9. Nutrient load from forestry

- Forestry land 261 940 km^2
  - Forest land 202 680 km^2
  - Poorly productive forest land 25 010 km^2
  - Unproductive land 32 280 km^2
  - Forest roads, depots, etc. 1980 km^2
- Mineral soils 66%, peatland 34%
- Pine 50%, spruce 30%, herbaceous 20%
- Tree volume 2.4 km^3
- Load caused by
  - Ditching,
  - Felling + site preparation
  - Fertilizing
- Based on SYKE's estimate relatively low nutrient load nationally
  - 230 t y^{-1} P (6%), 3300 t y^{-1} N (5%)
  - N:P ratio 14
- Locally important (eastern and northern Finland), loads otherwise pristine areas (upstream lakes & brooks)
- Alteration of channels, runoff, water levels and erosion
- Bioeconomy?

Nutrient load
Agriculture vs. forestry

	Agriculture	Forestry
Area (km^2)	22 785	261 940
Management	Annually	1-2 times in forest's life cycle
Managed area	Most of the fields (expect fallow)	1-2% of forested land
Preparation of soil	No-till…ploughing	Mounding, harrowing, screefing
Nutrient inputs	Fertilizers, manure	Fertilizers
Soil type	Often fine	Often coarse/moraine, peat
Hydrology	Surface runoff, drainage flow	Sub-surface flow, percolation to ground waters
P load ($t\ y^{-1}$)	1800	230
N load ($t\ y^{-1}$)	30 200	3300
Form of nutrients	Particulate, dissolved	Particulate, dissolved fraction largely organic
Load caused by	Harvest, tillage, fertilizing	Harvest, soil preparation, ditching, fertilizing
Abatement		

Humus

Photo: Timo Vänni, Teemu Näykki

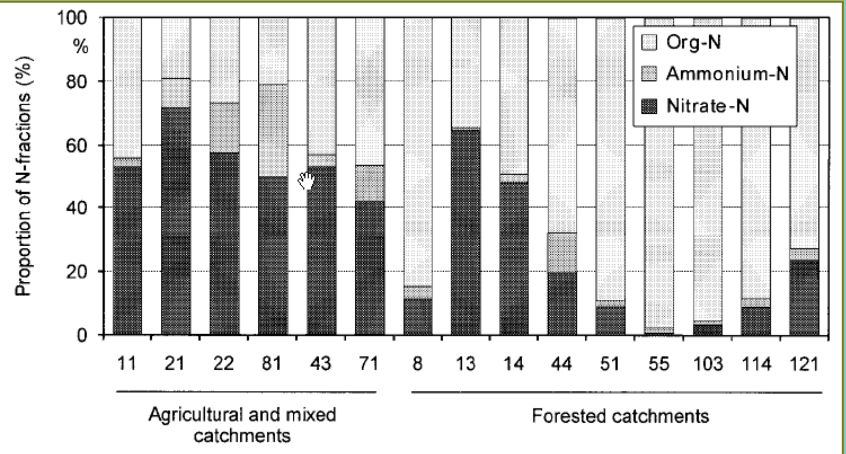
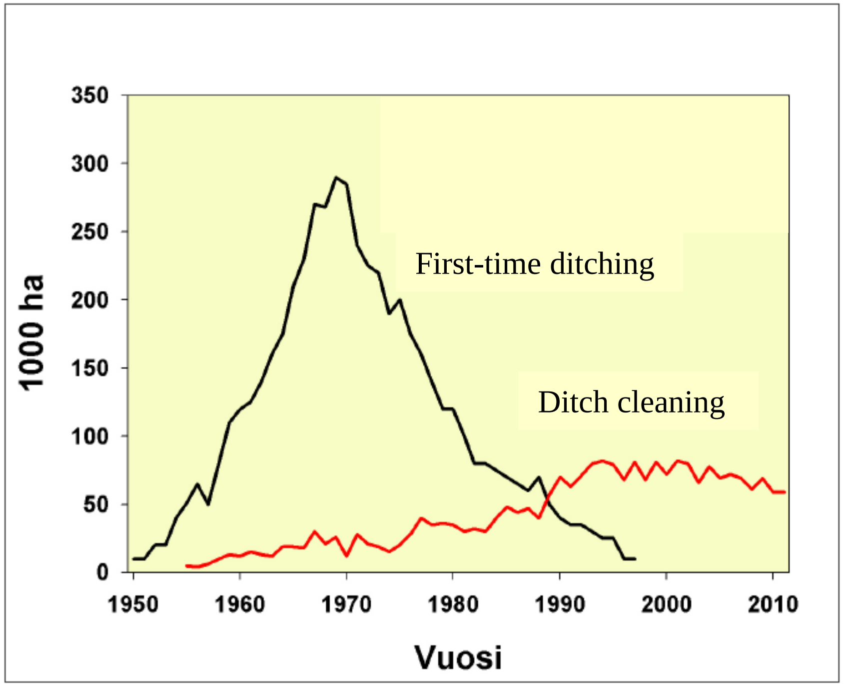


Figure 3. Average proportions of nitrate-N, ammonium-N and organic-N of the total nitrogen loss (1981–1997) in small catchments. The numbers of catchments refer to those in Table I.

Vuorenmaa ym. (2002)

Forestry drainage

- Drainage of peatland and paludified mineral soils one of the most drastic alterations of catchments occurring in 1900s
  - Started in 1930s, peak in 1965–1974, stopped by 1999/2000
  - Especially in northern Ostrobothnia
  - Forest ditch legth in Finland 1 500 000 km
  - Drained area 47 000 km^2 (53% peatland)
  - Pristine peatlands largely in northern Finland
- Reclamation of old drainage systems
  - Cleaning of old vegetated or filled ditches, supplementation of dicth network
  - Increased from 1980s (mean 770 $km^2\ y^{-1}$, 1997-2006)



Kuva 1. Uudisojitusten ja kunnostusojitusten pinta-alat Suomessa vuosina 1950–2011 (Metsätilastollinen vuosikirja, Metsäntutkimuslaitos).

Drainage lowers the ground-water table

- Drainage leads to
  - Increased runoff, but when tree stands develop may be lower than before drainage
  - Water level drawdown (by few decimeters), which enhances aeration and mineralization of peat
  - Biomass production shifts from understory vegetation to the tree stand
  - Increased foliage biomass captures more nutrients from wet and dry deposition
  - Hydraulic conductivity of soil decreases with peat decomposition
- Drainage increases nutrient losses
  - Earlier view
    - The losses achieve the pre-ditching level at least in 20–30 years
    - Forestry operations in drained peatlands increase nutrient losses only temporarily and the losses return back to pre-treatment levels within 10 years

Erosion caused by ditching

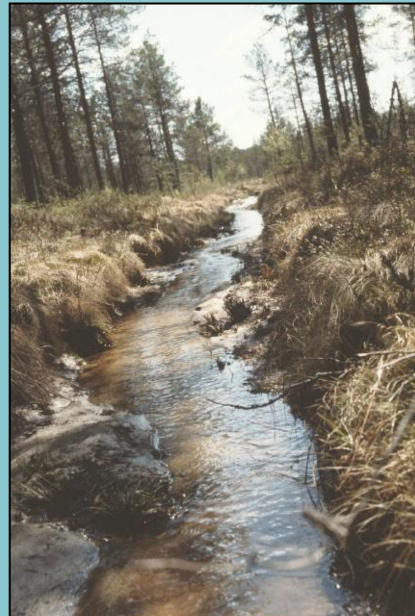
- **Digging and ditch erosion → TSS transport increases**
  - **First-time ditching**
    - **Up to 200 t km^{-2} y^{-1} on sandy soils, lower in peat soils**
  - **Ditch cleaning can produce similar erosion rates as first-time ditching**
  - **Particulate P**
  - **Dissolved P losses low, impact on eutrophication?**
- **Does N loss increase?**
  - **NH_4 originating from anaerobic peat layers (anaerobia and acidity prevent nitrification)**
  - **Improved tree growth may prevent the increase in N losses**

Photo: Kaarle Kenttämies

A delta formed by eroded soil when settled upon entrance to a lake (Loppi)

Ditch caused a permanent lowering of the water level in a lake

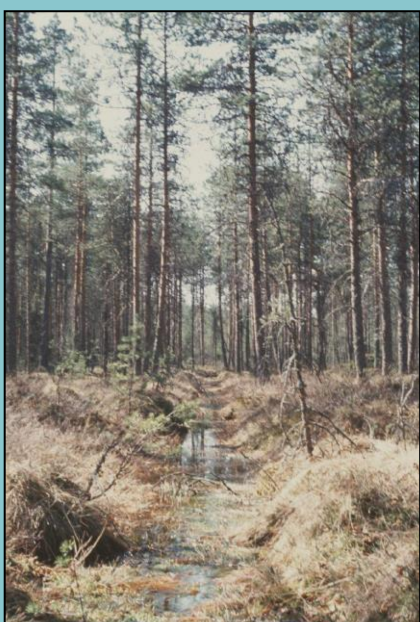
Eroded material settled on ditch bed



Ditch on sandy soil is filling with eroded soil

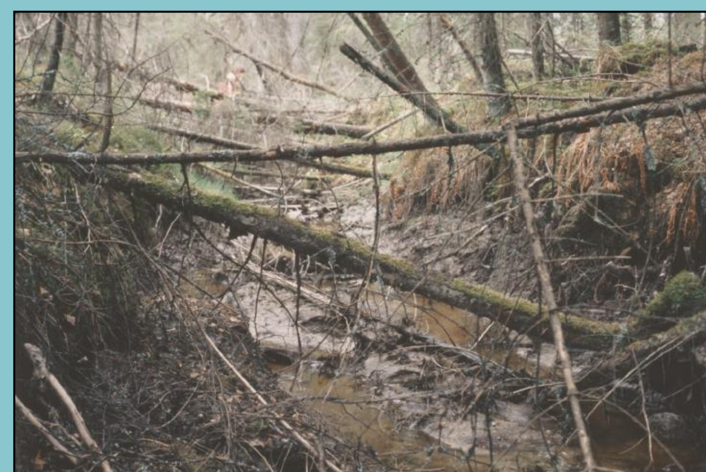
Ditch in peatland is more durable that ditch in sandy soil

Newish ditch



Ditch is filling up

Stabilized ditch



In erosive soil ditches do not stabilize

Photos: Kaarle Kenttämies

Minimizing nutrient losses in ditching

- Avoiding insignificant ditching
- Digging in a dry period, work distributed to several years
- Strongly eroded or sloping ditches not be reclaimed
- Avoiding digging into mineral soil layers
- Breaks in cleaning and digging (kaivu- ja perkauskatkot), silt traps (lietekuopat),overland flow fields (pintavalutuskentät)…
- Avoiding cleaining 10 m before water courses
- No management in groundwater areas

Overland flow fields
- Retain 70−90% of TSS
- Recommended area: 1−2% of catchment

Settling ponds
- Retain 30−60% of TSS
- Especially coarse fraction
- Flow velocity at maximum 1 cm s^{-1}
- Water detention time at least 1 h

Source: Marjo Palviainen

Ditch not digged into a lake

Ditch led to a sandy soil

Settling pond

Photos: Kaarle Kenttämies

A new study on drainage
Nieminen et al. (2017)

- TN and TP concentrations in runoff from drained peatland forests increase with time
  - Both TP and the TN concentrations more than doubled during 40 years
  - How long do the concentrations still increase?
- Nutrient concentrations higher than in pristine sites only after several decades from first-time drainage
  - Earlier studies focused on “recently drained” (20–30 years ago) areas, where the increase not yet visible
- Hypothesis for the increase
  - The subsidence of mire surface after initial drainage + supplementary drainage or ditch cleaning → the ditches may reach the mineral soil below peat → Contact of waters with mineral subsoils may cause long-term erosion and loss of PP
  - PP and N may increase because the highly decomposed peats in old drainage areas are eroded more easily than the less decomposed peats in recently drained areas
  - Dissolved N may increase due to climatic warming that increases mineralization more in old than recently drained areas because of lower water levels caused by higher transpiration demand of the larger tree stand
  - Larger tree stands in older drainage areas capture more atmospheric dry and wet deposition N than the smaller stands in recently drained areas
  - Most likely explanation: the increase in N mineralization with years since drainage of peatland forests is a natural drainage succession process and some of the mineralized N is lost by leaching

A silt trap

Felling

Murtopuro, Nurmes, in 1980s 300 ha was felled in one instance

Photos: Kaarle Kenttämies

- Felling areas registered since 1970
  - Regeneration cutting (clear-cut) 741–1739 km^2 y^{-1} (1990–2009)
  - Site treatment 970 km^2 (v. 2010)
    - Aims to improve water resources, airation, temperature, nutrient status
  - Notice to the Finnish Forest Centre (metsäkeskus), legality monitored by sampling
- Hydrology may be changed up to 20 years
  - Runoff increases (plant uptake, interception and evapotranspiration reduced)
  - Water table may rise → summer runoff increases
  - Surface runoff increases in soil with poor hydraulic conductivity
  - Floods become more fluctuating, as shading decreased and snow melts faster
- Nutrient losses increase
  - Plant uptake decreases (surface vegetation important)
  - In clear-cut the amount of cutting residues and root biomass may exceed the removed wood, surface vegetation dies → dissolved nutrients also released
  - Nitrification and mineralisation may increase
  - Erosion increases as vegetation does not anymore protect the soil
  - Soil preparation further increases the losses
  - Effects last for 10–20 years, the highest during the first years
  - Groundwater NO_3 concentratios may increase

Site treatment

Screefing (laikutus)
- Humus layer is removed
- Gaining in popularity

Harrowing (äestys)
- Tillage depth max. 10 cm
- Mineral soil unveiled
- Gaining in popularity

Photo: Kaarle Kenttämies

Mounding (mätästys) after clear-cut, common in northern Finland

Thinning

Photos: Kaarle Kenttämies

Thinning usually causes little nutrient load

Tractor ruts erode in fine soils

A new study on load caused by felling

Palviainen et al. (2014)

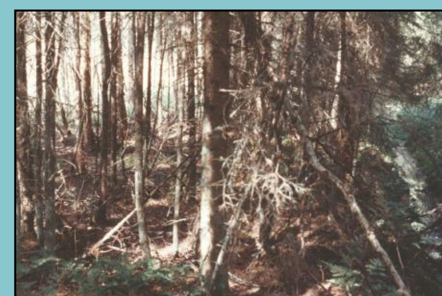
- Today, clear-cutting areas smaller, soil preparation lighter and buffer zones ”compulsory”
- Catchments
  - Porkkavaara (control), Kangasvaara (34% felled felled and prepared), Iso-Kauhea (11%), Korsukorpi (8%)
  - All catchments within 30 km range
- Felling residuals left on ground + buffer zones along brooks, soils prepared mainly by harrowing
- Nutrient losses calculated using linear interpolation
- Calibration period before felling (5-8 years) + monitoring after felling (6-14 years)
- Nutrient losses before felling ”typical”
- After felling
  - Runoff increased only in Kangasvaara (1-30 %), where the managed areas the highest and topography sloping
  - TN, TON, NO_3-N, RP and TSS loads increased only in Kangasvaara
  - NO_3-N concentrations increased in Kangasvaara due to
    - Latvusto ei enää sitonut laskeuman N:ä
    - Larger amount of snow
    - Puiden ja aluskasvillisuuden N-oton vähentyminen
    - Nitrification was enhanced
  - TSS increased in all managed areas (by 16-291%)
- Conclusion: Felling using modern methods may increase N, P and TSS load for more than 10 years, but effect quite small, if a relatively small area of the catchment is felled

Buffer zones

Unmanaged zones along lakes, rivers and brooks

- **hould be fully vegetated and water should flow slowly through the zone**

Photo: Metla/Oksanen



Photos: Kaarle Kenttämies

Trees in buffer zones are suspectible to wind

P retention in buffer zones depends on the amount of Al and Fe oxides in soil (Väänänen et al. 2007)

- **Buffer zone area had better P binding ability than the clear-cut area**
- **A new sampling after a few years showed that P-binding ability was decreased**
- **Dissolved P is released from logging residues**
- **P was not lost**
  - **Was moved to deeper soil layers**
  - **Plant uptake**

Forest fertilizing

www.mhy.fi

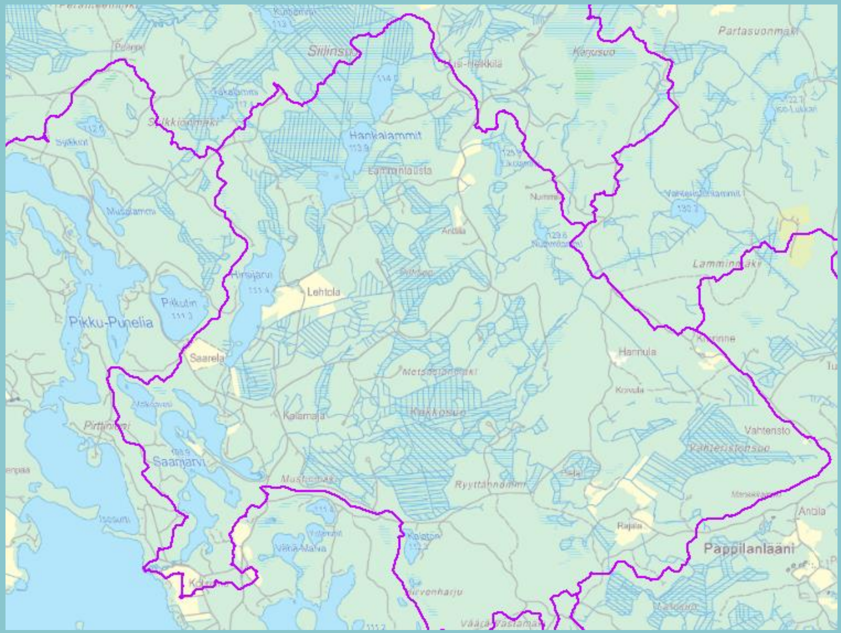
- Started in 1950s, 1970s up to 2400 km^2, 2010: 450 km^2
- ”Health fertilizing” (Metsien terveyslannoitus)
  - Ash (=P + K + B + Ca), B or PK
  - B deficit in spruce stands in old slash-and-burn areas on mineral soils
  - B-K-P deficit in drained peatlands
  - Improves nutrient ”imbalance” of soil
  - Supported by KeMeRa (Kestävän metsätalouden rahoitustuki, Act on the Financing of Sustainable Forestry)
- Forests on peatland
  - Peat binds P poorly, but has lots of N → P, K or B the limiting nutrient
  - Almost stopped at the beginning of 1990s, recently increased 100–150 km^2
- Forests on mineral soils
  - N limiting
- N fertilizers: NH_4, NO_3, urea, ammonium nitrate
- P fertilizers: raw phosphate (northern Africa, Siilinjärvi) or superphosphate
- In 1977–1988, PK fertilizer contained 15–20% soluble P
  - Today fertilizer less soluble, losses lower
  - FePK and ash show lower losses than raw phosphate
- Part of fertilizers directly on ditches and brooks

An alternative estimate on nutrient load

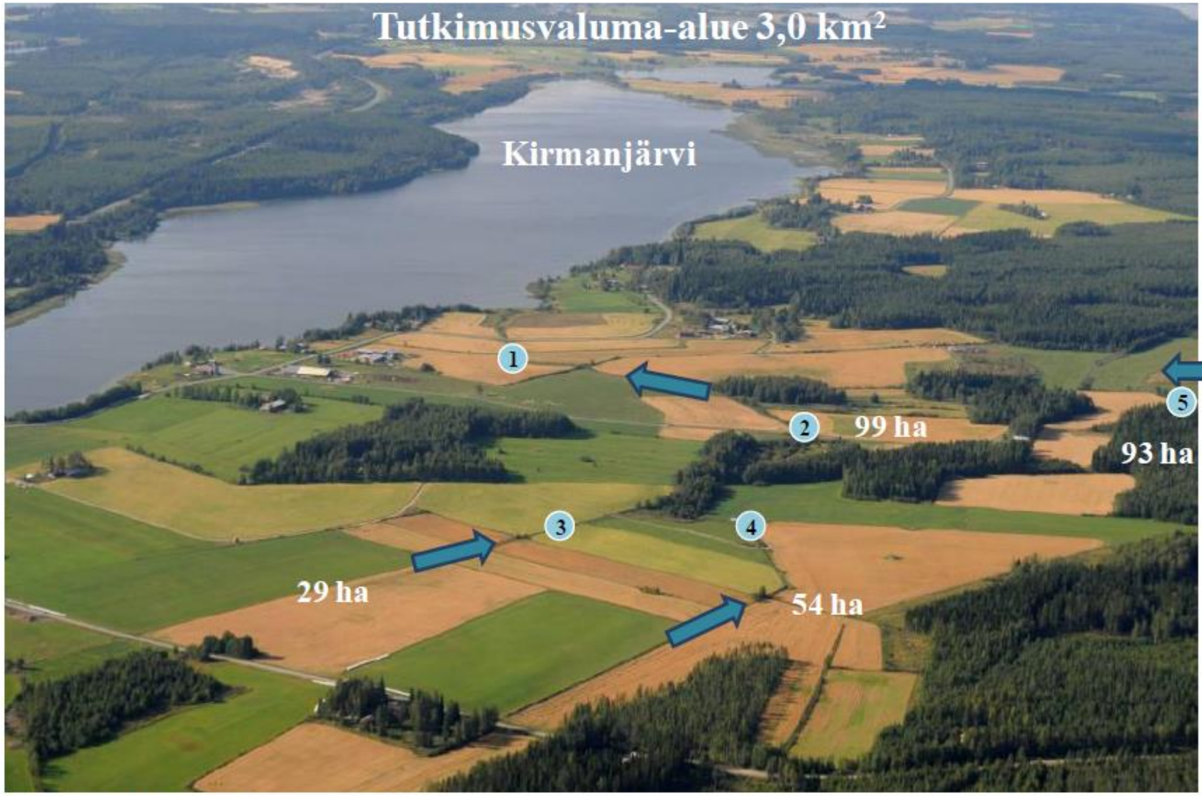
- Specific nutrient load from forested small catchments with ordinary forestry practices
  - Mean 9 kg km^{-2} y^{-1} P and 250 kg km^{-2} y^{-1} N (1981–1995; Vuorenmaa ym. 2002),
  - 10.5 kg km^{-2} y^{-1} P and 190 kg km^{-2} y^{-1} N, northern Finland (1962–1992; Saukkonen and Kortelainen 1995)
  - 10.2 kg km^{-2} y^{-1} P, Northern Sweden (1969–1987; Lövgren and Olsson 1990)
- If load from forestry = above values minus natural background loss, then
- Nutrient load caused by forestry in Finland, formed in an area of 202 680 km^2 (forest land)
  - 800 t y^{-1} P and 10 000 t y^{-1} N, as compared with the SYKE's estimate
  - 230 t y^{-1} P and 3300 t y^{-1} N

A paleolimnological study on forest lake

- **Lake Saarijärvi (Loppi)**
  - **Eutrophication began in early 1900s**
  - **Humus compounds increased due to drainage in 1950s**
  - **Rapid eutrophication in 1970s due to fertilizing and maintenance ditching**
  - **New fertilizing in 1985**
  - **Yet today, algal blooms and hypoxia**
- ***Gonyostomum semen***
  - **Flagellated microalga**
  - **An invasive species**
  - **Skin irritation for caused by ejections of slime threads from trichocysts**
  - **In brown-water lakes with a high P concentration**



A paleolimnological study on agricultural lake



Kuva 1. Ravinnekuormituksen seurantaverkoston viisi mittauspistettä Ruostepuron osavaluma-alueen (3,0 km^2) ojissa Pohjois-Savossa Iisalmessa. 1 = Kirmanjärveen laskevassa Ruostepurossa oleva mittauspiste, 2 = Sumppilammen kosteikon alapuolella oleva mittauspiste, 3 = peltovaltainen seuranta-alue (pelto-% 100), 4 = pelto- ja metsävaltainen seuranta-alue (pelto-% n. 50, metsä-% n. 50) ja 5 = metsävaltainen seuranta-alue (metsä-% lähes 100; sisältää myös haja-asutusta). Kuva: MTT/Perttu Virkajärvi.

- Lake eutrophic with cyanobacterial blooms for centuries
- Naturally eutrophic lake typ
- The state decreased to ”moderate” in 1800s
- Worsened again in 1960s
- Kauppila et al. (2012)

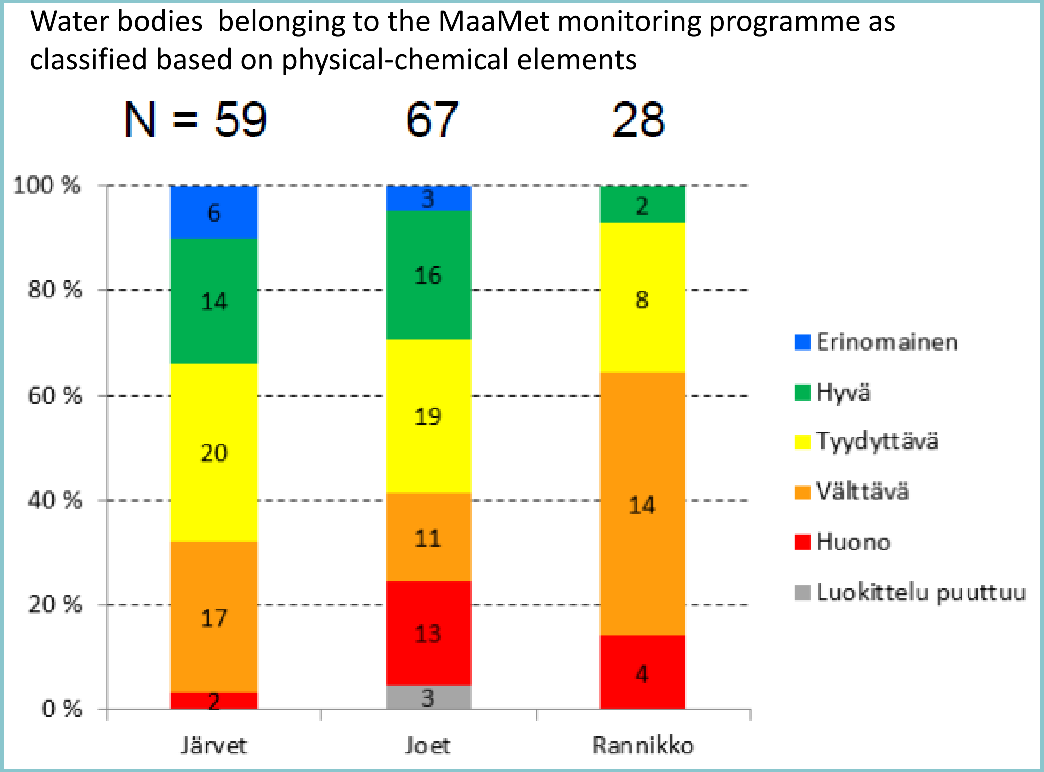
Effect of land use on the occurrence of cyanobacterial blooms

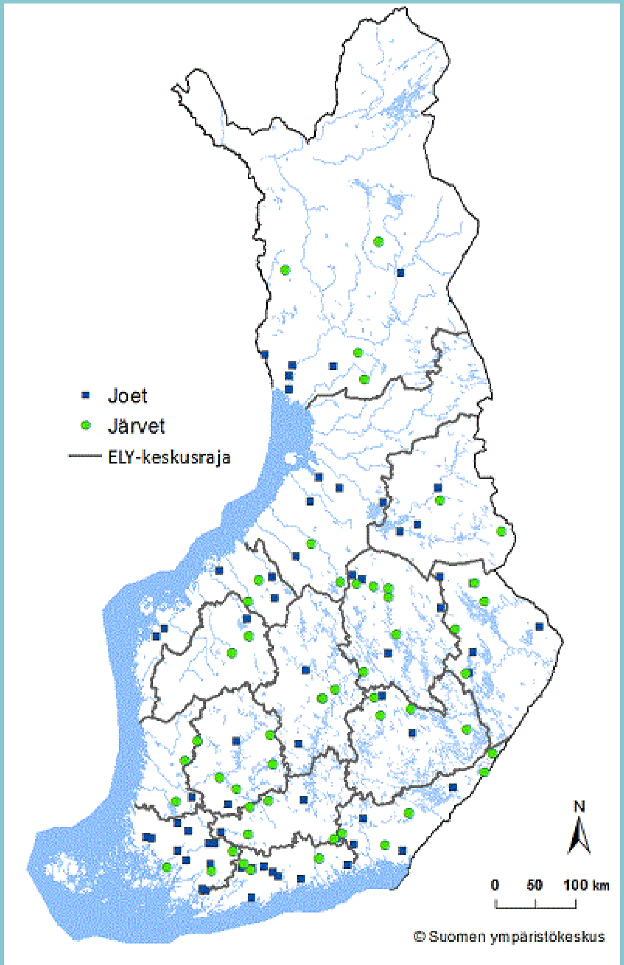
Kauppi et al. (1990)

60 lakes with cyanobacterial blooms

- 13 loaded by wastewaters
  - Median TP 68 μg l^{-1}, TN 1000 μg l^{-1}
  - Eutrophied in 1900s (paleolimnology)
- 33 agricultural lakes
  - Strong blooms nearly yearly
  - Median TP 50 μg l^{-1}, TN 960 μg l^{-1}, concentrations correlated with field-% in the catchment
  - Eutrophic for long, in some cases eutrophication increased in recent decades
- 10 forest lakes
  - Cyanobacterial blooms only occasionally
  - Median TP 37 μg l^{-1}, TN 680 μg l^{-1}
  - Eutrophied during last 20–30 years
- 4 lakes
  - No significant anthropogenic impact

MaaMet project





Kartta. Maa- ja metsätalouden kuormituksen aiheuttamien vaikutusten seurantakohteet

- MaaMet rivers as classified based on biological elements
  - The ecological quality standard values of periphyton, bottom fauna and fish decreased with an increase in field-% of catchment
- MaaMet lakes as classified based on biological elements
  - The ecological quality standard values of phytoplankton, macrophytes and periphyton decreased with an increase in field-% of catchment
  - Fish showed clear response to agriculture, more unclear response to forestry

Source: Aroviita, Mannio (SYKE), Rask (RKTL

Peat mining

- Area 680 km^2
  - In total 1100 km^2, 1.2% peat area
- Production fluctuates annually depending on hydrology and economy
- Mostly used in energy prodution (milled peat - jyrsinturve, sod peat - palaturve)
  - Noin 10 % muuhun käyttöön
- Mainly in Ostrobothnia, also elsewhere
- Experience damage especially in
  - Central Finland, Pirkanmaa, southern Savolax
- One peat area can ”produce” peat about 30 years, after which the area is forested, restored back to peatland…
- Load depends on hydrology, SYKE’s estimate: 17 t y^{-1} P, 435 t y^{-1} N
- Locally important
- Overland flow, vegetation fields and reservoirs, sedimentation ponds, chemical purification

Ekholm

Fur farming

- In Finland 1 200 fur farms (2008), mainly in Ostrobothnia
- 3 100 000 animals (blue fox, mink, polecat, raccoon, silver fox)
- In combination with farms or as an independent livelyhood
  - Employing 6000–7000 people
- Fodder consists of about 80% domestic raw material
  - Slaughter house wastes (25%)
  - Cereals
  - Fish
- SYKE's load estimate 45 t y^{-1} P and 430 t y^{-1} N
  - Locally important
- On the other hand…
  - With fish 200 t y^{-1} P removed from the Baltic Sea
- Manure contains high amount of sparingly soluble P
  - Usage high (agri-environmental subsidies enable twice the amount of P given in fur animal manure than in commercial fertilizers)
  - -> Soil-test P increased locally

Sparse population

- About 850 000 inhabitants (and 300 000 permanently used estates) not connected to sewer systems
  - Especially in Uusimaa, Varsinais-Suomi and Pohjanmaa
- Summer cottages (461 400 in 2002): part-time use by about one million people
  - Standard of equipment increased
- On-site treatment
  - Traditional treatment facilities insufficient
  - Water act (1961) required that lavatory wastewater had to be treated at least by a septic tank
  - In septic tanks (one to three in a line) part of solid fraction settles
- Sparse population second largest source of P load
  - Nearly 10% P load, 3% N load
  - Local effect
  - Ground waters
  - Pathogens, medicinal residues, hormones…
- Load estimate
  - 1.8 g d^{-1} $person^{-1}$ P, 12 g d^{-1} N $person^{-1}$
  - → 0.66 kg y^{-1} $person^{-1}$ P, 4.4 kg y^{-1} N $person^{-1}$ × 1 000 000 persons
  - = 660 t y^{-1} P, 4400 t y^{-1} N, of which estimated to enter surface waters:
      - Sparse population: 395 t y^{-1} P, 2650 t y^{-1} N (Rontu and Santala 1995)
      - Plus holiday houses: 415 t y^{-1} P, 2700 t y^{-1} N (Rontu and Santala 1995)
    - N : P about 7
  - Compare with the load by persons connected to a sewer system175 t a^{-1} P, 10 800 t a^{-1} N

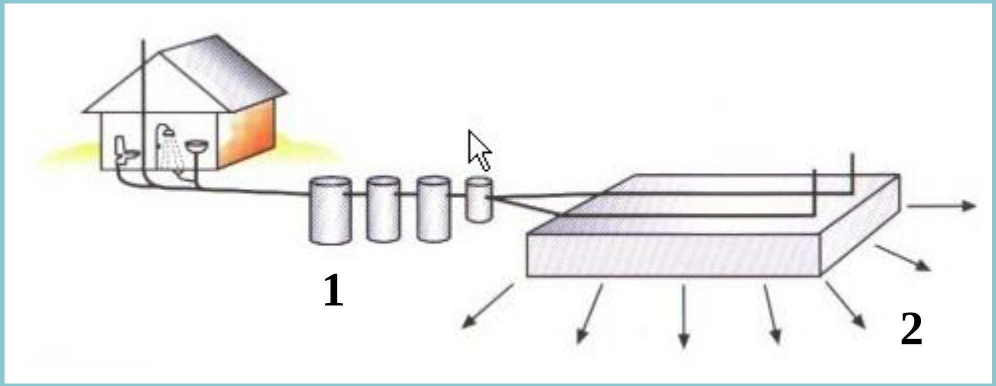
Government Decree on Treating Domestic Wastewater in Areas Outside Sewer Networks

- Untreated wastewater
  - BOD_7 50 g d^{-1}, P 2.2 g d^{-1}, N 14 g d^{-1}
- These values have to be reduced by: BOD_7 80%, TP 70%, TN 30%
- In pollution sensitive areas (designated by a municipality) : BOD_7 90%, TP 85%, TN 40%
- Wastewater systems **must be** upgraded to fulfill therequirements
  - By 31.10.2019, if the estate located at maximum 100 m from a watercourse or the Baltic Sea (16% of estates) or on a groundwater area (7%)
    - Exception if wastewater amount is small or the costs excessive
  - On next major renovation if elsewhere
- Wastewater systems does not have to **be** upgraded
  - The permanent resident born before 9.3.1943
  - Wastewaters will be lead to sewer systems
  - Wastewater amount is negligible and there is no water closet
  - The construction licence allowed after 2004
- Also concerns dairies

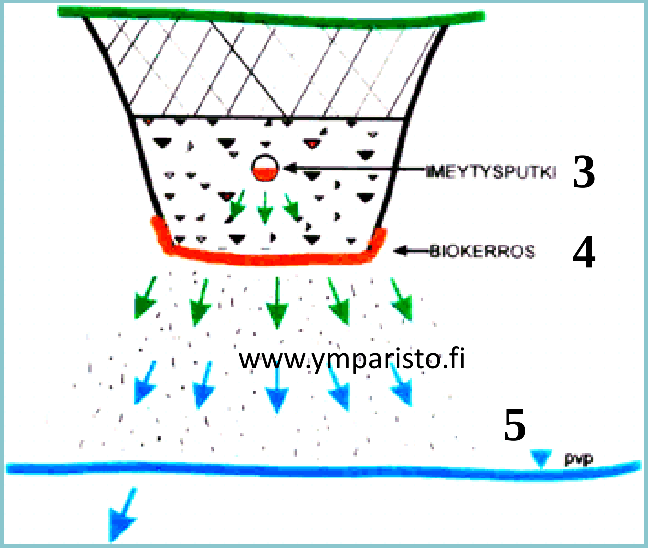
On-site treatment

- Method depends on
  - Toilet type and level of equipments
  - Water supply
  - Recipient
  - Density of population
- Connection to sewer systems
  - Principal choice
  - Neighbouring estates can built a joint sewer system and purification plant
    - Rare
- Collecting wastewater and transport to treatment plant
- Small plants
  - Require little space but lof of maintenance
  - Many different methods, e.g. batch treatment plants
- Soil infiltration, sand filters, composting toilets

Soil infiltration



1. **Pretreatment in 3-part septic tank**
2. **Clarified water led through a distribution well to perforated distribution pipes**



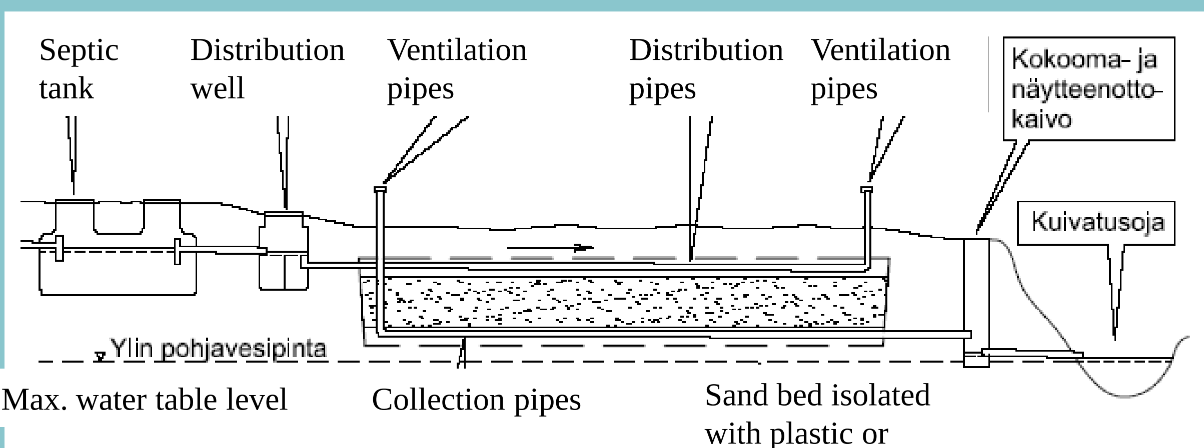
3. **From distribution pipes to gravel layer, where water spread laterally and downward**
4. **A bioactive layer promotes decomposition of organic matter, P bound by soil particles, bacteria will be destroyed (unlike viruses), N removed only little**
5. **Water infiltrates to natural soil layers and moves downward to groundwater**

www.vsyliitto.fi/haja-asutuksen_jatevedet.shtml

Only in sites with a deep, not too dense or coarse soil layer and where no harm is anticipated to household wells, other water supply and ground water. Suits well to grey waters.

Buried sand filter (maasuodattamo)

- Excavated to poorly water conducting soil, or isolated field, filled with gravel and sand
- Wastewater purified as it moves through the sand bed (microbial activity, adsorption)
- Efficient reduction of organic matter and bacteria, P removal may be enhanced by a separata unit



Kuva 1. Tavallisen maasuodattamon pituusleikkaus.

Vilpas ym. (2005)

A study on the load from sparse population

Särkelä and Lahti (2013)

The share of toilet waters in the total loading from the sparse population

- At least 90% N, 80% P, 80% total O_2 consumption (= org. matter + NH_4), 98% fecal bacteria
- Why toilet water (1/3) mixed with purer washing waters (2/3)?
- Even when meeting the requirements of the decree, wastewaters contain high amount of *E. coli* and NH_4-N
- Diluting water enters from surroundings the soil infiltration systems –> results on the performance too optimistic
- Small treatment plants show varying performance and are suspectible to interferences
- Recommendation: toilet and other wastewater should have separate sewer systems and treatment
  - Composting of toilet waste
  - Calcium stabilized toilet waste collected by a cesspool
  - Use of nutrients as fertilizers

Urban runoff/stormwater

- In a natural environment, most water is taken up by vegetation
  - Remainder percolates to ground water or forms surface runoff
- In urban environment
  - Streets, yards and roofs prevent infiltration
  - Efficient drainage ands sewer systems
  - Precipitation 10% higher in large cities than in the surrounding area, evaporation lower

  → Surface runoff increases and becomes more fluctuating
- Runoff coefficient
  - Impervious surface 40%, about 20% precipitation forms immediate runoff
- The larger the area of sealed vertical and horizontal surface, the higher the share of atmospheric deposition entering surface runoff
- Combined sewer system (sekaviemäröinti)
  - Urban runoff causes problems in sewage treatment plants
    - Flow variation, low temperature, by-passes
  - In downtown areas in old cities
- Separate sewerage (erillisviemäröinti)
  - Most common
  - Urban runoff led untreated to surface waters (exceptions gas stations, indistrial areas…)
  - Increased surface runoff and straigthened routes increase floods and cause erosion
  - Infiltration structures, detention ponds, wetlands, green roofs

Nutrient load by urban runoff

- Little national-scale data, mainly case-studies
- Vallikallio vs. Laaksolahti
  - TSS 20 000 vs. 10 000 kg km^{-2} y^{-1} (<10 000–120 000 kg km^{-2} y^{-1})
  - TP 40 vs. 20 kg km^{-2} y^{-1} (20–200 kg km^{-2} a^{-1})
  - TN 900 vs. 500 kg km^{-2} y^{-1} (200–1000 kg km^{-2} a^{-1})
- SYKE's estimate of national load
  - 90 t y^{-1} P, 1100 t y^{-1} N

Figure 2. Aerial photos of SR before (2001) and after (2007) construction works (aerial photos provided by the City of Espoo).

Saunalahdenranta (Sillanpää 2013)

Photo: Sari Mitikka

Brief summary on diffuse pollution

Causes

- Tillage/preparation of soil, removal of vegetation, nutrient inputs, human wastes, traffic
- Linked to world population and its need of food, energy and stuff
  - 2100: > $11 \cdot 10^9$ people
  - Eutrophication can increase 2–3-fold

Transport

- By water and wind

Uncertainties in

- Magniture, spatial and temporal distribution, impacts on surface water, abatement

Decrease by

- Lowering nutrient inputs (amount and spreading), erosion control, capturing nutrients already left the soil, own choices…

Forms of P and N

- Chemical determinations of especially P do not identify distinct chemical compounds but ”operational” fractions
- Biological availability unclear (particulate P, organic N)

Reactions of P in soil – *From apatite to Fe and Al oxides*

- Spesific ligand exchange

Reactions of N in soil – *From air to organic matter*

- Organic matter, microbiology

Reactions in sediments

- Microbiological oxidation-reduction reactions
- Coupled biogeochemical cycles (P, N, S, Fe, C)

References

- Kauppi L, Knuuttila S, Sandman K, Eskonen K, Luokkanen S, Liehu A, 1990. Role of landuse in the occurrence of blue-green algal blooms. Verh. Internat. Verein. Limnol. 24:671–676.
- Löfgren S, Olsson H. 1990. Nitrogen and phosphorus input to surface waters in Sweden (in Swedish). Naturvårdsverket, Report 3692, Solna.
- Nieminen M, Sallantaus T, Ukonmaanaho L, Nieminen TM, Sarkkola S. 2017. Nitrogen and phosphorus concentrations in discharge from drained peatland forests are increasing. Science of the Total Environment 609:974-981.
- Palviainen, Finér, Laurén, Launiainen, Piirainen, Mattsson, Starr. 2014. Nitrogen, Phosphorus, Carbon, and Suspended Solids Loads from Forest Clear-Cutting and Site Preparation: Long-Term Paired Catchment Studies from Eastern Finland. Ambio 43:218-233.
- Rontu M, Santala E. 1995. Haja-asutuksen jätevesien käsittely. Vesi- ja ympäristöhallituksen monistesarja nro 584.
- Sillanpää N, 2013. Effects of suburban development on runoff generation and water quality. Aalto University publication series Doctoral Dissertations 160/2013.
- Särkelä A & Lahti K, 2013. Haja-asutuksen jätevesien koostumus ja jätevesijärjestelmien toimivuus. Vantaanjoen ja Helsingin seudun vesiensuojeluyhdistys. Julkaisu 68.
- Vuorenmaa J, Rekolainen S, Lepistö A, Kenttämies K, Kauppila P. 2002. Losses on nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s. Environmental Monitoring and Assessment 76:213-248.
- Väänänen R, Kenttämies K, Nieminen M, Ilvesniemi H. 2007. Phosphorus retention properties of forest humus layer in buffer zones and clear-cut areas in southern Finland. Boreal Environment Research 12:601-609.
- Saukkonen S, Kortelainen P. 1995. Impact of Forestry Practices on the Leaching of Nutrients and Organic Matter (in Finnish), in Saukkonen S, Kenttämies K (eds.), Joint Research Project on the Adverse Effects of Forest Management on the Aquatic Environment and their Abatement. Final Report. Finnish Environment No. 2, Finnish Environment Institute, Helsinki.