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# Summary

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Ditch network maintenance (DNM) is carried out in order to sustain or increase tree growth. DNM includes operations aimed at improving drainage when a high groundwater level impairs tree growth. DNM should be financially justifiable and its harmful impacts on water quality should be minimized. Water protection should be considered when the suitability of DNM is assessed. In the present manual, technical instructions and materials required for constructing water protection structures are presented. The structures in question are fully described in the report “Good practices for ditch network maintenance to protect water quality in the Baltic Sea Region” (Finér et al. 2018). The purpose of these water protection structures is to reduce the transport of suspended solids (SS), nitrogen (N) and phosphorus (P) to downstream watercourses during and after DNM on forest land. In addition to the water protection structures used in DNM, examples of structures used to increase water retention in forest landscapes are briefly presented in the manual. It should be emphasized that the need for retaining water in forests is expected to increase due to climate change.

# Preface

This manual is produced as part of the WAMBAF (Water Management in Baltic Forests) Tool Box project, funded by the EU Baltic Sea Region Interreg Programme during April 2019–February 2021. The WAMBAF Tool Box project is a continuation of the WAMBAF project period which ran from March 2016 to February 2019; this was initiated to tackle the problems relating to water quality after forestry operations in the Baltic Sea Region. The first versions of sections 1.3.1 and 1.3.5 for the manual were written by Antti Leinonen, sections 1.3.2 and 1.3.6 by Laura Härkönen and Samuli Joensuu and section 1.3.4 by Juha Jämsén. Section 2 on water retention was written by Edward Pierzgalski. Leena Finér edited and compiled the manual, and all co-authors contributed to the writing.

**Key words:** bottom dam, ditch cleaning, peak flow control, peatland, restored wetland, retention pond, sedimentation pit, sedimentation pond, uncleaned ditch, water protection, water retention, wetland buffer

# Summary in Finnish

Ojia kunnostetaan suometsissä puuston kasvun ylläpitämiseksi ja/tai sen lisäämiseksi. Ojien kunnostuksella parannetaan kuivatustilaa alueilla, joissa korkealla oleva pohjavesipinta heikentää puuston kasvua. Ojien kunnostuksen tulee olla taloudellisesti kannattavaa ja sen haitalliset vesistövaikutukset tulee minimoida. Vesiensuojelu on huomioitava jo ojien kunnostustarvetta arvioitaessa. Tässä julkaisussa annetaan ohjeita vesiensuojelurakenteiden rakentamiseen ja materiaalien valintaan. Vesiensuojelurakenteet on tarkemmin kuvattu julkaisussa ” WAMBAF – Hyvät käytännöt kunnostusojituksen vesiensuojeluun Itämeren alueelle” (Finér ym. 2019). Vesiensuojelurakenteiden tarkoituksena on vähentää kiintoaineen sekä typen ja fosforin huuhtoutumista vesistöihin ojien kunnostuksen aikana ja sen jälkeen. Tässä julkaisussa annetaan myös esimerkkejä rakenteista, joita voi käyttää veden pidättämiseen metsäalueilla. Veden pidättämisen tarpeen on arvioitu lisääntyvän tulevassa ilmastossa.

# Contents

# 1. Water protection in DNM

## 1.1. Introduction

The primary aim of ditch network maintenance (DNM) is to sustain and/or improve forest growth by appropriately managing drainage. DNM should be financially justifiable and its harmful impacts on water quality should be minimized; water protection should be considered when the suitability of DNM is assessed. An assessment of the suitability of DNM to improve drainage includes several steps, which are summarized in Appendix 1 and described in detail in Finér et al. (2018).

In the present manual, the technical instructions and materials required for constructing water protection structures described by Finér et al. (2018) are presented. The purpose of these water protection structures in the Baltic Sea Region is to reduce the transport of suspended solids (SS), nitrogen (N) and phosphorus (P) to watercourses during and after DNM on forest land.

When executing DNM operations, national legislation and also, for certified forests, the national forest certification standards must be followed.

We hope that this manual will 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 definitions of the terminology used, we refer readers to the list at the end of this manual.

## 1.2. Planning water protection structures

Managing water quality to reduce SS and nutrient release and transport from drained forest sites at DNM can be achieved mainly by: i) controlling drainage intensity, i.e. the length of the original ditches being cleaned plus possible new supplementary ditches being excavated in the drained area, as well as the depth, width and the slope of these ditches; ii) reducing the velocity and erosive force of drainage water; and iii) capturing the SS and nutrients released after DNM but before they enter the receiving watercourse. Overall, it is very important to avoid erosion, since when soil erosion occurs it is difficult to capture and retain the eroded material. The drainage intensity, water velocity and erosive force can all be controlled by leaving some ditches or ditch stretches uncleaned and by avoiding deepening the ditches. Water velocity and the erosive force of drainage water can also be controlled by constructing bottom dams and peak flow control (PFC) structures. In addition, PFC structures together with sedimentation pits and ponds can capture SS and associated nutrients transported with water. Except for SS, wetland buffers can also capture dissolved nutrients. When possible, several water protection measures and structures should be used at DNM sites. When planning water protection, special attention should be paid in areas where drainage water is conveyed to a highly sensitive or valuable water body. The planning process should include the following four steps presented in sections 1.2.1–1.2.4. Although the two steps “establishing the suitability of DNM” and “mapping” of a drained site comprise a partly interactive process as they depend on information from each other, in the following they are described in two separate sections.

### 1.2.1. Establish the suitability of DNM for the site

It is important to establish the suitability of DNM carefully. Only select sites where DNM is expected to sustain or increase tree growth and to be economically justifiable. A suggested decision support flowchart is given in Appendix 1. Detailed information on how to do the assessment and to establish the degree of suitability is presented by Finér et al. (2018).

Regarding the groundwater level for adequate tree growth at a drained forest site, it is suggested that it should be about at least 35–40 cm or deeper below the soil surface during the late growing season (Finér et al. 2018 and references therein). Hence, a shallower level can motivate a DNM operation.

### 1.2.2. Map the site

#### *Catchment area and location of watercourses*

Delineate the *entire catchment area hosting the drainage site on a topographic map* (Fig. 1). This can be done by studying, for example, existing maps of stream and ditch networks in the catchment, or by using digital catchment delineation tools. When the entire catchment area with the potential DNM area is identified, the *location of all watercourses and ditches* are mapped; existing GIS-tools, maps, old drainage plans and aerial photographs can be helpful. Field examination of the performance of the existing ditch network is also necessary. In addition, the downstream watercourses receiving drainage water need to be assessed and their need for protection identified.

#### *Identify drainage and collector ditches*

For planning the type, number and location of the proposed water protection structures, it is important to classify the existing ditches into two categories: *drainage ditches* and *collector ditches* (Fig. 1). The purpose of drainage ditches is to lower the groundwater level in their immediate surrounding area. Collector ditches *gather* the water from the drainage ditches – thereby maintaining their drainage function – and transport water from the drained site. At the DNM site there can also be *separator ditches* that are made to keep water from flowing from the upper part of the catchment area into the DNM area: only water from the actual DNM area should be conducted to the water protection structures.

#### *Ditch spacing and orientation*

Determine the *catchment area of single ditches and ditch slope along their entire length, as well as the soil type and soil texture* (see Table in the list of terms section below) *in ditch beds and banks*. This information is needed for planning DNM and water protection. Accurate information on the soil type needs to be acquired from a field visit, since the resolution of the existing soil type maps may be inadequate. For example, if the slope of the ditch bottom is steeper than that recommended for the shear strength of the soil then the risk of erosion is significantly increased. Also, the effective drainage area of ditches is dependent on *the hydraulic conductivity of the soil, i.e. the ability of the soil to transmit water*.

On average, efficient drainage is achieved within 20–25 m on both sides of ditches in Finnish conditions. If ditch spacing is greater than 80 m (in Finnish conditions) and digging new supplementary ditches is not possible, it is wise to refrain from DNM as the effect on drainage is likely to be inadequate. Maintaining single isolated ditches is not advised, because their direct drainage effect is limited to their immediate surroundings; in addition, they are often located in places where their target is to conduct water from a larger area, which may contribute to a high risk of erosion. On the other hand, if these single ditches can cope with transporting high water volumes, this usually helps to maintain their capacity to conduct water in sufficient quantities after first-time ditching.

*Orientation of ditches* must also be considered: when ditches in a DNM area are oriented along the slope of the area (i.e. perpendicular to contours), their drainage effect is not optimal and erosion can be elevated during peak flows. To obtain an optimal drainage effect and to lower erosion risks, ditches should be oriented perpendicular to the main slope, and the length gradient of the ditch should be between 0.2–0.5%. If the orientation of the existing ditch network is problematic with regard to drainage efficiency and erosion risks, reconsider the overall suitability of DNM in the area.

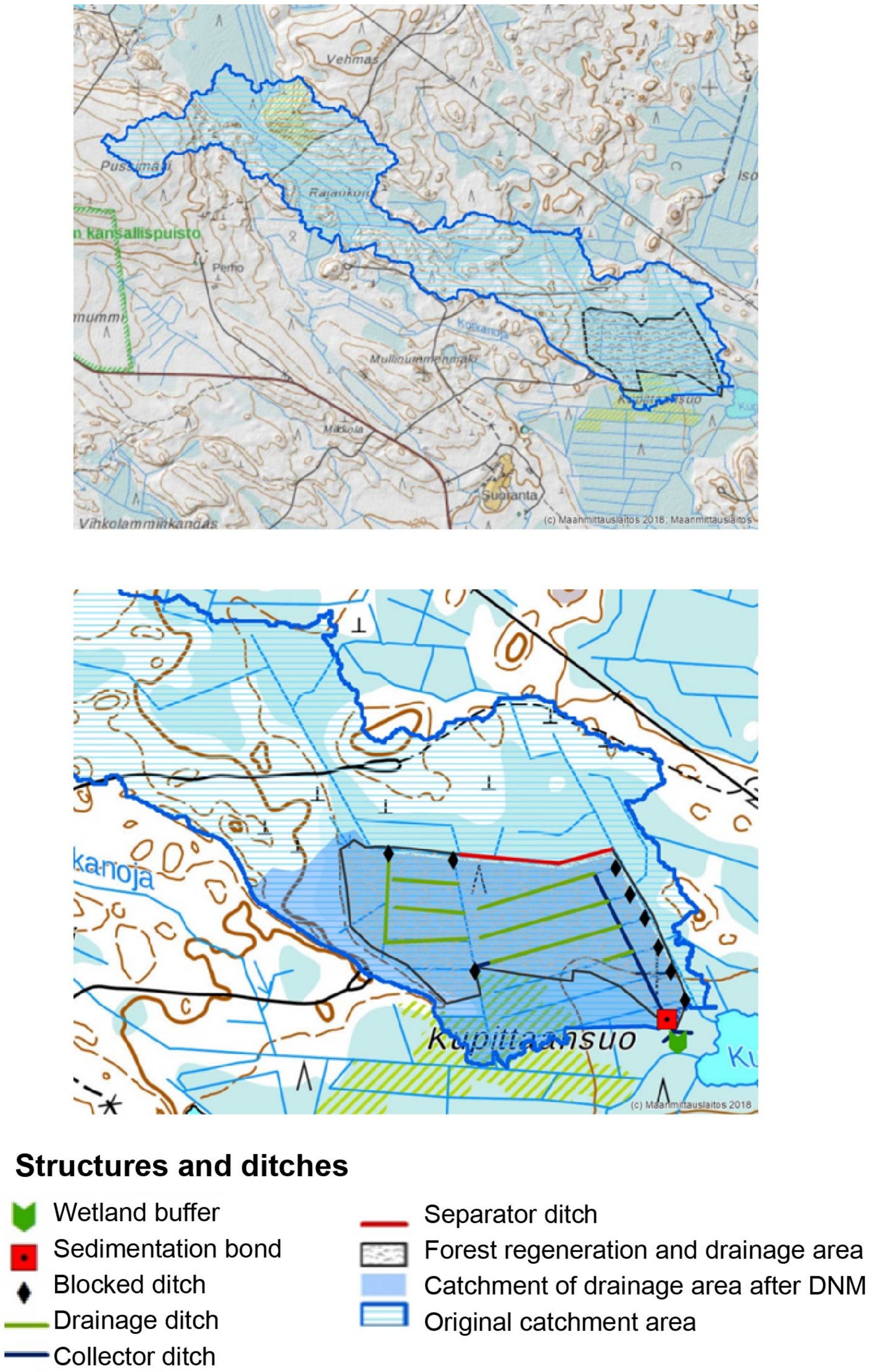


**Figure 1.** The upper map shows a catchment (demarked in blue) located in southern Finland. Inside this catchment (black dotted line), the Kupittaansuo ditch network maintenance and clear-cut area is located. The lower map shows a close-up of the Kupittaansuo area. Different types of ditches and water protection structures are marked with symbols. Maps by National Land Survey of Finland and Antti Leinonen.

### 1.2.3. Plan the water protection structures

A flowchart illustrating the logical order of planning and choosing water protection structures in DNM areas is shown in Fig. 2.

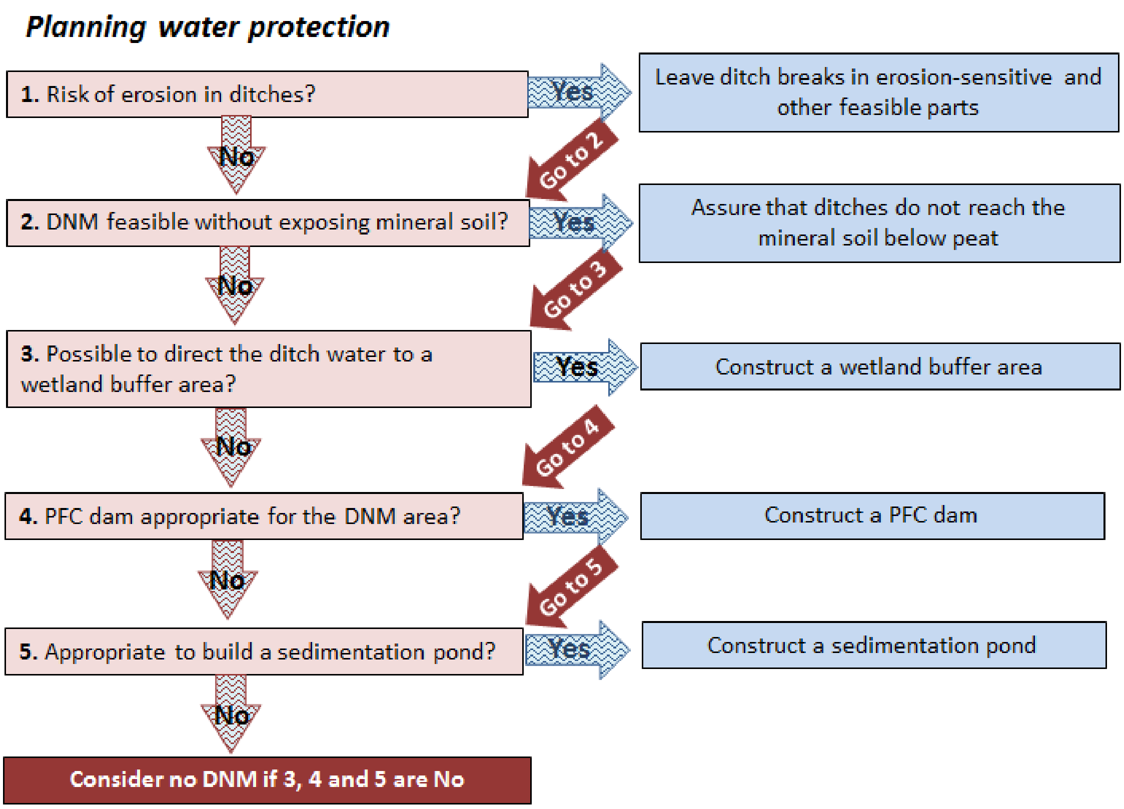


**Figure 2.** A flowchart illustrating the logical order of planning water protection structures that may be effective in areas where DNM has been found to be suitable. PFC = peak flow control. Flowchart from Finér et al. (2018).

### 1.2.4. Plan the operation and communicate

The ditches to be cleaned and the type and location of the water protection structures are preferably documented on a map of the DNM area (Fig. 1). The map, together with clear working instructions for the DNM operation, is distributed to the machine operator well before the start of the work. A general principle is that the first task of the DNM operation is to construct the water protection structures, which are supposed to capture eroded SS. DNM operations should be avoided during periods of high water flow. If it is also intended to carry out timber harvesting within the DNM area, then it is appropriate to plan these operations simultaneously; trees which grow along the ditches and potentially obstruct the DNM operation can be removed during the harvesting operation. Also, any logging residues deposited in the ditches during the harvesting can also be removed during DNM.

## 1.3. Water protection structures in a DNM area

Sections 1.3.1 to 1.3.6 present technical instructions and lists of materials needed for constructing the water protection structures that have been described. In addition, the expected function and appropriate location of each structure are presented; the need for monitoring and maintenance to ensure optimum functioning is also discussed.

Our knowledge on the efficiency of uncleaned ditches and ditch stretches, sedimentation pits and bottom dams in reducing the transport of N, P and SS to surface waters is mainly based on practical experience. There are a number of experimental studies showing the efficiency of PFC structures, wetland buffers and sedimentation ponds in water protection (see Finér et al. 2018 and Nieminen et al. 2018 and references therein).

### 1.3.1. Uncleaned ditches and ditch stretches

*Function*

To avoid erosion and transport of SS to receiving waters, it is essential to *critically evaluate the actual need of DNM for every ditch separately.* To achieve efficient drainage with minimum ditch cleaning an option is to leave some uncleaned ditches and ditch breaks within the DNM area (Fig. 3). The function of such uncleaned ditches and ditch stretches is to reduce water velocity and hence also the transport of SS from a DNM area.

**Figure 3.** Examples of a drainage ditch (left) and a collector ditch (right) on sites where first-time ditching has promoted forest growth in Sweden. Some stretches of the ditches have been left uncleaned, and sedimentation pits have been dug every 100 to 200 metres along the ditches. Photos by Bo Leijon.

*Location*

Categorization into drainage ditches and collector ditches (see section 1.2.2 and Fig. 1) is useful for assessing the need for maintenance of individual ditches. A ruleset for this (for both categories) is given below.

*Drainage ditches:*

- If the groundwater level before cleaning is deeper than 35–40 cm within 20–25 m distance besides a ditch, consider leaving it uncleaned.
- Leave breaks in cleaning in ditch stretches where the length gradient of the ditch exceeds circa 0.5% or where there are signs of erosion in ditch banks or bottoms.
- A break in ditch cleaning should be at least 10 m long. Otherwise it may be flushed away.
- Consider leaving breaks in cleaning before connecting a drainage ditch to a collector ditch.
- Keep in mind that a break in cleaning can raise the water level in the drainage ditch and may locally affect the groundwater level and tree growth.
- To minimize the erosion risk in drainage ditches, no water coming from outside the drainage area should be diverted into the drainage ditches. (This refers to drainage water from e.g. roadside ditches, ditches in agricultural land, old ditches outside the drainage area, etc.)

*Collector ditches:*

- The water flux in collector ditches is often higher than in drainage ditches; consequently, the erosion risk of collector ditches is considerably higher compared to drainage ditches.
- For collector ditches, the general rule should be that they are not cleaned, since the desired drainage effect is achieved by the drainage ditches, and erosion risk is plausibly severe in the collector ditches. Especially in cases where the collector ditch funnels water through a drained area, it is advised to avoid cleaning the collector ditch. If it is not possible to leave collector ditches untouched, *only those ditches or stretches of collector ditches should be cleaned* which are necessary for their functioning and maintaining the water level in the drainage area 35–40 cm below the soil surface during the growing season.
- During snowmelt and heavy rainfall, the water level can be raised in collector ditches without affecting tree growth in the drained area.
- To help to identify collector ditches, different GIS-datasets which represent flow accumulation or flow order of the channels can be used.

### 1.3.2. Sedimentation pits

*Function and location*

Sedimentation pits are insets that are dug in drainage ditches (Fig. 4). They are made at approximately 100 m intervals and right upstream of every ditch crossing of drainage ditches. The volume of sedimentation pits usually varies from one to two cubic metres. Sedimentation pits may retain coarse SS during and after a DNM operation. Since sedimentation pits are quite small their retaining capacity is very limited and the sedimented material may be easily flushed away, for example during periods of high water flow. Therefore, the justification for their construction should be carefully considered before work begins.

*Materials and construction*

No materials are needed. Sedimentation pits are dug by an excavator.

*Monitoring and maintenance*

No monitoring and maintenance is needed. Sedimentation pits may retain coarse SS in conjunction with the DNM operation.

**Figure 4.** Sedimentation pits in drainage ditches in southern Sweden. Photos by Eva Ring (left) and by Anja Lomander (right).

## 1.3.3. Bottom dams

### *Function and location*

The aim of installing a bottom dam is to reduce the slope of the ditch, consequently reducing the water velocity. This entails reduced risk of erosion and enhanced probability of sedimentation of eroded material, preventing its further transport. The dams are constructed by putting stones, wood or other materials on the bottoms of collector ditches (Fig. 5).

Bottom dams are mainly used in ditches in areas that are susceptible to erosion. The water velocity in ditches can also be reduced by using uncleaned ditch stretches (see section 1.3.1). In addition, temporary dams, made of logging residues, can be used in ditches during DNM operations to reduce erosion by slowing down the water velocity. However, these temporary dams need to be removed when the operation is over.

### *Construction*

In ditches where the water velocity is low, a bottom dam can be constructed simply by using filter fabric and stones or breakstone upholstery. In ditches where the water velocity is high, a supporting wall is also needed (Figs. 5 and 6). A supporting wall can be made of planks (using a tongue-and-groove system) or water-resistant plywood.

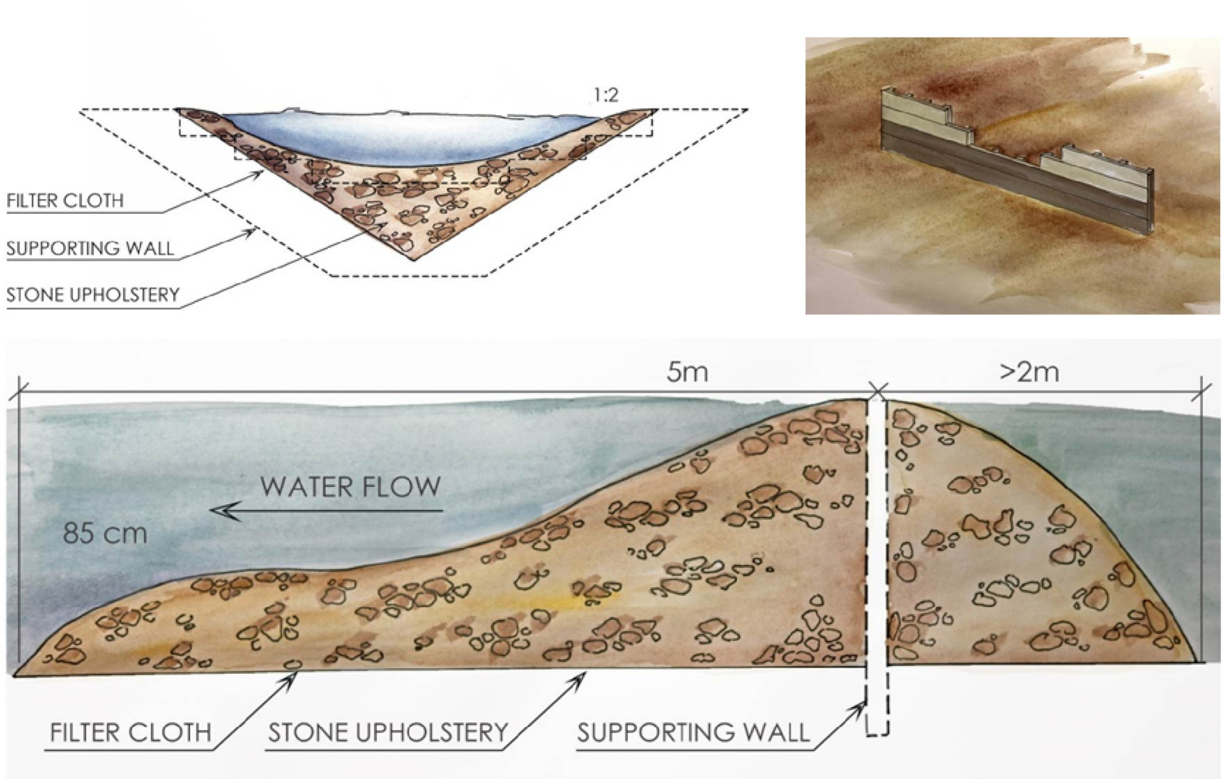


**Figure 5.** A cross-section in scale 1:2 (above, left) and longitudinal cross-section (below) of a bottom dam and the supporting wall before the stone upholstery is piled around it (above, right). Figures by Ilze Pauliņa.

**Figure 6.** To the left a bottom dam in operation. Photo by Leena Finér. To the right, a supporting wall under construction: it is placed in the middle of the bottom dam across the ditch where the water velocity is expected to be high. Photo by Matti Seppälä.

Bottom dams should be constructed during a dry period in summer. However, to avoid soil disturbance, it is a good idea to transport the stone material to the site when the soil is frozen to avoid soil disturbance by forestry machines. The used stones and breakstone material must be coarse (particle size in the region of 200–400 mm). The type and size of material must be selected taking into account the water velocity in the ditch; the construction material must not be displaced by the water.

The construction of a bottom dam proceeds as described below:

- The first construction operation is to excavate a slanted edge for the dam.
- Thereafter the supporting wall is installed in the middle of the bottom dam across the ditch, in a way so that its bottom reaches the mineral soil – such soil which is not easily eroded – and the edges of the wall are far enough outside the sides of the ditch.
- Filter cloth is spread over the bottom and the sides of the ditch and the supporting wall. The pelts of the filter fabric are placed perpendicular to the direction of the ditch. If several pelts of the filter cloth are used, the edges of the pelts are placed on top of each other, so that the edge of an upstream pelt always is on top of the next downstream pelt. A roughly 50 cm wide edge of the most upstream filter cloth pelt is excavated in soil perpendicular to the ditch bottom to prevent the water flowing under the dam.
- Using an excavator, the stone upholstery is placed on top of the filter cloth and to some extent also downstream of the bottom dam.

### *Materials*

- An excavator is needed for the work
- Planks with tongue and groove or water-resistant plywood (if a supporting wall is needed)
- Filter cloth
- Stones or breakstone material (particle size 200–400 mm)

### *Monitoring and maintenance*

The proper functioning of the bottom dam must be ensured at the end of the construction.

## 1.3.4. Peak flow control structures

### *Function*

PFC structures are used to prevent and/or reduce soil erosion in DNM areas (Fig. 7). They also enhance sedimentation of eroded SS on the ditch bottoms or in water protection structures installed in the actual ditch system. The function of a PFC structure is to reduce water velocity in the upstream ditches by damming water temporarily during peak flow periods, but without affecting tree growth and drainage of the area (Figs. 7 and 8). PFC structures can retain on average 61% of SS, 45% of total nitrogen and 47% of total phosphorus transported with water, and during peak flows the retention can be close to 90% (Marttila 2010).

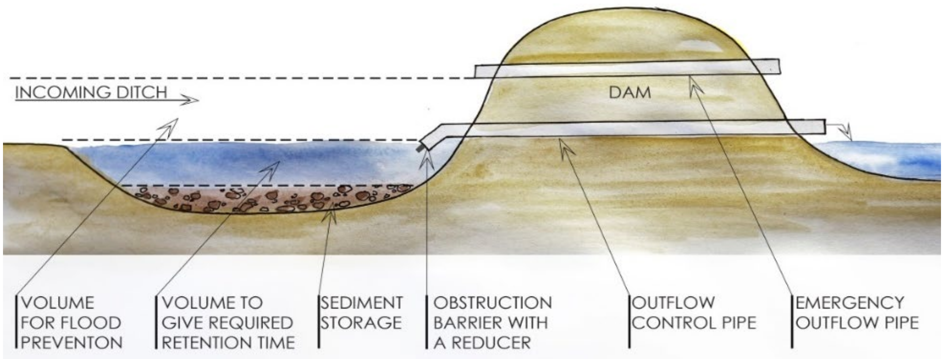


**Figure 7.** A peak flow control structure. The lower, outflow control pipe is installed at the level needed for sufficient drainage of the forest area upstream of the structure. This level is usually the same as the bottom of the ditch draining to the dam (the bottom of the ditch shown in the Figure on the left). The upper, emergency overflow pipe is installed 30–40 cm below the surface level of the surrounding ground. Great care should be taken when installing the pipes: do not allow any water to pass by outside the pipes as this can cause erosion of the dam wall. Figure by Ilze Pauliņa.

**Figure 8.** Peak flow control structures at two of the WAMBAF demonstration sites. Note the two visible pipes at the Tobo site in central Sweden (left). Photo by Lars Högbom. Currently, in Vengasoja in central Finland, the upper emergency outflow pipe is visible, the reducer attached to the outflow control pipe is below the water surface (right). Photo by Leena Finér.

### *Location*

The use of PFC structures is recommended in ditch networks where the damming effect of the structure can affect most of the cleaned ditches. Mapping the potential location for a PFC structure in a DNM area can be done by using 3D-terrain model maps, soil profiles and information on the land use and location of existing ditches. The potential effects of the structure can be studied by using GIS-tools. The best damming effect is usually achieved in collector ditches and at their crossings (Fig. 9).

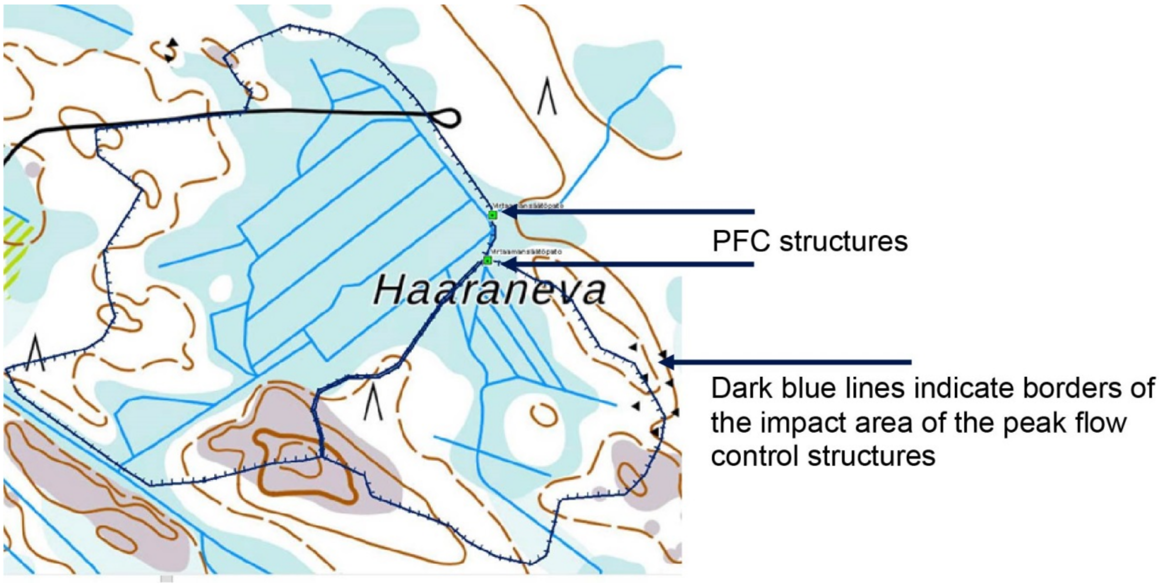


**Figure 9.** Haaraneva ditch network maintenance area in central Finland. Two peak flow control structures (green squares) are located at the outlet of the ditch system. Map by National Land Survey of Finland and Juha Jämsén.

*Construction*

To determine the dimensions of a PFC structure, information on the upstream catchment area, the amount of runoff entering the structure and its water transmittance capacity is needed.

- The area of the catchment can be estimated from maps or by using digital catchment area determination tools.
- Nomograms and calculation tools can be used for estimating runoff (see section 1.3.6 and Marttila 2010).

The dimensions of the PFC structure are based on the required damming effect: the aim is to dam water during peak flow without having a negative impact on tree growth. Therefore, it is important to know the correct drainage capacity of the outflow control pipe to be installed. The water transmittance capacity of pipes can be estimated by using pipe-specific transmittance equations (Marttila 2010). The diameter of the PFC pipes that is needed can be determined directly by using catchment area-based nomograms developed for central Finland (Fig. 10). To use these nomograms in other regions requires adjusting the dimensions of the pipes to the local runoff rates.

The construction of PFC structures is done with an excavator (Fig. 11) before starting a DNM operation. Soil materials found at the site are used for constructing the dam.

If the soil on the site is easily eroded or susceptible to frost heaving, suitable alternative material can be transported to the site for constructing the PFC structure. In the outflow control pipe an obstruction barrier is used in order to prevent big particles floating at the water surface from entering and blocking the outflow control pipe (Fig. 12). Usually, an adapter is also needed to reduce the diameter of the pipe to the desired dimensions (Fig. 10).

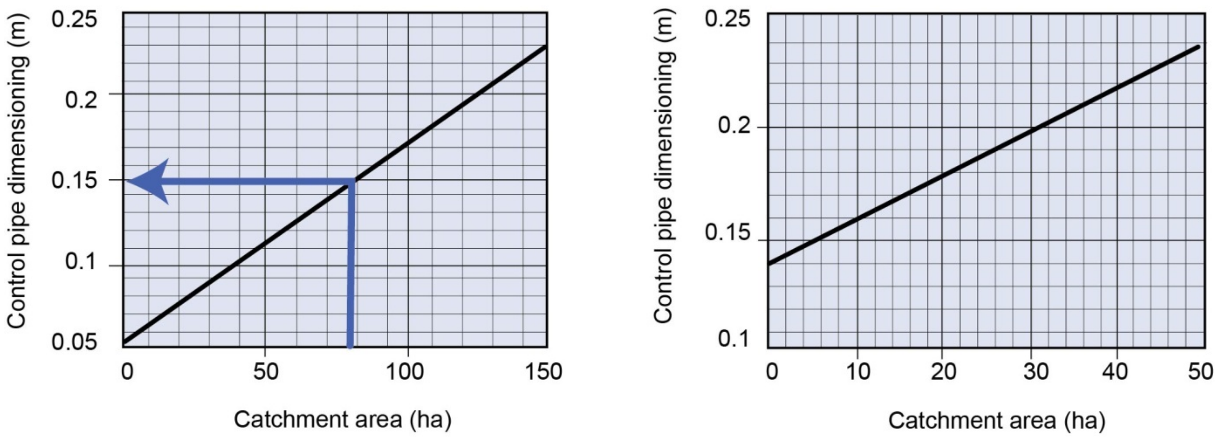


**Figure 10.** Nomograms used for determining the diameter of outflow control pipes in peak flow control structures in Finland (Marttila 2010). The left one is used in large catchments where there are undrained areas upstream of the peak flow control structure. The one to the right is used in catchments where the whole area is drained, or in areas where there are also dams downstream of the peak flow control structure. The blue lines indicate how to use the nomogram in large catchments; in the example, the entire catchment area is 80 ha, and according to the nomogram the outflow control pipe should have a diameter of 0.15 m.

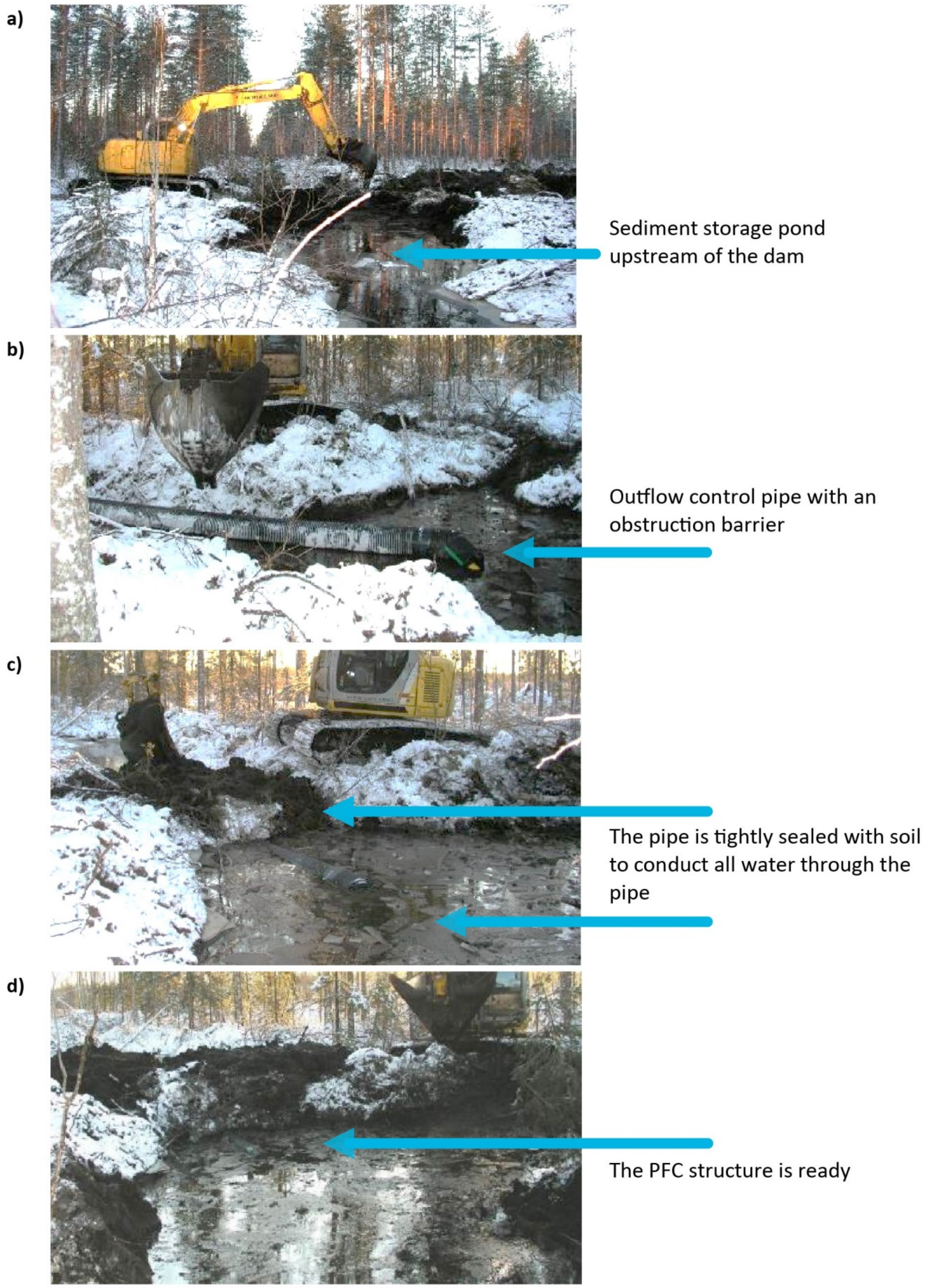


**Figure 11.** Steps in the construction of a peak flow control structure: a) First, a sediment storage pond is constructed upstream of the peak flow control structure; b) thereafter, the outflow control pipe is installed; c) the peak flow control dam wall is then sealed with peat; and d) the construction is ready and in functioning mode. Note that no emergency outflow pipe was constructed. Photos by Juha Jämsén.


**Figure 12.** An example of an obstruction barrier with a reducer. The angle of the obstruction barrier in the photo is 45 degrees. However, the angle can also be 90 degrees, since such obstruction barriers may usually be more easily available. Photo by Juha Jämsén.

*Materials*

- Pipes: minimum length 6 m, outer diameter minimum 200 mm
- Obstruction barriers, designed to keep the end of the outflow pipe under the water level on the upstream side and to allow the desired flow and prevent the blockage of the pipe (Fig. 12). Obstruction barriers can be ordered from the pipe manufacturers, if they are not readily available elsewhere.
- Reducers, to be attached to the obstruction barriers for reducing the end of the pipe to the desired diameter (Figs. 10 and 12). Reducers can also be made by fitting a lid with a hole of the required diameter at the end of the pipe.

*During construction attention should be paid to the following issues:*

- The obstruction barrier should be attached tightly to the outflow control pipe, which can be done, e.g., by using screws.
- A minimum distance of 60 cm must be left between the inlet of the outflow control pipe and the bottom of the pond.
- Pipes must be installed horizontally without leaving any big particles, e.g. stones, under them. The dam wall, preferably consisting of peat, should be sealed tightly around the pipes, only allowing water flow through the pipes, not outside them.
- The dam should be constructed 10–30 cm above the level of the surrounding ground and it should be sealed tightly to prevent water outflow over the structure during peak flow events. Using peat instead of easily eroded mineral soils is preferred and strongly recommended.
- The sides of the dam should be inclined and sealed tightly.

*Monitoring and maintenance*

There is a risk of pipes becoming blocked during the DNM operation when peat or other objects are released and transported with the drainage water. Therefore, it is important to monitor the functioning of the structure during DNM operations. The function of the structure also needs to be checked when the DNM has been finished. Moreover, it is recommended to inspect and ensure the correct functioning of the PFC structure during the first spring after the DNM and after extreme flows thereafter. It is usually sufficient to check that the transmittance of water in the pipes continues and to remove anything blocking the pipes.

## 1.3.5. Wetland buffers

### *Function*

Wetland buffers are constructed by distributing drainage waters from ditches through surface flows before reaching a stream or lake (Fig. 13). A wetland buffer can be constructed by blocking an existing collector ditch. During surface flows, SS can be retained in the wetland buffer by the vegetation; if the residence time of the water is sufficiently extended some soluble nutrients can be taken up by the vegetation. For good functioning, the size of the wetland buffer should be at least 0.5–1% of the whole catchment area. In favorable conditions, high amounts of SS and adhered mineral elements may be deposited within peat and surface vegetation of the buffer (Nieminen et al. 2015). *Wetland buffers are among the most efficient water protection structures at DNM sites, and therefore they should be used whenever and wherever possible.*

### *Location*

When planning wetland buffers, precise information about the topography and surface elevation of the potential area is needed, in order to estimate whether construction of the planned buffer is actually feasible. Wetland buffers raise the water table in the upstream ditch network (Fig. 14). Hence, wetland buffers cannot be constructed in totally flat areas, because in such locations they cause flooding, which has negative impact on tree growth. Ideal areas for creating wetland buffers are either open or sparsely forested peatlands, where a high groundwater level does not cause economical losses due to impaired tree growth.

Before selecting the place where the collector ditch is blocked, the elevation of a shallow ditch, that will be dug to lead water to the surface flow initiation points, should also be carefully determined. Preliminary planning can be done in the office by using digital elevation models and a ditch profile tool (Fig. 15) to accurately target the field work in the potential areas are marked for the construction of wetland buffers. The elevation measurements and the final determination of the place for the blocks and the new ditches should be done in the field with level or tachymeter.

**Figure 13.** A wetland buffer in central Finland (left), and water from a drainage area being conducted to a pristine mire in eastern Finland (right). Photos by Antti Leinonen.

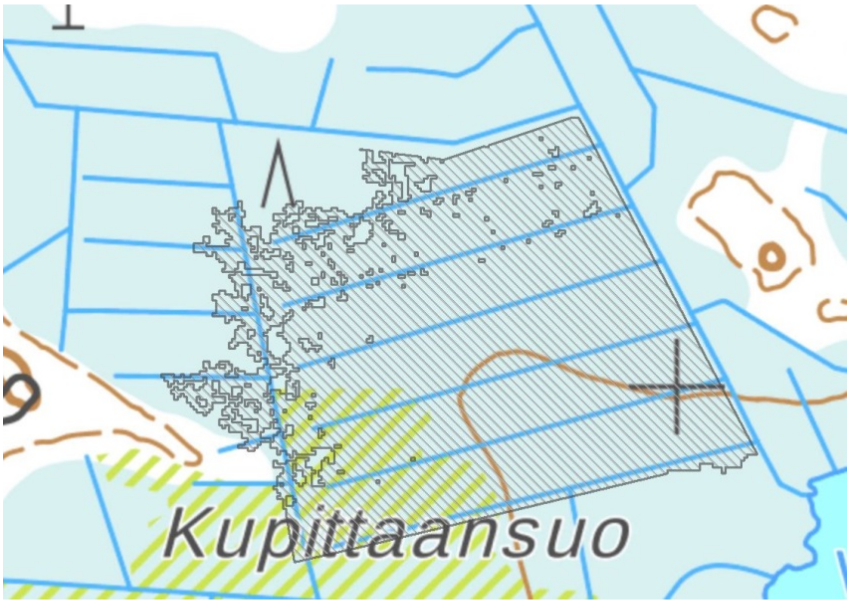


**Figure 14.** Figure showing the area where groundwater level is affected (shaded area) by the wetland buffer in the Kupittaansuo ditch network maintenance area in southern Finland. Map by National Land Survey of Finland and Juha Jämsén and Antti Leinonen.

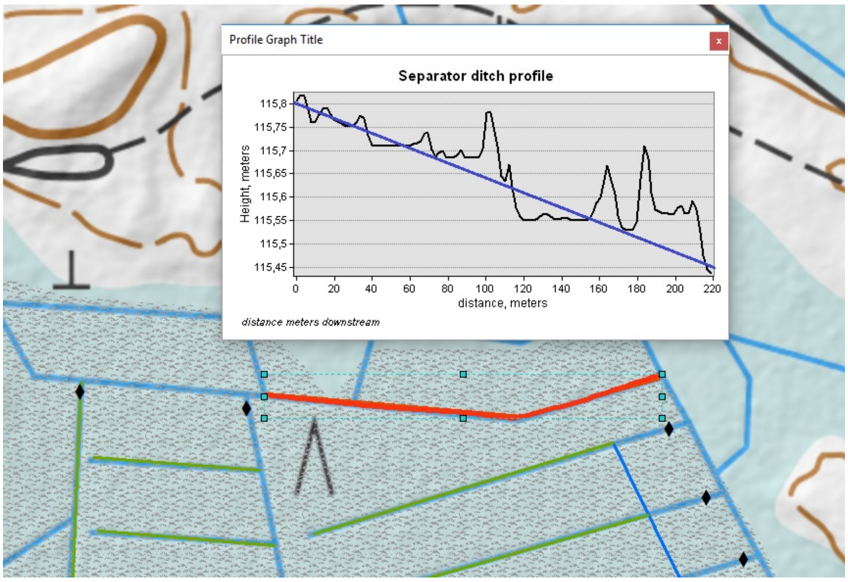


**Figure 15.** An example of using a ditch profile tool for visualzing the inclination of a ditch in the Kupittaansuo ditch network maintenance area shown in Fig. 1. Figures by National Land Survey of Finland and Antti Leinonen.

### *Construction*

A wetland buffer can be constructed by blocking an existing collector ditch with soil from the actual site or with other material (e.g. logs, filter cloth) to direct the water flow into the wetland buffer (Fig. 16). Undecomposed peat is the best soil material for this purpose; coarse mineral soil and fine mineral soil containing very coarse particles are unsuitable, since water easily filtrates through them. For a solid blocking, the ditch length filled with soil should be at least ten metres long, and the soil should be packed carefully. If water velocity is high, filter cloth can be used to strengthen the filling. The soil in the filling will gradually settle, and the filling should therefore be made at a minimum of a half a metre above the surface of the surrounding ground.

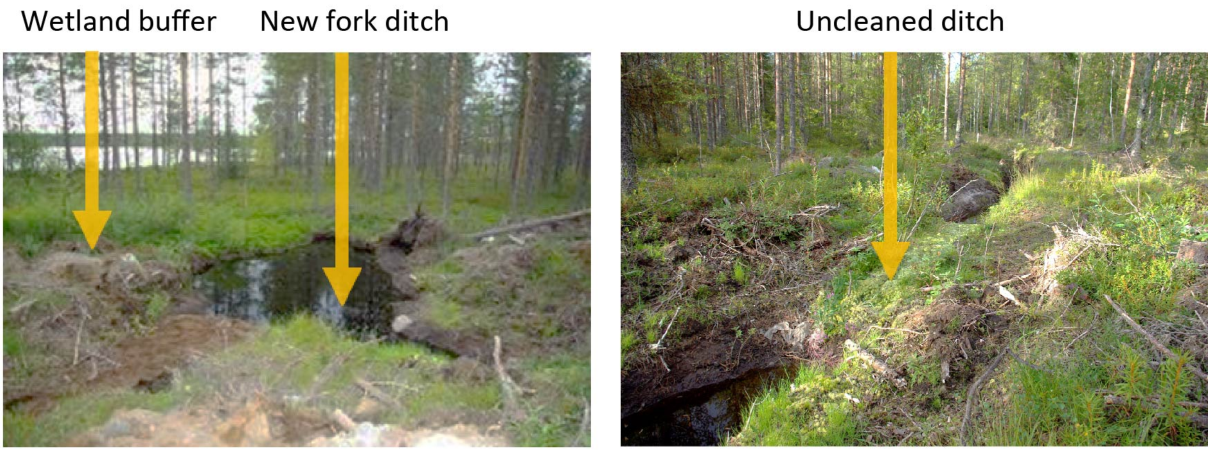


**Figure 16.** A new ditch dug in the form of a fork (Y) in order to distribute water to a wetland buffer in Finland (left), and an uncleaned part of a ditch (right). Photos by Eva Ring.

Depending on the terrain, a new shallow ditch can also be dug into the buffer at the start of the surface flow (Fig. 16). It is essential that water spreads evenly across the whole wetland buffer; this can be further enhanced by digging a shallow ditch in the form of a fork to feed water evenly into the whole buffer. Distributing water evenly in the buffer will increase the retention time, and thus enhance the retention of SS and nutrient uptake. In order to prevent erosion and export of retained SS from the buffer, it is important not to lead all waters to one spot, especially if the water velocity is high. Special attention and extra careful planning should be done in cases where the wetland buffer is collecting water from areas larger than 50 ha.

### *Materials*

Soil materials found at the site are used for blocking ditches. Eventually, logs or filter cloth are used for blocking.

### *Monitoring and maintenance*

After construction, the even distribution of the water should be checked, and if necessary adjustments made.

## 1.3.6. Sedimentation ponds

### *Function*

The function of sedimentation ponds is based on their ability to slow down the velocity of the incoming water and enhance the sedimentation of SS at the bottom of the pond (Fig. 17). Sedimentation ponds can reduce the transportation of SS and their associated nutrients, but not soluble nutrients. Sedimentation ponds are most efficient in drainage areas where the ditch bottoms consist of gravel or coarse sand. In such areas, sedimentation ponds can retain 30–50% or at maximum 60–70% of the SS transported with water (Joensuu et al. 1999).

*Water protection in DNM areas should not be based solely on the use of sedimentation ponds*; instead, all suitable water protection measures that reduce erosion should be used. Sedimentation ponds should not be the primary method, especially in areas where the peat layer is thick, i.e. the ditch bottoms do not reach the mineral soil layers in the drainage area. Eroded peat cannot be retained in sedimentation ponds. On the other hand, sedimentation ponds should not be used at all when the ditch bottom material is clay, since it does not sedimentate easily once eroded. The efficiency of sedimentation ponds can be increased by connecting them with a PFC structure, a wetland buffer or by leading the pond water to a vegetated and uncleaned ditch.

**Figure 17.** To the left, a newly constructed sedimentation pond in Latvia (photo by Zane Lībiete); to the right, a 20-year-old sedimentation pond in central Finland. Photo by Tommi Tenhola.

### *Location*

The size of a sedimentation pond is determined by considering the amount of incoming water. When planning the pond, it should be kept in mind that the size of the pond should not be too large and difficult to construct. The catchment area served by a sedimentation pond should not be larger than 40–50 ha. This means that in large drainage areas several ponds should be installed instead of one large pond constructed in the main outlet of the area. Also, drainage water should be led into the ponds from one direction only, i.e. ponds should not be placed at a junction of multiple ditches.

When planning the location of sedimentation ponds, in addition to the amount of water flow to the ponds, the soil type must also be considered. Sedimentation ponds should be located preferably in drainage areas where the soil consists of gravel or coarse sand.

Sedimentation ponds should not be constructed in areas which are regularly flooded, and in addition they should not be located in areas where they would receive considerable amounts of water from outside the drainage area.

### *Construction*

The appropriate dimensions of a sedimentation pond will depend on the amount of water it receives. The calculations for the dimensions start by predicting the mean maximum spring runoff (MHQ), which is equal to the mean of the highest daily runoff during a normal year (determined from data over a long period of time, for example 30 years). In Finland MHQ is determined by using equations based on experimental studies on small forested catchments (Seuna 1983; Fig. 18). The use of MHQ is justified, since most of the SS transportation takes place during spring runoff.

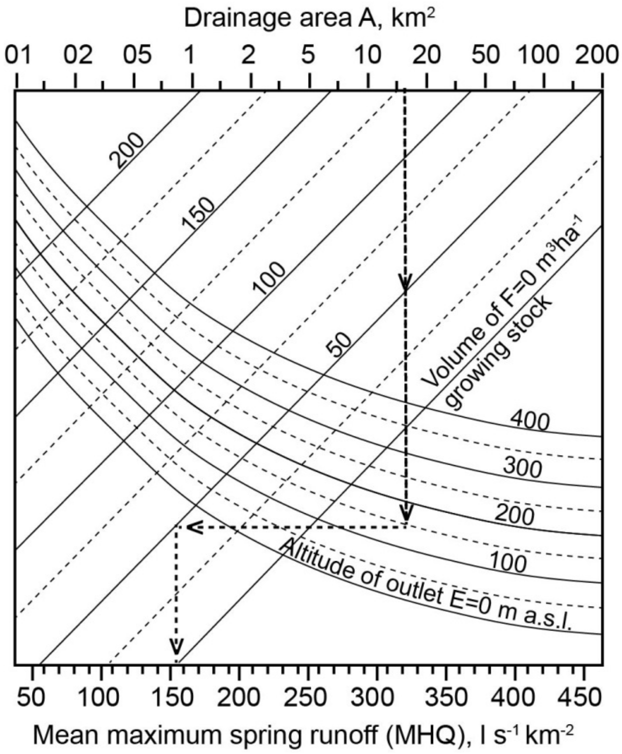


**Figure 18.** A nomogram for determining the mean maximum spring runoff (MHQ). MHQ = $113A^{-1/3} + 0.34E - 1.9F + 158$ (Seuna 1983). MHQ is defined as the largest instantaneous runoff peak observed during the snowmelt period. The nomogram is based on ≥10 years' monitoring data from 37 small catchments located in different parts of Finland. The example (dotted angled line) shows that MHQ is 155 mm for a drainage site, the area (A) of which is 16 km$^2$, the altitude (E) of its outlet is 150 m above sea level (a.s.l.) and the mean volume of growing stock (F) in the area is 50 m$^3$ha$^{-1}$. Figure modified from Seuna (1983).

The required dimensions of the sedimentation ponds are usually based on the settling velocity of coarse silt, i.e. particles with a diameter >0.02 mm, which is 1 m/hour (Fig. 19). The water surface area of a pond is calculated by using the settling velocity of coarse silt and estimated runoff to the pond; the relationship Q/A (in m/h) is used for calculating the dimensions of the ponds. It is good to keep in mind that coarse silt and sand often contain finer particles that do not settle. Sedimentation ponds retain particles that have a settling velocity (m/h) equal to or higher than the estimated runoff (Q, in m$^3$/h) divided by the water surface area (A, in m$^2$) of the pond. MHQ (l/s/ha) can be used to estimate the runoff Q (Q = MHQ × a / 1000 × 3600), where a is the sedimentation ponds' catchment area in ha, 1000 is the conversion factor from liters to cubic meters and 3600 is the conversion factor from seconds to hours. It must also be considered that the area of the pond depends also on the slope of the banks and on the water level in the pond at the time of determination.

In addition, the maximum velocity which allows for the settling of coarse silt is considered when the dimensions of the pond are determined. Turbulence disturbs the settling of particles; to prevent the formation of high turbulence, the maximum allowable velocity of water in the pond is 1–2 m/s. Sharp corners within the pond should be avoided, and the pond should deepen gradually towards the upstream end in order to diminish turbulence.

Construction of a sill at the downstream end of the pond improves its efficiency by increasing the retention time of the water. Adding a PFC structure at the outlet of the pond is recommended when possible.

Sedimentation can occur inside the pond only in accumulation areas where water brings the eroded material. Hence the ratio between the width and the length of the pond should be 1:3–1:7 in order to allow the water to distribute evenly inside the pond (Fig. 20). Soil type and the depth of the pond should also be considered when constructing the slopes of the pond banks. When the soil type is that of fine and easily eroded material, the slope of the banks should be at maximum 1:2 (Fig. 20). When ponds are constructed in undecomposed peat the slopes can be steeper; however, the slopes and the banks of the pond need to be constructed in such a way that they allow any animals which may fall in to climb out. The soil removed from the pond bottom should be piled far enough from the pond to minimize the risk of the collapse of the banks and the movement of the soil back into the pond. An area 2–3 times the area of the pond should be reserved for sealing and landscaping the soil material that has been removed during construction. In areas with people present, consider constructing fences around the ponds.

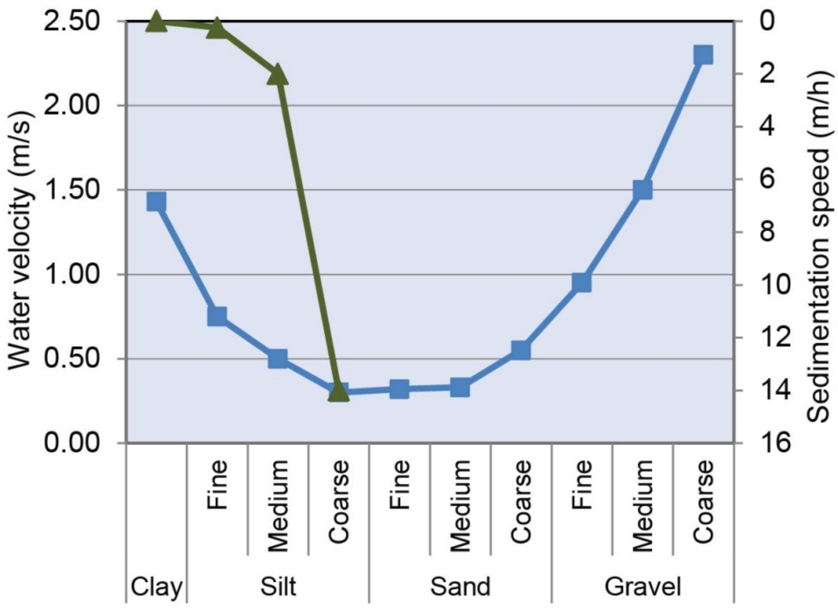


**Figure 19.** The impact of water velocity on the transportation and sedimentation of different soil particle sizes (see Table in the list of terms section below). The blue line shows the water velocity needed for a soil particle to start to move in water; the dark green line shows the sedimentation speed of soil particles in still water.

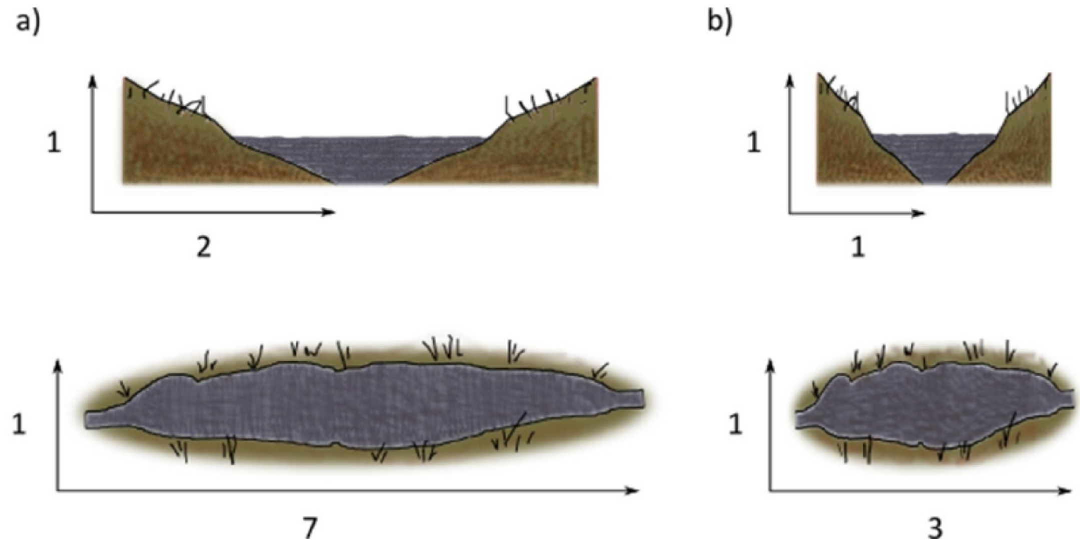


**Figure 20.** A schematic drawing of slopes (above) and aerial views (below) of two sedimentation ponds. a) pond in an area where soil is easily eroded (slope 1:2 and length/width ratio 1:7); and b) pond in an area where soil does not erode (slope 1:1 and length/width ratio 1:3). Figure by Laura Härkönen.

It is also important to consider what happens when the pond starts to fill with eroded material: the more the pond is filled, the less effective it will be in retaining fine particles. Easily eroded soils coming to rest in the ditch bottoms will fill the pond in a short time. For the functioning and maintenance of the pond, it should be deeper at the upstream end, where filling is fast due to the rapid sedimentation of coarse material.

### *Materials needed*

Sedimentation ponds are constructed with an excavator. Materials are usually found on site. For constructing a sill/dam, see section 1.3.3, and for a PFC structure section 1.3.4.

### *Monitoring and maintenance*

Sedimentation ponds should be located in a site that allows ease of access for cleaning, since the degree of filling has a big impact on a pond's efficiency. Sedimentation of silt is significantly reduced far before the pond becomes fully filled with sediments, and it can start to be a source of SS. Thus, the sedimentation process in the pond needs to be regularly monitored. The cleaning of the pond may, on the other hand, increase the export of SS; the need for cleaning must therefore be thoroughly considered. Old, vegetated sedimentation ponds, for example, do not need cleaning, since they can act like constructed wetlands (Fig. 21).

**Figure 21.** A 20-year-old sedimentation pond in Finland where the vegetation has started to grow; the pond works like a small wetland. Photo by Tommi Tenhola.

# 2. Controlled drainage and water retention in forests

## 2.1. Introduction

Apart from DNM aiming solely to export drainage water, there are forest sites only periodically in need of drainage, or which are in need of retaining water at certain periods. Projected changes in climate may lead to water shortages and increase the need for water retention in forests. Long periods without precipitation will result in low river water flows and lower groundwater levels, inevitably leading to drier soils. The increase in air temperature also enhances plant transpiration and evaporation from soil and water surfaces. Furthermore, in warm winters snow melts early and reduces water resources in the beginning of growing season; these phenomena are already causing water deficits in the southern part of the Baltic Sea Region.

The ditch network removes excess water from moist forest areas. However, if the ditch network lacks structures to regulate the water outflow, the drainage system can cause over-drying and a water deficit during dry periods. This is the case, for example, when the groundwater level is regulated by the evapotranspiration of trees and there is no longer a need for drainage, but the drainage system is still functioning (as it was e.g. at the forest regeneration phase when it was needed). Flooding or periodic high groundwater levels occur in the forests of the southern Baltic Sea Region countries, but this situation is much rarer than one of dryness. This suggests that under climatic conditions with periods of both excess water and drought, ditches should have a dual function, i.e. to allow for periodic drainage and work as sub-irrigation systems, which slow or stop the water outflow from the catchment. For this purpose, two types of damming structures are used, which either maintain a constant water level, or regulate as appropriate the water level in the ditches or streams. These types of structures, which are used in Poland, are described in the following section. Damming structures were also described in section 3.3, but there their main aim was to reduce transport of SS to surface waters. When planning water retention structures, their impacts on erosion processes and biodiversity also need to be considered and documented. Moreover, national legislation must be followed, and in certified forests the national forest certification standards should also be strictly adhered to.

## 2.2. Damming structures

### 2.2.1. Constant damming structures

Structures for constant damming are sills (Figs. 22–24), which make a barrier in a stream or a ditch and raise the water level upstream. They are preferred in some situations (e.g. in moist areas), since they do not require regular maintenance. In such situations, where elevated decomposition organic soil is unwanted, sills are used in ditches or watercourses to maintain a constant level of groundwater.

In forests, sills are usually made of wood or stones, or a combination of the two together with a wooden construction aimed at hindering the decrease of water level under the desired threshold level. Sills of small (from 10 to 50 cm) height are usually used; the height should be adapted to the local conditions. As a rule, thresholds up to 25 cm in height are acceptable, although for some fish species such sills are difficult to pass. The migration of organisms can be made possible by constructing “close-to-nature type” fish passes connected to the sills (Figs. 25 and 26). An example of a dam made of soil across a stream is presented in Fig. 27.

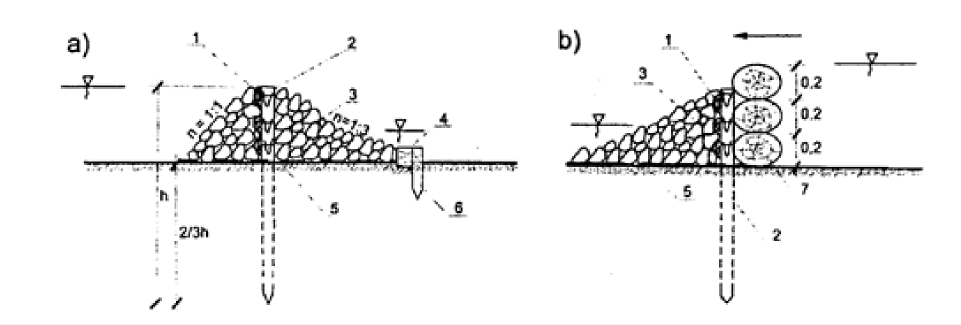


**Figure 22.** Examples of sills made of: a) wood and stones; b) wooden logs and stones. 1 – wooden slat, 2 – wooden pole, 3 – stones, 4 – wooden beam, 5 – geotextile, 6 – small pile, 7 – wooden log, h – log length. Figures by Jędryka.

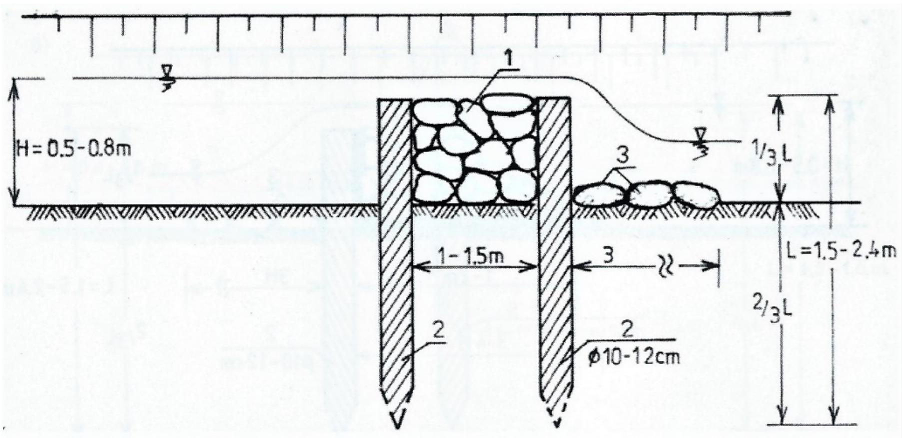


**Figure 23.** Sills made of wooden pales and stones: 1 and 3 – stones, 2 – wooden pales. Figure by Waldemar Mioduszewski.

**Figure 24.** A sill constructed from wood. Photo by Andrzej Ryś.

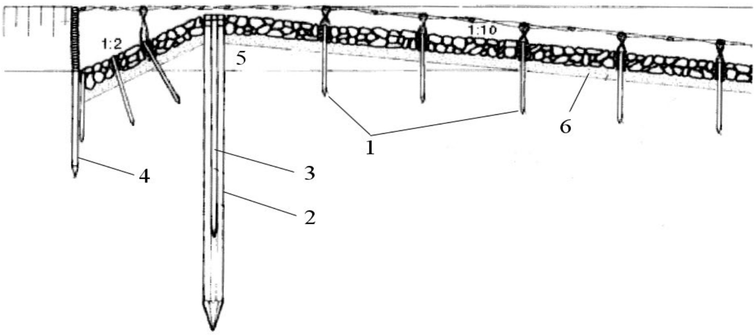


**Figure 25.** A cross-section of a sill connected with rifle-type fish passes. 1 – a bundle of wooden pins (1 m length), 2 – wooden wall, 3 – pales (0.2 m diameter), 4 – wooden pegs (1.3 m length), 5 – clay, 6 – gabion mat. Figure by Stepaniuk.

**Figure 26.** Sills with fish passes belonging to the “close-to-nature types” and called as bottom ramp and slope. Their sill has a rough surface and extends over the entire river width with as shallow slope as possible, to overcome a level difference of the river bottom (FAO.2002). Photo by Andrzej Ryś.

**Figure 27.** A dam constructed of stones and wooden materials and covered by soil being built across a stream. Photo by Andrzej Ryś.

## 2.2.2. Damming structures with water level control

To increase groundwater storage in the catchment and in particular to raise groundwater levels during dry periods, drainage systems equipped with devices for periodical damming may be used to regulate the water outflow (controlled drainage). Sluice gates are mainly used for this purpose (Figs. 28 and 29). The retention function of the sluice gates depends primarily on how fast the water in the stream/ditch infiltrates to the groundwater. Sometimes it may be beneficial to use sluice gates to facilitate the infiltration of rainwater (through the bottom and slopes of the streams/ditches) to groundwater. However, great care should be taken here, as that may, under certain conditions, cause excessive water infiltration to groundwater and consequently over-drying of the area. In some situations, positive effects can be achieved by slightly changing the direction of the ditch water flow and by extending the drainage network, which together reduces the water velocity.

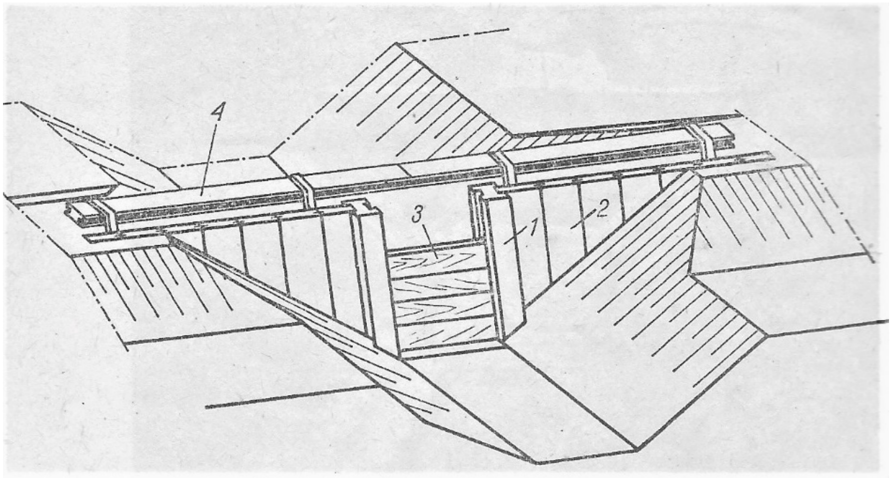


**Figure 28.** A small wooden sluice gate on the drainage ditch: 1 – logs, 2 – wall, 3 – boards for water level control, 4 – footbridge for maintenance of structure. Figure by Zygmunt Rytel.

**Figure 29.** A sluice gate built in a stream to contol water level. Photo by Michał Wróbel.

## 2.2.3. Retention ponds

Water ponds (reservoirs) are used to increase water retention in forests (Figs. 30–33). Reservoirs in forest areas are usually small in terms of area (less than one hectar to a maximum of several hectares, usually not exceeding 5 ha). The basis for establishing the dimensions and then implementing reservoirs should be hydrological calculations showing: (i) the possibility of filling the reservoir with surface water flow from the catchment (or in some cases also with groundwater and precipitation), and (ii) confirmation of the ability of any reservoir to perform its functions. The impacts of a reservoir will depend on its size, location in the landscape, hydrogeological conditions, the natural environment surrounding and the quality of inflow water. Despite the fact that reservoirs may collect relatively small volumes of water and have a limited impact on forests, they may still provide valuable ecological functions; for example, they are open water surfaces in forests, breeding places for birds and amphibians and wildlife refuges – they also regulate forest microclimates. In the design work and decision-making, the conclusions of an environmental impact assessment should be taken into account. In particular, it should be considered whether it is possible to extend the reservoir outside the watercourse bed; such a solution would allow for the maintenance of the ecological corridor.

The location of a reservoir should have an appropriate source of water, and the terrain ought not to be so difficult as to create too much expense in terms of construction. Depending on the functions of the reservoir, the following factors, among others, should be considered in its construction: access to water by forest animals, roads for water intake, for fire protection and sprinklers, for example, in forest nurseries, etc. If the proposed reservoir is likely to be important for waterbirds then islands should be incorporated in the design. The reservoir should also have a natural shape and it should be integrated into the surroundings. Minimizing the need for maintenance should be considered in the design of the structures; in the case of proposed recreational use, tourist infrastructure issues should also be anticipated and the water quality should be analysed. A larger number of small ponds can have a bigger ecological impact than a small number of large reservoirs.

**Figure 30.** Small water reservoirs in mountain areas of Poland. Photos by Michał Wróbel.

**Figure 31.** Water reservoirs in lowland forest in Poland. Photo by Andrzej Stolarek.

**Figure 32.** A gabion sill for outflow of water from a reservoir in Poland. Photo by Edward Pierzgalski.

**Figure 33.** Hydraulic structures controlling water outflow from the reservoirs. Photo by Michał Wróbel.

## 2.2.4. Restoring hydrology of drained peatlands and wetlands in forests

Restoring the hydrology of drained peatlands and former wetlands is important for water retention in forests. Restoration aims to mitigate the periodic excess or shortage of water around the wetland, or even within the whole catchment if the wetland is large enough. Wetlands are also important for biodiversity, and to initiate the desired plant succession the groundwater level should be maintained at a depth of 20–40 cm from the soil surface depending on the habitat. Figures 34 and 35 show examples of wetland restoration deployed by establishing sluice gates on drainage ditches to stop water outflow.

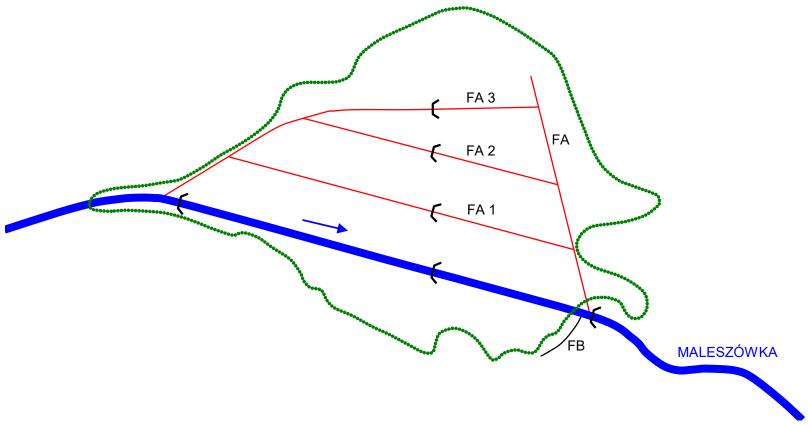


**Figure 34.** A peatland in Poland with several sluice gates used to regulate the groundwater level in the drained area. The peatland border is indicated by a green line, the river Malaszówka by a blue line, the ditches by red lines and the sluice gates by black lines.

**Figure 35.** A wetland before (left) and after (right) restoration. Photos by Katarzyna Winiczenko.

# List of terms

**A bottom dam** is a structure made of stones and wood, placed in a collector ditch and intended to reduce water velocity and thereby enhance sedimentation of eroded material. See section 1.3.3.

**A collector ditch** collects drainage water from several drainage ditches and transports it downstream.

**A drainage ditch** affects drainage by bringing about lower groundwater levels and feeding drainage water to a collector ditch.

**Ditch network maintenance** (DNM) comprises a set of activities that includes cleaning existing ditches and the creation of supplementary ditches for sustaining or improving forest growth.

**A fork ditch** is a ditch dug in the form of a fork. Fork ditches are dug to distribute water to a wetland buffer.

**Pales** are large wooden pegs; using them enables tight walls to be built across a ditch or river.

**Peak flow control** is created by a dam and a set of pipes that reduce the water flow from DNM areas during high flows, and thereby reduce erosion and transport of eroded solids and particulate nutrients to watercourses. See section 1.3.4.

**A rifle** is a structure fulfilling the function of a sill and a ramp, enabling non-erosive flow of water dammed up by a sill to the water level below; this construction also acts as a fish pass.

**Sedimentation pits** are widened sections of ditches, where water flows through a wider cross-sectional area, thereby reducing the flow rate. The aim of a sedimentation pit (1-2 $m^3$) is to capture solids eroded from ditches and to avoid their transport to downstream watercourses. See section 1.3.2.

**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 downstream watercourses. See section 1.3.6.

**A separator ditch** is made to keep water from flowing from the upper part of the catchment area into the DNM area.

**A sill** is a low structure across a ditch or river protruding above the bottom, aiming to constantly raise the level of flowing water. Wooden or wooden and stone sills are most often built in forests.

**A sluice gate** is a gate which may be opened or closed to allow or prevent the passage of water through a ditch or a stream. It is used to transform a non-controllable drainage system into a controlled one.

**Soil type:**

**Table.** Soil groups and particle size fractions according to the International Standard ISO 14688-1:2017 Geotechnical investigation and testing – Identification and classification of soil – Part 1: Identification and description.

| Soil group | Particle size fractions | Range of particle sizes, mm |
|---|---|---|
| **Very coarse soil** | Large boulder | >630 |
| | Boulder | >200 to ≤630 |
| | Cobble | >63 to ≤200 |
| **Coarse soil** | Gravel | >2.0 to ≤63 |
| | Coarse gravel | >20 to ≤63 |
| | Medium gravel | >6.3 to ≤20 |
| | Fine gravel | >2.0 to ≤6.3 |
| | Sand | >0.063 to ≤2.0 |
| | Coarse sand | >0.63 to ≤2.0 |
| | Medium sand | >0.20 to ≤0.63 |
| | Fine sand | >0.063 to ≤0.20 |
| **Fine soil** | Silt | >0.002 to ≤0.063 |
| | Coarse silt | >0.02 to ≤0.063 |
| | Medium silt | >0.0063 to ≤0.02 |
| | Fine silt | >0.002 to ≤0.0063 |
| | Clay | ≤0.002 |

**Spillways or overfalls** are hydrotechnical constructions used to take water from a reservoir/pond or to reduce water level during a flood.

**Uncleaned ditches** and **ditch stretches** are sections of ditches that are not cleaned, with the purpose of reducing the water flow rate and, consequently, reduce erosion and increase capturing eroded solids. See section 1.3.1.

**Wetland buffers** (overland flow areas) are natural or restored wetland areas where runoff (drainage water) from DNM areas is distributed. Wetland buffers retain SS and nutrients transported from DNM areas. Their recommended size is 0.5–1% of the whole catchment area. See section 1.3.5.

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# Appendix 1

Decision flow chart for assessing the suitability of DNM

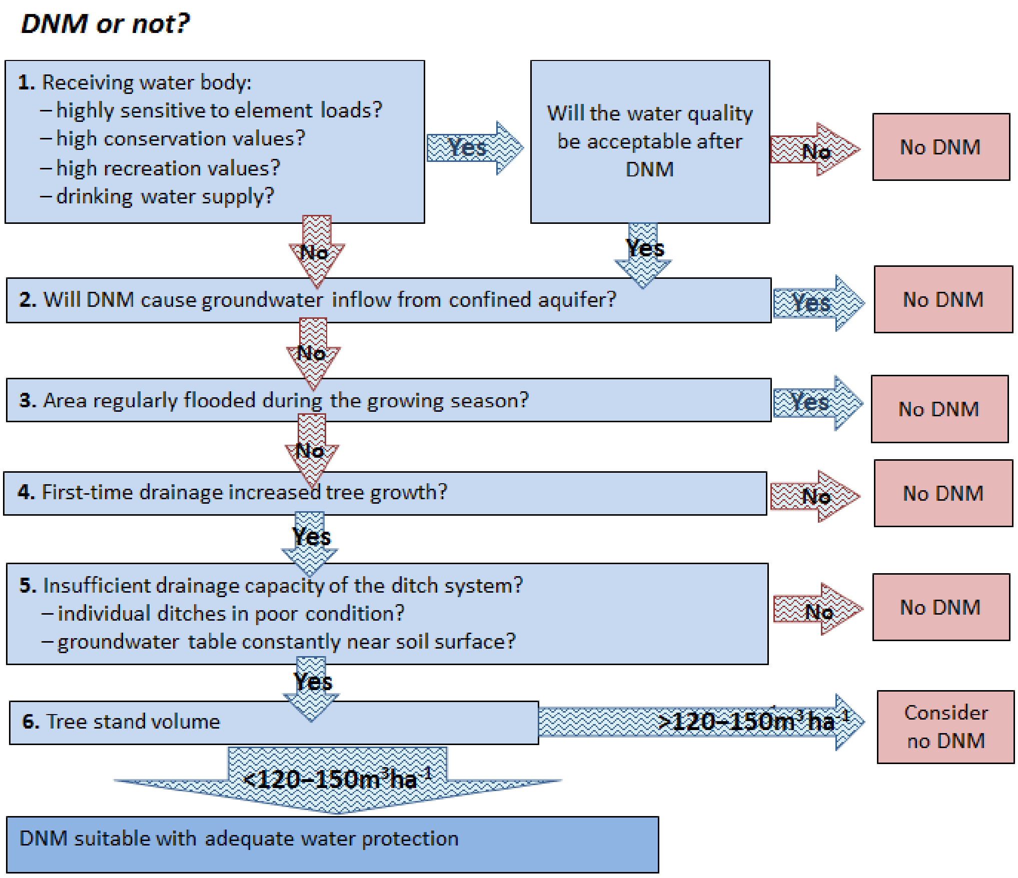


**Figure 36.** A flowchart which can be used for assessing the suitability of DNM. See details in the report "WAMBAF - Good practices for ditch network maintenance" (Finér et al. 2018).

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