WAMBAF

Forest drainage and water protection in the Baltic Sea Region countries – current knowledge, methods and areas for development

1. Introduction

This document was prepared by members of the WAMBAF project and some invited external experts. The project is running between 1.3.2016 - 28.2.2019 and is financed by the EU Baltic Sea Region Interreg program. It was initiated to find solutions for the detrimental effects of forestry activities on water quality.

This project places special emphasis on freshwater quality with respect to export of nutrients, suspended solids and mercury. WAMBAF focuses on three main factors that significantly impact water quality:

- riparian forests
- forest drainage
- beaver activity.

Here we summarize the findings of a review conducted in 2016 to evaluate

- the existing knowledge of how forest drainage and water retention affect nutrient, suspended solids and mercury leaching
- the efficiency of current water protection measures
- the current tools and methods that are used to plan water protection measures in forest drainage
- the current legislation, certification standards, and guidelines that govern forest drainage and water retention activities in the various Baltic Sea Region (BSR) countries.

The research material consists of literature surveys and information that was received from experts in Estonia, Finland, Latvia, Lithuania, Poland and Sweden.

2. Definition of key terms

Drainage and water retention include activities which influence the hydrology of forest sites. Drainage activities consist of first-time drainage, ditch network maintenance (Fig. 1), and remedial drainage.

First time drainage refers to an intentional decrease of the groundwater table of pristine peatlands or paludified mineral soils to improve forest growth. In Finland and Sweden, this

Figure 1. A new machine innovation called "Varanen" carrying out ditch network maintenance in Sweden. Photo by Anja Lomander.

decrease is achieved by digging open ditches that are 0.5 – 1.0 meters deep. The ditches in the Baltic countries and Poland are dug even deeper due to flat reliefs and deep mineral gleyic soils (Figs. 2 and 3).

Ditch network maintenance includes the cleaning of existing ditches and digging of supplementary ditches to improve forest growth.

Remedial drainage describes the use of ditches to lower a groundwater table that has temporarily increased, or to transfer surface waters from an area that has recently been harvested. In Sweden, this is usually performed by digging open ditches that are 0.3 – 0.5 meters deep. The same method is also used in Latvia, and the depth of remedial ditches may not exceed 0.4 m (0.3 m in the state forests). In Finland, this method is called "ditch-mounding", as small mounds of the soil that was removed from ditches are used to plant tree seedlings.

Water retention utilizes forest management methods, for example, selecting species that has a low interception capability, and technical operations such as construction of reservoirs and dams, digging ditches and wetland restoration to raise the groundwater table and/or increase water storage in a forest area. Water retention dams are used in Poland to prevent problems caused by droughts and floods (Fig. 3).

Figure 2. Forest drainage in Lithuania. Photo by Dovilė Čiuldienė.

Water protection structures

Sedimentation/silt traps are small pits at the bottom of ditches which capture solids that have eroded from the ditch banks and bottoms. These pits serve to reduce the transport of solids to water bodies. In Finland, these pits are usually <1 meter deep and are constructed at 100 meter intervals.

Breaks in cleaning and digging of ditches are short sections of the ditches that are not cleaned. The purpose of these breaks is to slow the runoff velocity which prevents erosion and retain eroded solids from upstream in the ditch network.

Sedimentation ponds/basins are temporary ponds that are constructed near the outlets of drainage areas to capture eroded solids and reduce their transport to downstream water bodies (Figs. 4, 5 and 6). In Finland, the surface area of a sedimentation pond is 3 - 8 m^2 multiplied by the size of the catchment area in hectares, and the depth is 2 meter. One sedimentation pond is built for every 40 ha in a catchment area and if the area of a catchment >40 ha more ponds are needed. In Latvia, construction of sedimentation ponds is mandatory in state forests if the length of the drainage system exceeds 0.8 km; the pond is 0.5 m deeper than the ditch bottom and the length of the pond varies from 30 to 50 meter.

Overland flow areas/fields are undrained areas where the runoff from upstream drained areas is distributed (Fig. 7). Overland flow areas retain solids and nutrients that are transported from the drained areas. In Finland, their recommended size is 0.5 – 1 percent of the catchment area.

Peak runoff control utilizes dams and a set of control pipes to regulate runoff from the drained areas during high flows (Fig. 8). Peak runoff control reduces the transport of eroded solids and nutrients to downstream water bodies.

Constructed wetlands function to retain solids and nutrients by natural processes including sedimentation, denitrification and plant uptake to reduce their transport to downstream water bodies (Fig. 9). They usually consist of interconnected vegetated ponds that control water flow.

Figure 3. A water retention dam in a Polish ditch network. Photo by Wojciech Gil.

3. Forest drainage in the Baltic Sea Region countries

Most of the European peatlands (Histosols) are found in the following BSR countries (Fig. 10)

- Estonia
- Finland
- Latvia
- Lithuania
- Poland
- Sweden

The total area of peatlands in these countries is approximately 19.5 Mha (Table 1). These BSR countries rely on drainage to sustain and improve forest growth on peatlands and paludified mineral soils; thus, approximately 10 Mha of peatlands have been drained for forestry.

Finland and Sweden have the largest area and density of drained peatlands. There is almost no first-time forest drainage currently being carried out in the BSR countries, and the main type of forest water management is ditch network maintenance. In Finland, the total annual growth of forests is 104 Mm^3 (Peltola 2014), with peatland forests contributing 25 percent of this growth (Päivänen and Hånell 2012): ditch network maintenance is annually carried out on 50 000 ha to sustain and improve forest growth on drained peatlands.

Figure 4. A sedimentation pond in Sweden. Photo by Ulf Sikström.

In Sweden, remedial ditching is annually carried out on 4 000 ha to temporarily manage groundwater conditions in regeneration areas. However, statistics are not available for every BSR countries. In the southern parts of the Baltic Sea Region, for example, in Poland and to a small extent in Lithuania, water retention is a safety measure used against droughts and floods.

Figure 5. A sedimentation pond and a dam made of stones in Finland. Photo by Leena Finér.

4. Water management and water protection

Drainage and water retention affect runoff water quality

The water management operations that are used in forestry can increase the mobilization of nutrients, suspended solids and metals such as mercury. Nitrogen and phosphorus leaching increases eutrophication in waterbodies, while the transport of suspended solids changes water colour and how far solar radiation can penetrate. The sedimentation of solids negatively impacts aquatic habitats and organisms. Mercury can accumulate in food webs and methylmercury is highly neurotoxic.

The impacts of first-time forest drainage on element leaching have been studied in Finland and Sweden (Ahtiainen and Huttunen 1999, Finér et al. 2010, Launiainen et al. 2014, Simonsson 1987). The results showed that first-time drainage significantly increases the mobilization of suspended solids and, to a smaller extent, the leaching of nutrients (Table 2).

In Finland, over 40 catchments were used to study how ditch network maintenance impacts water quality. The results showed that ditch network maintenance significantly increases the mobilization of suspended solids and phosphorus. However, the maintenance did not affect the leaching of total nitrogen (Table 2).

Figure 6. A sedimentation pond in Latvia. Photo by Zane Libiete.

The results also showed that the impacts of forest drainage are most noticeable 1 – 3 years after the operation. The situation then gradually improves until background levels are achieved in 10 – 20 years. The leaching of mercury was studied using two ditch network maintenance areas in Sweden. In one of the areas, mercury concentrations increased for a few days after the operation (observed maximum was 160 ng L^{-1}) and the annual load increased by 15 percent during the first year, but no changes were observed in the other area (Hansen et al. 2013).

The effects of water retention on water quality have been studied in Poland and published in Polish).

Knowledge on the efficiency of water protection measures

The best approach regarding water protection is to avoid unnecessary drainage. For example, nutrient-poor sites where first-time drainage has not improved forest growth do not require ditch network maintenance. Moreover, ditch network maintenance can be delayed until after final cutting at sites where the evapotranspiration of trees can maintain the desired water balance within the stand.
A study from Finland showed that tree stand volumes of 120 – 150 m^3 ha^{-1} provide sufficient evapotranspiration to maintain good aeration in the root zone (Sarkkola et al. 2013). No such information is available from the other Baltic Sea countries. However, in confined groundwater areas, evapotranspiration alone cannot maintain soil aeration and drainage is needed.

A total of 30 studies that investigate the effects of various drainage and water retention operations on water quality have been published by the BSR countries. However, one study from Sweden did not focus on water protection and the Polish studies evaluated the impacts of forestry on water quality.

Figure 7. An overland flow area in Finland. Photo by Antti Leinonen.

The 30 studies included 140 study catchments and 54 study plots, some of which were inside the studied catchments. The studies carried out in Finland have been published in English while studies from other countries were published in English or in the national language. Except for one older study from Finland, the studies on water protection were performed between 1991 and 2009. Half of the studies did not monitor the undrained condition before the drainage operation. The undrained control period, when included, was longer than three years. The effects of drainage operations were usually monitored for more than three years.

In general, no water protection measures were used in conjunction with the first-time drainage because until a few decades ago there, was only limited awareness about the importance of water protection. Only one study has been carried out in Finland to study how efficient an unmanaged riparian zone, in this case one that was left between the ditch network and downstream water body, is at preventing the leaching of suspended solids and nutrients (Ahtiainen and Huttunen 1999). According to the results, the undrained riparian zone retained 20 percent of the total nitrogen load and could not hinder excess loads of suspended solid and phosphorus after first-time drainage.

Various structures – sedimentation ponds and traps, overland flow areas, peak runoff control, constructed wetlands, breaks in cleaning and digging – are currently used in ditch network maintenance to avoid harmful effects on surface waters. Most of the studies that have investigated how to mitigate the negative effects of forest drainage operations have focused on the utilization of sedimentation ponds and overland flow areas. As seen in Table 3, these two strategies have been studied at the largest number of sites.

Figure 8. A peak runoff control structure in Finland. The lower pipe is orange and the upper pipe is black. Photo by Antti Leinonen.

On average, sedimentation ponds retain 25 percent and overland flow areas 50 percent of the inflow of suspended solids, but they do not seem to retain any phosphorus (Table 3). The parameters that have been monitored most frequently include nitrogen and phosphorus compounds. Only one study monitored mercury levels.

Since ditch network maintenance has a low impact on the leaching of nitrogen, it seems that sedimentation ponds do not affect nitrogen transport. The retention efficiency of overland flow areas depends on the size of the area and the extent to which the flowing water is in contact with the soil (Saari 2014, Silvan 2005).

Generally, overland flow areas function better than sedimentation ponds in retaining suspended solids, and they also retain nutrients through vegetation uptake (Silvan 2005). However, flooding and the formation of water flow paths (preferential flow) can decrease retention efficiency. The peak runoff control method has been shown to be effective in reducing suspended solid and nutrient loads (Marttila and Klove 2009, Marttila et al. 2010), but more research is needed to demonstrate its efficiency.

The large variations in efficiency between the different methods depend on local factors such as the area of the water protection structure in relation to the catchment area

- soil type

- water flow paths
- vegetation type
- coverage.

In this way, the selection of an approach for mitigating the negative effects of forest drainage operations should be guided by a clear understanding of catchment characteristics.

Figure 9. A constructed wetland in Finland. Photo by Sirpa Piirainen.

Needs for further research and development

Certain areas were identified to have a need for more scientific knowledge and further development of water protection measures in forest drainage. These were:

- A better understanding of how element loads and concentrations impact surface water biology.
- The adaptation of forest management and water protection practices to new hydrological conditions that may arise as a result of a changing climate.
- A better understanding of the efficiency of different water protection structures and their combinations. Besides nutrients, studies should focus on the retention of

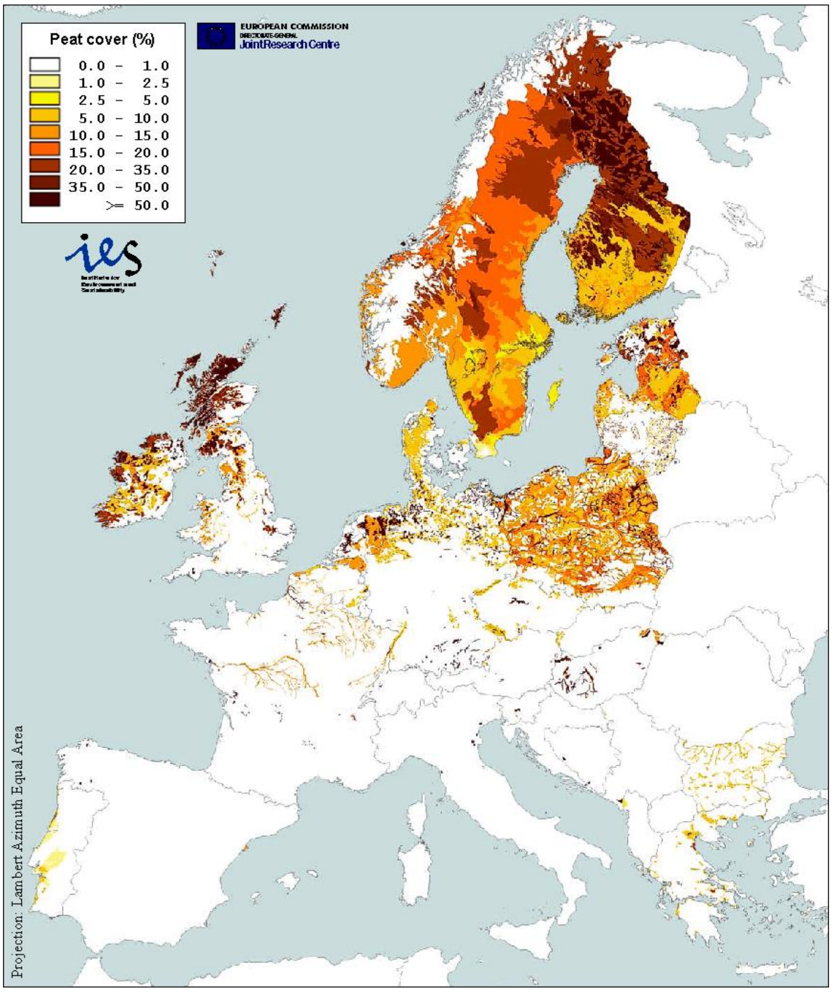

Figure 10. The relative extent (%) of histosols (peatlands) in the Soil Mapping Units of the European Soil Database (Montanarella et al. 2006, reproduced with permission from Mires and Peat 1(01) 2006, http://mires-and-peat.net/).

hazardous substances, bed sediment load (load which moves at the bottom of ditches) and iron.

- The development of new water protection methods for sites where ditch network maintenance and final cutting are used in combination.
- Identification of soil types that readily erode, leach hazardous substances (mercury, for instance), or are susceptible to sulphide oxidation.
- An evaluation of the profitability from an economic point of view of the entire forest management chain (drainage, thinning, and clear-cutting) for drained peatlands.
- A better understanding of how forestry activities and the levels of toxins in biota are connected.

- A better understanding of the composition of suspended solids and dissolved organic carbon.
- Identification of forests on peatland and other paludified soils that do not require drainage — high evapotranspiration or low production sites.

Table 1. The total area of peatlands (including paludified upland soils), area drained for forestry, total ditch length and mean ditch length per hectare of forest land in the Baltic Sea Region countries. The definition of peatland varies between countries, and, for this reason, the figures are not fully comparable. The main type of current forest water management is also shown in the table (DTM=ditch network maintenance).

Country	Peatland, Mha	Drained, Mha	Total ditch length on forest land, km	Mean ditch length per ha of forest land, m ha^{-1}	Main type(s) of forest water management
Estonia	1.20[1]	0.56[1]	97 169[2]	174	DTM
Finland	8.76[3]	5.96[3]	1 300 000[4]	218	DTM
Latvia	1.14[5]	0.5[5]	43 000[6]	86	DTM
Lithuania	0.65[7]	0.4[8]	15 000[8]	31[8]	DTM
Poland	1.30[5]	0.86[9]	430 000[9]	50	DTM and water retention
Sweden	6.4[10]	1.5-2[10]	600 000[11]	400	DTM and remedial drainage
In total	19.45	9.78-10.3	2 485 169		

[1]Estonian Mires Inventory, published on Sep. 6, 2011
[2]Estonian Environmental Agency (KAUR), answer to a special enquiry on Oct. 16, 2014 by E. Lode
[3]Peltola 2014
[4]Estimated based on knowledge that ditches are located at 30-40 m intervals over 5.96 Mha
[5]Paavilainen and Päivänen 1995
[6]Refers to public forest land only
[7]Taminskas et al. 2011
[8]Ruseckas and Urbaitis 2013
[9]Wisniewski 1996, mainly upland soils
[10]Päivänen and Hånell 2012
[11]Estimated based on knowledge that ditches are located at 25 m intervals over 1.5 Mha

- Identification of aquatic and terrestrial areas with high biodiversity value.
- A better understanding of the efficiencies of water protection structures in different hydrological conditions, e.g. peatlands formed as a result of discharge from a confined aquifer.
- An evaluation of the changes in vegetation, on the ecological and trophic levels, that occurs in pristine peatlands when they are used as overland flow areas.
- Knowledge of how different excavator scoops (U-shaped instead of V-shaped, Fig. 1) impact sediment load, when used for ditch network maintenance.

- An understanding of how beaver management contributes to water quality protection.
- An evaluation of how wetlands constructed as game hunting grounds to water protection.

5. Planning and demonstration of water protection

Planning of water protection

Good planning is essential to the success of water protection measures. At the moment, there are only a few tools available for planning water protection associated with forest drainage operations in the BSR. Five tools were developed in Finland, along with two tools in Sweden and one tool in Lithuania. However, these tools are available only in national languages, which strongly limit their use in the other countries.

Table 2. The background nutrient loads from forest areas in Finland, along with the excess loads of nitrogen, phosphorus and suspended solids resulting from forest drainage in Finland. Loads are in kg ha^{-1} over 10 years.

	Nitrogen	Phosphorus	Suspended solids
First-time drainage[1]	+23	+1.7	+2460
Ditch network maintenance[2]	0	0 - +1.0	+210-973
Background load[3]	3-23	0.2-1.5	9-475

[1]Ahtiainen & Huttunen 1999, no water protection methods were used
[2]Joensuu et al. 1999, Joensuu 2002, Nieminen et al. 2010, water protection methods were used
[3]Mattsson et al. 2003, Kortelainen et al. 2006, Finér et al. 2010

In Finland, the RLGis –tool is used for estimating the erosion risk of planned ditches (Fig. 11). This information can be used to plan effective water protection structures. The KUHA –tool is used in Finland to calculate the annual suspended solid and total phosphorus loads caused by forest drainage and other forest operations carried out in the same catchment. It can also be used to plan water protection measures as well as in the scheduling of different operations to avoid peak loads. In Lithuania, there is a tool for runoff regulation while a Swedish tool enables the user to collect information about the drainage system as a base for determining relevant management actions. Both of these tools operate at a catchment level.

Demonstration areas

Demonstrations, whether they are in field or "virtual" conditions, are an effective way to learn how to plan or construct different water protection structures or to understand the effects of forest drainage on water. Permanent demonstration areas for forest drainage have been established only in Latvia and Lithuania. Six sites in Latvia are used for demonstrating how forest drainage affects water quality and one site in Lithuania is used to demonstrate water quality monitoring. The other BSR countries use only temporary demonstration areas for these purposes.

Areas of planning and demonstration that need further research and development

- Efficient utilization of laser scanned data in the development of planning tools.
- Development of digital planning tools that combine GIS with best practice guidelines.
- Development of tools for calculating the dimensions of water protection structures.
- Inclusion of cost-efficiency calculations in the tools.
- Water protection plans for drainage and water retention operations.
- Use of water protection planning tools that cover all relevant areas of the catchment, and include all of the forestry operations that affect water quality.
- Implementation of a water protection planning toolbox of best practices covering: sedimentation ponds and traps, dams, overland flow areas, peak runoff control, constructed wetlands.
- Development of a system that could monitor the impacts of different water protection structures and their combinations using permanent and temporary networks or study sites.
- Harmonization of load calculation methods among countries.
- Knowledge sharing between countries.
- Tools should be able to account for between-country differences in site conditions.
- Co-operation between foresters and other land users (farmers, hunters, fishermen).
- Establishment of demonstration areas to educate authorities, forest owners and forest operation entrepreneurs and to provide training for how to use the water protection planning tools and implement the best practices.
- Establishment of permanent demonstration areas that cover both geographic variation and the variation in water protection structures. Areas should be conveniently located, i.e. near main cities to decrease travel costs. Good supplementary materials are also needed.
- Areas demonstrating the use of wetlands as game hunting grounds already exist in Finland (www.kosteikko.fi; 10 areas are introduced in English) and should be included to the demonstration area network.

6. Forest drainage in legislation and certification systems

Legislation

Most of the BSR countries are members of European Union and thus implement the EU's Water Framework Directive (WFD, 2000/60/EC) and its daughter directives in their national legislation. The main objectives of the WFD are that all waters within the EU will reach a good ecological status and that quality standards will be set for hazardous substances in water. Forest drainage is not specified in the WFD. However, Estonia, Finland and Latvia require an Environment Impact Assessment (EIA, Directive 2011/92/EU) procedure for large forest drainage operations (>200 ha in Finland and >100 ha in Estonia and Latvia).

Table 3. The retention of suspended solids, phosphorus and nitrogen by the different water protection structures (% of the inflow) after ditch network maintenance. Mean, range and the number of study areas are shown in the table.

	Suspended solids	n	Phosphorus	n	Nitrogen	n
Sedimentation ponds	-25% (-50% — +28%)	40[1]	±0%[2]	37[3]	±0[2]	37[3]
Overland flow areas	-50% (-100% — +10%)	9[4]	±0%[2]	10[4]	-78% — ±0 %[2]	9[4]
Peak runoff control	-86%	7[5]	-67%[6]	7[5]	±0[6]	7[5]
Constructed wetlands	-76% — -16%)	2[7]	±0%[2]	2	±0[2]	2

[1]Joensuu et al. 1999
[2]Dissolved phosphorus or nitrogen
[3]Joensuu et al. 2002
[4]Hynninen et al. 2011, Nieminen et al. 2010, Saari et al. 2010a, Saari et al. 2010b, Saari et al. 2013, Libiete 2015.
[5]Marttila and Kløve 2009, Marttila et al. 2010
[6]Unfiltered phosphorus
[7]Joensuu et al. 2012

The national legislation considering forest drainage differs between BSR countries. For example, Estonia has forbidden the establishment of new drainage systems (Nature Conservation Act, 1.7.2015). The Water Act (18.1.2016) regulates water protection measures, and the Land Improvement Act (4.9.2015) regulates the technical parameters of drainage systems.In Lithuania, the technical parameters of drainage are regulated by the Drainage Act (9.12.1993). In Latvia, the Amelioration Act includes general prescriptions for drainage systems and their maintenance (Act, 25.1.2010) but technical parameters for drainage systems are given in the Regulations Nr. 329 "Concerning the Latvian building standard LBN 224-15" (30.6.2015). The legislation in Finland (Water Act, 2011/587) and Sweden requires that the authorities are notified before any drainage operations, and in Sweden, new drainage is preceded by permission from the authorities (Forestry Act 1979/429 and the Environmental Code 1998/808). In Finland, drainage operations, which receive subsidies from the government according to the Act on the Financing of Sustainable Forestry (2015/34), need to include an approved water protection plan. In Poland, permission is required for all water infrastructure investments in forests (Water Act, 2001).

The legislation regarding water protection and forestry has recently changed in many BSR countries; thus, no immediate developments in the legislation are foreseen. However, the various BSR countries still need to further harmonize how they implement the WFD. The idea that "the culprit has to compensate the damages" should be considered when legislation for improving water protection is next revised.

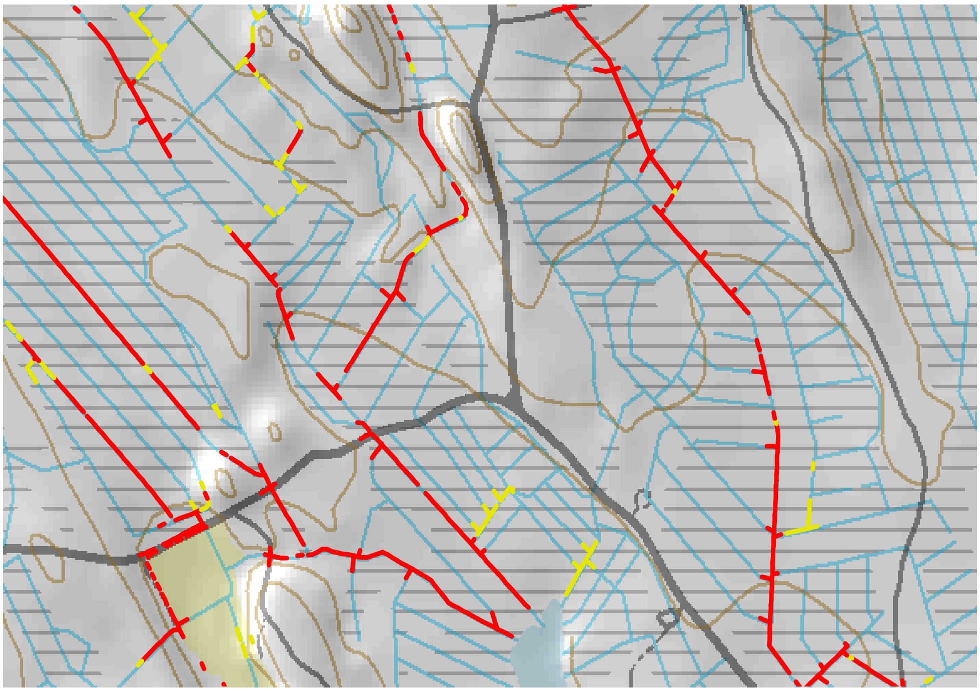

Figure 11. A map of a drainage area and the output of an RLGis analysis, which shows ditches with high (red), considerable (yellow) and low (blue) erosion risk. A forest road (gray line) and altitude contour lines (pale brown lines) are also indicated on the map. The analysis was done by the Finnish Forest Centre.

Forest certification

The area of voluntarily FSC (The Forest Stewardship Council) certified forests varies from 6 percent to 57 percent between the BSR countries while the area of PEFC (Programme for the Endorsement of Forest Certification) certified forests ranges from 23 percent to 79 percent. However, forests can be certified by both systems. Both systems are implemented according to national standards that have been developed independently in each country, and they must also adhere to applicable national laws.

The basic principle is that when the regulations are included in the legal Acts, they are not further elaborated upon in the certification standards and vice versa. When the Acts do not specify certain regulations or their details they can be included in the certification standards. In this way, the certification standards of some countries include detailed regulations. Both certification systems have specific national standards for forest drainage.

Figure 12. Ditch network maintenance in Finland. Photo by Markku Saarinen.

In Finland and Sweden, both systems allow drainage, but only on earlier drained peatlands and at sites where tree growth improved after first-time drainage. In addition, in Finland, Latvia and Sweden, both systems set high priority to the protection of biodiversity. In Sweden, Latvia and Finland, the PEFC certification system requires measures to hinder the transportation of sediments to surface waters. In Sweden, the FSC certification requires construction of sedimentation ponds.

In both Finland and Sweden, the FSC certification system does not allow ditches to drain directly into surface waters, i.e. an undrained riparian zone must be left between the drainage area and the water body. Furthermore, in Finland, ditching is not allowed on sulphide rich soils, on groundwater areas or on highly eroding soils (Fig. 12). In Poland, both systems focus on water retention in forests. In general, the water protection regulations of the FSC certification system are more specific and strict than those of the PEFC certification system. An evaluation is needed to find out which system is more effective at protecting waters.

Guidelines

Specific guidelines for forest drainage are available for forest owners and forest managers in Finland and Lithuania. In Finland, the guidelines include detailed instructions for designing water protection structures:
(http://tapio.fi/julkaisut-ja-raportit/metsanhoidon-suositukset-verkkojulkaisut/).

All of the BSR countries should develop publicly accessible guidelines that would include the best water protection practices that have been identified in the other countries. These new guidelines should take into account national differences in soil conditions and vegetation types.

7. More information

Web pages of the WAMBAF -project:
http://www.skogsstyrelsen.se/en/AUTHORITY/International-activities/WAMBAF/

https://www.interreg-Baltic.eu/fileadmin/user_upload/about_programme/
Cooperation_priorities/P2_Natural_resources/R011_Water_management_in_Baltic_forests.pdf

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