Climate change resilient water management measures in agriculture in Finland

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Abstract

In Finland only about 15% of agricultural fields can be cultivated without drainage. About 58% of field area has subsurface drains and 27% ditch drains. The distance between the place of discharge of field drainage and the closest body of water is on average 2.3 km (median 1 km). Presently the drainage systems incorporate only in rare cases wetlands and other elements for reducing nutrient flux and for balancing water flow.

In Nordic regions climate change will deteriorate winter time weather conditions: snow cover is going to have a greatly reduced duration, and a lot of the precipitation will be rain instead of snow. This has repercussions for agriculture and drainage and their environmental impacts. Previously snow cover protected agricultural fields during winter from erosion and nutrient leakage. It has been already observed that agricultural fields have become more prone for erosion and consequently unprecedentedly high nutrient concentrations have been recorded in rivers downstream from agricultural areas after heavy rains and during a time when the fields had a small amount of vegetation cover. Additionally the changes in the timing and amount of precipitation can cause a need to change recommendations for dimensioning of drainage systems.

Sustainable practices in drainage such as two-stage drainage channels, constructed wetlands, sedimentation ponds and floodplains should become the standard practice in Finland in order to control the eutrophication problems caused by agricultural drainage. In order to reach this goal several societal and political problems should be solved. For example there would be a need to reserve larger land areas for drainage. This is especially problematic when considering the EU's Common Agricultural Policies, which include agricultural subsidies paid for farmers per cultivated hectare – the farmers see it especially problematic if they have to give up farming area. Despite the societal and political problems two-stage drainage channels have been implemented in few cases in Finland. Several good examples of usage of wetlands, submerged dams and floodplains also exist. We will go through some of the examples and present the environmental benefits of the solutions.

KEYWORDS: two-stage drainage, sustainable agriculture, climate change, Finland

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1 Introduction

1.1 Rethinking drainage

In Finnish agriculture effective drainage systems are the most important component of infrastructure. Without it agricultural production in the cold and rainy climate of the northern Europe would not be possible**.** While enabling agricultural production, the drainage systems have decreased the water holding capacity of watersheds, caused increased vulnerability to erosion if measures for erosion control are not utilized and also carbon leakage from organic soils. The general problem is that the drainage systems using traditional designs do not include elements which withhold flux of particulate matter.

In the Nordic areas effects of climate change will cause increases in erosion and in leakage of nutrients by year 2050. This will cause a higher eutrophication pressure of the aquatic systems especially in watersheds with high amount of agricultural areas. There is a potential for avoiding this scenario, if more environmentally friendly agricultural practices are used or if new practices are developed.

There is still an untapped potential in drainage systems with benefits for aquatic systems and biodiversity. Restructuring drainage would require changes in many subsidies, policies and even in attitudes towards water protection in agriculture.

1.2 History of environmental effects of agriculture and drainage in Finland

There has been a long road of development with water protection, as well as with environmentally friendly agricultural practices and their research (Vuorenmaa et al., 2002), (Tattari et al., 2016). At the same time agriculture has gone through fundamental changes.

In Finland drainage channels are privately owned. They are governed through communities of local landowners (drainage communities). State of Finland has been compensating for the costs related to drainage operations for several decades. Lately there has been a discussion, if the compensations are anymore justified.

Almost whole agricultural land area in Finland had basic drainage networks by the end of the 1960's. The drainage networks opened new straight and fast connections from agricultural fields to lakes and rivers. Traditional main ditches were designed to be straight, even and with steep sides – as efficient hydraulically as possible. This kind of basic drainage networks channel water efficiently away from fields, and offer no means for reducing the environmental impact of nutrient flux from agricultural fields to natural aquatic ecosystems (Puustinen et al., 1994).

Drainage depth was for a long time determined based on the depth which is most beneficial for cultivated plants (60-80 cm). Nowadays the depth is determined by the soil's load bearing capacity for heavy machinery (120-130 cm). Deepening of drainage depth has caused increased environmental impact from organic soils, as organic matter became vulnerable to erosion and degradation. Large areas of drained organic soils have since slowly turned to mineral soils. On mineral soils deeper drainage depth does not cause increases in environmental impact, if agricultural practices are otherwise sustainable.

Because of the increase in drainage depth and new connections between agricultural fields and natural aquatic ecosystems, water flow from agricultural fields to aquatic systems has become more variable than before i.e. the buffering capacity of drainage areas has decreased. This has been especially notable in watersheds where also forest areas have been drained.

Finnish agriculture has gone through a lot of changes on the long timescale. According to national statistics since the 1960's agricultural land area has decreased (from 2.7 million ha to 2.2 million ha), there has been a change from grassland farming to spring cereals (grassland area has decreased from 1.4 million ha to 0.6 million ha), fertilizer use has increased and mechanical tillage has become widespread. All this has been possible because of efficient drainage systems.

As drainage and agricultural practices became more efficient, also erosion and nutrient flux from agricultural fields has increased. Anthropogenic eutrophication of water systems originates mainly from agriculture (50% of nitrogen and 60% of phosphorus). After Finland joined the EU in 1995, several agricultural practices for reduction of water pollution have been implemented through agri-environmental schemes, which have been widely popular among farmers.

Despite the popularity of agri-environmental schemes, only slight reductions of phosphorus loading of water systems have been observed in agricultural areas and nitrogen pollution seems to have even increased. On the average water pollution caused by agriculture have remained on the same level as during the 1990's, around 15 kg-N ha^{-1} yr^{-1} and 1.1 kg-P ha^{-1} yr^{-1} (Vuorenmaa et al., 2002), (Tattari et al., 2016).

There have been several different views about reasons behind the low effectivity of agri-environmental practices. Suggested reasons have been for example changes in arable land area and centralization of non-cereal and animal farming (Aakkula and Leppänen, 2014). Another reason could be that the effects are masked by high variability in other anthropogenic and natural sources of nutrients.

Now the main problems are: how to prepare for impacts of climate change in drainage operations and in agri-environmental schemes, what kind of role drainage systems should have in future, and is it possible to reduce environmental impacts of agriculture through drainage practices. These problems are related to the following questions, which will be addressed in this article:

1) how widely should water protection measures for agriculture be implemented
2) what kind measures would improve the buffering capacity of catchments
3) can two-stage drainage systems improve the state of the environment.

This article will go through the history of development and the needs to improve water protection measures within Finnish agriculture, and how have we reached these conclusions.

2 Materials and methods

2.1 Hydrology – precipitation and runoff

Long-term (1960-2015) average precipitation in southern and southwestern Finland has been 700 mm (Table 1), of which 40% becomes runoff and about 60% evaporates. Typically during growth season evaporation is 120-130 mm larger than precipitation, causing a deficiency of water. The runoff during growth season is only 10% of total runoff during a year and the rest occurs outside growth season – during a time, when a large proportion of agricultural fields lack vegetation cover (tillage is usually done during autumn).

Majority of yearly runoff has typically, until the last few years, occurred during spring when snow cover melts off. Precipitation during autumn season is usually also high. The most relevant issue is, that the majority of runoff and fluxes of nutrients and particulate matter occur outside growth season, during only few weeks (when temperatures are above zero Celsius) (Puustinen et al., 2007), (Veijalainen, 2012).

Table 1. Average precipitation during a year (mm), average runoff during a year (mm) and proportion of seasonal runoff of the total annual runoff (%) during years 1961-1991 (statics of Finnish Meteorological Institute published in for example Vakkilainen 2009).

Region	Precipitation mm	Runoff during a year (mm) and proportion of seasonal runoff of the total annual runoff (%)				
		Year	Spring	Summer	Autumn	Winter
Southern Finland	700 <	300 - 400	45	10	25	20
Central Finland	600-700	< 300	50	15	25	10
Northern Finland	500 - 600	400 <	45	25	20	10

2.2 Runoff and agricultural drainage

Drainage water from agricultural fields flows on the surface, in subsurface drains and as groundwater. Several factors such as slope of fields, soil type and soil compaction influence the routes water flows take.

In Finland about 60% of arable land has subsurface drains. About 25% of agricultural plots have open ditches, and there drainage intensity is weaker. Only about 15% of arable land is cultivated without open or subsurface drainage. There is no significant difference in water pollution if fields are drained through subsurface or open drainage.

Basic drainages have typically dimensions to fit in floods which occur once every 20 years. However, the dimensions are calculated based on the climate conditions which have prevailed over the last decades.

Average distance between place of discharge from field drainage and inflow to closest natural aquatic system is 2.3 km (median 1.0 km). Especially during spring floods the delay between discharge from fields to receiving body of water is very short. This inevitably means that the buffering capacity of drainage areas is small and that drainage water have the same quality when inflowing to a body of water as they had when they were outflowing from agricultural fields (Puustinen et al., 1994).

2.3 Evaluation of water pollution levels - monitoring and models

Nutrient pollution from various sources has been monitored through water sampling for over 30 years in small catchments (Tattari et al., 2016). In addition particulate matter and nutrient fluxes have been researched at experimental setups for decades (Puustinen et al., 2010), (Uusi-Kämppä, 2010), (Turtola, 1999). The research and monitoring have given a good picture about the factors which influence the load on aquatic ecosystems.

In addition to field research, several internationally and nationally developed models have been introduced to practice. The most important ones are ICECREAM, INCA and SWAT models (Malve et al., 2016). For practical work in Finland VEMALA and RUSLE models are most commonly used (Lilja et al., 2016), (Huttunen et al., 2016). Additionally, a model based on experimental research was developed (VIHMA tool) (Puustinen et al., 2010). It can be used to estimate particulate matter and nutrient loading from agriculture on aquatic systems. The models and the data they are based on have been utilized for decades in estimation of environmental impact of agriculture and in designing agri-environmental schemes for reducing the impacts.

Up to last few years monitoring practice has been based on water sampling, but lately there is a move towards continuous water quality measurements. Continuous measurements enable acquiring better quality of data about flood situations and nutrient concentrations in discharge (Linjama et al., 2010). It has been observed that nutrient load on water systems is probably higher than previously has been assumed. The error has been caused by too infrequent water sampling, which has often missed the high discharges of water and nutrients which occur after heavy rains and snow-melt events (Figure 1).

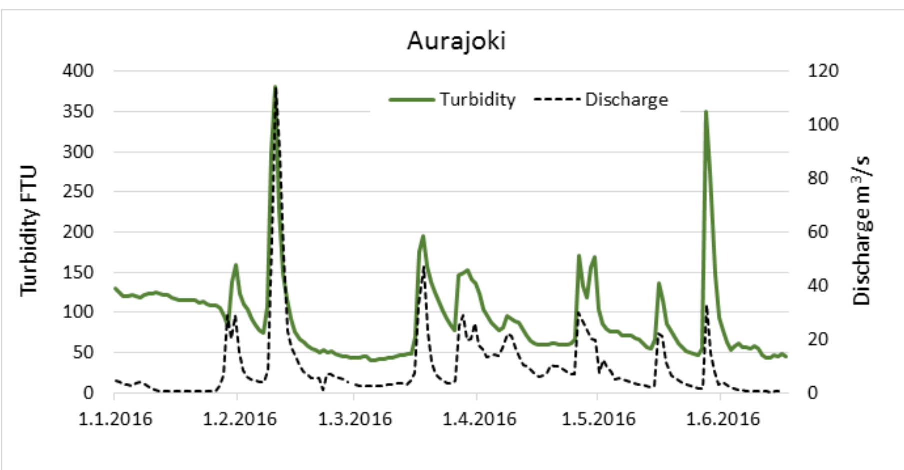

Figure 1 (Marjo Tarvainen, unpublished). Turbidity and discharge volume measured in Aurajoki with continuous water quality and quantity monitoring from January to June in 2016. If turbidity was estimated based on water sampling during the same period, conclusions could vary a lot based on timing of sampling.

2.4 Nutrient loading of aquatic systems

Many different point and diffuse sources cause nutrient loading on aquatic systems (Table 2). Notably, natural background loading is very large. Agriculture is clearly the largest source of anthropogenic nutrient pollution. On average agricultural nutrient pollution is 15 kg-N ha^{-1} yr^{-1} and 1.1 kg-P ha^{-1} yr^{-1} (Vuorenmaa et al., 2002), (Tattari et al., 2016).

Table 2. Average particulate matter and nutrient loading from various sources to aquatic systems. Here both diffuse and point source loading have anthropogenic origin.

Character of nutrient source	Particulate matter and nutrient load 1000 kg yr^{-1}		
	Particulate matter	Total phosphorus	Total nitrogen
Natural background flux	155 000	1500	39 500
Diffuse sources	1 621 600	3550	51000
○ *Agriculture*	1 340 000	2 400	33 000
Point sources	18 800	485	16334
Total	1 795 400	5 535	106 834

Agricultural particulate matter and nutrient loading to aquatic systems have been increasing since 1950-60 up to their present levels (Kauppi, 1984), (Rekolainen, 1989). During this time annual amounts of precipitation and runoff have remained stable. Increased nutrient loading to aquatic systems is thus caused by increases in the concentrations of nutrients in discharge. This is related to the many changes which have occurred in agriculture.

Notably, inter-annual variation in nutrient pollution to aquatic systems caused by hydrological climate conditions is very large and is clearly visible in monitoring results (Vuorenmaa et al 2002, Tattari et al 2016). In years with wet and mild winters agricultural loading is much larger than during years with dry and cold winters (Puustinen et al., 2007).

Since 1990’s agricultural nutrient pollution to aquatic systems has remained constant. Small changes in arable land area have had no observable influence on the load (Vuorenmaa et al., 2002), (Tattari et al., 2016).

2.5 Management of discharge and nutrient fluxes in agriculture

Presently used measures targeted at preventing water pollution are: sustainable farming practices on the fields, vegetative buffer zones along the edges of fields and measures which are done outside of arable land area such as constructed wetlands. Their main goal is to decrease erosion, which will also reduce nutrient discharge.

Both sustainable farming practices and vegetative buffer zones are supported through EU’s agri-environmental schemes programme. Since 1995 farms increasingly took part into the programme and at present about 90% of arable land area has joined it.

The effects of the programme were positive. As usage of mineral fertilizers decreased, also gross nutrients balance on arable land decreased by 35% for nitrogen and by 60% for phosphorus by year 2010. Land area ploughed during autumn decreased from 1.2-1.3 million hectares to 0.5 million hectares. Autumn tillage has been replaced with various forms of practices which have vegetative cover during winter: stubble cultivation 200 000 ha, spring tillage with stubble during winter 360 000 ha and direct sowing 156 000 ha. Area of established vegetative buffer zones is about 8000 ha and also a few hundreds of new constructed wetlands have been implemented (National agricultural statistics).

The systematic implementation of basic drainage network was a long term project, which was mostly finalised by the end of the 1970's. After that drainage projects have been mostly major overhauls or refurbishments. Overhauls are done based on the old designs and dimensions. Two-stage drainage or other sustainable solutions have not been implemented except for few exceptions.

2.6 Impacts of climate change on precipitation and discharge

In Finland the impacts of climate change will be most pronounced during winter - the winters will be much milder and will cause the Southern Finland to remain without a continuous snow cover through winter (Jylhä et al., 2008), (Olsson et al., 2015). Majority of precipitation during winter will be rainfall instead of snow. Later the same effects will occur also in Central Finland. The milder winters will lead to disappearance of typical spring floods, because there will no longer be a lot of snow melting away at once. Instead of continuous snow cover the snow will fall and melt away several times per winter. The same will happen for frost in soil. These changes will lead to high amount erosion and discharge of particulate matter and particulate phosphorus - even when the total amount of discharged drainage water would remain constant (Puustinen et al., 2007). If also the amount of precipitation will increase during winter, then the erosion rate and phosphorus flux to aquatic systems can be triple on agricultural fields without wintertime vegetative cover (Puustinen et al., 2007).

3 Results and conclusions

3.1 Effectiveness of agri-environmental schemes and management of water pollution

Even though changes in agricultural practices and in the amount of agri-environmental schemes taken into practice have been large, it was not observable in monitoring results of small catchments (Tattari et al., 2016). The effect of the agri-environmental schemes was estimated with VIHMA-model by comparing year 2010 with a year before Finland joined the EU (pre-1995): the schemes reduced the amount of particulate matter, nitrogen and phosphorus flux from agriculture to water systems by 16-22% (Table 3) (Puustinen unpublished). The estimation was done for years when hydrological climate conditions were average.

However, if the climatic change towards milder winters is taken into account (Table 3), the effect of the improved practices and agri-environmental schemes is significantly smaller. In practice, the improvement would be within the natural variation and not observable in monitoring results.

In Table 3 the listed estimates of effects from measures on the fields (implemented agri-environmental measures on arable land), riparian buffer zones, constructed wetlands (too few for statistical significance), total (total estimated effect of implemented measures in 2010 in hydrologically average years), mild winters (estimated effect of measures implemented on arable land in 2010, taking into account a change towards milder winters) and total potential (what could be achieved if measures were implemented more efficiently – taking into account change towards milder winters) are given for suspended solids (SS), particulate phosphorus (PP), dissolved reactive phosphorus (DRP), total phosphorus (TotP) and nitrate (NO_3-N).

Table 3. Impact of agri-environmental schemes on agricultural nutrient discharge to water systems (%), when comparing years 1990-94 to year 2010 (Puustinen unpublished). See text for further explanation.

Environmental measures	Change in agricultural nutrient discharge (%) at present amount of implemented measures and at different scenarios				
	Erosion (SS)	**PP**	**DRP**	**TotP**	**NO_3-N**
Measures on the fields	-22	-16	11	-6	-19
Riparian buffer zones	-2	-3	1	-2	-1
Constructed wetlands	-	-	-	-	-
Total	-24	-19	12	-8	-20
Mild winters	-9	-4	14	3	-10
Total potential	-32	-25	12	-13	-19

Similar preliminary results were obtained from ICECREAM and VEMALA models, which predict increase in phosphorus loading from arable land area by year 2050 (Figure 2) (Huttunen unpublished). These estimates show a variable change for different catchments in years 2020-29, because the base years (2005-2014) were already unusually warm and wet.

If all potential environmental measures were put into use, it would possible to reach big reductions in nutrient leakage from agriculture - if climate change was not happening. Because of that, in future Finland will need more efficient measures than are presently used - larger land area covered by present measures, better targeting to vulnerable areas, and also completely new measures (Silander et al., 2006), (Huttunen et al., 2015). Measures targeting soil and drainage have potential and will be a major focus in future.

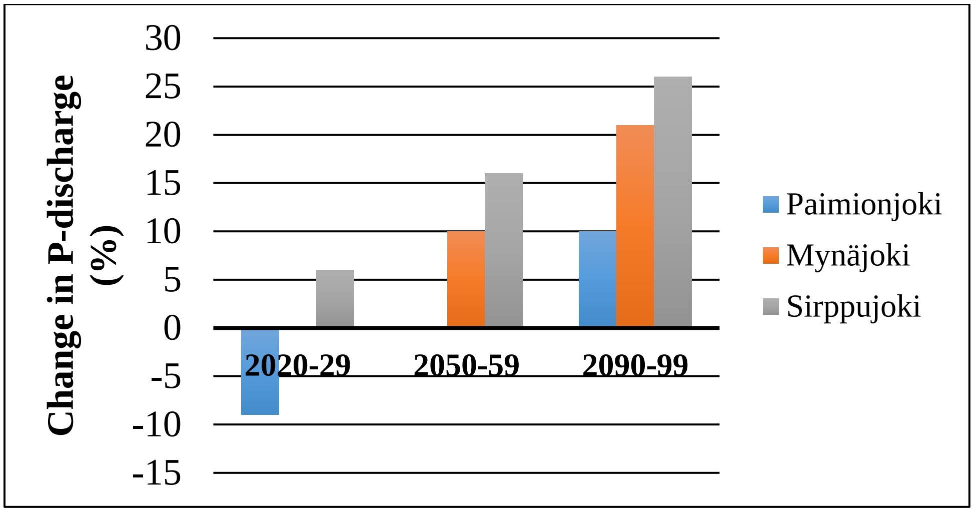

Figure 2. Preliminary estimation of impacts of climate change on phosphorus discharge from agriculture in three catchments in Southwestern Finland (Paimionjoki, Mynäjoki, Sirppujoki) in comparison to years 2005-14 (Huttunen unpublished). The phosphorus discharge will increase by year 2050, assuming the present level of agri-environmental practices. Results from ICECREAM and VEMALA models, using A1Bmean climate change scenario.

It is also possible that within few years continuous monitoring of water will improve the knowledge about nutrient fluxes from agriculture, as well as and will improve the understanding about the need for agri-environmental measures.

3.2 New measures targeting drainage

Several different arguments for implementing into wider practice the two-stage drainage have been presented: they are part of blue and green infrastructure in rural landscape, forming corridors for various species, improve biodiversity, and at the best case scenario bring back habitats which were lost when open field drainage was changed to subsurface drainage. They are one type of catchment scale agro-ecological solution (Wezel et al., 2016) with both water quality and ecological benefits.

In management of drainage water and nutrient loading an essential feature of catchments and drainage areas is buffering capacity: how much can different structures delay the flow of water without causing waterlogging or other problems. Two-stage drainage with channels for normal water and high water can easily be supplemented with sedimentation ponds and constructed wetlands. All of these structures can improve the buffering capacity.

The implementation of sustainable rural drainage systems should take place whenever a need for major overhaul occurs. It will be needed to estimate how much of the climate change impacts can be compensated with increasing the implementation of agri-environmental measures and how much with two-stage drainage. It is also needed to research: how important factor is buffering capacity or delay between point of discharge from a field and inflow to a body of water, how it influences nutrient loading and if the effect is comparable to constructed wetlands. Also the most environmentally efficient dimensioning of a two-stage drainage is still an open question.

A related question is how will climate change influence precipitation and how will it affect discharge. It will remain to be seen if disappearance of spring floods will cause more continuous discharge throughout winter. This could allow using smaller dimensions for ditches.

There are still several practical problems, which prohibit a wide use of two-stage ditch design. The problems are often related to agricultural subsidies and present agri-environmental schemes. Agricultural subsidies were not planned to allow easy cooperation between farms, which would be needed for reforming basic drainage networks. Despite these problems a few pilots of two-stage drainage has been carried out in Finland.

3.3 Functional principles of two-stage drainage

In contrast to several other agri-environmental methods, two-stage drainage channel's main functional principle is based on flood situations (Figure 3). During floods water level rises until it reaches the flood plains, where speed of drainage water is slowed down and particulate matter can settle down on the flood plain. If the channel also includes constructed wetlands and wider areas of flood plains, then the efficiency of particulate matter removal is improved.

Environmental benefits of a two-stage drainage channel were estimated in a PhD-thesis published in 2016 (Västilä, 2016). According to the estimate up to 20% of particulate matter flux could settled on the flood plains of a 1 kilometre long two-stage ditch. Also the results suggested that vegetation should be kept quite short, so that it will not restrict water flow during flood events too much.

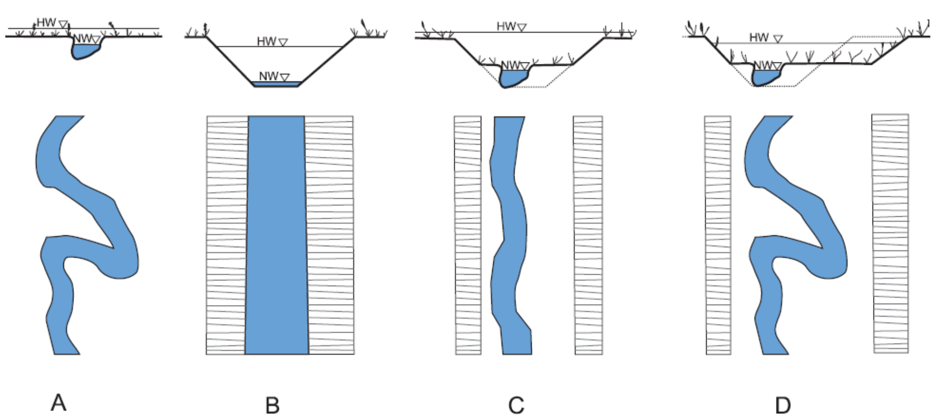

Figure 3. A) Natural brook, B) traditional main ditch, C) two-stage drainage channel, D) two-stage drainage channel after several years of operation.

Example 1: Ritobäcken

Ritobäcken is a small brook in Southern Finland. The brook is part of the Natura 2000-network, flows through agricultural area before discharging to a national park and is a habitat for a protected population of trout.

When a major overhaul of the part flowing through agricultural area became under evaluation, it was recommended that drainage depth should not be increased and the channels vulnerability to erosion should be especially considered. Because of these reasons a major overhaul using old designs and dimensions was considered to be not allowable.

In 2010 Ritobäcken was overhauled into a two-stage channel (Figure 4). Since then no maintenance has been needed, but now bushes are taking it over slowly. Now there is a need to plan how maintenance should be carried out – there is no previous experience with it in Finland.

Experience with the pilot showed that subsurface drains which discharge to a two-stage channel should be shortened, so that the drained water from fields is discharged on top of the flood plains. If sub drains continue below the flood plain, they will get blocked up very easily.

Figure 4 (Elsi Kauppinen). Two-stage channel at Ritobäcken six years after construction work.

Example 2: Leppioja

Leppioja is a ditch at a region with acid sulphate soils in Northern Finland. Because of the soil type, it is not allowed to increase drainage depth. However, the area had regular flooding on the fields during spring time. These reasons left as an only option to renovate the ditch to a two-stage drainage channel (Figure 5). Some sedimentation ponds and erosion control measures were also incorporated into the plan.

Figure 5 (Elsi Kauppinen). Two-stage drainage channel at Leppioja, a few years after construction work. Connections to subsurface drains for easier flushing are visible on the sides.

At Leppioja subdrains were cut short to end before the flood plains. This is especially valuable at this region, because at acid sulphate soils subdrains are very prone to becoming obstructed and have to be flushed once per year. The flood plain offers an easy access and working area for the drain flushing work.

Other experience gained at Leppioja was that at acid sulphate soil areas the renovation to a two-stage drainage channel should be carried out as one sided work whenever possible. Some parts of the channel still have no vegetation after few years, because the soil is too acid. If one side of the channel was left as it was, without construction work, it would limit the amount of erosion.

Example 3: Mättäänoja

Mättäänoja is a drainage ditch in southwestern Finland (Figure 7). It will hopefully be the first example of a two-stage channel in Finland, where the original idea came from land owners. The plans for the overhaul have been prepared, and at present the landowners are ready to apply for funding. The main goal is to make the area less prone for flooding. The area used to be a swamp, until it was drained for agricultural use. Slowly the organic soils have become more compacted and drainage depth has decreased (now less than 50 cm).

Figure 7 (Elsi Kauppinen). Mättäänoja-ditch in April 2016, before growth season. Low drainage depth is causing the fields to have regular flooding after snow melt and heavy rains.

4 Conclusions

Impacts of climate change in Finland will mainly cause environmental degradation. If we want to adapt to the changes and avoid the degradation, then water protection measures should be more efficient in future. Even though adoption of agri-environmental measures was large in scale, its impacts have been not been visible in water systems because the effects of climate change are already eroding away the potential positive results.

In 60's and 70's the state of Finland supported financially the construction of hundreds of thousands of hectares of basic drainage network. Nowadays still every year hundreds of hectares of major overhauls receive funding from the state. In comparison to these numbers, the total amount of established environmental measures within drainage network has been very low: few hundreds of hectares of constructed wetlands and a couple of examples of two-stage drainage channels.

There is a need to evaluate if governmental funding for drainage network overhauls should have more strict environmental standards, how sustainable drainage practices could become the norm and how is it possible to increase the buffering capacity of drainage areas. To solve these problems we still need to improve the possibilities for cooperation between farms by changing the agricultural subsidies. Drainage and blue/green infrastructure will be important aspects in adapting to climate change and in development of sustainability of practices in the future.

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