MANCHESTER 1824
The University of Manchester

Seeking water resource resilience at national, regional and landscape scales in England and Wales

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National scale water supply-demand planning

Andrew Slaughter, James Tomlinson,
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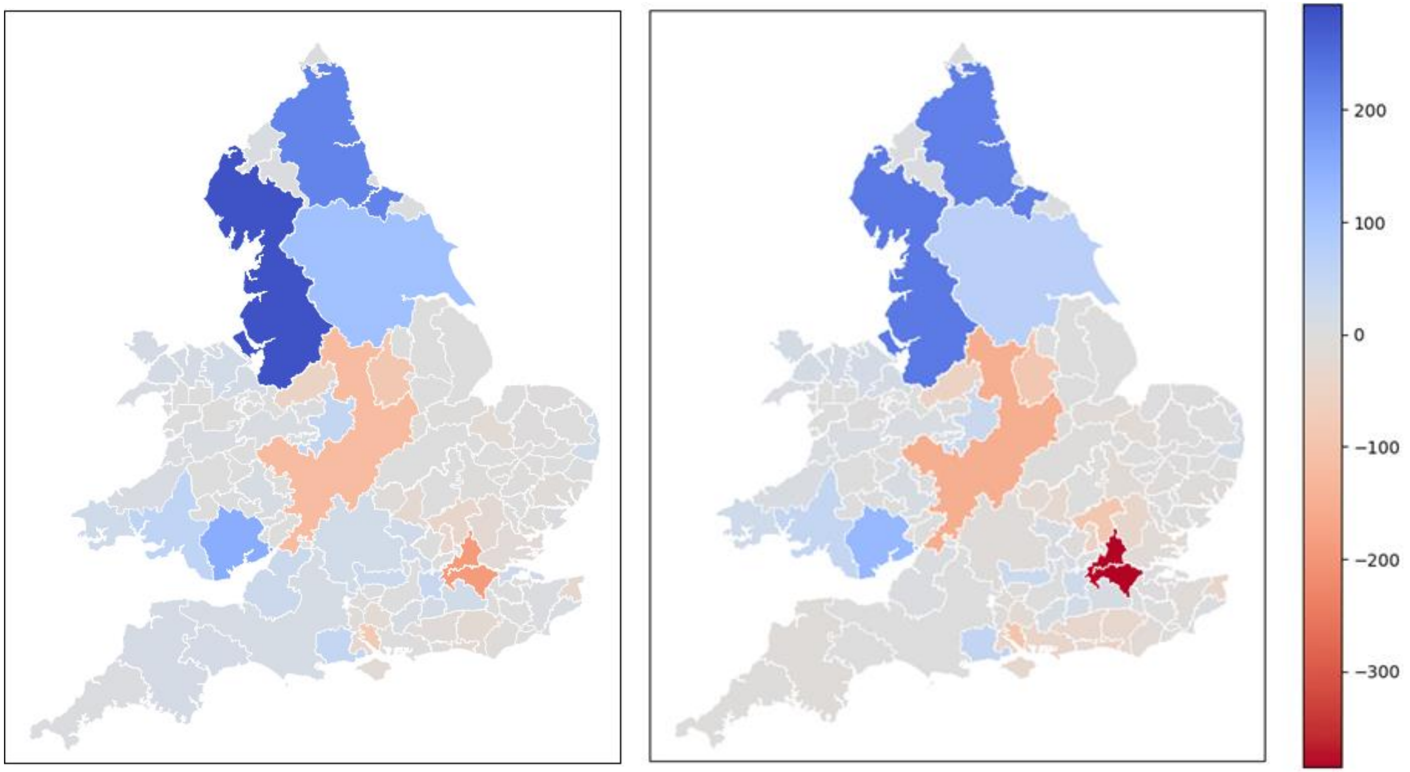
National supply-demand modelling objectives

- **Aim**: identify efficient mixes of future new supply and transfer options nationally using existing water company data. National supply-demand model provides unconstrained top-down look at the how different WRZs could work together at national scale to cost-effectively meet demands, potentially using some new transfers not currently in company plans.

- **Tool**: This project has extended an annual supply-demand model of England at water resources zone (WRZ) scale originally built by the National Framework for Water Resources. It now covers England and Wales. It can run in both simulation or search (multi-objective optimisation) modes.

Supply-demand balance before options in 2050

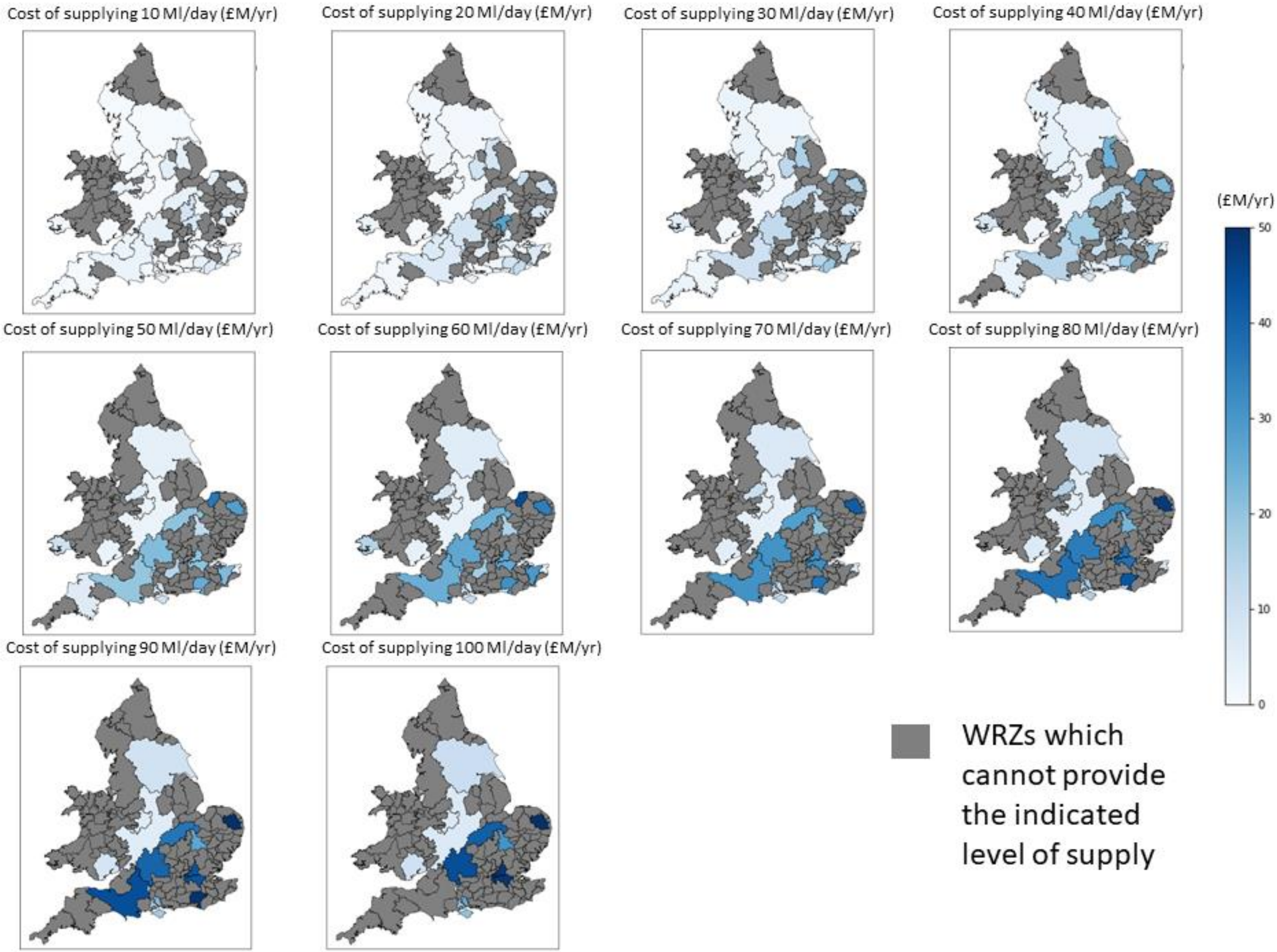


Demand: 2019 Plan (118 l/h/d)
1:200 resilience
Low sustainability reductions
(WRMP19: 250 Ml/d)

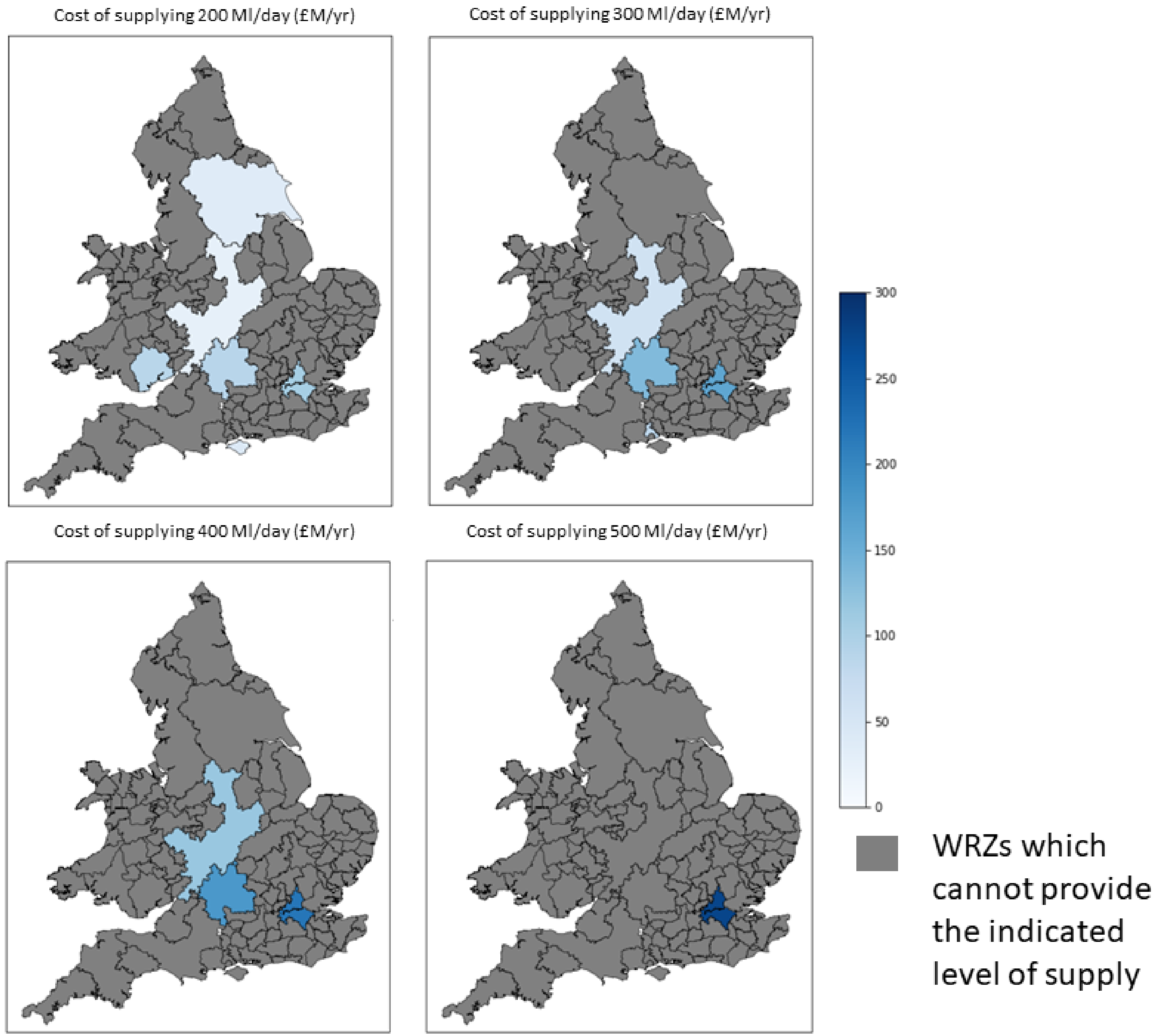
Demand: 2019 Plan (118 l/h/d)
1:500 resilience
High sustainability reductions
(National Framework : 721 Ml/d)

- Surpluses: UU Strategic Grid, NWL Kielder, YWS Grid Surface Water Zone, DCW SEWCUS.
- Deficits: TWS London and SVT Strategic Grid.

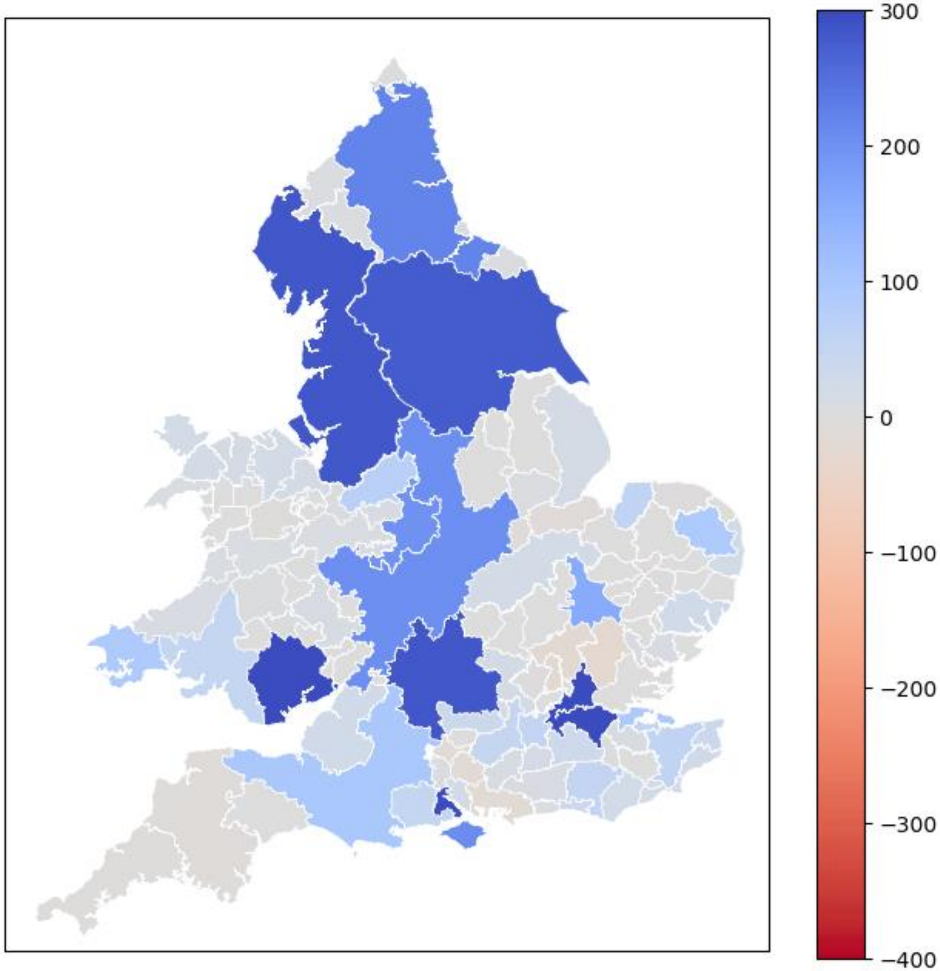
Which zones can provide additional supply in 2050?



Which zones can provide additional supply in 2050?



Supply-demand balance after all supply options in 2050



Demand: 2019 Plan (118 l/h/d)
1:500 resilience
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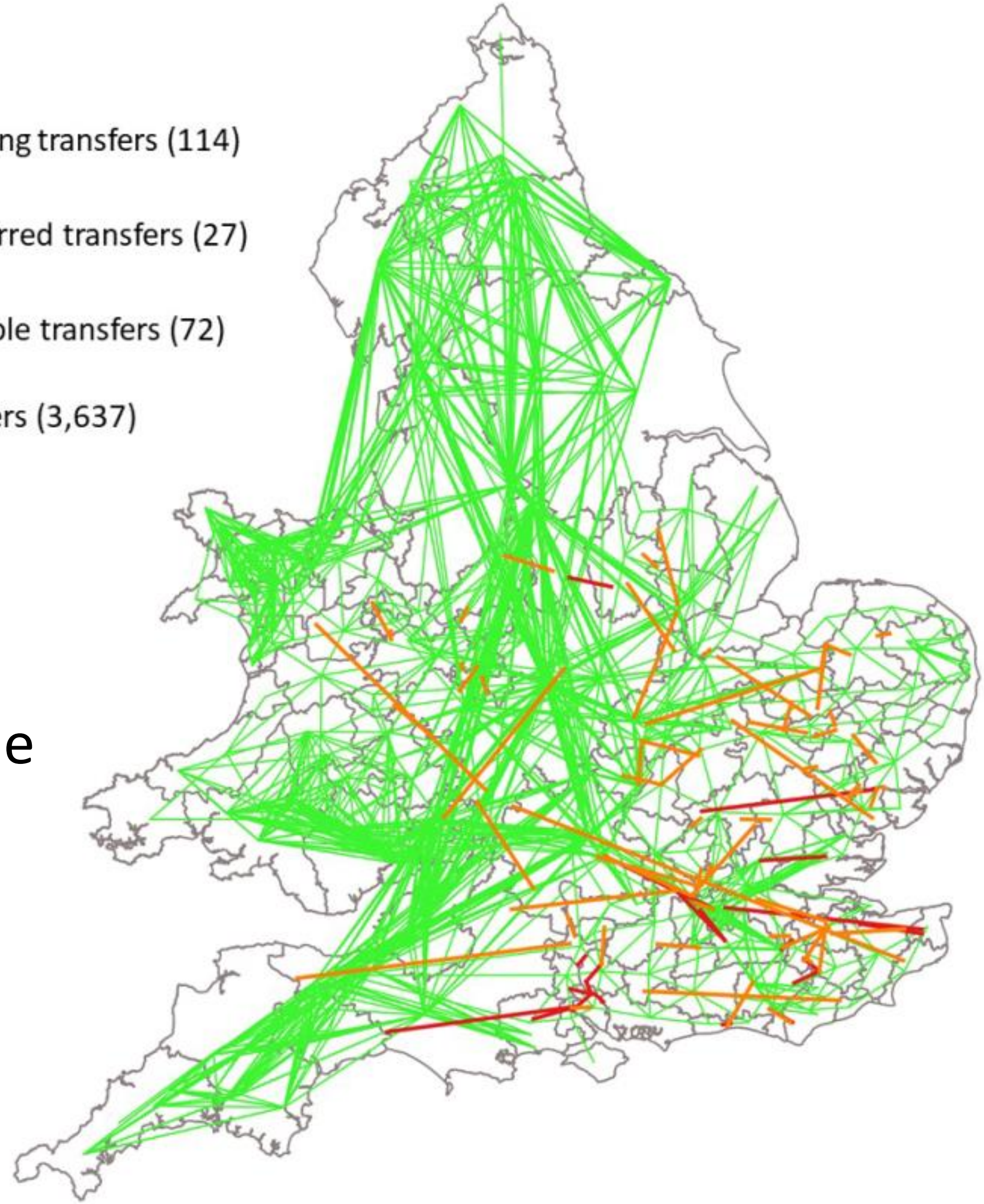
(National Framework : 721 Ml/d)



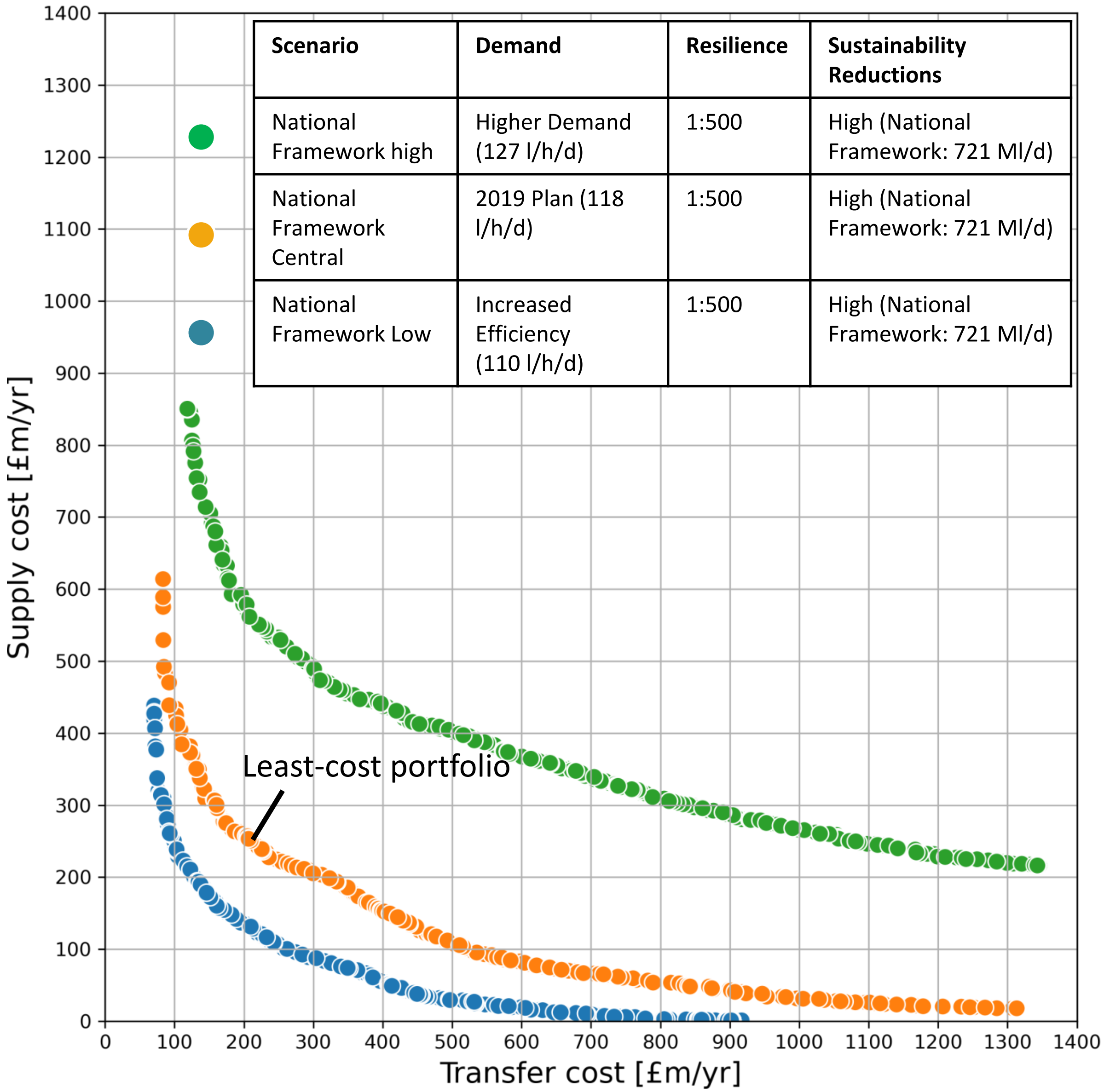
Existing, preferred, feasible and possible transfers for 2050

National Supply-Demand Model

- Simulation mode:
  - Pywr simulates annual supply-demand balance per WRZ in England and Wales (for 1 or multiple years)
  - Transfers are used to fill deficits, using shorter transfers first. If a deficit is unavoidable, it is recorded.

- Search mode (multi-objective optimisation):
  - WRZ supply options and transfers needed to meet supply-demand balance can be optimised.
  - Objectives: minimise WRZ supply option AISCs, minimise transfer AISCs, + potentially others
  - Can be solved for 1 year (e.g. 2050), or a sequence of years (e.g. 2030, 2035, …, 2050)

Optimised portfolios trade–off plot

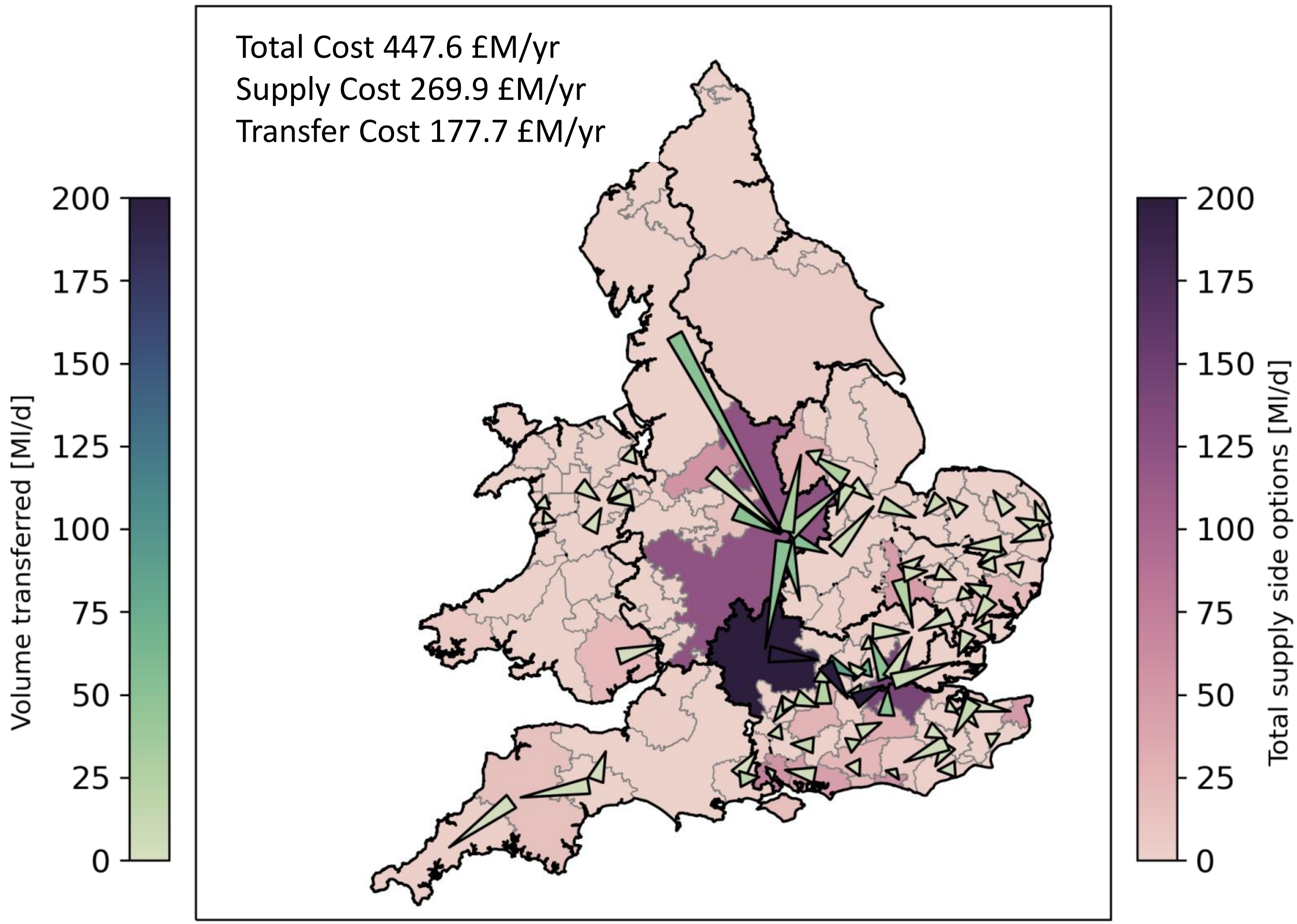


Scenario	Demand	Resilience	Sustainability Reductions
National Framework high	Higher Demand (127 l/h/d)	1:500	High (National Framework: 721 Ml/d)
National Framework Central	2019 Plan (118 l/h/d)	1:500	High (National Framework: 721 Ml/d)
National Framework Low	Increased Efficiency (110 l/h/d)	1:500	High (National Framework: 721 Ml/d)

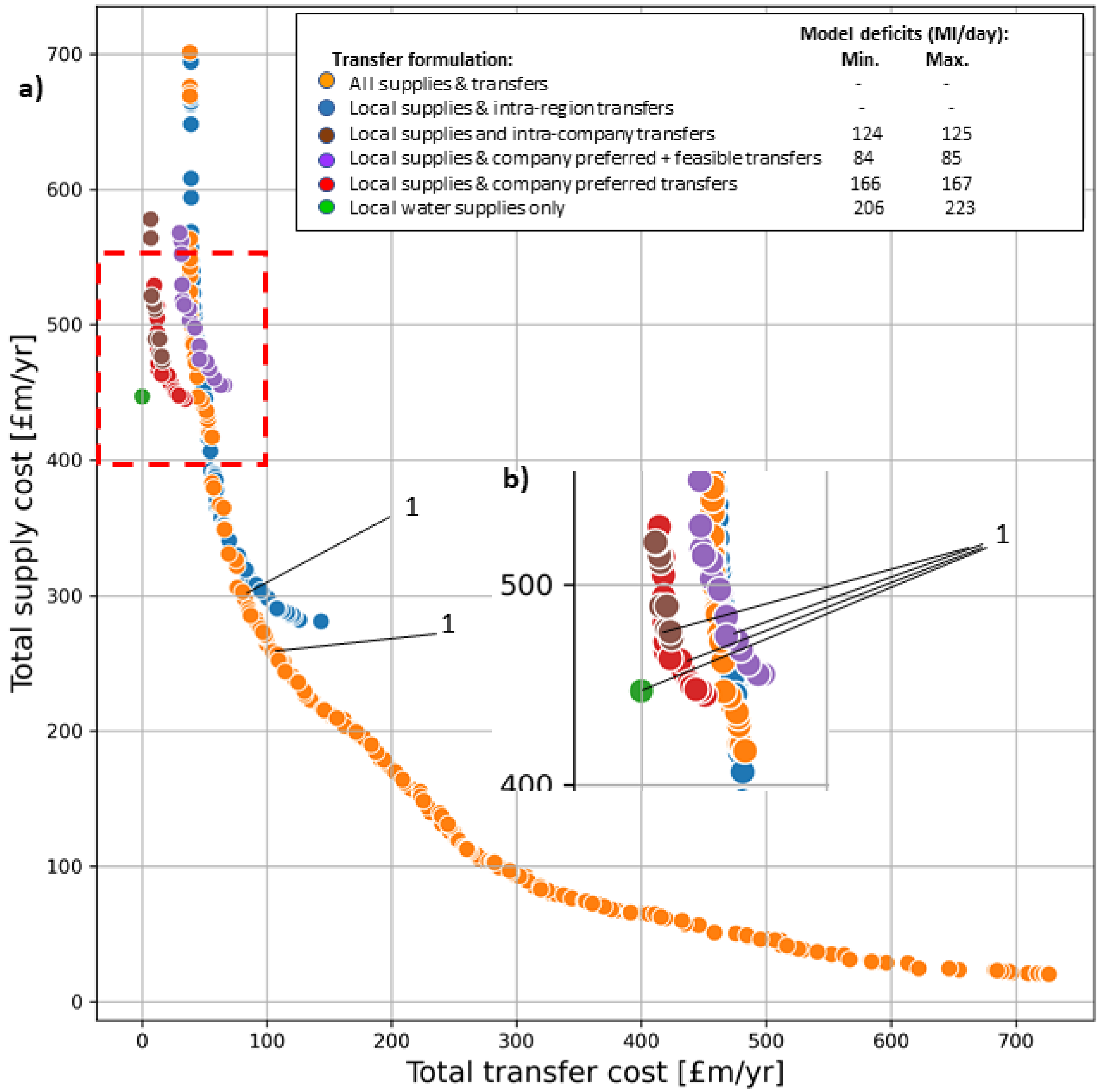
- Demand can be met by different mixes of local supply options and transfers, the most cost efficient portfolios are identified in these trade-off plots for different scenarios.
- Costs increase with higher demand.
- Introducing some transfers lowers supply costs.
- Deficits can be met exclusively by transfers in the central and low demand scenarios.
- Different 'regions' of the trade-off front imply different policy priorities (e.g. a policy minimising transfers would consider portfolios at top left)

What options does the model pick for the least-cost portfolio? (shown in Central scenario of last slide)

- SWOX, Svt Strategic Grid and London build the most local supply options.
- Major transfer from SWOX to London.
- Major intra-regional transfer from UU Strategic Resource Zone to SVT Strategic Grid.
- Inter-regional transfers between WRW and WRE, WRW and WRSE.
- Many small and short transfers in WRE and WRSE.



What might be to gain from collaborating across companies and regions?

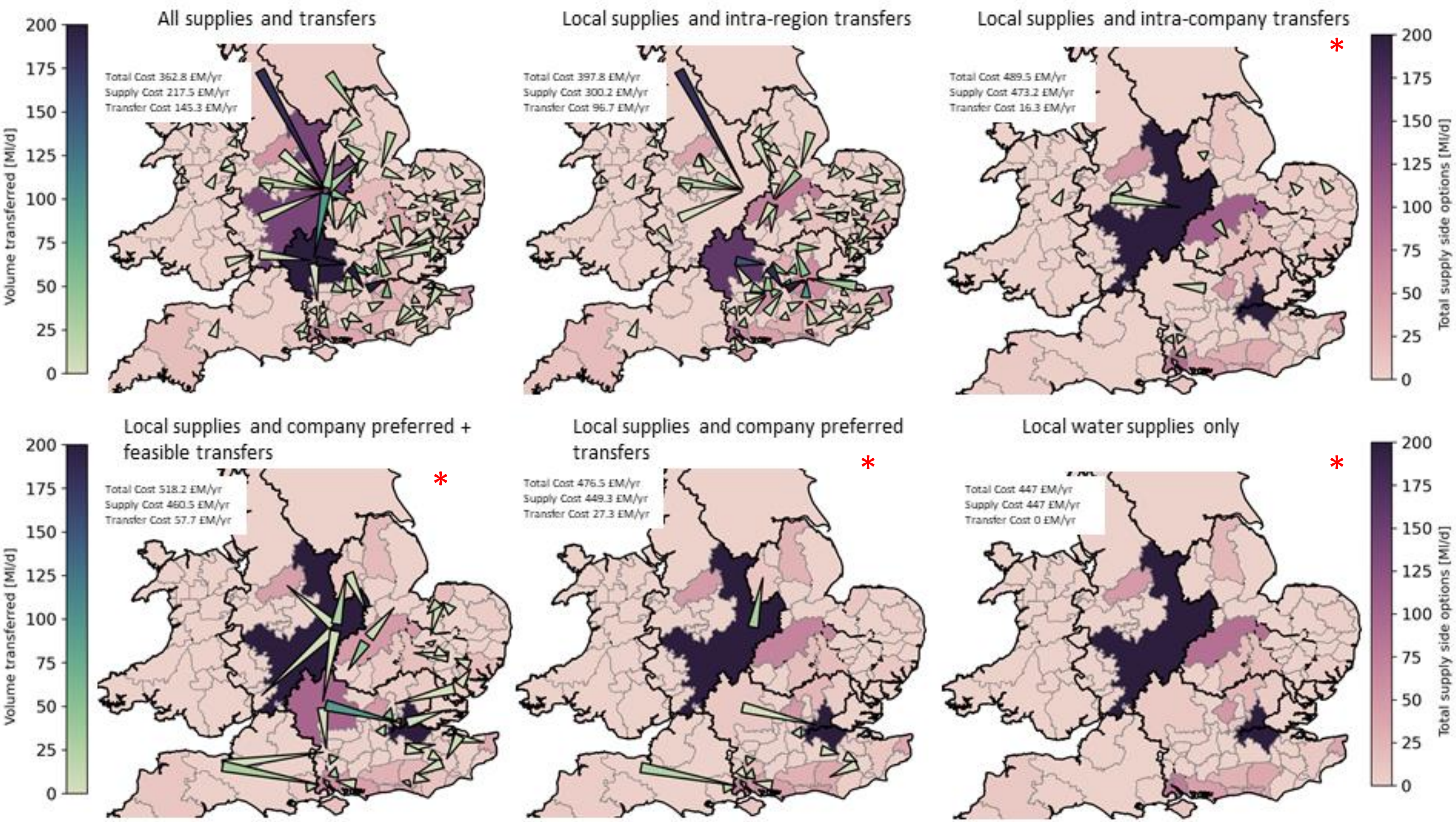


'1' indicates the least-cost portfolio for each trade-off front

- Scenario = NF Central [Demands: 2019 plan (118 l/h/d), Resilience: 1:500, high sustainability reductions (721 Ml/d)]
- Transfers considered in company plans are insufficient to meet future demands.
- Consideration of inter-regional transfers can considerably reduce total costs.
- Co-operation between different companies and regions is needed to facilitate the required transfers.

What might be to gain from collaborating across companies and regions?

Least-cost portfolios for each portfolio trade-off plot indicated by ‘1’ in the previous slide



* 2050 estimated water demands not fully met

Some initial lessons

- The preferred and feasible sets of transfers considered by companies in the 2019 price review are insufficient to avoid a deficit by 2050 under challenging demand, drought resilience and environmental scenarios.

- Greater collaboration evidenced through use of inter-regional transfers reduces costs and helps balance supply and demand.

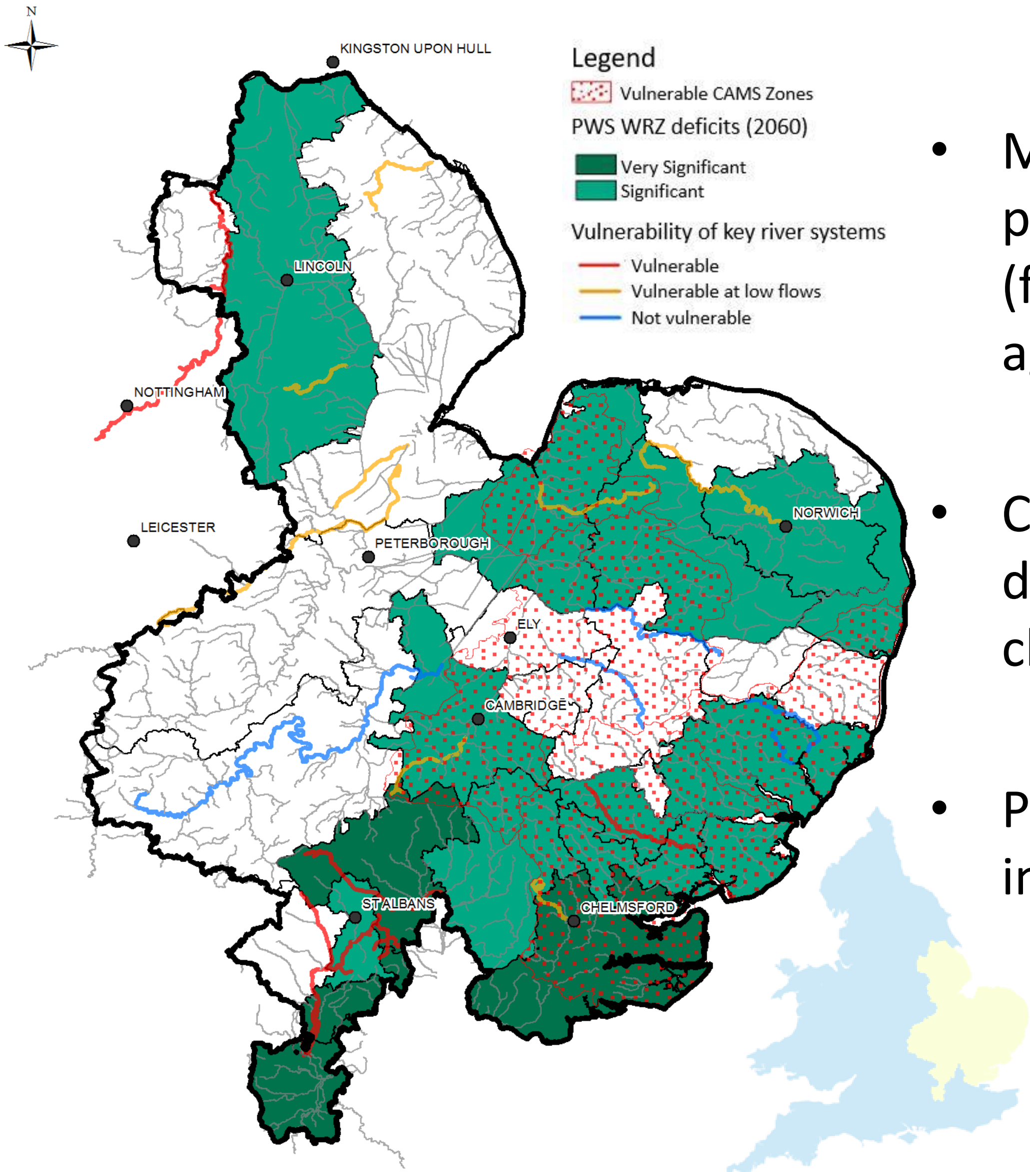
- Exploiting synergies at national scale and exploiting new cost efficient connections decreases national costs (expressed as average incremental social costs) by up to 24% compared to current company plans.

- The model, through seeking cost efficient synergies at national scale, is able to meet higher demands, including for the environment, at higher service levels at a cost similar currently planned water supplies.

Planning regional multi-sector water resource systems in East England

Evgenii Matrosov, James Tomlinson, Steve Moncaster, Geoff Darch, Julien Harou

Water Resources East (WRE)



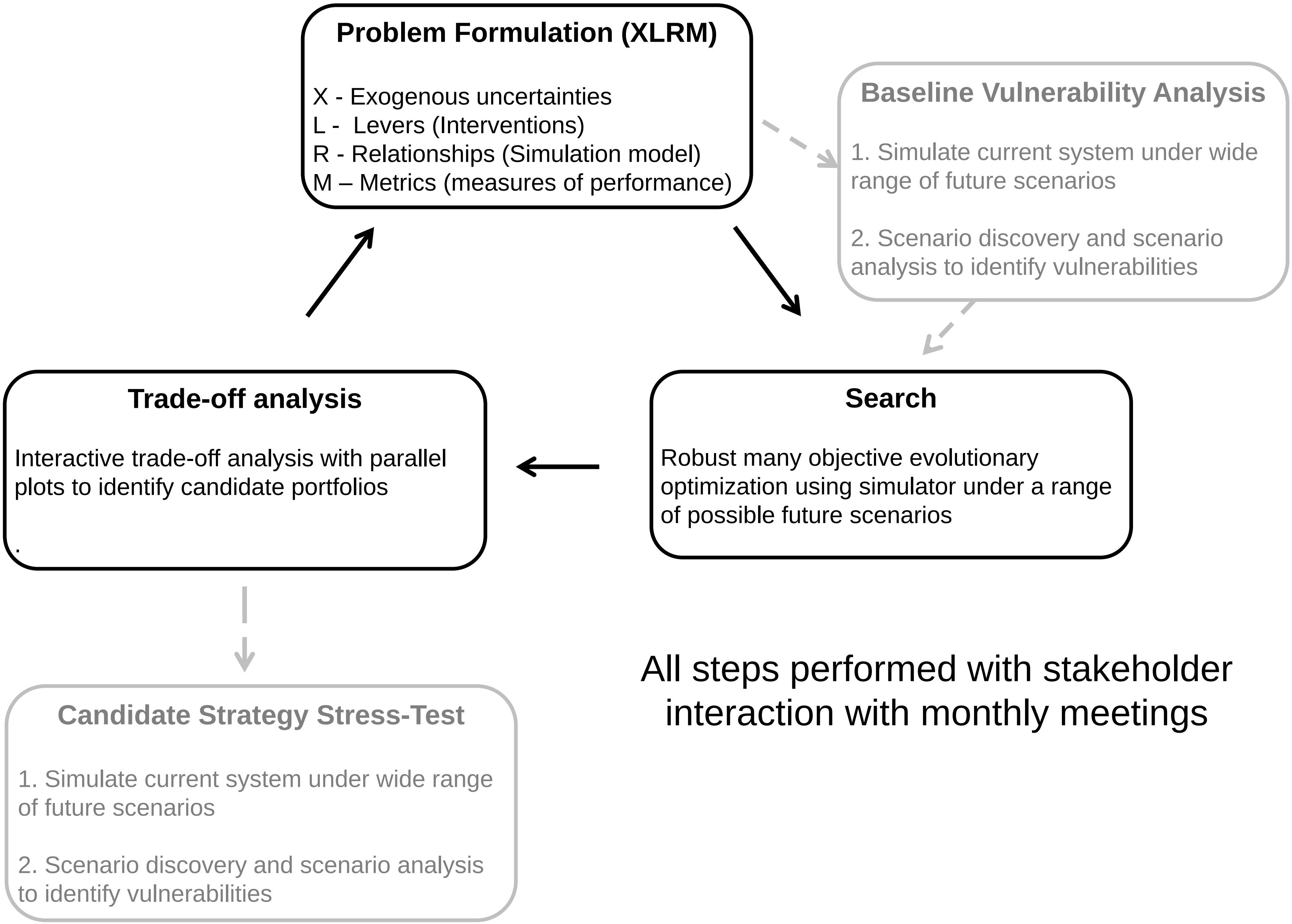
- Multi-sector regional planning project including public water supply (four utilities), the environment, agriculture and energy for the 2060s
- Climate change effects on supply and demand growth pose planning challenges
- Pilot study, next phase to be included in formal planning process

Planning question

What combination of supply, demand management, and policy interventions (portfolio) meets stakeholder performance requirements efficiently under future uncertainty?

Water Resources East: Sector objectives

- Public water supply
  - Low capital & operating costs -> customer bills
  - Water use restrictions frequency within acceptable Levels of Service
- Agriculture
  - Agricultural supply to meet or exceed 2060 projections
- Environment
  - Minimise deviation from target environmental flows
- Energy
  - Maximise energy license while minimising abstraction failures



Problem Formulation (XLRM)
X - Exogenous uncertainties
L - Levers (Interventions)
R - Relationships (Simulation model)
M – Metrics (measures of performance)
Baseline Vulnerability Analysis
1. Simulate current system under wide range of future scenarios
2. Scenario discovery and scenario analysis to identify vulnerabilities
Trade-off analysis
Interactive trade-off analysis with parallel plots to identify candidate portfolios
Search
Robust many objective evolutionary optimization using simulator under a range of possible future scenarios
Candidate Strategy Stress-Test
1. Simulate current system under wide range of future scenarios
2. Scenario discovery and scenario analysis to identify vulnerabilities
All steps performed with stakeholder interaction with monthly meetings

Metrics

- Metrics developed with stakeholders from the four sectors
- Different levels of aggregation leads to many metrics (>1200)
  - Stakeholder groups (e.g. water utilities)
  - Zonal metrics
  - Regional metrics

Metrics summary

Public Water Supply

- Zonal reliability and resilience (levels 1-4)
- Zonal deficit

Agriculture

- Zonal supply
- Zonal reliability and resilience (levels 1-4)
- Zonal deficit

Energy

- Total license
- Reliability and resilience

Environment

- Deviation from target and modelled flow duration curve at sensitive sites

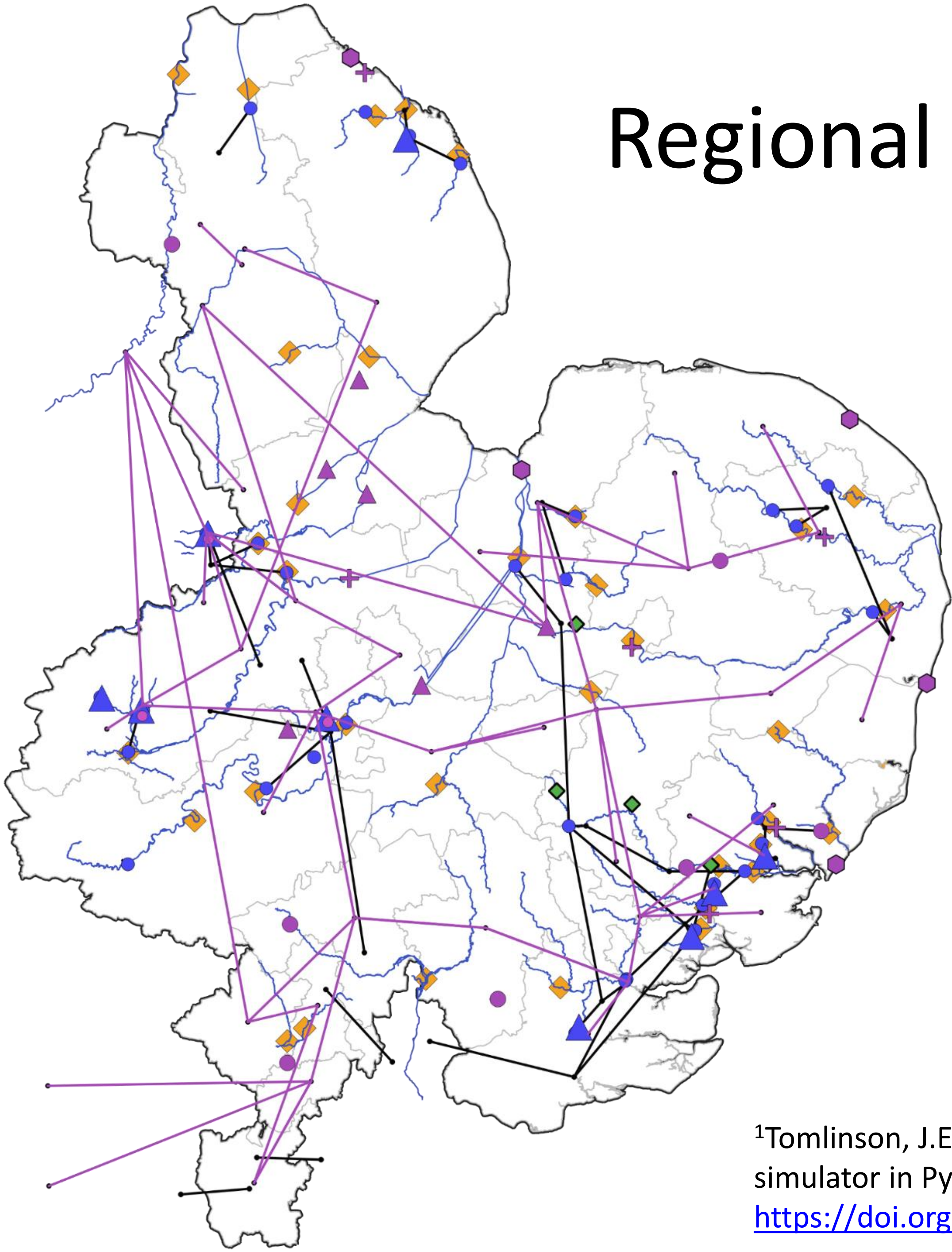
Costs

- Capital and operating costs

Flow and storage

- Total imported water
- Flow duration curves of transfers
- Storage duration curves of reservoirs

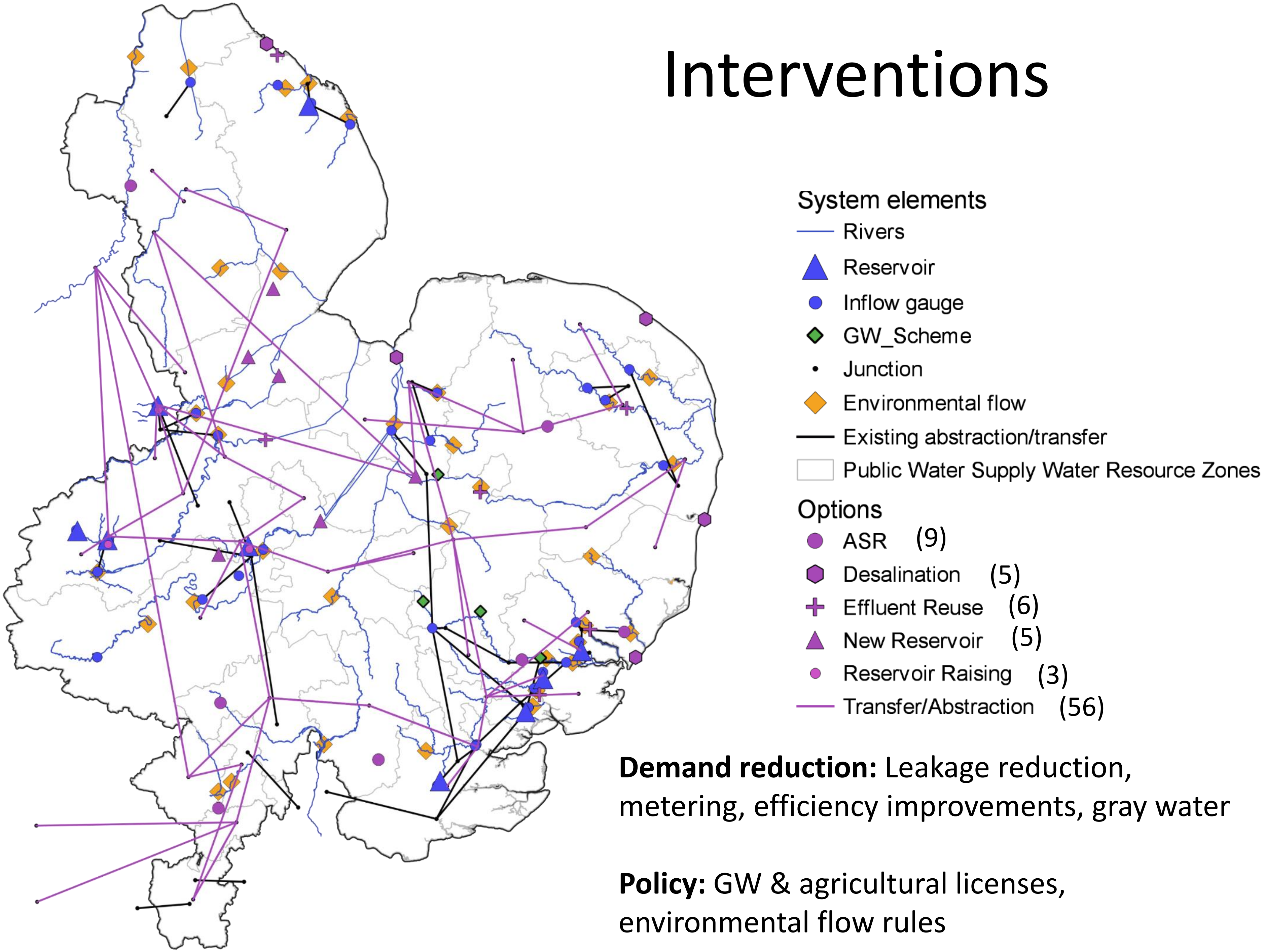
Regional simulation model



- System modelled using open-source generalized water resource system simulator Pywr[1]
  - Includes SW/GW interactions
- 1031 nodes, 1423 links

[1]Tomlinson, J.E., Arnott, J.H. and Harou, J.J., 2020. A water resource simulator in Python. Environmental Modelling & Software. https://doi.org/10.1016/j.envsoft.2020.104635

Interventions



Demand reduction: Leakage reduction, metering, efficiency improvements, gray water

Policy: GW & agricultural licenses, environmental flow rules

Robust many-objective evolutionary optimisation

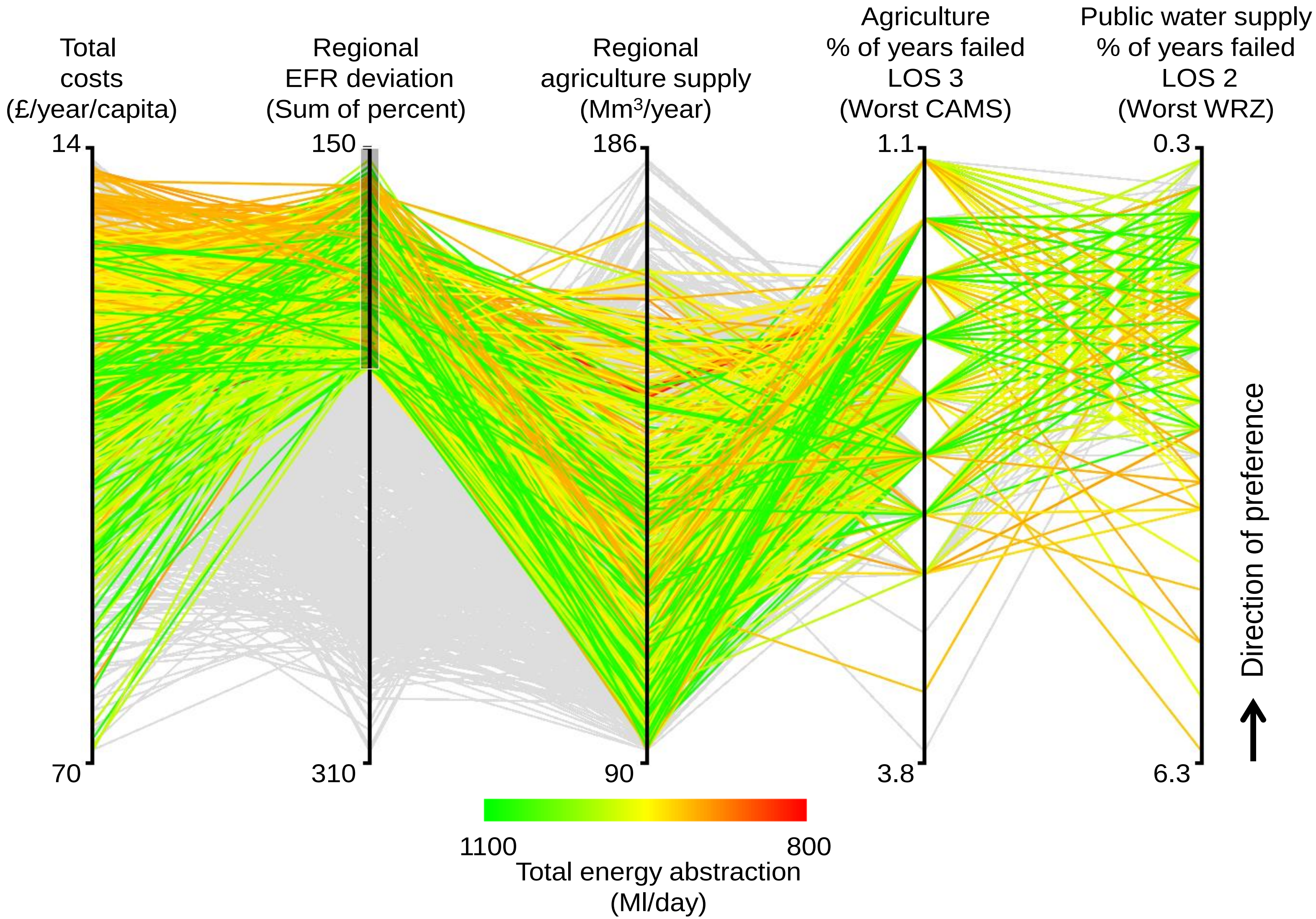
Simulator connects to search algorithm to find which interventions (supply, demand) most efficiently meet system objectives, and what trade-offs are implied in these high performing system designs.

Many-objective search formulation

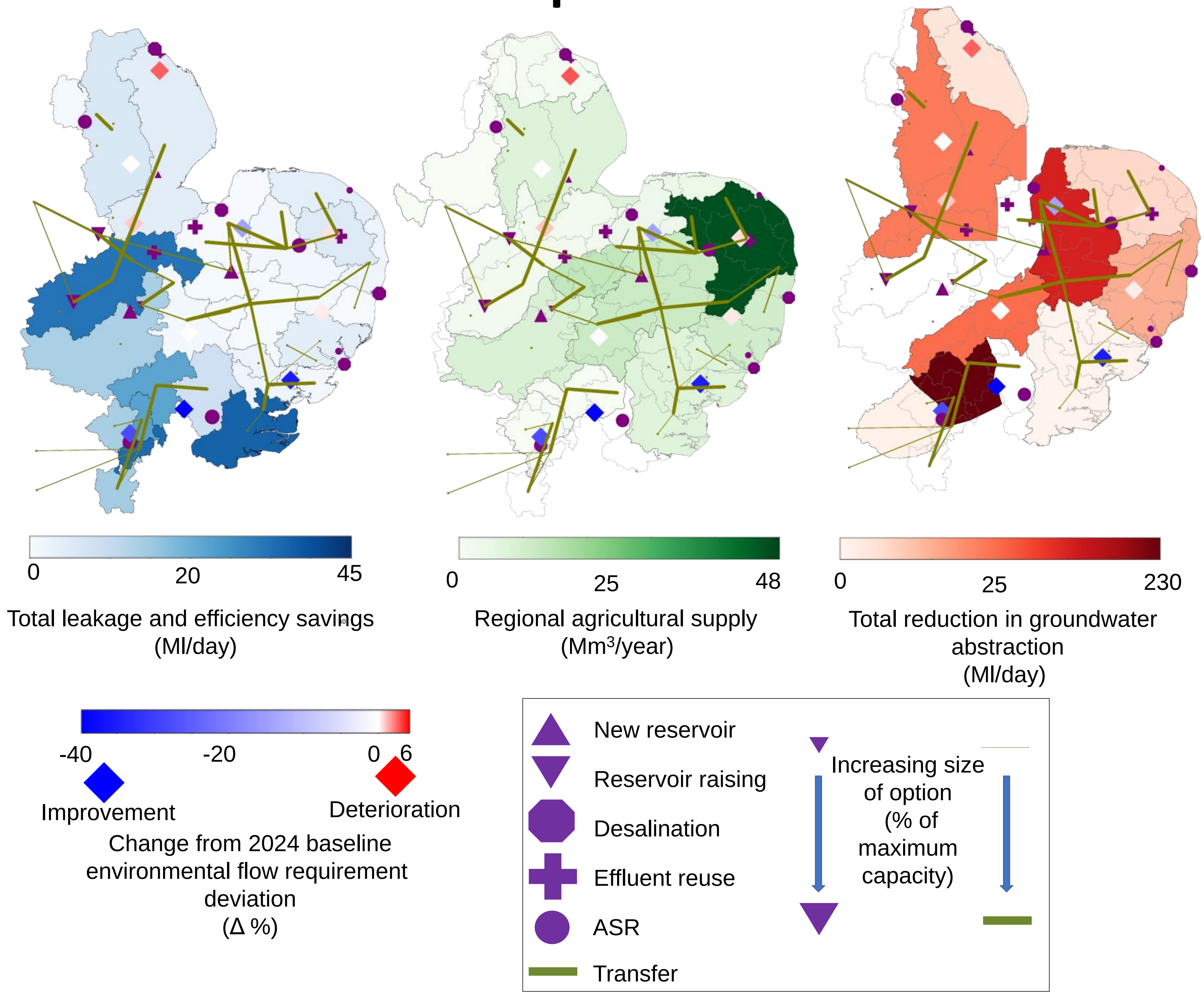
Subset of 6 metrics used as objectives, all other metrics tracked within optimization

Objectives (6 total)	**Decisions**
Minimize	*Supply and demand management*
• Total costs • Deviation from target environmental flow duration curves	• Implement intervention option and its capacity
Maximize	*Policy*
• Regional agriculture and energy licenses • Regional reliability of public water supply and agriculture sectors	• Agriculture, energy, utility GW licenses • Minimum environmental flow rules • 203 optimisation decisions

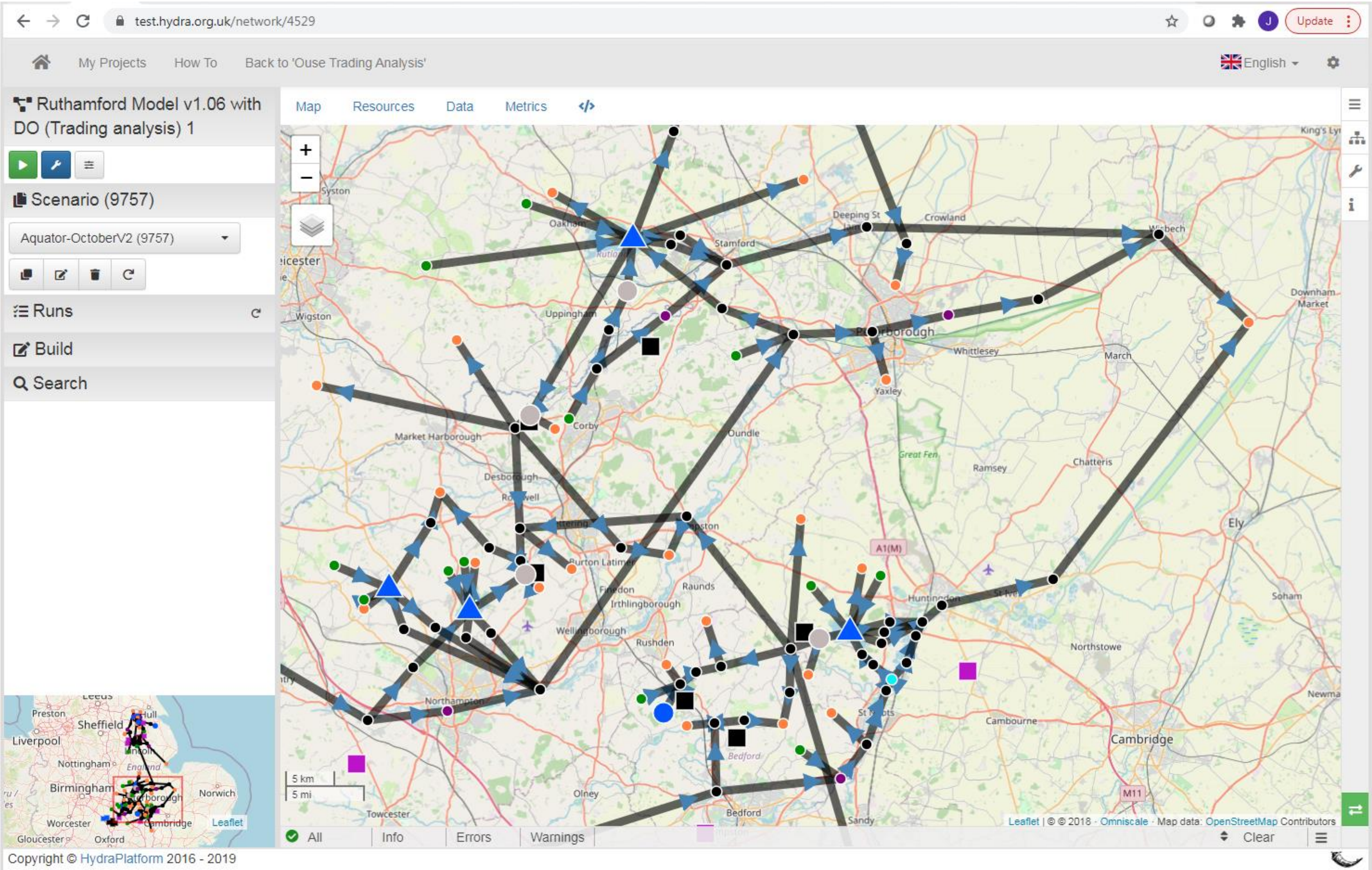
Regional trade-off set



WRE portfolio



WRE user interface



Discussion/Conclusions

- Sophisticated performance-based multi-sector planning in possible and practical
- Good regional performance does not always imply good local performance
- The approach helps identify portfolios of interventions that meet and balance stakeholder aspirations
- Future work could address water-energy and water supply-food synergies, and adaptive planning

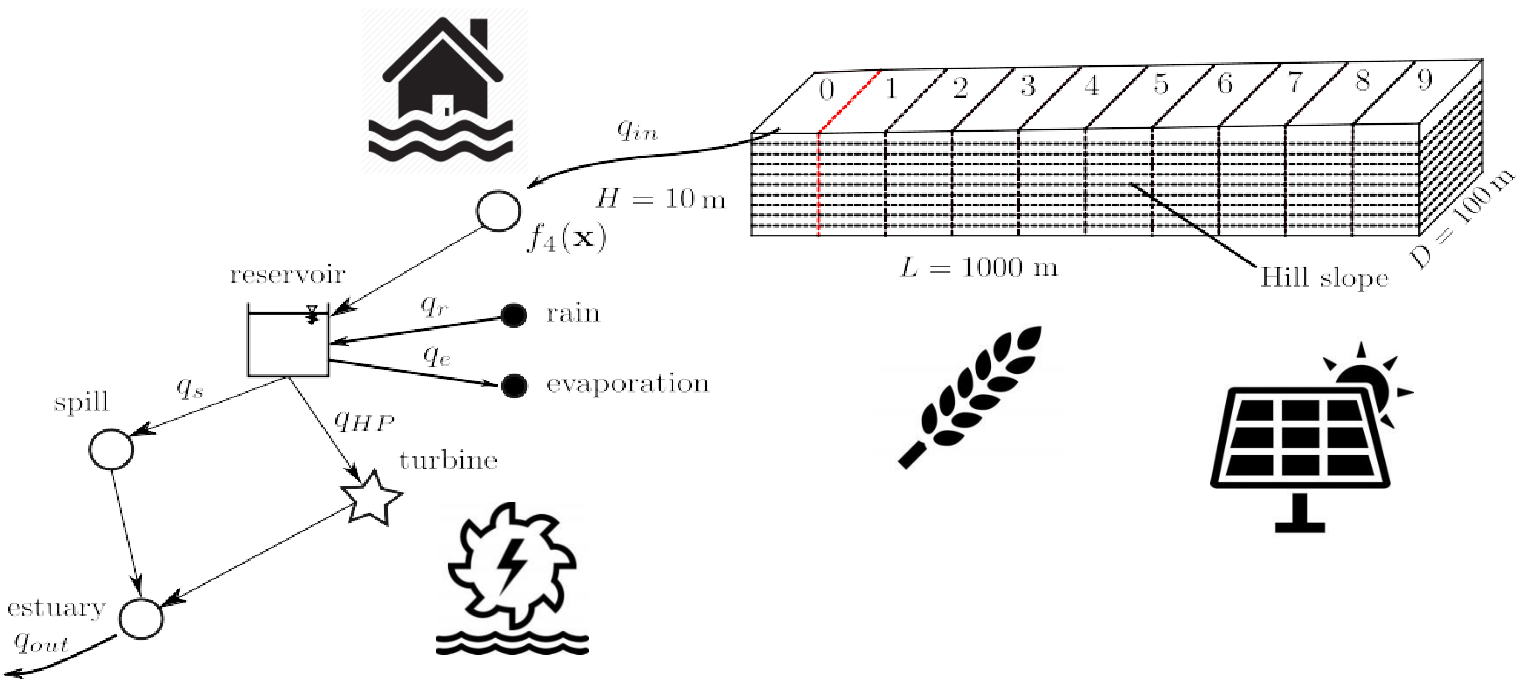
Local (catchment) scale multi-criteria water-land management

Tomasz Janus, Daniela Anghileri,
Stefan Kollet, Justin Sheffield, Julien Harou

Approach and synthetic application

How does land use in a catchment affect water services?

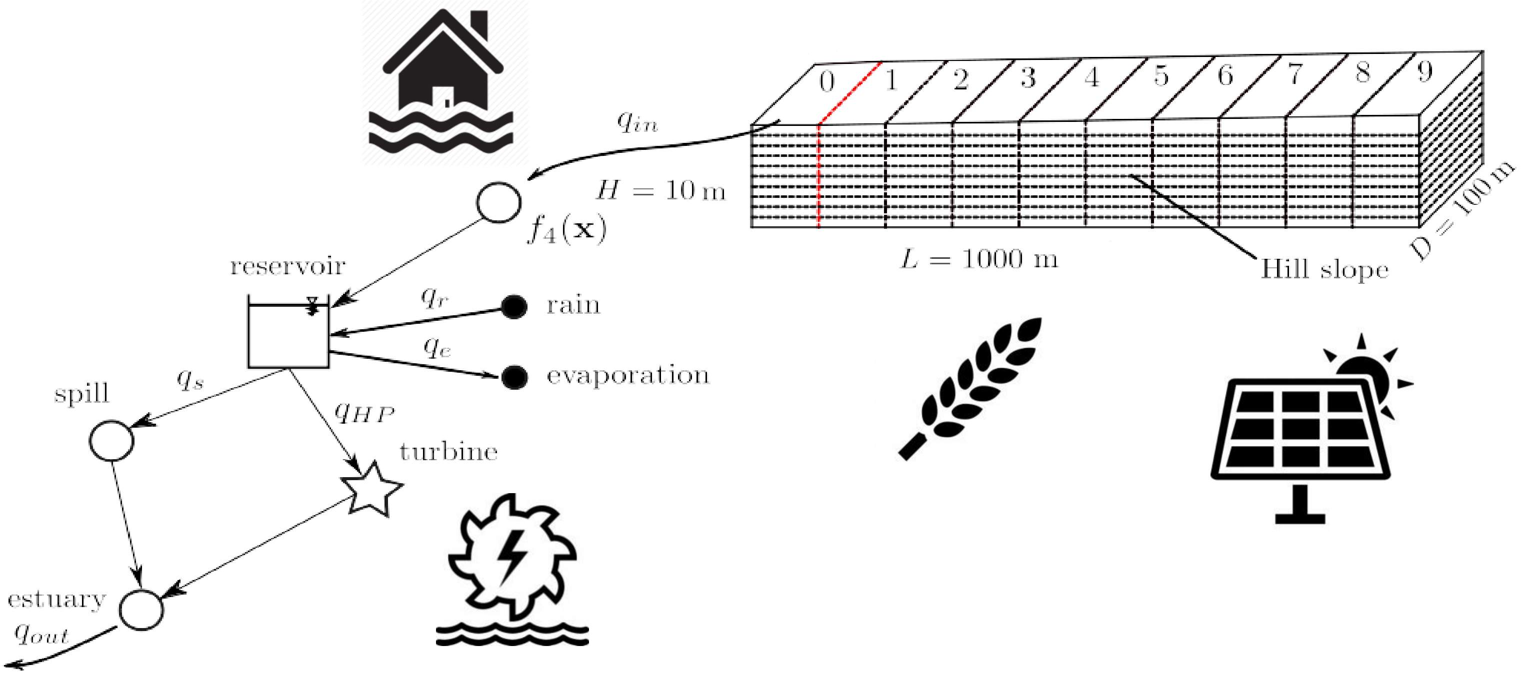
What land cover classes (between forest, cropland, grassland, bare soil) promote food production, energy production (via hydro or solar) and flood control? We also track and optimise for land cover diversity.



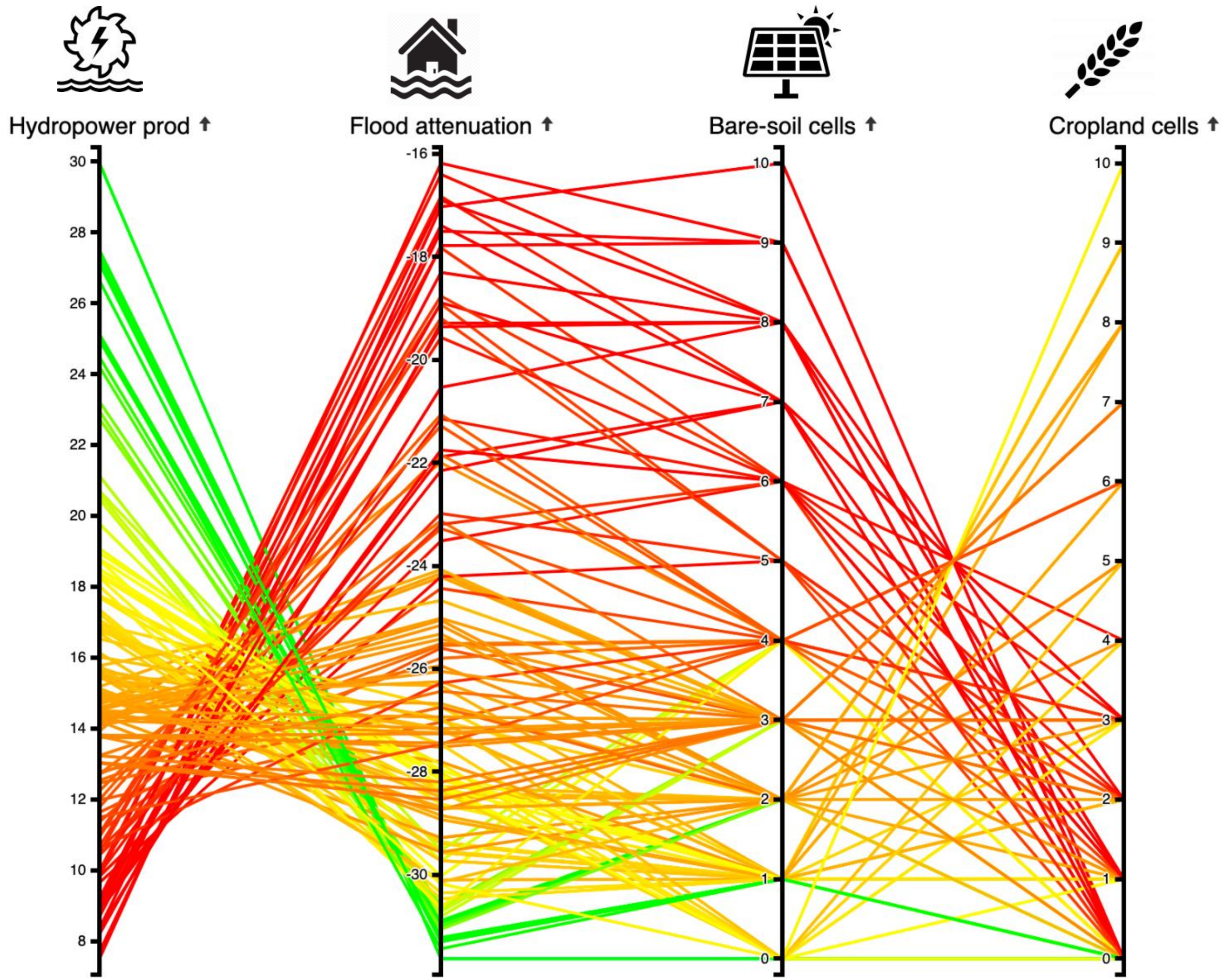
Approach and synthetic application

Methods:

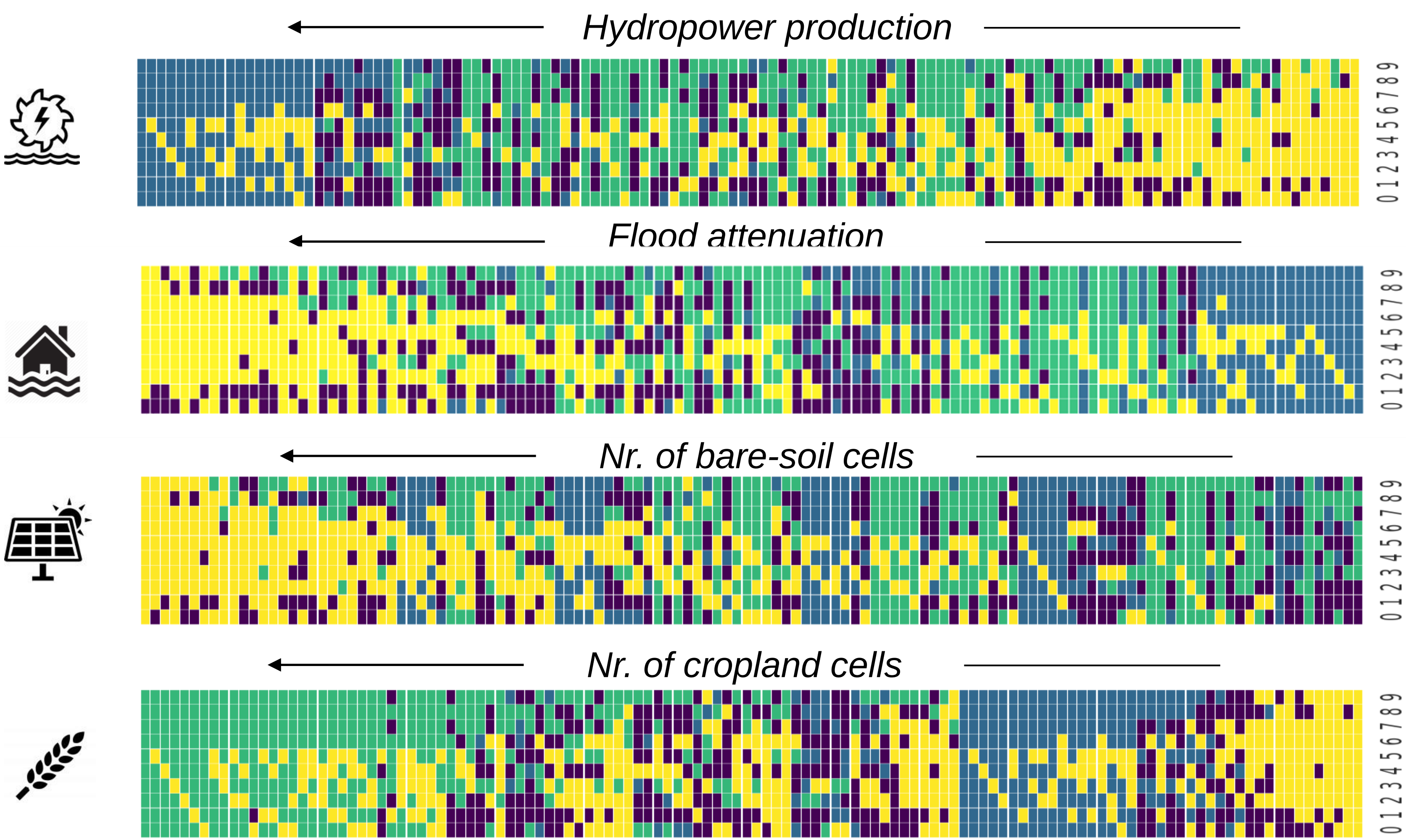
- Link physically based spatially distributed hydrological model (Parflow) to a water management simulator (Pywr).
- Optimise with multi-objective heuristic search.



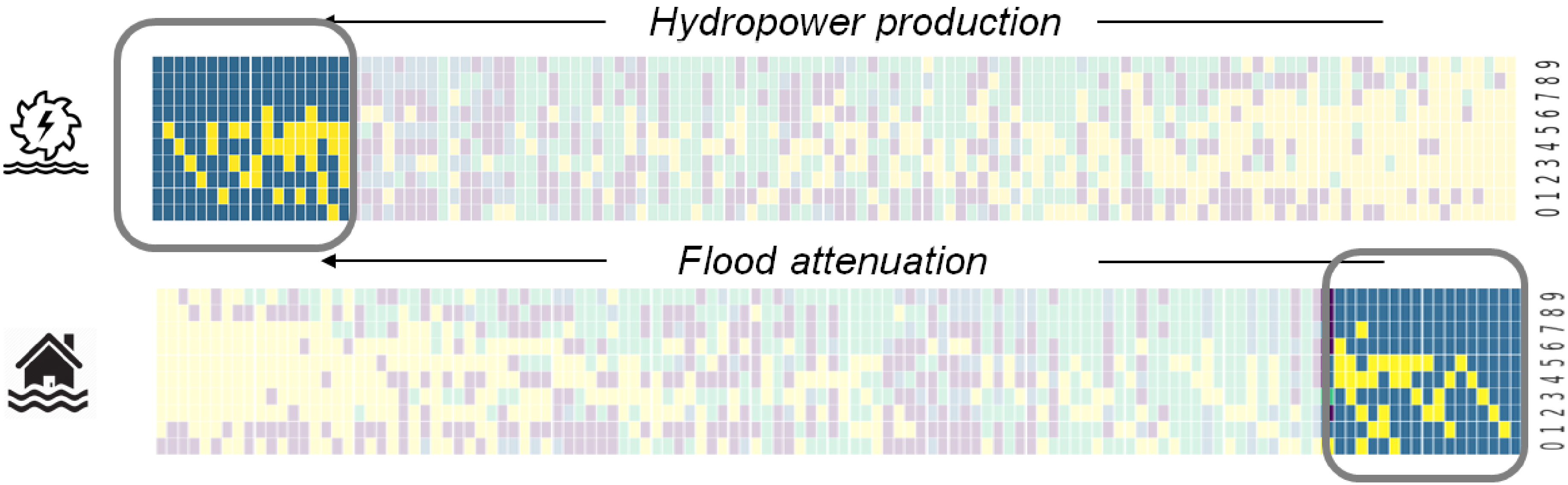
Efficient portfolios of land-use

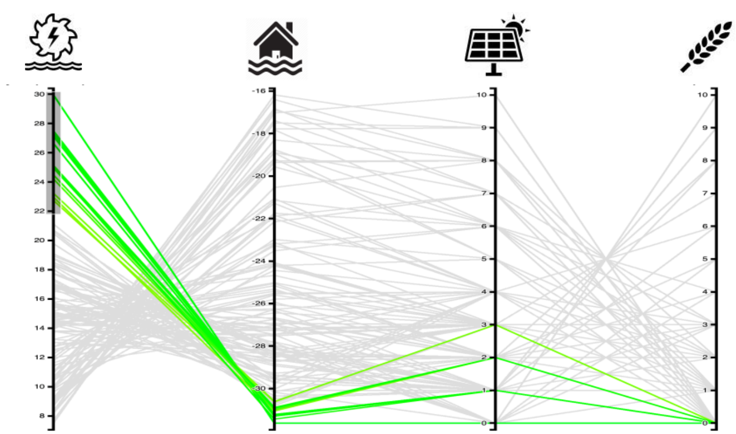


Efficient spatial land uses



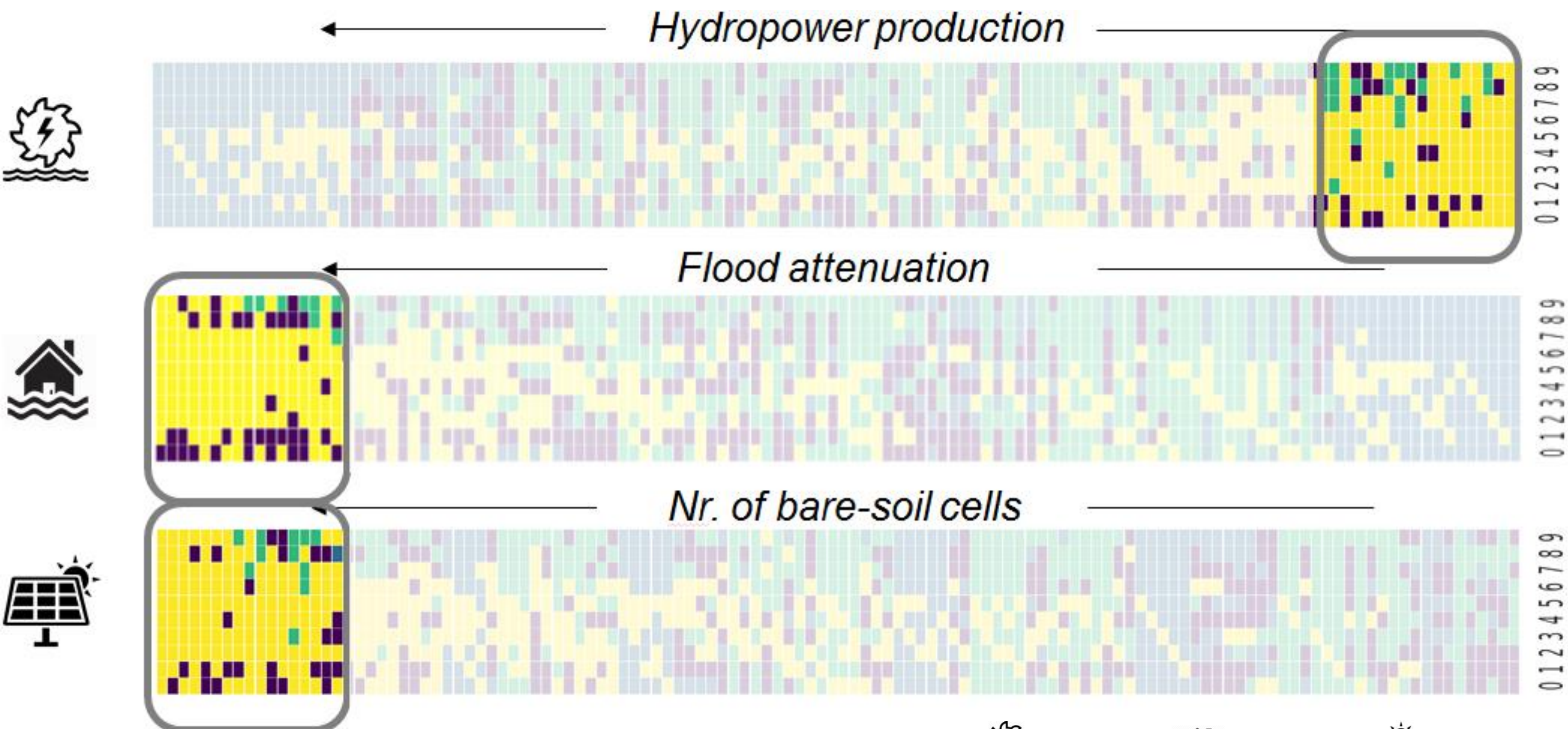
Hydropower vs. flood control



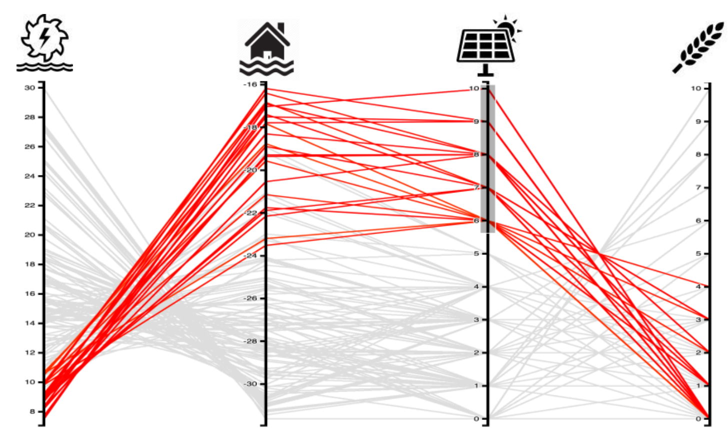


Uniform grassland landcover reduces ET and allows for the maximum water flow volume available for hydropower production, which however cause floods.

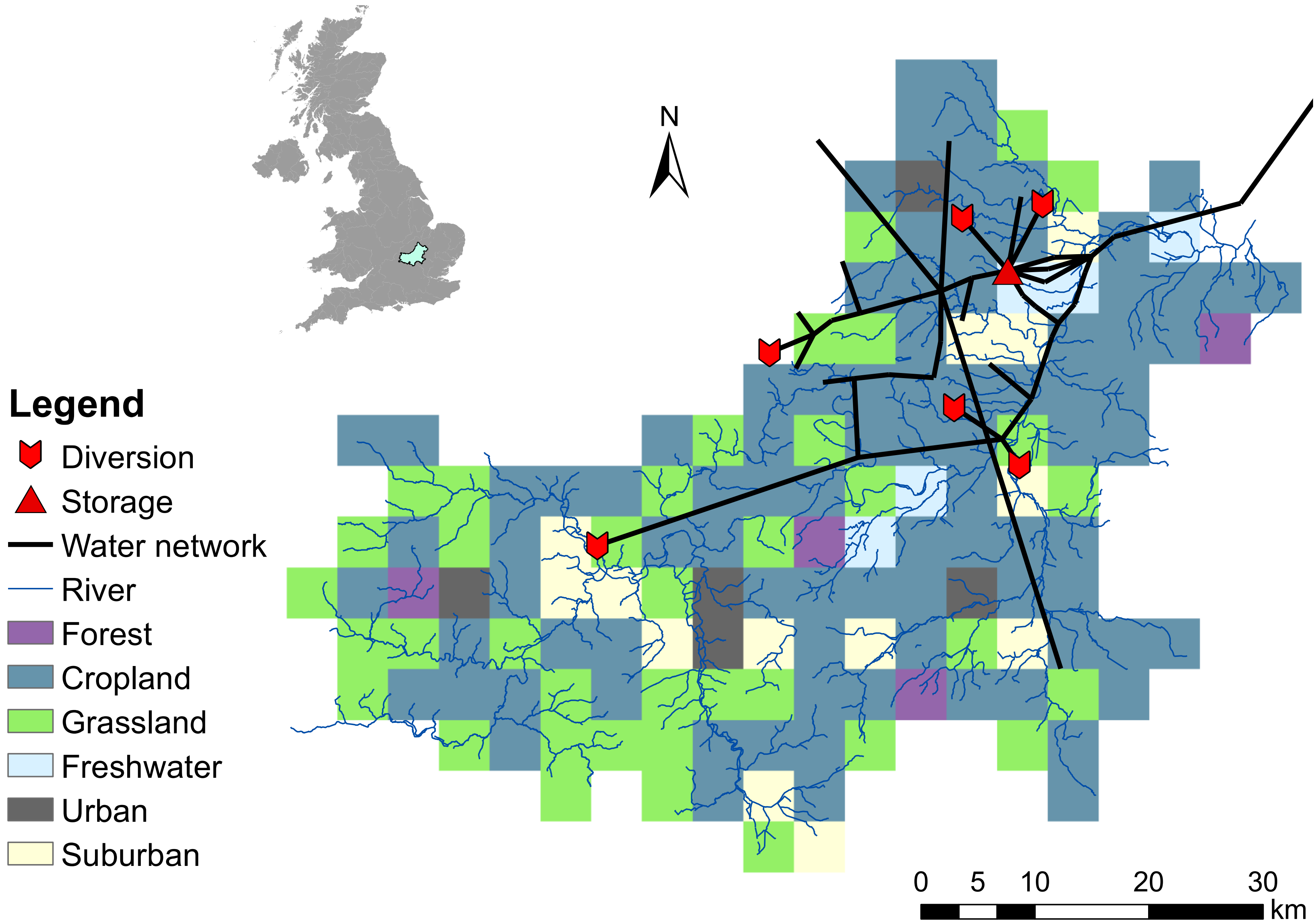
Land for solar would reduce floods and compensate for lost hydropower



This scenario would favor bare soil and forest preferentially closer to the river (cell 0) as they increase ET.

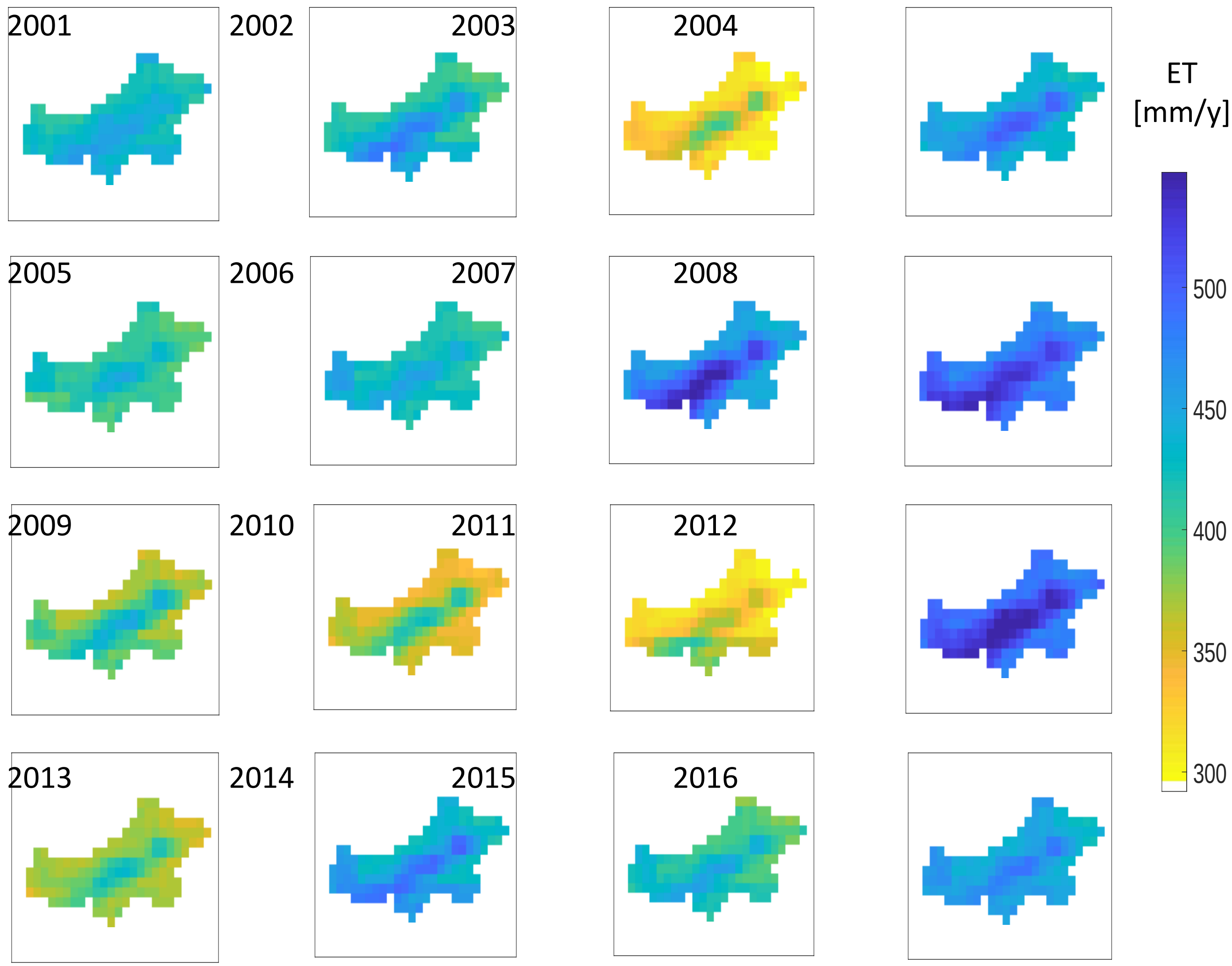


In progress: Upper and Bedford Ouse Catchment



Aim for climate robust trade-offs?

Does climate impact trade-offs?



Interannual variability of mean annual ET

Overall conclusions

- Seeking resilient water resource solutions can be tackled at different scales (national, regional, catchment)
- A similar approach (simulation-based multi-criteria analysis and design) can be applied at these different scales
- This water planning approach shows promise for integrated land-water planning