How should model structural uncertainty in modelling water resources management problems shape evaluations of their operations?

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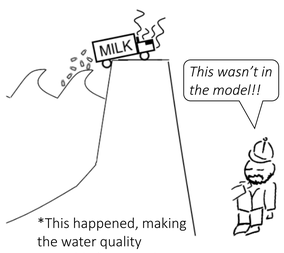
1. Many uncertainties contribute to scepticism about model realism in reservoir operations modelling

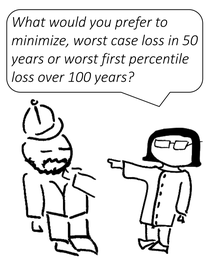
Model structure *No one yet!*



*This happened, making the water quality unusable for a week

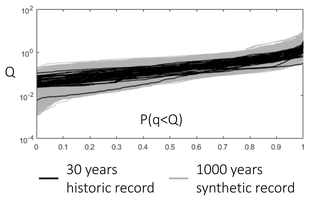
Parametric *Trinidade et al. 2017*

Objective *Quinn et al. 2017*

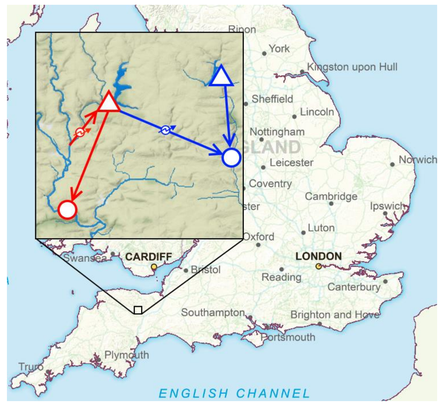


Forcing *Zeff et al. 2014*

Longer time-series are needed to capture hydrologic uncertainty; this is achieved by using stochastic flow generation.



2. We study a 2-reservoir water supply system in the South West of the UK



The system supplies water to two treatment works while minimizing pump costs. Two companies operate half of the system each, with one reservoir as a shared resource. The water treatment works for Company 1 (West) supplies in the order of 400,000 people. The treatment works for Company 2 (East) supplies in the order of 150,000 people.

3. How does the performance of an operation solution change when evaluated with different model structural assumptions?

A: Define rival framings

Case study: Each framing is a collection of modelling choices. Here we define 6 framings from 5 modelling choices

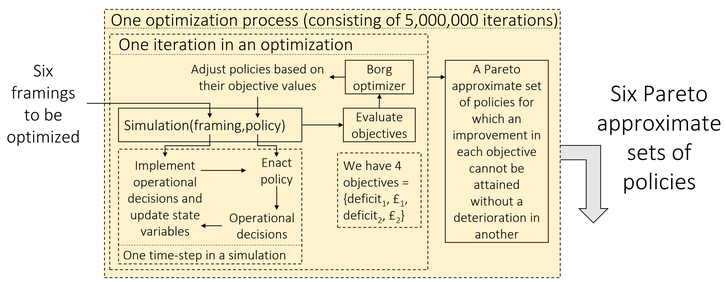
Framing	Evaporation	Pump breaks	Inflow	Demand	Company cooperation
1:Basic-UC	×	×	AR(1)	AR(1)	×
2:AR(1)-UC	✓	✓	AR(1)	AR(1)	×
3:Full-UC	✓	✓	AR(2)	AR(2)	×
4:Basic-C	×	×	AR(1)	AR(1)	✓
5:AR(1)-C	✓	✓	AR(1)	AR(1)	✓
6:Full-C	✓	✓	AR(2)	AR(2)	✓

× = Not included, ✓ = Included,
AR(P) = periodic autoregressive model of lag P

Six framings to be optimized

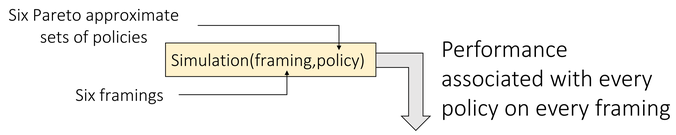
B: Optimize operations for each framing

Case study: For each framing, we solve a multi-objective problem (which results in a Pareto approximate set of operating policies).



C: Re-evaluate operations under framings they were not optimized for

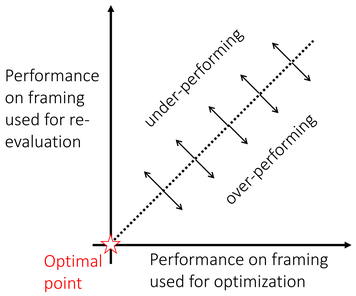
Case study: We take the policies that have been optimized and re-evaluate them on all framings with an expended ensemble size (i.e. for an ensemble of 10,000 years we are certain that the objective values are within 1% of the value they would take for an ensemble of 100,000 years).



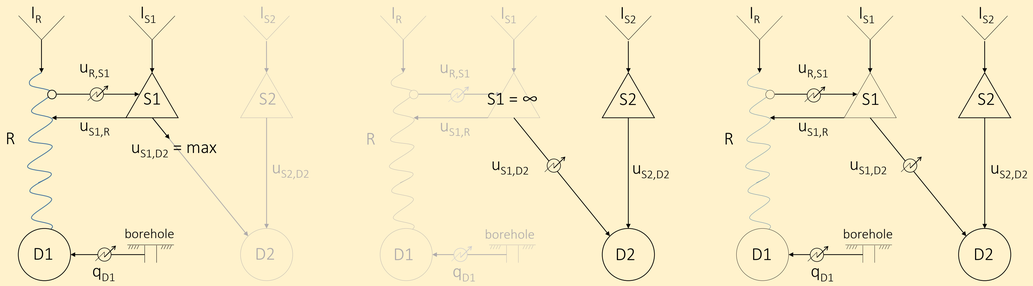
D: Analyse the stability of the performances across framings

i.e. how worse/better off are you when you make a given modelling choice if that choice is not 'correct'?

We answer this question with objective-objective plots showing performance in optimized framing against performance in re-evaluated framing (example for a single objective to be minimized, right)



Additional case study information



We show how companies would 'view' the system if they were not cooperating their operations.

'Uncooperative' operation is simulated by two models, one for the decisions and objectives associated with each company.

'Cooperative' operation uses a single simulation model where decisions are made by a centralised decision maker.

Legend

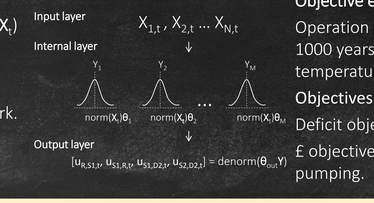
- Uncontrolled flow
- River Exe
- Controlled flow
- Reservoir node
- Demand node (i.e. water treatment works)
- Pumped controlled flow

Detailed information for detail orientated people

Definition of our operation policy:

$[u_{R,S1,t}, u_{S1,R,t}, u_{S1,D2,t}, u_{S2,D2,t}] = m(\theta, X_t)$

'm' describes a network of radial basis policy functions with M internal nodes (example right). 'θ' contains the weights of this network. 'X_t' contains N state variables (we include storages, demands and inflows).



Objective evaluation:

Operation policies are simulated at a daily time-step for 1000 years of synthetic forcing (demand, inflow and temperature created by periodic autoregressive models).

Objectives = {$deficit_1$, $£_1$, $deficit_2$, $£_2$}

Deficit objectives are the expected daily squared deficit.

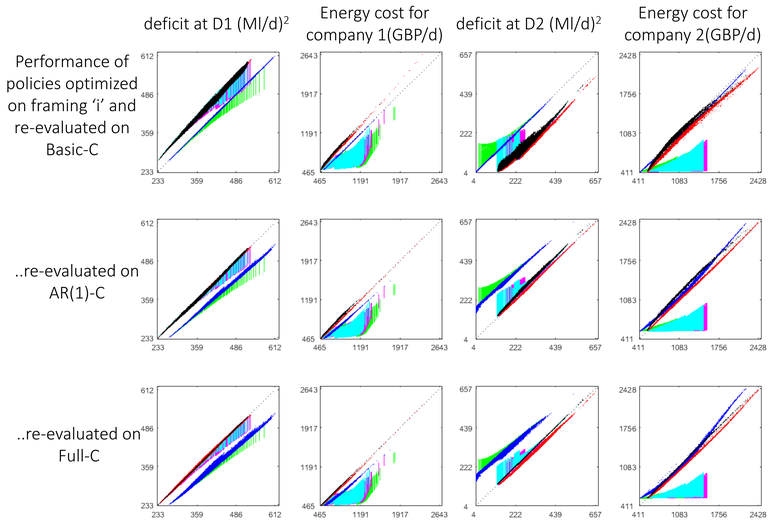
£ objectives are the expected daily energy costs for pumping.

4. Modelling choices strongly influence how operations are evaluated

Framings (i): 1:Basic-UC, 2:AR(1)-UC, 3:Full-UC, 4:Basic-C, 5:AR(1)-C, 6:Full-C

Analysis:

Framings 1, 2 and 3 result in big differences upon re-evaluation for all objectives, while framings 1 and 4 cause underperformance in the deficit estimates.



Performance of policies optimized on framing 'i' and evaluated on 'i'

Concluding remarks:

The modelling choices we embed into the selected framings are generally an informal part of the model building process.

Often there is little quantitative evidence to support these choices.

These choices matter.

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Zeff, H. B., Kasprzyk, J. R., Herman, J. D., Reed, P. M., and Characklis, G., Water Resources Research, 2014