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Appendix I

Best Management Practices for the drinking water protection forests

BOKU

University of Natural Resources and Applied
Life Sciences - Vienna

March 2007

The KATER II project was funded by means of the ERDF.

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Content

Acknowledgements

The members of the study group gratefully acknowledge Dr. Gerhard Kuschnig for his ceaseless work as project coordinator, which was crucial for all the participants of the KATER II project and especially for the effectual working progress in the field of land use category forestry.

We are grateful to Dipl.Ing. Hans Sailer, director of the Vienna Water Works, who enabled the project fulfilment as project leader, and to Dipl.Ing. Dr. Wolfgang Zerobin, who supported the project during its whole time span.

Our thanks are also directed to Dipl.Ing. Andreas Januskovecz, director of the Municipal Department of Forestry and Agriculture of Vienna, who facilitated the intensive collaboration with his department. We also want to communicate our gratefulness to Dipl.Ing. Werner Fleck, who supported the working tasks of the project by the allocation of crucial databases, like the forest management map and the forest site map. We are especially grateful to Dipl.Ing. Herbert Weidinger and Dipl.Ing. Alexander Mrkvicka, who supported the project by the provision of the forest site mapping data set, which was managed by them. For the provision of the forest management data base we want to communicate our gratefulness to Dipl.Ing. Dr. Franz Fischer and Dipl.Ing. Karin Fasching. Further we want gratefully acknowledge all the people, who contributed to the forest site mapping survey, which was a crucial database for the hydrotope model.

We want to thank the staff of Prisma Solutions, above all Ms. Cornelia Stehlik, Dipl.Ing. Nik Widmann and Dr. Stefan Kollarits, who kept a fruitful climate of cooperation during all working tasks. Our special gratefulness is communicated to all the partners of KATER II project, the participants from Slovenia, Molise, Veneto and Croatia. In this sense we want to thank each single participant for the inspiring cooperation and the continuous trans-national collaboration.

From the University of Natural Resources and Applied Life Sciences we want to acknowledge Ao. Univ.Prof. Dipl.Ing. Dr. Herbert Hager for his guidance in the course of the international University Excursions and his support given by the supervision of students. We are especially grateful to Ao. Univ.Prof. Dipl.Ing. Dr. Andreas Muhar, who supported the project on the level of scientific peer reviews and assistance for specific GIS-applications.

Our further thanks are directed to Ing. Hans Tobler and Ing. Christoph Rigler, who supported the field work for the hydrotope survey and the maintenance of the monitoring stations.

We also are grateful to Dipl.Ing. Peter Gulas, Dipl.Ing. Bernhard Mang, Dipl.Ing. Hubert Mayer, Dipl.Ing. Irmfried Hanreich and Dipl.Ing. Peter Lepkowicz, who supported the field work with accommodation facilities and by the provision of information regarding the water protection regions.

We appreciate the support given by Mr. Josef Böck, Mr. Josef Stanglauer, Mr. Ernst Formann, Mr. Bernhard Laminger, Mr. Josef Döller and Mr. Dietmar Pfatschbacher in the course of field work.

Further thanks are communicated to Ing. Manfred Arrer, Ing. Rainer Huber and Ing. Bernhard Knapil as representatives of all the foresters of the drinking water protection forest regions, who supported the field working tasks directly.

We also gratefully acknowledge Dipl.Ing. Dr. Christian Holtermann for his technical support in the course of the maintenance of the monitoring stations and Mag.Dr. Elisabeth Rigler for her contributions during the first project phase.

Our gratefulness is also dedicated to Mrs. Bronwyn Fida, who edited carefully the text of the Handbook and Appendix I.

Last but not least we want to thank our partners for their patience during working periods, when we were submerged within the forests or in front of the computers.

1. Introduction

Best management practices (BMPs) for forests were defined in order to optimise the functionality of the forest stands regarding different purposes. Silvicultural practices are important factors in determining water yield and quality from forested watersheds (Twery & Hornbeck, 2001). Coming from Northern America, where huge clear-cuts are still conducted, BMPs were defined for large logging areas in order to moderate negative effects on streams. Several Best Management Practices (BMPs) are used in forestry operations to moderate the impact of logging on stream water quality. These include the setting of roads away from streams, the drainage and rehabilitation of tracks and roads after harvesting, the use of riparian strips, and restrictions of logging activities in relation to catchment slopes, soil type and rainfall. These practices are designed to achieve two significant objectives: firstly to control erosion on a site and secondly to minimize the delivery of sediment and pollutants off-site to natural drainage lines (Wallbrink & Croke, 2002).

The role of forested stream buffers (riparian strips) for the non-point source (NPS) pollution assimilation was also highlighted by Basnyat et al. (2000).

Within the Washington watershed analysis program, scientific analysts identified watershed areas that are sensitive to forest practices, subsequently land managers developed watershed-specific rules or prescriptions that prescribe forestry activities in those sensitive areas. These prescriptions were tested and evaluated regarding their scientific soundness (Collins & Pess, 1997).

In Kentucky (USA), two out of three small watersheds were harvested (clear-cut), one with application of BMPs, the second without BMPs. Clear-cutting resulted in increased concentrations of nitrate and other nutrients compared with the uncut watershed, and concentrations were highest on the non-BMP watershed (Arthur et al., 1998).

Only a few references were found regarding BMPs on karstic areas. Most of the studies conducted in karst areas focused on agricultural themes. One study focused on water quality improvement in the area of carbonate aquifers in grazed land watersheds. Little effects on water quality improvement due to the application of BMPs were found. However in one case, a significant decrease of faecal coliform concentrations was observed in subterranean drainage from one targeted sinkhole, after dairy cattle were permanently excluded from the sinkhole (Boyer, 2005). Also within an agricultural used watershed in Kentucky (USA), it was formulated, that future BMP programs in karst areas should emphasize buffer strips around sinkholes, excluding livestock from streams and karst windows, and withdrawing land from production (Currens, 2002).

Of course, the situation within the water protection zone in the Northeastern Calcareous Alps of Austria is different. The main focus for the definition of BMPs is land-use category forestry. Some very crucial aspects of best practices in water protection forestry are already fulfilled. For example, clear-cuts have already been forbidden within the water protection zone for more than 20 years (Anonymus, 2001), which excludes the main focus of BMPs within the USA, that is the moderation of negative effects of clear-cuts on stream water. Additionally, the occurrence of surface runoff is not very common in the karstic areas of the headwater regions in Austria. However, buffer strips close to streams, dolines and sink holes can also be regarded as useful BMPs in Austria.

The water protection forests owned by the City of Vienna are already managed by a ‘close to nature’ forest management. There was for example elaborated a site classification system, which supports the choice of appropriate harvesting systems in the protection forests. The model, if applied to the water protection forests, indicates by far more cable-yarding areas than sites for tractor-skidding (Fleck & Vacik, 2006).

The forest site mapping survey was also an initiative of the Municipal Department of Forestry and Agriculture of the City of Vienna. The purpose of this study was the survey and description of the basic growth conditions of the water protection forests (Weidinger and Mrkvicka, 2001; Koeck et al., 2001; Fraissl et al., 1997; Gatterbauer et al., 1996).

Subsequently, a forest-hydrological monitoring program was set up in order to identify and quantify processes regarding different forest stand qualities within three defined hydrotopes (Koeck et al., 2001a). This monitoring program was set up by the City of Vienna and was perpetuated in the course of KATER II project.

The main focus of this work is the definition of BMPs for a forested karstic region, where water protection measures in forestry were already implemented for decades. Therefore, the rules focus on the optimisation of water protection functionality of forest stands within the different hydrotopes of the karstic headwater regions (Koeck et al., 2006).

The definition of the optimisation potential as BMP was conducted for all different hydrotope types, which were described within the KATER II handbook. The following BMP description will focus on a general formalisation of best practices, which are able to be applied on the whole forested water protection zone. More detailed descriptions will focus on the specific hydrotope groups. Additionally, within the KATER II handbook, the optimal status of forest vegetation was defined for each hydrotope category of the headwater regions.

So it is obvious, that Appendix I (BMPs) has to be used together with the KATER II handbook and the corresponding GIS-based maps in order to receive an integrated view on the potential for an optimisation of water protection functionality of forest stands within the karstic headwater regions in Austria.

2. Best Management Practices in general: Principles

There exist BMPs, which can be formulated for the whole forested area of the drinking water protection headwaters of the Austrian pilot area. These more general rules focus on processes within forests, which occur on all different hydrotope sites in a similar way or have a similar significance for all hydrotope areas.

The basis of all recommendations at the level of forestry is the purpose of drinking water protection. This encompasses the aim, to guarantee high quality drinking water supply from the karstic springs with a more or less balanced discharge during the year.

As a basic condition for the forested headwater regions it can be concluded, that the areas should be forested with trees. Trees provide erosion control, cooling of the soil horizons (Koeck et al., 2002) and protection of the humus layers. Additionally, forest stands should be formed by all tree species, which can populate the specific hydrotope site. This creates a higher elasticity of the forest ecosystem (functional group) in the case of environmental changes (Chapin III et al., 1997).

2.1 Crown cover percentage of forest stands

Crown cover percentage of forest stands within the drinking water protection headwaters should range between clearly defined margins. These margins were formulated for every specific hydrotope type. In general, it can be said, that within subalpine forest hydrotopes, crown cover percentage should range between 60 % and 80 %. Within most of the other hydrotope groups, crown cover percentage should range between 70 % and 90 % (please look within KATER II handbook for the recommended crown cover percentage for each hydrotope type, see chapter 5). The lower margin of crown cover percentage can be explained by an increased danger of wind destruction of the respective forest stands.

If closed forest stands are opened in the course of silvicultural measures, and the crown cover percentage is reduced below 60 %, the result is a significant danger of the treated forest stands been blown down and damaged by wind (Mosandl & El-Kateb, 1988). The application of shelterwood-cutting with high intensities of crown cover reduction results in the high risks of storm damage (Mosandl, 1993). The fact that the strong reduction of crown cover percentage of a forest stand leads to a significant increase of the danger of storm damage was also documented by Schütz et al. (2006).

So, the decrease of crown cover percentage below 60 % can be regarded as significantly increasing the danger of forest stands been blown down by wind. This danger cannot be accepted within the water protection zone, because erosion processes have to be avoided there. Therefore, the lowest margins of crown cover percentage of forest stands should never be exceeded.

The upper margin of crown cover percentage is because of the necessity for a continuous regeneration process of the forest stands within the water protection headwaters, which is the basis for the establishment of continuous cover forests (CCF). In order to guarantee this, crown cover percentage should not reach 100 %. On 10-20 % of the hydrotope area, regeneration processes should be able to take place. This necessity explains the upper margins of crown cover percentage.

For further information please see chapter 4.2 of the KATER II handbook.

2.2 Sustained prohibition of clear-cuts

The clear-cutting technique as silvicultural concept is currently still applied in many forest areas on the planet. Especially in Northern America, huge clear-cuts still can be seen as the most important logging activity. Within the water protection forests of the City of Vienna, clear-cutting has been forbidden for more than 20 years (Anonymus, 2001).

The negative effects of clear-cutting were expounded and documented in many studies. Classic studies, like those of Likens & Bormann (1995) pointed out, that increased nitrification and mineralisation rates occurred after clear-cuts, causing increased matter concentrations within the streams. This dynamic was also demonstrated by Reynolds et al. (1992). In the course of a comparison between a clear-cut area with a mature forest stand, a shelterwood cutting area and a group selection system, it was shown, that the highest in-situ nitrogen-mineralisation rates were found on the clear-cur area. Nitrogen-mineralisation rate was the lowest on the area of the mature forest stand (Prescott, 1997). A paired watershed experiment in Northern Carolina (USA) showed, that in comparison with the control watershed, stream water in the case of the clear-cut watershed had significantly increased concentrations of suspended matter, total nitrogen, total phosphorus and faecal coliform bacteria (Ensign & Mallin, 2001).

This is only an excerpt of literature regarding the effects of clear-cutting on stream water quality. It can be concluded, that international scientific publications support the prohibition of clear-cut technique within the water protection forests. This prohibition has to be sustained in the future in order to guarantee the prevention of the negative effects of clear-cuts.

2.3 Continuous cover forests

If clear-cuts are forbidden, the establishment of continuous cover forests (CCF) becomes possible. As a consequence of the negative effects of clear-cuts or strong reductions of the forest cover, it is of interest, to put the focus of forestry within water protection headwaters on the sustained forest cover on each hydrotope area. The sustained forest cover, with a guarantee of a crown cover percentage within defined constraints (for each hydrotope, based on the specific forest-ecological boundary conditions) would avoid intensive mobilisation processes of soil and humus substances caused by forest cover reduction. This can be reached by application of the ‘continuous cover forest’ concept (German: Dauerwald-Konzept), which was defined for the first time by Möller (1922). The concept of ‘continuous cover forest’ has as an overall purpose the maintenance of forest cover over time and space, postulating uneven-aged forest stands. The different phases of forest development can be found within one forest stand in the case of ‘continuous cover forests’, which is different from forest areas, which are treated by clear-cut techniques, where the forest development phases are spatially distributed and related to the time span from the clear-cut application (Thomasius, 1996).

Continuous cover forests can be reached on every hydrotope type within the headwater regions. The specific requirements for this silvicultural concept have to be adapted to each hydrotope type. More detailed descriptions regarding achieving ‘continuous cover forests’ within each hydrotope are given in chapter 3 of this Appendix and in chapter 5 of the KATER II handbook.

2.4 Continuous regeneration process

In order to achieve continuous cover forests (CCF), a continual regeneration process is necessary. As defined within chapter 2.4, the forest stands within the headwater regions should exhibit areas, where the regeneration process can take place. In order to fulfil this crucial requirement of CCF, it is necessary to provide areas, where enough light reaches the forest soils for the initiation of the regeneration dynamics. This should not cover the whole area of a forest stand, because the need of structured forests is required in the headwater regions. Instead, small gaps (openings) within the forest stands should be created, which should consist of between 10 % and 20 % of the forest stand area, but the gaps should be as small as possible. The upper limit of the small openings (gaps) should be one tree-length in diameter, but if possible, they also can be significantly smaller. The primary requirement is that regeneration processes are initiated on them.

The gaps can be free of trees (German: Lochhiebe) or can still possess a loose forest cover, if the *group selection system* is applied (German: Femelschlag-Verfahren) (see chapter 3.2).

One important requirement for the regeneration process is, that all tree species, which should be present within one hydrotope, are also represented in the tree species distribution of the regeneration phase. The required tree species distribution of each hydrotope was defined in chapter 5 of the KATER II handbook. All tree species in regeneration phase have to be represented in high quantities and the saplings and young trees should show high vitality. Browsing damage as the biggest obstacle for the succession of tree regeneration should be dealt with by the provision of forest-ecologically sustainable wild ungulate densities (see chapter 2.8).

2.5 Structured forest stands

As mentioned before, the forest stands within the drinking water protection zone have to be structured. Single-layered forest stands are not desired, because this implies first off all, that all trees are the same age. This fact negates the requirement of continuous cover forests (CCF). The opposite of single layered forest stands are structured forest stands, where all age classes are represented. Due to the presence of all age classes within the forest stands, as well as the dbh-(diameter in breast height)-distribution is very wide. The structure should be given horizontally and vertically.

The spatial distribution of the different age classes and tree heights should not be homogenous but clustered. Clusters of forest succession phases should range from small gap expansions of about 40 m^2 up to gaps with a diameter of one tree length (as maximum). Structured forest stands show a higher stability against wind damage than single-layered ones.

If thinning measures in forest stands are applied early enough, they still appear to be an effective measure for improving stability. The fact, that irregular forest (i.e. mixed planter forests with spruce and fir) turned out to be significantly more resistant to ‘Lothar’ (storm system with strong winds in Europe in 1999) than regular forest, supports this finding (Schütz et al., 2006).

If the thinning measures are fulfilled in a way, that provides horizontal forest stand structure, it may be even more effective in improving stand stability.

A further advantage of structured forests is the high snow accumulation potential, which is created by the small gaps during the whole succession phases of these stands (see chapter 9.2.1 within the KATER II handbook).

2.6 Foster stability and vitality of forest stands

Stability of the forest stands within all defined hydrotopes of the water protection headwaters is a very important feature. Only stable forest stands can guarantee the water protection functionality. In the course of silvicultural measures, the stability of tree individuals is therefore an important decision criterion. Stability describes the inner constitution of a forest ecosystem, to maintain its inner constitution in the course of its interaction with the existent life-world conditions, meaning the ecosystems resists and to remain quasi unchanged (Otto, 1994). Within this context, it is necessary to clarify some terms. *Elasticity* of a forest ecosystem describes the situation, if a disturbing factor causes a change, which can be revoked by the ecological system itself, if the disturbing factor does not operate any more. The *resilience* of a forest ecosystem describes for example its resistance towards wind- or snow damage (Mayer, 1992).

Only stable and vital forest stands are able to protect the ecosystem in a sustainable way from erosion processes. Erosion processes, like soil erosion, root-plate erosion or humus decomposition processes, have to be minimized within water protection forests, therefore the stability of tree individuals and forest stands gains importance.

The stability of tree individuals may also be defined by the relation of height and diameter of the tree. For example in the case of spruce, the susceptibility to snow damage can be minimized by the regulation of the height-diameter ratio. Low values of the height-diameter ratio show a higher stability against snow damage than higher ones (Mayer, 1992).

In connection with stability, tree vitality has to be mentioned too. Vitality describes the attribute of a tree or a forest stand to utilize the given life-world conditions by showing strong and healthy growth, to activate power of resistance towards the impact of destructive environmental influence, to heal damage (e.g. rock fall impacts) and to regenerate abundantly in a generative or vegetative way. The term vitality is a qualitative factor, which cannot be defined exactly in a quantitative way (Otto, 1994). Vitality is also defined as the degree of robustness of a species or population to tolerate life-world conditions (Schäfer & Tischler, 1983).

The assessment of tree and forest stand stability and vitality in every case has to be fulfilled by the foresters on the specific sites. They have intimate knowledge of the forest stands, so that decisions about stability and vitality of tree individuals and forest stands are based upon sound knowledge.

It is important, that the most stable and/or vital tree individuals have to remain within the forest stands. On the other hand, tree individuals with low stability and vitality should be removed, if reductions of the forest stand volume are intended.

2.7 Limitation of the forest stand volume reduction

The necessity to limit the forest stand volume reduction within water protection forests is due to the fact, that the felling of each single tree causes an increase of the matter-concentrations within soil water (v. Wilpert et al., 2000; Bartsch, 1998). In order to minimize this effect, it was recommended, that the percentage of forest stand volume reduction in the course of silvicultural measures within the water protection forests of the Catskill Mountains (New York, USA) should be limited to 10-15 % of the forest stand volume (Murdoch, 1998). Within the same water protection zone, Wang et al. (2006) have proved that a forest stand volume reduction of 33 % already caused a significant increase of matter-concentrations (like nitrate) within the stream water.

For the maintenance of forest stand stability (see chapter 2.4) and additionally for the purpose of a minimization of matter concentrations within soil water, the forest stand volume reduction within the water protection forests in the Austrian pilot area should be limited to 15-25 % of the current stand volume. This limitation should be restrained in the course of any silvicultural measures within the water protection forests.

The preservation of an appropriate level of biomass accumulation in line with the structural interface of forest stand and forest site is of interest as well as the improvement of the degree of self-regulation of the forest stands (Ussiri et al., 2007; Thomasius, 1996; Likens & Bormann, 1995; Krapfenbauer, 1983). The removal of living and dead biomass should be kept on a low level, what implies that the utilisation of wood beyond the classical type of timber yield should be omitted.

2.8 Hunting activities who foster forest-ecologically sustainable ungulate densities

As described in chapter 8 of the KATER II handbook, the regeneration dynamics are of crucial importance for forest succession. If the density of the wild ungulate game species is too high, forest regeneration may be seriously hampered or even stopped. In order to guarantee stable forest stands within the headwater regions currently and in the future, the wild ungulate densities have to be balanced on a level, which allows the vital regeneration dynamics of all necessary tree species. Especially the regeneration dynamics of fir (*Abies alba*) have to be nurtured by the creation of forest-ecologically balanced wild ungulate densities. The regeneration process of all broadleaved tree species, fir, larch and in some cases spruce can be improved by this measure. The only chance to reach forest-ecologically balanced wild ungulate densities is the implementation of appropriate hunting activities and by the creation of close to nature forest stands (Reimoser & Gossow, 1996).

For the successful application of many further BMPs, a forest-ecologically sustainable wild ungulate density is the basic condition. The sole criterion for determining the requisite hunting quota has to be the state of regeneration (Eiberle & Zehnder, 1985; Suda, 1990). For more information regarding regeneration dynamics and hunting please see chapter 8 of the KATER II handbook.

2.9 Foster old, huge and vital tree individuals

It is important, to leave old and huge trees in the forest stands, provided that they fulfil the criteria for stability and vitality. This means turning away from the classical yield regulation by age classes, which followed a strict rotation length for the whole forest stand. The forest stand age was limited in the mountain forest area, to between 100 and 150 years (Mayer, 1992). The importance for old and vital trees to stay within the forest stands is because of their genetic potential and the root- and total-biomass of these tree individuals. Old and huge tree individuals can provide stability for the whole forest stand 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.

Plants collaborate with many micro-organisms in the rhizosphere to form mutualistic associations. One of the best examples is the mycorrhizal symbiosis. Here, fungi supports plants with mineral nutrients and other services and the fungi, in turn, receive photosynthates from the autotrophic plants (Van der Heijden & Sanders, 2002). Implications of mycorrhizal links and interplant transfer for ecosystems are, that it assists seedling establishment near mature plants by allowing seedlings to become colonised more rapidly or to tap into an established CMN (common mycorrhizal network) supported by other plants. It also reduces competitive dominance and promotes species diversity by allowing C or nutrients to directly flow from sufficient to deficient plants, resulting in a more even distribution of C and nutrients (Simard et al., 2002). Different plant species can be compatible with the same species of mycorrhizal fungi and be connected to one another by a common mycelium. There is a further possibility that carbon is distributed below-ground among plants across resource gradients, other than light, that affect relative photosynthetic potential within a mycorrhizally linked plant community. Such a mechanism would offer an explanation for the ability of species-rich communities to maitain productivity during drought or where nutrients are limiting (Simard et al., 1997)

In Australia, scientists were able to show, that water yield in the case of a watershed stocked with old trees of the species *Eucalyptus regnans* or *Eucalyptus sieberi* was higher than water yield in the case of a watershed populated with young forest stands of this tree species. The older tree individuals have a lower transpiration demand than young trees of this species (Vertessy, 1998; Roberts et al., 2001; Vertessy et al., 2001). Similar studies within the alpine areas of Europe do not exist, but would be of crucial interest for forest hydrology.

The genetic diversity and potential given by old and huge trees of all species within a hydrotope is an indispensable factor for the sustainable forest succession in future.

2.10 Deadwood

Coarse deadwood should be present within all forest hydrotope areas of the drinking water protection headwaters. A tree during the time span from just before its death, as well as during the specific decomposition-phases, is a habitat and an ecological niche for a large amount of organisms and succession-chains which form in specific micro-habitats on continually decomposing tree trunks. Life and death are therefore inseparable in an undisturbed forest (Otto, 1994). Within the montane spruce-fir-beech forest belt, especially upright deadwood with strong diameters has an outstanding relevance as habitat and brood chamber for important bird species like woodpecker species, Tengmalm’s Owl or the European Pygmy-Owl. The latter species can, by way of the depletion of the mouse population, contribute significantly to the regeneration-advancement of the tree species. Both Tengmalm’s Owl and European Pygmy-Owl inhabit brood caves, which were created by woodpecker species. Main source for nutrition for both owl species during the incubation period are mouse species (Bezzel, 1985).

The relevance of deadwood for biodiversity was mostly underestimated in the past. It was possible to show, that wood caves created by woodpeckers-species in strong upright deadwood trunks, subsequently may be populated by bat, squirrel, marten-species and owl-species. It is also important to mention the first inhabitants of deadwood, like fungi, bacteria, mites and nematodes (Krajick, 2001).

For the water protection functionality of forests, coarse deadwood (trunks with strong diameters, upright and horizontal) have a predominant relevance because of the impacts previously mentioned, which nurture forest stand stability. This stand stability is created for example by the regulation of the mouse population by owls and the result ensures regeneration dynamics of beech. On the other hand, the decomposing woody parts of the trees are an area where water storage takes place.Therefore, the presence of coarse deadwood (upright and horizontal) has to be advanced on all hydrotope areas, so that a minimal proportion of deadwood of 3-4 fm per hectar within the montane zone and 5-6 fm per hectar within the subalpine zone is given in all hydrotopes.

2.11 Buffer strips around dolines, sinkholes and streams

Dolines are areas, which are very highly vulnerable with regards to karst aquifer contamination. The vulnerability is due to the fact that dolines and sinkholes are mostly directly connected from surface water to karst aquifers. In order to minimize the danger of any contamination, forestry operations should not be carried out in dolines and sinkholes. Additionally, it would be of relevance to define buffer strips around dolines and sinkholes, where forest vegetation can never be cut. Only silvicultural measures for forest stand stabilisation within the buffer strips should be allowed.

Forested buffer strips close to streams and lakes should also be defined in order prevent the open water bodies from direct infiltration of nutrients or sediments, which can be created by logging activities. The effectiveness of riparian buffer strips as retention area for sediments and nutrients has been proved by various studies (Wallbrink et al., 2002). The riparian area is the transition between aquatic and terrestrial characteristics of soil, water, vegetation and landform. As such, they contain unique species combinations and are especially important to protecting water quality as well as the food chain and physical structure of aquatic habitats. State BMPs normally require buffer strips of one or more tree lengths on both sides of perennial stream channels to protect the stream and riparian area (Twery & Hornbeck, 2001).

Close to streams, the constitution of the forest hydrotope types 904 and 905 (chapter 5.10, KATER II handbook) gains importance.

Similar to the riparian zones, the buffer strips can also be seen as appropriate in the case of dolines and sinkholes. The buffer strip width should be greater than one tree length in all cases. Around dolines, this results in a circular buffer area of more than one tree length in width. Within an agriculturally used karstic landscape, cattle were excluded from the sinkholes, which had a positive effect on water quality of the corresponding subterranean drainage (Boyer, 2005).

3. Best Management Practices in general: Silvicultural techniques

3.1 Thinning operations with specific purposes

The thinning operations within forest stands of the water protection area have to focus on specific purposes. In order to receive stable and structured forest stands, thinning has to be a structural thinning. Vital and stable trees should remain and less vital ones can be removed. 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.

The concept of the *structural thinning* follows the purpose of the stabilisation of the forest stand and the creation of a continuous cover forest. Additionally to selected and nurtured trees from the uppermost forest stand layer, tree individuals from the medium layer (and primary layers) of the forest stand are also selected and nurtured. An essential aim of the concept of structural thinning is that the distribution of tree diameter becomes wider (Reininger, 1987). The concept of structural thinning is of crucial importance in connection with the transformation of homogeneous, single-layered conifer stands into mixed and unevenly-aged forest stands.

3.2 Regeneration techniques

For the purpose of forest stand regeneration, the application of the *group selection system* (Femelschlag-Verfahren - Mayer, 1992) is recommended within the montane and high montane zone, where forest hydrotopes with higher proportions of broadleaved tree species can be found. Only, if the presence of beech within the actual forest stand is given, this regeneration technique should be applied. The spatial extension of group selection cutting areas within the water protection zone should be limited with the maximum of one tree length in diameter, but should be smaller, if at all possible. The most important fact should be the initiation of the regeneration process. On sunny slopes, the extension of the group selection areas may be smaller, because the specific site conditions involve more sunlight for the regeneration initiation process in comparison with northern exposed sites. The group selection system implies the opening of the forest cover on the defined area, but some trees remain upright and provide a loose forest cover on the group selection area. The remaining trees should preferentially be beech trees, because beech does not have a wide radius for seed distribution. So, the growth of beech saplings within the *group selection cutting* area can be facilitated.

It is of crucial importance that in the course of the application of the *group selection system* the creation of unevenly-aged and structured forest stands remains the purpose. This can be achieved, if this system is applied within a forest stand of a hydrotope on a spatially limited area, in accordance with the limitation of the stand volume reduction (see chapter 2.8). After the application of the first part of the *group selection system* it is of importance, to wait, until the regeneration process has established on the treated area and can be characterised as the secure thicket phase of forest succession. If this is accomplished, the next area of the forest stand can be treated with the *group selection system.* If the regeneration process is not hampered by any influences, this system leads to a transformation of forest stands to multi-layered and mixed stands within the time span of about 100 years or more. The indicator for the application of the next step of this silvicultural measure is the stage of development of the regeneration phase. By the selection of an adequate spacing of the *group selection cutting* areas, the stability of the forest stand is still given and the realisation of unevenly-aged and structured forest stands in future is guaranteed. The areas for *group selection cutting* should be selected with regards to stability of trees. If instable tree individuals are present, the *group selection cutting* should exclude these trees and surrounding ones from the forest stands.

In the case of subalpine conifer-forest hydrotopes, or also in the case of homogeneous conifer plantations within the montane and high montane zone, the creation of small gaps without remaining forest cover within this area (*gap-system,* in German: Lochhieb) seems to be more adequate as a regeneration concept. The gaps should also be as small as possible in order to create as little impact on the soil water chemistry as possible. The upper limit is recommended at one tree length in diameter. In some exceptional cases within the subalpine zone, the gaps may reach up to one and a half tree lengths in diameter, if the regeneration dynamics depend on more sunlight on these cool hydrotope sites. Also the use of nurse-log regeneration techniques may be necessary within this elevation zone (see chapter 3.11). The advantage of the *gap-system* is, the fact that no trees remain in the treated area, which diminishes the danger of logging damage.

Again, the creation of unevenly-aged and structured forest stands is the ultimate aim of this silvicultural concept. Therefore, this concept has to be applied on stand level, like the before mentioned *group selection system.*

Both regeneration techniques follow the principle of natural regeneration of all tree species. This system of course requires the presence of all necessary tree species within the mature forest stands, where regeneration dynamics have to be induced. If it is possible to achieve the defined regeneration purpose (for each hydrotope, see chapter 5 in KATER II handbook) with natural regeneration techniques, this can be regarded as optimal. Young trees, which stem from natural regeneration processes, are regarded as the more stable individuals compared with planted individuals. Natural regeneration leads to a better exploitation of the natural production forces (Mayer, 1992).

The regeneration techniques have to contribute to the requirement of a continuous regeneration process within the forest stands of the water protection forests (see chapter 2.5).

3.3 Afforestation measures

If required tree species for the regeneration dynamics are not present within the mature forest stand, it may be possible that despite this fact, the species are present within the regeneration layer of the forest stand. Therefore it is necessary to monitor the regeneration dynamics within each hydrotope area. Regarding the succession phases ‘tree saplings’ and ‘young trees’ (trees below 1,3 m height), it is necessary to have precise records on all tree species represented. If necessary species of the defined optimal tree species distribution of each hydrotope (see chapter 5 in KATER II handbook) are missing or are not represented with sufficient quantity or quality, afforestation measures become mandatory. In these cases, afforestation is the only way to introduce necessary tree species into the respective forest stands. If it were not executed, forest stand stability and also the water protection functionality of the future forests would be diminished.

This emphasizes the significance of appropriate afforestation measures in the defined cases. Tree species, which should be afforested in many cases, are fir (*Abies alba*), beech (*Fagus sylvatica*), larch (*Larix decidua*), pine species (*Pinus spec.*), elm species (*Ulmus spec.*) and yew (*Taxus baccata*). Potentially, any tree species of the hydrotope groups within the water protection headwaters may have to be afforested in exceptional cases.

3.4 Selection of the adequate timber harvesting technique

Within the water protection zone, erosion processes caused by timber yield activities should be minimized. This objective can only be accomplished, if the applied timber harvesting technique takes the site conditions into account. Within the water protection forests of the City of Vienna, there was elaborated a site classification system, which supports the choice of appropriate harvesting systems in the protection forests. Cable-yarding causes less soil disturbances than tractor-skidding. Only on favourable sites, tractor-skidding is allowed for timber harvesting. The model, if applied to the water protection forests, indicates by far more cable-yarding areas than sites for tractor-skidding (Fleck & Vacik, 2006).

Tractor-skidding can cause soil compaction that diminishes the water infiltration capacity of the forest soils (Eichhorn, 1993). If tractor-skidding is applied as a timber harvesting method, the soils should be frozen or dry and the tracks should be covered with branches from conifer trees in order to minimize soil compaction.

3.5 Nurse-log regeneration technique

Within the high-montane and subalpine zone, regeneration dynamics may be hampered by cold soil- and air- temperatures. Especially within the subalpine forest hydrotopes, which also have clayey soil formations, regeneration of the forest trees is often difficult to reach, because of the mostly humid and cold soil layers that do not provide the necessary micro-climate. In many cases, regeneration dynamics are restricted to micro-ridges or tree cadavers, which are already horizontal. Regeneration, which is initiated by horizontal tree cadavers, is called nurse-log regeneration.

Picture 1: Nurse-log regeneration of spruce and larch within a subalpine hydrotope.

On the tree cadavers and also within the radiation space of them, the micro-climate is improved so much, that saplings of conifer tree species and also of broadleaved tree species begin to grow there.

Horizontal tree cadaver does not provide nurse-log from the beginning, first it has to enter into the decomposition processes. Decomposition of spruce starts very quickly once it has contact with the forest soil. Horizontal dead wood as nurse-log is so much the better if it has strong dimensions (‘coarse deadwood’) and if the bark is still covering the trunk (Otto, 1994). Dead wood without bark can be treated with the chain saw by making longitudinal cut, which improves the moisture penetration into the dead trunk, which subsequently improves the conditions for the tree saplings (Haeffner, 1996).

The horizontal trunks should be placed intentionally at the micro-sites of the small gaps (either natural ones or created ones by application of the *gap system*), where forest regeneration is intended. Nurse-log regeneration is mostly the only kind of regeneration within the subalpine forest hydrotopes (Koeck et al., 2001). It can be found on the dead and decomposed trunks as well as close to them, where their infrared radiation space is still given. Picture 1 shows one example of nurse-log regeneration.

Picture 2: Mature spruce trees (*Picea abies*) within a subalpine hydrotope, growing in cluster structure, established from nurse-log regeneration.

4. Best Management Practices within hydrotope groups

For all hydrotope groups, specific best management practices for the optimisation of the water protection functionality of the forest stands were defined. First of all, it should be mentioned, that in chapter 5 of the KATER II handbook, the general settings for the forest stand features with regard to an optimal water protection functionality are defined. There, the tree species, which can grow within the hydrotope, the necessary tree species distribution and the crown cover percentage on the specific hydrotope sites are formulated beside further parameters for each hydrotope.

Within this chapter, the specific needs for best management practices for each hydrotope group are defined. The requirements for the initiation of regeneration dynamics are defined for each hydrotope groups as well as specific conditions

As a further step a model was developed for the water protection functionality of each hydrotope site within the headwater regions. As a basis for the GIS-based model, several variables have been used. The model was based on points and weights of the specific parameters. The most important parameter was the relation between broadleaved tree species and conifer tree species, which was defined for each hydrotope type within chapter 5 of the KATER II handbook. This relation receives a relative high weight (3, see Tab. 1) and was calculated for all the water protection forests, using the forest management book database (MA 49, 2007).

Table 1: Date categories and their weights used for the water protection functionality (WPF) model

Data category	**Weight**
Relation conifers to broadleaved tree species (RCB)	3
Crown cover percentage	4
Layering of the forest stands	3
Age structure	3

Further data categories drawn from the forest management book are the crown cover percentage (weight 4, see Tab. 1), the layering and the age structure of the forest stands (weight 3, see Tab. 1).

All the parameters were assessed by the application of a point system, which ranges from 1 to 5 (Tab. 2). In chapter 5 of the KATER II handbook (KH), the points regarding the relation of conifers to broadleaved tree species are defined for each hydrotope in the respective thematic tables. The different parameters received points regarding their water protection functionality fulfilment (Tab.2), which was multiplied with the respective weight of the parameter (Tab. 1). All the parameters were added and subsequently divided by the total number of assessed parameters. The final calculation for each hydrotope site, defining the water protection fulfilment of the respective forest stands, was displayed in a GIS-based map (Table 2).

Table 2: WPF – point system used in the GIS-based model

Points.	**1**	**2**	**3**	**4**	**5**
Relevance:	Very Low WPF	Low WPF	Medium WPF	High WPF	Very High WPF

WPF…degree of water protection functionality fulfilment.

4.1 Black pine forest hydrotopes (I)

Within the group of black pine forest hydrotopes, the pure conifer forest hydrotopes (101, 102, 104, 105) should be treated by *structural thinning* (see chapter 3.1) exclusively. The thinning operations should focus on the enhancement of stand stability and structural diversity. Only if instable tree individuals are present within a forest stand, should the thinning operations be initiated. The application of the group selection system and the gap system does not seem to be necessary, because structural thinning in most of the cases may create enough light on the forest floor for the initiation of regeneration dynamics.

The succession of the regeneration phase of the black pine forest hydrotopes is strongly dependant on the wild ungulate density. Especially black pine (*Pinus nigra var. austriaca*) is often browsed by chamois.

The mosaic hydrotope types 103 and 106 can also be treated by the application of structural thinning, but in some cases, also the group selection system (see chapter 3.2) may be adequate.

The detailed description of the WPF system and the points related to each parameter used for the GIS-modelling, are described in table 3.

The spatial extension of hydrotope group I ranges up to 7,9 % (654 ha, Tab. 143 of KH) of the forest area in headwater region Hischwang and up to 0,3 % (18,5 ha, Tab. 144 of KH) in headwater region Nasswald, while it is missing in Wildalpen area.

Table 3: WPF – system used in the GIS model, applied to hydrotope group I

Black pine forest hydrotope (I)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	4	4	16
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	2	2	4
	2	3	2	6
	3	5	2	10
	4	5	2	10
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

4.2 Red pine forest hydrotopes (II)

The red pine forest hydrotopes should also be treated exclusively with *structural thinning* in the case of instable tree individuals. Again it does not seem to be necessary to apply the group selection system. For the maintenance of a continuous regeneration dynamic, structural thinning can allow enough light to reach the forest floor.

The most important tasks within this hydrotope group can therefore be described by stand stabilisation, the advancement of horizontal and vertical structure and the safeguarding of the regeneration dynamics.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 4.

The spatial extension of hydrotope group II is not very big. Within the headwaters region Wildalpen, it can be found on 1,2 % of the forest area (113,8 ha, Tab. 142 of KH), in Hirschwang on 0,1 % of the forest area (4,3 ha, Tab. 143 of KH) and in Nasswald on 0,2 % of the forest area (13,9 ha, Tab. 144 of KH).

Table 4: WPF – system used in the GIS model, applied to hydrotope group II

Red pine forest hydrotope (II)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	4	4	16
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	2	2	4
	2	3	2	6
	3	5	2	10
	4	5	2	10
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

4.3 Beech-Forest Hydrotopes (III)

The beech forest hydrotopes can be found within the easternmost area of the headwater regions. In order to accomplish forest stand stabilisation and the advancement of forest stand structure, *structural thinning* can be applied in the case of instable tree individuals. For the initiation of regeneration dynamics, the application of the *group selection system* is recommended (see chapter 3.2). The size of the created openings should range between a half to one tree length, depending on the exposition of the hydrotope site.

If homogenous conifer plantations on the hydrotope area should be transformed into beech forest stands, the *gap system* (see chapter 3.2) could be applied. In the parts of the forest stands, which are not treated by the gap system, *structural thinning* could be applied in a subdued way with regards to the quantity of felled stems. The limitation of the forest stand volume reduction (see chapter 2.7) has to be considered in the course of all silvicultural measures. Vitality and stability of the forest stands has to be the ultimate ambition of all silvicultural measures. Afforestation measures in the case of beech may be necessary, if it is missing in regeneration phase.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 5.

The spatial extension of the beech forest hydrotopes reaches 12,3 % of the forest area in Hirschwang region (1024,6 ha, Tab. 143 of KH) and 1,5 % of the forest area in Nasswald region (87 ha, Tab. 144 of KH). The hydrotope group is not present in Wildalpen region.

Table 5: WPF – system used in the GIS model, applied to hydrotope group III

Beech forest hydrotope (III)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	3	4	12
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	3	2	6
	4	4	2	8
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

4.4 Beech-Fir-Forest Hydrotopes (IV)

The beech-fir forest hydrotopes can be found in Hirschwang region on 9,3 % of the forested area (776,7 ha, Tab. 143 of KH) and in Nasswald region on 10,3 % of the forested area (618,5 Ha, Tab. 144 of KH), while they are absent in Wildalpen region.

In natural mixed forest stands of this hydrotope group, the improvement of the forest stand structure and stability could be achieved by application of *structural thinning*. The initiation of the regeneration dynamics could be achieved by the application of the *group selection system,* which should be conducted as described in chapter 3.2.

In the case of homogeneous conifer plantations, the execution of the *gap system* would be more appropriate (see chapter 3.2). In the created gaps, beech and fir would have to be planted, if they do not appear in the course of the natural regeneration dynamics.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 6.

Table 6: WPF – system used in the GIS model, applied to hydrotope group IV

Beech-fir forest hydrotope (IV)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	3	4	12
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	3	2	6
	4	4	2	8
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

4.5 Spruce-Fir-Beech-Forest Hydrotopes (V, VI, VII)

These are the hydrotope groups with the vastest distribution within the headwater regions. Group V for example spreads over 38,2 % of the forest area in Wildalpen region (3665,2 ha, Tab. 142 of KH), over 33,8 % of the forest area in Hirschwang region (2812,2 ha, Tab. 143 of KH) and over 29,7 % of the forest area in Nasswald region (1776,2 ha, Tab. 144 of KH). The wide spread occurrence of this hydrotope group underlines its significance for water protection functionality.

Group V consists of 10 hydrotope types, which differ greatly in some aspects. In all of the hydrotope types in group V, forest stand stability and structural diversity can be improved by application of *structural thinning.* Again, the presence of instable tree individuals should indicate the timing of the initial phase of this silvicultural measure.

For most of the types, the adequate concept for the initiation of regeneration dynamics in the case of naturally mixed forest stands is the *group selection system.* If executed, the limits of spatial extension and temporal advancement should be considered as defined in chapter 3.2.

In the case of hydrotope type 506 and 703 (see chapter 5.6.6 and 5.8.3 of KH), which occurs on boulder sites, naturally mixed stands should be regenerated by application of the *gap system.* Only gaps with an extension of one tree height in diameter can ensure the vital regeneration of larch (*Larix decidua*) in this case, which can be regarded as crucial tree species for stand stabilisation within this hydrotope.

Regeneration dynamics within homogeneous conifer plantations should also be treated with the *gap system* (see chapter 3.2). If within the regeneration phase of the forest stands, tree species of

Table 7: WPF – system used in the GIS model, applied to hydrotope groups V, VI, VII

Spruce-fir-beech forest hydrotopes (V, VI, VII)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	3	4	12
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	3	2	6
	4	4	2	8
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

the defined set are missing, these would have to be planted in order to be present in the future forest stands.

The hydrotope group VI, which exhibits soil formations on the silicatic bedrock ‘Werfener Schichten’, especially needs fir (*Abies alba*) as a stabilizing tree species. Therefore, the presence of this tree species has to be ensured in every stage of forest succession and of course has to be afforested, if it does not appear in the regeneration phase of the respective forest stands. All the other features in relation to thinning and regeneration concepts are the same as in the case of group V.

Hydrotope group VII occurs within the high montane zone, which implies lower soil- and air temperatures and higher snow pack during winter seasons. This may demand the application of nurse-log regeneration techniques (see chapter 3.5). Felled stems would have to be placed in the areas, where the regeneration dynamics are intended to take place. In these cases, the *gap system* would have to be applied as a regeneration technique (see chapter 3.2). All the other features in relation to thinning and regeneration concepts are the same as in the case of group V.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 7.

4.6 Maple Forest Hydrotopes (VIII)

The group of maple forest hydrotopes occurs preferentially in valleys, ditches or close to the base of deep valleys. The spatial extension of this hydrotope group was calculated as high 1,4 % of the forest

Table 8: WPF – system used in the GIS model, applied to hydrotope group VIII

Maple forest hydrotopes (VIII)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	3	4	12
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	3	2	6
	4	4	2	8
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age of the oldest layer >=3/10 proportion	< 160 years	3	2	6
	160-200 years	5	2	10
	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

area in Wildalpen region (129,4 ha, Tab. 142 of KH), 1,3 % of the forest area in Hirschwang (105,5 ha, Tab. 143 of KH) and 6,5 % of the forest area in Nasswald region (387,3 ha, Tab. 144 of KH). In many cases, this hydrotope group can be found close to the karstic springs.

For forest stand stabilisation and improvement of vertical and horizontal structures, *structural thinning* (see chapter 3.1) should be applied. Any advancement of regeneration dynamics can be accomplished by the execution of the *group selection system,* if the mature forest stand is naturally mixed (see chapter 3.2). In the case of homogeneous conifer plantations, the application of the *gap system* seems to be more adequate (see chapter 3.2).

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 8.

4.7 Alder- and Floodplain-Forest Hydrotopes (IX)

The spatial extension of the hydrotope group IX is not very extensive, because the sites, where they can occur are limited by the specific life-world conditions within the alpine karstic headwaters. In Wildalpen region, the extension is the largest at 1 % of the total forest area (94 ha, Tab. 142 of KH), while in Hirschwang region, 0,2 % of the total forest area (18,4 ha, see Tab. 143 of KH) and in Nasswald region 0,7 % of the total forest area (41,6 ha, see Tab. 144 of KH) are cover by hydrotope group IX.

Table 9: WPF – system used in the GIS model, applied to hydrotope group IX

Alder forest hydrotopes (IX)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	3	4	12
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	2	2	4
	2	3	2	6
	3	4	2	8
	4	5	2	10
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

The importance of the hydrotope types 904 and 905 (see chapter 5.10.4 & 5.10.5 of KH) is as a result of theirs position close to streams. Therefore, only *structural thinning* should be applied in order to activate regeneration dynamics and improve stability and structural diversity of the respective forest stands. The maintenance of forested buffer strips around the streams (see chapter 2.11) can be guaranteed by an adequate application of this silvicultural technique.

All the other hydrotope types of group IX can be treated with *structural thinning* as well as with the *group selection system* or the *gap system* for the initiation of regeneration dynamics.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 9.

4.8 Montane Spruce- and Conifer-Forest Hydrotopes (X)

Montane spruce- and conifer hydrotopes occur on very specific sites, where the growth conditions do not allow the succession of broadleaved tree species. The spatial extension of hydrotope group X is not very high. Within the headwater region Wildalpen, it can be found on 1,5 % of the total forest area (147 ha, see Tab. 142 of KH), in Hirschwang region on 0,9 % of the total forest area (78,1 ha, see Tab. 143 of KH) and in Nasswald region on 0,6 % of the total forest area (37,6 ha, see Tab. 144 of KH).

In the case of hydrotope type 1001, where silicatic bedrock are given, all silvicultural measures described in chapter 3, can be applied.

Table 10: WPF – system used in the GIS model, applied to hydrotope group X

Montane conifer forest hydrotopes (X)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	4	4	16
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	3	2	6
	3	5	2	10
	4	5	2	10
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

Hydrotope type 1003 can be described as very highly vulnerable, silvicultural operations should not be conducted within this hydrotope. Hydrotope 1002 can be treated by the application of *structural thinning* for the optimisation of stability and structural diversity of the forest stand. Only in exceptional cases, the *group selection system* should be applied for the initiation of regeneration dynamics, taking into account, that the spatial extension should be as small as possible on this hydrotope area.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 10.

4.9 High montane / subalpine Spruce-(Larch)-Forest Hydrotopes

The natural subalpine conifer hydrotopes can be found in relatively wide spread area. Within the headwaters region Wildalpen, hydrotope group XI spreads over 7,1 % of the total forest area (683 ha, see Tab. 142 in KH), in headwaters region Hirschwang, it spreads over 9,9 % of the total forest area (823,7 ha, see Tab. 143 of KH) and in headwaters region Nasswald, it spreads over 17,9 % of the total forest area (1072,4 ha, see Tab. 144 of KH).

For the initialisation of regeneration dynamics, the application of the *gap system* seems to be adequate. The trees grow in clusters within hydrotope group XI, which provides stability against strong winds and snow damage. Therefore it is of great importance, to either leave whole tree clusters as they are, or to cut a whole cluster in order to create space for regeneration dynamics or snow storage.

Table 11: WPF – system used in the GIS model, applied to hydrotope group XI

Subalpine spruce-(larch-) forest hydrotopes (XI)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,8	3	4	12
	0,6-0,8	5	4	20
	0,5-0,6	4	4	16
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	4	2	8
	4	5	2	10
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

For the improvement of snow storage, the created gaps should range from between 30 m^2 and 150 m^2. For the purpose of regeneration initialisation, the created gaps should extend up to one or (at the upper limit) one and a half tree lengths in diameter. If possible, the gaps should be as small as possible. In the gaps, nurse-log regeneration techniques should be applied (see chapter 3.5) in order to foster the growth of tree saplings.

In some cases, the afforestation of fir (*Abies alba*) could be necessary, if this tree species is not present within the mature forest stands, but should be present within the respective hydrotope. Fir can stabilize the forest stands within the subalpine hydrotopes, if the soil conditions are suitable for its growth. The specific subalpine hydrotopes including fir in the optimised forest stands are defined in chapter 5.12 of the KATER II handbook (KH).

The application of *structural thinning* is not recommended within hydrotope group XI, because this measure would dissolve the integrity of the tree clusters.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 11.

4.10 Larch Forest Hydrotopes (XII)

Larch forest hydrotopes can be found on steep and shady slopes at high altitudes of the headwaters regions. The spatial extension is not very high, in Hirschwang region, hydrotope group XII is missing.

Table 12: WPF – system used in the GIS model, applied to hydrotope group XII

Larch - forest hydrotopes (XII)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,8	3	4	12
	0,6-0,8	5	4	20
	0,5-0,6	4	4	16
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	4	2	8
	4	5	2	10
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

In headwaters region Wildalpen, hydrotope group XII extends over 2,9 % of the total forest area (273,4 ha, see Tab. 142 of KH) and in headwaters region Nasswald it extends over 0,5 % of the total forest area (30,9 ha, see Tab. 144 of KH).

In the larch forest hydrotopes, silvicultural measures have not been applied for the past decades. In order to optimise forest stand stability and structure and also for the initialisation of regeneration dynamics, *structural thinning* may be applied in some exceptional cases. More importantly is the fulfilment of forest-ecologically sustainable wild ungulate densities in order to nurture natural regeneration within this hydrotope group, which generally is very vital and abundant. Fraying damage on young tree individuals of larch is the biggest obstacle for the sustainable regeneration dynamics within this hydrotope group, but actually do not occur on all sites.

The application of the *group selection system* or the *gap system* is not recommended within this hydrotope group.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 12.

4.11 Fluffy Oak-Forest Hydrotopes (IXX)

Hydrotope group IXX only occurs in the easternmost part of headwaters region Hirschwang. It spreads over 0,5 % of the total forest area (39 ham see Tab. 143 of KH). As silvicultural measure for the

Table 13: WPF – system used in the GIS model, applied to hydrotope group IXX

Fluffy Oak forest hydrotopes (IXX)

Factor	Characteristic	Points (1-5)	Weight (1-4)	Sum
Crown cover percentage	>0,9	4	4	16
	0,7-0,9	5	4	20
	0,5-0,7	4	4	16
	0,3-0,5	2	4	8
	<=0,3	1	4	4
Tree species diversity	1 tree species	1	2	2
	2	2	2	4
	3	3	2	6
	4	4	2	8
	5	5	2	10
	6+ tree species	5	2	10
Layering	single-layered	1	3	3
	two-layered	3	3	9
	multi-layered	5	3	15
Age	< 160 years	3	2	6
of the oldest layer	160-200 years	5	2	10
>=3/10 proportion	>200 years	2	2	4
Age-Structure	even aged	1	3	3
	2 age classes	3	3	9
	uneven aged	5	3	15

optimisation of stand stability and structural diversity, *structural thinning* may be applied, if vitality of single tree species is not appropriate.

The *group selection system* could be an appropriate measure, if the regeneration of fluffy oak (*Quercus pubescens*) should be nurtured. The option to abstain from any silvicultural measures should be considered. This option will be the most appropriate in the case of the very rocky hydrotope sites, where the trees reach only marginal heights.

A detailed description of the WPF system and the points related to each parameter used for the GIS-modelling are described in table 13.

4.12 Further hydrotope categories

All further hydrotope categories do not exhibit forest cover in the classic sense or extend over areas that are too small to be considered in the GIS-based model. Hydrotope types with forest cover in a very specific form are the dwarf pine forest hydrotopes (group XIII). These are bush-forests, which are not treated by silviculture.

For this hydrotope group, silvicultural measures may be of greater importance, if the alpine pastures loose its influence within the alpine and subalpine regions of the headwaters regions. This situation could lead to a progressive invasion of dwarf pine on actual grassland areas. If tourist activities such as hiking are still to be possible in these areas, at least the tracks have to be cleared in dwarf pine vegetation.

A more important issue for silvicultural measures within the dwarf pine hydrotope group could be the improvement of the forest-hydrological situation. Erosive processes could be minimised on steep slopes, if dwarf pine were planted there. On the other hand, the snow accumulation process could be optimised in the area of this hydrotope group, if a minimal proportion of alpine and subalpine pasture areas would be maintained. On these areas, snow tends to melt later in spring time in comparison to dwarf pine areas (see chapter 9.2.1 of KH). On designated pasture areas, dwarf pine seedlings could be removed in order to sustain a mosaic between dwarf pine and pasture areas. This could maintain a very efficient snow accumulation and snow thawing pattern between these two vegetation types, which would be of interest for water protection purposes.

5. Summary

Best Management Practices (BMPs) were defined in the USA in order to moderate the negative effects of clear-cuts on stream water quality. Within the forested headwater regions in Austria, BMPs were defined with the purpose of an optimisation of the drinking water protection functionality of the forest stands. The situation within the headwater regions is already different, because for example clear-cuts are already forbidden for more than two decades and water protection has been a defined goal in forestry for many decades.

BMPs were therefore formulated for a different purpose. The definition was conducted on three different levels of itemization. The first level deals with BMPs as general principles for silviculture. Very important is that the crown cover percentage of the forest stands ranges between 70 % and 90 % in the montane zone, and 60 % and 80 % in the subalpine zone. This is because forest stand stability would be diminished, if crown cover percentage were lower, and regeneration processes would be hampered, if it were to be higher than the defined margins.

The fact, that clear-cuts have a negative impact on hydrology, is supported by many international studies therefore the prohibition of clear-cuts should be sustained. Continuous cover forests should be developed instead. A basic condition for the fulfilment of continuous cover forest is a continuous regeneration process within the forest stands. Moreover, the forest stands should exhibit structural diversity, which demands a wide diameter distribution, different age classes and height levels within one forest stand.

The most important selection criteria for foresters within the drinking water protection forests are tree stability and vitality. Vitale and stable tree individuals have to remain within the forest stands, regardless of their age or shape. On the other hand, instability is the most important reason for the implementation of silvicultural measures.

The limitation of forest stand volume reduction in the course of any silvicultural measures is an important rule for the prevention of contaminations of the karst aquifers. The limit was defined between 15 % and 25 % of forest stand volume.

A basic condition for the successful accomplishment of any silvicultural measures is forest-ecologically sustainable density of wild ungulates. Only if this is maintained, forest regeneration may take place in the way that is required for water protection purposes.

Old, huge and vital trees should remain within the forest stands, because they enrich genetic variability and can furthermore supply young trees with nutrients. Also the presence of deadwood within the forest stands is of relevance for biodiversity, which can enhance forest stand stability and also foster the regeneration process e.g. via the reduction of mouse population density by owl species. Dead wood is also an area, where water storage takes place.

Around dolines, sinkholes and streams, buffer strips of dense forest vegetation should be sustained, because they may moderate the introduction of pollutants into the karst aquifers.

The application of silvicultural measures has to be carried out with the focus on water protection. Within this context, structural thinning, the group selection system and the gap system can be applied in appropriate ways within the different hydrotopes, which are suitable. Each hydrotope group was defined regarding its suitability for the mentioned silvicultural techniques.

Afforestation measures have to be conducted, if required tree species are not represented within the regeneration phase of the respective forest stands.

The timber harvesting technique has to be adapted to the site conditions. Cable-yarding is often more preferred than tractor skidding. A model applied to the water protection forests indicates by far more cable-yarding areas than sites for tractor-skidding.

Within the subalpine zone, the nurse-log regeneration technique is in many cases the only way for the initialisation of an adequate regeneration process.

For all hydrotope groups, specific best management practices for the optimisation of the water protection functionality of the forest stands were defined. As a further step a model was created for the description of the water protection functionality of each hydrotope site within the headwater regions. The results of the modelling were displayed in a GIS-based map.

The KATER II handbook has to be used together with this Appendix, in order to receive an integral view on the potential of an optimisation of the drinking water protection functionality of forest stands within the Austrian pilot area.

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