Managing Transborder Water Resources Under Environmental and Economic Uncertainty

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Overview

- Challenges in water resources management
- Environmental and economic uncertainty / population development
- Principles of coupled economic-hydrologic modeling
- Modeling the resource allocation conflict in the Syr Dayra basin, Central Asia
- Conclusions
Crisis of Freshwater Scarcity

Approx. 2.4 billion people are living in highly water-stressed areas ($i > 0.4$)

\[ i = \frac{W - S}{Q} \]

- $i$: scarcity index
- $W$: withdrawals by all sectors
- $S$: desalinated water use
- $Q$: total renewable freshwater supply
Grand Challenges in Freshwater Resources Management

- Decrease of low flow of rivers
- Changes in seasonal runoff patterns of rivers due to glacier melt
- Large-scale depletion of aquifers
- Surface and groundwater pollution
- Soil salinization in drylands irrigation
- Drying up of wetlands and irretrievable loss of biodiversity
Stressors

• Environmental uncertainty - Climate change impacts ...  
  – amount of annually renewable freshwater available  
  – timing of availability  

• Economic uncertainty  
  – World market crop & energy prices development and volatility  

• Growing population numbers
Impacts of a Changing Climate on Land Surface Hydrology

• Changes in global precipitation patterns not well understood and uncertain

• Direction and magnitude of surface temperature relatively consistent

• Changes in the seasonality of water supply due to runoff will occur in snow-melt dominated, mid-latitude basins

• Note: More than one-sixth of the global population lives in snow-melt dominated, low reservoir storage regions (esp. in Southern and Central Asia)
Illustration: Change in Runoff Timing

- Simple rainfall-runoff toy-model example:
  - 3 degree warming over 40 years in snowmelt driven basin with glacier storage.
  - Model: Glacier / Snow / Soil moisture / groundwater storage

- To note:
  - Water availability in dry summer months decreases between 10 - 20 %.
  - *Impacts on downstream irrigated agriculture!*
  - Winter / Early spring runoff greatly increases. *Changes for adverse impacts due to winter flooding.*
  - *Temporary increase in absolute runoff due to glacier melt pose additional threat of flooding in critical months.*
  - Existing management strategies clearly inappropriate!
Example: Hydrological Impacts in Central Asia

Streamflow reduction

- Reduction of renewable water availability by ~ 40 % by 2100 relative to present day discharge
- Long-term reduction in dry season discharge by ~ 50 % by 2100

Change in runoff timing


Fig. 4. Relative changes in river flow multi-model non-weighted ensemble mean (2081–2100 vs 1981–2000) for 19 models, as used in analysis by Nohara et al. (2006).
Crop / Energy Price Development

Crop Prices

Crude Oil Price

- National agricultural and energy sector strategies are motivated by (among other things):
  - *food and energy security / self-sufficiency*
  - *import-substitution practices*
- World market prices are crucial determinants of water allocation policies!
Populations are expanding in regions where it is difficult to grow food.
Coupled Hydrological-Economic Modeling

DEMAND SIDE
resources users
change and use resources
determines resource endowment

SUPPLY SIDE
environment
determines resource endowment

economic / strategic interaction given institutional environment

economic scenarios (e.g. high vs. low price)

environmental scenarios (e.g. transient climate)

SUPPLY SIDE

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Coupled Hydrological-Economic Modeling

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Benefits of Integrated Hydrological-Economic Modeling

• Decision-making tools for shared scenario assessment help *building mutual confidence* in situations of conflict and *reduce system vulnerability*

• Assessment of *Status Quo* and *Need Identification* for the design of *enforceable institutional resources sharing mechanisms*

• Determination of *management tradeoffs*
Decision-making tools for shared scenario assessment help *building mutual confidence* in situations of conflict.

Utility is e.g. [monetary benefit], [reliability of access], [(risk)$^{-1}$].

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Assessment of *Status Quo* and *Need Identification* for the design of *enforceable institutional resources sharing mechanisms*.
Determination of management tradeoffs

- Determination of management tradeoffs
- Status Quo
- Undesirable outcome
- Desirable outcome
- Upstream utility
- Downstream utility
- Tradeoffs
- Status Quo

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Resources Allocation Conflict in the Syr Darya Basin, Central Asia

- Length: 2'800 km (Nile: 6'735 km)
- 93% of mean annual flow (~ 1000 m³/s) is regulated
- Catchment size: ~ 250’000 km²
- Snowmelt dominated runoff with spring / summer flood
- 3.4 mio ha irrigated land (2005)
- 75% runoff generated in upstream Kyrgyzstan, Glacier volume: ~ 130 km³
- Downstream Economies (UZ, KA) heavily dependent on irr. agriculture (1960-90: 40 – 50 % of GDP, 20 - 30 % of GDP thereafter)
Snowmelt peaks in spring and summer

Hydropower discharge peak in winter

Cooperative Resources Sharing During Soviet Times

- 1976: Toktogul Reservoir completed
- 1991: Demise of USSR
- 1998: CAEC Agreement
- 2006: Now

**Periods**

- **Period 1**
- **Period 2**
- **Period 3**

**Winter**

- Below market price
- Hydrocarbon energy

**Locations**

- **KA**
- **TA**
- **UZ**
- **KY**
- **CAEP**
- **Aral Sea**

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Noncooperative Post-Independence Regime

1976
Toktogul Reservoir completed

1991
demise of USSR

1998
CAEC Agreement

2006
now

Period 1

Period 2

Period 3

Time t

Independent republics

KA

TA

UZ

KY

Aral Sea

CAEP

Question: How to manage infrastructure and resources given ongoing conflict and uncertainty regarding future?
Supply-Side Rainfall-Runoff Model

- Low Syr
- Mid Syr
- Fergana
- Naryn

Hydropower production facilities

Catchment nodes

River nodes

Reservoirs

Subcatchments

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Characteristics and Performance of Hydrological Model

- Semi-distributed, node-based mass balance model for watershed (MikeBasin)
- Hydrographic network and sub-catchment discretization based on global SRTM topography dataset.
- Model is entirely remotely-sensed data driven and benchmarked against in-situ station data.
- Radar altimetry data obtained for 4 reservoirs (ERS/ENVISAT)
- Assimilation of altimetry data leads to considerable improvements in model performance
Coupling to Demand-Side Model

Demand centers (agricultural & electricity)
Aspects of Demand Side Modeling

• Demand side model cast as stochastic game accounting for
  – strategic interaction
  – imperfect competition (few interacting economic agents)
  – environmental and economic uncertainties
  – asymmetric information

• Exchange economy and resources price formation implemented as continuous double auctions
  – endogenous price formation (departure from scenario-based approach)

• Mechanisms of resource sharing investigated via particular specifications of objective functions
  – e.g. cooperative compensation regime vs. non-cooperative regime
Conclusions

• Reassessment of pre-existing and design of new and improved freshwater resources sharing mechanisms necessary in many snow and glacier melt driven basins

• Coupled computational hydrologic-economic models are needed to quantify outcomes of alternative allocations strategies

• Representation of economic tradeoffs important

• Computation of equilibrium allocation outcomes informs on institutional performance and should guide future allocation policies