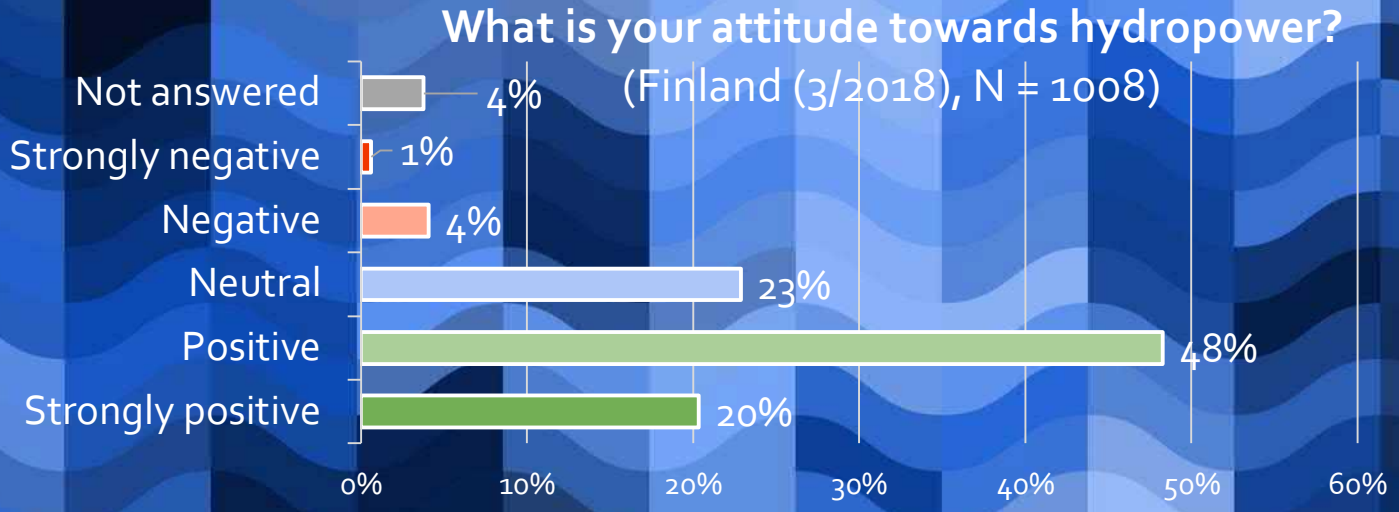
Hydropower in Finland and Kemijoki River

WAT-E2080 - Water and Governance L

Sakke Rantala, Kemijoki Oy
Heini Auvinen, Fortum Oyj



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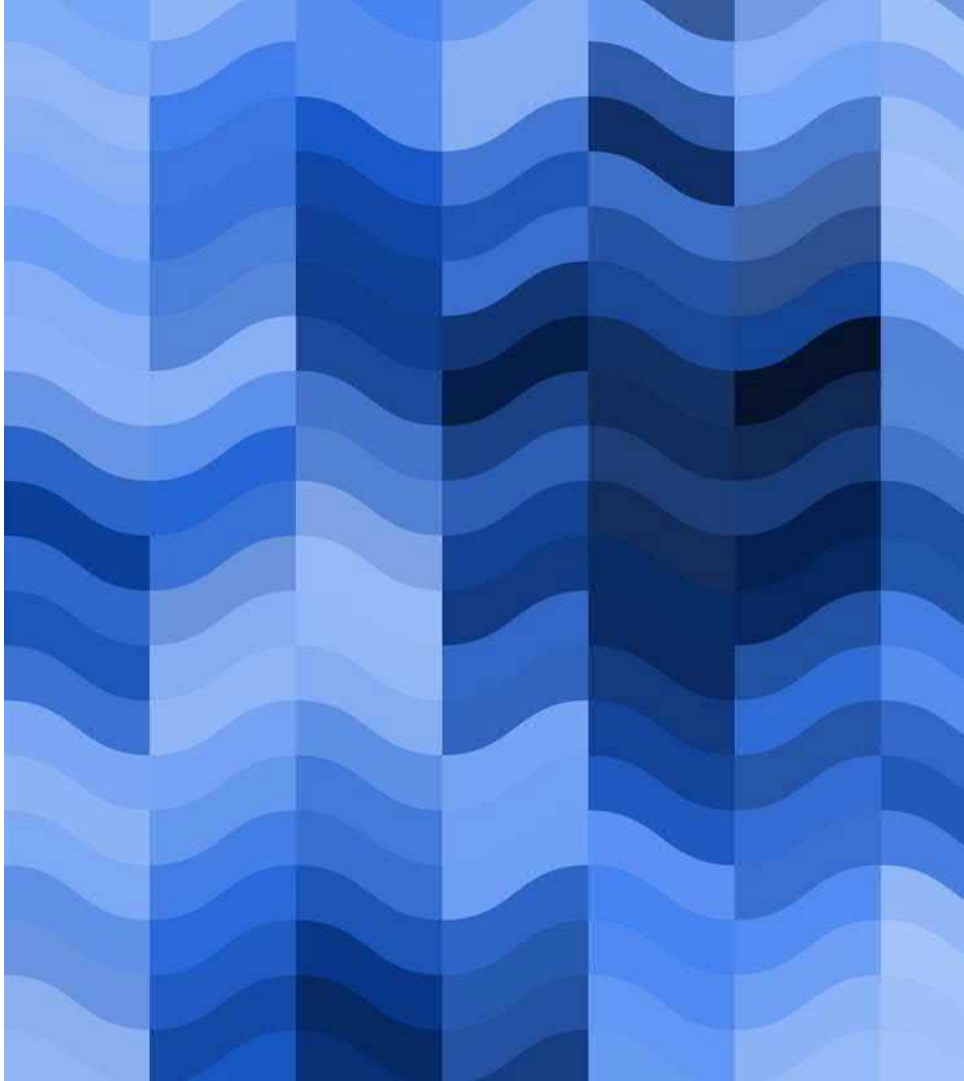
- Kemijoki-extra
- (Data analysis)



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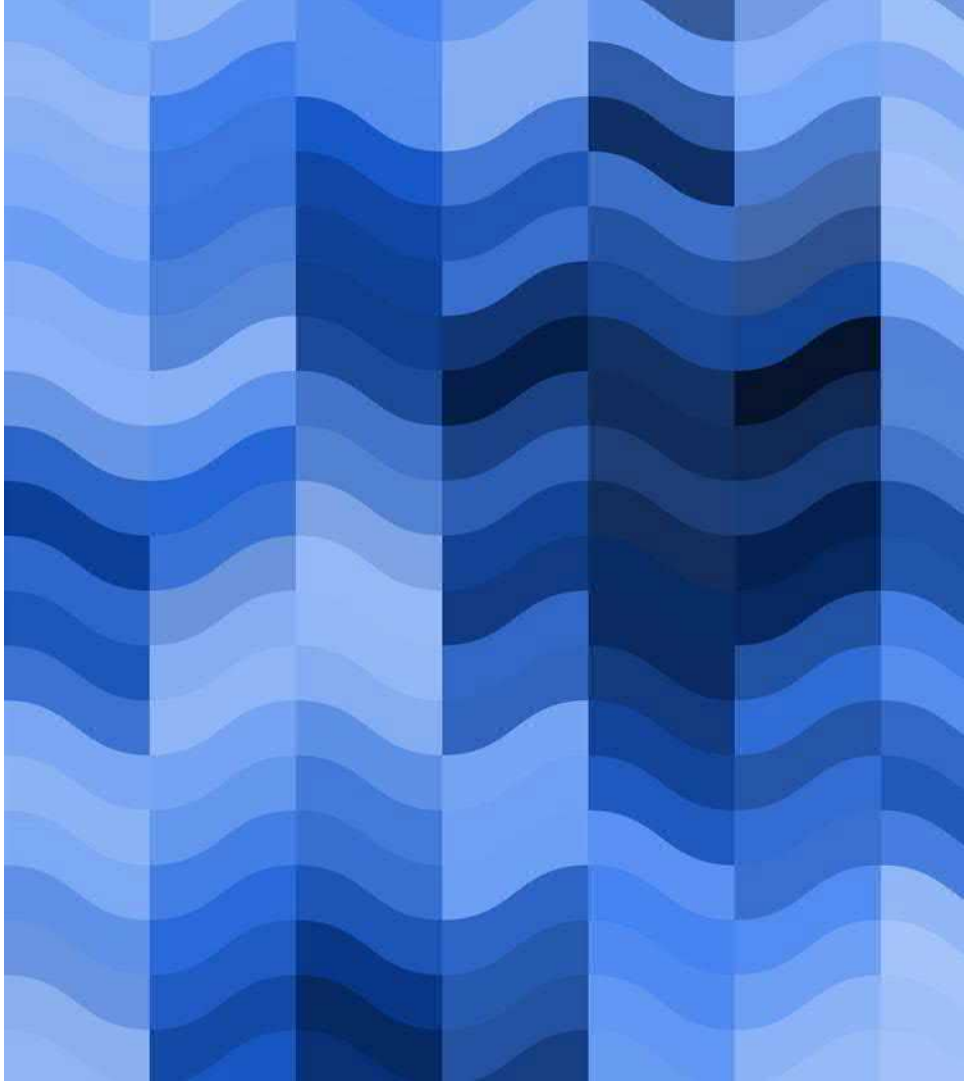


Apply!

› Two open positions, DL 30.1.2019

› https://www.kemijoki.fi/viestinta/tiedotteet-ja-uutiset.html?opened=612

KONETEKNIIKAN ASIANTUNTIJA

Tulet työskentelemään vesivoimalaitosten koneteknisten järjestelmien ja kunnossapidon asiantuntijana ja osallistut kunnossapidon kehitystehtäviin sekä vastaat osaltasi investointiprojektien toteutuksesta. Pääset hyödyntämään näkemystäsi uusien teknologioiden mahdollisuuksista.

Toivomme sinulta:
- osaamista suunnittelusta, asennuksista ja kunnossapidosta
- uuden teknologian tuntemusta ja projektiosaamista
- korkeakoulututkintoa, esim. DI/insinööri

YMPÄRISTÖASIANTUNTIJA

Tulet työskentelemään ympäristöasioiden asiantuntijatehtävissä. Osallistut laaja-alaisesti ympäristöasioiden suunnitteluun, toteutukseen ja kehittämiseen. Myös viranomais- ja muiden sidosryhmäyhteyksien hoitaminen ovat oleellinen osa tehtävää.

Toivomme sinulta:
- kalabiologista osaamista
- ympäristölainsäädännön tuntemusta
- korkeakoulututkintoa, esim. FM/DI

KEHITY VESIVOIMAN HUIPPUOSAAJAKSI

Tarjoamme mielenkiintoisen ja haastavan tehtävän, viihtyisän työympäristön sekä osaavan työyhteisön tuen. Arvostamme kykyä työskennellä itsenäisesti ja ottaa vastuuta, pitkäjänteisyyttä ja rohkeutta löytää innovatiivisia ratkaisuja. Jos sinulla on mutkaton ja positiivinen ote työntekoon, sovit hyvin joukkoomme.

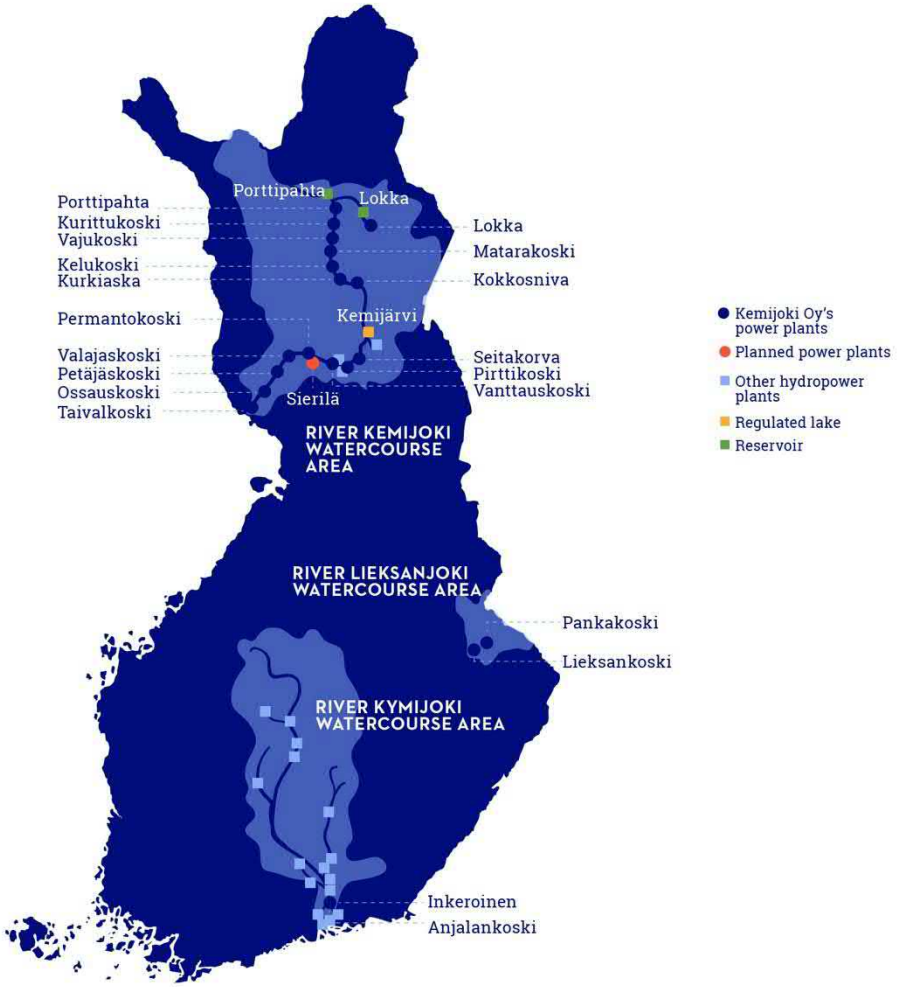
Täytä hakemuslomake palkkatoiveineen ja liitä mukaan hakemuskirje sekä CV:si 30.1.2019 mennessä osoitteessa uratori.mps.fi.

Lisätiedot:

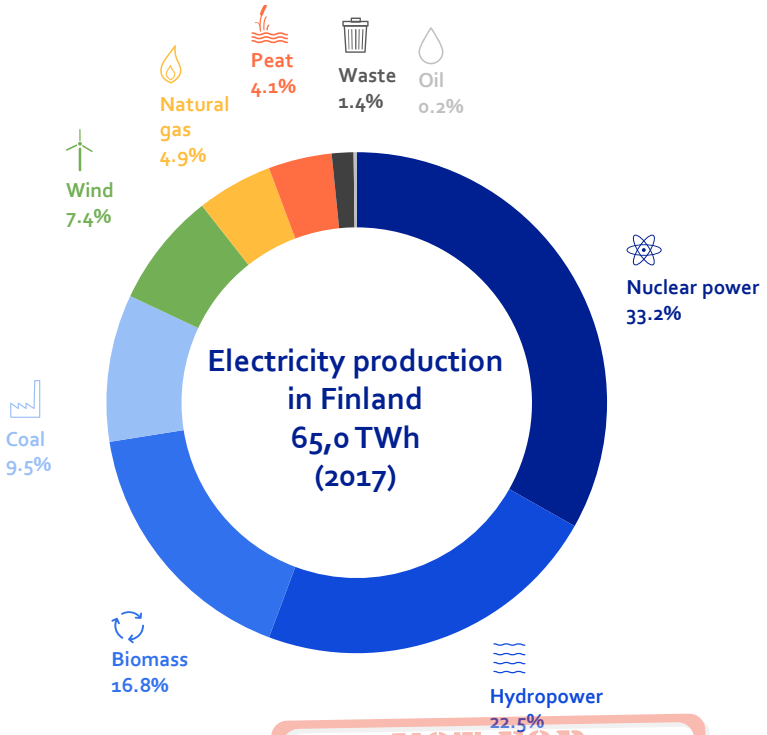
Lisätietoja tehtävästä ja yrityksestä antaa MPS-konsultti Arto Savela, puh. 040 729 6600.

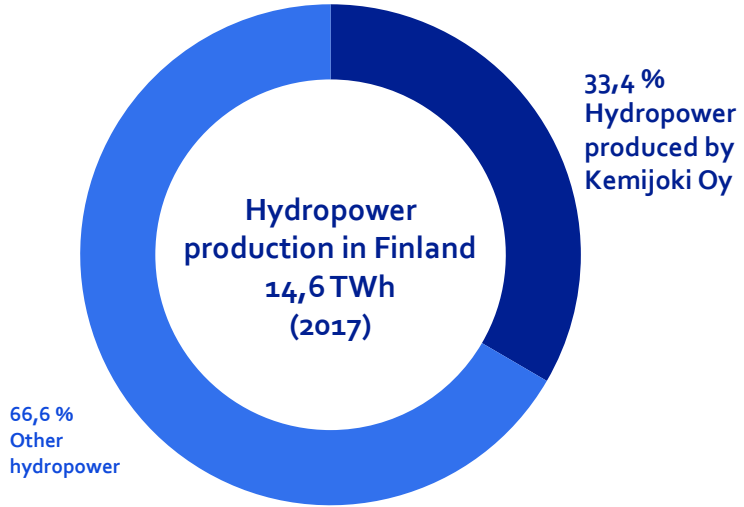
Kemijoki Oy in brief

- 20 hydropower plants, 3 watercourse areas
  - 36 generators
  - >1100MW
  - 5743 GWh in 2016
- Agile operating model
  - Personnel <40
- Diverse and extent group of stakeholders
  - >1000 km of riverside



We produce a third of the hydropower in Finland





Corporate responsibility program 2019-2023

LOCALLY HEALTHY PEOPLE AND NATURE

TOWARDS A CARBON NEUTRAL FINLAND OF THE FUTURE

PIONEER IN HYDROPOWER

ELECTRICITY SAFELY, COST-EFFICIENTLY AND IN ACCORDANCE WITH PERMIT OBLIGATIONS

Sustainable hydroelectricity with partners

- **We are a commissioner and expert organization of hydropower production.** This means that we acquire most of our operations from service providers.
- **Thanks to our agile and partner-based operating model,** we are able to produce hydroelectricity cost-effectively.
- **Thanks to our partner model,** new opportunities have been and are still being created in Lapland for both growth companies and large companies.
- **According to a partnership survey conducted in 2016,** the corporate responsibility index of the partner network was 4.3 (scale 1–5). The criteria are employee reputation, cost efficiency, work safety, environmental matters and stakeholder communications.

VOIMALOHI OY
Fish planting obligations

Caverion
Use and maintenance of Kemijoki power plants

maint partner
Use and maintenance of Lieksajoki power plants

MITTA
Liability and environmental work

storaenso
Use, maintenance and monitoring of Kymijoki power plants

KEMIJOKI
Kumppanimme

fortum
Production planning and control room operations and financing (2016)

enfo
ICT services

ADMINISTER
Financial administration and payroll

Hill+Knowlton Strategies
Communications services

caruna
Electricity transmission

FONDIA
Legal services

These are our goals

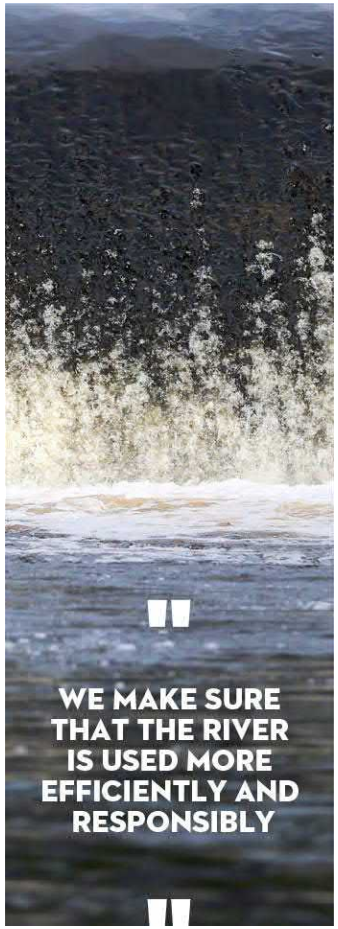
- **Our vision** is to be the most respected and responsible producer of renewable hydropower in 2025.
- **Our most important goal** is to produce hydroelectricity for our shareholders cost-effectively.

OUR STRATEGIC GOALS

WE ARE THE MOST COST-EFFECTIVE

WE ARE THE MOST INNOVATIVE

WE ENSURE THAT THE ELECTRIC SYSTEM REMAINS OPERATIONAL



Kemijoki Oy's history

Finland lost about 30 percent of its hydropower in the 1944 peace treaty. Electricity was needed for reconstruction and industrial development.

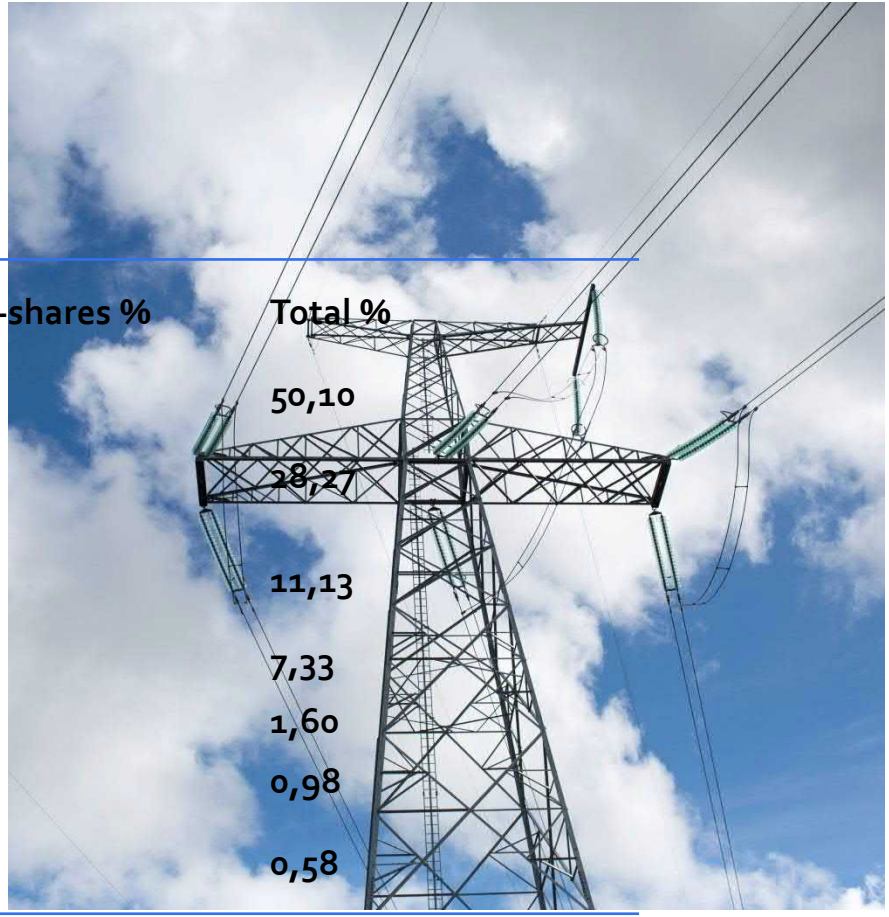




- 1954 – Kemijoki Oy is founded
- 1957 – First power plant, Petäjäskoski, is completed
- 1954 - 1976 – Power plants are built in quick succession – a new power plant is completed nearly every other year in Kemijoki
- 1966 – Regulation of Kemijärvi begins
- 1967 – Lokka reservoir is completed
- 1970 – Porttipahta reservoir is completed
- 1981 - 2001 – Power plants are built. New plant in Kitinen every other year
- 2001 – Final power plant, Kelukoski, is completed at the river Kitinen
- 1996 - 2014 – The main river bed's machinery is renewed and power is increased
- 2014 – Final capacity increase in Seitakorva
- 2013 – Kemijoki Oy decides to change the company's operating model
- 2014 – Most of Kemijoki Oy's operations are outsourced to external service providers
- 2016 – New operating model in place
- Hydropower is produced even more efficiently

The company's shareholders

	Hydropower %	Money-shares %	Total %
Finnish government	0,00	52,37	50,10
Fortum Power and Heat Oy	63,79	26,66	28,27
Lapin Sähkövoima Oy	10,62	11,16	11,13
UPM Energy Oy	19,00	6,81	7,33
Helen Oy	3,91	1,50	1,60
Ounastuotanto Oy	1,64	0,95	0,98
Napapiirin Energia ja Vesi Oy	1,04	0,56	0,58



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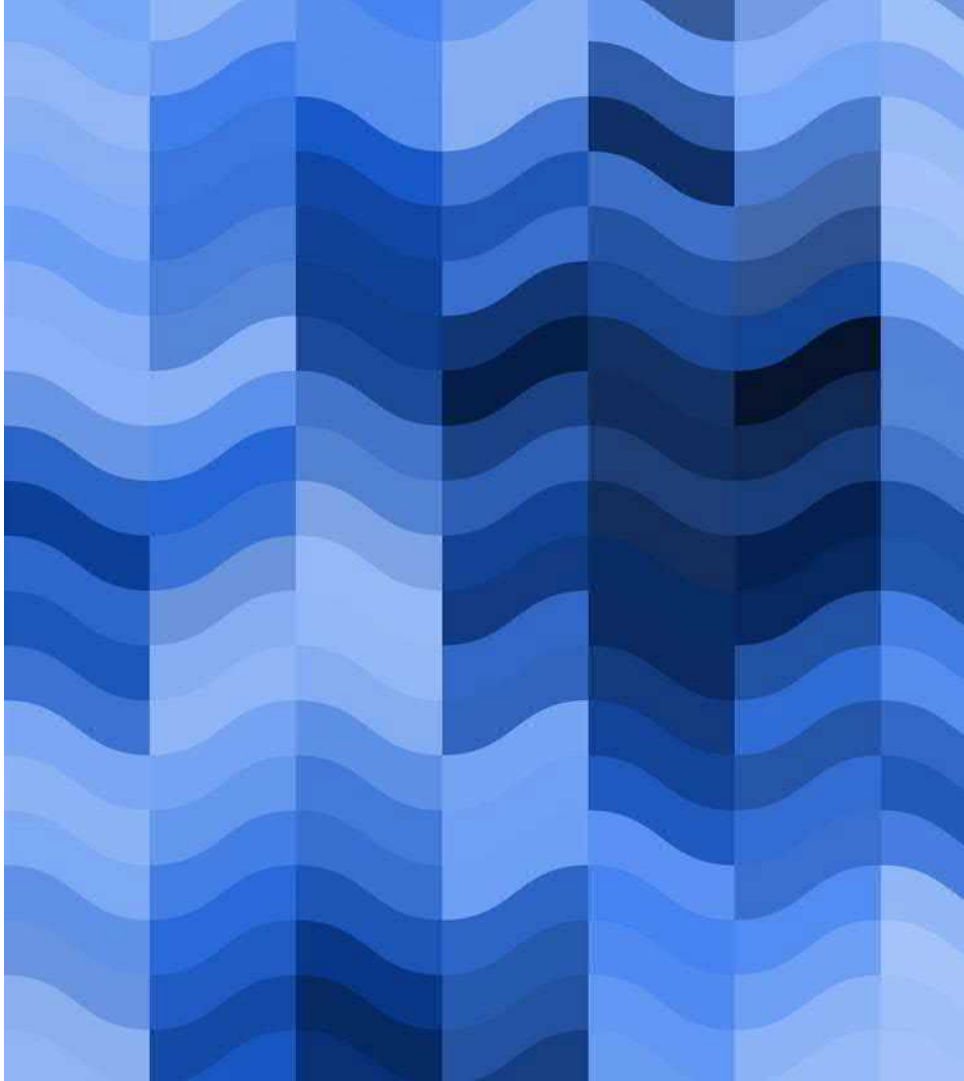
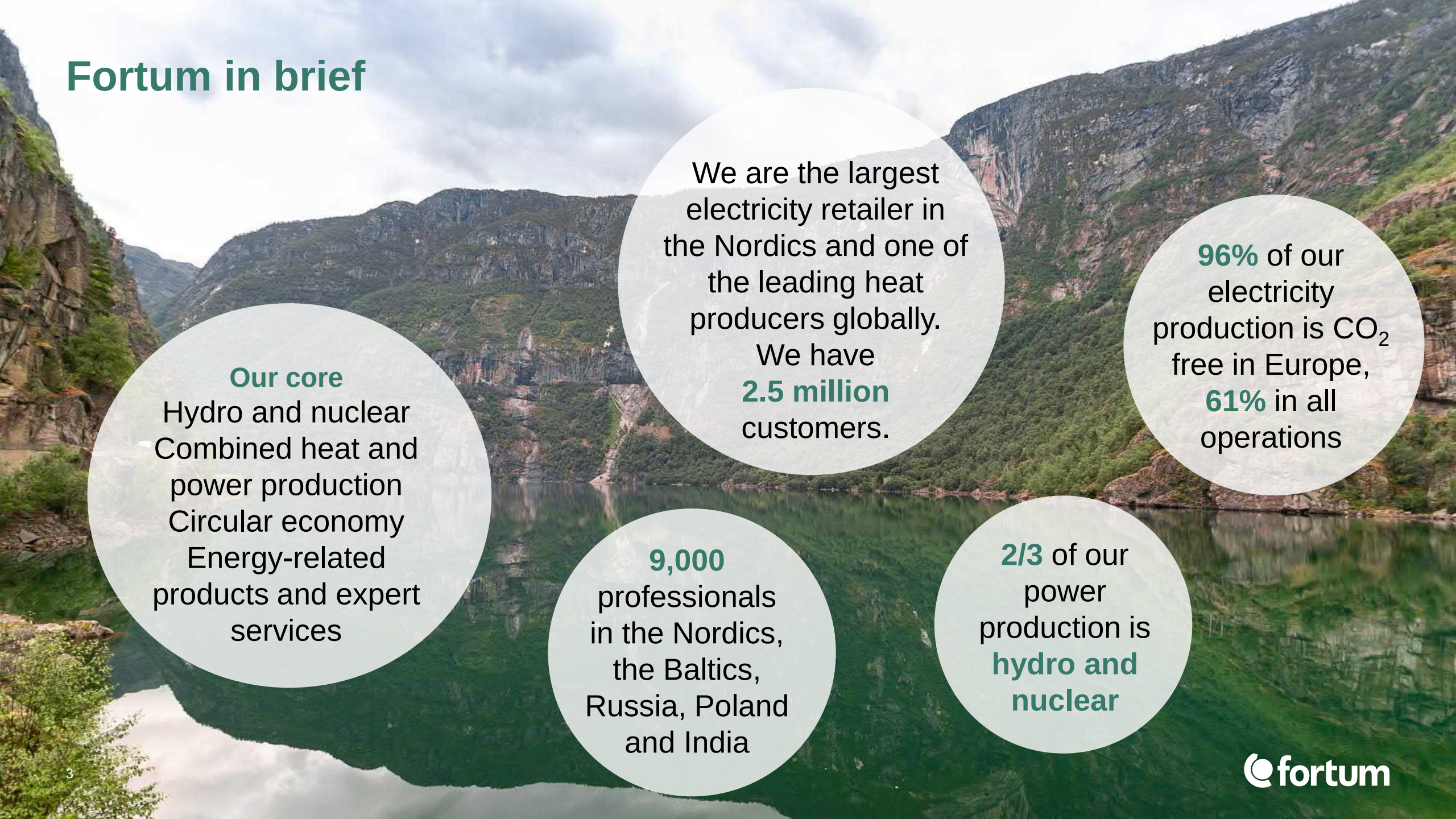



This is Fortum
Join the change
fortum

Fortum in brief



Our core
Hydro and nuclear
Combined heat and power production
Circular economy
Energy-related products and expert services

We are the largest electricity retailer in the Nordics and one of the leading heat producers globally. We have **2.5 million** customers.

96% of our electricity production is CO_2 free in Europe, **61%** in all operations

9,000 professionals in the Nordics, the Baltics, Russia, Poland and India

2/3 of our power production is **hydro and nuclear**

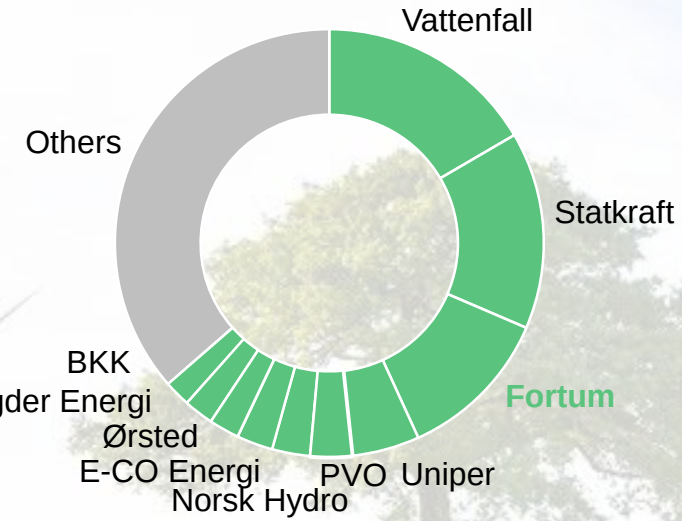
Our Nordic market position

Fortum has the largest electricity customer base in the Nordics

Power generation in 2016

395 TWh

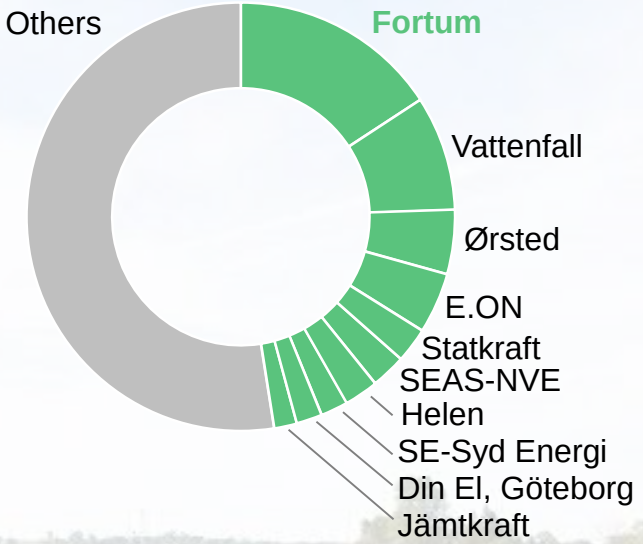
>350 companies



Electricity retail

15 million customers

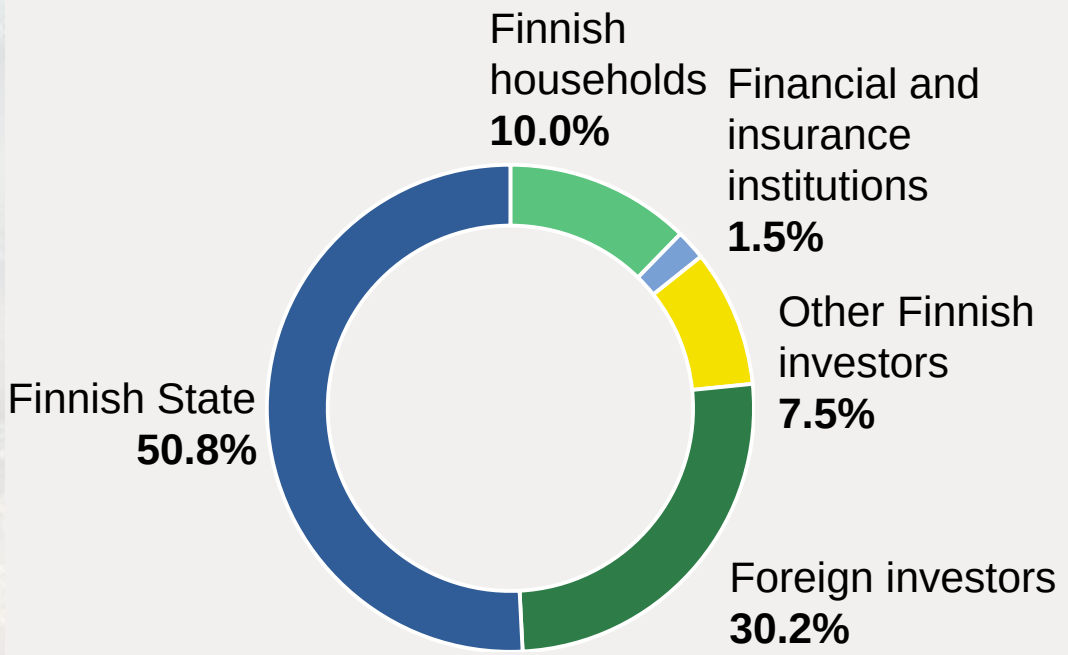
~350 companies



Source: Fortum, company data, shares of the largest actors, pro forma 2016 figures (Fortum incl. Hafslund's 1.1 million customers)

We have approx. 130,000 shareholders

- Power and heat company in the Nordic countries, Russia, Poland and the Baltics
- Listed on the Helsinki Stock Exchange since 1998
- Among the most traded shares on the Nasdaq Helsinki stock exchange
- Market cap ~17 billion euros



30 April 2018

Sustainable world, sustainable business

Towards a low-carbon energy system

"2/3 of global emissions are from the production and use of energy"

A transition to low-carbon and renewable generation is crucial.

It increases the share of **intermittent power** production and the need for **demand response** and flexible generation capacity.

The increased need for resource efficiency paves the way for **circular economy** solutions.

Source: World Energy Outlook Special Report on Energy and Climate Change, IEA, June 2015

fortum

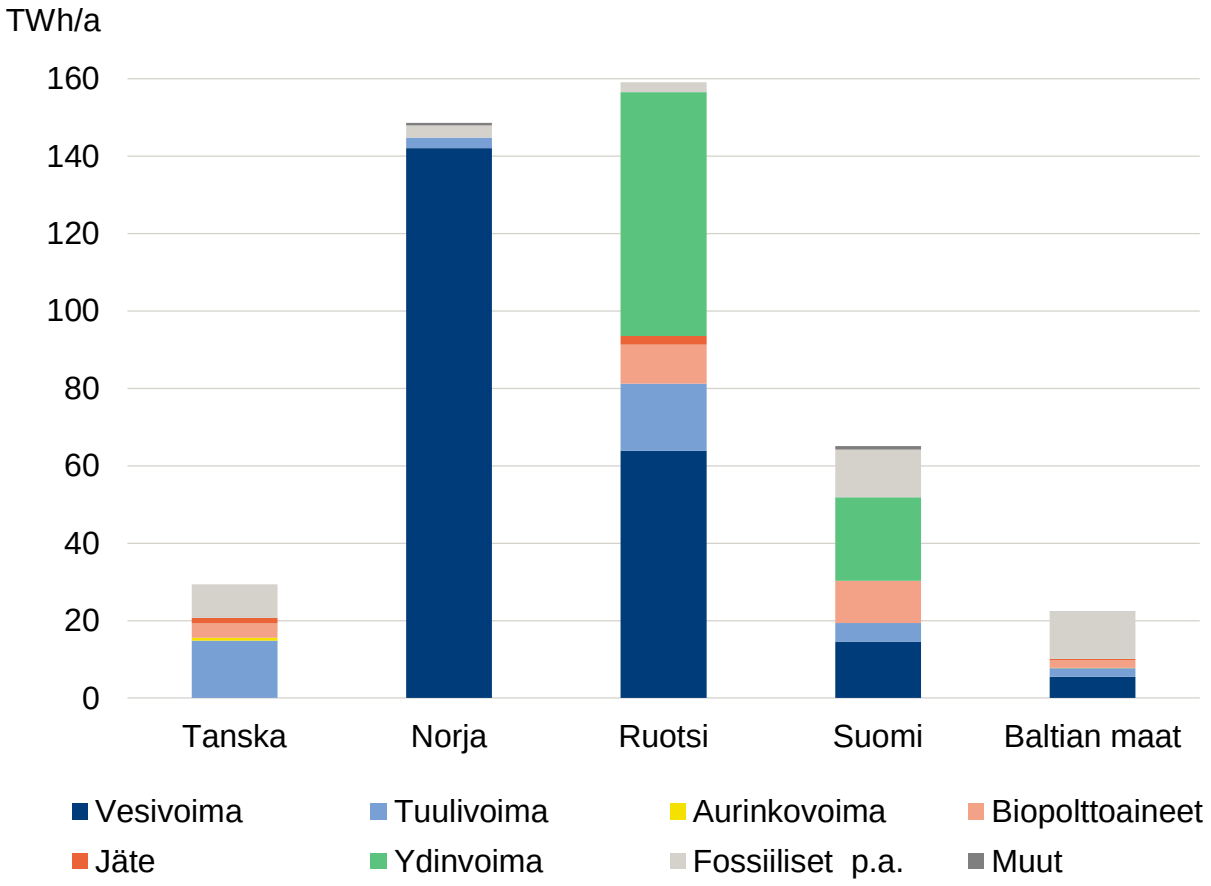
Hydropower at the core of renewable energy

We operate around **160 hydropower** plants in the Nordics. Hydropower has been used to produce emissions-free renewable energy for 100 years.

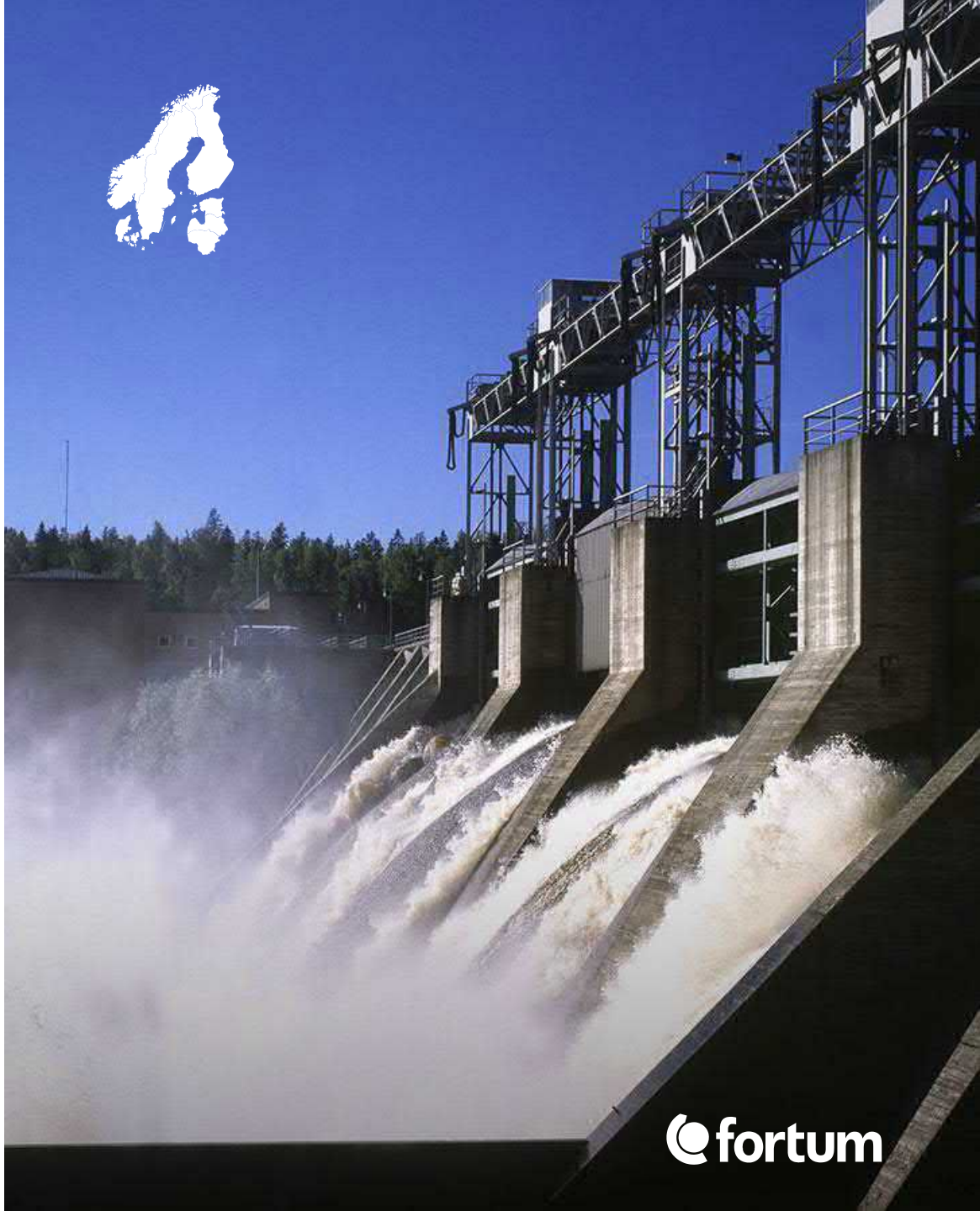
Hydropower is **crucial for the future** renewable energy system. We are currently developing strategies to develop our rivers for the future. Hydropower ensures that we have **electricity when we need** it the most.

Hydro power is the Nordic core

Electricity production in the Nordics 2017

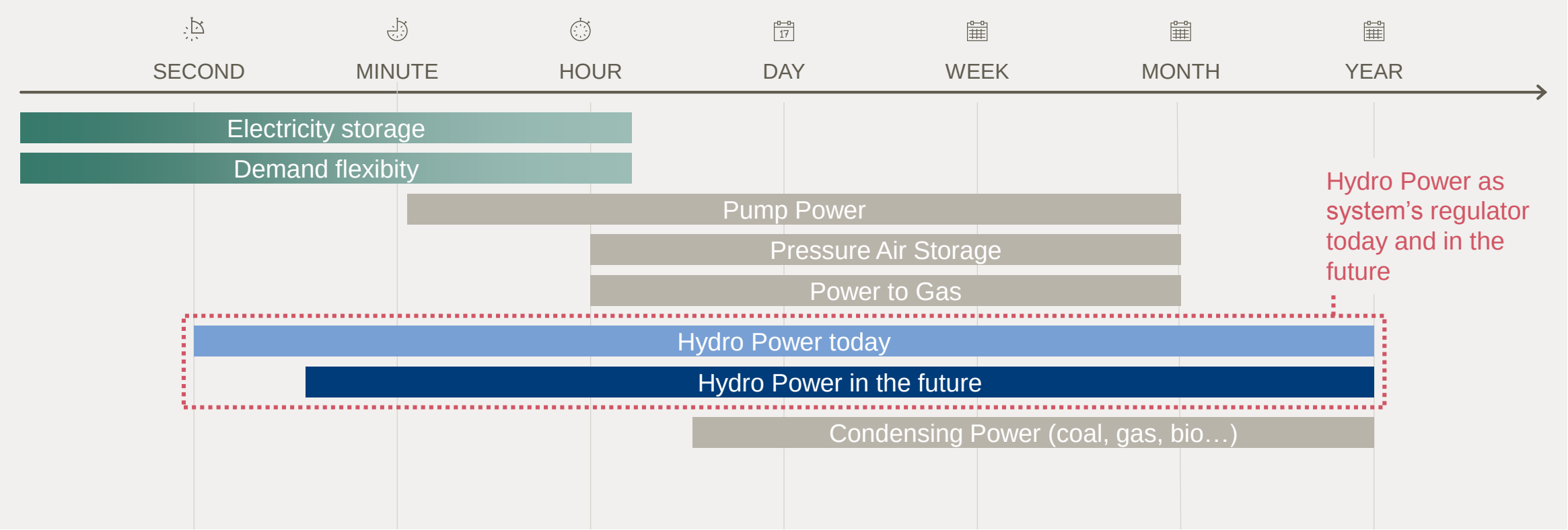


Lähde: ENTSO-E Statistical Factsheet 2017



Energy system needs flexibility on all time horizons

Hydro Power, Batteries and Demand flexibility all have their role



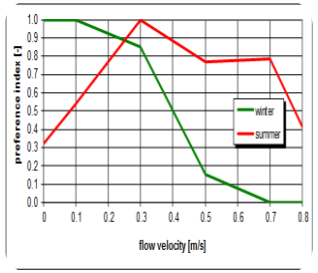
Short term regulation: impacts on the river?

fortum

Habitat modelling

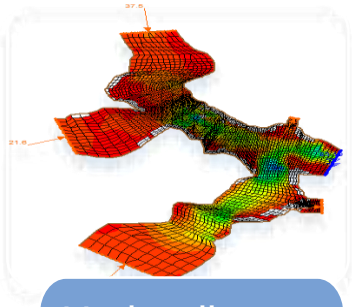
Observations

- Observed preferences for:
- Depth,
- velocity,
- substrate



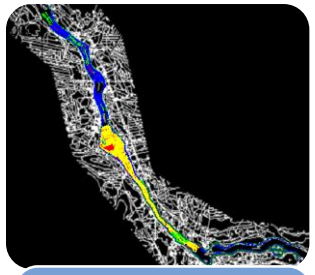
Habitat preference

- Indeces for different species and life stages



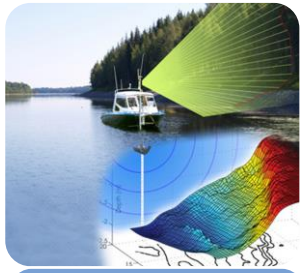
Hydraulic modelling

- Discharges
- Velocity & water level for each cell
- Additional parameters



Bathymetry

- Elevation model of river bed

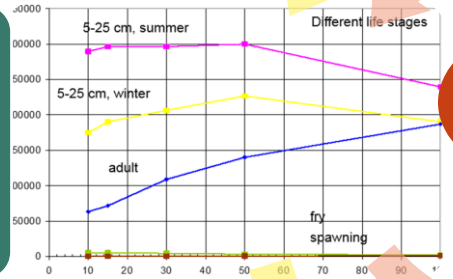


Measurements

- Bathymetry
- Water level, flow rate
- River bed properties (e.g. particle size classification)

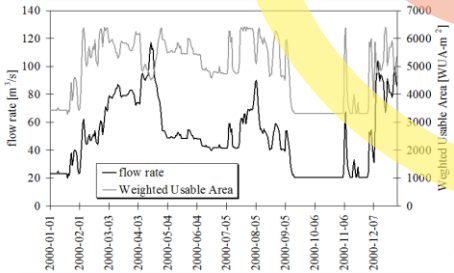
Habitat value calculation (IFIM)

- For different discharges
- For several species and life stages



Seasonal variation

- Discharge
- Amount of suitable habitat



Change Discharge

Channel Modification or Restoration

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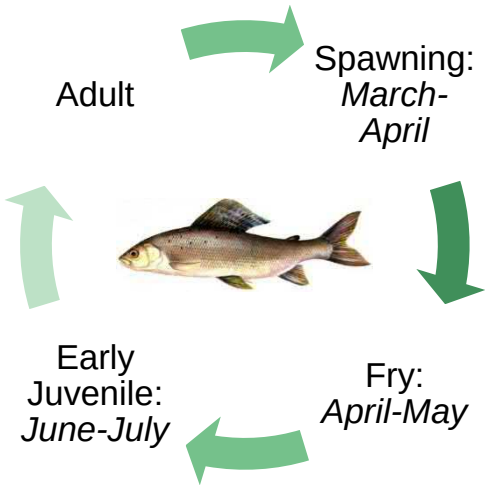
Case example:
Ecohydraulic modelling at River Oreälven, Sweden

- Quantify regulation impact on local **grayling** population:
  Habitat availability and relocation with changing discharge



- *How would more flexible regulation affect the river's flow conditions and graylings' habitat availability between two power plants?*
- *How fast is the change in the river environment when discharge is changed?*

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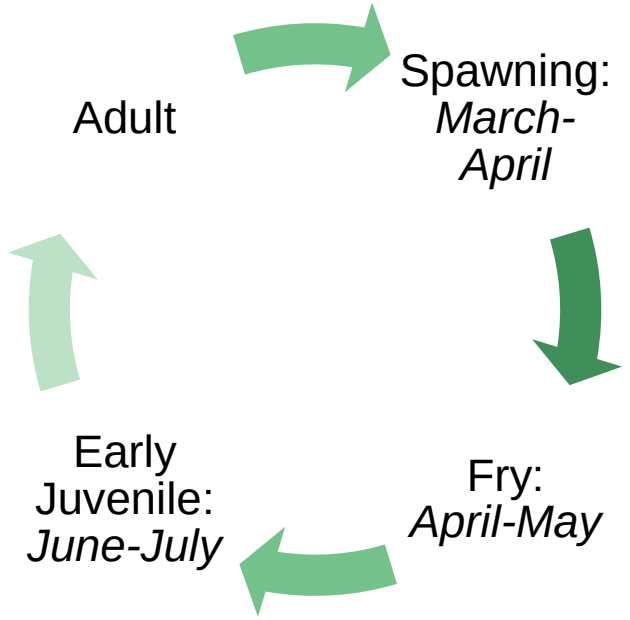
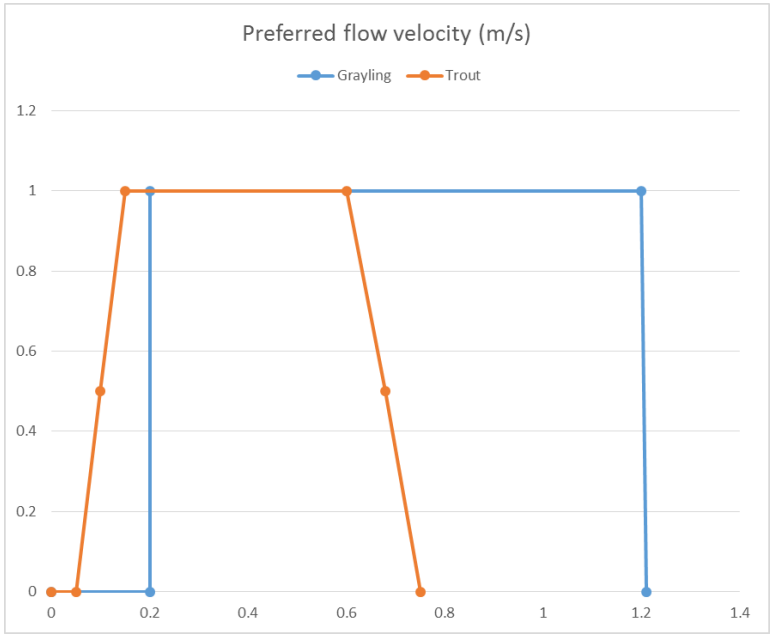
Grayling's habitat requirements



- Focus on modelling the most sensitive life stages
  - Spawning
  - Larvae
  - Fry
  - Early summer juvenile

- Main problems for young graylings in spring /early summer are:
  - Stranding
  - Drift
  - Risk of eggs ending up on dry land



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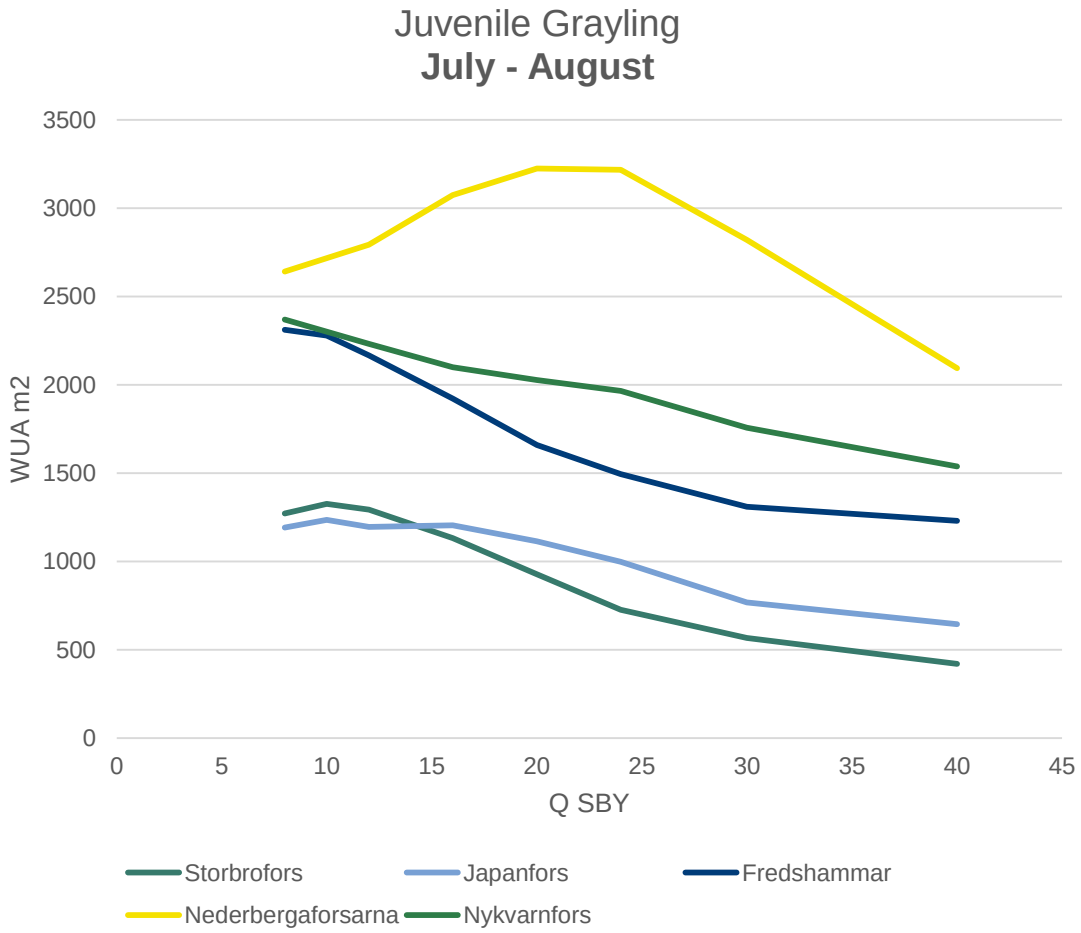
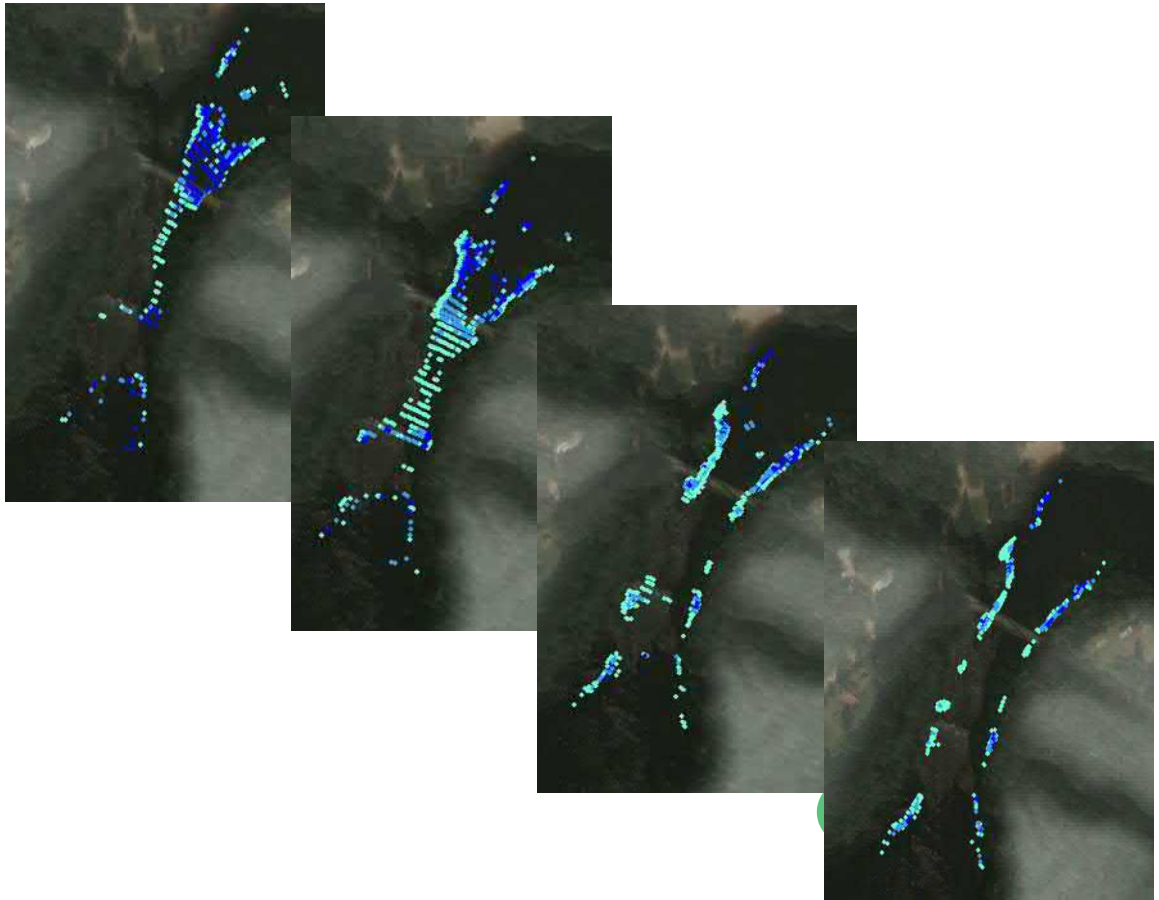
Evaluating short term regulation impacts on fish habitat conditions

Q	Overlap of habitat area, when discharge changes to… [m3/s]						
	8	12	16	20	24	30	40
8	100%	70%	48%	33%	22%	14%	9%
12	75%	100%	70%	51%	17%	17%	7%
16	55%	76%	100%	74%	52%	29%	9%
20	40%	57%	78%	100%	71%	44%	16%
24	29%	42%	59%	78%	100%	65%	30%
30	21%	23%	37%	53%	72%	100%	54%
40	16%	12%	14%	25%	42%	68%	100%





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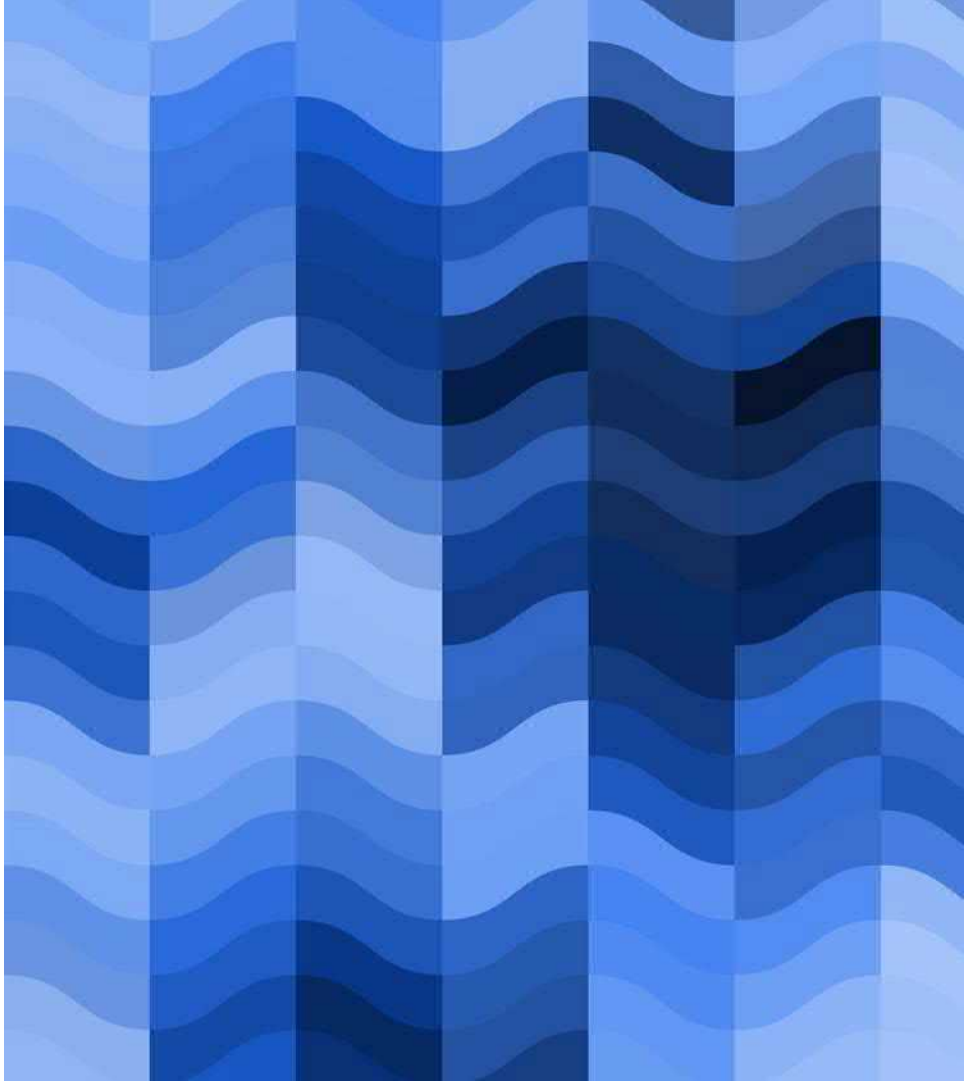


How does the climate change impact on the operation areas of Kemijoki Oy?

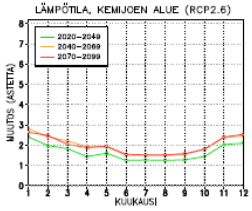
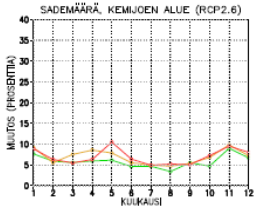
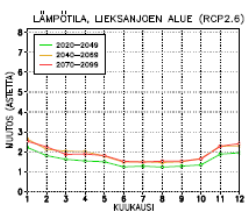
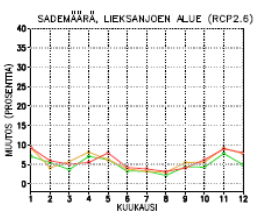
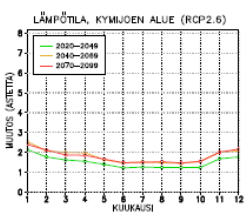
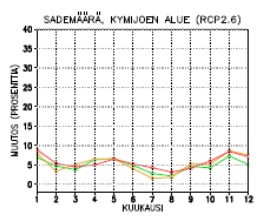
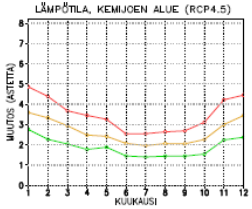
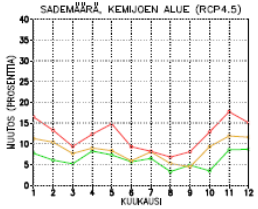
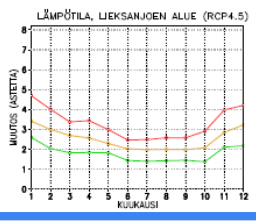
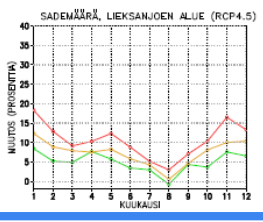
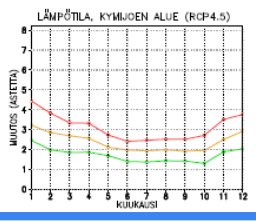
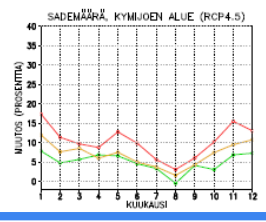
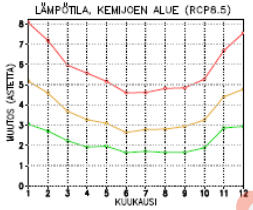
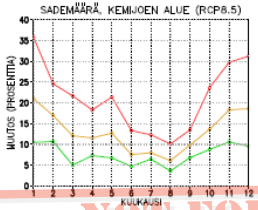
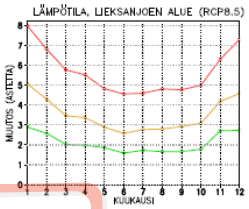
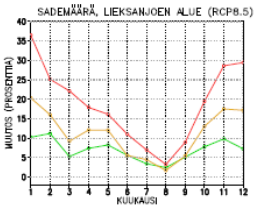
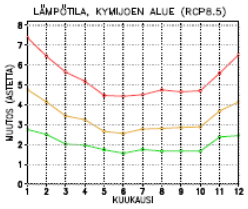
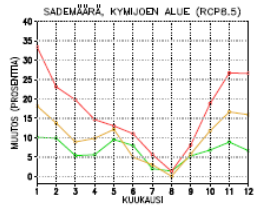
Ilmastonmuutoksen vaikutuksia Kemijoki Oy:n toiminta-alueella

Finnish Meteorological Institute and Finnish Environment institute, 2018

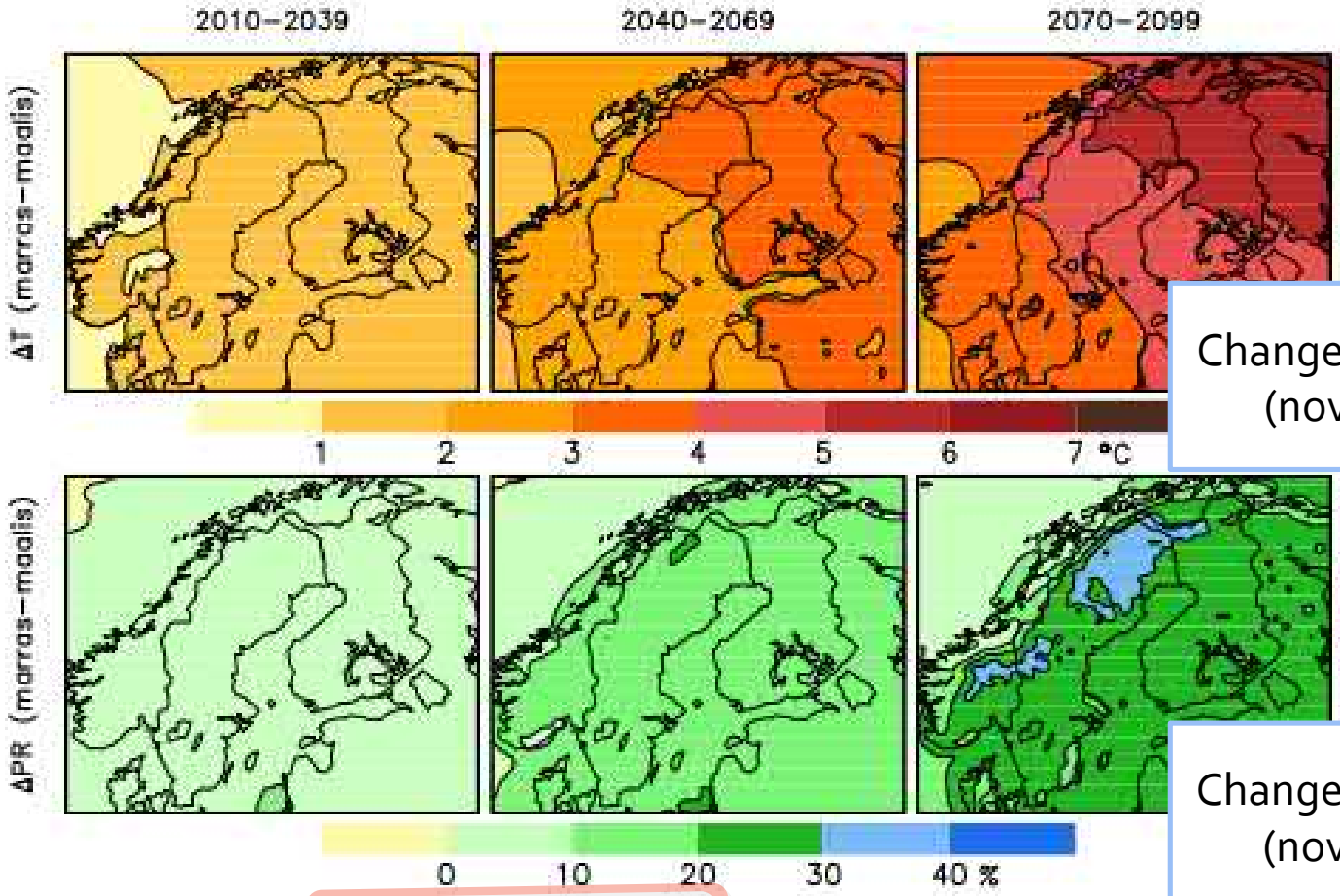
https://www.kemijoki.fi/media/esitykset/kemijokioy_ilmastonmuutos_raportti.pdf?fbclid=IwAR3fMKVYxhBRRbN_LSKxoTsIjgkC6E04OvtRTlFFsXKYYYoTqewIj4xhEWk

Forecasts of different scenarios

2020–2049
2040–2069
2070–2099

	Kemijoki		Lieksanjoki		Kymijoki	
	TEMPERATURE	PRECIPITATION	TEMPERATURE	PRECIPITATION	TEMPERATURE	PRECIPITATION
RCP2.5						
RCP4.5						
RCP8.5						

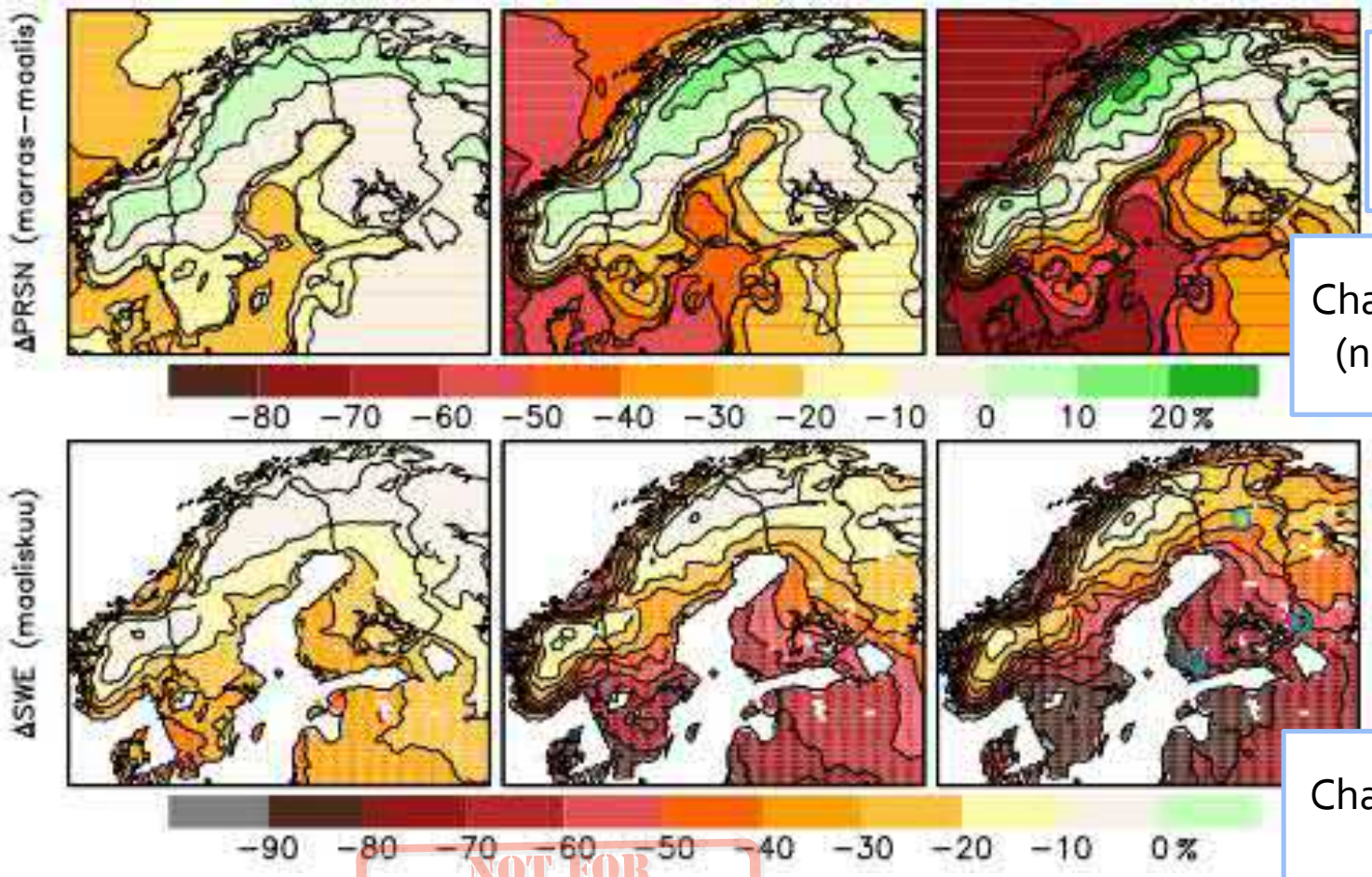
Source: Ilmastonmuutoksen vaikutuksia Kemijoki Oy:n toiminta-alueella Suomenympäristökeskus, Ilmatieteen laitos (2018)



Base 1971-2000 (Ruosteenoja, 2013)

Change in temperature (°C) (november – march)

Change in precipitation (%) (november – march)

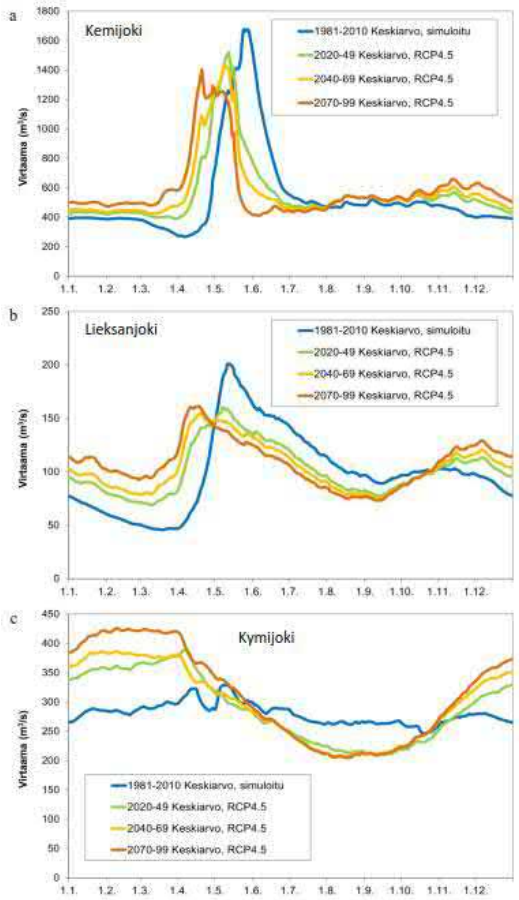


Base 1971-2000 (Ruosteenoja, 2013)

Change in snowfall (%) (november – march)

Change in snow water eq. (%) (march)

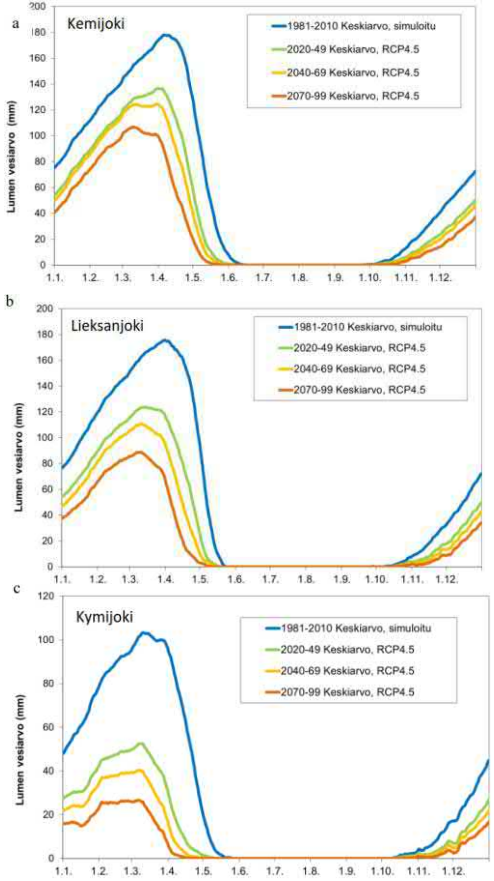
FLOW



- Local impacts differ on different water-shed areas
- Floods getting smaller, winter time discharge increase

1981-2010	Mean, simulated
2020-49	Mean, RCP4.5
2040-69	Mean, RCP4.5
2070-99	Mean, RCP4.5

SWE

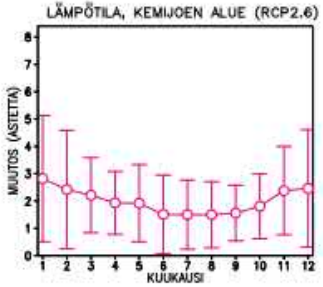


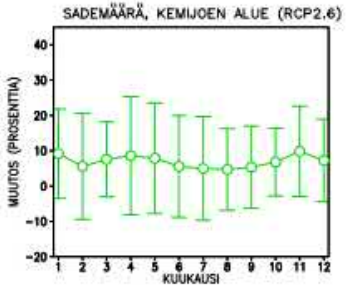
Lähde: Ilmastonmuutoksen vaikutuksia Kemijoki Oy:n toiminta-alueella Suomen ympäristökeskus, Ilmatieteen laitos (2018)

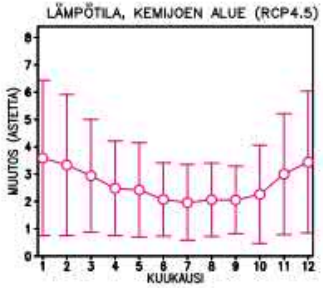
High uncertainty

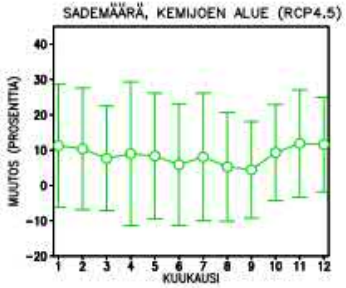
- Temperature rises and precipitation increases *on average*
- Things to consider: gate design, design flood, production, permissions, ecology, transition phase

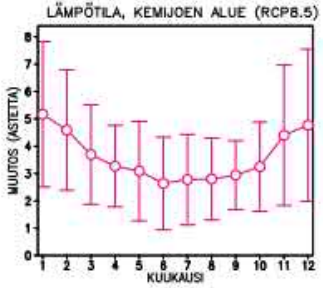
	WET	DRY
COLD		
WARM		

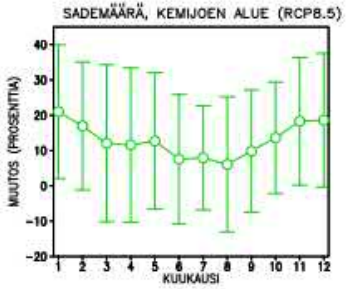












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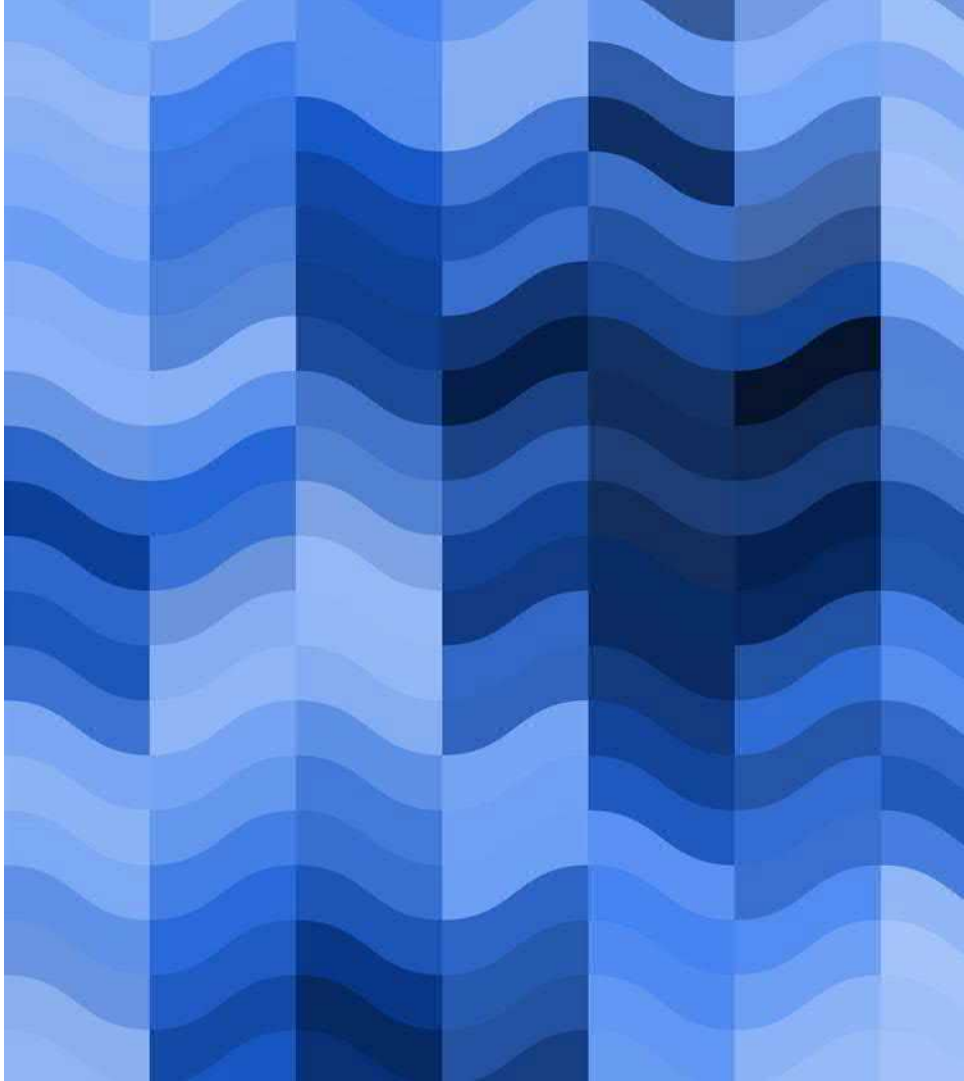
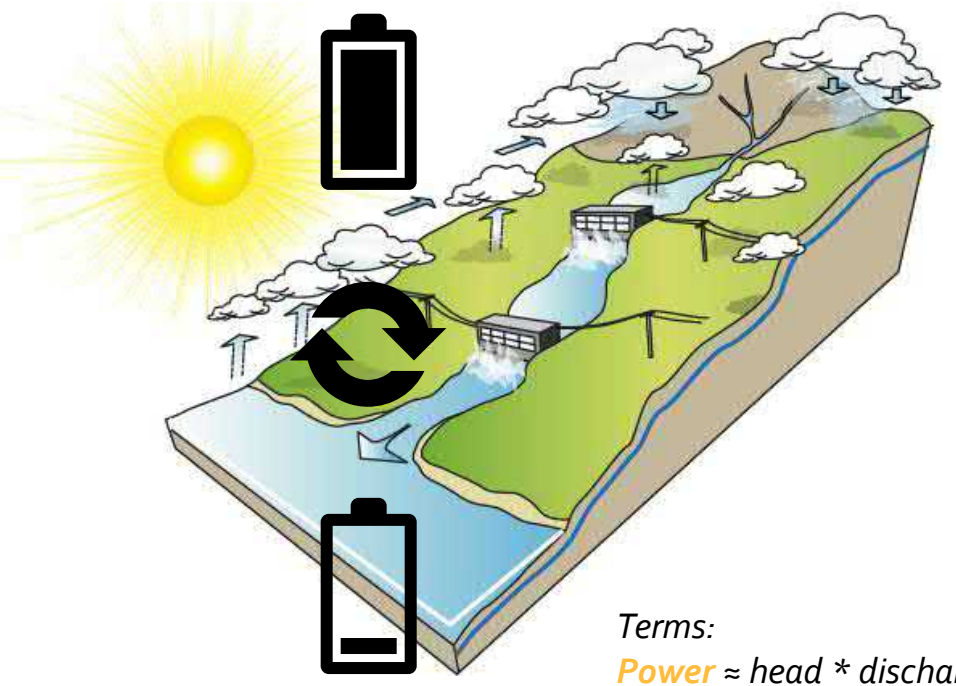
- (Data analysis)

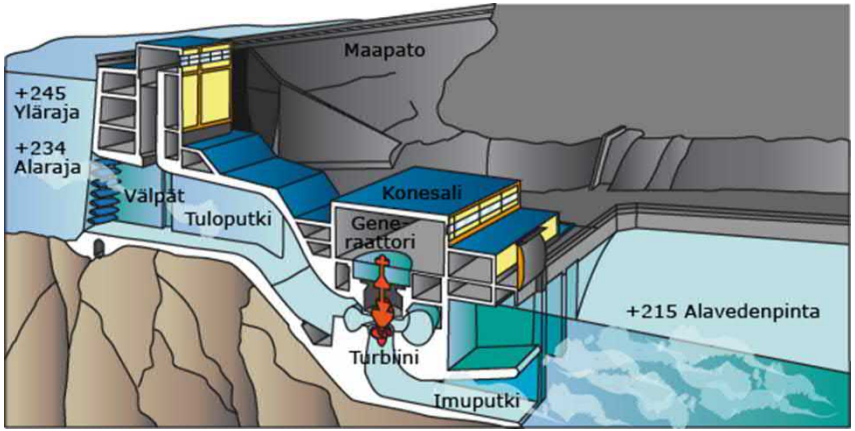


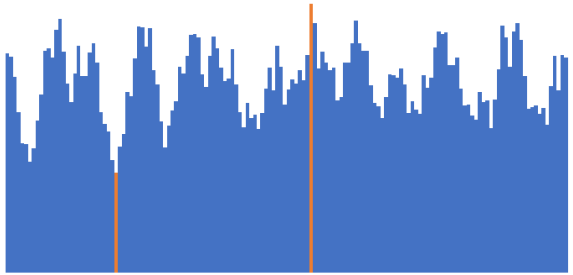
Hydropower keeps Finland running

PHYSICS

Hydro gets its energy from the Sun





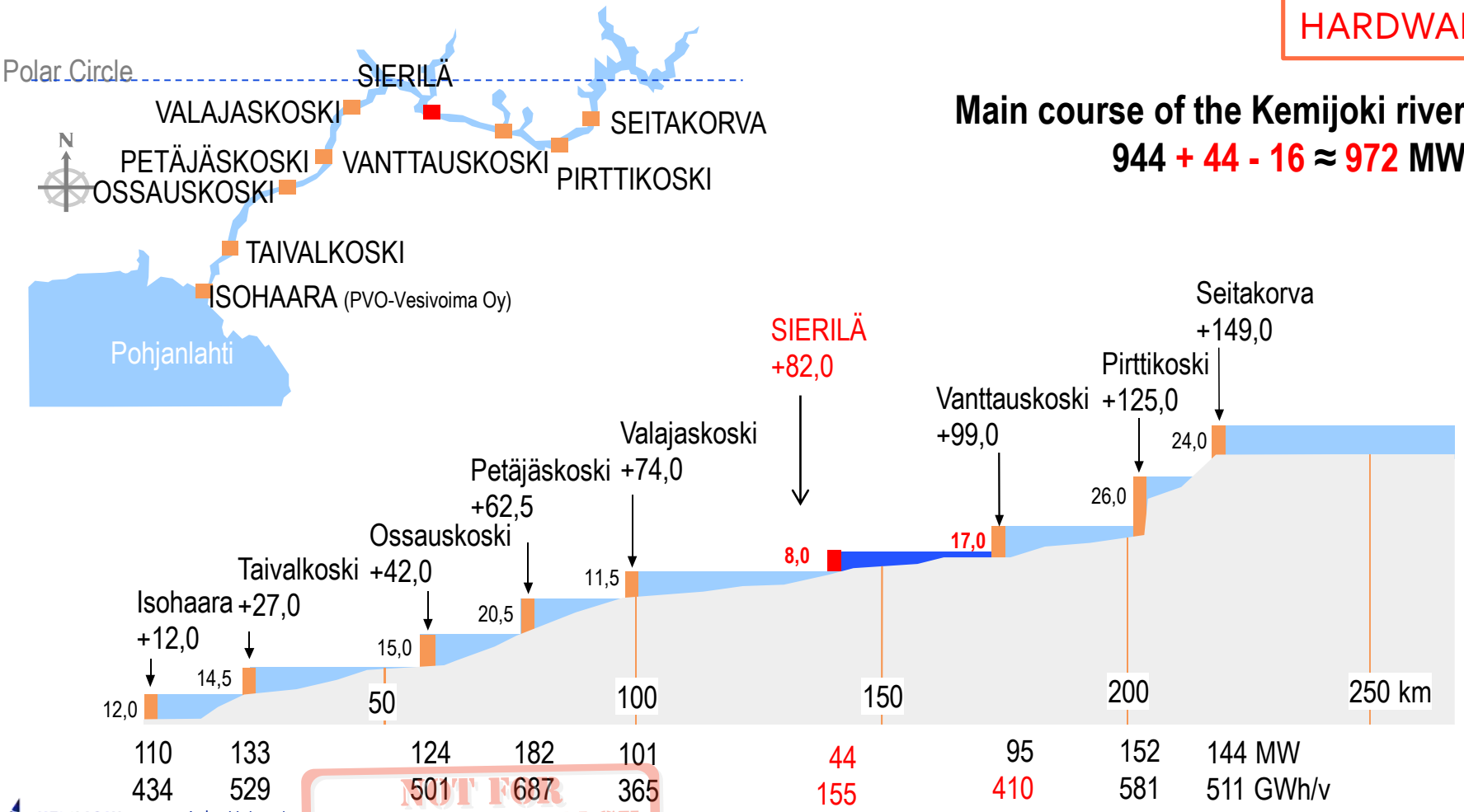


Terms:
*Power ≈ head * discharge*
Energy is power for some time

HARDWARE

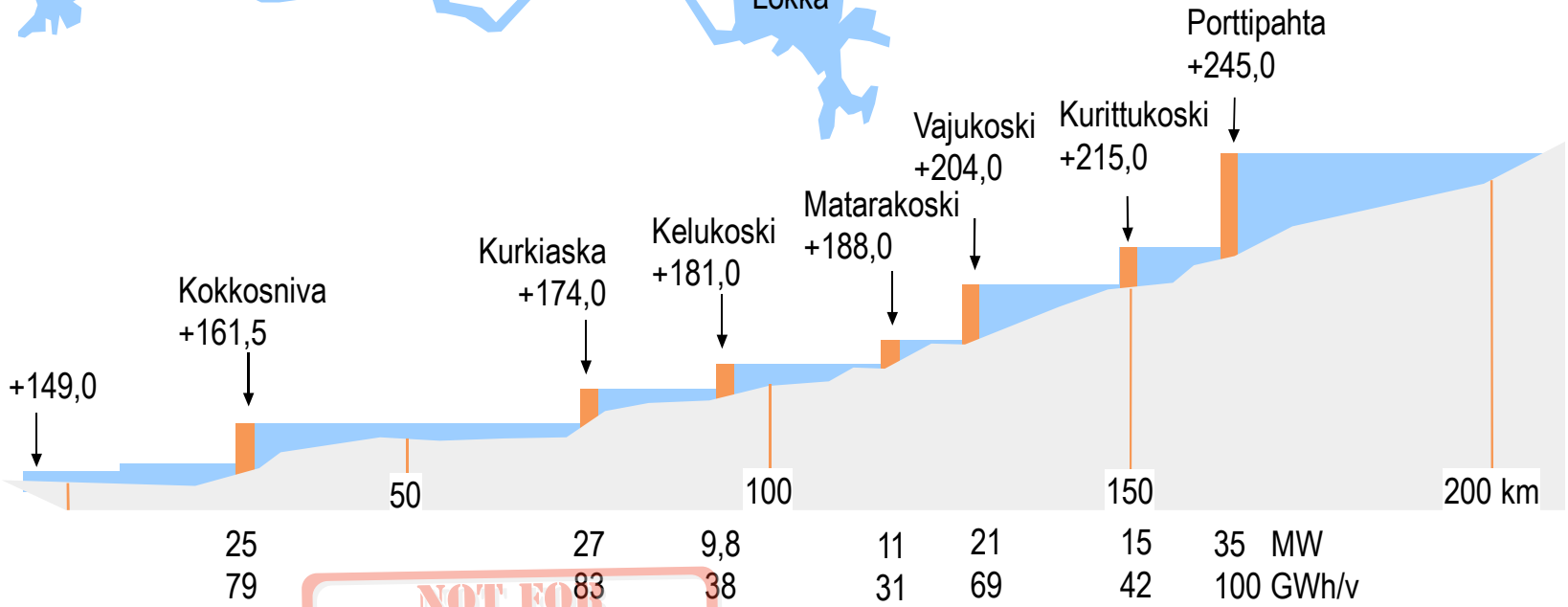
Main course of the Kemijoki river

944 + 44 - 16 ≈ 972 MW

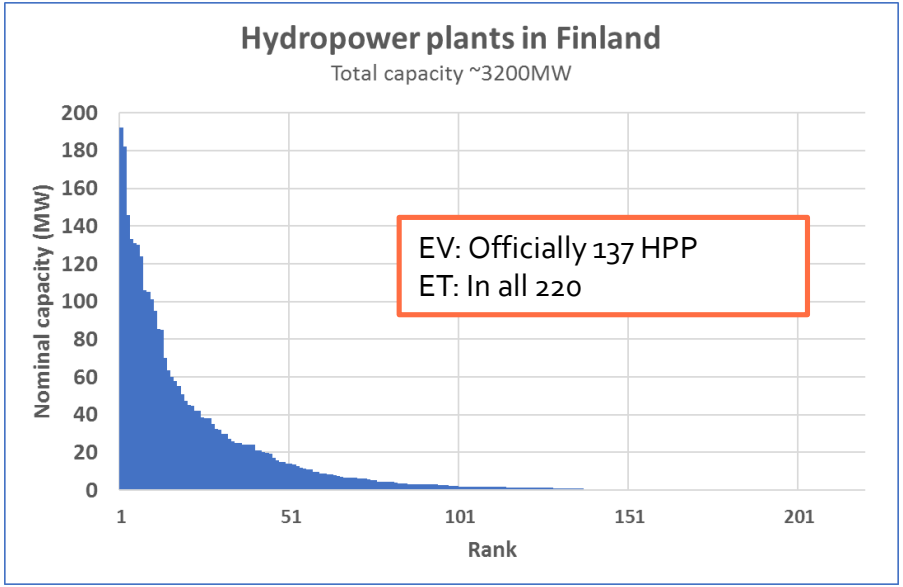


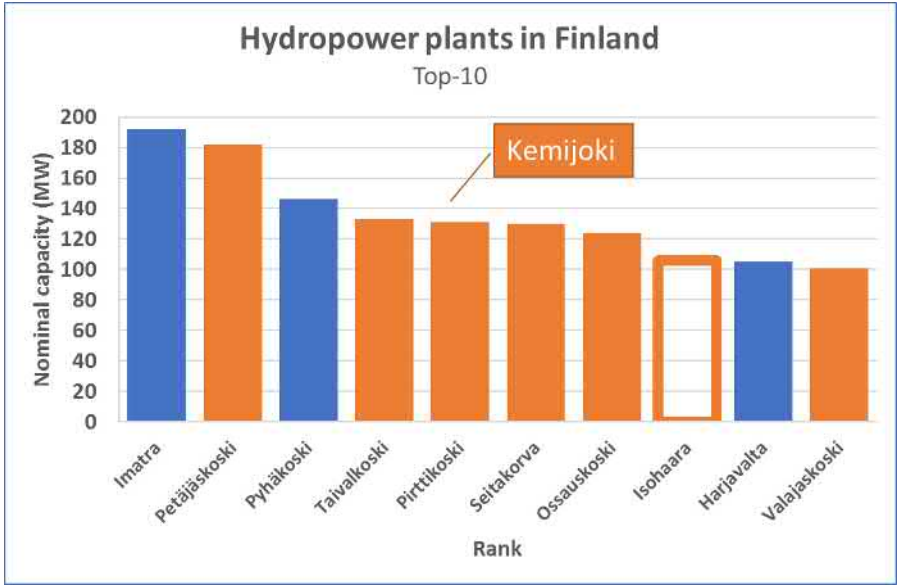
HARDWARE

Kitinen 144 MW/442 GWh
+ Lieksan- ja Kymijoen 70MW/352GWh



Kemijoki's plants are among the biggest in Finland





Source: Energy Authority Power plant register (1.1.2019)

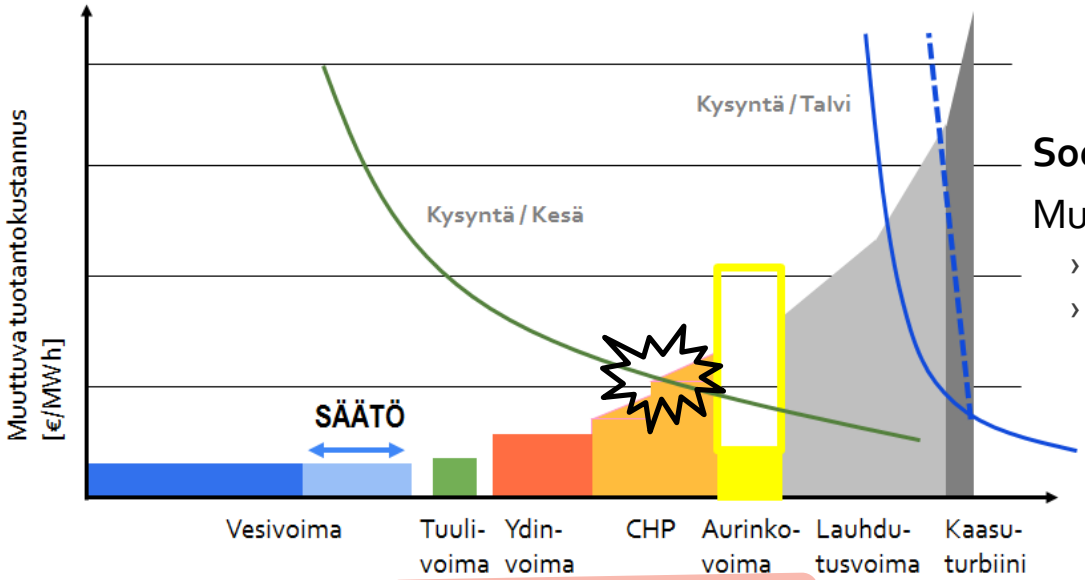
Flexible hydro enhances the market efficiency

SOFTWARE

Production = Consumption

FINGRID

NORD POOL



Social welfare → Market model

Multidimensional markets

- Spatial X time X products
- Integration towards continental Europe

The flexibility of hydro decreases market price because it is activated when the demand is at its highest (price signal)

What we know about the future is that …

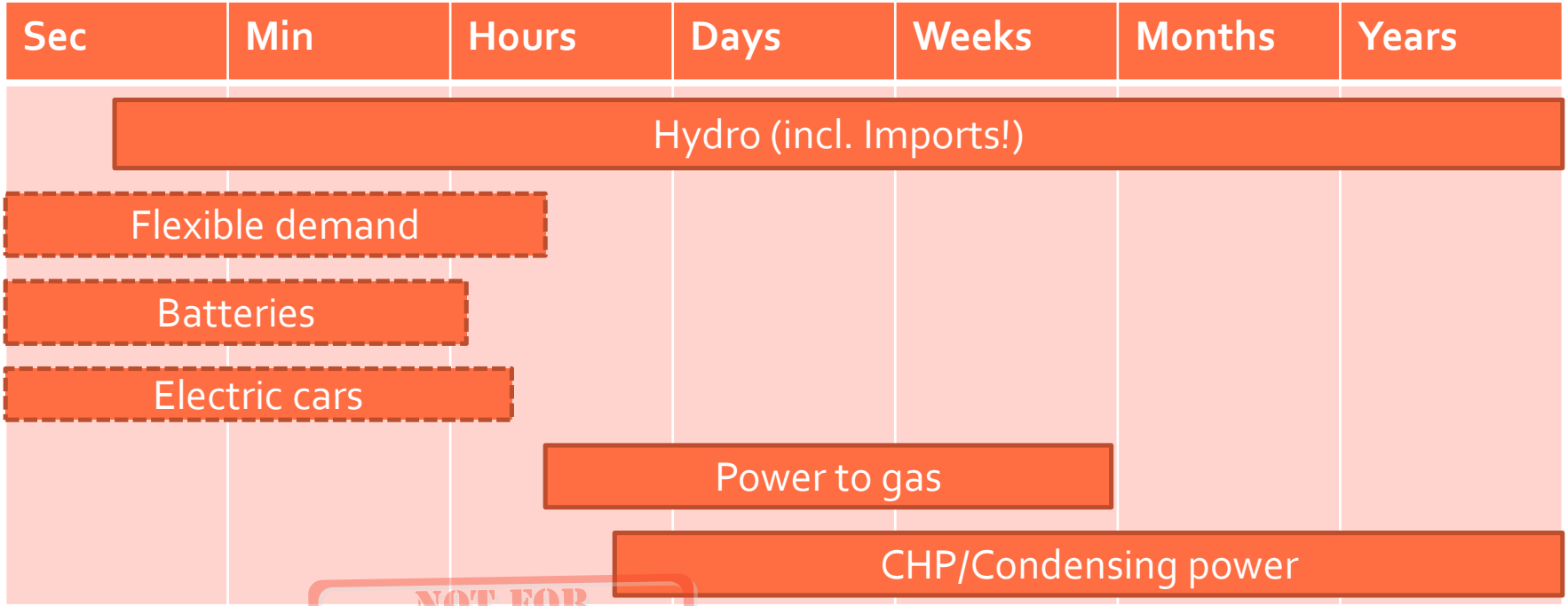
- Integration towards continental Europe
  - More transmission capacity
  - Market structures
- (Much) more intermittent production (with no variable cost?)
- Digitalization opens new business opportunities

Wind forecast previous day

Wind forecast previous hour

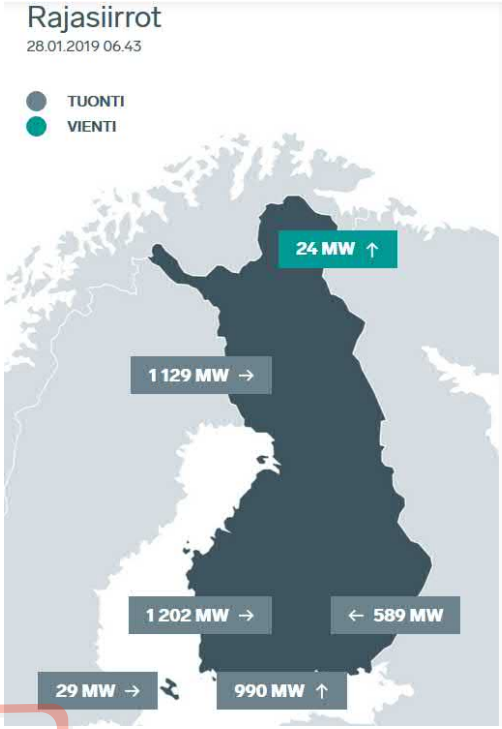
Actual wind production

..the system needs flexibility



Finland imports about 20 TWh each year

- Price formed in the spot market
- 28.1.2019 morning
  - 3900 MWh/h * 58,85€/MWh ~ 230 000€/h
- Annually ~ 1 billion
- Soon we compete with the continental Europe



Kulutus Suomessa

14 270 MW

Tuotanto Suomessa

10 406 MW

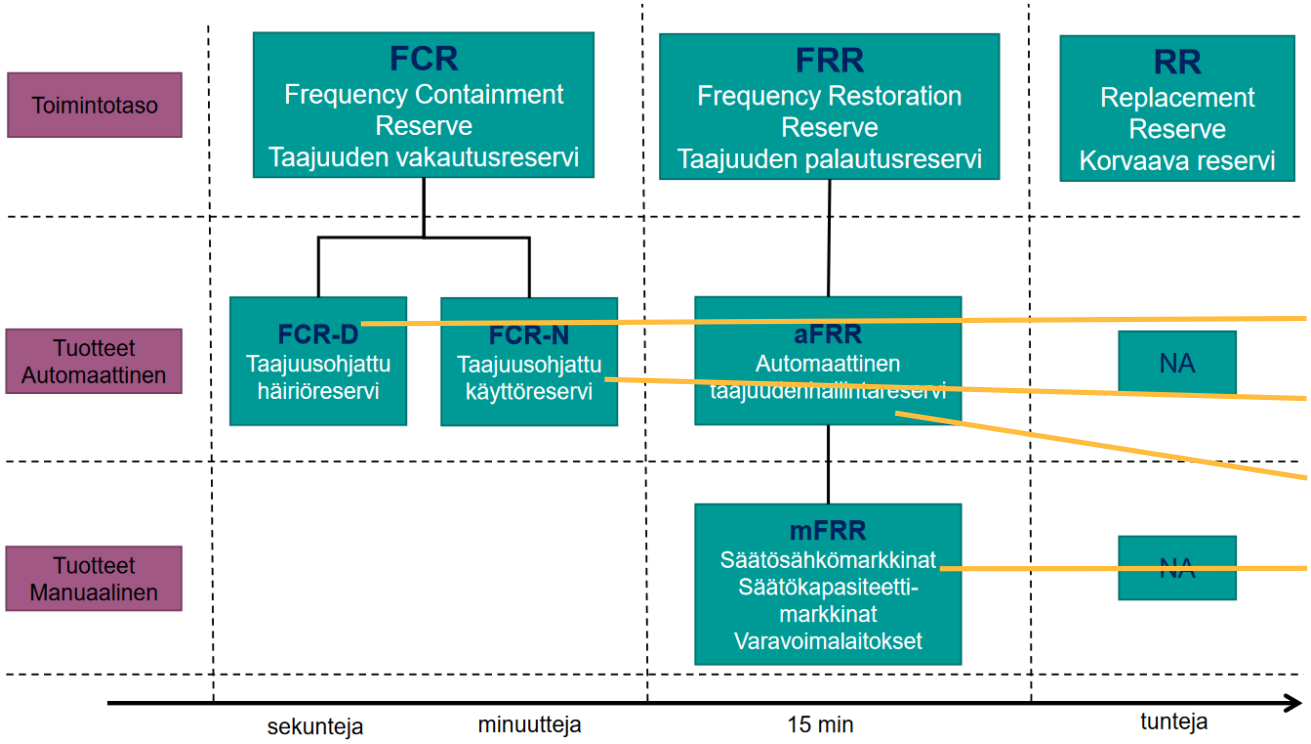
Vesivoima	1 407 MW
Ydinvoima	2 801 MW
Yhteistuotanto (kaukolämpö)	2 945 MW
Yhteistuotanto (teollisuus)	1 677 MW
Tuulivoima	1 042 MW
Aurinkovoima	0 MW
Muu tuotanto	526 MW
Tehoreservi	0 MW
Tuonti/vienti (netto)	−3 848 MW

Hydropower is flexible and can be controlled

Spinning reserves	Hourly dispatch (optimization)	Regulation	Hydro storage (Lokka and Porttipahta)

Period	1		2		3		4
	1s…30min	-	5min…7 d	-	1d…6mm	-	1w…3a

Reserve products procured in the Nordic countries



Proportion of hydropower (FI)

>50%

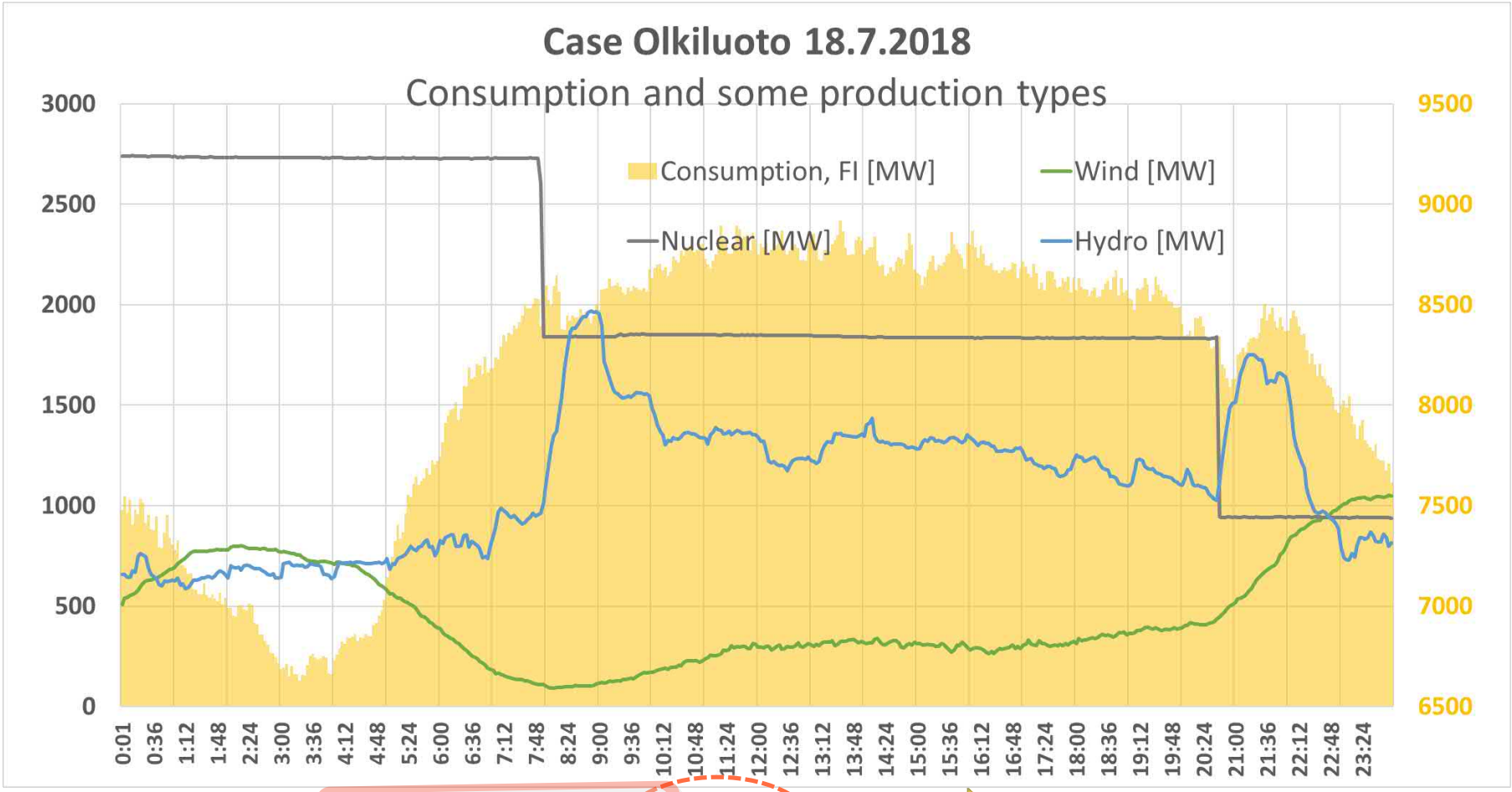
>75%

100%

UP > 80%
DOWN > 95%

FINGRID

KEMIJOKI Aalto University



Hydropower is the leading renewable source for electricity generation globally

HYDROPOWER IS THE LARGEST SOURCE OF RENEWABLE ELECTRICITY IN THE WORLD

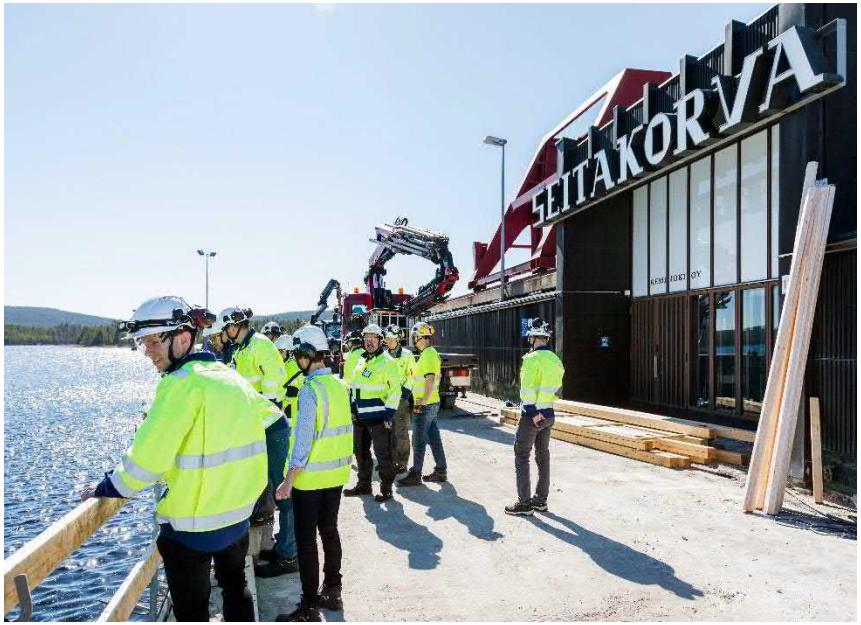
Hydropower generated over 16% of the world's electricity in 2016. Hydropower supplied over 70% of all renewable electricity.

Worldwide generation by hydropower in 2016:

4,102 TWh

New installed capacity of hydropower in 2016:

31.5 GW



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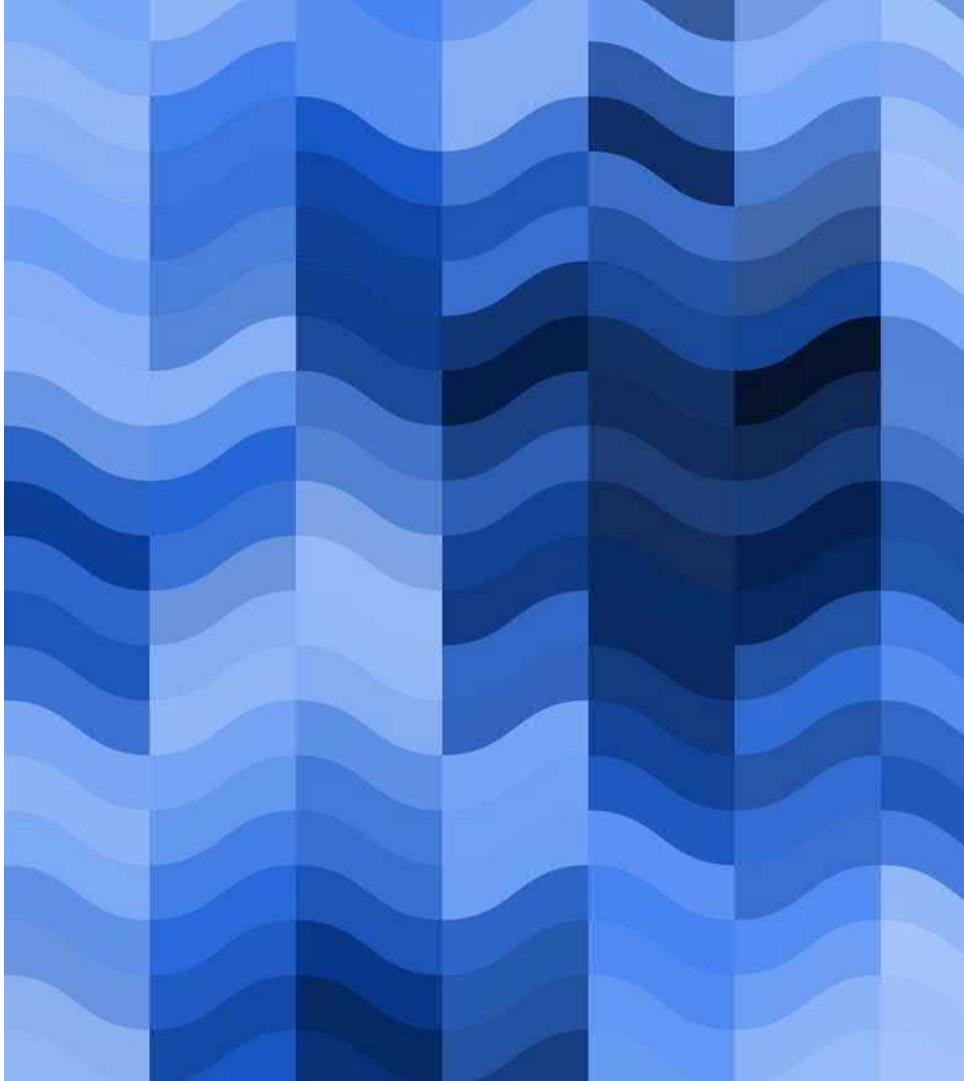


Vuoksi

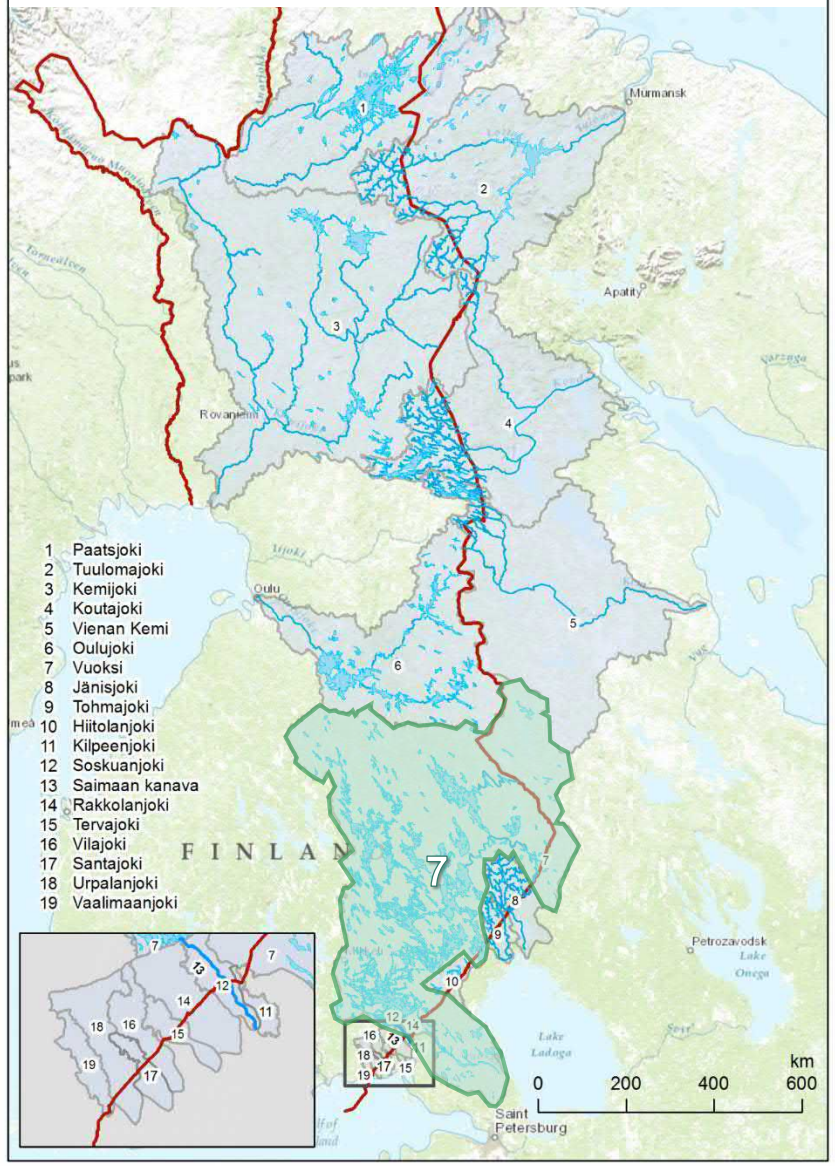
fortum

Transboundary Water Commission

Regulation of Vuoksi

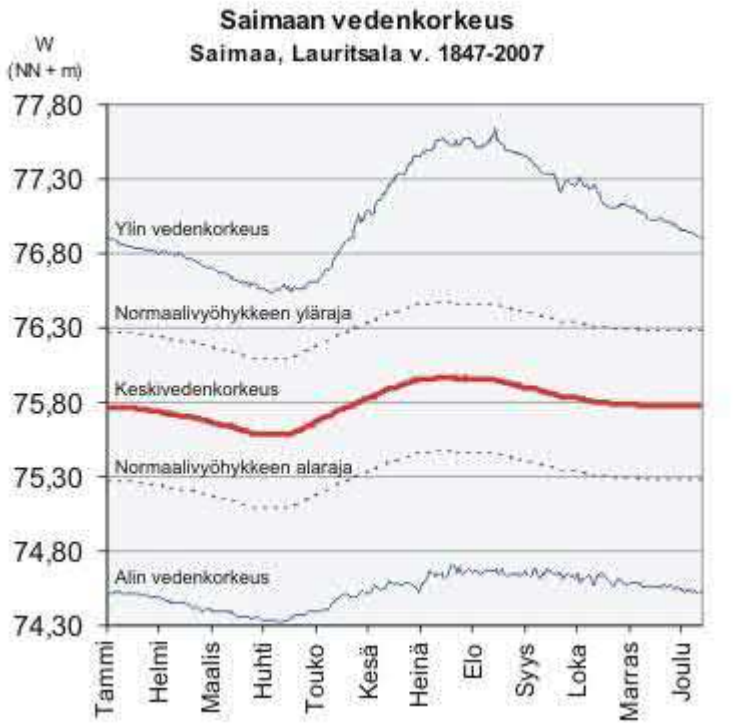
- Transboundary water commission implements agreement between the nations (1964), covering water use, management and protection in the 19 transboundary watersheds
- On the Agenda
  - Regulation of Vuoksi and Lake Saimaa for flood or drought mgmt
  - Implementation of agreement between Imatra and Svetogorsk power plants
  - Water quality and protection
  - Prevention of negative impacts for fish populations and migration

Finnish – Russian transboundary watersheds



Source: Transboundary Water Commission

Regulation of Lake Saimaa



- Regulation rules for Saimaa agreed by agreement between Finland and Russia
- Damages and benefits evaluation managed by Transboundary Water Commission

- Natural discharge curve is the basis
- Discharge is regulated in flood and drought situations (+/- 0.5 m)
- Discharge is considered as a weekly average

Master’s thesis

fortum

Masters Thesis:
Laura Savikoski, University of Eastern Finland Law School

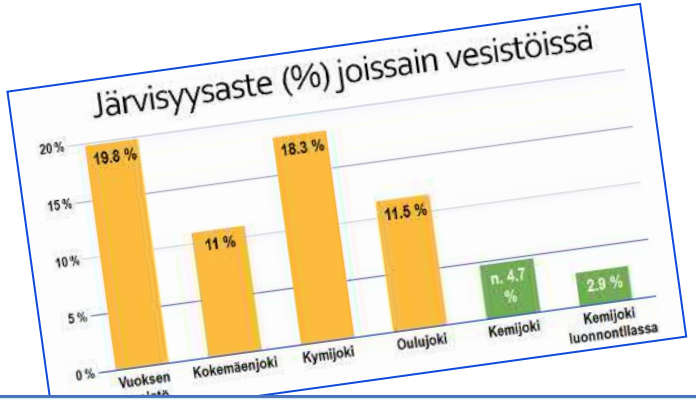
The EU Water Framework Directive Article 4.7 application in hydro power projects – Comparative perspectives from Finland, Scotland and Austria.

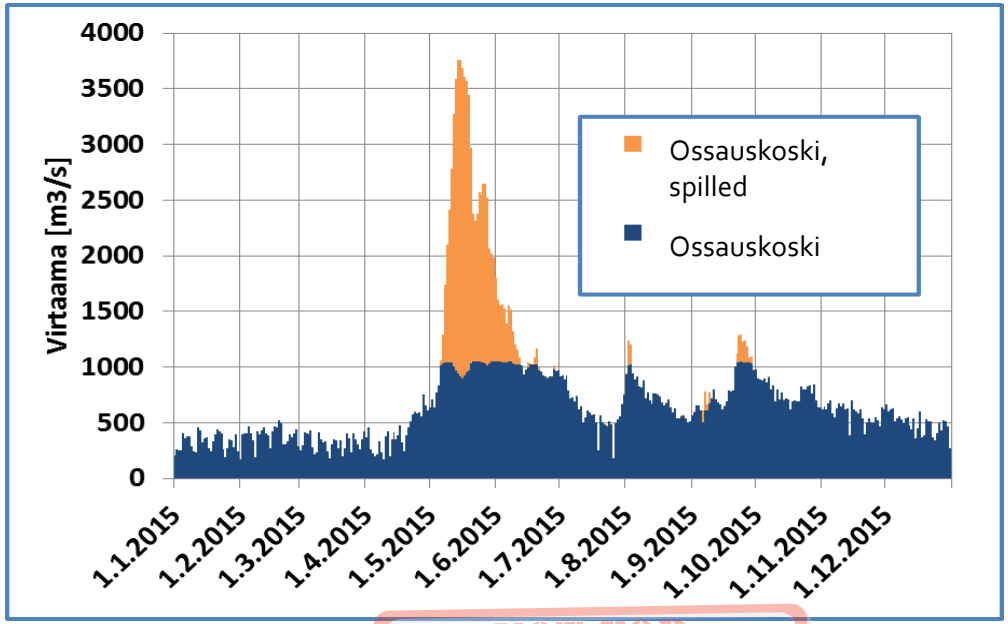
- Comparison of how different countries have applied WFD exception with respect to building hydro power
- Particular attention has been paid on procedural questions, as well as in how clauses substantial conditions, including climate and environmental impacts, are considered by the competent authorities in the Member States.

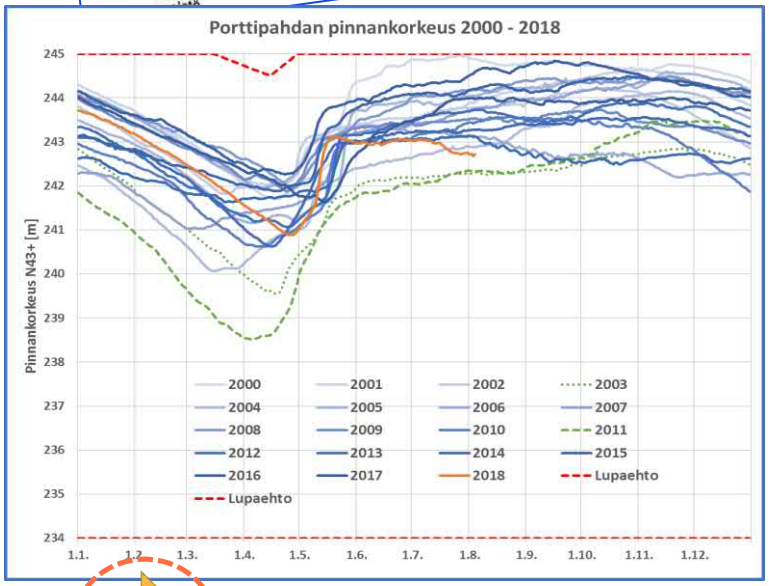
- Approaches and practice vary a lot from one country to next!
- The level at which decisions are made to grant exception is an important factor
  - Local authority <> Governmental
  - Project based <> fixed 6 year terms

fortum

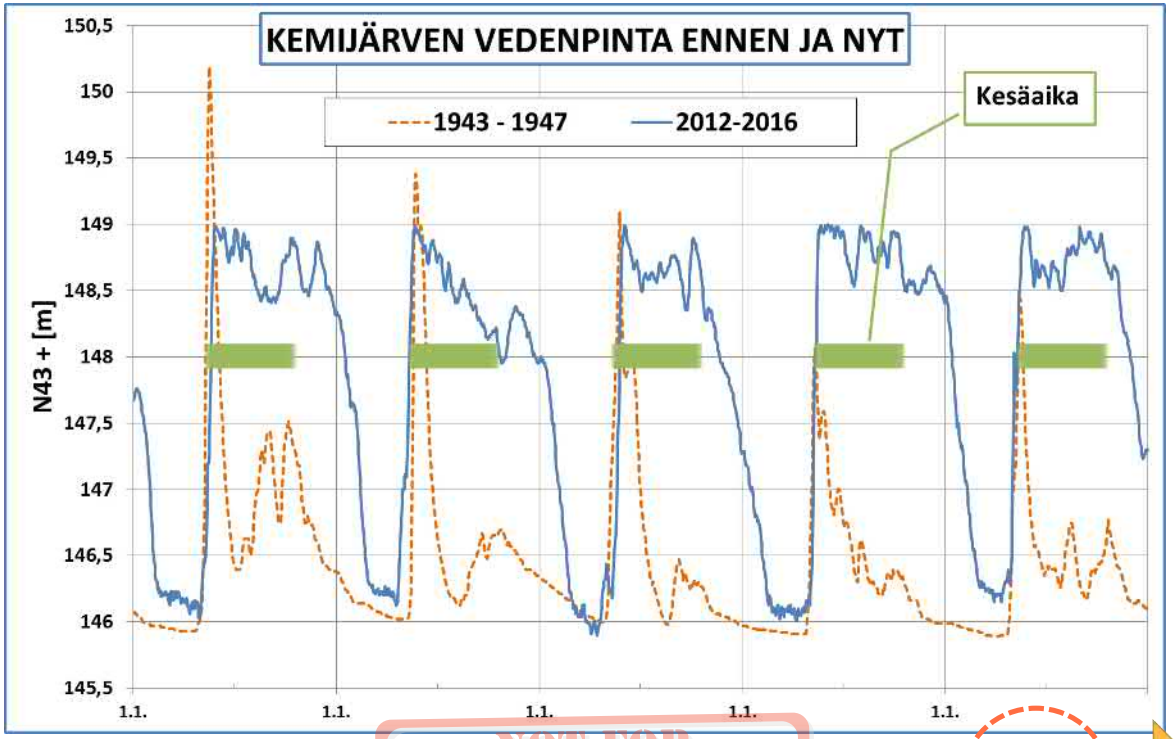
Energy is stored for future needs

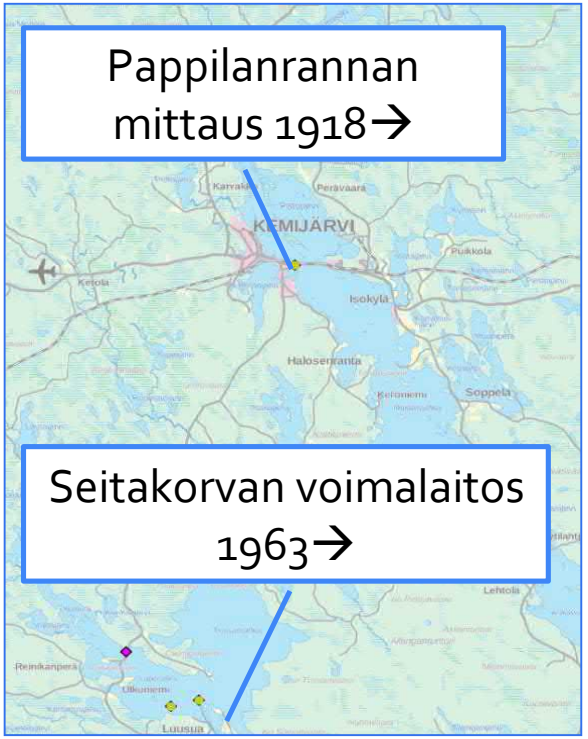




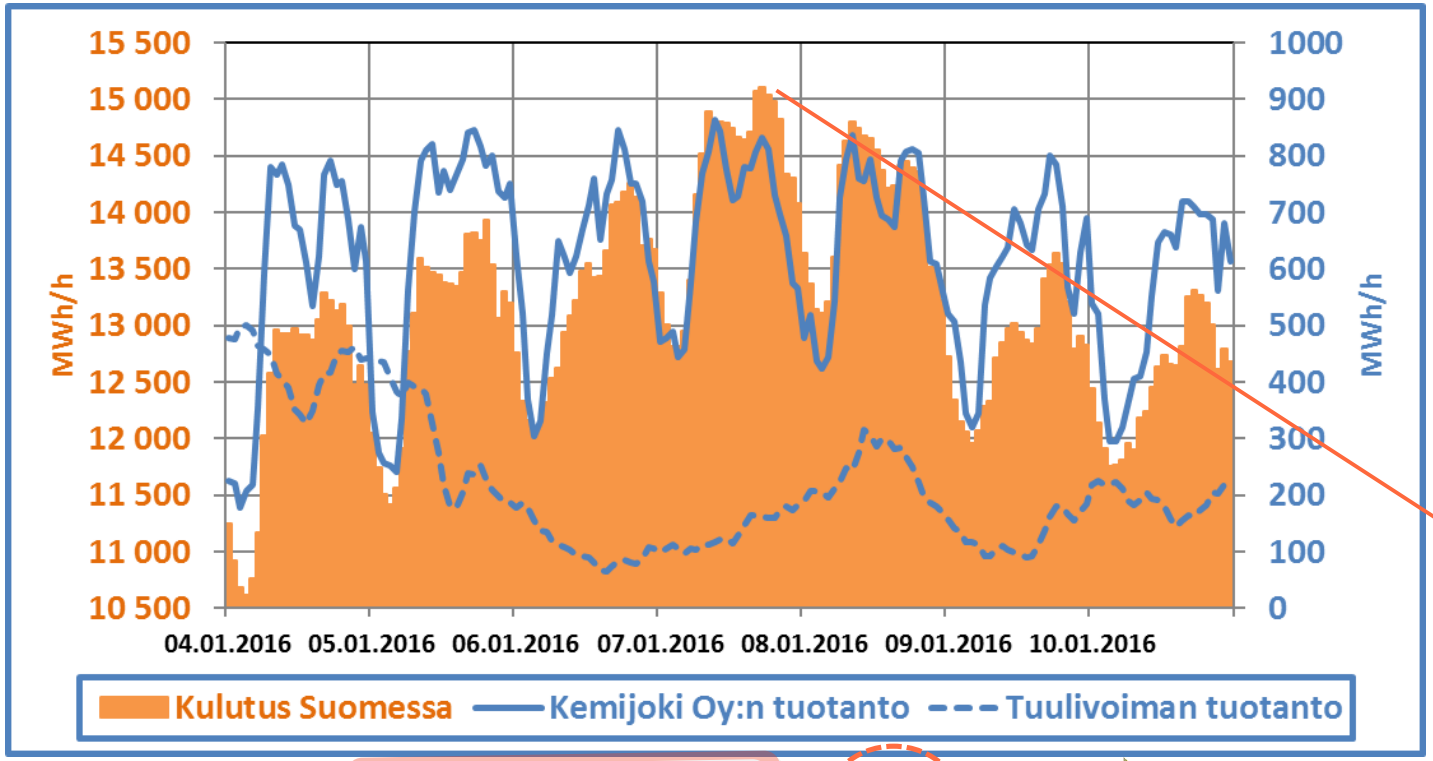


What if not regulated?

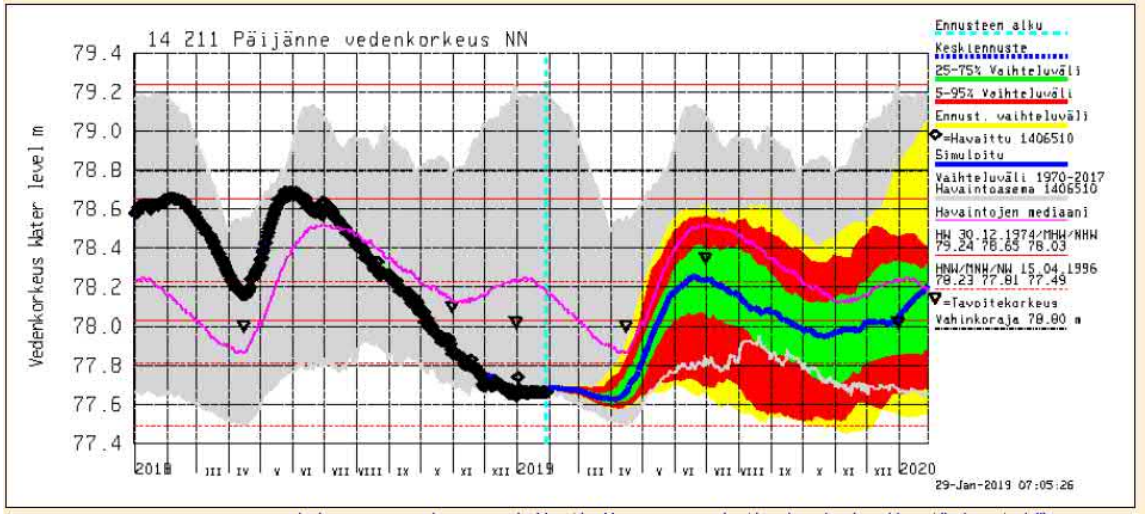




Lakes are like batteries



- Kaikkien aikojen kulutusennätys 7.1.2016 klo 17-18
  - Pakkasta -25°C
  - Tuontia **4231** MWh/h



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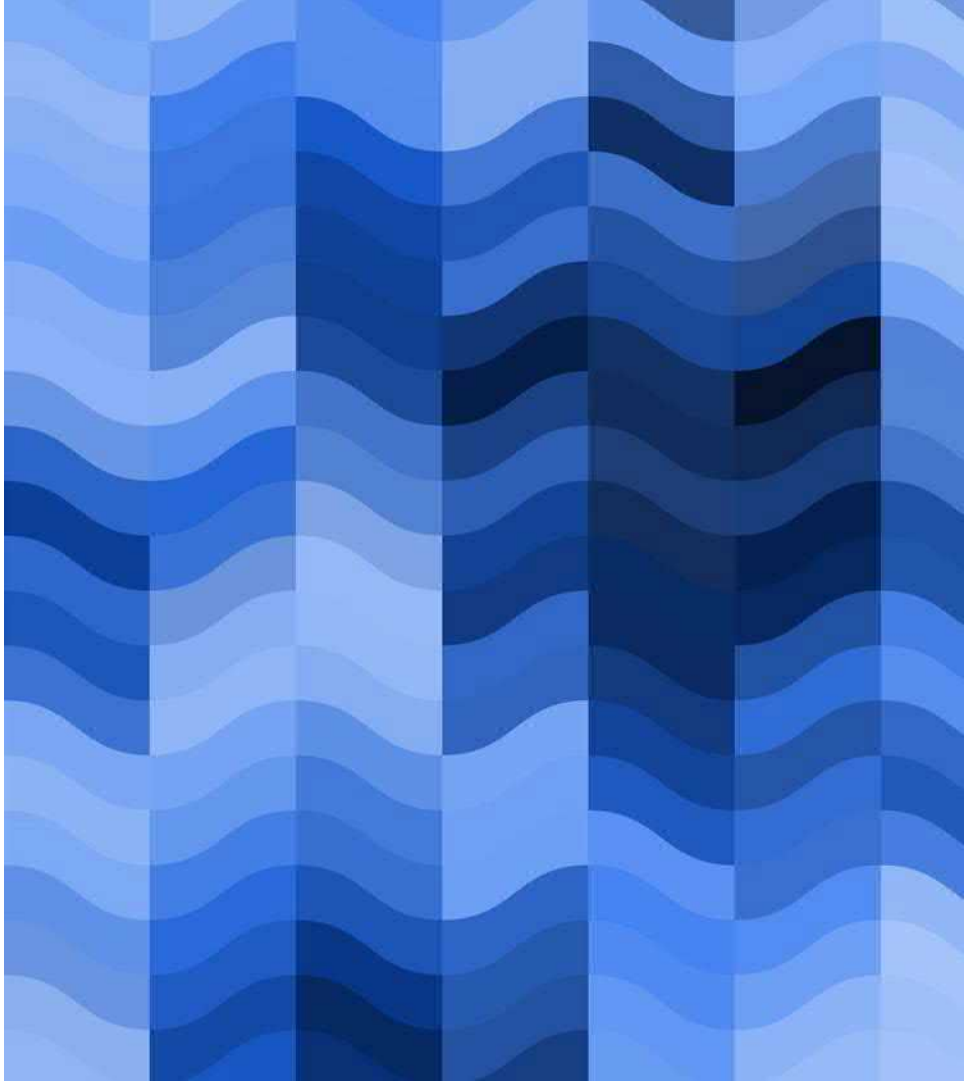
- Regulation
- **Permission process and WFD**
- Kemijoki-extra
- (Data analysis)



Legistlation and permitting

fortum

Water Act and licencing process

- According to Water Act Hydro power plants and regulation require a license
  - Rules for using a reservoir/river for regulation
  - Compensation for damages
  - Obligations, incl. observation and environmental obligations

- License is permanent
- License obligations may be revised by application
- License obligations may be given with a time limit

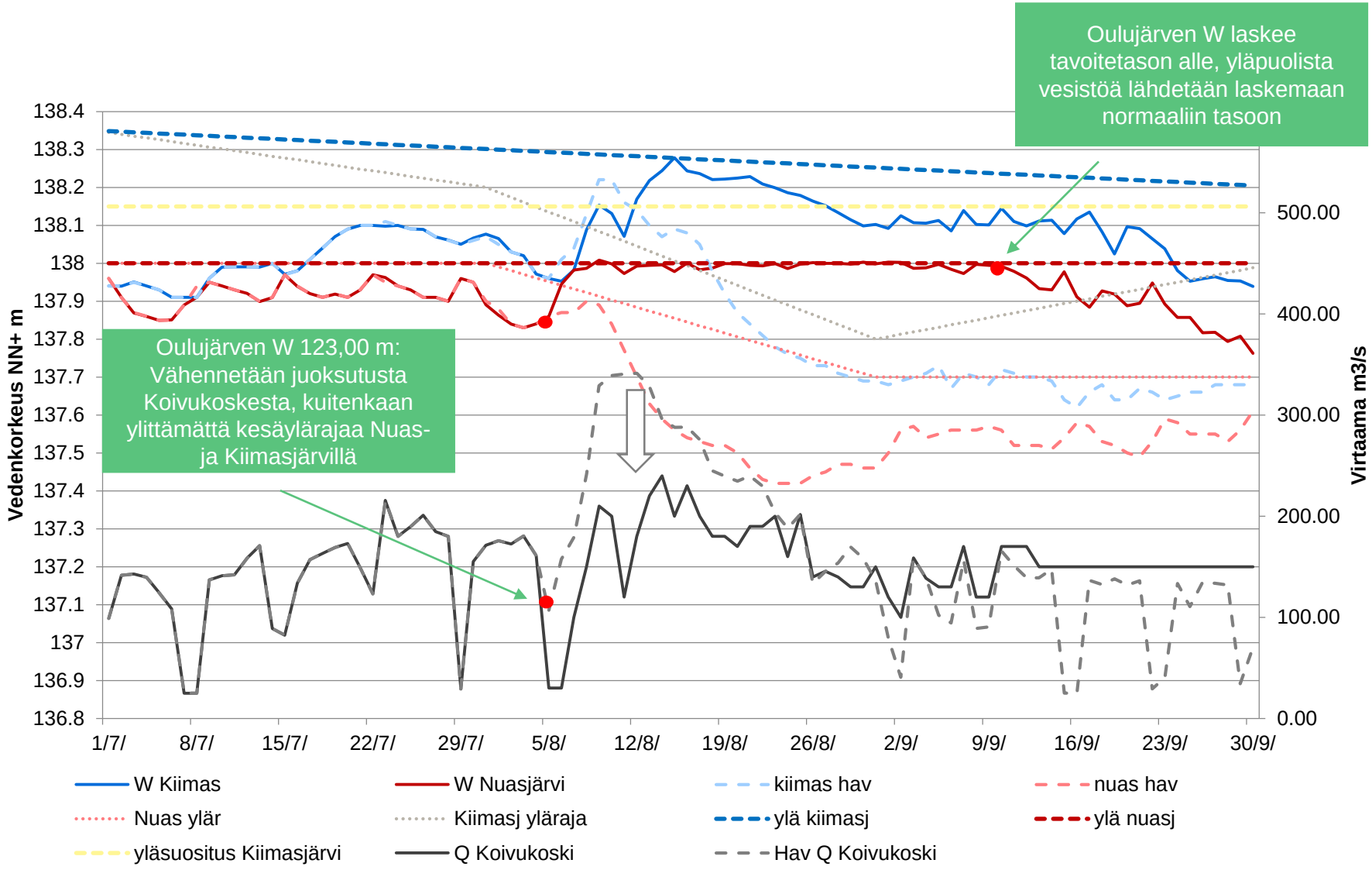
Case Sotkamonjärvi

Permit application to improve flood mitigation for Oulujoki river system

- Following exceptional floods of the Oulujoki river system in 2012, a study was carried out to find out how similar situations could be better mitigated in the future
- Planning project and negotiotions with authorities (ELY) 2013-2014
  - Calculation of damages during flood situations with existing and proposed regulation rules

    -> Clear indication that overall damages are smaller if changes are applied
  - Stakeholder communication and local discussion on proposed changes
- Application handed in for permit process (AVI) 2016
- Decision on approval of application 2019
  - No appeals were left on the decision!

Kiimas- ja Nuasjärvi 2012



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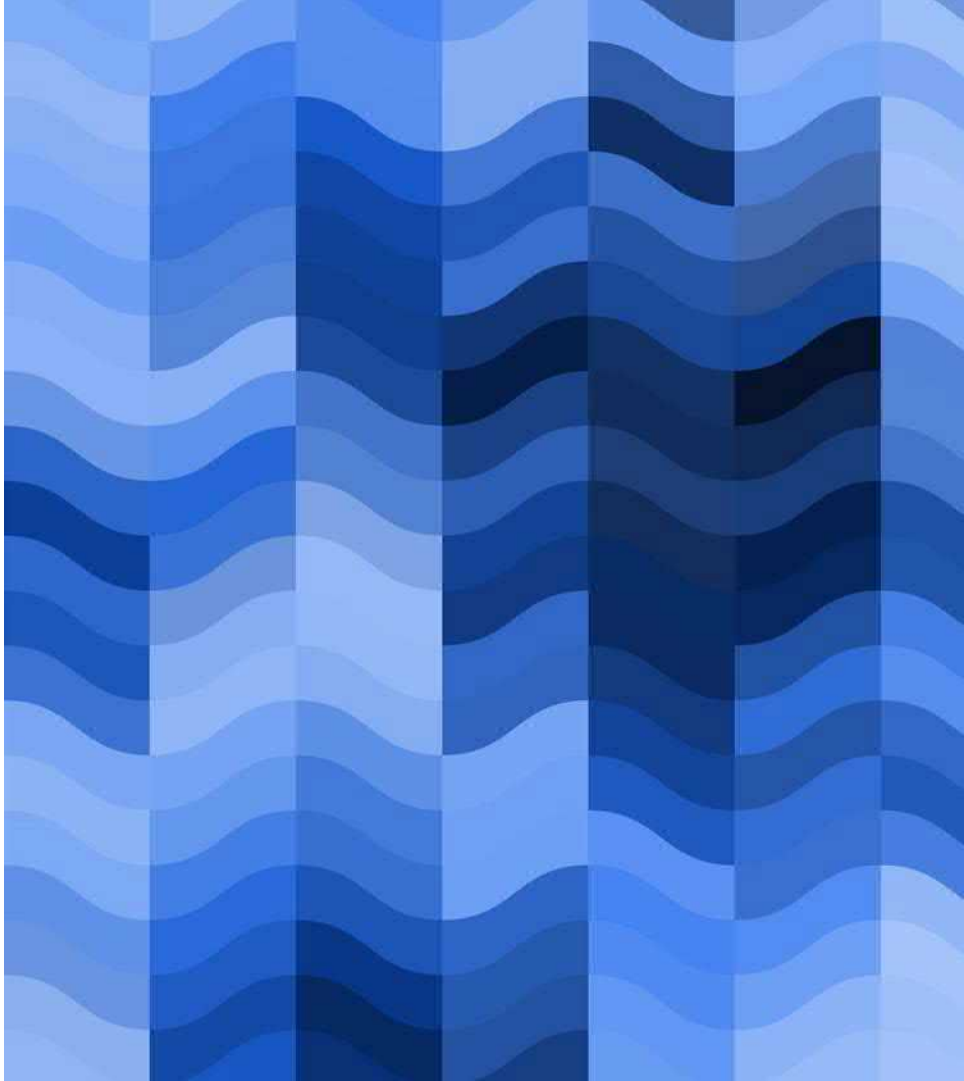
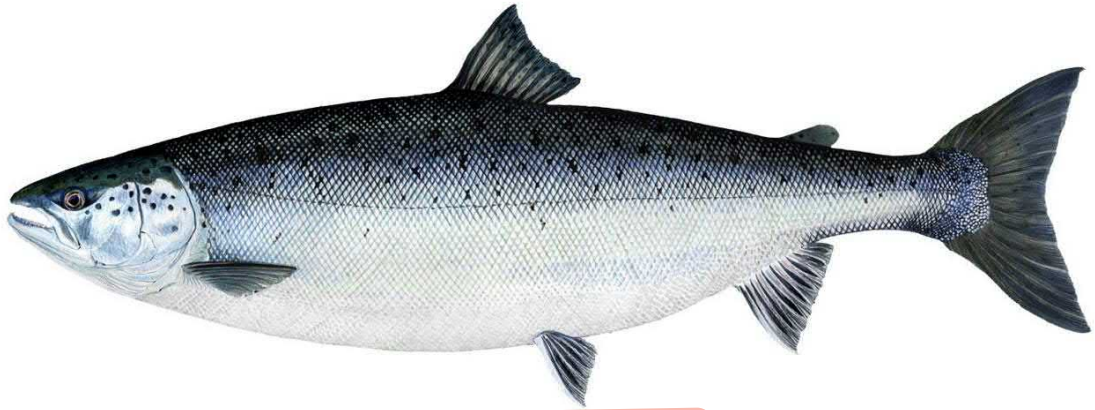


Taivalkoski fishpass

www.kemijoki.fi/otakantaa

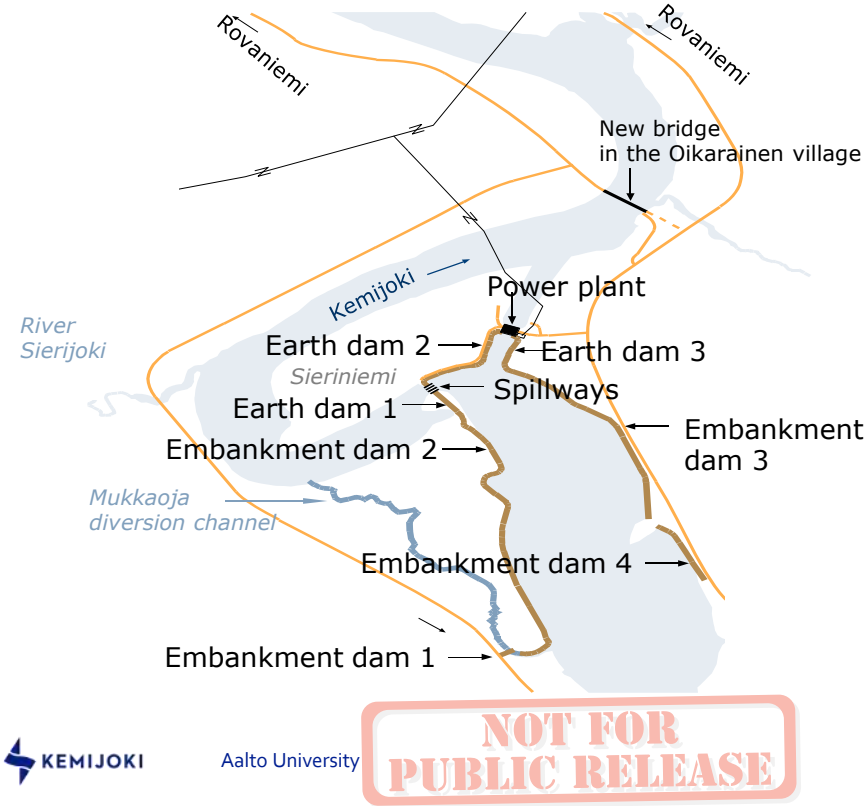
KERRO MIELIPITEESI

padon ohitusratkaisusta Kemijoen Taivalkoskelle



NOT FOR PUBLIC RELEASE

Sierilä project: Technical information



Basics	
Dam reservoir surface area	14 km²
New water area	3.6 km²
Top water level	N43 +82,00
Head	8 m
Utilizable flow	650 m³/s
Nominal output of plant	44 MW *(net ca.28 MW)*
Yearly energy	155 GWh/a *(net ca.110GWh)*

Ground and water areas in total	Surface area (HA)	%
Kemijoki Oy's ownership	1,246	85

Architectural plans for the facade

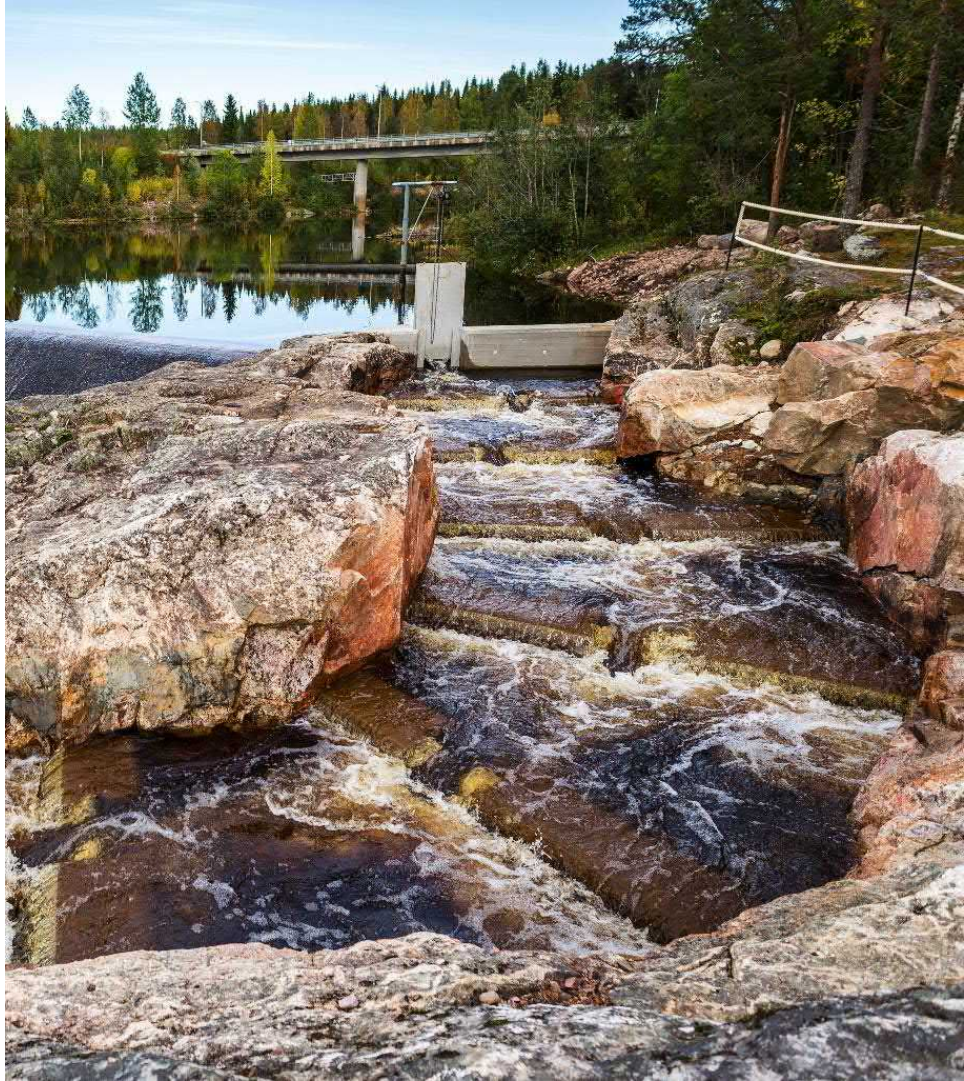
A visit centre is included in the architectural plans

Application of Lapland ELY Centre to AVI Northern Finland to modify the fish obligations set to Kemijoki

- 18.3.2017
- AVI still preprocessing
  - ?!

The Autti fishpass

- In the beginning of autumn 2016, history was made in Autti when a new fish pass opened. Thanks for the execution go to Autti fishery association!
- The aim of the fish pass is to strengthen the natural fish population of the Autti river.
- We funded the construction in half with the Centre for Economic Development, Transport and the Environment in Lapland.



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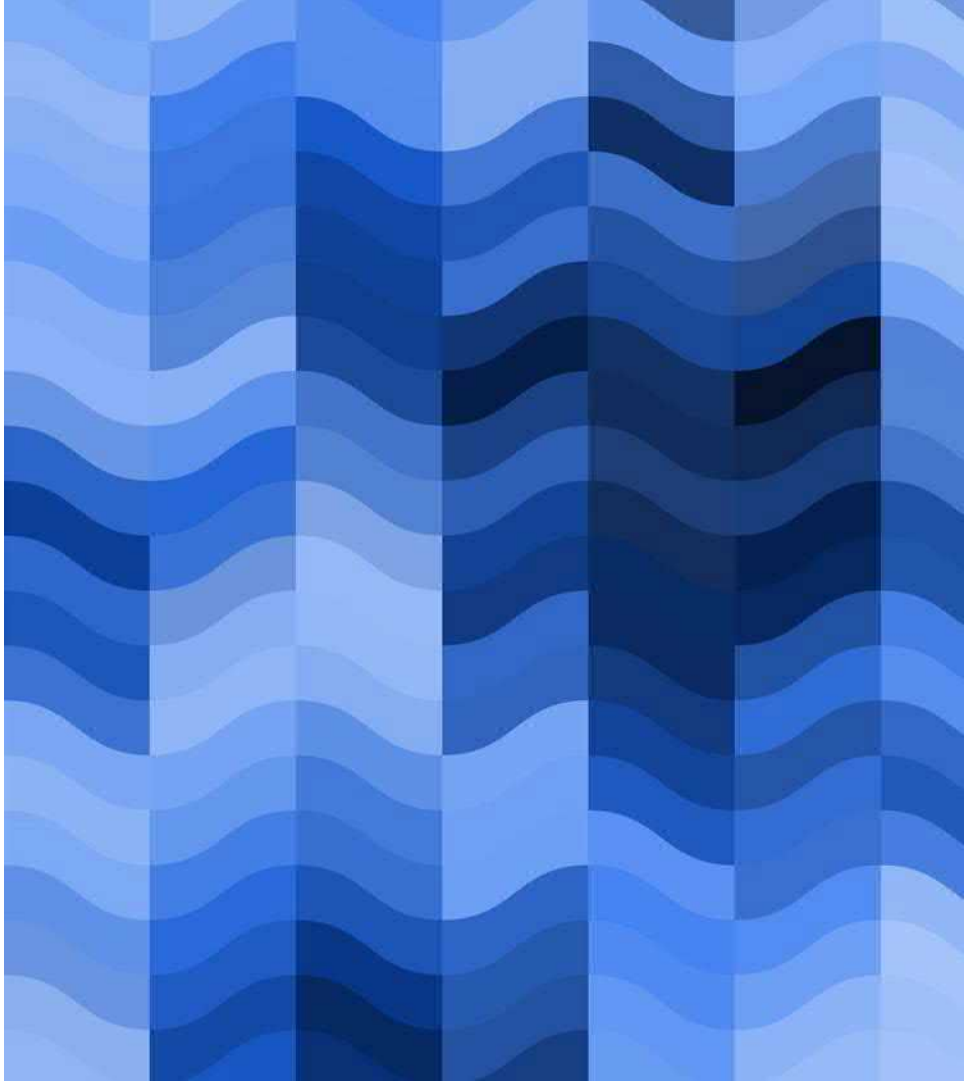


Changes in short term river flow regulation and hydropeaking in Nordic rivers

Faisal Bin Ashraf[1], Ali Torabi Haghighi[1], Joakim Riml[2], Knut Alfredsen[3], Jarkko J. Koskela[4], Bjørn Kløve[1] & Hannu Marttila[1]

Quantifying short-term changes in river flow is important in understanding the environmental impacts of hydropower generation. Energy markets can change rapidly and energy demand fluctuates at sub-daily scales, which may cause corresponding changes in regulated river flow (hydropeaking). Due to increasing use of renewable energy, in future hydropower will play a greater role as a load balancing power source. This may increase current hydropeaking levels in Nordic river systems, creating challenges in maintaining a healthy ecological status. This study examined driving forces for hydropeaking in Nordic rivers using extensive datasets from 150 sites with hourly time step river discharge data. It also investigated the influence of increased wind power production on hydropeaking. The data revealed that hydropeaking is at high levels in the Nordic rivers and have seen an increase over the last decade and especially over the past few years. These results indicate that increased building for renewable energy may increase hydropeaking in Nordic rivers.

Hydropeaking indicators. To study hydropeaking properties in catchments, we used the indices developed by Carolli *et al.* in 2015[34]. The first indicator, HP1, is a dimensionless measure of the magnitude of hydropeaking and is the annual median of daily $HP1_i$ values, calculated as the difference between maximum and minimum discharge over the ith day, normalized by the mean daily discharge. It is expressed as:

$$HP1_i = \frac{Q_{max,i} - Q_{min,i}}{Q_{mean,i}}, \quad i \in [1, 365] \tag{3}$$

$$HP1 = median(HP1_i) \tag{4}$$

$$\mathrm{HP1_{monthly}} = \text{aggregated monthly mean}(\mathrm{HP1}_i) \tag{5}$$

where subscript $_i$ is day of the year, $Q_{max,i}$ and $Q_{min,I}$ are the maximum and minimum discharge, respectively, and $Q_{mean,i}$ is mean daily discharge.

The second indicator, HP2, measures ramping rate, i.e., the temporal rate of discharge changes[34], and is defined as:

$$(HP2_k)_i = \left(\frac{\Delta Q_k}{\Delta t_k}\right) = \left(\frac{Q_k - Q_{k-1}}{t_k - t_{k-1}}\right)_i, \quad i \in [1, 365] \tag{6}$$

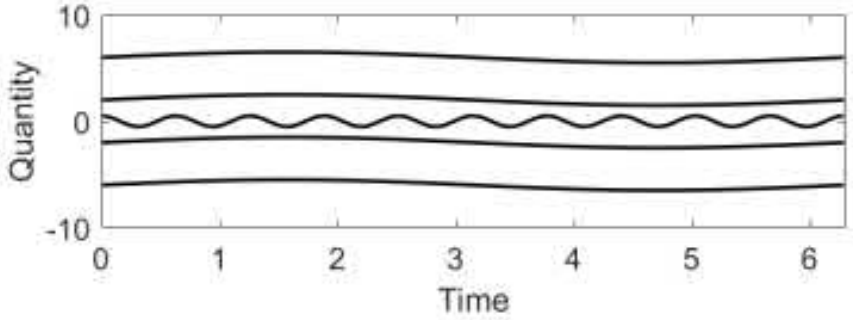
$$HP2_i = P_{90}|(HP2_k)_i|; \tag{7}$$

$$HP2 = median(HP2_i). \tag{8}$$

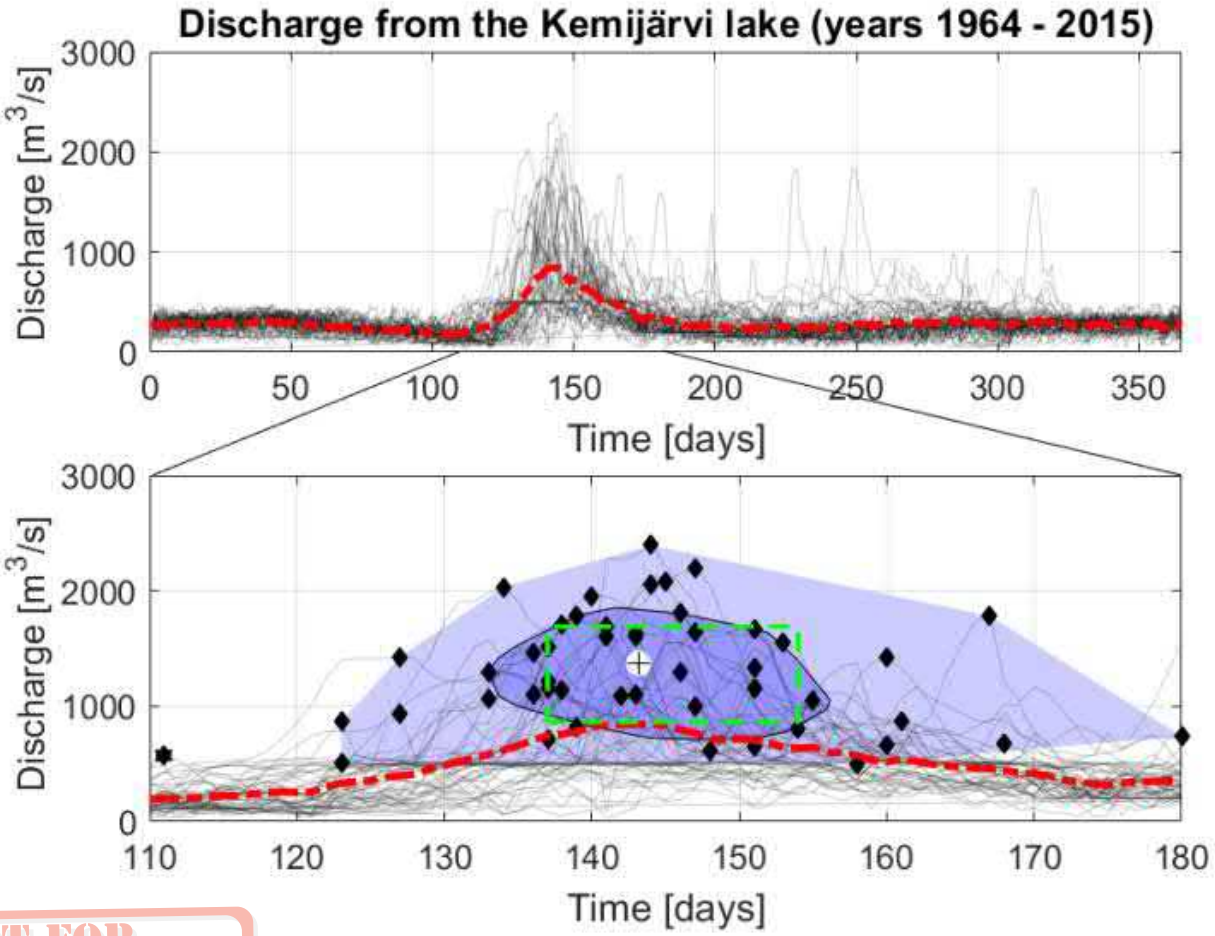
$$\mathrm{HP2_{monthly}} = \text{aggregated monthly mean } (\mathrm{HP2}_i) \tag{9}$$

Functional Data Analysis FDA

- Point → Function
  - P-point
  - Px\infty-function
- Center → Depth



FDA



Functional Data Analysis FDA

$$MFHD_{N,T}(\mathbf{Y}_i, \alpha) = \sum_{j=1}^{T} w_{\alpha,N}(t_j) HD_N^j(\mathbf{Y}_i^j) \quad (14)$$

$$HD_N^j(\mathbf{y}) = \frac{1}{N} \min_{\mathbf{u}, \|\mathbf{u}\|=1} \#\{y_N : \mathbf{u}^T \mathbf{Y}_i^j \geq \mathbf{u}^T \mathbf{y}\} \quad (15)$$

MFHD gives more weight to time points where the variation is more significant. The weight function $w_{\alpha,N}$ (eq. 16) takes into account the amplitude variability at each time by considering volume of the convex hull of the depth region (vol). The depth region at level α for any depth function $D_{\mathcal{F}_N}$ is defined in the equation 17.

$$w_{\alpha,N}(t_j) = \frac{(t_{j+1} - t_j) vol(D_\alpha(\mathcal{F}_Y^j))}{\sum_{j=1}^{T} (t_{j+1} - t_j) vol(D_\alpha(\mathcal{F}_Y^j))} \quad (16)$$

$$D_\alpha(F_N) = \{\mathbf{x} \in \mathbb{R}^k : D(\mathbf{x}; F_N) \geq \alpha\} \quad (17)$$

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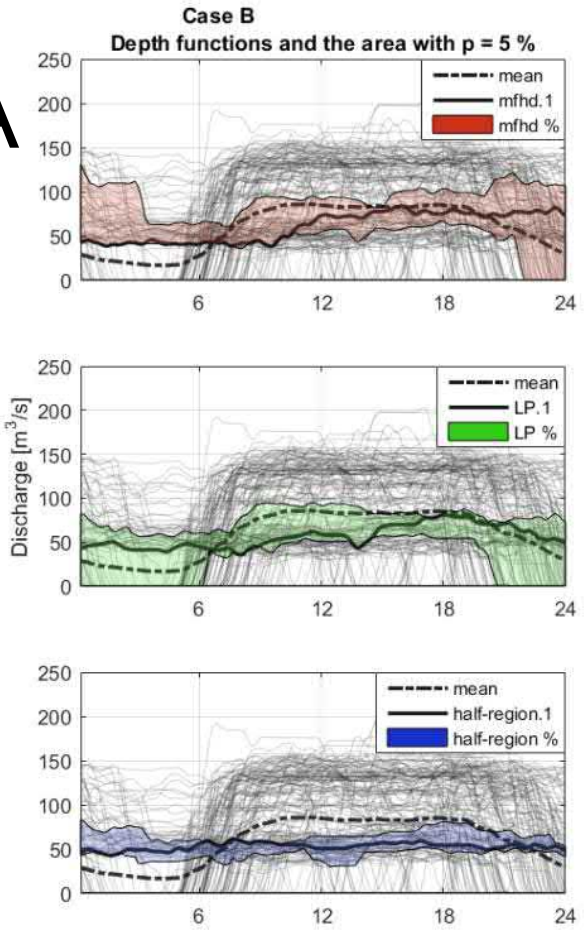
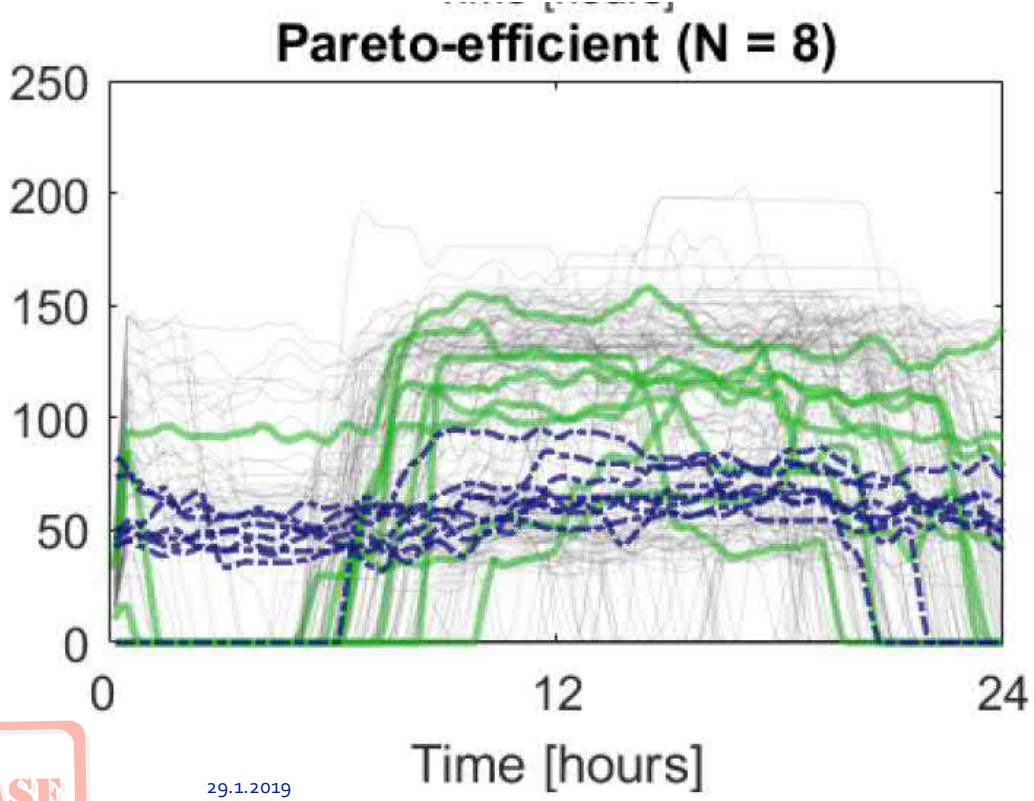
› Not working?



Functional Data Analysis FDA

- Pareto Depth for Functional Data
  - (An article in peer-review)



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