Managing Transborder Water Resources Under Environmental and Economic Uncertainty

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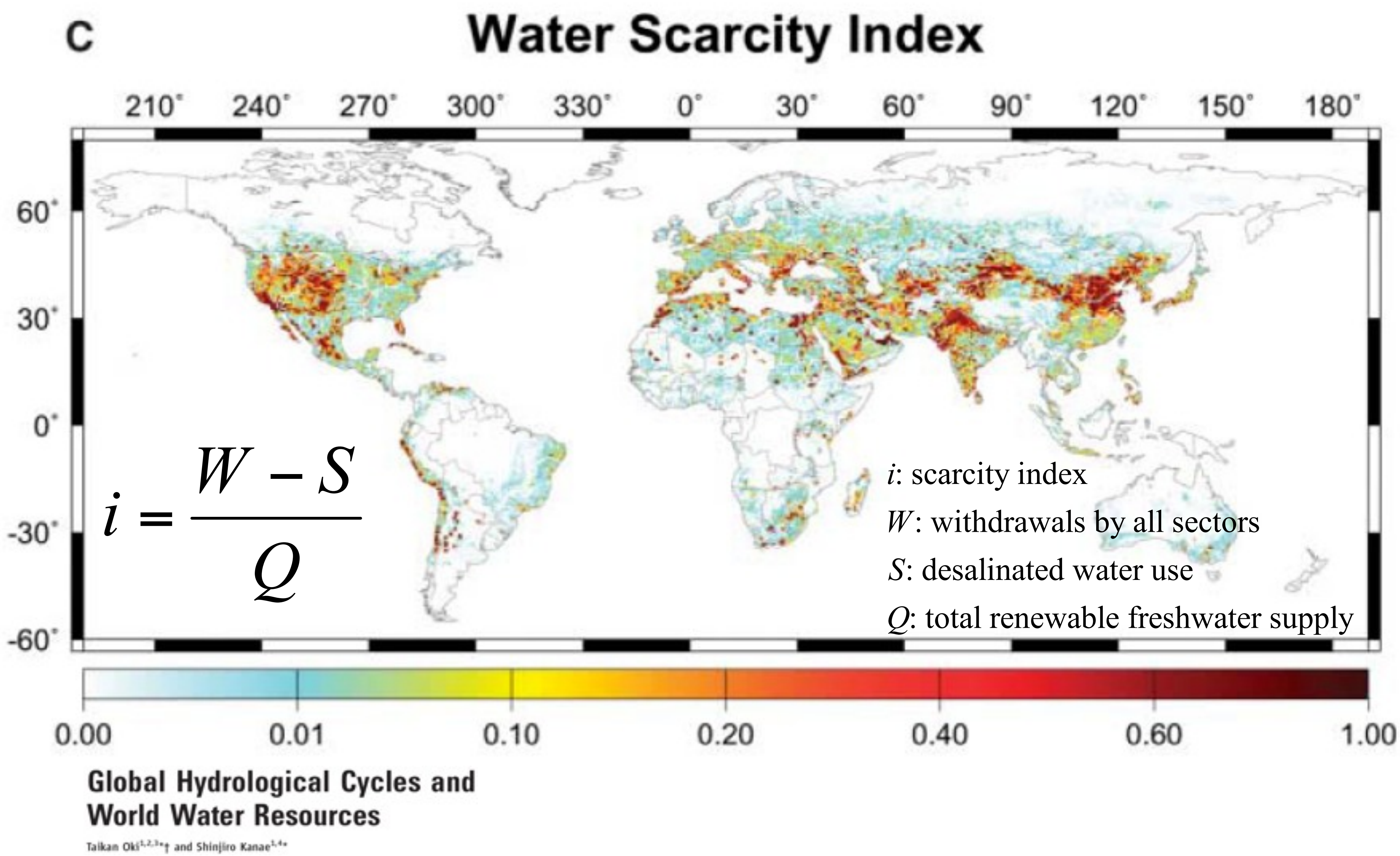
Overview

- 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 ($i > 0.4$)

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

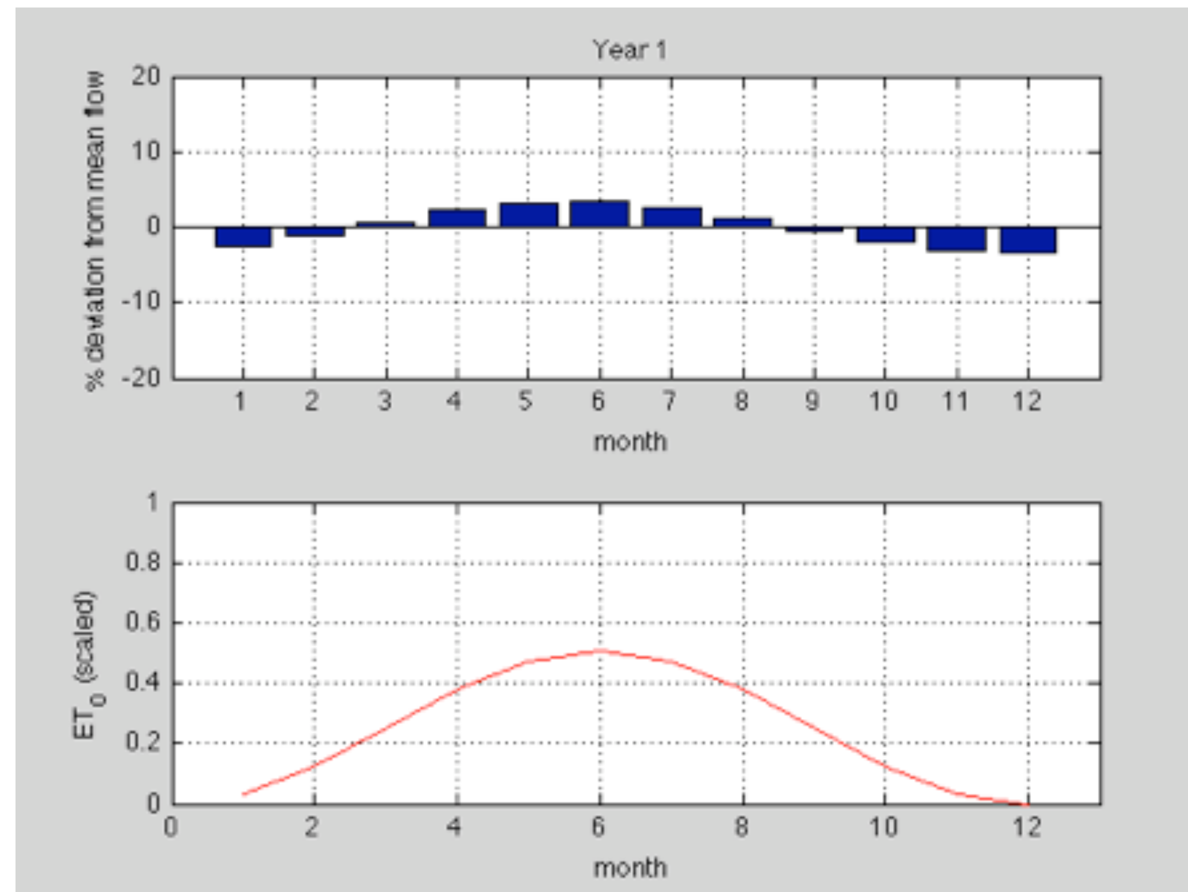
- Environmental uncertainty - Climate change impacts ...
  - amount of annually renewable freshwater available
  - timing of availability
- Economic uncertainty
  - World market crop & energy prices development and volatility
- Growing population numbers

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

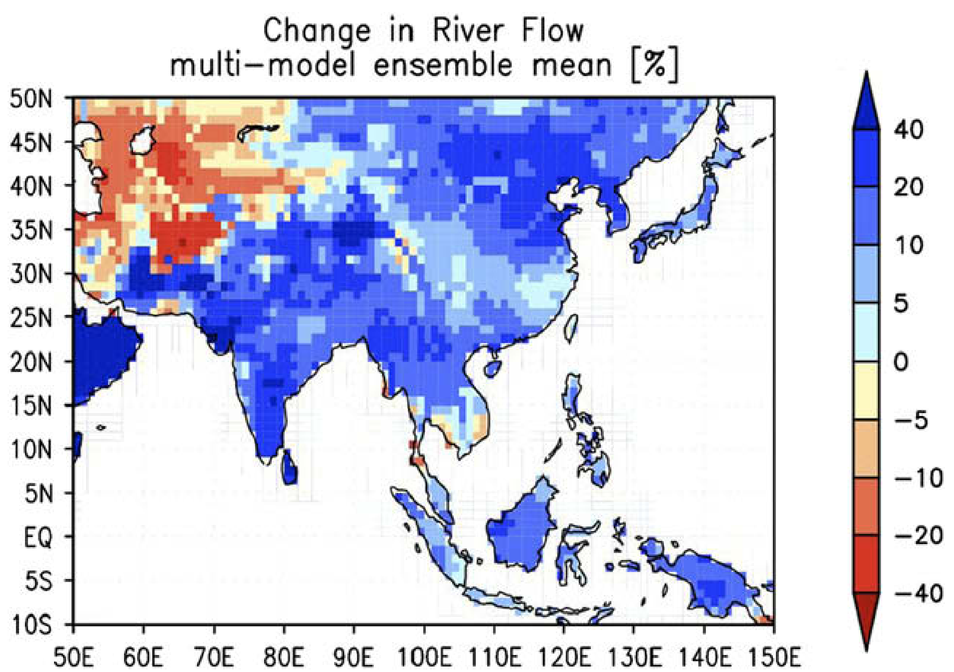
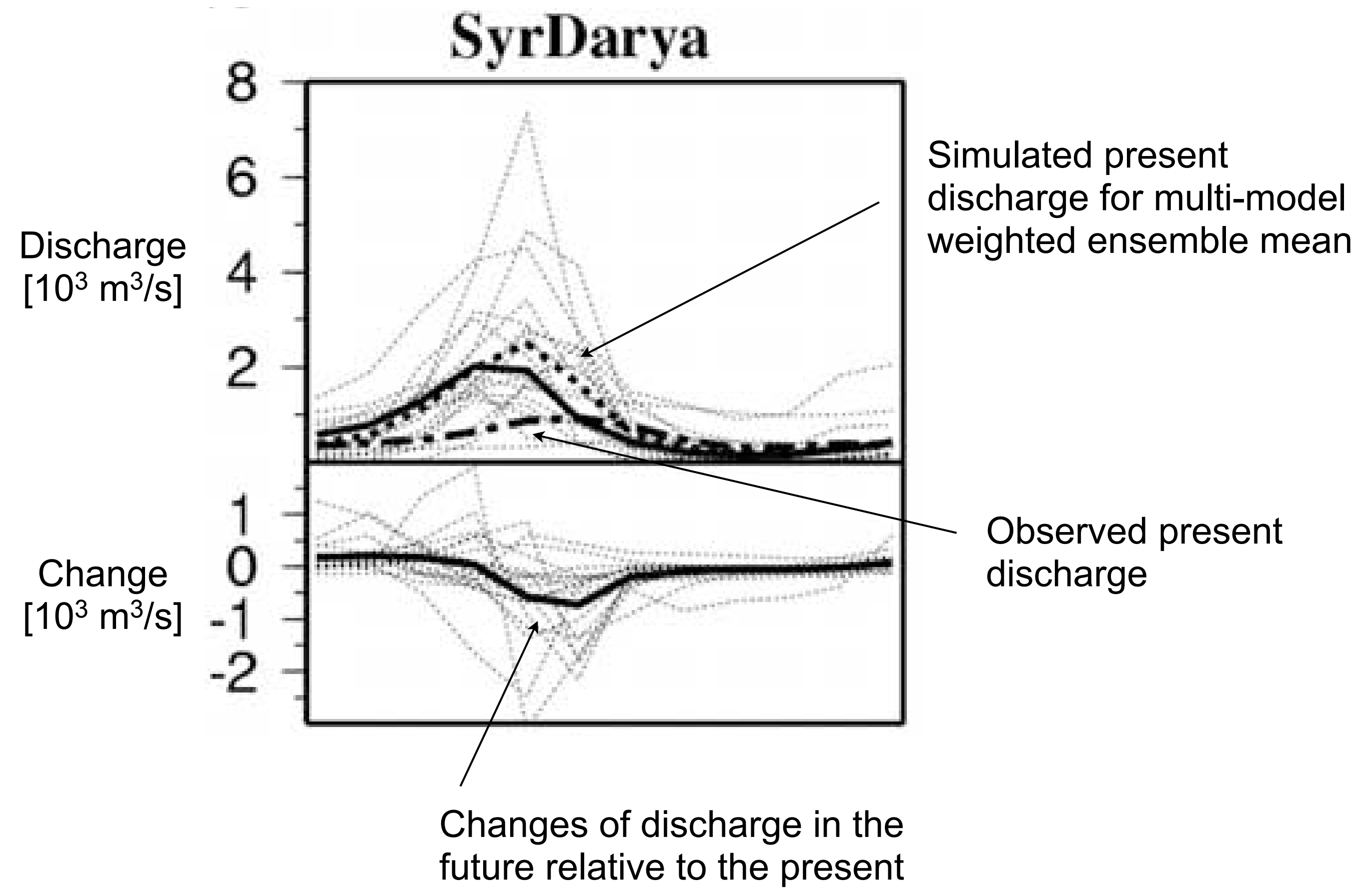


Fig. 4. Relative changes in river flow multi-model non-weighted ensemble mean (2081–2100 *vs* 1981–2000) for 19 models, as used in analysis by Nohara et al. (2006).

Source: **Kundzewicz, Z. W. et al.**, Discharge of large Asian rivers - Observations and projections, Quarternary International (2009), doi: 10.1016/j.quaint.2009.01.011

Change in runoff timing

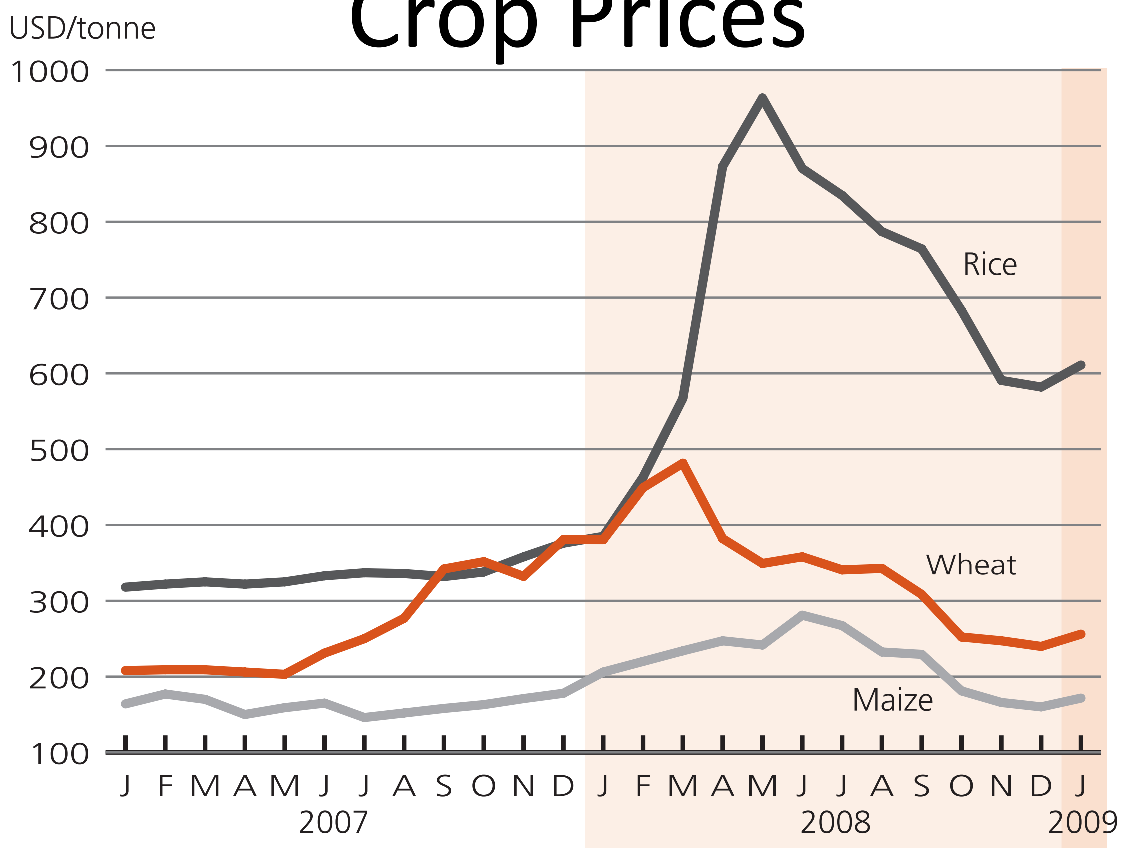


Source: **Nohara, D. et al.**, Impact of Climate Change on River Discharge Projected by Multimodel Ensemble, J. of Hydrometeorology, Vol. 7, 2006

- 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

Crop / Energy Price Development

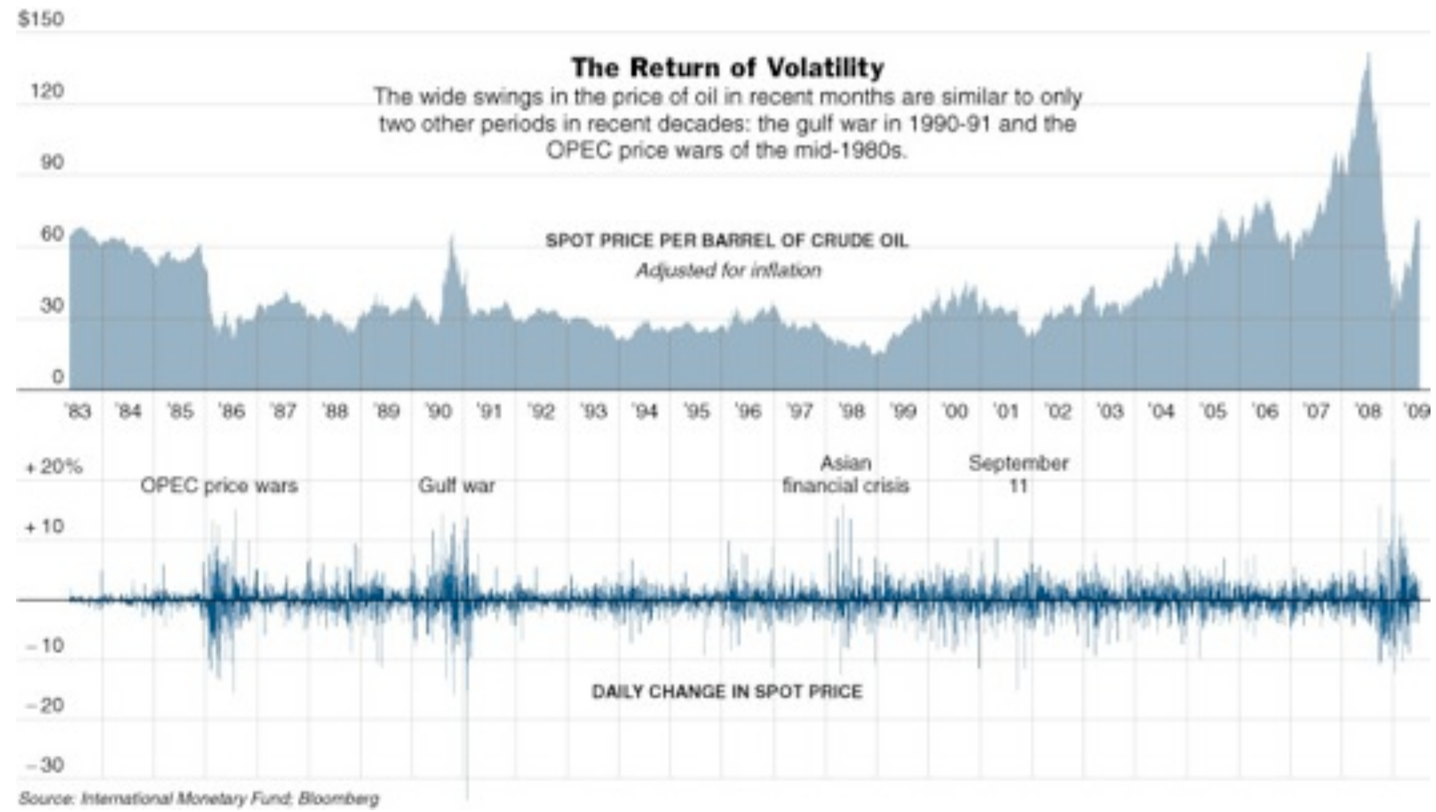
Crop Prices



Note: Prices refer to monthly average.

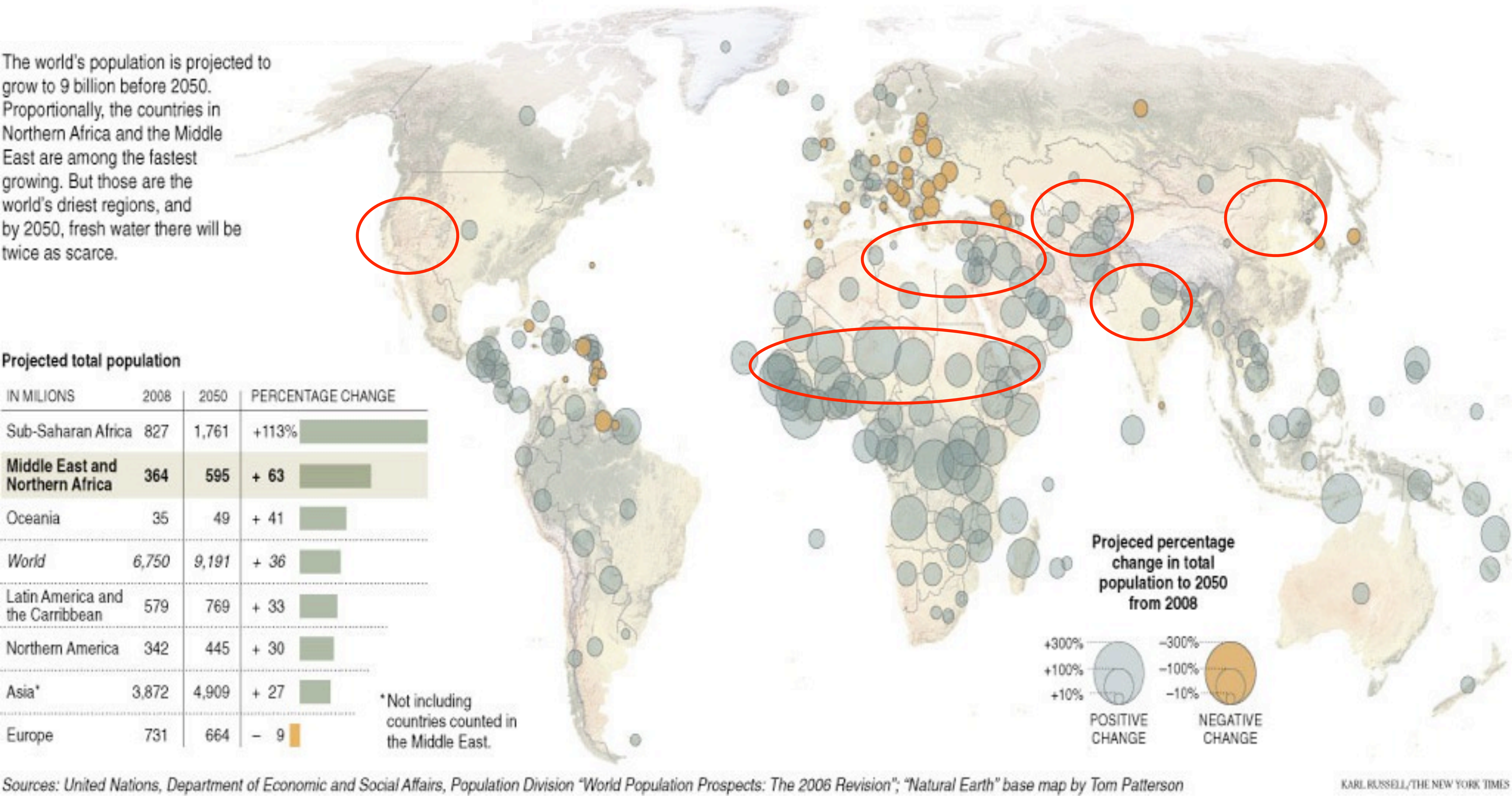
Source: FAO, Crop Prospects and Food Situation, No. 1, February 2009

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!

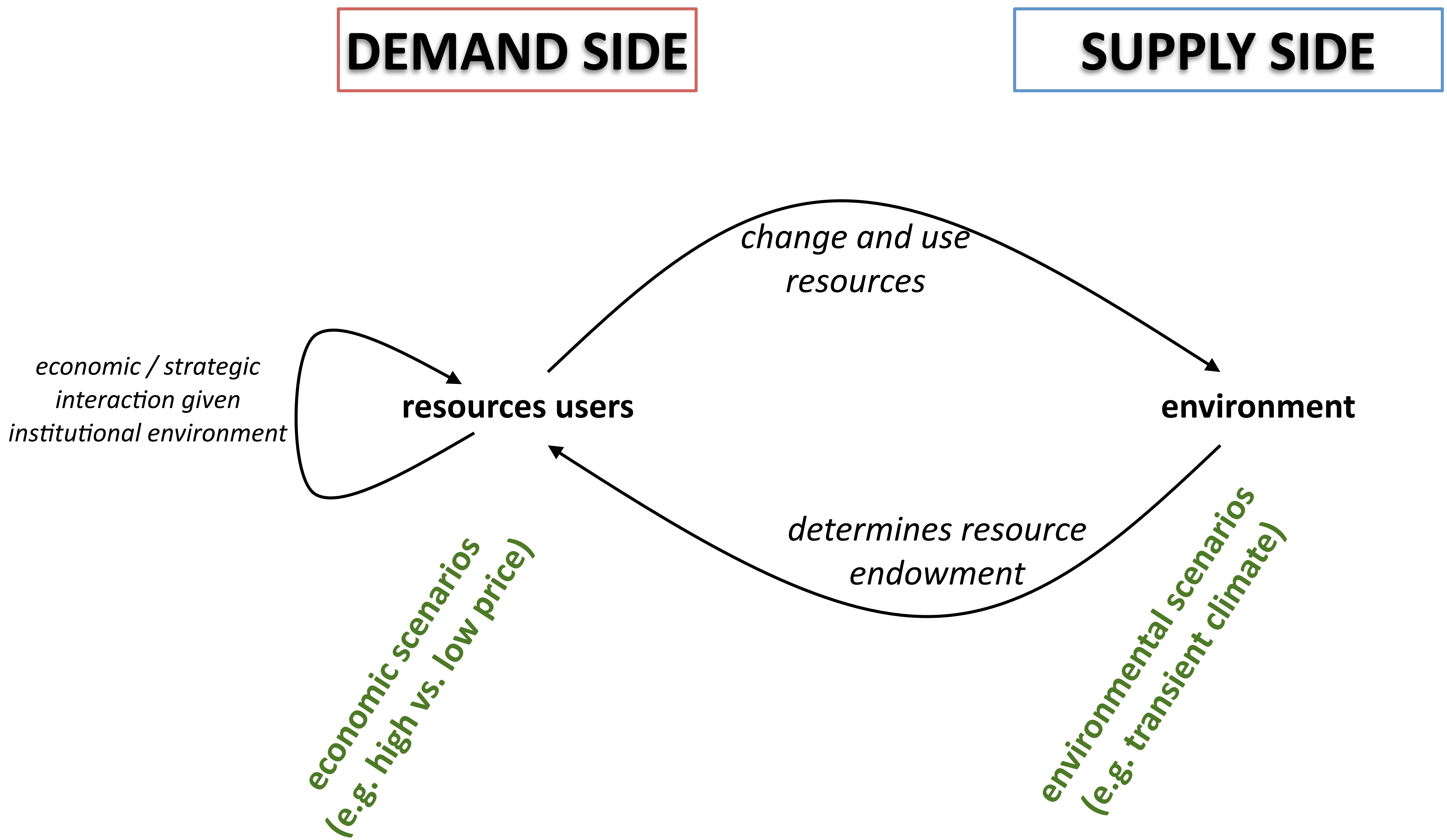
Population Development



IN MILIONS	2008	2050	PERCENTAGE CHANGE
Sub-Saharan Africa	827	1,761	+113%
Middle East and Northern Africa	**364**	**595**	**+ 63**
Oceania	35	49	+ 41
World	*6,750*	*9,191*	*+ 36*
Latin America and the Carribbean	579	769	+ 33
Northern America	342	445	+ 30
Asia*	3,872	4,909	+ 27
Europe	731	664	− 9

Populations are expanding in regions where it is difficult to grow food.

Coupled Hydrological-Economic Modeling



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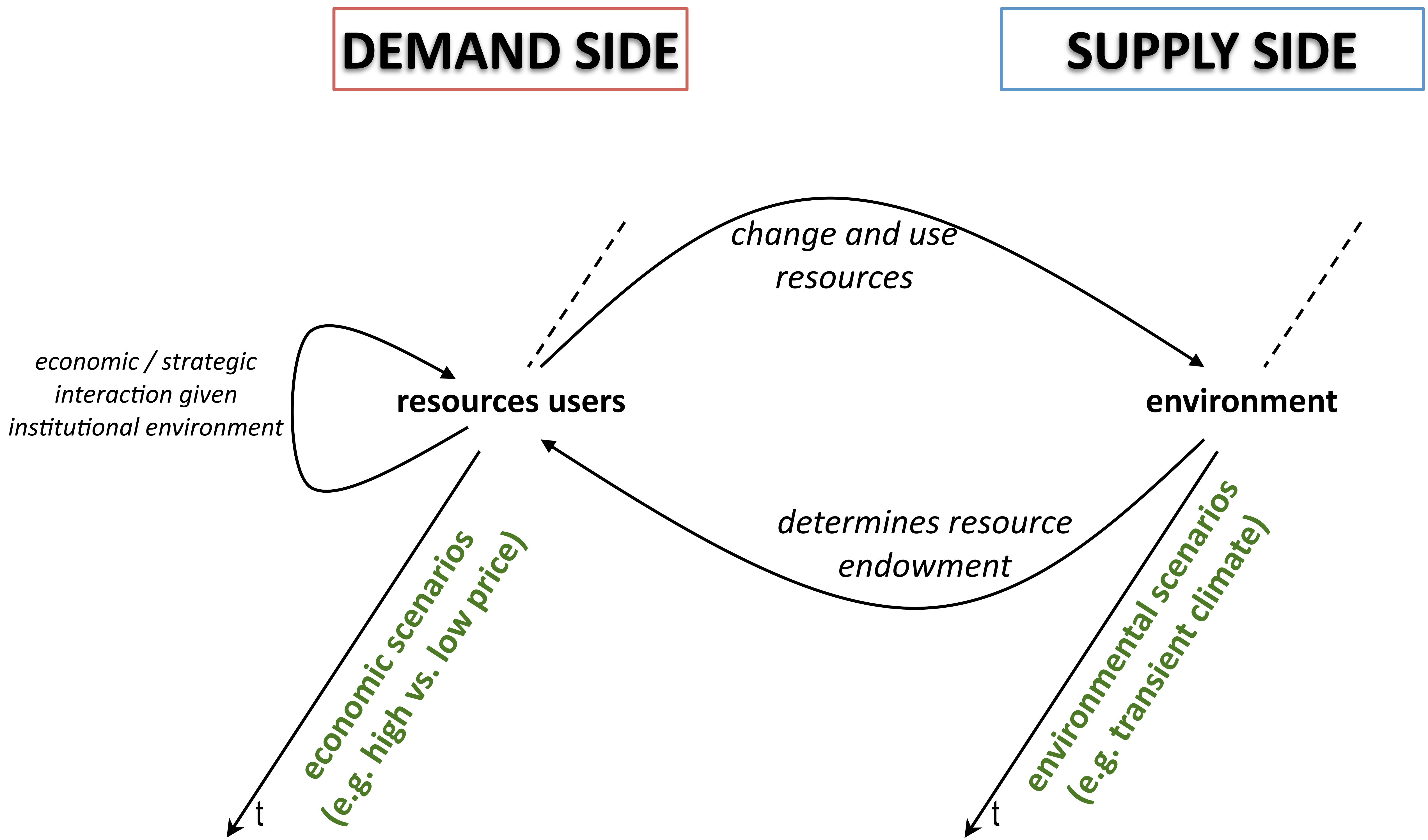

Benefits of Integrated Hydrological-Economic Modeling

- 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*

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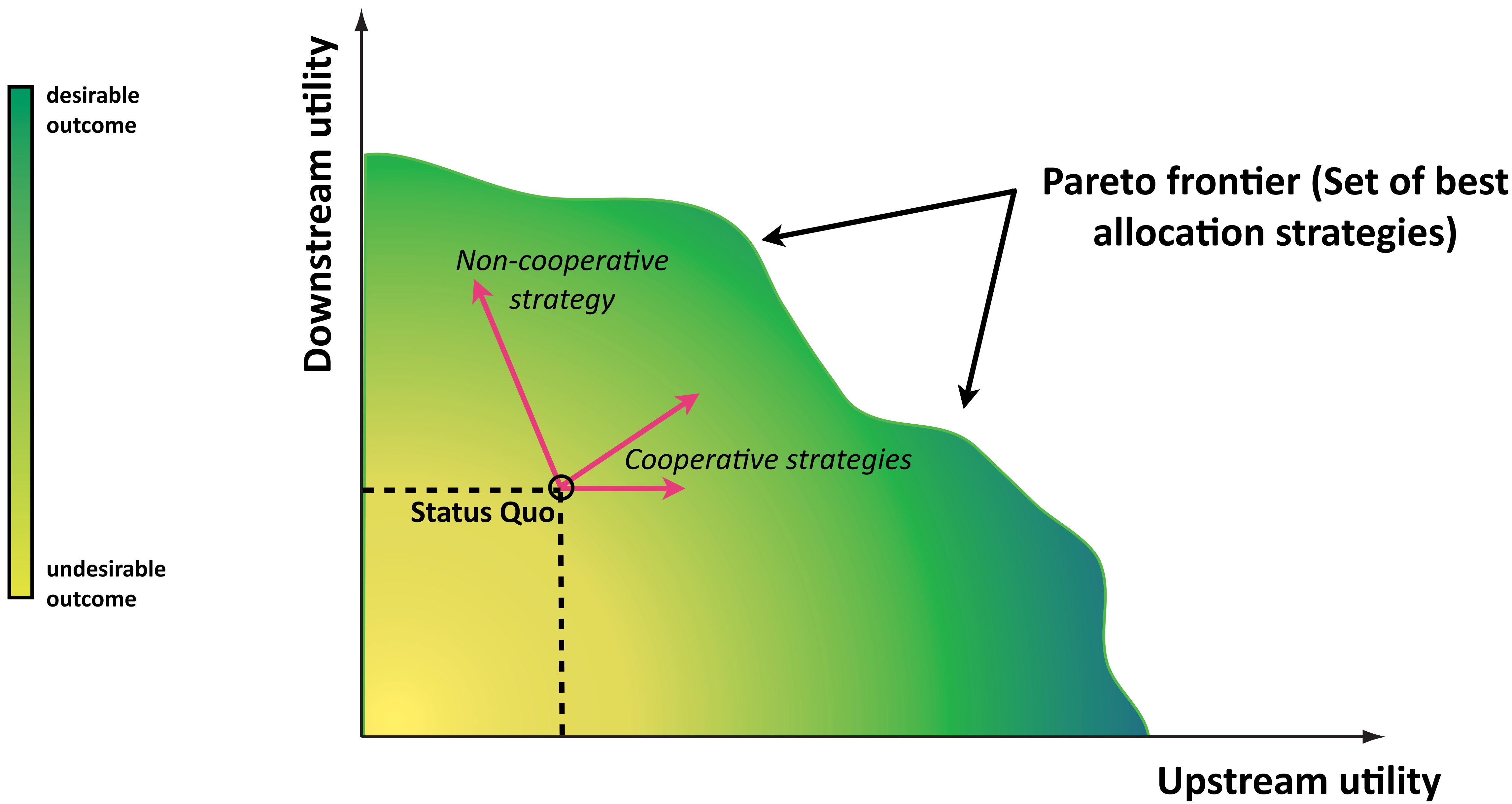
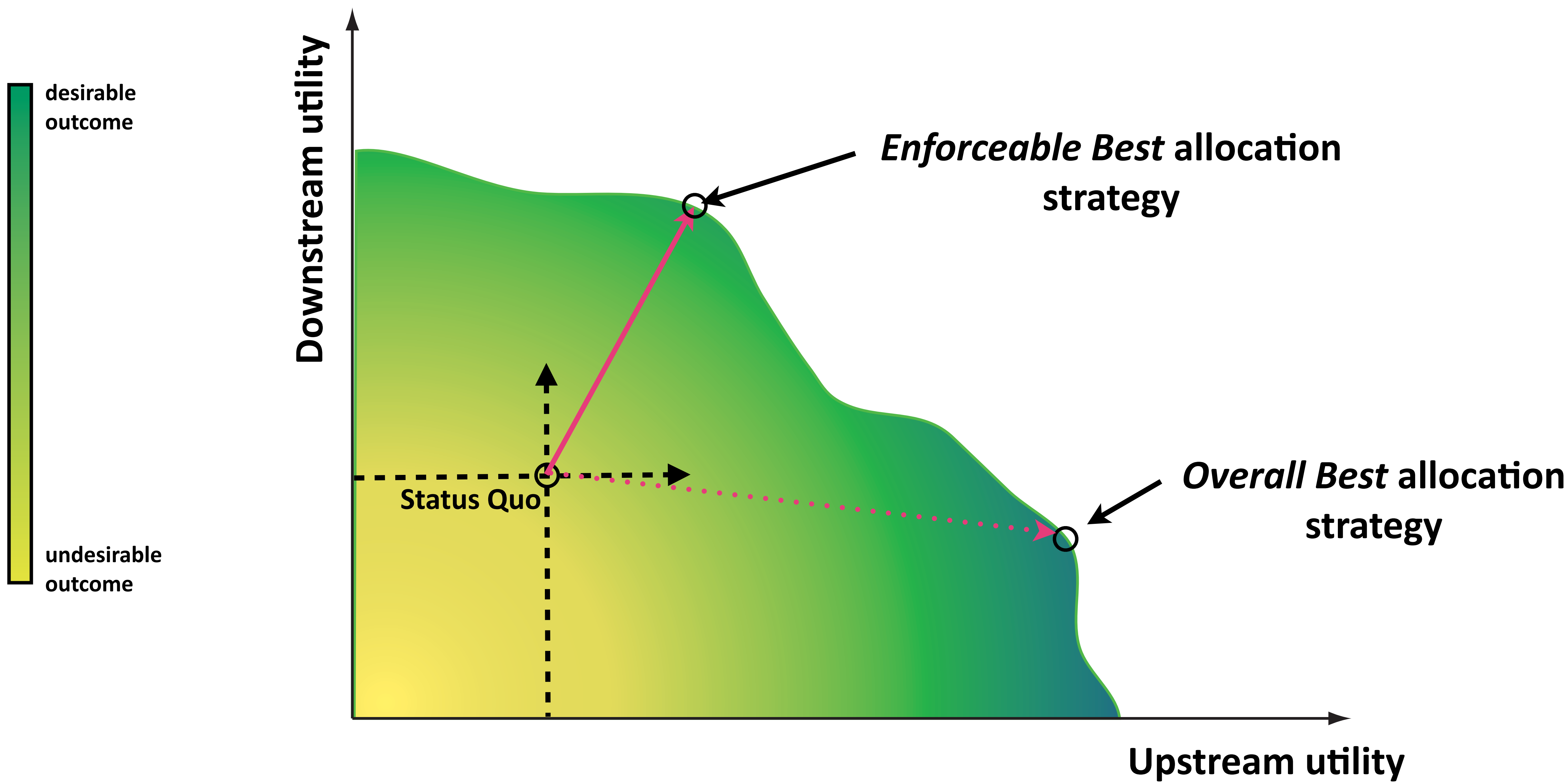
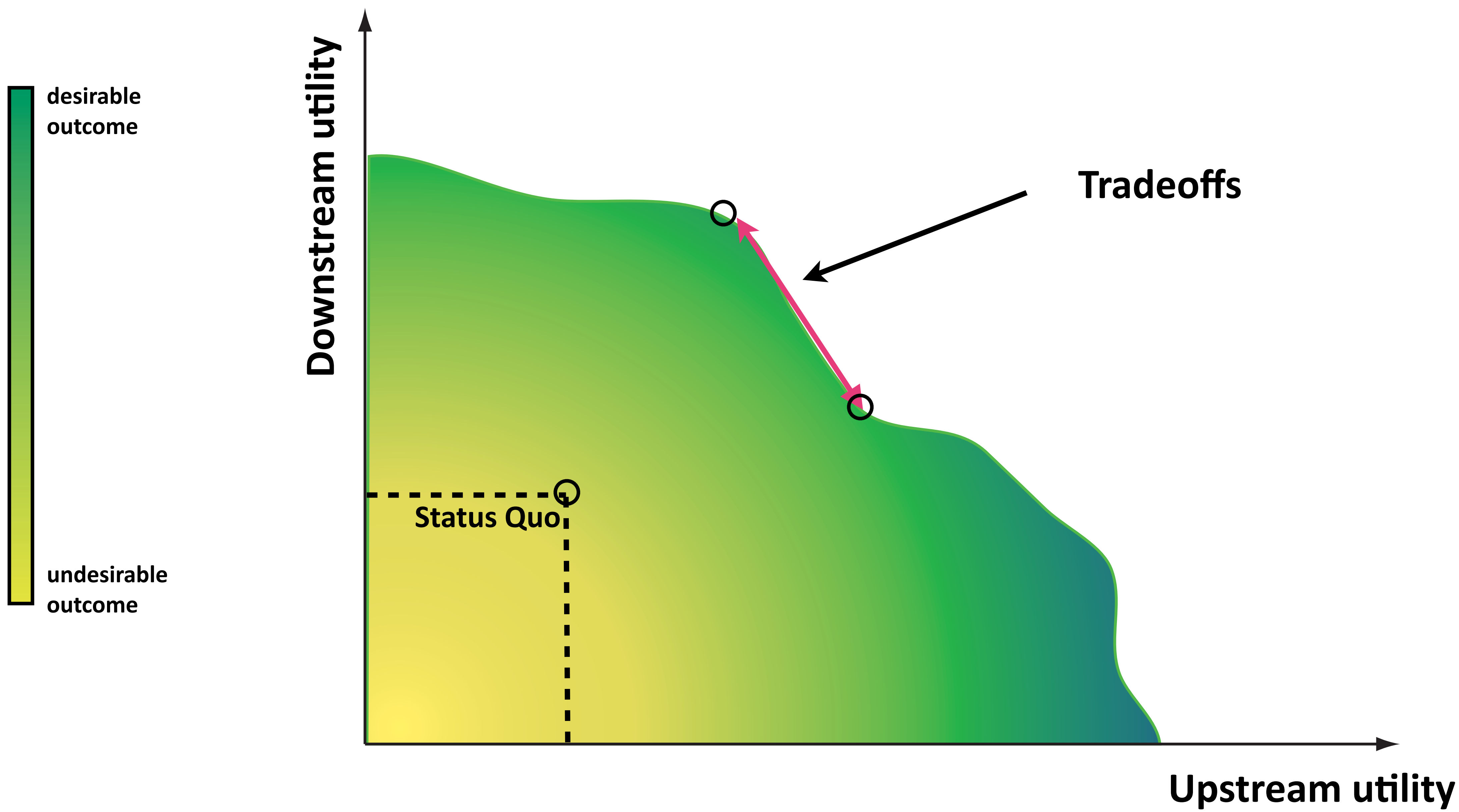


Utility is e.g. [monetary benefit], [reliability of access], [$(\text{risk})^{-1}$]

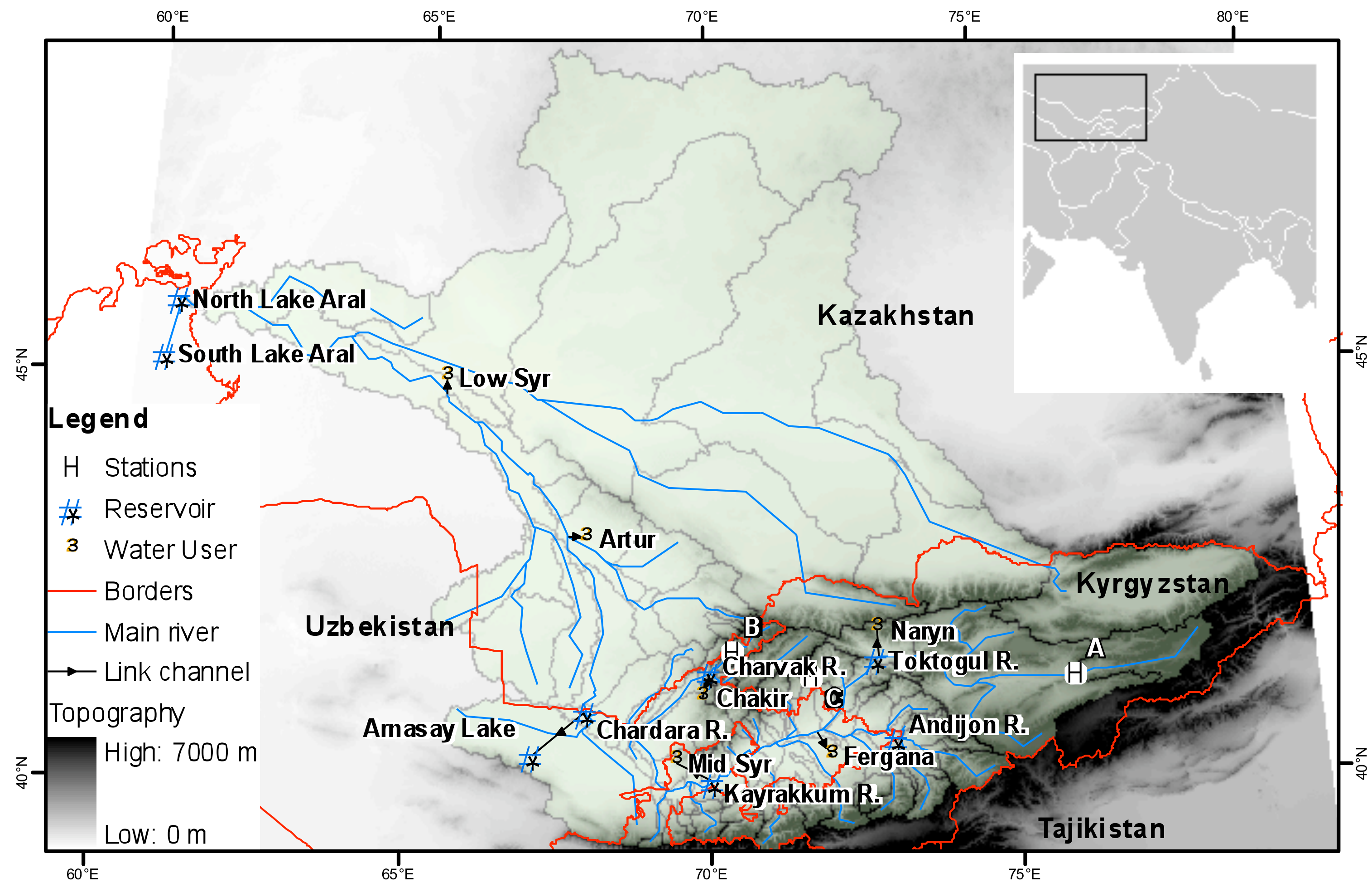
Assessment of *Status Quo* and *Need Identification* for the design of *enforceable institutional resources sharing mechanisms*



Determination of *management tradeoffs*

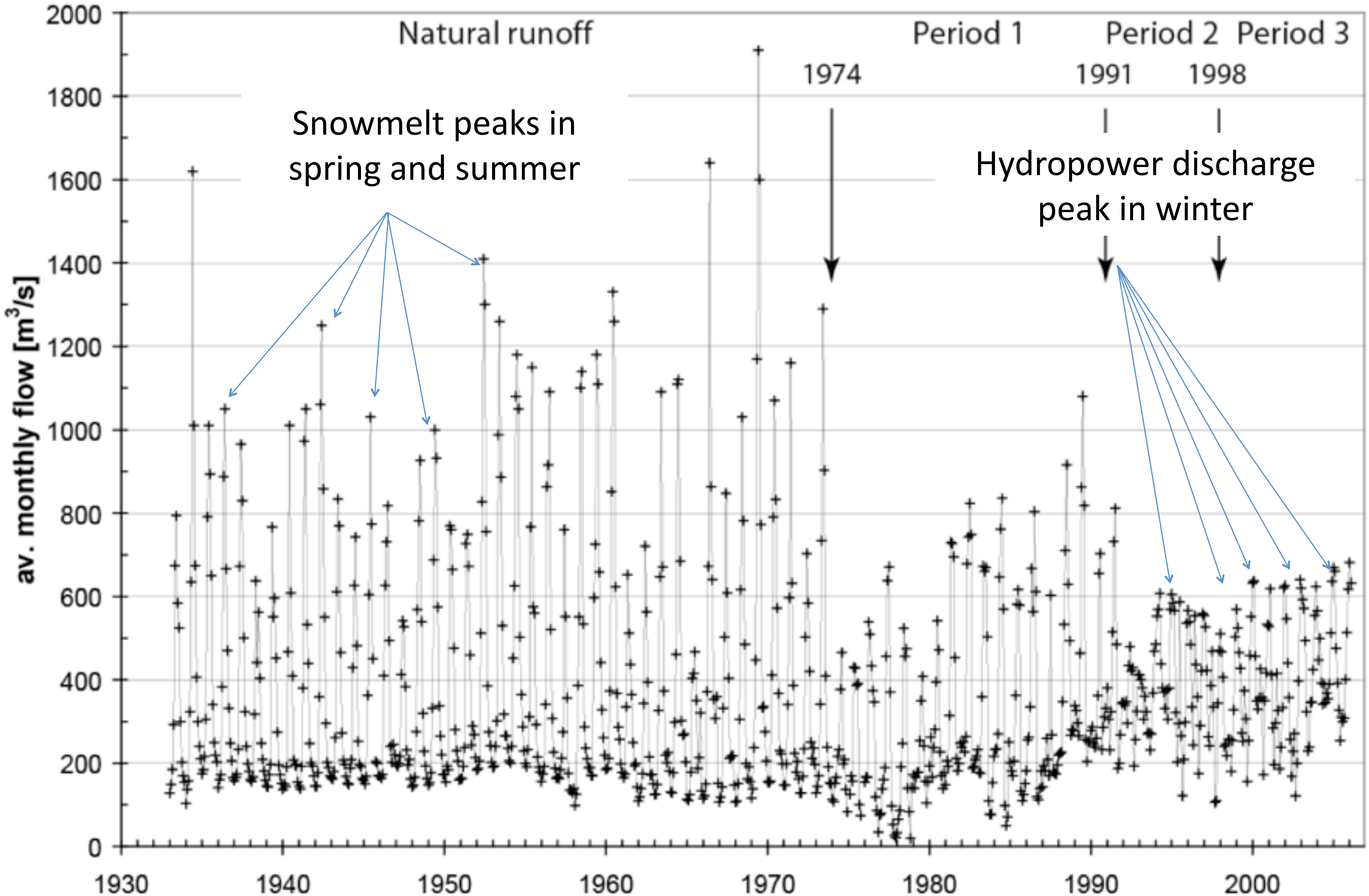


Resources Allocation Conflict in the Syr Darya Basin, Central Asia



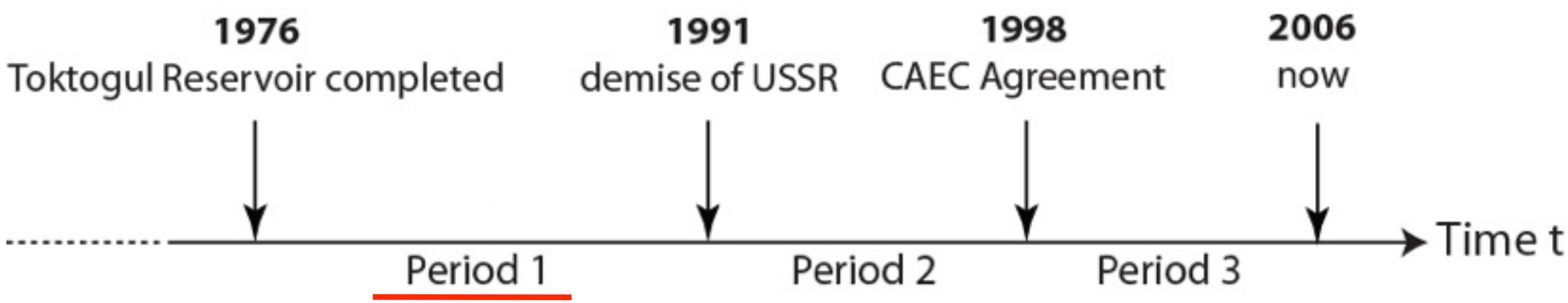
• Length: 2'800 km (Nile: 6'735 km)	• 93% of mean annual flow (~ 1000 m^3/s) is regulated
• Catchment size: ~ 250'000 km^2	• Population: ~ 20 million (2000)
• Snowmelt dominated runoff with spring / summer flood	• 3.4 mio ha irrigated land (2005)
• 75% runoff generated in upstream Kyrgyzstan, Glacier volume: ~ 130 km^3	• Downstream Economies (UZ, KA) heavily dependent on irr. agriculture (1960-90: 40 – 50 % of GDP, 20 - 30 % of GDP thereafter)

The Nature of the Upstream - Downstream Conflict in the Syr Darya

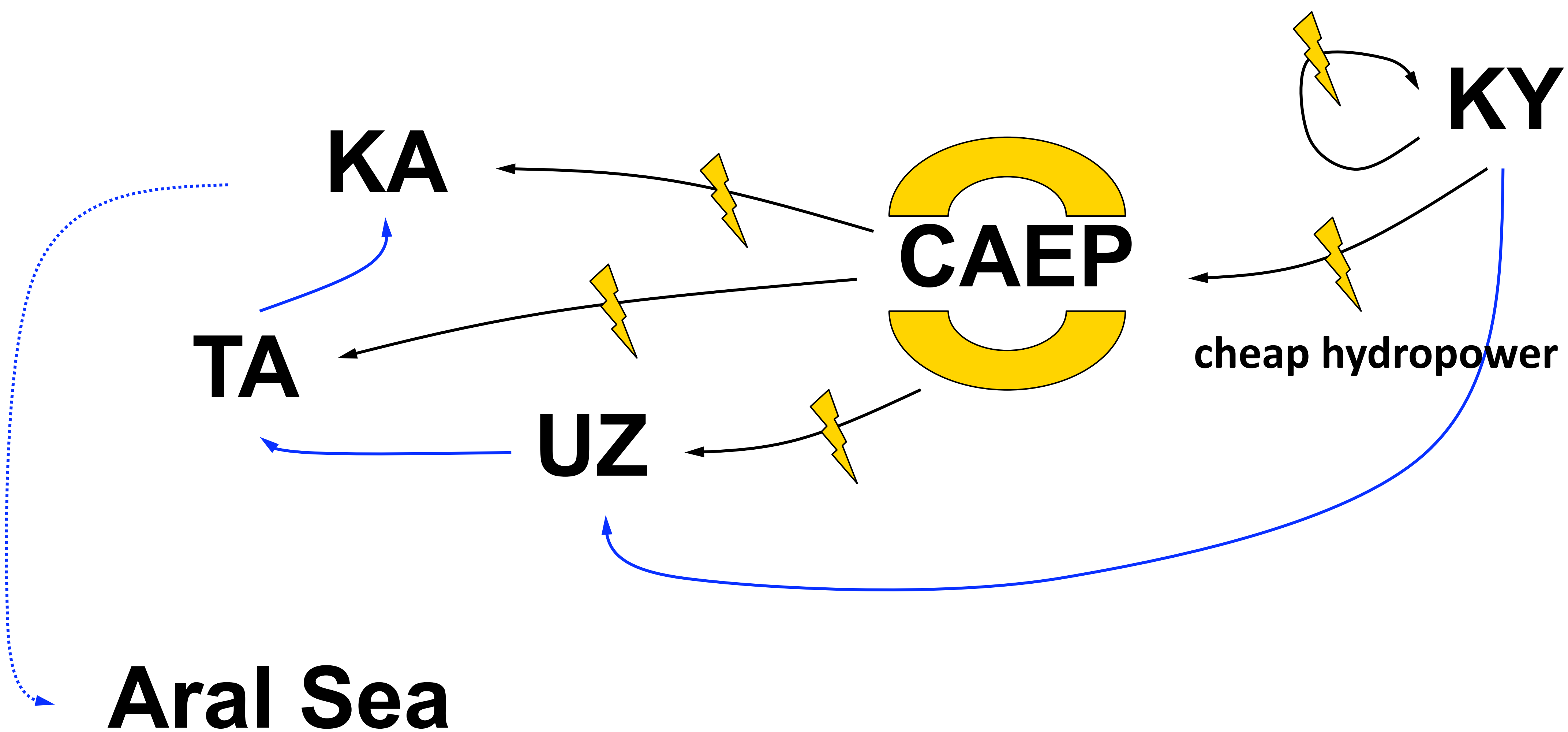


Source: **Siegfried, T., and T. Bernauer** (2007), Estimating the performance of international regulatory regimes: Methodology and empirical application to international water management in the Naryn/Syr Darya basin, Water Resour. Res., 43, W11406, doi:10.1029/2006WR005738.

Cooperative Resources Sharing During Soviet Times



Summer



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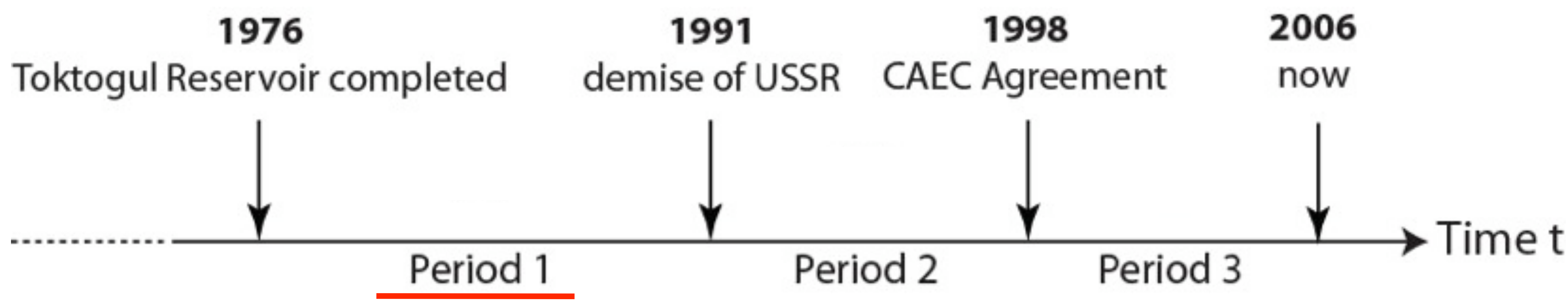
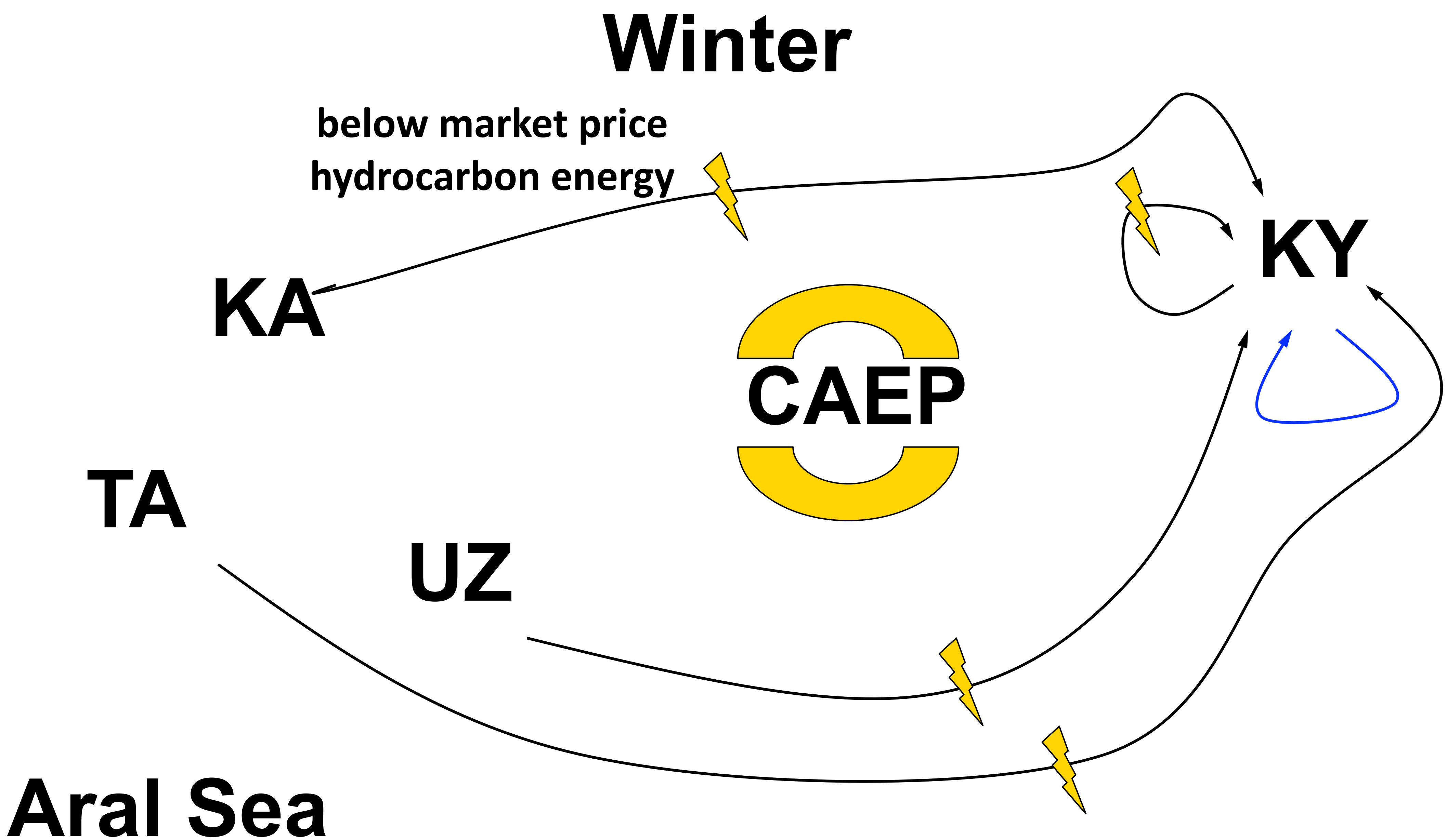
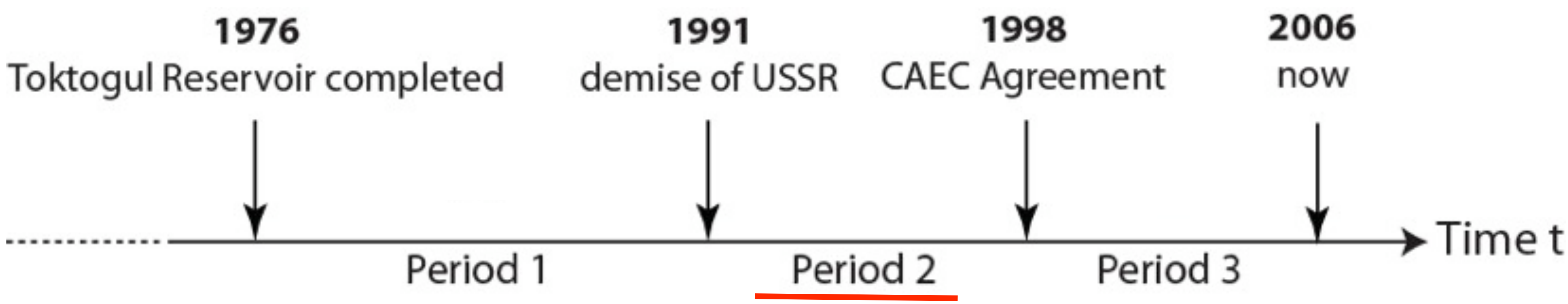




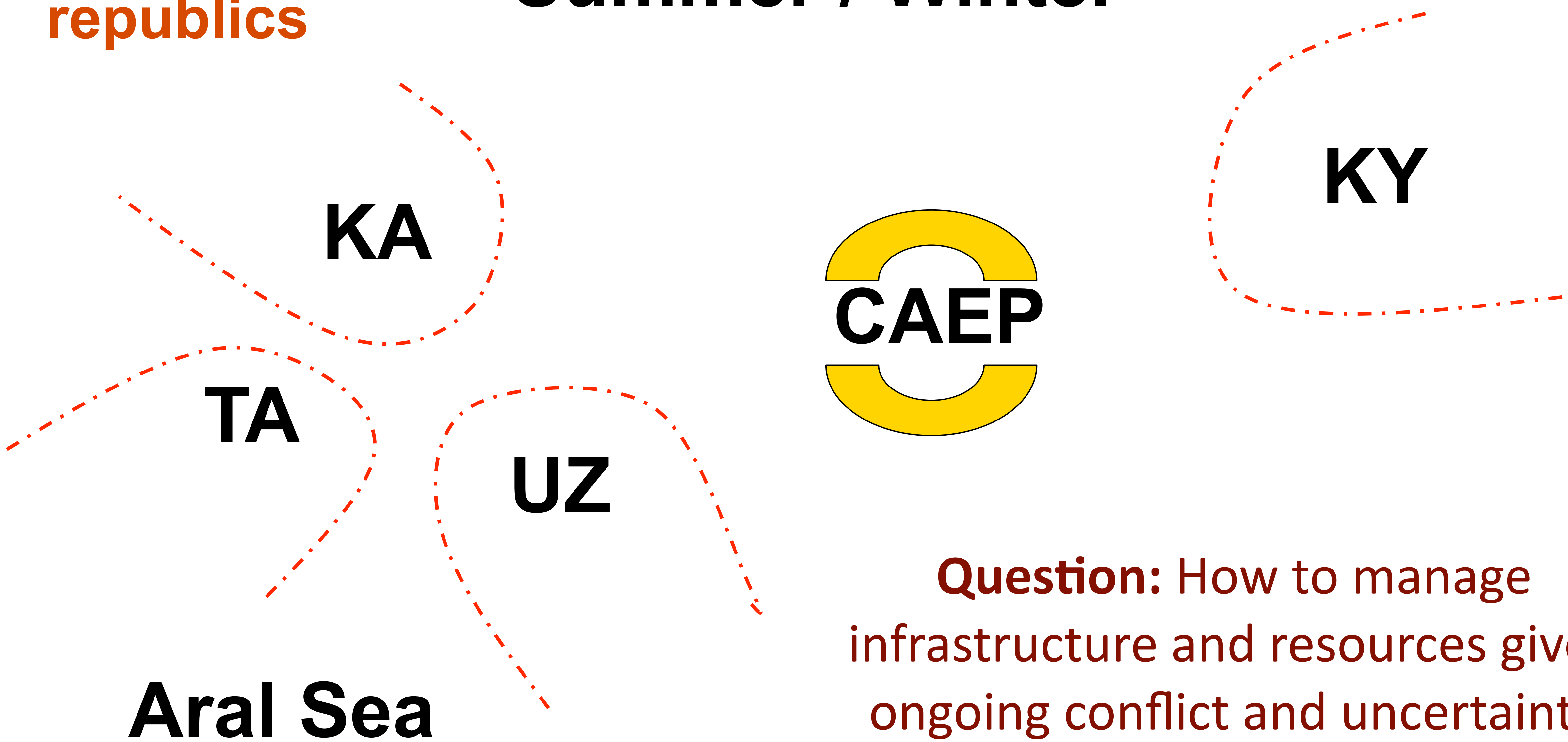
Sunday, July 12, 2009

Noncooperative Post-Independence Regime



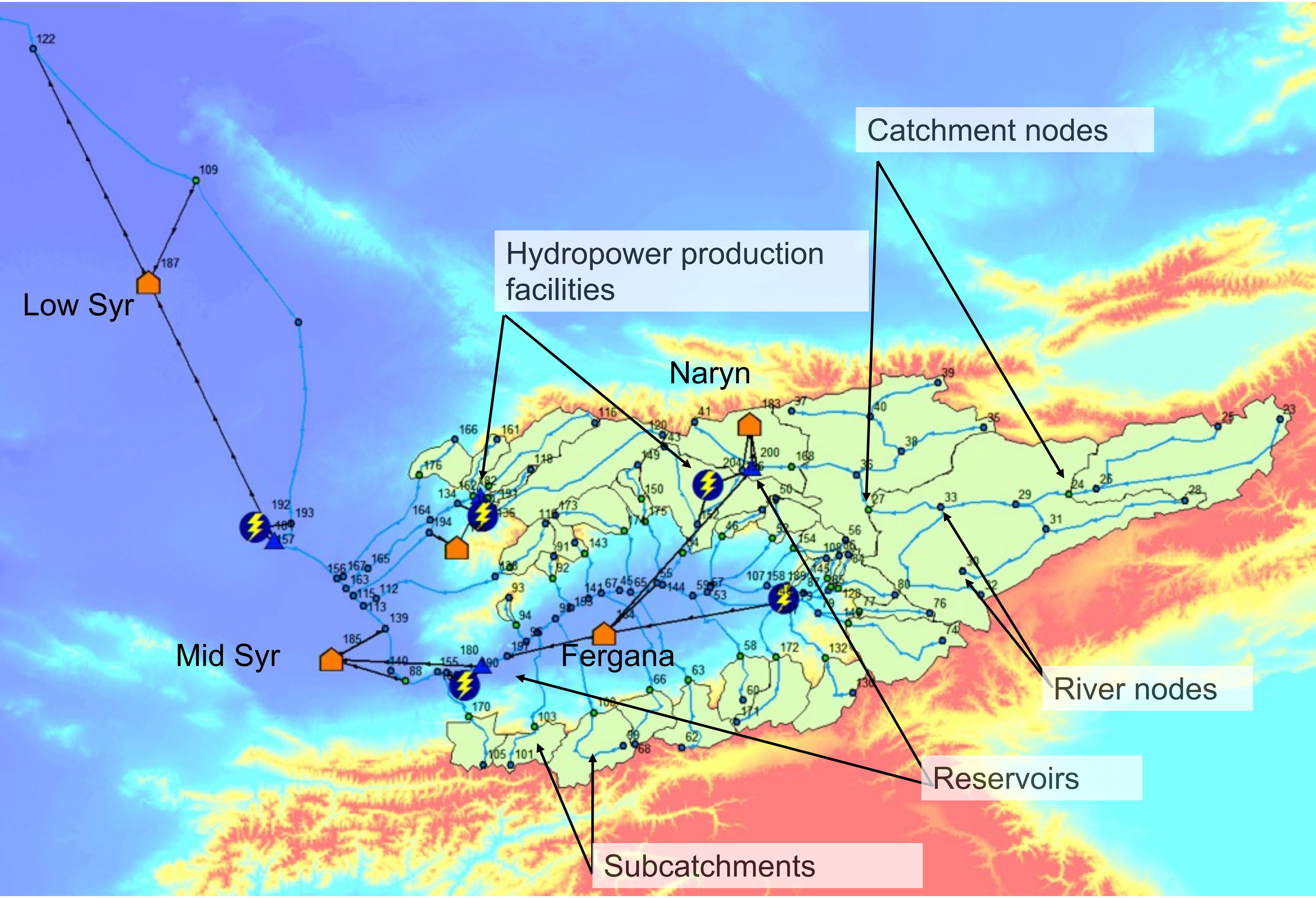
Independent republics

Summer / Winter



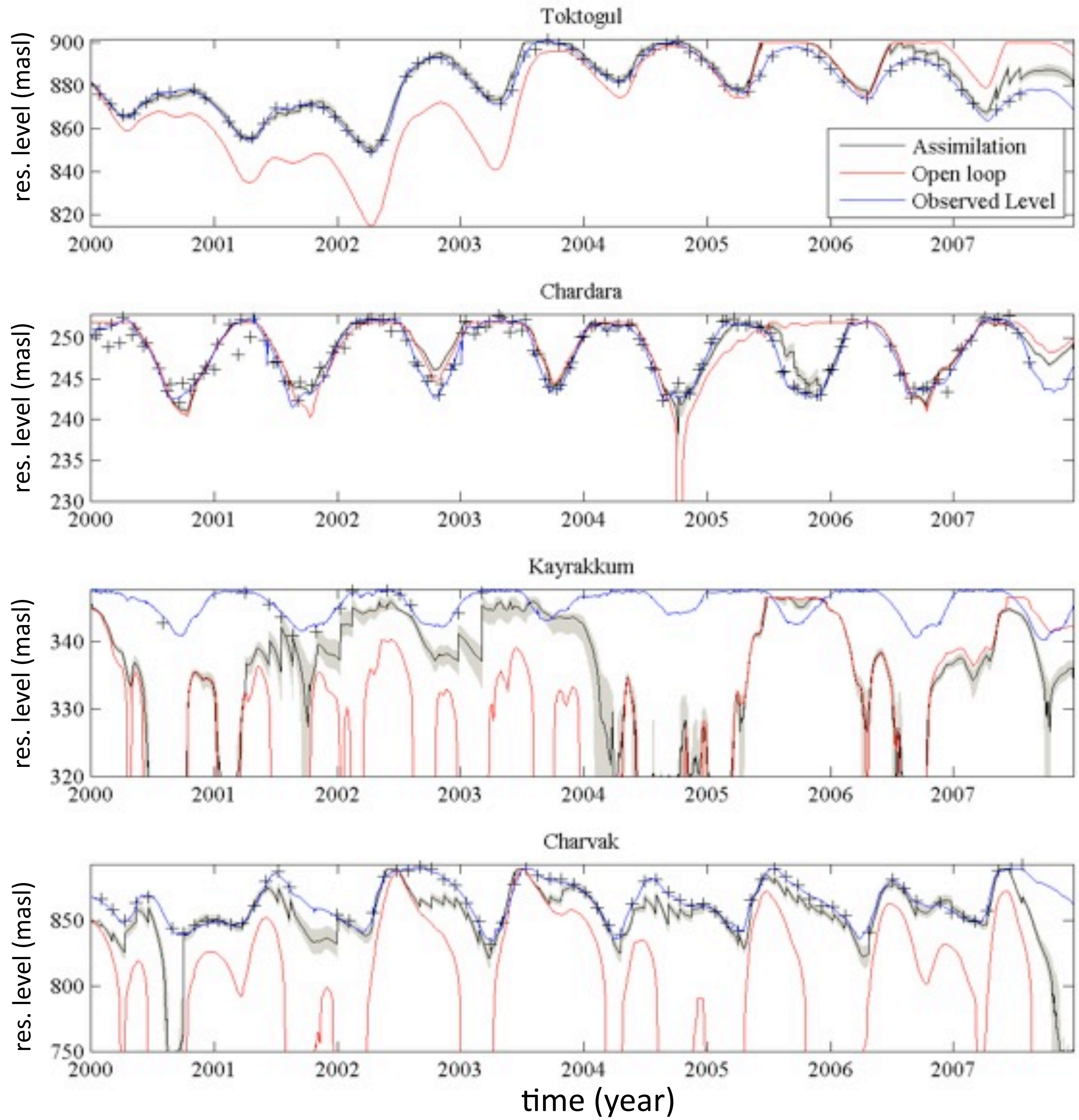
Question: How to manage infrastructure and resources given ongoing conflict and uncertainty regarding future?

Supply-Side Rainfall-Runoff Model



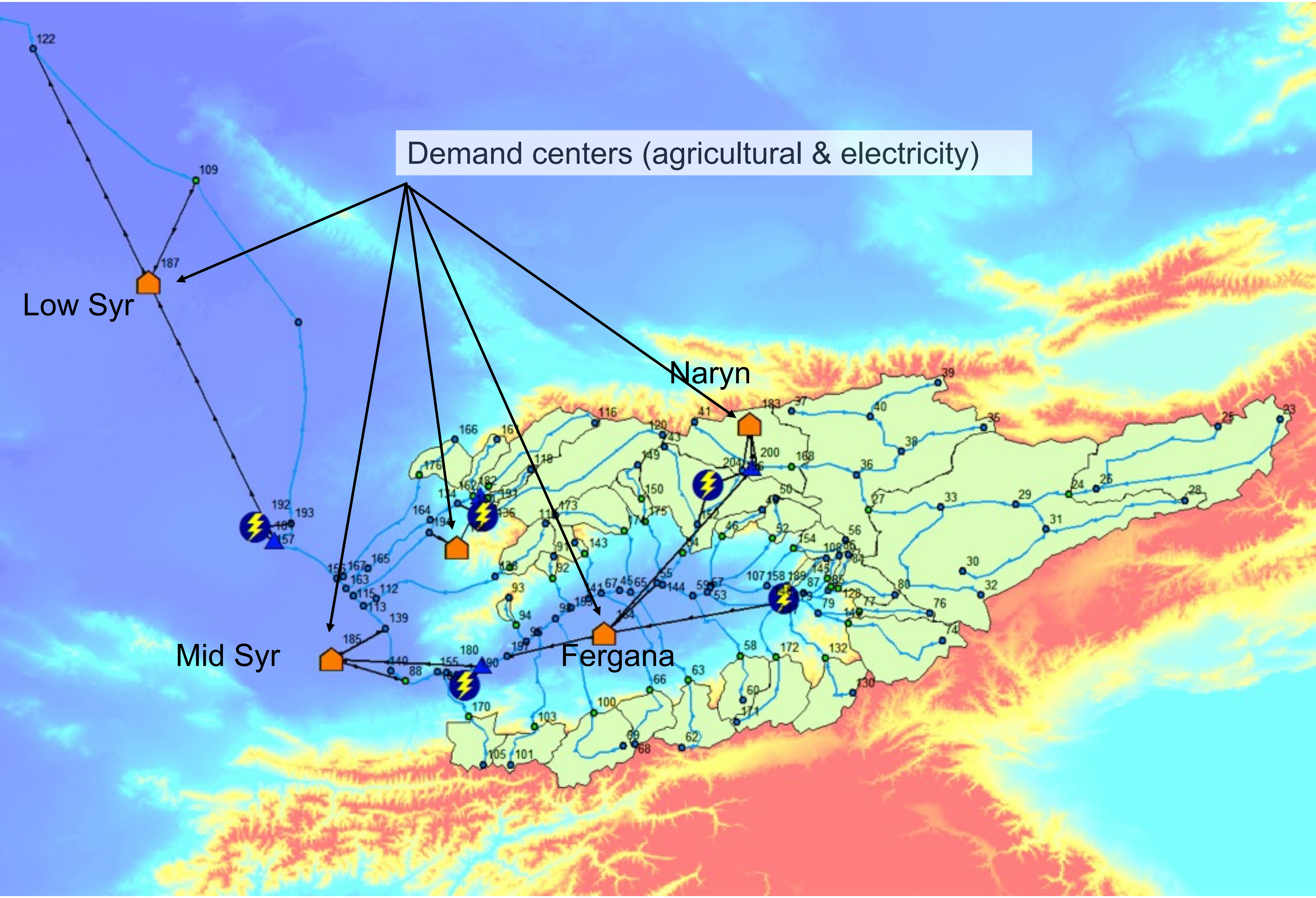
Characteristics and Performance of Hydrological Model

- 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



Source: **Peireira-Cardenal et al. (submitted to Journal of Hydrology)**

Coupling to Demand-Side Model



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