PROLINE-CE
WORKPACKAGE T2, ACTIVITY T2.2

IMPLEMENTATION OF BEST PRACTICES FOR WATER PROTECTION IN PILOT ACTIONS

D.T2.2.2 PARTNER-SPECIFIC PILOT ACTION DOCUMENTATIONS

PILOT ACTION: PA1.1 City of Vienna - Vienna Water

Lead Institution	PP2 - Vienna Water
Contributor/s	See next page
Lead Author/s	Christian Reszler, Roland Koeck
Date last release	November 28, 2018

Contributors, name and surname	Institution
Gerhard Kuschnig	PP2 - Vienna Water
Christian Reszler	JR-AquaConSol
Roland Koeck Eduard Hochbichler	PP3, LP/PP1 - University of Natural Resources and Life Sciences, Vienna –Department of Forest- and Soil Sciences, Institute of Silviculture PP3, LP/PP1 - University of Natural Resources and Life Sciences, Vienna –Department of Forest- and Soil Sciences, Institute of Silviculture

TABLE OF CONTENTS

1. Introduction

Best management practices (hereinafter BMPs) for drinking water protection and management derived from T1 were reviewed and relevant BMPs were selected for particular pilot action. Implementation status of BMPs was verified in Pilot Actions (T2); in case of lacks identified, possibilities of improvement and implementation were also assessed. Drinking water protection and management and best practices are strategically implemented in the pilot actions, in order to achieve a function-oriented land-use based spatial management for water protection at the operational level. Measures and actions were analysed and proposed concerning mitigation of extremes and achieving a sustainable drinking water level. PROLINE-CE pilot actions reflect the broad range of possible conflicts regarding drinking water protection, such as: forest ecosystem service function; land-use planning conflicts; flooding issues; impact of climate change and land-use changes; demonstration of effectiveness of measures including ecosystem services and economic efficiency.

Review of main land use conflicts and BMPs on Pilot Action level has already been done in Pilot Action BMPs reports, which were a basis for *D.T2.1.2 Transnational case review of best management practices in pilot actions*. Description of natural characteristics of Pilot Site is presented in *D.T.1.4 Descriptive documentation of pilot actions and related issues*.

Activities within Pilot Action were done according to set-up which was described in *D.T2.1.5 Set-up report about adaptation of the transnational concept to pilot action level*.

The Deliverable *D.T2.2.4 Partner-specific interim pilot action progress report* presented preliminary work reports regarding the implementation of best management practices for drinking water protection in pilot action PA1.1 City of Vienna - Vienna Water.

In this report further experiences gained in the pilot action PA1.1 - City of Vienna - Vienna Water are presented, as well as description of performance of pilot activities and first outlining of foreseeable solutions.

2. Testing of BMPs in Pilot Action

Within the Pilot Action 1.1 there were tested several BMP's. One main focus is modelling of infiltration and surface flow. The second focus are the moutainous grasslands, which are in PA1.1 the subalpine and alpine pastures. The implementation of all BMP's is essential for drinking water supply security provided by Vienna Water.

■ Identified GAP provoking action		
GAP short name	**Infiltration and surface flow affecting spring quality are not known**	
GAP short description	Occurrence of surface runoff and corresponding erosion processes can lead to input of solutes/contaminants into a karst system that may affect spring quality. The longer the flow paths the more likely erosion and solute input into the system occur. A spatially distributed hydrological model is needed to identify surface runoff patterns at different hydrological conditions, e.g., during summer storms, in a catchment.	
■ Best management Practice / Management Action		
Name of BMP	**Surface flow - spring dynamic Zeller Staritzen**	
Type of land use regarded	General – the hazards. Pressures and impacts of various land use activities can be assessed	
Location	Zeller Staritzen and central Hochschwab	
BMP description	Applying a rainfall/run-off model based on observed and defined processes as well as measured and mapped parameters the spatial patterns of surface run-off and infiltration will be determined. The results are used for optimizing land use management and formulating water safety plans in a risk-based procedure by comparing the patterns with potential contamination loads, e.g. from cattle grazing.	
Advantages of this BMP in PA	Infiltration and surface run-off are important to assess the vulnerability of the groundwater	
Challenges of this BMP in PA	Implementation of different parameters in the model.	
Relevance	Water protection functionality	high
	Cost of the measure	Ãpp. €150.000,-
	Duration of implementation	till 2019/04
	Time interval of sustainability	Basic information for catchment management; sustainability not limited
Limitations	Can the simulations reproduce the observed spring dynamics	
Implementation of the BMP in PA	Implementation is in progress	

Comments	
References / sources	Report: modelling Hochschwab – spatial patterns of surface run-off

▪ **Identified GAP provoking action**		
GAP short name	**Erosion processes around water troughs for cattle due to open soils without vegetation cover, as well as washing out faeces.**	
GAP short description	Erosion take place where water troughs for cattle are placed in concentrated manner. Cattle is frequently trampling the soils around the troughs, hence destroying the vegetation cover there. Erosion dynamics and concentrated amounts of faeces are the result of this situation.	
▪ **Best management Practice / Management Action**		
Name of BMP	**Placing of water troughs for cattle more frequently, avoiding concentrations of cattle / Concrete basements for the troughs and their surroundings**	
Type of land use regarded	Subalpine and alpine pastures (mountain grasslands)	
Location	Zeller Staritzen and Central Hochschwab	
BMP description	Water troughs are an important tool for the subalpine and alpine pastures within karstic mountains, as water has to be provided there for grazing livestock (cattle). In order to avoid the creation of erosion dynamics and concentrations of faeces, more troughs should be provided and distributed strategically over the whole alpine pasture. This should ensure enough drinking water for the cattle, bring the cattle close to envisaged areas of the pastures and avoid erosion dynamics. The addition of concrete plates (concrete basements) for the troughs, also helps to avoid erosion dynamics.	
Advantages of this BMP in PA	Avoiding erosion dynamics within the context of alpine pastures is essential for drinking water supply security. Hence it is of interest to implement an alpine pasture strategy. Part of such a strategy is the spacing of the water troughs for cattle and also the construction of concrete basements in cases where this is possible. The avoidance of erosion and of concentrated cattle faeces around those troughs is the main advantage of this BMP.	
Challenges of this BMP in PA	Challenging is that the construction of concrete basements for the troughs is not easy at many locations of the alpine pastures. Another challenge is the lack of water within the karstic environment of the alpine pastures in PA1.1. Hence the sites where water troughs for cattle can be placed are naturally limited.	
Relevance	Water protection functionality	High
	Cost of the measure	Low-Medium

	Duration of implementation	Continuous
	Time interval of sustainability	Immediate until the time-span of the duration of implementation
Limitations	Water troughs for cattle can only be placed on sites where water is available.	
Implementation of the BMP in PA	The implementation of this BMP has been fulfilled for the major part of PA1.1, in some cases the implementation is on the way.	
Comments	Water for cattle is an essential question within karstic alpine pasture areas. The lack of water in the higher elevations of these mountain ranges creates the need to solve the question of water provision. Within this decision-space also the issues of drinking water supply security have to be integrated. Hence a strategical spacing of the water troughs becomes a mandatory BMP.	
References / sources	Gregory Egger 2018	

■ **Identified GAP provoking action**		
GAP short name	**Grazing of cattle in or close to dolines and sinkholes**	
GAP short description	As dolines and sinkholes have direct connection to the karst aquifer, grazing of cattle within or close to those karstic features constitutes a high risk for source water contamination.	
■ **Best management Practice / Management Action**		
Name of BMP	**Fencing of dolines and sinkholes in order to keep cattle in distance from those karstic features**	
Type of land use regarded	Subalpine and alpine pastures (mountain grassland)	
Location	Zeller Staritzen and central Hochschwab	
BMP description	At all active pastures within the Hochschwab massif the karstic features dolines and sinkholes are fenced out in order to minimize the risk of source water contamination with faeces stemming from cattle or other grazing livestock. The fences have to be kept in functional condition and hence have to be checked through the mountain pasture staff.	
Advantages of this BMP in PA	The protection of the karstic aquifers from direct infiltration and percolation of faeces stemming from grazing livestock (above all cattle) is central part of the drinking water supply security strategy.	
Challenges of this BMP in PA	One challenge is that in case of strong precipitation events faeces of grazing livestock may be washed into dolines and sinkholes, despite the fact that the animals are fenced out from those features. This challenge can be faced through construction of derivation dams.	
Relevance	Water protection functionality	High

	Cost of the measure	Low
	Duration of implementation	Continuous
	Time interval of sustainability	Immediate until the time-span of the duration of implementation
Limitations	Only well-known karstic features can be fenced out from grazing livestock. If there should exist unknown karstic features, the BMP cannot be applied.	
Implementation of the BMP in PA	The implementation of this BMP has been fulfilled for the major part of PA1.1, in some cases the implementation is on the way.	
Comments	Despite the fact that alpine and subalpine pastures are in contradiction to drinking water supply security, the implementation of this BMP helps to reduce the risk of contamination of the source waters. The existence of subalpine and alpine pastures is related to old servitude rights. Hence the BMP has to be highlighted as significant measure for water suppliers.	
References / sources	Gregory Egger 2018	

Identified GAP provoking action	
GAP short name	**Unwanted grazing patterns of cattle**
GAP short description	Cattle tends to graze following unknown patterns which lead to problems on alpine pastures (overgrazing, grazing within vulnerable areas, under-grazing).
Best management Practice / Management Action	
Name of BMP	**Grazing management for cattle on alpine pastures**
Type of land use regarded	Subalpine and alpine pastures (mountain grasslands)
Location	Zeller Staritzen and Central Hochschwab
BMP description	“Grazing management” involves a planning strategy for the whole summer season on alpine pastures. Vulnerable areas in terms of potential karst aquifer contamination should be excluded from grazing or from intensive grazing. Such vulnerable areas are characterized through e.g. low soil depth, high gravel content on soil surface, open areas without vegetation cover or by the specific karst formations dolines and sinkholes. Overgrazing of alpine pasture areas should also be avoided as it leads to erosion processes through soil trampling caused by cattle or other grazing livestock. Under-grazing on the other hand should be avoided as it can involve degradation of the quality of the vegetation cover (in terms of fodder-quality for grazing livestock). “Grazing management” avoids all above mentioned shortcomings of alpine pastures and provides a spatial explicit timing and spacing of grazing possibilities for cattle (or other grazing livestock). This spacing can be

	implemented through e.g. the utilization of fences.	
Advantages of this BMP in PA	Grazing management for cattle on alpine pastures has the great advantage that areas which are overgrazed can be released, areas which are under-grazed can be focused and areas which are not wanted to be grazed can be excluded. The whole scheme of grazing during the summer season on the alpine pasture can be planned with “grazing management” and results of modelling or scientific facts can be included in the planning process.	
Challenges of this BMP in PA	The challenge of “grazing management” is given through the need of a planning process, which has to involve detailed awareness about the quality of the alpine pasture areas in terms of “fodder-quality”, vulnerable areas and the number of livestock which will be present during the alpine pasture season.	
Relevance	Water protection functionality	High
	Cost of the measure	Medium
	Duration of implementation	Continuous
	Time interval of sustainability	Immediate until the time-span of duration of implementation
Limitations	This BMP is limited in present times because of the lacking experience and/or expertise among the alpine pasture personnel for such a planning process.	
Implementation of the BMP in PA	The implementation of this BMP has not been fulfilled within PA 1.1 until now. Persuasive efforts and stakeholder-trainings would be necessary for such an implementation.	
Comments	Despite the fact that alpine and subalpine pastures are in contradiction to drinking water supply security, the implementation of this BMP would help to reduce the risk of contamination of the source waters. The existence of subalpine and alpine pastures is related to old servitude rights. Hence this BMP has to be highlighted as significant measure for water suppliers.	
References / sources	Gregory Egger 2018	

3. Activities in the Pilot Action

Mapping, monitoring, survey and modelling activities were performed and are continued in the PA since 1992 for the catchment areas of Vienna Water. The activities comprise the description and investigation of the karst system (atmosphere, soil, vegetation, geology and water).

3.1. Hydrogeological process-oriented mapping (done)

The current modelling significantly relies on existing mapping results of dominant runoff generation mechanisms, obtained by a method combining classical hydrogeological mapping methods with hydrological process identification. This method is based on (i) local data collection in the field (e.g. soil moisture, grain size distribution), (ii) a visual assessment from a distance at the landscape scale (e.g. traces of surface runoff) and (iii) prior spatial information (e.g. geological map, terrain model). The idea is to map a large number of points and polygons with less detail rather than few points with a lot of detail. Strictly applying (hydro)geological mapping principles implies that only those items are included which are possible to categorize in the field. These principles are extended by the focus on variables that can be assessed from a distance in the landscape and the "process-oriented" view. This enables to map a large area, in a high alpine, remote region, without using a regionalization model (Reszler et al., 2018). In the case of the Zeller Staritzen an area of app. 90 km² is covered. The field mapping was used to specify a "surface runoff propensity index", which represents an index of how frequently surface runoff may occur. The index was favourably tested against patterns of sink holes.

Figure 1 shows an example of mapping results. Infiltration capacity was classified into three classes: high (HIN), medium (MIN) and low (LIN).

In the current modelling work, the mapping results are used to support the parameterization of a spatially distributed hydrological model, based on the "Dominant Processes Concept" (e.g. Grayson and Blöschl, 2000).

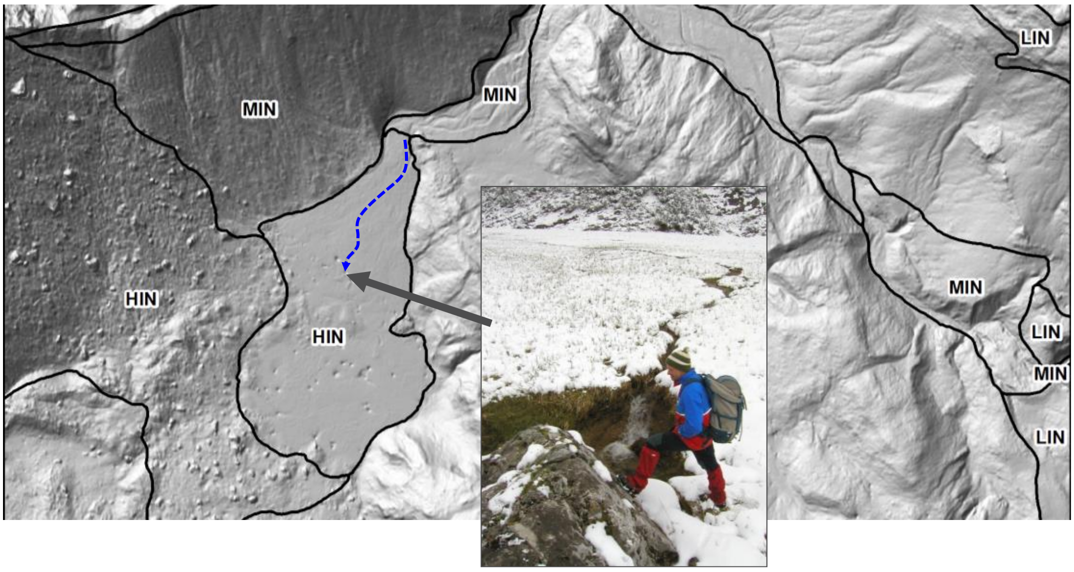

Figure 1: Example of mapping results in the Spitzboden/Wasserboden area of the Hochschwab. Infiltration capacity was classified into three classes: high (HIN), medium (MIN) and low (LIN). The small creek in the center of the polygon sinks entirely into the karst system. DTM is derived from the 1m Laserscan.

3.2. Spring monitoring (continuous work)

Spring monitoring is a basic task of water suppliers. According to results of research projects all springs used by Vienna Water for water supply are monitored. The decision which parameters are monitored depends on the relevance and characteristic of the springs. The data are stored in a databank (HYDRAS). The monitoring methods are depending on to technical innovation and legal requirements. The time span of documentation of the data depends on the spring and parameter. Discharge, physical, chemical and microbial parameters are monitored.

3.3. Meteorological monitoring (continuous work)

In the catchments of Vienna Water, a meteorological monitoring system has been set up parallel to the spring monitoring. It is coupled and operated in cooperation with federal and regional hydro-meteorological agencies. The location of the measuring stations and monitored parameters are based on the results of research projects. The data are also stored in HYDRAS. In various research projects analyses regarding water cycles, recharge areas, reaction to heavy precipitation events, and snowmelt have been performed. Long term data are available in analogue and/or digital form.

3.4. List of available thematical maps

- Vegetation: forest and alpine meadows
- Karst morphology and Speleology: karst features and documentation of caves
- Geology: Hydrological characterisation of deformation processes and assessment of hydrological relevance of tectonic features

3.5. Distributed snow modelling (done)

The catchments of the Vienna Water Works are covered by a distributed snow model based on the physically based model of Blöschl et al. (2002). The model is driven by available meteorological and climate data in the region. Results and the timing of snow melt in spring/summer are spatially validated against satellite (MODIS) snow cover data as well as snow depth and snow water equivalent data obtained by snow courses (Komma et al., 2015). Currently, model simulations are available until 2016.

3.6. Rainfall-runoff modelling (in progress)

3.6.1. Introduction

Occurrence of surface runoff and corresponding erosion processes can lead to input of solutes/contaminants into a karst system that may affect spring quality. A spatially distributed hydrological model is used to identify surface runoff patterns at different hydrological conditions, e.g., during summer storms, in a catchment. A priori parameters are found based on the mapping results according to the so-called “Dominant Processes Concept” (e.g., Grayson and Blöschl 2000, Reszler et al., 2008). The idea is that parameters are dominant on an area for representing a certain process at a particular hydrological situation (e.g., event type, soil moisture status). The simulated hydrographs are tested against observed runoff in a sub-catchment. The spatial patterns of the frequency of surface runoff simulated by the model are interpreted based on the mapping results and compared with the spatial distribution of observed sink holes in the area. Additionally, the infiltration simulated by the model is tested against observed spring discharges. For the latter, the simulated infiltration at the surface is coupled with a conceptual model to account for the drainage within the karst system.

3.6.2. Model and data

The continuous spatially distributed water balance model KAMPUS (Blöschl et al. 2008; Reszler et al. 2006, Figure 2) is used. It is in operational use for flood forecasting in Austria and therefore well suited for surface runoff simulation. It consists of a snow routine, a soil moisture routine and a flow routing routine. The snow routine represents snow accumulation and snow melt by a simple degree-day concept that divides precipitation into snow and rainfall and accounts for snowmelt. Alternatively, results from the distributed snow model are used for a better representation of snow accumulation and snow melt. Rainfall and snowmelt are partitioned into a component that increases soil moisture and a component that contributes to runoff by a nonlinear function, depending on the maximum soil moisture storage. Soil moisture can only decrease by evapotranspiration which is estimated from potential evapotranspiration and air temperature. For calculating potential evapotranspiration, the method of Blaney-Criddle, modified by Schrödter (1985) is used. Runoff routing on the hillslope is represented by an upper zone and two lower reservoirs. Rainfall and snowmelt that contribute to runoff enter the upper zone reservoir and leave this reservoir through three paths: percolation to the lower reservoirs defined by a percolation rate, outflow from the reservoir with a fast storage coefficient that represents interflow and, additionally, when a defined threshold is exceeded, outflow through a further outlet with a very fast storage coefficient that represents surface or near surface runoff. Percolation into the two lower reservoirs is split into two components by a defined percentage. The two lower reservoirs represent groundwater and deep groundwater flow. The storage coefficients of interflow and shallow groundwater flow are allowed to vary linearly depending on the soil moisture. Bypass flow is incorporated that routes precipitation directly into groundwater. The original vertical structure is extended by a module for infiltration excess. In every pixel, at very high intensities parameters of soil storage are reduced, and bypass and deep percolation is set to zero. This is necessary, because in karstic areas and debris deep percolation dominates but infiltration excess can lead to temporary surface runoff which cannot be captured by the original structure. Total runoff is calculated on a pixel as the sum of the outflows from all reservoirs and aggregated to sub catchments. Sub catchment runoff is routed through the stream network by a cascade of linear reservoirs.

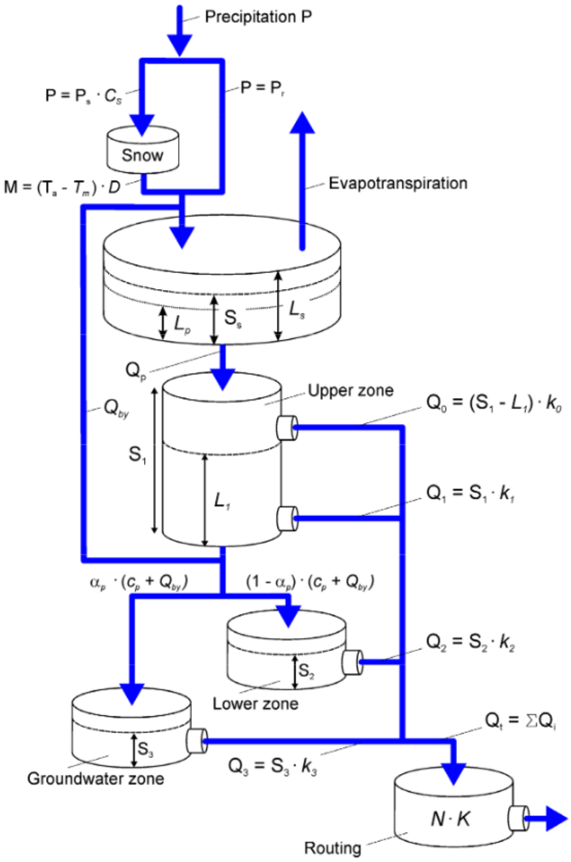

Figure 2: Model structure of KAMPUS (Blöschl et al. 2008, redrawn with more detail by Nester et al., 2011).

The horizontal structure mainly follows the HRUs from the existing mapping results. The model works on a 50 m grid with a 15 min time step and requires spatial fields of precipitation and temperature in this spatial and temporal resolution. Station values of precipitation and temperature are interpolated with a time step of 15 min on the model grid.

In the region stations are operated by the Vienna Water Works and the Hydrographic Service of Styria. Table 1 shows the available stations in the wider Hochschwab/Zeller Staritzen area including the mean annual precipitation in the study period from 2009 to 2016.

Table 1: Mean annual precipitation from 2009 to 2016 and station altitude at the stations in the wider region of Zeller Staritzen/Hochschwab (Operator MA31: stations of the Vienna Water Works; HD Stmk: stations of the Hydrographic Service Styria).

Station	Operator	Altitude (m a.s.l.)	Mean annual precip. 2009 - 2016
Brunnsattel	HD Stmk	872	1590
Seeau	HD Stmk	650	1640
Hinterwildalpen	MA31	800	1641
Wildalpen	HD Stmk	610	1599
Winterhoehe	MA31	670	1491
Kreuzpfaeder-Siebensee	MA31	1270	1919
Sonnschienalm	MA31	1520	2157
Trawies	HD Stmk	1000	1587
Buchberg	HD Stmk	1299	1299
Edelboden	MA31	880	1828
Weichselboden	HD Stmk	680	1595
Seewiesen	HD Stmk	980	1506
Gollrad/Wegscheid	HD Stmk	850	1471
Brunngraben	HD Stmk	710	1405

3.6.3. Parameter identification/calibration

Since model calibration is limited in karstic areas, parameter identification was performed in three steps:

a) For characteristic areas (End-Members from Figure 3, and bare rock) a priori parameter values were selected, so that the expected dominant processes are represented, and the corresponding runoff reaction is simulated. A plausibility check of simulations with the use of hypothetical rainfall scenarios was performed. For this purpose, the mapping method was mainly developed to include this “process-oriented” view.

b) The first step is followed by the selection of a priori parameters for all HRUs (“intermediate” forms) from hydrological process understanding, also based on the mapping results.

c) Test with rainfall-runoff data at the Spitzboden (1.35 km^2): A temporary gauge was installed at the small creek before it sinks into the karst system (see Figure 1). Calibration to runoff data was performed and the spatial patterns of surface runoff at different events were interpreted. This procedure is possible for the areas contributing to the runoff captured at the gauge.

d) Upscaling of the parameters to the entire study area by similarity measures

e) Use of percolation data from a cave located in the epikarst (Exel 2014) to estimate near-surface storage, response and residence times in heavily karstified limestone

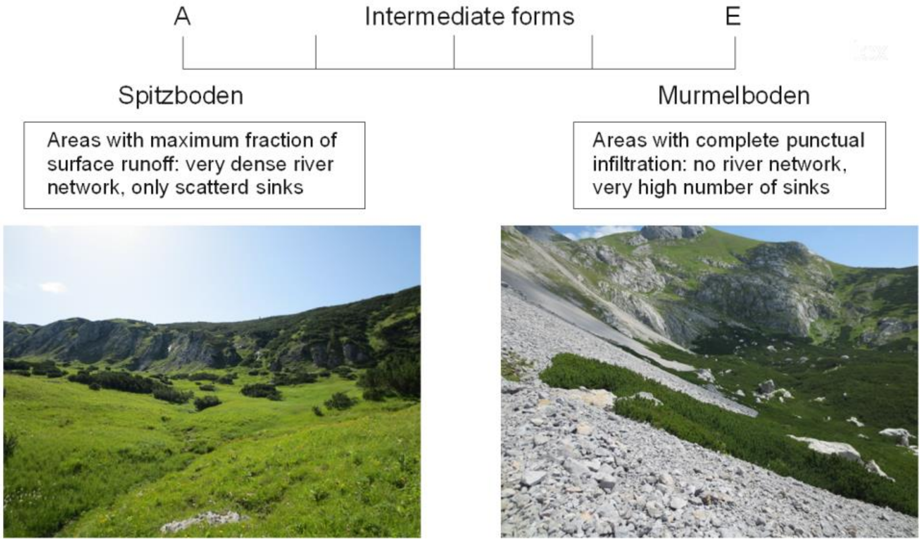

Figure 3: Characteristic areas (End-Members) with dominant infiltration/runoff generation mechanisms.

Figure 4 shows the results of the calibration in the catchment of the Spitzboden gauge. The lowest panel shows the excellent fit of the simulated hydrograph to the observations, particularly during the recessions. The second panel from the bottom shows the runoff response of the contributing areas (HRUs). The short, heavy rainstorm in August 2013 (50 mm in 45 min) produced a steep rise of the hydrograph and a quick drop off to the same base flow level as before the event. This indicates that only the surface runoff from the directly connected bare rock areas contributed to the runoff in the creek. Components with linger storage (interflow, shallow groundwater flow) from the areas with soils and debris do not contribute. Soil moisture was low at the beginning of the event. The dynamics are represented well in the simulation where the main contribution is surface runoff from the bare rock areas (Hortonian overland flow). In the other areas the simulated contribution is low, i.e., most of the rainfall is stored in the soils and debris which gives an indication of the magnitude of the corresponding surface runoff threshold parameter.

The extreme event in 2013 with dry antecedent conditions also allows making estimates of the parameters regarding infiltration excess in the catchment. Figure 5 shows traces of a temporary flow path above highly permeable sediment after the extreme event on 4 August 2013. At the station Trawies located in the centre of the study area, near the point in Figure 5, 84 mm in 60 min and 93 mm in 75 min, respectively, was recorded. This corresponds to a return period of T = 5-10 years. The main flow path collected surface runoff from the steep upslope areas (bare rock and debris) associated with the infiltration excess mechanism. For setting the threshold parameter for surface runoff, the steep descending limb at the event indicates that subsurface flow components are not involved and most of the runoff occurs as surface runoff. The parameter is therefore set to a low value (L1 = 5 mm). The threshold for infiltration excess was set to Icrit = 20mm/15min.

The smaller events in September and particularly the larger event in October show different situations. The simulated contribution of the areas with soils and debris dominates compared to the surface runoff from the bare rock. The main surface runoff is simulated on the areas with organic soils after the small soil storage is exhausted (saturation overland flow).

A comparison of the annual runoff volume of the simulations with that of the observation clearly showed that, as the hydrogeological mapping suggested, the hydrographic catchment is smaller than the topographic catchment of the gauge. For example, simulated subsurface runoff at the karstic areas within the catchment, is multiplied with a karst factor of fk=0.1 to accurately represent runoff volume in the plotted period. Surface runoff is allowed to contribute but does only occur very rarely. This suggests that about 90% of the infiltrated water does not reach the stream network at the Spitzboden, but drains into the neighboring catchments, but still towards the main karst springs at the bottom of the Hochschwab massif. According to the hydrogeological mapping, this is plausible in this part of the Spitzboden catchment.

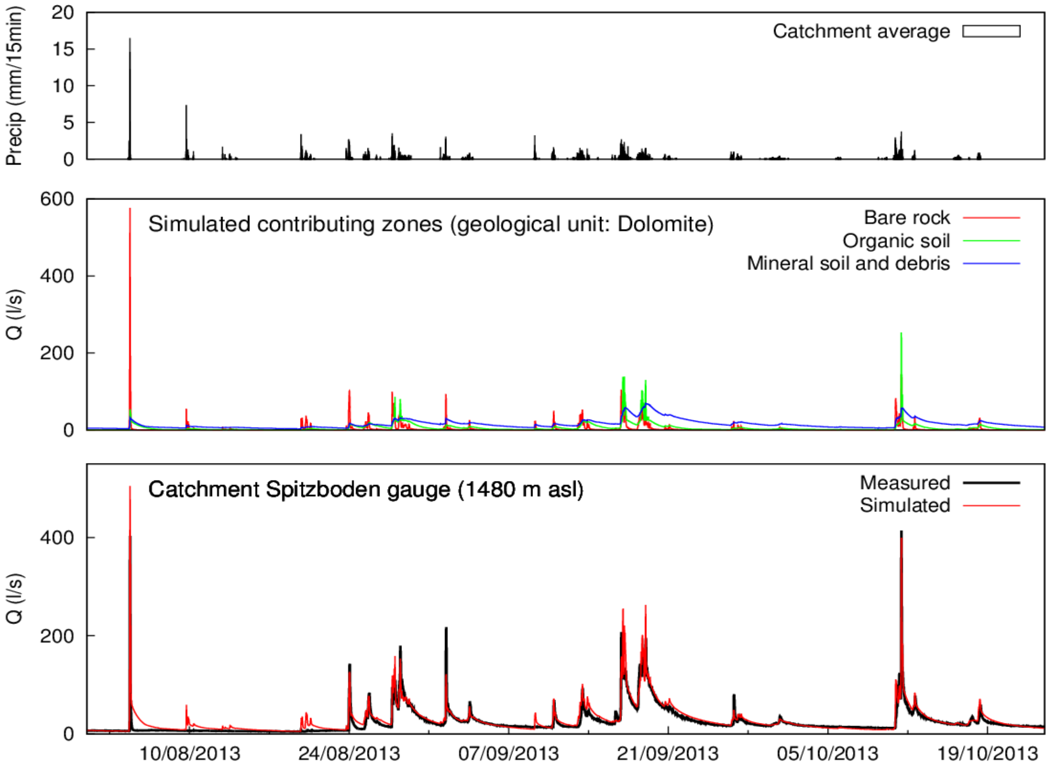

Figure 4: Calibration of parameters of the contributing HRUs in the catchment of the Spitzboden gauge at 1480 m a.s.l. Period 1 July 2013 to 1 December 2013. Panels from top to bottom: catchment precipitation, simulated runoff dynamics of the contributing areas (HRUs), and comparison between simulated and observed hydrographs at the catchment outlet.

Figure 5: Examples of traces of surface runoff paths from the extreme event on 4 August 2013 (Reszler et al., 2018). Thin blue arrows: surface runoff traces on highly permeable gravel/debris; thick blue arrows: larger surface runoff paths, collecting runoff from larger areas during the event. The main water flow path in the left photo ends at the edge of the rock wall, and the right photo shows the situation at the foot of the wall. The red circle indicates the leafless vegetation caused by a temporary waterfall (water and debris).

3.6.4. Results of surface runoff patterns

Besides surface runoff dynamics, main modeling results are dynamic surface runoff patterns, which are analyzed for different event types, e.g., different spatially and temporally distributed rainfall events, and different hydrological conditions, e.g., dry conditions in summer, snow melt situations.

Figure 6 shows as an example the spatial patterns during an event on July 21, 2012 in the Zeller Staritzen region. The temporal rainfall distribution during this event is indicated by data of the station Edelboden (15 min values) plotted within the figure. The time of the snapshot is marked by a red arrow in the rainfall plot. This event started at July 20, around 18:00 and lasted over app. 12 hours showing large intensities at the beginning at the event and lower, but still relatively high intensities (1-2 mm/15min) towards the end of the event. Total rainfall sum in Edelboden was recorded with 71.2 mm. Antecedent soil moisture conditions were relatively wet. After the first high intensity block (plot above) only a few areas show surface runoff, which means that antecedent saturation status as well as rainfall intensities in wide parts of the catchment are not sufficient so that surface runoff is simulated. Only those areas respond to the rainfall, which show very low infiltration capacity, e.g., dolomitic bare rock (areas in red colour in the centre of the figure) or permanently saturated, water-logged areas. At the second snapshot towards the end of the event (below) in much more areas surface runoff is simulated. As the rainfall continues more areas get saturated and contribute to surface runoff, also those areas which show some (shallow) soil or debris layer above karstified limestone and steep slopes. However, maximum intensities of surface runoff are relatively low (app. 1.5 - 2 mm/15 min).

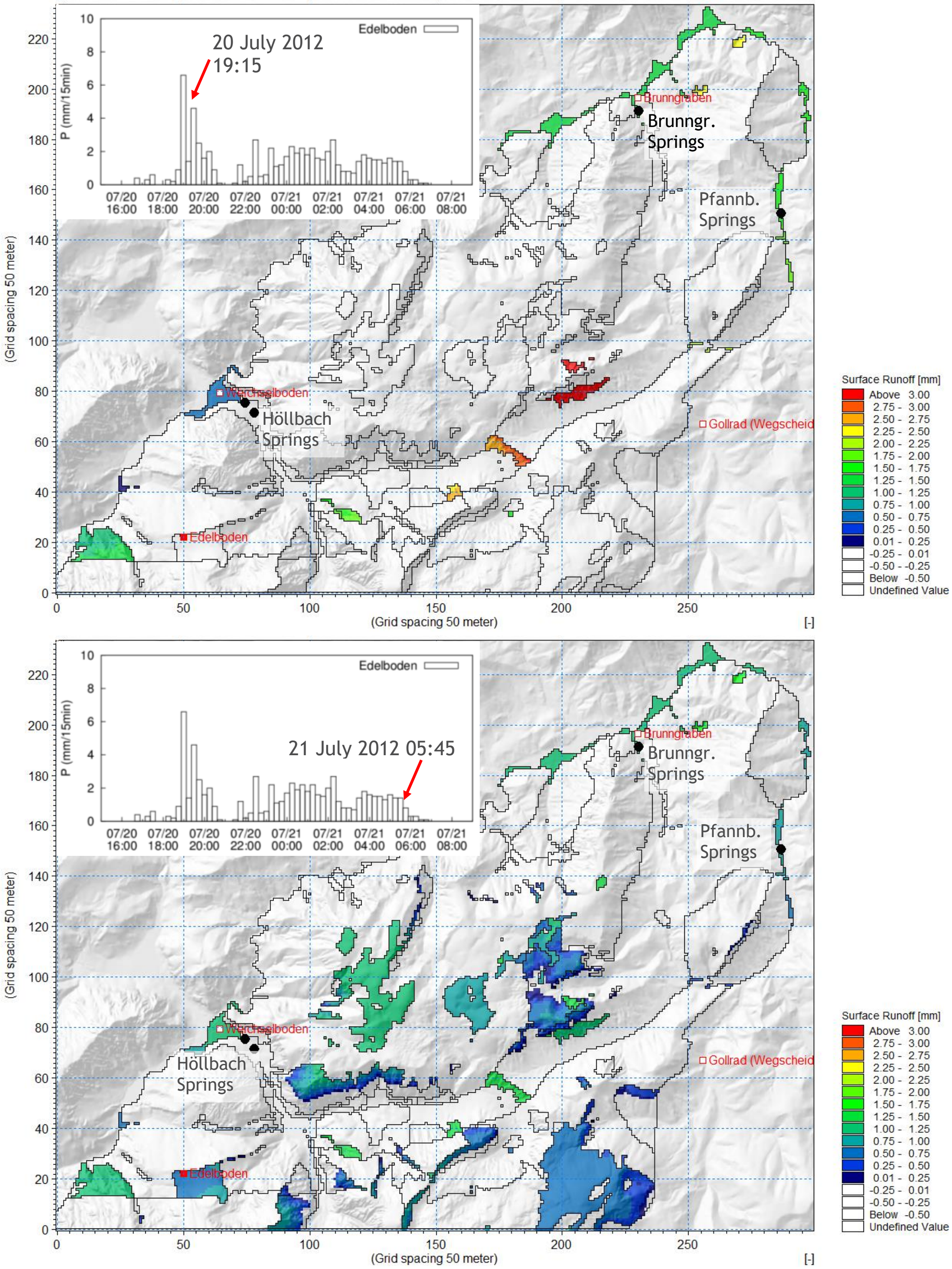

Figure 6: Results of simulated spatial patterns in the Zeller Staritzen area at a long duration event at 20 / 21 July 2012. Above: snapshot after the high intensity rainfall block at the beginning the event; below: snapshot towards the end of the event. The thin lines are the mapped polygons.

3.6.5. Main goals and application

From long-term simulations frequency of surface runoff occurrence, particularly in the summer months, on an area is derived (ongoing work). This frequency is an indicator for the ability of the landscape to produce and convey surface runoff. Both the surface propensity index from the existing mapping and the distributed hydrological modelling results are used to assist in safeguarding the quality of the water supply from karst aquifers. The results are used for optimizing land management and formulating water safety plans in a risk-based procedure. This is done by comparing the surface runoff patterns with spatial and temporal fields of potential contamination loads. Climate change effects are not subject in this study.

Additionally, water balance considerations from the hydrological model output at the main springs also enables a test of previously estimated catchment boundaries. As it is often the case in karstic catchments, the hydrographic are not identical with the topographic catchment boundaries.

3.7. Stakeholder-information about alpine pasture issues

All issues related to alpine pastures are of great importance for the overall drinking water protection policy and actuation within the drinking water protection zone (DWPZ) of Vienna Water. Hence information about basic interdependencies within the context of alpine pastures is relevant for the key stakeholder, the staff of Vienna Water. Only if information of the staff is given on a high level, guidelines for the alpine pastures can be set up and the compliance to them can be claimed.

In the course of stakeholder information days both staff from Vienna Water and from the alpine pasture farmers were informed about essential dynamics and interdependencies of alpine pastures. The presentation was given through scientific experts.

The major Best Practices for alpine pastures were presented. Those cover the application of management practices to avoid (A) erosion dynamics (open soils without vegetation cover) around water troughs for cattle, (B) grazing of cattle in or close to dolines and sinkholes and (C) unwanted grazing patterns of cattle. Those were identified as major gaps within the DWPZ.

Also, further potential gaps (unwanted management practices) were presented, like the spraying of liquid manure on alpine pastures (what is forbidden), clearing of dwarf pine vegetation for pastures and subsequent milling of the upper soils, or the concentration of manure on parts of the pasture. All those practices should be avoided in future. The alpine pasture staff was convinced about the negative impacts of those unwanted management practices, which was a major step towards the implementation of Best Practices. The staff of Vienna Water was informed about the basic dynamics caused by such unwanted management practices (potential gaps) and hence possesses all necessary tools to contribute to the avoidance of them.

The most important Best Practices (BMP’s) within the DWPZ were identified. Those are (A) Placing of water troughs for cattle more frequently, avoiding concentrations of cattle / Concrete basements for the troughs and their surroundings, (B) Fencing of dolines and sinkholes in order to keep cattle in distance from those karstic features and (C) Grazing management for cattle on alpine pastures. The implementation of those crucial BMP's is essential and will be tracked through the staff of Vienna Water.

Some of the BMP's are already implemented on the area of some alpine pastures within the DWPZ. The sustainable and continuous implementation of the BMP's for alpine pastures (mountain grasslands) within the whole DWPZ will be tracked in presence and future through Vienna Water staff. For this essential task in the field of source water protection the stakeholder training was essential.

3.8. Solutions for case specific adaptation of best management practices

All four selected BMP's for PA 1.1 are described in the following tables (Tab. 1-2). The most important issues are highlighted there.

Table 2: Overview about gaps and BMP's in PA 1.1.

Actual management practice (GAP)		Infiltration and surface flow affecting spring quality are not known	Erosion processes around water troughs for cattle due to open soils without vegetation cover, as well as washing out faeces.
Proposed BMP		Surface flow – spring dynamic Zeller Staritzen	Placing of water troughs for cattle more frequently, avoiding concentrations of cattle / Concrete basements for the troughs and their surroundings
Proposed solutions and recommendations	Adaptation of existing land use management practices	Potentially, if necessary	This is a fundamental adaption of existing alpine pasture practices.
	Adaptation of existing flood/drought management practices	Surface flow is the source of flooding processes hence the enhanced understanding of surface flow through modelling will contribute to flood management practices.	The BMP is of minor relevance for flood/drought management practices.
	Adaptation of policy guidelines	No policy guidelines will have to be adapted.	There is no need for policy guideline adaptation.
Remaining issues to be solved		---	---

Table 3: Overview about gaps and BMP's in PA 1.1.

Actual management practice (GAP)		Grazing of cattle in or close to dolines and sinkholes	Unwanted grazing patterns of cattle
Proposed BMP		Fencing of dolines and sinkholes in order to keep cattle in distance from those karstic features	Grazing management for cattle on alpine pastures
Proposed solutions and recommendations	adaptation of existing land use management practices	Those fences around dolines and sinkholes are a true adaptation of alpine pasture management practices.	Grazing management for cattle and other grazing livestock on alpine pastures can be regarded as major step towards best practices implementation. Its realisation will be challenging.
	Adaptation of existing flood/drought management practices	The BMP is not relevant for flood/drought management practices as it covers above all water quality issues.	The BMP is also relevant for flood management practices as it avoids erosion dynamics.
	Adaptation of policy guidelines	No policy guidelines will have to be adapted.	No policy guidelines will have to be adapted.
Remaining issues to be solved		---	---

4. Conclusions

Best management practice in alpine karst catchments of the Vienna Water Works comprise continuous meteorological and hydrological monitoring as well as hydrogeological mapping and modelling activities. These data and methods enable early warning activities and catchment management for drinking water protection, and continuous karst water research to support management activities.

With the applied mapping and modelling method processes on the surface (surface runoff patterns and infiltration) in a karstic catchment are captured. Spring monitoring provides data of discharge amount and quality and their analyses yield some insights into the general karst system behavior. Remaining gap is the detailed representation of the water movement and solute transport from the surface (soil, epikarst) towards the springs. This gap is closed in the parallel project CAMARO-D: In this project a quantitative model is developed to simulate timing and volume of the water flow and transport of water pollutants through the complex karstic aquifers in the catchments of the Vienna Water Works. Input into the system is the simulated spatially distributed infiltration provided by the hydrological model.

Another crucial field of best management practice covers the current alpine pasture areas within the drinking water protection zone (DWPZ). The stakeholder events within this thematic field both informed the staff of Vienna Water about the most important issues about alpine pastures and also convinced the farmers who run alpine pastures about the need to avoid specific bad practices and to apply Best Management Practices (BMP’s).

There were identified some very important BMP’s within the DWPZ of Vienna Water. Those are (A) Placing of water troughs for cattle more frequently, avoiding concentrations of cattle / Concrete basements for the troughs and their surroundings, (B) Fencing of dolines and sinkholes in order to keep cattle in distance from those karstic features and (C) Grazing management for cattle on alpine pastures. If implemented those BMP’s contribute to an improvement of drinking source water protection.

5. References

- Blöschl, G., R. Kirnbauer, J. Jansa, K. Kraus, G. Kuschnig, and Ch. Reszler (2002): Einsatz von Fernerkundungsmethoden zur Eichung und Verifikation eines flächendetaillierten Schneemodells. Österreichische Wasser- und Abfallwirtschaft, 54 (1/2), 1-16, Springer-Verlag 2002.
- Blöschl, G., Ch. Reszler, and J. Komma (2008): A spatially distributed flash flood forecasting model. Environmental Modelling & Software, 23 (4), 464-478; doi:10.1016/j.envsoft.2007.06.010
- Egger, G. (2018). Evaluation of yield and intensity of land use of alpine pastures in the area of “DWPZ Vienna Water” in Austria. Presentation at the Stakeholder Training session within the DWPZ.
- Exel, T. (2014): Niederschlags-Ereignis Beprobung einer oberflächennahen Höhle zur Abschätzung des Speichervermögens der Bodenzone und des Epikarsts am Hochschwabplateau. Master thesis Universität für Bodenkultur (Institut für angewandte Geologie).
- Grayson, R.B., and G. Blöschl (Eds) (2000): Spatial Patterns in Catchment Hydrology: Observations and Modelling. Cambridge University Press, Cambridge, UK, 404 pp.
- Komma, J., J. Parajka, C. Reszler, H. Stadler, and G. Blöschl (2015): Schneedaten aus der Fernerkundung in der hydrologischen Modellierung – Anwendungsbeispiele in Österreich. Österreichische Wasser-und Abfallwirtschaft, 67 (11), 432-440. Springer-Verlag Wien 2015; doi: 10.1007/s00506-015-0272-5.
- Reszler, C., J. Komma, G. Blöschl, and D. Gutknecht (2006): Ein Ansatz zur Identifikation flächendetaillierter Abflussmodelle für die Hochwasservorhersage. Hydrologie und Wasserbewirtschaftung, 50 (5), 220–232.
- Reszler, C., J. Komma, G. Blöschl, and D. Gutknecht (2008): Dominante Prozesse und Ereignistypen zur Plausibilisierung flächendetaillierter Niederschlag-Abflussmodelle. Hydrologie und Wasserbewirtschaftung, 52 (3), 120-131.
- Reszler, C., J. Komma, H. Stadler, E. Strobl, and Blöschl, G. (2018): A propensity index for surface runoff on a karst plateau, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-228, in review.
- Schrödter, H.: Verdunstung – Anwendungsorientierte Meßverfahren und Bestimmungsmethoden. Springer Verlag, 186 p., 1985.