BALTIC COMPASS

REPORT

Measures for water protection and nutrient reduction

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Content

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1. Introduction

1.1. Background and motives

The exploitation of land for agriculture in Europe during the 20th century has been characterised by intensive drainage of the landscape to increase the available area for crop production. The Baltic drainage basin has been no exception and large areas of natural wetlands in the Baltic Sea region were drained during the second half of the 20th century. This intensified land use has led to a reduced water basin reservoir capacity as well as increased runoff and decreased residence time of water and sediments. Changes, which in the next step aggravate the process of eutrophication caused by impoverished natural retention processes of residual nutrients, now ending up in lakes and water courses, with the Baltic Sea as the final recipient. In combination with efforts to optimise the use of nutrients and to decrease losses from both diffuse and point sources, construction of wetlands as well as restoration of former natural wetlands offers a possibility to restore the natural nutrient retaining capacity of the land, thus decreasing the nutrient load in the Baltic Sea.

1.2. Goals

Since the year of 2000 the European Union member states have adopted the EU water Framework Directive which requires that all types of water; surface and ground water, rivers, water courses, lakes and costal water, must be protected and reach good ecological and chemical quality prior to the year of 2015. In order to reach that goal the member parties have agreed on the following country-wise provisional nutrient reduction requirements:

Table 1. Data showing country-wise provisional nutrient reduction requirements as agreed in Baltic Sea Action Plan. (HELCOM BSAP, 2007)

	Phosphorus (tons)	Nitrogen(tons)
Denmark	16	17 210
Estonia	220	900
Finland	150	1 200
Germany	240	5 620
Latvia	300	2 560
Lithuania	880	11 750
Poland	8 760	62 400
Russia	2 500	6 970
Sweden	290	20 780

Moreover the member parties also have acknowledged agriculture as the main source of diffuse nutrient inputs to the Baltic Sea why implementation of measures for reducing phosphorus and nitrogen losses from agriculture is of great importance. The contracting parties shall apply measures and take into account best available technology to prevent pollution originating from agricultural activity. Basic principles that are to be followed and implemented, at a minimum basis, into countries national legislations or guidelines concerning water protection measures and nutrient reduction areas is as follows:

"*Protection measures should be established to prevent nutrient losses to water particularly as regards*

> *- Surface water: buffer zones, riparian zones or sedimentation ponds should be established, if necessary.*
> *- Ground water: Ground water protective zones should be established if necessary. Appropriate measures such as reduced fertilisation rates, zones where manure spreading is prohibited and permanent grassland areas should be established.*
> *- Nutrient reduction areas: Wetland areas should be retained and where possible restored, to be able to reduce plant nutrient losses and to retain biological diversity*."

(Citation from: HELCOM 29/2008. Revised Annex III "*Criteria and Measures Concerning the Prevention of Pollution from Land-Based Sources*". Part II: Prevention of Pollution from Agriculture)

In this context the aim is to highlight the best available measures of those suggested above and to communicate how, were and when to implement the measures for an optimal effect.

1.3. The task of the project

The task of this project is therefore to:

- Identify and describe best available technologies for water protection and reduction of nutrients from water runoff in agricultural areas.

- Communicate useful guide-lines to the main operators, i.e. agricultural advisory organizations, farmers' organizations and authorities, on how to put the best available technologies in to practice at the farm level.

1.3.1. Instructions to the reader

This hand book gives a thorough presentation of the selected priority measures regarding theoretical as well as practical substances needed for implementation. Initially, common parameters, such as climate, topography, soil conditions, ecological state of the recipient etc., needed to be considered are presented in a more general perspective. In the following three chapters deeper information is presented for each measure concerning more specific parameters such as; impact on nutrient reduction, function, design, maintenance, permissions and commitments, financial requirements etc.

The aim is to give agricultural councils and advisers, farmer federations as well as individual farmers and other land owners a useful instructive tool to use in combination with their professional experiences and knowledge about site-specific conditions, from a regional as well as local perspective, for implementation in the field.

Sedimentation ponds and constructed wetlands as measures have much in common regarding function, optimization, maintenance, technical requirements etc. To avoid iteration all shared characteristics are not described in equal detail in each individual chapter why it is appropriate to study both chapter four (sedimentation ponds) and five (constructed wetlands) independent of which of the two measures that are to be implemented.

In order to keep the text readable the numbers of references written within the text is limited. Instead, each chapter has its own reference list to facilitate for readers to find more literature in the area of specific interest. With some exceptions the referred literature is written and published in English. Digitally available literature is referred to with a direct internet address and are recommended to explore for more detailed information, practical experiences and innovative experiments.

2. Best available technologies for water protection and retention of nutrients

Examples of measures for reducing nutrient losses from agriculture may be based on land use involving conversion of arable land to extensive grassland, soil management practice, livestock management, etc. Measures may also be based on the farm infrastructure level such as the establishment of wetlands and buffer zones, cutting the direct transportation of nutrients before it reaches the recipient which will be the focus in this “hand book”. A Danish study has shown that the establishment of wetlands and buffer zones is the most cost effective measures to reduce nutrient losses when compared to measures involving live stock density, conversion of arable land etc. (Jacobsen et al. 2004; 2011).

In general the reduction of nitrogen during winter is limited due to low micro biological activity in cold temperatures. A Finnish study, ongoing since 1995 suggest that to compensate for the low nitrogen reduction during winter all farms in a watershed needs to apply additional measures beside the ones related to husbandry. The results from the study showed that compensation is possible if a combination of buffer zones, sedimentation ponds and constructed wetlands are established along with innovative measures such as active filter systems etc. (Ventelä, 2010).

2.1. Selected priority measures

The three best available techniques for water protection and nutrient retention selected for presentation and recommendation within this “hand book”:

(i) Buffer zones, i.e. establishment of unfertilized areas with permanent vegetative cover alongside aquatic environments such as water courses and lakes acting as a mechanical barrier that reduces erosion, flow velocity, and the movement of nutrients into the water.

(ii) Sedimentation ponds, i.e. establishment of small sedimentation ponds to retard the water flow and induce optimal conditions for sedimentation of particle bound nutrients.

(iii) Constructed wetlands, i.e. establishment of wetlands to create opportunities to retain nutrients through sedimentation as well as both biological and chemical processes.

2.2. Locating the areas in need for measures

Examples of areas were implementation of water protective and nutrient retaining measures may be of great need and therefore should be located are as follow:

- Areas characterised by erosion problems related to soil properties
- Areas exposed to pulsative runoff due to heavy precipitation or snow melt
- Boreal cold climate areas with periods of freezing and thawing
- Hilly areas resulting in high water runoff velocity
- Areas with insufficient natural environments for nutrient retention
- Areas with intensive agriculture close to a recipient
- Bare soil or sparsely vegetative soil during winter time
- Areas where the recipient in known to be vulnerable and in need of protection
- Areas known to have point-sources, i.e. nutrition loaded residual water from a dairy farm etc. that needs to be treated

Most commonly, two or more of the listed circumstances occur at the same time motivating implementation of measures even more.

2.2.1. Climate and rain regimes

Soil erosion by water is a widespread problem throughout Europe and especially in the Mediterranean region due to long dry periods followed by heavy erosive rain, falling on steep slopes with sensitive soils. In the north and central parts of Europe the erosion is generally less as the rain is more evenly distributed over the year and the slopes are gentler (Jones et al, 2003). Still, erosion is a severe problem all over Europe and is also an increasing problem.

Heavy rains resulting in substantial surface runoff cause the largest erosion. Independently for how long the rain continues, the highest erosion occur during the initial minutes to hours after the surface runoff starts and then decline, as the most erosion sensitive material has been swept away.

In boreal areas with periods of freezing and thawing and substantial water runoff the consequences for nutrient losses may be severe. When the soil is frozen the infiltration capacity is low resulting in large surface run-off. In addition, the nutrients are being released from the thawing soil surface further enhancing the risk of high losses of eroded particles and nutrients. During cold periods biological activity that otherwise increase stabilization and retention of soil particles and nutrients are low.

2.2.2. Soil properties

Soils are not equally sensitive to erosion. Depending on the distribution of particle size dominating particle size soils get unique characteristics in terms of structure, water holding capacity, infiltration, swelling and cracking etc. A less structured soil, with small and light soil particles is more sensitive for erosion. Soils that develop a hard and crusty soil surface and crack during drier periods may result in severe surface water velocity with erosion as a consequence. From an agronomic perspective, nutrient loss associated with suspended solids through surface run-off in the primary pathway of phosphorous loss from agricultural fields.

Light soils consisting of a mix of silt (particle size 0,002-0,06 mm Ø) and clay (< 0,002 mm Ø) are sensitive to erosion. These soils are not very well structured and the fine particles are easily clogged in the soil water and severe amounts of particles may be lost through water runoff. As the soil easily clogs the infiltration capacity may also be negatively affected as the clogging close the pores and the water cannot infiltrate through the soil profile but stays on the surface making the erosion even worse.

Sandy soils, dominated by sand (particle size 0,06-2,0 mm Ø) generally have a more stabile pore system that does not clog why surface runoff rarely happens on a sandy soil. The sand works as a filter through which surplus water infiltrates often in a horizontal evenly distributed pattern.

Soils more dominated by clay, light to stiff clay soils, are not so erosion sensitive as silty soils. Clay particles easily lump together forming larger particles and aggregates that stabilize the soil. However, when a clay soil dries, cracks and larger so called macro-pores are formed. A heavy rain fall may under these circumstances sweep away particles, smaller aggregates as well as nutrients both on the surface and through the cracks and macro-pores. If a field with clay soil is badly drained and water saturated spots may occur, the aggregates can break it to smaller pieces that may be clogged and lost through transportation with water.

2.2.3. Nutrients properties

The mechanisms behind the losses of nitrogen and phosphorous from agricultural areas differ. The implementation of a measure does not necessarily have the same reduction impact on both nitrogen and phosphorus why it is often necessary to make special adjustments and combinations of several measures in order to obtain both nitrogen and phosphorus reduction.

Both nitrogen and phosphorus is lost from cultivated areas through transportation within the water. Surplus water is leaving the field in two ways; as horizontal surface run-off until it end up in a ditch or a watercourse, or as leaching infiltrated through the soil ending up in the tile system. The distribution between surface run-off and leaching varies between fields and moments strongly related to soil properties, gradient and water velocity. Nitrogen may also be lost to the atmosphere as ammonia but on the field this only happens during a limited period when large amounts of manure or urine containing high loads of ammonia is spread on a field.

Phosphorus occur both as dissolved phosphorus in the soil water and as phosphorus bound to soil particles. The dissolved phosphorus may infiltrate through the soil profile as leakage and lost with the water running in the tiles. However, various studies have indicated that particulate phosphorus is the predominant form exported from agricultural lands. As much as 62 to 99% of total phosphorus has been found associated to particles in run-off water from agricultural soil. The particulate phosphorus may also infiltrate but do seldom reach the tile system as the particles adheres to the walls of the soil pores. The particulate phosphorus is most often lost due to horizontal transportation within the surface runoff. But if the soil is a clay soil macro-pores and cracks are common through which the water may quickly be drained with a risk of high losses of both dissolved and particulate phosphorus as a result.

Nitrogen is found as nitrate, nitrite or ammonium or bound to organic material, and not associated with mineral particles in the same way as phosphorous. Processes that affect removal and retention of nitrogen are manifold and the most important in this is microbial transformation of ammonium to nitrate (nitrification) and nitrate to harmless N_2 gas (denitrification), plant and microbial uptake, sequestration in sediments and leaching. The leakage of nitrogen mainly occurs as nitrate dissolved in the water leaving the cultivated areas through surface run-off and as infiltration ending up in the tile system.

Conclusively, to improve the reduction of both phosphorus and nitrogen it is necessary to consider measures optimizing not only one but several nutrient reducing processes.

2.2.4. Phosphorus Index – a tool to locate high risk areas

In several countries large efforts are made to develop and use “phosphorus index” as a tool to locate high risk areas. The phosphorus index provides information of phosphorus load and mobility in cultivation areas together with information of water flow regime. Locations having high phosphorus load as well as mobility and at least occasionally high water regimes are estimated as high risk locations and in need of water protective measures. In Denmark and Norway, as an example, the risk assessment and location of the “hot-spots” are based on information of expected phosphorus losses through surface water, erosion, macro-pore flow and infiltration, all data obtained through the phosphorus-index (Heckrath et al.2009; Bechmann, 2005).

In Sweden a refined version of a conditional phosphorus risk index for phosphorus losses has been developed. New results have recently been presented stating that up to 10% of the cultivated areas in Sweden was estimated to be a potential source for phosphorus losses. Moreover unsatisfactory drained soil with an increased risk of frequent water-logging and visible surface water rills was also identified as potential important transport areas why re-draining is needed (Ulén et al, 2011). The development of these phosphorus indexes and making them user-friendly improve their potential as highly useful tools for agricultural advisers to use in their cooperation with farmers and landowners.

2.3. Means to realize the goals

The EU Common Agricultural Policy (CAP) is promoting sustainable agriculture in a global environment, ensuring that the environment is protected for future generations and funding opportunities are given under the Common

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Agricultural Policy. Funding is also available as Complimentary National Direct payments (CNDP) that are realized as production-detached aid.

Farmers may apply for means supporting agro-environment measures such as reduction of erosion, establishment of buffer zones, establishment and maintenance of wetlands etc. Applications for support can be made under various support schemes through each regional agriculture department. EU Direct Payment department as a division of RSS is responsible for making payments to eligible applicants.

More information regarding CAP funding opportunities and shared management is presented in the web site:
http://ec.europa.eu/agriculture/grants/index_en.htm

Links to web sites providing information for each individual member state on beneficiaries of CAP payments is available at:
http://ec.europa.eu/agriculture/funding/index_en.pdf

3. Buffer zones

Buffer zones are vegetated areas between fields and water courses, or erosion sensitive sites such as surface water wells or sites with high ground water levels. Any cultivation, fertilisation or the use of pesticides within buffer zones is to be prohibited. The vegetation should be kept dense and plants should be established if needed for maintenance. It is not allowed to use the zones for production or grazing.

3.1. Impact on nutrient reduction

The effect that buffer zones have on nutrient loads has been studied and evaluated both in short and long term studies. The Nordic countries have had a particular interest to evaluate the seasonal variation in buffer zones efficiency, i.e. summer or winter period. Long term studies in Norway and Finland have shown that although large variations between years do occur, the overall reduction results are very good and that buffer zones function equally well during summer and winter time. Moreover, long term studies in Finland show that the efficiency of buffer zones tends to increase with time.

Buffer zones with a width of 5 to 10 meters have been studied in Denmark, Finland and Norway and the results have shown a reduction of total phosphorus of 42 – 96 %, nitrogen 27 – 81 %, soil particles 55 – 97 % and a reduction of organic material of 83 – 90%, also presented in Table 2. More experiences from Denmark show that retention of dissolved phosphorus in buffer zones are not as pronounced as retention of particulate phosphorus and is often below 0,5 kg P $ha^{-1}year^{-1}$ compared with 128 kg of particulate P $ha^{-1}year^{-1}$.

Table 2. Reduction of phosphorus, nitrogen, soil particles and organic material in buffer zones expressed as percentage of incoming load. (Hoffman et al, 2009)

	Retention in buffer zone (%)
Total phosphorus	45 – 96
Total nitrogen	27 – 81
Soil particles	55 – 97
Organic material	83 - 90

3.1.1. Function and efficiency

Buffer zones reduces flow velocity and function as a mechanical filter obstructing eroded aggregates and soil particles, particulate phosphorous and other soil borne pollutants, such as pesticides and herbicides, in the surface run-off from ending up in watercourses, wells, ground water etc. The main process working is that the buffer zone reduces the speed of surface run-off and makes it possible for the water to infiltrate in to the soil. The permanent vegetation stabilizes the soil and binds the eroded soil aggregates that are deposited in the zone. The phosphorous bound to particles is also deposited in the buffer zone. The bulk of the sediment particles and phosphorous is deposited in the top layer of the buffer zone.

The higher the load, the higher the reduction!
In the boreal zone, the main part of the surface run-off occurs during winter leading to a larger transport of particles and phosphorous as the infiltration capacity of frozen soil is low. The amount of retained phosphorous, soil particles and organic material in the buffer zone was, however, larger during the winter period than during summer. As the amount and size of particles transported with the surface water increases, as it does during winter time, the effect from the buffer zone grows as these large particles easily fall out together with the phosphorous bound to them. The higher the load, the higher the reduction provided by buffer zones. Concentrations of dissolved phosphorous are, however, not reduced much as deposition does not apply to dissolved substances.

An additional benefit of buffers zones is that they offer protection against the erosive force of river and creek water during high flow periods. By decreasing the flow velocity and the amount of inundation of crop land they contribute to decreasing the amount of nutrients and sediments that is picked up by floods. A scenario that is most crucial during winter time when the soil is bare or just sparsely covered with crop residues and highly exposed for transportation by the flooded water.

As the buffer zones mainly come into contact and operate on the surface water run-off and not on the water infiltrated through the soil profile the main effect is gained on reduction of phosphorous and eroded soil particles and not on reduction of nitrogen.

The efficiency of buffer zones is affected by the width of the zone, gradient of the field, soil type and by the variety and density of zone vegetation, more thoroughly described in more detail in the following sections.

3.2. Where and when to establish a buffer zone

3.2.1. On the productive arable land

A buffer zone is established on productive arable land adjacent to water, i.e. watercourse carrying water all year around, a pond, a lake or a gulf. Buffer zones are also recommended in erosion sensitive areas such as around surface water wells or surrounding sites with high ground water levels. Unlike the buffer zones along watercourses or lakes, this latter type of buffer zone may be established right in the middle of a field, depending on where the erosion sensitive area or slump high groundwater level area is situated.

A good thumb rule for locating the most beneficial site for a buffer zone at a particular farm is to focus on where erosion problems are most obvious. If the runoff water is turbid there definitely is a need for a buffer zone. Establishing a buffer zone is advisable when there is direct groundwater contact in regularly submerged depressions above a shallow aquifer or around an erosion threatened well. Should it not be possible to establish a buffer zone directly adjacent to the recipient water body, a buffer zone can be established elsewhere along the flow path of the runoff water. Se Figure 1 illustrating different locations for buffer zones. If it is difficult to locate the sites on a farm that need treatment most urgently , it is recommended to study the surface water movements right after a heavy rain or during the snow melting period, to locate the entry sites of turbid water to the water body.

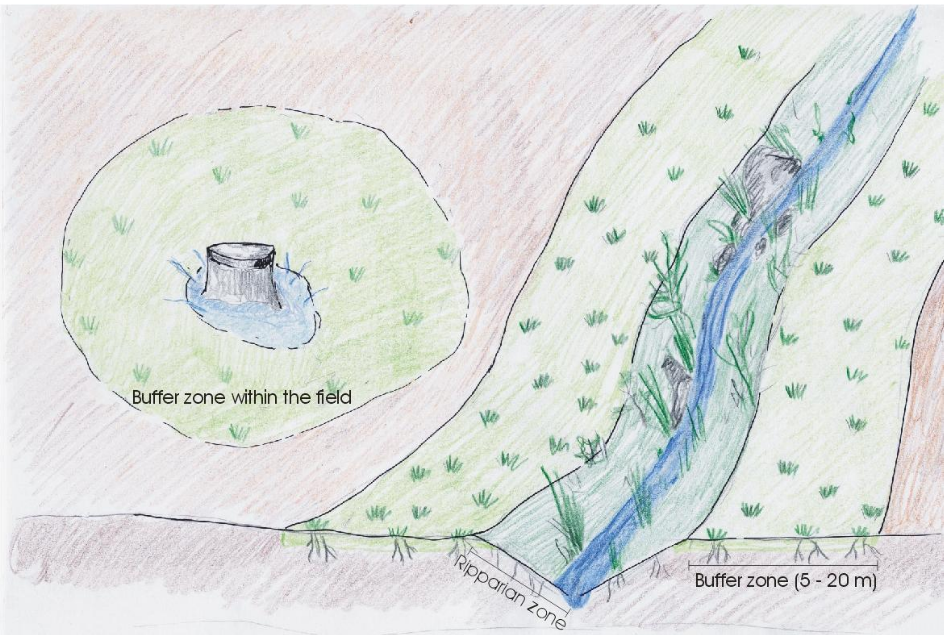

Figure 1. Buffer zones shall be established on productive arable land between a field and a watercourse or within a field to, for example, to protect a surface water well from erosion. (Illustration: S Owenius).

3.2.2. On erosion sensitive soil

Depending on the type of soil the water passes through the soil profile down to the ground water in different ways. Sandy soils are characterized by high infiltration rate, where water primarily moves downward with a horizontal, evenly distributed pattern towards the groundwater. It is primarily dissolved phosphorous that reaches all the way down to ground water level and drainage tiles as the particulate matter is absorbed in the small soil pores. Under sandy conditions, with the exception of silty sandy soils (discussed below), there is seldom a problem with surface run-off and no need for buffer zones.

If the soil is less porous i.e. containing more clay, it often remain cold and wet in spring and larger cracks and pores (macro-pores) are common through which not only dissolved phosphorous but also larger soil particles and the phosphorus adhered to them can be transported rapidly. Heavier soils with this kind of crack or macro-pore flow, i.e. preferential flow, generally results in larger losses of phosphorus to the watercourses compared with lighter soils that more slowly filter the water. Under these circumstances it is a good investment to establish a buffer zone.

However, the soil most sensitive for erosion and thus particularly in need of buffer zones, is characterised by both light (silty) and heavy (clay) soil fractions. Silty soils are generally not very structured with little aggregation, making silt highly susceptible for erosion and subsequent run off with the surface water flow.

3.3. The design of the buffer zone

3.3.1. Width of the zone and gradient of the field

The reduction of phosphorous, nitrogen, particles and organic matter increase with the width of the buffer zone. The width of a well functioning buffer zone may vary between 5 and 20 meters depending on the prevailing circumstances. The most important factors to consider when setting the width of a buffer zone is; the gradient, the length and the sensitivity of erosion of the field. If a field slopes more than 10 percent toward the recipient water body or well, a broader zone is necessary.

Buffer zones surrounding an erosion sensitive area within a field do not necessarily have to have the same width. If the slope of a field varies around a depression or well the width of the buffer zone surrounding it can vary as well. A general recommendation is to carefully monitor newly established buffer zones performances. In case the water continues to form rivulets that breaks through the buffer zone further widening is required. A high surface porosity of the buffer zone is desirable to improve interception of surface runoff.

3.3.2. Vegetation cover

To ensure that the filter capacity of a buffer zone is high it is important to keep the zone under permanent dense plant cover, usually a mix of grass species or grasses and legumes, Figure 2. Norwegian experiences have shown that the quality of the vegetation in terms of stiffness, height and especially density is more important than the choice of specific species. Mixed vegetation with varying root-depth ensures a long period of plant uptake of nutrients from both top soil as well as deeper soil layers and enhances stabilisation of the soil profile by the plant roots within the buffer zone. It is recommended to choose pioneer species that quickly germinate and develop and at the same time are strong and resistant. Examples of such species are a mix of *Poa pratensis* and *Festuca rubra*, or on soil poorer in nutrients a mix of *Agrostis capillaris* and *Festuca ovina*.

Include bushes and trees in a buffer zone increases surface roughness even more and has been shown to significantly increase reduction results during winter time compared to pure grass vegetation. The root systems of trees continue to take up nutrients also during parts of the winter period and stabilise the soil even more as the roots reaches deeper soil layers. Suitable species are *Alnus*, *Salix* or *Betula* as they have a high nutrient uptake and relatively sparse foliage that does not give too muck shadow on the buffer zone. Results from studying buffer zones with grey alder (*Alnus incana*) in Estonia showed that plant uptake of both nitrogen and phosphorus in younger stands was significantly higher than in older forests. Immobilisation of phosphorus through plant uptake contributes with a temporarily immobilization of up to 15 kg of phosphorus per ha and year. But compared to the main reduction process, i.e. deposition through sedimentation of particles, corresponding to as much as 128 kg phosphorus per ha and year as seen in Danish studies the vegetation has a lower impact.

Figure 2. A recently cut buffer zone between a field and a watercourse hidden behind the vegetation in the riparian zone (Photo: S Owenius).

3.4. Further possible improvements

The removal efficiency can be further improved by application of chemical agents such as granules based on iron (Fe) or calcium (Ca) to the buffer zone. These chemicals immobilize the dissolved reactive phosphorous in the run-off water and improve the nutrient retaining efficiency of the buffer zone. This practice can be of particular importance under boreal conditions where periods of freezing and thawing sometimes result in high surface run-off (Uusi-Kämppä and Jauhiainen, 2010).

Prior to the establishment of a buffer zone it is important to make sure that the riparian zone directly lining the creek or river also is in good condition and not damaged by erosion or landslip, as erosion of banks is a large contributor to the sediment load of creeks and rivers as well. Should the banks be damaged or sloped steeper than 45 bank restoration by grading and replanting is recommended. Banks should be graded to 2:1or shallower slopes and may need stabilisation by the application of geotextiles or live plant stakes to prevent the continued input of suspended sediments and nutrients by erosion.

3.5. Maintenance

Careful buffer zone maintenance and monitoring is of key importance to performance. Studies in Finland have shown that a buffer zone that is carefully attended in terms of establishment of covering vegetation and regular cutting and removal of the plant residues improves the reduction of total phosphorus with 10% and dissolved phosphorus with as much as 60% compared to if the buffer zone was left to develop vegetation without special attendance.

During the winter period with freezing-thawing conditions there is a high risk that phosphorous as well as nitrogen leaches from frost-damaged vegetation. It is therefore recommended to cut and remove the vegetation from buffer zones regularly and in any case before winter. Cutting grass also causes the sods to become more dense and thus more effective as a filter and flow obstruction, Figure 2. The already accumulated phosphorous in the buffer zone is also reduced. The harvested vegetation is rich in nutrients and may very well be used as a green manure, but in less sensitive areas.

It is also possible to allow the buffer zone to develop more freely, which can be more favorable from a biodiversity point of view. However, to keep a more diverse vegetation of flowering herbs and grasses it is necessary to cut the vegetation at least once a year. The best time to do that is after the flowers have set their seeds. The cut off vegetation has to be removed.

Make sure that trees and bushes in the riparian zone do not grow too tall. Otherwise they might shade the buffer zones vegetation too much, resulting in less dense vegetation which will impair the functioning of the buffer zone. On the other hand, shade from overhanging riparian vegetation is an important factor in increasing aquatic biodiversity in creeks and rivers.

A carefully maintained buffer zone may stay well functioning for a long time depending on how high the load of losses to the buffer zone is. A life-span of at least 15 years or more is reasonable. The main part of phosphorus and soil particles is deposited in the surface layer of the buffer zone. To prevent the risk of losses from the buffer zone, that has been in use for ca ten years, and to prolong its life-span the top accumulation layer of the zone can be removed and recycled on cultivated land. When this has been done it is important to reestablish the vegetation cover as soon as possible to retain a well functioning buffer zone. To avoid pollution risks due to presence of large industry or other pollution sources the removed accumulation layer needs to be analysed prior to recirculation.

3.6. Technical requirements

The need for machinery for buffer zone implementation and maintenance is low. The vegetation needs to be seeded which can be done by hand or with machinery most likely already available at most farms. Most farmers will also have access to clipping equipment for maintenance of the buffer zones. In case the riparian zone needs to be planed off prior to the establishment of a buffer zone graders, excavators or backhoes might be needed.

3.7. Economical requirements

Buffer zones are easily implemented and not very expensive. The costs for implementation are only invested man hours, seeds for proper buffer zone vegetation, fuel and potentially machinery maintenance or rent. The seed mix generally represents the largest part of the needed investment. Once the buffer zone is established it only requires small costs for maintenance. An inevitable consequence of establishing buffer zones is the loss of area available for cropping. This is why subsidies are offered to compensate losses of income.

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3.8. Permissions and commitments

No special permission is needed to establish buffer zones at the farm level and the farmer/land owner is fully responsible for both the establishment and maintenance. However, to get economical subsidies a contract has to be written between the farmer and the responsible authority. With this contract the two parts agree on the commitments to be followed to be eligible for economic support. The contract is conclusive for a five year period during which the authority has the responsibility to verify that the contracts conditions are being followed.

3.9. Subsidizes

The guidelines for granting subsidizes vary between EU member counties. In Denmark, as one example, further 20 000 hectares of buffer zones will be established before 2015. They have chosen to grant economic support equaling 152 EUR/hectare and year (= 1 200 DKK) for establishment of 10 – 20 meter wide buffer zones along watercourses and lakes, bigger than 100 m^2. In case a specially valuable or sensitive species worthy of protections is found in the area, additional financial support may be granted. In Sweden 7 000 ha of buffer zones are to be established prior to 2013 and eventually another 2 000 ha prior to 2015 offering a larger economic support for buffer zones established in high productive agricultural areas. Buffer zones in high productive areas will be economically compensated with 430 EUR /ha and year (= 4 000 SEK) to compare with 323 EUR/ha (= 3 000 SEK) in less productive areas. Moreover, an inter-field buffer zones must exceed an area of 0,25 ha to be granted economical support of 538 EUR/ha (= 5 000 SEK/ha).

T o stimulate establishment of buffer zones it is recommended that production areas along water courses suitable for buffer zones only is granted subsidise for establishing buffer zones and nothing else to prevent non- water protective concurring alternatives.

At present the use of trees within the buffer zone varies between countries. In Sweden for example trees are not allowed to be established on the buffer zone, but are recommended in the riparian zone closer to the water. However, as the trees have a positive impact on nutrient reduction, especially during the winter period, it is recommended that all countries supports the development of more permanent zones premiering the establishment of both shrubs and trees.

3.10. Other values and potentials

Buffer zones protect the surface water from direct contact with fertilizers and pesticides as it is not allowed to use pesticides within the buffer zone. It also functions as a pesticide-filter and provides good conditions for biological and chemical breakdown of pesticides and other pollutions.

Freshly spread manure containing loads of *E. coli* and *Streptococcus* can constitute a sanitary problem if it reaches the water environment. However, a five to ten meter wide buffer zone has proven to protect the watercourse thanks to high retention capacity also of faecal bacteria (Davidsson, 2003). While retained in the buffer zone the faecal bacteria are not viable very long under terrestrial conditions and UV radiation.

As an additional benefit the buffer zones vegetation stabilizes the "riparian zone" by slowing down the run off water, thus reducing erosion and landslip. Buffer zones offer a diverse habitat and can be of great importance to birds, mammals, and insects for nesting, feeding, transportation and protection. The water in the recipient is not only improved by the decrease in nutrient load, but also by shading vegetation (especially from vegetation on the south riparian zone). Shade lowers the temperature in the water causing a higher oxygen level, decreased evapotranspiration, and reduces the amount of water plant biomass. Overhanging vegetation also provides cover from predation to many invertebrates and young fish. The buffer zone can also be used for recreation.
For those who have a special interest in biodiversity, there are endless opportunities to enrich the buffer zone by establishing flowering herbs and plants setting a lot of seeds to benefits insects, seed-eating birds etc.

Buffer zones

- Vegetated areas on productive arable land
- Along a watercourse, a lake, the sea or within a field on erosion sensitive sites
- 5 – 20 meter wide depending on erosion sensitivity, runoff-regime, field gradient, P-load, status of the recipient.
- Prohibited to use fertilizers, manure or pesticides within the zone.
- Prohibited to use the zone for cultivation or grazing.
- BZs reduce flow velocity and function as a mechanical filter.
- BZs retain eroded aggregates, soil particles, and particulate phosphorous and other pollutants.
- The higher the load, the higher the reduction!
- Kept under permanent dense plant cover, usually grasses or grasses and legumes.
- Vegetation with varying root-depth increase plant uptake and stabilisation of the soil profile.
- Regular cutting and removal of the plant residues to keep the dense vegetation cover and improve phosphorus reduction and life-span of the zone.
- The life-span of a buffer zone may be 15 years or more, if well maintained.
- Low need for machinery for implementation and maintenance.
- Easily implemented and not very expensive.
- No special permission is needed for establishment.
- The farmer is responsible for establishment and maintenance.
- For economical subsidies a five year conclusive contract is written between farmer and responsible authority.

4. Sedimentation ponds

A sedimentation pond is a constructed small surface flow pond/wetland designed primarily to retain phosphorus and the large particle fraction of suspended sediments. The ground laying principle for their functioning is simple: decreasing the flow velocity of the water to facilitate sedimentation of particulates and nutrients adhered to them. Pond construction under certain circumstances may be as simple as widening a section in a ditch to create a pond. Under other circumstances, a pond will have to be dug. Because the treatment process is based on uncomplicated physical principles, there is only a minimal requirement for technology and maintenance. Below the main advantages and limitations for the use of sedimentation ponds is listed.

Advantages

+ Sedimentation ponds provide long-term removal and storage of suspended particles and other pollutants, through physical and biological processes.
+ Aquatic and terrestrial habitat is created by establishing by sedimentation ponds, especially when vegetated shore areas are included in the design.
+ Through their water storage capacity sedimentation ponds can offer flood control benefits in addition to water quality benefits.
+ Sedimentation ponds can be used to treat the runoff from large drainage areas.

Limitations

- An adequate supply of runoff must be certain to maintain pool depth throughout the year.
- Settling ponds can attract undesired waterfowl populations, causing increased fecal coliform export
- Heavy storms with turbulent flow may cause mixing and subsequent re-suspension of previously deposited particles.
- Seasonal algal blooms can result in export of organic material and thus nutrients.

4.1. Phosphorus removal efficiency

Within Europe, Norway is probably the country with the longest experience from using sedimentation ponds as a measure for phosphorus reduction, establishing the first ponds in 1990. Comparisons of the results from established ponds in different areas of Norway revealed relatively large variation in phosphorus reduction even though all the studied ponds were designed with the aim to retain as much phosphorus as possible (Braskerud and Hauge, 2008). Reduction rates for particles ranged from 22 to 89 kg/m^2, corresponding to 45 to 68 %, whilst reduction of total phosphorus varied between 37 – 58 g/m^2 corresponding to 23 to 42% (Table 3). It was concluded that the shape and constitution of the catchment area has a large impact on the differences in reduction efficiency between ponds.

Table 3: Average retention of phosphorus and particles in four Norwegian sedimentation ponds.

Pond nr	Pond area (m^2)	Percent of run-off area	Retention of phosphor (% of P-load)	Specific retention of phosphorus (g/m^2/year)	Retention of particles (% of load)	Specific retention of particles (g/m^2/year)
1	900	0,06	42	51	66	83
2	345	0,07	27	58	45	89
3	870	0,08	23	37	62	36
4	840	0,38	42	46	68	22

4.2. Function and efficiency

Sedimentation ponds are primarily designed and implemented for optimized capture of particle bound phosphorus eroded from arable fields. As dissolved substances do not fall out these ponds have a much smaller impact on concentrations of dissolved nutrients or pesticides. Still, the sedimentation pond manages to reduce both dissolved nutrients as well as pesticide to quite large extent. This is largely due to an increased residence time of the water, which facilitates microbial decomposition, adhesion to bio films, chemical transformations as well as plant uptake. Spatial heterogeneity in terms of depth, slope, flow velocity and shading within ponds will offer sites with optimal conditions to each of the above reduction principles.

4.2.1. The reduction of particulate phosphorus is best when it counts!

During periods of extensive rain or snowmelt flow velocities tend to be high and subsequently the reduction of dissolved nutrients in sedimentation ponds is low, as residence times are insufficient for plant uptake or microbial or chemical transformation. As water enters a pond during normal flow conditions the flow velocity will gradually decrease with distance from the inlet. As the flow velocity determines which particles sizes fall out and which ones remain suspended, this gradual slowing of the water will result in a gradient of particles sizes on the pond bottom, with the largest particles close to the inlet and the smallest nearest the outlet. The thickness of the accumulated sediment layer also tends to be highest close to the inlet.

During high flow periods the flow velocity reduction is much diminished but heavy particles fall out under these conditions nevertheless. As the water’s sediment load also is at its peak during storm events, the absolute deposition of sediments in kg/m^2 is also at its maximum during these periods. Thus sedimentation ponds effectively remove large sediment particles even during high flow circumstances. From a relative perspective, of course the removal efficiency in percent is higher during low flow periods.

Studies have also showed that the removal of phosphorus increases with concentration. With a high concentration exposure to suspended particles, vegetation, microorganisms, sediment layer etc. increases, resulting in more phosphorus retained in the pond. This positive correlation between concentration and removal is also observed for nitrogen and other pollutants. The conclusion is that the reduction of phosphorus is best when it counts!

4.3. Where and when to establish a sedimentation pond

4.3.1. Where

Sedimentation ponds are suitable for establishment in highly intensive small-scale agriculture in erosion sensitive areas. In areas with a complex topography with a lot of crack-formations and thin soil layers sensitive to erosion or in areas dominated by small rotation farming it can be difficult to fit in a large-scale water holding magazines, such as constructed wetlands as a measure for nutrient reduction. Under these circumstances it can be a good alternative to only use a relatively small and narrow section within the banks of a drainage ditch on the lower parts of a farm as a sedimentation pond, Figure 3 and 4. Proximity to a sensitive recipient burdened by euthrophication may also legitimise the establishment of a sedimentation pond. Ponds may also be established within the flood plains of high order streams draining agricultural land.

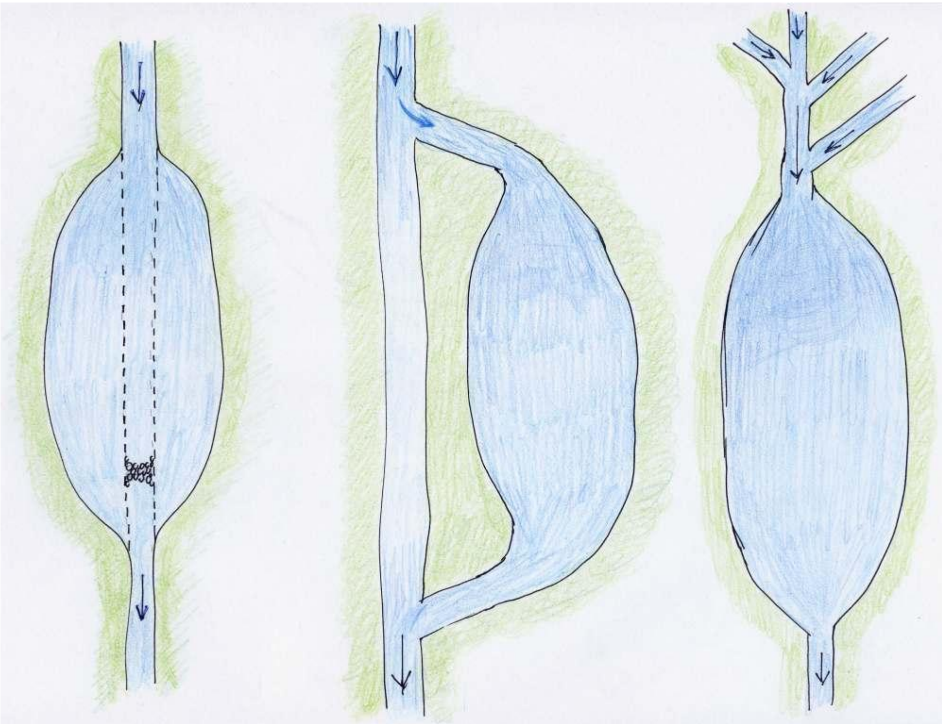

Figure 3. A sedimentation pond may be established within the banks of a drainage ditch or beside or within a high order stream. The drawing to the left illustrates how a pond may be created by damming a ditch. (Illustration: S. Owenius)

There are several ways to ensure adequate water supply to sedimentation ponds. Ponds may be supplied with water via a pipeline system with euthrophicated surface water from low order streams, draining agricultural land. Under climatic conditions that allow adequate precipitation the main inflow can come directly from runoff and diverted tile drainage water.

Figure 4. This sedimentation pond was established by widening a section in a ditch. In the foreground, right after the inlet, is the deeper sedimentation basin. (Photo: S. Owenius)

Common ways to establish a sedimentation pond are through damming or excavating. If the area features natural depressions or slopes damming is recommended as it is easier and most cost efficient than excavation. An additional benefit to damming is that there is less disturbance of the soil and thus less risk of creating a connection to fast draining sand or gravel layers that may lie under ground. This would lead to quick water loss from the pond and contamination of the ground water. Excavated ponds are more suitable for arid climates as they are often deeper and thus have a smaller surface area to volume ration, which reduced water loss due to evapotranspiration.

The most important factor for ensuring proper pond functioning is a thorough site analysis prior to construction. Especially when excavating, ponds should not be placed in fast draining sandy or gravel soils. Crevices, sinks and channels in finer sediment layers that have historically dried out are also to be avoided. The costs for a decent geotechnical analysis are minimal compared to potential cost for repairing or sealing a pond placed at an unsuitable site.

Regardless of the pond type you are planning, a preparation of the future bottom of the pond will be necessary. Trees, stones and vegetation are to be removed and any potential crevices are to be filled with impermeable material prior to construction. Soils rich in clay (more than 10%) can be first scarified and subsequently compacted with a sheep foot roller.

Substrates that are more permeable can be made less permeable with a variety of measures described below.

- Clay blankets; a layer of soil rich in clay (>20%) can be laid on top of the existing soil and compacted. A minimum blanket thickness of 30 cm is recommended.

- Bentonite lining; for smaller ponds lining with bentonite, a colloidal clay type that can absorb several times its own weight in water and expand its volume by more than 8 times, is an option. However, the cost of bentonite and its transport to the site make this a less suitable option for larger ponds. Care must be given to make sure the bentonite never dries out as it will develop crevices when it does.
- Chemical additives; so called dispersing agents can rearrange the clay particles in the soil causing the collapse of an open structure to a more impermeable one. Common dispersing agents that can be worked into a soil prior to compaction are sodiumpolyphospates sodium chloride (kitchen salt) and other sodium salts.
- Waterproof liners; materials such as polyethylene foil, caoutchouc rubber, vinyl and asphalt-lined materials are suitable ways to seal a pond. All these materials are structurally weak but when un-punctured they provide a good seal.

When excavating a pond side slopes are to be kept shallow, preferably sloped less than 1:2 but never steeper than 1:1 slope. Shallow slopes have many benefits; they are less susceptible to erosion, vegetation can be established easier, they allow grazing and access to any machinery needed for pond maintenance.

4.4. Dimensioning

The ponds are relatively small representing approximately 0.1 – 0.5 % of the run-off area and should be established high upstream in the runoff area as close as possible to the source of the pollutions. The size of the runoff area per each sedimentation pond may be somewhere around 20 – 100 ha (0,2 – 1 km^3). With larger drainage areas the construction of several smaller ponds is preferable over the construction of one large pond. To find the right dimensions for a sedimentation pond you need to calculate the average as well as peak water run-off in the particular area.

4.4.1. Design for optimized function

A sedimentation pond is often constructed by widening a section of a ditch into a series of ponds that provide different environments thus stimulating different reduction processes, se Figure 5. The first section always constitutes of a basin for sedimentation followed by sections of alternating wetland vegetation and dryer vegetation filter surfaces. Depending on the prevailing circumstances and need for reduction the sections following the sedimentation basing may with great advantage be duplicated. As mentioned above the size of a sedimentation pond is rather small. Concerning dissolved phosphorus a high reduction efficiency of at least 50% have shown to require a somewhat larger pond, up to 4% of the drainage area, as the reduction of dissolved phosphorus is caused by additional processes requiring more time. In case the bulk of phosphorus is dissolved it is recommended to increase pond size.

The inlet - a sedimentation basin

The first section, the sedimentation basin is the deepest part of the pond with a water depth of 1-2 meter (2 m is traditional in NO and US), figure 5 and 8a. The area of the basing should be no less than 20-30% of the total area of the sedimentation pond and its size and depth should be designed according to the prevailing sediment load and with account to the need of maintenance. A smaller basin will need to be dredged more often. The function of the basin is to quickly reduce the velocity of the incoming water and subsequently detain the water long enough to facilitate sedimentation of the coarser sediments and aggregates.

Sections with wetland vegetation

After passing through the sedimentation basin the water enters a more shallow wetland section, covered with typical wetland plants, Figure 5, 8a and 10. This section provides good conditions for sedimentation of smaller particles still in suspension. The wetland vegetation works as a filter that further slows down and spreads out the water over a wide area to facilitate maximal surface contact between suspended particles and vegetation and pond bottom. The vegetation is also important for oxygenating the water and as an environment for biological and chemical transformation and decomposition processes. The surface of the vegetation is covered in an active bio-film of microorganisms that transforms nutrients (especially nitrogen), decomposes organic compounds, and removes pollutants from the water column. The chemical transformations that take place can make nutrients more available for plant uptake. The root system of the emergent vegetation stabilises the sediment layer and binds the small particles that are deposited, preventing their transport further down the pond. Shallow depths of 0,2 – 0,5 m are recommended to ensure proper functioning of wetland sections. Vegetation is best spread evenly. Many species of emergent wetland plant have been shown to provide good effects i.e. *Carex ssp*, *Schoenoplectus ssp*, *Iris*, *Sparganium ssp*, The use of endemic species is always to be preferred.

In case there is no other option than to establish a sedimentation pond under suboptimal conditions such as with steep slopes that cannot be graded or on erosive soil types, it is recommended to include a second wetland filter prior to the outlet to further induce the sedimentation and reduction efficiency.

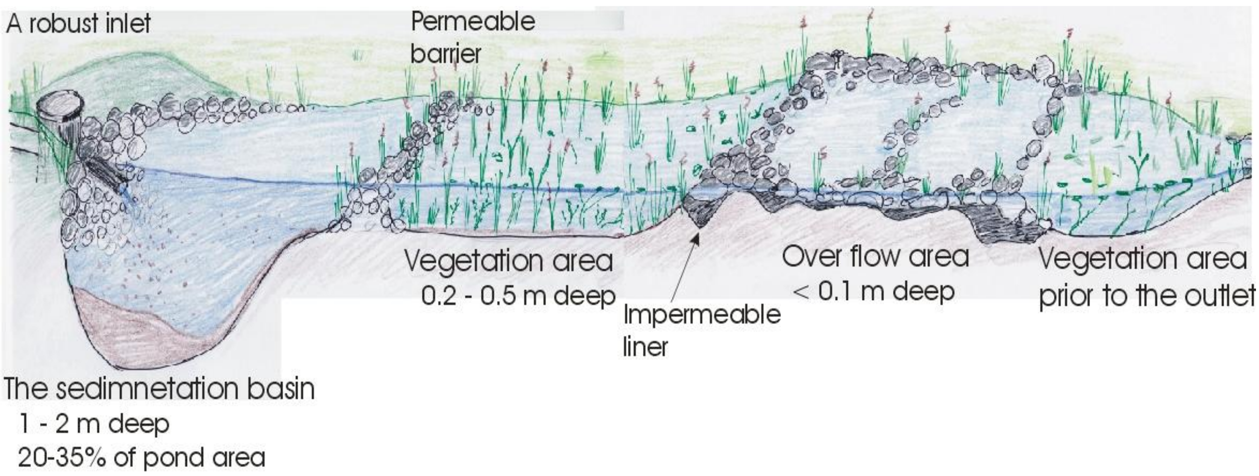

Figure 5. The deep basin for sedimentation is closest to the inlet followed by a permeable barrier thorough which the water percolate and enter the shallower wetland vegetation section. Thereafter the water reaches the overflow area. The underlying soil is protected from erosion by using an impermeable canvas under the stones. Prior to the outlet a second wetland section with deeper water level and vegetation perform a final polish of the water. (Illustration: S. Owenius)

Overflow area

A third section type, the overflow area, is an area bedded with coarse material such as gravel and stones and with a water depth of 10 cm or less. To prevent clogging of the underlying soil an impermeable liner is placed in-between the underlying soil and the gravel layer, se Figure 5. Alternatively, this section can also be planted with grasses and sedges, such as *Phalaris arundinacea*, *Glyceria fluitans*, *Agrostis ssp*., *Carex acuta*, *Cares riparia* etc. The presence of vegetation stabilizes the bottom layer and reduces clogging. The main functions of this section are oxygenation of the water by percolating into the air filled interstices of the coarse material and further sedimentation during periods with high water levels, Figure 6 and 10. The oxygenation of the water is extremely important to ensure a stable and continuous chemical binding of phosphorus in the pond as this requires aerobic conditions. Overflow areas have been shown to successfully maintain oxygen levels favourable for phosphorus binding (Braskerud and Hauge, 2008). High oxygen levels also facilitate microbial activity that transforms soluble nitrate into gas (nitrification/denitrification) and the transformation/degradation of other pollutions. Shallow water conditions also increase the exposure to ultraviolet (UV) light that both increases the chemical transformation of pollutants as well as strongly reduces the viability of faecal bacteria that will be present in runoff from farms with animal husbandry.

Their shallow depth makes overflow areas extremely susceptible to erosion and resuspension of particles during high flow conditions and therefore this type of section never should be the final section in a sedimentation pond. The outlet structure of a sedimentation pond should rather always be preceded by a deep-water section in order to make sure that the suspended sediment load of the outflow is minimal. For low need of maintenance the outlet structure should be kept simple and be equipped with some water regulating mechanism.

Figure 6. The water is percolating between the stones and the vegetation in this overflow area resulting in reduction of particles and nutrients through increased deposition, increased surface contact between water and bio-film, aeration, plant uptake etc. (Photo: S. Owenius)

Barriers preventing erosion

Separation of the different sections by barriers or thresholds to prevent erosion and spread the water is recommended. The barriers should be permeable but at the same time stable enough to withstand high water flow and rough winter conditions, Figures 5, 7 and 8b. One possible construction uses a core of clay covered in canvas to prevent clogging covered by riprap, coarse gravel or stone. At normal flow the water should percolate through the barriers and at high flow the water must be allowed to pass over to prevent flooding. An additional option to further promote active binding of phosphorus in the filtering barriers is by adding a phosphor adsorbing material with a high pH, such as leca, i.e. porous clay granules, or other natural materials in the construction of the barriers.

Make sure to use sufficiently heavy stones in areas known to have a periodically high water flow as water flowing at high may result in severe erosion damages. Minimum grain diameter and mass under various discharge condition are given in Table 4.

Table 4. Recommended minimum grain diameter and mass to use under various discharge condition.

Discharge (m^3/s)	Grain size (cm)	Grain mass (kg)
<0.5	≥20	≥15
0.5-1.0	≥35	≥75
1.0-2.0	≥50	≥200

The pond and its sections must be sized such that they can accommodate high flows and sediment loads that occur during extreme precipitation and snowmelt. The pond has to posses sufficient hydrological capacity to capture and treat nutrient loads even during peak runoff events. The figure below illustrates a schematic picture of how to combine and put together a series of sections into a sedimentation pond.

Figure 7. The permeable barrier in this sedimentation pond is made of coarse gravel and stones. During normal runoff the water is filtered through the bar-

rier, having a large active surface. During high plow the water may also pas over the barrier into the following section. (Photo: S. Owenius)

Figure 8a. This is another example of a deep sedimentation basin in the inlet, the inlet-pipe is visible in the left corner. The deeper secion is characterized by an open water space followed by dense vegetation as the shallower wet-land section begins in the background. (Photo: S.Owenius.)

Figure 8b. A threshold is placed in-between the deep basin and the vegetation section to make sure that the water spreads over a larger area. (Photo: S.Owenius)

Figur 8c. This sedimentation pond is also established by widening a section in an already existing ditch. The banks of the pond are stabilized by coarse gravel to prevent erosion and buffer zones are established on the field along the pond and ditch. (Photo: S. Owenius)

4.5. Maintenanse

4.5.1. Erosion

All pond sections and structures should be regularly visually checked for erosion damage, most specifically after high flood events.

4.5.2. Vegetation

Monitor how the vegetation develops. Make sure that the wetland section stays covered with vegetation up to 60-80 % by continuous re-establishment of plants if needed. If the vegetation becomes too dense in some parts of the pond and starts to channel the water between dense stands of vegetation rather than spreading it widely it is necessary to remove some of the vegetation to redistribute the flow evenly over the whole surface. Make sure that the vegetation grows across the pond from edge to edge rather that along the pond.

4.5.3. Sediment

The accumulated sediment in the sedimentation basin needs to be removed on a regular basis to maintain adequate storage capacity and prevent resuspension. How often dredging is needed depends on the volume of the sedimentation basin and the sediment load of the inflow. Check the amounts of accumulated sediments regularly (at least biennially) to evaluate when it is time to dredge the basin. Dredging will probably have to be conducted at least every fifth year. To lower the work effort and to minimise damages during sediment removal it is important to prepare for maintenance access already during construction. Slopes should be shallow and stable enough to hold heavy machines. Building an access ramp for machines such as dragline excavators out of grass pavers, concrete or asphalt is also an option.

The removed masses are rich in nutrients and represent top soil losses from the farm. Therefore it is in most cases highly recommended to re-circulate them on the farm as a nutrient amendment. With high pollution risks due to for instance the presence of large industry or other pollution sources in the catchment the sediment needs to be analysed prior to re-circulation.

The life-span of a sedimentation pond is dependent on how well it is maintained. As long as the sedimentation basin is regularly dredged (the dredging frequency adjusted to the load) the pond has the potential to develop into a stable ecosystem that may function over a long time perspective (20-30 years). Technical structures and material used in the construction may need to be replaced or further stabilized within a five to ten year period.

4.6. Technical requirements

4.6.1. Machinery and instruments

Several types of machinery may be used during construction and maintenance:

- Leveling instrument and a GPS is needed for proper measures of levels and coordinates. If maps with sufficiently detailed contours are available this may not be necessary.
- Bulldozers are suitable for damming and excavation during the establishment of the small ponds. Because they can only push and not heave up loads they are cost inefficient for moving soil over longer distances. For digging larger ponds excavators and diggers are more efficient.
- Slopes may be brought to grade with the use of grading equipment.
- In areas with saturated soils, a dragline excavator is the only equipment that can excavate without entering the wet area. Dragline excavators are also the only machines suitable for dredging the ponds under submerged conditions.
- Maintenance of vegetation may require a small trimmer to use standing on the shore or in shallow water. A reed cutter or amphibian cutter may be needed to cut the vegetation on larger areas.

4.6.2. Maps

During planning it is advisable to consult maps and drawings showing:
- Topography with detailed information of watershed structure
- Soil and geology (P-index information)
- Precipitation or water runoff
- Cultural heritage or old maps from the area to locate former wetlands areas
- Property borders
- GIS-layers with information of vulnerability of recipients in the area
- Depth and location of existing tiles, wells etc. in case they need to be disconnected or redirected or to avoid damage.
- Road, cables for electricity, telephone wires, etc.

4.6.3. Material

Examples of structures and materials needed for pond operation:

- Wells, in concrete or plastic, for water regulation in the inlet and outlet that enables cutting of or regulate the water supply during maintenance.
- Tiles and tile-connections to connect the drainage tile system and to transport the water to the wetland.
- Coarse gravel, riprap and stones to stabilize erosive areas around inlets and outlets and for construction of permeable but stabile barriers between pond sections or within the wetland.
- Concrete in case stones and gravels in the inlet or elsewhere needs to be fixed for sufficient stability. Canvass or plastic liners or benthonic clay to seal underlying original soil to prevent erosion or interference of intrusive ground water.
- Leca (loam granules), sea shells or other porous material to improve phosphor-binding capacity within the permeable barriers.
- Potentially an emergency spillway to help divert the largest floods past the pond.
- Wetland vegetation, if possible from a lake nearby to use plants adapted for the prevailing conditions in the area.

Figure 9. The inlet in this Norwegian sedimentation pond is designed in simple and robust way. The dimension of the inlet pipe in generous and stones and gravel are used in the banks and on the pond floor to stabilize and prevent erosion and landslip. An uncultivated buffer zone is established and trees are planted along the deepest part of the sedimentation pond. Trees that will have multi functions in the future, stabilizing the soil and preventing erosion, nutrient uptake, shading etc. (Photo: S. Owenius)

4.7. Economical requirement

An example value for the construction costs for a sedimentation pond in Sweden (Börling, 2009) is 14 000 €, for an 835 m^2 pond, in a watershed with the size 1 900 m^2, draining 30 ha of productive agricultural land, pasture and forest. The costs were divided into the following posts: 16% of expenses for leveling, 78% for digging and 6 % for bank stabilisation and the establishment of vegetation. A corresponding example value based on Danish experiences from establishments of optimised sedimentation ponds is 6 700 – 10 700 € (Jacobsen, 2009). In Norway costs for construction, operation and cost per reduced kg phosphorus based on experiences from 77 sedimentation ponds has been analysed and the result is presented in Table 5. A comparison of the costs in relation to the size of the ponds show that ponds larger than 3 000 m^2 ware most cost-effective and that ponds smaller than 1 000 m^2 the most expensive in terms of cost-effectiveness.

Table 5. Average costs for construction, operation and cost-effectiveness in terms of cost/kg reduced P of sedimentation ponds in Norway, (Hauge et al, 2008).

Size (m^2)	Number of ponds	Construction costs (€/m^2)	Operational costs (€/m^2/y)	Cost-effectiveness (€/kg reduced P)
< 1 000	27	31	2,4	68
1 000 – 3 000	39	18	1,3	38
> 3 000	11	12	0,9	24

4.8. Permissions and commitments

Always notify and consult the authorities as soon as possible before establishing a sedimentation pond, especially in case more than one landowner is affected by the plans. As the establishment of a sedimentation pond concerns and effects the hydrology, the responsible authorities must verify that environmental legislation is not violated.

For obtaining a permit, it is necessary to make a detailed plan presenting the measure, including all calculations for dimensioning, expenses, cost effectiveness and impact on the area concerned and its hydrology. Demands will vary depending on EU member state but the authorities are obliged to give information of what the written plan should contain. Based on the given information and environmental circumstances in the actual area that might need special care, such as sensitive flora or fauna or a sensitive cultural area etc. the authorities make decisions if special care must be taken.

To avoid legal problems it is mandatory to always notify adjacent property owners and give them time to make appeals to the plans. Ownership of parcels can be established by contacting the local land registry office. Construction can commence after a permit has been received and if all adjacent owners have either given their written approval or have not objected to the plans before the legal deadline for appeals.

Keep in contact with the authorities over time to be prepared in good time if/when the permission or agreement must be renewed and to notify them prior to maintenance activities such as removal of accumulated sediments from the basin.

When the sedimentation pond is finally established, the authorities will likely provide a list of operational terms to be followed by the farmer or landowner. The specific content of the list of terms or commitments may vary between member states, but certain rules apply EU-wide. Some examples of practices not allowed in sedimentation ponds anywhere are:

- application of manure or fertilizers
- application of pesticides
- application of lime
- stocking with crayfish or fish
- feeding of fauna

The pond has to be maintained according to the demands given by the authorities during at least 10 years after which permits need renewal.

4.9. Subsidizes

Economical support for establishment of sedimentation ponds in agricultural settings with risk for high phosphorus losses may be granted. Based on the same project plane mentioned above the responsible authorities will make the decision whether the planned construction meets all requirements. One important criterion the design must fulfill to be eligible for subsidies is that, at a minimum, the design contains a deep basin in the inlet followed by a shallow vegetative area, i.e. characteristic properties of a sedimentation pond. Other criteria that will be evaluated are the placement of the pond, soil type, phosphorus load and risk of losses in the area, closeness to sensitive recipients in need for protection etc.

No subsidies are given for maintenance of sedimentation ponds at present. As they become more abundant around the Baltic Sea and as their efficiency as a phosphorus removal mechanism becomes better documented, regulations concerning sedimentation ponds, subsidies and commitments will probably get more detailed.

It is recommended to consult the agriculture and rural development web site for member states providing information on beneficiaries and payments: http://ec.europa.eu/agriculture/funding/

4.10. Other values and potentials

Even if the main focus may lie on the removal of phosphorus and particles, sedimentation ponds do have additional beneficial effects on the concentrations of other nutrient i.e. nitrogen, sanitary pathogens i.e. viruses and bacteria, and pesticides in run off entering natural surface waters after treatment.

By the removal of sediments and nutrients ponds reduce or prevent the euthrophication and damming and filling in of lakes and streams, thus protecting important fish spawn areas. As they provide habitats to a wide spectrum of wetland flora and fauna (many species on endangered species lists are wetland species) they even have a positive impact on biodiversity.

To improve the reduction capacity of a sedimentation pond it is possible to apply thresholds or mechanical filters containing carrier material with high phosphorus adsorption capacity. During wintertime, when run-off is high and biological activity is low, it may be a good investment to use these physical and chemical means to reduce the concentrations of nutrients prior to or within the pond.

In Denmark interesting developments of optimizing the nitrogen reduction effect in sedimentation ponds is managed by using a specially developed filter-matrix through which the water are forced. The matrix has an extensively enlarged surface area on which active micro organisms grow. In average the internal surface area of such a matrix with the size of 10 x 35 x 0.7 meters (width/length/depth) correspond to an area equaling 3-5 ha (Jacobsen, 2009).

Figure 10. A sedimentation pond under establishment close to lake Bornsjön, south of Stockholm, Sweden. The pond area (835 m^2) equals 0,3 % of the catchment area. Top: The inlet and the deep sedimentation basin is seen in the background followed by a section of wetland vegetation and a shallow overflow section in the left corner. Notice the gently sloping edges. Down: Prior to the outlet in the left corner, a second wetland vegetation section is established with a deeper finish. Notice the thresholds within the vegetation section creating varying water levels. (Photo: Pia Kynkäänniemi, SLU)

Sedimentation ponds

- A small surface flow pond/wetland established close to the source of the pollutions.
- Suitable in highly intensive small-scale agriculture in erosion sensitive areas.
- Represents 0.1 – 0.5 % of a run-off area of 20 to 100 ha per each sedimentation pond.
- Specially designed for capture of eroded particle bound phosphorus
- Also manage to reduce dissolved nutrients and pesticide to quite large extent
- The higher the load, the higher the reduction!
- The increased residence time facilitate sedimentation of particulates and nutrients adhered to them, microbial decomposition, adhesion to bio-films, chemical transformations as well as plant uptake.
- Constructed by widening and damming a section in a ditch or by excavating.
- Side slopes are to be kept shallow, preferably less than 1:2.
- Constructed as a series of pond-sections providing different environments stimulating different reduction processes.
  Characteristic sections are:
  i) 1-2 meter deep sedimentation basin in the inlet
  ii) 0,2 – 0,5 meter deep wetland vegetation sections
  iii) 0,1 meter shallow overflow sections
  iv) Permeable barriers and thresholds between and within sections
- Keep the wetland section covered with vegetation up to 60-80 %.
- Too dense vegetation may need to be removed to avoid channeling rather than spreading.
- Make sure to establish a deeper section prior to the outlet.
- Regularly check for erosion damage and the amounts of accumulated sediments.
- Remove accumulated sediment in the sedimentation basin on a regular basis.
- The removed masses may be re-circulated on the farm, if not polluted by heavy metals or other pollutants.
- The life-span may be 20-30 years if well maintained.
- Several types of machinery, instruments, maps and material is needed during construction and maintenance.
- Notify and consult the authorities to obtain a permit before establishing a sedimentation pond.
- Maintain the pond according to the demands given by the authorities during at least 10 years after which permits need renewal.
- Some examples of practices not allowed in sedimentation ponds are:
  i) application of manure or fertilizers
  ii) application of pesticides
  iii) application of lime
  iv) stocking with crayfish or fish
  v) feeding of fauna
- Economical support for establishment may be granted.

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5. Constructed wetlands

Large free water surface wetlands are designed and constructed primarily for removal of nutrients, e.g. nitrogen and phosphorous and other pollutants such as pesticides and heavy metals, from runoff water. A constructed wetland provides heterogenic water regimes and environments needed for different nutrient retention processes. It is common that a wetland consists of a combination of areas with a permanently high water level, more or less covered with typical wetland vegetation, as well as periodically waterlogged areas with shallow water.

5.1. Impact on nutrient reduction

It is difficult to predict the effect of constructed wetlands in agricultural areas and results from trying to do so show a scattered result. Each wetland is established under unique circumstances with retention capacity determining parameters, such as discharge, nutrient load, placement, design, and maintenance varying between them. Therefore, the reduction of nutrients in wetlands varies, sometimes a lot, within and between years depending on a number of factors. The potential reduction capacity within a wetland under optimal conditions may very well exceed 1 000 kg N and 40 kg P per hectare wetland and year.

In wetlands in North America receiving water highly loaded with nitrate, 10 mg/l, the yearly reduction of nitrogen was more than 1 000 kg per hectare wetland area. In Norway, small wetlands receiving high loads of nutrients retained between 500 to 2 850 kg nitrogen per hectare and year. In that particular situation the reduction efficiency was explained by high proportions of particularly bound organic nitrogen reduced by sedimentation. Varying results are also seen in Sweden were wetlands receiving low loads of nutrients reduced 34 kg of nitrogen and 2,9 kg of phosphorus per ha and year as a mean between the years 1996 - 2006. In another area in Sweden the reduction of nitrogen in a wetland varied from 600 to 1 400 kg ha^{-1} only during the first year of monitoring. The reduction of phosphorus during the same year was ca 100 kg ha^{-1}.

Conclusively, the reduction in relation to nutrient load varies between 20 to 90 % for nitrogen and 25 to 100 % for phosphorus. Based on the current knowledge of and experience with constructed wetlands in intensive agricultural settings, plausible expected retention rates for nitrogen and phosphorus are 250-500 kg N/ha/y and 5-10 kg P/ha/y respectively.

5.2. Function and efficiency

Fundamentally, important variables for a well functioning wetland are the size of the watershed, the land-use within the watershed, the hydraulic efficiency and the waters residence time. More specifically, the long-term efficiency of nutrient retention is related to a number of physical, biological and chemical variables described below, see also Figure 11. Considering the retention of phosphorus in a long-term perspective, the formation of new sediments and soils in constructed wetlands is the only sustainable process that can permanently sequester phosphorus.

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Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)
Baltic Sea Region Programme 2007-2013

5.2.1. Physical factors:

- Hydrology and the hydraulic efficiency of the in- and outlet structures
- Evenly distributed flow over the wetland area for optimal surface contact with particles, sediment, vegetation, micro organisms etc.
- Sufficient residence time to facilitate nutrient reduction processes, such as sedimentation, microbial and chemical transformation and plant uptake.
- Loads and size distribution of particles in the water.
- An immediate reduction of water velocity to enhance sedimentation
- Filtration of the water through vegetation, barriers, overflow-areas etc.
- Stabilization by vegetation, i.e. plant roots stabilizes the wetland floor as well as the deposited sediments preventing resuspension and subsequent transportation of sediment downstream.
- Water rippling (movements) aerating the water, necessary for nitrification (microbial transformation of ammonium to nitrate) among other processes.
- Stagnant, anaerobic water, often in deeper sections, necessary for denitrification (microbial transformation of nitrate to nitrogen gas, N_2).

5.2.2. Biological factors

- A well established bio-film on all filter surfaces, which transforms pollutants into harmless forms, such as by for instance transforming bioavailable nitrogen, i.e. ammonia, nitrite, and nitrate, into, harmless nitrogen gas (nitrification and denitrification).
- Healthy vegetation to take up nutrients and pollutants and allows for their subsequent removal from the system by harvesting.
- Favourable conditions in the root zone, or rhizosphere, where the interactions between roots, microorganisms, soil, water, nutrients and pollutants enhance several reduction processes.
- Parts of bio-accumulated nutrients and pollutants are sequestered in the sediment as organic material deposit as sediment.

5.2.3. Chemical factors

- Aerobic conditions. A sufficient supply of oxygen is crucial for stable binding of phosphorus to, especially iron (Fe), microbial transformation of ammonia to nitrate (nitrification), and oxidation or transformation of pollutants
- Anaerobic conditions necessary for denitrification (microbial transformation of nitrate to nitrogen gas, N_2).
- A stable and more or less neutral pH (avoid low pH) assures a stabile chemical binding of phosphorus to aluminium (Al) and is also favourable for biological processes.
- Exposure to sunlight and UV-radiation to increase chemical breakdown of pollutants and to remove pathogens.

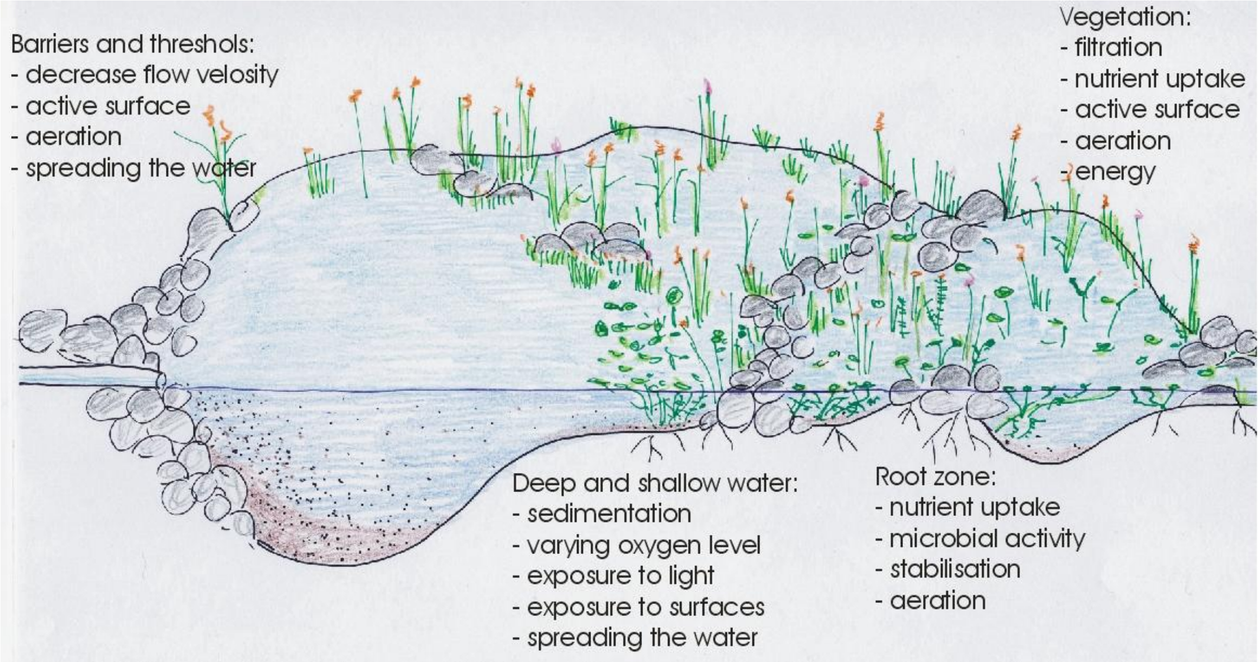

Figure 11. A wetland is a complete ecosystem consisting of a spectrum of different environments optimal for a large number of processes all playing important parts in the water protective and nutrient reducing function. This cross section of a constructed wetland illustrates some of the important environments and processes, such as sedimentation, surface contact between water and stone, vegetation, sediment etc. important for microbial activity, plant uptake, aeration, the important root-zone, vegetation and barriers retaining and filtering the water etc. (Illustration: S. Owenius)

5.3. Placement and design

Wetlands may be established for different reasons, i.e. water protection, enhancement of biodiversity, water storage, fishing etc. When water quality issues are the predominant reason for construction the following criteria may be used:

- The wetland is to be planned in an area with intense cultivation and with a high load of water carried pollutants.
- Naturally occurring nutrient retention processes in the area between the agricultural land and the recipient are estimated to be low and insufficient.
- Sufficient residence time and hydraulic efficiency can be obtained at the chosen site.
- The recipient is classified as highly vulnerable and is in need for protective measures

5.3.1. Placement

To secure a sufficient water supply to maintain emersed conditions all year around, a constructed wetland should be established in a relatively large watershed, Figure 12. If possible, a watershed of 200 ha per hectare established wetland is recommended. Moreover, it is very important that at least 60-75% or more of the watershed area is used for intensive agriculture resulting in high nutrient load to the wetland. If the majority of the watershed is covered by natural landscapes such as forests, there will likely be no need for a treatment wetland.

Wetland size should equal approximately 0.5 – 4 % of the total drainage area. A large wetland (≥ 3 ha) may sometimes be difficult to accomadate at a small farm, in which case it is recommended to try and realise it by cooperation with neighboring property owners. Wetlands are best placed as far downstream in the drainage network, and as close to the recipient to be protected as possible. Naturally occurring historically inundated depressions are an obvious and often cost effective placement option, due to smaller earthwork expenses. Optimally the landscape surrounding a constructed wetland is rather flat and open without trees for predating birds to use for scouting and hunting eggs, ducklings and baby birds.

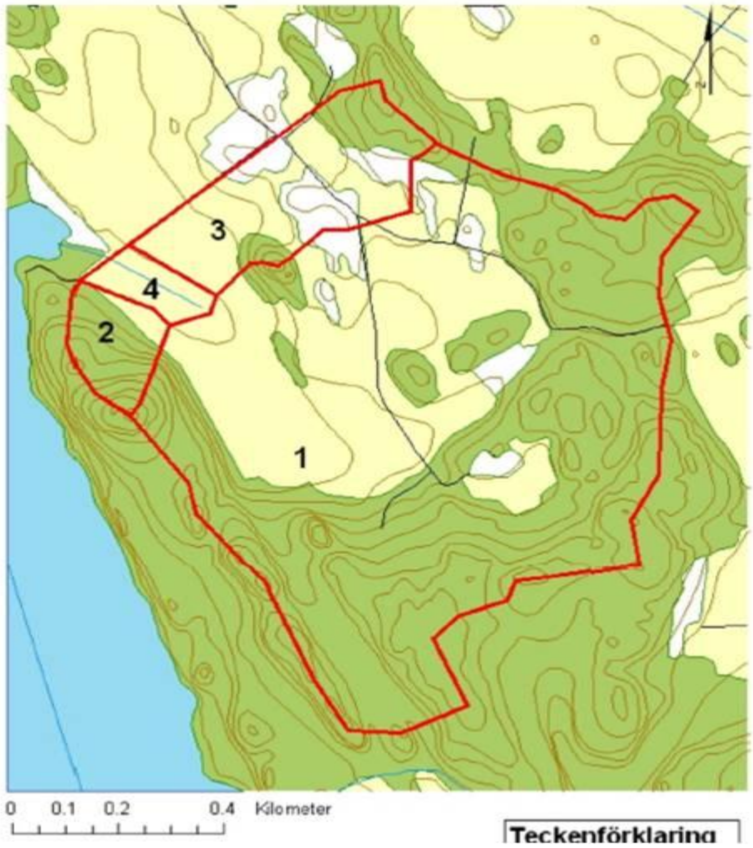

Figure 12. A watershed with a total area of 98 ha consisting of 56% forest land, 35% cultivated land, 7% grazing land and 2% constructed wetland (=2% of watershed). The watershed is divided in sections de-watered into the wetland through separate water pathways, either through tile systems or as diffuse runoff. The wetland was created in section 4 close to the recipient.

During the past century, many wetlands all over the world have been drained or heavily encroached upon at an alarming rate for cultivation purposes. It is estimated that by 1993 half the world's wetlands had been drained. These drained wetlands have since then often been fertilized resulting in substantial accumulation of phosphorus that may be of great impact on P retention capacity if these former wetland areas are re-inundated. First, the phosphorus retention capacity of these soils may be very low as they already have a high load and secondly, there may be a risk of losses of accumulated phosphorus when re-wetting the area. To avoid this scenario soil analysis to establish the accumulated phosphorus load in the area is recommended. If the soil is estimated to have a low phosphorus binding capacity due to an already high load it is a good idea to remove the top soil prior to wetting the area. The removal of the phosphorus saturated top soil will most likely improve the phosphorus absorption capacity also in a long term perspective if the underlying soil has a good binding capacity. An alternative could possibly be to cover the original soil with compact layer of benthonic clay or a rubber canvas.

5.3.2. Design

When designing a wetland for nutrient removal all the important variables mentioned above should be considered with the aim to establish different environments and conditions within the wetland optimal for different retention processes. When designing a wetland the fundamental objective should be ”Irregularity rather than regularity”, in other words aim for endless variations and no straight lines or right angles, Figure 13.

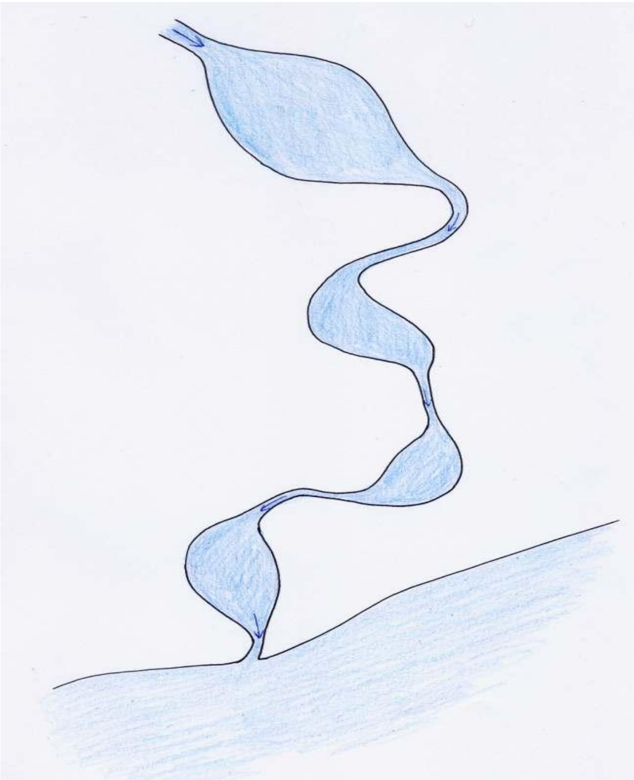

Figure 13. Avoid straight lines and right angles when designing a wetland. Aim for heterogeneity in shape, depth, bottom and vegetation roughness, water velocity, numbers of inlets and outlets etc. (Illustration: S. Owenius)

Restore or construct?

From an ecological and cultural point of view the restoration or re-wetting of former wetlands is to be favored. Chances of retaining well functioning and naturally adapted wetland vegetation also increases by doing do as viable seeds of wetland species may still be present in the soil. If priority lies with high nutrient retention efficiency, the creation of a new wetland may be a better alternative as this allows for a greater degree of freedom with the design.

Water supply

The incoming water may be transported through first order tiles gathering drained water from a larger part of the watershed. Water may also reach the wetland as more diffuse surface run-off or through scattered smaller tile systems, se Figure 3 in section 4.3.1 and Figure 14 below.

Figure 14. Top; construction of the wetland in Södra Stene, Sweden, supplied with water from a first order ditch collecting runoff water from parts of the watershed via the tile systems. Also diffuse water runoff enters the wetland established next to the ditch and closely upstream (75m) to the recipient Lake- Sillen (Photo: Per Richard Bernström). Down, a photo of the newly established wetland (2.1 ha) in early spring 2004(Photo: Jonas Andersson).

Filters and barriers for sufficient turn-over time and surface contact

To assure water retention and surface contact the water needs to be evenly spread over the entire wetland and is not to be allowed to take short-cuts through the system. This may be accomplished by the establishment of filtering vegetation or by including physical barriers or thresholds that force the water to spread. Under most circumstances it is best to start spreading the flow immediately after the inlet structure. The barriers for slowing down and spreading the flow may be constructed as described in section 4.4.1 or alternatively by fixing a canvass screen right through the water profile as seen in Figure 15.

Figure 15. A canvass screen was mounted across the inlet to cut the flow and force the water to spread. When the photo was taken the water level in the wetland was temporarily lowered for maintenance (Photo: Jonas Andersson).

The actual residence time of the water in a wetland can be established by adding a tracer chemical and may deviate substantially from the theoretical residence time (volume divided by daily inflow). A comparison between theoretical and actual water residence time in a constructed wetland in Södra Stene, Sweden, resulted in a difference of 24 days. The theoretical residence time was 33 days and the actual one was only 9 days. Wetland shape and bottom- and vegetation roughness are main factors that impact actual residence time. Consequently, the implementation of obstacles and filter-barriers distributed over the wetland must be taken into account rather than barely relying on having enough volume to ensure efficient retention.

Flat shores and shallow water

The shores of the wetland must be flat and carefully planned-off with a slope of 1:10. The predominant depth of the water should be shallow, 0,2-0,3 m (see Figure 16). But to facilitate efficient sedimentation early in the inlet, as well as prior to the outlet deeper basins of around 2 meters depth are to be established at these locations.

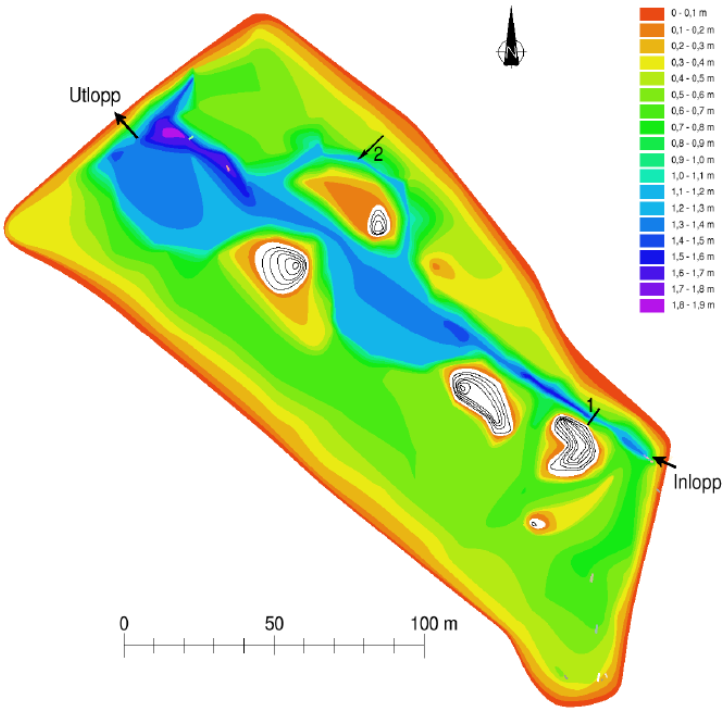

Figure 16. A map showing the variation in depth in the Södra Stene wetland. Orange/yellow=0,1-0,4 m; green shades= 0,4-1,0 m; turquoise/light blue = 1,1-1,3m; Dark blue/Purple = 1,4 – 1,9 m (Illustration by Jonas Andersson).

Damming or excavating?

By performing a geodetic survey of the area, commonly consisting of drilling at the located site, detailed information can be obtained about soil conditions from top soil layers down to a specific depth and the level of the ground water surface. Based on these data it is possible to estimate the stability and permeability of the soil and potential risk of landslides and instability. An alternative way to control the soil condition in the area is to dig test pits with a backhoe or small excavator. Through this procedure similar information about soil types and there characteristics in the soil profile may be obtained at the same time as the practical experiences from digging and piling will give basic information about soil stability and permeability.

A careful leveling of the area, including levels and coordinates of the areas for piling up excavated material, the areas required for the establishment of tiles, culverts, ditches, barriers, and thresholds. It is recommended to also include roads, neighboring properties, and any easements for wires for electricity or telephone or wastewater pipes.

After completion of the survey the optimal position, shape and water level can be determined. Favorable locations for deeper and shallow areas, where to put surplus soil and to create thresholds can also be pinpointed with the survey results. The construction of the wetland may be done either by damming or by excavating. Damming is possible if there is a natural depression in the area and usually requires less interference regarding moving soil masses etc. Wetlands larger than 2 hectares are most commonly dammed. If there is no natural depression, excavation is necessary. Excavation requires more effort and careful planning of where to get rid of surplus soil and to make sure that the wetland is kept shallow and fits the landscape. Excavation includes a certain risk of digging too deep, potentially causing problems with intrusive ground water. Occasionally it may be necessary to install pumps to maintain the desired water level in the wetland, but as this practice is both expensive and energy consuming, it is to be reserved for larger wetlands only. In Figure 17 and 18 two examples of excavation and damming are illustrated.

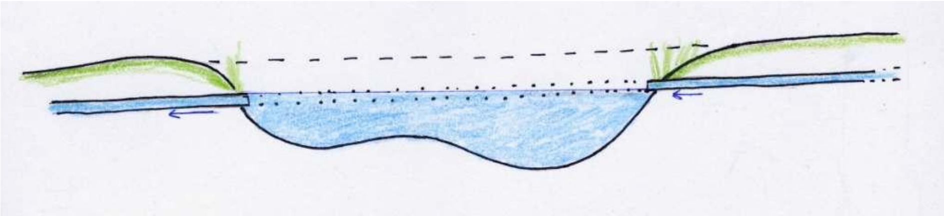

Figure 17. A wetland can be established by excavating and cutting of the drainage tile, that may act as in and outlet in the wetland. The original ground level and tile is dotted in the schematic illustration.

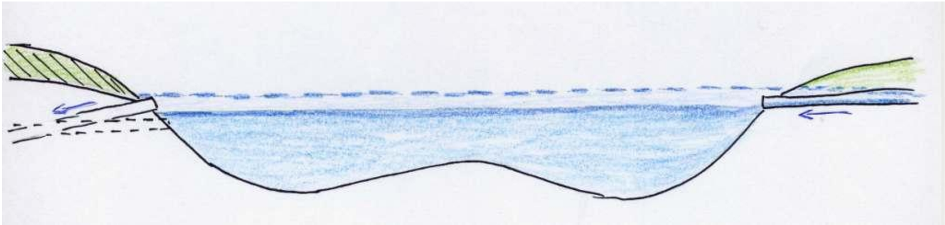

Figure 18. This example illustrate how the water level may be raised through damming by lifting the pipe in the outlet to a higher level. A pile heap of residue spoil is used to increase the ground level in the outlet.

Get professional help!

It is recommended consulting a professional, well-experienced designer to get help with adjusting the design and the use of surplus soil in the most functional as well as cost-effective way as possible. The risk of disturbances to neighboring property, draining tiles, cultural heritages, electric cables, roads etc. is also diminished with the help from a professional.

Prepare for manual regulation of water levels

In- and outlet structures that enable the manipulation of the water level by hand are strongly recommended as the ability to lower the water level during for instance maintenance, repair, or alterations may be of great value, se Figure 19 and 20. Manually increasing the degree of inundation may also be of great value to temporarily increase storage capacity, prolong the residence time, or as a means to suppress dense vegetation by drowning. Figure 16 illustrates a simple solution how to regulate the water level.

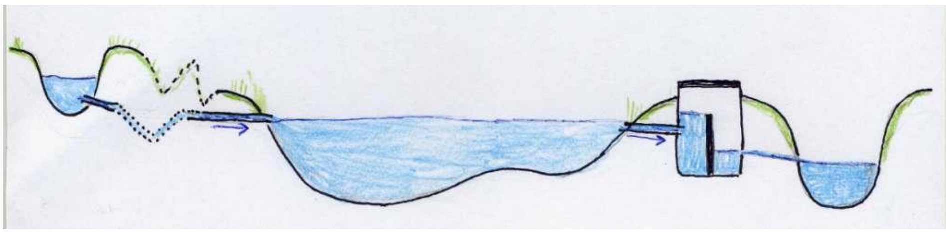

Figure 19. The wetland may easily be supplied by water from a higher level up stream through a pipe entering the wetland. The water level may be regulated through the well in the outlet.

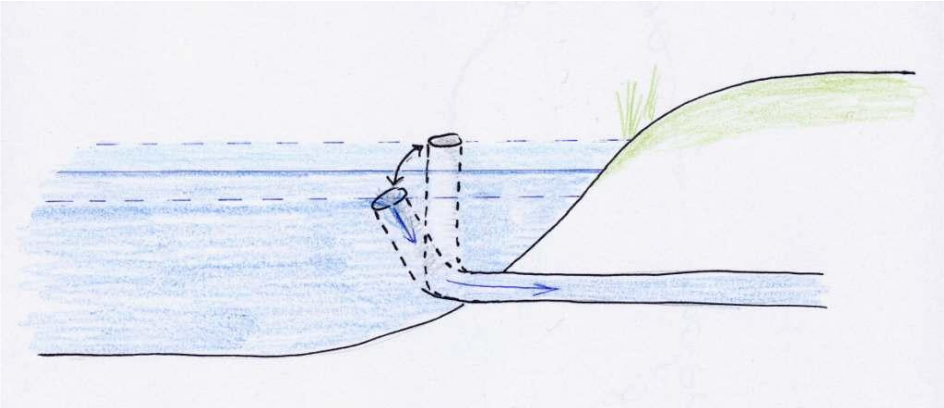

Figure 20. By using an angled pipe in the outlet the water level in the wetland can easily be regulated by a manual hand grip turning the pipe sideways.

Establishment of vegetation

As mentioned before wetland vegetation functions as a mechanical filter, offers surfaces covered with active bio-film, supplies microorganisms with energy (carbon), aerates the water, facilitates plant uptake, and stabilises the deposited sediments, Figure 21.

Typical wetland vegetation consists of both emergent and submerged wetland plant species. Mixed vegetation is optimal to benefit from the variations in properties and strategy between different species. Emergent species such as *Typha*, *Phragmites*, *Carex*, *Schoenoplectris*, *Phalaris ssp.* etc. have rather stiff stems that can withstand high flow and they have an important impact on reducing near-bottom water velocity in deep sections, thus improving sedimentation of smaller clay particles. The water is filtered between the bio-film covered stems with great impact on nutrient and pollution reduction. Moreover, the roots of emergent vegetation stabilise the wetland bottom, preventing resuspension and export form the system. Submerged species such as *Potamogeton ssp*., *Elodea canadensis*, *Callitriche ssp*. float in the water column and help oxygenate the water, improve the contact surface, as well as direct uptake of nutrients and pollutions from the water.

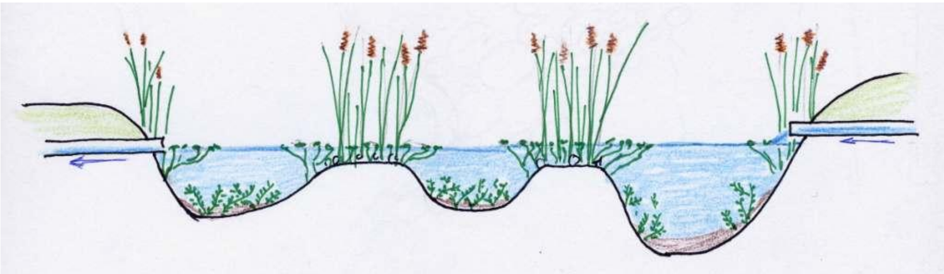

Figure 21. By varying the depth of the water numbers of emergent and submergent plant species will establish, each with important impact on the function of the wetland. The shallower sections with denser vegetation also force the water to spread over a larger area.

Natural establishment and succession of proper wetland vegetation will occur even though this may take several years. To be able to take advantage of the beneficial properties of vegetation as soon as possible, it is suggested to establish plants manually, at the very least in areas estimated to be in special need for vegetation for example to prevent erosion or other damages.

A relatively diverse distribution of plant species tends to occur even in recently constructed wetlands even if often two or three species, most commonly *Typha latifolia, Schoenoplectris lacustris, Juncus ssp*. tend to dominate. The species richness in a wetland depends on factors such as the location, size, shape of the shoreline, depth, and maintenance. In recently established wetlands pioneer species are more common than in older wetlands where the flora has developed into a more perennial woody flora represented by for instance *Schoenoplectris ssp, Carex ssp, Typha ssp, Alnus ssp*., and *Salix ssp*.

5.4. Maintenance

5.4.1. Functional verification

Regularly observe all functional parts to make sure they are in god shape. Look for damages caused by erosion, landslip, rough wintertime or damaged or damming vegetation. Study hydraulic conditions during both low and high flow to learn the normal paths of the water in order to quickly discover changes and unwanted flow paths.

5.4.2. Maintenance of the vegetation

Often newly established wetlands are overgrown with dense stands of vegetation dominated by one or two species, commonly *Typha ssp*. *Phragmites australis* or *Glyceria maxima*. Too dense vegetative cover increases the risk of flooding or the creation of flow short-cuts with negative effects on nutrient reduction. By cutting the area having a too dense and uniform vegetation at two separate occasions during the same vegetative season the dominating species will be suppressed and at the same time other competitive species will be able to establish. Counteracting the domination by a handful of emergent species will also benefit the establishment of submerged vegetation. To benefit most from the cutting management, one of the cutting operations should be performed during late summer.

In general, the shallower areas of a wetland require more maintenance as the overgrowth of vegetation mostly occurs in these sections. Annual cutting in late summer is needed to maintain an evenly distributed vegetative cover that filters the water for optimal contact surface area between vegetation and the nutrients and pollutions in the water. To maintain a good hydrologic regime and filter effect the wetland vegetation should stretch from shore to shore perpendicular to flow.

To ease vegetation maintenance, especially cutting, it is recommended to temporarily lower the water surface level in the wetland if possible. However, the drained period should be kept as short as possible to avoid even more seeds from *Typha* to germinate at the bare wetland shores. An alternative way to suppress dense vegetation is to do the opposite, to temporarily raise the water level in the wetland. A combination of cutting closely followed by drowning the damaged and sensitive stems gives even better results. Figure 22 shows the visual effects from combining cutting and drowning but in this case by cutting the vegetation below the water surface in a Swedish wetland.

Figure 22. The left photo illustrates the dominating *Typha latifolia* prior to cutting in august 2005. The vegetation was cut only once below the water surface. The right photo, taken two years later, shows the result were *Thypha latifolia* has been replaced by *Potamogeton natans* and *Typha angustifolia*. (Photo: Sören Eriksson)

A third alternative is to let grazing animals do the job, Figure 23. Cattle have the advantage of grazing the vegetation both along the flat shoreline as well as in the shallow parts of the water. Keeping grazing animals on the shores also creates favorable conditions for the establishement of a large diversity of flora and fauna.

Figure 23. Grazing Highland Cattle is an alternative way to maintain the vegetation.

A well maintained wetland has the potential of develop in to a stable ecosystem that may keep a high function during a long time perspective (more than 20 years). However, to keep the ecosystem stable it will sooner or later be necessary to dredge, primarily the sections close to the inlet where the main part of the sedimentation takes place. How often depends on the load of water, particles and nutrients on the wetland. Technical parts probably will need to be restored or exchanged now and then over time.

5.4.3. Evaluation of wetland efficiency

Regular data collection is important to monitor the nutrient retention capacity in established wetlands over time. So far wetlands with monitoring programs are few and far between which is why proper evaluation of their effect on nutrient reduction in relation to different parameters has been limited. Collected data are crucial for the development of models that evaluate the efficiency in relation to different parameters. Important data to be used as input in such models are for instance:

- placement and design of the wetland
- wetland volume (area and depth) and water residence time
- the size of the watershed
- land-use in the watershed
- nutrient load

5.5. Technical requirements

More or less the same technical requirements as recommended in chapter 4 for establishment of sedimentation pond are also required for the creating of wetlands. For more detailed information and recommendations, see section 4.6.

Figure 24. Excavators are commonly needed during the construction.

5.6. Economical requirement

Costs for establishing a wetland depends on factors such as size, construction method, and technical requirements. On average, the cost for excavation and removal of soil may average 3 € per m^3. Based on calculations made for already established wetlands the average cost is somewhere around 26 500 € per hectare wetland. It is possible to apply for economic support for both establishment and maintenance of wetlands constructed for water protection and nutrient retention. Table 7 presents two examples of economic requirement for construction and cost-efficiency, based on amount of reduced nitrogen.

Table 7. Average cost for construction of a wetland and reduction of nitrogen based on experience from 2 900 ha of constructed wetlands in Denmark and 75 ha of constructed wetlands in the Höje-river watershed area in south of Sweden (Theil-Nielsen, Persson and Kamp Nielsen, 2005).

	Construction costs (cost / ha wetland)	N-reduction (kg ha^{-1} $year^{-1}$)	Nitrogen cost efficiency (cost / kg reduced N)
Denmark	46 000 DKK = 6 170 EUR*	265	10 DDK = 1,3 EUR
Sweden	149 000 SEK = 16 500 EUR	560	16 SEK = 1,8 EUR

*Based on exchange rate dated 110509.

The construction of wetlands as a measure for water quality improvement in agricultural settings is cost efficient. Additionally, wetlands are multifunctional ecosystems that offer several ecosystem services besides nutrient retention, some of them with a high potential for further development in the future. A reasonable cost for reducing nutrient transport to the sea by the establishment of wetlands is 2,5 to 3,5 € per kg of nitrogen and 9 to 11 € per kg of phosphorus.

5.7. Permission and commitments

In order to be time and cost efficient it is recommendable to acquire information about all the applicable laws, policies and subsidies, from the responsible authorities in the initial phase of the planning. For the same reason early contact and coordination with all affected property owners is also recommended. As the establishment of a constructed wetland affects the hydrology, the authorities will review the plans for potential violation of environmental legislation. Authorities may also have specific demands for wetland operation and maintenance and may require revisions to the plan prior to issuing the permit necessary for construction to commence.

Submitting thoroughly reviewed and complete plans with calculations for dimensions, environmental and hydraulic impact predictions, construction details, and cost estimates for construction and maintenance, will ease the above process and reduce the chances that amendments are required. Based on the supplied information and site specific circumstances such as the presence of sensitive flora, fauna or cultural heritage the authorities will decide if and how special care must be taken.

Keep in contact with the authorities over time to be informed when permits or agreements must be renewed and to notify them of larger maintenance operations such as removing accumulated sediments from the basin.

5.8. Subsidizes

The interest for constructed wetlands as a multifunctional measure for improving water quality has grown strongly since the late 1980's. Subsequently, several forms of economical support for their establishment and maintenance have developed in several countries. To support continued construction of wetlands for reducing diffuse nutrient losses, country specific budgets have been made to set aside money to enable establishment.

5.8.1. Each country sets its own budget

Denmark for example, is planning to establish another 10 000 ha of constructed wetlands to reach a reduction of nitrogen losses from agriculture of 1 130 ton prior the year 2015. The reduction of 30 tons of phosphorous is planned to be accomplished mainly by measures in riparian zones and flood beds. The budget set aside for constructed wetlands is approximately 132 million € divided over the years. Initially 38 million € were invested to be used each year during the years 2010 and 2011. Thereafter, 13 million € will be invested on yearly basis during the years 2012 to 2015. The investment covering measures in the riparian zones and flood beds corresponds to a yearly sum of 1.8 million € during the whole period 2010-2015 (Danish food industry agency, 2011).

This budget covers all expenses involved in the step-wise planning and preparation for establishing highly effective wetlands. In short these steps are:

- Analysing needs, possibilities and limitations. Active search for areas with high potential located in sensitive and high risk areas with high nutrient loads, as well as an active search for interested farmers and/or land owners.
- Technical desktop review, i.e. gather and analyse information and data, maps, GIS- and hydrological data. Describing the current conditions in the watershed and surrounding landscape.
- Property / estate investigation, i.e. establish ownership of the farms and adjacent properties. Analyse potential for conflicting interests such as fishing, protection of habitats or preservation of cultural heritage.
- Investments necessary for establishment, i.e. covering for material, equipment use and man hours needed.
- Expropriations, i.e. covering for costs to buy-out private properties needed for the establishment.

5.8.2. Direct support for the farmer

The applicable amount of subsidy for individual farmers or land owners may vary between countries. In Sweden for example, farmers may apply for a subsidy covering up to 90% of the needed investment, that based upon previous construction experiences was set at 26 800 € ha^{-1} wetland. Subsidies that cover wetland maintenance are also available. To find the specific details concerning subsidises in specific countries it is recommended to consult the agriculture and rural development web site for member states providing information on beneficiaries and payments: http://ec.europa.eu/agriculture/funding/

Other sources of financial support such as local or private programs for the promotion of wetland construction or restoration may be available as well. It is certainly worth the effort of looking for support for species and habitat protection from foundations such as Life+, Nature 2000, RAMSAR, Global Nature Fond, or from local municipalities or even the private sector.

5.9. Additional benefits and potentials

It has already been mentioned that wetlands are multifunctional ecosystems with numerous additional benefits such as improved biodiversity, water storage capacity, resource recovery, irrigation possibilities, production, re-cycling of nutrients, and potential for recreational and educational purposes. There is a lot of literature available that describes how to operate a wetland to support bird life, amphibians, crayfish, and specific flora or to serve as a valuable spawning and nursery area for fish. The possibility of making a positive contribution to biodiversity and a community's recreational attractiveness can be an important argument to convince farmers to participate.

Wetlands also have a remarkably capacity of removing other pollutants, such as metals, bacteria, pesticides, toxic substances such as oil residues, fat, phenolic substances, and drug residues through decomposition, transformation, bio-accumulation or accumulation in the sediment. A wetland in Norway for example reduced the incoming load of pesticides by 67%. This wetland trait may be of special interest for protecting recipients that receive storm water or polluted water from point-sources. Most wetlands in agricultural settings also receive residual water from animal husbandry with high loads of faecal bacteria such as *E.coli* and *Streptococcus*. A Swedish wetland receiving water from a pig farm reduced the amounts of *E.coli* and *Streptococcus* in the incoming water with 75 to 99,5% and > 95% respectively.

Re-cycling of nutrients and top soil particles is accomplished when removed sediments and plant material is distributed on the cultivating land. In case there is a risk that the sediments are polluted by for instance heavy metals, chemical analyses must be performed prior to re-circulation.

Another so far almost untapped potential function is to use the wetland biomass for energy production. As the efforts to produce biogas are increasing, so does the need for raw material to digest in the fermentation chambers. Using harvested wetland vegetation as raw material in biogas production is therefore an option to be further explored and developed, and a potential future financial incentive to farmers.

Created wetlands

- Large free water surface wetlands best placed far downstream in the drainage network close to the recipient to be protected.
- Size of the watershed, the land-use within the watershed, the hydraulic efficiency and the waters residence time are fundamentally important variables for a well functioning wetland.
- Established in relatively large watersheds, 200 ha watershed per hectare wetland is recommended.
- At least 60-75% or more of the watershed area should be intensive agriculture land resulting in high nutrient loads.
- The wetland size should equal 0.5 to 4 % of the drainage area.
- Establishment of large wetlands (≥ 3 ha) may require cooperation with neighboring property owners.
- Designed primarily for removal of nutrients, e.g. nitrogen and phosphorous and other pollutants.
- Long-term efficiency of nutrient retention is related to physical, biological and chemical variables such as: flow velocity and distribution, residence time, nutrient load and loads and size of particles, sedimentation, a well functioning bio-film on filter surfaces, healthy vegetation and favorable conditions in the root zone, aerobic and anaerobic conditions, a stable and neutral pH, sunlight and UV-radiation, etc.
- A good thumb rule when designing a wetland is ”*Irregularity rather than regularity*”
- Get professional help with designing and construction of the wetland in the most functional and cost-effective way as possible.
- A wetland for optimized nutrient reduction may be constructed through damming and/or excavating.
- Filters and barriers should be included for sufficient turn-over time (at least 1-2 days) and surface contact.
- Establish flat shores and varyingly shallow and deeper water sections.
- Prepare for manual regulation of water levels to facilitate maintenance or other technical operations.
- Typical wetland vegetation consists of both emergent and submerged wetland plant species.
- Mixed vegetation is optimal to benefit from the variations in properties and strategy between different species.
- Regularly observe functional parts and look for damages caused by erosion, landslip, rough wintertime etc. to be able to repair in good time.
- Remove too dense vegetation to avoid the risk of flooding and channeling of water rather than spreading.
- A well maintained wetland may have a long lifetime, at a minimum 20 years.
- Several types of machinery, instruments, maps and material is needed during construction and maintenance.
- Establishment-costs depend on local conditions, size, construction method, technical requirements etc.
- Acquire information about applicable laws, policies and subsidies from the responsible authorities in the initial phase of the planning.
- Contact and coordination with all affected property owners.
- Economical support for establishment may be granted.

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