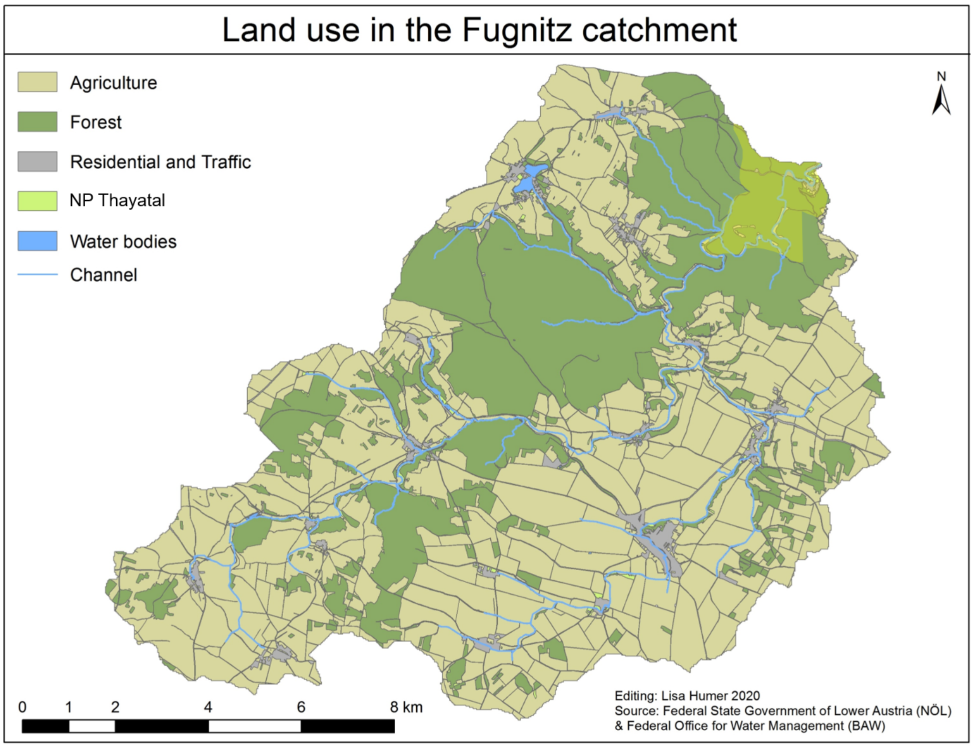


Figure 3.4: Land use and area of the national park Thayatal in the Fugnitz catchment.

In the 13th century, extensive deforestation made the area usable for agriculture and led to significant changes of the hydrological system and sediment dynamics in the catchment (Poeppl et al., 2015) Because of its topography and soil quality, most of the catchment belongs to the so-called "corn-chamber" of Austria, one of the most intensive agriculturally used areas of the country (Rungaldier, 1970). Most of the farmers practice conventional cultivation with ploughing in autumn, which lead to uncovered fields in late autumn and early winter. The crop rotations mostly contain corn, canola, winter wheat, and alfalfa. (Luetzenburg, 2019) Furthermore, some pond systems are located in the study area. They are mostly used extensively for fishing or as fire water ponds. Along the steeper slopes of the upper and middle reaches are mainly coniferous forests, while along the lower reaches, seminatural deciduous forests are dominating. (Poeppl, 2010)

3.5 National Park Thayatal

The national park Thayatal has an area of 13.3 km^2 and is therefore the smallest national park in Austria. It is only one part of the bigger bilateral national park Thayatal/ Podyjí, which has a combined area of around 80 km^2. (`https://www.np-thayatal.at/de/pages/eckdaten-36.aspx`) The Thaya river is the bordering river between Austria and the Czech Republic and was part of the Iron Curtain between 1945 and 1991. Due to this special position, the area was not exposed to anthropogenic pressure for 46 years. The local flora and fauna were able to thrive undisturbed, which made the area interesting for environmentalists after the fall of the Iron Curtain. On the Czech side of the Thaya, the national park Podyjí was founded already in 1991, while the Austrian national park was established in 2000. (Brunner, 2010)

In 2014 the water quality of the Fugnitz was investigated by Scheder and Gumpinger on the behalf of the national park Thayatal. The ecological state of the Fugnitz was evaluated in terms of the EU Water Framework Directive. The study showed a poor to moderate ecological state along the upper and middle reaches of the Fugnitz (see fig.3.5), which leads to water quality problems in the area of the national park downstream. The input of agricutural sediment induced high turbidity and germ load and was identified as the main cause for the poor ecological state. (Scheder & Gumpinger, 2014) It is in the interest of the national park to understand the sediment connectivity of the catchment in order to apply sustainable management measures to prevent eroded sediment from reaching the river channel network. This study aims to contribute to this goal.

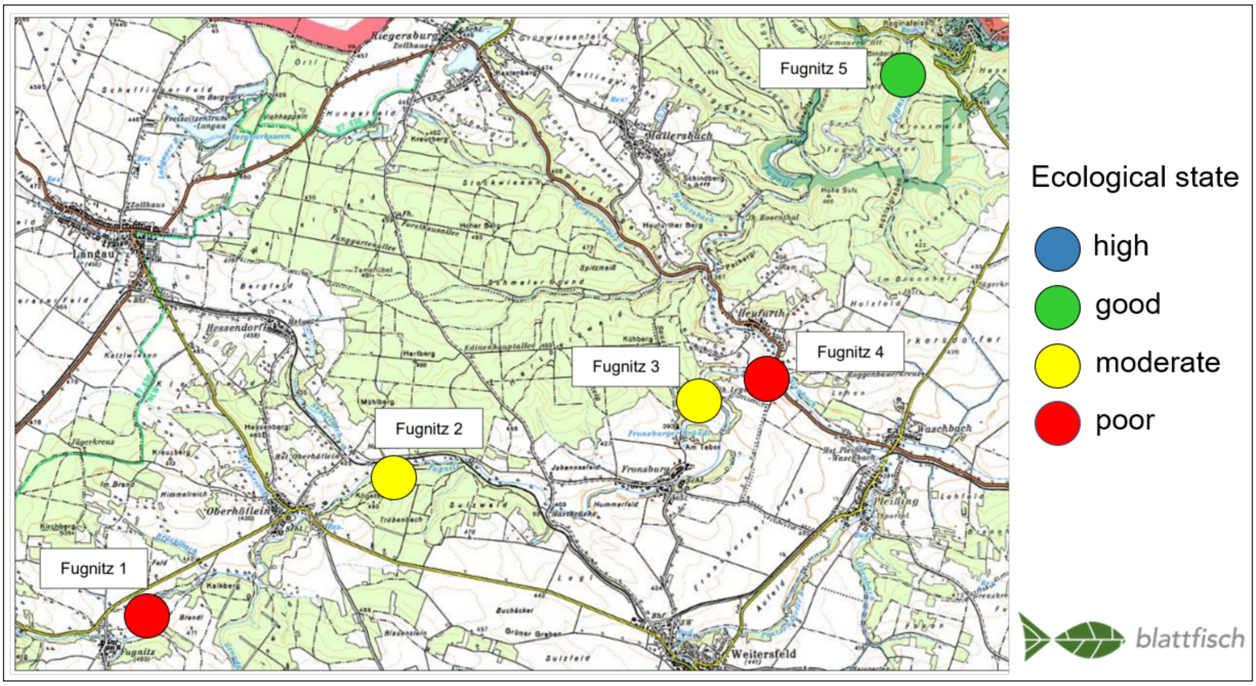


Figure 3.5: Ecological state of the Fugnitz in 2014 along five test sides (based on Scheder and Gumpinger 2014).

4 Methods

This chapter provides information about all methods that were used to answer the research questions of this study. Details about the WEPP-model that was introduced in chapter 2.1.5 are presented, as well as the data basis that was used for the model. Afterward, the methods used for the buffer strip investigation and the human-made flow path investigation are explained. That includes the preparation of the field work, the process of mapping and data gaining in the field, as well as the preprocessing of the collected data and the subsequent modeling with GeoWEPP.

4.1 The Water Erosion Prediction Project (WEPP)

The Water Erosion Prediction Project (WEPP) is an erosion simulation model that is based on fundamental physical principles that influence erosion mechanics (Laflen et al., 1991). It was established in 1995 by the United States Departments of Agriculture and predicts water-driven erosion on a small (hillslope) or large (catchment) scale (Flanagan & Nearing, 1995). It was developed to replace empirical models like USLE (Universal Soil Loss Equation) with a complex process-based approach that can locate soil erosion, link different impoundments, and predict runoff and sediment yield on a catchment basis. WEPP uses input variables on topography, climate, soil, landcover, and management to produce output information on average annual rainfall, soil loss, runoff, and sediment yield. (Flanagan et al., 2007) It was designed to assess the impact of agricultural management practices on erosion (Brooks et al., 2016). It can simulate the processes of infiltration, lateral flow, surface runoff, soil detachment, transport, deposition, and delivery. WEPP is able to divide the sediment yield into three particle size classes (sand, silt, clay) and two aggregate categories (small = mean diameter of 0.03 mm, large = mean diameter of 0.3 mm). (Flanagan & Livingston, 1995) This application is especially useful in the context of intensive land use activities and the connected risk of water body pollution. It is important to know where fine sediments are generated in order to apply effective sediment management to reduce phosphorus input. (Brooks et al., 2016)

The WEPP model can simulate erosion rates and patterns on hillslope and catchment scale (see fig. 4.1). The CLIGEN (CLImate GENerator) is integrated in WEPP. It is a stochastic weather generator that generates daily estimates of precipitation and individual storm parameters, based on past climate data. (Lobo et al., 2015) WEPP performs a continuous simulation over a chosen period of time so that the model can be run for years or based on one rainfall event. The output of soil loss, sediment deposition, sediment accumulation, and sediment delivery is a series of sum totals of the produced runoff within the chosen period. (Flanagan & Livingston, 1995) When performing a simulation on a single hillslope, the model allows the investigation of complex structures within single profiles (changes in topography, soil properties, land use or management) (M. Nearing et al., 1990). When modeling a whole catchment, the runoff, soil loss, and deposition for each hillslope are calculated first, then the model combines these results and performs runoff and sediment dynamics through the channels and impoundments for each time runoff is produced on one of the hillslopes. (Flanagan & Livingston, 1995)

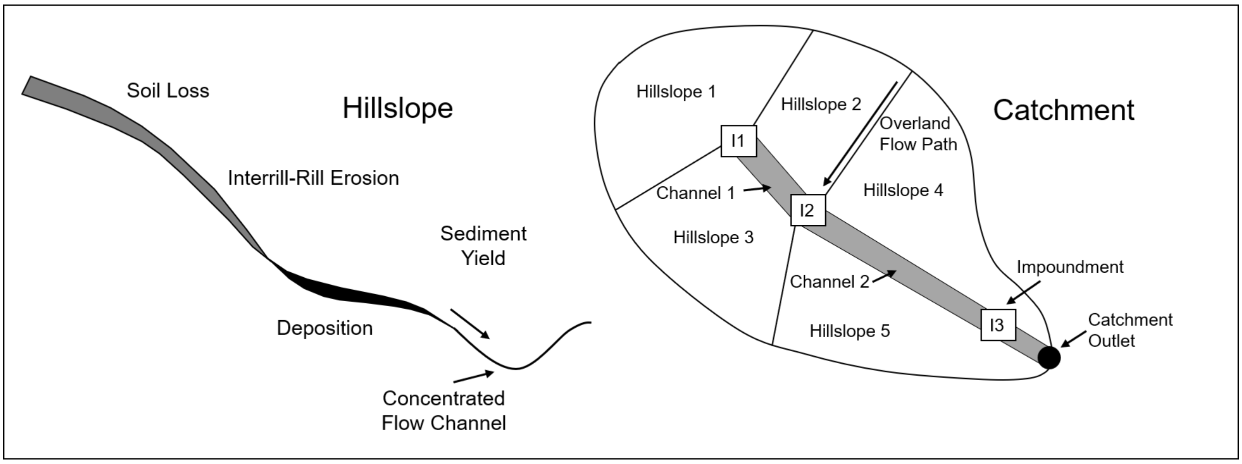


Figure 4.1: Scheme of WEPP on hillslope and catchment scale (based on Flanagan and Livingston 1995).

In order to apply erosion modeling across multiple spatial and temporal scales, the graphical user interface GeoWEPP was developed. It allows using WEPP through a wizard in ArcGIS. It is based on a digital elevation model (DEM), so it allows modeling on a high level of precision and accuracy if the quality of the available geo-spatial data is accordingly. (Renschler, 2003) The Topographical Analysis Software TOPAZ (Garbrecht & Martz, 1994) is integrated into GeoWEPP and delineates the basin and its subcatchments based on the critical source area and the minimum channel length, which can both be adjusted by the user. (Renschler et al., 2002) The model distinguishes between two methods, the watershed, and the flowpath method. The watershed method determines a representative profile based on the combined profiles within the hillslope and assigns the most dominant soil and landuse to it. The simulation runs on each hillslope, so the output values represent the amount of sediment leaving each hillslope and leading to the outlet point. This method is called the offsite assessment and allows a maximum of 2900 hillslopes and 1000 channels. The flowpath method does not use representative profiles, but the slope for the flowpath itself. It also keeps the complexity of the soil and landuse layers, so one flowpath can have different soils and landuses. The output values refer to the amount of sediment eroded and deposited in each raster cell. This is why it is called an onsite assessment. The main difference between those two methods is that the watershed method calculates the sediment yield of the catchment, while the flowpath method shows the soil loss for each portion of the catchment. (Minkowski & Renschler, 2008) The WEPP has been successfully used in many studies with different environmental settings (Grønsten & Lundekvam, 2006; Mahmoodabadi & Cerdà, 2013; Mirzaee et al., 2017). GeoWEPP was already used in the Fugnitz catchment to detect soil erosion hotspots and delineate manageable units for sediment management on the catchment scale. The combination of GeoWEPP modeling and field-based connectivity mapping showed to be a suitable approach for the investigation of lateral fine sediment connectivity. (Poeppl et al., 2019)

4.2 Data basis

To run the GeoWEPP model, several input files are necessary. An essential input parameter is the digital elevation model (DEM) of the Fugnitz catchment. For this thesis, a high-resolution (1 x 1 m) DEM that is based on aerial laser scanning data was provided by the Federal State Government of Lower Austria (NÖL). A shapefile and a corresponding table with information on soil properties in the study area were made available by the Federal Office for Water Management (BAW). (Haselberger, 2017) The files contain data about soil type, soil moisture, humus type and properties, coarser material, lime content, soil structure and texture, pH value, color, root penetration, grain size distribution, field capacity, and bulk density. These data were gained by field measurements and following geostatistical interpolation in a GIS-system (Walker et al., 2017). The BAW also provided information on landuse in the Fugnitz catchment. Based on CORINE-data (Bossard et al., 2000), a digital cadastral map, an Austrian forest map (ÖWK) (Bauerhansl et al., 2007), and INVEKOS-data (Nölle & Streit, 2002), a shapefile was produced by the BAW with information about 35 different landuse categories. The main categories are agricultural land, built up area, water bodies, and forest. (Haselberger, 2017)

Precipitation values were collected in a 15 min-interval with an Onset HOBO rain gauge in Waschbach from March to October 2018. Due to some temporary recording problems, missing precipitation values were replaced by data from a private station in Prutzendorf, that provides its data publicly on the weather underground website (`https://www.wunderground.com/dashboard/pws/IWEITERS56`).

4.3 Buffer strip investigation

To evaluate the efficiency of the existing vegetated buffer strips in the Fugnitz catchment, study sites were selected and observed for the growing season in 2018. Below the procedure of study site selection, data gaining in the field, and modeling will be described.

4.3.1 Preparation

Due to the big size of the study area (138.4 km^2), potential study sites were preselected by analyzing the topography of the catchment in ArcGIS. Some minimum requirements limited the choice of potential study sites. Fryirs et al.(2007) suggested a slope threshold of 2° for the investigation of sediment transport, but since steeper slopes provide potentially higher soil erosion rates (Maalim et al., 2013) a threshold of 4° was defined for the delineation of potential study sites. Since the increase in slope length increases the severity of erosion (Evans, 1980), the minimum slope length was set to 100 m. Another criteria was set for the location of the potential study sites. The slope had to border the channel of the Fugnitz or its tributaries directly. That criteria was chosen in accordance with the Austrian guidelines that only fund VBS directly bordering perennial water bodies (ÖPUL, 2015).

After this preselection, the potential study sites were investigated in the field. They had to feature a buffer strip between the field and the channel and a field crop that is prone to erosion. For this area, those field crops are mainly maize, pumpkin, thistle, and potatoes, due to their low density and coverage of soil.

Heavy rainfall events cause visible erosion patterns. Those were needed to visibly identify the overland sediment flow paths and measure the trapped sediment in the vegetated buffer strips. Therefore all occurring rainfall events in the catchment were observed with the installed Onset HOBO rain gauge at Waschbach and the public online rainfall animation by the Zentralanstalt für Meteorologie und Geodynamik (Central Institute for Meteorology and Geodynamics, `https://www.zamg.ac.at/cms/de/wetter/wetteranimation`) between March and October 2018.

4.3.2 Field mapping and field measurements

The study sites were visited after every rainfall event with a magnitude of at least 5 mm in 30 min. This threshold is based on several studies defining tha magnitude of erosive rainfall events (Fullen & Reed, 1986; Auerswald, 1996; Xie et al., 2002). The significant amount of sediment did not allow to remove and weigh it, because the volume and weight of the sediment exceeded the means of manual removal without the operation of machines. Therefore the visible trapped sediment in the buffer strips was measured manually with a tape measure to determine the volume. The height of the vegetation and the width of the buffer strip were gathered as well in order to evaluate their influence on the trapping efficiency. When the amount of sediment visibly exceeded the capacity of the buffer strip, the location of the entry points where the sediment entered the channel was recorded. On the field, its length, crop type, crop height, row width, and direction of cultivation were acquired in order to later implement the local data for the event in the GeoWEPP model.

4.3.3 Data preprocessing

For this study, a high-resolution DEM (1 x 1 m) of the whole catchment was available. To use it in GeoWEPP, it needed some preprocessing in ArcGIS. With the “fill” function of the

Spatial Analyst toolbox, all missing elevation values were added to make sure that the model can process the terrain information. The processing power of GeoWEPP is limited, so it was necessary to resample the data to reduce the size of the file. Since the catchment areas of the buffer strips are rather small, it was enough to resample the respective parts of the DEM to a 2 x 2 m resolution. Therefore the area around each buffer strip was minimized with the "clip" tool and afterward, a two-meter DEM of the area was generated with the "resample" tool. The 2 m resolution is a compromise between the computational power of the model and the accuracy to represent fine-scale landforms. Afterward, the data projection was changed to Universal Transverse Mercator (UTM), since GeoWEPP can only handle coordinates in this projection. With the tool "project raster", the coordinate system was changed to UTM zone 33N. The last step was to convert the raster file into an ASCII (American Standard Code for Information Interchange) text file. This was done using the "raster to ASCII" tool. Since the information on terrain, soil and landuse must be stored for each cell respectively, the data on soil and landuse had to be preprocessed in the same way as the DEM (clip, resample, project raster, raster to ASCII).

The soil raster file contains information on the soil type of every cell. WEPP uses additional soil parameters for each soil type: (Haselberger, 2017)

- name of the soil
- soil texture
- albedo of the bare, dry surface soil (%)
- interrill erodibility parameter (kg*s/m^4)
- initial saturation level of the soil profile (%)
- rill erodibility parameter (s/m)
- critical flow hydraulic shear (N/m^2)
- effective hydraulic conductivity of surface soil (mm/h)

The following data is stored for each assigned soil layer: (ibid.)

- soil texture (percentage of sand and clay)
- depth from soil surface to bottom of soil layer (mm)
- organic matter (volume) in the layer (%)
- cation exchange capacity in the layer (meq/100 g of soil)
- rock fragments by volume in the layer (%)

Two textfiles are necessary to link these soil parameter files with the spatial information: soilsmap.txt and soilsdp.txt. The values assigned to each soil type were based on information from literature, others were calculated by the model itself (ibid.). In the same way, the textfiles landcov.txt and landusedb.txt link the raster cell values with the provided landuse information. The landuse information was converted into the United States Geological Survey (USGS) coding system, so the originally provided 21 landuse classes of the BAW were translated into seven different USGS classes: (ibid.)

- open water
- low intensity residential
- bare rock/sand/clay
- mixed forest
- pasture
- small grains

The soil and landuse textfiles were created and provided by Stefan Haselberger for his study in the Fugnitz catchment 2017 (Haselberger, 2017).

Only event-based modeling is performed in this study, rather than simulations over more extended periods of time. Therefore, the management files created with WEPP only contain the information of each field at the time of the observed rainfall event. The management files are based on the conditions observed in the field (crop type, crop height, row width, direction of cultivation).

The climate file for the observed rainfall event is based on the data of the private station in Prutzendorf. It contains precipitation and temperature data with a resolution of five minutes. Gregor Luetzenburg provided the CLIGEN climate file for this study since the same climate data was used for his research in the Fugnitz catchment (Luetzenburg, 2019).

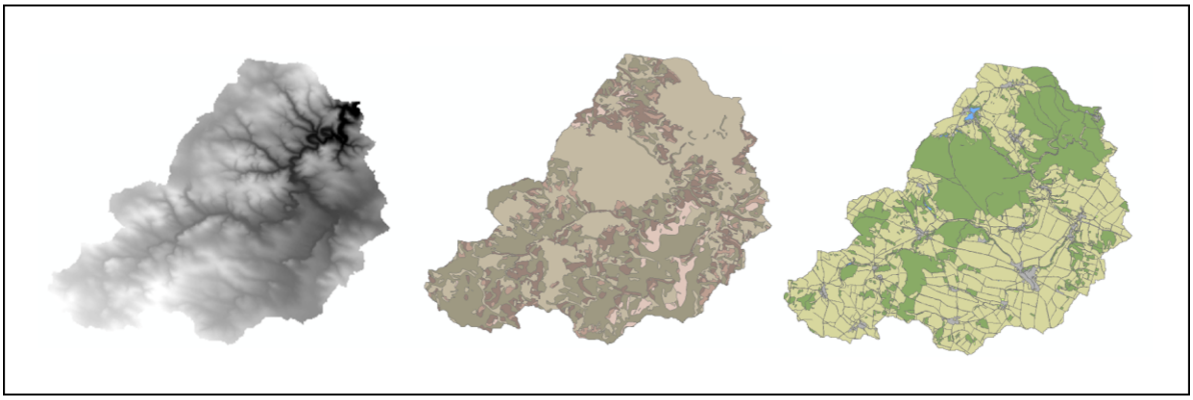


Figure 4.2: Input files for GeoWEPP: DEM, soil, land use (source: Federal State Government Lower Austria Federal Office for Water Management).

4.3.4 GeoWEPP modeling

To start working with the GeoWEPP toolbar in ArcGIS, the prepared ASCII files (DEM, soil, landuse) and the associated text files linking the parameter values and classes (soilsmap.txt, soilsdp.txt, landcov.txt, landusedb.txt) are uploaded with the GeoWEPP wizard. A new project is created and the files loaded into ArcGIS. With the GeoWEPP toolbar, a channel network is generated based on the DEM. Within the created channel network, the outlet point of the hillslope belonging to the buffer strip is selected. Based on that outlet point, a channel network and subcatchment are generated. For this step, a critical source area of 1 ha and a minimum source channel length of 2 m were chosen, considering the rather small size of the subcatchments and the high resolution of the DEM. To model the erosion of each subcatchment for the investigated rainfall event, the prepared CLIGEN climate file and the management file with the conditions at the time of the rainfall event, are uploaded into GeoWEPP. Since the simulation is based on one rainfall event, the number of years is one. Both methods, the watershed and flowpath method (see ch. 4.1), are chosen to get all required output data.

4.4 Human-made flow path investigation

To evaluate the role of human-made flow paths and their impact on sediment input in the local channel network, entry points where the stored sediment of anthropogenic ditches enters the running stream network, were mapped. Below the procedure of digital data preprocessing, data gaining in the field, and modeling will be described.

4.4.1 Preparation

Because of the big size of the catchment, potential entry points were preselected by analyzing the flow paths of the catchment in ArcGIS. The basis for the analysis was the provided DEM with a resolution of 1 x 1 m. After using the „fill“ function in order to add all missing evaluation values, a hillshade was generated. With the "flow direction" function of the Spatial Analyst toolbox, the channel network was delineated out of the previously produced hillshade. With the Spatial Analyst function "flow accumulation", a raster of accumulated flow to each cell was produced. The histogram of this layer showed the minimum and maximum values, as well as the mean and the standard deviation. Different thresholds were defined. By using the "reclassify" function, all values smaller or equal the threshold were set to "NoData" and all other values to 1. The created layers showed all parts of the channel network, where the accumulated flow is higher than the defined thresholds. The layer with the most realistic flow path network based on the knowledge of the catchment was chosen. This layer was overlayed with the layer of all channels with permanent flow. On the orthophotos, all points where both channel networks had a connection were checked out. When they appeared realistic, they were marked in order to be examined in the field.

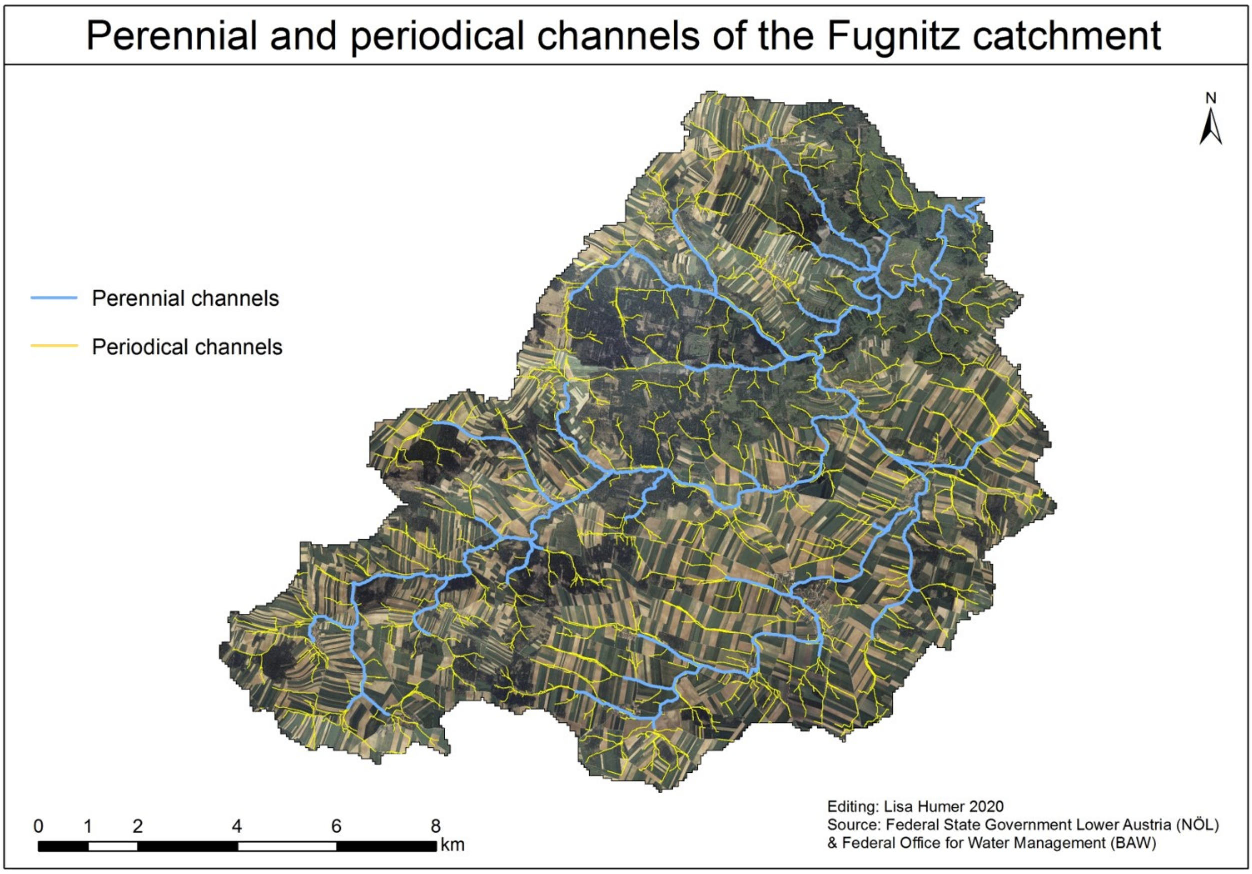


Figure 4.3: Perennial and periodical channels and their connecting points delineated on the basis of the DEM.

4.4.2 Connectivity mapping

The previously selected locations were checked out in the field. All points where visible anthropogenic channels drain into the perennial river channel network were mapped. A lot of connection points acquired by the preceding analysis on the basis of the DEM did not match the observations made in the field. Many of those deviations can be attributed to the fact that a lot of the human-made drainage system runs underground. Due to that many drainage channels are not depicted in the DEM and the flow lines produced on the basis of the DEM do not always correspond to reality. Especially in and around residential areas the drainage system was found to be subsurface. Field observations showed that artificial flow paths often drain into the channel system where bridges are located. Because of that observation, all bridges in the Fugnitz catchment were investigated during the connectivity mapping.

4.4.3 Data preprocessing

Because it was not possible to suppose the size of the subcatchment of each found entry point, the DEM of the whole catchment was needed for the GeoWEPP analysis. Due to the mentioned limited processing power, the DEM, the soil layer and the land-use layer were resampled to a resolution of 5 x 5 m. Afterward, the same steps were performed as for the buffer strip analyses (project raster, raster to ASCII).

4.4.4 GeoWEPP modeling

The produced ASCII files with a resolution of 5 x 5 m were loaded in GeoWEPP. The points determined by the connectivity mapping were defined as outlet points in the produced network system. In order to find out the possible amount of eroded sediment within each subcatchment during a high magnitude rainfall event, the GeoWEPP simulation was performed in the same way as the buffer strip analyses based on one rainfall event. It is only possible to assign one management to each subcatchment in GeoWEPP, and in this case, the simulation was for one event only, so the analyses were performed for two different managements. On the one hand, maize was chosen as one management, because it is prone to erosion. On the other hand, wheat was chosen as the second management because of its high density and coverage and its therefore reduced vulnerability to erosion. The comparison of both managements should help to build a realistic picture of the potential erosion rates within the subcatchments. The defined subcatchments of each entry point were only analyzed with the watershed method since the size of the most subcatchments would have exceeded the computation capacity of the program when using the flowpath method and the output data of the watershed method contains all information needed to answer the research questions of this study.

5 Results

The following chapter will summarize the results of this study. It is divided into two parts, the results of the buffer strip investigation and those of the human-made flow path investigation. Both chapters include the results of the fieldwork as well as the outcomes of the modeling with GeoWEPP.

5.1 VBS investigation

During the data gaining period in 2018, only one heavy rainfall event took place. On the 1st of June 2018, local thunderstorms occurred throughout the catchment between 12 am and 3 pm. In Prutzendorf, 36.1 mm of rainfall and a temperature drop of 13C were recorded during this period (see fig. 5.1). This high amount of precipitation within a short time period caused local floods (see fig. 5.2). Due to this event, field investigations were done on the 2nd of June 2018. Three buffer strips were surveyed after the event. All GeoWEPP models were performed for the rainfall event of the 1st of June 2018.

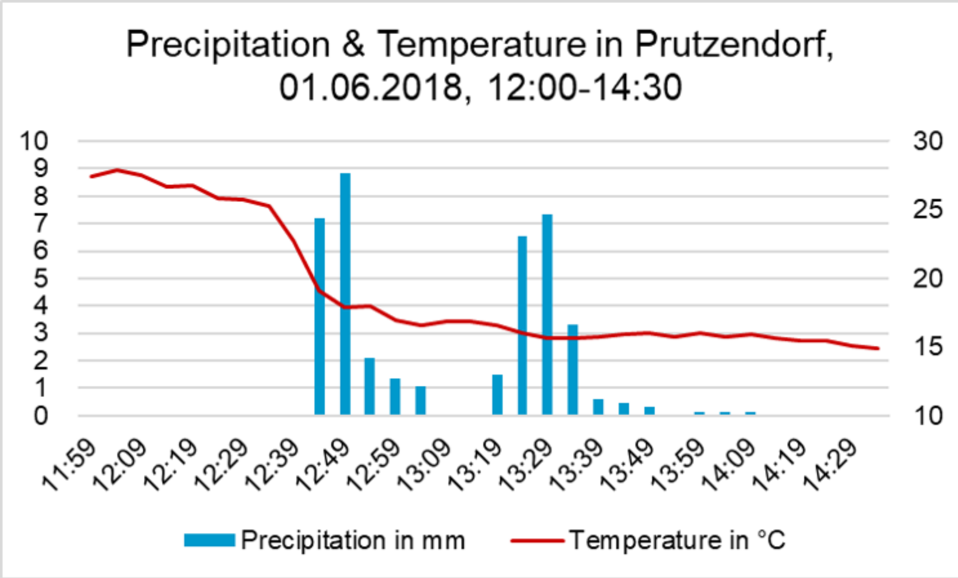


Figure 5.1: Progression of precipitation and temperature in Prutzendorf during the thunderstorm on the 1st of June 2018.(Data:`https://www.wunderground.com/dashboard/pws/IWEITERS56/table/2018-06-1/2018-06-1/daily`)

Figure 5.2: Flooded road between Weitersfeld and Prutzendorf during the heavy rainfall event on the 1st of June 2018. (Photo: Österreicher 2018)

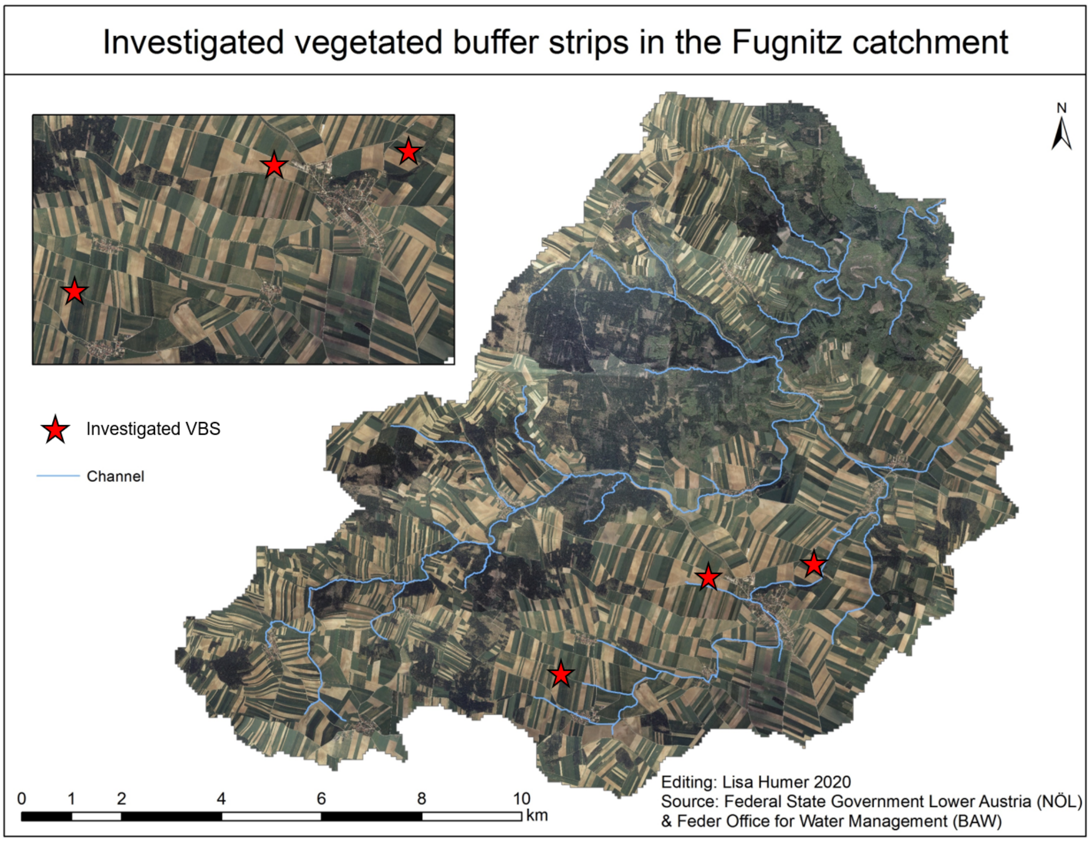


Figure 5.3: Location of the investigated vegetated buffer strips.

5.1.1 Buffer A

The first investigated buffer strip A is located in the north-west of the town Weitersfeld (see fig. 5.3). The hillslope has a straight plan form with a rectilinear profile at the top and middle slope, and a concave profile at the lower slope towards the channel. At the time of the survey, the appropriate field was vegetated with around 30 cm high pumpkin plants. The buffer strip was covered with about 50 cm tall grass and had a width of 4.5 m. The measured volume of the sediment that was trapped in the buffer strip totaled up to about 1.03 m^3. The presence of farm tracks shows that the strip is regularly used by agricultural vehicles. These farm tracks visibly constitute the areas with the most caught sediment. The buffer strip showed one path of sediment overflow with its entry point at the lower corner of the field. (see fig. 5.4)

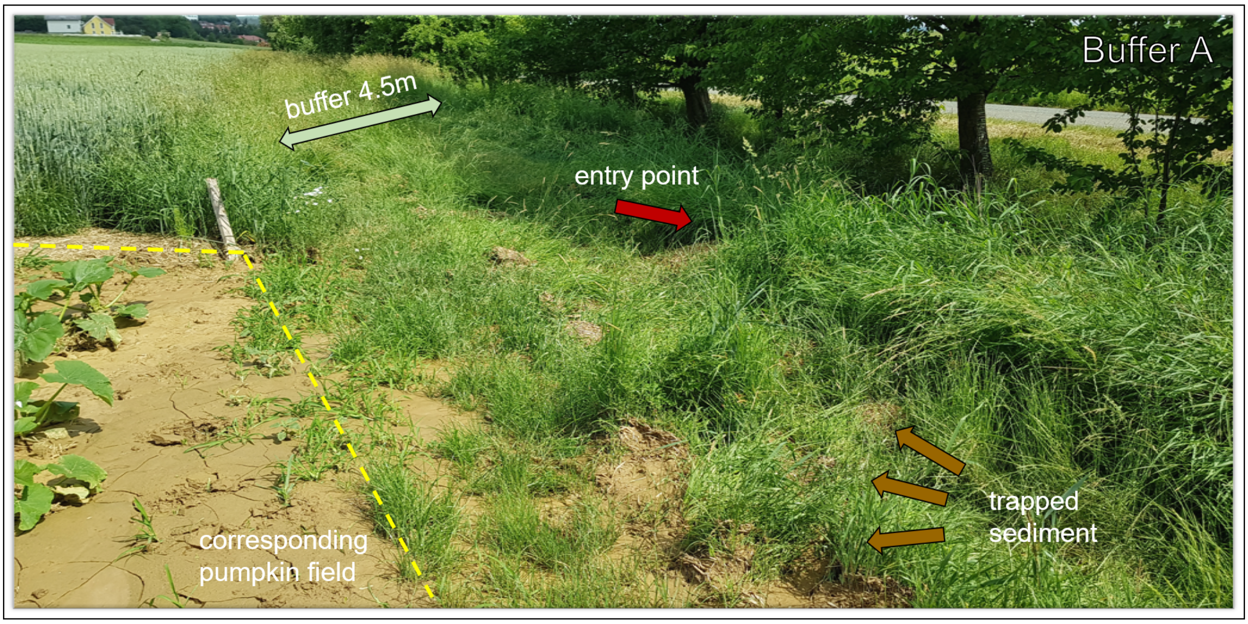


Figure 5.4: Observed erosion patterns of the investigated buffer strip A. (Photo: Humer 2018)

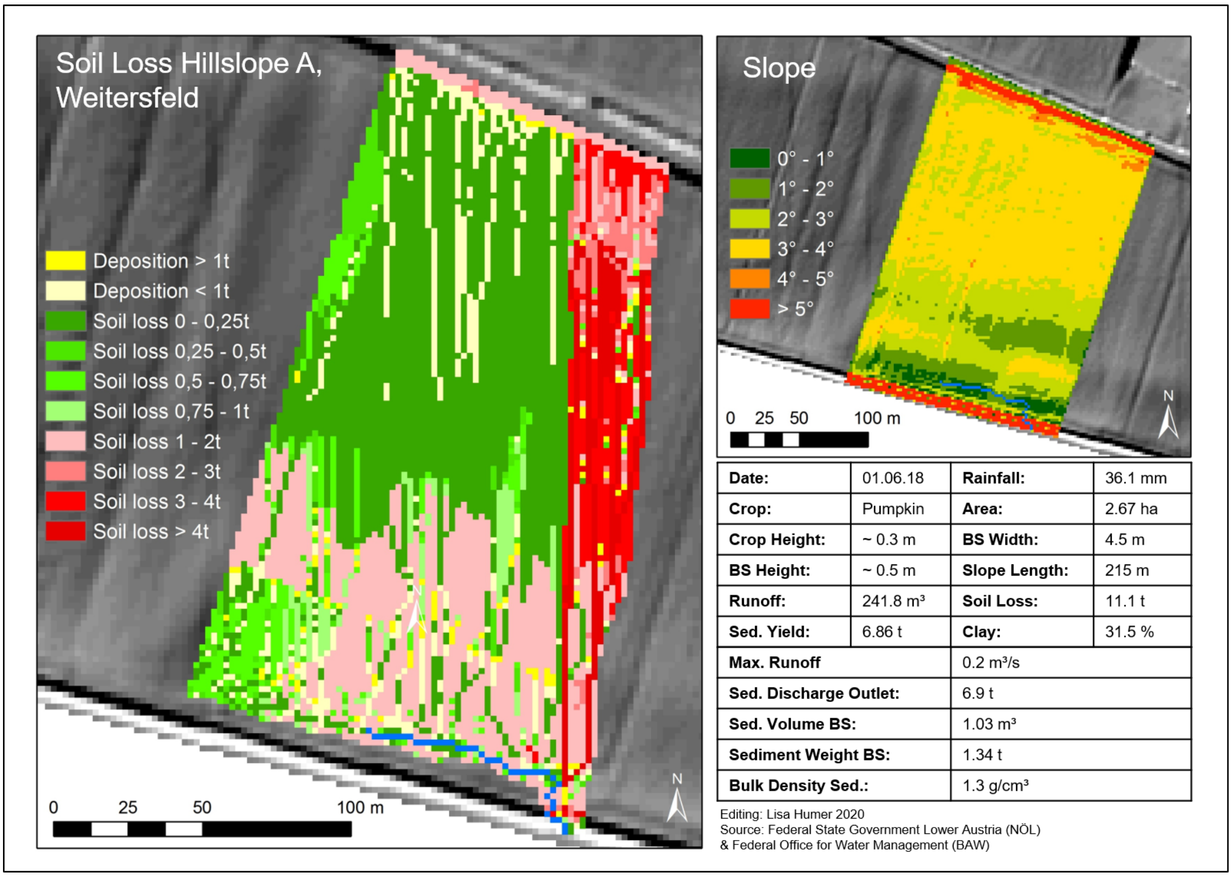
A GeoWEPP analysis of the surveyed slope was performed for the rainfall event of the 1st of June 2018, and the parameter gained in the field (see ch. 4.3.4). The subcatchment produced by the model has an area of 2.67 ha and a slope length of 215 m. The flow path generated by GeoWEPP on the basis of the DEM matches the path of overflow and the entry point observed in the field. Figure 5.5 shows the results of the GeoWEPP analysis of slope A. The output of the model displays the amount of soil loss, respectively, soil deposition for each pixel of the generated subcatchment. Soil loss describes the detachment of a soil particle and is shown in green and red colors, depending on the intensity. Soil deposition is displayed in yellow. The displayed output of the model shows the onsite effects of soil erosion. In order to have a comparing overview of the topography, the slope angle of the subcatchment is shown in the upper right corner of the figure. The model shows high soil loss along the eastern part and in the lower third of the slope. The perpendicular linear red line at the top of the slope indicates the bordering street, which is responsible for the high values in soil loss. In the upper part of the slope, lines of deposition run along the orientation of the slope. The deposition in the lower slope, where the slope angle is small, is more distributed and not necessarily running parallel to the slope orientation. In the lower slope, the soil loss is more significant, the closer it gets to the entry point. Overall the patterns of soil loss and disposition shown in the model agree with the prevalent topography.

Figure 5.5 summarizes the relevant data collected in the field and the onsite and offsite values calculated by GeoWEPP. The sediment discharge at the outlet is, in this case, the same as the sediment yield, since the model was calculated for only one hillslope and one event. Table 5.1 explains all displayed parameter.

For hillslope A the model calculated a sediment yield of 6.86 t and a total soil loss of 11.1 t. The sediment found in the buffer strip weighted 1.34 t, leaving a difference of 2.9 t. Therefore the efficiency of buffer A can just be stated approximately with 12 - 16%.

Table 5.1: Displayed parameters derived from GeoWEPP and fieldwork.

Runoff	Amount of runoff from the hillslope (GeoWEPP).
Max. Runoff	Max. runoff during the event (GeoWEPP).
Sediment Yield	Amount of sediment yield recorded at the outlet point (GeoWEPP).
Soil Loss	Amount of soil loss recorded for each investigated hillslope (GeoWEPP).
Clay	Percent of clay in particle (GeoWEPP).
Sediment Discharge Outlet	Average sediment yield recorded at outlet (GeoWEPP).
Sediment Volume Buffer Strip	Volume of the sediment trapped in the buffer (manually measured in the field).
Bulk Density Sediment	Bulk density of the local sediment derived from the soil texture stated in the soil information from the BAW.
Sediment Weight Buffer Strip	Weight of the trapped sediment calculated with the measured volume and the derived bulk density for the hillslope.



Date:	01.06.18	**Rainfall:**	36.1 mm
Crop:	Pumpkin	**Area:**	2.67 ha
Crop Height:	~ 0.3 m	**BS Width:**	4.5 m
BS Height:	~ 0.5 m	**Slope Length:**	215 m
Runoff:	241.8 m³	**Soil Loss:**	11.1 t
Sed. Yield:	6.86 t	**Clay:**	31.5 %
Max. Runoff		0.2 m³/s	
Sed. Discharge Outlet:		6.9 t	
Sed. Volume BS:		1.03 m³	
Sediment Weight BS:		1.34 t	
Bulk Density Sed.:		1.3 g/cm³	

Figure 5.5: Erosion model and values of buffer A.

5.1.2 Buffer B

The second surveyed buffer strip B is located in the north-east of the town Weitersfeld, to the right side of the street at the town's exit to Pleissing (see fig. 5.3). The hillslope has a convex plan form with a minimal concave profile and low slope angles at the top and middle slope, and a minimal concave plan form and profile with steep slope angles up to over 5° at the lower slope towards the channel. At the time of the investigation, the appropriate field was vegetated with around 30 cm high maize plants. The maize rows ran parallel to the slope, only the last seven rows at the bottom of the slop were arranged perpendicular to the slope, parallel to the buffer strip. The buffer strip was covered with about 50 cm high grass and had a width of 5 m. The measured volume of the sediment that was trapped in

the buffer strip totaled up to about 2.18 m^3. As well as buffer strip A, this strip also showed farm tracks where most of the sediment got caught (see fig. 5.6). The buffer strip showed two paths of sediment overflow with two entry points towards the north-eastern corner of the field. (see fig. 5.6)
GeoWEPP produced a two subcatchments (one for each entry point) with an area of 10.73ha and a slope length of 465 m. The generated flow paths match the paths of overflow and the entry points observed in the field. Figure 5.7 shows the results of the GeoWEPP analysis of slope B. The delineated onsite effects show high soil loss at the top of the slope, along the flow path in the center and towards the sides of the subcatchment in the lower half of the slope. The perpendicular linear red line at the top of the slope indicates the bordering street, which is responsible for the high values in soil loss. Apart from some small parts along the center and the bottom of the slope, there are nearly no areas of deposition. A total runoff of 551.7 m^3 was calculated during the rainfall event and a maximum runoff of 0.32 m^3/s (320 l/s). The calculated soil loss for the hillslope is 8.9 t, the sediment yield 5.74 t. The weight of the measured trapped sediment in the buffer strip amounts 2.86 t. This leaves a difference of 0.3 t. Based on those values, the trapping efficiency of buffer B for the given event was around 32%. The amount of clay is 26 %, which corresponds to the provided soil information.

Figure 5.6: Observed erosion patterns in buffer B. (Photos: Humer 2018)

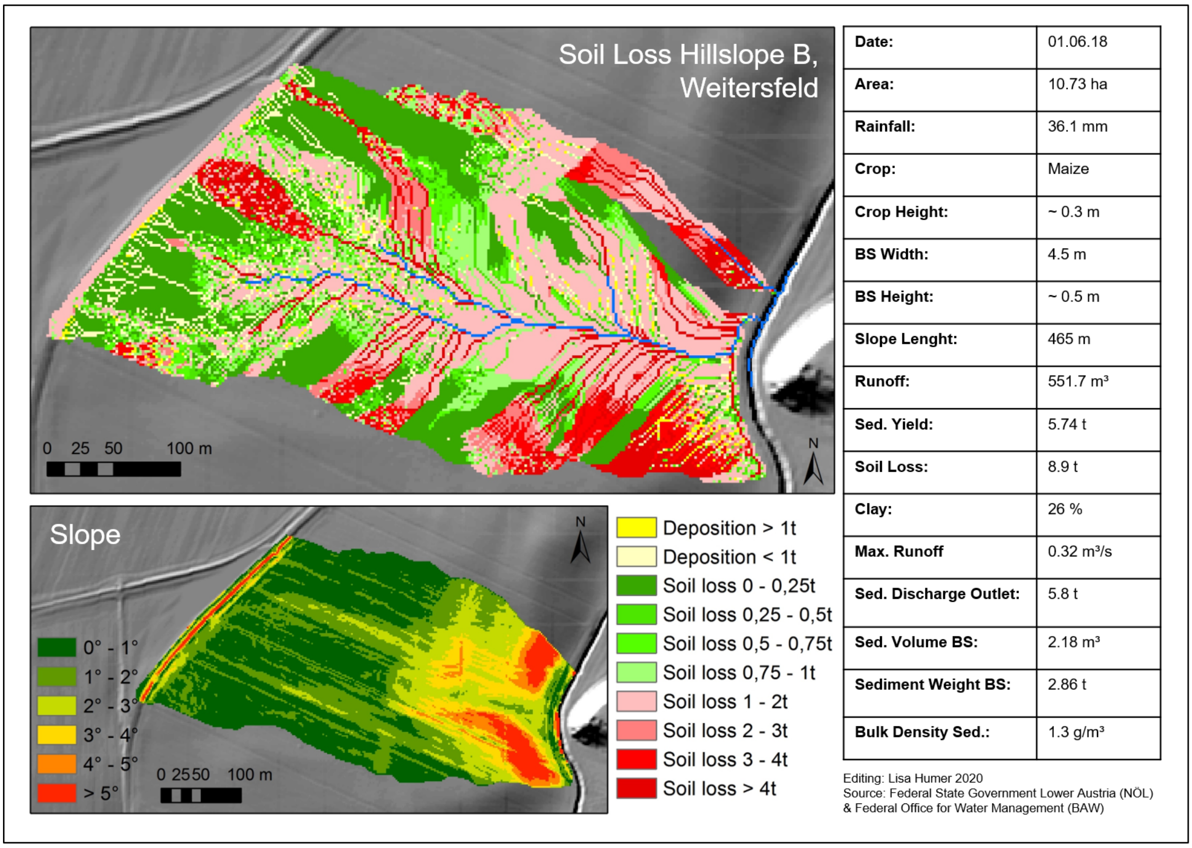


Figure 5.7: Erosion model and values of buffer B.

5.1.3 Buffer C

The third buffer strip is located close to the village Starrein (see fig. 5.3). The hillslope has a straight plan form with a minimal concave profile. The hillslope shows in general very low slope gradients, especially compared to hillslope A and B. At the time of the investigation, the appropriate field was vegetated with around 30 cm high maize plants, that were disposed perpendicular to the slope (see fig. 5.8). The buffer strip was covered with about 50 cm high grass and had a width of 4.5 m. The measured volume of the sediment that was trapped in the buffer strip totaled up to about 1.02 m^3. The buffer strip showed one path of sediment overflow with an entry point in the middle of the field.
The GeoWEPP model did not produce a subcatchment that was congruent to the observations in the field (see fig. 5.9). The calculated subcatchment for the observed entry point is mainly beyond the street (red line in the slope model). During the field work the street next to the observed fields was found to be a barrier for the flow coming from the western parts. On the basis of the field observations the produced subcatchment by GeoWEPP could not be validated.

Figure 5.8: Observed erosion patterns in buffer C.(Photos: Humer 2018)

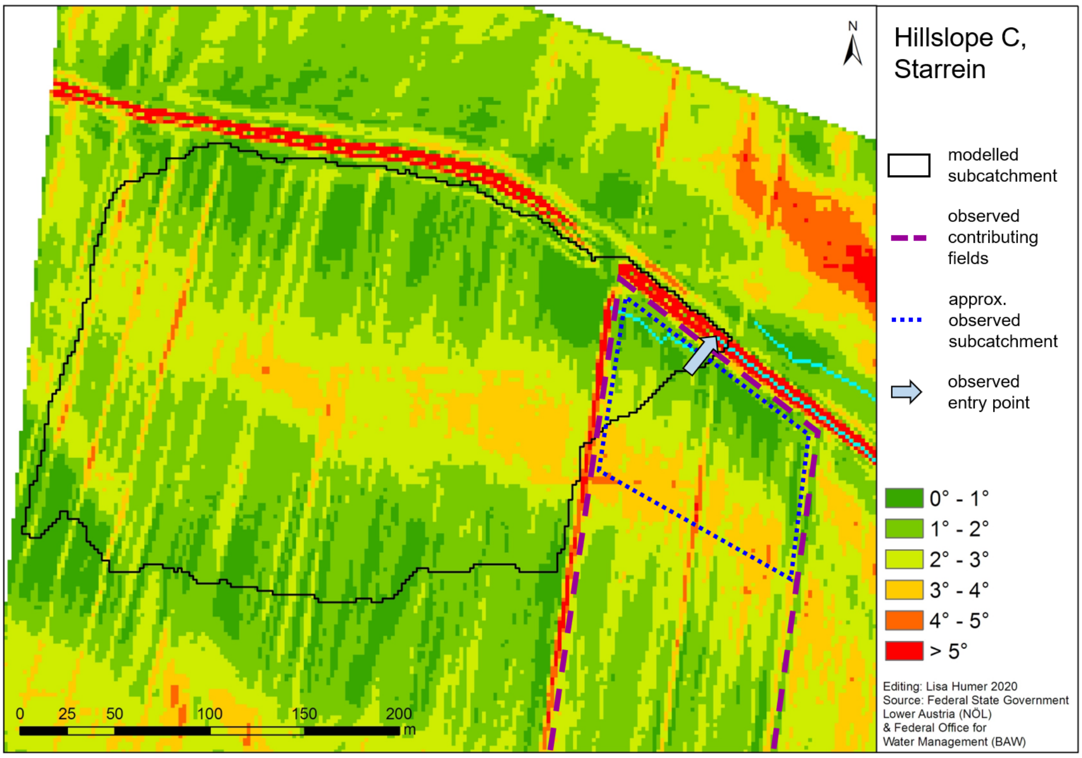


Figure 5.9: Observed subcatchments vs. modelled subcatchment by GeoWEPP.

5.2 Human-made flow path investigation

To evaluate the role of human-made flow paths and their impact on sediment input in the local channel network, entry points where the stored sediment of anthropogenic ditches enters the running stream network, were mapped (see ch. 4.4.2). Fourteen entry points were found throughout the catchment (see fig. 5.10). Most entry points were found at bridges, where roadside ditches often drain into water bodies (see fig. 5.11). The subcatchment of each entry point was calculated in GeoWEPP. Figure 5.12 shows the subcatchment of each entry point and the network of the permanent channel network and drainage channels and overland flow paths. In this study, only the superficial channels and entry points could be considered. During the fieldwork, a lot of subsurface drainage channels were observed, especially in the

residential areas. Those channels are not visible on the DEM and also hard to track.
For each subcatchment, GeoWEPP analyses were performed (see ch. 4.4.4). Since GeoWEPP only allows one management for event-based modeling, the analyses were performed for maize and wheat. The two cultivations were chosen to get the possible range of erosion rates from best-case to worst-case scenarios. The detailed results of these analyses can be found in the appendices. For each subcatchment, the most critical topographic parameters and the slope model are shown, as well as the relevant modeled erosion values for each scenario (wheat and maize) and a map with the landuse of each subcatchment. The following paragraph sums up the most important results shown in those figures.
The sizes of the subcatchments vary from 2.31 ha to 363.04 ha and cover an overall area of 768.97 ha. That corresponds to 5.56 % of the whole Fugnitz catchment. The slope angles reach from 0° up to 31.48°, and the mean slope angle of all subcatchments averages 3.79°. The elevation ranges between 391.52 m and 512.06 m a.s.l.. Those aggregated values for all subcatchments are displayed in table 5.2.
Due to the high variation in size, the sediment yield per hectare was calculated for each subcatchment. That allows to compare the results relatively. Subcatchments 5 and 7 have the biggest sediment yields per ha, ranging from 2.56 t/ha (wheat) up to 8.6 t/ha (maize). Subcatchments 4,6 and 11 show very low or no sediment yield values. Subcatchment 3 shows a soil loss that is five times bigger than the sediment yield. The biggest soil loss compared to the sediment yield is represented in subcatchment 11. The sediment yield amounts 44 kg for wheat and 100 kg for maize, while the soil loss reaches up to 436.7 t for wheat and 1250.7 t for maize. Subcatchment 1 has the highest peak runoffs with 1.84 m^3/s for wheat and 2.63 m^3/s for maize. All subcatchments produce an overall sediment yield of 540.56 t for wheat and 1324.05 t for maize. That means a sediment yield of 0.76 t/ha for wheat and 2.08 t/ha for maize. The total soil loss for all subcatchments adds up to 1452.7 t for wheat and 3435.3 t for maize.

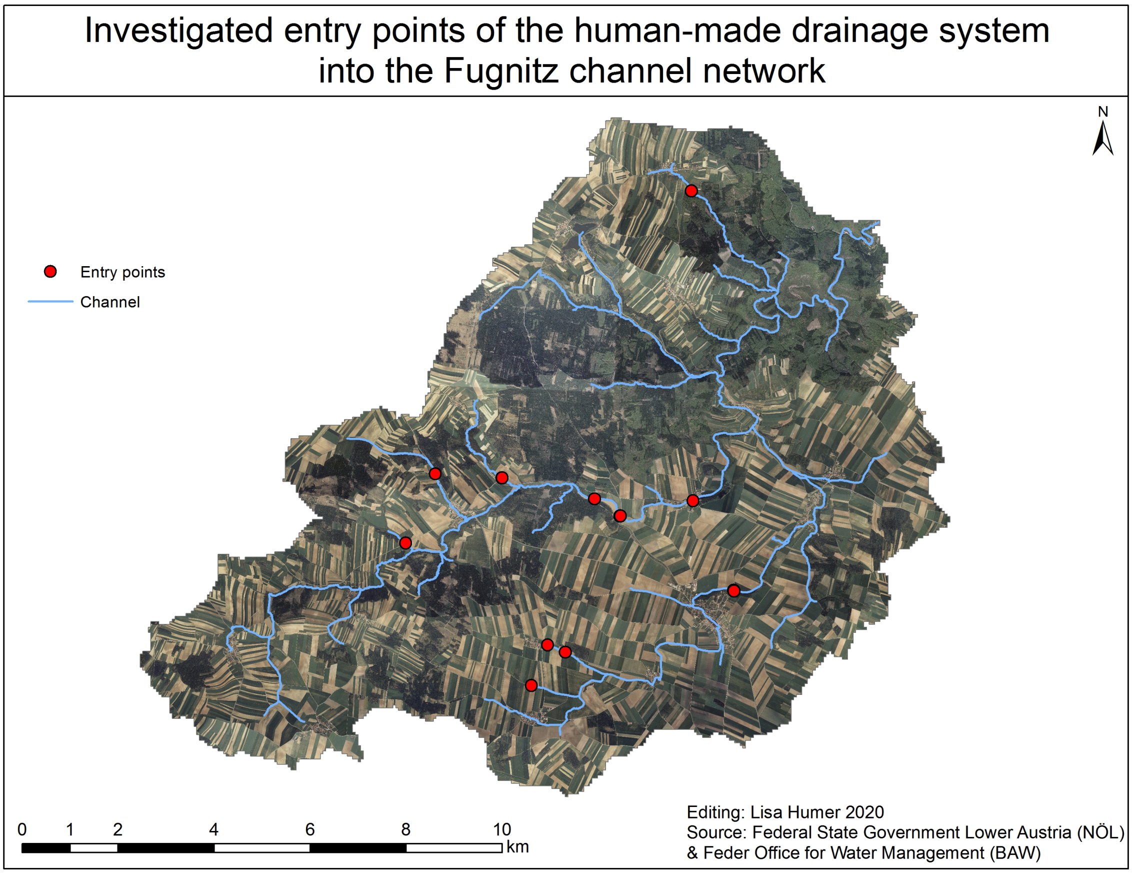


Figure 5.10: Locations of the investigated entry points.

Figure 5.11: Entry point of a roadside ditch into the Funitz at a bridge close to the village of Oberhöflein (Foto: Humer 2018).

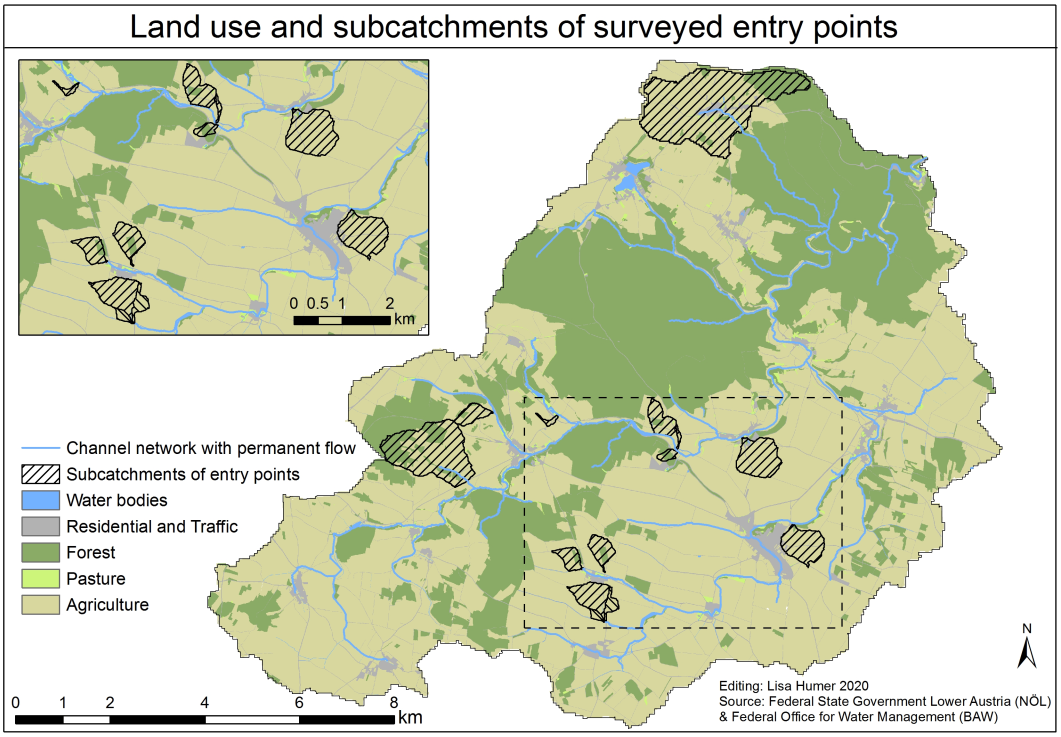


Figure 5.12: Modelled subcatchments of the entry points.

Table 5.2: Slope characteristics and erosion parameters of all subcatchments.

Subcatchments 1-14		
Area	768.97 ha	
Min. Elevation	391.52 m	
Max. Elevation	512.60 m	
Min. Slope	0°	
Max. Slope	31.48°	
Mean Slope	3.79°	
	Wheat	**Maize**
Peak Runoff (max)	1.84 m^3/s	2.63 m^3/s
Runoff Volume $\sum$	9682.57 m^3	16962.16 m^3
Sediment Yield $\sum$	540.56 t	1324.05 t
Soil Loss $\sum$	1452.70 t	3435.30 t
Sed. Yield / ha $\varnothing$	0.76 t	2.08 t
Clay $\varnothing$	22.6 %	21 %

6 Discussion

This chapter will give an interpretation of the results presented in the previous chapter. Based on these results, in combination with the latest research on the topic, the research questions that were stated at the beginning of this thesis will be answered. Afterward, possible policy recommendations based on the findings of this study will be given.

6.1 VBS investigation

The calculation of the GeoWEPP model endorses the observed and documented high intensity of the rainfall event on the 1st of June 2018. Photos from residents show flooded streets, and the model calculated a maximal runoff from one slope of 0.32 m^3/s (hillslope B). The Fugnitz has an average discharge of about 0.5 m/s at its outlet in Hardegg. This comparison shows the power and the high amount of water, that occurred during the event and activated a very dynamic sediment redistribution in the affected areas. Previous and subsequent field observations following events with lower intensities ($\tilde{1}$5-25 mm) showed no signs of sediment in the buffer strip, although erosion patterns were found in the fields.

For hillslope A the model calculated a sediment yield of 6.86 t and a total soil loss of 11.1 t. The sediment found in the buffer strip weighted 1.34 t. This leaves a difference of 2.9 t, meaning that the model reports a bigger deposition of sediment before the outlet point than measured in the field. Therefore the efficiency of buffer A can just be stated approximately with 12 - 16%. The manually gained data of sediment volume gives only an approximate value and is prone to deviations to reality. Therefore, an inaccuracy in the stated sediment weight is presumable. Nevertheless, this does not explain the whole discrepancy. Although the manually measured weight is just an approach to reality, it is highly improbable that the amount of trapped sediment was more than double of what was measured. Therefore, also an inaccuracy of the model has to be assumed. Haselberger (2017) worked with the GeoWEPP model in the Fugnitz catchment on comparable scales and already stated, that the model does not capture all deposition and soil loss areas that were observed in the field, particularly along slightly elevated field boundaries. Small-scale erosion patterns that can be very relevant on hillslope scale, cannot be represented entirely on the basis of a DEM with a 2 m resolution.

In the second observed hillslope (B), the weight of the trapped sediment amounts 2.86 t, the calculated total soil loss 8.9 t, and the sediment yield 5.74 t. In this case, the difference of 0.3 t is minor and can be reasoned by the approximation of the manually measured sediment volume. Buffer B trapped 32 % of the eroded sediment during the investigated event. All in all, the field observations and the calculated model of hillslope B are corresponding.

In the case of hillslope C, the field observations and the produced model were not congruent. The street next to the observed field was found to be a flow barrier, while the subcatchment produced by GeoWEPP included the area beyond the street. Hillslope C has rather low slope angles, also compared to the other two hillslopes. The overall flow direction of the modeled subcatchment that belongs to the identified entry point proceeds from south-west to north-east. The observed sediment flow went from south to north along the low gradient of the fields east of the street. Due to the high intensity of the rainfall event, high runoff and flow velocities occurred, which caused overland flow paths even along very low slope gradients. This and the already mentioned inaccuracy of the model to identify small-scale erosion patterns can explain the discrepancy between the observed and the modeled subcatchment. The observed subcatchment of the defined entry point was small, especially compared to the other two hillslopes. Small structures like vegetation or minor changes in the topography have a significant influence on small-scale erosion patterns. While the model delineates the flow paths based on the topography, fieldwork showed that the flow paths on that small scale highly depend on the vegetation structure of the field, plowing lines, and the structure of field boundaries. These small patterns are crucial when analyzing soil erosion on hillslope scale. (Vieira & Dabney, 2011) In order to model those structures in a centimeter range, it is necessary to have topographic data in a resolution of at least 5 cm and a model, that has enough capacity to process these high-resolution data (Quiquerez et al., 2014).

Hillslope A shows much higher amounts of soil loss, sediment yield, and trapped sediment compared to its size than hillslope B. Hillsope B has steeper slope gradients towards the foot of the slope, which favors erosion and accelerates velocity in this lower parts of the hillslope. Also, the length of the slope is longer in hillslope B. Based on the topography, it can be assumed that the erosion rates and the sediment overflow on hillslope B would be higher than on hillslope A because slope length and slope angle are the two most important factors of soil erosion in terms of topographical influence (Fournier, 2011). So why is it the other way around? This example shows the significant impact of management and crop type on soil erosion in agricultural areas (Dotterweich, 2013). On both hillslopes grew crops with a low density and a high amount of bare soil. On hillslope B maize was planted in perpendicular rows at the bottom of the slope. This has inhibiting repercussions on the flow paths since the perpendicular plowing and plant rows function as flow barriers (Blanco & Lal, 2008). Hillslope A had pumpkin in an early state of growth that showed a significant amount of bare soil due to the still small sizes of the leaves and bigger gaps between individual plants so that the rows did not work as flow barriers. Nevertheless, both hillslopes were very prone to erosion at the time of the monitored rainfall event.

The analysis of the role of vegetated buffer strips in preventing sediment from entering the channel system was one of the main objectives of this thesis. Therefore, the first research question reads as follows:

1. Do the evaluated vegetated buffer strips in the Fugnitz catchment prevent eroded agricultural fine sediment from reaching the river systems?

> *a) What is the role of the rainfall event magnitude?*
>
> *b) How do the field characteristics (e.g., topography, crop cover) influence sediment transport?*
>
> *c) How does the vegetation structure of the buffer strip influence its buffer capacity throughout the season?*

Throughout the time of monitoring (March - November 2018), only one heavy rainfall event produced enough runoff to observe sediment patterns in the vegetated buffer strips. Therefore, a comparison with another event is missing in this study. A comparable rainfall event occurred on the 16th of May 2018 with 37.6 mm precipitation (see fig. 6.1). After this event, erosion patterns were observed on the fields, but no signs of sediment in the buffer or sediment overflow from the fields into the buffer strips were found during fieldwork. Also, the residents did not report any flooding during this event. When looking at the rainfall distribution throughout the whole month of May 2018, it shows that it already rained on the days before the event on the 16th of May, while it did not rain for a week before the 1st of June 2018 (see fig. 6.2). It also rained during the morning of the 16.05.18, so the accumulated precipitation for that day is higher than for the 01.06.2018. So the rainfall event in June produced a higher runoff because the soil moisture was plausibly lower, and the rainfall was heavier during a shorter time comparing to the event in May. The kinetic energy of the rainfall event on the 1st of June was higher, and therefore the rainfall erosivity increased (Salles et al., 2002). The infiltration rate is a major control for the availability of water for surface runoff, which intensifies when the soil is dry (Morgan, 2006; Brooks et al., 2012). The comparison of the two rainfall events shows that it needs a high amount of runoff and high flow velocity to produce visible sediment overflow from the field into the vegetated buffer strips. So the magnitude of the rainfall event per time unit plays a crucial role for the sediment flow.

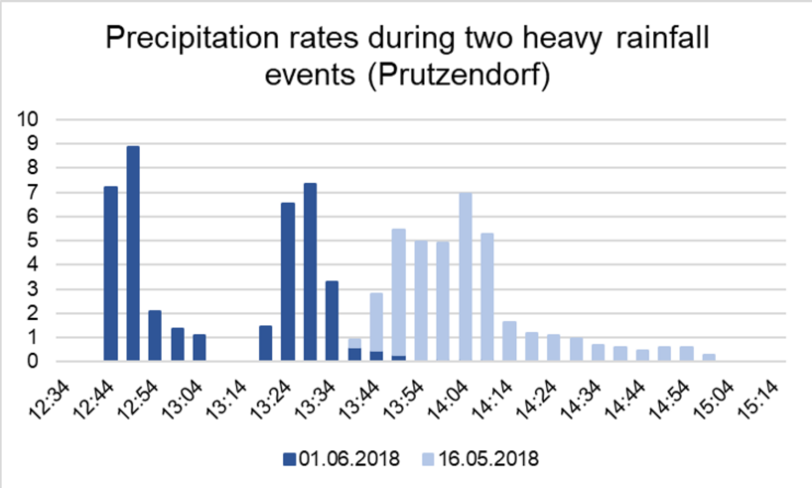


Figure 6.1: Comparison between the rainfall events of the 16.05.2018 and 01.06.2018.(Data:`https://www.wunderground.com/dashboard/pws/IWEITERS56`)

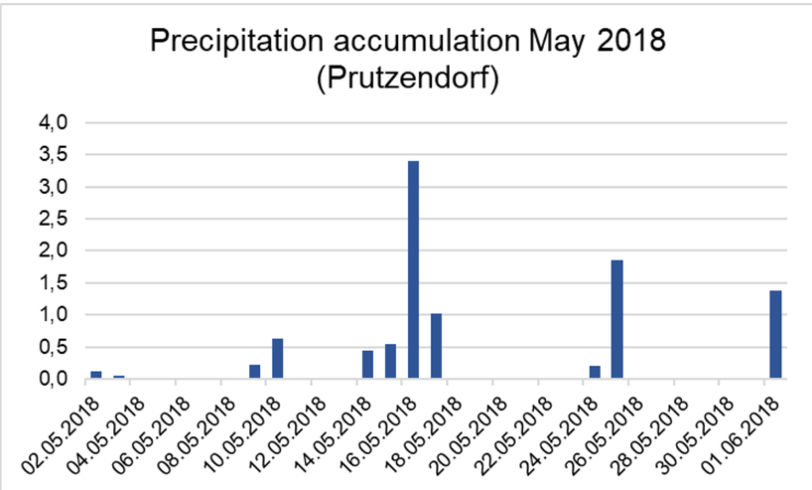


Figure 6.2: Recorded precipitation in Prutzendorf during May 2018.(Data:`https://www.wunderground.com/dashboard/pws/IWEITERS56`)

The sample size of this study does not allow to derive a valid magnitude threshold for the catchment. An approximation can be made when looking at the two events. The highest precipitation rate per five minutes for the event in May was 6.8 mm, for the event in June 8.85 mm. So a first assumption can be made considering a threshold somewhere between 6.8 and 8.85 mm. But it has to be stressed again that the sample size is to small and other parameters (e.g. soil moisture) have a too big influence in order to derive a valid threshold on the basis of this study.

The topography is one of the key factors in soil erosion by water. The underlying topography defines the possibility of sediment flow (Bracken & Croke, 2007; Emeis & Knoche, 2009). The comparison between hillslope A and hillslope B shows how big the influence of the crop cover is on soil erosion. Although hillslope B shows a topography that is more prone to erosion than hillslope A, the soil loss was more significant on hillslope A. The perpendicular rows of maize in the lower parts of hillslope B functioned as a barrier for sediment flow (Blanco & Lal, 2008). Nevertheless, both hillslopes were hit hard by the rainfall event, since both crop types come with big areas of bare soil on the field (Dotterweich, 2013). Other studies in the area brought comparable results concerning the influence of field management. Haselberger (2017) already stated in his research that the development of rill erosion is highly influenced by the direction of plow lines. Luetzenburg et al. (2019) concluded that crop cover and tillage practices generate a higher impact on soil erosion than climate change. It can be completed, that once the topography conforms to the requirements to make water erosion in agricultural areas possible, the occurrence and the intensity of soil erosion refer to the current crop type and management practices. Therefore, crop cover and management also have a strong influence, if the sediment from the fields reaches the buffer strip easily or not. Since only one heavy rainfall event produced enough runoff to observe sediment patterns in the vegetated buffer strips in 2018, the influence of the vegetation structure throughout the season could not be investigated. Nevertheless, some observations concerning the vegetation structure of the buffer strips were made.

After less intense rainfall events, no signs of sediment in the buffer or sediment overflow from the fields into the buffer strips were found, although the fields showed signs of erosion. The density and the height of the grass vegetation on the buffer strips were already thick and high after the events. Therefore it cannot be excluded that some sediment did enter the buffer strip with the low flow velocity. No signs of pressed down grass by sediment flow were found, but it is possible that sediment did trickle into the buffer strip and disappeared underneath the thick grass cover. But it still has to be assumed that just minor amounts of sediment did get trapped in the buffers this way. Generally, it can be said, that while minor precipitation already leads to visible erosion patterns on the fields (Haselberger, 2017), this study shows that it takes major rainfall events in order to have visible sediment flow in the vegetated buffer strips.

After the rainfall event in June, all observed buffer strips showed the highest amount of trapped sediment along the farm tracks (see fig. 5.6). The deepening worked as a sediment storage trap perpendicular to the sediment flow. Although all buffer strips did overflow during the observed event, it can be assumed that more sediment would have entered the channel if the buffer strips would not have had the farm tracks. The tracks along the buffer strips are not often used since the tracks are vegetated and not bare. It can be assumed that this helps to trap the sediment since the vegetation decrease the flow velocity, and the tracks itself do not produce any soil loss. Poeppl et al. (2012) already stated, that »the presence of farm tracks within the valley floor zone [...] leads to a disconnection between the valley floor zone and the riparian zone«.

This study shows that the vegetated buffer strips in the Fugnitz catchment did trap eroded agricultural fine sediment, but they did not prevent it from reaching the river systems. All investigated buffer strips showed signs of sediment overflow after the heavy rainfall event.

In order to assess the quality of the vegetated buffer strips in the Fugnitz catchment as a tool for sediment management, the second research question was formulated as follows:

2. Is the installation of buffer strips a suitable management tool to effectively prevent lateral fine sediment input to streams?

The results of the buffer strip analyses that were discussed before state, that it does take rainfall events with high intensity for the sediment to reach the buffer strip. The observed event also points out that once a rainfall event is intense enough to produce such high sediment flow, the investigated vegetated buffer strips all showed signs of overflow. The investigated buffer strips showed their biggest storage capacity along the deepening of the farm tracks. Considering the possibility of prompt occurring rainfall events, it is feasible that the buffer strips can function as a temporary sediment pool. The stored sediment can be easily mobilized during the next occurring rainfall event. Therefore it can be necessary to maintain the vegetated buffer strips after intense precipitation and remove the trapped sediment.

As stated at the outset of this thesis, there are lots of studies that state great efficiency of vegetated buffer strips in preventing lateral fine sediment input (Prosser et al., 2020). But these studies also show that the efficiency of the buffer strip depends apart from its vegetation structure, mainly on its width. The width of the buffer is often stated as the primary factor explaining pesticide trapping efficiency (FOCUS, 2007; Reichenberger et al., 2007). Stehle et al. (2016) observed that 5 m wide buffers provided 50% mitigation, while 10 m provided 90% when the buffers contained dense vegetation and no erosion rills. A study by Barfield et al. (1998) showed an increased trapping efficiency of soluble phosphorus (from 90.6% to 96.4%), ammonium (from 92.4% to 97.3%), and nitrate (from 95.1% to 97.3%) after increasing the buffer width from 4.57 to 13.72 m. The hydrologic flow energy rapidly decreases when vegetation density changes abruptly (Jobson & Froehlich, 1988), but the slowed-down flow still needs enough space to come to a halt, and the sediment needs space to deposit.

The recommended width of vegetated buffer strips highly depends on the local environment and is therefore hard to pinpoint to a concrete number. The Austrian Agri-environmental Programme (ÖPUL) recommends a minimum buffer strip width of 12 m, while some studies support a width up to 40 m to prevent sediment overflow (Mullan et al., 2016). Notwithstanding the above discrepancy, it can be concluded that the present buffer strips along the Fungnitz and its tributaries are not wide enough to work effectively. Apart from that, buffer strips are not consistently in place along the river system of the catchment. Most areas where the installation of buffer strips would be suggestive are in private ownership. Although the installation of buffer strips along the channel system is up for funding in Austria, the small patchwork like structure and thus the rather small field sizes and multiple ownerships within small territories make it hard to implement buffer strips as an effective and consistent management tool in the Fugnitz catchment. The funding for vegetated buffer strips only becomes effective along declared water bodies, with a minimum buffer width of 12m, without the use of fertilization and crop protection and with annual maintenance (ÖPUL, 2015). Considering the lack of buffer strips along the Fugnitz that meet these criteria, it can be assumed that the funding is not attractive enough for local farmers or that the information about possible funded management measures is not well-established in the communities.

6.2 Human-made flow paths investigation

Even with effective vegetated buffer strips along the river channels, the problem of coverage that was stated at the beginning of this study is still in place. The buffer strips just trap the sediment from the bordering fields of the perennial river channel system, while sediment from other fields throughout the catchment reaches human-made drainage ditches and periodical channels unhindered. Therefore, the third research question was postulated:

III. What is the role of human-made linear flow paths in terms of sediment input into the Fugnitz and its tributaries?

In the course of the connectivity mapping, fourteen entry points of human-made flow paths into the river channel system were found throughout the Fugnitz catchment. Dilly (2018) already mentioned a discrepancy between the connectivity computed on the basis of the DTM and the field observations due to the fact that the DTM does not represent all important factors affecting connectivity. During fieldwork, a lot of subsurface drainage systems were noticed, especially within residential areas. These subsurface channels are not represented in the DTM and also hard and sometimes even impossible to trace in the field. Therefore it has to be assumed that there is a high estimated number of unknown entry points in the catchment that were not discovered during the field investigation of this study.

The GeoWEPP model has a weakness when it comes to event-based modeling because it is only possible to set one management for each subcatchment. So the real diversity of crop types and management within the subcatchments cannot be displayed on event-basis. In order to still get an idea about the soil loss of the subcatchments during the investigated intense rainfall event, a crop cover of maize and wheat was set. The comparison between these two crop covers gives an approximate range of possible soil loss in the subcatchments. The highest absolute sediment yield has subcatchment 1 (the biggest subcatchment with 363.04 ha) with 595.1 t. With an assumed bulk density of 1.3 m, this amount of sediment equals a cube with a length of about 7.7 m. Since the whole agricultural area in one catchment will never be totally covered with maize, it can be presumed that the real sediment yield for the event was smaller. The high discrepancy between soil loss and sediment yield in subcatchment 11 shows how forested areas along the channel and horizontal barriers along the lower slopes (in this case, a street) prevent eroded sediment from reaching the channel system. The subcatchments 4 and 6 are very small and also show very low or no sediment

yield values. Both catchments have a rather long and narrow outline and streets running horizontally to the flow path, working as barriers towards the outlet points.
When looking at the runoffs that the rainfall event produced, the intense flooding in a short amount of time captured by the residents can be explained. The average calculated peak runoff of the subcatchments for all scenarios was 0.68 m/s. The average discharge of the Fugnitz at the outlet in Hardegg amounts 0.5 m/s. Since there are no field measurements of the actual sediment yield of the subcatchments, it is hard to verify the results of the model. Comparing the results of the model with the results of the investigated buffer strips and the results of the investigated target areas of Haselberger (2017) in the Fugnitz catchment, the calculated values of sediment yield and soil loss can be used to get an approximate idea of the dimension of soil erosion in the catchment.
Haselberger (2017) calculated an annual sediment discharge of 93,502,183 t at the outlet of the Fugnitz. On that basis, the sediment discharge of all found entry points for the maize scenario during the rainfall event in June 2018 (1324.05 t) would only cover 0.001 % of the total average annual sediment discharge of the whole Fugnitz catchment. As already stated by Haselberger (2017), the results of the model have to be handled with care, especially when dealing on a catchment-scale, since the limited computation capacity only allows a low-resolution DTM as input. The subcatchments of the investigated entry points were analyzed on the basis of a DTM with a resolution of 5 m, the calculation on catchment-scale by Haselberger (2017) was processed on the basis of a DTM with a resolution of 20 m. Comparing the overall soil loss per hectare of the detailed hillslope analyses conducted in this study, the results for the subcatchments are reasonable. The soil loss per hectare for the maize scenario averages 4.47 t/ha, the average soil loss per hectare for hillslope B averages 4.16 t/ha.
To conclude this section and to answer the previously stated research question, it can be said that the role of human-made linear flow paths in terms of sediment input into the river

channel network should not be underestimated or overlooked (Hösl et al., 2012). Studies show, that especially road networks and corresponding drainage ditches have a great influence on the hydrological patterns of a landscape (S. L. Liu et al., 2008). As already stated by Hösl et al. (2016), there are not enough studies providing information about the role of anthropogenic flow paths in lateral sediment input into river systems. This study built on this lack, but more studies have to follow in order to validate the influence of those structures. The comparison of the sediment yield from the analyzed subcatchments with the only available estimation of annual sediment discharge at the outlet point of the catchment (Haselberger, 2017) can lead to the conclusion that the human-made flow paths only play a minor role. Considering that the calculated sediment yield on catchment-scale has to be handled with care. The observations made in the field show that the anthropogenic flow paths should be included in sediment management plans on a catchment-scale, since major parts of the catchment can drain trough those entry points. A lot of road ditches and field drainage channels could not be followed to their outlets due to the mentioned subsurface routes, especially in residential areas. Therefore the real number of entry points of those flow paths into the river channel system is assumed to be many times higher than the declared fourteen of this study.

6.3 Implications for management

To combine the results of this study and translate them to specific guidance for local management, the fourth and last research question was developed:

IV. What are the options for improvement for the management of lateral sediment input measures in the Fugnitz catchment?

One of the main objectives of this study was to investigate the efficiency of the existing vegetated buffer strips in providing lateral sediment input. The investigated buffer strips all showed signs of overflow after an intense rainfall event. As discussed before, mainly the inadequate width is the reason for this inefficiency. Nevertheless, sediment got trapped in the buffer strips, especially along the tractor tracks, and numerous studies show great efficiency of vegetated buffer strips as a management tool against lateral sediment input in agricultural areas (Prosser et al., 2020). Therefore it can be recommended to widen the buffer strips along the Fugnitz and its tributaries to at least 12 m width (ÖPUL, 2015). Since the installation of buffer strips mainly has to happen on agricultural land in private ownership, the farmers need to be informed about the advantages. The installation of buffer strips can also be in the interest of the farmers because they get the possibility to redistribute the valuable trapped sediment back on their fields and get subsidies for the assigned land. The installation of vegetated buffer strips should not only be recommended and funded along the fields bordering the river channel network but also along all agricultural fields situated at a slope foot and along human-made flow paths throughout the whole catchment. Thereby the target area of sediment management enlarges and does not only tackle the fields along the river channel network. The present lack of funded vegetated buffer strips in the Fugnitz catchment can indicate that the current funding of 450 per hectare may not be attractive enough.

This study followed the stated research gap concerning the role of human-made linear flow paths (Hösl et al., 2012). During the connectivity mapping, it turned out, that numerous of those flow paths enter the river channel network unobstructed. As discussed before, many entry points of those anthropogenic ditches were found and investigated, but a much higher number of those entry points can be assumed. Therefore, further tracing of the outlet points of all existing human-made flow paths within the catchment is needed, especially in the areas where the drainage system runs underground. The installation of sediment traps at those entry points can be easier for local authorities to establish since they do not have to be installed on private land. The installation of those sediment traps can help to prevent eroded sediment from being flushed and transported into the river channel network. These measurements would also enlarge the area of sediment management beyond the fields directly bordering the Fungitz and its tributaries since wide areas of the catchment drain into the Fungitz through those anthropogenic flow paths. It is important to view sediment dynamics on the catchment-scale in order to implement an integrated management strategy (Fryirs et al., 2007; Brierley et al., 2006). When installing measurements like vegetated buffer strips or sediment traps, it is necessary to make sure that maintenance, especially after intense rainfall events, is provided so that the capacity of the measures can be assured (Prosser et al., 2020). Another factor that can deeply reduce sediment input is riparian vegetation. Poeppl et al. (2012) stated that vegetation, especially trees and shrubs that built dams by their plant roots, have buffering effects within a sediment cascade. In the upstream areas of the Fugnitz catchment, riparian vegetation is not continuously present along the narrow river channels, and fields often reach directly until the ditches. Thus it can be beneficial to allow the growth of riparian vegetation also in the upstream areas of the catchment.

Luetzenburg et al. (2019) considered the performance of GeoWEPP acceptable on the hillslope-scale. On catchment-scale, the erosion values of the model have to be questioned due to the low resolution of the DTM (Haselberger, 2017). When assessing soil erosion hotspots in a catchment with the size of the Fugnitz or bigger, the quality and spatial resolution of the input data is often difficult to obtain. Poeppl et al. stated in their study, that »combining GeoWEPP modeling of on-site soil loss for hillslopes and off-site sediment yields into channels [...] with field-based connectivity mapping has shown to be a suitable approach for the delineation of lateral fine sediment connectivity hotspots«. Therefore, the modeled values of this study for the investigated hillslopes and subcatchments in combination with the results of the field work can be used as indications when considering new management measurements. Nevertheless, a constant monitoring of the actual sediment load along the Fugnitz is recommended, in order to assess the success of installed sediment management measures, adjust management if necessary and to validate applied erosion models. An automated sediment sampler has already been installed at the Fungitz in the village of Heufurth. The analysis of this data will help to get more insights on the sediment load of the Fugnitz. Luetzenburg et al. (2019) stated that »reduced tillage practices could significantly lower hillslope soil loss and sediment discharge by more than 75% «. The problem of this is the implementation. The reduction of tillage practices depends on each individual farmer and can, as a result, not be a calculable measurement, as long as it is not implemented by law.

Possible improvements for the management of lateral sediment input measures in the Fugnitz catchment can be summarized as follows:

- Widening of the existing buffer strips
- Installation of vegetated buffer strips along all fields, not only along the ones bordering the river channel network
- Information campaign for farmers on the advantages of vegetated buffer strips and considerate tillage practices
- Funding of vegetated buffer strips throughout the whole catchment, not only along the river channel network
- Higher funding for farmers installing buffer strips, to make it more attractive
- Sediment traps at connecting points of human-made flow paths (e.g., roadside ditches) and the river channel network (special target area: bridges)
- Tracking of subsurface drainage systems and installation of sediment traps at connection points to the river channel network
- Maintenance of vegetated buffer strips and sediment traps after intense rainfall events

- Growth of riparian vegetation in the upstream areas of the catchment

- Monitoring of the actual sediment load and phosphorus level along the Fugnitz

7 Conclusion

VBS are in general an effective conservation measurement to prevent off-site effects of soil erosion. The VBS that are installed along some parts of the Fugnitz channel network trapped sediment after a heavy rainfall event, but due to the insufficient width of the buffers, they do not fulfill their possible potential. Therefore it can be concluded that the mere installation of VBS is not enough. The location, width and vegetation cover have to be considered.

Human-made linear flow paths play an important role in connecting sediment flow from agricultural areas and the river channel system. They can drain essential parts of the catchment and transport eroded sediment directly into the river channel system. Most studies on catchment scale do not consider anthropogenic structures and thus also miss out on the possibility of effective conservation measures along those flow paths. In order to catch up on this topic, more research about the influence of anthropogenic drainage networks has to be done.

For a successful management of soil erosion in sloping agricultural areas, off- and on-site effects have to be tackled on the catchment scale. That includes the management of the field by the farmers, the implementation of properly dimensioned buffer strips along all channel systems in the catchment, and to admit the growth of riparian vegetation when possible. Therefore, all stakeholders have to get on board and be included in the process. Farmers need to be informed and their tribute to conservation measures on their land has to be funded equitable.

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Appendices

Subcatchment 1			Wheat	Maize
Area	363.04 ha	Peak Runoff	1.84 m³/s	2.63 m³/s
Min. Elevation	420.61 m	Runoff Volume	9694.14 m³	14229.54 m³
Max. Elevation	509.15 m	Sediment Yield	330.28 t	595.1 t
Min. Slope	0°	Soil Loss	646.3 t	1097.7 t
Max. Slope	29.67°	Sed. Yield / ha	0.91 t	1.64 t
Mean Slope	3.59°	Clay	23.7 %	23.4 %

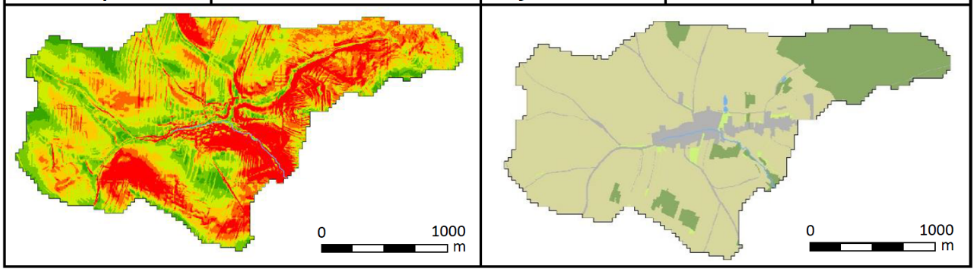

Figure A.1: Slope characteristics, erosion parameters and land use for subcatchment 1.

Subcatchment 2			Wheat	Maize
Area	61.28 ha	Peak Runoff	0.79 m³/s	1.25 m³/s
Min. Elevation	391.52 m	Runoff Volume	2190 m³	3639 m³
Max. Elevation	439.73 m	Sediment Yield	21.6 t	242.8 t
Min. Slope	0°	Soil Loss	37.6 t	322.7 t
Max. Slope	29.83 °	Sed. Yield / ha	0.35 t	3.96 t
Mean Slope	3.12 °	Clay	30.4 %	31.1 %

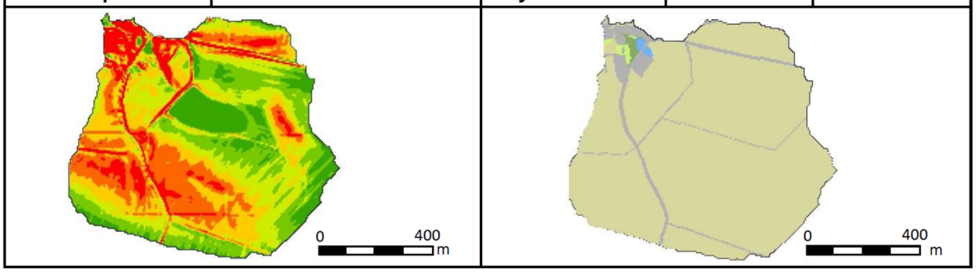

Figure A.2: Slope characteristics, erosion parameters and land use for subcatchment 2.

Subcatchment 3			Wheat	Maize
Area	6.83 ha	Peak Runoff	0.07 m³/s	0.07 m³/s
Min. Elevation	401.98 m	Runoff Volume	79.83 m³	79.83 m³
Max. Elevation	454.42 m	Sediment Yield	1.42 t	1.42 t
Min. Slope	0.02°	Soil Loss	7.3 t	7.3 t
Max. Slope	31.48°	Sed. Yield / ha	0.21 t	0.21 t
Mean Slope	8.63°	Clay	11.7 %	11.7 %

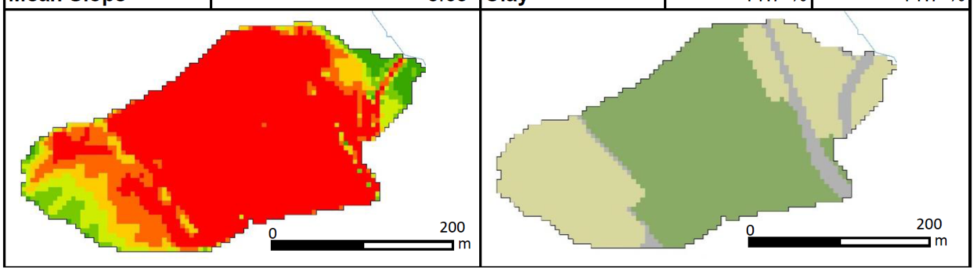

Figure A.3: Slope characteristics, erosion parameters and land use for subcatchment 3.

Subcatchment 4			Wheat	Maize
Area	2.31 ha	Peak Runoff	0.003 m³/s	0.003 m³/s
Min. Elevation	403.09 m	Runoff Volume	1.65 m³	1.65 m³
Max. Elevation	431.76 m	Sediment Yield	10.3 kg	10.3 kg
Min. Slope	0°	Soil Loss	0 t	0 t
Max. Slope	7.82°	Sed. Yield / ha	0.005 t	0.005 t
Mean Slope	3.12°	Clay	16.6 %	16.6 %

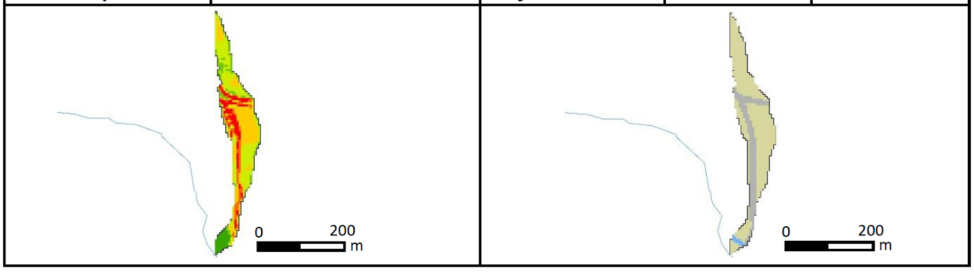

Figure B.1: Slope characteristics, erosion parameters and land use for subcatchment 4.

Subcatchment 5			Wheat	Maize
Area	27.23 ha	Peak Runoff	0.51 m³/s	0.64 m³/s
Min. Elevation	403.5 m	Runoff Volume	965.6 m³	1263.9 m³
Max. Elevation	466.83 m	Sediment Yield	71 t	135 t
Min. Slope	0.02°	Soil Loss	133.9 t	244.7 t
Max. Slope	29.64°	Sed. Yield / ha	2.61 t	5.96 t
Mean Slope	6.49°	Clay	29.7 %	30.6 %

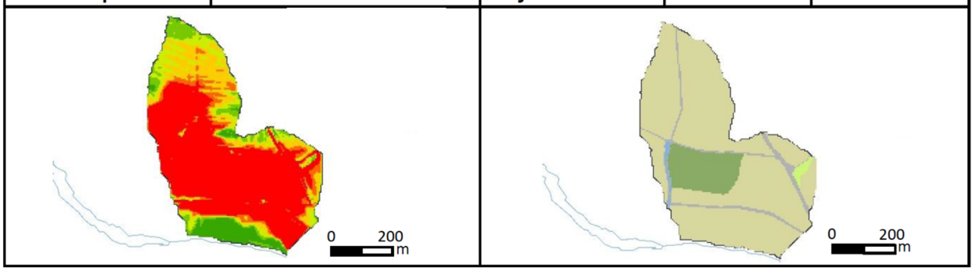

Figure B.2: Slope characteristics, erosion parameters and land use for subcatchment 5.

Subcatchment 6			Wheat	Maize
Area	3.45 ha	Peak Runoff	0.01 m³/s	0.01 m³/s
Min. Elevation	420.81 m	Runoff Volume	4.36 m³	4.36 m³
Max. Elevation	460.46 m	Sediment Yield	0 t	0 t
Min. Slope	0.04°	Soil Loss	0 t	0 t
Max. Slope	15.88°	Sed. Yield / ha	0 t	0 t
Mean Slope	4.03°	Clay	x	x

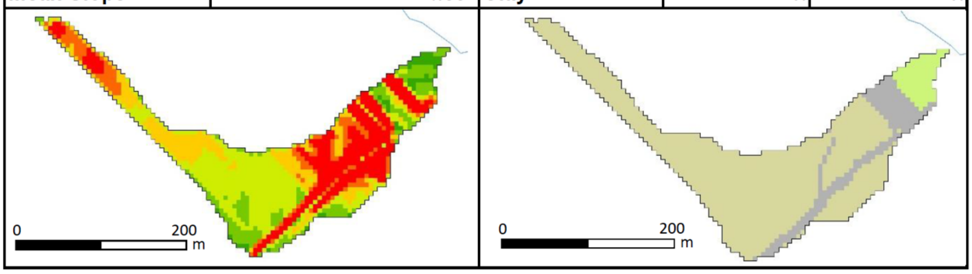

Figure B.3: Slope characteristics, erosion parameters and land use for subcatchment 6.

Subcatchment 7			Wheat	Maize
Area	19.94 ha	**Peak Runoff**	0.63 m³/s	0.84 m³/s
Min. Elevation	440.73 m	**Runoff Volume**	1096.4 m³	1525 m³
Max. Elevation	511.82 m	**Sediment Yield**	50.95 t	171.1 t
Min. Slope	0.12°	**Soil Loss**	66 t	205.7 t
Max. Slope	18.65°	**Sed. Yield / ha**	2.56 t	8.6 t
Mean Slope	5.55°	**Clay**	18.9 %	18.6 %

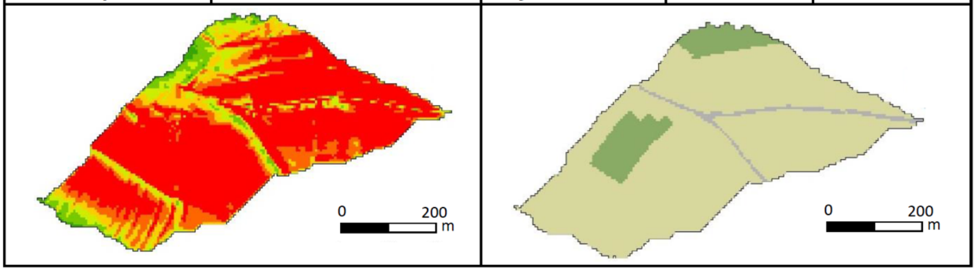

Figure C.1: Slope characteristics, erosion parameters and land use for subcatchment 7.

Subcatchment 8			Wheat	Maize
Area	4.39 ha	**Peak Runoff**	0.31 m³/s	0.34 m³/s
Min. Elevation	455.93 m	**Runoff Volume**	543.84 m³	607 m³
Max. Elevation	471.00 m	**Sediment Yield**	8.31 t	10.23 t
Min. Slope	0°	**Soil Loss**	16.4 t	18.6 t
Max. Slope	4.66°	**Sed. Yield / ha**	1.9 t	2.3 t
Mean Slope	2.32°	**Clay**	30.7 %	27.4 %

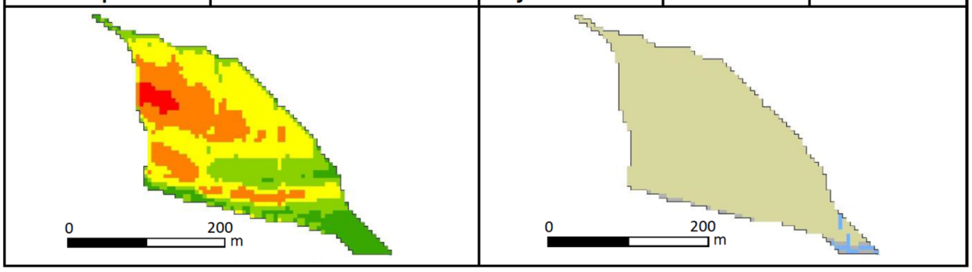

Figure C.2: Slope characteristics, erosion parameters and land use for subcatchment 8.

Subcatchment 9			Wheat	Maize
Area	36.77 ha	**Peak Runoff**	0.37 m³/s	0.61 m³/s
Min. Elevation	455.93 m	**Runoff Volume**	945.08 m³	1581.39 m³
Max. Elevation	481.52 m	**Sediment Yield**	5.26 t	12.54 t
Min. Slope	0°	**Soil Loss**	9.9 t	21.8 t
Max. Slope	5.57°	**Sed. Yield / ha**	0.14 t	0.34 t
Mean Slope	1.61°	**Clay**	16.2 %	15.7 %

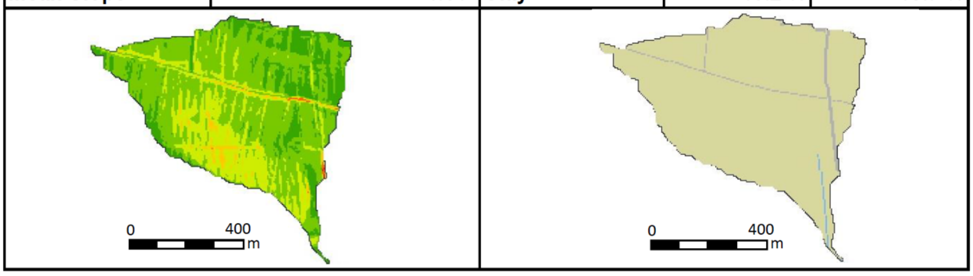

Figure C.3: Slope characteristics, erosion parameters and land use for subcatchment 9.

Subcatchment 10			Wheat	Maize
Area	9.22 ha	Peak Runoff	0.09 m³/s	0.19 m³/s
Min. Elevation	455.93 m	Runoff Volume	133.35 m³	317.72 m³
Max. Elevation	479.21 m	Sediment Yield	0.6 t	2.11 t
Min. Slope	0°	Soil Loss	1.2 t	3.9 t
Max. Slope	8.22°	Sed. Yield / ha	0.07 t	0.23 t
Mean Slope	1.3°	Clay	19.9 %	17.6 %

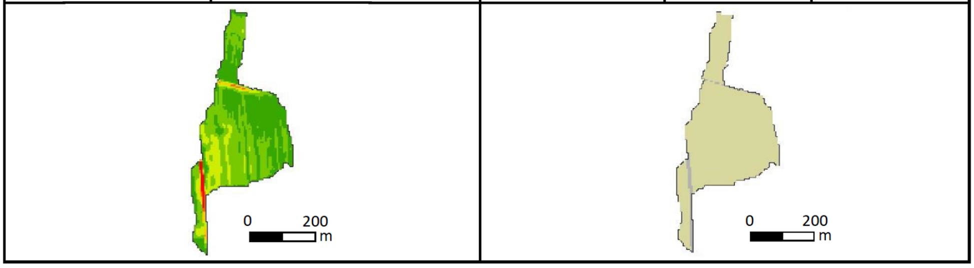

Figure D.1: Slope characteristics, erosion parameters and land use for subcatchment 10.

Subcatchment 11			Wheat	Maize
Area	172.57 ha	Peak Runoff	1.35 m³/s	2.11 m³/s
Min. Elevation	441.84 m	Runoff Volume	5330.71 m³	8704.86 m³
Max. Elevation	512.60 m	Sediment Yield	0.044 t	0.1 t
Min. Slope	0°	Soil Loss	436.7 t	1250.7 t
Max. Slope	26.2°	Sed. Yield / ha	0 t	0 t
Mean Slope	4.31°	Clay	41.6 %	31.5 %

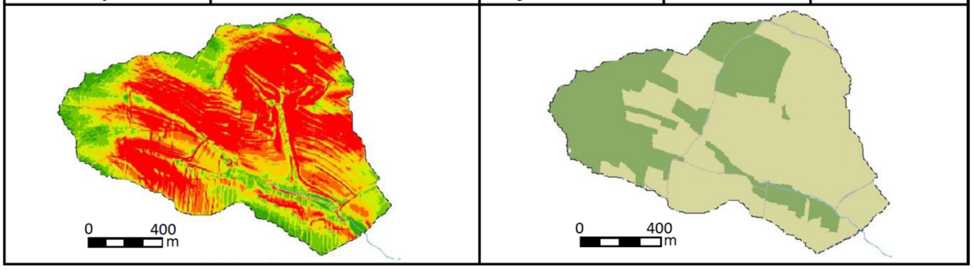

Figure D.2: Slope characteristics, erosion parameters and land use for subcatchment 11.

Subcatchment 12			Wheat	Maize
Area	51.67 ha	Peak Runoff	0.73 m³/s	1.01 m³/s
Min. Elevation	405.23 m	Runoff Volume	1923.37 m³	2639 m³
Max. Elevation	438.81 m	Sediment Yield	15.83 t	54.59 t
Min. Slope	0°	Soil Loss	32.3 t	93.90 t
Max. Slope	29.45°	Sed. Yield / ha	0.31 t	1.10 t
Mean Slope	2.8°	Clay	34.7 %	29.7 %

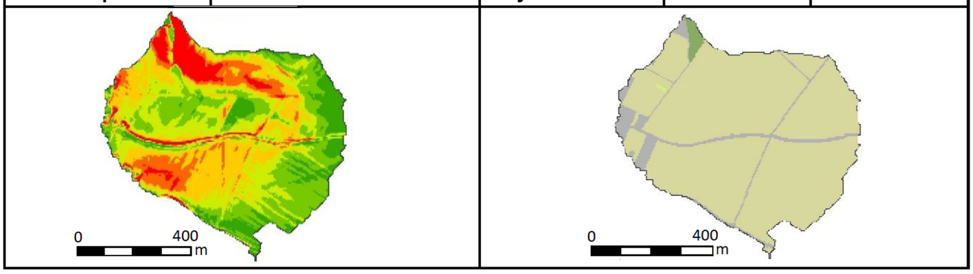

Figure D.3: Slope characteristics, erosion parameters and land use for subcatchment 12.

Subcatchment 13			Wheat	Maize
Area	22.67 ha	**Peak Runoff**	0.72 m³/s	0.92 m³/s
Min. Elevation	426.2 m	**Runoff Volume**	1481.07 m³	1937.13 m³
Max. Elevation	496.6 m	**Sediment Yield**	29.07 t	76.04 t
Min. Slope	0.02°	**Soil Loss**	56.60 t	130.20 t
Max. Slope	14.46°	**Sed. Yield / ha**	1.28 t	3.40 t
Mean Slope	3.28°	**Clay**	23.1 %	21.2 %

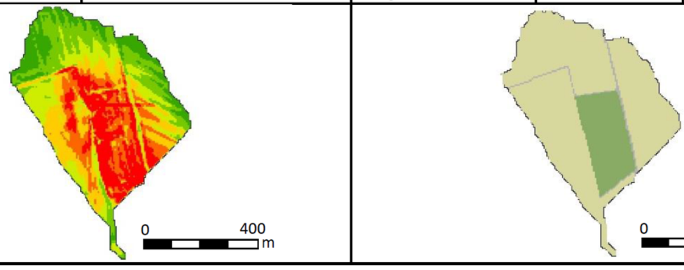

Figure E.1: Slope characteristics, erosion parameters and land use for subcatchment 13.

Subcatchment 14			Wheat	Maize
Area	17.6 ha	**Peak Runoff**	0.43 m³/s	0.64 m³/s
Min. Elevation	468.02 m	**Runoff Volume**	814.07 m³	1175.06 m³
Max. Elevation	499.25 m	**Sediment Yield**	6.19 t	23.01 t
Min. Slope	0.04°	**Soil Loss**	8.5 t	38.10 t
Max. Slope	11.76°	**Sed. Yield / ha**	0.35 t	1.31 t
Mean Slope	2.93°	**Clay**	19%	18.7 %

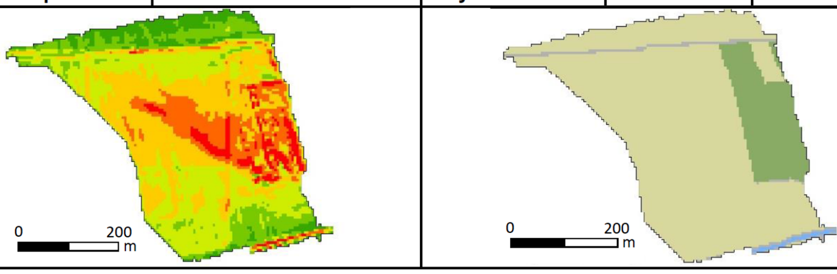

Figure E.2: Slope characteristics, erosion parameters and land use for subcatchment 14.