Wetland based buffer zone technology

Technology description:
General information & application area

Target Audience: Authorities, site owners, consultants, contractors

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Project website address: aquarehab.vito.be

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1 INTRODUCTION

The term wetlands refers to "areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (USA EPA Clean Water Act). This document is related to wetlands implemented as a buffer zone between agricultural land and water bodies like river water to intercept pollutants flowing towards surface water.
This technology description document intends to provide general information about this technology, and its application area and boundary conditions for authorities, consultants, contractors and site owners. The document was composed in the frame of the FP7 project AQUAREHAB (GA 226565), and comprises outcomes and lessons learned during this project. For more details the generic guideline can be consulted.

2 GENERAL PRINCIPLES OF THE WETLAND BASED BUFFER ZONE TECHNOLOGY

2.1 CONCEPT

Riparian buffer zones can be defined as permanently vegetated buffer zones between land and a water body, which are separately managed from the rest of a field or catchment with the aim to mitigate the runoff and drainage of various agricultural pollutants (nitrates and pesticides) or entry of such pollutants in surface water via upwelling subsurface water. Such riparian buffer zones can take the form of small forests, grass land and wetlands (Figure 1).

A.

B.

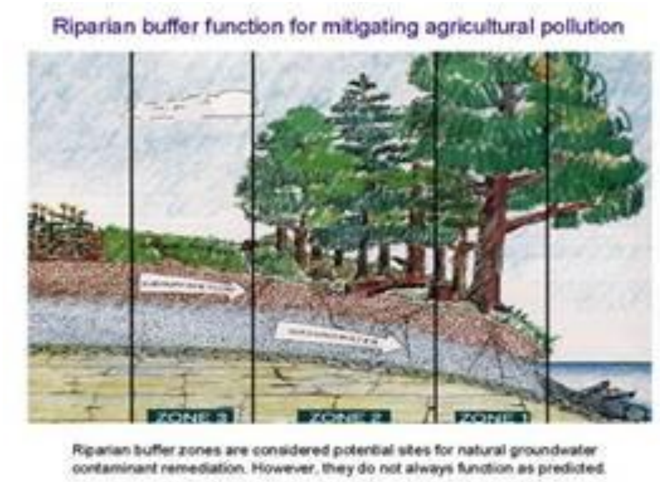

Figure 1: Representation of a wetland (A) and riparian buffer zone (B) for coping with diffuse pollution (pesticides, nitrate) in agricultural areas.

Roughly, for activity understanding and because of reasons of simplicity, a wetland zone can be divided in two major compartments, i.e., the above surface compartment" (also designated as “surficial” compartment) and the “subsurface compartment”. The surficial compartment receives nitrate and pesticides from agricultural land through drainage, erosion and run-off but during flooding also from the river itself. The subsurface compartment receives pollutants from the agricultural land through leaching. Nitrate is removed by plant-uptake and biological conversions while pesticide concentrations will be reduced by retention on soil particles, sorption and microbial degradation. In the “above surface compartment” also photodegradation can contribute to pesticide removal.

Transformation/restoration of agricultural land into a wetland system will supply a buffer zone between the land and the surface water body resulting into a longer flow path of pollutants to enter the river in which biotic and abiotic processes contribute to pollutant mitigation. AQUAREHAB results show that this flow path will also depend on the extent of flooding in case of subsurface contamination. Flooding will force the groundwater to well up through the peat layer (in case hydraulic conductivity of the peat layer is sufficiently high) and as such brings it in contact with organic carbon rich materials that stimulate denitrification and hence nitrate removal.

2.2 Targeted substances & reaction mechanisms

The substances targeted in this guidelines are pesticides and nitrate (Table 1). The guidelines are directed towards agricultural landscapes.

Table 1: Overview of substances that are targeted by the “wetland based buffer zone“ technology.

Targeted substances		Emission sources
Class	Specific substance	
Nutrients	Nitrate	Agriculture
Pesticides	Atrazine[1,6]	Agriculture
	Diuron[2]	Agriculture (vineyard)
	3,4-DCA[2]	Agriculture (vineyard)
	Glyphosate[2]	Agriculture (vineyard)
	Chlorpyrifos[3]	Agriculture
	Mecoprop[4]	Agriculture
	Metsulfuron-methyl[4]	Agriculture
	Isoproturon[4]	Agriculture
	Deltamethrin[5]	Agriculture
	Fluometuron[6]	Agriculture

Ref.: [1] (Anderson *et al.*, 2002), [2](Bois *et al.*, 2013), [3](Karpuzcu *et al.*, 2013), [4](Larsen *et al.*, 2001), [5](Muñoz-Leoz *et al.*, 2009), [6](Weaver *et al.*, 2004)

2.3 Development stage of the technology

Wetland restoration is often performed as a combined re-meandering of the river slopes and raise of the river bed to obtain hydroperiods (flooding) of the surrounding wetlands/riparian areas in wet periods. The technology of wetland restoration as such can be classified as a (commercially) available technology and has been used in full scale river restoration projects for instance in Denmark in the Odense river basin. Although the technology is well-known around Europe, the documentation of its contribution to pollutant mass removal and how this is translated into the "best" wetland restoration approach for pollutant mitigation, is limited. Therefore, the technology of wetland restoration directed towards pollutant mitigation can be considered as "emerging". The application of the models described in this guideline aims at directing wetland implementation and managing towards improved pollutant mitigation.

3 Applicability and boundary conditions of the technology

Different factors will influence the efficiency of pollutant removal activities in wetlands. In the "surficial compartment" and "subsurface compartment"

- Width of the wetland (distance between "producing" agricultural land and "receiving" surface water body)
- Vegetation and depth of the root zone where plants can take up nitrogen (Asmussen et al., 1979; Cooper, 1990). Vegetation can also supply oxygen for pesticide degradation but also DOC for denitrification.
- Hydrological flow paths that can for instance favor microbial denitrification (i.e., saturated anaerobic soils, adequate carbon supplies, floodplain connections)
- Existence of a peat layer, organic carbon content and hydraulic conductive of the peat layer
- Geohydrology of the subsurface: Hydrological flow paths, structure, organic carbon content, water chemistry (redox, oxygen concentrations, DOC concentrations, …).
- Redox conditions

Factors that are especially of importance for pesticide degradation in the surficial compartment are oxygen content in surficial water, TOC content in soil, number of pesticide degraders in soil. Factors that are important for the model of nitrate fate in the subsurface are zonation of redox, zonation of TOC content, hydraulic conductivity including of peat layer, flooding level, and geohydrology.

Positive co-effects of the wetland based buffer zone technology comprise protection of nature and preservation of biodiversity, provision of products (timber, fish, reeds, …), flood control, groundwater recharge, microclimate stabilization and surface water/sediment storage. Actually, currently, these are often the main drivers for installing wetlands.

In respect to negative co-effects, wetlands used to reduce nutrient loadings have been reported to become degraded (in case of overtaxing). Incomplete denitrification can release the greenhouse and ozone depleting gas, nitrous oxide. Methanogenic activities can release the greenhouse gas methane (Verhoeven et al., 2006). If plants are harvested, they will rerelease nitrogen in the soil.

4 Performance of the wetland based buffer zone technology

The **abatement rate** can be defined as the substance concentration after the technology implementation divided by the substance concentration before implementation of the technology.

A well designed wetland based buffer zone aims at an abatement rate close to 100%, which means that the flux reduction rate in the wetland for the pollutants is almost 100%. However, as currently wetlands are mostly not designed specifically for pollutant mitigation purposes, the abatement rates can be lower. Examples of numbers for N-removal in the above surface compartment vary from 90% with a nutrient load of 10 kg/ha/year and 40-50% in case of 1000 kg/ha/year. Pesticide degradation rates in wetland systems have hardly been studied.

After installation, the wetland based buffer zones needs regular maintenance to maintain the "above surface compartment" wetland functionalities and ensure longevity. These maintenance measures and their frequency of application include activities related to vegetation control (mowing, planting of species, grazing), control of pests and dredging (as sedimentation may fill up a controlled flooding basin and compromise water storage in the long run). Some researchers postulate that "above surface compartment" wetlands nutrient removal efficiency declines with wetland age with nutrient reduction functioning becoming reduced with 50% after 50 years.

5 COST OF THE TECHNOLOGY

Investment and operating costs will depend on the size of the area and site-specificities (hydrogeology) of the area which has to be restored/was restored and local labour costs. As a lead, the investment cost of the re-meandering of a 10 km stretch of the Odense river and concomitant re-establishment of 350 ha wetland was 0.8 MEURO (2003-prices (exclusive VAT)). Other numbers of installation costs found in literature are $3,500 to $80,000 per acre in the US. Additional costs might include costs related to the landowner compensation (if applicable). Annual operating costs will be minimal and will include costs related to control/maintenance measures and monitoring. Costs are available for a controlled flooding basin in Bernissem (Sint-Truiden, Belgium) along the Melsterbeek that was installed in 2009. The total cost of purchasing the area of 14 ha was 0.6 Meuro. The additional total cost of construction was estimated to be 184 keuro. However, for this specific project, (pristine) soil from sewage construction works was used to build the levees, reducing the actual construction including labour cost, to 0 euro (Watering van Sint-Truiden, personal communication, April 25, 2012).

6 GENERIC APPROACH TO DETERMINE APPLICABILITY OF WETLANDS BASED BUFFER ZONE TECHNOLOGY

6.1 EVALUATING NITRATE REMOVAL

The following stepped approach can be followed to evaluate the applicability of the wetland based buffer zone technology:

STEP 1: Hydrological connection between wetland and catchment

The rationale is to start by evaluating how a specific wetland is connected to a contributing catchment, as this influences the water flows towards the wetland (Figure 2). The following characteristics are needed to understand the general wetland hydrology (for more specifics, see below);

- 3D physiography of the wetland-catchment continuum, i.e., topography, catchment size, geology. This information can be gathered from digital elevation models and existing or new well bores.

- Estimates of recharge (e.g. from climate stations recording precipitation and net evapotranspiration)
- River stage to record in- and out-of-bank floods

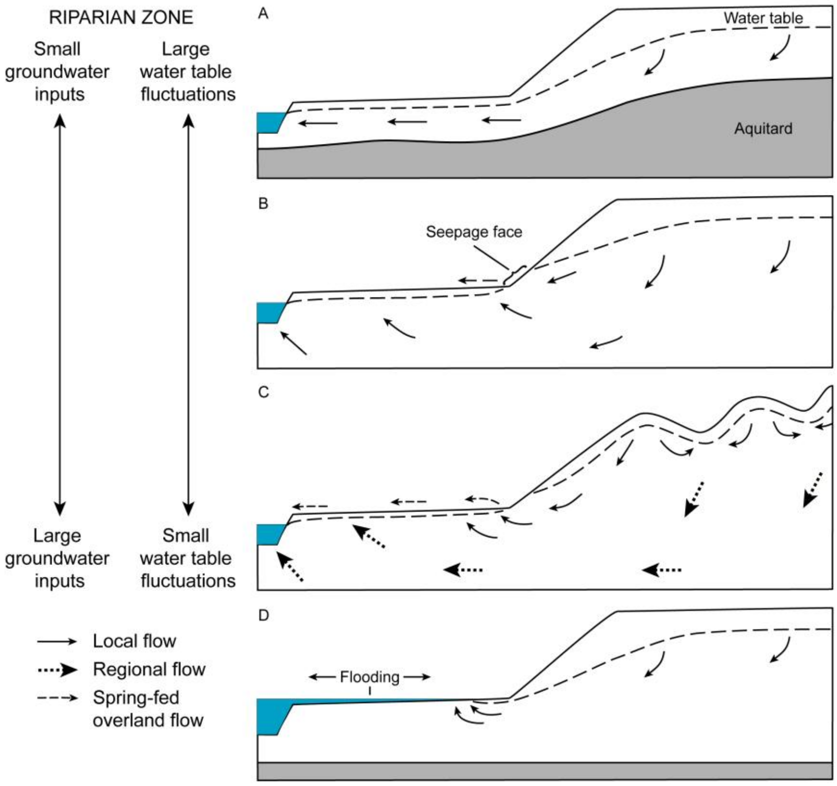

Figure 2: Wetland connected to the contributing catchment in three different ways (adapted from Hill, 1996).

STEP 2: Characterization of hydrogeology and hydrochemistry

Wetland hydrogeology and hydrochemistry are notoriously heterogeneous and optimally a suite of methods are needed to characterize the wetland, comprising dimensioning and topography of the wetland, geophysics, deep boreholes, hand-drillings, network of multilevel piezometers, hydraulic tests, discharge measurements.

Methods used to develop a conceptual model of the wetland hydrochemistry are:

- Strategy for sampling of groundwater and river water - *Needed to map redox zones, indicate denitrification areas, and used in the model to calibrate reactive parameters*
- Groundwater age tracers - *Useful to estimate denitrification rates without a numerical model.*
- Collection of soil cores for laboratory experiments.

STEP 3: Characterization of soil and organic sources

The objective of this step is to explore the amount and type of organic carbon in the soils and materials and the feasibility to release DOC that could stimulate denitrification. Soil samples collected during step 2 activities as well as other materials from the site (e.g. vegetables, wood) can be used for characterisation of the organic carbon.

STEP 4: Anoxic laboratory batch denitrification experiments

The objective of this step is to explore directly via lab scale experiments the capacity of denitrification in soil, which can be performed as a function of depth under anoxic conditions (nitrogen bubbling) and thermostatic temperature control (representative temperature of groundwater). Addition of extra carbon source to some test conditions allows to evaluate potential limitation of the denitrification by DOC.

6.2 Evaluating pesticide removal

Evaluation of the applicability of the wetland based buffer zone technology for pesticides is focussed on evaluating the pesticide removal capacity by either sorption and biodegradation.

Assess sorption of pesticides to wetland sediment

Adsorption of pesticides to soil largely determines the fate of these compounds in wetlands and depends on both the compound itself and soil characteristics. Strong sorbing compounds interact strongly with soil and therefore can be retained easily within wetlands, whereas these compounds are rather not bio-available, leading to lower degradation. Via labscale tests the sorption capacity of a soil-pestide system can be quantified via the adsorption coefficient (Kd).

Assess pesticide biodegradation and mineralization capacity/rates

The microbial degradation of pesticides depends on a number of biotic and abiotic constraints. In the first place, micro-organisms that are able to degrade (mineralize) the pesticide of interest, have to be present. This can be tested in a laboratory setup with idealized conditions referred to below as 'pesticide mineralization assay' (1). When micro-organisms are present, physicochemical conditions of the microenvironment should be suitable for degradation of the compound. Pesticide degradation is often, but not always, an aerobic process, and oxygen is mostly limited in wetland sediment or in subsoil. Therefore, the mineralization of pesticides should be tested in different redox conditions (2). Next, sorption and diffusion of the pesticide in wetland sediment may reduce the bioavailability and concentration of the pesticide, leading to lower mineralization of the compound in wetlands. Accordingly, the mineralization of the pesticide should be tested in realistic conditions, which can be achieved in microcosm systems (4). Sorption and diffusion obscure the actual mineralization kinetics of a pesticide, consequently, kinetics of degradation (mineralization) can only be determined (3) from experiments in idealized conditions.

6.3 Approaches to improve the nitrate/pesticide removal in wetlands

Nitrate removal in above subsurface compartment

Mechanisms and processes responsible for nitrate removal Jensen et al. (2013b) are (1) hydraulic residence time (τ_G), i.e., how quickly will nitrate move from the wetland margin to the river, (2) Denitrification rate, (3) permeability contrasts between a surficial peat layer and the more permeable wetland aquifer and (4) Flooding frequency and length of flooding (hydroperiods).
Nitrate removal in a wetland can be increased by (i) hydraulic manipulation (increase of hydraulic retention time), (ii) providing additional carbon source as electron donor and (iii) reducing oxygen concentration. Modelling can be a good tool to simulate different scenarios.

Pesticide removal

Measures to increase pesticide degradation rates in wetlands may comprise bioaugmentation, addition of nutrients, and adopting the design of the wetland to realise a high hydraulic retention time of the water in the wetland.

6.4 Monitoring effects of wetland restoration on surface water status

Classification of the ecological and chemical status is made, based on the following scheme (Figure 3).

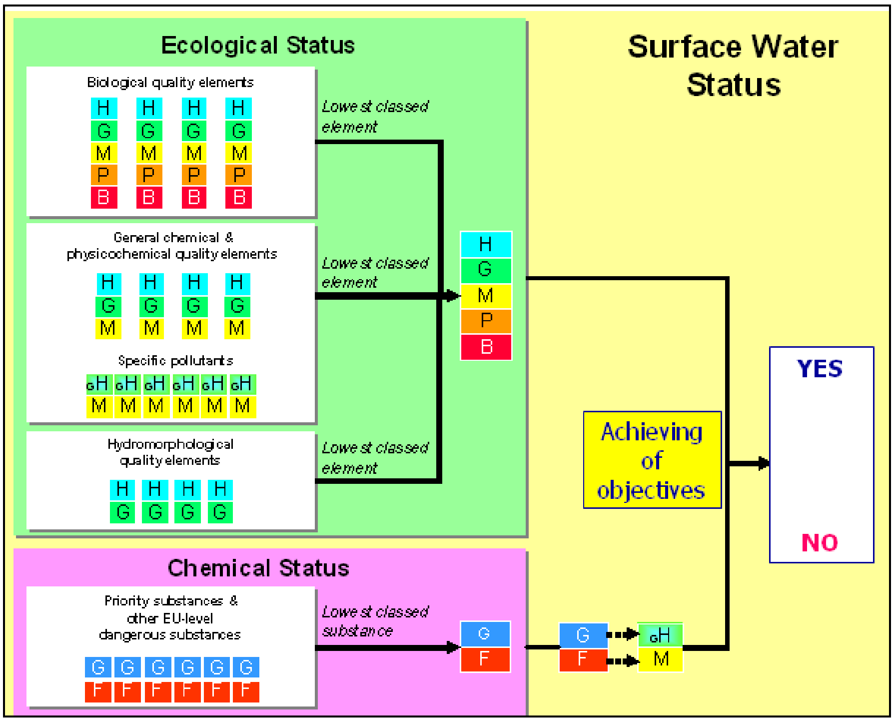

Figure 3: Basic scheme of ecological and chemical status assessment including quality elements. Ecological status is classified according to 5 categories: H – High; G – Good; M – moderate; P – Poor and B – Bad.

7 Contacts

This document was composed with input from:

Company/Institute	Contact person(s)	Contribution
Catholic University of Leuven (Belgium)	Dirk Springael dirk.springael@biw.kuleuven.be Pieter Vandermeeren	Biodegradation of pesticide Monitoring of wetlands
University of Copenhagen (Denmark)	Peter Engesgaard pe@geol.ku.dk Jannick Jensen	Modelling Wetland characterisation
CTM Centre Tecnologic (Spain)	Vicens Marti vicens.marti@ctm.com.es Montse Calderer	Denitrification
Geological Survey of Denmark and Greenland	Jens Aamands jeaa@geus.dk Bertel Nilsson	Pesticide biodegradation Wetland characterisation

Company/Institute	Contact person(s)	Contribution
(Denmark)	Anders Johnson	
Environmental Institute (Slovakia)	Corina Carpentier Jaroslav Slobodnik slobodnik@ei.sk	Monitoring - ecology

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