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Impacts of Climate Change on Reservoir Management and Downstream Watershed

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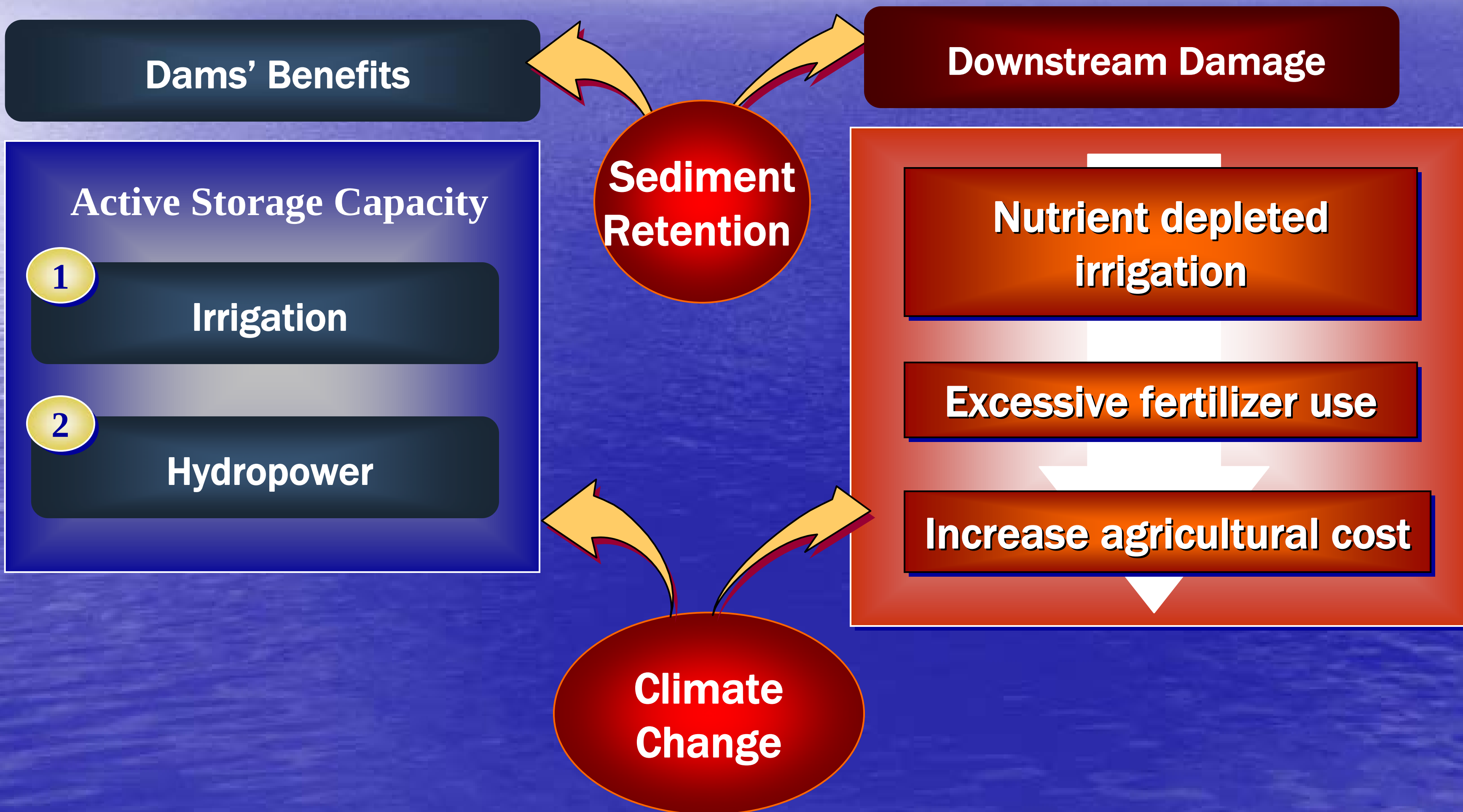
Motivation

Dams have beneficial aspects but can also cause downstream damages, moreover its benefits can be reduced by sedimentation and climate change



Existing Literature

There are moderate number of study on sedimentation and reservoir management, also many scientists investigate the impacts of climate change on water resource and agriculture

Sedimentation & Reservoir

- Palmieri, Shah, and Dinar (2001) develop a theoretical model
- Palmieri et al. (2003) and Kawashima et al. (2003) have introduced a model that allows the ranking of alternative sediment management strategies
- WCD (2000) and Adams (2000) introduce the relationship between sediment impoundment by dam and downstream fertilizer consumption

Climate Change Impacts

- Conway & Hulme (1996) introduce the impacts of climate change on water resource
- El-shaer et al. (1997) calculate possible impacts of temperature rise on agriculture
- Beyene et al. (2007) develop a hydrologic model that can analyze the impacts of climate change on watershed under various scenarios

Theoretical Model: Assumptions

To analyze impacts of climate change on reservoir and downstream agriculture, following assumptions must hold:

- **Reservoir only provides irrigation and hydropower benefits to society**
- **Downstream agriculture purely relies on irrigation water from the reservoir**
- **Downstream agriculture only use water and fertilizer as inputs**
- **Fertilizer consumption has strong relationship with sediment retention**
- **Reservoir only uses hydrosuction as sediment removal strategy**
- **Climate change impacts temperature, precipitation, and evaporation rate, all of which leads to changes in mean annual water runoff**

Theoretical Model: Reservoir-level

Reliable reservoir water yield can be calculated by Gould's-gamma function (Morris and Fan, 1998)

1

Water Yield Function

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

Where:

W_t = reservoir yield at time t

S_t = remaining reservoir capacity at time t

δ_t = adjustment factor for climate change

V_{in} = mean annual incoming water flow

Zpr^2 = standard normal variation of p%

sd^2 = standard deviation of incoming flows

Gd = adjustment factor to approximate the Gamma distribution

Theoretical Model: Reservoir-level

Reservoir manager tries to maximize lifetime net benefits of reservoir by periodic sediment removal that can recover storage capacity of reservoir

2

Dynamic of dam benefits

$$Max\ DB_t = \int_{t=0}^{T} \left\{ P_W \cdot W_t(\delta_t, S_t) - C(X_t) - OMC \right\} e^{-rt} dt + SVe^{-rT} - IC$$

Subject to: $\dot{S} = \partial S / \partial t = -M + X_t \qquad 0 \le X_t \le M$

Where:

P_W = price of water considering irrigation and hydropower

$C(X_t)$ = cost of sediment removal (X) by hydrosuction

OMC = annual operation cost of reservoir

SVe^{-rT} = salvage value of reservoir at terminal time (T)

IC = initial construction cost of dam

M = incoming sediment

Theoretical Model: Downstream Agriculture

Farmers try to maximize their lifetime net benefits. Control variable for famer is only amount of fertilizer use

3

Dynamic of agriculture

$$Max\ NB_{DF} = \int_{t=0}^{T} \left[\eta \cdot \left\{ P_c \cdot Y(F,U,W) - k \cdot F \right\} \right] e^{-rt}\, dt$$

Where:

NB_{DF} = net benefits of downstream agriculture

η = total agriculture area

P_c = price of crop

$Y(\bullet)$ = production function where assumed to be Cobb-Douglas function

F = fertilizer consumption

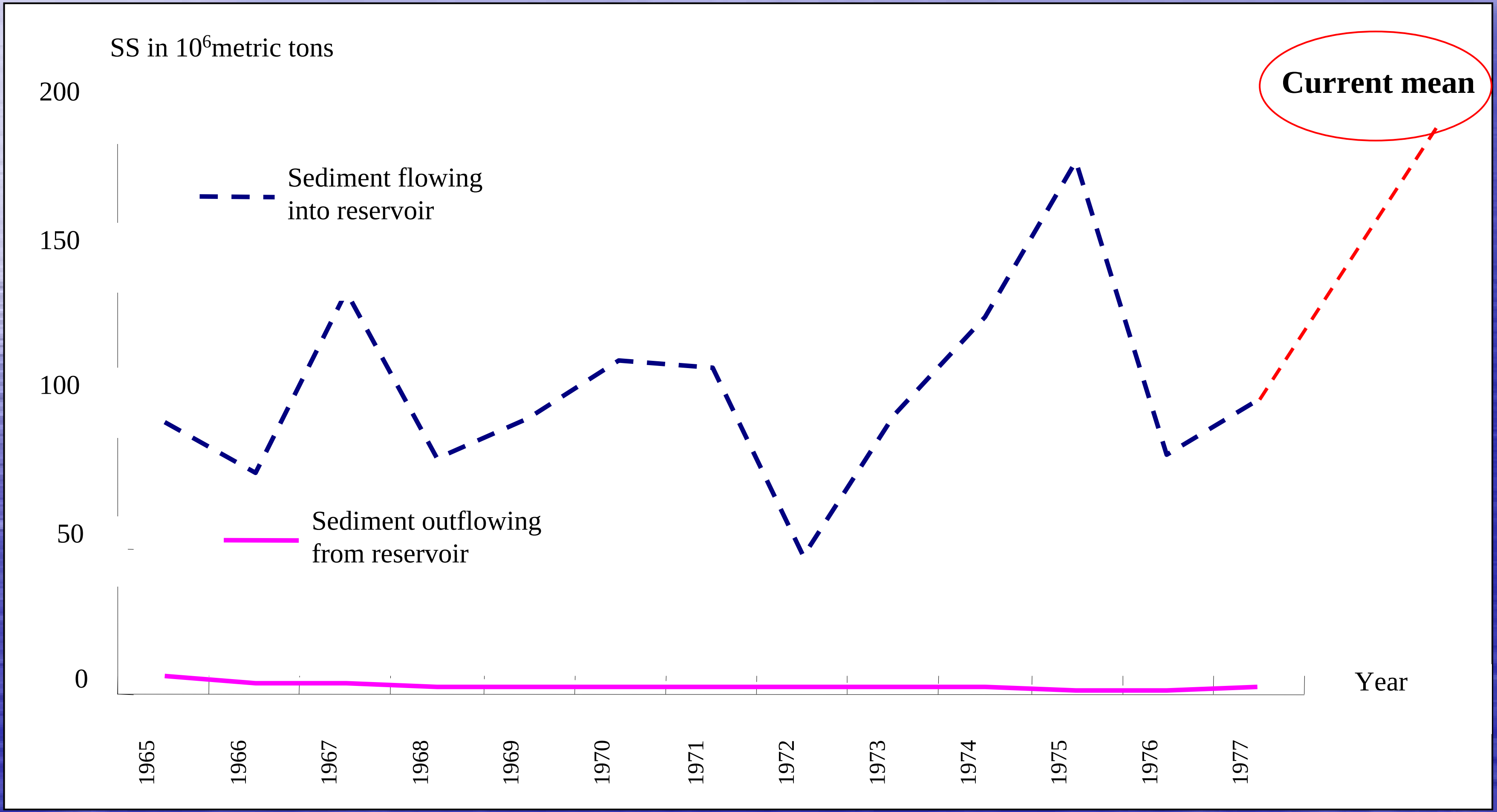
W = amount of irrigation

k = unit cost of fertilizer

U = sediment released from the reservoir

Background of Case Study

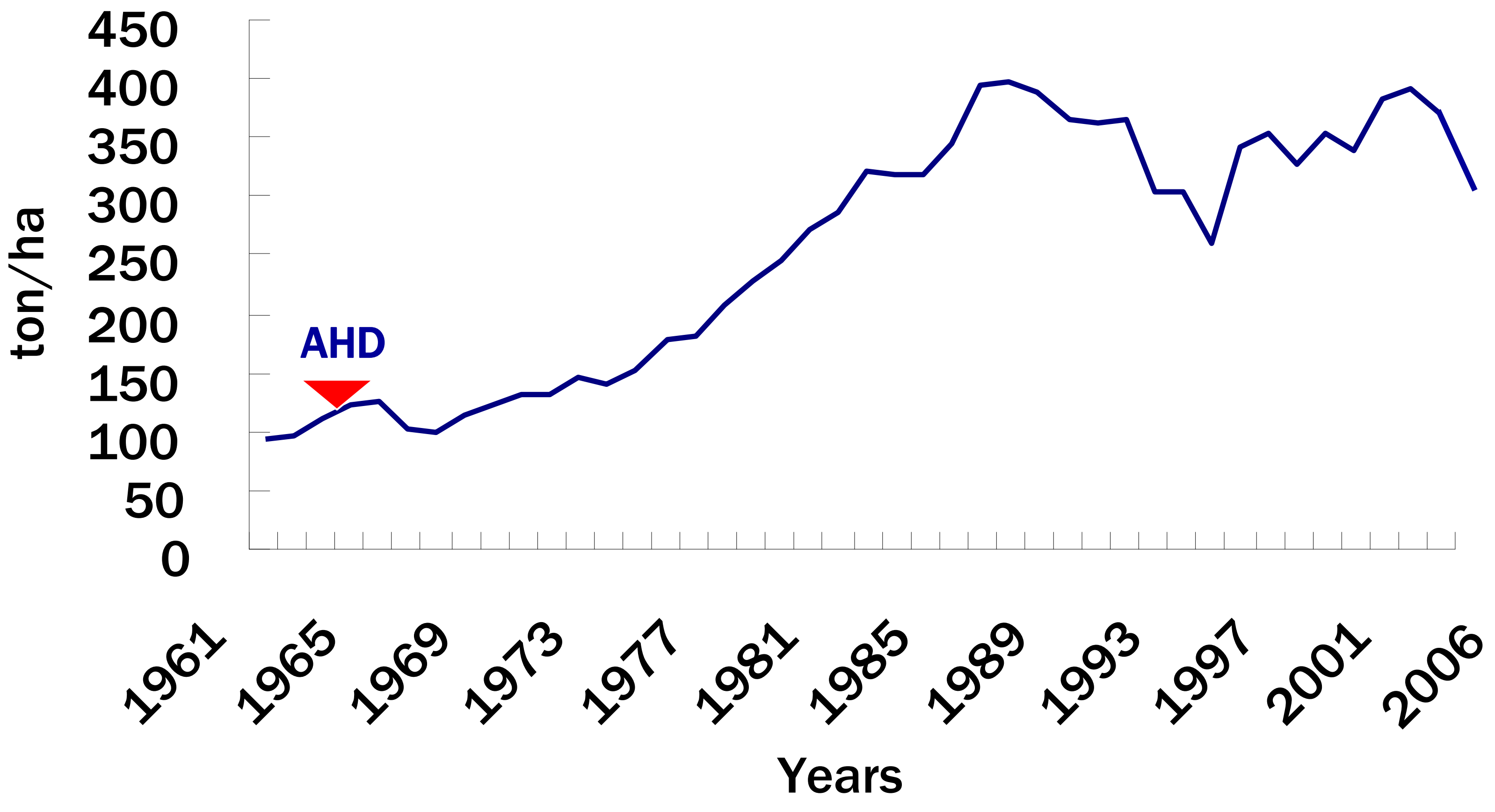
Aswan High Dam in Egypt impounds most of incoming sediment from upstream



Source: International Lake Environment Committee Database

Background of Case Study

Due to high sediment impoundment, downstream fertilizer consumption has been increased



Source: FAOSTAT

Background of Case Study

Aswan High Dam in Egypt is vulnerable to climate change (Beyene et al. 2007)

	1 2010 ~ 2039	2 2040 ~ 2069	3 2070 ~ 2099	4 2100 ~
Temperature	+1.39°	+3.11°	+4.19°	+4.19°
Potential Evaporation	-4%	-6%	-6%	-6%
Mean Annual Runoff	+11%	-8%	-16%	-16%

Results

The following parameters are used to calculate the benefits to farmers and the reservoir as well as climate change impacts

Description		Value	Unit
Average price of crops		215	$/tons
Cost of fertilizer		160	$/tons
Price of water		0.05	$\$/m^3$
Discount rate		5	%
Installation cost of hydrosuction		500	Million $
Annual operation and management cost of dam		10	Million $
Annual deposition of silt in the reservoir		200	Million m^3
Mean water inflow		80	Billion m^3
Trap efficiency		99	%
Climate change adjustment factor	2010-2039	11	%
	2040-2069	-8	%
	2070-2099	-16	%
	2100-	-16	%

Results

Unit: Billion $

		DB	FB	SB
W/o Climate Change	Baseline	72.89 (159 yrs)	30.02	102.91
	Social Planner	74.02 (sustainable)	35.19	109.21 (+6.1%)
W/ Climate Change	Baseline	66.44 (159 yrs)	28.77	95.21
	Social Planner	73.97 (sustainable)	34.88	108.85 (+5.7%)
Impacts	Baseline	-6.45 (-8.8%)	-1.25 (-4.2%)	-7.7 (-7.5%)
	Social Planner	-0.05 (-0.06%)	-0.31 (-0.88%)	-0.36 (-0.32%)

Conclusion

W/O sediment control

- In the reservoir-level, without practicing sediment removal management, the impact of climate change is approximately $6.5 billion under current climate change scenario considered
- In the downstream agriculture, climate change impact is about $1.3 billion
- Total climate change impact on Egypt is approximately $7.7 billion, which is equivalent of 7.5% reduction in social net benefits

Conclusion

- Considering optimal sediment removal technique in reservoir-level, climate change impacts can be reduced to 0.32%, that is $360 million
- Suffice to say that proper sediment control not only benefits the reservoir but also downstream agriculture
- However, under worse climate change scenario all of these losses may become larger
- Improvement of data quality and availability would make our results reliable for policy purpose

Thank you