COUNTRY-SPECIFIC BEST MANAGEMENT PRACTICE REPORT

GERMANY (BAVARIA)

VERSION 1

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1. Content

2. Introduction

The aim of this concept is to provide the review of best practices regarding different types of land use (agriculture, grassland, forestry) respectively vegetation cover (wetland), aiming at water protection and mitigating floods, resulting from several studies lined out in former projects (please refer to CC WARE and Orientgate projects)

Task Please make a list of measures for Best practices distributed to the clusters. The name of best practice measure should be created by the first letters of respective clusters and its subcategories (for example BP MF1 – Best practice for mountain region, subcategory forest).

3. Mountain sites

3.1 Forest

BP MF1 Avoiding wide-area open spaces in the forest canopy cover

Sites covered by forest in mountain areas have an important protection function for downhill located areas. Mountain forests can reduce the intensity of flood events, provide ecosystem services typical of forest soils (e.g., water purification and water regulation) and protect downhill (downstream) located land use units. Clear-cuttings and deforestation in these areas mostly leave widespread open spaces in the canopy cover and transform these previous protection zones to potential risk areas in the catchment. Besides the risk of uncovered and thus unprotected areas, steep slopes and shallow soils increase the potential risk associated with open spaces in the forest canopy cover in mountain sites.

Basically, interception and transpiration losses on clear-cutting and deforestation sites tend to zero. Thus, the water retention capacity is substantially decreased. Conversely, the increased impact of rainfall on the soil surface can favor the generation of surface runoff which additionally is enhanced through decreased macroporosity and soil compaction as a result of area-wide timber harvesting. MOHR et al. (2013) found out that clear-cutting areas can either be a sink or a source for runoff and erosion strongly depending on the soil microtopography and the rainfall intensity. Intense surface runoff and soil erosion processes thus can occur once a specific threshold of rainfall intensity (20 mm h^{-1} according th MOHR et al. [2013]) has been reached and a connectivity of the soil microtopography has been generated. Moreover, MEGAHAN (1983) showed that clear-cuttings can significantly increase the peak snow water equivalent and snow melt rates in mountain areas leading to increased direct runoff, erosion and slope instability. As a consequence, areas located at a lower elevation can be affected adversely, e.g. in case of flash floods, and their ecosystem services can suffer substantial damages. Especially for convective storm events this fact is of primary importance.

Clear-cuttings and deforestations foster mineralization and nitrification processes by enhanced solar radiation acting on the unprotected surface. A further logical consequence of thinned forest stands is a decreased uptake of nutrients by the roots which increases the provision of different ions to be leached. BÄUMLER et al. (1999) described such an enhanced solution load in the discharge as a consequence of forest thinning in the Bavarian alps. Enhanced mineralization processes as well as an increased nutrient provision in general can lead to an increased leaching of water pollutants into the receiving streamwater or the groundwater (ROTHE et al., 2004; WEIS et al., 2008).

While deforestations should generally be prohibited in drinking water protection zones (DWPZ), clear-cuttings should be avoided above a certain threshold (e.g. > 5000 m^2). By avoiding area-wide open spaces the forest maintains its protective function for its own system (tree stand, soil, soil ecosystem) as well as for all downhill located areas and hinders an enhanced discharge of nitrate as well as an enhanced runoff contribution of direct runoff resulting from overland flow or snow melt. In this way, erosion and soil degradation in general are limited and the topsoil of the forest maintains its ecosystem services in terms of water regulation and water purification. Moreover, downhill located areas also benefit from the protective function of the forest since the concerned land use units and their ecosystem services are protected from upstream hazards. Especially in DWPZ the protection forest is of vital importance to maintain the water protective function of the whole area.

However, it is important to note that a dense canopy cover limits the water provisioning of the forest ecosystem due to greater transpiration and interception losses.

Advantages

- positive impacts on the ecosystem service water regulation and water quality regulation
- protection of downslope located areas
- preservation of soil stress
- fosters natural regeneration of the forest
- increasing activity of soil organisms enhances the soil (aggregate) structure and decomposition processes
- decreased diffusive discharge of nutrients (e.g. nitrate)

Challanges:

- enhancing ecosystem services such as water provisioning

BF MF2 Implementation of a resource-friendly exploitation system in mountain sites

The intensive use of heavy machinery for timber harvesting has harmful impacts on the forest soils. Especially in mountain areas, the vulnerability of forest sites to anthropogenic impacts is increased due to low depths of the groundwater table and too small catchment areas (LfU, 2014). Depending on the soil texture and antecedent moisture conditions, the soil may suffer surface compaction or even ground seepage. Surfaces that experienced such disturbances by intensive forest operations are not likely to recover on the short or mid-term scale. Klaes et al. (2016) showed that the textual and structural soil disturbances as a result of timber harvesting with heavy equipment are still significant after ten years of recovery on fine-textured forest soils.

Soil compaction substantially reduces the infiltration capacity. As a consequence surface run-off and erosion processes increase while the water recharge decreases. Moreover, the transfer and the storage of nutrients may be hindered as a result of physico-chemical disturbances of the mineral properties (SCHEFFER et al., 2010).

To reduce the disturbances resulting from forest operations to a minimum, an integrated forest management system has to be established to sustainably exploit the forest in mountain sites. Such a system has to be coordinated with the responsible water authorities and mainly includes the development of a road network and skid trails. The rock material for the road network should correspond to the local geology. In this context, any kind of contamination with geogenic substrates has to be avoided. Skid trails should be arranged in a predefined distance. To further protect the skid trails from ground seepage a maximum wheel load of the harvest machinery should be considered, e.g. max. 4t (LfU, 2014).

For the development of such a forest exploitation system, the soils, the drainage patterns and the surrounding landscapes of the considered area have to be taken into account as well (NOBLE, 1997). Exploitation has to be implemented in a resource-friendly manner, meaning that any kind of soil disturbances, nutrient losses, water table drawdowns and cuttings of water-bearing layers have to be avoided. For example, the use of cable logging, horse logging or motor-manual harvesting techniques should be considered (LWF, 2002). Moreover, it is crucial to adapt the date of logging to the current wheather conditions. If possible, some dates for logging should be planned in winter when the soil is frozen. It is important that for each structural modification in the forest an area-wide infiltration has to be assured.

Generally, any kind of interferences in the soil system should be avoided in drinking water protection zones (DWPZ) (e.g. part of the regulations in the inner protection zone II of Bavarian DWPZ). By reducing the disturbances of timber harvesting to a minimum, the forest and its soils maintain their ecosystem services water provision, water regulation and water quality regulation.

Advantages

- positive impacts on the ecosystem service water regulation, water provision and water quality regulation
- protection of downslope located areas
- preservation of soil stress
- fosters natural regeneration process

Challanges:

- measure implementation requires a comprehensive planning process
- proposed logging techniques can be complex

3.2 Grassland

BP MG1 Preservation of the turf on grazed alpine grasslands

Grasslands in mountain areas are typically used for alpine farming and grazing. The impact of grazing activities can have serious consequences for shallow topsoils and thus for the water balance as well.

LAMARQUE et al. (2011) identified the ecosystem services water quantity (provision), water quality (regulation) and natural hazard regulation (including water regulation) as three of the most important functions of alpine grasslands. The turf, the humus content of the topsoil along with a loosely-layered, not compacted soil structure of grasslands, favor the water storage capacity and the process of water purification. Bioturbation further enhances the soil (aggregate) structure; it improves the connectivity of macropores and enhances the water storage and infiltration capacity (SCHEFFER et al., 2010). Additionally, the intensity of bioturbation positively correlates with the distribution of macropores which in turn is crucially important for the water provision and water regulation function of the grassland.

Through intensive grazing and livestock trampling the turf properties can persistently deteriorate. As a consequence the mentioned ecosystem services of the turf and the underlying soil layer(s) to store and retent water degrade. NGUYEN et al. (1998) indicated the impact of intensive grazing especially on steep slopes. Livestock trampling leads to an increased bulk density in the topsoil which conversely increases the surface runoff and contaminant discharge (e.g. nitrate and phosphorus). The outwash of nitrate can further be increased through livestock urine and feces acting as point sources for contamination (STOUT et al., 1997). Similar results have been obtained by COURNANE et al. (2011). The increase of bulk density is attributed to a reduction of macroporosity in the topsoil as a result of livestock trampling (LEITINGER et al., 2010).

To sustainably protect the ecosystem services of grasslands in drinking water protection zones of mountain areas, grazing activities are prohibited in zone II while further limitations should be implemented in zone III. An adaptation to a sound grazing strategy can limit the extensive soil degradation through livestock trampling to sustain the turf qualities and the physical properties of the soil system. Moreover, the exposure to water pollutants is reduced due to a lower input from animal feces and reduced conversion of biomass. This measure thus hinders an enhanced outwash of contaminants into the receiving waters and maintains the ecosystem services water regulation and water provision of grasslands.

Advantages

- positive impacts on the ecosystem service water provision, water regulation and water quality regulation
- protection of downslope located areas

- preservation of soil stress
- increasing activity of soil organisms enhances the soil (aggregate) structure and the connectivity of water paths
- decreased diffusive discharge of nutrients (e.g. nitrate)

Challanges:

- measure implementation and control of grazing activities

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
BP MF1	High	Middle	Short	High
BP MF2	High	Middle	Middle	Middle
BP MG1	High	Low	Short	Middle

4. Plain sites

4.1 Agriculture

BP PA1 Conversion of arable land to grassland

Many studies emphasized that agricultural land use practices usually stress the soil system and the quality of the groundwater due to tillage with heavy machinery and contamination with fertilizers and pesticides (e.g. GISH et al., 1991; KANWAR et al., 1993; PATNI et al., 1998). Especially in drinking water protection zones, this arable lands pose a risk for the drinking water protection due to the proximity to the water extraction plants.

Land use conversion from arable land to grassland has been proven to be an efficient measure to reduce the negative environmental impacts on the groundwater as well as on the soil. Grassland sites do not require the application of fertilizers or herbicides (only for single species treatment) and are characterized by an efficient utilization of the existing nitrogen sources.

Grasslands are less tilled with heavy machinery which avoids a degradation of the site conditions and allows a continuous recovery of the former arable use. By waiving the use of heavy machinery, the soil loosens its structure which improves the infiltration capacity as well as the water transfer in previously stressed soil layers. These processes are enhanced through the root zone of the turf.

Moreover, the organic matter content of the topsoil increases after the implementation of a grassland favoring the water storage capacity and the process of water purification (MILLER et al., 1990). Since grasslands are not used with the same intensity as arable lands the acitivity of soil organisms increaes and fosters bioturbation processes (BAUCHHENß, 2005). Bioturbation positively affects the soil (aggregate) structure; it improves the connectivity of macropores and enhances the water infiltration capacity (WEILER et al., 2002; SCHEFFER et al., 2010). Additionally, the intensity of bioturbation positively correlates with the density of macropores which in turn is a key factor for the vertical water transferability and thus the ecosystem service water provision. In contrast, inceased interception and evapotranspiration losses may hinder the ecosystem service water provision but do positively affect the water regulation function.

A dense turf provides a protection function against erosion processes, soil aggregate destabilization and evaporation losses. The turf decreases the susceptibility to surface sealing and lower the probability of breaching the infiltration capacity and the resulting Hortonian Overland Flow. Analogous to less surface sealing and enhanced vertical connectivity this measure can enhance the mitigation of floods in small catchment areas during convective storm events (DWA, 2015).

Depending on the site and main crop characteristics, the cultivation of leguminous species should be refrained. Leguminous crops increase the amount of plant-available nitrogen in symbiosis with bacteria (rhizobiaceae).

Advantages

- positive impact on the ecosystem service water provision,
- mainly positive impacts on the ecosytem services water regulation and water quality regulation, as far as the macropore system does not enhance quick discharges
- preservation of soil stress and recovery of (physical) soil properties
- increasing activity of soil organisms enhances the soil (aggregate) structure, the connectivity of water paths and decomposition processes
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)
- decreased diffusive discharge of nutrients (e.g. nitrate)

Challenges:

- need for scarification to avoid hydrophobic effects of matted roots (SCHOBEL, 2005)
- economic efficiency depending on production emphasis of the farmer

BP PA2 Implementation of a permanent and extensive plant coverage with catch crops

Exposed and uncovered surfaces represent unprotected areas which are susceptible to negative environmental influences. Splash effects of rainfall can destroy soil aggregates and lower the water storage capacity. More detached, fine-textured soil particles can favor surface sealing processes and lower the infiltration capacity. Moreover, harvest residues on temporally unused lands are likely to foster the mineralisation of nitrogen and lead to increasing amounts of nitrate in the topsoil which can enhance the diffused discharge into the groundwater (SCHEFFER et al., 2010).

In order to lower these negative effects on the ecosystem services water quality regulation and water regulation, catch crops are frequently used to cover the soil surface between successive plantings. Catch crops are mostly fast-growing species which overlast the intermediate phase between two main crops and at best remove excess nutrients. Moreover, catch crops are also cultivated simultaneously with species that require a wider row spacing (e.g. maize fields or vineyards) to cover the bare soil between the crop rows. These catch crop species have to be adapted to the main crop since both should not be in nourishment competition for nutrients and at best benefit from each other.

The cultivation of catch crops can significantly decrease the nitrate leaching (e.g. greening in winter). Depending on the species, catch crops can store a certain amount of nitrate which is mineralised after the harvest and thus available for the following main crops (THORUP-CHRISTENSEN et al., 2003; SCHEFFER et al., 2010). Moreover, catch crops cover the bare soil and increase the content of organic matter in the topsoil. Thus, these plantings protect the soil from soil aggregate destabilization and erosion processes. The increased content of organic matter also hinders surface sealing and the related probability to increased surface runoff (MEISINGER et al, 1991; GLAB et al., 2008). Catch crops also increase interception and transpirtation losses and may thus counteract the ecosystem service water provision.

Depending on the site and main crop characteristics, the cultivation of leguminous species as catch crops should be refrained. Leguminous crops increase the amount of plant-available nitrogen in symbiosis with bacteria (rhizobiaceae).

Advantages:

- positive impacts on the ecosystem services water regulation and water quality regulation
- fostering a more efficient use of the growing space
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)

- decreased diffusive discharge of nutrients (e.g. nitrate)
- coupling with other measures (e.g. extensive crop rotations, conservation tillage) can enhance the effect of catch crop cultivation

Challenges

- enhancing ecosystem service water provision

BP PA3 Fostering extensive crop rotations (Werntal)

The basic intention of farmers is to obtain the maximum economic benefit from his estates. In this context the tendency towards intensively-used farmlands is not more than a logical consequence. An intensively-used farmland enhances the cultivation of economically profitable crops always seeking to increase the efficiency of the production factor "soil". As a result, the use of yield-improving (genetic) seeds, synthetic fertilizers, pesticides as well as the use of non-conserving tillage methods (conventional tillage) can be considered as the basis for the intensification of farmlands. Moreover, rising world market prices and current legal regulations in agricultural policy foster the intensification of farmlands as well.

However, the intensive use of farmlands may lead to an increasing exposure to negative environmental impacts, such as stormwater runoff, high discharge of contaminants (e.g. nitrate and phosphorous) and soil erosion. In this context, an integrated management of the crop rotation systematics (extensive crop rotations) can make a sginificant contribution to reduce the likelihood of those hazards. Such an adapted management strategy has to be economically viable and environmentally compatible at the same time.

The concept of extensive crop rotations can be considered as a part of the concept of low-input farming to which conservation tillage is associated. The objective of this management strategy is to reduce the required input of (synthetic) pesticides and fertilizers by harmonizing the crop rotation strategy. This could mean that a previous crop should leave, as far as possible, optimal site conditions for a subsequent crop to minimize the use of production inputs (DIEBEL et al., 1992).

Due to less production inputs the pollution of surface waters and the groundwater can be avoided to a certain extent. The implementation strategy of extensive crop rotations should incorporate aspects to conserve the structural and textual properties of the soil as well as the soil fertility. If adapted in an adequate manner, this measure can enhance the ecosystem services water quality regulation, water provision and water regulation.

Advantages:

- positive impacts on the ecosystem services water provision, water regulation and water quality regulation
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers, genetic engineering)
- decreased diffusive discharge of nutrients (e.g. nitrate)
- coupling with other measures (e.g. catch crop cultivation, conservation tillage) can enhance the effect of extensive crop rotations

Challenges:

- selecting adequate crop rotations and simultaneously sustaining the economic efficiency for the farmer

BP PA4 Conversion of intensively-used agricultural lands to short-rotation plantations (SRP)

Short-rotation plantations (SRP) represent extensive agricultural land use measures which mainly serve for the production of firewood. The plantation focus is principally based on fast-growing tree species, such as poplars or willows, which are ready to harvest in between 3 to 8 years depending on the site and species characteristics. At harvest, the trees are cut near the soil surface leaving a small part of the trunk. This trunk rest puts out new shoots in spring time so that a new sowing as well as tillage are not required. The new shoots benefit from the existing root structure of the harvested stand since the existing root network simplifies the nutrient and water uptake (ZACIOS et al., 2011).

A use of heavy machinery is only required at the initial phase for site preparation from intensive agricultural use to SRP sites as well as for the harvest. Moreover, SRP plants create a deeper-reaching root system due to their longer growth phases compared to annual crops. Thus, the root system of SRP plants also develops in soil layers under the former plowing depth and loosens up the whole soil structure. Thanks to less soil compaction, the prevention of soil tillage and a high availability of organic matter an increase of activity of soil organisms, e.g. earthworms, is favored. These structural changes of the soil system can improve the water storage capacity of the soil as well as the water transferability to deeper soil layers (ZACIOS et al., 2012, ZACIOS et al. 2015).

The interception and transpiration losses generally increase as a consequence of the land use change due to a dense and continuous vegetation cover, increased water uptake from deeper soil layers and greater leaf areas (e.g. of poplars). These changes have a two-fold effect: On the one hand, the canopy cover continuosly protects the soil surface from erosion processes and increases the water retention. Thus, the conversion to SRP sites is positively affecting the ecosystem services water quality regulation and water regulation. On the other hand, the water recharge of the water supplying aquifer decreases. ZACIOS et al. (2012) calculated a decrease of recharge of 75% on SRP sites in Kaufering (Bavaria).

Furthermore, SRP sites foster the ecosystem service water quality regulation by avoiding the use of fertilizers. ZACIOS et al. (2012) showed that the discharge of substances from the soil as well as the input of matter into the groundwater decreased following the land use change. For nitrate, they calculated a decrease of 50% compared to the amount of outwash from the former agricultural area.

Advantages:

- positive impacts on the ecosystem services water regulation and water quality regulation
- preservation of soil stress and recovery of (physical) soil properties

- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)
- decreased diffusive discharge of nutrients (e.g. nitrate)

Challenges:

- enhancing the ecosystem service water provision
- implementation costs
- economic efficiency depending on production emphasis of the farmer

BP PA5 Conversion of soil tillage to non-turning methods

Traditional tillage, or more precisely conventional tillage is usually based on soil-turning methods, such as plowing. Thereby the topsoil is loosened and turned so that the organic residues are extensively and equally distributed folded in the topsoil. Primarily, this measure is used to prepare the agricultural land for the following sowing. The plowing also provides a mechanical weed control and enhances the aeration of the topsoil (SCHEFFER et al., 2010). However, this technique can adversely affect the ecosystem services water provision, water regulation and water quality regulation.

This technique destroys the aggregate structure of the topsoil due to the mechanical impact of the plow. The increased aeration in the topsoil fosters the decomposition (mineralisation) process of the organic matter and thus reduces the humus content (SCHEFFER et al., 2010). Both, the destroyed aggregate structure as well as the reduction of the humus content reduce the water storage capacity as well as the purification and filtering function of the topsoil. For example, KANWAR (1985) described higher nitrate leaching from conventional tillage sites than from no-till sites.

In terms of susceptibility to erosion, the detachment of particles intensifies and increases the amount of eroded material. Moreover, the susceptibility to interflow processes at the plowing pan and surface runoff processes in response to surface sealing increases as well (SHIPITALO et al., 2000; BRONSTERT et al., 2002). These fast discharge units can also carry significant amounts of nitrate and phosphorous and thus pose a risk for the receiving waters (GOSS et al., 1993). 126 147 165

A transition from conventional soil tillage to non-turning alternatives (conservation tillage) counteracts these negative impacts of soil-turning methods. The concept of conservation tillage can be considered as a part of the the concept of low-input farming to which the concept of extensive crop rotations is associated as well. Conservation tillage fosters the preservation of the soil structure and its pore system so that the soil maintains its water transferability and storage capacity. Especially the preservation of the vertical pores is of vital importance for water infiltration at the soil surface (SHIPITALO et al., 2000). Moreover, the humus content of the topsoil increases compared to conventional tillage favoring the water storage capacity and the process of water purification. Since the topsoil is not turned in conservation tillage the acitivity of soil organisms does not decrease and keeps the bioturbation on an adequate level (BAUCHHENß, 2005). Bioturbation positively affects the soil (aggregate) structure; it improves the connectivity of macropores and enhances the infiltration (SCHEFFER et al., 2010). Additionally, the intensity of bioturbation positively correlates with the distribution of macropores which in turn is crucially important for the water provision and water regulation function of the soil system.

Since the organic residues are alomost completely left on the soil surface they provide a protection function against erosion and evaporation. Furthermore, these residues decrease the susceptibility to surface sealing and lower the probability of breaching the infiltration capacity and the resulting Hortonian Overland Flow. Analogous to less surface sealing and enhanced vertical connectivity this measure can enhance the mitigation of floods in small catchment areas during convective storm events (DWA, 2015).

In summary, conservation tillage may increase the water use efficiency and helps the soil to maintain its ecosystem services water regulation, water provision and water quality regulation on an adequate level.

Advantages:

- positive impacts on the ecosystem services water regulation and water quality regulation
- preservation of soil stress and recovery of (physical) soil properties
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)
- decreased diffusive discharge of nutrients (e.g. nitrate)
- increasing activity of soil organisms enhances the soil (aggregate) structure, the connectivity of water paths and decomposition processes
- coupling with other measures (e.g. extensive crop rotations, catch crop cultivation) can enhance the effect of conservation tillage

Challenges

- enhancing ecosystem service water provision
- likely to need more herbicides which can be hindered with other measures, e.g. catch crop cultivation

4.2 Grassland

BP PG1 Preservation of permanent grasslands

The conversion from arable land to grassland is not the only measures that can positively affect the ecosystem services water provision, water quality regulation and water regulation. The preservation of permanent grasslands is at least of equal importance. By definition, a permanent grassland is an *'agricultural land which is currently, and has been for five years or more, used to grow grass and other herbaceous forage, even though that land has been ploughed up and seeded with another variety of herbaceous forage other than that which was previously grown on it during that period'* (ECJ, 2014). This definition has been introduced by the European Court of Justice (ECJ) as a result of a legal dispute of a German farmer who considered reseeding actions on his grassland sites would break the five-years regulation so that he keeps the status *'arable land'* for these sites. Generally, farmers try to avoid the status of permanent grasslands due to a lower sales value and the ban on plowing. Thus, the implementation of ecologically valuable permanent grasslands is difficult since the economic value of arable land sites and permanent grasslands as well as the legal restrictions on both land use entities mostly are of top priority.

According to the legal restriction a degradation of the site conditions with heavy machinery is avoided by law. Thus, soils of permanent grasslands are characterized by a loosened structure which have an enhanced water storage and retention capacity compared to more compacted, tilled soils on arable lands. In this context, Ajayi et al. (2016) evidence the importance of long-term soil recovery for the physical soil properties on permanent grasslands fostering the water-related ecosystem services.

The enriched content of soil organic matter of the topsoil of a permanent grassland favors the water storage capacity and the process of water purification. Since permanent grasslands are not intensively used, the acitivity of soil organisms is high and keeps the bioturbation on an adequate level (BAUCHHENß, 2005). Bioturbation positively affects the soil (aggregate) structure; it improves the connectivity of macropores and enhances the infiltration capacity (SCHEFFER et al., 2010). Additionally, the intensity of bioturbation positively correlates with the distribution of macropores which in turn is crucially important for the water provision and water regulation function of the soil system.

A dense turf on permanent grasslands provides a protection function against erosion processes, soil aggregate destabilization and evaporation losses. The turf decreases the susceptibility to surface sealing and lower the probability of breaching the infiltration capacity and the resulting Hortonian Overland Flow. Analogous to less surface sealing, enhanced vertical connectivity and increased losses through interception and evaporation, this measure can enhance the mitigation of floods in small catchment areas during convective storm events (DWA, 2015).

It is important to note that a plowing up of permanent grasslands can signifcantly increase the leaching of nitrate since on the one hand, huge amounts of organic matter can be decomposed by soil organisms and on the other hand, the natural nutrient uptake by vegetation is interrupted (WHITMORE et al., 1992). The decomposition process is also enhanced by a high solar radiation acting on the unprotected surface. Thus, the preservation of permanent grasslands in drinking water protection zones represents a valuable contribution to protect the drinking water quality.

Advantages

- positive impacts on the ecosystem service water provision, water regulation and water quality regulation
- preservation of soil stress and recovery of (physical) soil properties
- increasing activity of soil organisms enhances the soil (aggregate) structure, the connectivity of water paths and decomposition processes
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)
- decreased diffusive discharge of nutrients (e.g. nitrate)

Challanges:

- need for scarification to avoid hydrophobic effects of matted roots (SCHOBEL, 2005)
- economic efficiency depending on production emphasis of the farmer
- "permanent grassland" definition introduced by the ECJ: lose of status "arable land", lower sales value, ban on plowing

4.3 Wetland

4.4 Forest

BP PF1 Forest conversion from monoculture to mixed forest

In the course of land use intensification in agriculture as well as in forestry during the last centuries, the pressure on forest ecosystems increased significantly (WORRELL et al., 1997). To supply the increasing traditional demand of the timber processing industry as well as new demands, such as biofuels (GUNDERSEN et al., 2011), monoculture plantations are of great economic importance since their main function is to provide a high yield. Thus, the forestry management and the harvest strategy are primarily designed to purpose the greatest economic benefits. Basically, spruce and other coniferous woods represent frequent forms of monocultures in silviculture.

The conversion from monocultures to mixed forest stands has several positive effects on the ecosystem functions water provision, water quality regulation and water regulation.

In terms of water quantity, coniferous monocultures increase the total water loss due to both higher water storage capacity and greater interception as e.g. short vegetation plantations (CANNELL, 1999). The soil rooting structure of mixed forest stands is far more heterogeneous than soils cultivated with monoculture plantations based on a balanced relationship between deep-rooted and shallow-rooted trees as well as coarse and fine roots. These increase the macroporosity also in deeper soil layers leading to an enhanced connectivity and water transfer to the subsoil in response to rain events (BURGESS et al., 2001). Moreover, SCHUME et al. (2004) indicate that mixed forest stands show higher water absorption capacities than spruce monocultures under dry conditions in summer enabling the forest ecosystem to reduce the run-off contribution during convective storm events. Both properties of polyculture stands can improve the ecosystem service water regulation.

A mixed forest can also positively affect the ecosystem service water provision. BOSCH et al. (1982) and JOST et al. (2004) show that soil water recharge is higher in deciduous forest stands than in coniferous monocultures due to greater interception losses. A greater share of deciduous hardwood stands in a mixed forest thus causes smaller interception losses especially during autumn and winter season. These "open windows" in the canopy cover can increase the transfer of water into the soil system which is especially relevant in drinking water protection zones (DWPZ).

CANNELL (1999) and WAUER et al. (2008) point out that monocultures, especially spruce forests, typically increase the transfer from airpollutants into the terrestrial ecosystem compared to short vegetation plantations and thus enrich the soil water with nitrogen and/or sulphur compounds. Moreover, BRANDTBERG et al. (2004) indicate that the quality of organic matter in the litter layer is less under spruce monocultures compared to spruce-birche mixed stands (expressed by C/N-ratios) emphasizing that polyculture alternatives increase the filtering effect of the organic soil layer. A conversion from monoculture to mixed forest will thus foster the water purification function of a stable litter layer as well as the filtering through a textual and sound soil structure. These effects of polyculture alternatives cause an amelioration of the ecosystem service water quality regulations and may enhance the water quality in DWPZ.

Advantages

- positive impacts on the ecosystem services water regulation, water provision, water quality regulation
- a mixed forest is more stable than monoculture plantations and thus able to resist natural disturbances such as windthrow or pest infestations
- increasing activity of soil organisms enhances the soil (aggregate) structure, the connectivity of water paths and decomposition processes
- decreased diffusive discharge of nutrients (e.g. nitrate)
- decreased interception due to leafless trees in autumn and winter increasing ground water recharge
- water regulation and flood mitigation due to interception losses in spring and summer as well as higher water absorption also from deeper soil layers providing protection against convective storm events

Challanges:

- the mitigating effect of forests is limited to small-scale watersheds as well as small-scale flood events. The effect of flood mitigating measures in forest ecosystems are negligible in large catchments and for intense flood events (CALDER, 2007)
- the measure requires a long-term implementation as well as a customized choice of tree species

BP PF2 Natural forest regeneration of mixed-forests using single-tree-selection technique

Natural forest regeneration is a technique to naturally reproduce forest stands without any kind of artificial and controlled sowing techniques. Different possibilities of natural reproduction exist that constitute the main drivers for natural forest regeneration: vegetative reproduction as a form of asexual reproduction (seedless, sporeless) and natural sowing of surrounding trees.

To implement a natural forest regeneration, the forest management pursues a sound wood harvest technique based on a single-tree-selection. Single trees are selected by a species-dependent exploitable diameter or exploitable weight, respectively. Moreover, the forest management evaluates the vital and stable trees which are worth to leave in order to provide a healthy genetic base for natural reproduction. In this way a quasi-natural selection process takes place between the species that fosters the vitality, stability and resilience of the forest stand.

Since trees with specific exploitable properties basically have a diameter-corresponding treetop (crown), they leave an "open window" in the canopy cover following the harvest. Due to greater insolation and potentially increased water availability (less interception) these areas have adequate site characteristics for natural forest regeneration. Additionally, the forest management avoids widespread open spaces similar to those arising from clear-cutting to ensure the nutrient provision by surrounding trees on regeneration sites and to prevent the soil surface from extensively increasing temperatures. Thus, the ecosystem function water quality regulation is enhanced compared to extensive open spaces since mineralisation and nitrification processes do not increase significantly and thus limiting the amount of nitrate leaching.

This measure fosters the spreading of understorey vegetation and positvely affects the ecosystem functions water regulation and water quality regulation. Understorey vegetation creates a double-layer forest and enhances the filtering properties of the forest. The susceptibility to erosion (especially splash-erosion) decreases simultaneously and thus hinders an outwash of sediments as well as particulate substances into the pre-flooder (CALDER, 2007). In the progress of single-tree removals around already existing regeneration spaces a coney-shaped wood stand structure emerges due to differences in tree height by ongoing natural regeneration.

A mixed forest can also positively affect the ecosystem service water provision. BOSCH et al. (1982) and JOST et al. (2004) show that soil water recharge is higher in deciduous forest stands than in coniferous monocultures due to greater interception losses. A greater share of deciduous hardwood stands in a mixed forest thus causes smaller interception losses especially during autumn and winter season. These "open windows" in the canopy cover can increase the transfer of water into the soil system which is especially relevant in drinking water protection zones (DWPZ).

Since natural regeneration enhances the vitality and the stability of the forest ecosystem, it is more resilient to disturbances, such as bark beetle infestation or windthrow.

Advantages:

- positive impacts on the ecosystem services water regulation, water provision, water quality regulation
- low initialcosts to implement this measure in case the desired tree species are present and no further site preparation is required
- optimal adaptation to the specific site
- decreased leaching of nutrients (e.g. nitrate)
- decreased interception due to leafless trees in autumn and winter increasing ground water recharge
- water regulation and flood mitigation due to interception losses in spring and summer as well as higher water absorption also from deeper soil layers providing protection against convective storm events

Challenges:

- measures are required to protect the young stands (underwood) from browsing by game, e.g. an adequate deadwood management
- stand has to provide different tree species and vital genetics to implement natural regeneration
- the mitigating effect of forests is limited to small-scale watersheds as well as small-scale flood events. The effect of flood mitigating measures in forest ecosystems are negligible in large catchments and for intense flood events (CALDER, 2007)

BP PF3 Implementation of a resource-friendly exploitation system

The intensive use of heavy machinery for timber harvesting has harmful impacts on the forest soils. Depending on the soil texture and precedent moisture conditions the soil may suffer surface compaction or even ground seepage. Surfaces that experienced such disturbances by intensive forest operations are not likely to recover on the short or mid-term scale. Klaes et al. (2016) showed that the textual and structural soil disturbances as a result of timber harvesting with heavy machinery are still significant after ten years of recovery on fine-textured forest soils.

Soil compaction substantially reduces the infiltration capacity. As a consequence surface run-off and erosion processes increase while the water recharge decreases. To reduce the disturbances resulting from forest operations to a minimum, an integrated forest management system has to be established to sustainably exploit the forest. Such a system includes the development of a road network, storage strips and sites as well as other elements of the exploitation, e.g. passages, retaining walls and ditches. Moreover, the exploitation system integrates skid trails that should be arranged in a predefined distance (e.g. 30m). For the development of a ressource-friendly exploitation system, the soils, the drainage patterns and the surrounding landscapes of the considered forest have to be taken into account as well (NOBLE, 1997). This system has to be implemented resource-friendly, meaning that any kind of soil disturbances, nutrient loss, water table drawdowns and cuttings of water-bearing layers have to be avoided. To do so it is crucial to adapt the date of logging to the current wheather conditions. If possible, some dates for logging should be planned in winter when the soil is frozen.

In this context, any kind of interferences in the soil system in drinking water protection zones (DWPZ) should be prohibited by law (e.g. part of the regulations in the inner protection zone II of Bavarian DWPZ). By reducing the disturbances of timber harvesting to a minimum, the forest and its soils maintain their ecosystem services water provision, water regulation and water quality regulation.

Advantages

- positive impacts on the ecosystem service water regulation, water provision and water quality regulation
- decreased leaching of nutrients (e.g. nitrate)
- preservation of soil stress
- fosters natural regeneration process

Challanges:

- measure implementation requires a comprehensive planning process

BP PF4 Establishment of an adequate deadwood management

The presence and leaving of deadwood in forest ecosystems plays an important role for the biodiversity. Therefore it was proposed and has been accepted as an indicator for biodiversity on the pan-european level (GOVIL, 2002). In Bavaria, the establishment of an adequate deadwood management in state-owned forests is regulated by law, whereas this implementation is still voluntary in privately owned forests.

Deadwood provides a rich source of nutrients that is continuously released in the process of its decomposition. In particular carbon, calcium and magnesium are provided. In this way, on the one hand this management practice enhances the formation of humus and on the other hand improves the silvicultural productivity. Moreover, deadwood represents an important habitat and ecological niche for several micro- and macroorganisms, e.g. fungus-types, bacteria, different woodpecker species and owls, and thus enable a species-rich ecosystem.

Deadwood is an integral part of the soil development process. While fostering the production of humus, deadwood directly helps to increase the water storage capacity of the uppermost soil layer. A thick humus-layer on the one hand enhances the purification of seepage water and on the other hand increases the water storage capacity of the soil. Hence, an adapted deadwood management enhances the ecosystem functions water provision, water regulation and water quality regulation. Moreover, deadwood locally regulates the microclimate and helps to keep the living conditions near the soil surface more constant (SCHIEGG PASINELLI et al., 2002). In terms of soil degradation, deadwood also locally hinders erosion processes and inhibts the outwash of nutrients and soil particles.

The advantages of an adequate deadwood content go beyond its direct impacts on the water-related ecosystem functions. In fact, it also positively affects other forest management practices, e.g. natural regeneration. The natural regeneration of spruce, fir and swiss stone pines has been proved to be very effective on deadwood (SCHIEGG PASINELLI et al., 2002). Additionally, deadwood helps to protect the young stands from browsing by game making the natural regeneration process more efficient.

The ecologically-valuable properties of an adequate deadwood content are prerequisites to obtain a stable, vital and especially resilient forest which can fulfil its protective function.

Advantages:

- positive impacts on the ecosystem services water regulation, water provision, water quality regulation
- provision of nutrients and thus improvement of silvicultural productivity
- protective function from browsing by game of young stands

- coupling with other measures (e.g. natural forest regeneration of mixed-forests) can enhance the effect of an adequate deadwood management

Challenges:

- may hamper logging procedure
- may enhance the vulnerability to bark beetle infestations and forest fires

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
BP PA1	High	Low	Low	Low
BP PA2	High	Middle	Low	Low
BP PA3	High	Middle	Middle	Low
BP PA4	Low	High	Middle	Middle
BP PA5	Middle	Middle	Low	Middle
BP PG1	High	Low	Low	Low
BP PF1	High	Middle	High	High
BP PF2	High	Low (if stand comprises adequate tree species)	High	High
BP PF3	High	Middle-High	Middle (depending on preconditions)	Middle
BP PF4	Middle	Low	Middle	Middle

5. Special sites

5.1 Dry areas

5.2 Riparian strips

BP SR1 Implementation of extensively-used grasslands

Riparian strips represent sensitive ecosystems due to their natural interface between the catchment area and the river system. These strips are either affected by the dynamics of the adjacent river or the inflow from the catchment or even both. These strips represent sensitive areas especially in drinking water protection zones of river bank filtrate extraction plants.

An adapted land use management of these sites is of vital importance to keep or even to improve their protective function during flood events and low water discharge as well as their potential to purify the inflow coming from the catchment area and to regulate the diffused discharge of nutrients into the river.

Extensively used grasslands represent good land use options for riparian strips. To maintain the ecosystem service water quality regulation of riparian strips the use of fertilizers and pesticides should be prohibited for riparian strips. Due to the proximity and connectivity to both the river and bank filtrate extraction plants these substances can quickly be transported towards one of them. To provide further protection the plowing up of these sites has to be prohibited. In this context, an intensive grazing has to be avoided as well since livestock excretions may provide sources of contamination as well. Grazing should be limited to one or two times a year.

By avoiding intensive grazing on these sites a destruction of the turf by cattle treading can be reduced. To prevent riparian strip grasslands from further degradation the tillage with heavy machinery should be prohibited. Thus, the soil loosens its structure which improves the infiltration capacity as well as the water retention capacity. These processes are additionally enhanced through the root zone of the turf. A dense turf also provides a protection function against soil aggregate destabilization, surface sealing, erosion processes and evaporation losses. Since grasslands typically have a high surface roughness they serve as a momentum sink for overland flow and thus improve the eocsystem service water regulation.

Moreover, the organic matter content of the topsoil on grassland sites favors the water storage capacity and the process of water purification. By avoiding an intensively use of grasslands in raparian strips the acitivity of soil organisms is encouraged and keeps the bioturbation on an adequate level (BAUCHHENß, 2005). Bioturbation positively affects the soil (aggregate) structure; it improves the connectivity of macropores and enhances the water storage and infiltration capacity (SCHEFFER et al., 2010). Additionally, the intensity of bioturbation positively correlates with the distribution of macropores which in turn is crucially important for the water storage and water retention capacity of the soil system. An incease of interception and transpiration losses on grasslands in general counteract the ecosystem service water provision but do positively affect the water regulation function.

Advantages

- positive impacts on the ecosystem service water provision, water regulation and water quality regulation
- preservation of soil stress and recovery of (physical) soil properties
- increasing activity of soil organisms enhances the soil (aggregate) structure, the connectivity of water paths and decomposition processes
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)
- decreased diffused discharge of nutrients (e.g. nitrate)

Challanges:

- need for scarification to avoid hydrophobic effects of matted roots (SCHOBEL, 2005)
- economic efficiency depending on production emphasis of the farmer

BP SR2 Conversion of intensively-used riparian strips to short-rotation plantations (SRP)

Short-rotation plantations (SRP) are extensive agricultural land use measures which mainly serve for the production of firewood. The plantation focus is principally based on fast-growing tree species, such as poplars or willows, which are ready to harvest in between 3 to 8 years depending on the site and species characteristics. Moreover, SRP sites do not need the use of fertilizers to increase the productivity. At harvest, the trees are cut near the soil surface leaving a small part of the trunk. This trunk rest puts out new shoots in spring time so that a new sowing as well as tillage are not required. The new shoots benefit from the existing root structure of the harvested stand since the existing root network simplifies the nutrient and water uptake (ZACIOS et al., 2011).

A use of heavy machinery is only required at the initial phase for site preparation from intensive agricultural use to SRP sites as well as for the harvest. Moreover, SRP plants create a deeper-reaching root system due to their longer growth phases compared to annual crops. Thus, the root system of SRP plants also develops in soil layers under the former plowing depth and loosens up the whole soil structure. Thanks to less soil compaction, the prevention of soil tillage and a high availability of organic matter an increase of activity of soil organisms, e.g. earthworms, is favored. These structural changes of the soil system can improve the water storage capacity of the soil as well as the water transferability to depper soil layers (ZACIOS et al., 2012, ZACIOS et al. 2015).

The interception and transpiration losses generally increase as a consequence of the land use change due to a dense and continuous vegetation cover, increased water uptake from deeper soil layers and greater leaf areas (e.g. of poplars). Hence, the conversion to SRP sites is positively affecting the ecosystem service water regulation. Moreover, the canopy cover reduces the particle detachment through splash effects while the understorey vegetation increases the retention of already detached sediments. Both, the canopy cover and the understorey vegetation prevent the water body as well as a near water extraction plant (e.g. bank filtration) from an oversupply of nutrients and thus contribute to the water quality regulation (ZACIOS et al. 2015).

Advantages:

- positive impacts on the ecosystem services water regulation and water quality regulation
- preservation of soil stress and recovery of (physical) soil properties
- decreased use of production inputs (e.g. synthetic pesticides, fertilizers)
- decreased diffused discharge of nutrients (e.g. nitrate)

Challenges:

- enhancing the ecosystem service water provision
- implementation costs
- economic efficiency depending on production emphasis of the farmer

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
BP SR1	High	Middle	Middle	Middle
BP SR2	High	Middle	Middle	Middle

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