Climate Change, Hydropower Dam Capacity, and Flood-Overtopping

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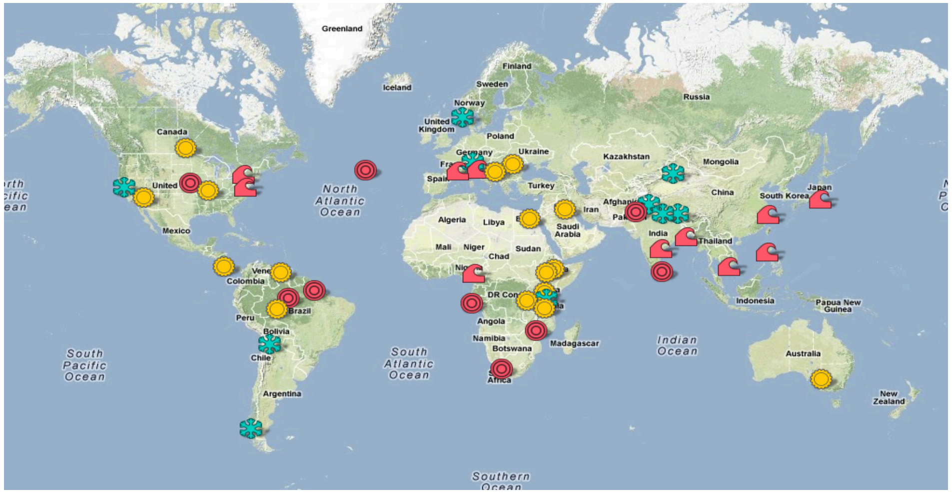
UCONN

Motivation

- Dam construction has increased rapidly, especially in developing countries
- Climate change is likely to impact **future water and sediment flows** in rivers
- It is important to consider these factors in deciding the capacity of a dam, the size of the spillway and the timing of dam construction and removal



Existing Literatures

- **Palmieri, Shah, Annandale & Dinar (2003)** used dynamic optimization methodology to analyze life cycle management of a dam that has a given reservoir capacity and is subject to sedimentation
- **Nassopoulos et al. (2012)** performed benefit-cost analysis for reservoir capacity determination when water flows are variable due to climate change
- **Xie & Zilberman (2014)** developed a theoretical economic model for determining optimal capacities of diversion dams which incorporates stochastic water inflows
- **Beilfuss & Triet (2014)** introduced the impact of climate change on Mekong river basin hydrology and hydropower generation
- **Shrestha et al. (2012)** evaluated the impact of climate change on sediment yield in the Mekong river basin
- **Keskinen et al. (2009)** estimated the monthly discharges and flood level of the Mekong at Kratie based on climate change

Contributions

- Our research modifies the RESCON model to allow annual incoming sediment as well as water inflow to be impacted by climate change
- The dam failure cost is also incorporated into the model based on expected annual peak flood flow trends
- The focus of our attention is determination of optimal reservoir capacity and timing of construction and removal rather than sediment management
- Another innovation is determination of an optimally sized spillway to protect against flood overtopping

Theoretical Model: Assumptions

For purposes of simplification, we limit our analysis of initial reservoir capacity choice to a deterministic setting and to a hydroelectric dam that has the following features:

- Reservoir capacity declines over time with sedimentation, but no sediment removal is allowed
- Dam is decommissioned after it is silted
- All water stored in the wet season is utilized in the dry season of the same year
- Climate change impacts temperature, precipitation, and evaporation rates, all of which leads to changes in mean annual water and sediment inflows and the peak flood level

Theoretical Model: Optimal Dam Capacity

The hydroelectric dam's initial reservoir capacity (S_0) is chosen to maximize its lifetime net present value

$$\max_{S_0,R} NPV = \int_{t=0}^{T} \{P_w * W_t(S_t, \delta_t) - OMC(S_0)\} e^{-rt} dt - CC(S_0) - RC(S_0)e^{-rT} - SC(R)$$

$$\textit{subject to:} \quad \frac{ds}{dt} = -(1+\theta_t)M_t, \quad S_0 \leq V_{in}, \quad W_t \leq V_{in}$$

Where: $OMC(S_0) = omc * c * S_0$

$CC(S_0) = c * S_0$

$SC(R) = m * R$

omc = maintenance and operation coefficient

c = unit cost of dam construction

m = spillway capacity coefficient

Theoretical Model: Optimal Dam Capacity

Notation:

S_0 = initial reservoir capacity

P_w = price of water considering hydroelectricity

$OMC(S_0)$ = annual maintenance and operation cost

$CC(S_0)$ = construction cost

$RC(S_0)$ = removal cost of reservoir at terminal time (T)

$SC(R)$ = spillway construction cost

R = spillway capacity

M_t = annual incoming sediment

θ_t = climate change adjustment factor for incoming sediment

Theoretical Model: Water Yield Function

Reliable water yield can be calculated by Gould’ s gamma function (Morris and Fan, 1998) as adapted to climate change situations by Lee, Yoon and Shah (2009)

$$W_t(S_t, \delta_t) = \frac{4 \cdot S_t \cdot (1+\delta_t) \cdot V_{in} - Zpr^2 \cdot sd^2 + 4 \cdot Gd \cdot sd^2}{4 \cdot (S_t + \frac{Gd}{(1+\delta_t) \cdot V_{in}} \cdot sd^2)}$$

Where: W_t = reservoir yield at time t

S_t = remaining reservoir capacity at year t

δ_t = climate change adjustment factor for water inflow

V_{in} = mean annual water inflow

Zpr = standard normal variate of p%

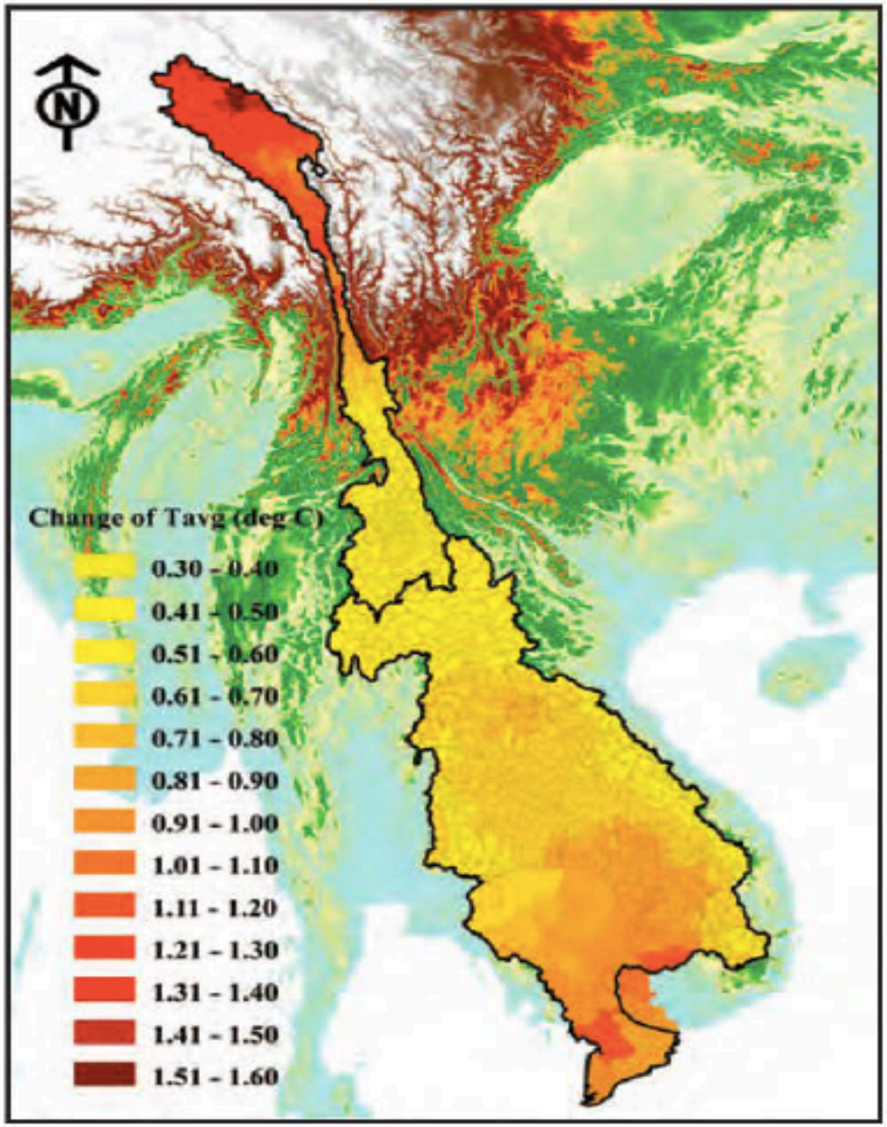
Gd = adjustment factor to approximate the Gamma distribution

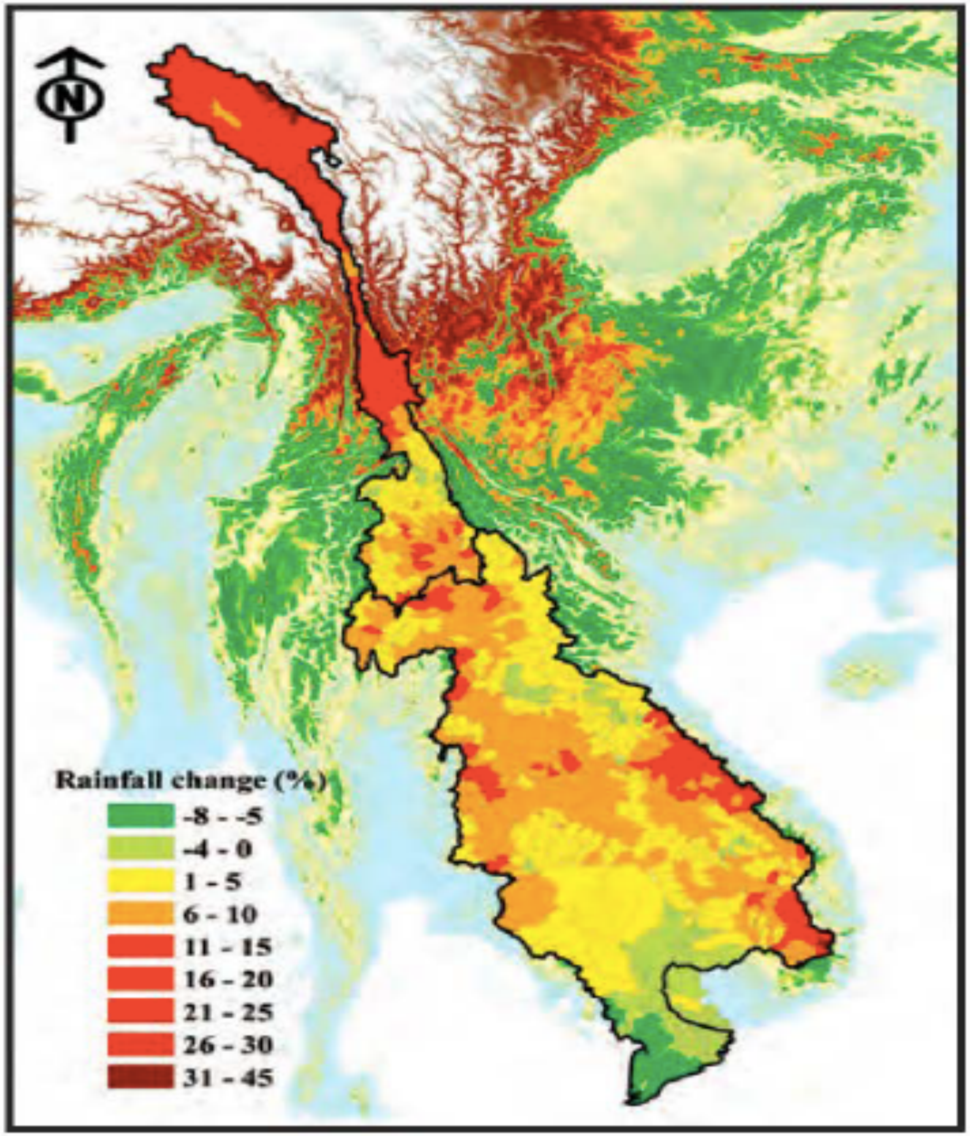
sd = standard deviation of incoming flows

Existing and Planned Dams on the Mainstream Mekong River

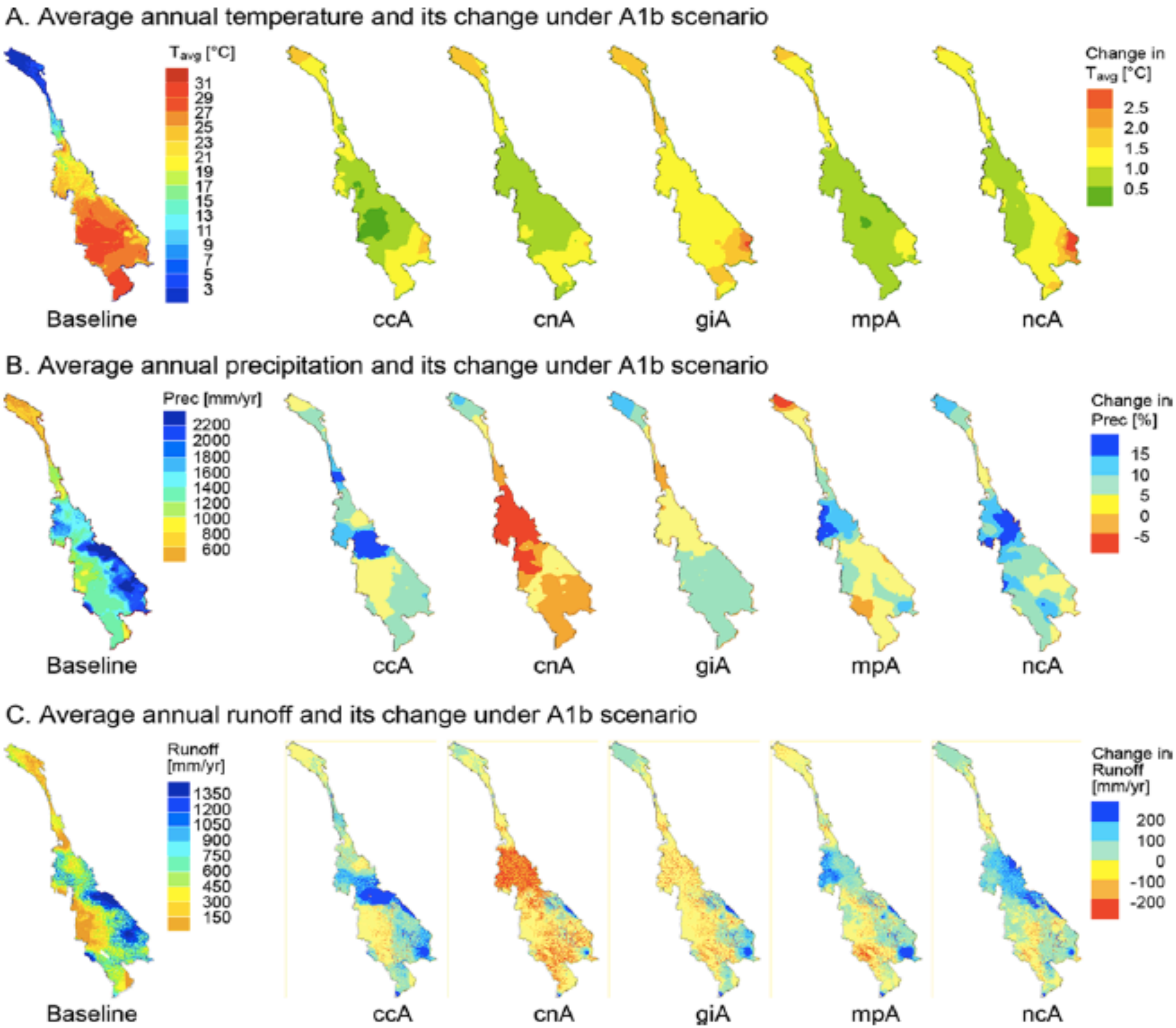
Source: www.internationalriver.org

50 years Climate Predictions for Case Study Area: Temperature & Precipitation Changes



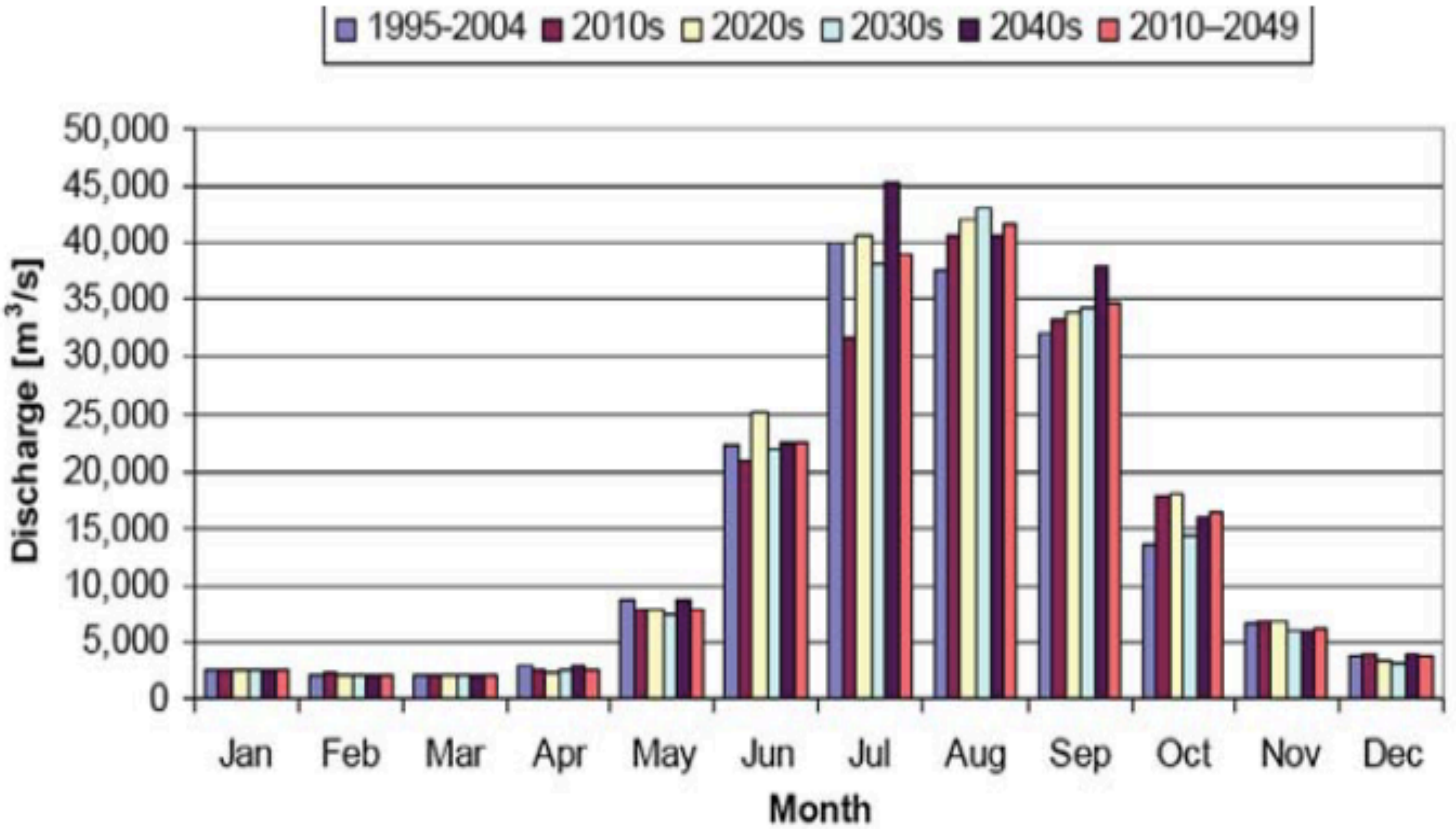


Source: Hoanh et al. 2010



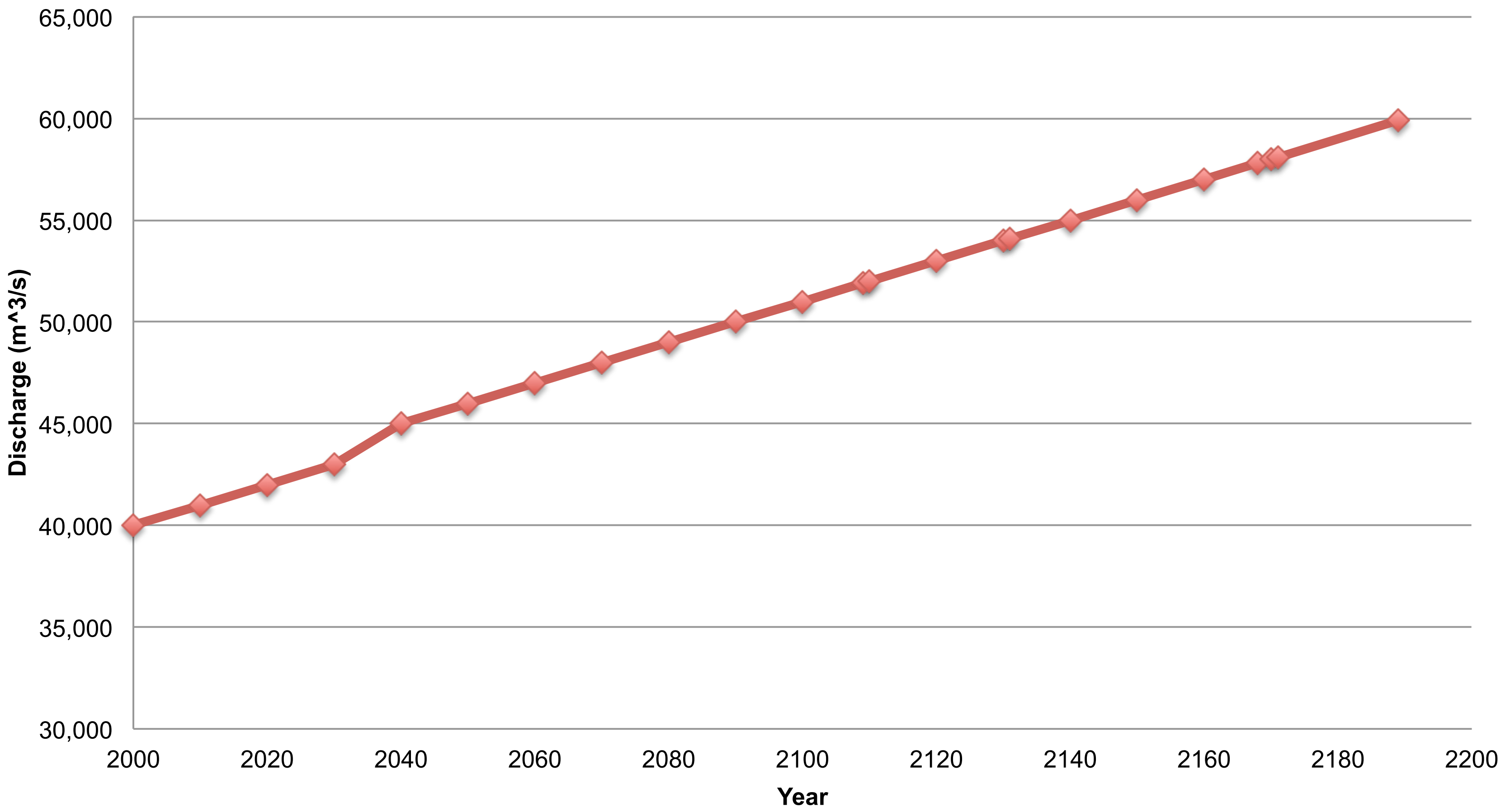
Source:Lauri et al. 2012

Peak Flood Discharge Prediction with Climate change: Sambor Dam (Planned)



Source: Marko Keskinen et al. 2009

Peak Flood Trend Prediction: Sambor Dam



Data for Case Study: Sambor Dam

Description	Value	Units
Price of water	0.25	$/m3
Mean annual water inflow	435,196.8	Million m3
Standard deviation of incoming flows	600	Million m3
Standard normal variation of p%	2.33	-
Adjustment factor of gamma distribution	1.5	-
Unit cost of dam construction	1.3	$/m3
Operations and maintenance coefficient	0.1	-
Annual incoming sedimentation	33.18	Million m3
Annual water Inflow adjustment based on climate change (IPCC)	-0.002	%
Annual incoming sediment rate adjustment based on climate change	+/-0.3	%
Coefficient of Spillway capacity	0.1	-

Results

	Reservoir Capacity (Million m3)	Spillway Capacity (m3/s)	Net Present Value (Million $)	Period of Operation(y)
Designed	3794	17,668	-	-
Vin & *Mt* Constant	5015	58,000	1,993,972	151
Vin Decreasing *Mt* Constant	5014	58,000	1,993,029	151
Vin Decreasing *Mt* Increasing	6003	57,800	1,991,559	148
Vin Decreasing *Mt* Decreasing	4190	59,900	1,994,266	169

Summary and Conclusion

- Optimal choice of dam capacity is significantly impacted by climatic factors, water availability and the rate of incoming sediment
- Decreasing annual water inflow coupled with increasing incoming sediment result in a relatively large reservoir capacity for Sambor dam
- Decreasing annual water inflow coupled with decreasing incoming sediment yield the highest net present value of Sambor dam and the longest period of operation time
- Increasing peak flood trend leads to larger optimal spillway capacity for dams that last longer
- Improvement of data quality and availability would make our results more reliable for policy purposes
- Sedimentation management and uncertainty will be considered in the next version of our model for optimal choice of dam capacity

Thank you