MOVING WELL SOLUTION TO OPTIMAL, MULTI-OBJECTIVE GROUNDWATER USE

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METHOD AND APPLICATION

T. Siegfried & W. Kinzelbach, 14. 03. 2011

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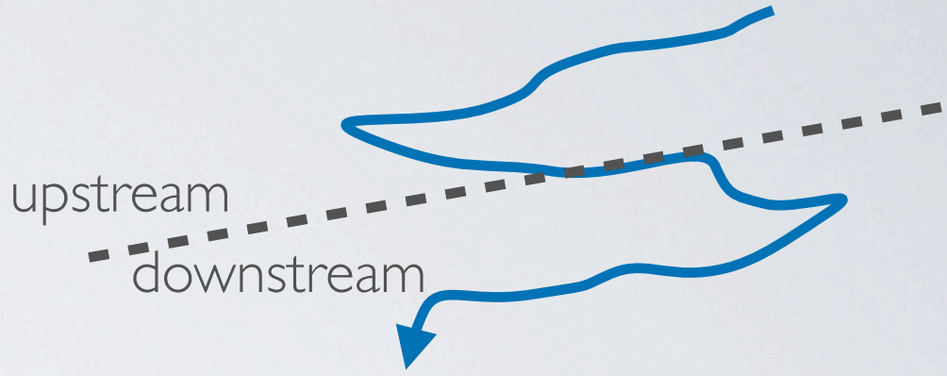
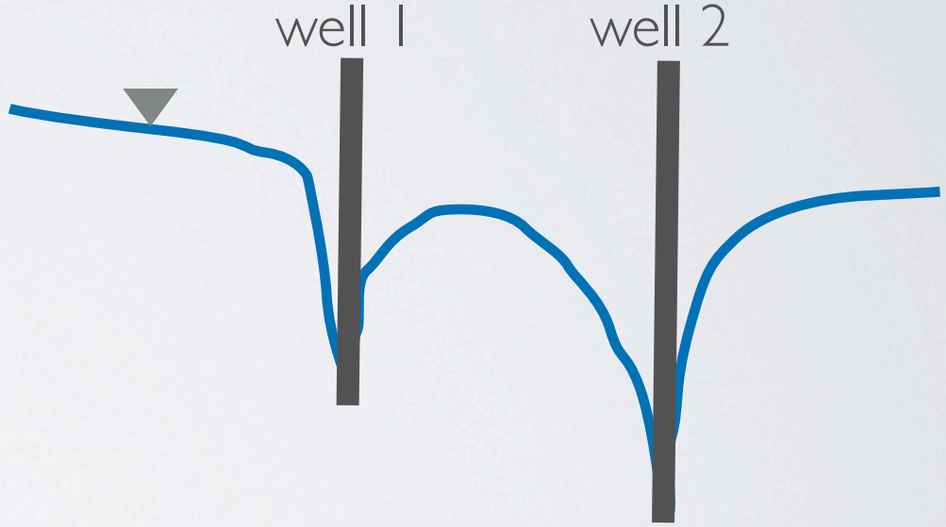
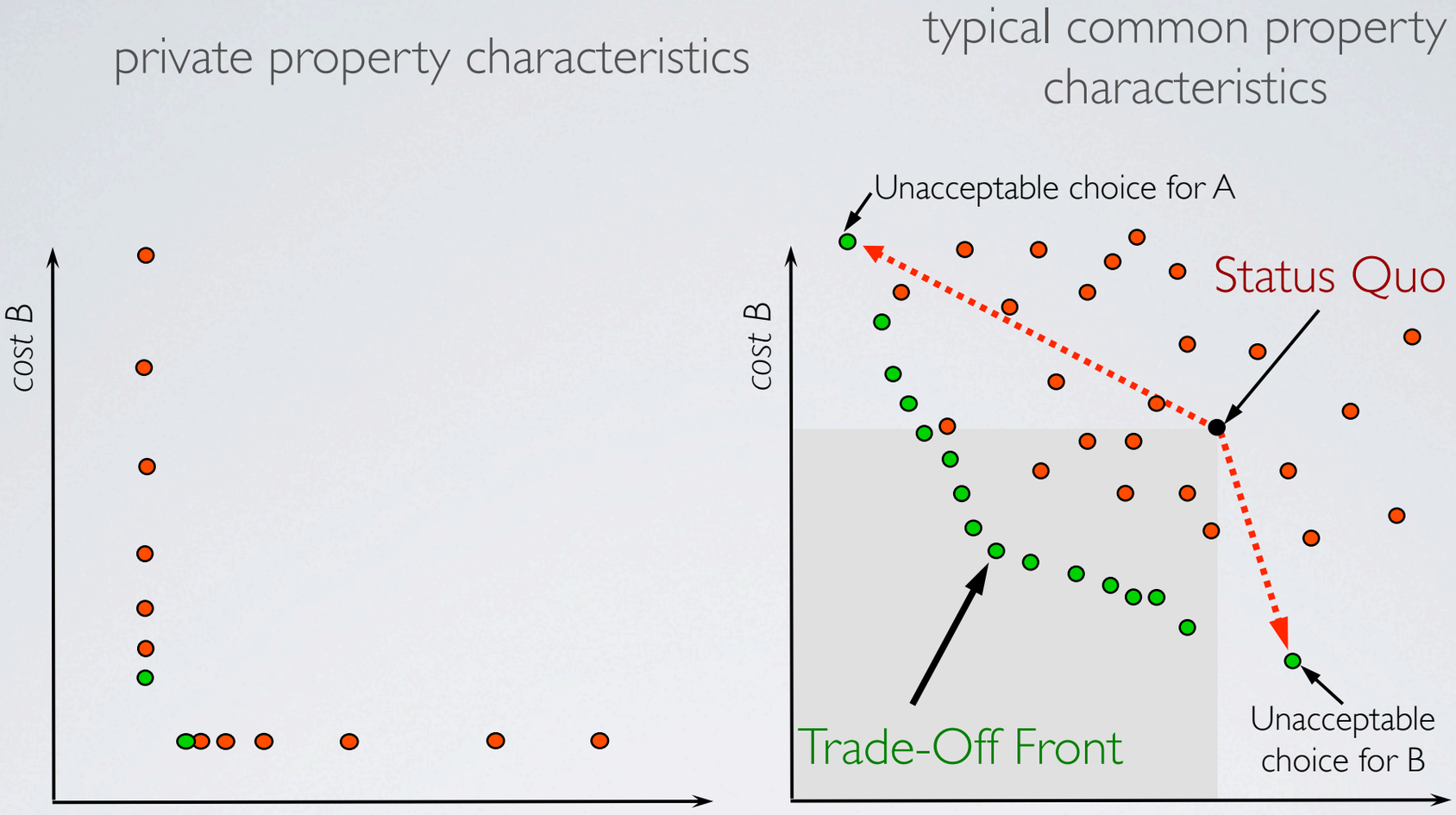
ETH

COMMON PROPERTY CHARACTERISTICS OF WATER RESOURCES

- Surface Water
  - Externalities in flow direction only
- Groundwater
  - Complex externalities depending on hydrogeology
- Type of externalities
  - quantity (volume/timing) & quality
  - negative & positive



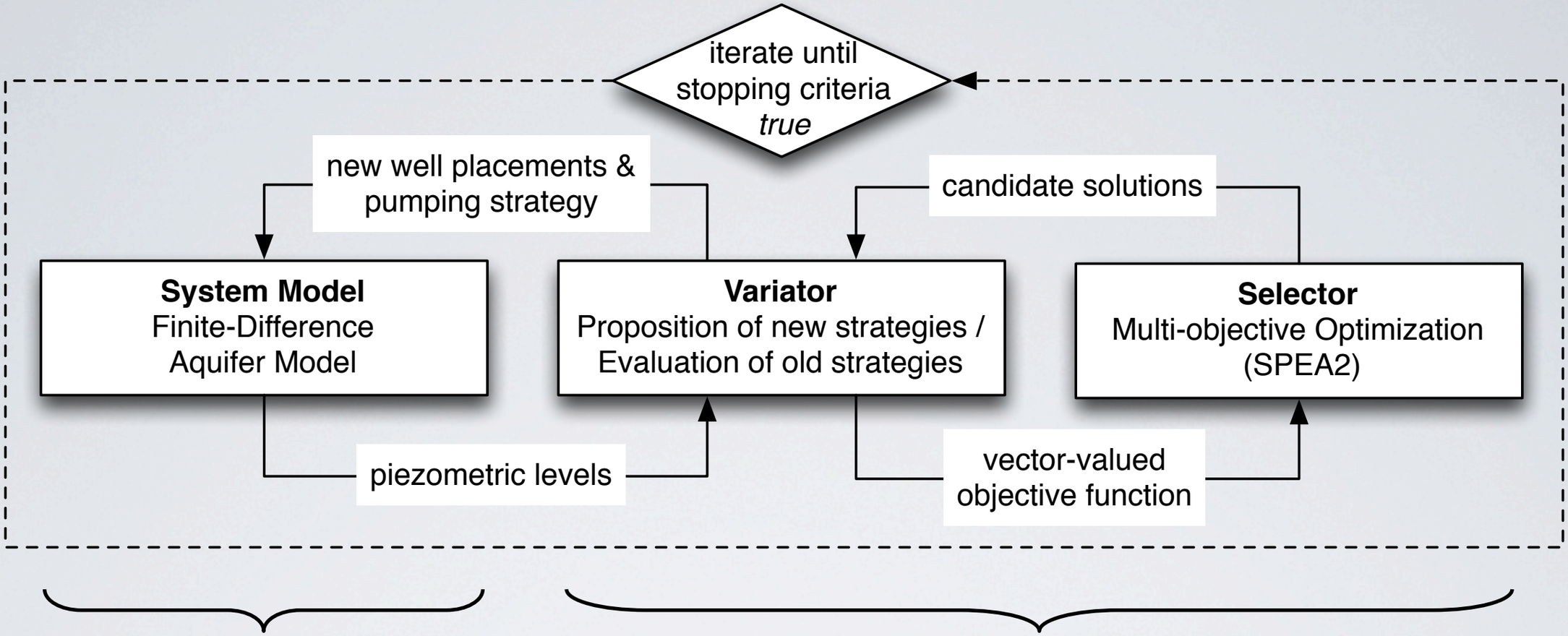




MULTIPLE OBJECTIVES IN WATER MANAGEMENT

- Key questions
  - What are the tradeoffs?
  - Gains & costs of Cooperation and implications for enforceability?
- Key task for answering those
  - Approximating the Pareto front

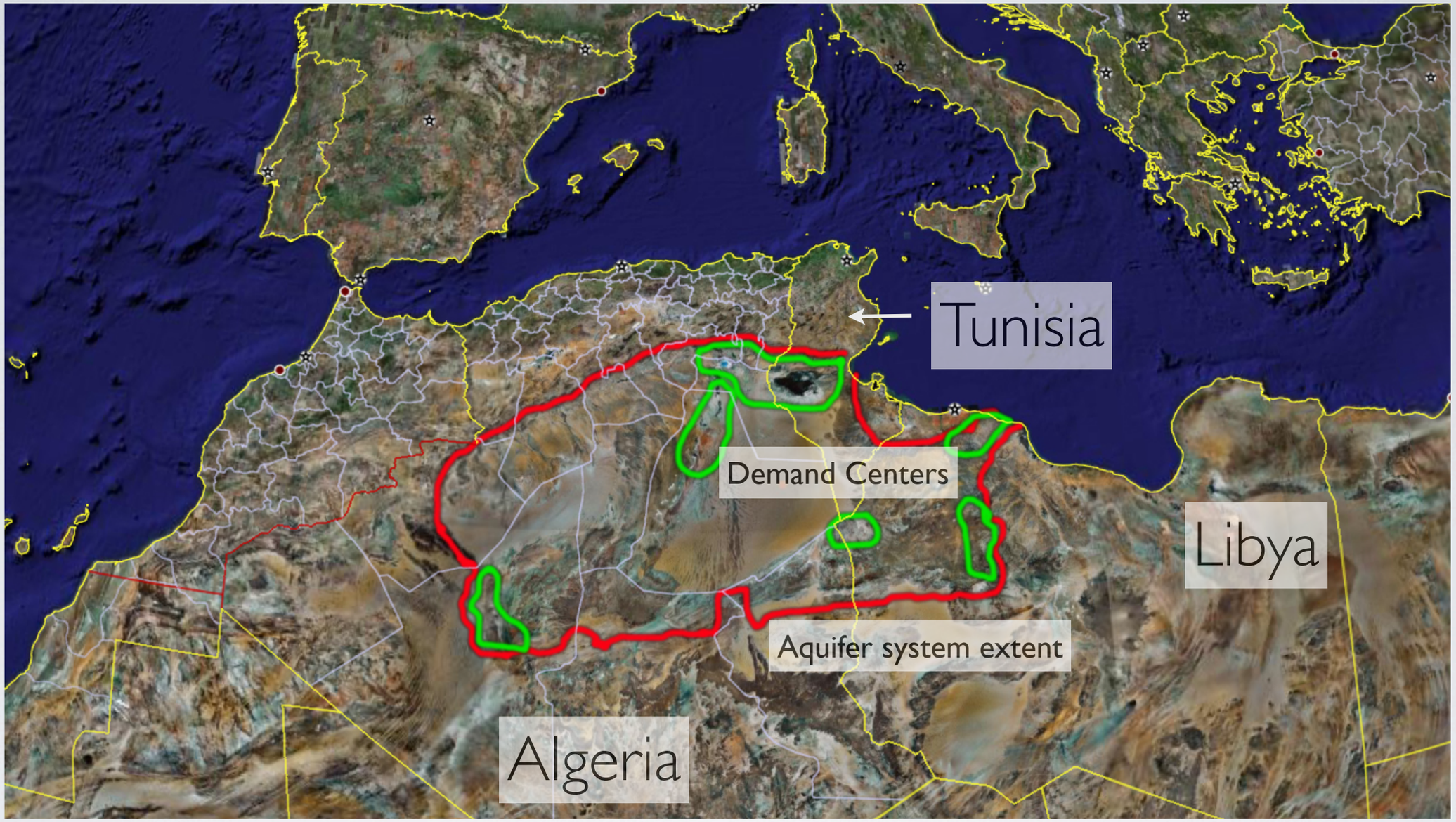
Source: Siegfried (2005)



ALGORITHM

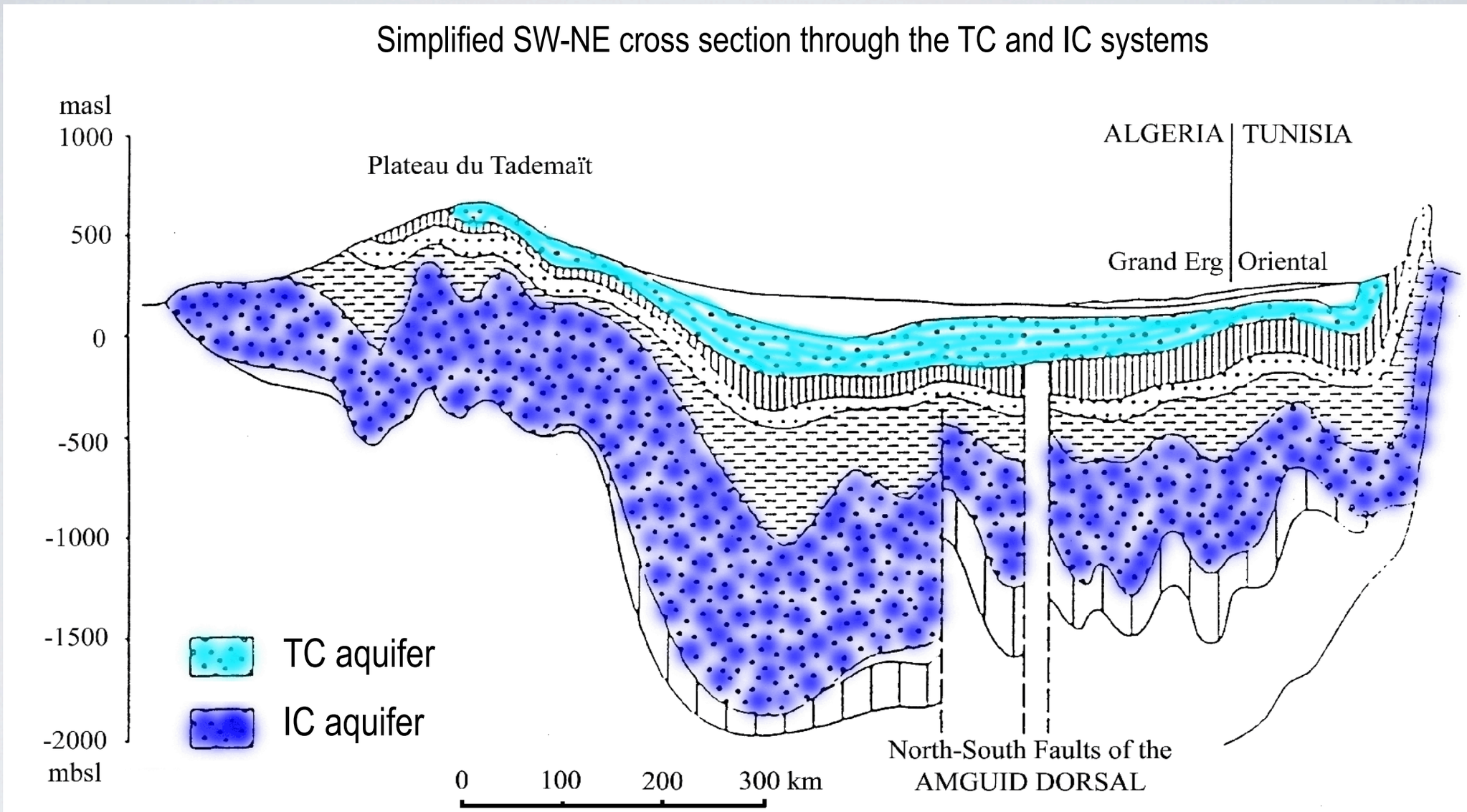
Multi-Objective Evolutionary Algorithm propagates a family of allocation strategies and improves them successively through concepts borrowed from natural evolution (selection / mutation / etc.)

Source: Siegfried (2009)



APPLICATION - NORTH-WEST SAHARA AQUIFER SYSTEM

Transboundary (common-pool) fossil groundwater reserve shared by Algeria, Libya & Tunisia

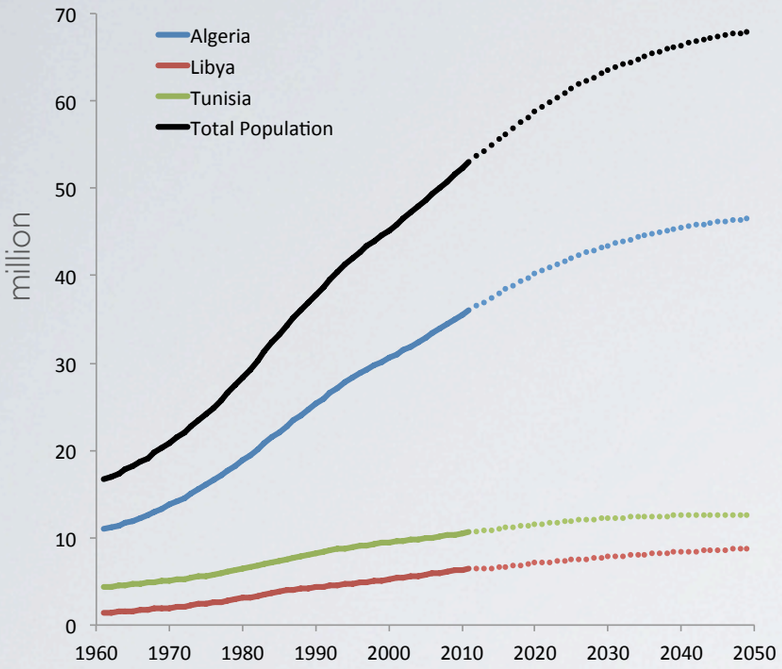


AQUIFERS

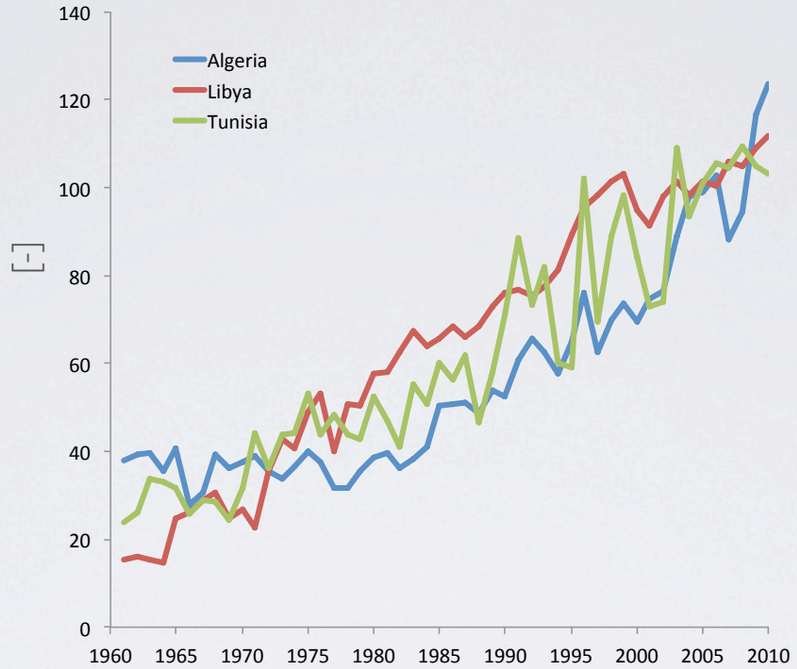
TC: Terminal Complex
IC: Intercalary Continental

Source: Mamou (1990)

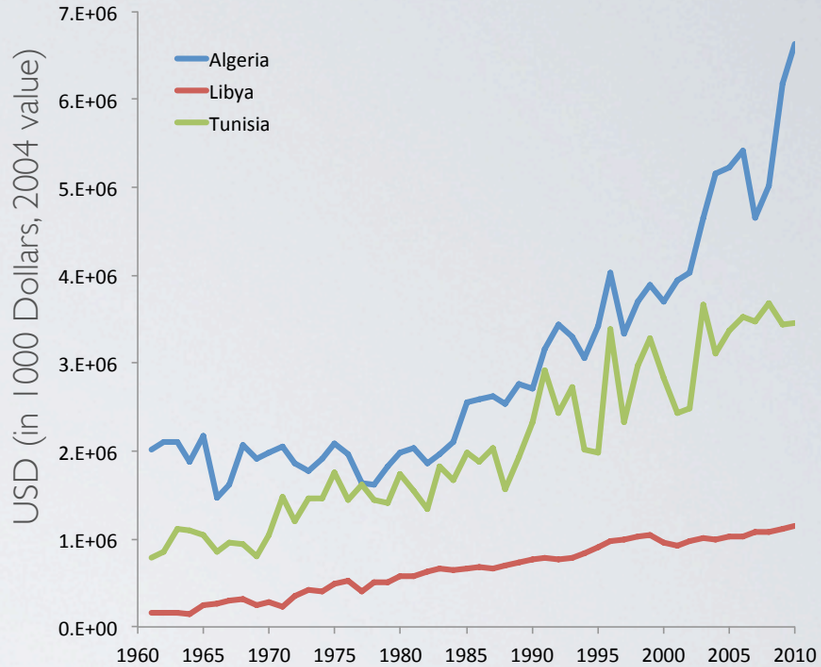
Population Development



Agricultural Production (Index)



Net Value Added (Ag.)



SOCIO-ECONOMIC DEVELOPMENT

Countries motivated by food security considerations & policies of self-sufficiency through import-substitution

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Expected rise of groundwater pumping from 100 m^3/s in 2010 to 500 m^3/s in 2050

Source: FAOSTAT (2012)

FUTURE

- Recharge: ~30 m^3/s
- Stored volume: ~ 100'000 km^3
- Exploitable volume: ~10'000 km^3
- Future max. expected demand (year 2050): ~500 m^3/s

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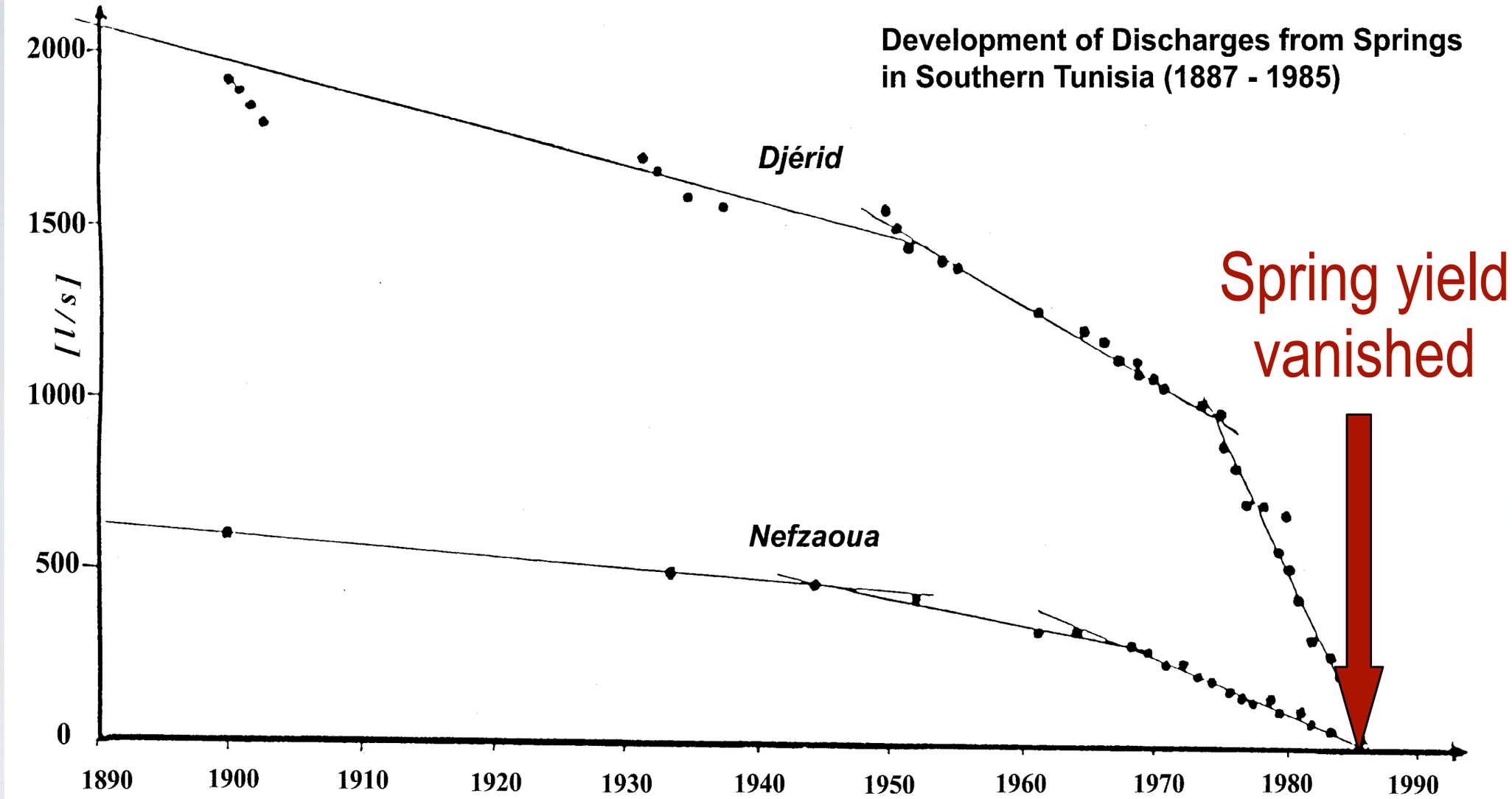
➡ Why worry?



ADVERSE DEVELOPMENTS

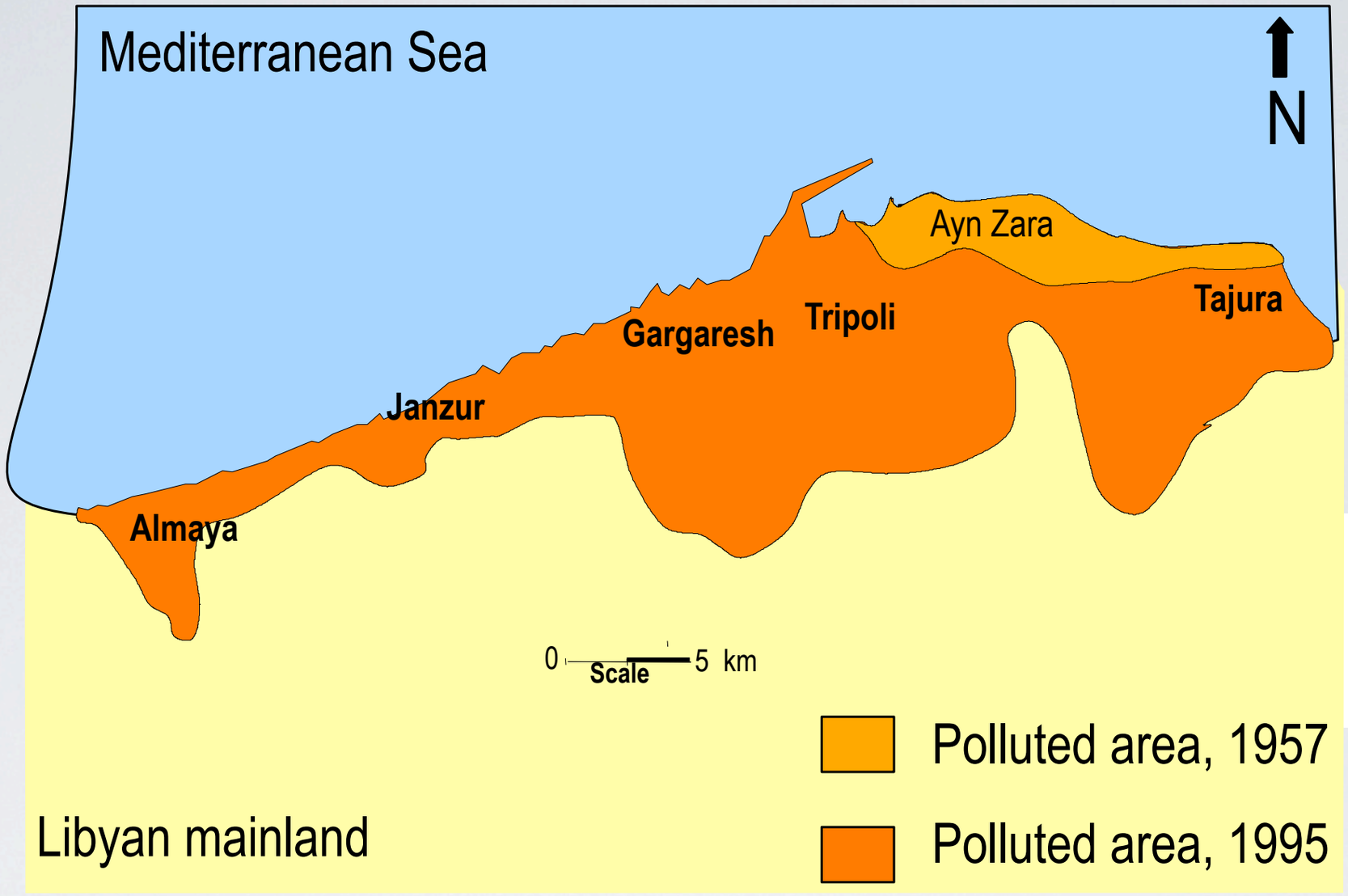
Declining piezometric levels → no more water harvesting 'for free'

Source: Mamou, 1991

ADVERSE DEVELOPMENTS

- Deterioration of groundwater quality
- Widespread soil salinization and soil fertility decline

Source: T. Siegfried

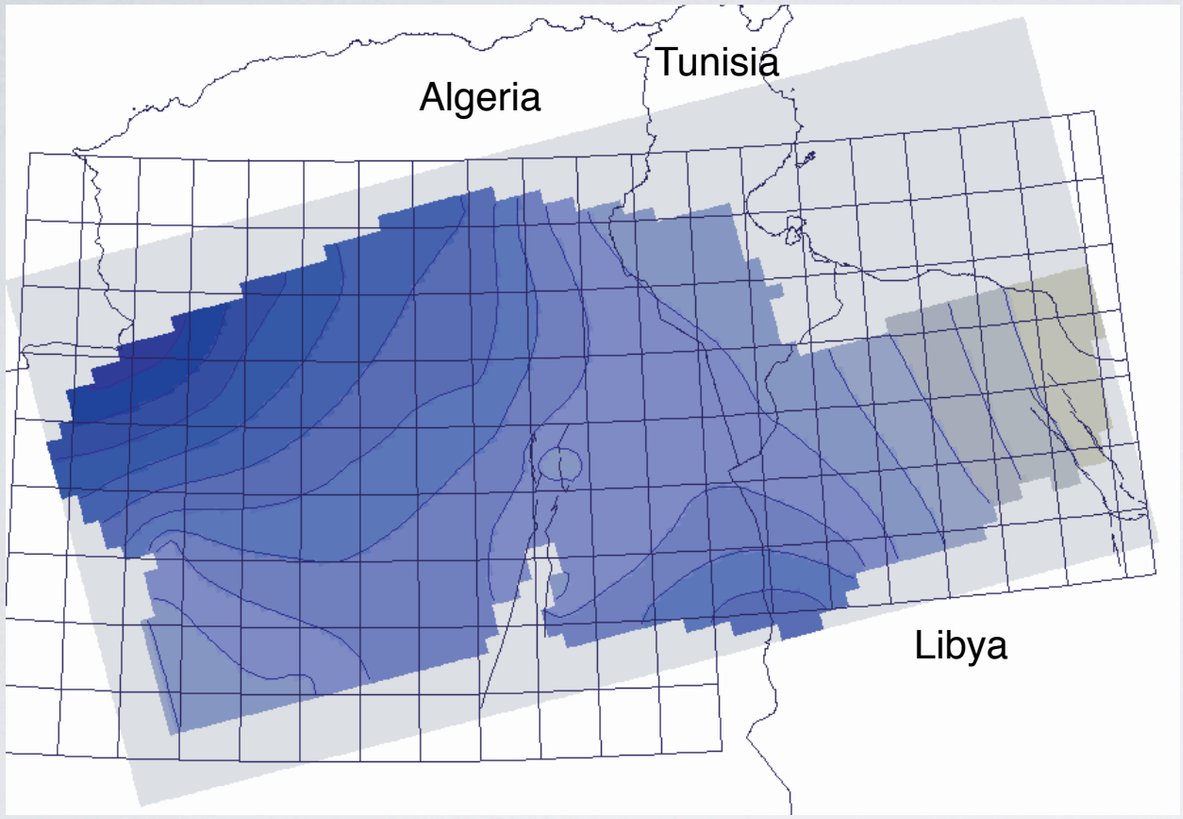


ADVERSE DEVELOPMENTS

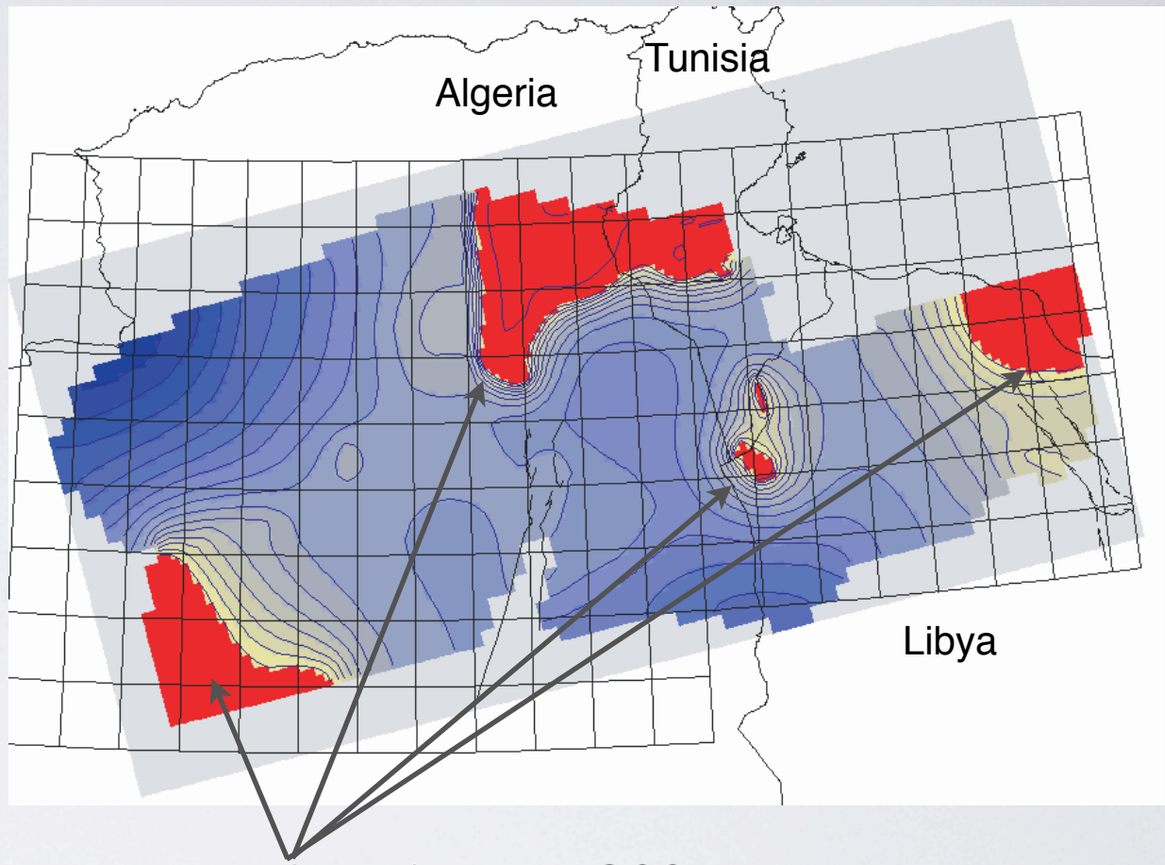
Saline seawater intrusion along coastline

Source: P. Pallas (personal communication)

CI: Piezometric levels 1950



CI: Piezometric levels 2050



ADVERSE DEVELOPMENTS

Forbiddingly high drawdowns over time,
esp. in Algerian / Tunisian Chott regions

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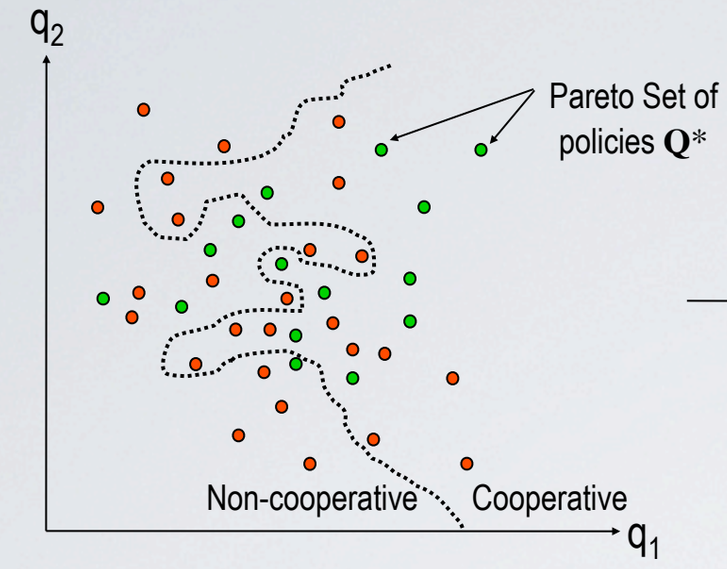
KEY QUESTION: Benefits from optimal, cooperative pumping?

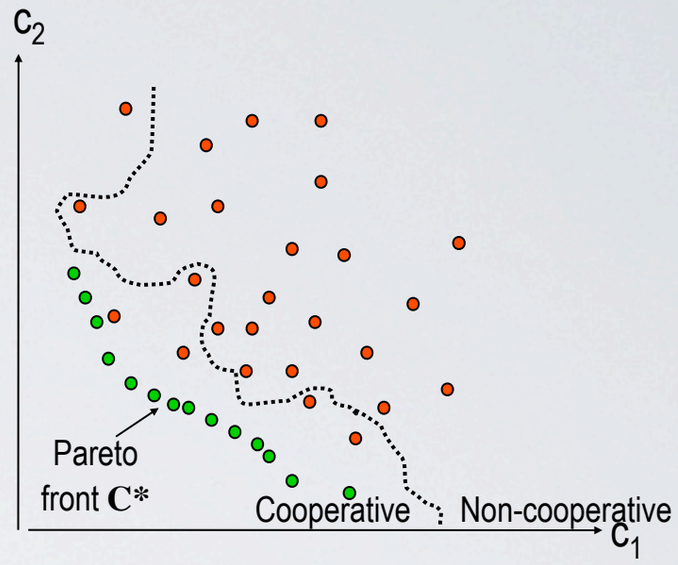
Source: Beck & Siegfried (2002)

Decision Space Q, Pumping (X,t)



$$C = f(Q)$$

Objective Space C, **Σ** COSTS



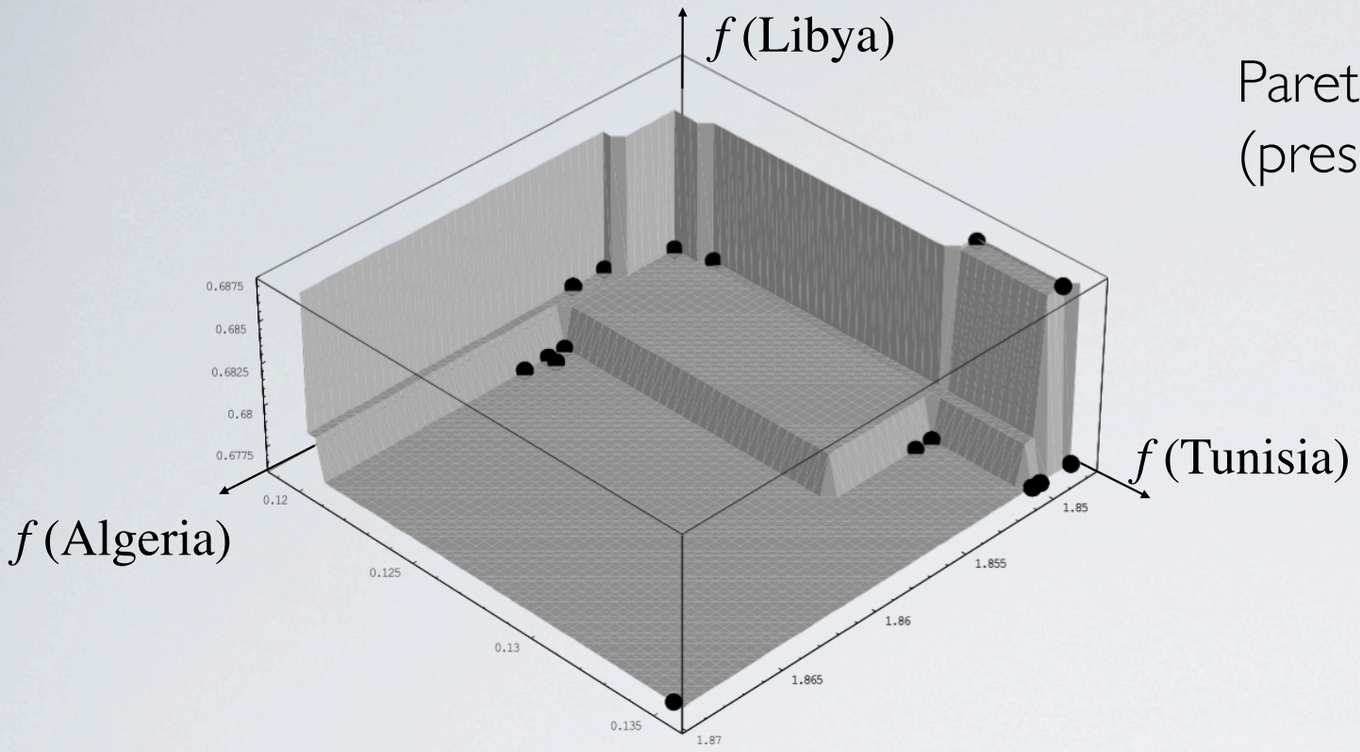
Resource Model + Economic Model

Multi-Objective Optimization Framework

APPROXIMATING THE PARETO SET

Coupled simulation & multi-objective optimization approach

Source: Siegfried (2009)



Pareto (Trade-Off) Surface
(present costs, year 2000)

Rise of per unit provision costs relative to year 2000 per unit costs

	Status Quo	Cooperation
Algeria	**35**	**8**
Tunisia	**31**	**3**
Libya	**29**	**4**

KEY FINDING

Per unit costs rise can be greatly reduced with intelligent pumping

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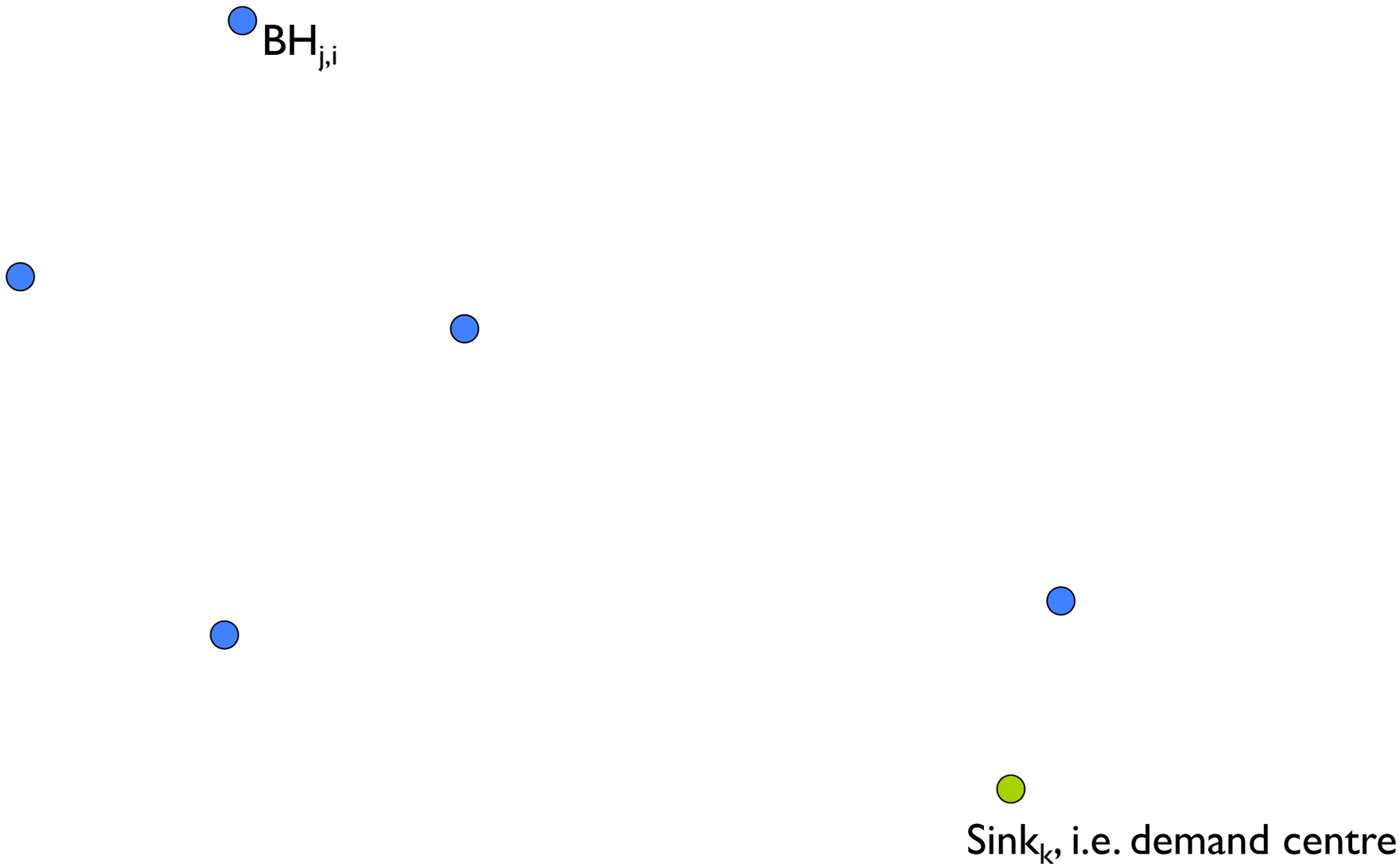
- Each country can gain from following the 'best' cooperative strategy
- Gains are key incentives with regard to enforcement

Source: Siegfried (2005, 2007, 2009)

Characteristics of Optimal Solutions



Intermittent pumping between well fields & aquifers

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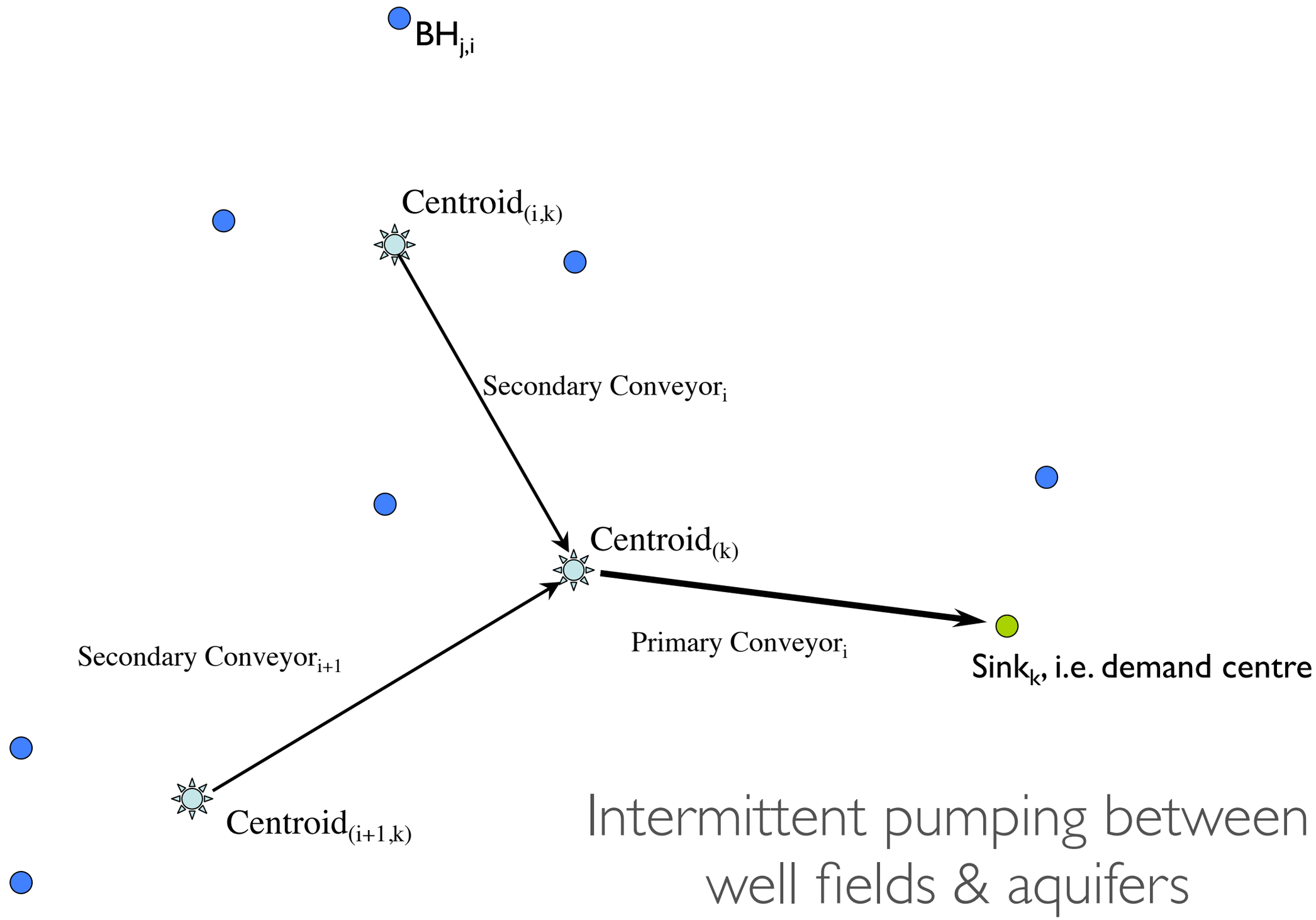

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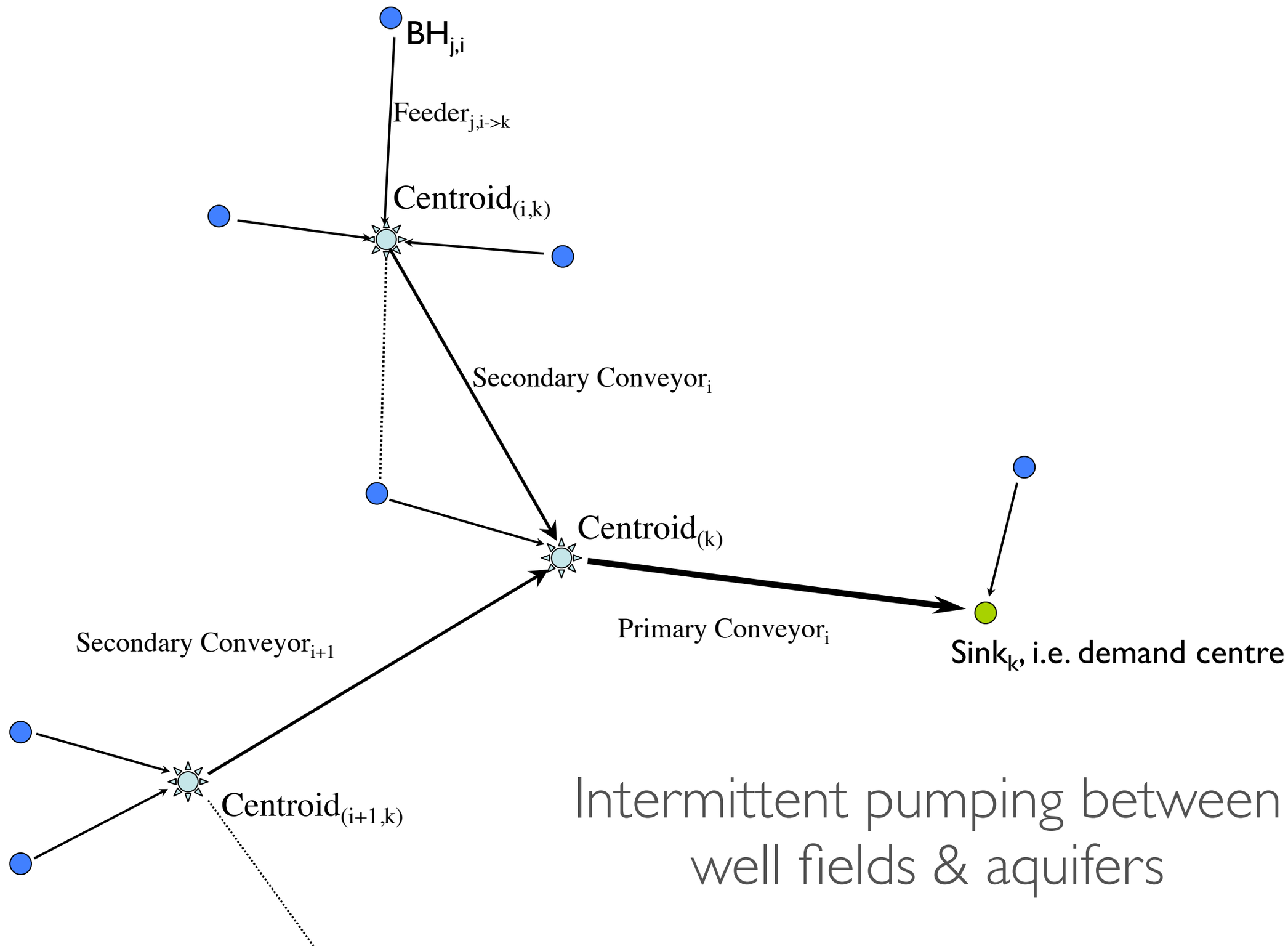

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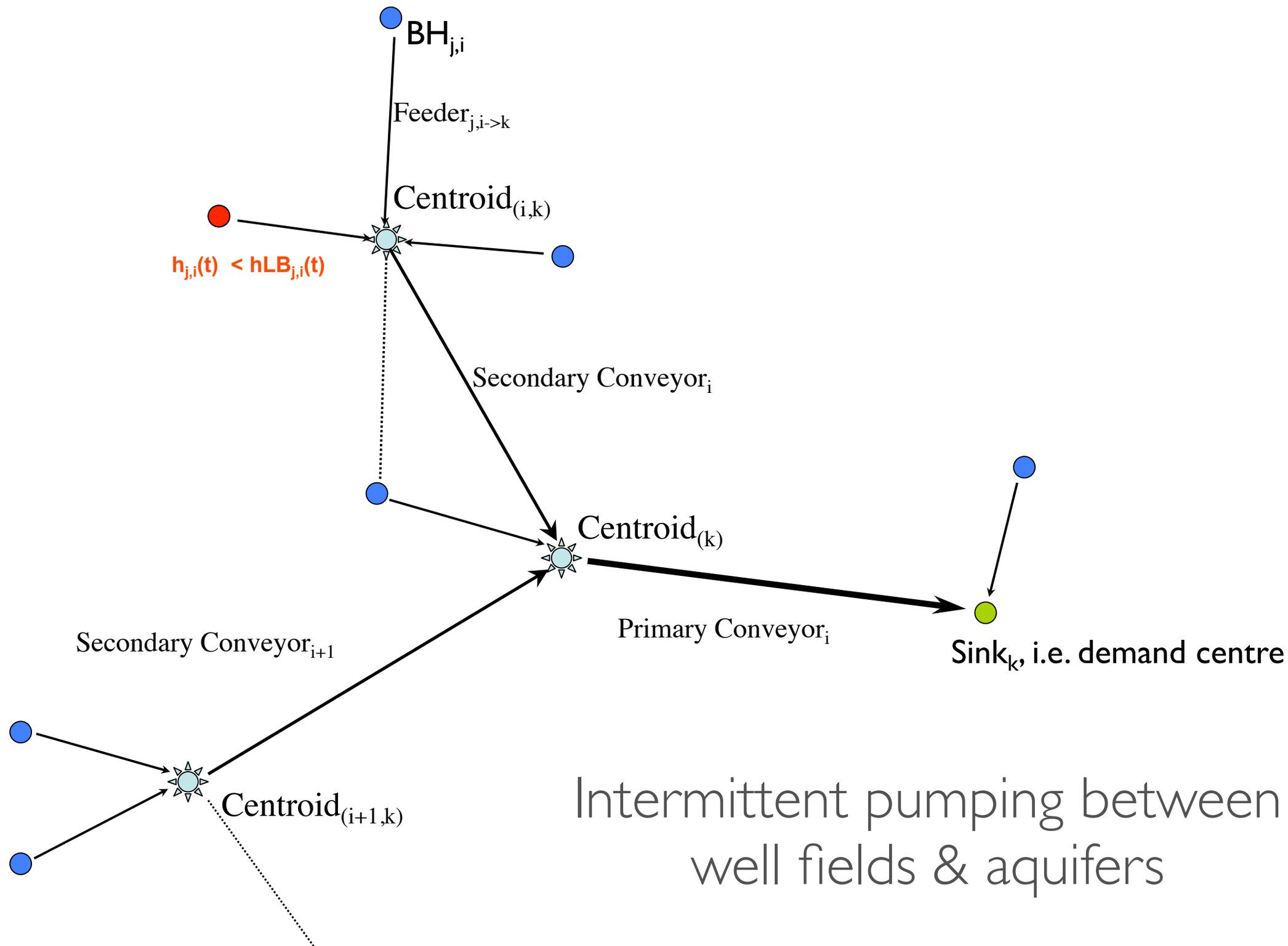

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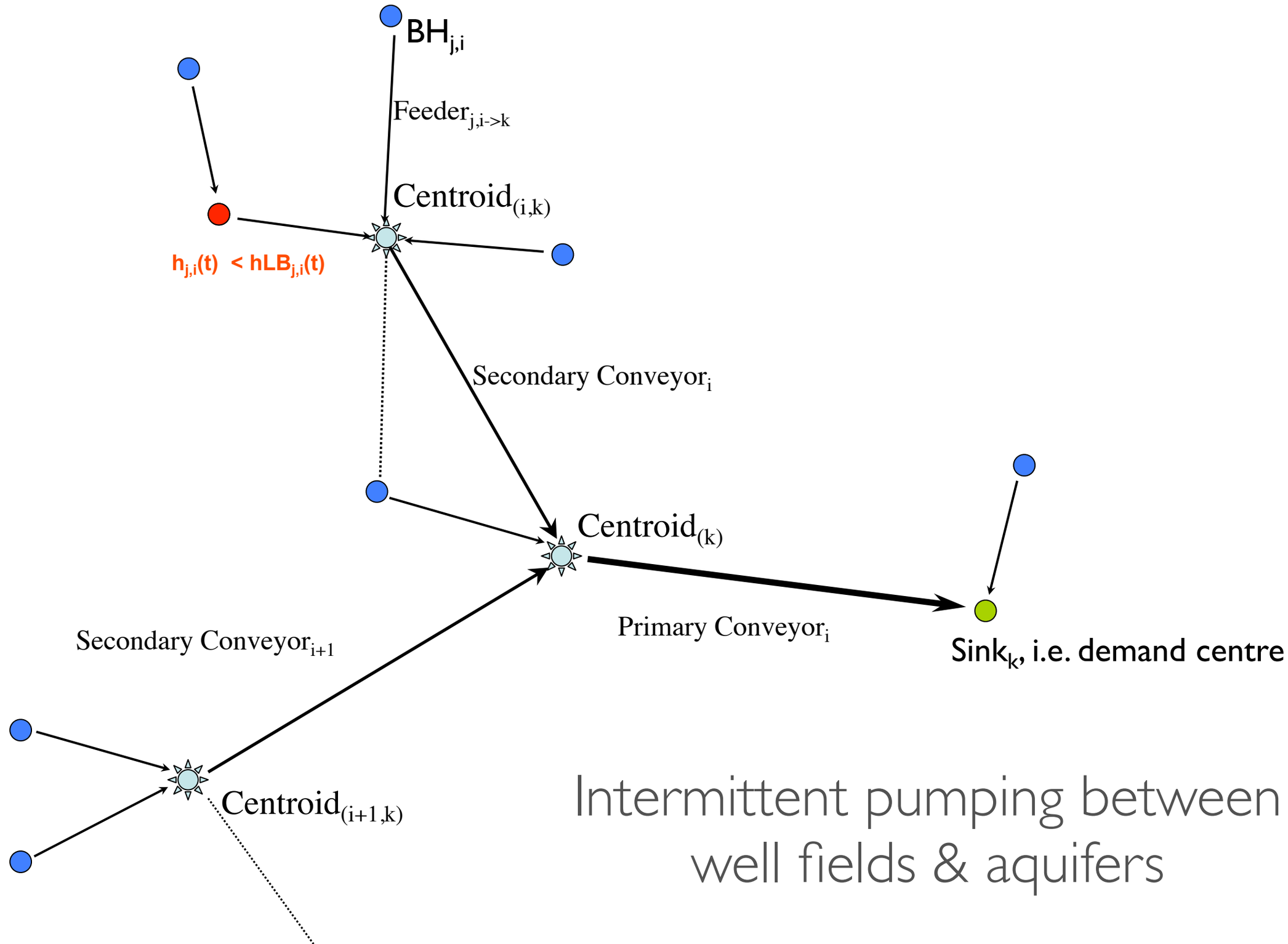

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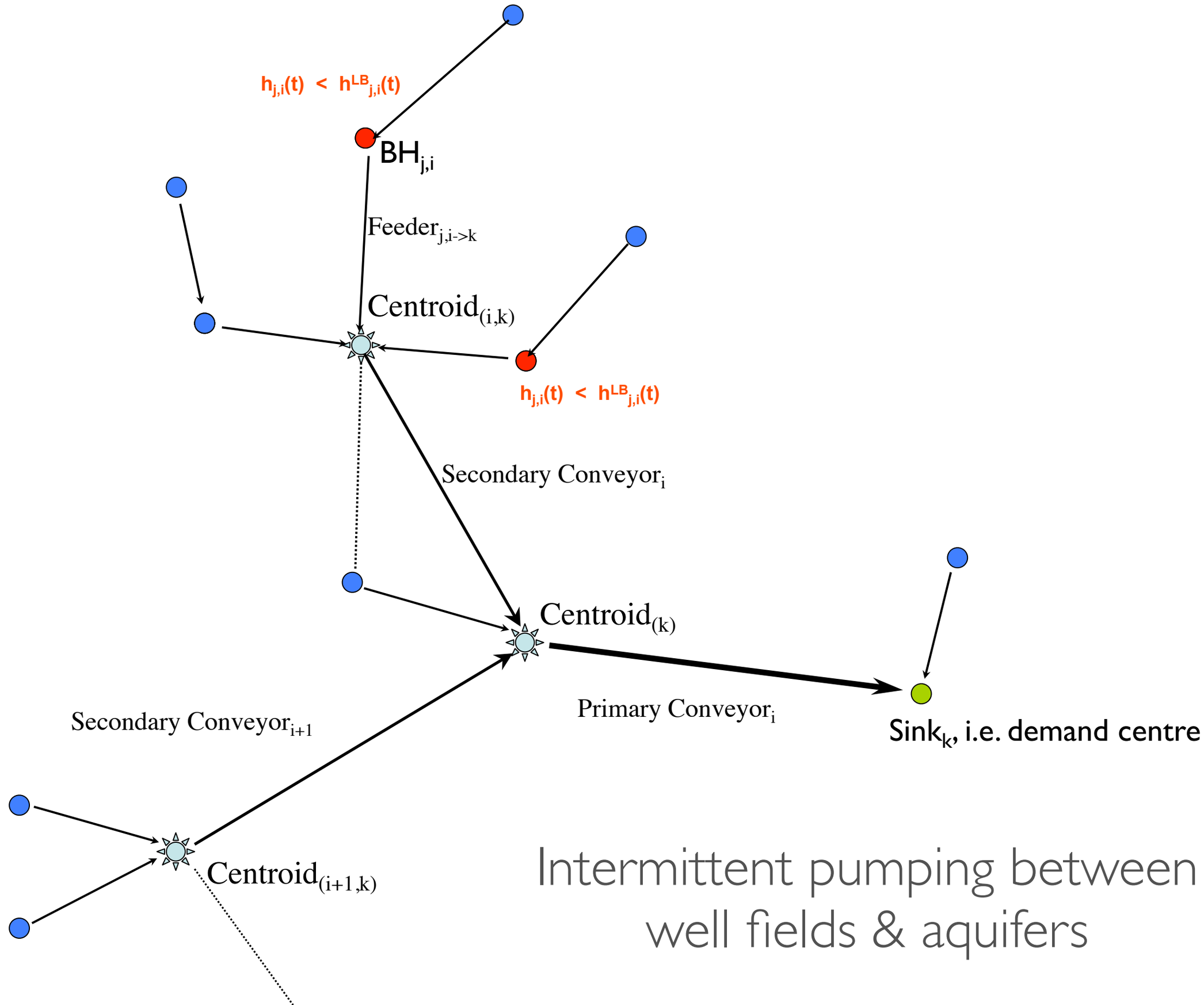
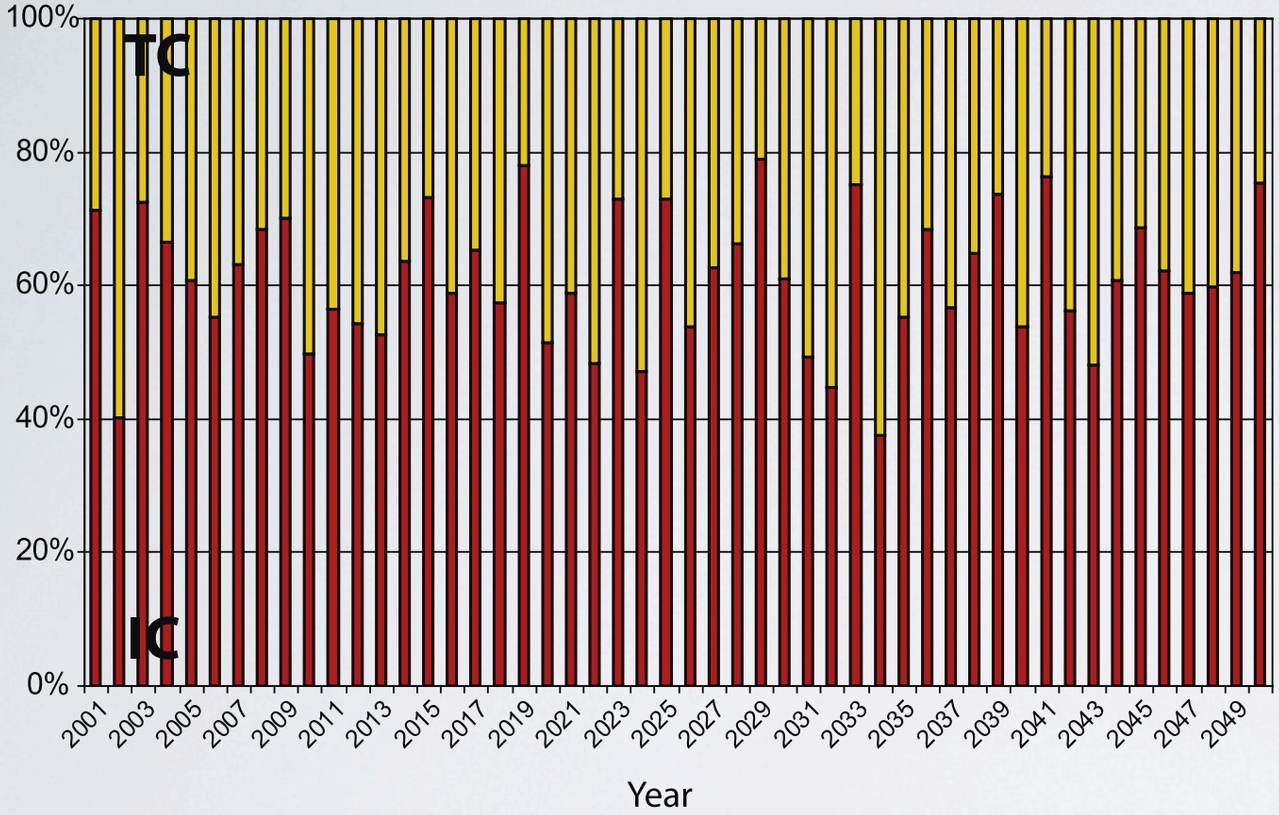
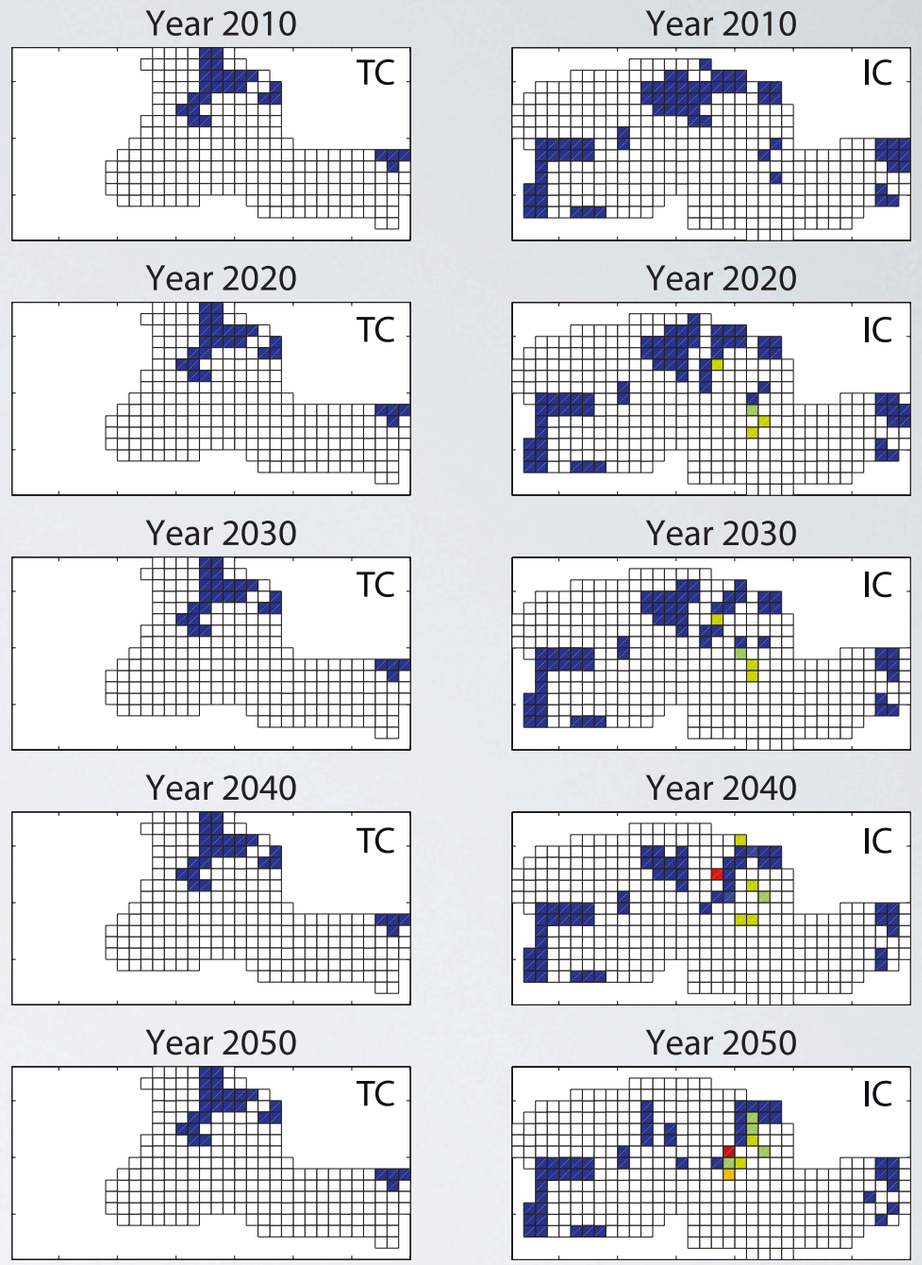


Intermittent pumping between well fields & aquifers

Supply source



Active pumping locations



CHARACTERISTICS OF OPTIMAL SOLUTIONS

Intermittent pumping between aquifers & well fields

Source: Siegfried (2005, 2007, 2009)

CONCLUSIONS

- Successful development of multi-objective optimization algorithm for approximating Pareto fronts
- Allows to identify optimal space-time pumping strategies in arbitrarily complex aquifers
- Benefits & costs from cooperative resource use can be quantified
  - In the case of the NWSAS, cooperation means coordination
- Crucial input for decision-making and subsequent bargaining

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Contact

Tobias Siegfried
hydrosolutions ltd., Zürich, Switzerland
siegfried@hydrosolutions.ch