PROLINE-CE

WORKPACKAGE T1, ACTIVITY T1.2

REVIEW OF BEST MANAGEMENT PRACTICES FOR DRINKING WATER SUPPLY ISSUES

D.T1.2.1 Country-specific best management practice reports

AUSTRIA

February, 2017

Contributors, name and surname	Institution
Elisabeth Gerhardt *	Federal Research and Training Centre for Forests, Natural Hazards and Landscape
Hubert Siegel *	Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management; Forest Department
Roland Koeck *	University of Natural Resources and Life Sciences, Vienna (BOKU), Department of Forest- and Soil Sciences, Institute of Silviculture
Christian Reszler *	JR-AquaConSol, Joanneum Research company
Gerhard Kuschnig *	Municipality of the City of Vienna, MA 31 – Vienna Water

* shared first authorship

Content

1. 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 . The Best Practice Catalogue is partially derived from the SEE project CC-WARE and further projects respectively studies.

Best management practices are divided into the three clusters according to WP T2 (Pilots) and contain a general description, advantages and challenges of the respective measure. Each measure is evaluated due to its respective water protection functionality, costs, duration of implementation and time interval of sustainability.

The name of best practice measure is created by the first letters of the respective cluster and its subcategories (for example BP MF1 – Best practice for mountain region, subcategory forest). If the relevant measure also fits to another cluster the respective additional valid cluster is added with brackets.

2. Mountain sites

2.1. Forest

2.1.1. BP MF1 Avoidance of the clear-cut technique

Description of the measure

The clear-cut technique (CCT) as silvicultural measure for timber yield and subsequent artificial recruitment techniques does not conform with water protection requirements, as it can cause contaminations of the aquifer or streams with nutrients and solid matter mobilized from plant, humus and soil compartments. Additionally CCT creates top-soil drought conditions, what causes water repellency of the soil and humus layers. Water repellency of the top soils increases surface runoff processes and hence is in contradiction to flood mitigation and also decreases groundwater recharge.

Measure advantages

Avoidance of CCT opens the path for a consistent water protection strategy. It assures the avoidance of the most threatening processes caused by forestry in terms of drinking water protection and flood prevention.

Challenges

The resistance of foresters towards the avoidance of CCT may be very strong, as CCT can be regarded as the most important silvicultural system applied in timber-yield forestry in Austria. It will need a lot of knowledge transfer strategies to convince foresters in Austria about this step.

2.1.2. BP MF2 Establishment of a Continuous Cover Forest System

Description of the measure

Continuous Cover Forest System (CCF) ensures a sustained provision of the forest functions for drinking water protection and flood prevention. The forest stands of CCF are multi-layered, uneven-aged and built up by the potential tree species diversity of the specific forest site. Forest management activities have to be applied on small spatial scales hence supporting a low disturbance regime. CCF forms an excellent basis for drinking water protection and flood prevention.

Measure advantages

CCF as true alternative to the clear cut technique provides the basis for a consistent strategy in forestry with the overall purpose of drinking water protection and/or flood prevention. It ensures the water protection functionality of forest ecosystems over space and time.

Challenges

In Austria the application of CCF requires in most of the cases specific training, as the majority of foresters are used to apply the clear cut technique. PROLINE_CE can provide such as first step in the course of the stakeholder workshops.

2.1.3. BP MF3 Defined Crown Cover Percentage of Forest Stands

Description of the measure

The actual given crown cover percentage of forest stands has to range between 70 % and 90 % in colline to montane areas and between 60 % and 80 % in subalpine areas. This guarantees a high degree of stability towards disturbances like wind storms and additionally provides enough space and light for a continuous regeneration process. Mobilization processes in soil and humus layers are kept on a low level and it can be regarded as basic requirement for the establishment of CCF and for the sustained provision of the water protection functionality of forest ecosystems.

Measure advantages

The defined crown cover percentage for forest stands provides a clear frame for forestry in DWPZ. It is a very important BP and helps to secure the water protection functionality of forest ecosystems (together with other BP’s).

Challenges

As timber production was and is the overall purpose for most of the Austrian forest regions, this BP can create discussions among foresters, as it requires a fundamental change in silvicultural concept and measure application.

2.1.4. BP MF4 Limitation of the Percentage of Timber Extraction

Description of the measure

The limitation of the percentage of timber extraction with 10-25 % of the forest stand volume during each silvicultural measure guarantees a low disturbance regime in forested DWPA. It helps to sustain stability of the forest stands and has to be applied together with the margins for crown cover percentage (BP MF3). The cutting frequency has also to be integrated.

Measure advantages

The limitation of the percentage of timber extraction has the great advantage that together with the application of BP MF 3 the sustained stability and resiliency of the forest stands and forest ecosystems can be facilitated. This is a basic condition for the protection of drinking water resources and from floods.

Challenges

Again the habitual management procedures in Austrian forestry will be an obstacle for the application of this BP, as it requires from the foresters a fundamental shift of timber yield patterns. Drinking water protection as overall purpose is still rather new and unknown for most of the foresters in Austria.

2.1.5. BP MF5 Continuous Regeneration Dynamics

Description of the measure

Forest stands in DWPZ have to host a continuous regeneration phase on minimum 10-20 % of their spatial extension. This ensures the highest degree of resilience, as in case of disturbances the water protection functionality of the forest can be restored the fastest way. Continuous regeneration is a basis condition for CCF, as it provides the basis for uneven-aged forest stands. In case of natural forest stands it also ensures the natural regeneration of autochthonous genetic material, which is of crucial importance for stability and resilience, especially under climate change.

Measure advantages

Continuous regeneration dynamics provide a basic condition for forest ecosystem stability and resiliency. Only if young trees can grow without hindrances in all forest stands and ecosystems, the system stability and also the water protection functionality are given on a high level.

Challenges

In Austria the high wild ungulate densities are the greatest threat for a continuous regeneration dynamic. Browsing damages occur wide spread and also several DWPZ are affected. To solve this issue is a true challenge, as the hunter organisations have a strong lobby and do not want to have significant changes, as those could affect their hunting habits.

2.1.6. BP MF6 Foster Stability, Vitality and Resilience of the Forest Ecosystems

Description of the measure

In DWPZ stability, vitality and resilience of the forest ecosystems are the most important features. Stable forest ecosystems and forest stands can resist any given disturbance. In case of strong disturbances, resilient forest ecosystems can recover their water protection functionality rapidly. The vitality of the tree individuals and of the whole forest ecosystem is the basic condition for stability and resilience.

Measure advantages

Stability, vitality and resilience are the most important features of forest ecosystems in DWPZ. Hence any activities to foster those are important for drinking source water protection and flood prevention. The purpose in silviculture moves from high quality timber trees towards stable and vital trees, what makes a definite difference.

Challenges

This change in silviculture requires again a renunciation from habitual procedures in forest management. The foresters have to be trained towards perceiving the most stable and vital trees and also towards a consequent implementation of fostering stable and vital tree individuals.

2.1.7. BP MF7 Tree Species Diversity According to the Natural Forest Community

Description of the measure

Tree species diversity according to the natural forest community guarantees the highest level of stability and resilience. Tree species diversity provides a high level of adaptability, also under climate change. Forest stands created by diverse tree species can utilize a broader scope of the forest soils, if deep-rooting and shallow-rooting trees are growing together. Knowledge about spatial distribution of the natural forest communities (forest hydrotopes) is required for the operational stratification of the DWPA and adaptive forest management. Man-made plantations with not-natural tree species should be transformed gradually to stands dominated by native species, depending on the local experience and legislation.

Measure advantages

In many Austrian forests tree species diversity according to the natural forest community is a definite advantage, as homogeneous conifer plantations are actually dominating the forests. Especially in times of climate change tree species diversity becomes mandatory for achieving forest ecosystem stability. Diversity has also positive side effects, like e.g. for conservation purposes.

Challenges

In some forest areas there can be expected resistance against tree species diversity according to the natural forest community, if the habitual forestry practices had a strong focus on conifer plantations or other homogeneous timber yield focused plantations.

2.1.8. BP MF8 Improve the structural diversity of the forest stands

Description of the measure

Forest stands in DWPZ should be structured vertically and horizontally. This involves tree species diversity as well as uneven-aged and multi-layered forest stands. Structural diverse forest stands are a basic requirement for continuous cover forest systems. Stability and resilience are improved in case of structural diverse forest stands.

Measure advantages

Structural diversity in forest ecosystems provides an improvement of forest stand stability and additionally is necessary for CCF (continuous cover forest systems). Hence it has to be followed as purpose in forest management within DWPZ to achieve structural diversity.

Challenges

As most of Austrian forest stands are based on the age-class system, structural diversity is actually not very common. Most of the forest stands are even-aged and only single-layered. The change of silvicultural practices towards structural diverse forest stands will have to involve both persuasive efforts and training of the foresters.

2.1.9. BP MF9 Forest Ecologically Sustainable Wild Ungulate Densities

Description of the measure

High wild ungulate densities provoke severe browsing damages on tree seedlings and saplings, fraying damages and bark-peeling damages. Those inhibit the natural regeneration process of whole forest ecosystems or destabilize those. Natural regeneration is the crucial process in forest ecosystems, which has to be given on an optimal level for all present tree species, especially within DWPA. This can only be guaranteed, if the wild ungulate densities are regulated to a forest ecologically sustainable level, hence providing vital regeneration of all tree species.

Measure advantages

Forest ecologically sustainable wild ungulate densities provide the huge advantage, that the forest ecosystems can evolve naturally, can grow according to their natural inner dynamics. This includes a vital regeneration layer within the forest stands, encompassing all tree species of the respective natural forest community. It is the most essential precondition for providing the water protection functionality of forest ecosystems.

Challenges

In Austria the high level of wild ungulate densities is the greatest threat for a continuous regeneration dynamic. Browsing damages occur wide spread and also several DWPZ are affected. To solve this issue is a true challenge, as the hunter organisations have a strong lobby and do not want to have significant changes, as those could affect their hunting habits. To establish forest ecologically sustainable wild ungulate densities can be regarded as the main challenge in the Austrian forest sector.

2.1.10. BP MF10 Protection of the Gene Pool of the Autochthonous Tree Species

Description of the measure

Autochthonous tree species have evolved since thousands of years in their specific forest regions. They carry the genetic information, which allowed them the survival of the past climate changes in those areas. They are the basis for the establishment of the natural forest communities (BP MF 7). Tree species diversity is dependent on them.

Measure advantages

Autochthonous tree species are the basic requirement for forest ecosystem stability. They carry a lot of genetic diversity and are the best in coping with the local climatic conditions. In times of climate change their value becomes priceless.

Challenges

In Austria in some regions it could already become difficult to find autochthonous tree species, especially in such where only Norway spruce (*Picea abies*) was planted, always using only the varieties with the greatest increment levels. Again persistence can be expected, if the change from high-timber-yield species towards more stable autochthonous species is envisaged.

2.1.11. BP MF11 Foster old, huge and vital tree individuals

Description of the measure

Old, huge and vital tree individuals carry excellent genetic information. They can supply younger and smaller tree individuals with nutrients via their common mykorrhizal network. Thereby they provide a substantial contribution to forest stand stability. Therefore they have to be selected and protected, so that they can provide their services as long as possible.

Measure advantages

The genetic information provided by old, huge and vital tree individuals has a high value for the sustainability of the forest ecosystem. Old and huge tree individuals can provide stability for the whole forest stand (in a quasi mechanical way) and are also important for the nutrition of young trees (including the regeneration phase), who may receive nutrients from the old trees via the mycorrhiza-interconnected root system.

Challenges

The old, huge and vital tree individuals have to be selected for remaining in a forest stand. In recent times huge trees in Austria are in general selected for being cut. This change of behaviour has to be achieved through information and persuasive efforts.

2.1.12. BP MF12 Adequate Dead-Wood Content

Description of the measure

In DWPZ, coarse dead-wood has to be present in each forest area in adequate quantity and quality. Coarse dead-wood is a habitat and an ecological niche for many organisms with relevance for forest stability, especially insects. Also owl species, which depend on standing dead-wood, can improve forest stand stability by controlling mouse populations. Lying coarse deadwood provides space for nurse-log regeneration.

Measure advantages

Deadwood is an important feature of biodiversity in forests as it improves the ecological conditions and hence is a pre-condition for the establishment of stable and vital forest ecosystems. Dead-wood keeps the forest ecosystems alive, as the multitude of organisms living in and on it can be explained as fundamental for the interdependencies within forests. The measure does not cost very much and the effect is strong. Besides, dead-wood also acts as water storage.

Challenges

To keep standing and lying dead-wood in forest stands is still a challenge for some foresters, as they have the tendency to yield each single tree. Again in some cases the change of behaviour has to be achieved through information and persuasive efforts.

2.1.13. BP MF13 Buffer Strips along Streams, Dolines and Sinkholes

Description of the measure

Streams are sensitive sectors in many DWPZ and hence have to be protected with highest priority. Buffer strips with dense and vital forest cover can protect the streams from direct infiltration of sediments or nutrient loads and from lateral erosion. Forest vegetation has to be stable in buffer strips and management operations have to be carried out extremely cautious. Dolines and sinkholes are karstic features and deserve the same attention like streams, buffer strips are also an adequate solution there.

Measure advantages

The protection of the stream-banks from lateral erosion processes through a vital forest cover can be regarded as the most crucial effect of buffer strips, as lateral erosion could mobilize huge amounts of soil-, gravel- and rock material, endangering both water supply facilities and human infrastructure in general. But also the protection from nutrient loads and sediments is relevant. Buffer strips along streams are one of the classical Best Practices on global scale. Additionally the shadowing effect of them on the stream is relevant for keeping the waters relatively cool.

Challenges

Actually there can be identified a trend in Austria, where Buffer Strips along streams are clear-cut. This trend has to be reversed, as the protection from lateral erosion processes is more important. The balance between driftwood prevention and preservation of the forest cover along streams has to be found, what maybe could lead to multi-dimensional discussions in some cases. The most important purpose within this context has to be the most efficient flood mitigation/prevention/protection functionality of the system Streams/Forest Ecosystems. It will have to come to a trade-off between lateral erosion prevention and drift-wood prevention. The huge threat-potential of lateral erosion processes has to be taken into account (see symbol picture lateral erosion processes, Figure 1 & Figure 2). This situation is valid for both mountain and plain (flatland) stream systems.

Figure 1. Lateral erosion processes in a steep mountain stream system where a forested buffer-strip is lacking totally. The site is situated within the subalpine forest zone, where the potential natural forest community is Birch-Forest (Betula litwinowii), symbol picture, Georgia, Kazbegi-District.

Figure 2. The same stream system in downstream-view towards a scree-cone site area. Lateral erosion processes are present since centennials and have destroyed the close village Kazbegi through mudflow in the past (symbol picture).

2.1.14. BP MF14 Adaptive Forest Management under Climate Change

Description of the measure

Climate change can alter the growth conditions for forest ecosystems significantly. For ensuring the provision of the ecosystem service (ES) ‘drinking water protection’, adaptive forest management towards climate change has to be applied. This involves a strategic procedure, where the evaluation of both climate development regarding the climate change scenarios and of forest succession has to be carried before concept-design. The concept-design of adaptive management can demand various measures like e.g. the support of the migration of certain indigenous tree species.

Measure advantages

Adaptive forest management under climate change ensures the provision of the Ecosystem Service (ES) 'Drinking Water Protection' over space and time. This is elementary for water protection issues.

Challenges

In Austria there actually can be identified various attempts to adapt forest ecosystems towards climate change. The most important fact in DWPZ is the use of indigenous tree species for reaching this goal, what could result in discussions in various cases, as there can be identified a tendency to use alien conifer or deciduous tree species for adaptation. This could be very dangerous as their stability in our climate is not proved. Hence the use of alien species for forestations or afforestations is not acceptable within DWPZ. Again in some cases information transfer and persuasive efforts will have to be applied.

2.1.15. BP MF15 Natural Forest Succession in Case of Stable Forest Ecosystems

Description of the measure

In some cases forest ecosystems already fulfil all criteria of an adequate drinking water protection forest. Tree species diversity and distribution, uneven-aged and multi-layered structure of the forests are given and stability, vitality and resilience have to be given on an optimal level. Wild ungulate densities are forest-ecologically balanced and the self-regulating force of such forest ecosystems is given on a high level. If all these criteria are fulfilled, forest management measures within those forest ecosystems can be suspended and natural succession can take place, until an urgent need for management measures implementation should arise.

Measure advantages

This measure assures a low disturbance regime for the included forest areas. This is of crucial interest for water protection. Also conservation targets can be achieved with this measure.

Challenges

It is not very common in Austria to let natural forest succession take place outside from national parks and natural forest reserves. Within DWPZ this measure could be a solution for achieving necessary goals, but again persuasive efforts will have to be applied.

2.1.16. BP MF16 Small-Scale Regeneration Techniques

Description of the measure

Within DWPZ the applied regeneration techniques have to be carried out on small-scale areas. This is an essential contrast to the clear-cut technique and supports forest stand stability during the mostly natural regeneration phase. The adequate techniques are e.g. group selection cuts, single tree cuts or small-scale gap cuts. There has to be given the balance between light-provision for the regeneration of the forest trees and the stability of the remaining forest stand.

Measure advantages

Small Scale regeneration techniques like single tree cutting, small gap cutting or group selection system assure a low disturbance regime within the context of forest management measures and give advantage of the natural seed regeneration. This allows and supports the overall purpose of drinking water protection. The remaining forest stands can be kept in stable conditions and the conditions for natural or artificial regeneration dynamics are created.

Challenges

Small scale regeneration techniques are in the clear-cut country Austria not very common, but in general well known. In some DWPZ they are common (City of Vienna) or have been tested (in Waidhofen/Ybbs during the project CC-WaterS). The need to apply them within DWPZ will have to encompass information transfer and persuasive efforts.

2.1.17. BP MF17 Structural Thinning Operations

Description of the measure

In order to create uneven-aged and multi-layered forest stands, *structural thinning* can be applied. The focus is on the improvement of forest stand stability. Stable trees remain and unstable ones are removed. The structure of the forests is improved in terms of the creation of uneven-aged and multilayered stands with a wide diameter-distribution. The spatial distribution of the thinning measures is determined by the improvement of structure and stability within the forest stands. The structure of the forest stands should be given on a horizontal and vertical level. Also the tree species diversity according to the forest hydrotope type (natural forest community) has to be given and hence is facilitated by structural thinning.

Measure advantages

Structural thinning can create more stable forest stands by widening the diameter-distribution, by the way increasing the age-distribution and structural diversity of them. This supports forest stand stability and resiliency and facilitates the establishment of the intended continuous cover forest system (CCF).

Challenges

Structural thinning is not very well known in Austria's forestry enterprises and hence will need to be teached to foresters.

2.1.18. BP MF18 Artificial Recruitment Techniques

Description of the measure

Artificial recruitment techniques become necessary in cases, if the natural regeneration dynamics do not provide adequate results in terms of tree species composition and/or of quantity of tree seedlings and saplings. It is mandatory to use autochthonous plant material in order to maintain forest stand stability in a sustainable way. Artificial recruitment may also become necessary as measure under climate change, if migrating tree species have to be supported.

Measure advantages

Artificial recruitment techniques are in some cases the only way to establish regeneration phases within forest ecosystems. Hence they are an indispensible factor for the facilitation of stable forest ecosystems. It never can be excluded that there arises the need for the application of artificial recruitment techniques. It is of crucial importance to use only indigenous tree species according to the forest hydrotope type (natural forest community) for planting.

Challenges

Artificial recruitment techniques are very well established in Austrian forestry hence their application should be easy. The use of indigenous tree species only will provoke in some cases discussions – these have to be lead with the purpose of transporting the cornerstones of source water protection through adaptive forest management.

2.1.19. BP MF19 Forest Fire Prevention

Description of the measure

Forest fire prevention is of vital interest for the integrity of forest ecosystems, especially if they are providing a continuous protection of drinking water supply. Climate change and other challenges threaten forests and their protection and production functionality. According climate change simulations forest fires could increase in future. For this reason it is necessary that forest management practices address principles that ensure fire prevention. Fire prevention measures require attention from all authorities, especially from those responsible for forest management. Forest fire prevention does not only protect life, environment and natural heritage, but in most cases is the most effective strategy to reduce damages.

Measure advantages

As the effects and impacts of forest fires are disastrous for the water protection functionality of forest ecosystems (both for drinking water protection and for flood prevention), forest fire prevention becomes crucial for DWPZ. Especially in countries with a high risk of forest fires this is of prior importance, but also other countries like Austria have to be aware about the threat of forest fires and should have prevention and mitigation concepts available.

Challenges

As Austria is a quite humid country, the forest fire prevention concepts are not that wide spread like e.g. in Mediterranean countries. Despite this fact the forest fire preventions concepts and strategies have to be elaborated for DWPZ.

2.1.20. BP MF20 Limitation of Forest Roads

Description of the measure

Forest Road construction and maintenance can cause several adverse impacts on water bodies and should hence be limited in DWPZ. The increase of surface runoff and of water storage loss is the main negative effect. Only in cases, if forest roads are necessary for the stabilization of forest areas, their construction could be considered. In those cases their construction has to meet strict environmental restrictions.

Measure advantages

For avoiding potential contaminations and hydrological adverse impacts caused by forest roads, the limitation of their construction within DWPZ is an indispensible need.

Challenges

In Austria forest roads and their construction is a cornerstone of “normal management situations”. Foresters love to construct forest roads. Hence it is very difficult to convince them about the need of abstaining from constructing them. Focused information transfer and persuasive efforts will have to be applied.

2.1.21. BP MF21 Adequate Timber Yield Techniques

Description of the measure

In DWPZ the applied timber yield techniques should prevent the disturbance of the soil- and humus layers. In the case of mountainous forest sites the application of the cable-crane system or animal-traction systems is recommended. The tractor-skidding method should only be applied in exceptional cases and the soils must then be frozen or dry. With the cable-crane system the assortment-technique (cut to the length method) has to be applied and the whole-tree harvesting method has to be avoided. In flat areas the tractor-skidder method has to be applied in times when the soils are frozen.

Measure advantages

The application of adequate timber yield techniques has the advantage that the soil and humus layers are kept in desirable conditions, by the way providing the full level of forest ecosystem services “water protection”. Also the remaining forest stand can be kept stable.

Challenges

In many cases there will be a tendency to apply the cheaper tractor-skidding method, also in steep terrain. This will have to be opposed, as within DWPZ only the water protection functionality and the ways to protect this should be followed. Again focused information transfer and persuasive efforts will have to be applied.

2.1.22. BP MF22 Prohibition of the Use of Chemicals in Forestry Practices

Description of the measure

Chemicals like fertilizers, pesticides or herbicides are substances which form a threat for water quality and hence should not be present in forested DWPA. In forests their use is generally only marginal. Despite this fact their use has to be prohibited within forested DWPA. The absence of the application of those chemicals is a crucial advantage of forested watersheds in contrast to agriculturally used ones.

Measure advantages

Pesticides and other agro-chemicals form a strong threat for source water quality in agriculturally used watersheds. The absence of the application of those chemicals is a crucial advantage of forested watersheds in contrast to agriculturally used ones. Hence this measure has to be applied with ultimate consequence.

Challenges

In Austria the application of chemicals in forestry is rare, but in some cases present. Within DWPZ the use of chemicals is in general prohibited. If this should not be the case, focused information transfer and persuasive efforts will have to be applied.

2.1.23. BP MF23 Source Water Protection Policy and Institutional Implications

Description of the measure

In Austria, like in most of the CE partner countries were identified substantial administrative deficits in legislation within the context of the protection of DWPZ and source water quality and quantity. An integrated source water protection policy (SWPP) has to integrate all potential impact factors on water resources. The establishment of an adequate legislative and administrative frame would be a fitting outcome.

Measure advantages

Integrated source water protection policy takes all potential drivers, pressures and impacts on drinking water resources into account and defines routines for adequate response. This results in an encompassing drinking water protection and flood prevention/mitigation policy, which secures water resources.

Challenges

In Austria the PROLINE-CE output DriFlu Charta will form a step towards the elaboration and implementation of such an integrated source water protection policy.

2.1.24. BP MF24 Integrative Planning Strategy for Watersheds (Forest Ecosystems with drinking water protection as focus)

Description of the measure

The operative activities within watersheds (DWPZ) need a detailed planning process in order to be efficient. The water protection functionality (WPF) of the forest ecosystems has to be given over space and time. Deviations from an optimal WPF have to be detected by the screening of the current forest dynamics (monitoring). A GIS-based integrative planning strategy provides an efficient schedule for improving or maintaining the WPF of the forest ecosystems. Integration of all relevant impacts on source water protection into the planning strategy is required. The implementation of an adequate watershed classification according to the regional indicators, like e.g. vulnerability of the local ecosystems, tree species sets, etc. have to be set up for each DWPZ.

Measure advantages

The integrative planning strategy would establish a structured and operative tool for well established management for DWPZ.

Challenges

The establishment of an integrative planning strategy in DWPZ would need the commitment towards such. It would be a huge step for the Austrian drinking water protection sector.

Table 1. Forests-AT: Relevance of the measures

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
"Avoidance of the clear-cut technique"	High	Low	Long Term	Long Term
"Establishment of a Continuous Cover Forest System"	High	Medium	Long Term	Long Term
"Defined Crown Cover Percentage of Forest Stands"	High	Medium	Long Term	Long Term
"Limitation of the Percent-age of Timber Extraction"	High	Medium	Long Term	Long Term
"Continuous Regeneration Dynamics"	High	Low	Long Term	Long Term
"Foster Stability, Vitality and Resilience of the Forest Ecosystems"	High	Low	Long Term	Long Term
"Tree Species Diversity According to the Natural Forest Community"	High	High	Long Term	Long Term
"Improve the structural diversity of the forest stands"	Medium	Medium	Long Term	Long Term
"Forest Ecologically Sustainable Wild Ungulate Densities"	High	Medium	Long Term	Long Term
"Protection of the Gene Pool of the Autochthonous Tree Species"	High	Medium	Long Term	Long Term

“Foster old, huge and vital tree individuals”	High	Low	Long Term	Long Term
“Adequate Dead-Wood Content“	High	Low	Long Term	Long Term
“Buffer Strips along Streams, Dolines and Sinkholes”	High	Medium	Long Term	Long Term
“Adaptive Forest Management under Climate Change”	High	High - Medium	Long Term	Long Term
“Natural Forest Succession in Case of Stable Forest Ecosystems”	High	Medium	Long Term	Long Term
“Small-Scale Regeneration Techniques“	High	Low	Long Term	Long Term
“Structural Thinning Operations“	Medium	Medium	Long Term	Long Term
“Artificial Recruitment Techniques“	High	High	Long Term	Long Term
“Forest Fire Prevention“	High	High	Long Term	Long Term
“Limitation of Forest Roads“	High	Low	Long Term	Long Term
“Adequate Timber Yield Techniques“	High	High	Short Term	Medium Term
“Prohibition of the Use of Chemicals in Forestry Practices”	High	Low	Long Term	Long Term
“Source Water Protection Policy and Institutional Implications”	High	High	Long Term	Long Term
“Integrative Planning Strategy for Watersheds (Forest Ecosystems with drinking water protection as focus)	High	High	Long Term	Long Term

2.2. Grassland

2.2.1. BP MG1 Establishment or enhancement of grassland by regeneration process

Description of the measure

Alpine ecosystems are characterised by unfavourable climatic conditions with limiting effects on growth and bio-mass production of plants that are increasing with altitude. At an altitude of 2000 m, the number of growing days (average daily temperatures > 5°C) is reduced to 67 days. In alpine environments, vegetation has therefore a growing season of two to three months to establish. Because of the limited growing period, restoration activities at high altitudes should be carried out the first weeks after snow melt. The results of investigations on climatic site conditions indicate that large scale interventions and thus restoration with seed mixtures generally should be avoided above altitudes of 2.400 m.

Above timberline, more dense vegetation with a cover of about 80 % is recommended. Therefore, a sufficient combination of application technique and adapted seed mixture, reaching the minimum requirement of sustainable vegetation with 70 to 80 % cover within the first two vegetation periods has to be the goal behind restoration in high altitudes. Under average conditions of high altitudes the necessary minimum demand on cover can be achieved in the second vegetation period at the earliest. This requires application techniques with sufficient protection of top soil for the first two vegetation periods.

The best protection against erosion can only be reached by additional cover of the top soil with straw mulching, hay mulching, different mats, nets, three-dimensional mats etc. causing a clear decrease of superficial soil losses and water flow rate.

Measure advantages

One of the most severe problems within recultivation works in mountainous areas (with 30-45% slope gradient) is the increased surface run-off and soil erosion (B. Krautzer, AREC). Seeding procedures with adequate protection against erosion are important requirements for a successful revegetation. Without the adequate cover of the top soil indigenous and fast-growing species show a comparable bad erosion-behaviour within the first 4-8 weeks after seeding.

In view of an economic evaluation, the set up costs indicate that commercial seed mixtures would be much cheaper than seed mixtures including indigenous species. But when looking at the years following the set up the sites that use commercial seed mixtures have to calculate with follow up costs (reseeding and steady fertilisation). So in the long term in order to reach a sustainable restoration the use of indigenous species is meaningful not only from an ecological but also from an economical standpoint.

Challenges

Within the whole alpine area, thousands of hectares are affected every year, e.g. by ski slopes, ski lifts, tourist infrastructure, improvement of alpine pastures and roads. After intervention, those areas are re-seeded and normally used as pastures. Such areas, mainly within the sub-alpine and alpine stage, are one of the most sensible parts of the Alps. Every intervention in such alpine living spaces leads to interference that requires different technical and ecological measurements to reach the goal of a sustainable restoration of those affected areas. This can only be reached with the help of indigenous plant material. For want of indigenous vegetation, seed mixtures have to be used in most cases.

On 8 localities of the Alps, in different altitudes from 1.230 m to 2.340 m, the research project "Seed Propagation of Indigenous Species and their Use for Restoration of Eroded Areas in the Alps" (FAIR CT98-4024, short title "ALPEROS"), supported by the EC, was carried out in order to assess the possibilities to restore damaged areas using a combination of improved application techniques combined with seed mixtures of indigenous species.

To get basic information about the effects of different application techniques on superficial soil losses and water flow rate, a mobile erosion facility with three chambers was built up at the location Hochwurzen (1,830 m ASL) in order to measure erosion in dependence on different application techniques after restoration.

2.2.2. BP M(P)G2 Establishment or enhancement of grassland by sowing or planting

Description of the measure

Only autochthonous or regional seed from the natural surroundings of the respective construction project is optimally adjusted to the specific site conditions. As it usually origins from high-quality crops rich in species, it generates an especially dense, dynamic and powerful root system. The choice of the target vegetation must be based on the natural vegetation of the site to gain ecological stability and ensure a higher resistance to environmental stress and diseases and reducing therefore the maintenance demands and costs.

Measure advantages

Due to the especially dense, dynamic and powerful root system an optimal protection against soil erosion and the improvement of biodiversity can be guaranteed. Technical functions of primary importance in terms of the stabilisation properties of plants in the frame of soil and water bioengineering interventions are:

- Covering of the ground using plant communities as protection against heavy precipitation, soil erosion by water and wind
- Mechanical anchoring and buttressing of the soil by the roots.

- Cohesion and stabilisation of the soil trough the aggregation of soil particles by plant roots, humus, mycorrhizae and micro-fauna as well as interlocking or anchoring of topsoil and subsoil and prevention of the washout of fine material through their retention and filtering by the network of fine roots.
- Slowing down and diverting air and water flow. Effects in the area of the root, in particular compression through the increase in root thickness, soil loosening due to movement of the root system induced by the movement of the stem and branches and soil compaction due to the weight of the vegetation.
- Increase in overall soil cohesion through the extraction of water by evapotranspiration
- Positive management of the local and regional water balance trough the evaporation of soil water, retention of precipitation water, retention of soil water and balanced water infiltration.

But in areas with no or only little vegetation in gullies and other drainage channels intensive rainfall events may cause strong surface run-off causing intense erosion. That is why a dense vegetation cover is needed as associated with complementary measures to increase the roughness of the surface. A suitable coverage with vegetation such as wood, bushes and hedges can be used to regulate the water regime particular in extreme or very disturb sites like gullies, steep slopes or other erosion prone areas. The impact of these bioengineering measures can be especially important in catchments which are situated above an area of flood risk as well as a catchment belonging to hydro-dam and other constructions of water supply.

Challenges

Research on grassland farming in the alpine area exists in Austria since 1889. After successful breeding of cultivars of forage crops, a comprehensive programme for breeding of grasses and legumes for the use in seed mixtures for permanent grassland has been started. Additionally, also a programme for the propagation of seed of alpine and subalpine ecotypes for erosion protection and landscaping has been conducted.

One result of these efforts is the launch of a special cultivar. A number of indigenous species have been selected during the last years, optimising the production and harvesting technique for successful seed production.

The slow growing rate of the alpine grasses and forbs, their subsequently low competitive capacity and their susceptibility to fungal diseases make seed production difficult in context of organic farming. Therefore, 18 subalpine and alpine grasses, legumes and herbs have been selected by means of intensive research procedures, to be propagated and used for high zone restoration.

In Austria indigenous seed mixtures for different altitudes and site conditions are available on the market.

2.2.3. BP M(P)G3 Supporting guidance for creation of low-input grassland to convert arable land at risk of erosion or flooding

Description of the measure

The purpose of this Best Practice is to establish a new sward by sowing a low productivity grass mix containing at least four flowering species. The sward has to be established before beginning of June (in the first year) – sawing in spring or autumn. The wildflower mixture should be made up of autochthonous species. At least 15 per cent of the mixture should be herbs and the rest grasses.

Grazing animals are good at creating variety with their trampling, dunging and eating. Grazing should be at light to moderate levels to keep the sward at a range of heights and to allow some plants to flower. A way to create as diverse habitats as possible and to consider as many species as possible is „rotational grazing", which means a spatial and temporal change of grazed and un-grazed areas. Where no stock are available to graze, grassland should be cut (not before mid of August) to a height between five and ten centimetres.

Measure advantages

The benefit of this BP is the improvement of soil and water quality as well as biodiversity within arable fields which are prone to flooding and / or soil erosion. The grass area should be located within fields or areas at risk to help prevent soil erosion. For example:

- particularly long uninterrupted slopes
- field valleys, low corners or other areas which tend to concentrate run-off
- light soils (with a relatively high sand or silt content) tend to be more prone to erosion particularly those with a low organic matter content
- areas which drain directly to a watercourse will be of greater risk of transferring eroded soil to the watercourse
- areas with flooding risk (adjacent to watercourses)

Challenges

In Austria the so-called "Austrian Agrarian Environmental Programme" ÖPUL for environmentally friendly management of agrarian land provides a funding system for certain sustainable measures:

- Protection, restoration and conservation of biodiversity also in Natura 2000 sites, endangered or rural areas, land management with high nature value
- Enhancement of water management incl. manure management and pesticides
- reduction of soil erosion, enhancement of soil management

- reduction of emissions from agriculture (through site-appropriate cultivation, reduction of fertilisation, field-related fertilisation accounting in combination with soil samples, compulsory participation at trainings)
- promotion of carbon storage in agriculture and forestry
- Nitrate Action Plan 2012: regulation of nitrate-fertiliser
- Promotion of buffer strips, especially along water courses to avoid erosion and pollution through nutrients
- Groundwater 2020 (in Upper Austria): comprehensive protection of groundwater sources and the respective funding of sustainable land use management measures

2.2.4. BP M(P)G4 Weed control in particular against invasive plant species

Description of the measure

Invasive plant species are considered as one of the major threats to biodiversity. They can reduce yields from agriculture, forestry and fisheries, are known to decrease water availability and to cause land degradation. They suppress native plants that play an important role in binding soil with their roots and may thereby contribute to increased soil erosion. The main identified costs in Europe comprise eradication and control costs and damage to agriculture, forestry, commercial fisheries, infrastructure and human health. Comprehensive management measures against these invasive plant species have to be pursued continuously by all countries to minimize their expansion.

Measure advantages

Through intensive destruction of invasive species, especially plant species as they are most important concerning water resources protection and flood mitigation, native species can spread over their original range and provide again the necessary ecosystem services (e.g. minimizing soil erosion and land degradation, improvement of water quality).

Challenges

The REGULATION (EU) No 1143/2014 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species has been implemented in national law since 1st January 2015 and is to be applied directly. A surveillance system and official controls need to be implemented as well as management of invasive alien species that are widely spread.

The prevention and control of invasive plant species in Austria is organized and managed by the nine federal provinces. Based on the nature protection laws, several institutions offer information tools and practical instructions as well as special courses and trainings (e.g. OEWAV, Mountain and Nature Protection Associations and public bodies). Numerous projects are being implemented in practice.

In Austria several guidelines, directives, regulations, action plans, management plans, Funding Programmes (Life+, Leader, Rural Development Programme 2014-2020, Framework Programmes, Environmental Programmes (e.g. ÖPUL in Austria), information campaigns and initiatives, specific regional and national projects are actually conducted. Main goal is the optimization of existing legal instruments and tools for implementation and monitoring together with voluntary measures, but clearing invasive alien species is an expensive business.

Some Best practice examples in Austria:

- **Effective management in Carinthian nature parks** „Dobratsch and Weißensee" against *Fallopia japonica* and *Impatiens glandulifera*. The priority initiative in co-operation with "ARGE Naturschutz" is relevant for the protection of biodiversity. Management plans include repressing of invasive plants, public awareness and voluntary measures (articles in newspapers, municipality newsletters, and clear directions for disposal).
- **School initiatives (science practice) in District Liezen (Styria)** together with Mountain and Nature Rescue Service, Styrian Society of Nature Conservation, Austrian Service for Torrent and Avalanche Control, District Office, local municipalities. The annual activities include active management, monitoring, research activities, documentation, public awareness, information brochures, science in school activities (outdoor activities, matriculation projects, internships and information workshops).
- **LIFE Nature Project "Gesäuse"** (Styria, Enns valley):
- The **LIFE project „Flusslandschaft Enns"** (2011-2015): "Conservation strategies for forests and torrents in the region ´Gesäuse´ incl. management of invasive plant species (especially Impatiens glandulifera) forms the starting point of the renaturation of the river Enns. The management plan for invasive species was implemented at the different river sections with ongoing activities.
- **LIFE+ Project Ausseerland** (http://www.bundesforste.at/natur-erlebnis/life-projekt-ausseerland.html); management plan for invasive plant species

2.2.5. BP M(P)G5 Reduction of nutrient inputs into water resources

Description of the measure

Due to land use management measures within grassland/agricultural areas concerning adequate fertilisation, especially adjacent to water courses and lakes, water pollution through nutrients can be mostly prevented. Following measures should be considered: optimum timing of application, reduction of fertiliser-amount, special techniques of application, avoidance of soil compaction, and maintenance/establishment of a dense grass sward.

By means of indicator plants the specific site status can be identified (A. Bohner, AREC). Changes of site characteristics as well as wrong fertilisation and cultivation measures can be recognised at an early stage. Site specific improvement measures and the adequate demand for fertilisation can be estimated accordingly.

Measure advantages

Through suitable cultivation measures within arable and grassland areas losses of nutrients (e.g. phosphorus) to the groundwater and surface water can be reduced and the respective water quality will be improved.

Challenges

In the framework of the INTERREG IV project "Gewässer-Zukunft" (2009-2013) – "Water-future: reduction of nutrient inputs into surface waters in the cultural landscape of the Bavarian and Austrian foothills of the Alps" a sustainable improvement of the water quality of river ´Antiesen´ in Upper Austria was envisaged. To reach this target, phosphorus inputs from agricultural used areas have to be reduced. Most of the grassland soils investigated exhibit very low levels of CAL-soluble phosphorus. Arable land, cropped with cereals, maize or oil plants (rapeseed, flax), has on average higher contents of CAL-soluble phosphorus in the topsoil than grassland. In the agricultural used soils, the levels of water-soluble phosphorus in the uppermost 15 cm are sometimes very high, increasing the risk of greater phosphorus losses in surface runoff in dissolved form on slopes.

Within the INTERREG IIIA project "Nachhaltige Landwirtschaft in der EU Regionalen Seenlandschaft" (2004-2007) – sustainable fertilisation of drained grassland areas in the EU Regio-Alpine upland lake landscape was developed. The primary aim of this study was to develop suitable measures to reduce losses of phosphorus from agricultural used soils to the groundwater and to the surface water in the catchments of Mondsee, Irrsee and Waginger-Tachinger See. In the study area grassland is a very important land-use pattern. Therefore, phosphorus losses from grassland by surface runoff are prevailing. In order to minimize these phosphorus losses the optimum timing of fertilizer application, the avoidance of soil compaction, and the maintenance or establishment of a dense grass sward without gaps are important measures. On sites very susceptible to leaching and surface runoff – especially nearby surface waters - measures such as reduction in the rate of phosphorus-fertilizer application or cessation of fertilizing and the resulting decrease in management intensity as well as – especially on drained grassland - special techniques of slurry application (for example flat injection) are further effective and sustainable measures for the protection of the groundwater and the surface water in the long-term.

2.2.6. BP MG6 Site-appropriate extensive management of mountain pasture land

Description of the measure

Through the abandonment of pastures or inadequate intensive management measures in mountainous areas the adequate ecosystem service "protection of surface and soil" gets lost. Mudslides and erosion processes increase and important areas and soils are destroyed as the former vegetation and its root-system changes. After intensive fertilisation or abandonment of pastures the rooting decreases and thus the potential risk of erosion processes increases. Fallow lands of 15 up to 20 years are the most unstable areas (TASSER et al., 2004).

Within sensible sites (e.g. steep gullies, sensitive wetland areas, DWPZ) also erosion processes and soil losses can occur by trampling damages through livestock. Grazing should be accordingly limited or totally abandoned within these areas. On already destroyed sites the improvement of the sward through site-specific seeds should be conducted supplemented with adequate fertilisation. Important in this connection is the diversity of the vegetation to provide different root-lengths, so that the interlocking with the underground and the stabilisation of the topsoil get improved.

Measure advantages

Site-appropriate management of pastures cause a positive effect on water storage capacity and run-off behaviour during rainfall. The risk of dangerous torrent-flows or erosion processes throughout heavy rainfalls decreases.

Challenges

The adequate extensive management of mountain pastures is very labour-intensive, difficult and uneconomic. Therefore in some areas of Austria the danger of abandoned pastures in the mountains increases.

Nevertheless some positive examples exist, e.g.:

Within the **DWPZ of the City of Vienna**, cattle-grazing is regulated in a way, that dolines and sink-holes are fenced so that cattle cannot approach these highly vulnerable sites. Through these measures the critical dung of cattle is intended to be kept in distance to the areas, which have direct connection to the aquifer. In order to avoid the direct entrance of precipitation water also technical constructions were used, like e.g. dams which prevent precipitation water from directly flowing into dolines or sinkholes. The water can subsequently infiltrate slowly via the soil matrix, so that the potential contaminants are reduced (soils are acting like a filter). Additionally for avoiding erosion processes and consequently threat for source water quality by trampling damages through livestock (above all cattle), fencing of erosive sites was done for keeping livestock away from there. A subsequent planting with autochthonous vegetation is a further step towards prevention of such erosion processes.

Table 2. Grassland-AT: Relevance of the measures

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
"Establishment or enhancement of grassland by regeneration process"	High	High	Medium	Long Term
"Establishment or enhancement of grassland by sowing or planting"	Medium	Medium	Medium	Long Term
"Supporting guidance for creation of low-input grassland"	High	Medium	Long Term	Long Term
"Weed control against invasive plant species"	High	High	Long Term	Long Term
"Reduction of nutrient inputs into water resources"	High	Medium	Medium	Long Term
"Site-appropriate extensive management of mountain pastures"	High	High	Long Term	Long Term

2.3. Agriculture

Following Best Management Practices are more valid for "mountain sites" in terms of extensive agriculture as these measures mainly aim at retention of water and do not require an intensive cultivation.

2.3.1. BP M(P)A1 Maintaining the share of grassland

Description of the measure

The total share of grassland within a farm/district/region remains unchanged. Whenever grassland is converted into arable land, arable land has to get converted into grassland elsewhere.

Measure advantages

Grassland is a highly effective measure to stabilize the soil surface and decrease soil erosion. Stabilisation of soil also helps to improve the hydraulic properties of soil thus increasing infiltration capacity and decreasing surface runoff. BP A1 is easy to control.

Challenges

Willingness to accept this measure is good because it is compliant with current practice and does not interfere with agricultural management decisions in single farms. There is also a certain choice to select grassland areas.

2.3.2. BP M(P)A2 No conversion of grassland into arable land

Description of the measure

Existing grassland may not be converted into arable land. This measure is a step further to BP M(P)A1. Again the total share of grassland within a farm/district/region remains unchanged but there is no choice on the location of future grassland areas.

Measure advantages

Grassland is a highly effective measure to stabilize the soil surface and decrease soil erosion. Stabilisation of soil also helps to improve the hydraulic properties of soil thus increasing infiltration capacity and decreasing surface runoff. BP M(P)A2 is easy to control.

Challenges

Acceptance for this measure is lower as compared to BP M(P)A1 because no choice to select future grassland areas exists.

2.3.3. BP M(P)A3 Retention ponds

Description of the measure

Retention ponds are manmade structures that are built at crucial sites of concentrated runoff within catchments. They are designed to retain some portion of the superficially flowing water. Different strategies exist to construct retention ponds. They differ on in construction details, but also in placement strategies within catchments. Placement strategies within catchments mainly may be divided into ‘end of pipe’ strategies with a placement at some outlet point of a catchment and a 'distributed' placement strategy using sub-catchment outlets to place retention ponds. Depending on the choice of a particular placement strategy, the design of retention ponds will considerably be different. Typically 'end of pipe' strategies need much larger volumes and higher erection costs. For both placement strategies, detailed knowledge about surface runoff pathways within catchments is a necessary prerequisite.

Measure advantages

Retention ponds are able to effectively retain some amount of surface runoff during rainfall events if properly designed. They may thus be used to smooth peak flow rates. If it is possible to identify suitable sites for instalment within catchments it would be possible to avoid the 'end of pipe' strategy. Potentially retention ponds distributed over sub-catchments also offer the possibility to minimize implementation costs. However this largely depends on agricultural volunteers which would offer land to implement such structures. This usually needs either existing awareness of the contribution of agricultural land to flood generation or measures to generate such awareness.

Challenges

Retention ponds are among the most expensive measures to retain water in catchments. When collecting surface water during rainfall events they may also collect large quantities of sediment, nutrients and undesired elements (heavy metals, pesticides….). This may increase maintenance costs. It is therefore highly important to combine the use of retention ponds with adequate measures to retain sediment already on agricultural land.

2.3.4. BP M(P)A4 Linear retention features

Description of the measure

Linear retention features are living or dead hedges that are placed temporarily or semi permanently across concentrated surface runoff flow paths. As already indicated with other best management practices the practical implementation of this measure may vary considerably. Main differences concern the use of either dead or living obstructions and the widths and implementation techniques.

Measure advantages

Linear retention features obstruct the free flow of surface runoff. They reduce flow velocity and create temporary retention. To a certain extent this leads to increased infiltration and sediment deposition. Similarly to retention ponds they may act as buffer element to smooth runoff peaks for surface runoff. Because linear features are typically placed within smaller sub-catchment areas, they also do provide some possibility to follow a distributed placement strategy.

Challenges

Application of this measure needs knowledge of the actual flow paths within a catchment. To be most effective, the catchments amount of delivering water to linear features should not be too large. Linear retentions features do not have a very high effectivity but they have relatively little implementation costs.

Table 3. Agriculture-AT: Relevance of the measures

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
"Maintaining the share of grassland"	Medium	Low	Long Term	Long Term
"No conversion of grassland into arable land"	Medium	Low	Long Term	Long Term
"Retention ponds"	Medium	High	Short Term	Short Term
"Linear retention features"	Medium	Medium	Long Term	Long Term

2.4. BP Mountain Sites – Karst Research (Overall land-use types)

2.4.1. BP MK1 Systematic and area-covering mapping, long-time monitoring and scientific investigations of catchment areas

Description of the measure

In order to plan and design appropriate measures in water protection zones it is necessary to know the system and to understand the processes which influence water quantity and quality. Vienna Water started therefore a systematic effort called "Karstforschung" (karst research) in 1992. This program is still in progress. The system karst is not restricted to physical parameters but covers also ecological, economic and social issues.

The prerequisite is the description of the system. This includes mapping, measuring of parameters and cataloguing land use activities.

Based on the description and monitoring it is possible to develop models to understand contamination processes in the specific catchment, to predict and quantify impacts of hazards on water resources.

Measure advantages

It is possible to implement measures which are precisely located, focused on the hazard and minimise the risk for water ressources. The reasons for implementing measures are transparent, comprehensible and scientific-based.

Challenges

Such a program is complex, time-consuming and also expensive. It needs much coordination and therefore a good structured organisation.

2.4.2. BP MK2 Installation of a climatological – meteorological monitoring system

Description of the measure

Existing meteorological monitoring systems – mostly installed on national level – are not sufficient to take the special needs of water suppliers in large karstic areas into account.

Especially the density of stations and - at least in Austria - stations above 800 m a.s.l. are scarce. Additionally parameters like radiation are not measured at most stations. The timely resolution is also not sufficient for many evaluations and analyses.

Data of climate and meteorological parameters are necessary for water balance and system dynamics assessment. Long term monitoring (climate) is necessary to identify possible trends due to changes in climate or land use, and that the storage term in water balance can be neglected. For event based analyses, high temporal resolution and on-line transmission is required, particularly regarding precipitation data when they are used in early warning systems (i.e. rainfall thresholds).

In general, stations in high alpine regions require a significant maintenance effort and permanent data check. Besides data voids due to station or transmission failure, particularly precipitation measurement in winter is affected by wind induced errors (snow catch deficit, e.g., Sevruk et al., 2009). Air temperature is less critical. For assessing spring discharge dynamics it can often be incorporated in order to identify whether precipitation in the catchment has fallen as snow or as rain. Sometimes other climate data can be necessary (humidity, radiation), if comprehensive snow melt models incorporating energy balance algorithms are applied for a quantification of snow storage (e.g., Blöschl et al., 2002). Snow melt can significantly influences long term spring discharge in spring and summer.

Usually, system dynamics are assessed in event based analyses. Therefore, meteorological and hydrological parameters are plotted in same figure. Figure shows an example of a typical limestone karst spring. The course of the parameters during the event illustrates that the hydraulic reaction (Q) occurs prior to solute transport parameters (SAC254) at the spring, which can often be observed at karst springs. Simultaneously, the plotted SAC254 shows no reaction to the first hydraulic reaction. This indicates very clearly that hydraulic reaction and mass transport are distinguished and give different insights to the aquifer system. Travel times can be estimated if the rainfall distribution is known and incorporated into the analysis. In the plotted case the hydraulic response of the main event is very quick, which indicates a significant contribution of preferential flow paths.

The difference in the SAC254 and turbidity dynamics illustrates that different sources of sediments are captured by the two parameters. Turbidity response is quicker, which indicates an immediate mobilization of sediments within the karst system, whereas SAC254 (sediments from the surface) shows a delayed response. In a spring quality management the time series of environmental isotope and microbiological parameters can be incorporated and interpreted in the same way. This requires specific event monitoring and event analysis procedures (e.g., Stadler et al., 2008; Leis et al., 2012).

Measure advantages

Measurements can be used for analyses as shown below. Thus a better understanding of impacts of meteorological events is possible.

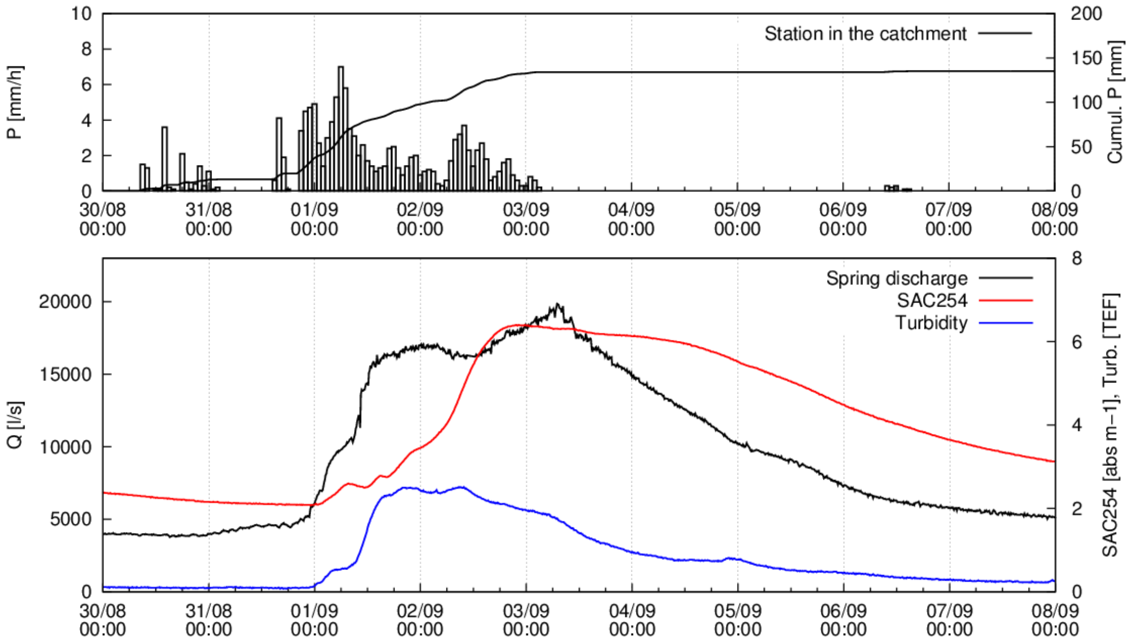

Figure 3. Example of an event based assessment of different parameters.

Water suppliers can also use the online data to manage the water out-take of different springs and therefore ensure a continuous water supply according to the demand.

Challenges

The installation is costly and the maintenance and support service of the stations is a big effort. An appropriate date management has to be provided. Last but not least the interpretation of the data has to be ensured which is an additional effort.

2.4.3. BP MK3 Installation of a hydrological monitoring system

Description of the measure

The monitoring of springs is an essential task for water suppliers. Discharge, physical, chemical and biological parameters should be monitored in near real time to allow for appropriate reactions in due time.

Continuous measurement of spring discharge allows for quantification of amount and dynamics of a karst spring. Frequency of measurements has to be chosen in consistency with the general system behaviour. As alpine karst aquifers can have short response times to rainfall events, especially to torrential rains, mostly a short time interval is required. Analysis is focused on water balance and storage characteristics; however, catchment boundaries are generally not known in karst, and additional hydrogeological information has to be incorporated (mapping, discharge measurements in neighbouring catchments). Regional discharge-altitude relations, regional water balance modelling and isotope data (altitude effect of the stable isotopes ^{18}O and ^{2}H) can also assist in identification of recharge areas (e.g., Benischke et al., 2010).

Recession analysis of spring hydrographs, i.e. analysing the descending limb of the hydrograph after the rainfall has stopped, is an important method in storage characteristics evaluation. By fitting simple models (exponential) using different recession times in different phases of the descending limb, flow components can be separated. Particularly the rapidly responding flow in preferential flow paths (faults, fissures and pipes) can be separated from the slowly descending base flow (matrix).

Also, continuous time series evaluation can be performed using filter algorithms. Figure 3 shows an example of applying an exponential filter (Chapman und Maxwell, 1996) with different recession parameters (time constants in days) for estimation the fraction of base-flow compared to the total discharge of a limestone karst spring. The plotted case shows a very high fraction of bas flow (between 40 and 50%). The different time constants are directly related to different system response times that can represent different flow paths.

For water quality analyses following parameters are typically monitored at karst springs:

- Electric conductivity
- Water temperature
- Turbidity
- The Spectral Absorption Coefficient at 254nm (SAC254)
- Less often and with lower frequency: environmental isotopes (^{18}O and ^{2}H) and microbiological parameters

Water temperature and, in particular, electric conductivity indicate mixing behaviour of water flows of different origins, i.e. old water from the storage vs. fresh rain water through preferential flow paths. By measuring turbidity (optical methods) sediments that may affect spring quality during intensive rainfall events can be evaluated. Often early warning systems for spring discharge diversion are based on a turbidity threshold. Increased turbidity can have two reasons: first, sediments within the karst system are mobilized by rapidly percolating surface waters, and second, material is originated from the surface and mobilized by soil erosion, also as a consequence of high rainfall intensities. These two processes can be distinguished by their response times: generally the turbidity induced by karst system sediments shows an earlier reaction to the rainfall than the turbidity induced by surface material.

The SAC254 is widely used as a proxy for surface erosion of organic material in karst hydrogeology (Stadler et al., 2010). The difference between the turbidity and the SAC254 dynamics can often be used to identify the origin of the material. Sampling microbial loads (e.g., E. Coli) provide complementary data concerning water quality. However, sampling is very time consuming and cost insensitive, so it is only done during short term sampling experiments (e.g., Farnleitner et al., 2005).

Stable environmental isotopes (^{18}O and ^{2}H) serve as an ideal tracer and can also be used to determine origin, mass transport and mixing of karst water. They can be used to separate the flow components event water and baseflow of discharge of karst springs using simple mixing equations. Isotope investigations include also parts of the reservoir which are temporarily inactive contrary to the discharge recession which characterize only the part of the reservoir which can flow out without hydraulic stimulation. Also, the altitude effect is used to identify possible recharge areas. For this, isotope data in precipitation is necessary as a reference (it is assumed, that long term average of isotopic composition of precipitation and groundwater is the same). In Austria, isotope data are available from a station network on monthly basis (Kralik et al., 2003). Recently, also high frequency monitoring using Laser Spectroscopy (PICCARRO) is performed in order to assess water origin and mixing (Leis et al., 2012).

Measure advantages

Measurements can be used for analyses as shown below. Thus a better understanding of impacts of hydrological events is possible.

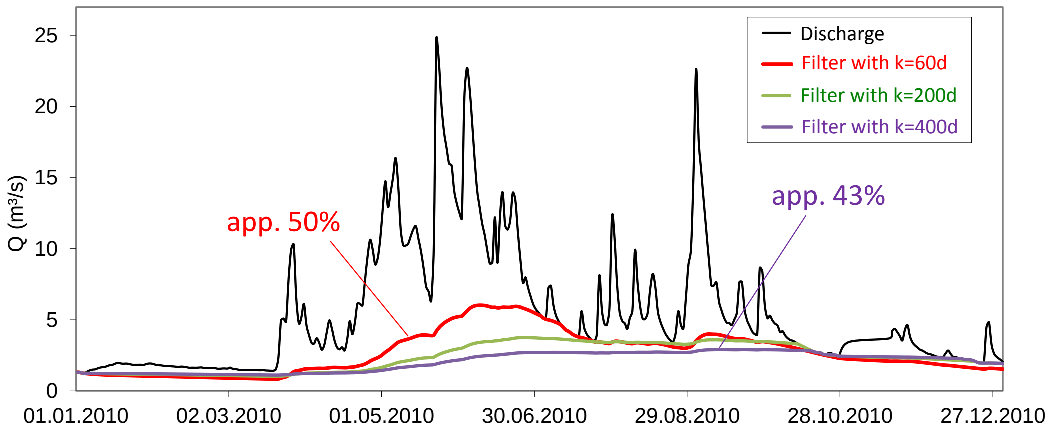

Figure 3. Example of base flow separation applying a base-flow filter (exponential).

Water suppliers can also use the online data to manage the water out-take of different springs and therefore ensure a continuous water supply according to the demand.

Challenges

The installation is costly and the maintenance and support service of the stations is a big effort. An appropriate date management has to be provided. Last but not least the interpretation of the data has to be ensured which is an additional effort.

2.4.4. BP MK4 Design of a hydrogeological map

Description of the measure

For planning of measures, risk assessment and preservation of evidence a hydrogeological map is a necessary instrument for water suppliers. It should include geological, tectonical-structural, morphological, pedological and vegetational information.

Geological maps of Austria, which represent the core result of systematic geological mapping, are available at the scale of 1:50.000, in some areas at the scale of 1:25.000. They represent the lithological and tectonic features. In most spring catchments of the Vienna Water Works, the geological setup induces an intensive karstification including different cave systems and a significant amount of surface karst forms like dolines, karren, polja and ponors. Tectonic structures influence the drainage significantly (e.g., Decker et al., 2006).

Hydrogeological maps take an intermediary position between geological and hydrological information. They are compiled in accordance to a detailed geological map with complimentary mapping, or, in some cases, with drillings or geophysical methods. Basic concept compiling the map is the hydrogeological quality rating of the rocks, in dependency to "Rock Quality Designation (RQD)" of exploration geology and described in Stadler et al. (2016). This hydrogeological quality rating describes fundamental properties of bedrock like karstification capability, tectonical stress pertaining to water storage capacity and permeability, bedding, underline and fall. The objective is to merge different lithological units to units with similar hydrogeological behaviour.

An example of a compiled hydrogeological map is given in Figure 4. Bright blue coloured are mainly limestones with strong karstification and thus, cracks and fissures predominantly lead to an immediate percolation into karst system. Dolomites (green) are mainly fissured aquifers, and surface runoff and lateral subsurface flow towards a draining network is more likely. Further content of the maps are typically tectonic structures (red lines), also obtained by mapping, main springs (blue points) and subsurface flow direction paths (blue arrows). In comprehensive studies, the tectonic structures and faults are additionally evaluated in terms of water draining capacity ("aquiclude" vs. "aquifer", e.g., Decker et al., 2006; Bauer et al., 2016).

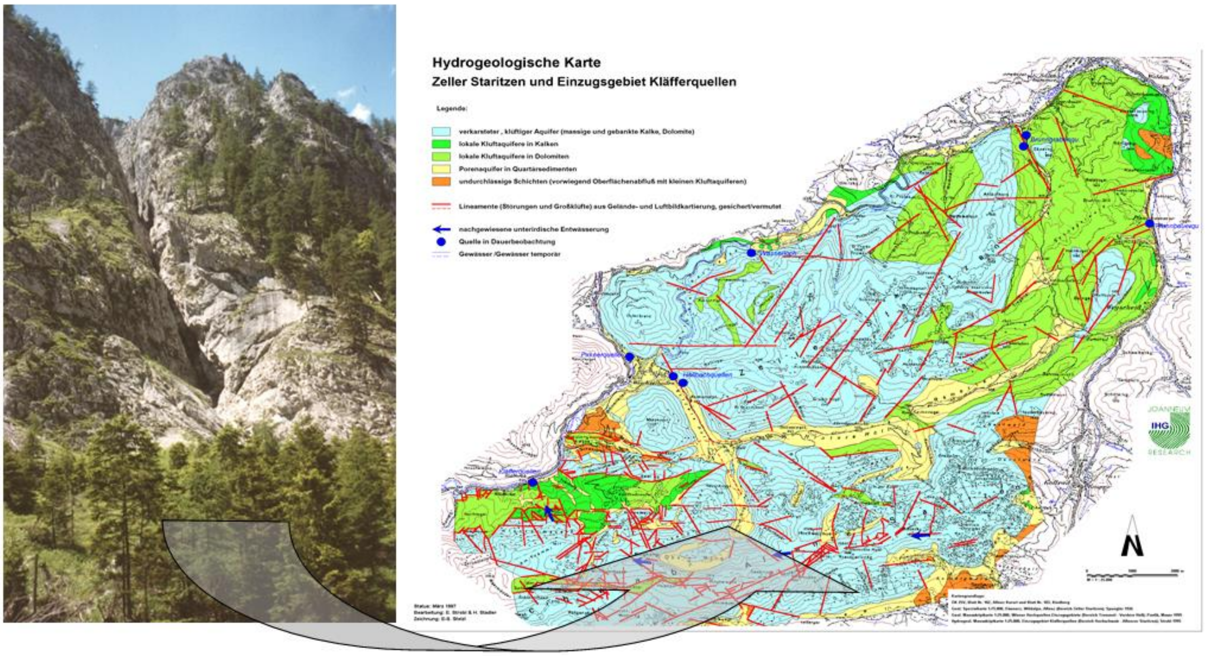

Figure 4. Examples of a hydrogeological map in the spring catchments of the Vienna Water Works taken from Stadler & Strobl (1997). Bright blue: limestones; green: dolomites with tectonic structures (red lines), main springs (blue points) and subsurface flow direction paths (blue arrows).

Measure advantages

Often a conceptual geological model can be built based on the available data in karst regions. For example, Jeannin et al. (2013) present the approach called KARSYS in Switzerland, which helps hydrogeologists to address in a pragmatic and efficient way the three following questions: 1. Where does the water of a karst spring come from? 2. Where (in the underground) does it flow through? 3. What are the groundwater reserves and where are they? It is based on a three dimensional model of the carbonate aquifer geometry (3D geological model) assembling all available information (e.g. geological maps, tectonics, estimated profiles) coupled to a series of simple fundamental principles of karst hydraulics.

Schematically, drainage in karst system can occur as shown in Figure 5. Precipitation falls on the thin soil/debris layer or directly into surface karst forms (e.g. dolines). Vegetation cover and evapotranspiration can often be neglected in high alpine regions. Short surface runoff paths are possible. Within the massif, an unsaturated, intermediate and saturated zone can be distinguished. Different flow paths are indicated in the zones, depending on the permeabilities of fissures and faults ("aquifer" vs. "aquiclude"). Slowly draining matrix flow can have a significant contribution to spring flow in many cases.

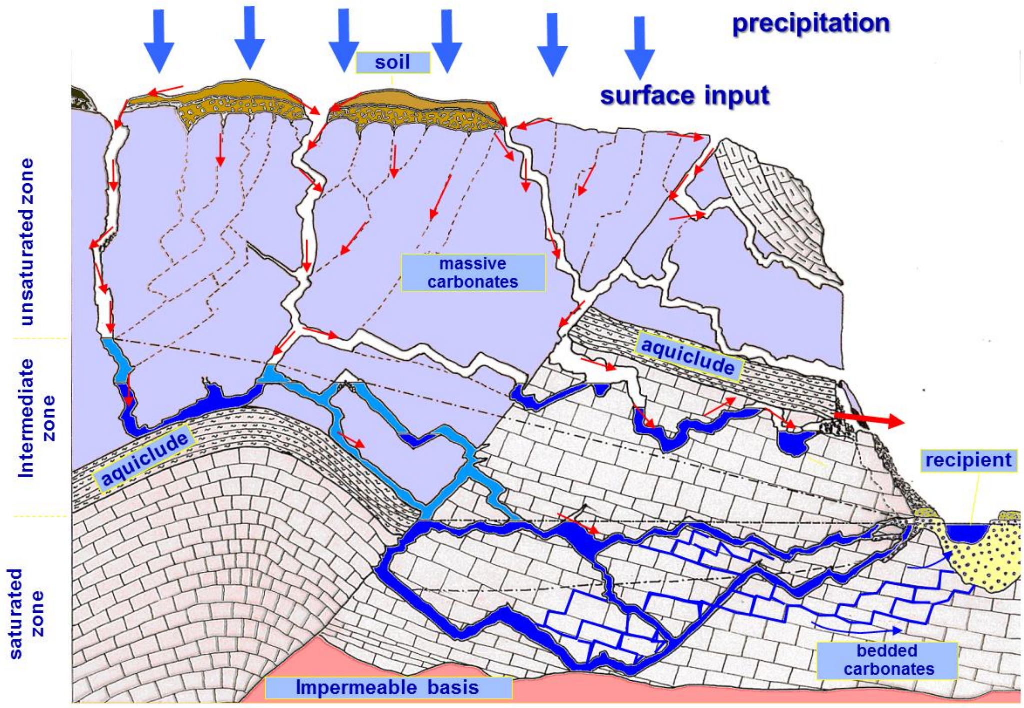

Figure 5. Example of a conceptual model of karst water drainage (modified from ÖWAV, 2007). The dashed and dotted lines indicate water levels at different hydrological situations: the uppermost lines denote situations during high infiltration rates and floods; the lower lines denote situation at low flow.

Challenges

The design is time consuming and needs input from different fields of expertise.

2.4.5. BP MK5 Paddock management of mountain pasture

Description of the measure

In most pastures in karstic areas there are sink holes, creeks and dolines. Those are sensible locations where potentially contaminated surface water may infiltrate into the aquifer. Paddock management allows to steer and direct farm animals away from sensible area but still allowing for sufficient grazing.

Measure advantages

The infiltration of contaminated water can be minimised. The advantage for farmers is that the whole area of the pasture can be grazed. On the long run this method helps to improve the quality of animal feed and limits the spreading of weed which is not grazed by animals.

Challenges

The fencing and the maintenance of the fences is time consuming. Water places are scarce in karstic areas and watering places or drinking troughs have to be provided.

2.4.6. BP MK6 Fencing out of sensible spots

Description of the measure

Instead of dividing a pasture in several paddocks the fencing out of sensible spots can achieve the same protection results.

Measure advantages

The infiltration of contaminated water can be minimised. Animals can go to existing watering places.

Challenges

The fencing and the maintenance of the fences is time consuming. Fencing out is often not possible since sensible spots are often drinking places for the animals.

2.4.7. BP MK7 Growing of vegetation around or along sensible spots

Description of the measure

Growing of local vegetation (mostly dwarf pine in Austrian alpine areas) around or along sensible spots.

Measure advantages

The growing may happen as a natural process. By planting the effort is low. No maintenance is necessary.

Challenges

The natural growing is very slow and may take decades and cannot be influenced. Planting shows often that growing and spreading does not succeed.

2.4.8. BP MK8 Installation of compost toilets in small mountain huts

Description of the measure

Approximately 22.000 mountain huts and refuges currently exist in the Alps. Most of them are situated in extreme locations where they are hard to access. Nevertheless, they generate relevant amounts of solid waste and wastewater. In order to protect the Alpine environment and to preserve drinking water resources, the wastewater generated by mountain huts and refuges must be properly disposed to minimize adverse impacts. For adapted sanitation systems, composting toilets are a possible system component, especially in the case of water shortage.

Composting toilets can be applied as component of the sanitation system at remote objects in the alpine region. Due to the extreme climatic conditions, the degradation efficiency of the composting process for the reduction of hygienic parameters is low or does not work at all. The not continous delivering of compost material is an additional challenge.

Vienna Water has in close cooperation with the University of Life Sciences in Vienna developed the toilet design and the composting (degradation) process in order to implement sanitation systems in the DWPZ.

Measure advantages

The composted faeces and wastewater may be disposed in the protection area with (almost) no hazard to the aquifer.

Challenges

The composting period takes for years. The investment is medium price. The handling needs training.

2.4.9. BP MK9 Forest Hydrotope Model data of the DWPZ

Description of the measure

DWPZ often spread over huge areas. Knowledge about the forest ecosystems within DWPZ is of crucial importance for defining the forest targets for drinking water protection or flood prevention. Forest site mapping surveys or forest hydrotope mapping surveys contribute those essential data for water protection. In the course of the mapping surveys, data about soils, soil vegetation, forest cover, site characteristics and the forest hydrotope type are collected and processed into a GIS-based model. The resulting Forest Hydrotope Model is an excellent base for the application of Best Practices in DWPZ, as it defines the specific frame in the region. The municipalities of Vienna and Waidhofen/Ybbs possess the Forest Hydrotope Model data for their DWPZ. The data base was generated through a site-covering forest site mapping survey (Vienna) and a site-covering forest hydrotope mapping survey (Waidhofen/Ybbs).

Measure advantages

The Forest Hydrotope Model provides all necessary data for the application of general Best Practices for water protection in DWPZ, as it defines the specific level, the site conditions in each region. It is the basis for the implementation of measures for drinking water protection and flood prevention in forested areas. It forms a central tool derived from Karst Research at the level of forest ecosystems. The model can also be applied in any other geological unit.

Challenges

The execution of forest site mapping or forest hydrotope mapping surveys requires efforts on both monetary and scientific level. Water suppliers in general are interested in sound basic rules for water protection and will hence be willing to finance the mapping survey. Another challenge is the fact that only few people have the competences to execute such a mapping survey in its full application (expertise on both plant-sociological and soil-science level).

Table 4. Karst-AT: Relevance of the measures

	Water protection functionality	**Cost of the measure**	**Duration of implementation**	**Time interval of sustainability**
"Systematic and area-covering mapping, long-time monitoring and scientific investigations of catchment areas"	High	High	Long Term	Long Term
"Installation of a climatological-meteorological monitoring system"	High	High	Medium	Long Term
"Installation of a hydrological monitoring system"	High	High	Medium	Long Term
"Design of a hydrogeological map"	High	High	Long Term	Long Term
"Paddock management of mountain pasture"	High	Medium	Short Term	Long Term
"Fencing out of sensible spots"	Medium	Low	Short Term	Long Term
"Growing of vegetation around or along sensible spots"	Medium	Low	Long Term	Long Term
"Installation of compost toilets in small mountain huts"	High	Medium	Short Term	Long Term
"Forest Hydrotope Model data of the DWPZ"	High	High	Medium Term	Long Term

3. Plain sites

3.1. Agriculture

The same catalogue of Best Practices like at „mountain sites“ (chapter 3.3) is also valid for „plain sites“, whereby following Best Practices are more valid for „plain sites“ with intensive agricultural use:

3.1.1. BP PA1 Conversion of arable land into grassland

Description of the measure

The total share of grassland within a farm/district/region increases by switching from arable land into grassland for particular areas.

Measure advantages

Grassland is a highly effective measure to stabilize the soil surface and decrease soil erosion. Stabilisation of soil also helps to improve the hydraulic properties of soil thus increasing infiltration capacity and decreasing surface runoff. BP PA1 is easy to control. Comparing with management practices M(P)A1 and M(P)A2, PA1 is certainly the most effective because it is able to improve the environmental situation instead of not deteriorating it.

Challenges

Willingness to accept this measure is little because usually it comes along with a decrease in agricultural income. It usually needs a large change in agricultural practices. This makes this measure also very expensive in terms of compensation payments that are necessary to balance the loss of income.

3.1.2. BP PA2 Planting/Maintenance of areas as green fallow when soil quality is low (Ackerzahl < 30)

Description of the measure

Arable land with very low soil quality may be taken out of the production process. Soil quality may be determined according to the Austrian taxpaying system for farmers (‘Einheitswert’) which is using a so called ‘Ackerzahl’ to determine the soil quality of each particular field of a farmer. If the ‘Ackerzahl’ drops below a certain value (for instance 30) very small yields are to be expected.

Measure advantages

Green fallow exhibits similar effects as grassland. It is thus a highly effective measure to stabilize the soil surface and decrease soil erosion. Stabilisation of soil also helps to improve the hydraulic properties of soil thus increasing infiltration capacity and decreasing surface runoff. BP PA2 is easy to control.

Challenges

Willingness to accept this measure depends largely on the amount of compensation payments. Farmers usually know quite well about the quality of their fields. For fields with low yields it may be easier to turn them into fallow.

3.1.3. BP PA3 Filter strips along permanent streams

Description of the measure

Filter strips are zones of extensive management alongside of permanent streams. They may consist of permanent vegetation such as riparian trees and bushes or strips of grassland which are managed with low intensity. The width and the type of vegetation strongly influence the effectiveness of the measure.

Measure advantages

The measure will reduce sediment input and input of coarser materials into streams thus affecting those processes within streams that may interact with increased retention of water for instance clogging of pipes or decreasing retention capacity of retention ponds. Improved habitat for a wide range of biota is considered a positive side effect. Depending on the actual type of the measure a huge difference in effectiveness may be observed. Strip widths below 25 m will not be very effective. In addition the effectiveness is also largely depending on the size of the catchment area entering the buffer strip. Some small effect may be expected from increased infiltration within the buffer strip. BP PA3 is easy to control.

Challenges

As usual when dealing with agricultural land willingness to accept this measure depends largely on the amount of compensation payments. In agricultural areas with relatively high rainfall amounts it is quite common to establish at least riparian filter strips made of trees and shrubs. It would be desirable though to also establish grassed riparian areas because of higher retention effectiveness.

3.1.4. BP PA4 Grassed waterways

Description of the measure

Grassed waterways can be thought as filter strips along “thalweg” situations, which are zones within catchments where surface runoff accumulates. In contrast to filter strips they are mainly placed within catchments. They are managed with low intensity as permanent grassland. Fertilisation is not desirable because they are designed to act as sinks for nutrients, sediment and, to a certain extent also for water.

Measure advantages

Correctly applied, the retention effectiveness for sediment and associated nutrients is very high. There is also some effectiveness to increase infiltration of surface runoff. Additional side effects include a better connection of landscape elements that may act as habitat for biota. BP PA4 is easy to control.

Challenges

The measure needs thorough landscape planning to be implemented efficiently. This is because a) the measure usually occupies agriculturally used land thus exhibiting negative economical side effects, and b) good planning is necessary to guarantee good hydrological effectiveness.

3.1.5. BP PA5 Cover crops

Description of the measure

Basic idea of this measure is to plant crops that keep arable land covered during winter time. A large variety of different cover crops exists. In addition the effectiveness will depend largely on the time of seeding. If seeding time is too late in the year, crop cover will not sufficiently develop and the positive effect will decrease. This measure is a prerequisite to measure BP PA6 (conservation tillage).

Measure advantages

Living or dead plant material protects the soil surface against sealing. Biomass will in addition increase soil biota activity and organic carbon content of soil. All these effects positively affect infiltration of rainfall water and reduce surface runoff. In contrast to measure PA3 which follows an ‘end of pipe’ strategy, use of cover crops protects land exactly where surface runoff is generated, within agriculturally used fields. It is easy to control.

Challenges

The measure is only effective during winter time because usually soil cover is destroyed before seeding to enable planting of cash crops. The highest effectiveness of this measure can be obtained in combination with BP PA6 (conservation tillage).

3.1.6. BP PA6 Conservation tillage

Description of the measure

This is an add-on to BP PA5 (cover crops). Before planting cash crops in spring soil no ploughing activity (complete turnaround of the soil surface) is carried out. Instead management is restricted to actions which do not turn the soil surface completely. This is called mulch seeding. In its extreme form, the soil surface is not managed at all. This is called direct drill. Seeding is done into either completely undisturbed soil (direct drill) or soil which has been disturbed only superficially (mulch seeding). A large variety of actual measures and different effectiveness exists depending on the type of machinery used. There exist also special cases such as strip tilling when soil is opened in rows only where seeds are placed.

Measure advantages

In general conservation tillage is deemed one of the most effective measures against soil loss and surface runoff that can be conducted on arable land. Dead or living biomass on the soil surface does not only improve soil infiltration (as already described for BP PA5), it also reduces surface runoff velocity due to an increased surface roughness of soil.

Challenges

Effectiveness of this measure depends largely on the amount of soil surface cover after seeding. As a rule of thumb soil surface covers of less than 30 % are deemed rather ineffective. Unfortunately, it is still quite common to remove soil surface cover as much as possible even when applying mulch seeding which – in the end – may reduce the actual effectiveness of mulch seeding largely. The measure is not easy to control as it needs an evaluation of percentage of soil cover after seeding.

3.1.7. BP PA6 Terracing

Description of the measure

Construction of terraces leads to a complete reshape of landscapes. It is most of all employed in landscapes that need to be used for some kind of agricultural activity although steep slopes are dominating. Different ways to construct terraces exist but independently of technique employed detailed construction plans are necessary to effectively install terraces. Because setting up of terraces is costly, terraces are most frequently installed when high revenue crops such as vine or orchards are grown.

Measure advantages

Terraces reduce slopes in landscape thus decreasing flow velocity of runoff and increasing infiltration. Variants exist that employ piped drains to divert surface runoff. This offers an additional possibility to effectively control and divert runoff in agriculturally used catchments. However, even without piped drains terraces are very effective tools for runoff control. BP PA6 belongs to the group of onsite measures, which exhibit distinct advantages over 'end of pipe' technologies such as BP PA3 (filter strips) or BP M(P)A3 (retention ponds) because onsite measures are a) relatively cheap compared to end of pipe measures and b) it is more effective to reduce surface runoff directly at those places where it initiates. Control of this measure is easy.

Challenges

Main drawbacks for instalment of terraces are very high costs. In addition, agricultural management is usually limited due to very small parcel sizes. This restricts practical implementation to high revenue crops.

3.1.8. BP PA7 Tillage across slope

Description of the measure

Agricultural management will not be carried out along the slope (upward – downward) but across the slope.

Measure advantages

Tillage across the slope creates micro roughness within fields and contributes to higher infiltration of surface water because of more superficial water storage and less flow velocity of surface runoff. This measure is most effective on less inclined slopes up to a slope of say 8-10%.

Challenges

Application of this measure largely depends on field dimensions. In Austria, field sizes are usually quite small. In addition with unsuitable geometric field proportions it may make little economic sense for farmers to carry out this measure. It should also be considered as an add-on measure because it is only suitable for particular field conditions. For arable land with steep slopes it has little effectiveness.

Table 5. Agriculture-AT: Relevance of the measures

	Water protection functionality	**Cost of the measure**	**Duration of implementation**	**Time interval of sustainability**
"Conversion of arable land into grassland"	Medium	Medium	Long Term	Long Term
"Planting/Maintenance of areas as green fallow when soil quality is low"	Medium	Medium	Long Term	Long Term
"Filter strips along permanent streams"	Medium	Medium	Long Term	Long Term
"Grassed waterways"	High	Medium	Long Term	Long Term
"Cover crops"	High	Low	Short Term	Short Term
"Conservation tillage"	High	High	Long Term	Long Term
"Terracing"	High	High	Long Term	Long Term
"Tillage across slope"	Medium	Low	Long Term	Long Term

3.2. Grassland

The same catalogue of Best Practices like at „mountain sites“ is valid for “plain sites” with only two exceptions, which are marked in chapter 3.2 – BP MG1 and BP MG6.

3.3. Wetlands

3.3.1. BP P1 Preservation and revitalization of wetlands on floodplains

Description of the measure

Floodplains are areas immediately adjacent to the stream and are periodically inundated with water. They present a vital part of the river ecosystem. The main function of these areas is carrying excess waters in time of flood events and consequently reducing the flood water's potential energy. Besides, the functions of these areas are improving water quality, reducing runoff and erosion, providing an environment for a diversity of plant and animal life and helping to sustain base flow of adjacent streams and rivers during drought conditions. Floodplains are also important regulators of the movement of energy and materials through the catchment area towards the river and water flowing from surrounding hills and across the floodplain.

Wetlands are often located within floodplains and provide important functions within the context of water quality and quantity. They work as natural water treatment areas, removing pollutants from inland river waters, maintain sufficient quantity of water during the whole year and represent one of the most productive and biologically diverse ecosystems, providing the essential breeding and feeding habitats for many species of water birds, fish, invertebrates and plants.

The preservation or revitalization of those wetlands encompasses all measures necessary for this purpose.

Measure advantages

The preservation of wetlands in floodplains is of crucial importance for both the protection of drinking water resources and for the protection from floods. Only if the wetland areas are in natural or close-to-nature conditions, their ecosystem services can be rated as functional for water protection.

Challenges

In Austria floodplain wetlands were under threat during the last half of the 20th century, when various hydro-electric power plants were constructed at the main rivers like Danube or Mur. In 1984 there were happening protests which allowed the creation of the “Donau-Auen National Park” (Danube Floodplain National Park). This national park protects now the hugest floodplain area and forest in Europe and also the wetlands within. This step was important for the preservation of this huge floodplain area, where the City of Vienna also derives drinking water for the supply in critical situations (drought periods or other challenging situations).

Other wetlands in floodplains do not have this protective status. In some cases there can still be identified demands within the context of the construction of hydro-electric power plants. The share of floodplain wetlands is actually very low in comparison to the times prior to human settlements (pre-neolithic phase). At those times the wetlands in the floodplains were a hindrance for human settlements (marshes and malaria) now the last floodplain wetlands have to be protected for the purposes of water protection. There still can be identified the need of persuasive efforts.

3.3.2. BP PW2 Creation and maintenance of riparian wetlands

Description of the measure

Riparian wetlands are typically narrow, wet areas that are adjacent to streams and are periodically water-logged because both surface and subsurface water flows toward them. The soils are in most of the cases alluvial (water deposited). They usually present the buffer zone between arable i.e. agricultural land and the stream. Therefore, the main function of the riparian wetlands is purification of the water. The riparian wetlands form part of the forested riparian buffer strips, but can be seen as unique type of riparian buffer strip.

Measure advantages

The riparian wetlands influence primarily water quality (i.e. reduction of the water pollution) of drainage water flowing through these areas. The main agricultural pollutants from the arable lands are nitrate (dissolved in water) and phosphorus (attached to soil particles), which are nutrients essential for crop growth but harmful to humans and animals in higher contents.

Mechanisms of nutrient removal within riparian areas include denitrification, assimilation by vegetation and transformation to ammonium and organic nitrogen followed by retention in the soils. All these mechanisms may occur in different seasons and environments. Removal of nutrients from surface inflows is induced by deposition of sediment-bound nutrients and exchange of dissolved nutrients with the soil/litter surface. Removal of nitrogen in subsurface flows can partly be explained by vegetation uptake, but the main mechanism for removal is usually denitrification.

The main and also the most researched mechanism is denitrification where soil bacteria convert nitrates to nitrogen gas that returns to the atmosphere. Natural floodplains can provide ideal conditions for denitrification, due to the occurrence of both saturated and non-saturated soils, a high organic matter concentration and a high water table.

Another crucial aspect is the protection from lateral erosion given by stable forest vegetation within these riparian strips. Lateral erosion can form a huge threat during flood events and could also harm drinking water resources.

Hence the creation or maintenance of riparian wetlands is a crucial measure, especially within DWPZ.

Challenges

In Austria the riparian wetlands have to be protected, as they currently do not have a specific status of protection. For all those sites there has to be found a trade-off between the protection from drift-wood and the protection from lateral erosion. This could provoke discussions among stakeholders but is an integral step towards protection from floods or their mitigation and towards an integral drinking water protection strategy. There still can be identified the need of persuasive efforts.

3.3.3. BP PW3 Establishment of constructed wetlands for water treatment

Description of the measure

The constructed wetlands operate on the principle of imitation of natural processes of self-cleaning or purification. The effective constructed wetland consists of the proper selection of plants and soil substrates as well as suitable water flow through wetland.

Nutrients are deposited into wetlands from storm-water runoff, from areas where fertilizers or manure have been applied and from leaking septic systems. These excess nutrients are often absorbed by wetland soils and taken up by plants and microorganisms reducing their concentrations in the discharge water before entering in the streams. Several investigations and actions around the world show constructed wetlands proved to be very successful for reducing the amount of nutrients in the environment.

Measure advantages

The constructed wetlands are able to reduce nutrients and suspended particles from water stemming from arable land (agriculture, livestock), e.g. in local depressions inside arable land to retain the excess water instead creating runoff through channels or streams. They allow a purification of municipal waste water (individual houses, settlements, tourist resorts etc.) instead of direct discharging the waste water by canal systems to streams. They can also act as filtering fields for wastewater before entering the environment. Constructed wetlands can also be used as purification of industrial waters (process waters and leachate; factories wastes, mine drainage, refinery process waters). Another potential application is the reduction of the storm-water runoff. They can be used as treatment of wastewater with possibility of water reuse (watering, fire-fighting, etc.).

Challenges

In Austria constructed wetlands are used in several occasions. Within DWPZ they may be used in exceptional cases. In general there can be identified a facilitating climate for constructed wetlands. In DWPZ their application might be useful in some exceptional cases, when no other measures for water purification can be selected.

3.3.4. BP PW4 Natural management of wetlands

Description of the measure

Management of nature protected areas (Natura2000 areas), e.g. wetland areas, are used as green infrastructure and natural retention against floods.

The aim of this Best Practice is to benefit a range of existing or newly created wetland habitats by maintaining appropriate grazing regimes. It can also be used to manage newly restored floodplains to help manage flood risk downstream.

Wetlands support a range of plant types and reducing or removing grazing during the summer and then grazing in the autumn will ensure that flowering species can set seed and germinate. Cutting should be conducted after mid of August and before end of September.

Measure advantages

Through adequate management concepts for wetland areas respectively Natura2000 areas the biodiversity of habitats, fauna and flora will be improved. Consequently also the function of the ecosystems, which provide us with important resources as oxygen, drinking water and food, playing an important role within the regulation of climate and protection against natural hazards, will be maintained.

Wetlands support a variety of plants, insects, amphibians, reptiles, mammals and birds. They also help slow water flow and act as natural water storage zones helping to reduce the impacts of flooding downstream.

Challenges

Wet meadows are species-rich ecosystems. They provide habitats for many rare and endangered species. With ongoing structural changes in agriculture, a great number of wet meadows are abandoned because their management requires a lot of manual work. Therefore, today’s challenge is to find sustainable management practices that are not very time-consuming and have a low environmental impact.

In some Austrian areas (e.g. Enns valley, Danube area and Mur) manifold **projects** were implemented:

- **"Protection of wetlands in the Enns valley"** (1995-1998) - main goals were the protection of wetland areas and protection and conservation of biodiversity incl. natural retention areas
- **LIFE-Project "Gesäuse"** (Enns valley): Management plan for invasive species
- **The LIFE project „River landscape Enns"** (2011-2015): Conservation strategies for forests and torrents in the region "Gesäuse" incl. management of invasive plant species were developed and renaturation measures of the river Enns were. The implementation of measures was an important step towards habitat improvement and the so called ´passive flood protection´ in specific stretches of the river Enns.
- In the framework of **"BE-Natur"**(INTERREG SEE, 2011-2015) - „Better management and implementation of NATURA 2000 sites" action plans for calcareous marshes, fens and wetlands were developed within the Styrian Enns valley and the "Ausseerland". The focus was laid on the development and bundling of procedures for sustainable agricultural use of protected areas and the awareness raising of their socio-economic value.
- The use of horses with modern equipment for mowing was established for wetland management in Natura 2000 sites in "Salzkammergut", Styria. The use of workhorses supports small-scale grassland farming and creates awareness for ecological sustainable landscape management practices. Mowing with horses has a low impact on wet soils and maintains the high biodiversity of wet meadows preventing forest and scrub encroachment. The ecological benefits are minimal noise, no emissions, no fossil fuels involved, and insects and birds can easily escape. Apart from mowing, horses could be used in versatile ways such as thinning of forests, clearing of bushes or dwarf shrubs, cultivation of potatoes and transport services. Working with horses also has positive effects on children, teenagers and people with mental problems.

Table 6. Wetlands-AT: Relevance of the measures

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
“Preservation and revitalization of wetlands on floodplains”	High	Medium	Long Term	Long Term
“Creation and maintenance of riparian wetlands”	High	Medium	Long Term	Long Term
“Establishment of constructed wetlands for water treatment”	High	Medium	Short Term	Long Term
“Natural management of wetlands”	High	Medium	Long Term	Long Term

3.4. Forest

The same catalogue of Best Practices like at „mountain sites“ is valid for „plain sites“ (flatlands). So see all statements in chapter 3.1.

4. Special sites

4.1. Dry areas

There are no dry areas in Austria.

4.2. Riparian strips

4.2.1. BP SR1 Creation and maintenance of riparian wetlands

Description of the measure

Riparian wetlands are typically narrow, wet areas that are adjacent to streams and are periodically water-logged because both surface and subsurface water flows toward them. The soils are in most of the cases alluvial (water deposited). They usually present the buffer zone between arable i.e. agricultural land and the stream. Therefore, the main function of the riparian wetlands is purification of the water. The riparian wetlands form part of the forested riparian buffer strips, but can be seen as unique type of riparian buffer strip.

Measure advantages

The riparian wetlands influence primarily water quality (i.e. reduction of the water pollution) of drainage water flowing through these areas. The main agricultural pollutants from the arable lands are nitrate (dissolved in water) and phosphorus (attached to soil particles), which are nutrients essential for crop growth but harmful to humans and animals in higher contents.

Mechanisms of nutrient removal within riparian areas include denitrification, assimilation by vegetation and transformation to ammonium and organic nitrogen followed by retention in the soils. All these mechanisms may occur in different seasons and environments. Removal of nutrients from surface inflows is induced by deposition of sediment-bound nutrients and exchange of dissolved nutrients with the soil/litter surface. Removal of nitrogen in subsurface flows can partly be explained by vegetation uptake, but the main mechanism for removal is usually denitrification.

The main and also the most researched mechanism is denitrification where soil bacteria convert nitrates to nitrogen gas that returns to the atmosphere. Natural floodplains can provide ideal conditions for denitrification, due to the occurrence of both saturated and non-saturated soils, a high organic matter concentration and a high water table.

Another crucial aspect is the protection from lateral erosion given by stable forest vegetation within these riparian strips. Lateral erosion can form a huge threat during flood events and could also harm drinking water resources.

Hence the creation or maintenance of riparian wetlands is a crucial measure, especially within DWPZ.

Challenges

In Austria the riparian wetlands have to be protected, as they currently do not have a specific status of protection. For all those sites there has to be found a trade-off between the protection from drift-wood and the protection from lateral erosion. This could provoke discussions among stakeholders but is an integral step towards protection from floods or their mitigation and towards an integral drinking water protection strategy. There still can be identified the need of persuasive efforts.

4.2.2. BP SR2 Buffer Strips along Streams

Description of the measure

Streams are sensitive sectors in many DWPZ and hence have to be protected with highest priority. Buffer strips with dense and vital forest cover can protect the streams from direct infiltration of sediments or nutrient loads and from lateral erosion. Forest vegetation has to be stable in buffer strips and management operations have to be carried out extremely cautious.

Measure advantages

The protection of the stream-banks from lateral erosion processes through a vital forest cover can be regarded as the most crucial effect of buffer strips, as lateral erosion could mobilize huge amounts of soil-, gravel- and rock material, endangering both water supply facilities and human infrastructure in general. But also the protection from nutrient loads and sediments is relevant. Buffer strips along streams are one of the classical Best Practices on global scale. Additionally the shadowing effect of them on the stream is relevant for keeping the waters relatively cool.

Challenges

Actually there can be identified a trend in Austria, where Buffer Strips along streams are clear-cut. This trend has to be reversed, as the protection from lateral erosion processes is more important. The balance between driftwood prevention and preservation of the forest cover along streams has to be found, what maybe could lead to multi-dimensional discussions in some cases. The most important purpose within this context has to be the most efficient flood mitigation/prevention/protection functionality of the system Streams/Forest Ecosystems. It will have to come to a trade-off between lateral erosion prevention and drift-wood prevention. The huge threat-potential of lateral erosion processes has to be taken into account. This situation is valid for both mountain and plain (flatland) stream systems.

4.2.3. BP SR3 Filter strips along permanent streams in agricultural areas

Description of the measure

Filter strips are zones of extensive management alongside of permanent streams. They may consist of permanent vegetation such as riparian trees and bushes or strips of grassland which are managed with low intensity. The width and the type of vegetation strongly influence the effectiveness of the measure.

Measure advantages

The measure will reduce sediment input and input of coarser materials into streams thus affecting those processes within streams that may interact with increased retention of water for instance clogging of pipes or decreasing retention capacity of retention ponds. Improved habitat for a wide range of biota is considered a positive side effect. Depending on the actual type of the measure a huge difference in effectiveness may be observed. Strip widths below 25 m will not be very effective. In addition the effectiveness is also largely depending on the size of the catchment area entering the buffer strip. Some small effect may be expected from increased infiltration within the buffer strip. BP PA5 is easy to control.

Challenges

As usual when dealing with agricultural land willingness to accept this measure depends largely on the amount of compensation payments. In agricultural areas with relatively high rainfall amounts it is quite common to establish at least riparian filter strips made of trees and shrubs. It would be desirable though to also establish grassed riparian areas because of higher retention effectiveness.

Table 7. Riparian Strips-AT: Relevance of the measures

	Water protection functionality	**Cost of the measure**	**Duration of implementation**	**Time interval of sustainability**
"Creation and maintenance of riparian wetlands"	High	Medium	Long Term	Long Term
"Buffer strips along streams"	High	Medium	Long Term	Long Term
"Filter strips along permanent streams in agricultural areas"	Medium	Medium	Long Term	Long Term

5. General Best practices

5.1. Catchment areas of Vienna Water Supply (VWS)

5.1.1. Introduction

The City of Vienna supplies its citizens since 1873 with drinking water from catchments situated in the Northern Calcerous Alps. Actually more than 95% of the water resources (some 380.000 m² per day) originate in those areas. The catchments comprise some 1000 km² and are also used for the water supply of Graz – the second largest city in Austria - and numerous local communities. In sum more than 2million people are supplied with drinking water from this area.

Situated in the mountains the elevations of the catchments range from some 450 m a.s.l. up to 2200 m a.s.l. The mountains are characterised by steep slopes and "flat" tops. On the slopes forests prevail, on the tops mountain pastures and "krummholz"-vegetation are dominant. The land uses are – besides water supply – forestry, mountain pasture and tourism. From the hydrogeological point of view the area can be described as karstic. Small settlements are situated in the valleys.

Figure 6. Map of Vienna and the water catchment areas

5.1.2. BP VWS1 Purchase of catchment areas

Description of the measure

When the centralised water supply of Vienna started in 1873 some area of the first spring – Kaiserbrunn – was given to the city of Vienna by the emperor. This symbolic act to acknowledge the importance of the centralised water supply for Vienna was the starting point for the strategy of purchasing areas important for catchment and spring protection. This strategy is still valid.

Measure advantages

Property is a very strong right in all European legal systems. Two thirds of the area is covered by forest and one third by pastures, meadows and stone. The city of Vienna owns some 325 km² in the area. This area is explicitly appointed for spring protection. The forest department of the city is managing the estate with the priority objective of water protection. On the area of some 1000 km² there is just one rack railway opened in 1897 and one cable car opened in 1926 which is peculiar in a touristic country like Austria. Also the extensive manner of the different land use activities is due to the ownership.

Additionally the water right is connected to the premises. Although the water right can be sold separately it is of advantage to own the parcels on which the springs are located.

As a single measure it is surely the most effective one for water protection reasons.

Challenges

The costs are the big problem. Additionally the owner of the premises needed for water protection has to be willing to sell.

5.1.3. BP VWS2 Decreed Water protection zones

Description of the measure

Areas used for water supply can be decreed by law as protection zones. Some activities are not allowed, other activities have to be approved by the public authorities. The authorities can also request specific conditions under which activities may be undertaken.

For the catchment areas of the city of Vienna there are two protection zones in force: „VO Schutz der Wasservorkommen im Schneeberg-, Rax- und Schneealpengebiet“ (BGBl. 353/1965) and „VO Schutz der Wasservorkommen im Hochschwabgebiet” (BGBl. 345/1973).

Measure advantage

The measure is quite effective. Water suppliers are parties in the official procedure and can forward documentary evidence.

Challenges

The negotiations with other stakeholders may take long time. The evidence asked from the water supplier by the authorities may take a long time to compile and may be costly.

5.1.4. BP VWS3 Spring protection tours

Description of the measure

Vienna Water undertakes so called “spring protection tours” in order to observe the catchment areas and document peculiarities. It is also important to communicate with other stakeholders (keepers of huts, herders, tourists,…) and get informed about their observations and possible needs and also to inform them about water protection measures and behaviour in water protection areas.

Measure advantage

It is the best possible information you can get about the situation in the catchment area concerning natural changes, land use trends and developments. The communication with other stakeholders helps to create mutual understanding and confidence.

Challenges

You have to have own staff in the region and depending on the area extension it takes time and the observations have to be documented and evaluated. There also has to be appropriate response.

5.1.5. BP VWS4 Helping implementing and maintaining disposal infrastructure

Description of the measure

Especially the disposal of fecal waste is crucial in water protection zones. Human fecals are the most dangerous contaminant for the water resources in the catchments of the city of Vienna. In mountain huts the problem is occurring and in most cases not easy to solve. There are different technical possibilities to dispose human fecal waste.

Measure advantage

The disposal of human fecals minimises the hazard of microbial contamination and thus reduces the risk for the water supply.

Challenge

This measure is also cost-intensive.

5.1.6. BP VWS5 Set up and implementing meteorological and hydrological measuring stations

Description of measure

All springs used for drinking water supply have to be equipped with sensors in order to assess water quality and quantity. Additionally an appropriate number of meteorological stations have to be set up and equipped with sensors measuring different parameters. The implementation has to be consulted by meteorological experts.

Measure advantage

Knowing about precipitation, discharge and many other parameters you are able to assess the quantity and quality of the tapped water. You can decide to direct the water to the end user or to divert the water to the receiving water. Additionally you can use the data for research activities, preservation of evidence in case of contaminations.

Challenge

In this case it is not only the cost of implementing the measuring system. It has also be maintained. For this own staff has to be trained in order to fix at least less serious problems. Additionally the data has to be processed and used for decisions.

5.1.7. BP VWS5 Karst research programme

Description of measure

In the late eighties of the last century it became evident – also due to the nuclear disaster of Tschernobyl and the following fall-out - that Vienna Water did not know enough about the karst system and the predominant processes governing water infiltration, storage and flow. Vienna Water decided to start a systematic and catchment area covering survey. Objective of the research activities is to support the supply of Vienna with drinking water in a sufficient quantity in a quality meeting all hygienic standards on every day in the year.

The tasks are mapping and describing the natural system. To gather, evaluate and interpret data and to study and interpret processes.

Measure advantage

Research activities help to describe and identify hazards, they help to assess and calculate risks. Research activities are indispensible when designing and locating specific measures. Research activities are necessary to minimise risk.

Results of research activities are the basis for evidence presented in official procedures deciding about activities of third parties.

They help to gain evidence in case of contamination. Evaluating research observations help to design measures to prevent future calamities.

Research activities are the bases for planning.

Challenge

A research programme like the karst research programme of Vienna Water is intended to be thorough, comprehensive and fundamental. This means it is long-lasting and costly. Some of the investigations are at the edge of science. Many different faculties are involved. The coordination effort is enormous. Sometimes it is not easy to find scientists who are able to perform the necessary tasks.

5.1.8. BP VWS6 Developing and implementing tools

Description of measure

An IT-System based on geographical information and connected to a data base storing the data from the monitoring stations was designed, planned and implemented at Vienna Water. It is continuously upgraded with each study and survey performed.

Measure advantage

Only such a tool where all results of the research activities and the data of the monitoring system are retrievable makes it possible to realize the goals and objectives intended but also necessary for an appropriate water supply system for almost 2 million people.

Challenge

The design of such an IT-system is labour-intensive, costly and long-lasting. To operate such a system effectively and to reach an adequate value from the system it needs well trained users, which is an additional effort.

Table 8. Vienna Water Supply-AT: Relevance of the measures

	Water protection functionality	Cost of the measure	Duration of implementation	Time interval of sustainability
"Purchase of catchment areas"	High	High	Short Term	Long Term
"Decreed water protection zones"	High	Medium	Long Term	Long Term
"Spring protection tours"	High	Low	Short Term	Long Term
"Helping implementing and maintaining disposal infrastructure"	High	Medium	Short to medium Term	Long Term
"Set up and implementing meteorological and hydrological measuring stations"	High	High	Medium Term	Long Term
"Karst research programme"	High	High	Long Term	Long Term
"Developing and implementing tools"	High	Low to medium	Long Term	Long Term

6. Literature

Amt der OÖ. Landesregierung, Abt. Oberflächengewässerwirtschaft (2013): Informationsbroschüre Oberflächengewässerschutz in der Landwirtschaft: Stoffeintrag durch Erosion, Phosphor; www.gewaesser-zukunft.eu

AREC (2014): Abschlussbericht BE-NATUR: Transnationales Management von Natura 2000 Gebieten (Better management and implementation of NATURA 2000 sites)

Bauer, H, T. C. Schröckenfuchs & K. Decker (2016): Hydrogeological properties of fault zones in a karstified carbonate aquifer (Northern Calcareous Alps, Austria). Hydrogeology Journal, 24p.; DOI 10.1007/s10040-016-1388-9

Benischke. R., Harum, T., Reszler, C., Saccon, P., Ortner, G., Ruch C. (2010): Karstentwässerung im Kaisergebirge (Tirol, Österreich): Abgrenzung hydrographischer Einzugsgebiete durch Kombination hydrogeologischer Untersuchungen mit Isotopenmethoden und hydrologischer Modellierung. Grundwasser 15, 43-57 (2010). doi:10.1007/s00767-009-0124-y

Blöschl, G., R. Kirnbauer, J. Jansa, K. Kraus, G. Kuschnig, D. Gutknecht & C. Reszler (2002): Einsatz von Fernerkundungsmethoden zur Eichung und Verifikation eines flächendetaillierten Schneemodells. Österreichische Wasser- und Abfallwirtschaft 54, 1-16.

Bohner, A. (2007): Gewässerschonende Düngung von drainierten Grünlandflächen im EU Regio-Voralpengebiet (Sustainable agriculture in the eu regional lake landscape)

Chapman, T.G. & A.I. Maxwell (1996), Baseflow separation – comparison of numerical methods with Tracer experiments. I.E. Aust. Natl. Conf. Publ. 96/05, 539-545.

Decker, K., Plan, L. & Reiter, F. (2006): Tectonic assessment of deep Groundwater Pathways in fractured and karstified Aquifers, Hochschwab Massif, Austria. Proceedings “All about Karst and Water, Vienna, pp. 138-142.

Farnleitner, A.H., I. Wilhartitz, G. Ryzinska, A. K. T. Kirschner, H.Stadler, M. M. Burtscher, R. Hornek, U. Szewzyk, G. Herndl & R. L. Mach (2005): Bacterial dynamics in spring water of alpine karst aquifers indicates the presence of stable autochthonous microbial endokarst communities. Environmental Microbiology, 7 (2005), 8; 1248 - 1259.

Goldscheider, N. (2015): Overview of Methods Applied in Karst Hydrogeology. In: Stevanović (Ed.) Karst Aquifers—Characterization and Engineering, Professional Practice in Earth Sciences, 127-145 (2015), Springer International Publishing. doi: 10.1007/978-3-319-12850-4_4. Print ISBN 978-3-319-12849-8, Online ISBN 978-3-319-12850-4

Jeannin, P.-Y., U. Eichenberger, M. Sinreich, J. Vouillamoz, A. Malard & E. Weber (2013): KARSYS: a pragmatic approach to karst hydrogeological system conceptualisation. Assessment of groundwater reserves and resources in Switzerland. Environmental Earth Sciences, 69(3), p. 999–1013.

Koeck, R., Hochbichler, E. (2014): CC-WARE Appendix: Recommendations for Adaptive Management Concepts –Best Practices for Forest Ecosystems in Mountains and Flatlands.

Reporting in Work Package 4 – Act. 4.2. SEE Project CC-WARE, www.ccware.eu – Output Documentation.

Kralik, M., W. Papesch & W. Stichler (2003): Austrian Network of Isotopes in Precipitation (ANIP): Quality assurance and climatological phenomenon in one of the oldest and densest networks in the world, in Isotope Hydrology and Integrated Water Resources Management, C&S Pap. Ser. 23, pp. 146– 149, Int. At. Energy Agency, Vienna.

Krautzer, B. (2003): Erosionsverhalten in Abhängigkeit von der Applikationsmethode (Soil erosion and water flow on slopes in dependence on application techniques)

Krautzer, B. (2003): Schutzwirkung verschiedener Begrünungsverfahren nach Rekultivierungen in Höhenlagen; EU-Project ALPEROS (1999-2002)

Krautzer, B. (2014-2020): OptiSaat: Optimierung der Saatgutproduktion standortgerechter Gräser und Leguminosen für die Grünlandwirtschaft und den Landschaftsbau im Alpenraum (Improving the productivity of seed production of grasses and forbs for grassland management and landscaping in Austria)

Ländliches Fortbildungsinstitut (2015): Almwirtschaftliches Basiswissen: Von der Bedeutung der Almen

Leis, A., Schmitt, R., Van Pelt, A., Plieschnegger, M., Harum, T., Zerobin, W. & H. Stadler (2013): Isotope investigations at an alpine karst aquifer by means of on-site measurements with high time resolution and near realtime data availability. Isotopes in Hydrology, Marine Ecosystems and Climate Change Studies - Proceedings of the International Symposium, 145-152.

LIFE+ Project Ausseerland: http://www.bundesforste.at/natur-erlebnis/life-projekt-ausseerland.html

ÖWAV (2007): Praktische Anleitung für die Nutzung und den Schutz von Karstvorkommen. ÖWAV-Regelblatt 201, 2., überarbeitete Auflage. Wien, 2007.

Sevruk, B., M. Ondrás, B. Chvíla (2009): The WMO precipitation measurement intercomparisons. Atmospheric Research, 92 (2009), 376–380.

Stadler, H. & E. Strobl (1997): Hydrogeologie Zeller Staritzen. Final report, Joanneum Research, April 1997.

Stadler, H., E. Klock, P. Skritek, R. L. Mach, W. Zerobin & A. H. Farnleitner (2010): The spectral absorption coefficient at 254 nm as a real-time early warning proxy for detecting faecal pollution events at alpine karst water resources. Water Science and Technology, 62 (8), 1898-1906, IWA Publishing.

Stadler, H., P. Skritek, R. Sommer, R.L. Mach, W. Zerobin & A.H. Farnleitner (2008): Microbiological monitoring and automated event sampling at karst springs using LEO-satellites. Water Science and Technology 58 (4), 899-909, IWA Publishing.

Stadler, P, H. Häusler, M. Rogger, D. Savio & H. Stadler (2016): A field work orientated approach for complex karst aquifer characterization In: Karst without boundaries, CRC Taylor&Francis, London 179-197. DOI 10.1201/b21380-16

Starz, W. (2009-2013): Anpassungsmöglichkeiten montaner Bio-Dauergrünlandwiesen an eine Nutzungsintensivierung (Adaptation strategies of mountainous hay meadows to intensified management regime in organic farming)