Water sharing policies for drought conditions to inform Grand Ethiopian Renaissance Dam operations

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2020 International Conference on the Nile and Grand Ethiopian Renaissance Dam: Science, Conflict Resolution and Cooperation

August 21, 2020

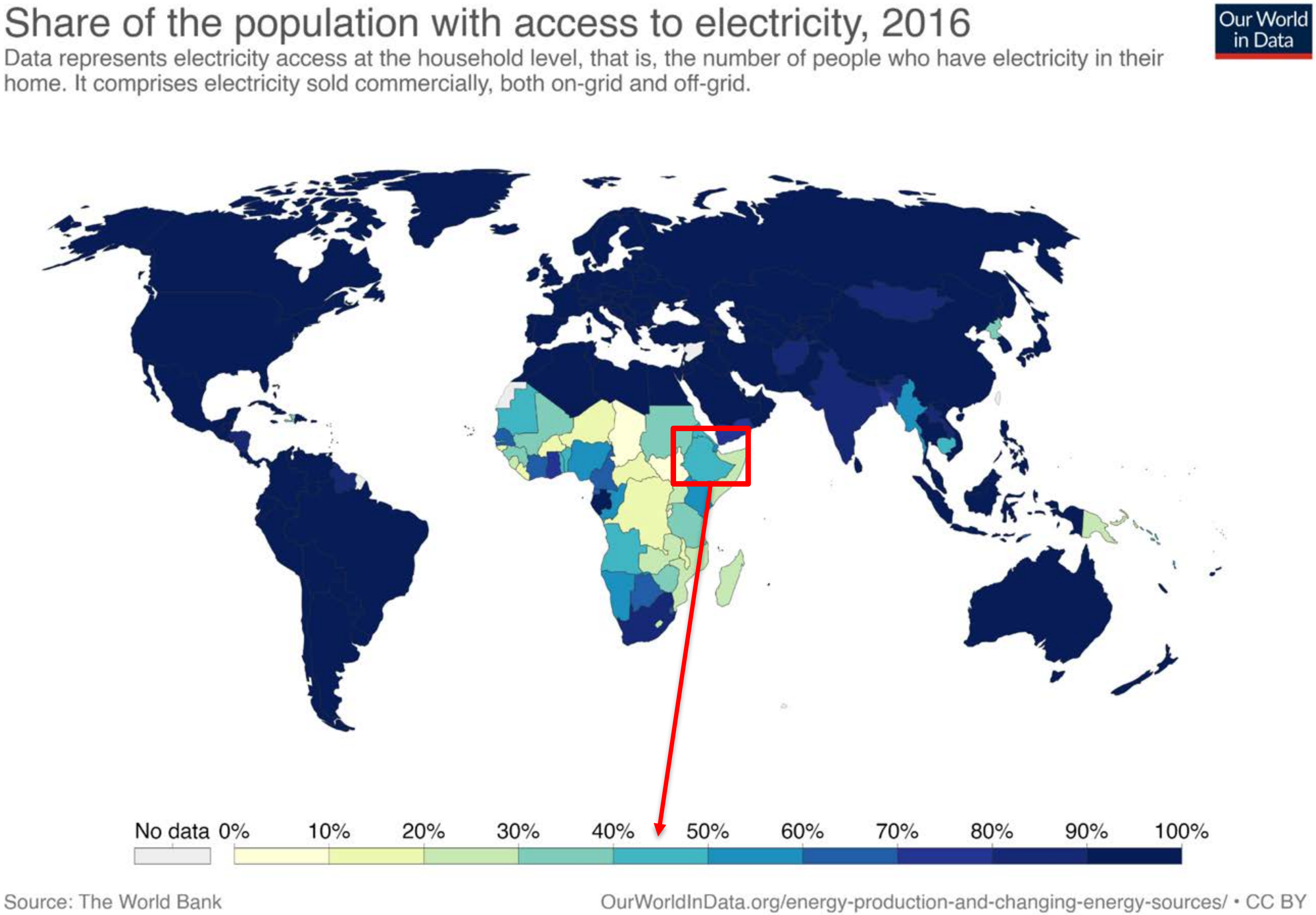
Nile basin and Grand Ethiopian Renaissance Dam (GERD)

The GERD situated on the Blue Nile River in western Ethiopia, will have an installed capacity of over 6,000 megawatts, and create a 74 cubic kilometer reservoir.

After construction, this dam will be the first major infrastructure project in Ethiopia on the main stem of the Blue Nile.

Grand Ethiopian Renaissance Dam (GERD)

GERD construction and electricity demand in Ethiopia



https://ourworldindata.org/energy-production-and-changing-energy-sources

Nile River conflicts and GERD operation

Water conflicts in Nile River Basin

- 60% of Ethiopian households are not covered by power grid and 40% of connected people suffers from disruptive power cuts.
- Most of Egyptians rely on Nile from drinking water to industrial use and irrigation.
- There is no legal framework for water allocation agreed by all riparian countries.

Impact of GERD operation

- The GERD operation can significantly alter downstream flows, potentially leading to water resources management conflicts and disputes. (e.g., by making other water infrastructures vulnerable to drought or flood)

Water Sharing for drought conditions

- Will there be enough water from the GERD reservoir to mitigate drought? (trade-off between power generation and drought mitigation)
- How the GERD will be operated, particularly during droughts?
- Is it possible to inform the drought mitigation with hydrological forecasts?

Water sharing policies for drought conditions

Drought mitigation policy development

Multi-objective optimization

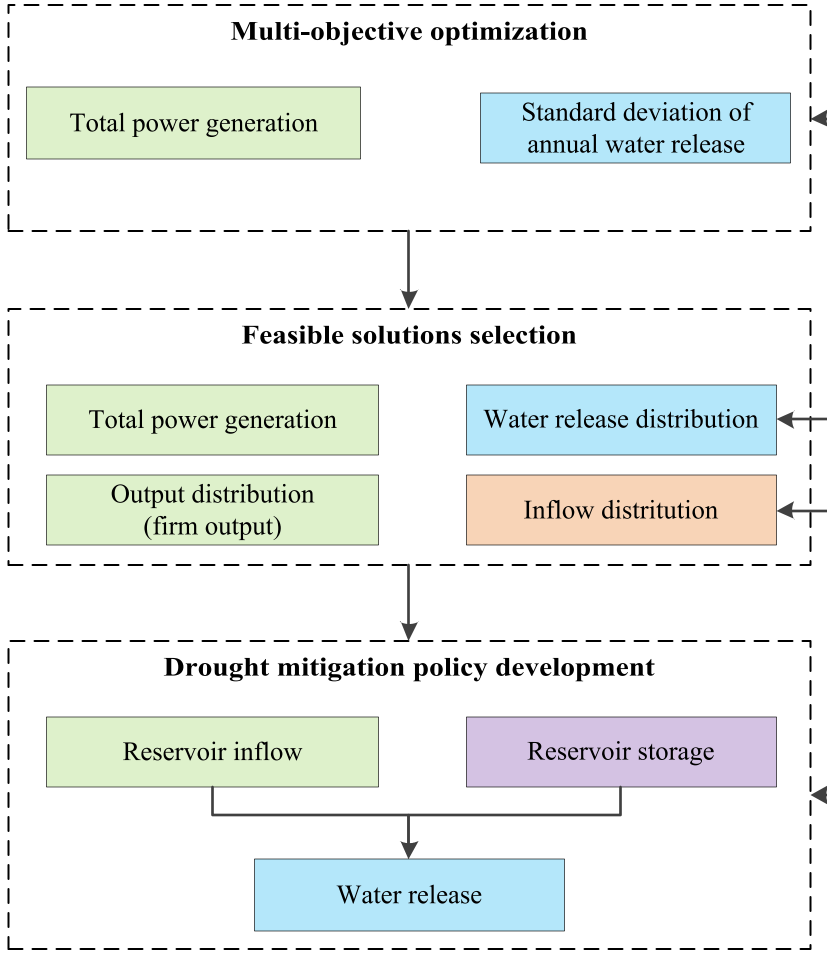
- Ensure enough water for power generation and drought mitigation simultaneously.

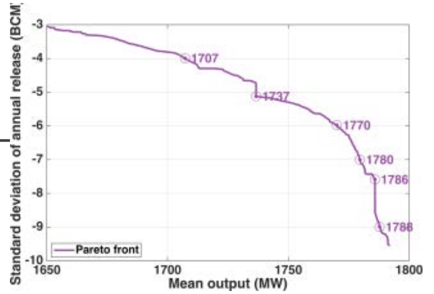
Water release analysis

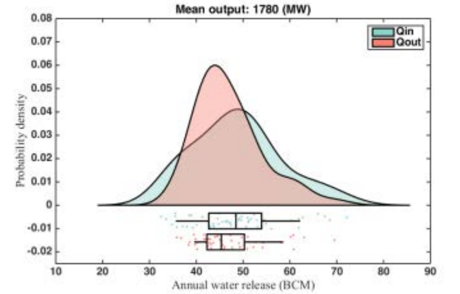
- Release enough water from the reservoir to help mitigate drought downstream.

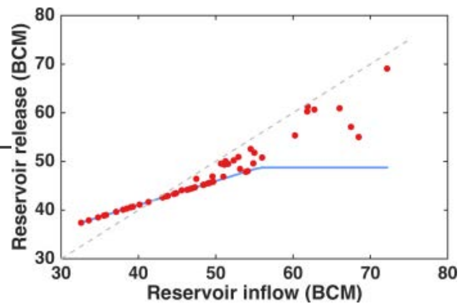
Drought mitigation policy

- Guide the GERD reservoir operation, especially in drought conditions.







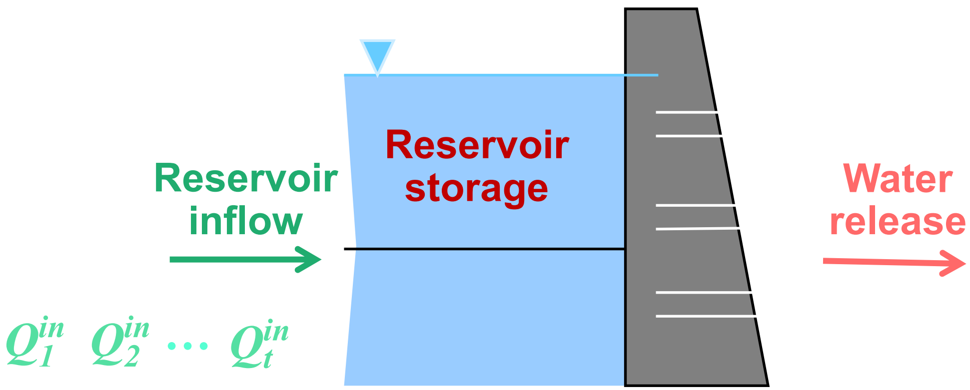


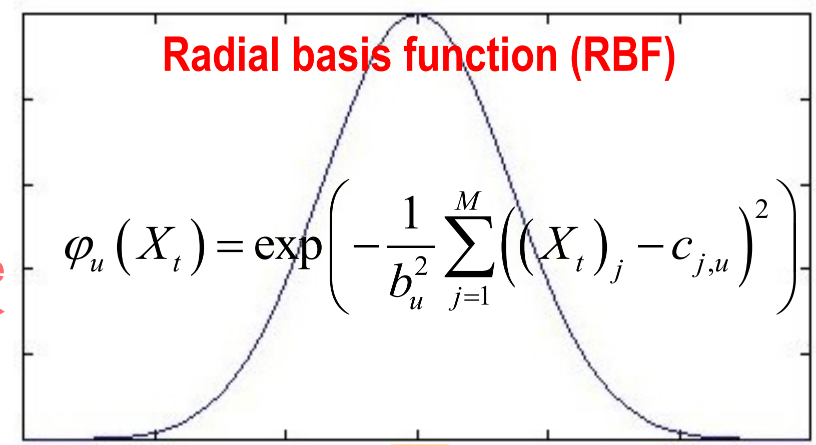
GERD reservoir operating rules

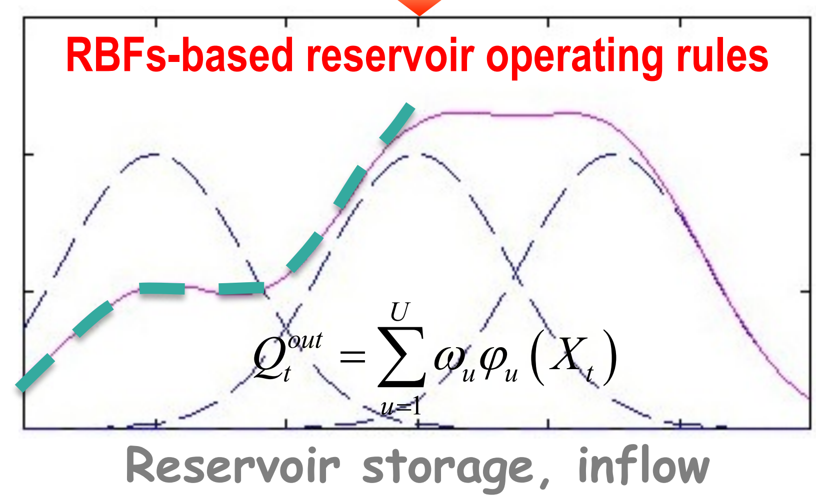
Radial basis functions (RBFs) for reservoir water release $Q_t^{out} = \text{RBFs}(X_t)$

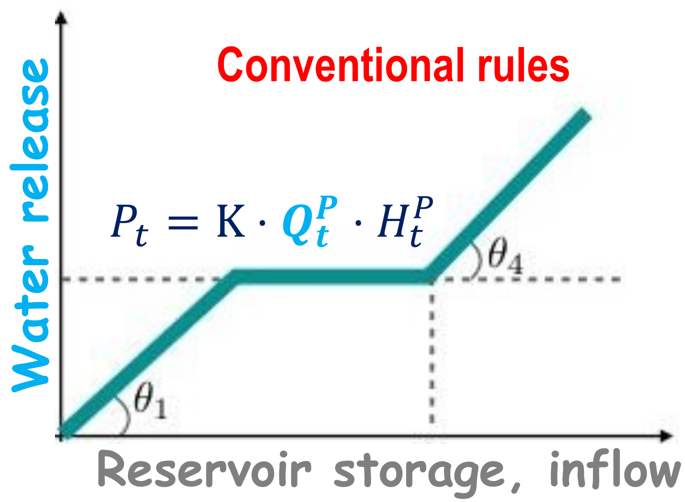
$\mathbf{X}_t = (S_t, Q_t^{in}, \tau_t)$

S_t, Q_t^{in}, and τ_t **are the reservoir storage, inflow, and seasonal information in period** t**, respectively.**



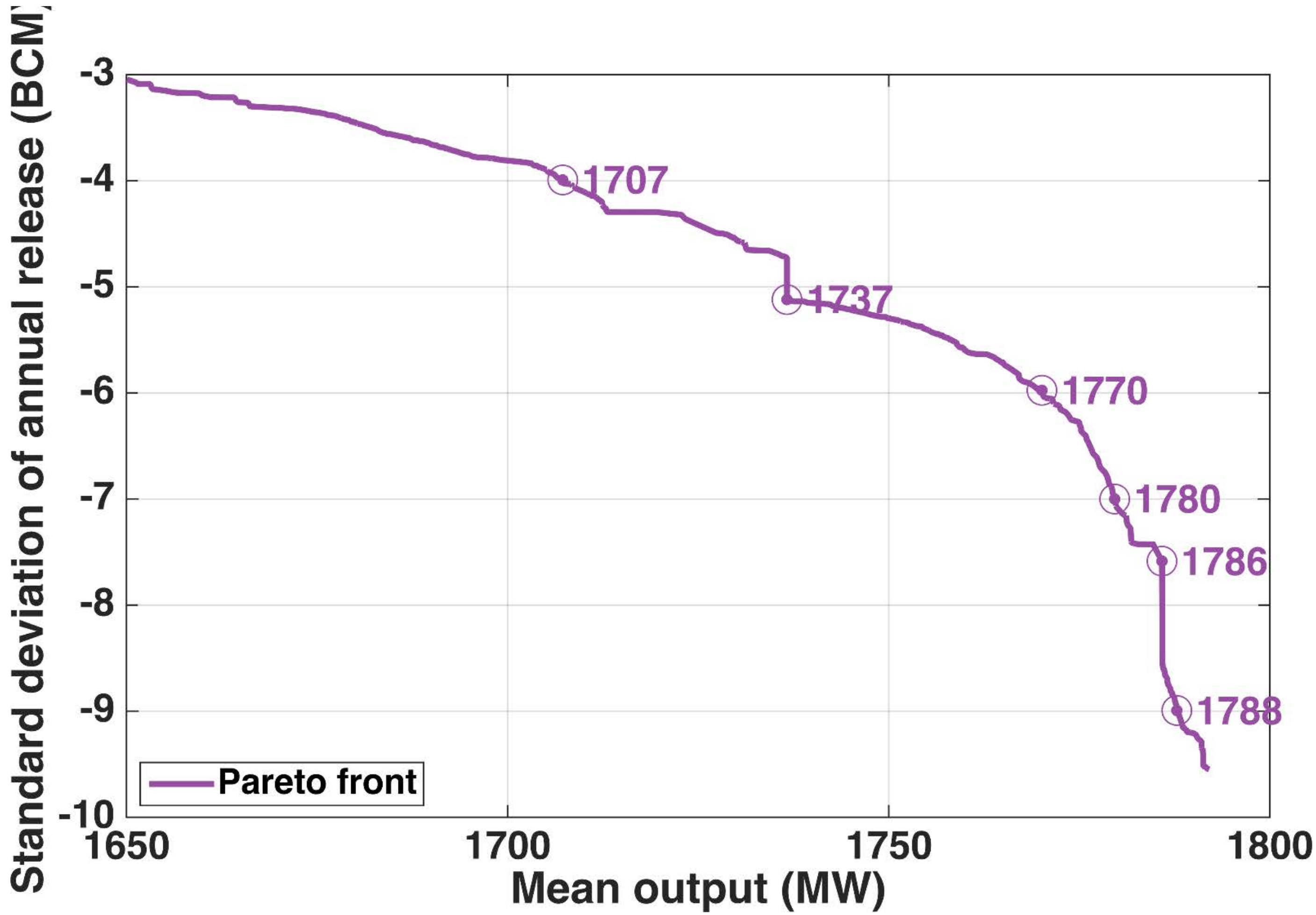






GERD reservoir operating rules optimization

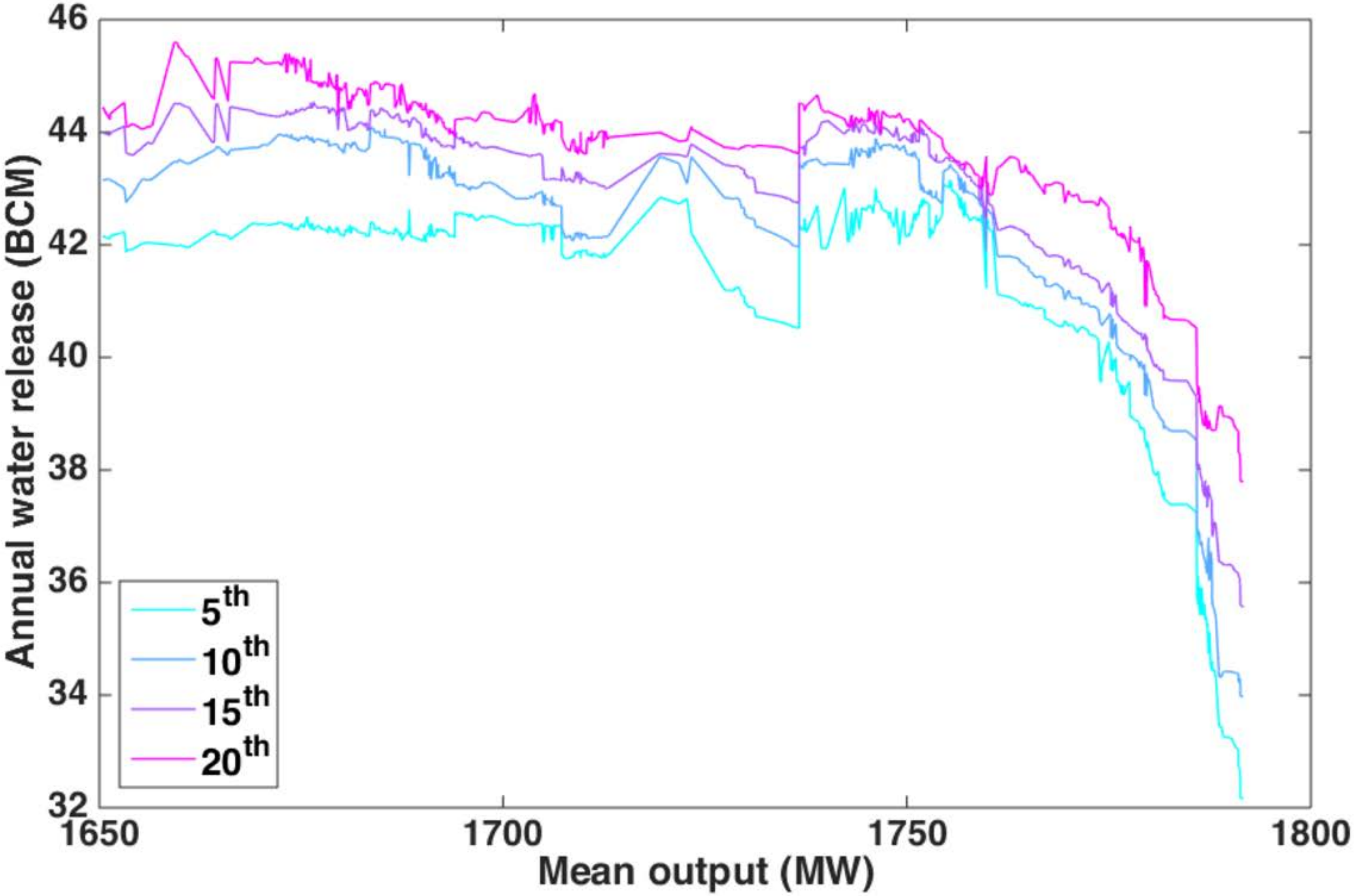
Pareto front of multi-objective optimization (1965-2017)



A slight decrease in power generation can lead to significant decrease in the standard deviation of annual water release

GERD reservoir operating rules optimization

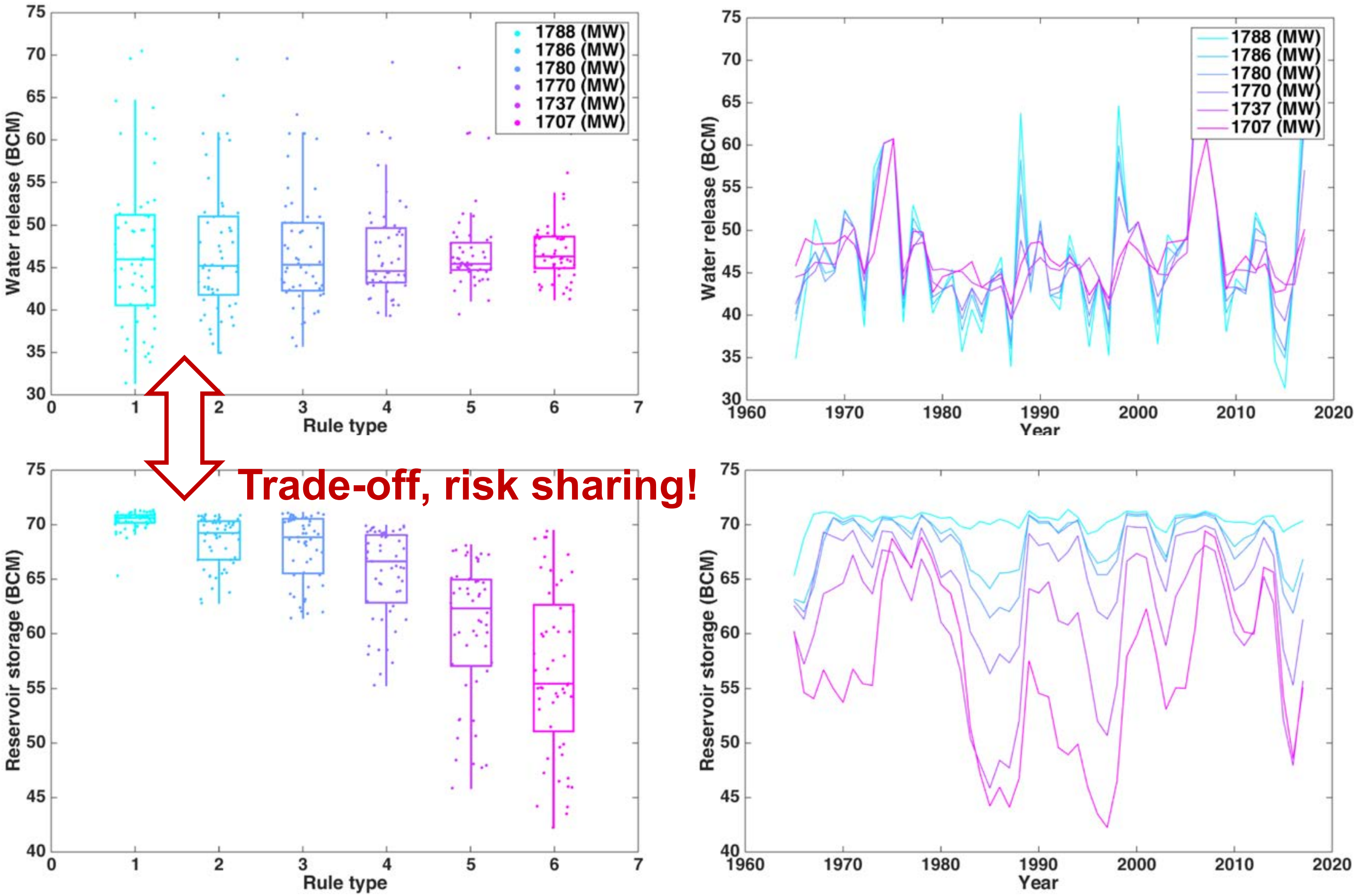
Power generation output and annual water release percentiles (1965-2017)



The Pareto front from multi-objective optimization can represent the trade-off between power generation and downstream water release in drought conditions.

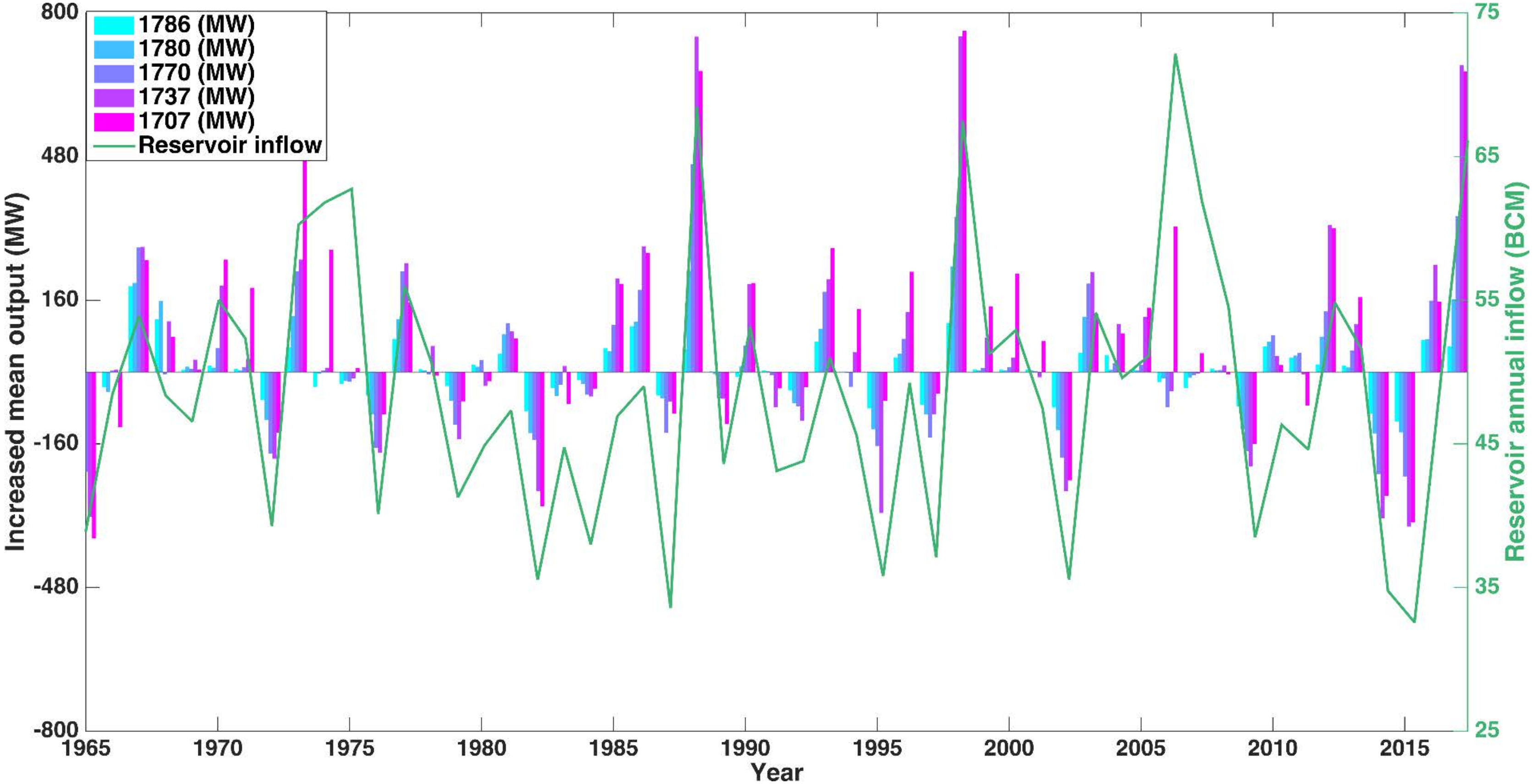
GERD reservoir operating rules optimization

Boxplots and values of annual reservoir water release and storage



GERD reservoir operating rules optimization

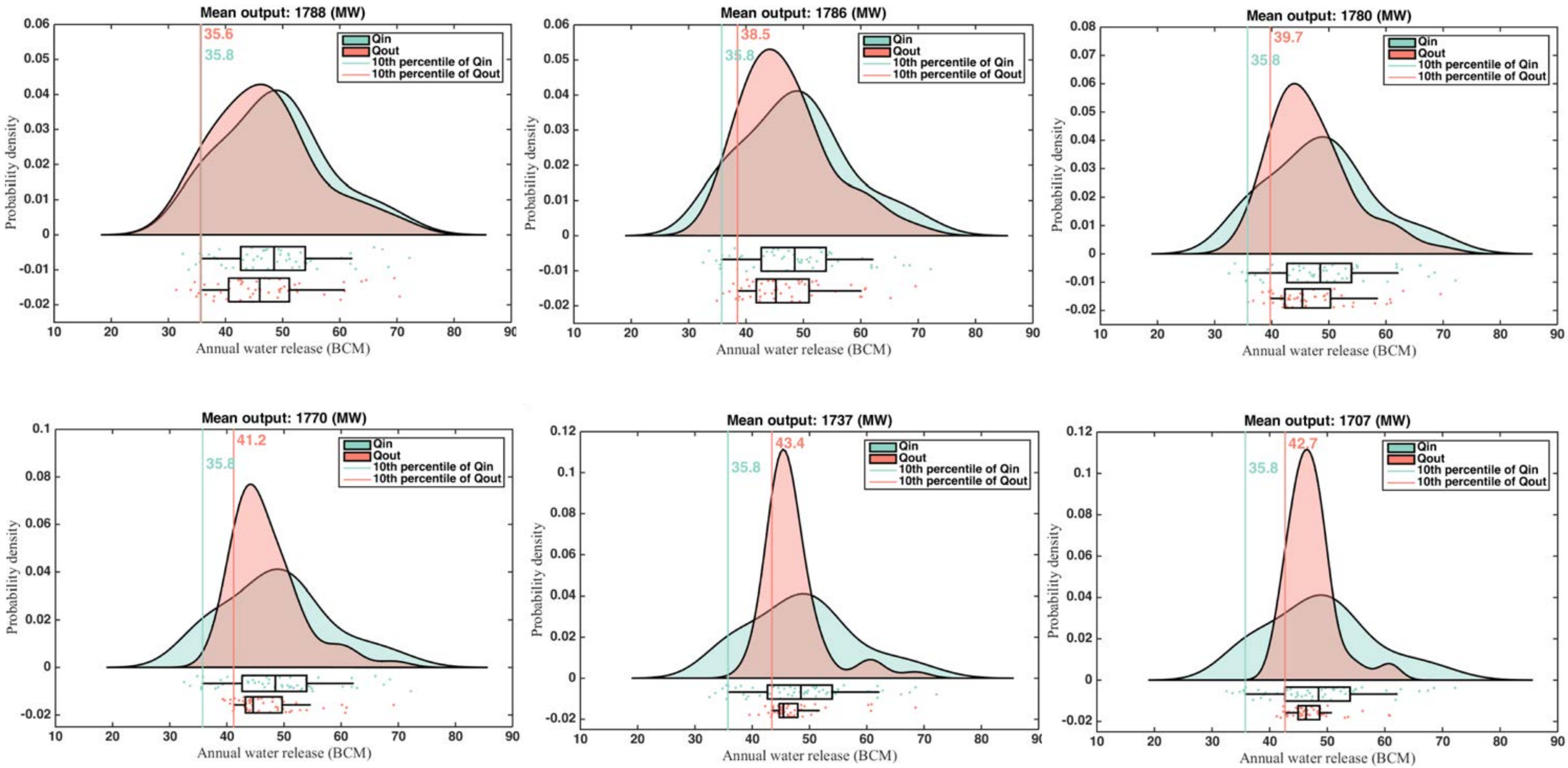
Increased power generation output (maximizing mean output) over other reservoir operating rules



Power-generation-oriented GERD operating rules increase power generation mainly in wet years by decreasing the water release in dry years to ensure high water level.

GERD reservoir operating rules optimization

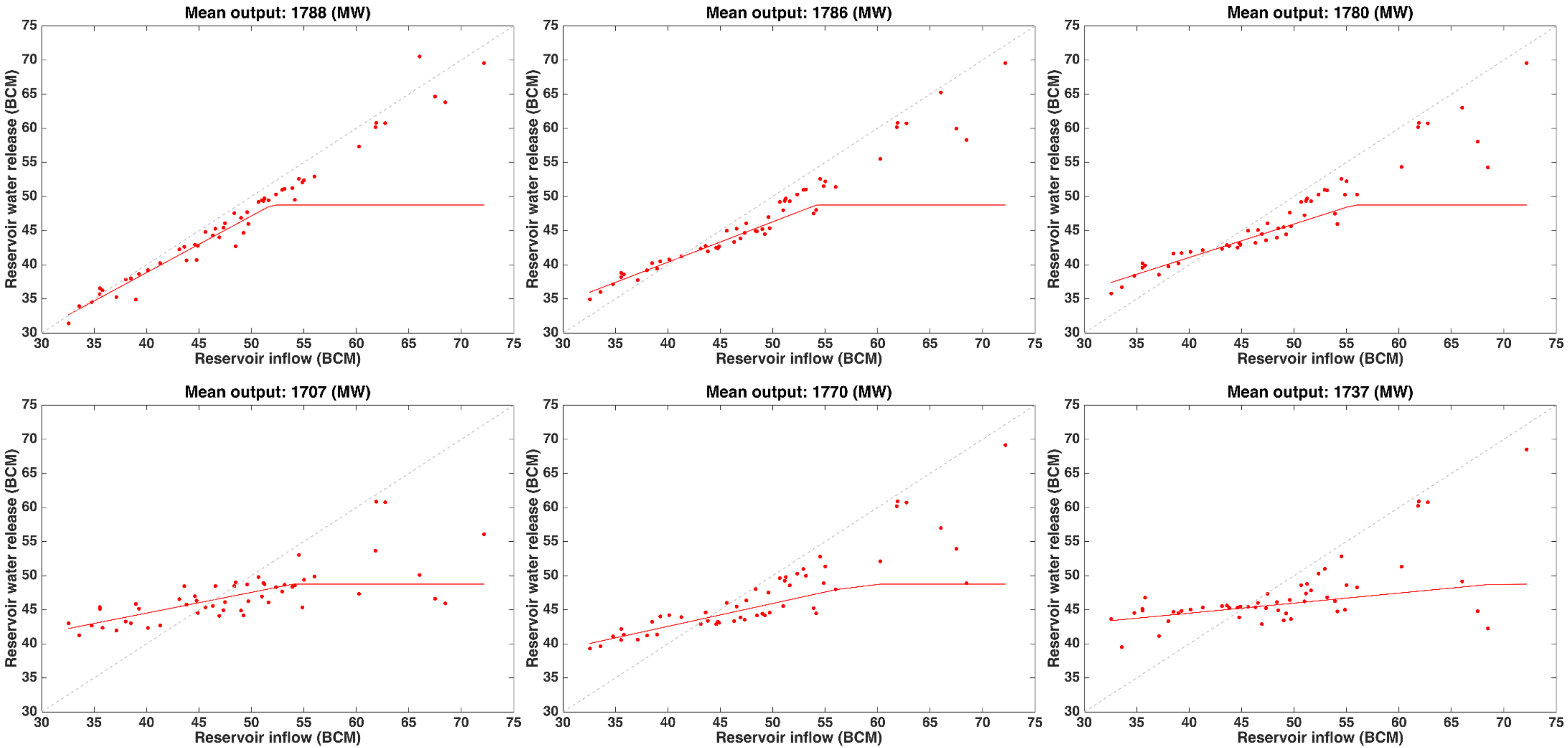
Kernel distribution of annual reservoir inflow (Qin) and water release (Qout)



The relationship between distributions of the GERD annual inflow and water release can be used to balance the GERD power generation and downstream drought mitigation.

GERD reservoir operating rules optimization

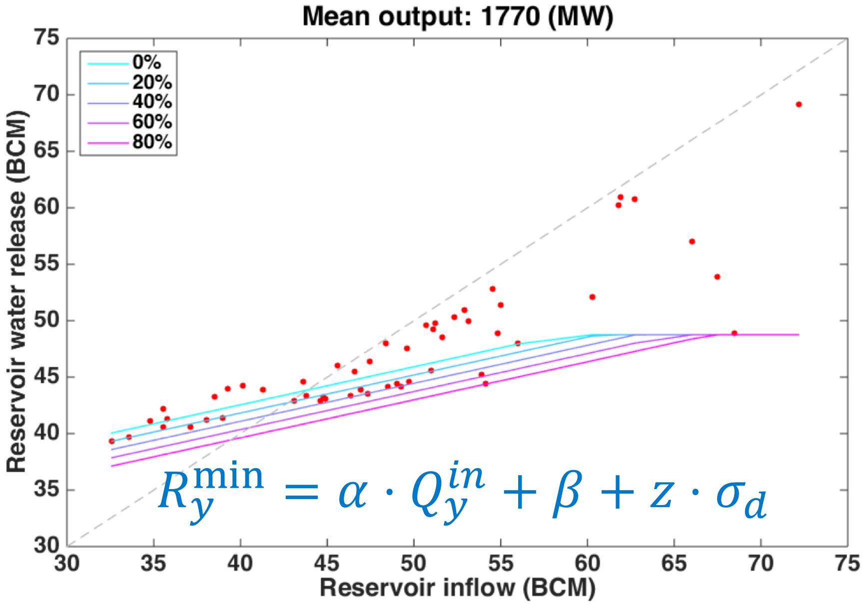
Relationship between annual reservoir inflow (Qin) and water release (Qout)

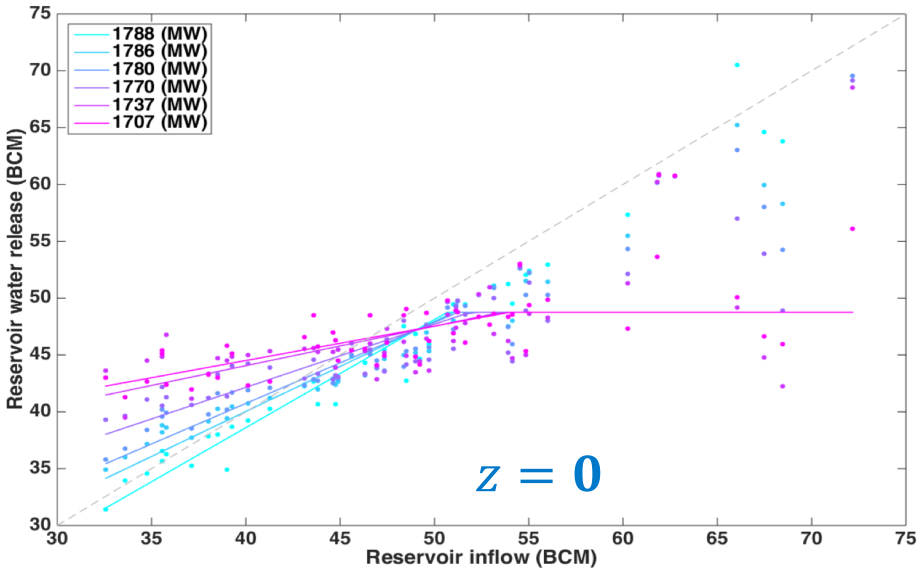


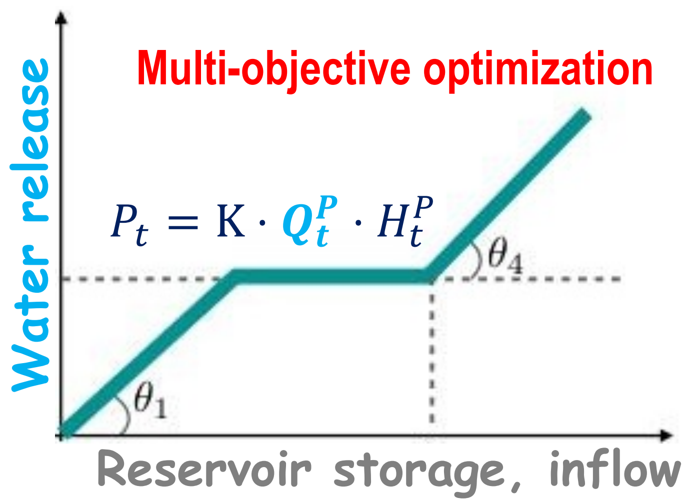
There is evident relationship between annual reservoir inflow and water release, which can be used to derive water sharing policies.

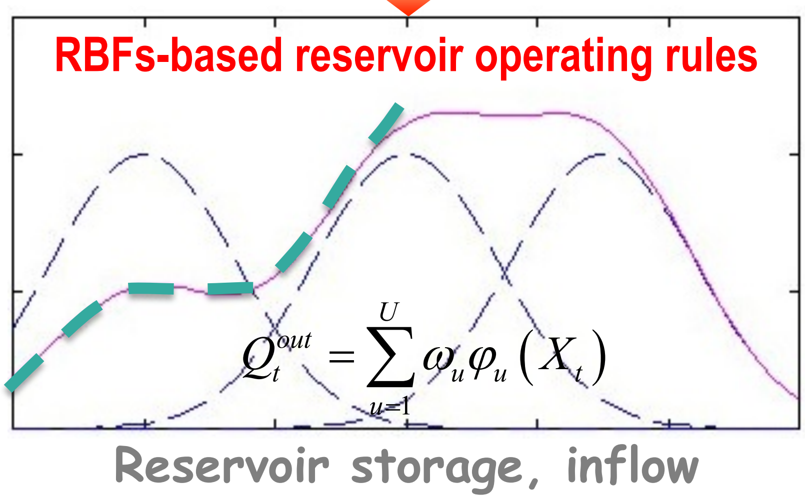
Water sharing policies for drought conditions

Drought mitigation policy



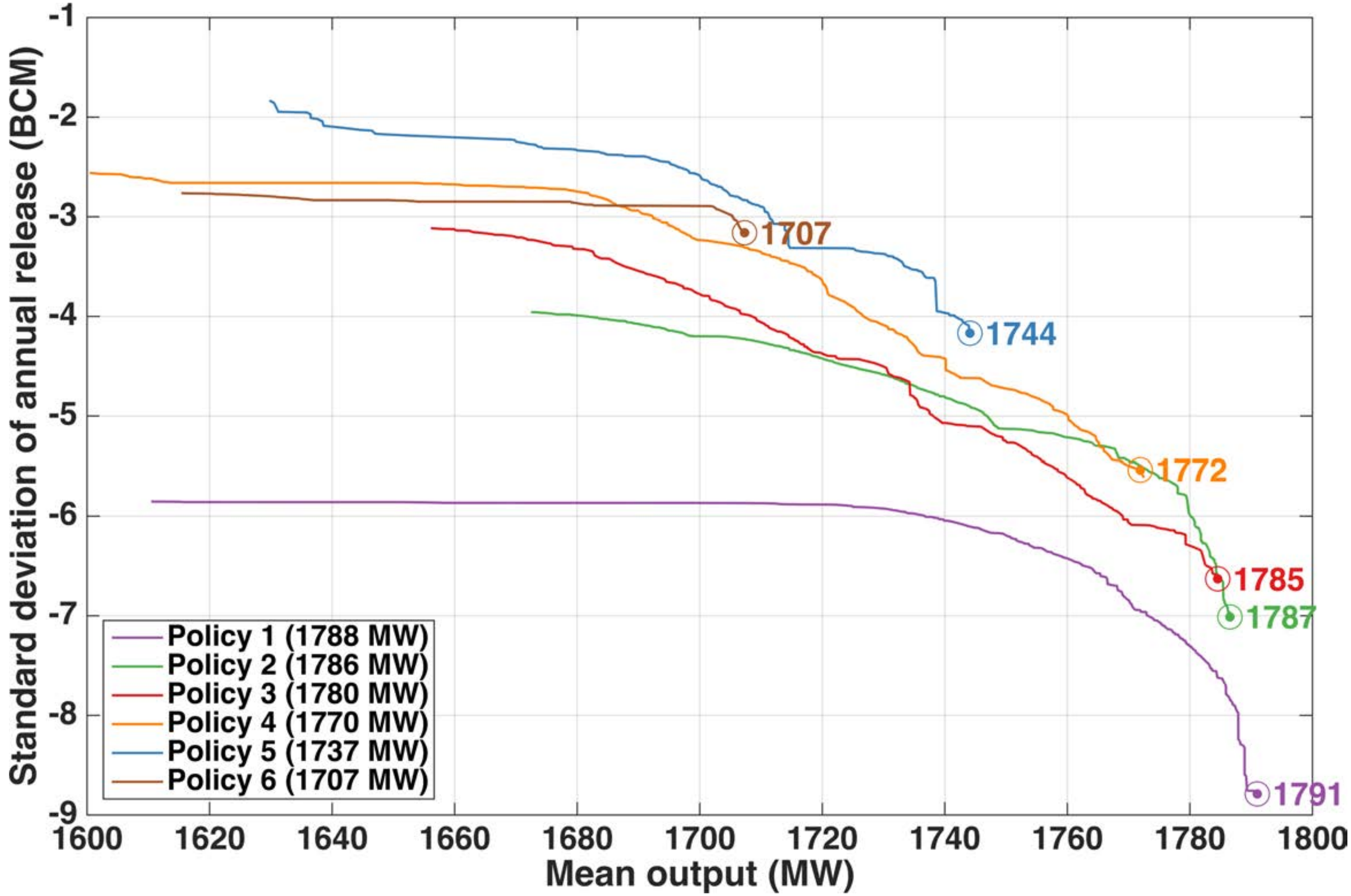






Water sharing policies for drought conditions

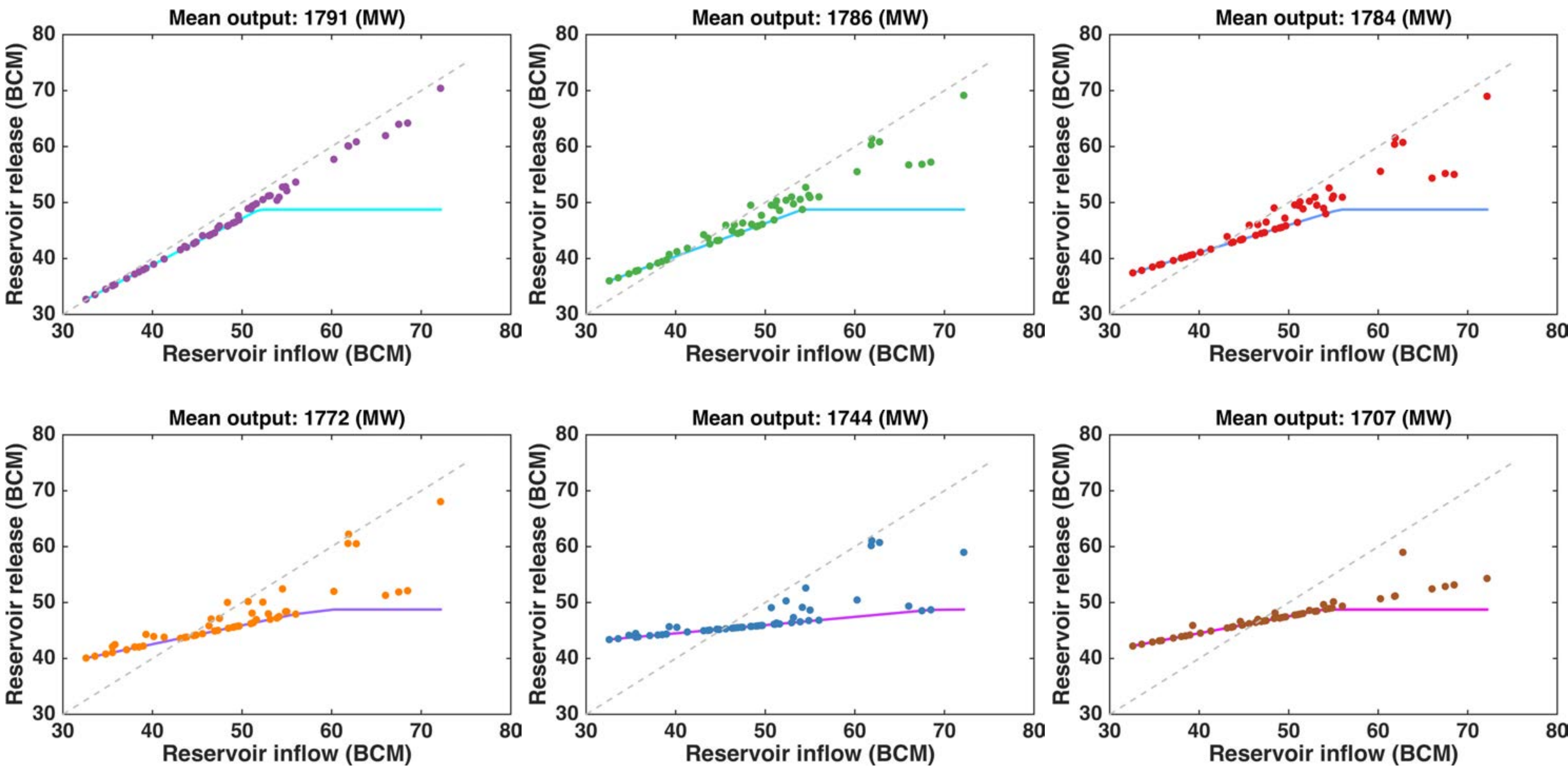
Pareto front with drought mitigation policies (1965-2017)



The maximum power generation optimized from the water sharing policy is close to the corresponding power generation.

Water sharing policies for drought conditions

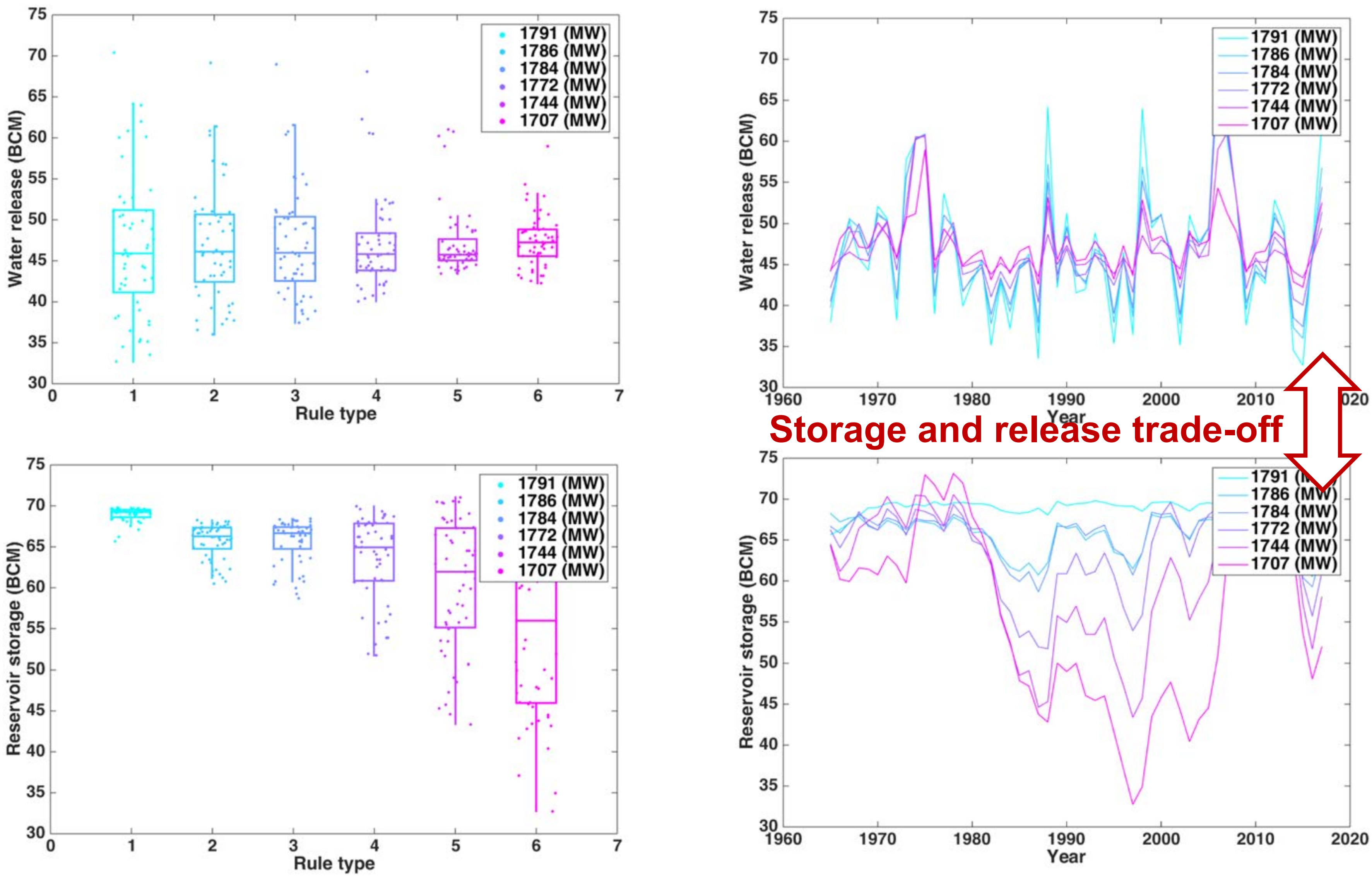
Relationship between annual reservoir inflow (Qin) and water release (Qout)



The water sharing policy can effectively mitigate the downstream drought without significantly decreasing power generation.

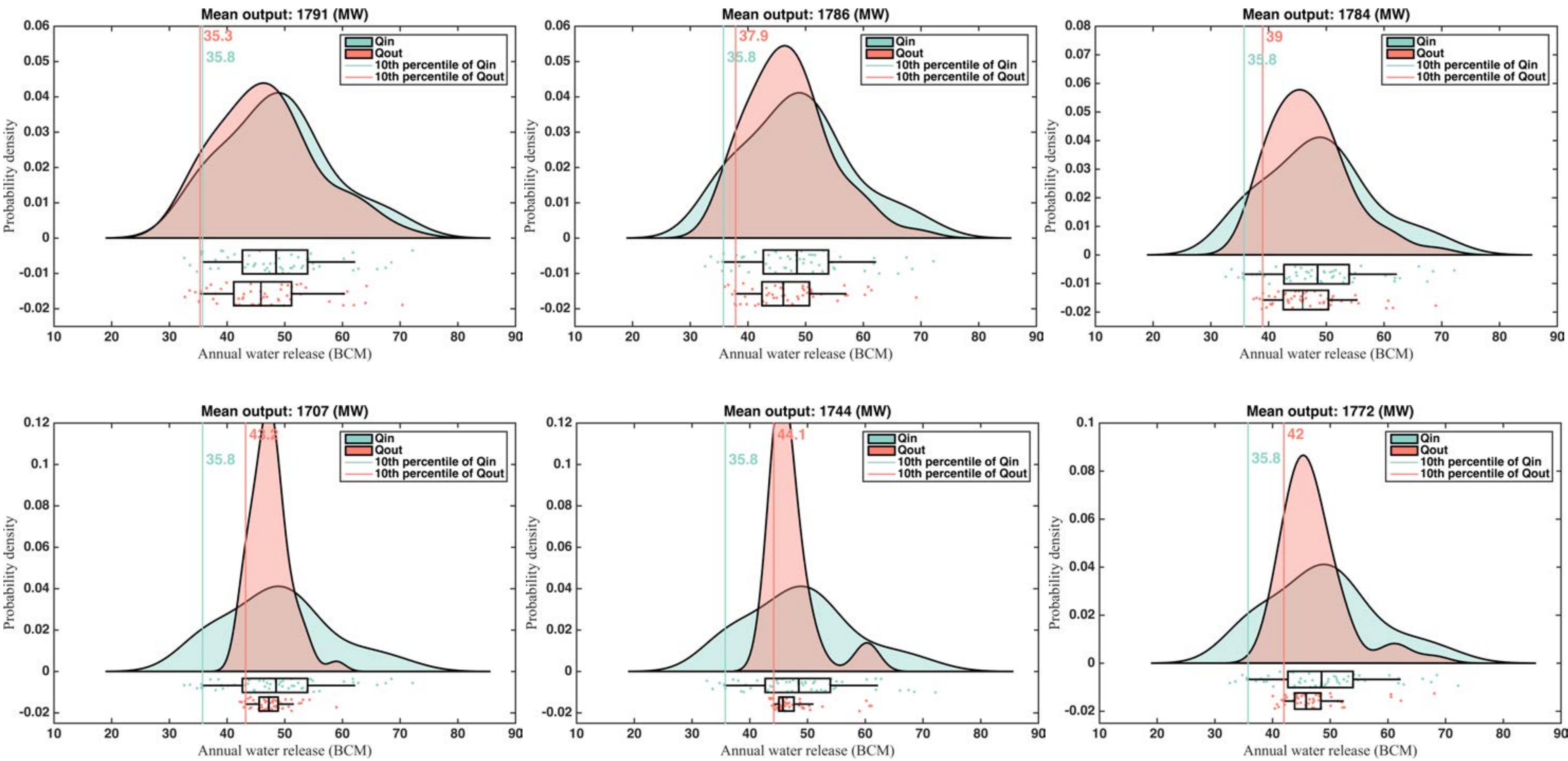
Water sharing policies for drought conditions

Boxplots and values of annual reservoir water release and storage



Water sharing policies for drought conditions

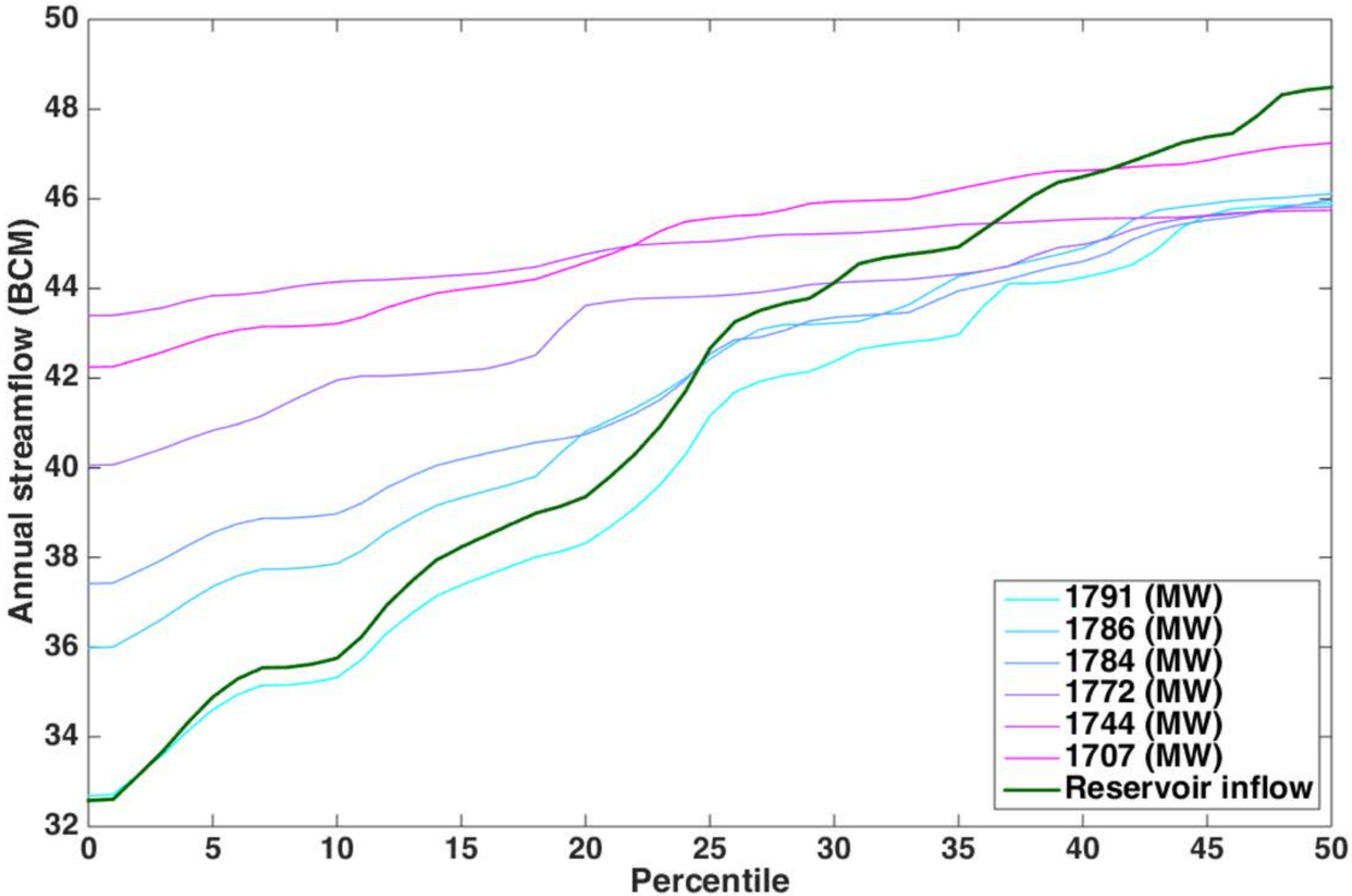
Kernel distribution of annual reservoir inflow (Qin) and water release (Qout)



Validation of the water sharing policy

Water sharing policies for drought conditions

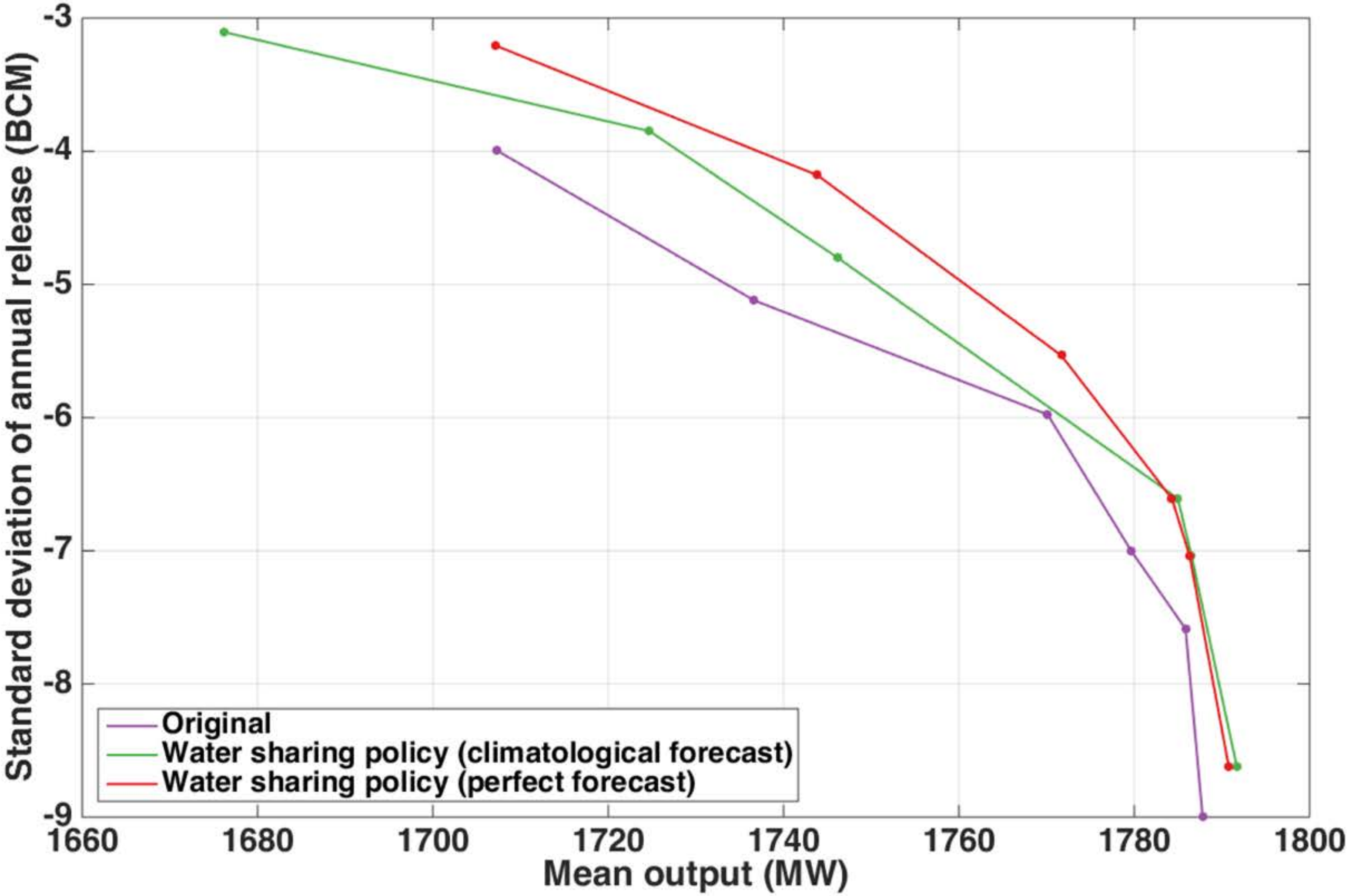
Percentiles of annual reservoir inflow and water release under various power generation levels



Water sharing policy validation and selection

Water sharing policies for drought conditions

Pareto fronts from original and water sharing policy optimization



The performance of water sharing policy is not sensitive to the forecast accuracy.

Summary

There is a trade-off between GERD hydropower generation and dry year water release, a slight decrease in power generation can lead to significant annual water release increase under dry conditions.

The relationship between distributions of the GERD annual inflow and water release can be used to balance the GERD power generation and downstream drought mitigation.

The water sharing policy derived from optimal GERD operating rules can effectively mitigate the downstream drought without significantly decreasing power generation.

Although the implement of water sharing policy relies on annual streamflow forecast, its performance is not sensitive to the forecast accuracy.

Acknowledgements

Paul Block, University of Wisconsin-Madison

Water Systems & Society Research Group
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Thank you very much!

Questions?