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Technical efficiency of existing risk reduction options in groundwater systems (D4.3.4)

With special consideration to the risk of contamination with nitrates from agriculture

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Author(s)
Ball, Thomas; Kiefer, Joachim; Sturm, Sebastian; Vieten, Beatrix (DVGW TZW Karlsruhe)

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Johan Åström (Chalmers)

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Summary

Groundwater is one of the most important sources for drinking water. Therefore it is important to guarantee its quality. Political regulations in form of directives like the EU Water Framework Directives (WFD; EC 2006) or regional ordinance like the SchALVO in Baden-Württemberg, Germany (SchALVO 2001) shall protect this key water source from contamination and reduce the risk of future pollution.

There are many different hazardous events like industrial spills and leakages, sewage plants, construction works (buildings, streets or tracks) or agriculture in groundwater catchment areas that can have negative impacts on the water quality.

Agriculture is known to be one of the main causes of groundwater pollution (BMU & UBA 2010). Due to their high nitrate concentrations, many groundwater bodies will most likely not reach the good chemical status according to the European WFD. As there are many possible hazardous events for groundwater, the task behind this report was to start studying the efficiency of measures to control contamination with nitrate and start to assess the efficiency of single agricultural measure.

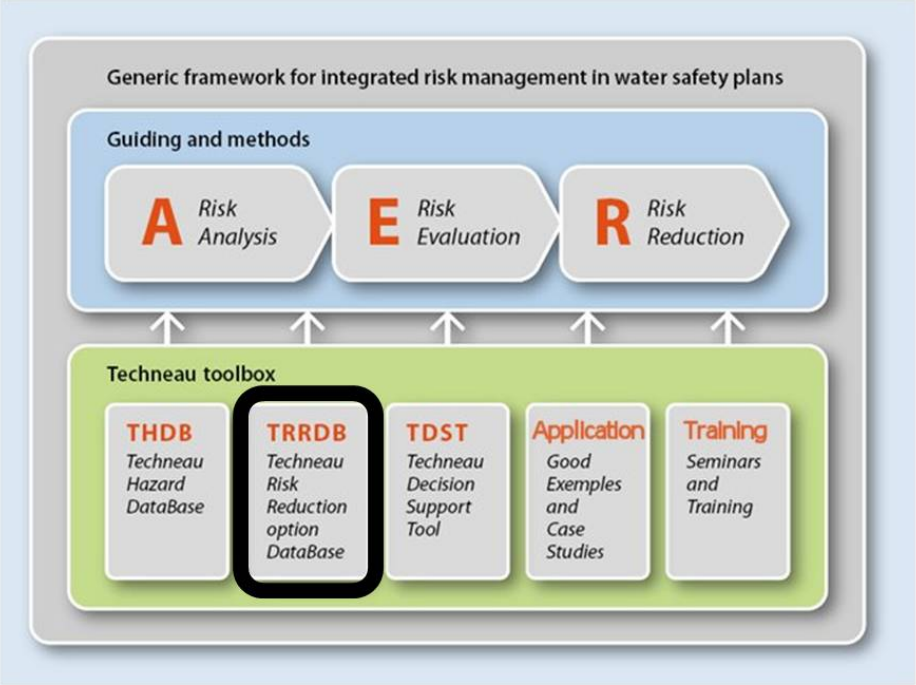
To select appropriate risk reduction options, it is important to have a detailed knowledge about the situation in the catchment and of the characteristics of the aquifer. Therefore an approach for an assessment of an aquifer is described in details as well as the survey about the land use, hydrogeological and hydro chemical situations in catchment areas. Furthermore the general conditions for risk reduction options are explored and a general measures' checklist is assembled.

Some risk reduction options for other hazards are listed in Appendix A.

Contents

1 Introduction

This report describes the effectiveness of risk reduction options developed for Groundwater catchments (D4.3.4). It should be read as an explanation to the Groundwater section in the database on Risk reduction options (TRRDB) for the water supply system, developed within the TECHNEAU project as illustrated below.



1.1 Overview of suggested risk reduction options for ground waters

The risk reduction options listed in the TECHNEAU database, TRRDB (TECHNEAU 2009), are for each hazardous event specified in three categories. It should be noted that the characteristics of the risk reduction options (RRO) differ significantly between these three categories. The categories are as follows:

- Control: organisational or regulation options
- Education and Information: personal options
- Barriers: technical options

Before one of these categories of RROs can be conducted, some essential background information should be gathered and clarified (Figure 1.1).

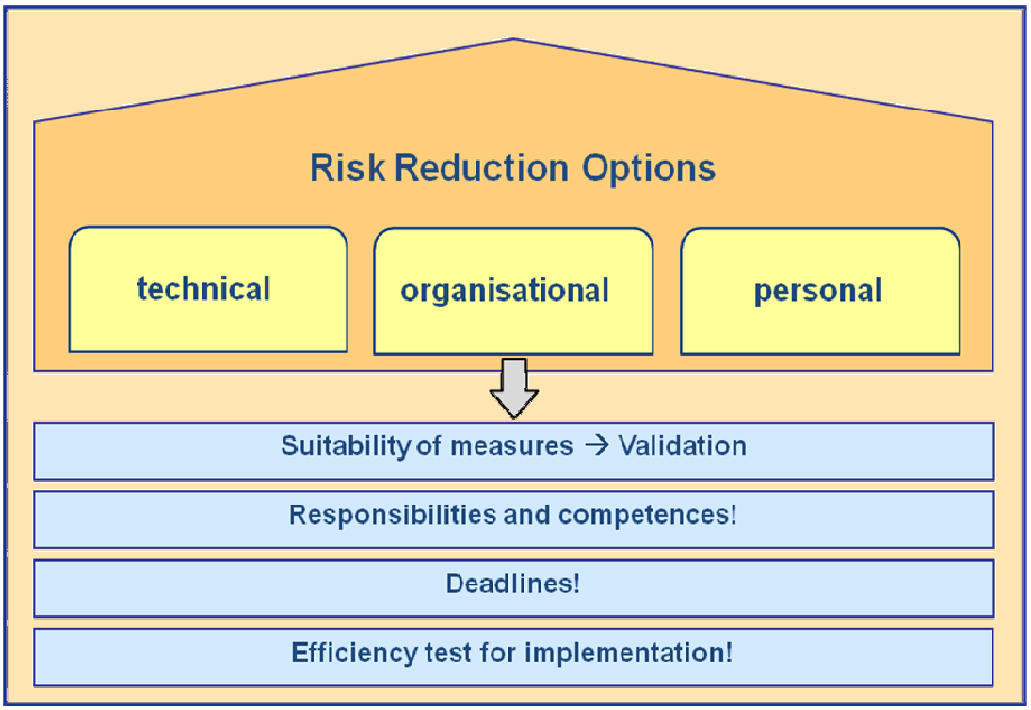


Fig. 1-1: The three categories of risk reduction options depend on the important background information, so that they can be carried out successful.

All three categories of risk reduction options are measures which are designed to control risks. These risks have to be rated severe enough to call for action after a risk assessment has been carried out. The measures shall aim to permanently eliminate or minimise risks.

The implementation of risk reduction options should follow a prioritisation of the identified risks while the selection of appropriate measures shall be based on the overall recognised technical rules. Procedures offering a high degree of process safety and operating stability shall be preferred.

The chosen option should be suitable for the existing situation, which means the measures have to be proven or they require a separate validation procedure. Measures or options shall be determined in such a way as to ensure the unambiguous definition of responsibilities, competences and deadlines. Also additional experts shall be commissioned to select and implement suitable measures, if necessary (DVGW, 2008).

Agriculture is known to be one of the main causes of groundwater pollution (BMU & UBA 2010). Due to their high nitrate concentrations, many groundwater bodies are probably not reaching the good chemical status according to the European WFD. Although there are many possible hazardous events for groundwater, the task here was to study the efficiency of measures to control contamination with nitrate and start to assess the efficiency of single agricultural measure.

One of the main risks for groundwater in the EU is the nitrogen (N) input from agriculture. Therefore the use of N in EU countries is subjected to constraints as given in the Nitrate Directive. It aims at reducing water pollution caused or induced by nitrates from agricultural sources and, further, at preventing such pollution. Member states must define Codes of Good Agricultural Practice (voluntary measures) for their whole national territory, as well as designate Nitrate Vulnerable Zones, where the risk of nitrate pollution would be high if actions prescribed in the Nitrate Directive were not taken (DIJK & BERGE, 2009).

Because of the high relevance of nitrate pollution from agriculture this report focuses on the prevention of nitrate contamination with agricultural measures.

1.2 How to use this report

This report gives suggestions on which kind of measure can be used in order to prevent and remediate contaminations with nitrate in groundwater with agriculture measures, further measures in land use and technical measures. Examples on Risk Reduction Options in the groundwater catchment and in groundwater abstraction with regard to other hazards/hazardous events are overviewed in the table in Appendix A. They are not exhaustive and the scope of action for water utilities is often limited in the catchment. Therefore cooperation with other stakeholders in the catchment may be crucial to implement a successful risk management strategy. A generic aspect of risk reduction options in groundwater catchment areas is that they always have to be adapted on the specific situation and geographic location factors. Therefore, to choose adequate measures, it is important to know all relevant geographic location factors like the hydrogeological, hydro chemical and climatic situation. In the following the approach for the assessment of the aquifer settings is described.

1.3 Approach for the assessment of an aquifer

To carry out an appropriate assessment of the aquifer settings, it is at first necessary to conduct an extensive inventory. This section gives an overview about the required data and information. This kind of inventory should consider:

- the development of the nitrate concentration in the groundwater
- relevant data of the water resource management (abstraction rates and development of water consumption)
- an overview about the available hydrogeological and hydro chemical information
- data on land use in the catchment area.

1.3.1 Survey

Initial Situation

To gain an overview about the initial situation, the nitrate concentration developments in raw water of the catchment area are of interest. Therefore all nitrate analysis results have to be compiled for the individual wells for at least the last ten years.

The development of the groundwater abstractions (annual amounts, maximum monthly and daily abstraction rates) should be compiled for the same period. A comparison with existing water rights allows estimation in regard to quantitative security. If necessary, the development of the water demand is also to be estimated for the total supply area.

The single drinking water supply plant should be briefly described. Thereby, are of interest, e.g. the depth of the wells and the location of the filter sections, but also the installation depth of the pumps and maximum pump rates.

For an overview about the water supply system a scheme for the entire water supply network should be compiled. It is also advisable to record details about the mixing possibilities of water from the neighbouring supply systems.

Size and location (map) of the water protection area are of interest as well as the regional and local regulations for protection areas (laws, directives, guidelines etc.).

Hydrogeological situation

To give an overview about the present hydrogeological situation, detailed information is required regarding the formation of the aquifer, the aquifer extent and the geometry.

Information about hydraulic parameters (e.g. hydraulic conductivity, storage coefficient, depth to the groundwater table) for the delimitation of the water protection area can be generally taken from hydrogeological experts' reports.

Information about protective cover of the groundwater (soil types, structure, (effective) field capacity, depth) allows an estimation of the time period required for seepage water to pass the unsaturated zone. In addition, to estimate the rate of groundwater recharge the regional climate situation has to be considered.

Some of these data can for example be taken from national atlases or national geological surveys. Based on collected data, a water balance can be provided for the total catchment area.

Hydro chemical situation

To gain an overview about the hydro chemical situation in the catchment area, the nitrate concentration developments groundwater have to be reviewed at least for the last 10 years. Thereby all available data of groundwater analysis has to be taken into account. If available, also the analytical results of private and irrigation wells should be included. In this context details of the observation wells (e.g. depth) are relevant.

On the basis of nitrate concentration's distribution in the upper groundwater level in the catchment area the origin of nitrate contaminations can be detected and identified.

Useful additional information are provided by nitrate analyses of water samples, taken from measuring points at different levels in the aquifer, as this can give indications of the vertical concentration's distribution.

If satisfactory information is available, a nitrate balance can be prepared for the total catchment area. This presupposes that a water balance has been carried out.

Land use in catchment areas

Agricultural or other types of land use are important in regard to their extension, but also to their location relative to the catchment area. To gain an overview about the land use, it is advisable to collect cultivated crops in early summer (June/July). At this date the crops are easy to identify. Thereby specialized crops are from particular interest. With this data collection it is possible to calculate the area's percentage of individual land use in catchment area. These investigations about land use describe the current situation. Additional information about essential changes in land use over the last 20 years (particularly land consolidation, tillage of former grassland) can also be collected. The location and extension of forests, settlement areas, surface waters etc. can be extracted e.g. from topographical maps.

To evaluate the potential of nitrate leaching, preferably all results of soil sampling of nitrogen content (nitrate and ammonium) should be considered as far as such data is available.

Result of the survey

An evaluation of site-specific risk reduction options can only be carried out if sufficient knowledge about the cause and origin of a nitrate contamination is available. After the collection of above mentioned basic information it is possible to analyze the current status and to identify possible causes and starting points for risk reduction options in order to mitigate contamination of groundwater. If agricultural use in the catchment area is identified as a possible origin of nitrate contamination, it should be investigated from present data whether certain crops, crop rotation or agriculture use, have been the primarily cause of groundwater contamination. Also it has to be estimated if nitrate contamination results only from a certain part of the water protection area. This can be for example due to intensive cultivation of special crops in areas with highly permeable soils.

1.3.2 Estimation for risk reduction options

If the nitrate contamination can be traced back to the agriculture, the chances to reduce the risk of nitrate contaminations in groundwater are higher by agriculture measures:

- the higher the part of agricultural land use is in the total catchment area. With a small part of the catchment being affected by agricultural land use, the chances of reducing the risk of nitrate contaminations in groundwater by agriculture measures are small.
- the faster and more complete the planned measures are implemented. The success also basically depends on whether the adequate risk control measures are sufficient.
- the closer the average nitrate leaching was at the acceptable emission value to achieve or to be below 50 mg/l (WFD environmental quality target) in seepage water over the last ten years. In these cases not very high nitrogen amounts are expected to be stored in the unsaturated zone and low nitrogen inputs are expected in the next years.
- the higher the denitrification capacity is in the protective cover. At a high capacity of denitrification a substantial part of nitrate nitrogen will already be turned to molecular gaseous nitrogen (N_2) or nitrous oxide (N_2O) in the soil that is not anymore subject for leaching. Such relations can exist e.g. in water-saturated, low permeable soils after heavy precipitation[1]. In

[1] When estimating denitrification positively for nitrate leaching it has to be considered that the developed nitrous oxide is one of six green house gases, which has to be re-

temperate climates, typical medium values for the rate of denitrification in soil range from 10 to 30 kg N/ha/a (FREDE & DABBERT (1998). From a literature survey undertaken at TZW to quantify the denitrification in the unsaturated zone (TZW 2004a), it was obvious that the current knowledge about denitrification in the "Dränzone"[2] is considerably less than for the evapotranspiration (ET) zone [3]. The information found in literature is evidence for that nitrate turnover is very low in the water-unsaturated area below the ET zone. However some researchers indicate possible nitrate depletion in the capillary zone or direct underneath the lowest level of long-standing groundwater. Additionally, it is to include that the capacity of denitrification is limited and depends e.g. on the ratio of water soluble organic carbon. Thereby, type and amount of the organic substance is the essential criteria to the intensity respectively the duration of denitrification.

- the higher the natural groundwater recharge is, and the lower the field capacity of the cover or rather the thickness of the unsaturated zone is. These components affect the exchange frequency of seepage water. At lower groundwater recharge and higher field capacity it can take several years until the soil water with high nitrate concentration is diluted in the unsaturated zone. At high groundwater recharges, low field capacity and low thickness to the groundwater table, the soil water can be replaced within 1-2 years.
- the more water in relation to the total storage volume of the aquifer flows away or is taken (sum discharge plus abstraction) and the faster the groundwater is flowed through. In these cases the groundwater stored in the aquifer is faster regenerated.

duced regarding to the Kyoto protocol, because the world wide emission of nitrous oxide contribute substantial to the green house effect (UBA 2004).

[2] Dränzone = water unsaturated area below the evapotranspiration (ET) zone

[3] ET zone = evapotranspiration zone; it enfolded the surface soil as well as the subsoil, which is partly rooted, partly root free up to a maximum hydraulic drainage divide

1.4 General condition for risk reduction options - Relevant geographic location factors

To estimate how much nitrate leaching can be tolerated to reach a certain nitrate concentration in seepage water, the mean nitrate concentration of the seepage water needs to be calculated according to the equation:

$$c(NO_3) = \frac{N_{out} \cdot 443}{GW_{new}}$$

$c(NO_3)$ = nitrate concentration of seepage water, in mg/l

N_{out} = nitrate leaching, in kg N/ha

GW_{new} = groundwater recharge, in mm/annum

Table 1 lists nitrate concentrations in the seepage water that are calculated for a nitrate leaching between 10 and 60 kg N/ha and groundwater recharge rates between 100 and 400 mm/a. Nitrate losses via denitrification in the root zone and during seepage passage were not included. Nitrate concentrations indicated in green are below the environmental quality standard according WFD of 50 mg/l.

Table 1: Mean nitrate concentrations of seepage water in mg/l for nitrate leaching between 10 and 60 kg N/ha und annual groundwater recharge between 100 and 400 mm

	Mean groundwater recharge in mm						
N_{out} in kg/ha	**100**	**150**	**200**	**250**	**300**	**350**	**400**
10	44	30	22	18	15	13	11
15	66	44	33	27	22	19	17
20	89	59	44	35	30	25	22
25	110	74	55	44	37	32	28
30	133	89	66	53	44	38	33
35	155	103	78	62	52	44	39
40	177	118	89	71	59	51	44
50	222	148	111	89	74	63	55
60	266	177	133	106	89	76	66

This means that at a groundwater recharge of 250 mm, a maximum average nitrate leaching of 25 kg N/ha can be tolerated, thereby the mean nitrate concentration in the recharged groundwater already falls below the critical value for drinking water of 50 mg/l.

Based on this initial survey and definition of targets the range of options to reach such low nitrate emissions have to be evaluated. The following section describes measures in agriculture that are suitable to reduce the input of nitrogen to the groundwater. They generally exceed the Code of Good Agricultural Practice (GAP). The measures focus primarily on the agriculturist.

2 Control options: regulations

Regulatory options are meant to be political measures for risk reduction. Depending on the political and legal circumstances these can be decisions, regulations, rules or directives on an international, national or regional level are relevant. These political instruments can lead to different results than other classes of RROs (like Education and Information or Barrier Options). Their fulfilment has to be monitored on a regular basis.

In this report the described regulations focus on the avoidance and mitigation of nitrate contamination of groundwater by agriculture.

2.1 EU Nitrates Directive & related European Directives

The Nitrates Directive (Council Directive 91/676/EEC; EEC 1991) aims to protect water quality across Europe by preventing nitrates from agricultural sources from polluting ground- and surface waters and by promoting Codes of Good Agricultural Practice. Agriculture remains a major source of water-related problems, and farmers need to continue to adopt more sustainable practices. Huge efforts are still needed in order to restore water to optimal quality across the EU (EU 2010).

The Nitrates Directive has close links with other EU policies concerning water, air, climate change and agriculture, and its implementation yields benefits in all these areas:

- Reducing nitrates is an integral part of the Water Framework Directive (2000), which establishes a comprehensive, cross-border approach to water protection organised around river basin districts (RBDs), with the aim of achieving good status for European bodies of water by 2015.

- The Groundwater Directive (2006) confirms that nitrate concentrations must not exceed the trigger value of 50 mg/l. Several Member States have set their own tighter limits, in order to reach good status.

All Member States have drawn up action programmes: there are more than 300 of them across the whole EU. The directive prescribes that member states are to take four major actions to realize this objective (DIJK & BERGE, 2009):

1. Member states have to define Codes of Good Agricultural Practice (voluntary measures) for the whole country with the aim of providing a general level of protection for all waters against pollution.
2. Member states are obliged to designate areas in their territory (nitrate Vulnerable Zones or NVZs) that drain into fresh surface waters and/or

groundwater that contain, or could contain more than 50 mg/l nitrate, if actions prescribed in the Nitrates Directive are not taken.

3. The Nitrates Directive compels member states to establish Action Programs with respect to NVZs so that the objectives of the Nitrates Directive can be realised.
4. Member states are obliged to implement suitable monitoring programs to establish the extent of nitrate pollution in waters and to assess the effectiveness of the Action Programs.

2.2 Reduction of arable land and conversion to permanent grassland

The EU-cross-compliance-regulation can be used for preservation of permanent grasslands. With a decline of the actually determined grassland proportion in the national average of e.g. for Germany more than 5 % in comparing to the basis value, area specific regulations should be ensure that obligation for new sowing of grassland is implemented in the core risk zones of water protection areas.

Furthermore legal regulations are necessary, which allows the obligation of permanent grassland in core risk zone in line with the RROs for general good reasons.

2.3 Requirements and further criteria regarding political measures

In the following some regulation options are listed. They shall be seen as an overview about the possibilities of political measures.

- Strict legal regulations for emission and immission values of a groundwater protecting cultivation, for example limitation of surplus in nitrogen balance from farm balance
- Implementation of site specific control programs
- Payments and direct support schemes for farmers should be coupled with environmental performance on the efficiency of the realized measures
- Calculation of the irrigation requirements on all irrigating areas. Irrigation amounts have to be documented and recorded by measurement techniques; limitation of the daily single irrigation rate; consideration of nitrate-nitrogen-content in the irrigation water on fertilization
- Duty of documentation for fertilization and cultivation measures
- No application of manure/organic fertilizer in the period of groundwater recharge (e.g. autumn to early spring); Regulations have to be adapted to regional climatic and agricultural situation (e.g. application preferred in spring to growing crops or application to permanent grassland end of September the latest; No application on organic soils)

3 Education and Information options

Education and information are important tools to give knowledge about certain circumstances to people who are affected. It is important for people to understand the background of recommendations and regulations before they change their behaviours. Literature, magazines or news paper articles summarize complex background stories and help people to understand them. Special trainee programs or workshops are helpful to deepen the knowledge to meet an understanding for necessary groundwater protection measures.

In this specific context it is important that the farmers understand the risk of nitrate contamination of groundwater after nitrate fertilisation and tillage operations. For the farmers the crop yield is of main importance, which in the past resulted in an enormous nitrate load to the agriculture. Through education, information and implementation of Good Agriculture Practice the farmer learned about appropriate use of nitrate fertiliser. The single farmer has not only to consider the Plant Protecting Act but also the Nitrate Directive and Groundwater Directive. The verification of the necessary professional knowledge and skills is directed in the plan protecting competence directive (BMELV 2008). Special attention should be on education and advanced training of the nitrate applicator.

Furthermore it is important to have adequate possibilities of consultation, education and qualification in regard to groundwater protection. Supporting programs by local authorities can raise the awareness for nitrate leaching.

Consultation with all stakeholders in the catchment will lead to common strategies and may result in a wide range of site specific and locally accepted risk reduction options.

Educational and informational measures

There are many options for education and information. The most important measures are listed below.

- Co-operation of agriculturists, water suppliers and specialized governmental agencies in regional working groups with the competence for making regional decisions
- Improvement and intensification of professional consultation regarding water-protecting agriculture
- Integration of groundwater protection topics in the agricultural vocational training
- Raise awareness among farmers for the problems of the local water supply through participating at obligatory meetings

4 Barrier options: technical efficiency

There are numerous agricultural measures to reduce nitrate inputs to groundwater. These can be seen as 'technical barriers' before the hazards (nitrate) enters the groundwater. The costs depend on the geographic location conditions, the local situation and quality of the groundwater. It is therefore not possible to give generic cost calculations. In the German federal state of Baden-Württemberg, the SchALVO regulates adjustment payment to farmers in water protection areas. For example, in areas classified for nitrate remediation purposes the general payment is 180, - €/ha per year (SchALVO, 2001).

The measures to avoid or to reduce the risk of nitrate contamination for groundwater are split thematically in five groups. The order of the listing within the groups reflects roughly the ranking in the estimation with regard to a groundwater conserving agriculture in the catchment areas. Often the rating is depending on individual cases. Also it is necessary to accomplish an area-specific measure catalogue for the respective water protection area considering the local conditions.

For specialized crops it is generally necessary to formulate culture specific requirements. However such special demands are not enclosed in the following listings.

4.1 Guidelines concerning the use or the crop rotation (examples)

The basic demand is a site-specific crop rotation (e.g. Haakh & Kaatz 2003, Kaatz et al. 2003).

Examples are:

- Abandonment of winter cereals after main crops with nitrogen rich crop residues, instead cultivation of possible perennial intercrops and of summer cereals
- Cultivation of early ripening sorts of maize with planned utilization of winter barley instead of winter wheat (Maize with nurse crops, cf. 4.3)
- Cultivation of winter barley instead of winter wheat after winter rape
- Groundwater protecting cultivation of energy crops (cf. 4.5)

4.2 Soil tillage

Possible approaches for risk reduction in this thematic field are:

- Total abandonment of tillage in autumn; for example, at maize fields this means: leave stubble until spring, at tobacco fields: leave if possible total tobacco stem until spring
- Preserving conventional tillage techniques: use of mulch or direct sowing procedures

- Soil conserving processing technology and regulations of utilization sequence on sensitive locations (Haakh & Kaatz 2003, Kaatz et al. 2003)
- Basic demand: Complete abandonment of grassland conversion

4.3 Catch crops/greening

Possible approaches for risk reduction in this thematic field are:

- Avoidance of fallow periods by nurse crops and greening using perennial green manure plants
- Change of catch crops/nurse crops in particular by late summer cereals not until spring, maximum 4 weeks before sowing of the following crop
- Sowing of the catch crops in mulch or direct sowing process
- Vegetable/lamb's lettuce growing: Abandonment of shallow rooting of last cultures in favour of deep rooting or perennial green plants
- Avoidance of fallow periods by nurse crops and greening using freeze off green manure plants (without Legume)

4.4 Fertilization

Possible approaches for risk reduction in this thematic field are:

- Decrease of surpluses in nitrogen balance from farming balances on a groundwater protecting level (regulatory requirements needed, compare 2.2)
- Corporate spreading of fertilizers ("collective fertilising" through contractors) in consideration of all nutrients after site specific determination of plant demand
- Reduction of recommended total N dispensations; about 40 , 30 or 20 %
- Focused application of N-stabilized fertilizers
- No N-fertilization in autumn to winter barley (basic demand: none N-fertilization to winter wheat, winter rye, Triticale, spelt)
- No N-fertilization in autumn to intercrops, field grass and permanent grassland
- Site specific determination of fertilization requirements on the basis of measuring principles (maize fields: late Nmin- measuring method (TZW 1993-1995)), possibly in community actions with organization of sampling and written fertilization recommendation
- Limitation of a maximum N-single doses of 50 kg N/ha with easy soluble fertilizers
- In the time of the planting, use oriented splitting of N-fertilization

- Adjustment of N-fertilization not for maximum amounts, but for long lasting average yields
- No N-fertilization to stray–rot and to stubble work
- Related documentation of fertilization and cultivation measures
- N-fertilization in autumn to winter rapeseed max. 40 kg N/ha until 01. September. (basic demand: no N-fertilization in autumn after potatoes and previous crop with nitrogen-rich harvest residues)
- N-fertilization in autumn to hardy intercrops max. 40 kg N/ha until 15. September (basic demand: no N- fertilization in autumn after potatoes and previous crop with nitrogen rich harvest residues)
- N-fertilization in autumn to winter field grass and grassland max. 40 kg N/ha until 15. September.
- basic demand: no N- fertilization to freezing intercrops in autumn

4.5 Manure amount, storage and distribution

Possible approaches for risk reduction in this thematic field are:

- Increase of the storage capacity of liquid manure for at least 6 month (depending on farm structure), improved liquid manure management (possible corporate)
- Increase of the storage capacity of solid manure for at least 6 month (depending on the farm structure)
- Use of state-of-the-art technology for application of liquid manure with ribbon-shape deposition and possibly immediate incorporation (basic demands during the application: low emission and high distribution exactness. This can be reached for example with the use of trailing hose, drag shoe, slit techniques, liquid manure injector)
- Application of solid manure with exact manure spreader
- Reduction of livestock density to max. 1,4 LU/ha (LU = livestock unit)
- Limitation of applied fertilizer amounts by the main nutrient, whose need is covered first
- Application of rotting dung (> 3 months storage time) from 01. February
- Determination of the nutrient content of manure before every application and related documentation
- Application of nitrification inhibitors with the application of liquid manure

4.6 Further measures in land use

In the most cases it will be unavoidable to use additional measures to keep or gain a nitrate concentration in the groundwater below 50 mg/l. A possibility is immediate conversion of arable land to grassland in particular core risk zones. Besides, e.g., the following especially effective measures can be seized:

- Area extensification by cultivation of Chinese silver grass ("Miscanthus sinensis giganteus", "reed"). This is a plant which counts to the renewable resources, remaining several years in the same location. It forms a very high and dense plant population and can absorb nitrate amounts in the soil efficiently. It shows varied possible uses and can be also used as an energy plant (cf. 2.2).
- Conversion of arable land or intensely used grassland in extensively used grassland: Concerning the possible uses of the green cut, the lacking inquiry for green cut is to be taken into consideration with decreasing cattle density. Another possiblility is the use as energy plants (cf. 2.2).
- Set-aside of agricultural land (preferentially perennial)
- Cultivation of Sudan grass, a forage grass which is resistant towards drought and also grows with late sowing very fast and is little demanding. Sudan grass can absorb nitrate nitrogen from the soil efficiently, like reed; nevertheless, it freeze off. It adapts itself to a wide spectrum of grounds, from heavy loamy ground up to sandy soil.
- Reduce the use of crops with high nitrate leaching potentials, e.g., by relocation from the catchment area.
- Extensive cultivation of energy plants: For the power generation of biogas, energy plants (grass, beet, maize, grain, Miscanthus) become considerably more important. From sugar beets, grain and maize bio ethanol can be gained and biodiesel from rape. Nevertheless, a groundwater preserving/extensive cultivation must be guaranteed.
- Groundwater preserving reforestation: In the groundwater below wooded areas low nitrate concentrations can be determined. Hence reforestations were often carried out by different water supplier in the catchment area in the past (OTTILLINGER 1997). Also in progress of ecological balance measures reforestation areas are often created in water protection areas (TZW in 2004b). However in the first years of the reallocation the discharge risk is relatively high. In particular with beforehand intensely farmed arable areas reforestations do not present suitable immediate measure to decrease nitrate leaching. The following other aspects have to be considered for the decision: Groundwater recharge decreases with increasing age of the forest and is lower for coniferous forest than for deciduous forest. This is particularly in areas with low seepage water rates of importance. At coniferous forests relatively high nitrogen amounts be-

tween 20 and 50 kg of N/ha and year are introduced through the so-called "cam-out effect" with the continuance precipitation. The areas are permanently revoke of the agricultural use, hence, additional surplus problems can appear, e.g., in areas with high farm fertilizer amount. In particular with base-poor parent rock material the negative consequences of the soil acidification on the seepage water quality are to be considered in the long term. In the first years additional costs will arise for tending measures. If these points were considered, or are not relevant, and a decision was made for reforestation, then this should occur very groundwater preserving. Thereby, at first the available nutrient amounts in the soil should be absorbed by e.g sowing grasses and perennial use of crop at first. After some years young trees should be planted without changing the total area of reforestration.

4.7 Technical measures

If the evaluation of agricultural measures shows that agricultural measures are not enough to reach the targets, or if the time of expected success is too long, then technical measures have to be considered. These may be in use only temporarily.

Possible technical barrier options in the waterworks include:

- Change of the well management: Change in the abstraction rate of nitrate contaminated wells in favour of wells with low nitrate concentrations (depending on hydrogeological situation).
- Temporary reduction of the total abstraction from one or more wells (compensation of missing water amount by other water sources). This measure can effect, e.g., only a reduction of nitrate concentration, if the nitrate contaminated water comes mainly from other catchment areas and lower nitrate input in the close range is present. To this, pumping tests can give more detailed information.
- Mixture of water with lower nitrate concentrations by acquisition of external raw or drinking water.
- Changes in treatment, in particular ifother solute contents cause problems in addition to nitrate
- Connection to another water supply or acquisition of external water with renunciation of the water protection area.

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6 Appendix A: RROs for different hazardous events (from TECHNEAU Hazard Database "THDB")

6.1 Groundwater catchment (including protection zones)

Sub-system: Components	**Hazardous event** (ref. from THDB)	**Hazardous event** (from THDB)	**Risk reduction options**								
			Control			**Education and Information**			**Barrier**		
			Ref.	Options	Hazard Type	Ref.	Options	Hazard Type	Ref.	Options	Hazard Type
2.1 Catchment area	2.1.1	Contamination by industrial operations (including continuous discharge as well as installations, construction work and other)	C2.1.1 a	**Restrictions/Guidelines** on industrial operations	P/C	E2.1.1 a	**Identify & Inform stakeholders**	P	B2.1.1 a	**Physical/Technical** (e.g. oil separator, oil trap, oil binder, absorptive or neutralizing material, facilities storing hazardous liquids equipped with collecting trays)	C
-			C2.1.1 b	**Monitoring** (Groundwater)	C	E2.1.1 b	**Qualification & Training** of personnel	P/C	B2.1.1 b	**Operational, primary** (e.g. changes in production process, substitution of hazardous liquids with less toxic chemicals)	P/C
-						E2.1.1c	**Action & Emergency plans**	C	B2.1.1 c	**Operational, secondary** (water treatment step as safety barrier, e.g. PAC)	C

Sub-system: Com-po-nents	**Haz-ardous event** (ref. from THDB)	**Hazardous event** (from THDB)	**Risk reduction options**								
			Control			**Education and Information**			**Barrier**		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
-	2.1.2	Contamination by waste water e.g. by WWTP, sewers, latrines	C2.1.2 a	**Restric-tions/Guidelin es** on waste water storage, transport and discharge	P/C	E2.1.2 a	**Identify & In-form stake-holders**	P	B2.1.2 a	**Physical/Technical** (e.g. double-walled wastewater pipes, ad-ditional rain spillway basin)	P
-			C2.1.2 b	**Monitoring** (Waste water, Surface Waters, Groundwater, Raw water)	C	E2.1.2 b	**Qualification & Training** of per-sonnel	P/C	B2.1.2 b	**Operational, primary** (enhanced waste water treatment)	P
-						E2.1.2c	**Action & Emer-gency plans** in case of overflow	C	B2.1.2 c	**Operational, secon-dary** (adjust drinking water treatment, e.g. disinfection)	C

Sub-system: Com-ponents	Haz-ardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
-	2.1.3	Leaching of contaminants by built constructions (e.g. landfills using waste or contaminated ground, dumpsites, traffic facilities, installations for handling, storage and deposition of waste materials or excavation residues)	C2.1.3 a	**Restrictions/Guidelines** on use, storage or transport of hazardous waste materials	P/C	E2.1.3	**Identify & Inform stakeholders**	P	B2.1.3	**Physical/Technical** (e.g. diversion of potentially contaminated runoff- and seepage water, clean-up or sealing of contaminated landfill)	C
-			C2.1.3 b	**Monitoring** (Seepage water, Groundwater)	C					**Operational, primary** (e.g. to deposit only pre-treated and tested material)	P/C
-										**Operational, secondary** (adjust drinking water treatment, e.g. activated carbon filtration)	C
-	2.1.4	Traffic, incl. accidents (railway tracks, airfields, roads, parking areas, petrol filling stations, air accidents) loss of oil by	C2.1.4 a	**Restrictions/Guidelines** on traffic (e.g. transport of hazardous substances, speed limit, no	P/C	E2.1.4	**Identify & Inform stakeholders** (e.g. road sign 'Water protection area')	P	B2.1.4 a	**Physical/Technical** (e.g. diversion of potentially contaminated surface-runoff, secured roads, e.g. guardrails, impermeable pavement surface)	C

Sub-system: Com-po-nents	Haz-ardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
		cars or boats		motor boats on surface waters)							
-			C2.1.4 b	**Monitoring** (Groundwater)	C	E2.1.4 b	**Qualification & Training** of per-sonnel (e.g. driver of Hazard-ous Cargo-trucks)	P/C	B2.1.4 b	**Operational, primary** (e.g. traffic manage-ment system, non-chemical weed-control on sealed surfaces)	P/C
-						E2.1.4c	**Action & Emer-gency plans** in case of accidents	C	B2.1.4 c	**Operational, secon-dary** (adjust drinking water treatment, e.g. activated carbon filtra-tion)	C
-	2.1.5	Construction ac-tivities with inter-ference in subsoil (e.g. waterway construction, instal-lations for handling or storage of haz-ardous substances, facilities for con-struction workers) (incl. accidents)	C2.1.5	**Restric-tions/Guidelin es** on Construc-tion activities	P/C	E2.1.5 a	**Identify & In-form stake-holders**	P	B2.1.5 a	**Physical/Technical** (e.g. to stockpile bind-ers, floating oil barri-ers, excavation of con-taminated soil)	C
-			C2.1.5 b	**Monitoring** (Groundwater)	C	E2.1.5 b	**Qualification & Training** of per-	P/C	B2.1.5 b	**Operational, primary** (e.g. adjust excavation	P/C

Sub-system: Com-po-nents	Haz-ardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
							sonnel			to groundwater table)	
-						E2.1.5c	**Action & Emer-gency plans** in case of accidents	C	B2.1.5 c	**Operational, secon-dary** (adjust drinking water treatment)	C
-	2.1.6	Increase of vulner-ability due to min-ing activities, gravel pits, excava-tions uncovering the GW, construc-tion of facilities for geothermal power purposes and /or small water supply systems	C2.1.6 a	**Restric-tions/Guidelin es** on mining and drilling (e.g. certified and tested ma-terial or quali-fied drilling companies)	P/C	E2.1.6 a	**Identify & In-form stake-holders** (e.g. drilling compa-nies)	P	B2.1.6 a	**Physical/Technical** (e.g. proper refilling of drillings, correct posi-tioning of bentonite layers)	C
-			C2.1.6 b	**Monitoring** (Groundwater)	C	E2.1.6 b	**Qualification & Training** of per-sonnel (e.g. of drilling compa-nies)	P/C	B2.1.6 b	**Operational, primary** (e.g. adjust excavation to groundwater table including a safety margin)	P/C
-						E2.1.6c	**Action & Emer-gency plans** in case of accidents	C	B2.1.6 c	**Operational, secon-dary** (adjust drinking water treatment)	C
-	2.1.7	Agriculture runoff containing fertiliz-ers, sludge, herbi-cides, etc.	C2.1.7 a	**Restric-tions/Guidelin es** on agricul-ture (e.g. use of	P/C	E2.1.7 a	**Identify & In-form stake-holders** (e.g. farmers, how to	P	B2.1.7 a	**Physical/Technical** (e.g. special spray valves to reduce wind-blown dispersal of	P/C

Sub-system: Com-po-nents	Haz-ardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
				pesticides, date of soil-tillage)			apply good agri-cultural practice)			pesticides)	
-			C2.1.7 b	**Monitoring** (Field survey, Soil & Groundwater sampling)	C	E2.1.7 b	**Qualification & Training** (e.g. demonstration projects of groundwater protective agri-culture	P/C	B2.1.7 b	**Operational, primary** (e.g. intercrops to re-duce nitrate leaching, adapted crop rotation, reduced pesticide use, organic farming, re-duced tillage)	P/C
-									B2.1.7 c	**Operational, secon-dary** (adjust drinking water treatment, e.g. nitrate or pesticide removal)	C
-	2.1.8	Manure spread or cattle in the zone	C2.1.8	**Restric-tions/Guidelin es** on pasturing and organic fertilising (e.g. no spreading of manure in win-ter and when the soil is satu-rated)	P/C	E2.1.8 a	**Identify & In-form stake-holders** (e.g. farmers, how to apply good agri-cultural practice)	P	B2.1.8 a	**Physical/Technical** (e.g. enhancement of the storage capacity for liquid manure)	P/C

Sub-system: Com-po-nents	Haz-ardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
-			C2.1.8 b	**Monitoring** (Soil & Groundwater)	C	E2.1.8 b	**Qualification & Training** (e.g. demonstration projects of groundwater protective agri-culture	P/C	B2.1.8 b	**Operational, primary** (e.g. rotation system of cattle to reduce pastur-ing intensity, limitation of livestock densities, surface banding and liquid manure injec-tion)	P/C
-									B2.1.8 c	**Operational, secon-dary** (adjust drinking water treatment, e.g. disinfection)	C
-	2.1.9	Geomorphologic and climatic inci-dents (e.g. extreme hydraulic events such as torrential rain, floods, ero-sion, landslides, karst land surface with open dolines)	C2.1.9 a	**Restric-tions/Guidelin es** on land-use in vulnerable areas (e.g. no pasturing on highly perme-able soils, no new buildings and no fuel storage in flood plains, no land-fills)	P/C	E2.1.9 a	**Identify & In-form stake-holders** (e.g. about location of vulnerable zones, delineation of flood plains)	P	B2.1.9 a	**Physical/Technical** (e.g. fencing around dolines, storm water storage basins)	P
-			C2.1.9 b	**Monitoring** (Field survey, Groundwater, Raw water, e.g.	C	E2.1.9 b	**Action & Emer-gency plans** (e.g. in case of acci-dents with liq-	C	B2.1.9 b	**Operational, secon-dary** (adjust drinking water abstraction, e.g. no abstraction during	C

Sub-system: Com-po-nents	Haz-ardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
				turbidity, bacte-ria)			uids hazardous to waters)			flooding or adjusted disinfection due to high turbidity)	
-	2.1.10	Accidents or spreading out of hazardous materi-als during recrea-tional or military activities (e.g. mass rallies, fish ponds, shooting galleries, sports facilities incl. motor sports, horse-race grounds, zoo / animal reserves, camps, campsites, military field exer-cises and training areas)	C2.1.1 0a	**Restric-tions/Guidelin es** on recrea-tional or mili-tary activities	P/C	E2.1.1 0a	**Identify & In-form stake-holders** (e.g. or-ganiser, visitors, sports persons)	P/C	B2.1.1 0a	**Physical/Technical** (e.g. sanitary facilities (portable toilets) , or-derly waste disposal)	

Sub-system: Com-po-nents	**Haz-ardous event** (ref. from THDB)	**Hazardous event** (from THDB)	**Risk reduction options**								
			Control			**Education and Information**			**Barrier**		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
-			C2.1.10b	**Monitoring** (Field survey, Groundwater)	C	E2.1.10b	**Qualification & Training** of personnel (e.g. camp site staff)		B2.1.10b	**Operational, primary** (e.g. arrangement of booths and venues, safety margins to abstraction facilities or monitoring wells)	
-	2.1.11	Contamination by forestry activities, wild life activities, natural fowl, dead animals, bird pest (flu)…	C2.1.11a	**Restrictions/Guidelines** on forestry activities (e.g. no clear-cutting, no wildlife feeding)	P/C	E2.1.11a	**Identify & Inform stakeholders** (e.g. foresters, lumbermen, rangers, hunters and walkers/hikers)	P	B2.1.11a	**Operational, primary** (e.g. site-adapted forestry)	
-			C2.1.11b	**Monitoring** (Field survey, Groundwater)	C	E2.1.11b	**Qualification & Training** of personnel (e.g. foresters, rangers)	C	B2.1.11b	**Operational, secondary** (adjust drinking water treatment, e.g. disinfection)	
-	2.1.12	Wetlands & flood plains not hydraulically separated from the aquifer	C2.1.12a	**Restrictions/Guidelines** on potentially hazardous activities	C	E2.1.12	**Identify & Inform stakeholders** (all land-use activities)	P	B2.1.12a	**Operational, primary** (e.g. design and operation of drainage management systems, flood protection)	

Sub-system: Com-po-nents	**Haz-ardous event** (ref. from THDB)	**Hazardous event** (from THDB)	**Risk reduction options**								
			Control			**Education and Information**			**Barrier**		
			Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type	Ref.	Options	Haz-ard Type
-			C2.1.1 2b	**Monitoring** (Field survey, Groundwater)	C				B2.1.1 2b	**Operational, secon-dary** (adjust drinking water treatment, e.g. disinfection)	
-	2.1.13	Groundwater aqui-fer is not suffi-ciently fed or water is abstracted by others	C2.1.1 3a	**Restric-tions/Guidelin es** on water abstraction by other parties	P	E2.1.1 3a	**Identify & In-form stake-holders** (e.g. farmers using irrigation, con-sumer, industry)	P	B2.1.1 3a	**Operational, primary** (measures to reduce water demand by oth-ers, decentralised infil-tration of run-off rain water)	
-			C2.1.1 3b	**Monitoring** (Groundwater level)	P/C	E2.1.1 3b	**Qualification & Training** of farm-ers on efficient irrigation meth-ods, industry and consumer on how to reduce water demand)	P/C	B2.1.1 3b	**Operational, secon-dary** (using artificial groundwater recharge or additional water sources)	
-						E2.1.1 3c	**Action & Emer-gency plans** in case of water scarcity	C			

Sub-system: Components	Hazardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and Information			Barrier		
			Ref.	Options	Hazard Type	Ref.	Options	Hazard Type	Ref.	Options	Hazard Type
-	2.1.14	Water temperature under 4°C	C2.1.14	**Monitoring** (Groundwater, Raw water)	C				B2.1.14	**Operational, secondary** (e.g. adjust treatment, water mains buried frost-proof)	C
-	2.1.15	Radioactivity fall-out	C2.1.15	**Monitoring** (Groundwater, Raw water)	C	E2.1.15	**Action & Emergency plans**	C	B2.1.15	**Operational, secondary** (alternative water supply, adjust treatment if adequate treatment step is available)	C
-	2.1.16 (cf. 2.1.17)	Plane in central catchment pond (cf. 2.1.17)	--	**--**		--	**--**		--	**--**	
-	2.1.17	Terrorist and vandalism actions	C2.1.17	**Restrictions/Guidelines** on access in the vulnerable parts of the catchment	P/C	E2.1.17a	**Qualification & Training** of water utility personnel, e.g. Emergency preparedness training)		B2.1.17a	**Physical/Technical** (e.g. fencing around inner protection zone)	P/C
-				**Monitoring** (Groundwater)	C	E2.1.17b	**Action & Emergency plans**			**Operational, secondary** (e.g. alternative water supply, water treatment step as safety barrier, e.g. PAC)	C
2.2 Monitoring system	2.2.1	Accident, defect, power failure, operational failure, sabotage, damaged	C2.2.1a	**Restrictions/Guidelines** on access near monitoring	P	E2.2.1a	**Qualification & Training** of water utility personnel (e.g. Work in-		B2.2.1a	**Physical/Technical** (e.g. secured locking caps, closing plugs, subsurface construc-	P

Sub-system: Components	**Hazardous event** (ref. from THDB)	**Hazardous event** (from THDB)	**Risk reduction options**								
			Control			**Education and Information**			**Barrier**		
			Ref.	Options	Hazard Type	Ref.	Options	Hazard Type	Ref.	Options	Hazard Type
		groundwater observation wells		devices			structions enclosed in the Operating Manual)			tion, alarm system)	
-			C2.2.1 b	**Monitoring** (Field survey, Groundwater)					B2.2.1 b	**Operational, secondary** (e.g. redundancy of power supply, stockpile of replacement parts and sampling/monitoring equipment)	C

Control - control options include: legal control and measurement control (early warning systems)

Ref. - reference number of option: C = control option, E = education and Identify & Information option, B = barrier option

Type - type of option: P = probability reducing option, C = consequence reducing option

6.2 Groundwater and infiltration water abstraction

Subsystem	Hazardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and information			Barrier		
			Ref.	Options	Type	Ref.	Options	Type	Ref.	Options	Type
5.1 Water abstraction facility											
Generic situation	5.1.1	Trees, roots, cracks in concrete (e.g. in chamber walls)	C5.1.1a	**Restrictions/Guidelines** on design, operation, and maintenance	P/C	E5.1.1a	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C	B5.1.1a	**Physical/Technical** (e.g. safety distance to trees, proper design, adequate material)	P/C
			C5.1.1b	**Monitoring** (e.g. field survey, camera inspections)	C				B5.1.1b	**Operational, primary** (e.g. cutting of trees)	P/C
									B5.1.1c	**Operational, secondary** (rehabilitation/refurbishment)	C
Generic situation	5.1.2	Infiltration of run-off water	C.5.1.2a	**Restrictions/Guidelines** on design, operation, and maintenance	P/C	E5.1.2a	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C	B5.1.2a	**Physical/Technical** (e.g. diversion ditch outside of inner catchment zone, abstraction facility built protected against flooding)	P/C

Subsystem	Hazardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and information			Barrier		
			Ref.	Options	Type	Ref.	Options	Type	Ref.	Options	Type
			C5.1.2b	**Monitoring** (field survey, raw water e.g. turbidity)	C				B5.1.2a	**Operational, secondary** (no abstraction during flooding or adjusted disinfection due to high turbidity, rehabilitation & refurbishment)	C
Openings in system	5.1.3	Contamination by flooding, sabotage, animals, etc	C5.1.3a	**Restrictions/Guidelines** on design, operation, and maintenance	P/C	E5.1.3a	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C	B5.1.3a	**Physical/Technical** (e.g. Safeguards of openings (valves, flaps, grating), alarm systems, screen doors & windows)	P/C
			C5.1.3b	**Monitoring** (field survey, raw water)	C	E5.1.3b	**Action & Emergency plans**	C	B5.1.3b	**Operational, secondary** (e.g. alternative water supply, water treatment step as safety barrier, e.g. PAC)	C
Asset protection (fences, closure)	5.1.4	Improper locking of the system and sabotage	C5.1.4a	**Restrictions/Guidelines** on access to abstraction site	P	E5.1.4a	**Identify & Inform stakeholders** (police, security firm)	P/C	B5.1.4	**Physical/Technical** (e.g. alarm systems, fencing around well, barbwire)	P/C
			C5.1.4b	**Restrictions/Guidelines** on design, operation, and maintenance	P/C	E5.1.4b	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C	B5.1.4b	**Operational, secondary** (e.g. alternative water supply, water treatment step as safety barrier, e.g. PAC)	C

Subsystem	Hazardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and information			Barrier		
			Ref.	Options	Type	Ref.	Options	Type	Ref.	Options	Type
			C5.1.4c	**Monitoring** (e.g. site survey, inspections)	C	E5.1.4c	**Action & Emergency plans**	C			
Bentonite layers	5.1.5	Improper or missing bentonite layers	C5.1.5a	**Restrictions/Guidelines** on design (quality criteria of executing company)	P/C	E5.1.5a	**Qualification & Training** (staff of executing company)		B5.1.5	**Physical/Technical** (e.g. refill of drillings or supplementary clay layers)	P/C
			C5.1.5b	**Monitoring** (e.g. geophysical investigation, camera inspection, tracer test)	C	E5.1.5b				**Operational, secondary** (e.g. rehabilitation & refurbishment)	C
Well chamber	5.1.6	Improper maintenance concept, flood alarm and sump pump lacking	C5.1.6a	**Restrictions/Guidelines** on design and maintenance	P/C	E5.1.6a	**Qualification & Training** of staff of executing company) and water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C		**Operational, secondary** (e.g. revision of maintenance concept, stockpile of replacement parts)	C
			C5.1.6b	**Monitoring** (e.g. site survey, inspections)	C						

Subsystem	Hazardous event (ref. from THDB)	Hazardous event (from THDB)	Risk reduction options								
			Control			Education and information			Barrier		
			Ref.	Options	Type	Ref.	Options	Type	Ref.	Options	Type
Well chamber	5.1.7	Clogging due to the chemical composition of the aquifer water	C5.1.7a	**Restrictions/Guidelines** on design, operation, and maintenance	P/C	E5.1.7a	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in the Operating Manual)	P/C	B5.1.7	**Operational, secondary** (e.g. rehabilitation & refurbishment)	C
			C5.1.7b	**Monitoring** (e.g. of water quality and quantity, pump tests, regular measurement of groundwater yield/delivery)	C						
Infiltration dams	5.1.8	Failures in operation of infiltration dams	C5.1.8a	**Restrictions/Guidelines** on design, operation, and maintenance	P/C	E5.1.8a	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C	B5.1.8	**Operational, secondary** (e.g. revision of maintenance concept, stockpile of replacement parts, rehabilitation & refurbishment)	C
			C5.1.8b	**Monitoring** (operational performance, e.g. infiltration tests)	C						

Subsystem	**Hazardous event** (ref. from THDB)	**Hazardous event** (from THDB)	**Risk reduction options**								
			Control			**Education and information**			**Barrier**		
			Ref.	Options	Type	Ref.	Options	Type	Ref.	Options	Type
5.3 Monitoring system	5.3.1	Accident, power failure, operational failure, sabotage, damaged monitoring devices	C5.3.1a	**Restrictions/Guidelines** on access near monitoring devices	P/C	E5.3.1a	**Qualification & Training** of water utility personnel (e.g. Work instructions enclosed in Operating Manual)	P/C	B5.3.1	**Operational, secondary** (e.g. revision of maintenance concept, stockpile of replacement parts, rehabilitation & refurbishment)	C
			C5.3.1b	**Monitoring** (Field survey, Groundwater)	C	E5.3.1b	**Action & Emergency plans**	C			

Control - control options include: legal control and measurement control (early warning systems)

Ref. - reference number of option: C = control option, E = education and information option, B = barrier option

Type - type of option: P = probability reducing option, C = consequence reducing option