An overview & examples of hydropower mitigation measures in Norway
- E-flows and minimum G-flows vs selected other hymo measures

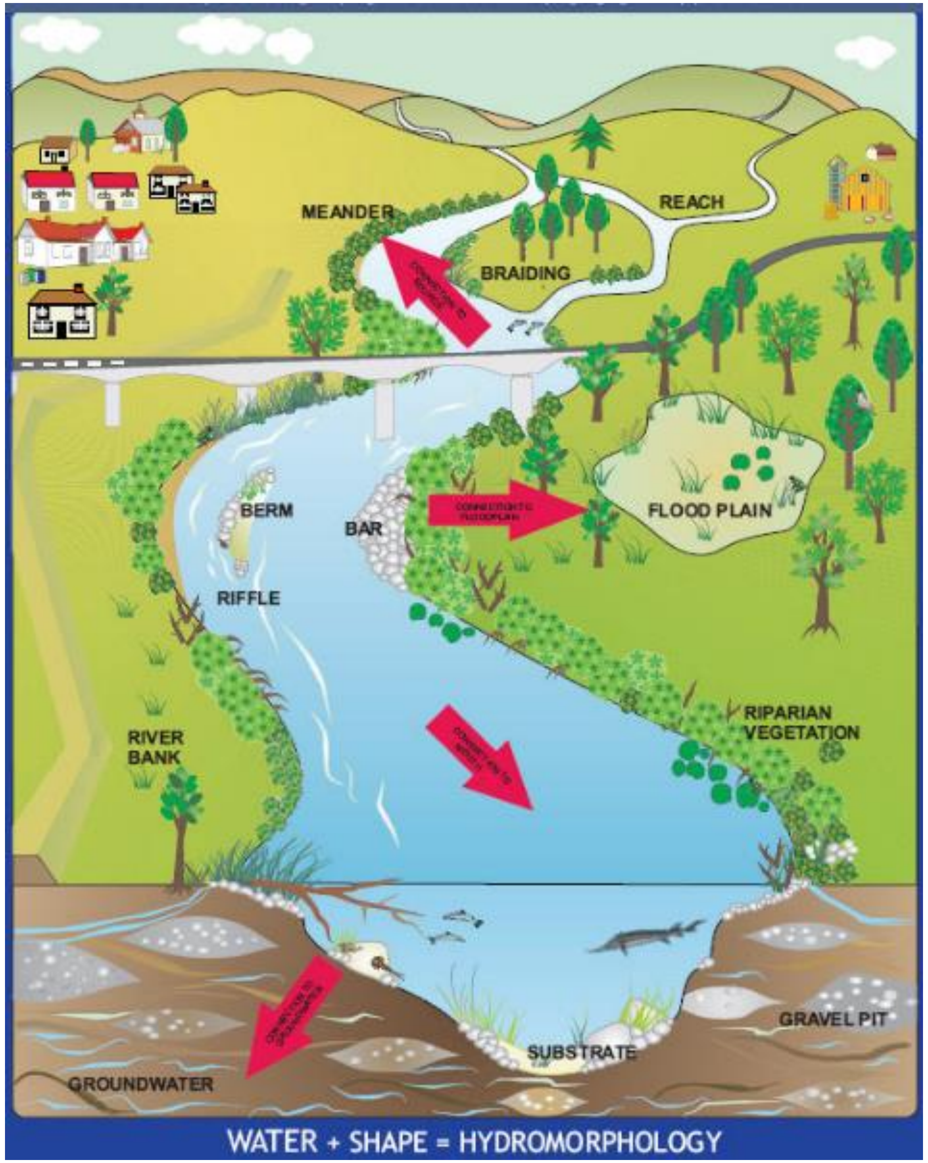
Nordic WFD Worskshop on Hymo
Gøteborg, 27 Sept 2024

Jo H. Halleraker, Norwegian Environment Agency

Ex – co-chair for "GEP core-group"

CIS Ad hoc Task Group on Hydromorphology

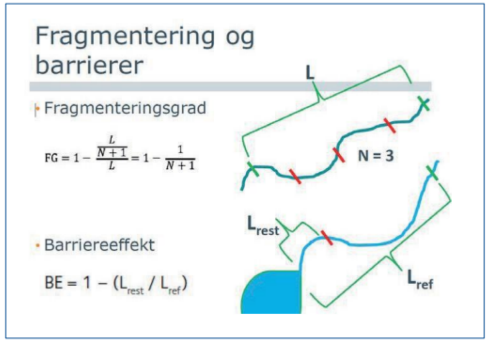
Hymo supporting the Norwegian fish index



Barriereeffekt beskriver i hvilken grad livsviktige habitater for bestandens overlevelse er blitt utilgjengelige gjennom menneskelig aktivitet, og er vanligvis aktuell som parameter for fisk som vandrer mellom sjø eller innsjø og gyteplasser i elv (dvs. laks, innsjø- og sjøaure, og sjørøye). I tilfeller der en har god kunnskap om viktige habitater, er parameteren også relevant innen elver. Barriereeffekt (BE) beskrives da som andelen av potensielt tilgjengelig gyteelv (L_{ref}) som er blitt utilgjengelig ved menneskeskapte inngrep.

$$BE = 1 - (L_{rest} / L_{ref})$$

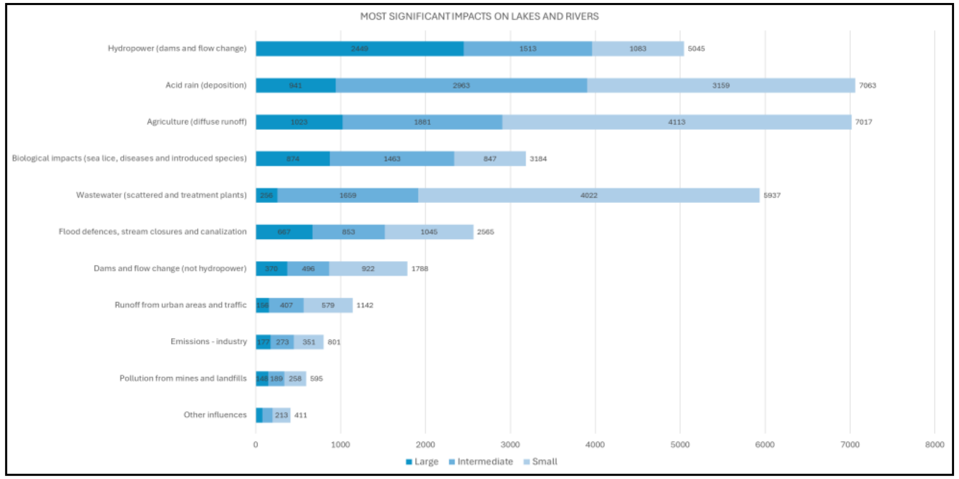
der L_{rest} er avstand fra innsjø eller fjord (eller overvintrings- eller sommerhabitat) til første kunstige vandringsbarriere. Det kan være stor forskjell mellom fiskearter og -størrelser mht. hvilke strukturer som fungerer som en barriere mot vandring.

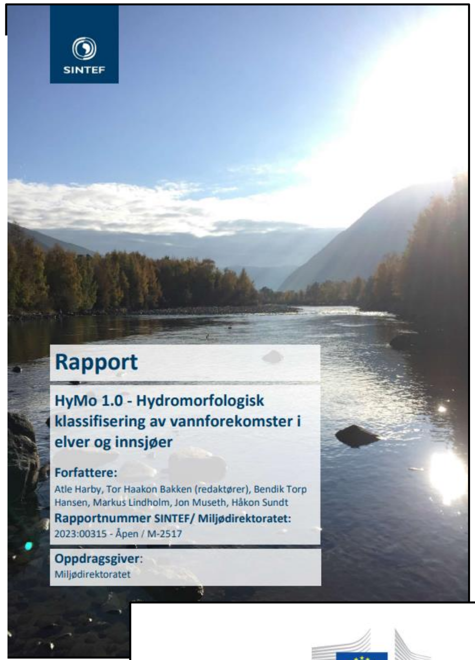


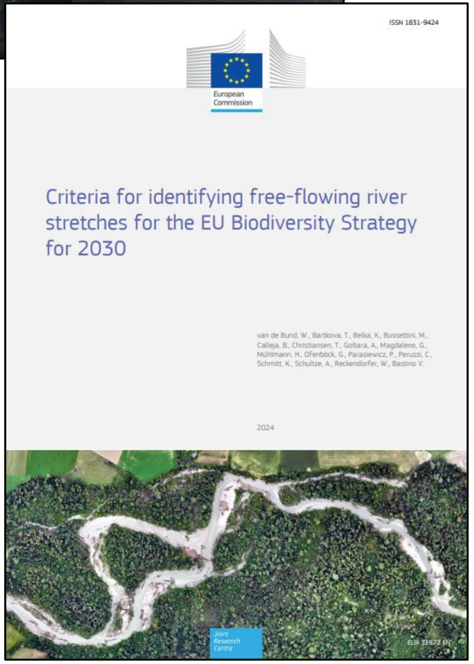
Figur 6.1 Illustrasjon av fragmenteringsgrad og barriæreeffekt. Fra Sandlund et. al (2013).

Tabell 6.18 Klassegrenser for påvirkningsfaktorene fragmenteringsgrad (FG) og barriereeffekt (BE).

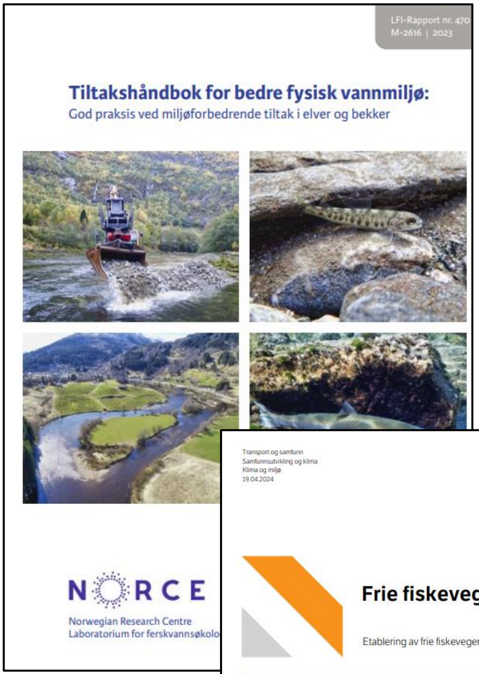
Belastningsgrad	Svært god	God	Moderat	Dårlig	Svært dårlig
FG		0,2-0,4	0,4-0,6	0,6-0,8	>0,8
BE		0,2-0,4	0,4-0,6	0,6-0,8	>0,8







Restore connectivity……ca 460 000 culverts in Norway….


LFI-Rapport nr. 470
M-2616 | 2023

Tiltakshåndbok for bedre fysisk vannmiljø:
God praksis ved miljøforbedrende tiltak i elver og bekker

NORCE
Norwegian Research Centre
Laboratorium for ferskvannsøkolo

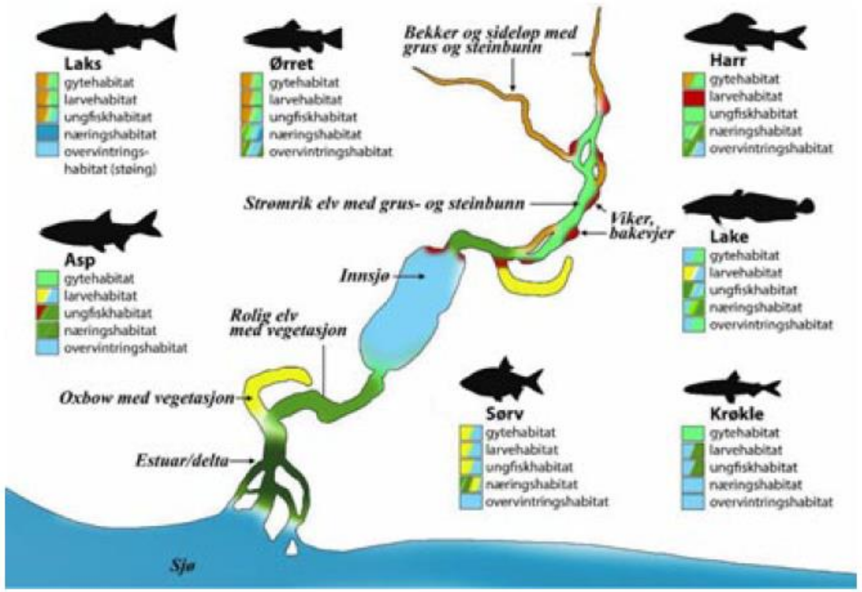

Statens vegvesen

Frie fiskeveger

Etablering av frie fiskeveger

STATENS VEGVESENS RAPPORTER Nr. 973

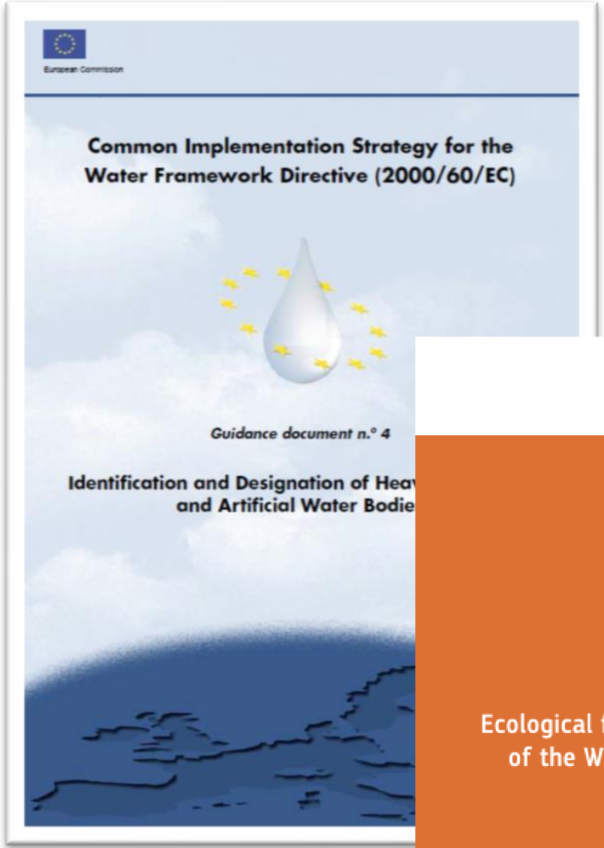
- How many are significant barriers (temporal/absolute)?
- What is the upstream restoration potential (and for which fish species)?
- Restore fish migration + climate adaptation
- Type of restoration measure normally without impact on the transport (= never? a reason for HMWBs…although costly measure)

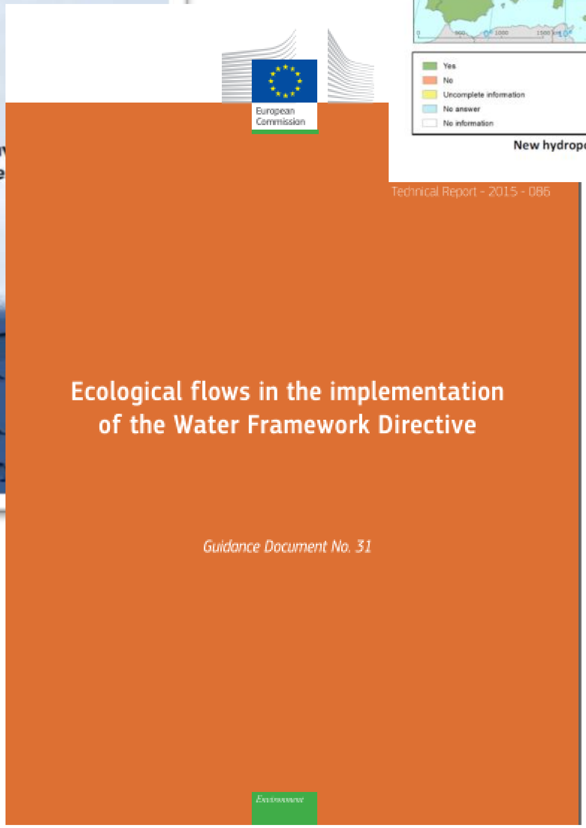


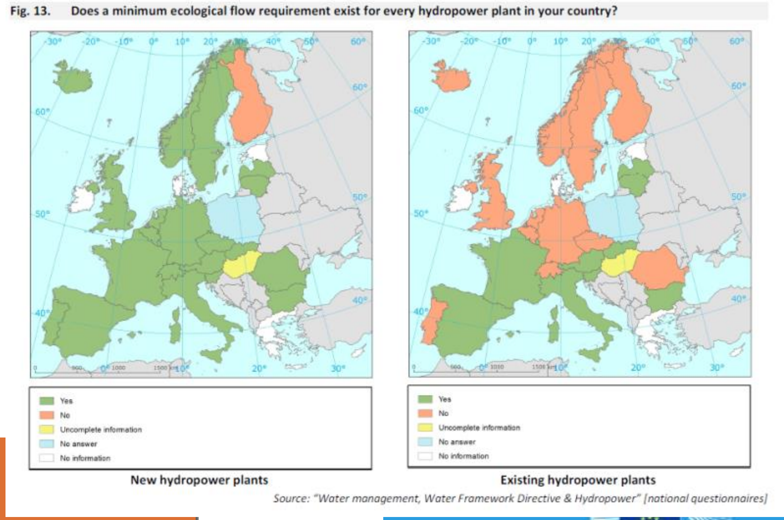
Source: amber.international

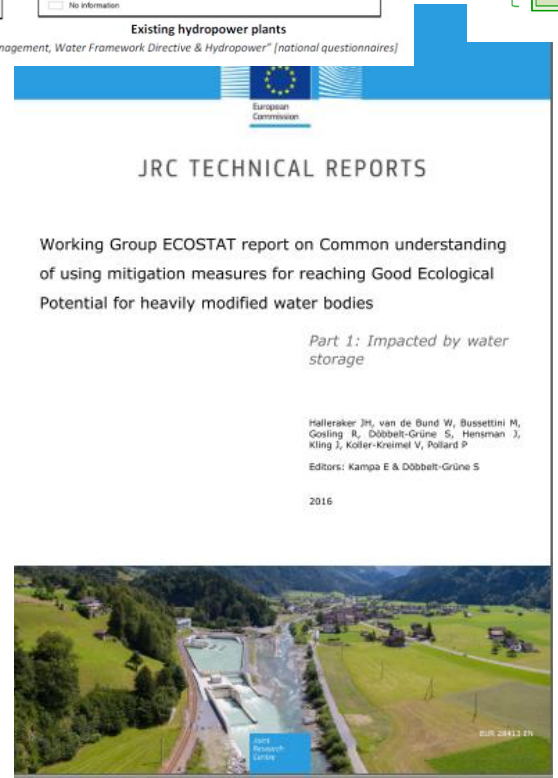
Culvert that allows fish/fauna passage.
Photo: Morten André Bergan.

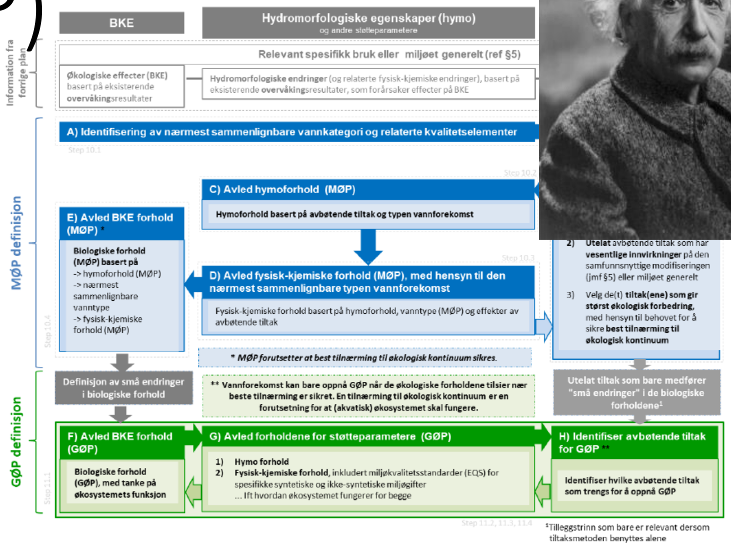
From «GEP core group»(2013) → ATG HYMO (2016 – 2018) → CIS guidance no 37 (steps for GEP)

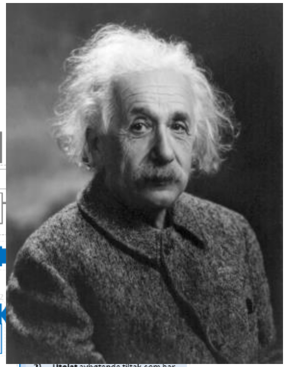












HOVEDPÅVIRKNING		Fysiske endringer i elveslette og bredder				Fysiske endringer i elvesengen					Tempe… gass…	
TILTAKSTYPER		Erosjonssikring (forbygninger, kanalisering langs elva)	Redusering av kantvegetasjon	Redusering av flomsone	Lateral konnektivitet i flomslette og sidevassdrag	Fjerning og tilførsler av masser	Endringer i elvemorfologi	Endringer i habitattyper	Endring i habitatkvalitet (substrat, gyting, skjul)	Fragmentering og barrierer (longitudonal konnekivitet)	Vanntemperatur	
RESTAURERING	Gjenåpning av bekker og elver, s. 50	++		++			++	++	++	+	+	
	Fjerning av terskler og demninger, s. 54	+		+		++	++	++	++	++	+	
	Naturtypisk morfologi, s. 58	++	+	++	+	++	++	++	++	++		
	Tilkoble elveslette og											

Ambitious international examples

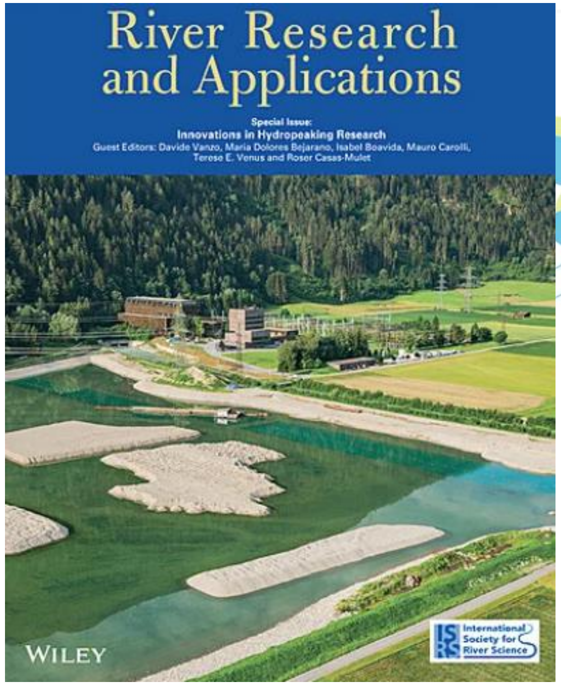
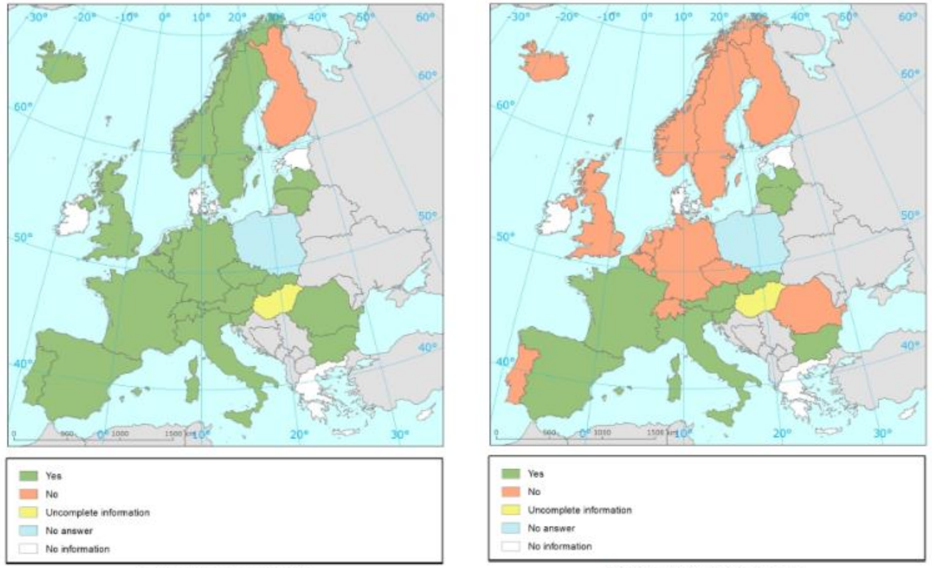


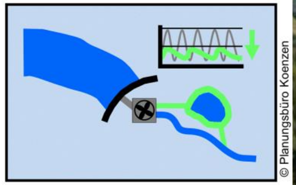
Fig. 13. Does a minimum ecological flow requirement exist for every hydropower plant in your country?



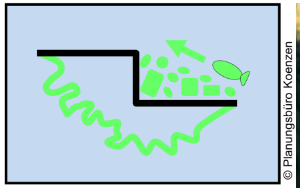
New hydropower plants

Existing hydropower plants

Source: "Water management, Water Framework Directive & Hydropower" [national questionnaires]



6. Mitigation for hydropeaking



1. Upstream continuity fish

Green standards

Mandatory mitigation measures legally fixed (relevant for new and existing hydropower plants)

Ecological continuity (fish passes)


© verbund

Ecological flow

(quantity, dynamics)

Generally: Minimising negative effects on river ecology

Impoundment:
change of river character,
losses in habitat diversity

Hydropeaking

Hydropeaking in Austria

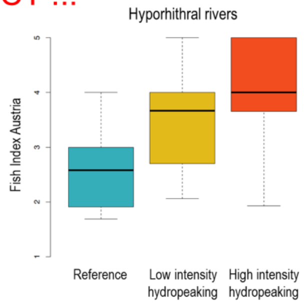
Around 800 km of rivers are affected by hydropeaking

Energy and Climate crisis!

More than 80 potential hydropeaking sources identified

!!! CONFLICT !!!

- Storage hydropower plants represent one third of the Austrian power plant capacity!
- Flexible energy production needed!



- Poor Ecological status!
- Grayling vulnerable!
- Danube Salmon endangered!
- Macroinvertebrates affected!

Most waterbodies are designated as HMWB

Biodiversity crisis!

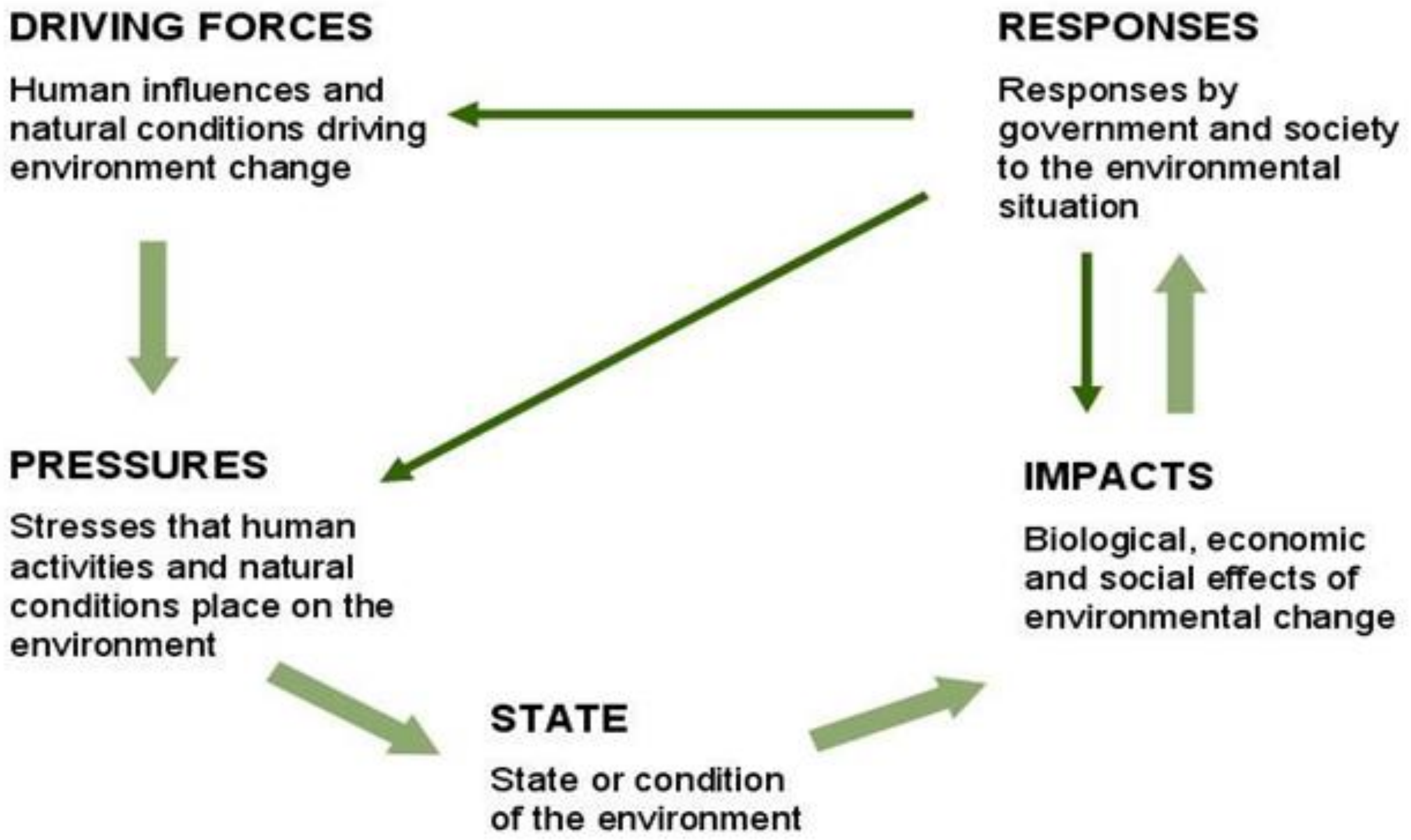
Strong differences in hydrological situations!

MITIGATION in heavily modified water bodies[1]:

- Impact on use
- Ecological benefits

[1]European Commission, 2020: Guidance Document No. 37 Steps for defining and assessing ecological potential for improving comparability of Heavily Modified Water Bodies, CIRCABC.

Site specific impacts – effects and mitigation needs to **restore ecological functionalities** (=GEP)



Fesability study of **relevant restoration or mitigation measure**

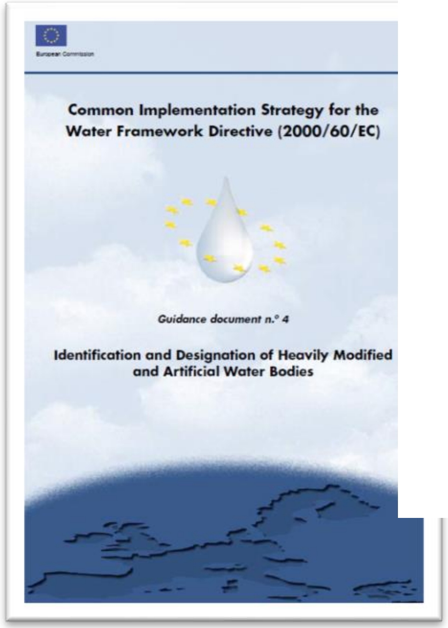
→Dam removal = «complete restoration»

→Restoring **ecological functionality** (> 90 % passability of relevant fish by BAT fish-pass solutions)

Emerging good mitigation measures

- European **measure library hierarchy** relevant to mitigate water storage due to HP, water supply impacts
- Eflows and best approximation to **ecological continuum**
- **Emerging good practice** evolve

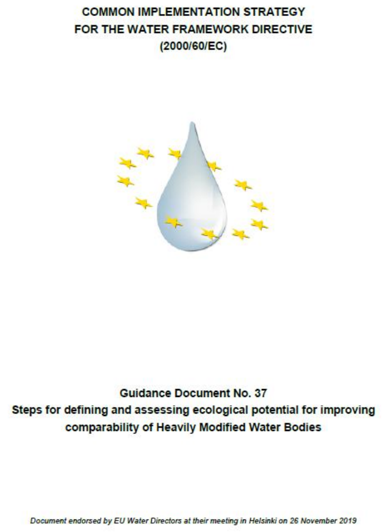
  over time


European Commission

Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

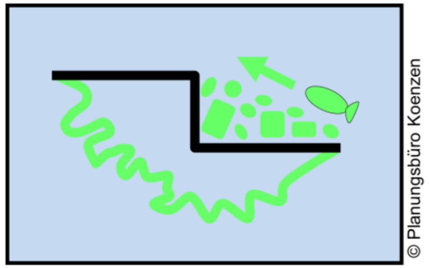
Guidance document n.° 4

Identification and Designation of Heavily Modified and Artificial Water Bodies

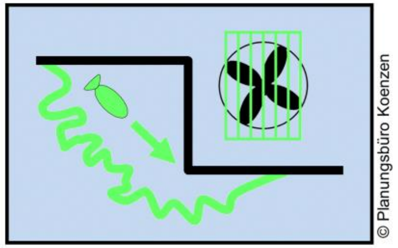

COMMON IMPLEMENTATION STRATEGY
FOR THE WATER FRAMEWORK DIRECTIVE
(2000/60/EC)

Guidance Document No. 37
Steps for defining and assessing ecological potential for improving comparability of Heavily Modified Water Bodies

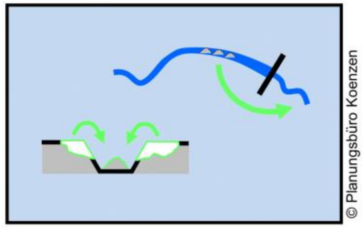
Document endorsed by EU Water Directors at their meeting in Helsinki on 26 November 2019



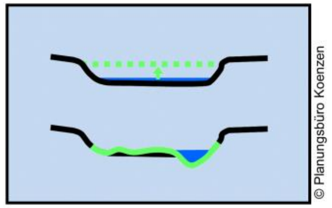
1. Upstream continuity fish



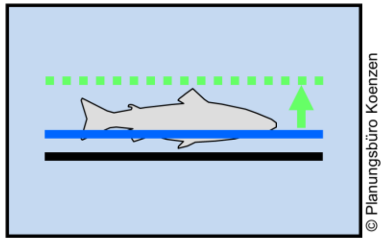
2. Downstream continuity fish



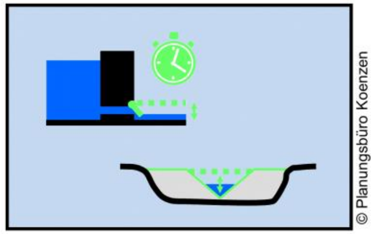
7. Mitigation for interrupted sediment movement



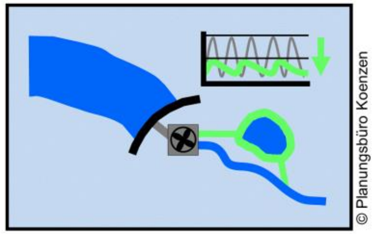
3. Mitigation low flow



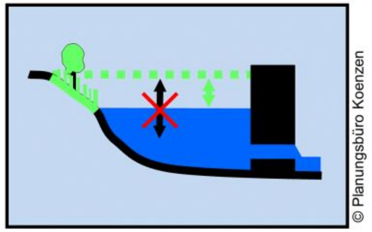
4. Mitigation fish flow



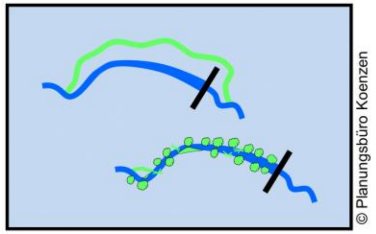
5. Mitigation variable flow



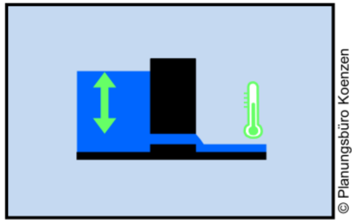
6. Mitigation for hydropeaking



8. Mitigation lake level



9. Mitigation ponded river flow

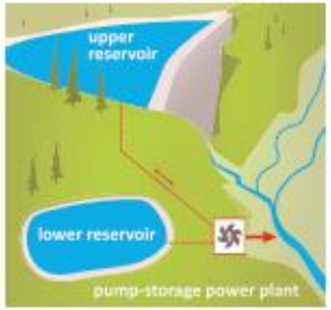


10. Mitigation for temperature

Diversion power plant

River power station

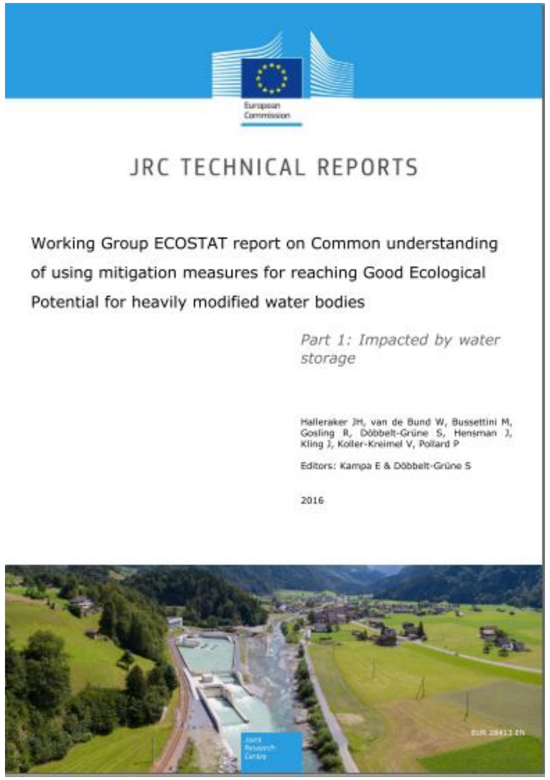
Storage power plant



Pump-storage power plant

Site dependent mitigation need based on characteristics

- Type of intakes/storage (storage vs Run-of-River HP)
  - Upstream impacts (littoral zone in lake reservoirs)
  - Potential for hydropeaking
  - Sediment continuity
  - Thermal stress
- Diversion HP or Turbine in the dam
  - By-pass Eflows
  - By-pass valve
  - Fish continuity
- HP outlet (tailrace into long rivers, lake reservoirs or the sea)
  - Stranding/flushing?
  - Supersaturation
- Impacted habitats and ecological communities
  - Natural vs artificial barriers
  - HP dam/outlet on anadrome reach


JRC TECHNICAL REPORTS

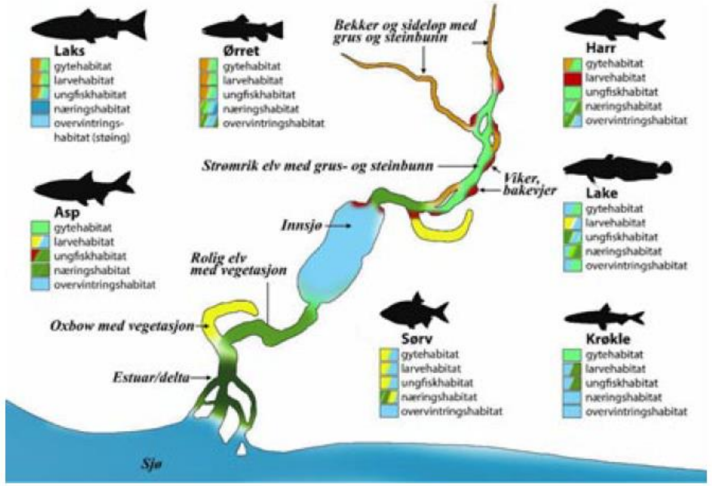
Working Group ECOSTAT report on Common understanding of using mitigation measures for reaching Good Ecological Potential for heavily modified water bodies

Part 1: Impacted by water storage

Halleraker JH, van de Bund W, Bussettini M, Gosling R, Döbbelt-Grüne S, Hensman J, Kling J, Koller-Kreimel V, Pollard P

Editors: Kampa E & Döbbelt-Grüne S

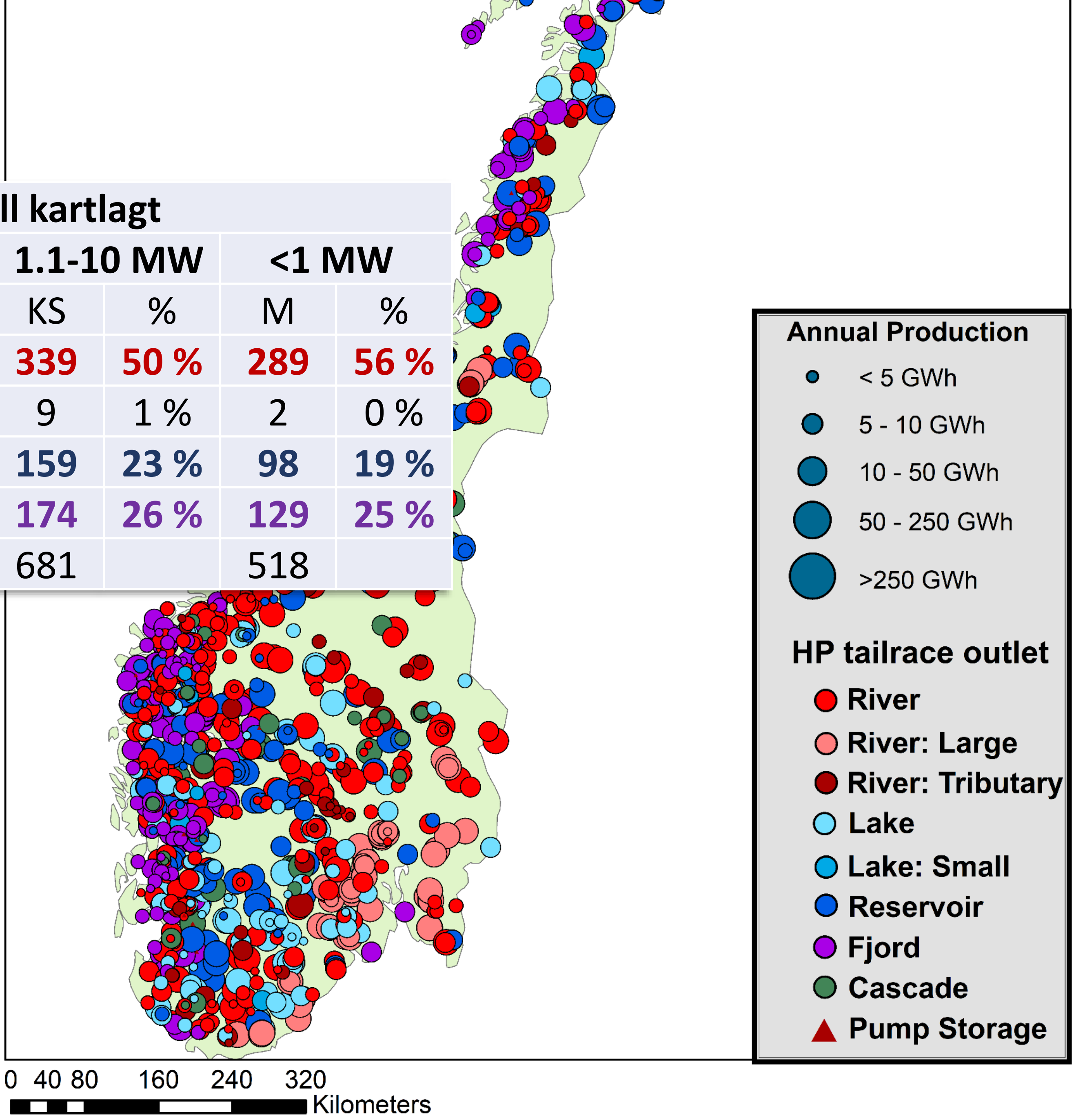
2016



Kraftverksutløp i Norge

	Totalt antall kartlagt							
	All str.		>10 MW		1.1-10 MW		<1 MW	
Kraftverksutløp til	**N**	**%**	K	%	KS	%	M	%
Elv (> 0,5 km)	**785**	**51 %**	**157**	**47 %**	**339**	**50 %**	**289**	**56 %**
«liten innsjø»	**17**	**1 %**	6	2 %	9	1 %	2	0 %
Innsjø/magasin	**370**	**24 %**	**113**	**34 %**	**159**	**23 %**	**98**	**19 %**
Fjord/sjø	**359**	**23 %**	**56**	**17 %**	**174**	**26 %**	**129**	**25 %**
Total	**1531**		332		681		518	

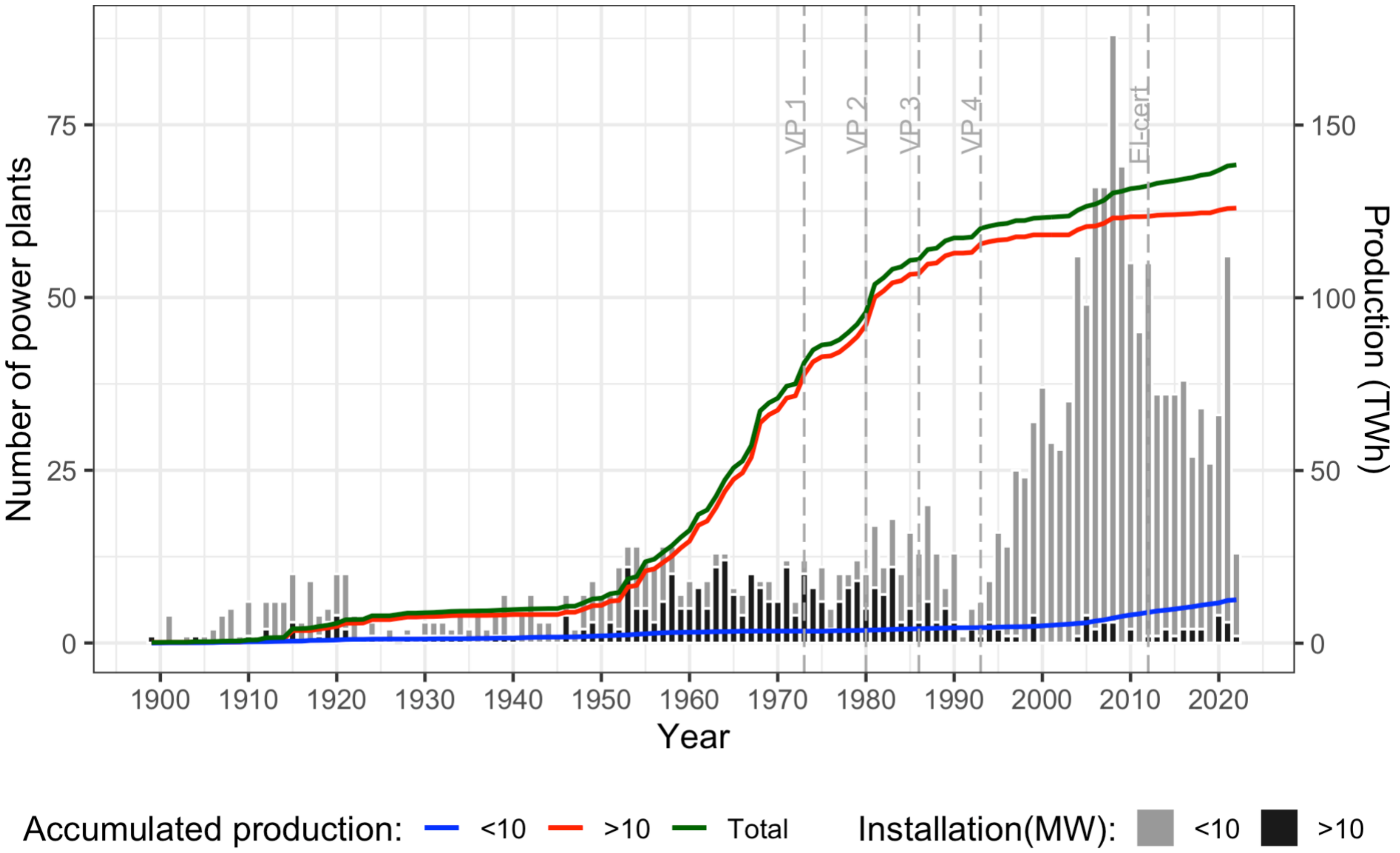
7 BÆREKRAFTIG REN ENERGI



Halleraker et al., (2022)

Small scale vs large scale **HP development in Norway**

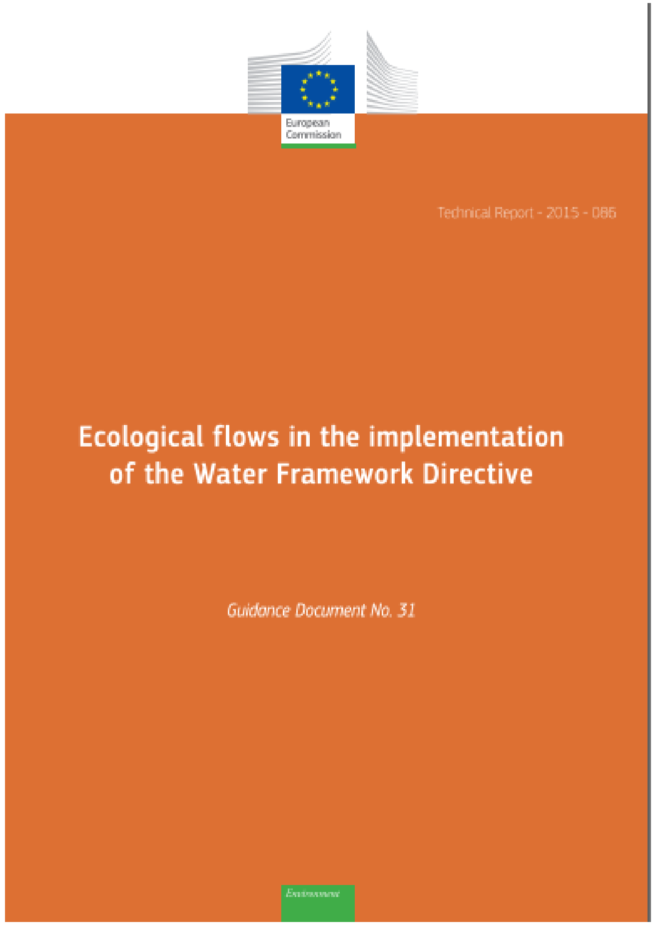
- VP 1-4 = Permanent Protected Water Courses
- **El-serticate**: «Green feed-in tarif to boost more renewable in Norway & Sweden
- HP < 1 MW only have CLF (and no other license requirements)



Source: Halleraker et al (in review) Development of hydropower impacts, water management and Eflow policies in Norway

Ecological (functioning) flows vs. Environmental flows

is not **the same as** the historical lowest minmum flow target (Gflows)



Flow requirements of aquatic ecosystems

- WFD provisions acknowledge the **critical role of water quantity and dynamics** in supporting the quality of aquatic ecosystems and the achievement of environmental objectives.

A working definition of ecological flows for WFD implementation

In the context of this Guidance, the Working Group adopted the term of "ecological flows" with the following working definition:

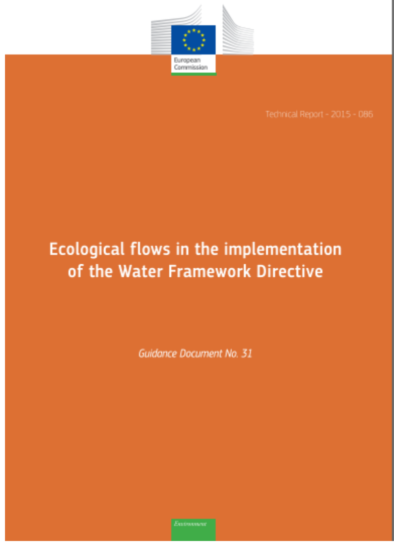
Visit Norway

https://www.visitnorway.com › nature-attractions › water...

10 of the world's tallest waterfalls are in Norway

Experience **Vøringsfossen** on a Hardangerfjord in a nutshell **tour** with Fjord Tours. For Norwegians, waterfalls are more than a good photo opportunity. Many ...

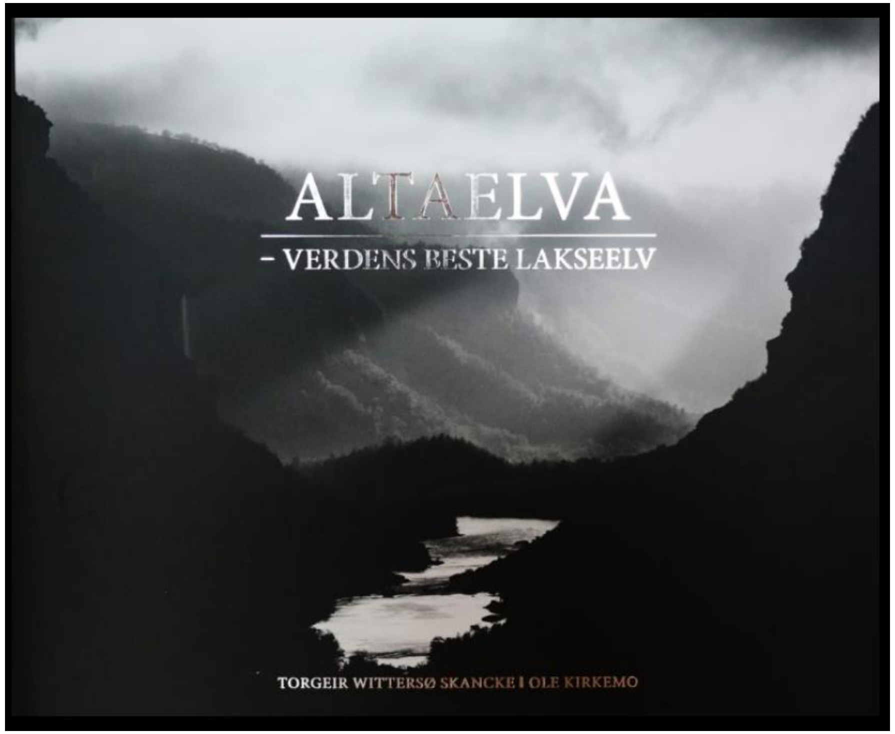
Alta – the Norwegian case in CIS Guidance no 35

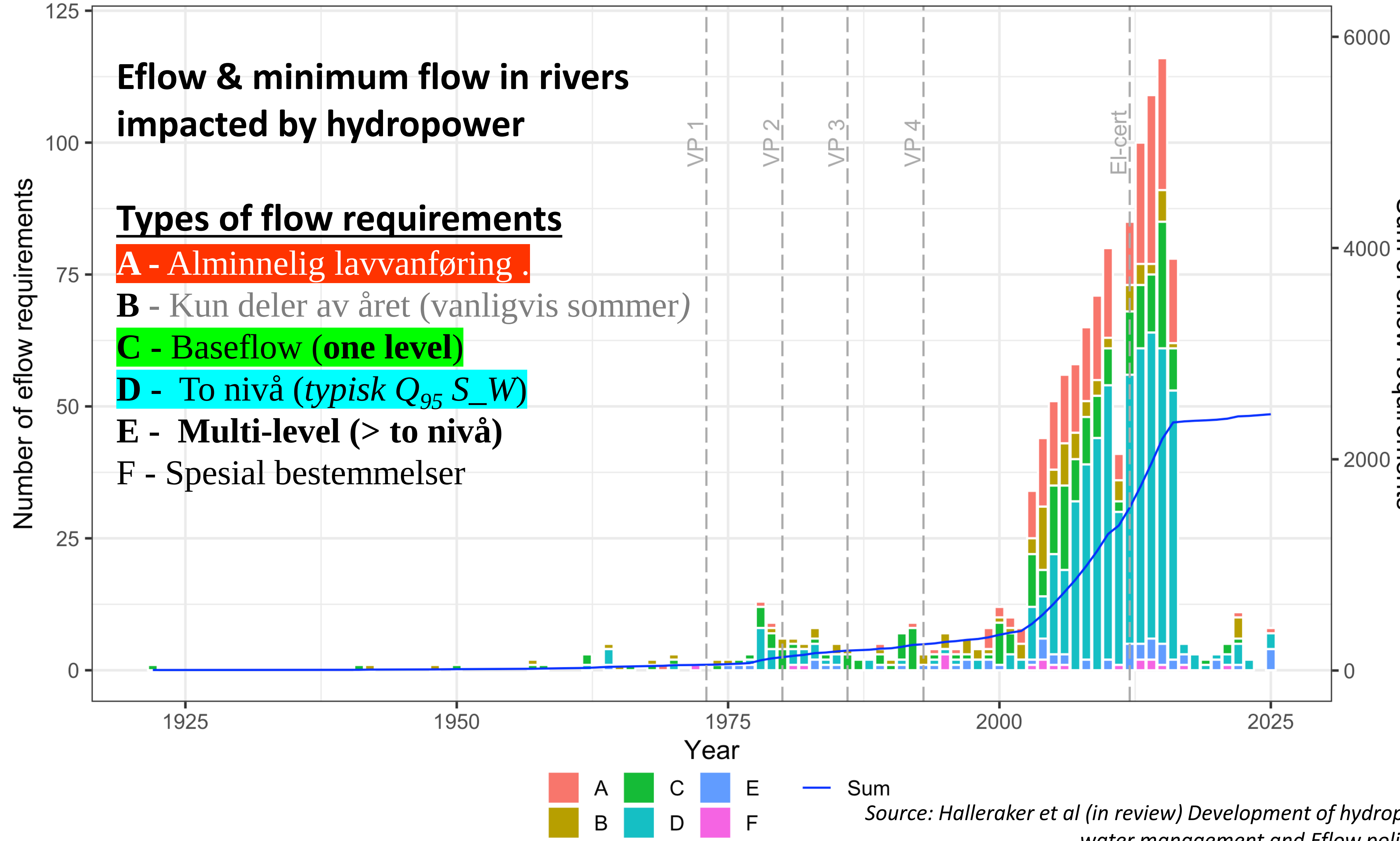


- The most controvesial HP projects in Norway
- Good example BUT **untypical**

Alta controversy

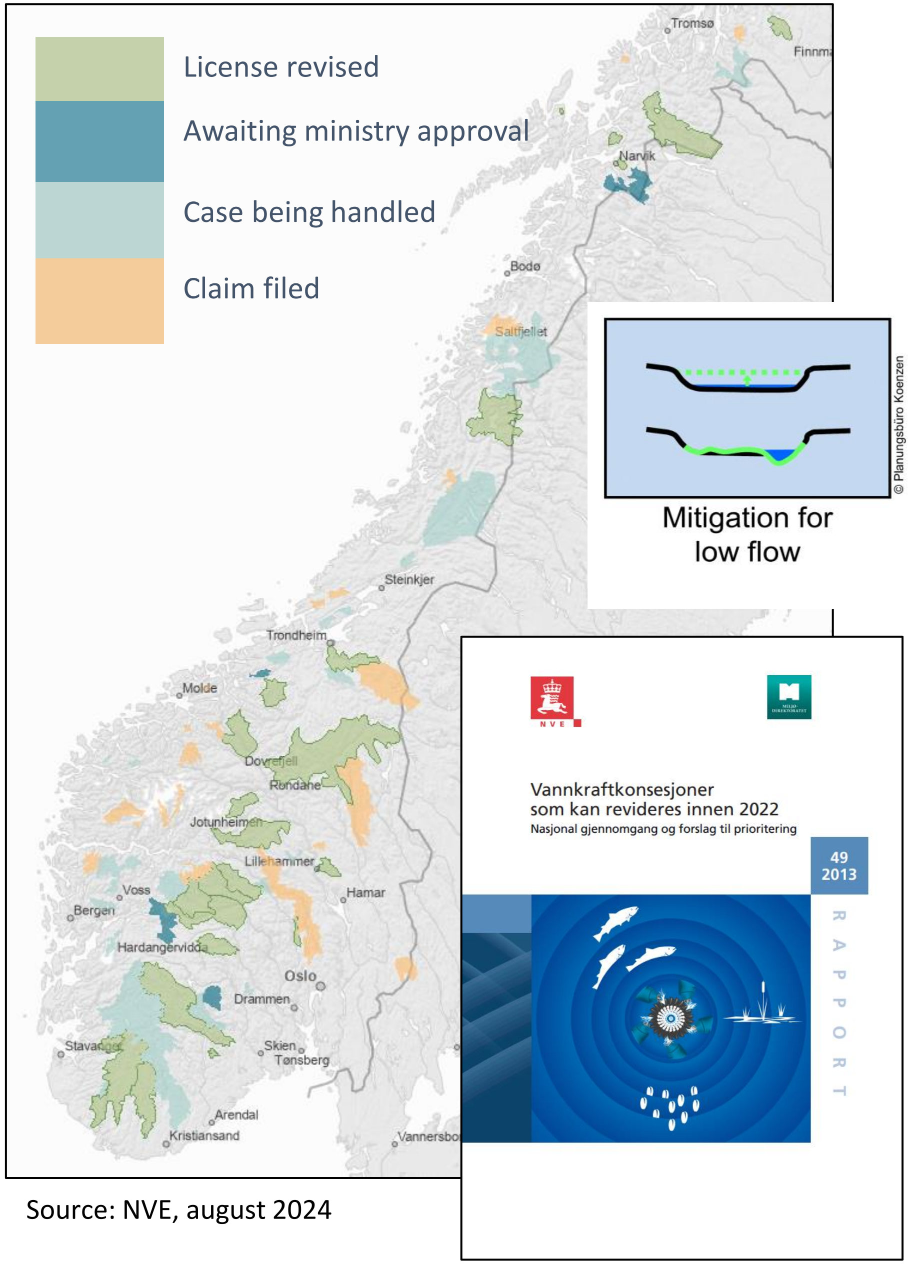
Blockade against Alta hydroelectric project on traditional Sámi territories. The project was completed in 1987."





Source: Halleraker et al (in review) Development of hydropower impacts, water management and Eflow policies in Norway

Revision of HP licenses & Adverse Effects on HP



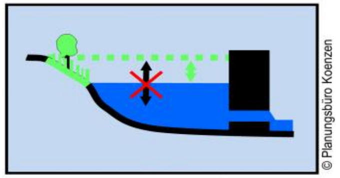
Source: NVE, august 2024

National assessment of costs/benefits in 2013.

→ Priority exercise

→ Highest priority 1.1 – 1.7 TWh

Estimated production loss so far is less then 30 % of the original Q_{95} estimate (NVE 49:2013).



Mitigation for lake level alteration

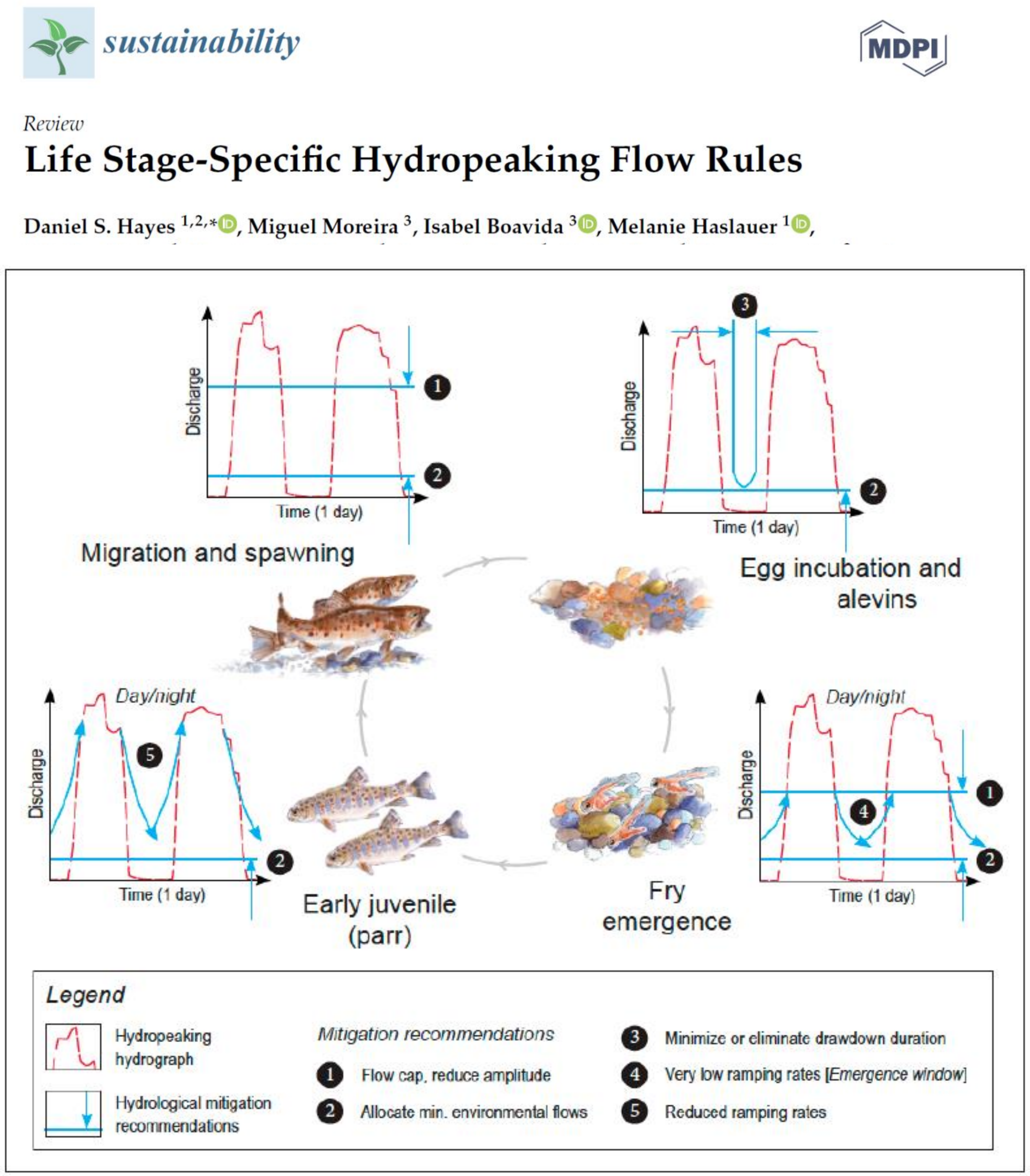
Climate inflow: Available water for HP production, **increased by 7% since 1960s**. (latest hydrological 30-years series)

A national estimate on "power loss" from all the total minimum flow requirement (incl all revision cases by 2023), in the range of **less than 1.5 %**

→ so, Norway would **have produced (in average) ca 1.8 TWh more** if we removed all flow requirements.

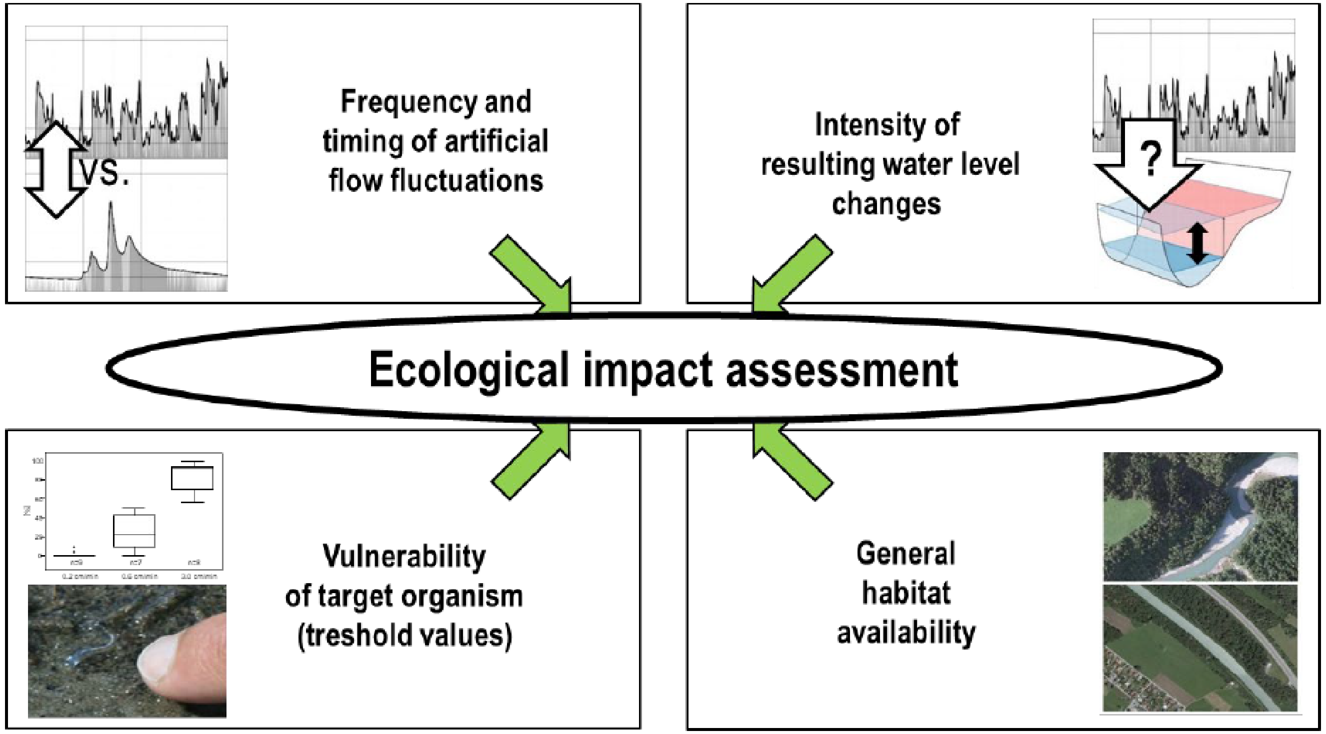
Reservoir filling restrictions " a no go measures" due to Sign Adv Effect upon HP use

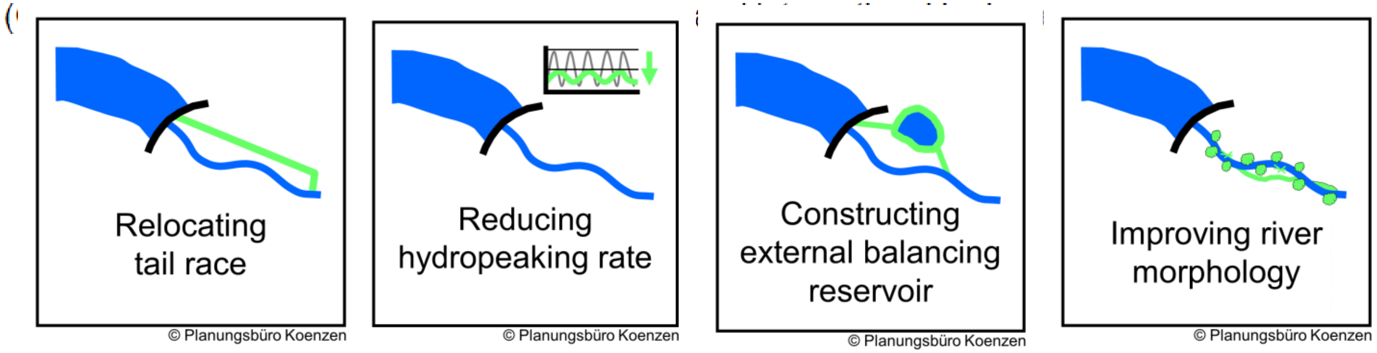
Ecosystem adapted & mitigated hydropower operations *(ecopeaking)*


sustainability
MDPI

Review
Life Stage-Specific Hydropeaking Flow Rules

Daniel S. Hayes [1,2,*], Miguel Moreira [3], Isabel Boavida [3], Melanie Haslauer [1],





Need to mitigate episodic (short term) and long lasting impacts *(if significant)*

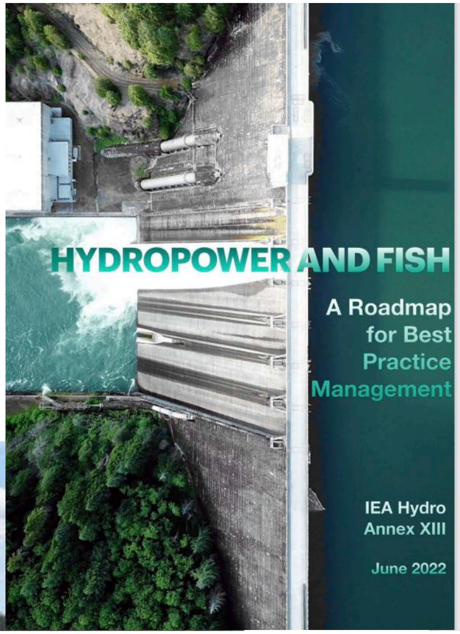
➢Harmful hydropeaking

Acknowledge «new impacts» and innovative solutions, e.g.

- Supersaturation
- Thermopeaking/ extreme temperatures
- HP turbine flow shut down

****

- Sediment management to avoid habitat degradation



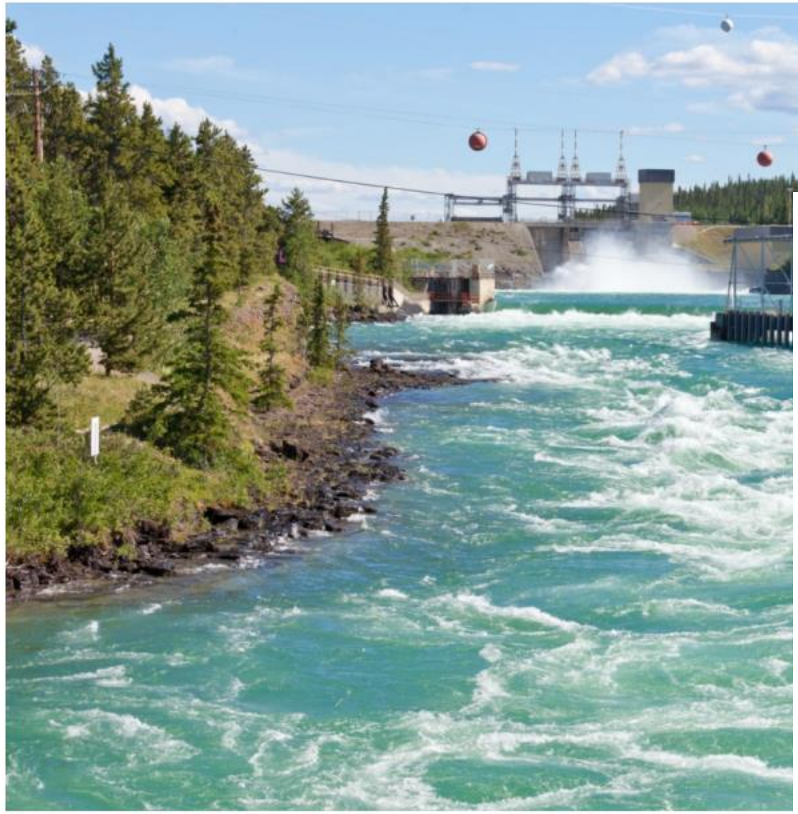


Figure 3.10 ***Near-surface supersaturated "white-water" release***
(Source: Pi-Lens/shutterstock.cor

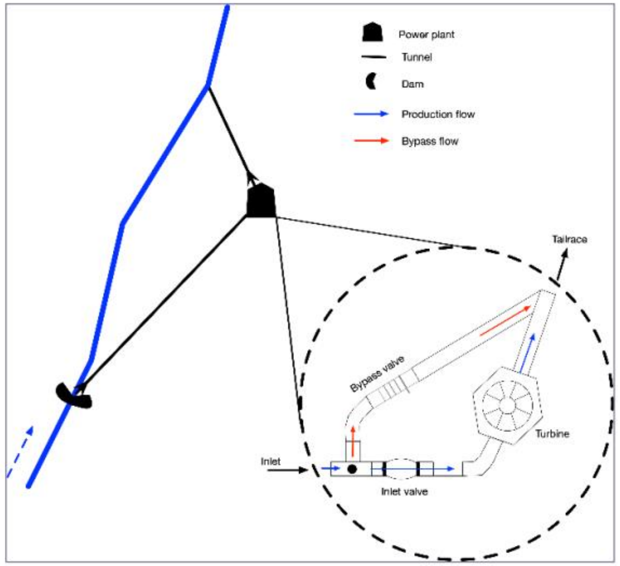
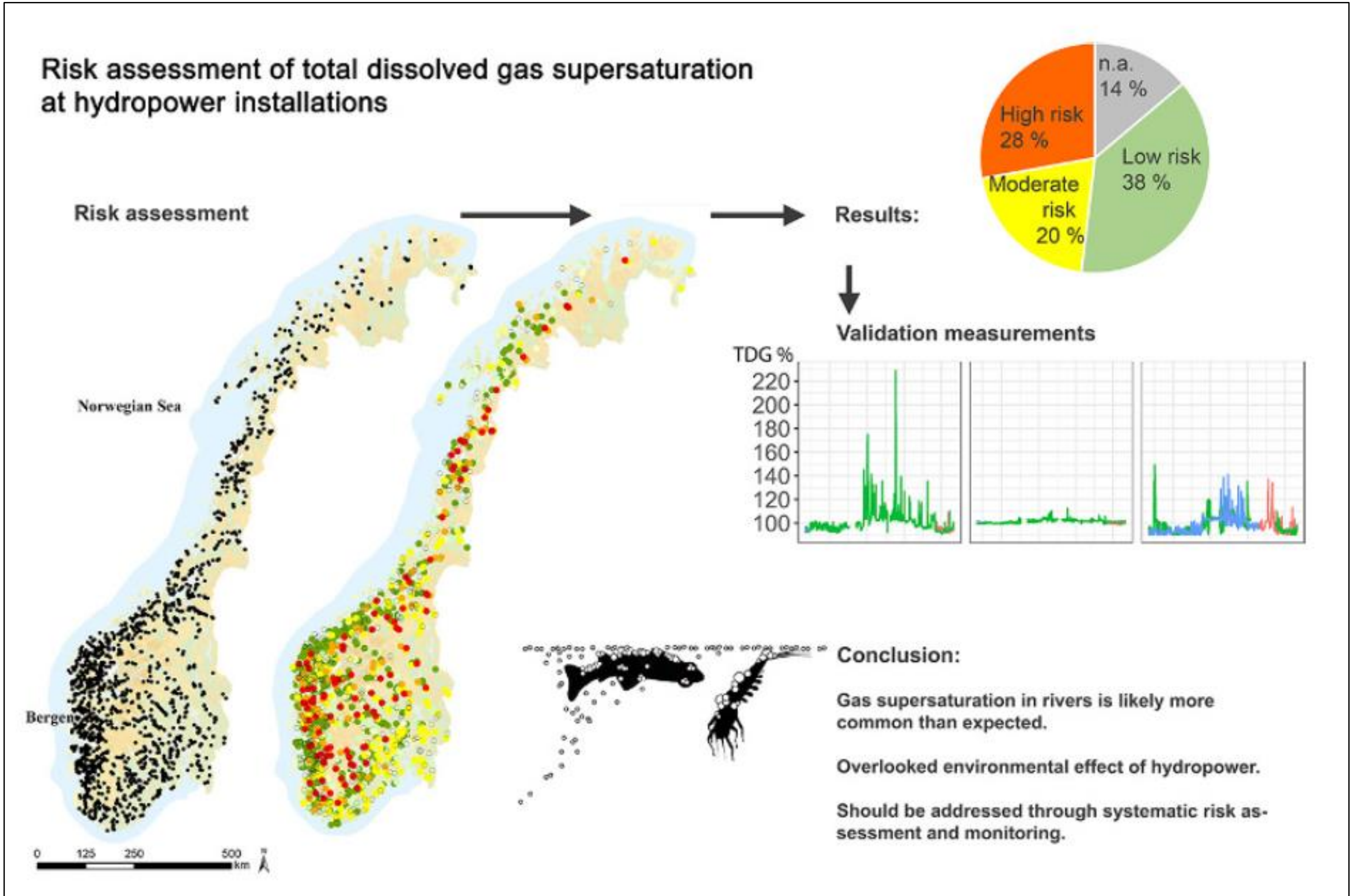


Figure 4.28 ***By-pass valve allows constant flow release downstream in case of emergency***
(modified from: [4.85])

High levels of supersaturation can occur at high head hydropow

Management *Sustainable options*

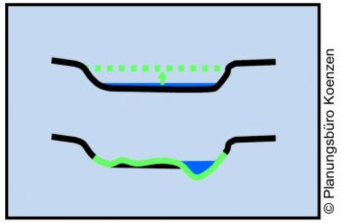


Pulg et al. (2024). Assessing the potential of gas supersaturation. SCTOT 948

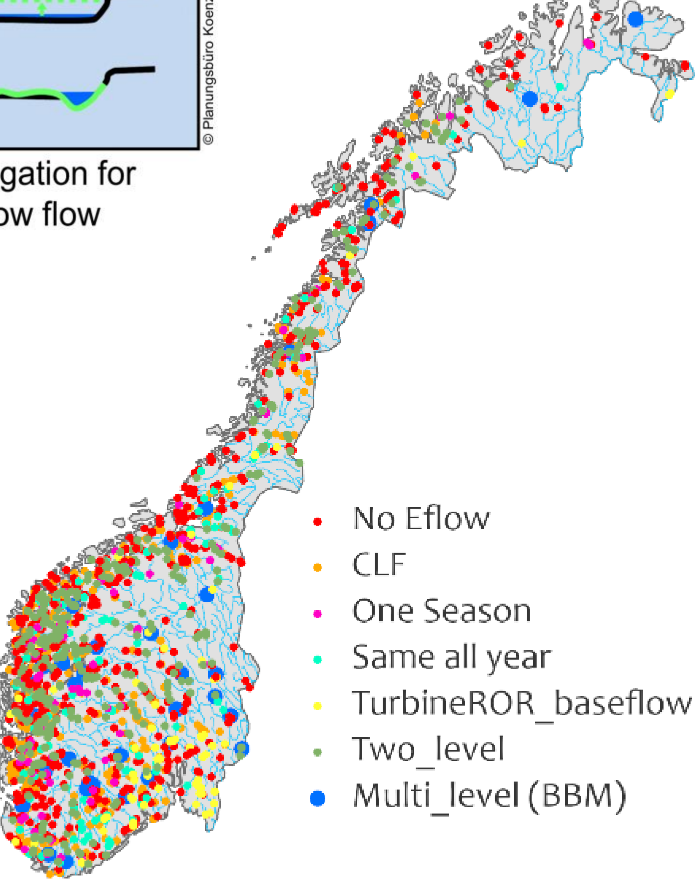
Reduction of TDGS - Total dissolved gas supersaturation

- Flow adjustments in secondary intakes
- Vacuum intakes
- Screen cleaners
- Alert systems
- Dilution
- Deflektor aeration

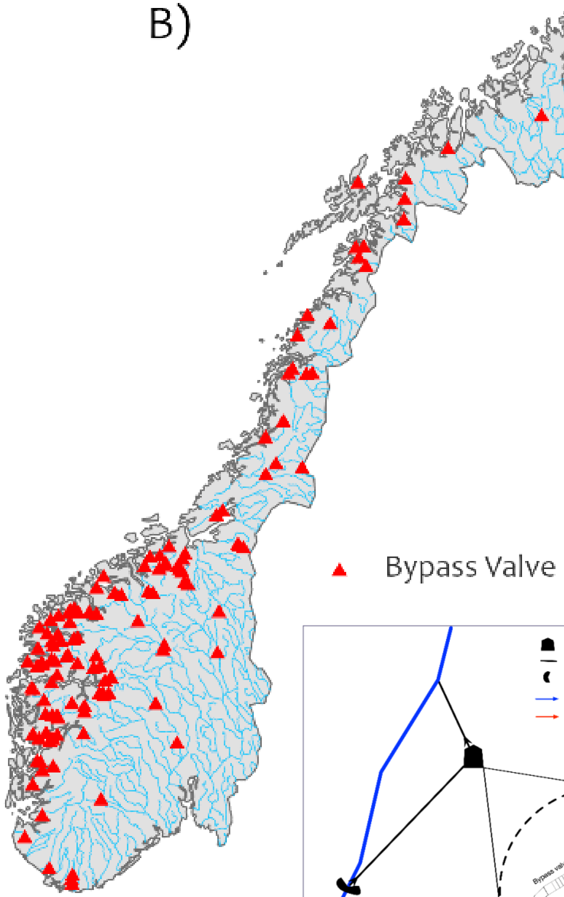
Status of HP mitigation measures



Mitigation for low flow



B)



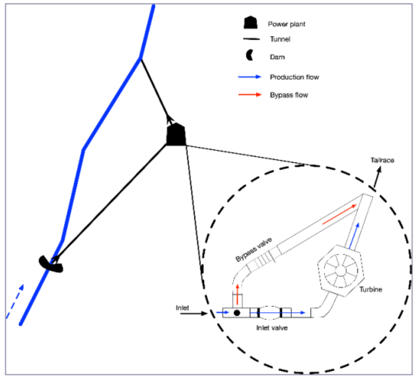
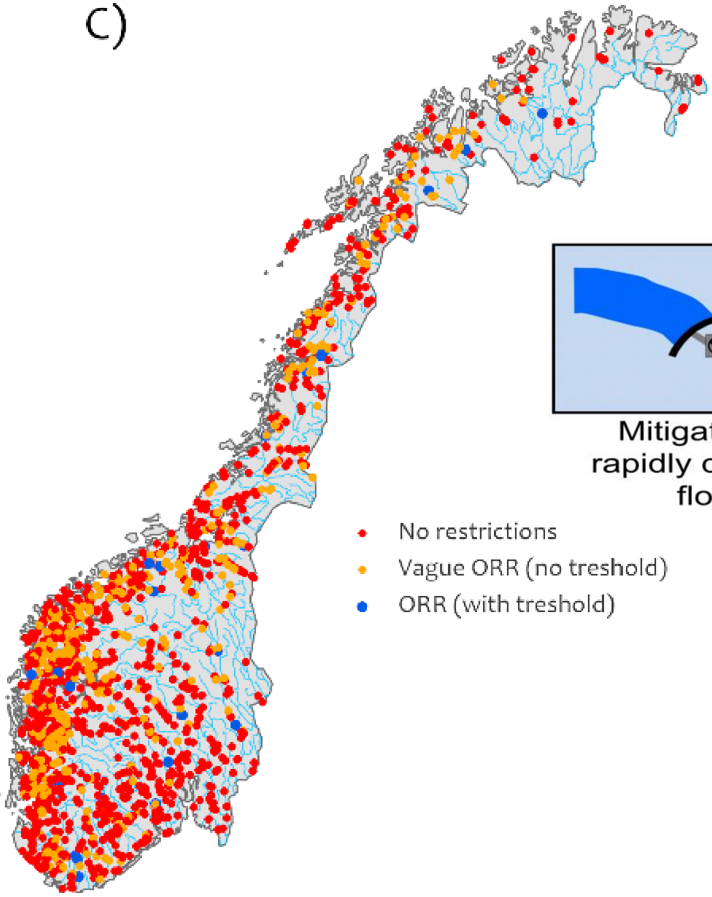
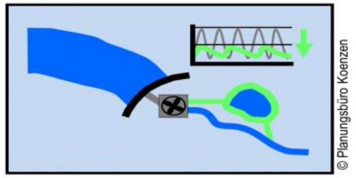


Figure 4.28 ***By-pass valve allows constant flow***

C)

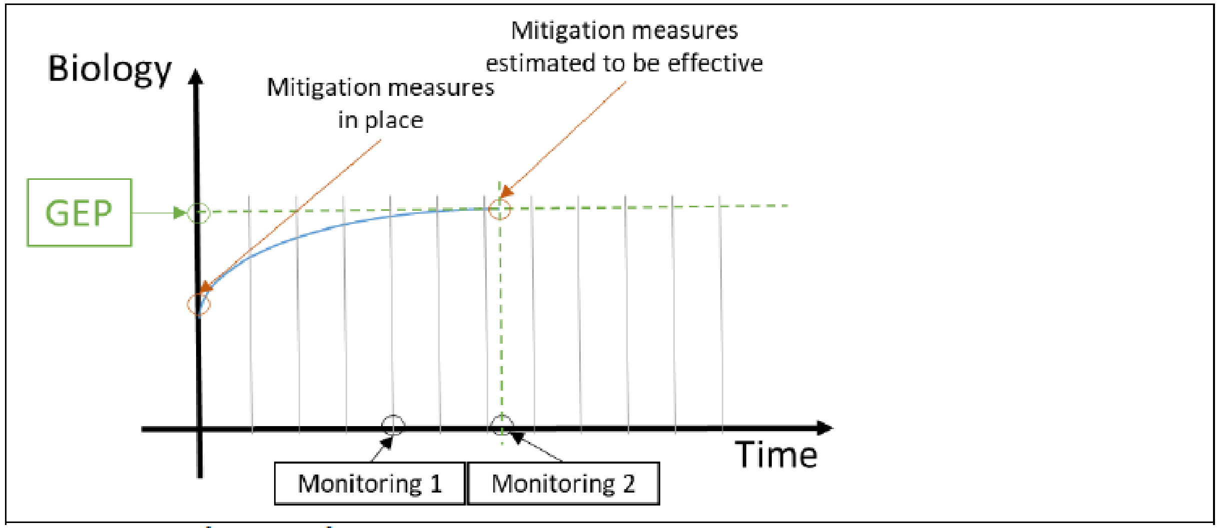




Mitigation for rapidly changing flows

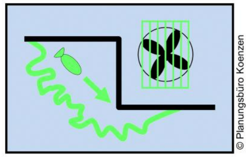
Monitoring of GEP => ecological functionality (and if needed adapt GEP-measures)

- Adaptiv management (or revisiting) is in practise a key → in particular if you do not have so much experience with type of measure
- *“GEP is hard to understand for “normal people”*

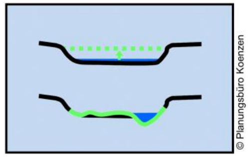


Figur 11. Overvåking for å klassifisere det økologiske potensialet til SMVF og vurdere den biologiske forbedringen (effekten) av avbøtende tiltak

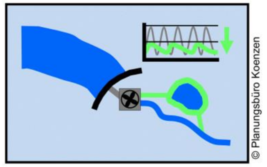
Sustainable hydropower – EU taxonomy



2. Downstream continuity fish



3. Mitigation low flow



6. Mitigation for hydropeaking

General requirements: **do no significant harm** to the good status or the good ecological potential of water bodies.

Checklist for hydropower:

- Comply with the WFD – **aim for GES or GEP**.
- All technically feasible and ecologically relevant mitigation measures:
  - ✓ Ensure downstream and upstream **fish migration**.
  - ✓ Ensure minimum **ecological flow**, incl hydropeaking mitigation.
  - ✓ Protect or enhance **habitats**.
- Monitoring of the **ecological efficiency.**

European Commission – FAQ:

'A water body which would remain under the 'lowered' objective under Article 4(5) of WFD without putting in place the necessary measures (ecologically and technically relevant) towards good potential, does not fulfil the DNSH criteria'.

To wrap ut

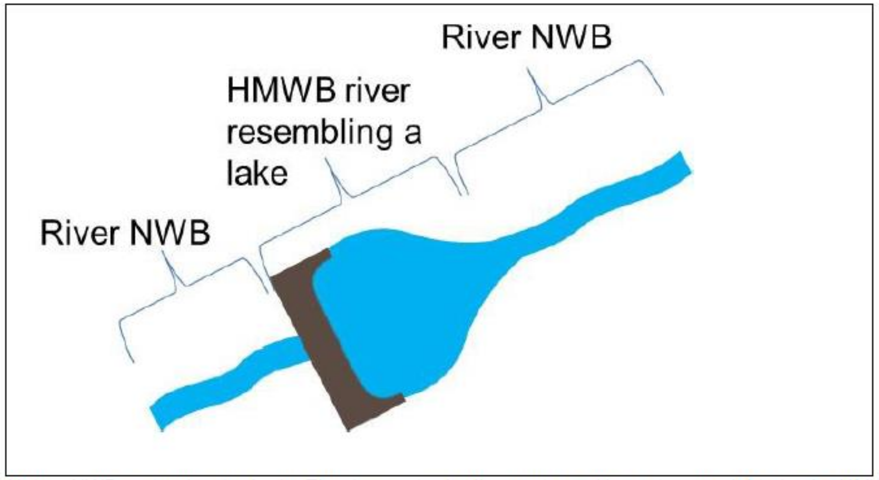
- Many ecological efficient mitigation measures without adverse effect on HP
- NO needs to scale up/intensify implementation of several types of MM
- Risk assessment
  - Episodic supersaturation
  - Harmful hydropeaking
  - Safe fish migration
- Monitoring of GEP (ecological functionality)

→also helpful to understand the concept for «normal people»

→ A requirement to fulfil HMWBs principles

- Free-flowing-river strategy/methodology
  - Restoring and assessing the **lateral connectivity**
  - Adverse effect on agriculture
  - Road culverts – in numbers a **massif challenge**….
- EUs taxonomy easier to catch?

Figure 8: Change of river into lake and links to upstream/downstream river sections



Notes: NWB=natural water body. The river water bodies upstream/downstream might also be HMWB but separate water bodies.

Strategic HP related governance

Scotland

- Flow restoration (limited to **% of renewable energy** production – moving target)

- PP principle in place

Sweden

- National mitigation strategy includes
- Best available mitigation standards
- Flow restoration threshold (SAE*) of **1.5 TWh** (2.3 %)
- National HP fund of to finance mitigation measures – **ca 900 mill €** (next 20 yrs)

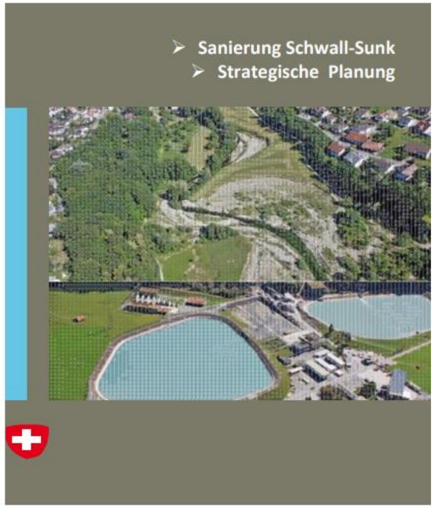
Norway

- Partly PP principle (for HP with modern license)

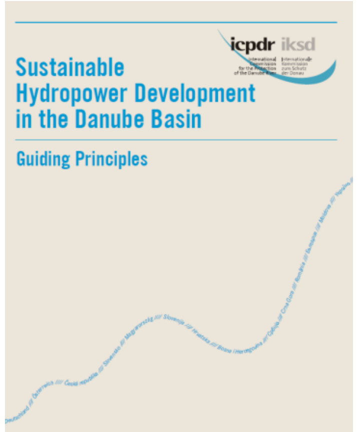
- Flow restoration threshold - limited to **1.7 TWh** (< 1.2 %)

- Several special HP related management plans established (next slide)

Norwegian Environment Agency



The alps



Danube basin (ICPDR)

- Sustainable HP guiding principles (2013)

Austria

- PP principles in place

- Ministry fund of **180 mill Euro** (2009 – 2015) to boost HP measure (up to 30% of costs)

- Mitigation measures (in forskrift)

- Evident based feasibility studies required

Switzerland

- Green label HP *(Ôkostrom)* been available since early 2004
- Detailed (legal) mitigation thresholds
- HP mitigation fee - electricity bill (2012-2030) to finance hypeak, sediment measures - ca **1.07 billion €**

Recommended reading for sustainble and ecosystem based hydropower development