Dams and adaptation to climate change – challenges and opportunities

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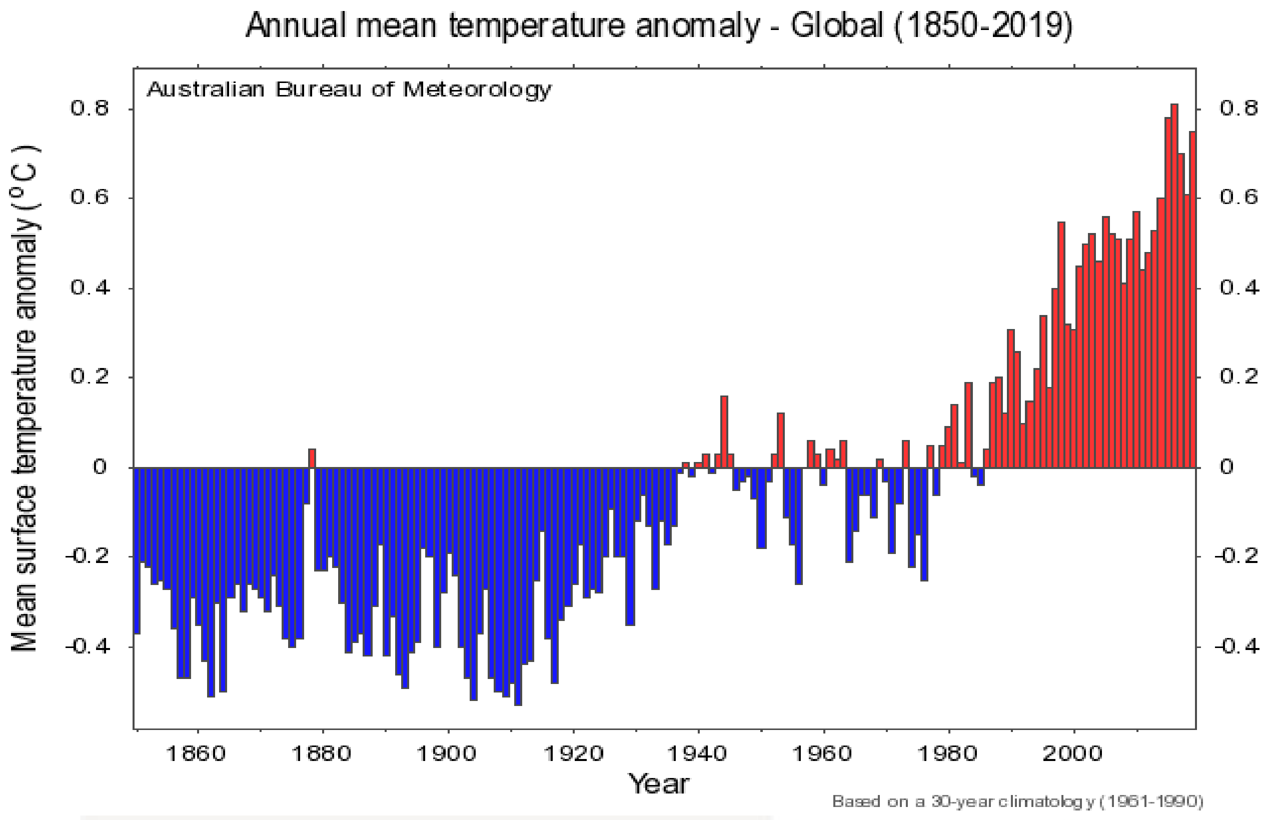
Representing ICOLD “Technical Committee on Climate Change, TC-Y”

Outline

- Introduction
- Three hypotheses & your opinions
- Drought risk adaptation investments
- Dams and floods
- Hydropower
- Conclusions

Introduction

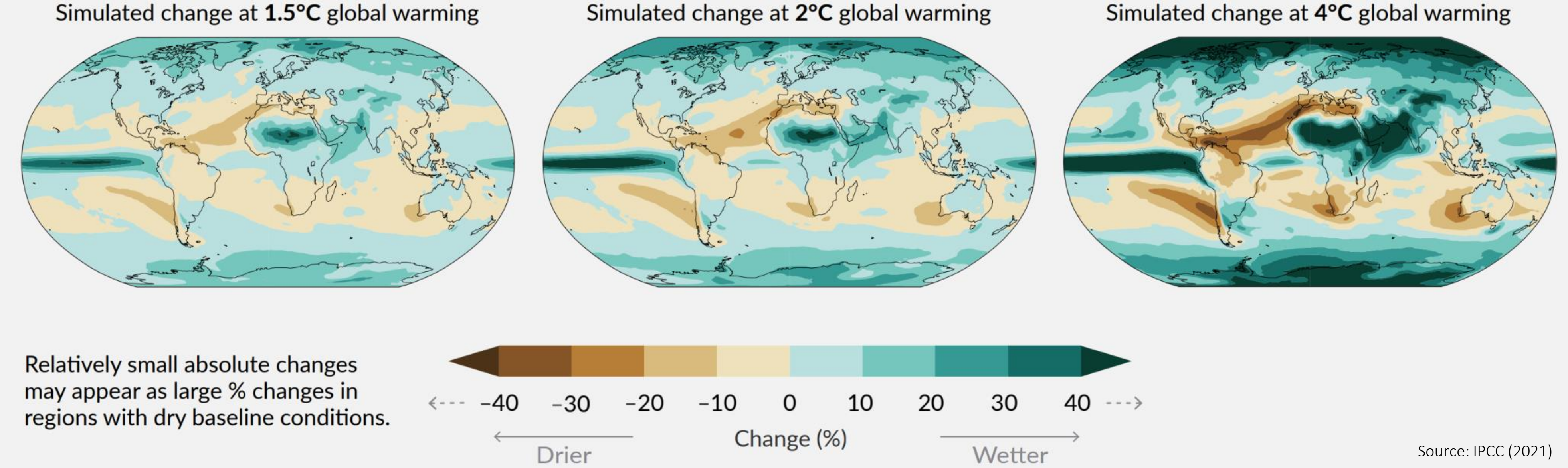
- Global warming > 1 K since pre-industrial era (2020)
- Increase on terrestrial lands even greater
- Rear view mirror (20 yrs): reality corresponds to most pessimistic scenarios
- Future precipitation changes less clear, with high regional or local uncertainty



Global temperature variation relative to the standard reference period of 1961 and 1990

Introduction

- Annual mean precipitation change (%) relative to 1850–1900



Source: IPCC (2021)

- Consensus: the global water cycle will intensify
- These changes cause implications/ interactions with water infrastructure

Three hypotheses & your opinions

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Hypothesis: Drought risk adaptation investments are worthwhile and should be expedited?

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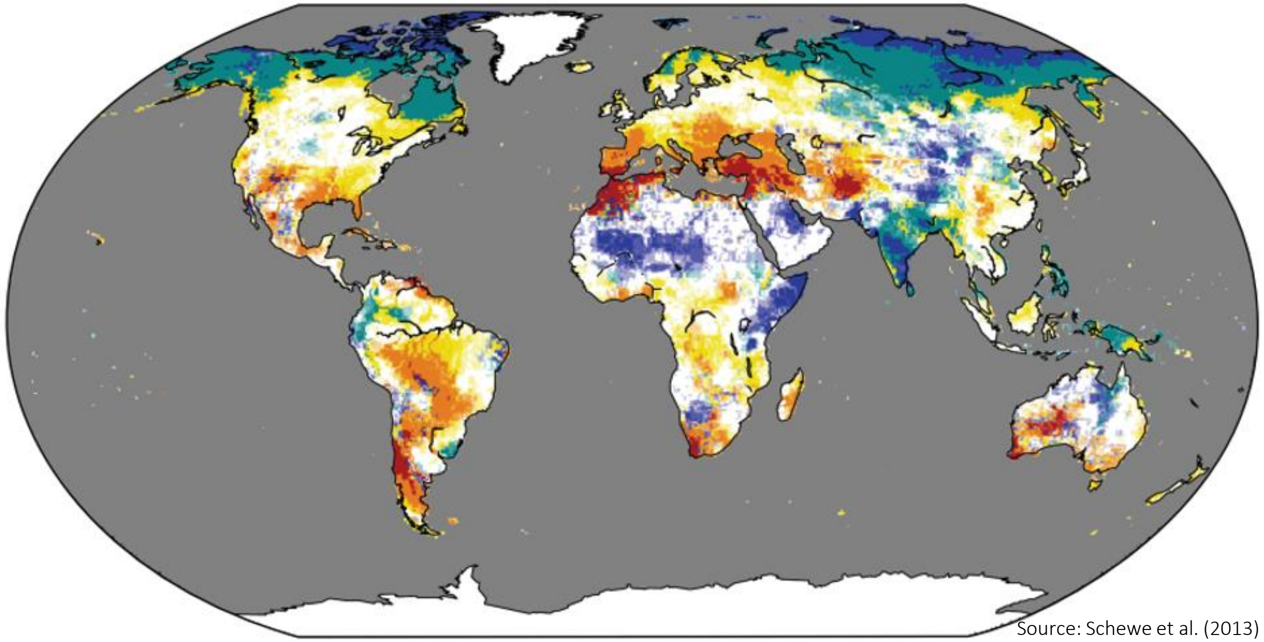
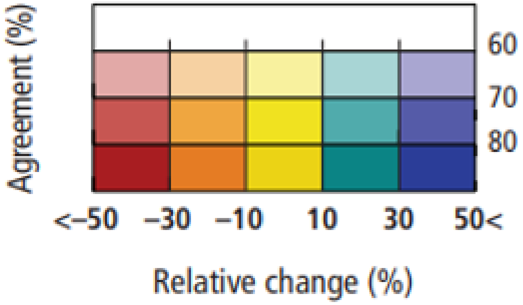
- Reliability of yield mainly affected by mean river flow and coefficient of variation (McMahon et a., 2007)
- Change of mean annual streamflow for a mean global temp rise of 2.7 K



Source: Schewe et al. (2013)

Percentage change of mean annual streamflow for a global mean temperature rise of 2°C above 1980–2010 (2.7°C above pre-industrial). Color hues show the multi-model mean change across 5 General Circulation Models (GCMs) and 11 Global Hydrological Models (GHMs), and saturation shows the agreement on the sign of change across all 55 GHM–GCM combinations (percentage of model runs agreeing on the sign of change)

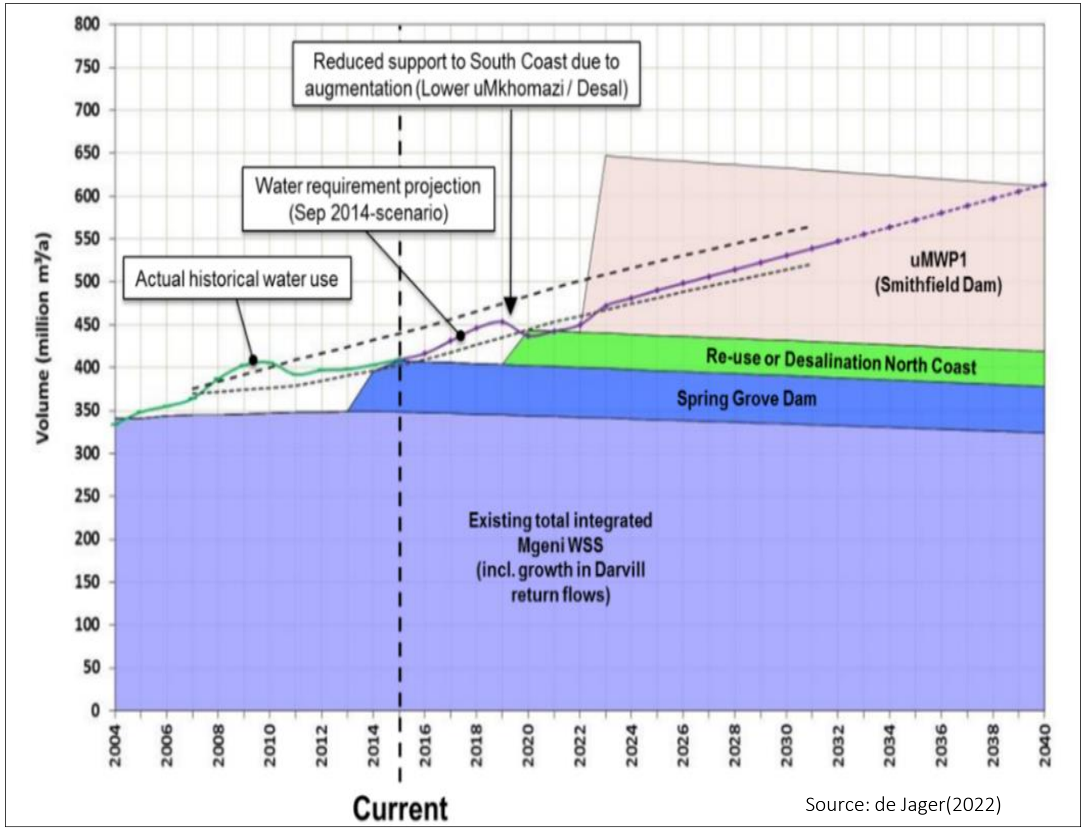


Hypothesis: Drought risk adaptation investments are worthwhile and should be expedited?

- Expect exposure of numerous regions to decreasing streamflows and increased drought duration and intensity, e.g. Southern Africa, Western Australia, Southern Chile, interior of South America, South-Western USA, Central Asia, Mediterranean region → increased risk for water shortages
- Resulting in:
  - (1) urgent need to improve management and operation of existing dams (non-structural adaptation to climate change)
  - (2) urgent need to improve water use efficiency of the largest abstractors → irrigation
  - (3) urgent need to plan and implement additional water storage infrastructure, also for carry-over in multi-year drought situations (structural adaptation to climate change) while also taking account of environmental water needs

Hypothesis: Drought risk adaptation investments are worthwhile and should be expedited?

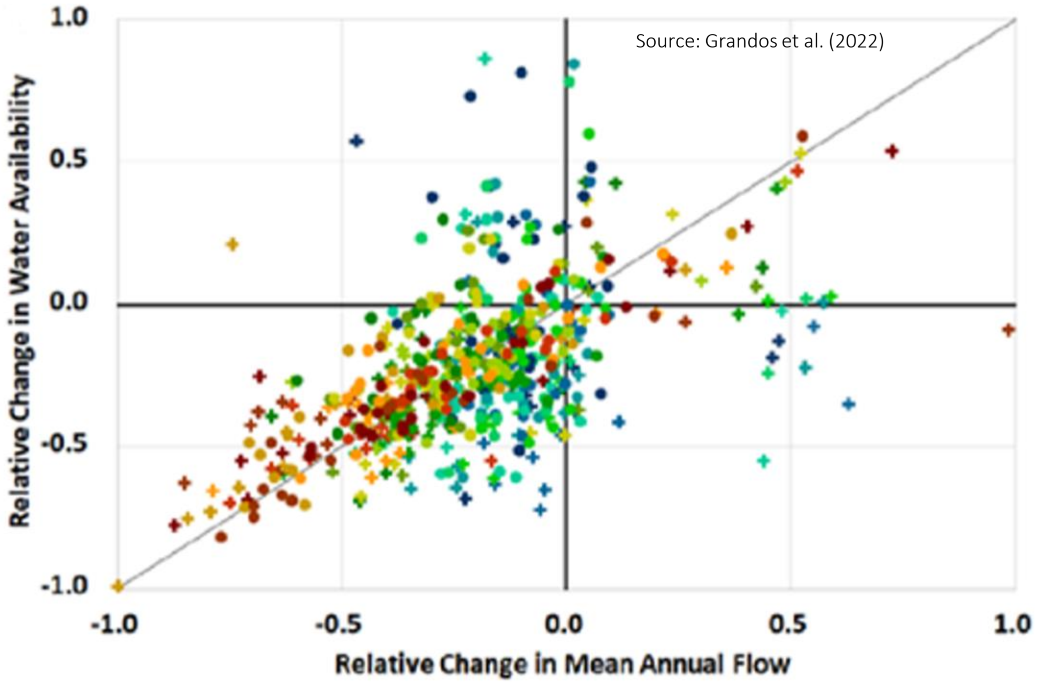
- South African **case study**: Mgeni River System, KwaZulu-Natal (2014)
- Mgeni River System main source for Greater Durban area
- Umgeni Water seeks to quanitfy risks and identify adaptation strategies
- 14 GCMs and 5 emission scenarios
- Modelled impacts on system yield
- Water balance graphs up to 2040 for two scenarios (drier, wetter)
- Assisted in assessing CC impacts on planning of interventions to augment water supply (Spring Grove and Smithfield Dams)



Source: de Jager(2022)

Hypothesis: drought risk adaptation investments are worthwhile and should be expedited

- Southern Europe **case study**: Performance of reservoir storage under climate change
- Project on 16 major watersheds in SE with numerous water supported sectors:
  agriculture, toursim, services
- 35 scenarios for 2070-2100 period
- Significant decrease in mean annual flow and strong increase in hydrol. variability
- Watersheds with small storage capacity → large decrease of potential water availability
- Increasing storage reduces uncertainty



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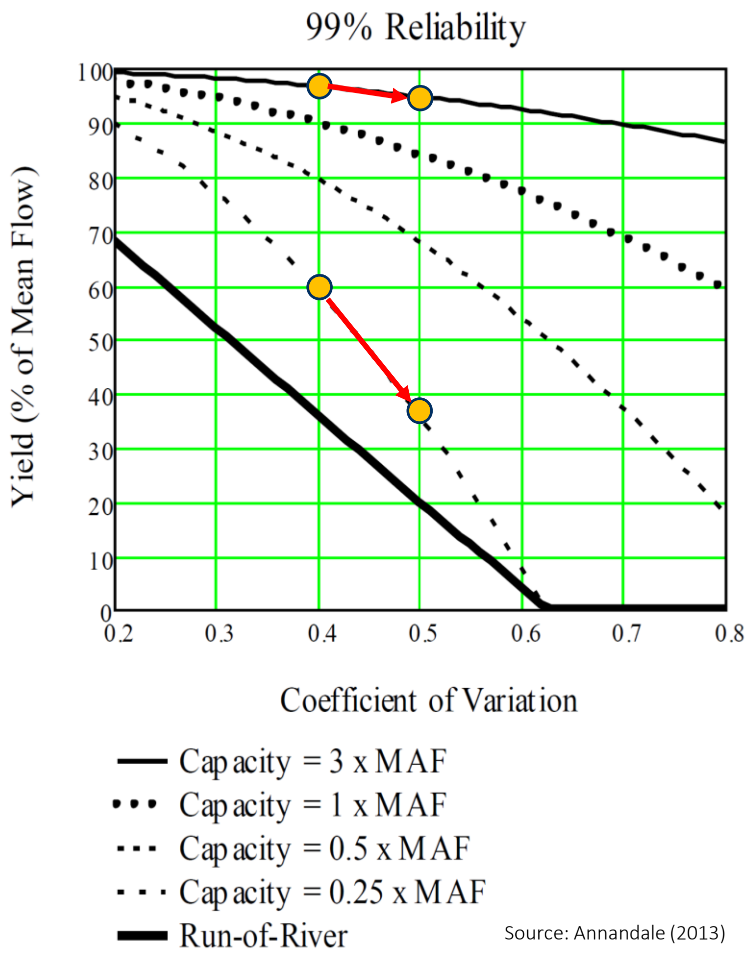
- Storage-yield-reliability graphs based on the Gould-Dincer equation
- We find that:

- run-of-river schemes and small reservoir storage are most sensitive and vulnerable to changes in flow variability

- large reservoir storage represents robust infrastructure

- And the latter contains an important additional element: economies of scale
- TC-Y's stance on the hypothesis: affirmative



Source: Annandale (2013)

Hypothesis: Climate change will cause increases of design floods?

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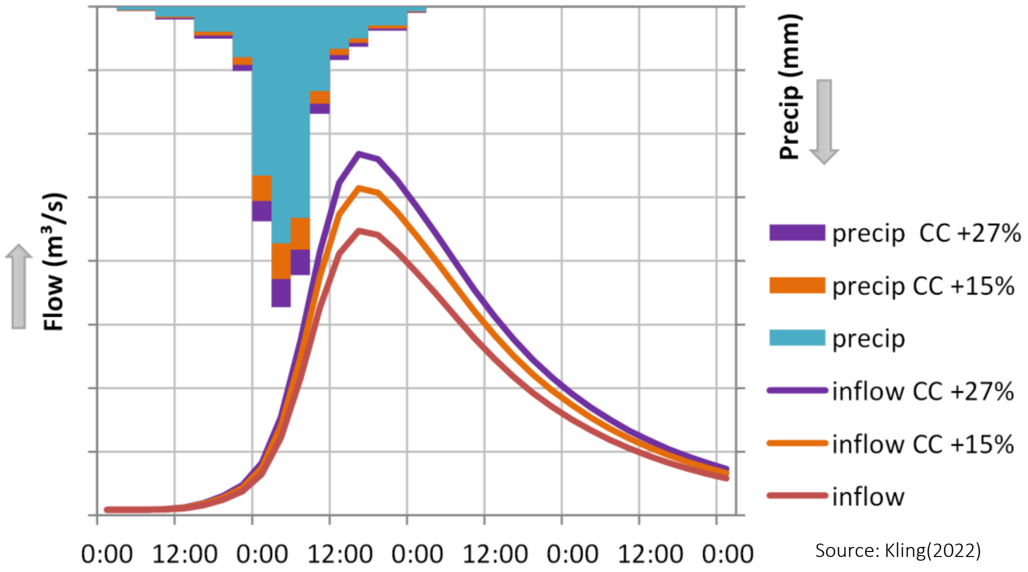
Six potential causes for increased flood events under climate change:

- Physics: based on Clausius-Clapeyron relationship, every 1 K temperature rise causes a 7 % increase in atmospheric moisture holding capacity
- Rain-on-snow events
- Rapid glacier-melt and Glacial Lake Outburst Floods (GLOFs)
- Landslides and soil erosion
- Increase in frequency and strength of tropical cyclones
- Changes in large-scale oscillation patterns

Hypothesis: Climate change will cause increases of design floods?

- Laos & Philippines **case study** (AFRY): Climate change impacts on extreme flood inflow in South-East Asia
- Dam safety reviews for several hydropower projects in SEA
- Affected by monsoon & typhoon events
- Calibrated rainfall-runoff-modell
- PMF as per WMO guidlines
- Used regional temperature projections
- Application of Clausius-Clapeyron-rel.
- Results for mid-century (+ 2K) and end of century
- Inform design, operations and warning



Source: Kling(2022)

Rainfall-runoff modelling to simulate flood inflow under different scenarios of extreme precipitation. Current and future precipitation scenarios considering climate change impact

Hypothesis: Climate change will cause increases of design floods?

- But…
- What is the actual temperature increase in the design flood month and during the actual event? (mean annual figures will not provide an answer)
- What is the increase in actual atmospheric moisture content?
- What is the resultant % increase in precipitation above reference?
- Will the temporal and spatial distribution of the design storm event change because of CC?
- To what extent will rainfall intensity increase?
- Will there be multiple flood peaks during short periods?

→ Subject of ongoing hydrological research

Hypothesis: Climate change will cause increases of design floods?

- And there could be several opposing / mitigating affects:
  - baseflow might have decreased with CC
  - antecedent catchment moisture might have decreased with CC
  - snow pack magnitude might have decreased with CC
  - timing of peak snow-melt might have moved out of sync with period of highest precipitation → reduced overlap due to CC
  - reservoirs may not fill, so there will be 'air space'
- How do these antagonistic factors (if and where they occur) play out on balance with the pure physics approach? Will design flood still increase or remain unchanged?
- Best practice (Sweden): Climate change considerations are part and parcel of the design flood criteria guidelines: periodic reviews and sensitivity analysis for climate scenarios

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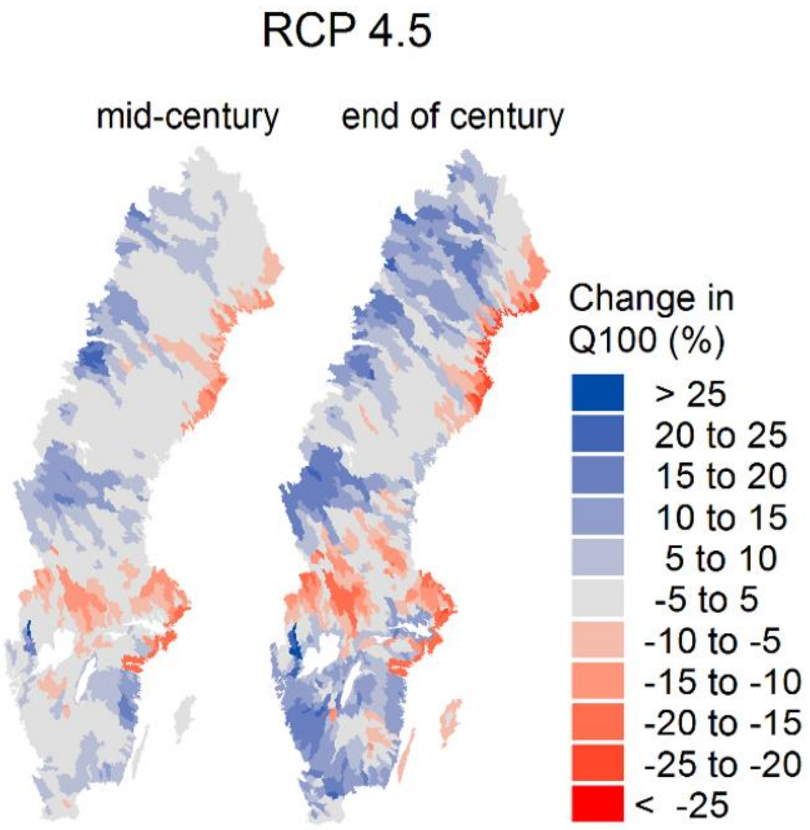
- Swedish **case study** (SMHI): Hydrological Projections based on representative concentration pathways
- Warming rate twice the global average
- Earlier spring flood onset
- Main flood drivers: Precipitation (South)
  Rain & snowmelt (Center & North)
- RCM (18 members) x conceptual hydrological model (HBV) for 100 rivers
- Changes in HQ_{100} for RCP4.5 and RCP8.5 at mid-century and end-of-century
- Open data @ www.smhi.se



Source: Hallberg (2022)

Hypothesis: Climate change will cause increases of design floods?

- To sum up this section:
  The cause & effect relationship between climate change and increasing design floods is less straight forward and linear than a quick jump to conclusions on atmospheric physics alone might imply.
- CC effects on extreme events is subject of intensive ongoing research
- Hence, based on the locally prevailing flood generation processes, the hypothesis "of increased design floods" will be true for many localities and might be false at many others
- Announcement: completion process of the new ICOLD-bulletin "Flood risk evolution associated to climate change" expected in 2023/24

Hypothesis: Climate change is bad news for hydropower?

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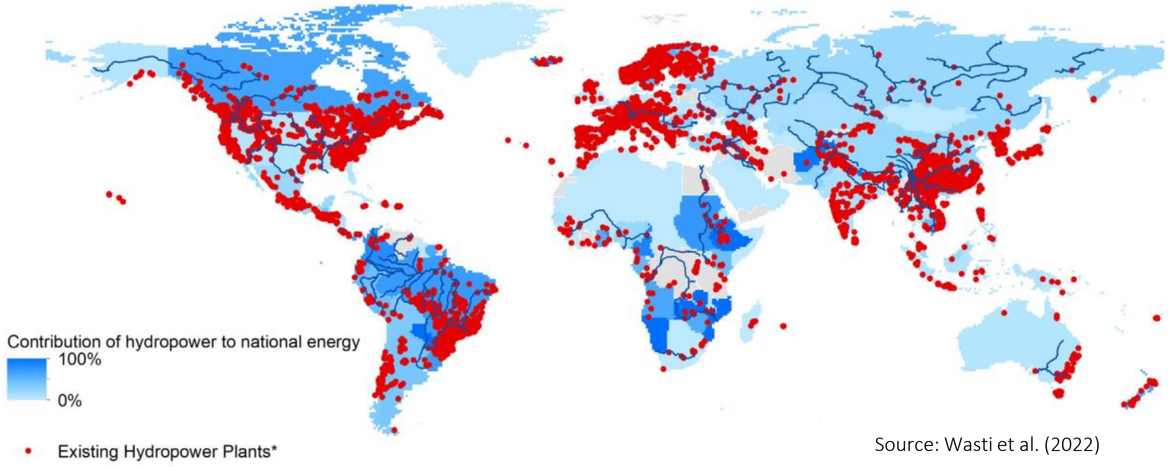
- Hydropower is the world's largest source of renewable energy, providing 16% of global electricity demand
- Some economies depend >90 % on hydropower → high societal impact
- Global hydropower sector is reliant on surface water flows of substantial and predictable volume. → This makes it vulnerable to climate change
- Direct effects: flow regime changes, modification of soil erosion and sedimentation
- Indirect effects (socio-economic): changes in power needs and power flexibility needs

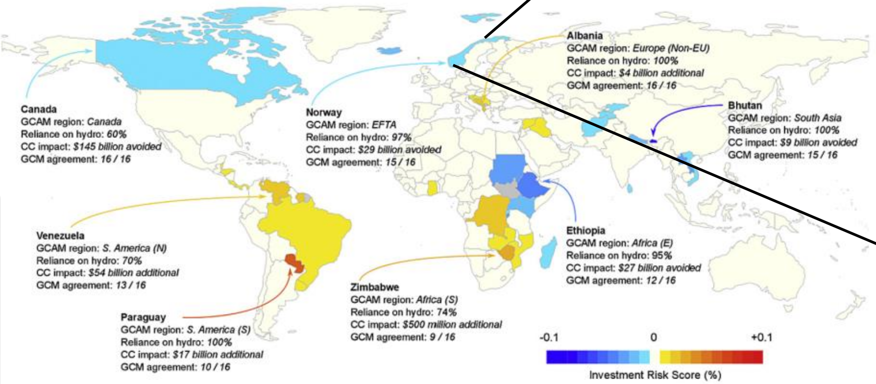


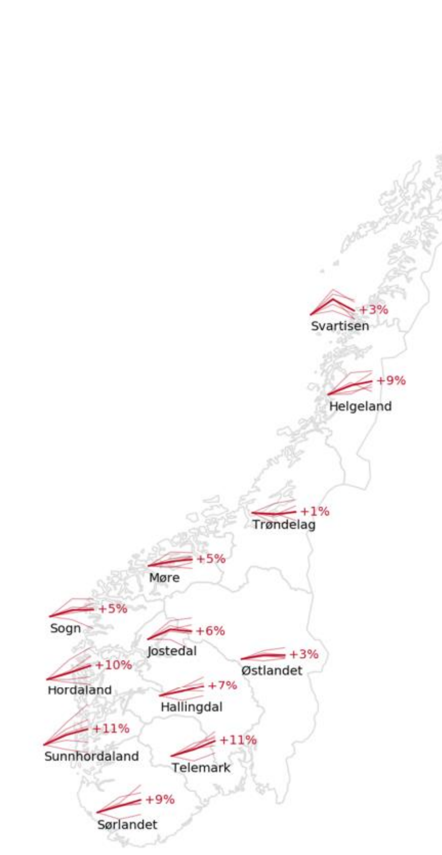
Source: Wasti et al. (2022)

Hypothesis: Climate change is bad news for hydropower?

- Global change assessment model Turner et al. (2017):
  - drying regions require US$ 1 tr this century to stay flat

  - wetting regions can avoid investments of similar magnitude





Change in hydropower inflow for regions in Norway. 2041-2071 and 2071-2100 compared to 1989-2018. Numbers for end of century. (*NVE, 2019*)

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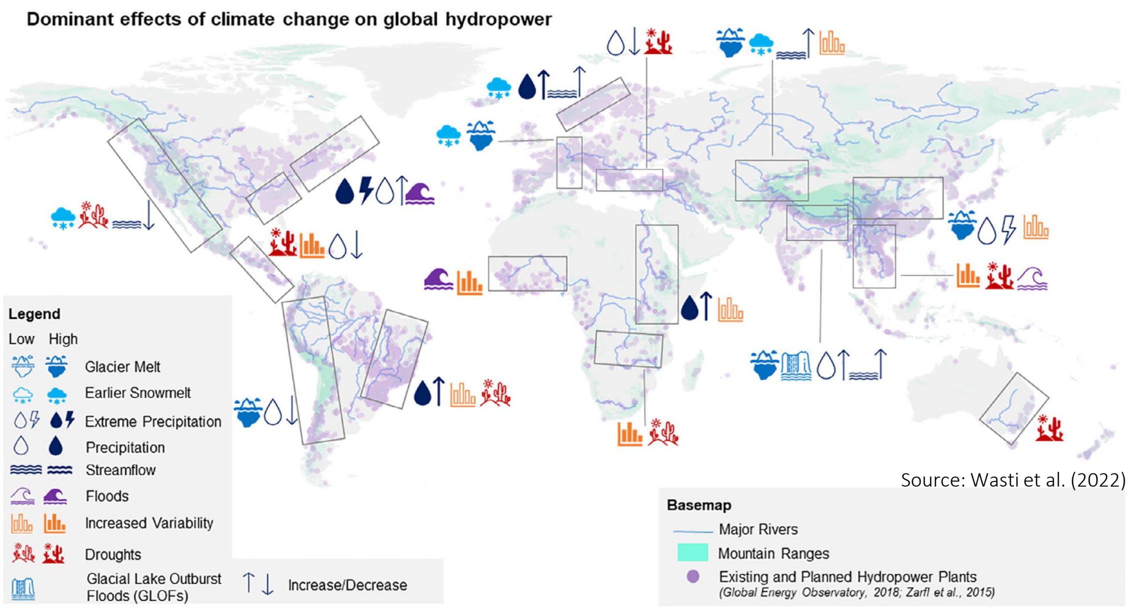
- Global review study by Wasti et al. (2022) of 106 papers: non-uniform impact of climate change on hydropower generation
- Four primary impact mechanisms were identified

(1) Depletion of permanent glacier and ice storage
(2) Reduction in seasonal snow storage with warmer winters
(3) Increased precip variability and intensification of extremes
(4) Increased evaporation and water demand



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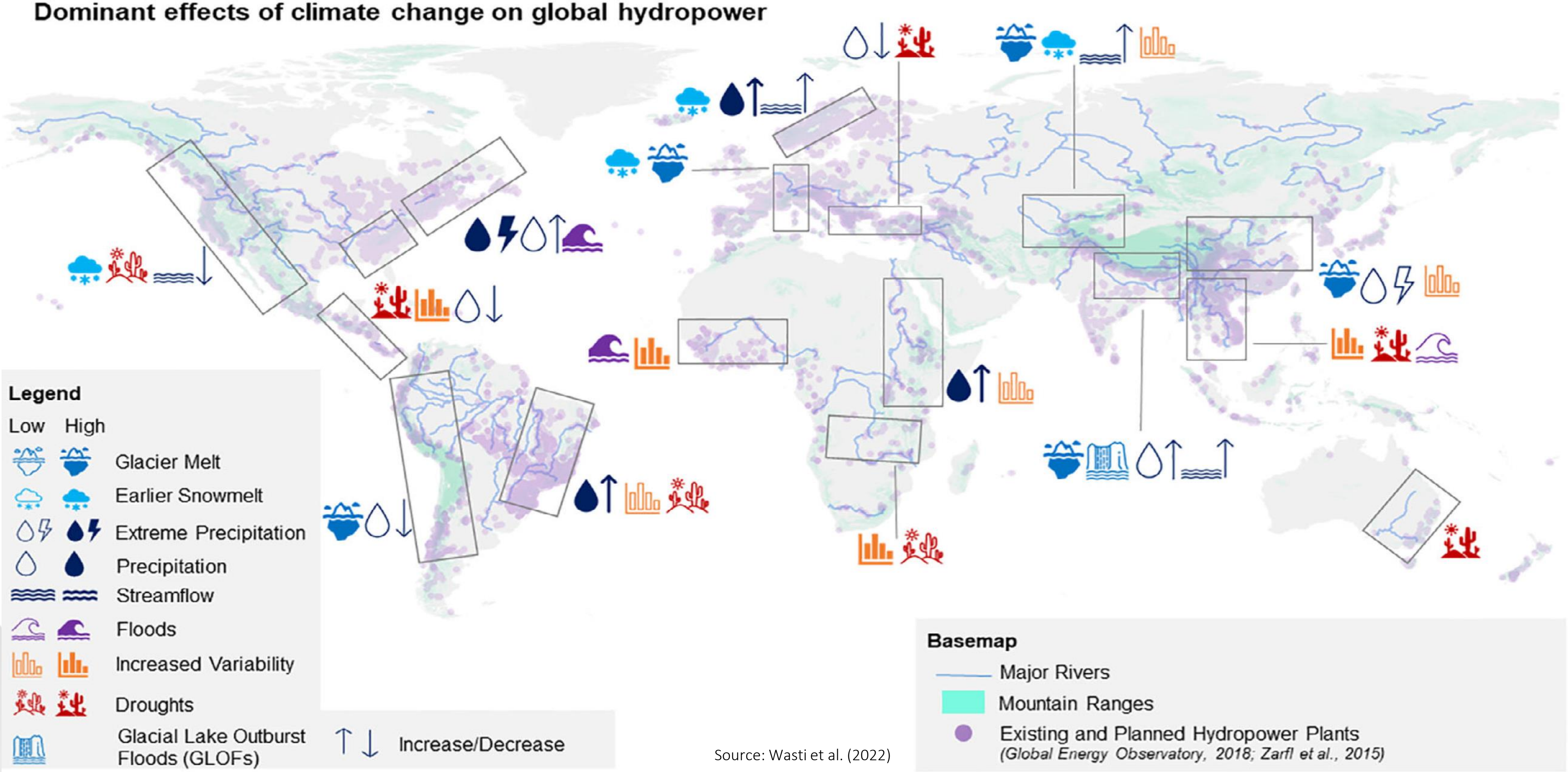
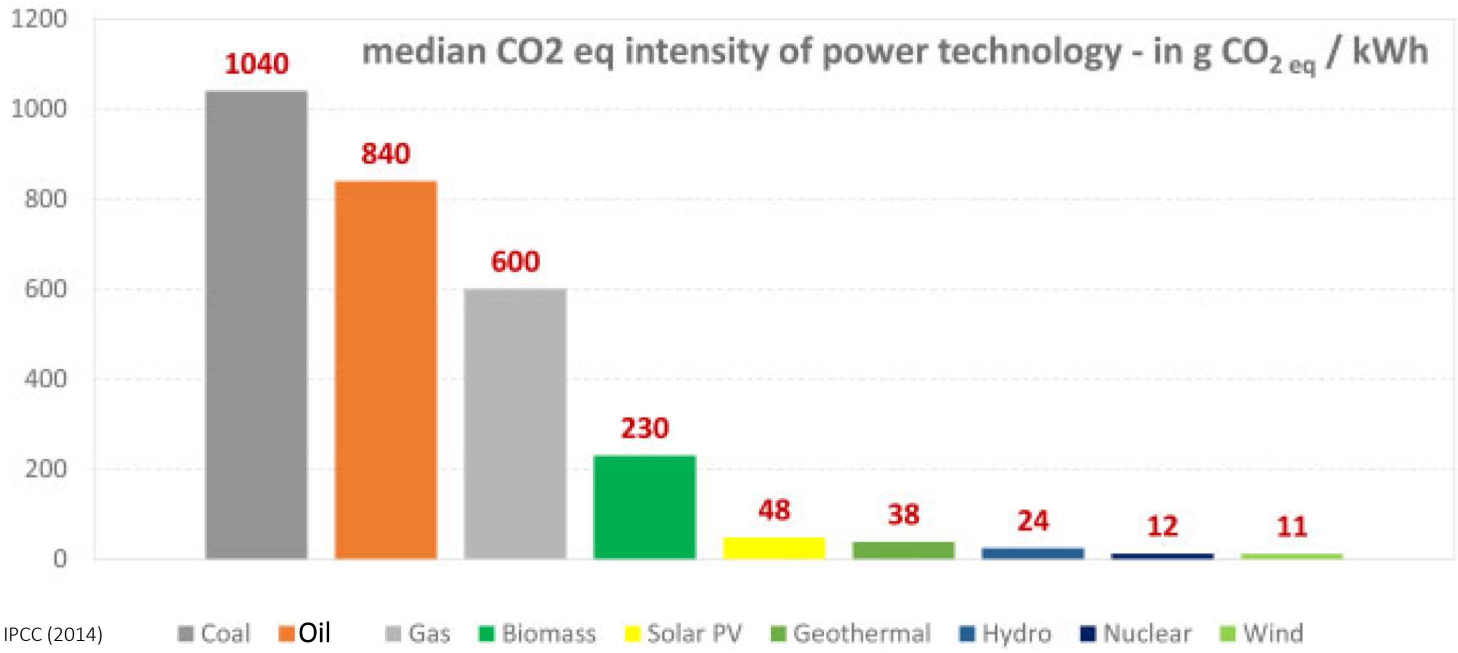


Source: Wasti et al. (2022)

Hypothesis: Climate change is bad news for hydropower?

- In the „old“ energy system, hydropower was often assigned the role of a reliable baseload provider
- In the„new“ energy system → very important roles for hydropower

(1) Ultra-low CO_2 emission factor



Source: IPCC (2014)

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(2) provision of flexibility services to electric grids

→ massive development of variable renewable energy with significant intermittency will have to be balanced by a fast response variable rate producer with: fast ramping reserve, inertia, black start capability

→ Hydropower as a catalyzer of the energy transition - could result in a renaissance of hydropower projects, also in the „old"economies:

- New pumped storage (see Trift case study and national survey in Switzerland)
- Hybridization of hydropower with battery storage, wind and floating PV in so-called virtual power plants (case studies Soflexhy (FRA) and Forshuvud Hybrid (SWE))
- Coupling hydropower generation with hydrogen generation

Conclusion

Conclusion

- Importance of detailed project-specific climate impact assessment

  (one good method is described in the IHA climate resilience guide, 2019)
- However, climate change projections at the site-level remain difficult

→ Adaptable management under uncertainty is very important

  - based on local data (precip, streamflow, snowcover, soil moisture)
  - short and medium-term forecasting
  - regular updating of reservoir operation rules (Angara River case study)

- The answer to the question of whether climate change is bad news for hydropower is clearly dependent on the location
- Surely, hydropower is good news for climate change adaptation, as HP is vital in transitioning to the new energy system

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THANK YOU FOR YOUR ATTENTION!

Three hypotheses & your opinions

- **Hypothesis 1**

„Drought risk adaptation investments in dams are worthwhile and should be expedited?“

- **Hypothesis 2**

„Climate change will cause increases of design floods?“

- **Hypothesis 3**

„Climate change is bad news for hydropower?“

YOUR VOTE: STRONGLY AGREE AGREE NEUTRAL DISAGREE STRONGLY DISAGREE

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