WAMBAF – Good Practices for Ditch Network Maintenance to Protect Water Quality in the Baltic Sea Region

Short version

Contents

Preface

This short version of "WAMBAF – Good practices for ditch network maintenance" was prepared within the WAMBAF project (Water Management in Baltic Forests), project period from 1.3.2016 to 28.2.2019, which was initiated to tackle the problems relating to water quality after forestry operations in the Baltic Sea Region. WAMBAF focuses on three main factors that significantly impact water quality: riparian forests, forest drainage and beaver activity. The main motivator for the project is to support the implementation of EU Water Framework Directive (WFD) (2000/60/EC). This short version is based on a more extensive report "WAMBAF – Good practices for ditch network maintenance" published in English (Finér et al. 2018).

1. Introduction

The primary aim of ditch network maintenance (DNM) is to sustain tree growth. DNM should be financially justifiable and its harmful impacts on water quality should be minimized. In "WAMBAF – Good practices for ditch network maintenance", special emphasis is placed on the reduction of the transport of suspended solids (SS), nitrogen (N) and phosphorus (P) to water bodies from forest areas after ditch network maintenance (DNM) on peatlands and paludified mineral soils in the Baltic Sea Region.

Here, we present (i) factors for assessing the suitability of DNM, (ii) the principles of DNM planning and water protection and (iii) the principles of monitoring the impacts of water protection and the importance of training for DNM.

When implementing DNM operations in different countries, national legislation and, for certified forests, also the forest certification systems need to be followed. We hope that this short version of good practices may serve as an inspiration and be helpful in the daily work of forest and environment managers, and other stakeholders who are involved in practical DNM operations in the Baltic Sea Region. For the terminology used in these good practices for DNM, we refer to the list at the end of this document and to the drainage-related documents prepared for the WAMBAF project in 2017, published in English and in national languages on the project web pages (https://www.skogsstyrelsen.se/en/wambaf/drainage/).

2. Assessment of the suitability of ditch network maintenance

Key messages:

- When establishing the suitability of DNM:
    - Attention must be paid to the characteristics of the receiving water body and the site-specific water conditions in the DNM area such as groundwater inflow from confined aquifers and susceptibility to flooding during the growing season.
    - The effect of first-time drainage, ditch drainage capacity and tree stand volume must be evaluated.
    - Other factors to consider: tree species composition, understory vegetation, soil characteristics and climate.

There are several factors to consider when establishing the suitability of DNM for a specific area. These factors and, where possible, guiding criteria are described below. It is important to note that DNM areas are usually heterogeneous and consist of forest stands and ditches with different water transport capacities. In assessing the suitability of DNM, both the tree stand properties (its evapotranspiration capacity) and this site-specific characteristics of the drainage area should be considered, which makes the decision-making highly complex. For example, having a tree stand with high evapotranspiration capacity in the downstream part of a drainage area (with, therefore, no need for DNM) and a low-stocked tree stand in the upstream part may sometimes necessitate cleaning the ditches in the downstream part to enable sufficient drainage for the whole area. The decision-making process for assessing the suitability of DNM is summarized in the flow chart shown in Figure 1.

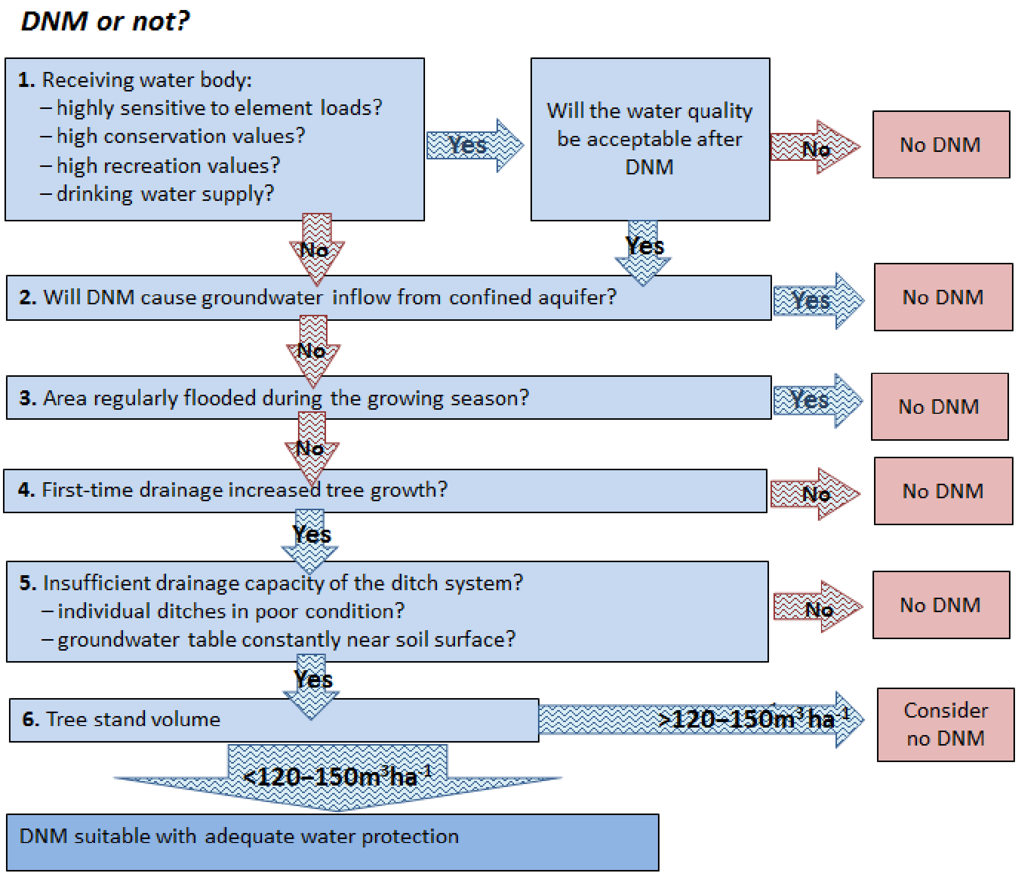


Figure 1. Prior to any decision concerning DNM, it is important to assess the suitability of DNM for the area in question. This decision flow chart illustrates the main factors, with some criteria given, to be considered when assessing the suitability of DNM. In Lithuania, if tree stand volumes are > 250 m^3 ha^{-1} in Scots pine and Norway spruce stands, no DNM should be considered. For the planning of water protection, see Figure 3.

Consideration 1: The ecological status and the sensitivity to pollution of the **receiving water body** both need to be taken into account when evaluating the potential impact of DNM on water quality. The information about the buffering capacity of the water body can be obtained from regional environment authorities within the EU countries. Also, high conservation or recreational values in the DNM area or the receiving water body need to be considered in order to decide if the whole DNM area, or parts of it, should be excluded from the DNM operation.

Consideration 2: In areas where DNM might affect the quantity or quality of the water in **aquifers** reserved for drinking water, DNM should be avoided or if unavoidable carried out with a high level of water protection.

Consideration 3: On areas **frequently affected by floods** during the growing season, DNM will not improve the drainage and such areas should be excluded from DNM. In addition, specific hydrogeological conditions, for example **confined aquifer discharge** and the **existence of sulfide deposits under peat layers**, can be reasons for avoiding DNM. Regional environmental authorities can be contacted for information on the location and management recommendations of such areas.

Consideration 4: If the **first-time drainage did not increase forest growth,** the area should be excluded from DNM. For example, in Finland, the annual volume growth after first-time drainage should exceed 1.5 m^3 ha^{-1}, and the tree stand should facilitate the production of high quality timber before DNM can be considered. Usually, forest stands not exceeding the 1.5 m^3 ha^{-1} growth limit are a poor supply of one or more nutrients, or are located in harsh climatic conditions in the northern latitudes.

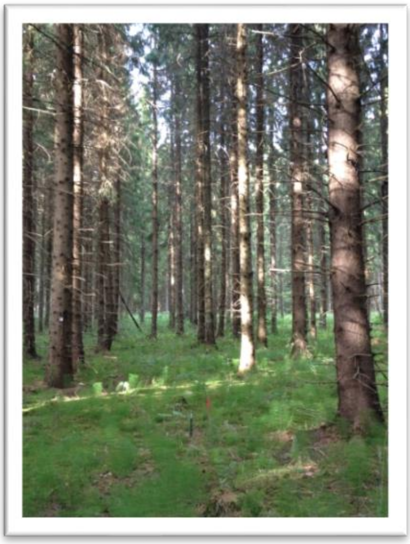
Consideration 5: Drainage capacity of ditches?

- Ditches eventually deteriorate and lose their **water transportation capacity** due to peat subsidence, blocking by vegetation, collapse of the walls, accumulation of harvest residues, sedimentation of eroded soils etc. Harvesting operations can also affect the functioning of ditches, particularly when forestry machinery has to cross over them. This deterioration of the ditch network may impair drainage conditions and reduce tree growth, which can be improved by DNM.
- Ditch deterioration and the subsequent impairment of drainage conditions and reduced tree growth are **gradual processes**. Thus, soil water conditions may be close to optimal for tree growth for a long time after first-time drainage.

- A **ground-water level (GWL) closer than 35–40 cm** to the soil surface during late growing season suggests that drainage capacity of the ditches is poor and DNM may be needed.

Consideration 6: The evapotranspiration of a forest stand strongly influences the water balance of a site and consequently, the soil water content and GWL.

- Evapotranspiration from the tree stand contributes little to the water balance in the **early phase of the rotation period**. The need for DNM often arises after final felling, but sometimes also after partial cuttings (commercial thinnings). Thinning may raise the GWL by up to 15 cm and clear-cutting by up to 40 cm. The magnitude of the GWL rise is dependent on (i) the pre-treatment GWL (the deeper the initial level, the greater rise), (ii) the size of the biomass removal (the greater the removal, the greater rise), and (iii) the hydraulic conductivity of the soil (the lower the conductivity, the greater the GWL rise). The effects of harvesting in sites with mineral soils on the GWL rise may be larger than in peat soils.
- In **highly stocked stands** with volumes exceeding 120–150 m^3 ha^{-1}, the evapotranspiration may be sufficient for maintaining good aeration in the soil. Hence DNM may not increase tree growth or lower the GWL, and thus may be an unnecessary operation in such forests (Photo 1). However, in such forest areas, cleaning of some ditches may be necessary for conveying water from upstream areas.
- It has been suggested that **fertilization** may be an alternative to DNM since appropriate nutrient addition usually increases leaf area and tree growth, and subsequently evapotranspiration.



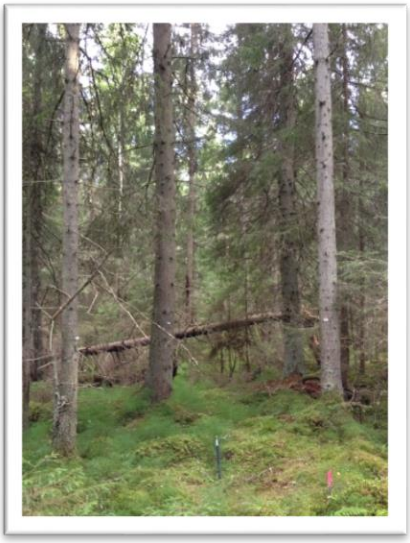


Photo 1. DNM may not increase tree growth in stands with volumes higher than 150 m^3 ha^{-1}, as for example in these Norway spruce stands in southern Sweden, because the evapotranspiration may provide adequate drainage. Photo Ulf Sikström.

Other considerations:

- **Tree species composition.** The evapotranspiration capacities of different tree species vary. Thus, if the stand contains a substantial proportion of a tree species with a high transpiration capacity, the need for DNM may be lower than for stands containing species with lower transpiration capacities even though the leaf areas are similar in both type of stands. For example, the transpiration capacity of birch leaves is higher that of pine and spruce leaves.
- **Composition of understory vegetation.** Increased coverage of moist-tolerant species especially *Sphagnum* mosses, sedges (*Carex* sp.) and shrubs (e.g. *Ledum palustre, Betula nana*, *Vaccinium uliginosum*), may indicate high GWL and the need for DNM. When the composition of understory vegetation on a peatland area consists mainly of the same species found in upland mineral soils, that indicates good aeration of the soil.

- **Soil characteristics**. The texture of mineral soil and the humification degree of peat soils can be used to estimate how easily the soil can be drained.
    - Well-humified peat soils with high bulk densities and fine-textured mineral soils (grain size <0.063 mm) have high water-retention capacities and low hydraulic conductivities. Thus, such sites are difficult to drain efficiently, and drainage may only lower GWL close to the ditches i.e. no more than about 5–15 m from them.
    - It is noteworthy that peat bulk density increases and its hydraulic conductivity decreases with time after drainage, due to the continuous decomposition of drained peat. Thus, it may become increasingly difficult to drain peat sites effectively in the future.
- **Climate**. The need for DNM after first-time drainage seems to arise earlier in northern locations compared to southern locations because there is less biological drainage (i.e. evapotranspiration) in the north due to slower stand development. Thus, drainage is more dependent on the condition of ditches in the north than in the south, where tree stands have larger stem volumes and biological drainage may dominate over the water transportation capacity of the ditch network.

Where DNM is found to be suitable, the next stage of the process is the actual planning of the operation and water protection measures. Good planning is essential for successful DNM and water protection.

3. Planning ditch network maintenance and water protection

Key messages:

- Water protection should be planned in conjuction with DNM.
- Water protection structures are constructed before any DNM.
- Avoiding erosion is of the utmost importance.
- Ditch sections showing signs of erosion are left uncleaned.
- Dam structures are used to reduce water velocity.
- Sedimentation pits and ponds are used to retain SS.
- Wetland buffers are effective in retaining both SS and dissolved nutrients.

3.1 Planning of water protection measures

The planning of DNM for a certain site should include not only the site but also the entire catchment with its stream and ditch network, as well as the downstream water bodies. The DNM plan should be documented and used during the drainage operation.

The planning starts by studying topographic maps of stream and ditch networks in the catchment including the drained area. Existing GIS tools, old maps and drainage plans, aerial photographs, field examination etc. can be used for the delineation of the entire forest catchment area and for the location of the existing ditches. Also, software developed by the WAMBAF project that uses LIDAR data is available for detecting ditches. Field examination of the performance of the existing ditch network is important, both from an ecological and an economic point of view.

Information about the catchment area of single ditches and slopes along their entire length, as well as the soil type in ditch beds and banks, is also needed for planning DNM.

Soil type information needs to be acquired from a field visit since the resolution of the existing soil type maps may be inadequate. If the slope of the ditch is steeper than that recommended for the shear strength of the soil, this will significantly increase the erosion risk. There is software which can be used for identifying the erosion risk within ditches (e.g. http://www.eia.fi/).

Special care in planning water protection should be undertaken where drainage water is conveyed to a highly sensitive or valuable water body. The ditches to be cleaned and the type and the location of the water protection structures can be documented on a map of the DNM area (Figure 2). A general principle is that the water protection structures which capture the released elements are constructed before any drainage operation is started. If timber harvesting is also planned to be carried out in the DNM area, it is useful to plan these operations together. The removal of the trees alongside ditches, which might be necessary when carrying out ditch cleaning using excavators, can be done alongside harvesting operations. Any logging residue deposited in the ditches at harvesting may then be removed during ditch cleaning.

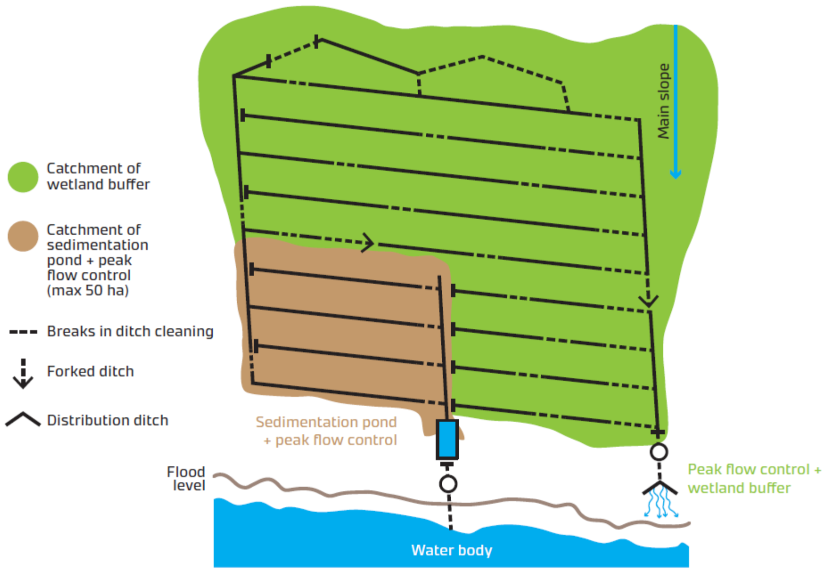


Figure 2. An example of a map showing a DNM area with water protection structures. It is important that the water protection structures are located outside areas which are frequently flooded. Figure modified from a figure by Metsähallitus Forestry Ltd.

Managing water quality in drained sites to reduce SS, nutrient release and transport from the drainage site can be achieved mainly by:

- controlling drainage intensity i.e. the length of the ditches in the DNM area, the depth and width of the ditches, and ditch slope
- reducing the velocity and erosive force of drainage water
- capturing the SS and nutrients released after drainage before they enter the receiving water body.

When possible, several water protection structures are used. A flowchart illustrating the logical order of planning water protection in DNM areas is shown in Figure 3.

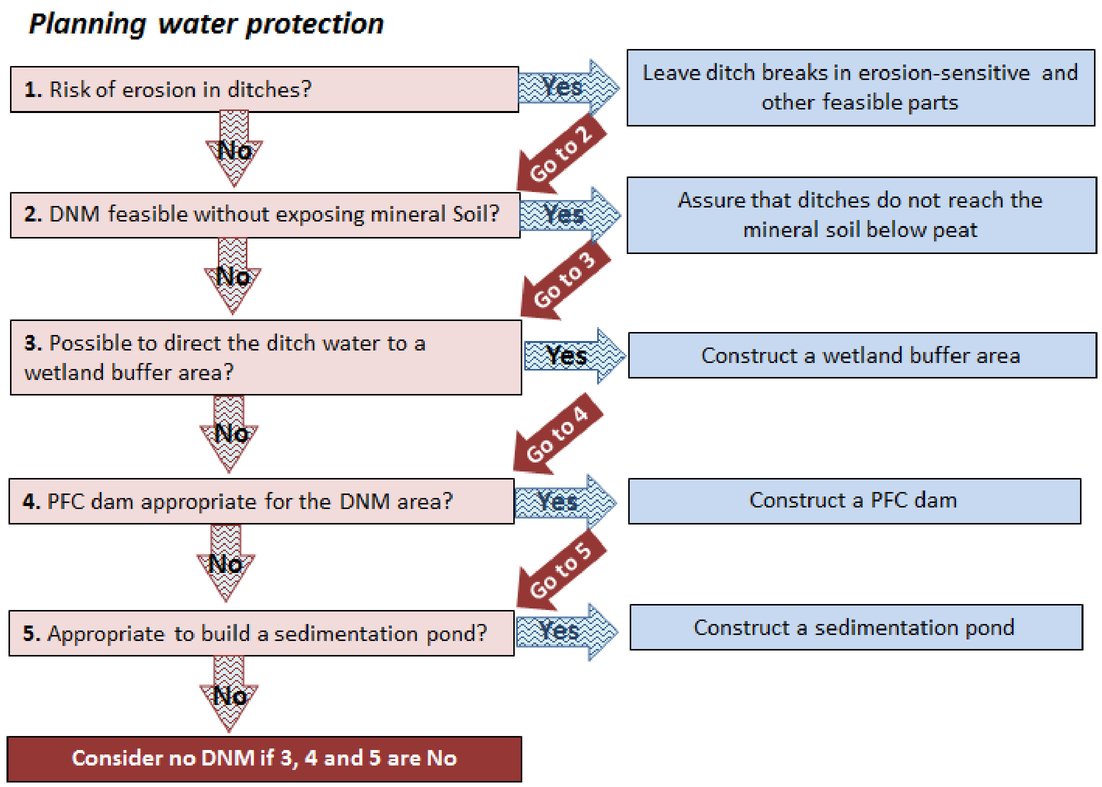


Figure 3. In areas where DNM is found to be suitable, water protection must be planned (see Figure 1). This flowchart illustrates the logical order of planning different water protection structures in DNM areas where DNM has been found to be suitable.

3.2 Controlling drainage intensity and ditch slope

First **identify the ditches** which need to be cleaned and the supplementary ditches which need to be excavated. The ditches with sufficient drainage capacity need not be treated.

- Ditches/stretches of **ditches which show signs of erosion** are identified and **left as uncleaned ditch breaks** (Photo 2). The velocity and erosive force of water are greater in the collector than the feeder ditches. Therefore, leaving stretches of collector ditches uncleaned – whenever possible without risking site drainage conditions – may be a particularly efficient means of reducing erosion in areas with a high erosion risk. Well-targeted breaks have the potential to decrease erosion effectively and are the only structure in the ditch network that can have a significant effect on ditch bank erosion.
- **DNM intensity can be controlled** by varying ditch width and depth. The depth of the ditches should be managed in such a way that they **do not enter the mineral soil underlying the peat**. By keeping the ditches in peat, the export of SS can be significantly reduced. This is especially true in DNM areas with fine-textured and medium-textured mineral soils (grain size <0.063 mm and 0.063–0.63 mm, respectively) below peat, because such soils are eroded more easily than coarse-textured mineral soils (grain size >0.63 mm). To clean only the bottoms of ditches and leave the ditch banks intact is a potential measure to reduce erosion.

Photo 2. A ditch in Latvia which should not have been cleaned because of the highly erodible soil causing high sediment load to downstream water bodies. Photo Zane Libieté.

3.3 Controlling the velocity and erosive force of drainage water

Different dam structures can be implemented to reduce the velocity and erosive force of water.

- **Peak flow control** (PFC) structures with runoff regulating pipes have been shown to reduce the transport of SS and particulate nutrients in DNM areas efficiently (Figure 4). A sedimentation pond is usually excavated above the PFC structure to retain the sediments released even with the PFC structure. PFC structures are not effective for reducing the export of dissolved elements in drainage water. Thus, they should not be designed to be used as the only water protection structure where the loads of dissolved elements are high.

  The efficiencies of dam structures without flow-through pipes, such as **submerged and above-ground-level dams** made of stones or soil, have received little attention. In constructing these dams, care should be taken that the effective area for water storage above the dam is sufficiently large for effective reduction in water flow velocity and that there is sufficient storage area for the retention of SS. One modeling study indicated that dams, which effectively pond the water above them, could have the potential to reduce SS exports significantly.

Peak flow control

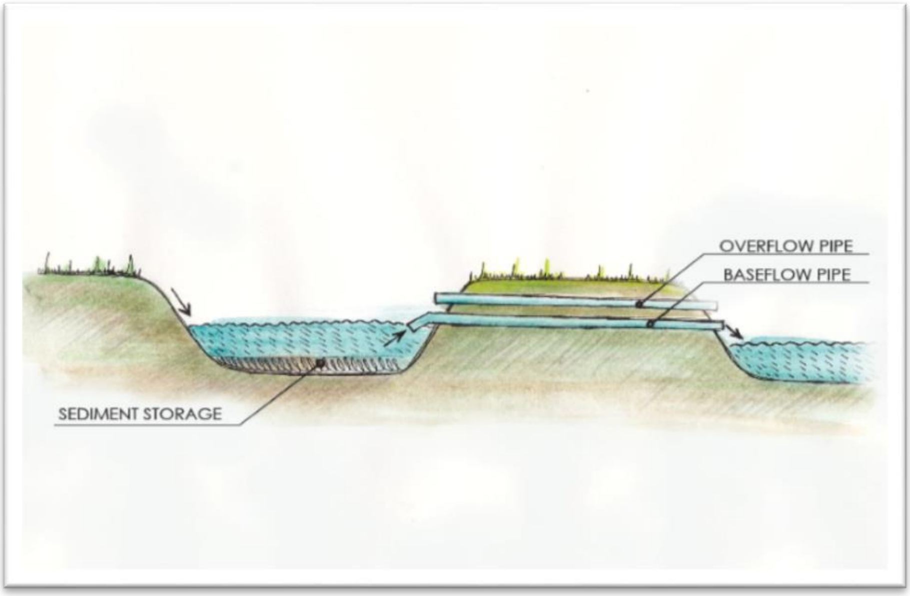


Figure 4. The photo shows an outlet of a peak flow control structure with two pipes constructed to reduce SS and particulate nutrient transport from a drained area in Central Finland. A sedimentation pond has been constructed upstream of the peak flow control structure (Photo Leena Finér). Underneath, a schematic drawing shows a peak flow control structure (Drawing Ilze Paulina).

The functioning of the PFC structure is dependent on correctly dimensioned pipes, that prevent high flow rates. Under optimal conditions, the whole drainage network acts as a water retention area with reduced water flow velocity and erosion risk during the peak flows. A critical point for the functioning of a PFC structure is the proper dimensioning of the base flow, which should be based on the catchment size, average slope, and regional precipitation patterns. While too small a pipe might cause too long water retention in the upstream ditch network, potentially decreasing tree vitality and growth, a pipe that is too large might have only a small effect on water flow regulation during peak flows.

To enhance the performance of the PFC structure, the base flow pipe can temporarily be sealed during low flow periods, both during and after DNM. A sedimentation pond is usually excavated above the PFC structure to retain the sediments which are released even with a PFC structure. A combined PFC/pond structure is justified because PFC is ineffective in retaining SS immediately after DNM when flow rates are low and SS concentrations are high. Sedimentation ponds are most effective during low flow conditions with simultaneous high SS concentrations.

3.4 Capture of released sediments and nutrients

The purpose of sediment pits and ponds is to capture sediment and particulate nutrients released from the DNM area before they enter the receiving water bodies. Pits and ponds are a deepened and widened section of a ditch, where water flows through a wider flow cross-sectional area, thereby reducing the flow rate (i.e. down to 0.2 m s^{-1} at least). This facilitates the deposition of suspended sediments to the bottom of the pond. In general, the sedimentation ponds are efficient for capturing particles with diameters greater than 0.05 mm, whereas smaller particles can be captured by the wetland buffers. Usually, sedimentation pits are constructed in the drainage ditches within the DNM area and the larger sedimentation ponds are constructed at the outlet ditches.

Sedimentation pits

So far operational guidelines for water quality protection in drained peatlands have suggested sedimentation pits (1–2 m^3) as a means to retain SS, but there are no empirical data concerning their efficiency. One modeling study indicated that sedimentation pits may sometimes even increase erosion by increasing flow velocity above them.

Sedimentation ponds

The efficiency of sedimentation ponds in reducing SS transport varies considerably depending on their design, and especially on the parameters pond volume and water retention time. Water retention time reduces as the pond is filled by sediment, thus regular removal of the deposited sediments is needed to maintain its efficiency. The efficiency of a pond is poor until the amount of sediment input increases to a high level, possibly because sediments do not settle down before they have formed bigger flocks or aggregates. Ponds should only be established in areas where the pond bottom and walls do not reach erosion-sensitive mineral subsoil.

Sedimentation pond

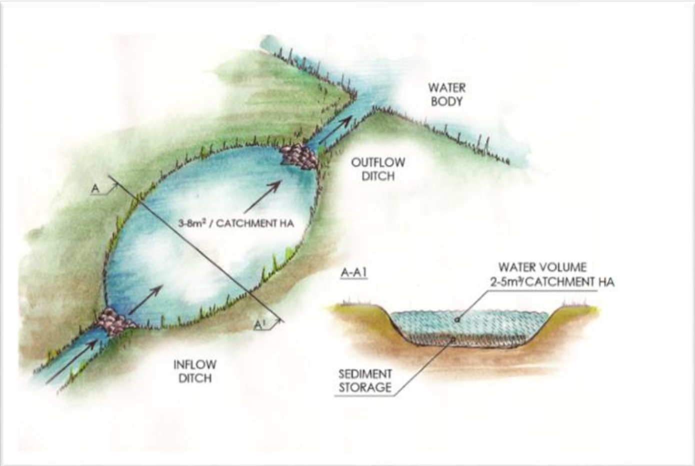


Figure 5. Top: Schematic diagrams of a sedimentation pond with recommended dimensions for SS retention. The outflow ditch is not cleaned. Cross-section A-A1 of the pond is illustrated on the right (Drawing Ilze Paulina). Bottom: The photo shows a sedimentation pond in Sweden (Photo Ulf Sikström).

Well-functioning sedimentation ponds reduce sediment transport by 30–40% and are particularly effective for the coarse-textured (grain size >0.63 mm) sediments. Very large ponds (>400 m3) might be needed to retain >50% of the SS loading. In areas where the inflowing sediment comprises either light organic particles or fine-textured (particle size <0.063 mm) mineral soil, sediment ponds should generally not be constructed. Here, wetland buffers may be more efficient.

Wetland buffers

Although wetland buffers have proved to be the most efficient water protection structure, their use in operational forestry is very limited. One major limitation to their use is that blocking or filling in the ditches in a designed wetland buffer area raises the GWL not only in the buffer area itself, but also in the upstream area. On sloping land, the area with a raised GWL above the buffer area may be just a few meters or tens of meters long but, in the very flat lowlands the rewetted area may extend several hundred meters from the buffer area.

Thus, the use of wetland buffers is restricted to areas where sloping land facilitates the construction of the buffer without severely disturbing tree growth in the upstream productive forest land. In flat areas, other water protection methods should be used instead of wetland buffers. Wetland buffers should also not be established on pristine mire areas with endangered plant species as vegetation in wetland buffer areas undergoes substantial changes due to increased nutrient input from the upstream DNM area.

Wetland buffer

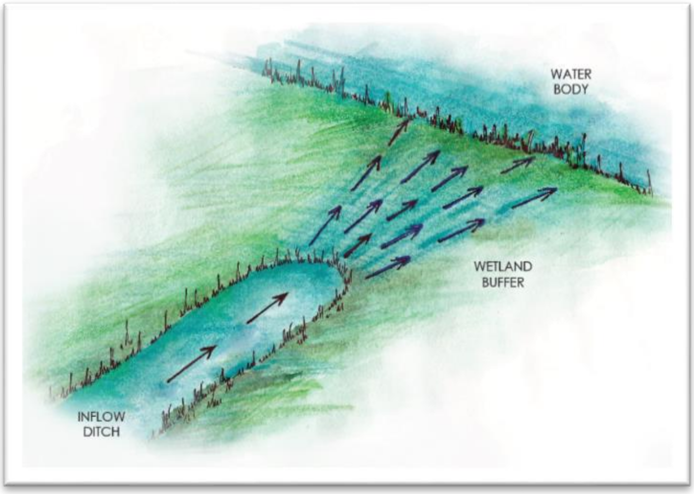


Figure 6. Top: The photo shows a wetland buffer (overland flow area) constructed to retain SS and dissolved and particulate nutrients from a drained area in northern Finland (Photo Antti Leinonen). Bottom: A schematic diagram of a wetland buffer (Drawing Ilze Paulina).

Natural and restored wetland buffers, also known as overland flow areas, are the most efficient of the different water protection structures at retaining SS and nutrients in drainage areas. Highly efficient SS retention has been reported, particularly where the SS inputs to buffer areas were large and the size of the buffer area was at least 0.5–1.0% of the size of the whole upstream catchment area. In addition, efficient retention of dissolved nutrients has been measured, especially after transient high nutrient loadings.

4. Monitoring and training

Key messages:

- Monitoring the efficiency of water protection measures is useful for developing water protection in DNM.
- Visual inspection of all water protection structures in DNM sites by the operators/field personnel and water quality monitoring networks organized by administrators are viable tools.
- Education in water protection is required for work on certified forest properties.
- Continuous education and training are needed for good quality DNM.

The efficiency of water protection measures in reducing the transport of SS and nutrients needs to be regularly monitored. The results should be analyzed and used to improve water protection practices and for evaluating the quality of the work. The EU Water Framework Directive, which requires all inland and coastal water bodies to reach at least "good" ecological status, defines quality standards for the concentrations of elements and hazardous substances in waters. Therefore, it is important to be aware of valid legislation and the ecological importance of water bodies being connected downstream of the DNM area.

A suggested minimum level of follow-up in daily forest operational work is **a visual inspection** of the quality of the constructed water protection structures according to predefined criteria. These criteria can be, for example, the volume of a sedimentation pond, the dimensions of the pipes in a PFC dam, the length of a wetland area, etc. This kind of self-monitoring could also be integrated with an external audit which may be required in certified forests.

Education and training are needed for planning and carrying out DNM and adequate water protection measures in forestry. Basic education is provided by the professional schools, colleges, universities and other organizations as a part of the education for a profession, or as supplementary education and training courses. Updating the knowledge from various sources of information and training by exercising profession are part of the everyday work. Areas have been established in different Baltic Sea Region countries to demonstrate DNM and implementation of good water protection practices.

5. More information

Finér, L., Čiuldienė, D., Libieté, Z. Lode, E., Nieminen, M., Pierzgalski, E., Ring, E., Strand, L & Sikström, U. 2018. WAMBAF – Good Practices for Ditch Network Maintenance to Protect Water Quality in the Baltic Sea Region. Natural Resources and bioeconomy studies 25/2018. Natural Resources Institute Finland (Luke), Helsinki.

Website of the WAMBAF project

About drainage on the WAMBAF website

List of terms

Ditch network maintenance (DNM) includes cleaning of existing ditches and creation of supplementary ditches for sustaining or improving forest growth.

Collector ditch: collects water from several ditches and transports it downstream.

Feeder ditch: a ditch which feeds water to a collector ditch.

Breaks in cleaning and digging of ditches: are sections of ditches that are not cleaned, with the purpose of reducing the water flow rate and capturing eroded solids.

Sedimentation pits: are widened sections of ditches, where water flows through a wider cross-sectional area, thereby reducing the flow rate. The aim of the pits (volume 1–2 m^3) is to capture solids eroded from ditches and to avoid their transport to water bodies.

Sedimentation ponds: are ponds constructed near the outlets of drainage areas where water flows through a wider cross-sectional area, thereby reducing the flow rate to capture eroded solids and to avoid their transport to water bodies. One pond with volume of 2–5 m^3 catchment ha^{-1} is constructed for a 40–50 ha DNM area.

Peak flow control (PFC): is created by dams and a set of control pipes which regulate water flow from DNM areas during high flows. Peak flow control reduces transport of eroded solids and particulate nutrients to water bodies.

Wetland buffers (Overland flow areas): are natural or restored wetland areas where runoff from DNM areas is distributed. Wetland buffers retain suspended solids and nutrients transported from DNM areas. Their recommended area is 0.5–1% of the catchment area.

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