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Entropy and reliability of water use via a statistical approach of scarcity

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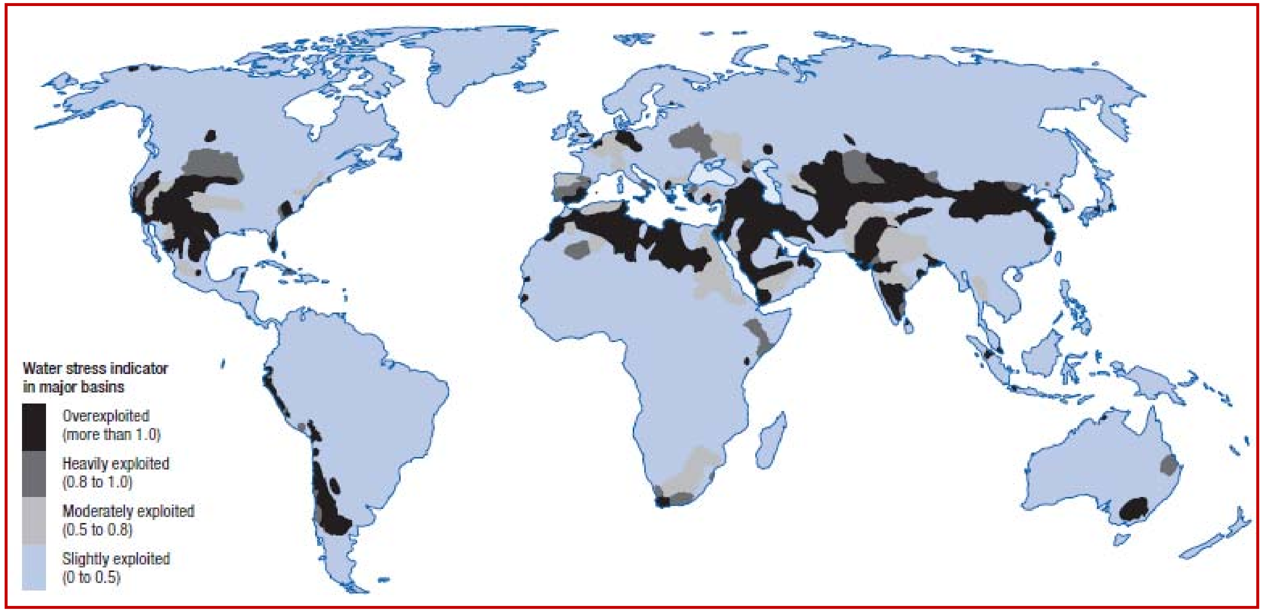
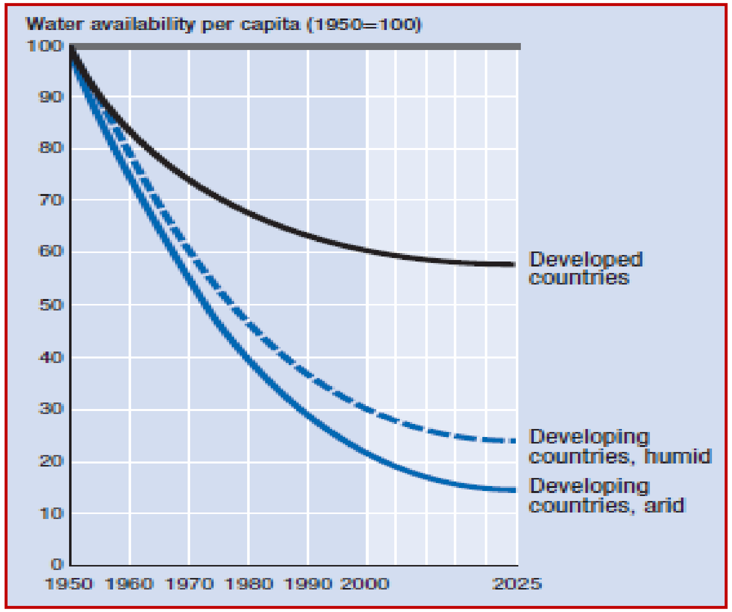
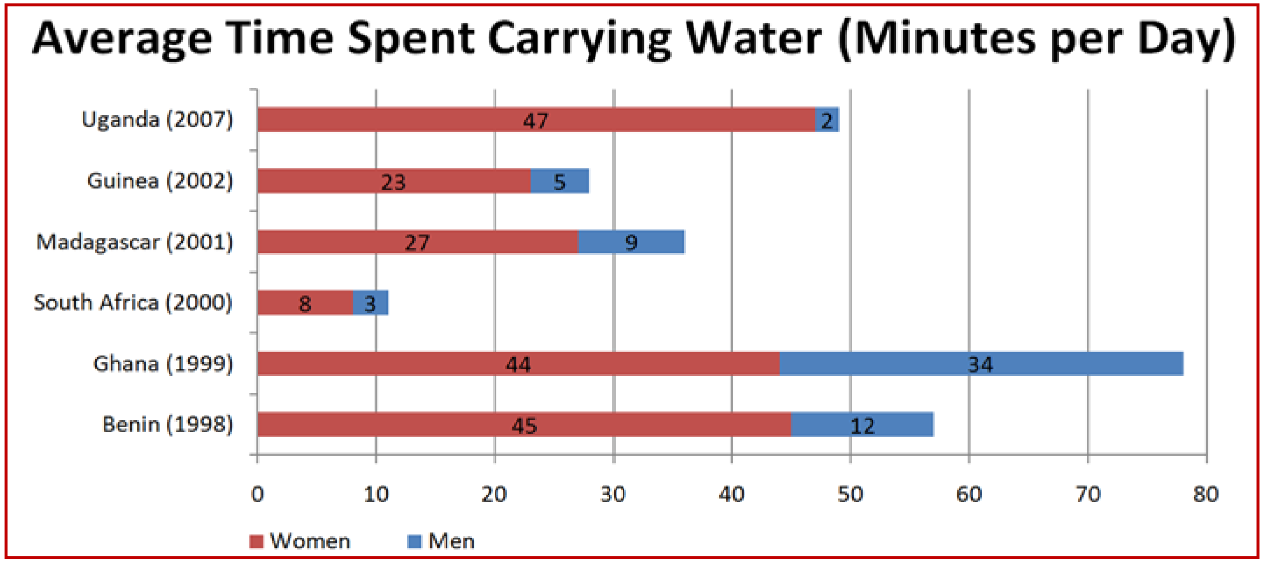
Water scarcity: Natural and Anthropogenic





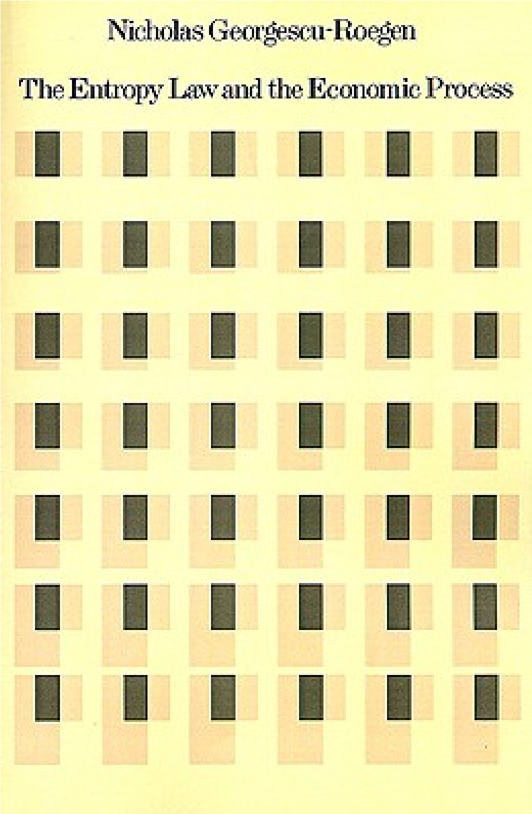
Source: ***Human Development Report (HDR), 2006***



Source: ***Moria et al. 2007; Wodon et al. 2006***

- Increasing water scarcity concerns the part of the developing world *without* storage capacity
- Water scarcity is *relative* and should be examined in integrative terms (both natural and economic)

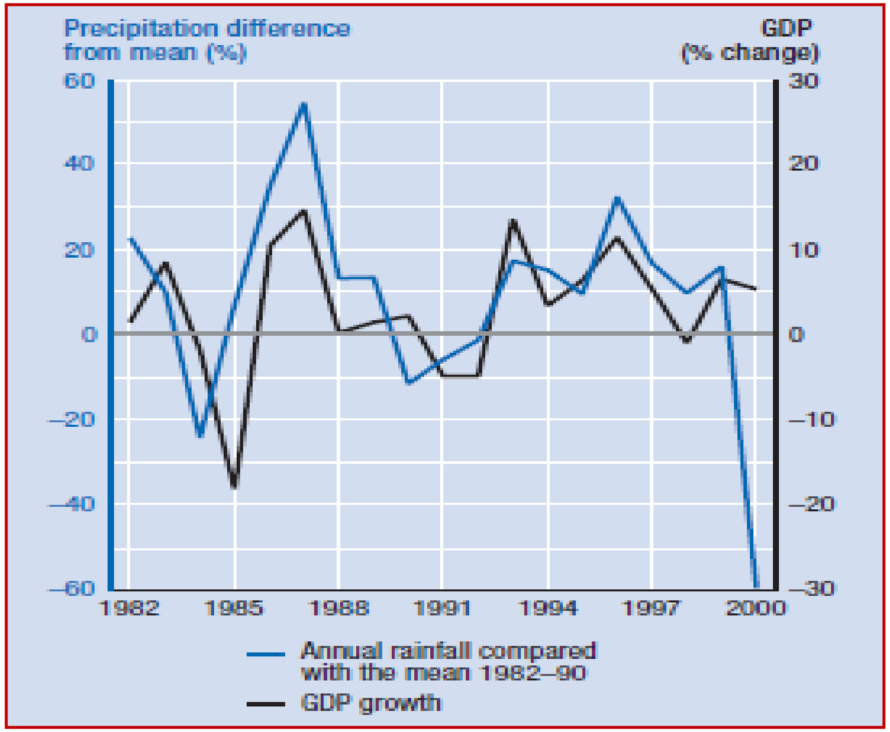
Entropy, water scarcity and economics



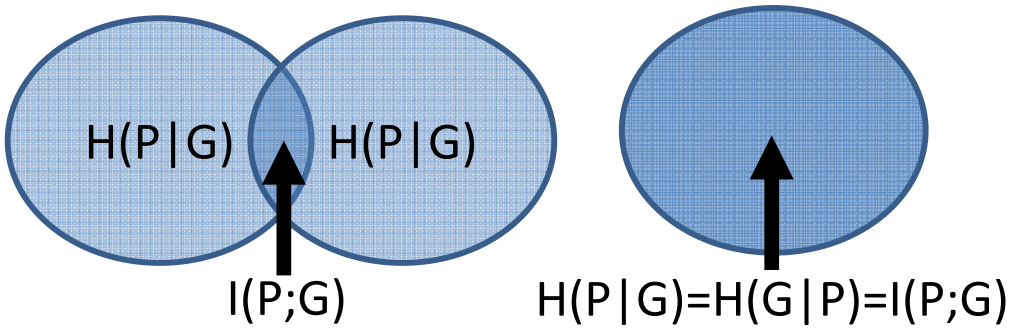
- The issue of industrial sustainability and reliability is immediately connected to *Entropy production* across natural resource use (*Roegen 1971*)
- Macroscopically, entropy is manifests as *energy unavailability* for further production of thermo-mechanical work
- Microscopically (statistically), entropy is manifested as *uncertainty*
- The economic utility of a natural resource is *reverse proportional to its entropy* or its uncertainty of availability (*Roegen 1986*)

- In Hydrology, the connection of entropy to scarcity requires the *examination of thermodynamic data* on hydrometeorological processes
- The adoption of *endogenous measures* (eg. water storage, efficiency and reuse) is the only way of (partially) controlling water availability, as the control of the natural phenomenon is not a feasible option

Natural availability and use: Mutual Information



<u>Source:</u> ***Human Development Report (HDR) 2006***

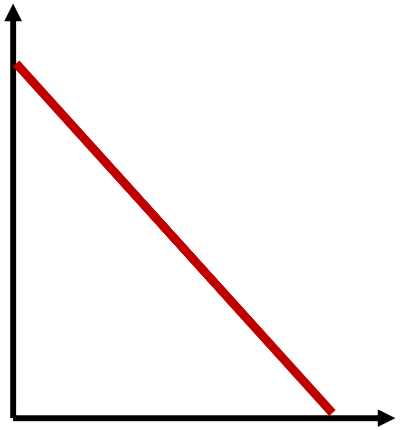


$$I(P;G) = \sum_{p \in P} \sum_{g \in G} P(p,g) \log \frac{P(p,g)}{P(p)P(g)}$$

Mutual Information concerns *correlation* and not causality

- In the absence of water buffering infrastructure, *Mutual Information* between *natural and economic phenomena* is expected to be high (<u>eg.</u> precipitation difference from mean can tell us much on the GDP growth of Ethiopia)
- Mutual Information is more accurate when there is *no time hysteresis*
- Methodologically, it is more convenient and accurate to calculate the *differential Mutual Information* in order to measure decoupling trends

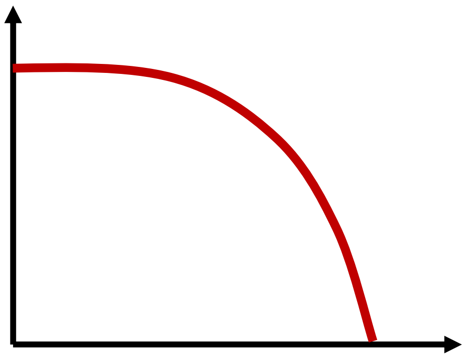
Pareto Frontier types and revealed water scarcities



A Pareto Frontier is a Production Possibility Frontier, which charts the *Marginal Rate of Substitution* (trade-off) ratio between two or more conflicting variables (eg. Reservoir level decrease for increased water provision reliability)

Three (3) major types of Pareto Frontiers (per 2 criteria):

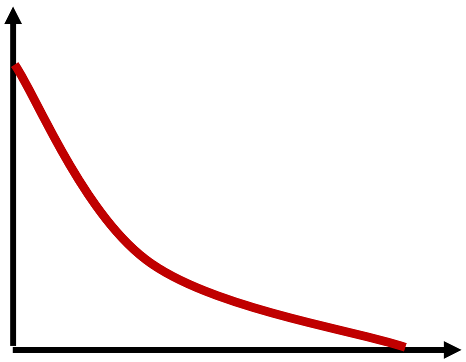
•Linear MRS (Constant Substitutability)



•Increasing MRS (Decreasing Substitutability and Increasing Complementarity)

•Decreasing MRS (Increasing Substitutability)

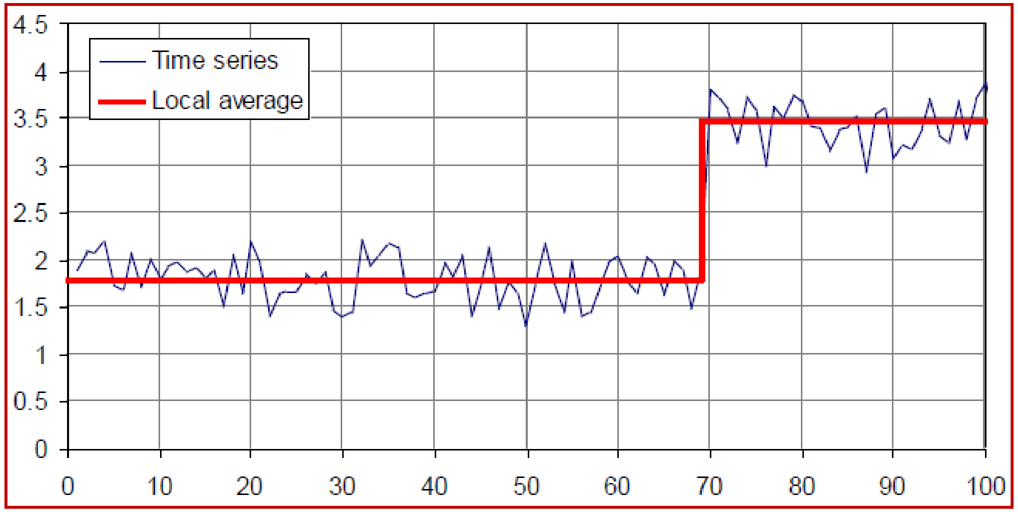
$$MRS = \partial X / \partial Y$$

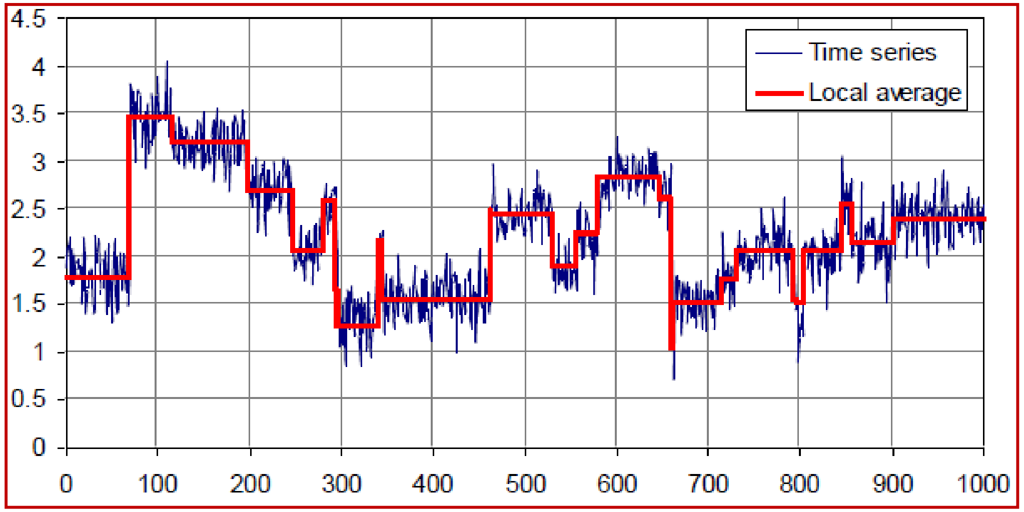


MRS Elasticity is considered more convenient to use as it is independent of effects of scale

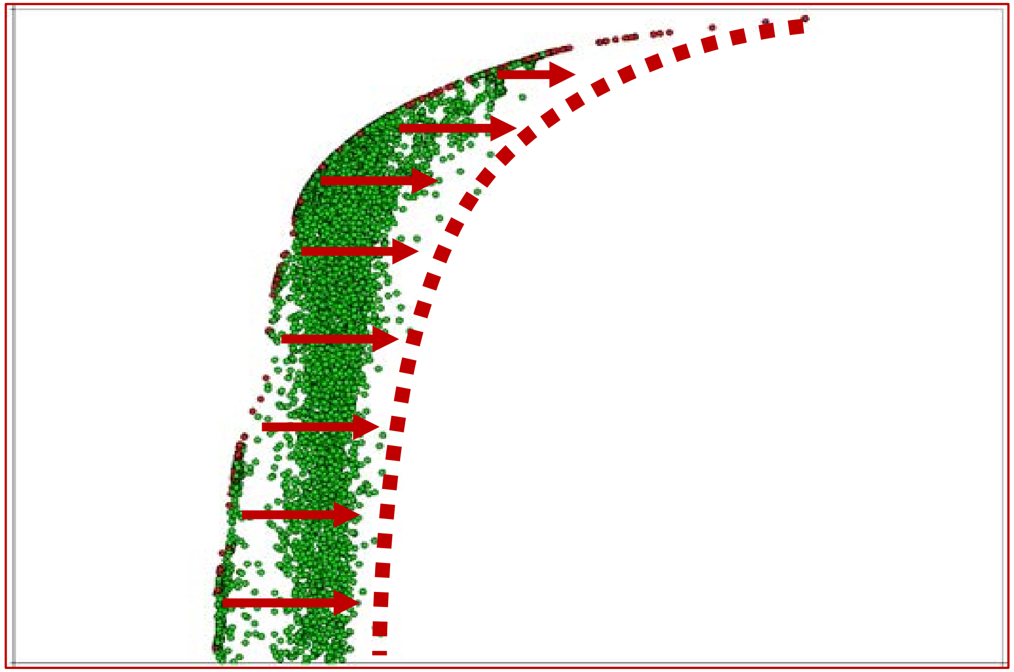
$$MRS_{Elasticity} = \left(\partial X / X\right) / \left(\partial Y / Y\right)$$

Pareto Frontiers under variability and persistence





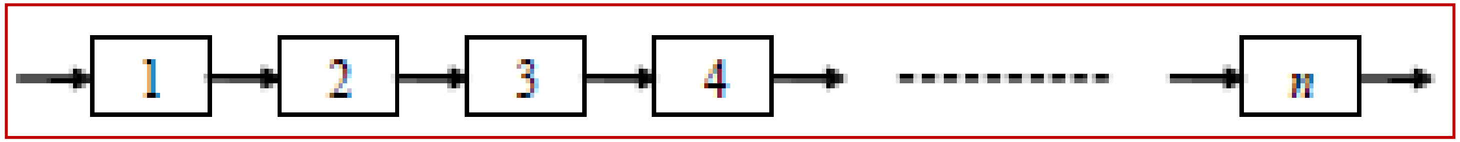
<u>Source:</u> ***Koutsoyannis 2011***



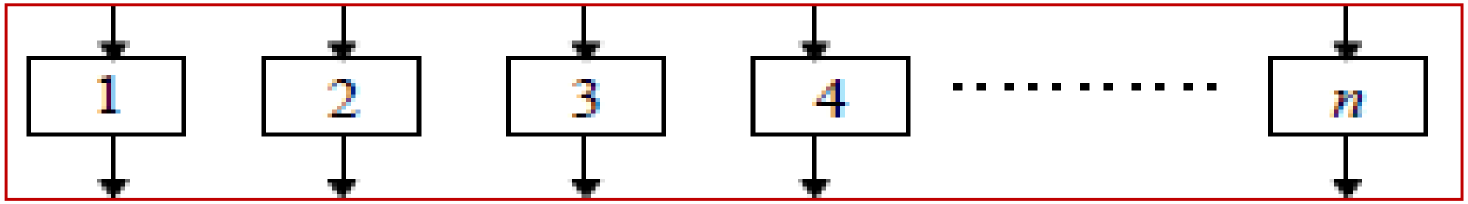
- Shifts in scales do not necessarily suggest statistical structural change (<u>eg.</u> shift towards non-stationarity), but perhaps *persistence*
- However, even due to persistence, *clustering of lows* is probable at a small time-frame
- Persistence *further restricts* the Pareto Frontier, as certain economic activities (<u>eg.</u> agriculture) cannot cope with it in the long-term → Reliability planning must concern longer periods

Reliability and hydro-system topology

- Hydro-system topology deals mainly with *spatial variability* of precipitation
- Hydro-system topology determines the degree of *statistical independence* between the reservoirs:
  - Linear topologies suffer from *excessive statistical dependence* they are very sensitive to total structural failure due to only a partial failure

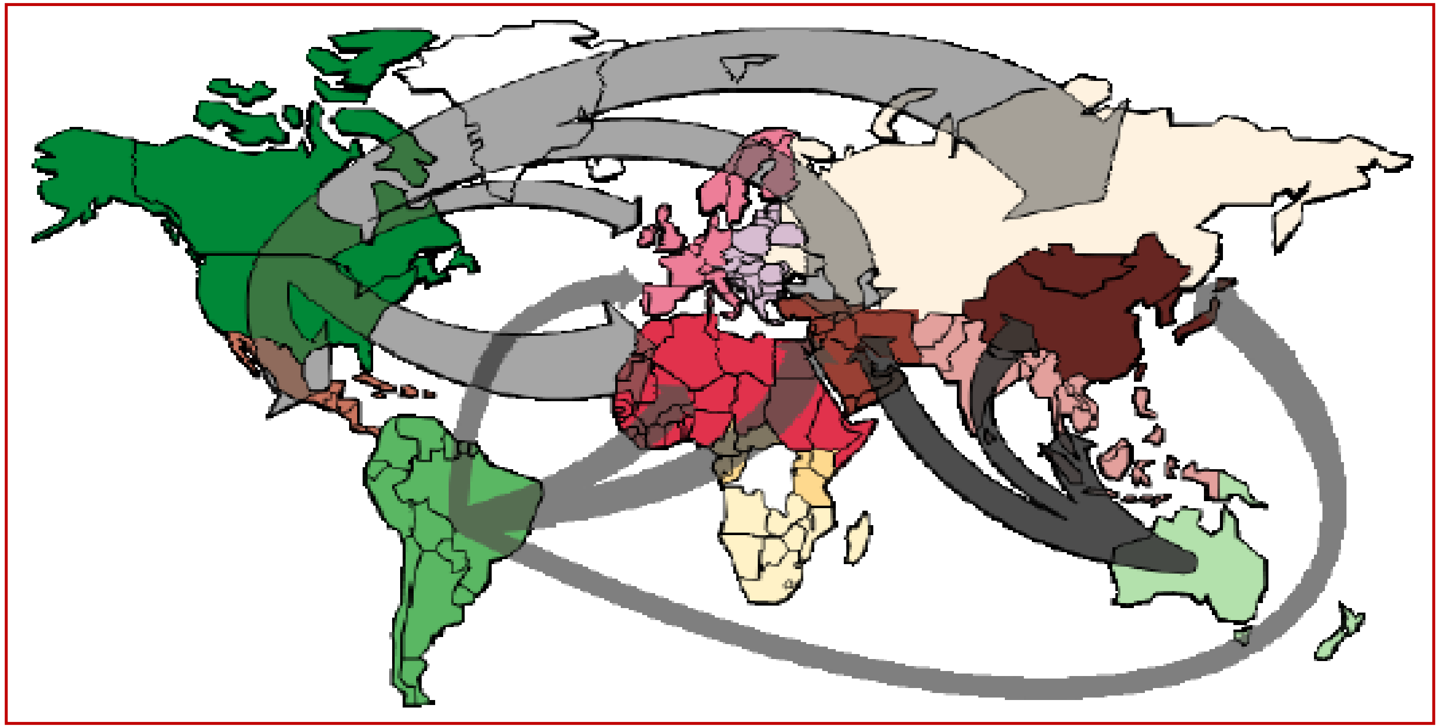


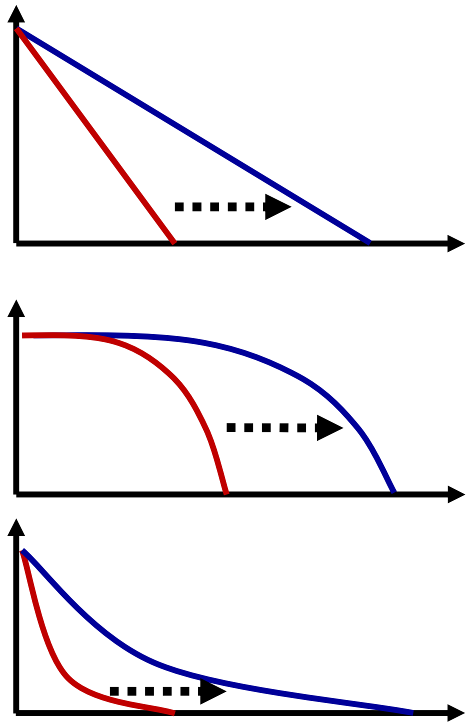
  - Parallel topologies suffer from *excessive statistical independence* and prevent reservoir complementarity under spatial variability of rainfall



  - Complex (combined) topologies have *increased cost* (in MRS terms) of construction (eg. Increased bounding of natural space and for more time)
- Hydro-system topology *affects the Pareto Frontier* (Possibility Production Curve), just as well as exogenous factors do (eg. Precipitation variability)

Embodied water and international trade





<u>Source: </u>*Yang et al. 2006*

- Through international trade of water-intensive commodities the importing country actually *incorporates* a part of the exporting country's water use reliability
- Activation of international trade of water-intensive commodities is *equivalent to a technological upgrade* via the upgrade of the Pareto Frontier
- Imports of water-intensive goods, *liberates resources* for other high added-value production (<u>eg.</u> Import of agricultural products in the Middle-East and use of domestic water for oil production)

Decoupling water use reliability from natural scarcity

- Water recovery and reuse *increases immediate availability* and reduces the statistical dependence from natural recharge frequency
- Water recovery and reuse, *re-inserts* used water to the economic system (circular economy)
- Water recovery and reuse *buffers natural scarcity* in persistent draught phenomena (<u>eg.</u> persistent downward Hurst currents)

Reuse Multiplier (W_M)

$$W_M = \frac{W_0}{(1-m)}$$

***W_o*:** Initial amount of extracted water

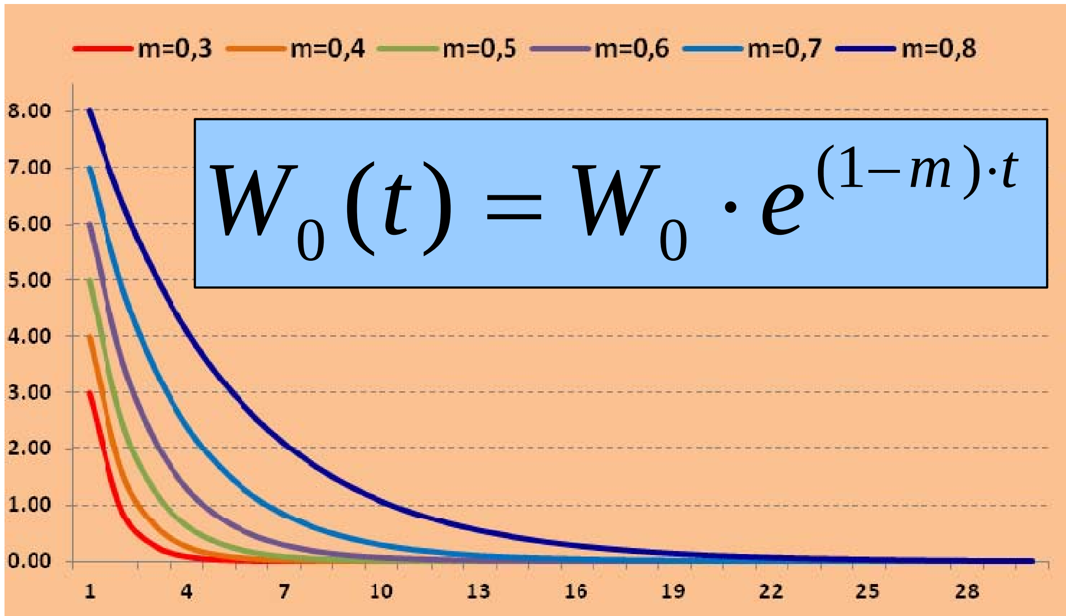
m: *Reuse coefficient (0<m<1)*

Agriculture: Demands 70-90% of total international freshwater use

Population: Estimated increase from 7 billion to 9 billion until 2050

Reuse: 80% of used water internationally is not reused

<u>Source:</u> ***United Nations World Water Development Report 4 (WWDR 4), 2012***



Entropy, water scarcity and economics again…

- In variable natural phenomena -such as the hydrological cycle- entropy *cannot be connected directly* to natural scarcity based only on precipitation statistics, as it might very well mean high probability of extreme precipitation events (over-availability)
- Entropy can parsimoniously connected to economic scarcity via the *increased opportunity cost* (trade-off ratio between conflicting variables)
  - Opportunity cost *does not necessarily* refer to financial cost
- Opportunity cost refers to the amount of production factors (reservoir level, reliability, natural space) that *have to be bounded over time* in order to produce a specific water availability state
  - Increased entropy signifies a larger amount of bounded production factors as the infrastructure has to be predicted to be reliable for a *wider amplitude* of events
- International trade via the comparative advantage that derives from water use specialization mitigates *uncertainty of supply and scarcity* as it is equivalent to the liberation of (previously) bounded production factors
- The fundamental base of economic science is its continuous effort to *reduce the statistical dependence* of human societies from natural phenomena
- Entropy is an *evolutionary force* (Koutsoyannis 2011) as it forces the economy to research and reduce its dependence from natural phenomena

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Thank you for your attention!!!

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Ready for Questions…