Workshop on Environmental Modelling and Regulation in Catchments

The Impact of Innovative Permitting Policy on Urban Waste Water System Performance

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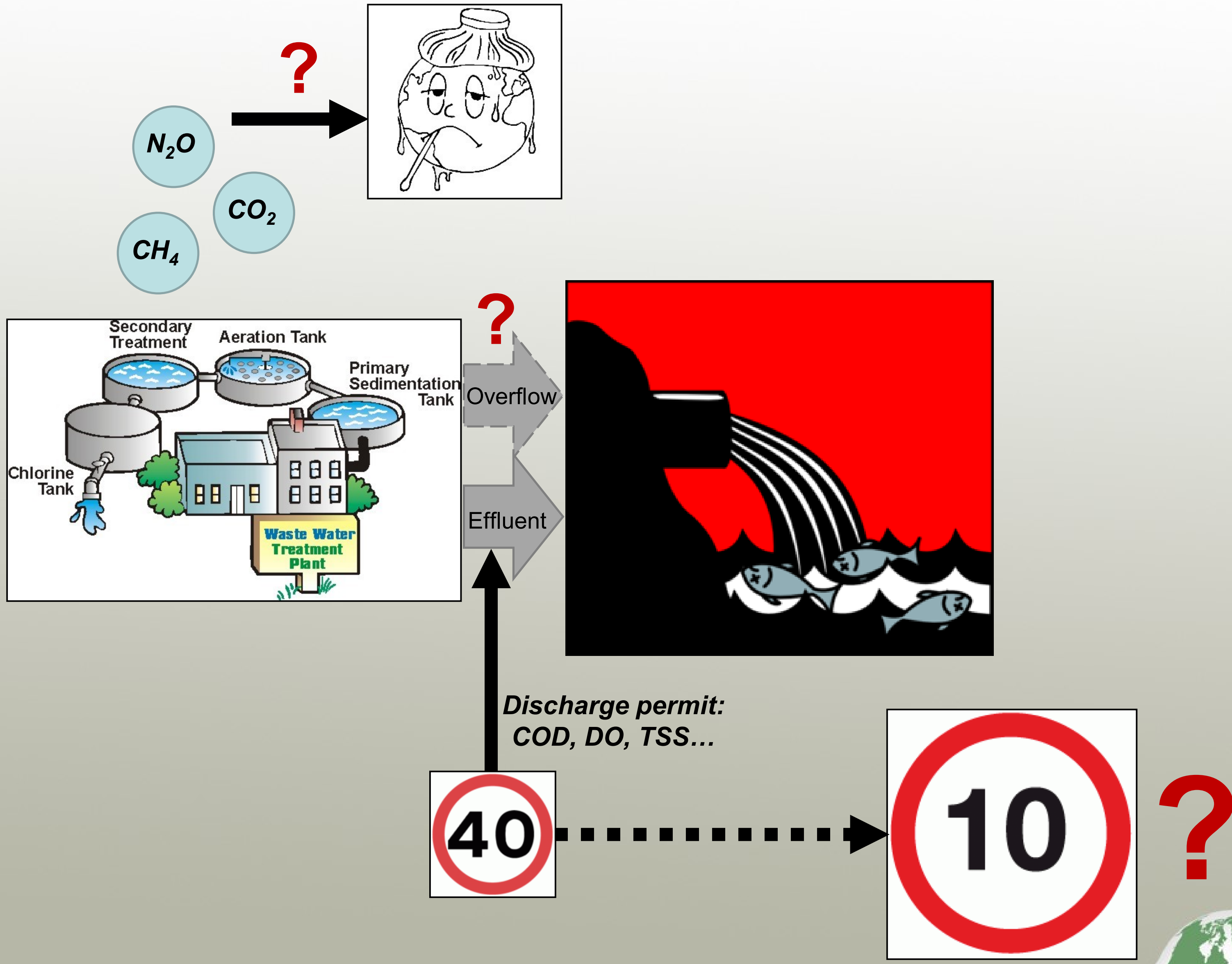
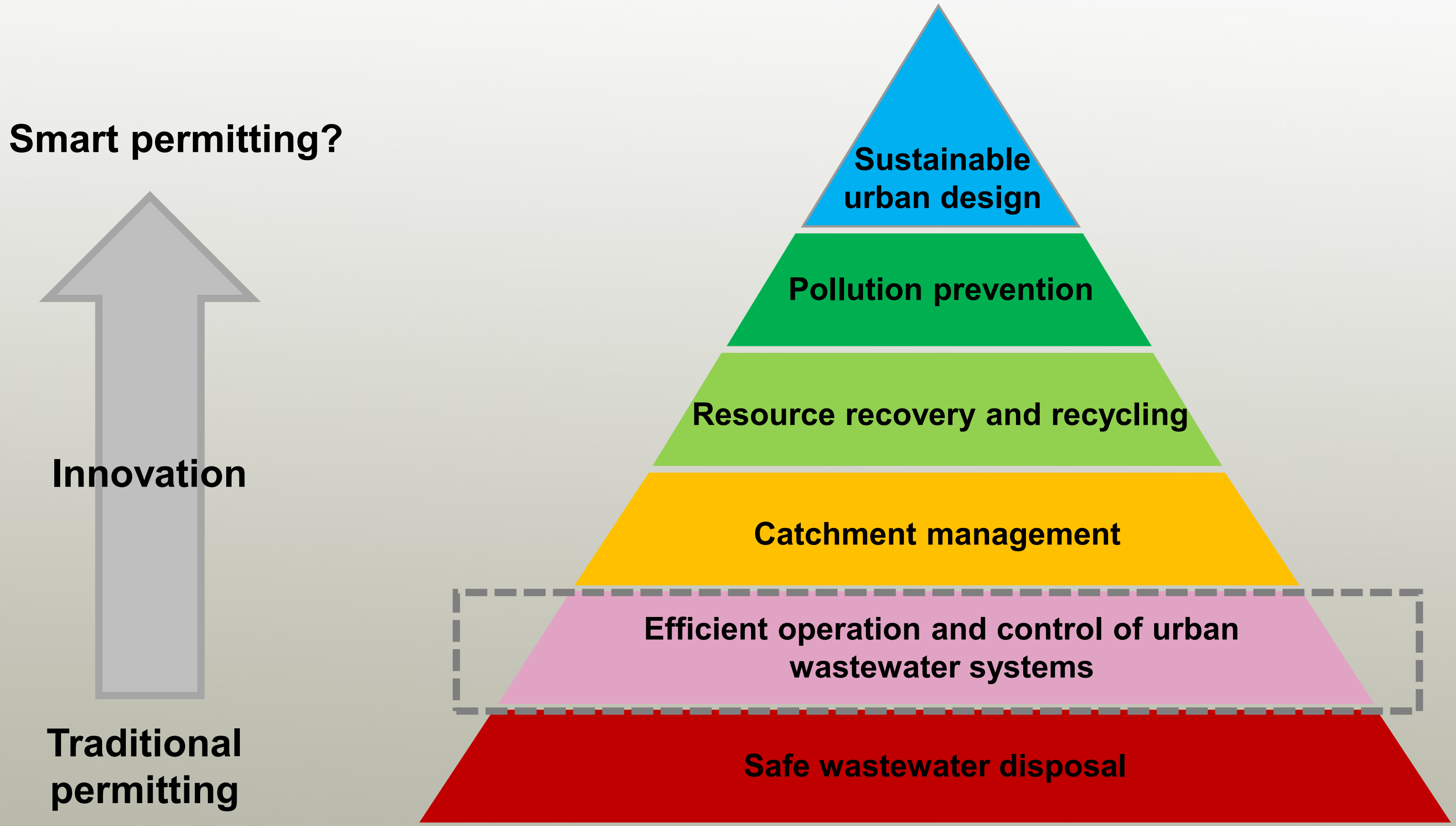
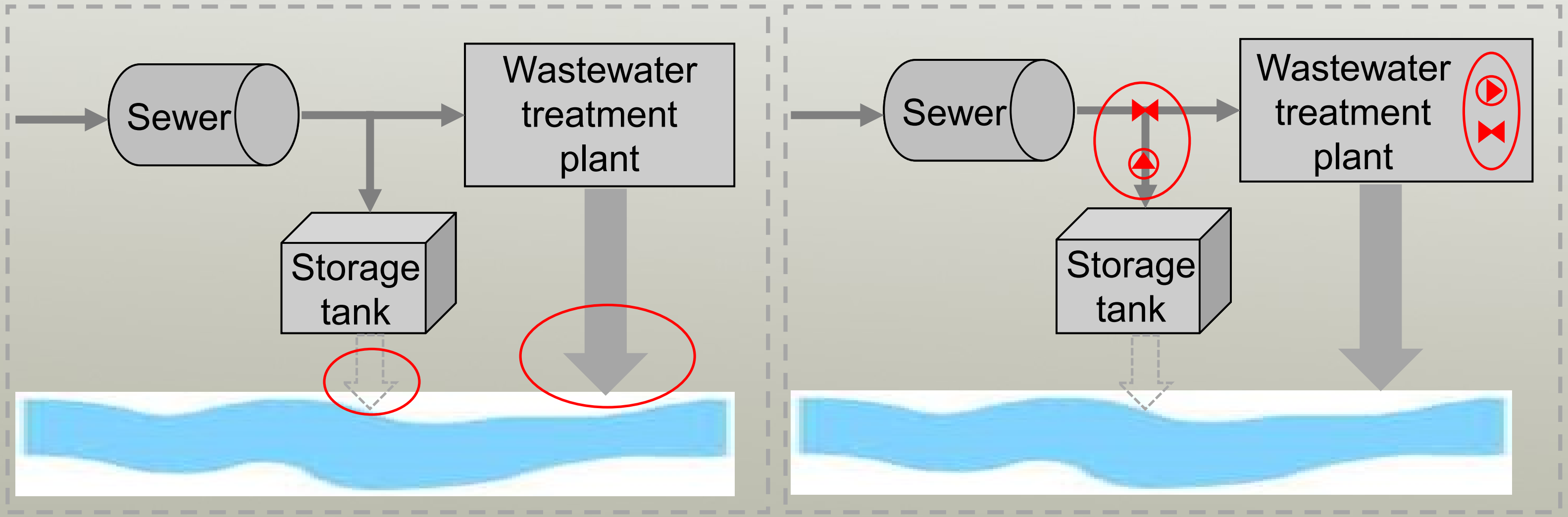


N_2O
CO_2
CH_4
?
Secondary Treatment
Aeration Tank
Primary Sedimentation Tank
Chlorine Tank
Waste Water Treatment Plant
?
Overflow
Effluent
Discharge permit:
COD, DO, TSS…
40
10
?


Smart permitting?
Innovation
Traditional permitting
Sustainable urban design
Pollution prevention
Resource recovery and recycling
Catchment management
Efficient operation and control of urban wastewater systems
Safe wastewater disposal

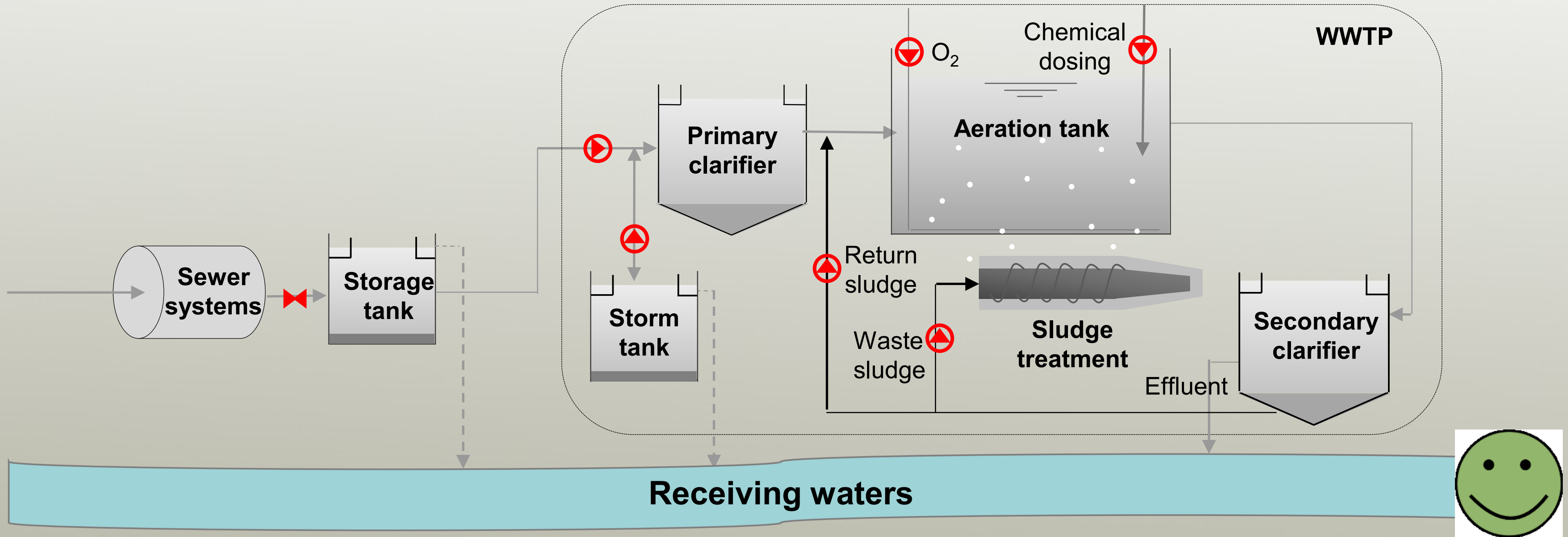
New permitting approach?

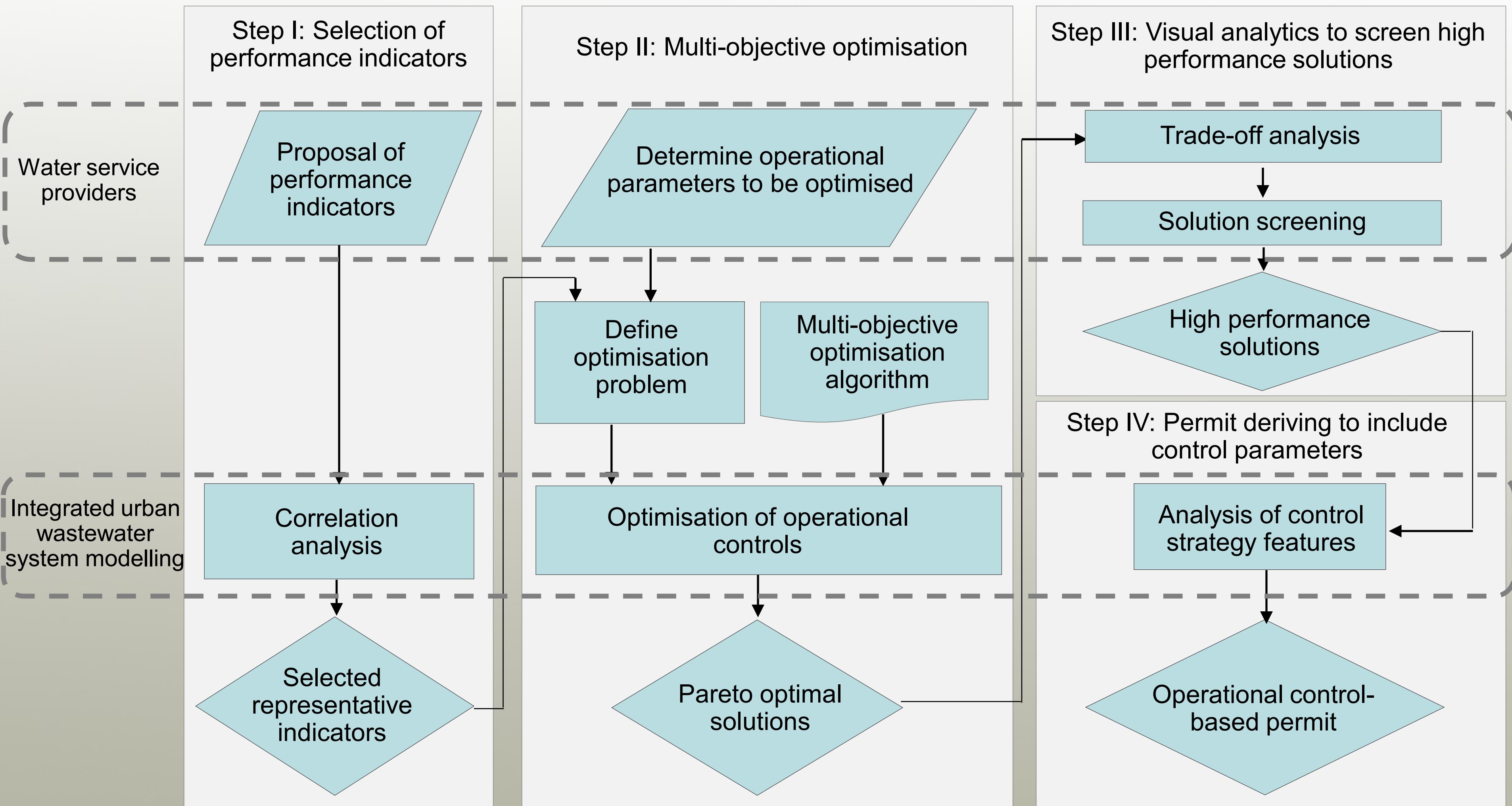
End-of-pipe limits to *Operational strategies*



(Meng et al. 2016, Water Research)

- ❑ **Optimisation of system operation/control**
- ❑ **Multi-benefits analysis**




Step I: Selection of performance indicators
Step II: Multi-objective optimisation
Step III: Visual analytics to screen high performance solutions
Water service providers
Proposal of performance indicators
Determine operational parameters to be optimised
Trade-off analysis
Solution screening
Define optimisation problem
Multi-objective optimisation algorithm
High performance solutions
Step IV: Permit deriving to include control parameters
Integrated urban wastewater system modelling
Correlation analysis
Optimisation of operational controls
Analysis of control strategy features
Selected representative indicators
Pareto optimal solutions
Operational control-based permit

Baseline scenario:
90%ile river water quality limit violated

↓ **Operational optimisation**

Optimised solutions:

- ☑ 90%ile river water quality limit?
- ☑ 99%ile river water quality limit?
- ☐ IUWWS performance?
- Cost;
- Effluent stability;
- Environmental risk;

Significant improvement!

Objectives:

Objective 1 = Min (cost)

Objective 2 = Min (Effluent standard deviation)

Objective 3 = Min (Environmental risk)

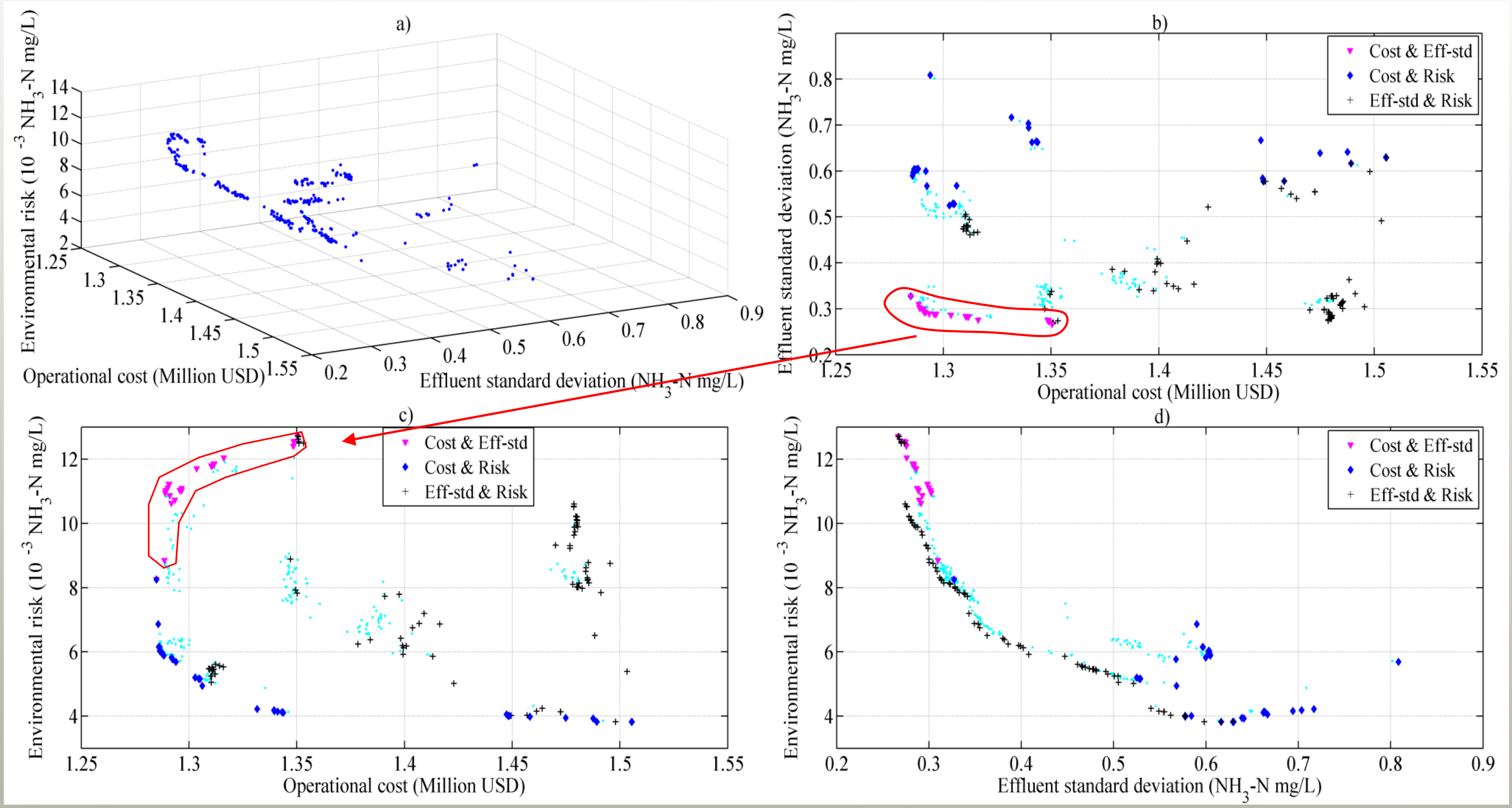
Optimization variables:

Operational variables at CSOs and in WWTP

Constraints:

Downstream river water quality targets

(i.e. 90%ile, 99%ile);


a)
b)
c)
d)
Environmental risk (10 -3 NH3-N mg/L)
Effluent standard deviation (NH3-N mg/L)
Operational cost (Million USD)
Cost & Eff-std
Cost & Risk
Eff-std & Risk

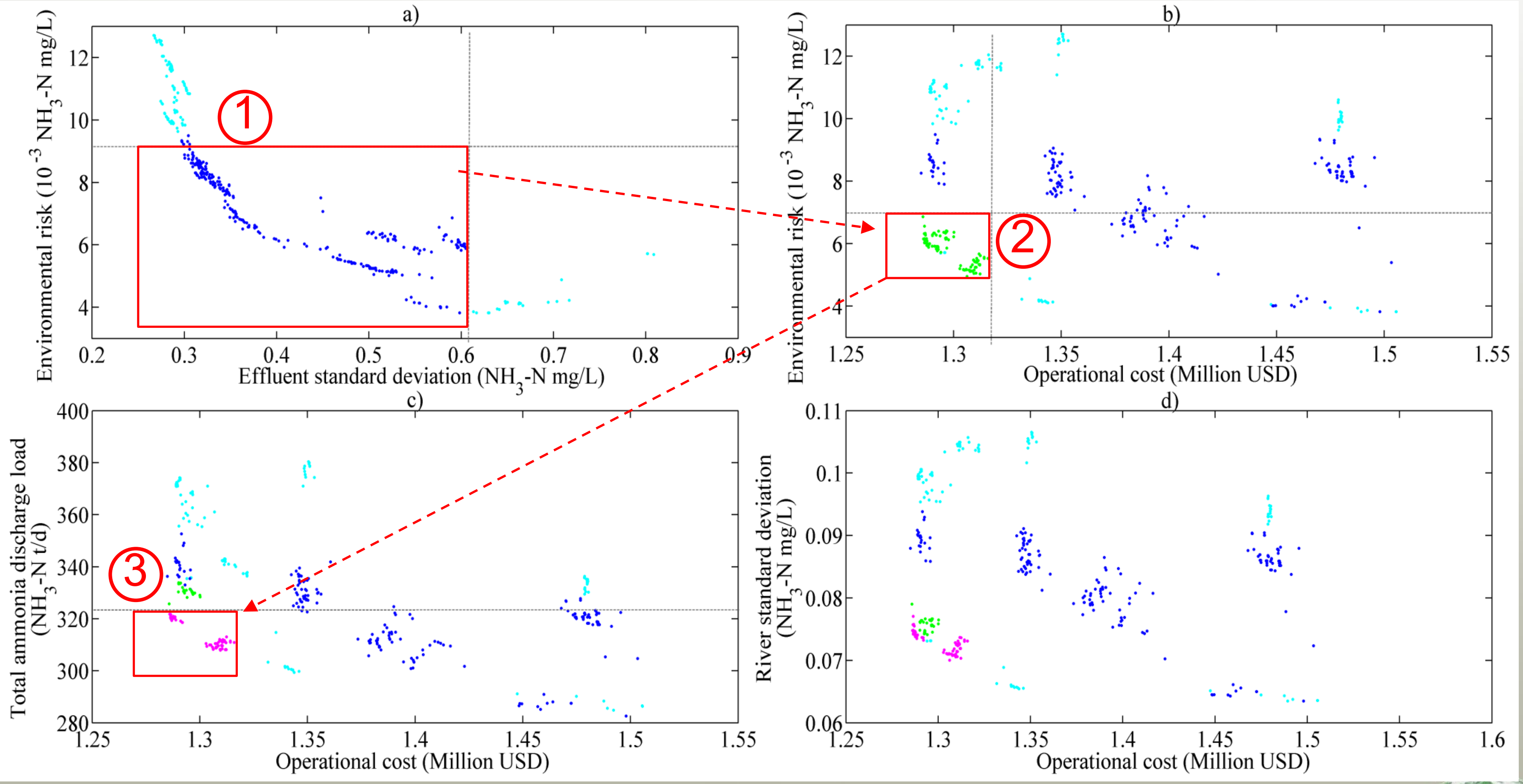


Figure 4 Screening of the Pareto optimal solutions through visual analytics

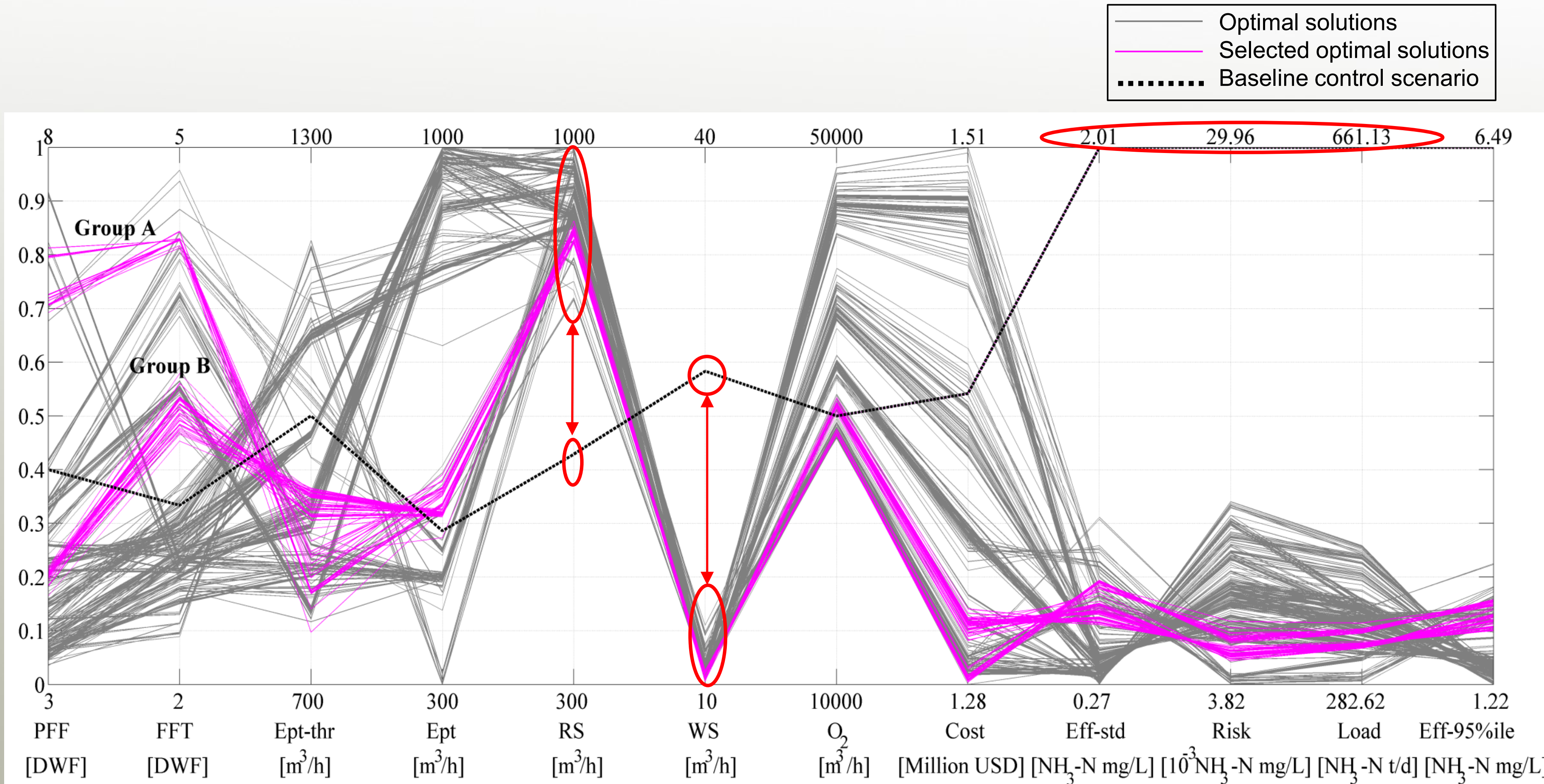
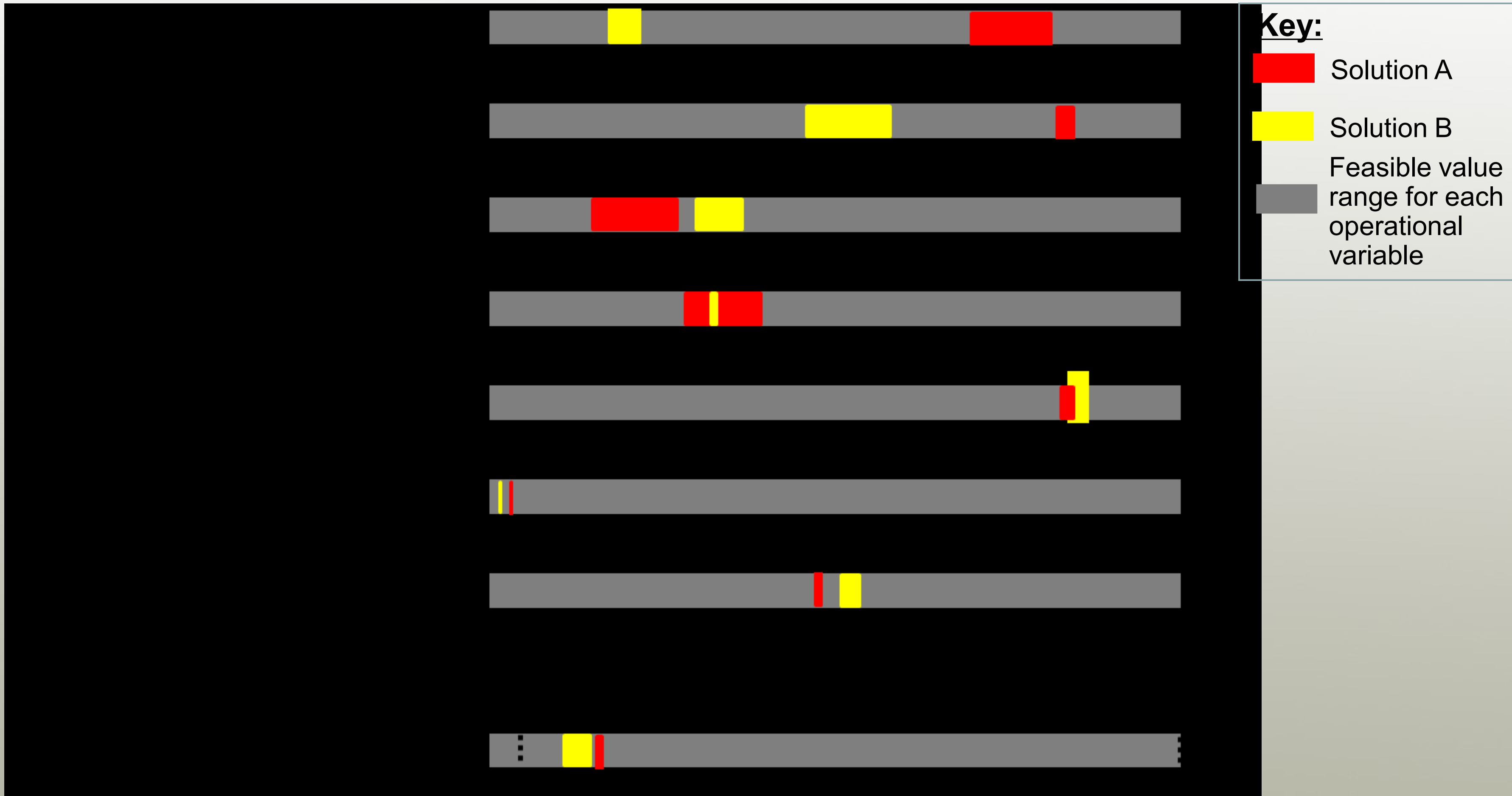


Figure 5 Operational variables and performance indicators of the selected solutions and their related effluent 95%ile concentration

Operational variables: PFF (Pass forward flow), FFT (flow to full treatment), Ept_thr (storm tank emptying threshold), Ept (storm tank emptying rate), RS (return sludge rate), WS (waste sludge rate), O_2 (aeration rate);
Performance indicators: Cost (operational cost), Eff-std (effluent standard deviation), Risk (environmental risk) and Load (total pollutant discharge load)


Key:
Solution A
Solution B
Feasible value range for each operational variable

Operational variables	Permit value	Permit range
Pass forward flow (dry weather flow, i.e. DWF)	6.7	[6.4, 7.1]
Flow to full treatment (DWF)	4.4	[4.4, 4.5]
Storm tank emptying threshold (m^3/h)	820	[784, 860]
Storm tank emptying rate (m^3/h)	530	[491, 573]
Return sludge pumping rate (m^3/h)	880	[875, 893]
Waste sludge pumping rate (m^3/h)	10.7	[10.6, 10.8]
Aeration rate (m^3/h)	28,800	[28,573, 29,039]

Compared to baseline control scenario:

50% less **energy cost**

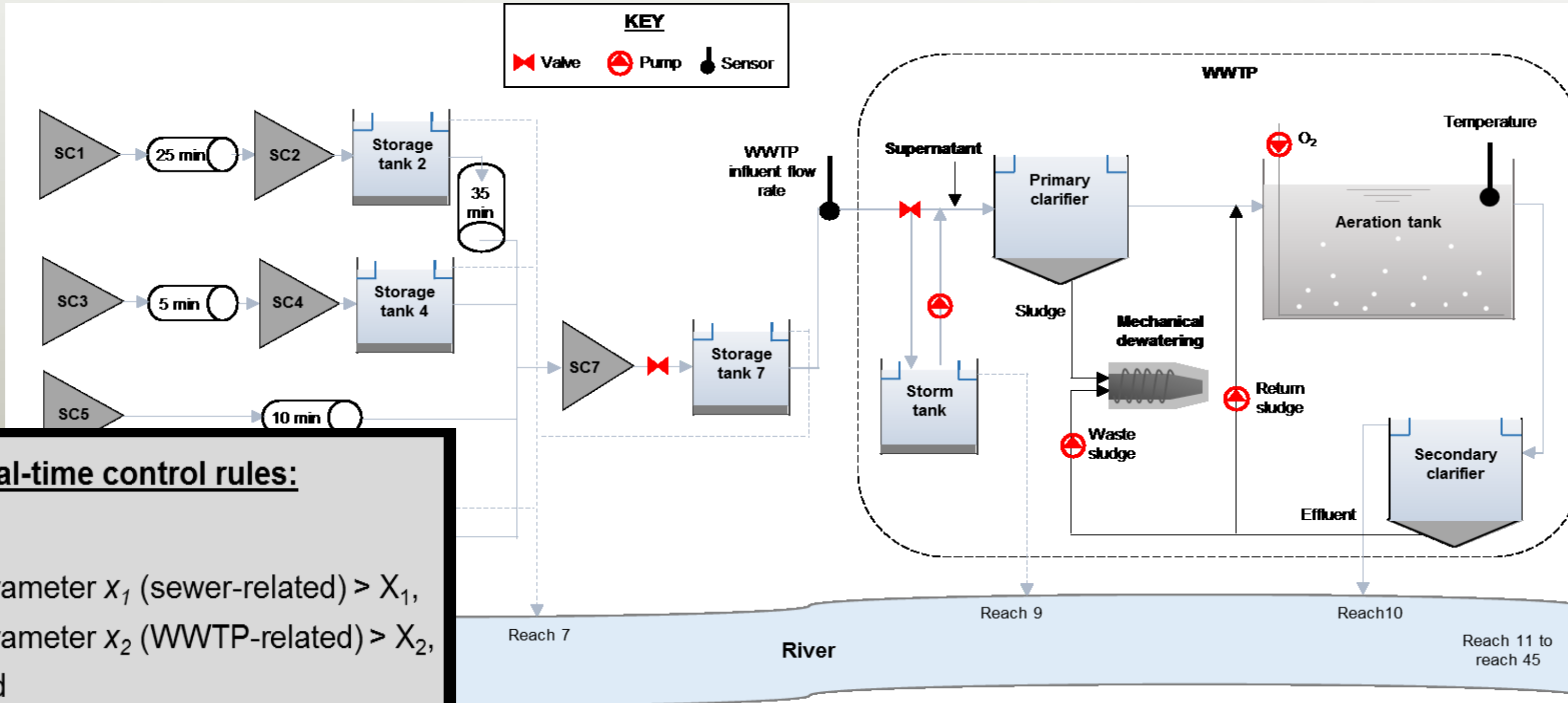
90% lower **pollutant discharge load**

80% higher operational **stability**

Performance indicator	Operational control-based permitting solutions	End-of-pipe permitting solutions
Effluent 95%ile concentration (NH_3-N mg/L)	[1.99, 2.06]	[1.23, 1.42]
Total operational cost (Million USD/year)	[1.28, **1.29**]	[1.28, 1.53]
Effluent standard deviation (NH_3-N mg/L)	[0.58, 0.61]	[0.27, 0.35]
Environmental risk (10^{-3} NH_3-N mg/L)	[**5.83, 6.56**]	[8.34, 11.96]
Total discharge load (t NH_3-N/d)	[319, **322**]	[310, 349]

More **reliable** and **energy-efficient** than end-of-pipe permitting approach

Integrated Real-Time Control



Real-time control rules:

IF

parameter x_1 (sewer-related) > X_1,

parameter x_2 (WWTP-related) > X_2,

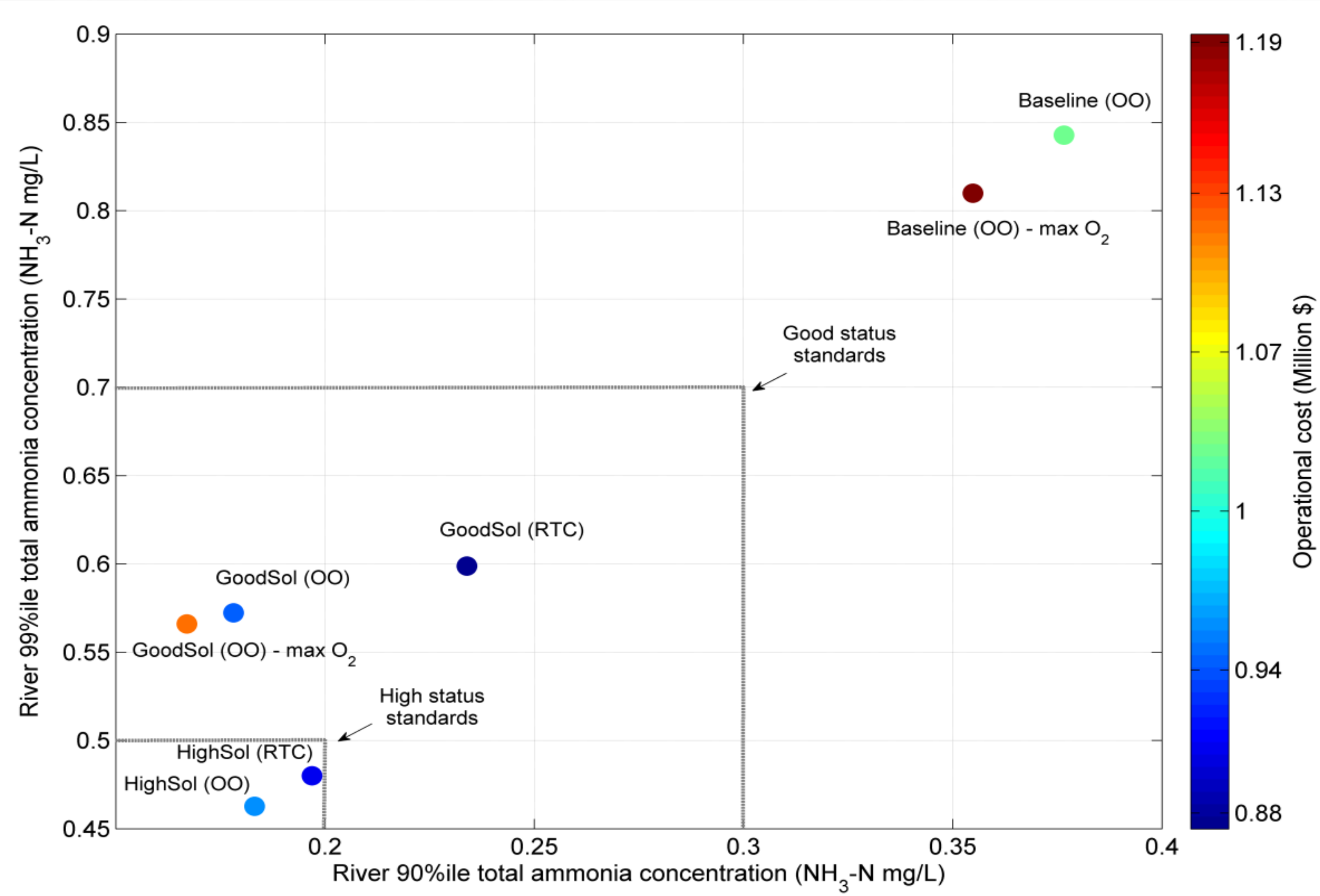
and

parameter x_3 (river-related) > X_3,

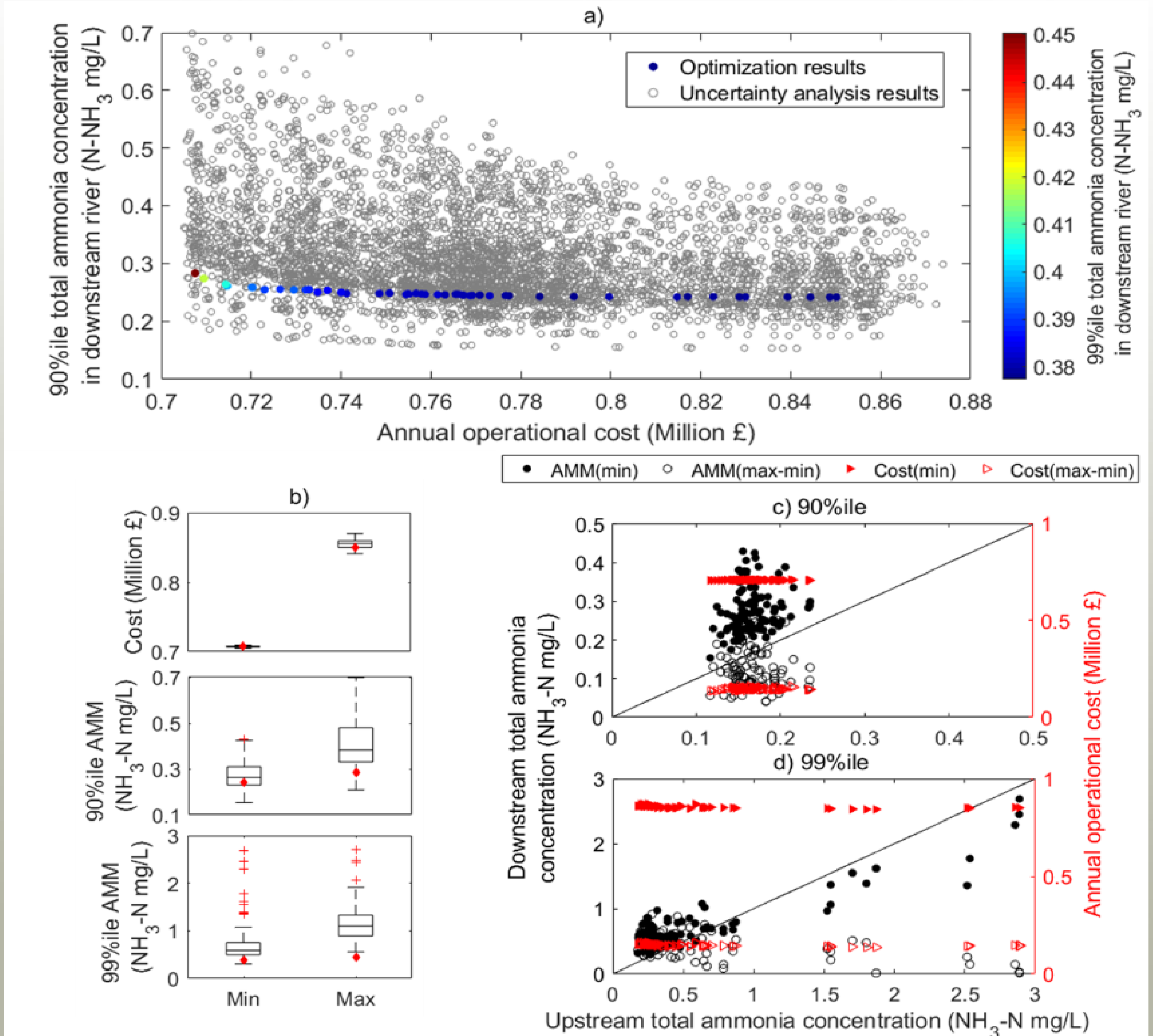
THEN

operational setting y = Y.

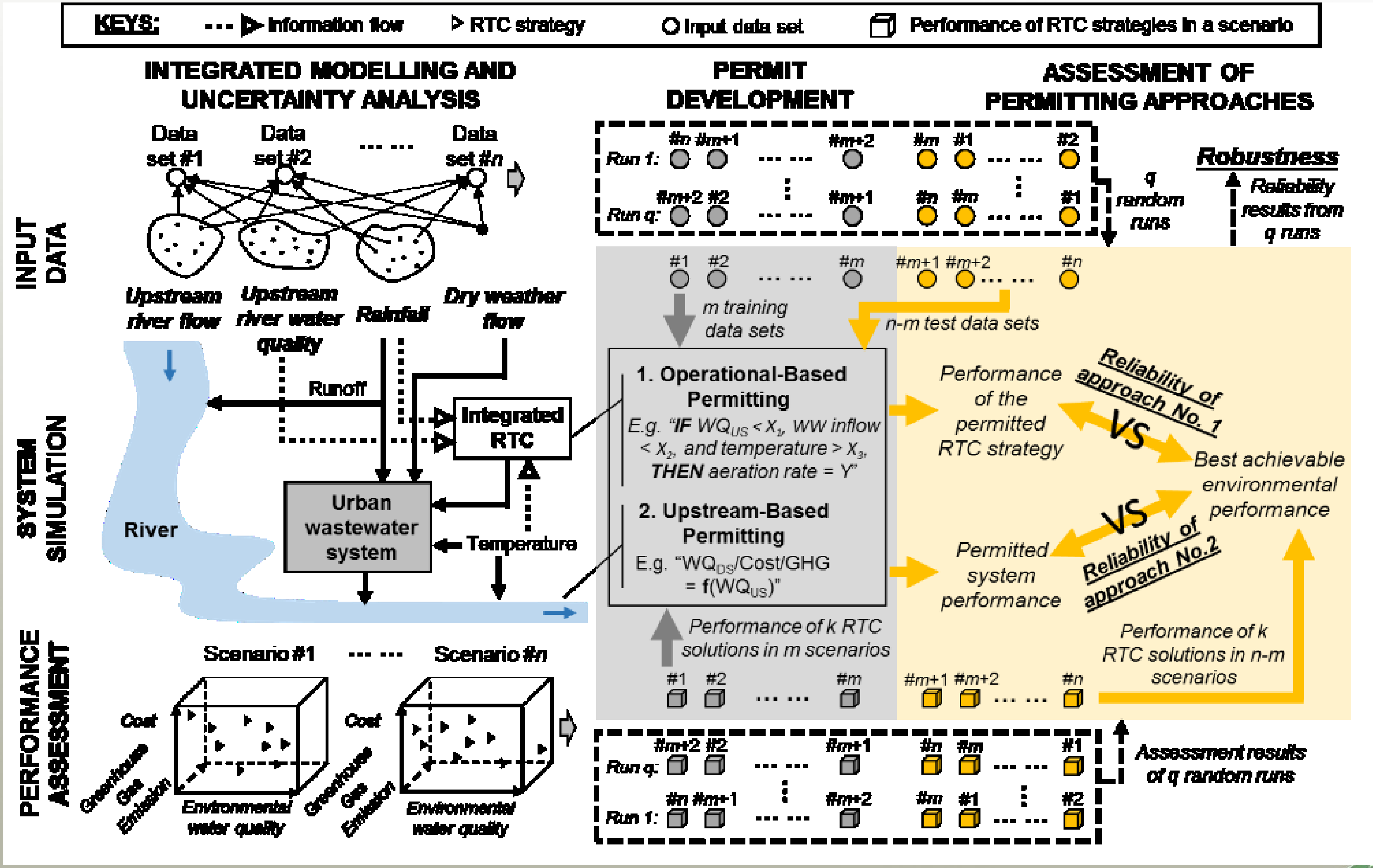
(Meng et al. 2017, Environmental Science and Technology)



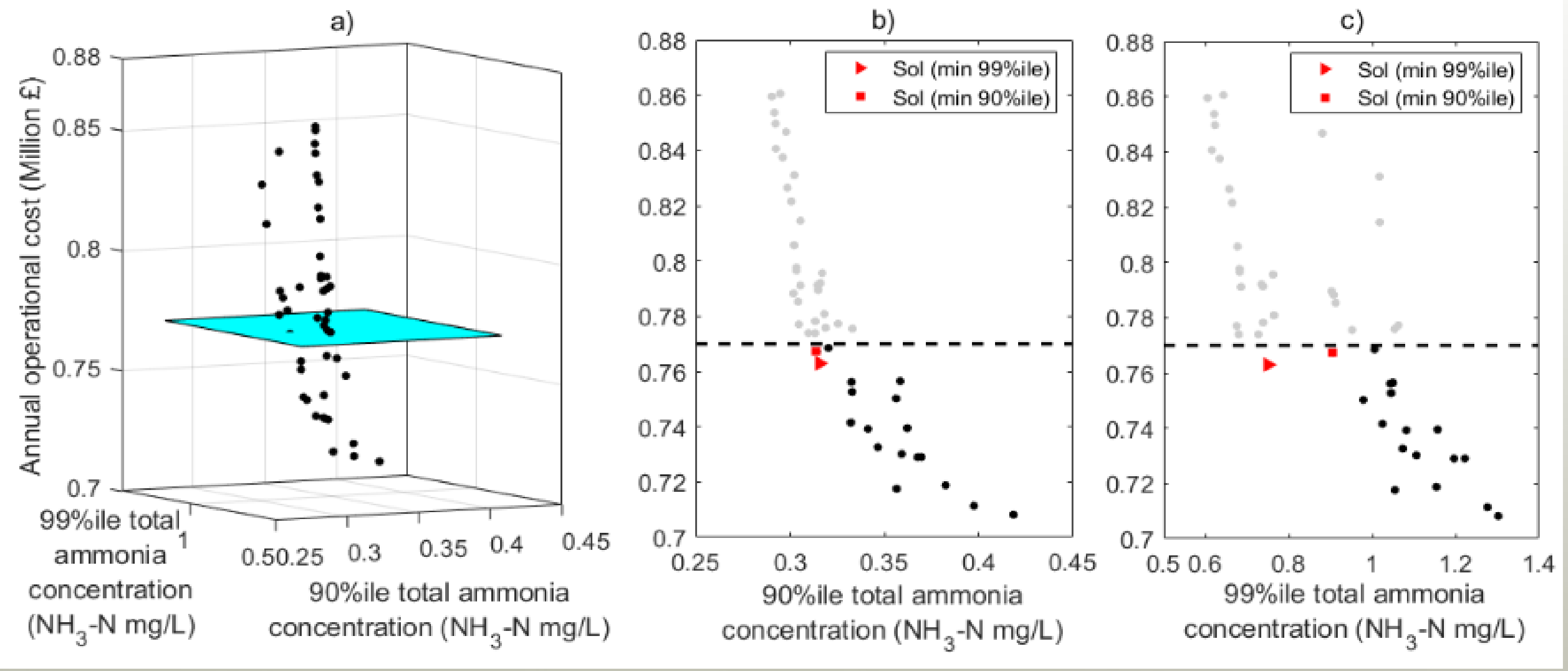
How to regulate?



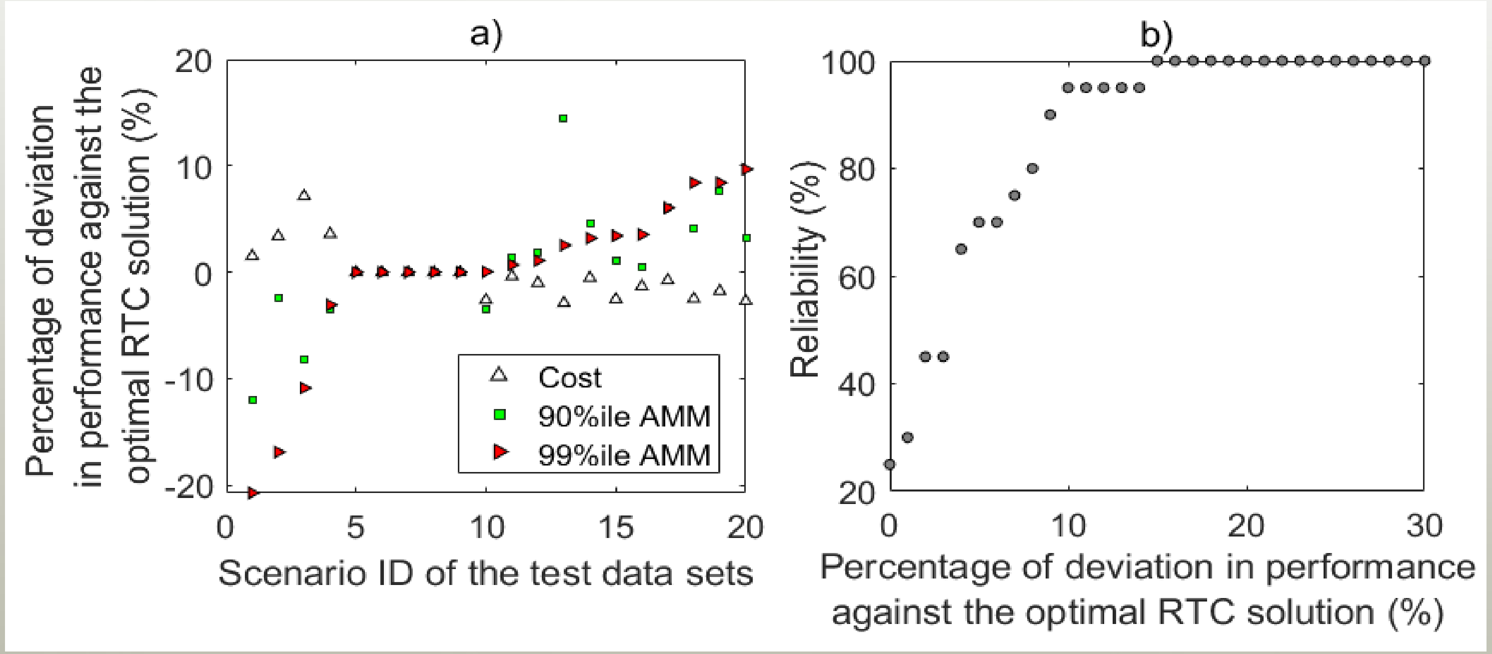
a)
90%ile total ammonia concentration in downstream river (N-NH3 mg/L)
Annual operational cost (Million £)
Optimization results
Uncertainty analysis results
99%ile total ammonia concentration in downstream river (N-NH3 mg/L)
AMM(min)
AMM(max-min)
Cost(min)
Cost(max-min)
b)
Cost (Million £)
90%ile AMM (NH3-N mg/L)
99%ile AMM (NH3-N mg/L)
Min
Max
c) 90%ile
d) 99%ile
Downstream total ammonia concentration (NH3-N mg/L)
Annual operational cost (Million £)
Upstream total ammonia concentration (NH3-N mg/L)



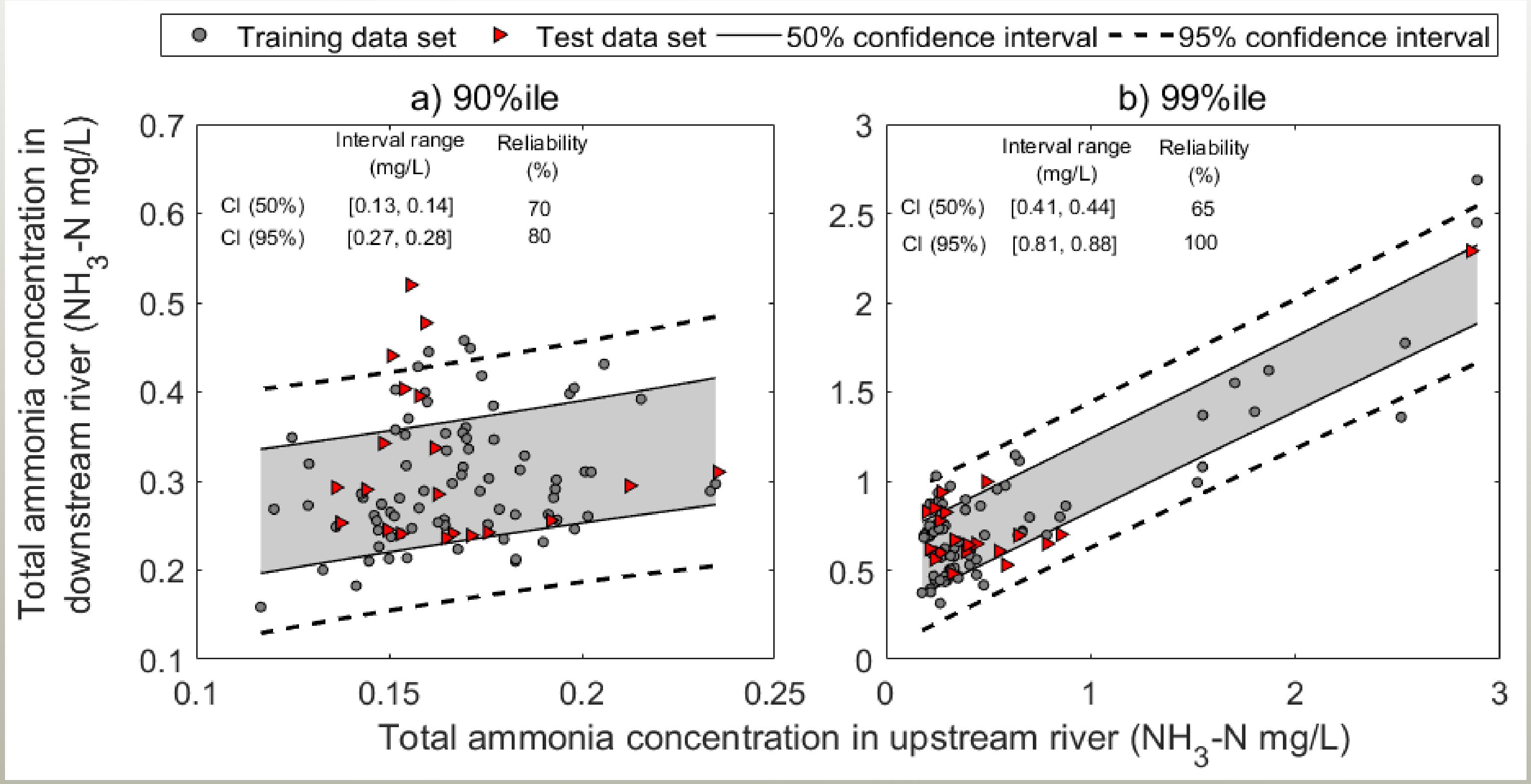
KEYS:
Information flow
RTC strategy
Input data set
Performance of RTC strategies in a scenario
INTEGRATED MODELLING AND UNCERTAINTY ANALYSIS
PERMIT DEVELOPMENT
ASSESSMENT OF PERMITTING APPROACHES
INPUT DATA
Data set #1
Data set #2
Data set #n
Upstream river flow
Upstream river water quality
Rainfall
Dry weather flow
SYSTEM SIMULATION
Runoff
Integrated RTC
Urban wastewater system
Temperature
River
PERFORMANCE ASSESSMENT
Scenario #1
Scenario #n
Cost
Greenhouse Gas Emission
Environmental water quality
Run 1:
Run q:
q random runs
Robustness
Reliability results from q runs
m training data sets
n-m test data sets
1. Operational-Based Permitting
E.g. "IF WQ_US < X_1, WW inflow < X_2, and temperature > X_3, THEN aeration rate = Y"
2. Upstream-Based Permitting
E.g. "WQ_DS/Cost/GHG = f(WQ_US)"
Performance of k RTC solutions in m scenarios
Performance of the permitted RTC strategy
Permitted system performance
Reliability of approach No. 1
Reliability of approach No.2
VS
Best achievable environmental performance
Performance of k RTC solutions in n-m scenarios
Assessment results of q random runs

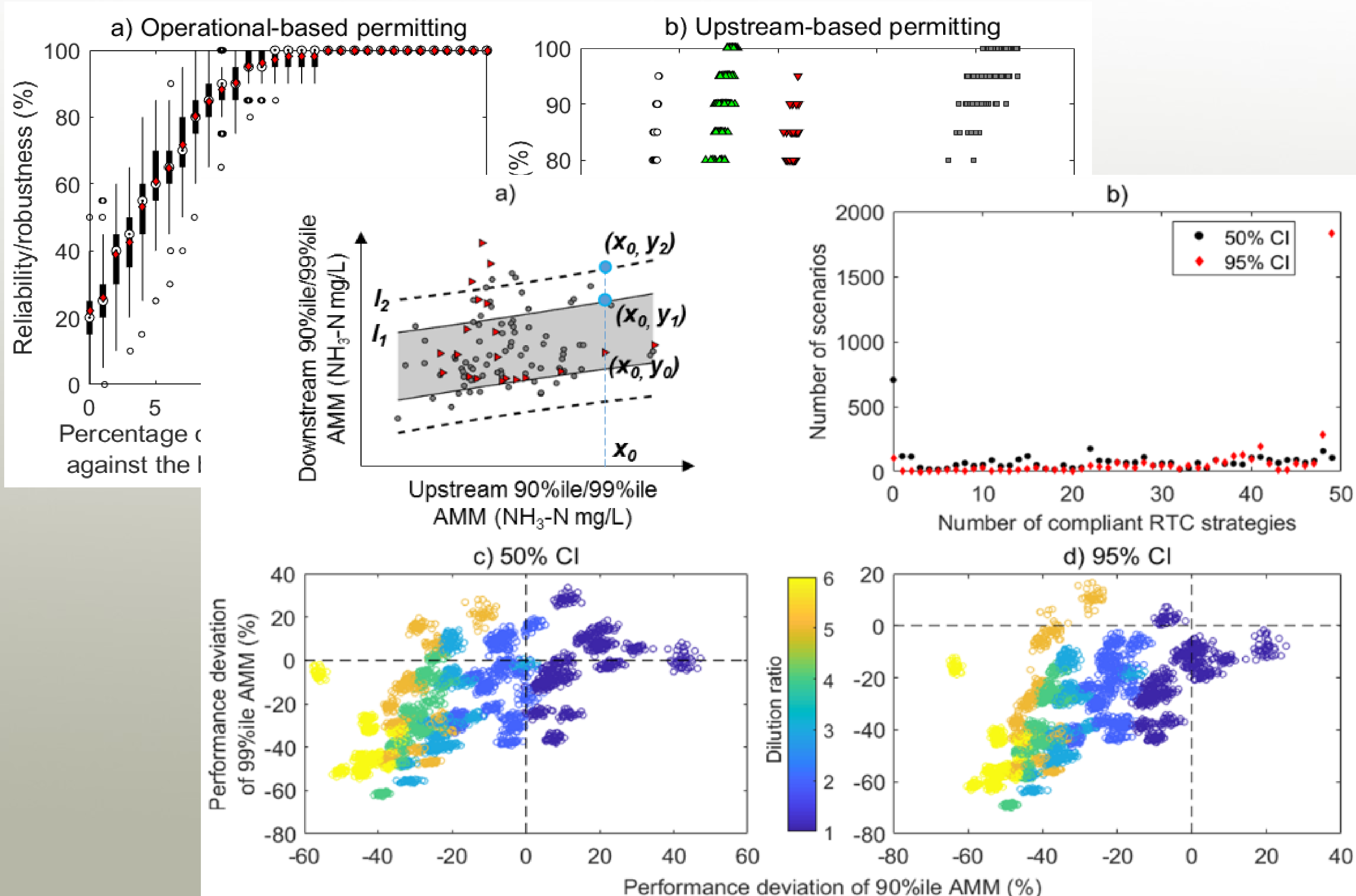

a)
b)
c)
Annual operational cost (Million £)
99%ile total ammonia concentration (NH3-N mg/L)
90%ile total ammonia concentration (NH3-N mg/L)
Sol (min 99%ile)
Sol (min 90%ile)

Operational-Based Permitting



Upstream-Based Permitting




a) Operational-based permitting
Reliability/robustness (%)
Percentage c
against the l
b) Upstream-based permitting
(%)
a)
Downstream 90%ile/99%ile AMM (NH_3-N mg/L)
Upstream 90%ile/99%ile AMM (NH_3-N mg/L)
l_2
l_1
(x_0, y_2)
(x_0, y_1)
(x_0, y_0)
x_0
b)
Number of scenarios
Number of compliant RTC strategies
50% CI
95% CI
c) 50% CI
d) 95% CI
Performance deviation of 99%ile AMM (%)
Performance deviation of 90%ile AMM (%)
Dilution ratio

Conclusions

1. The benefits of:

- Optimisation of system operation; and
- Integrated real-time control;
- Smart regulation for smart operation/technologies;

2. Operational based permitting is more reliable than the traditional outcome-based permitting in delivering desirable, overall environmental benefits.

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Reference:

F. Meng, G. Fu and D. Butler. Water quality permitting: From end-of-pipe to operational strategies. Water Research. 2016, 101: 114-126.

F. Meng, G. Fu, D. Butler. Cost-effective river water quality management using integrated real-time control technology. Environmental Science and Technology. 2017, 51 (17): 9876–9886.

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