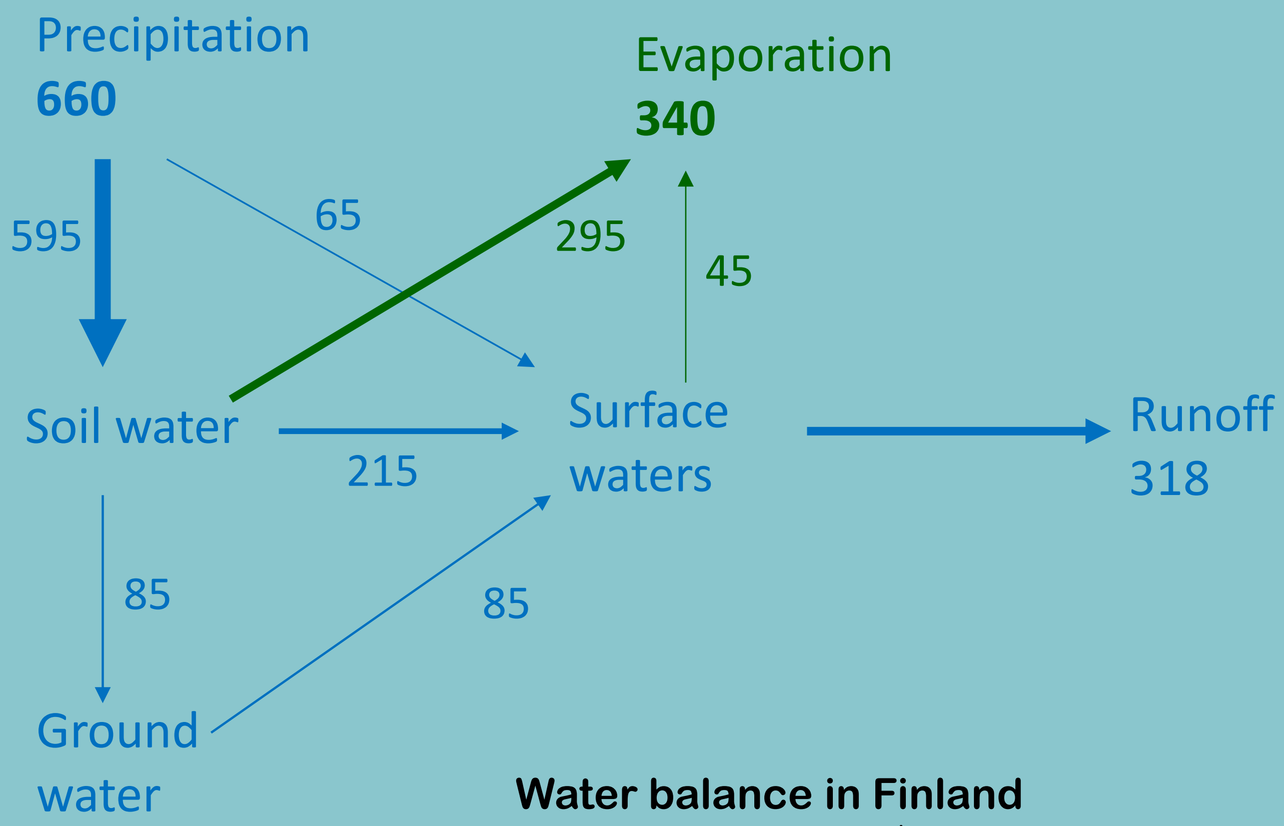
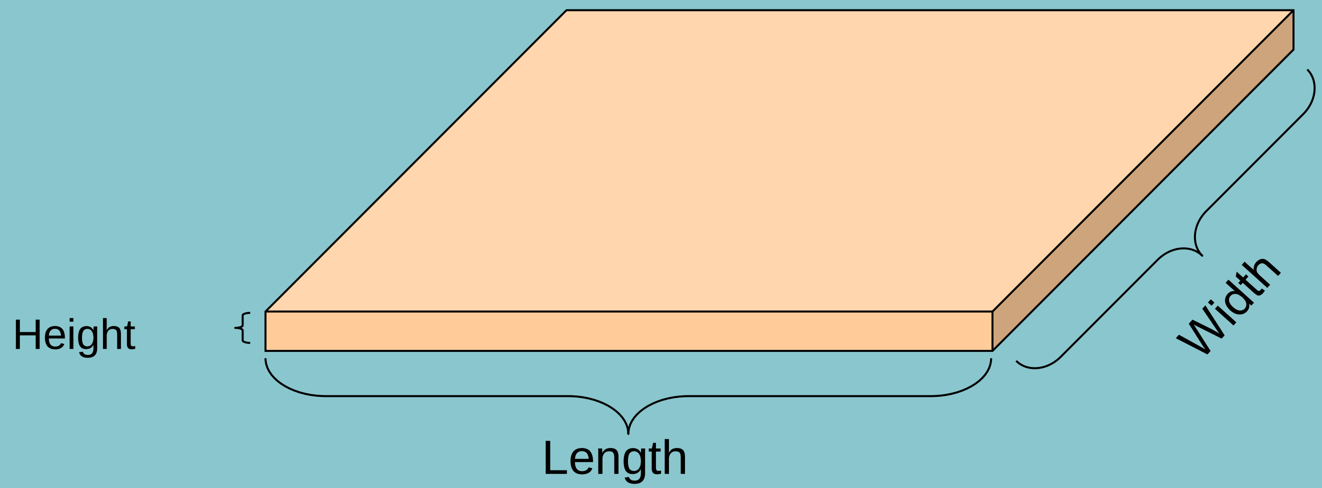
4. HYDROLOGY



Water balance in Finland 1960–1990 (mm y^{-1})

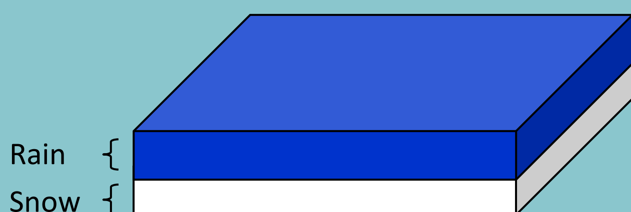
- **Unit in hydrology often**
  - **millimetre (mm)**
  - **1 mm = 1 l m^{-2} = 10 m^3 ha^{-1} = 1000 m^3 km^{-2}**

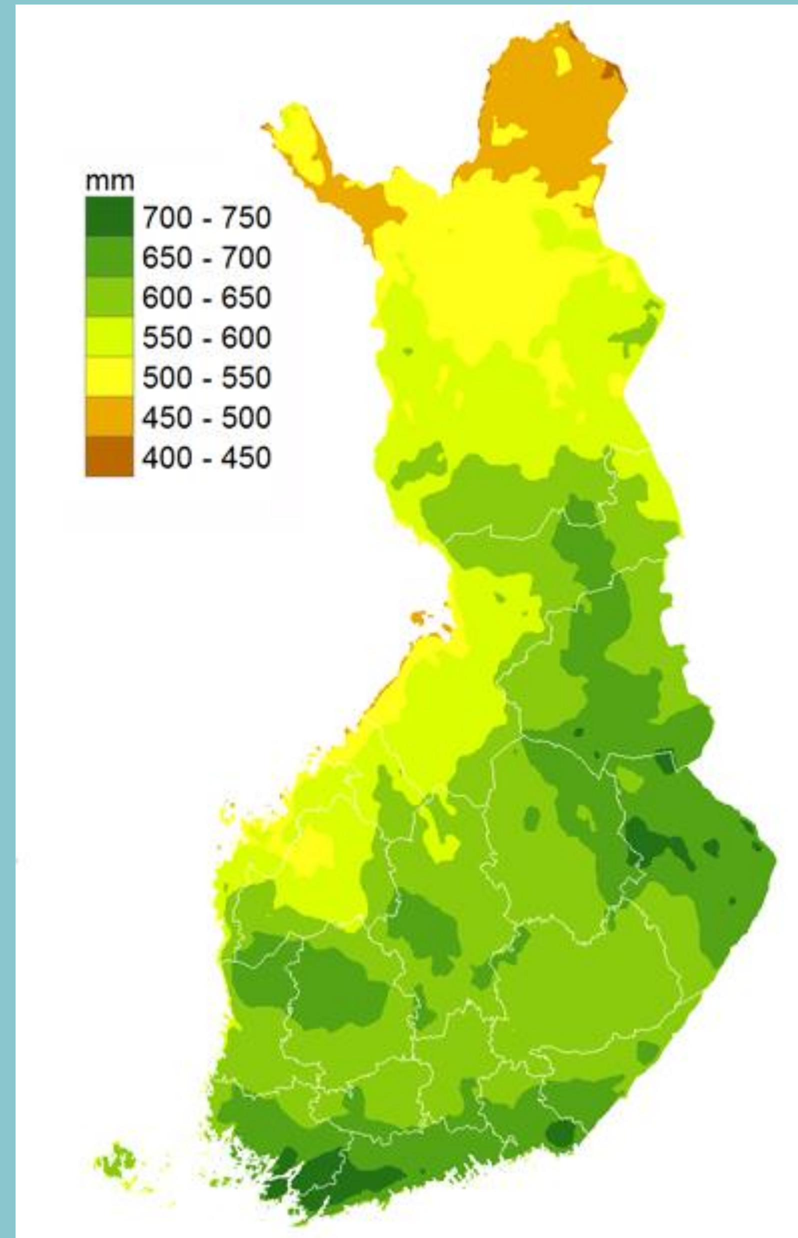


Precipitation

Precipitation = Water, snow, hail, dew, frost (kuura)

- **Mean annual precipitation**
  - **Finland (1961–1990): 660 mm y^{-1}**
  - **Europe: <25 mm ... >3000 mm y^{-1}**
  - **Global mean: 857 mm y^{-1}**
- **Maximum daily precipitation**
  - **Finland (Espoo, 1944): 198 mm d^{-1}**
  - **World (Réunion): 1825 mm d^{-1}**



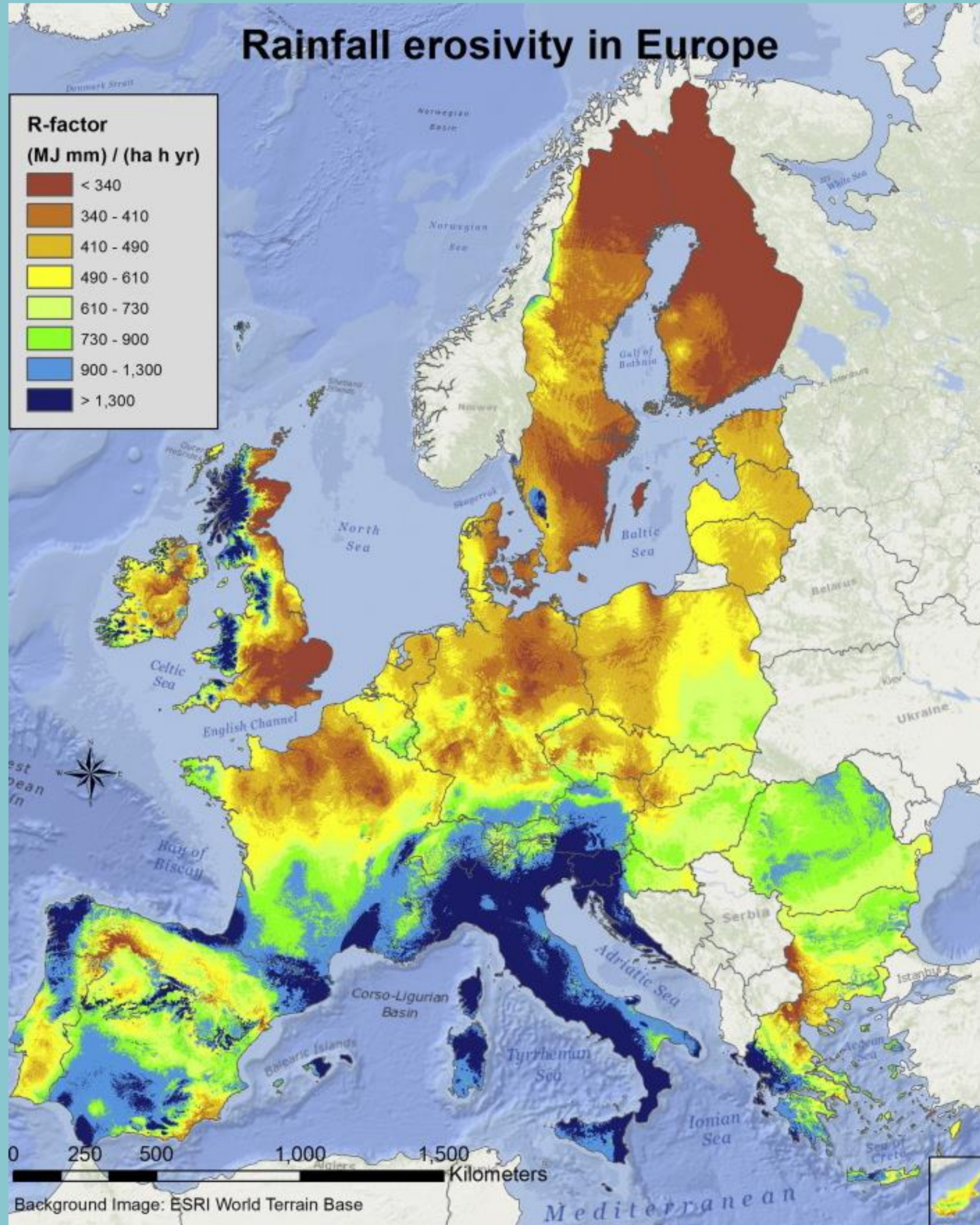


http://ilmatieteenlaitos.fi/vuositilastot

Characteristics of precipitation

- **Amount (mm)**
- **Intensity(mm h^{-1})**
  - **Tropical rains the most intensive (momentarily 150–200 mm h^{-1})**
  - ***'A hard rain's a-gonna fall'***
  - **With incresing intensity: larger drops, more drops per unit area and time**
- **Energy (J)**
  - **Enough to detach soil and sometimes destruct surface soil structure**
  - **Kinetic energy of a drop depends on its diameter (1–7 mm) and velocity (which also depends on the diameter)**
- **Drop size depends on**
  - **Intensity, wind…**
  - **Torrential rains D_{50}: 2–4 mm**
- **Erosive force**
  - **Intensity, duration, drop mass, diameter and velocity**
  - **Terms: Erosive rain, erodible soil**

R refers to USLE (see below)



Panagos et al. (2015)

Measurement of precipitation

- Measured in Finland since the end of 1800s
- Finnish Meteorological Institute (Ilmatieteen laitos) has <400 stations
- Measurements underestimate rain by 10–20%
- SYKE produces areal mean values for 110 catchments
- Water equivalent of snow
  - Finnish Environment Institute
  - About 150 lines
  - Line length 2–4 km
  - 80 depth measurements and 8 weighing per line
- Ground frost measured at 38 sites
  - Depth & surface thawing in open, forest and peat land areas
  - Methylene blue tubes

© Heidi Sjöblom

Kirsti Granlund, SYKE

Measurement of evapotranspiration

= Evaporation from moist surfaces + transpiration by plants

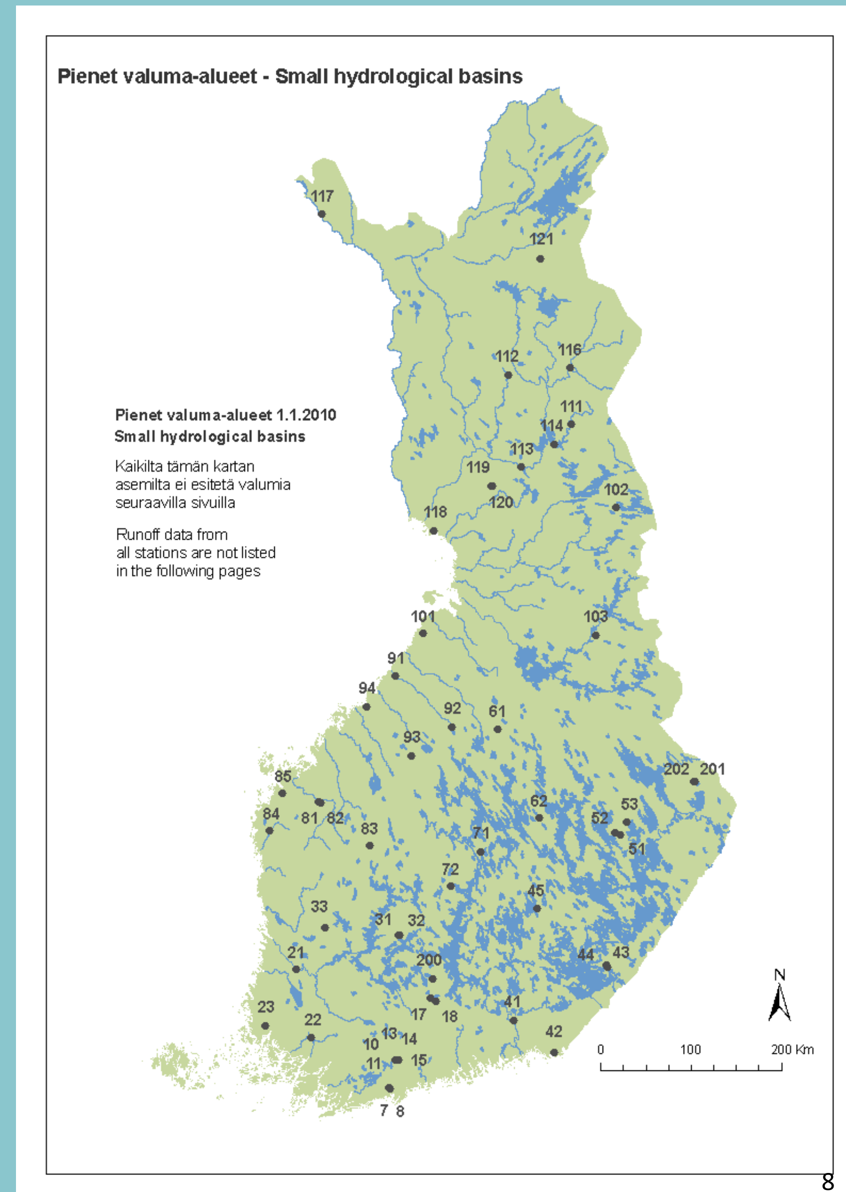
- Plants use water ”wastefully”
- Evapotranspiration difficult to estimate
- Potential evapotranspiration
  - Assumption that the amount of water does not restrict
- Measurement of potential evaporation (e.g. SYKE)
  - 12 stations in Finland
  - Daily measurement with Class A –evaporation pan
    - 1.1 m^2, water depth about 20 cm
    - Southern and central Finland: May to September
    - Northern Finland: one month shorter
- Hydrologically effective rainfall (HER)
  - Precipitation−interception−evaporation


© Johanna Korhonen

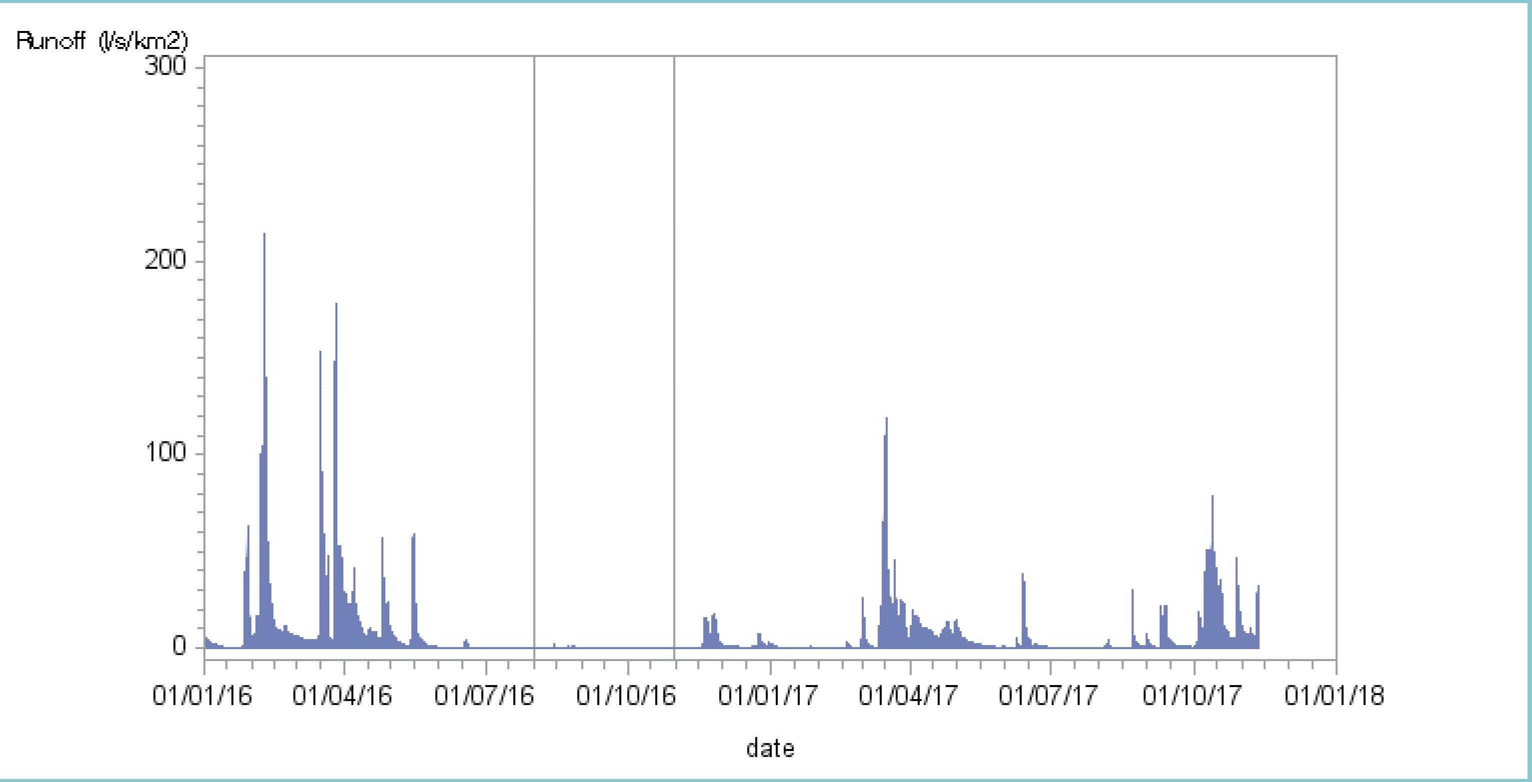
Runoff (q) measurement
Valunta

- Unit: mm, $l\ s^{-1}\ km^{-2}$
- SYKE monitores in 35 sites
  - Small (0,1–122 km^2) catchments with no lakes
  - Measuring weir and a water level measurement
  - Longest data series begin in 1958
- Range 0–1900 $l\ s^{-1}\ km^{-2}$
- Mean **10 $l\ s^{-1}\ km^{-2}$**, 318 mm a^{-1}

Photo: Jarkko Ylijoki



Runoff in the river Savijoki



Catchment area 15 km², of which
- **Field 39%, forest 57%: urban 4%, lakes 0%**

Mean runoff
- **2016: 6.2 l s^{-1} km^{-2}**
- **2017: 8.7 l s^{-1} km^{-2}**
- **1971–2010: 10.6 l s^{-1} km^{-2}, (max 317 l s^{-1} km^{-2})**

Discharge (Q) measurement
Virtaama

= Flow

- Unit: $m^3 s^{-1}$
- National network
  - More than 270 stations, of which about 160 are operated by SYKE and Centres for Economic Development, Transport and the Environment
  - Mostly located at natural river channels
- Additional sites monitored by hydropower companies
- Daily mean discharge
- Water level records and a rating curve
- Data from the Vuoksi starts in 1847
- Mean discharge from the territory of Finland in 1912–2004
  - 3296 $m^3 s^{-1}$

Photo: Jarmo Linjama

Measuring discharge in the Savijoki with an acoustic doppler current profile (ADCP)

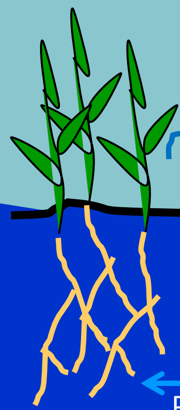
Measuring discharge by the ”salt” method

Routes of water in soil

1. Precipitation

- Vegetation captures up to 20–60% of precipitation
- Plants absorb water or water is evaporated
- Initiatlly high, lowers with the water saturation of foliage
- Reduces surface runoff and the kinetic energy of rain

2. Interseption



3. Evapotranspiration

8. Depression storage

9. Surface runoff/Overland flow
=1−(2+3+4+8)

4. Infiltration (imeyntä)
- Water enters the soil

Plant uptake

Matrix flow
- Water seeps evenly through soil column filling all the pore
- Deeper soil layers have high ability to bind P

5. Percolation (suodanta)
- Downward movements by gravity
- Matrix flow (coarse soils)
- Preferential/macropore flow (cracking, root channels, worm holes)

10. Interflow

Infiltration-excess overland flow
- Infiltration capacity of soil exceeded e.g. during a rain event

Saturation-excess overland flow
- Soil saturated by water due to a lateral flow
- Level of soil water rises above soil surface in sloping areas

Runoff Curve Number
- Empirical value on the share of surface runoff and infiltration for different soils and conditions

6. Drainage flow
- In case of prefential flow, water quality is similar to surface runoff (limited contact to deeper soil layers)

7. Ground water

Due to macropores drainage water is not necessarily clear

Photo: Helena Soinne (Luke)

Elina Röman nee Jaakkola, SYKE)

Cracking clay soil

Pasi Valkama, VHVSY

Drainage pipe

Structure of soil

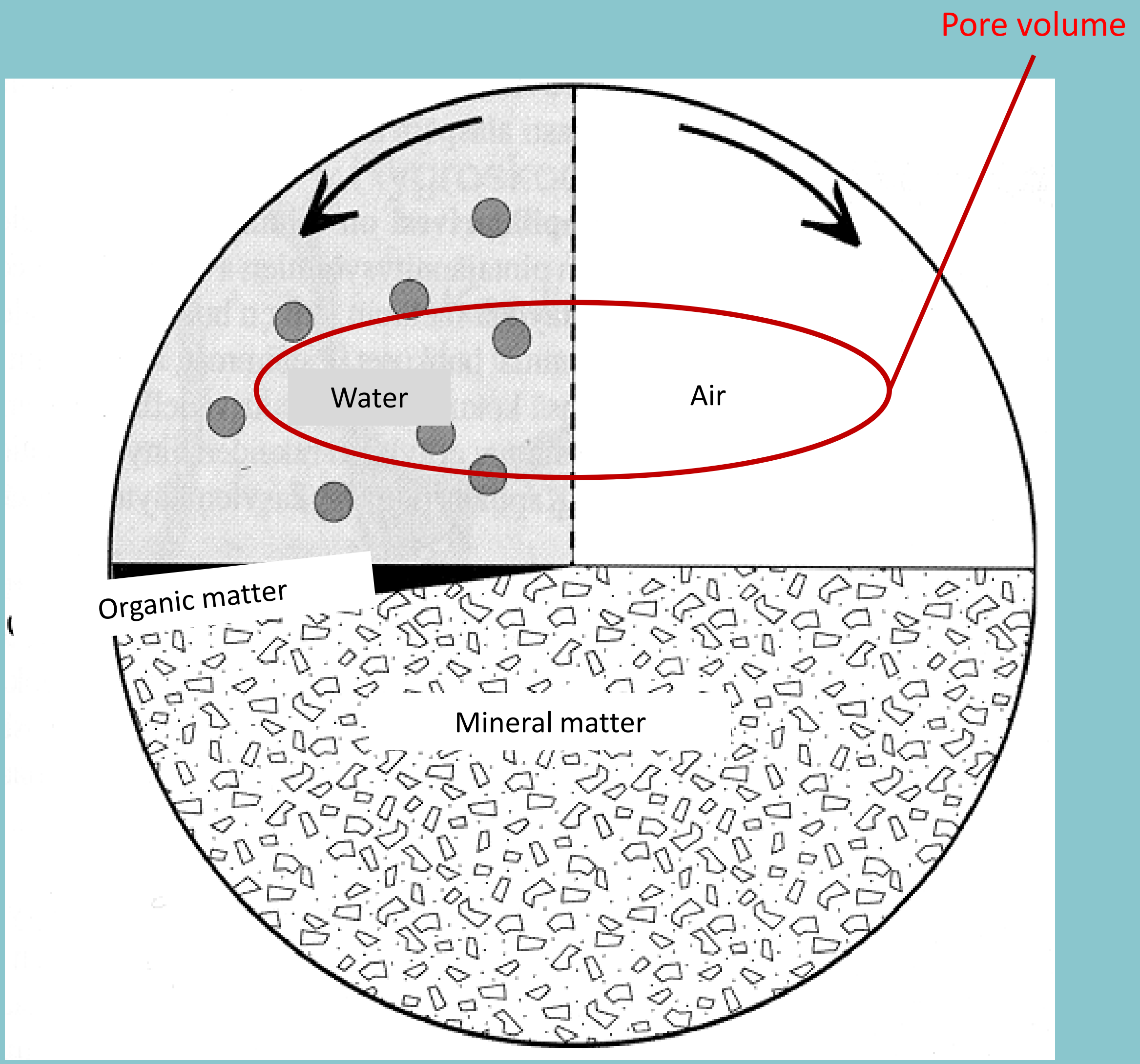
= Mineral particles and organic matter, their binding and grouping, and the air and water containing pores

- Mineral phase desbribed by its size class
  - Reminder: mineral phase consists largely of aluminosilicates that are build of silicon tetrahedra and aluminium octahedra + Al and Fe oxides
- Organic matter
  - Increases water holding capacity
    - Increases surface area and promotes aggregation
  - Improves soil structure
  - Provides nutrients for plants
  - Declining trend in the organic carbon content in Finnish agricultural soils

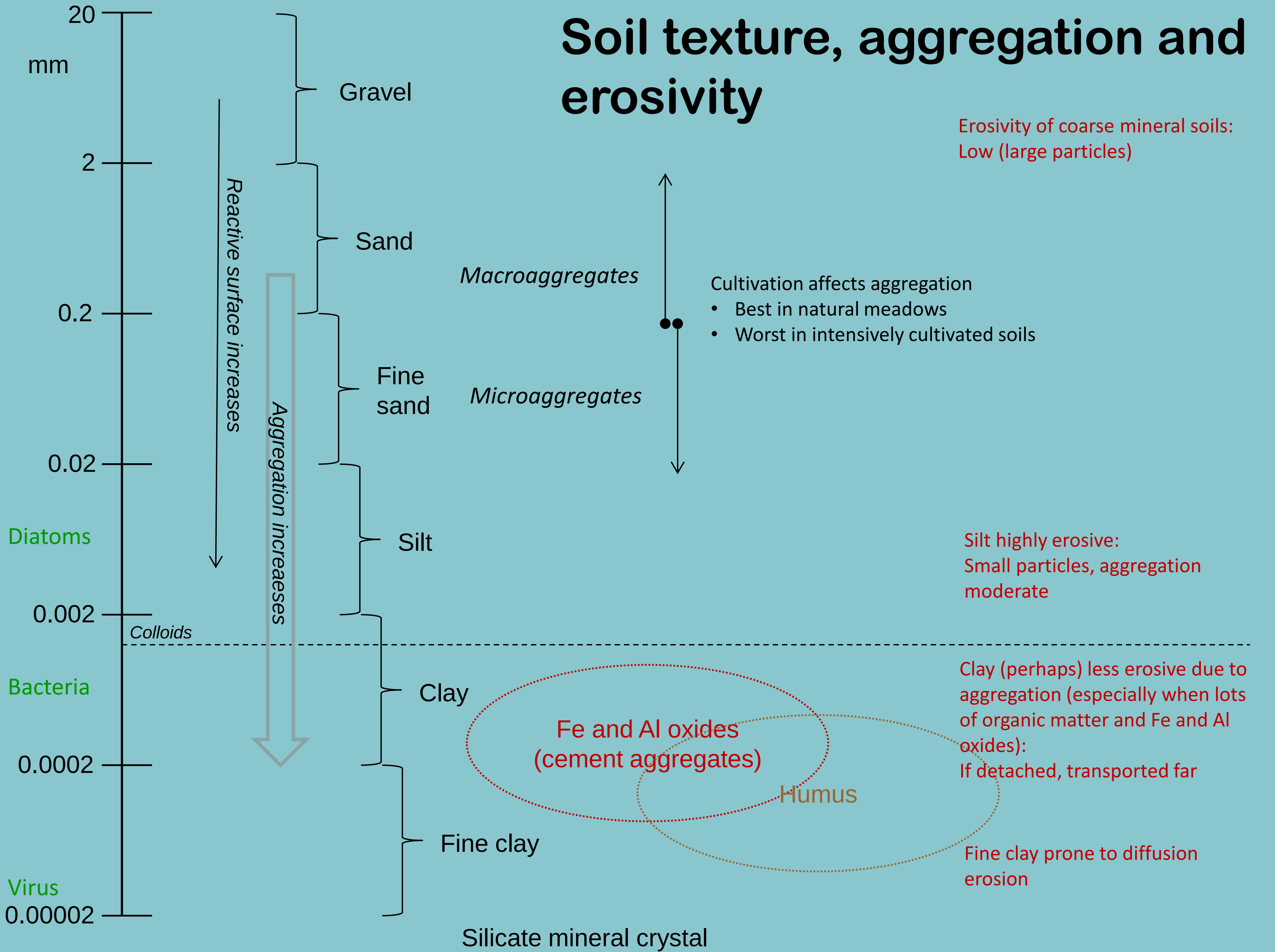
Alakukku (2016)

Optimal consistence of a mineral soil

- Soil structure affects cultivation, plant growth and nutrient load
- Good soil structure from a farming perspective
  - Water infiltrates rapidly
  - Water holding capacity sufficient for plants
  - Excessive water removed
  - Aggregates stable
  - Tillage easy
  - Does not siltate



Soil texture, aggregation and erosivity



Soil structure

Clay soil a weak aggregate structure

- Lacks different-sized pores
- Dense, wet, low percolation, poor root growth due to low O_2 concentration

Clay soil with a good aggregate structure

- Airy, different-sized pores
- Able to store and percolate water

Slide: Helena Soinne (Luke)

Soil aggregates

Durability of aggregate structure in moist conditions

- 4 weeks saturated with water

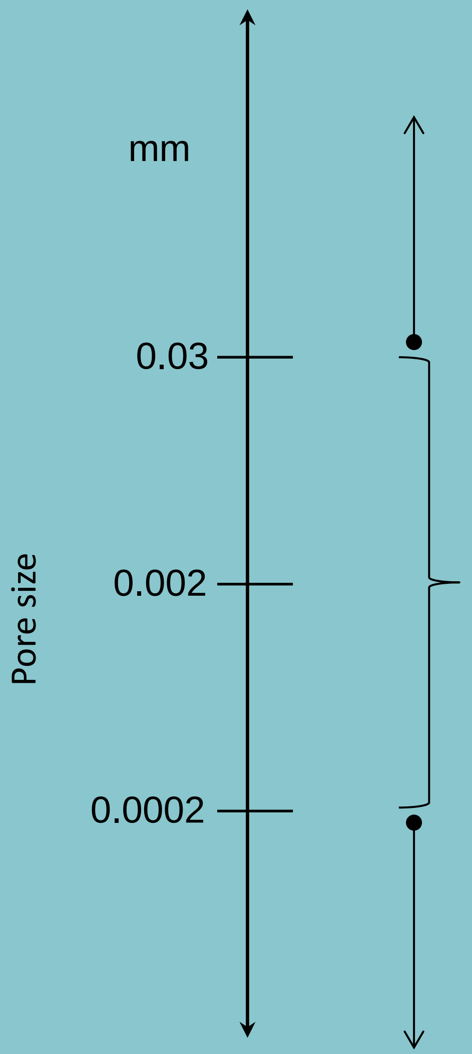
Strong aggregate structure reduces

- Silting and crusting
- Erosion
- Ensures percolation to deeper soil layers

Weak aggregate structure

Slide: Helena Soinne (Luke)

Soil pores



Macropores (> 30 µm)

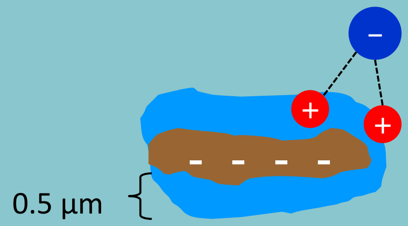
- Allow infiltration and thereby prevent siltation and reduce surface runoff
- Drain fast due to gravity
- Secure O_2 need of roots and microbes
- Allows root growth: the larger the root system, the more secure nutrient uptake

Middle-size pores (0.2–30 µm)

- Capillary water (also osmotic binding)
- Soil structure forms ”pipes” promoting capillary rise
- Secure water uptake by plants
- Gravity does not affect

Micropores

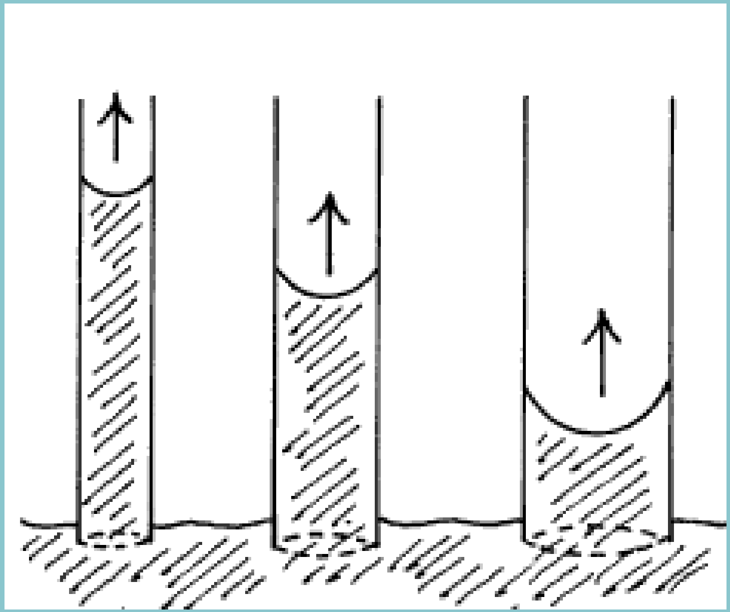
- Adsorption water
- Water not available to plants

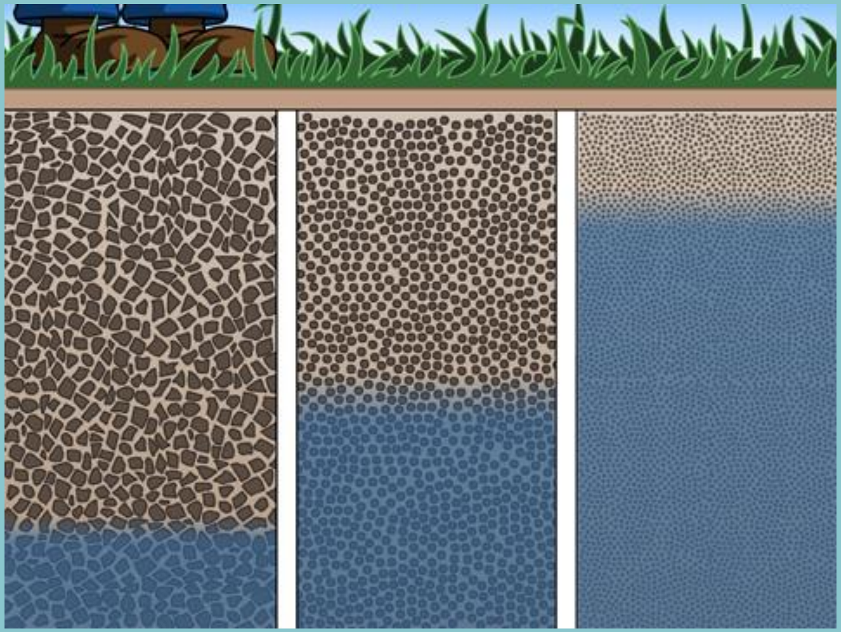


Macropores

Photo: Risto T. Seppälä, MTT

Capillary water depends on pore size

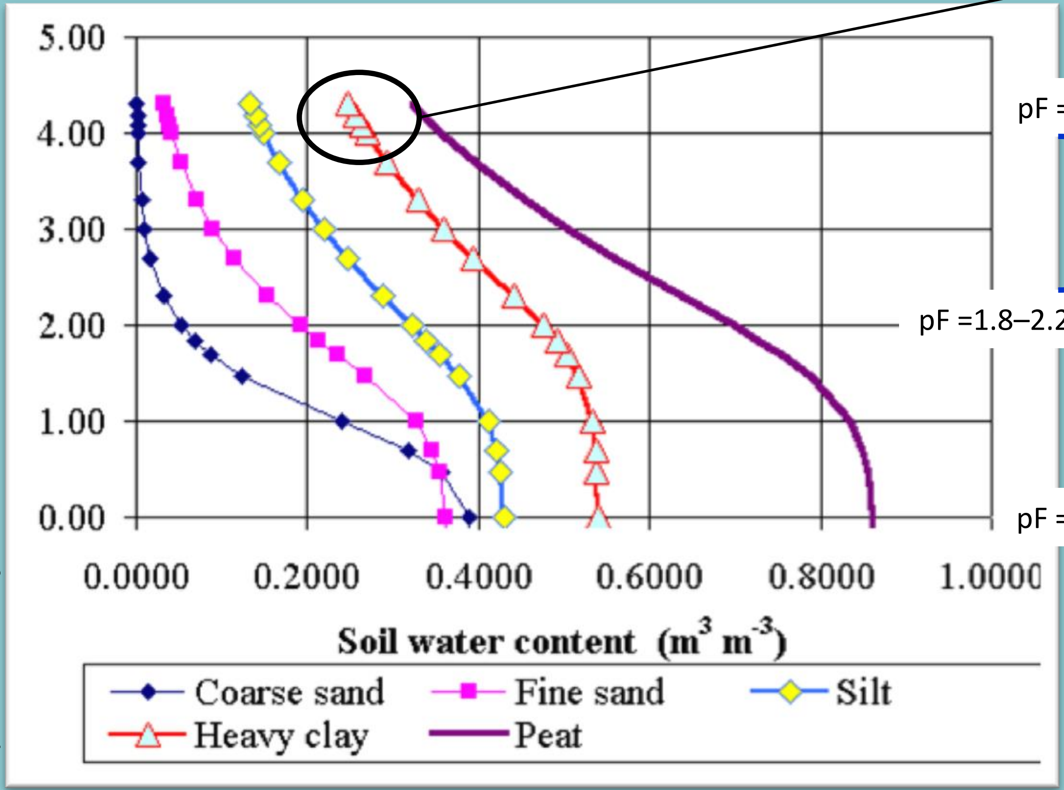




Slide: Salla Venäläinen, Sanna Kanerva, Martina Metzler

pF curve

pF-value
- Suction needed to remove water
(logarithm of water column, cm)



http://www.hut.fi/Yksikot/Rakennus/Vesitalous/index.html

Fine-textured soils have large pool of unavailable water, adsorption water

pF = 4.2: Wilting point, Water too tightly bound for plants

Plant available water

- Largely capillarily bound

pF =1.8–2.2: Field capacity, Soil drained ”dry”, gravity does not affect

pF = 0: Saturated soil, All pores filled with water

Erosion

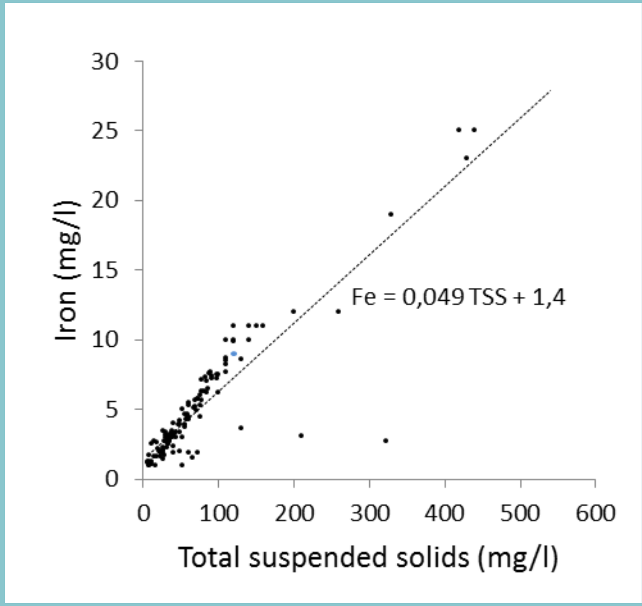
= detachment and transport of particles by water or wind

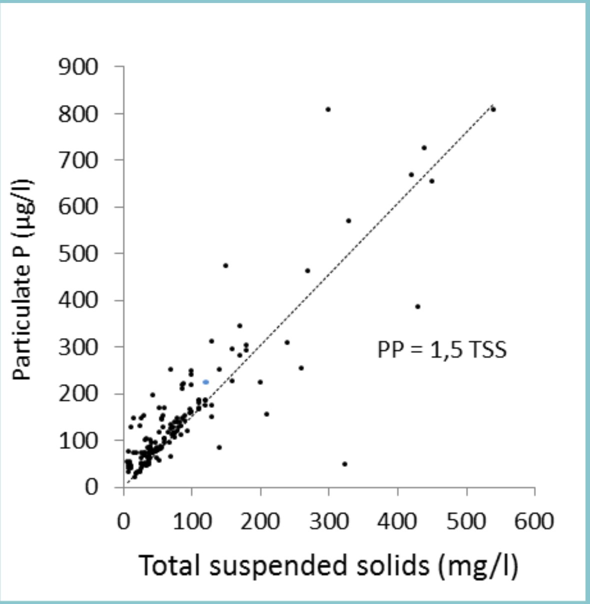
- Rivers transport to ocean 13–19 · 10^{15} g y^{-1} total suspended solids (TSS)
  - + attached nutrients, pesticides
  - The largest material flux from terrestrial to aquatic systems
- Increases turbidity
- Reduces euphotic layer and primary production
- Flocculates algae
- Affects fish
- Destructs habitats (spawning grounds, egg survival, benthic fauna)
- Impacts aesthetic value
- Decreases water volume
- Affects sediment mineralisation processes (see below)

Pasi Valkama, Vantaanjoen ja Helsingin seudun vesiensuojeluyhdistys

TSS = matter that is retained by a filter

Eroded soil carries a range of substances





The Savijoki (SAVE project)

Factors causing soil particles to be detached

I Wind

https://www.weather.gov/oun/events-19350414-maps

Deposition of nutrients

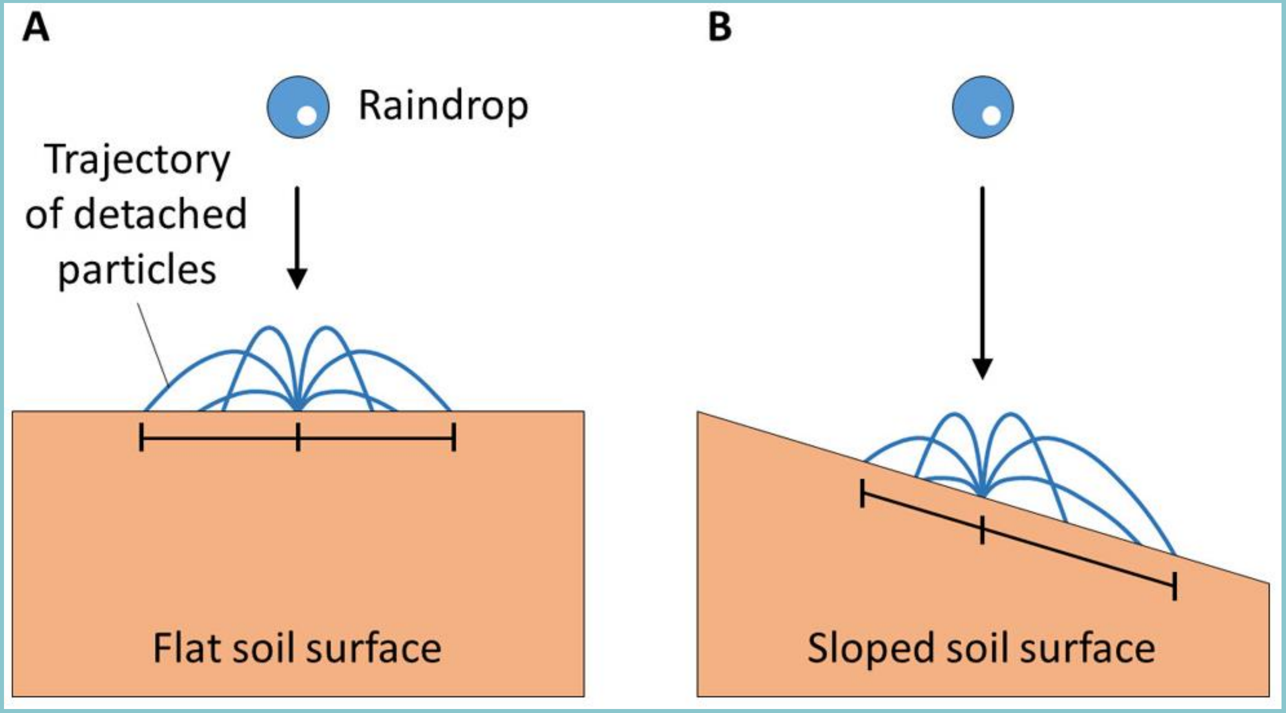
- 7-31 kg km^{-2} y^{-1} P (Vuorenmaa et al. 2001)
  - 80% of deposition in May-October
  - Partly natural
- 4 kg km^{-2} y^{-1} P (Lake Vesijärvi)
- SYKE's estimate of deposition directly to surface waters 190 t y^{-1} P and 10 200 t y^{-1} N

  -> 6 kg km^{-2} y^{-1} P, 300 kg km^{-2} y^{-1} N

Factors causing soil particles to be detached

II Splash effect, roiske-eroosio

- Kinetic energy of a rain drop detaches soil and transports it a small distance
- Intensity of rain more important than amount
- Thin water layer on soil strengthens the process
- Inclination increases transport
- Rain vs. snow

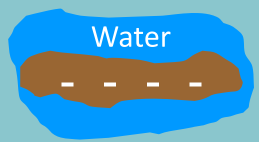


Fernández-Raga et al. (2017)

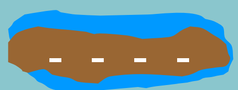
Factors causing soil particles to be detached

III Diffusion/dispersion

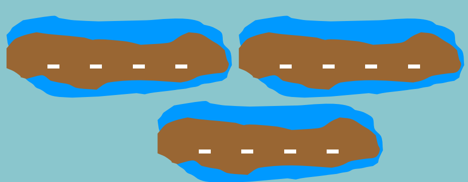
Particle attraction affected by wetting/drying



Soil particle with adsorbed water



Upon drying water sphere becomes thinner



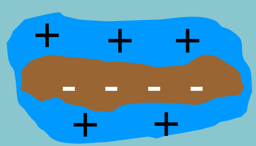
Particles can come closer and attach weakly together

- When soil is completely dried, the aggregates may endure wetting

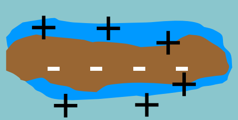
”Monovalent ions disperse, divalent aggregate”

- **Depends on the solvation radius and charge of ions**

Fine clay (<0.2 µm) is ”dissolved” in water



Electrical double layer: negatively charged soil particle surrounded by an equivalent amount of cations



Thickness of electrical double layer depends on the cations and ionic strength of soil solution

IV Slaking

Slaking

- **compression of air entrapped inside aggregates during rapid wetting causes disintegration of an aggregate into smaller particles**

Differential swelling or drying of soil components

Factors causing soil particles to be detached
V Overland flow

Sheet erosion (Pintaeroosio)
- **Uniform removal of soil in thin layers by the forces of raindrops and overland flow**
- **Transport and settling of soil particles depend on flow velocity**
- **With increasing velocity, flow becomes turbulent and its ability to detach and transport soil increases exponentially**
- **Slope increases velocity**

Aaro Närvänen, Luke

Devon Wildlife Trust

Rill erosion
Noroeroosio

- Removal of soil by concentrated water running through little streamlets
- Detachment occurs if the soil in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment
- As detachment continues or flow increases, rills will become wider and deeper
- Rills will be removed by tillage

Lower photo: Jarmo Linjama

Gully erosion

Gullies are not anymore removed by tillage

Djodjic & Villa (2015) https://envscot-csportal.org.uk/soilerosion/guide/

Bed/bank erosion

Photos: Maria Kämäri, SYKE

Natural erosion in the Pulmankijoki, northern Finland

The Kokemäenjoki, western Finland

Summary:
Erosion is affected by

1. Rain (intensity, duration, form), wind
2. Soil type and structure
   - Size of primary particles, aggregation
3. Frost
   - Erosion tends to be stronger during mild than severe winters
4. Topography
5. Vegetation
   - Protects the soil from drop impact, slowes down surface runoff, roots bind the soil
6. Tillage
7. Protective measures

Erosion rates in Finnish agricultural fields

Experimental field	Soil texture	Slope (%)	Plant/tillage	kg km^{-2} y^{-1}
Aurajoki	Clay	7–8	Autumn ploughing	210 000
			Winter wheat	157 000
			No-till	62 000
			Grass	57 000
Kotkanoja	Clay	2	Autumn ploughing	79 000
			Grass	61 000
Toholammi	Fine sand	0.5	Autumn ploughing	69 000
			Grass	34 000
Liperi	Clay	<0.5	Autumn ploughing	12 500
			Grass	5500
Forest				2000–20 000
Forest (clear-cut)				120 000

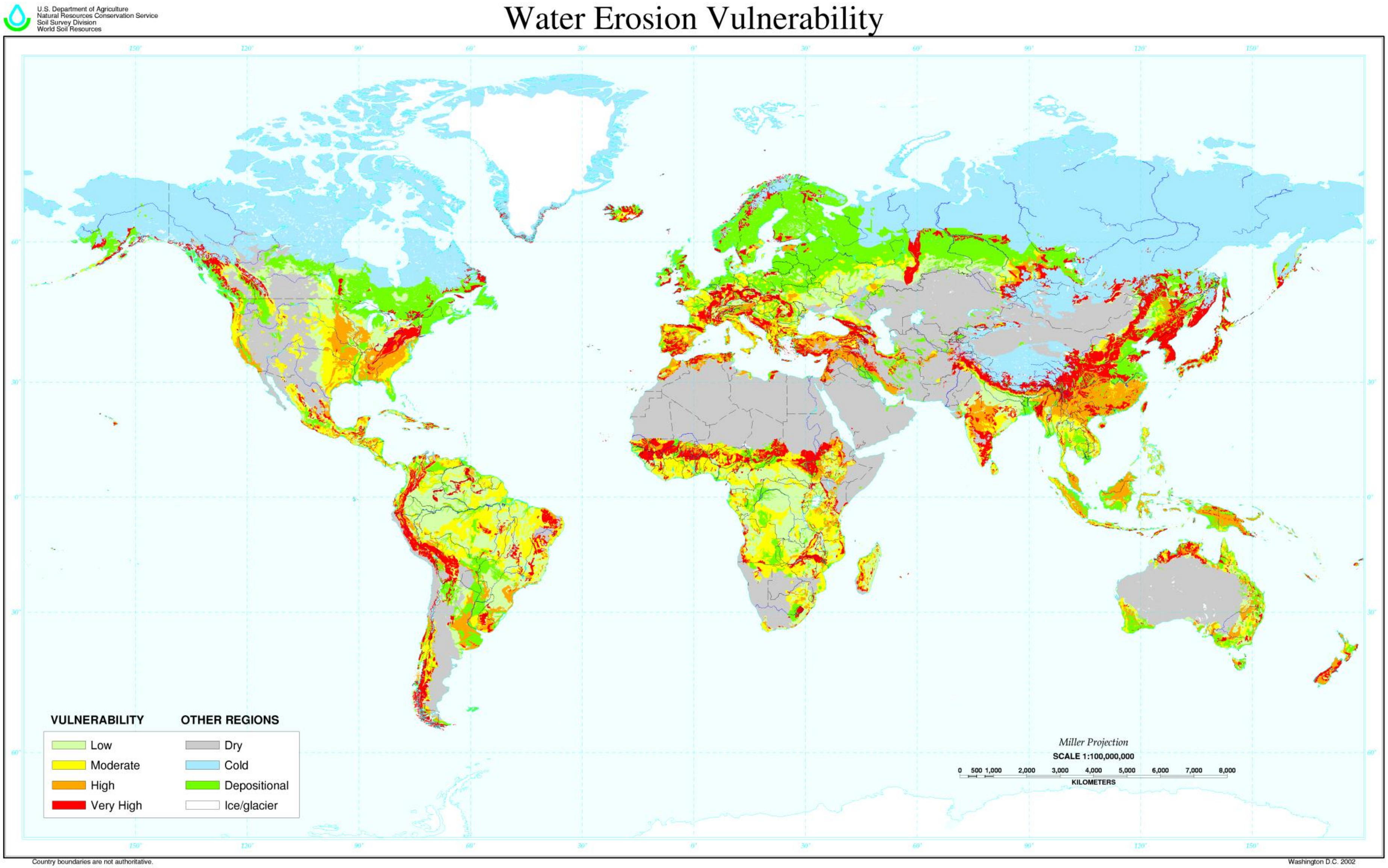
Maximum in literature: 600 000 kg km^{-2} y^{-1}

Puustinen et al. (2010)
Tattari & Rekolainen (2006)

An empirical model for estimating erosion

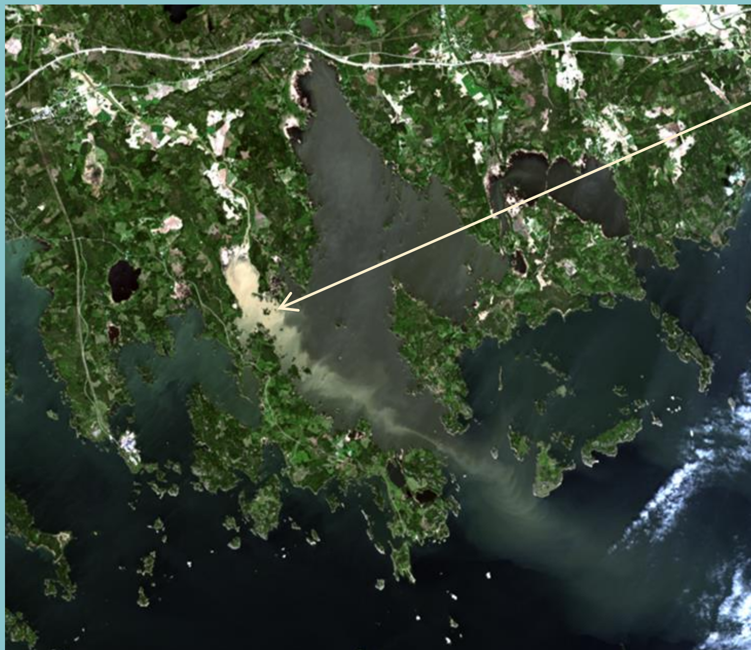
- RUSLE2015 model
  - Based on USLE and RUSLE (Revised Universal Soil Loss Equation)
  - GIS based erosion model (t ha^{-1} y^{-1})
  - R = Rain factor
  - K = Soil factor
  - C = Vegetation cover
  - LS = Length and slope of the field
  - P = Practices
- Analysis of established riparian zones in four areas
  - The Merikarvianjoki
    - 8/117 zones in areas with modelled erosion > 1000 kg ha^{-1} y^{-1}
  - The Ruskonjoki-Raisionjoki
    - 15/36
  - The Kiskon-Perniönjoki
    - 75/376
  - The Punkalaitumenjoki
    - 98/209

Water Erosion Vulnerability

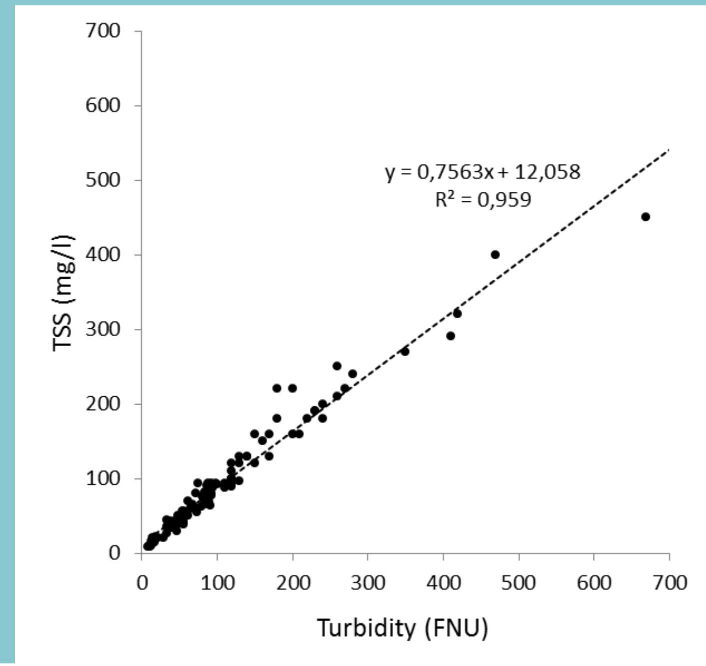


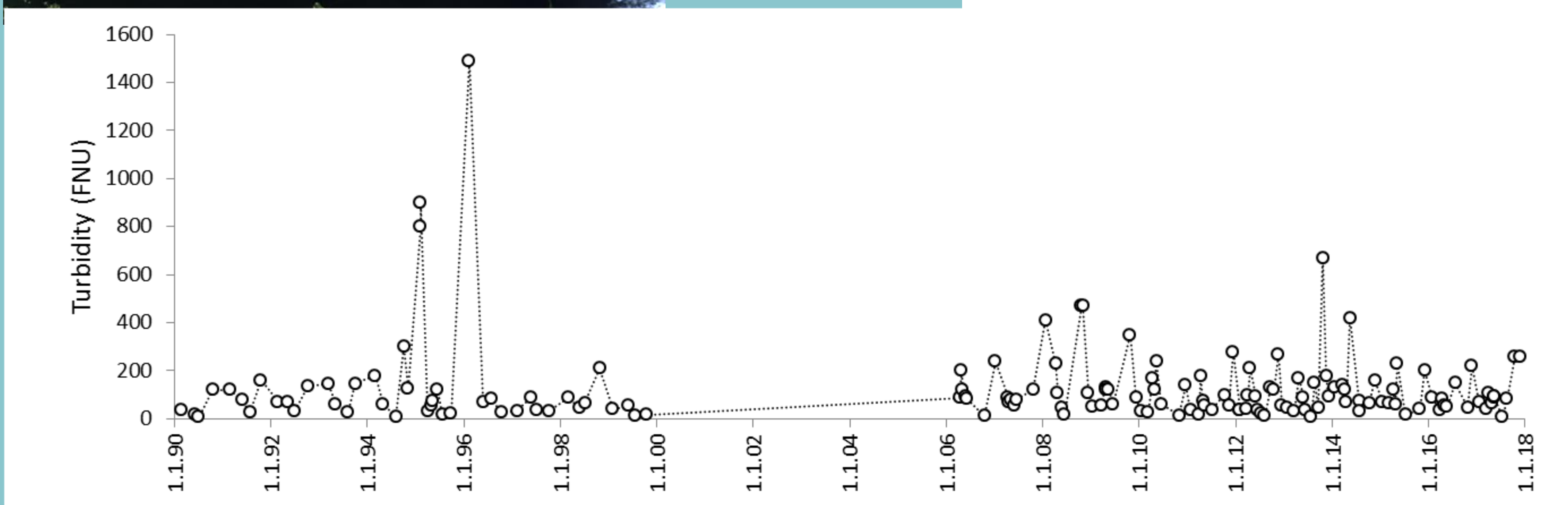
- **In Europe, more than 17% land area suspectible to erosion**
  - **More than 1/3 Mediterranean area has an erosion rate > 1 500 000 kg km^{-2} y^{-1}**
- **Erosion the highest in areas where hot and dry periods are followed by heavy rains, and in steep sloping areas (http://soilerosion.net)**

Suspended solids in the Taasianjoki



The River Taasianjoki
- 530 km²
- Lakes 0.5%
- Fields 30%





25.5.2015 Landsat 8 OLI (RGB photo), Original photo: USGS/NASA Landsat Program, processing: SYKE (2015)

Summer flood in 2004

The river Vantaa (1690 km^2, mean discharge 16 m^3 s^{-1}, fields 23%, lakes 2.3%)
Precipitation during 6 days (27.7–1.8.2004): 135 mm (recurrence 200–300 y)

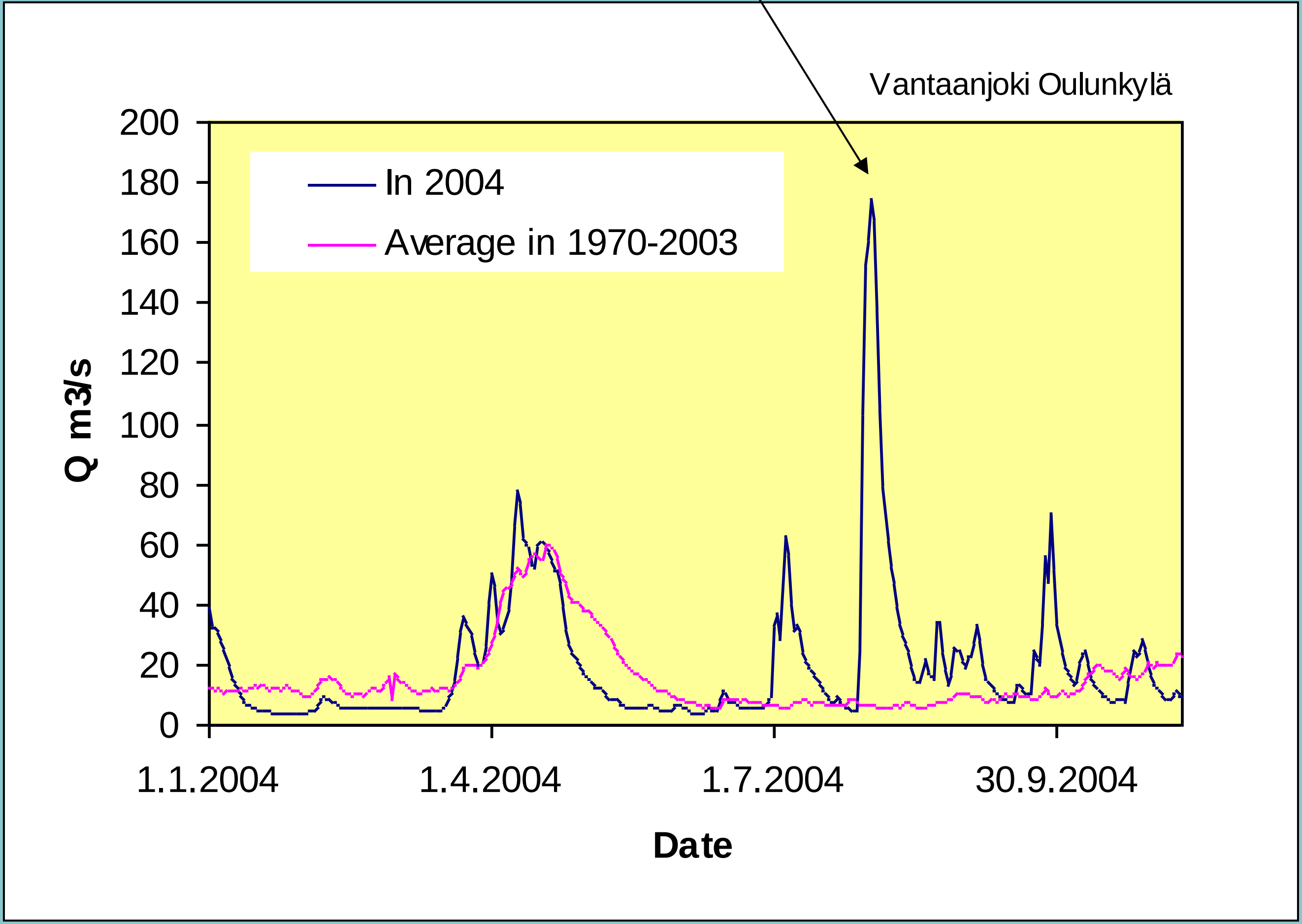
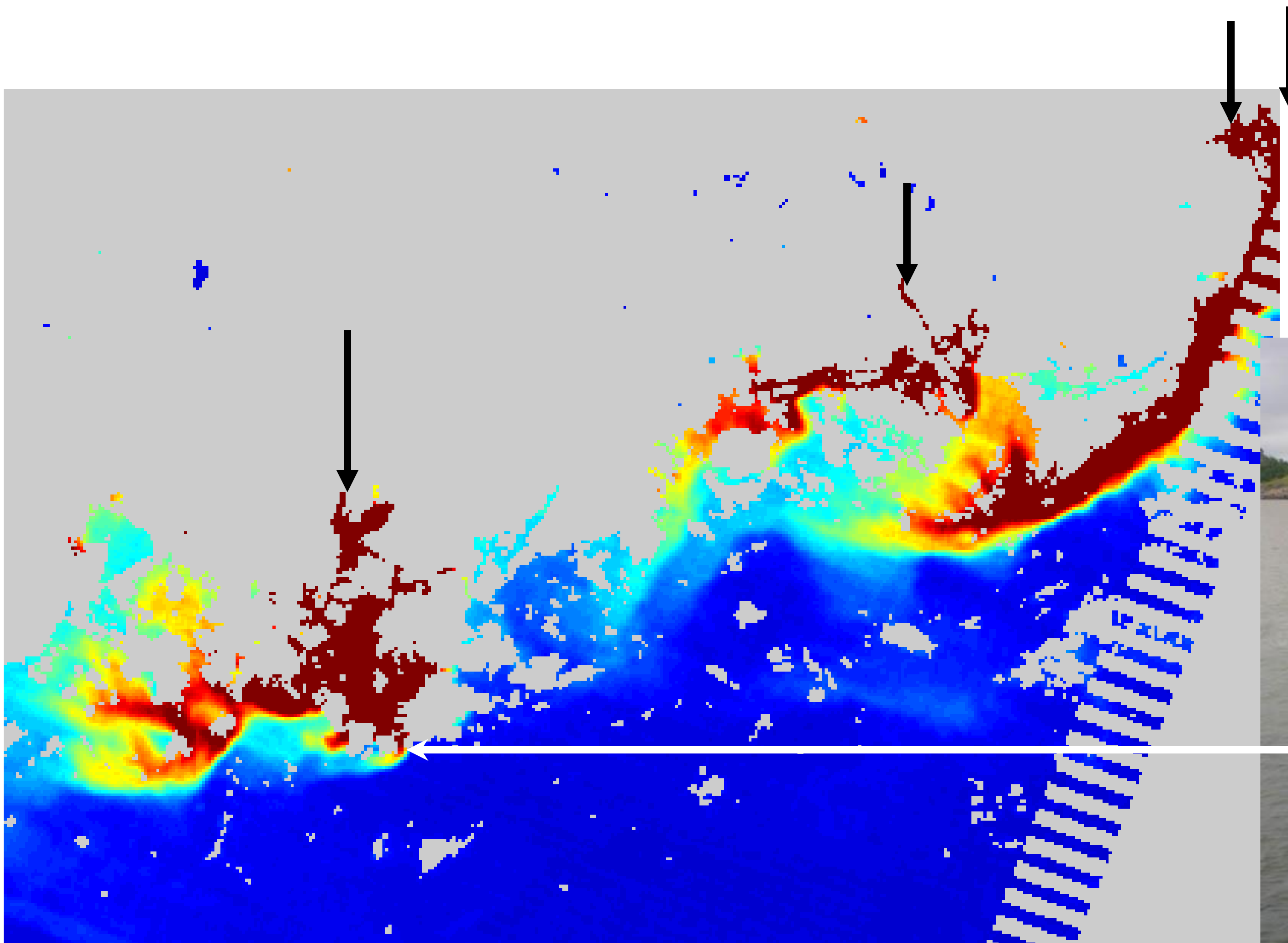
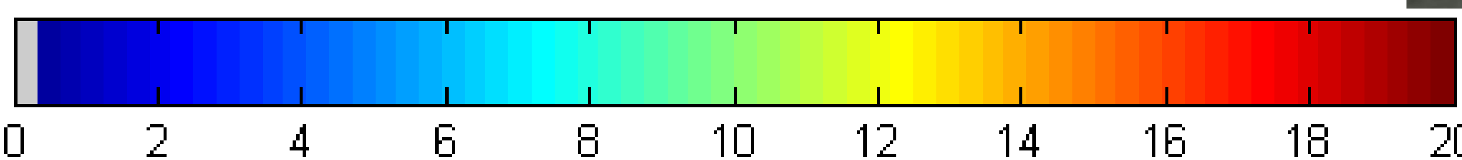


Photo: Vantaanjoen ja Helsingin seudun vesiensuojeluyhdistys

Kari Kallio, Sampsa Koponen, Jouni Pulliainen, Jenni Vepsäläinen & Timo Pyhälahti (SYKE, TKK)

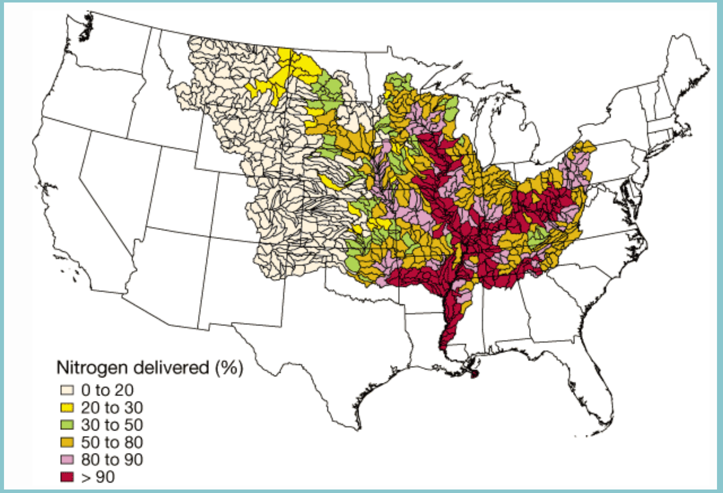
Turbidity (FNU) 5.8.2004 (LANDSAT5 TM)





On allocation of water protection measures

- Contributing areas
  - Are all field parcels similar in terms of load generation?
  - Slope, soil type, farming & forestry practices…
- Hydrological connectivity
  - Are all areas in the catchment similarly connected to receiving waters?
  - Density of channel network, physical barriers
- Critical source area = contributing area ∩ hydrological connectivity
- Settling, adsorption, assimilation, denitrification…
- 80:20 rule
  - The majority (”80%”) of nutrient losses (especially P) originate from a small (”20%”) portion of land
- Sediment delivery ratio
  - The larger the catchment, the lower share of detached soil transported to lower reaches
- Four catchments in southern Swedish (Djodjic & Villa 2015)
  - Critical areas for overland flow and erosion formed only 0.4–2.6% of total arable land
- Hydrological connectivity of fields in Finland (Puustinen ym. 1994)
  - 13% drainage water to ground
  - 87% to a main drain or a water body



Alexander et al. (2000)

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