What are the tradeoffs?
A many objective approach to water resources planning

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Why cost benefit analysis?

- **Flood Control Act of 1936: "appropriate federal activity"**

- **What projects should be funded?**

"…that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood control purposes **if the benefits to whomsoever they may acrue are in excess of the estimated costs**"

- **Is one objective enough?**

Photo # NH 90687   The Washington Navy Yard during the 1936 Potomac River flood

[Arnold, 1988; Reuss, 2005; Photo: US Navy]

Overview

- **Infrastructure planning in the Thames Basin**
- **Risk-based thresholds for water marketing in Texas**
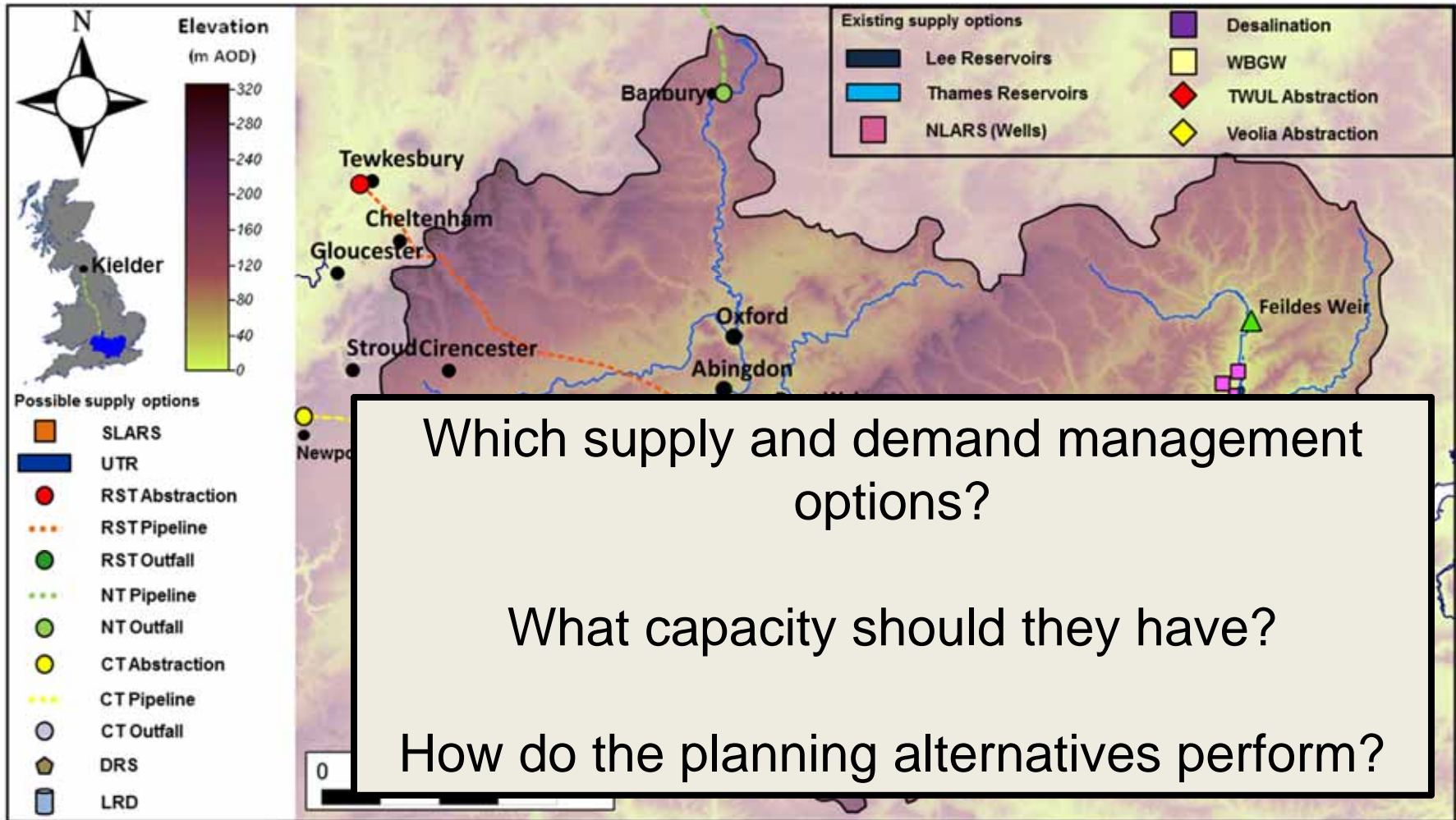- **Thoughts on RiverWare collaboration**

Thames Basin

- **Over 12.5 million inhabitants, projected 2 million increase by 2026**
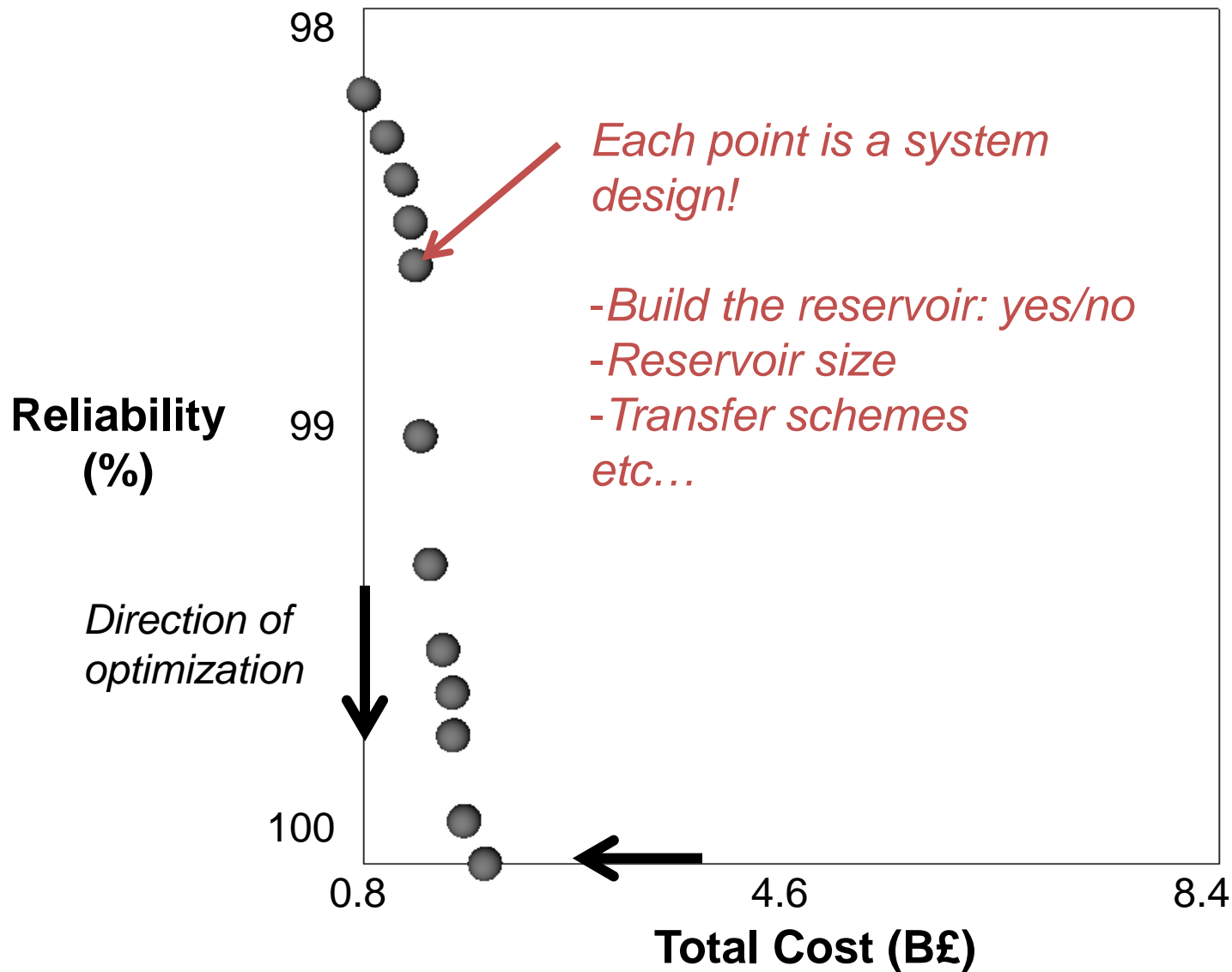- **6 major droughts in the last 90 years**
- **Climate change concerns**

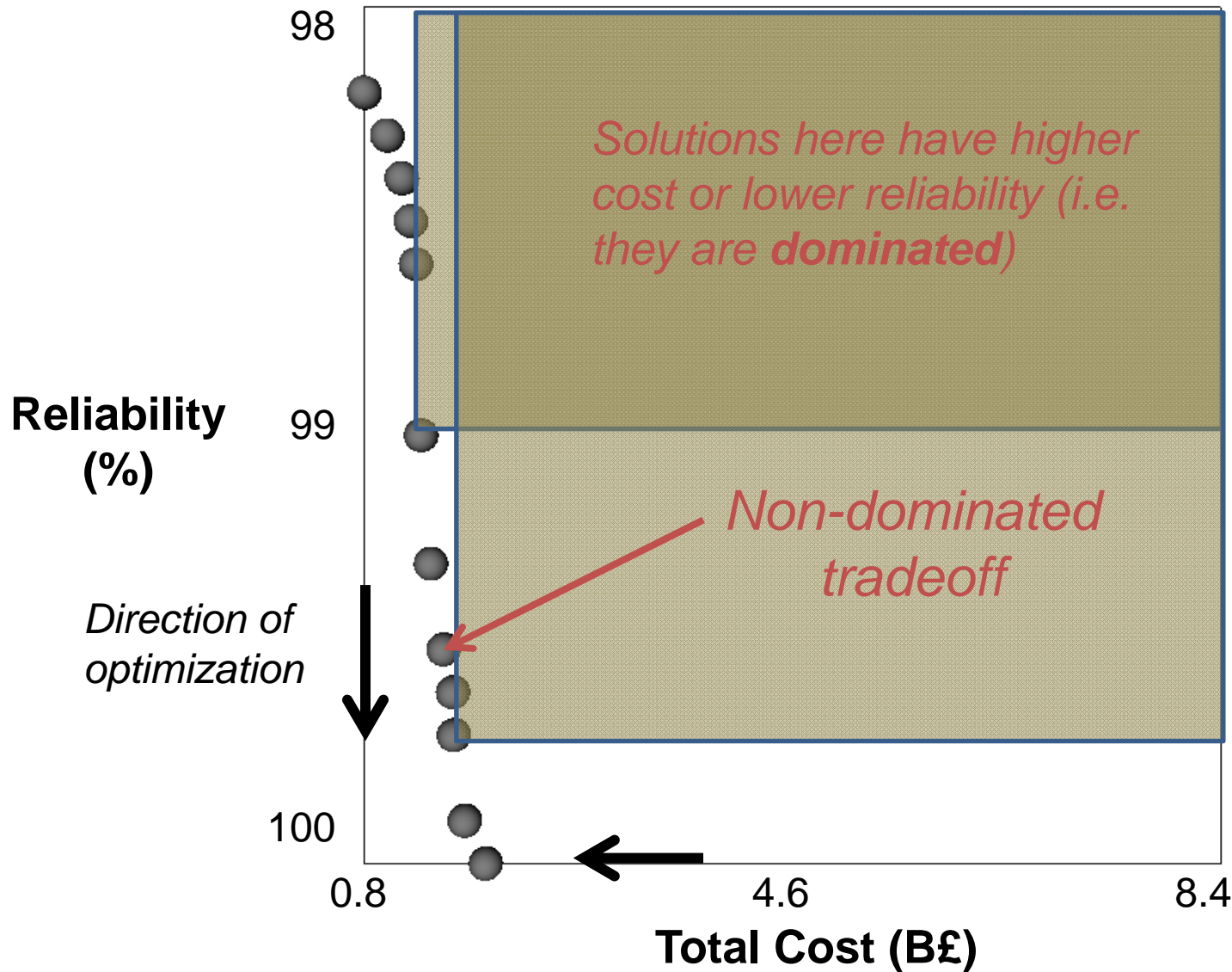*Thames Water drought poster March 2012, dailymail.co.uk*

Thames water resource system

Which supply and demand management options?
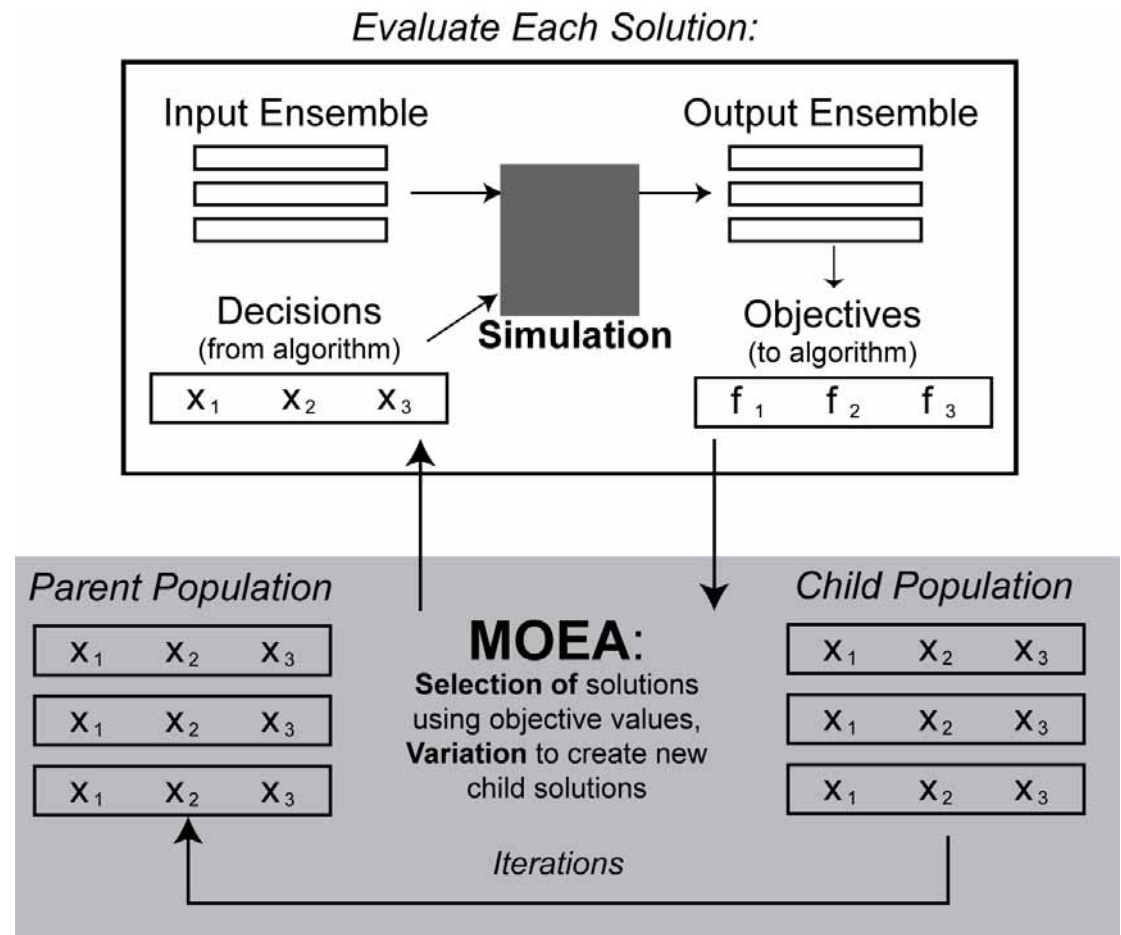
What capacity should they have?

How do the planning alternatives perform?

Two objectives: Non-domination

Reliability (%)

Each point is a system design!

-Build the reservoir: yes/no
-Reservoir size
-Transfer schemes etc…

Direction of optimization

98

99

100

0.8   4.6   8.4

Total Cost (B£)

Two objectives: Non-domination

Reliability (%)

98

99

100

Direction of optimization

*Solutions here have higher cost or lower reliability (i.e. they are **dominated**)*

Non-dominated tradeoff

0.8   4.6   8.4

Total Cost (B£)

Multiobjective Evolutionary Algorithms (MOEAs)

- **Global search**
- **Effective on difficult problems, e.g.:**
  - Many-Objective (>4 objectives)
  - Non-linear
  - Stochastic
- **This study uses ε-NSGAII [2]**

Evaluate Each Solution:

Input Ensemble

Output Ensemble

Decisions (from algorithm)

Simulation

Objectives (to algorithm)

x_1 x_2 x_3

f_1 f_2 f_3

Parent Population

Child Population

x_1 x_2 x_3

x_1 x_2 x_3

x_1 x_2 x_3

x_1 x_2 x_3

x_1 x_2 x_3

x_1 x_2 x_3

MOEA:
Selection of solutions using objective values, **Variation** to create new child solutions

Iterations

[2]Kollat, J. B. & Reed, P. M. 2006. Comparing state-of-the-art evolutionary multi-objective algorithms for long-term groundwater monitoring design. *Advances in Water Resources,* 29**,** 792-807.
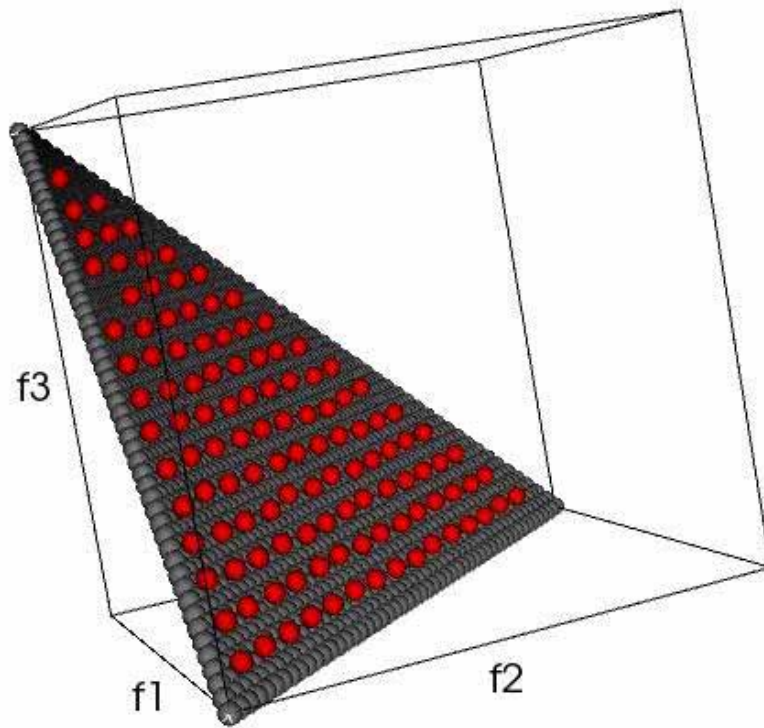
MOEA search process for a known test problem (DTLZ1)

A many-objective approach

- **Decision Variables (policy levers/infrastructure):**
  - Portfolios of seven supply options and four demand management options
  - Which schemes are activated? Their capacity?
- **Performance Objectives (7):**

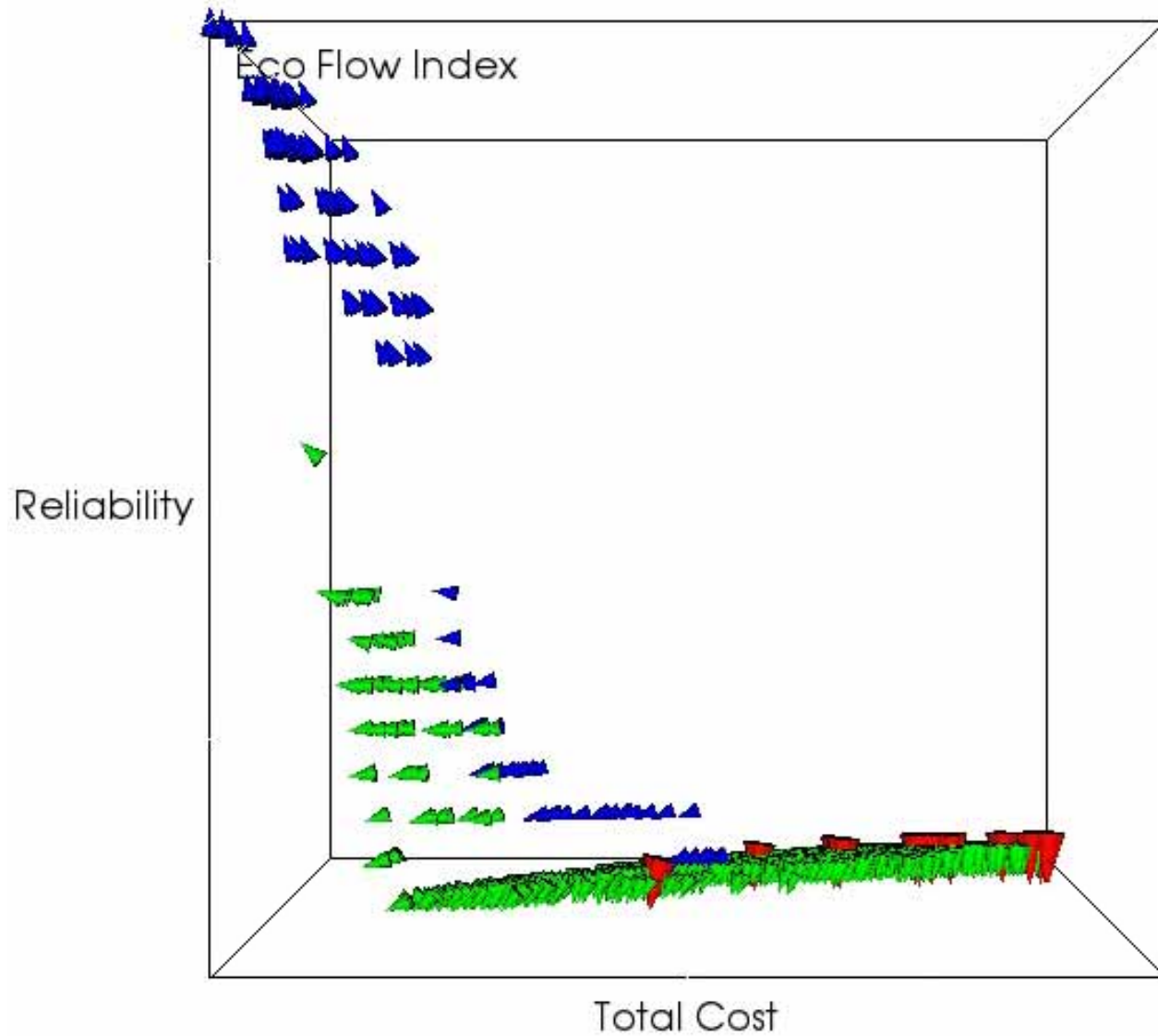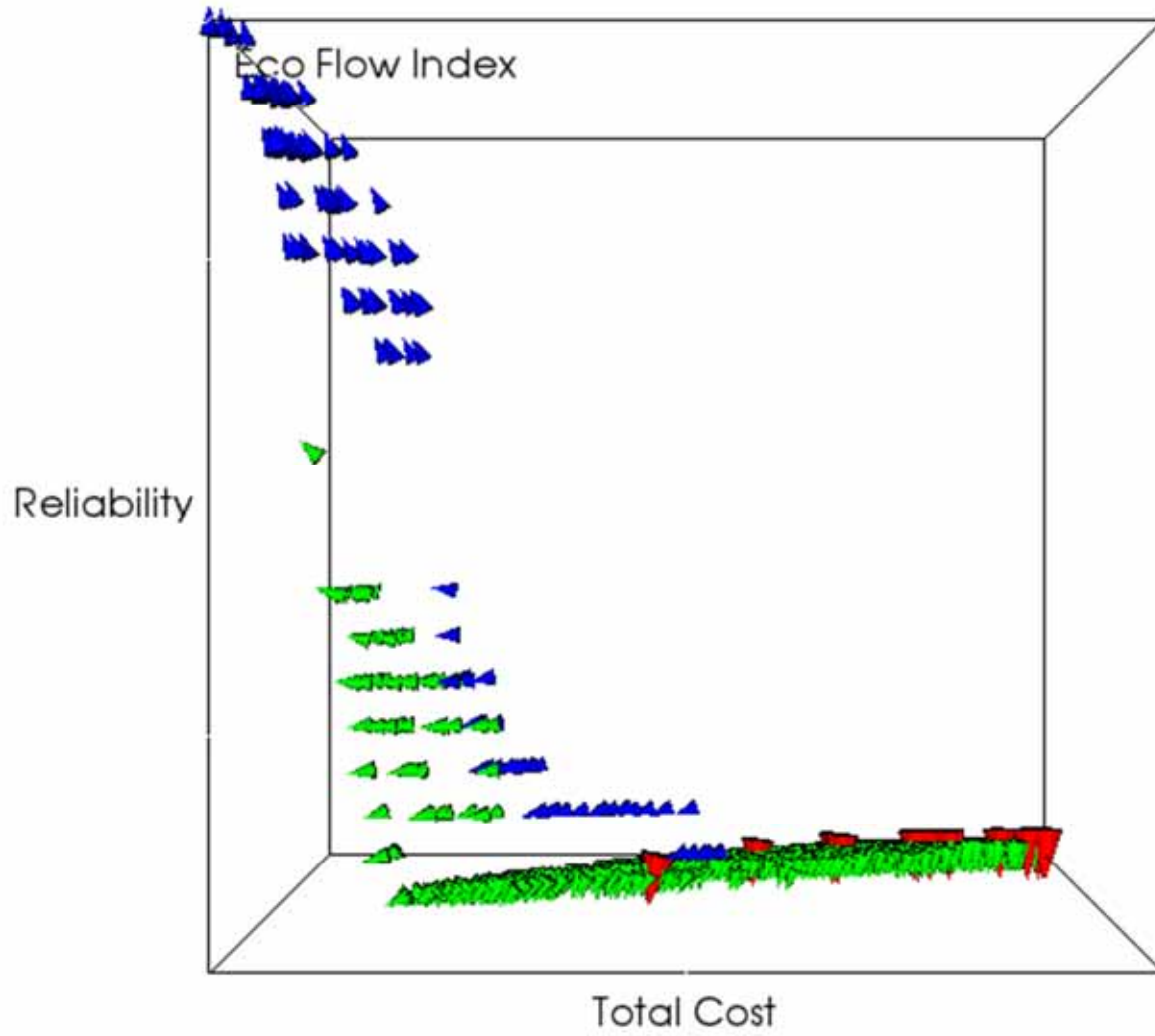|	
Min. Cost (Capital and Operating)	Investment
Min. Energy Use	
Max. Reliability (London)	Engineering Performance
Max. Storage Reliability	
Max. Storage Resilience	
Max. Minimum Storage Level	
Max. Shortage Index (Ecological Flow)	Environmental

- **Constraint: limit drought restriction frequency**
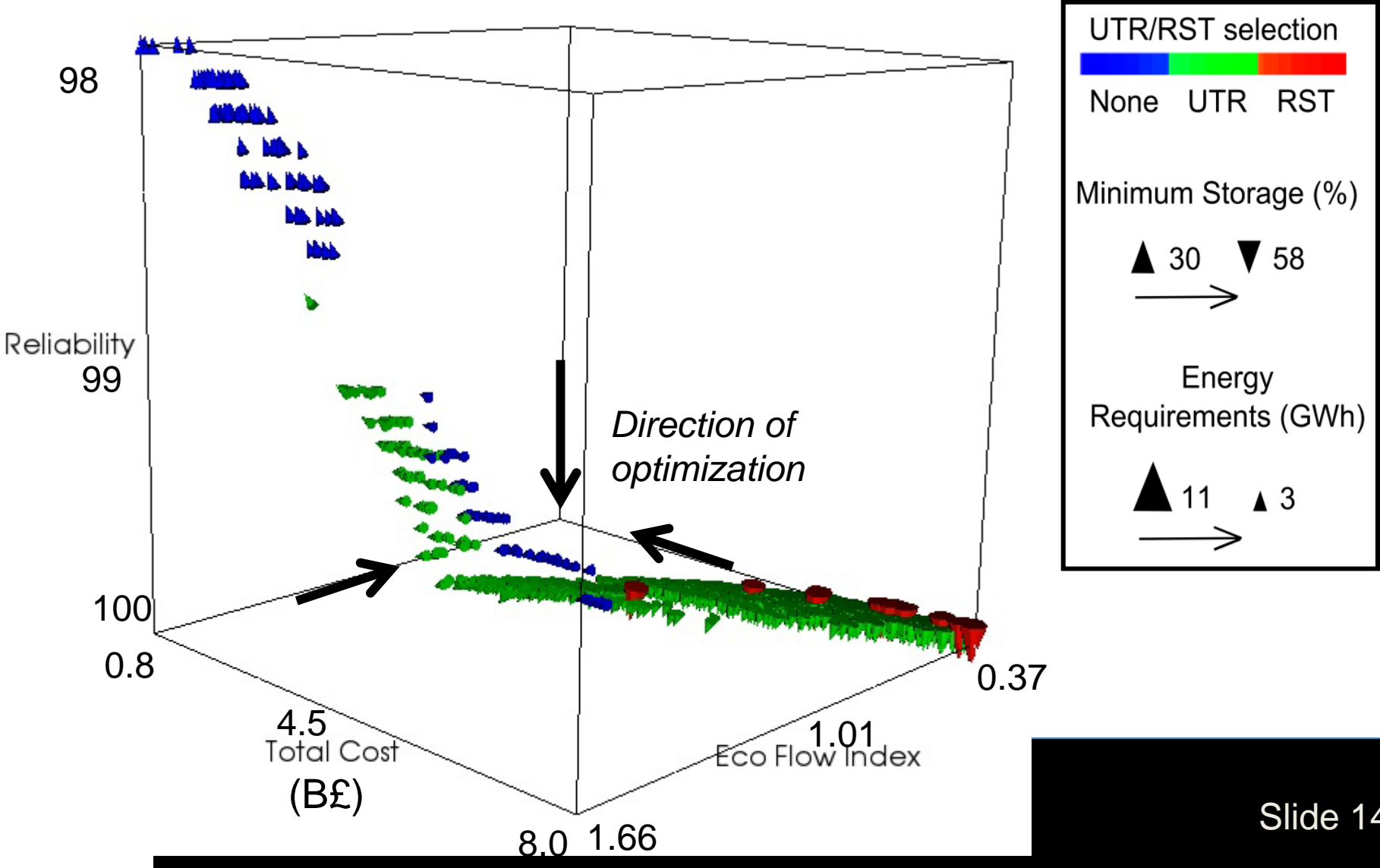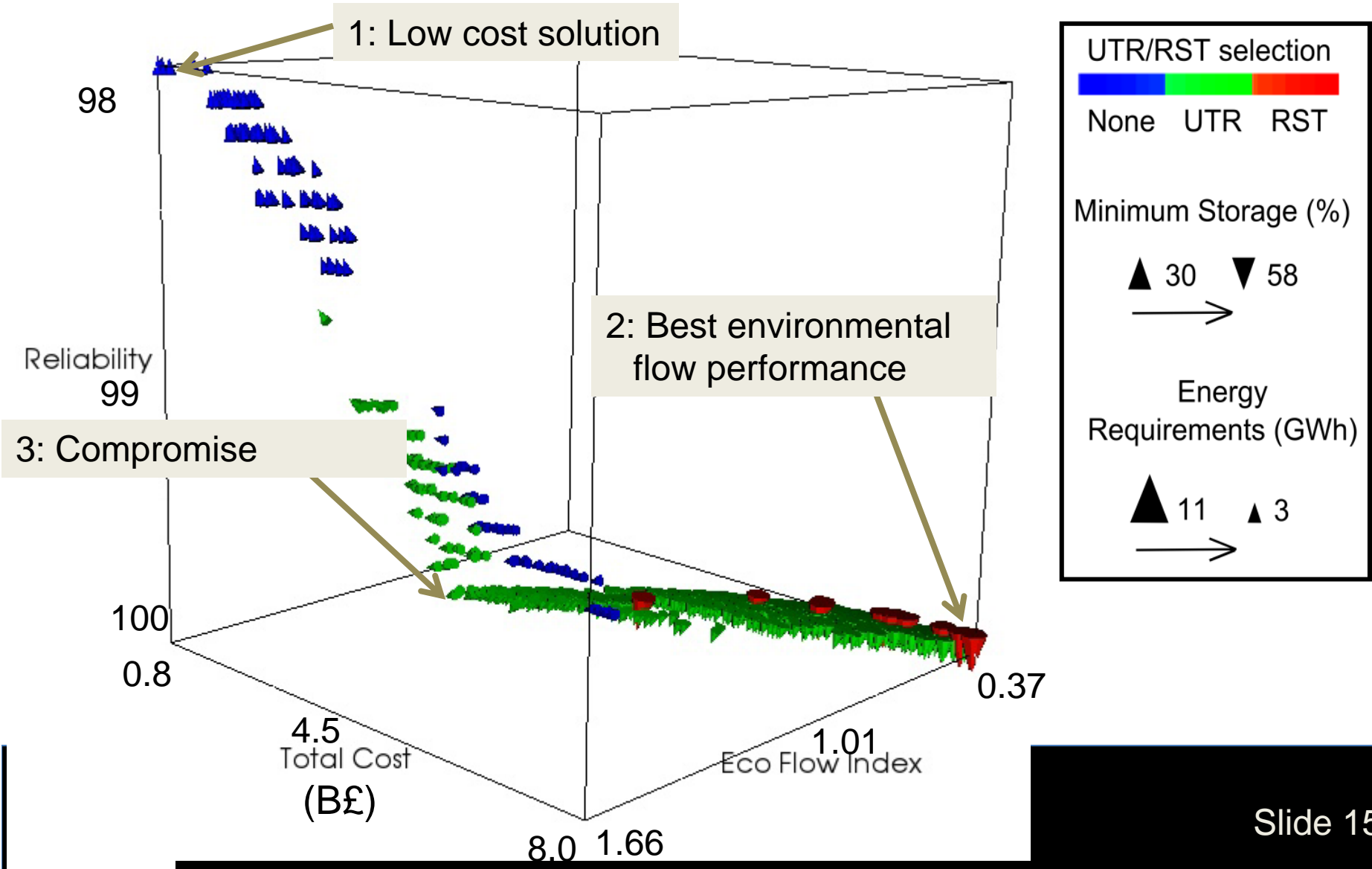
Eco Flow Index

Reliability

Total Cost
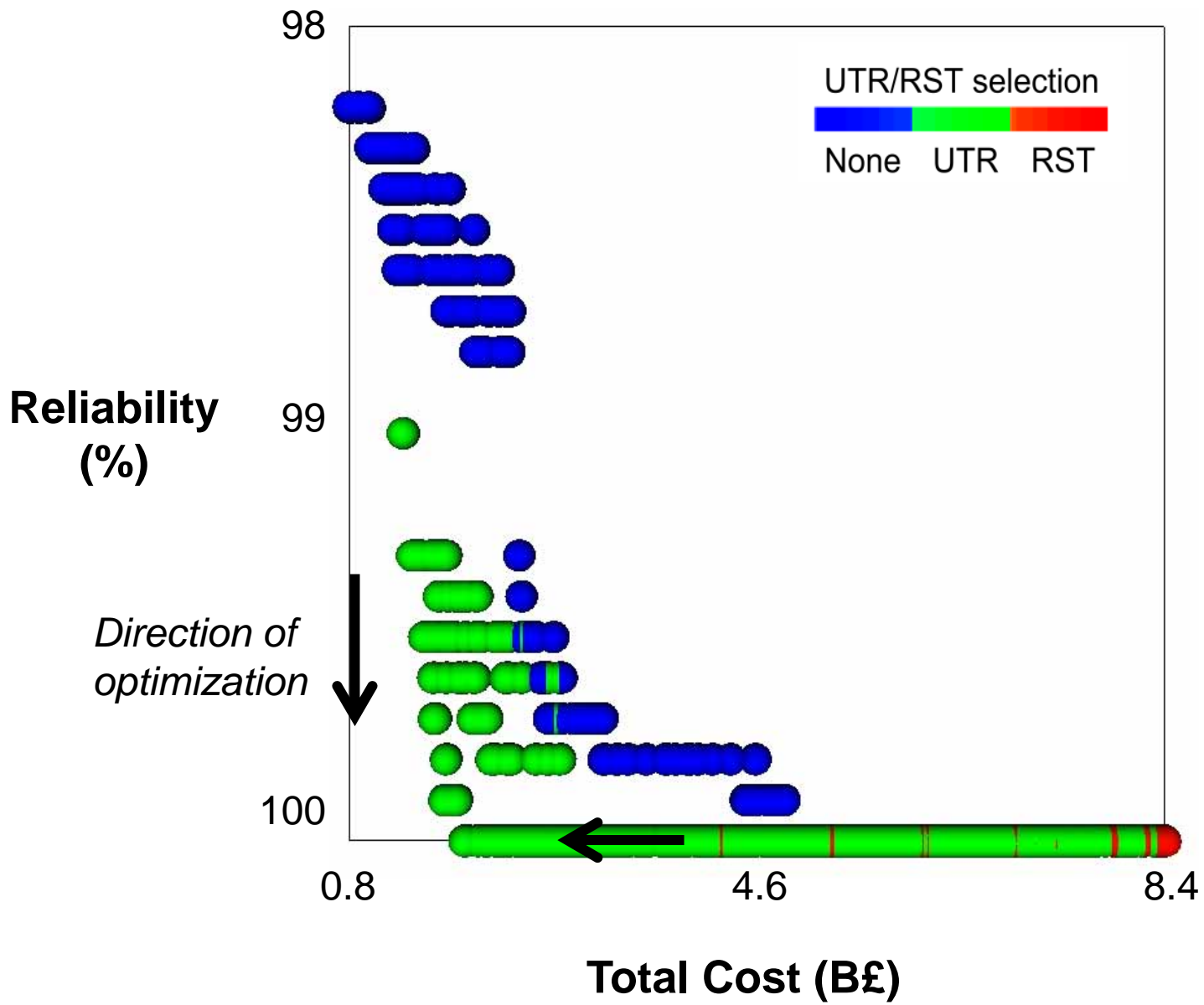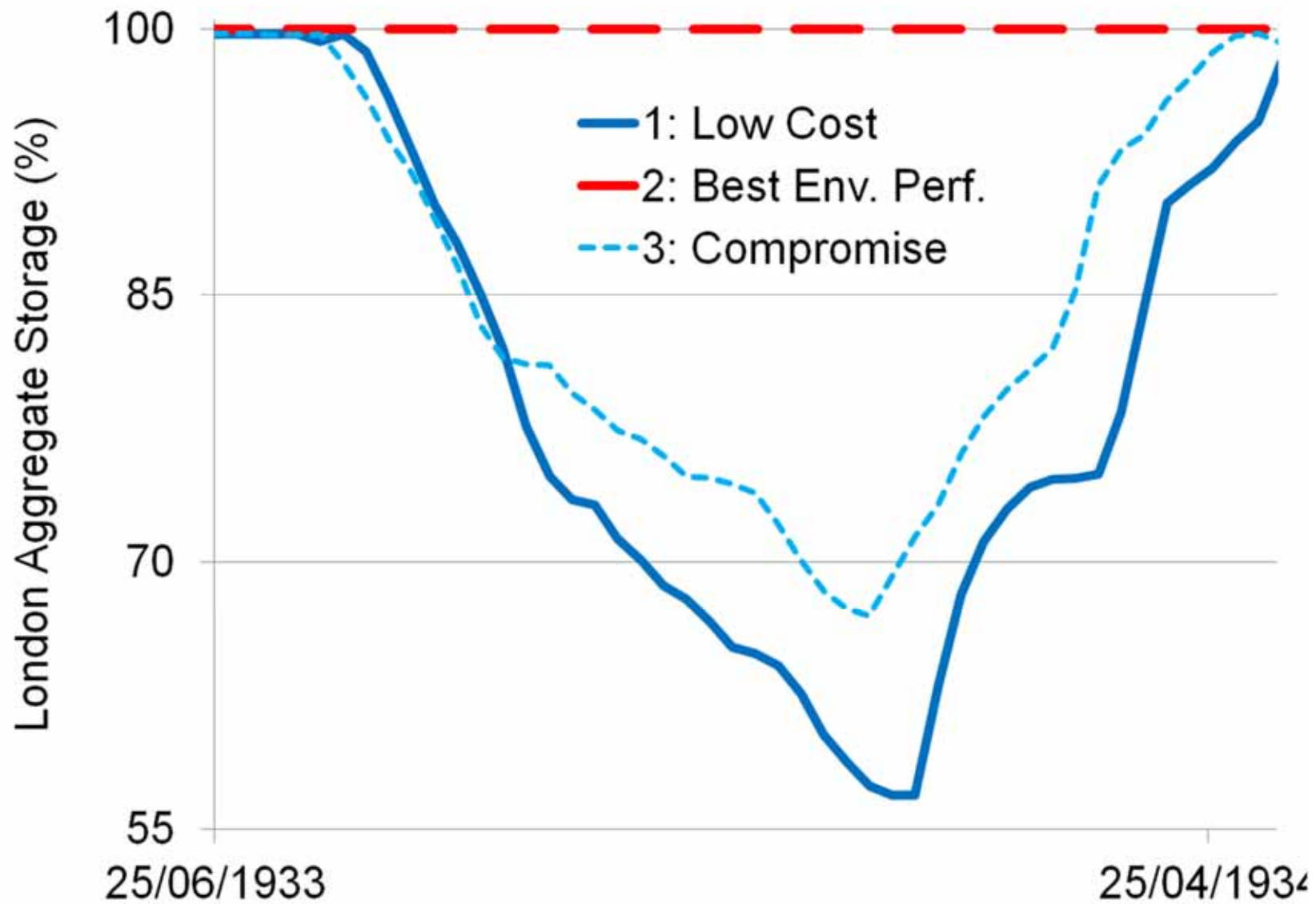
▲ Minimum Storage: -96.99000
▼ Minimum Storage: -99.80000
▲ Energy Req: 10729900.00000
′ Energy Req: 3362640.00000

Exploring tradeoffs in many objectives

Exploring tradeoffs in many objectives

1: Low cost solution

2: Best environmental flow performance

3: Compromise

98

Reliability
99

100

0.8

4.5

Total Cost
(B£)

8.0 1.66

1.01

Eco Flow Index

0.37

UTR/RST selection

None   UTR   RST

Minimum Storage (%)

▲ 30   ▼ 58

Energy
Requirements (GWh)

▲ 11   ▲ 3

Study 2: Risk-Based Thresholds for Water Marketing

If current supply < α, buy transfers to meet β:

- **Hypothetical city in Lower Rio Grande Valley, Texas**
- **Can city use transfers from agriculture to meet growing municipal needs?**
- **Monte Carlo simulation of water rights**

Ratio of Supply/Demand

Transfers

Current Supply

α = 1.5   β = 1.8
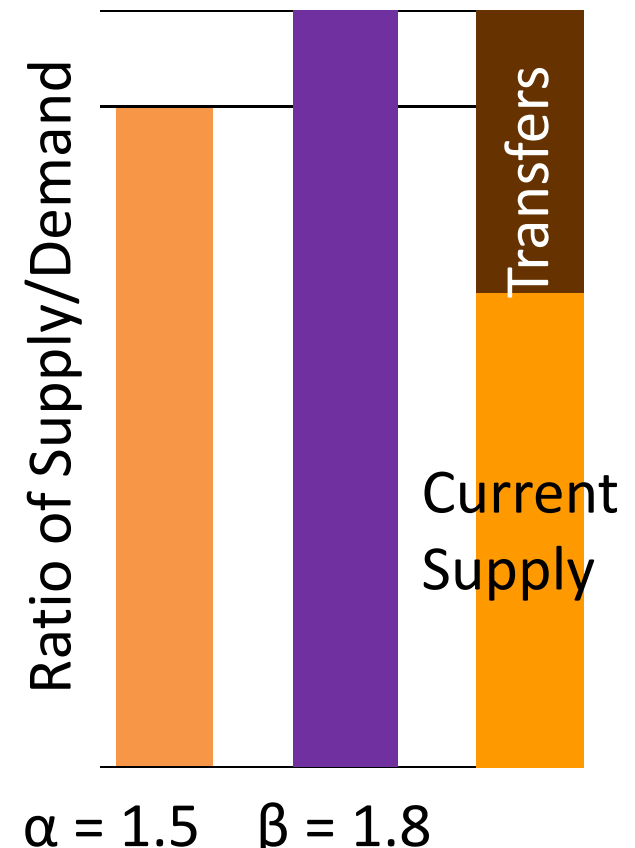
Results

- Visualize rights (color), leases (orientation), options (size)

- Two distinct groups of solutions:
  - rights-dominated (1)
  - market use (2)

- Over-reliance on traditional water supply raised costs and surplus water volumes!
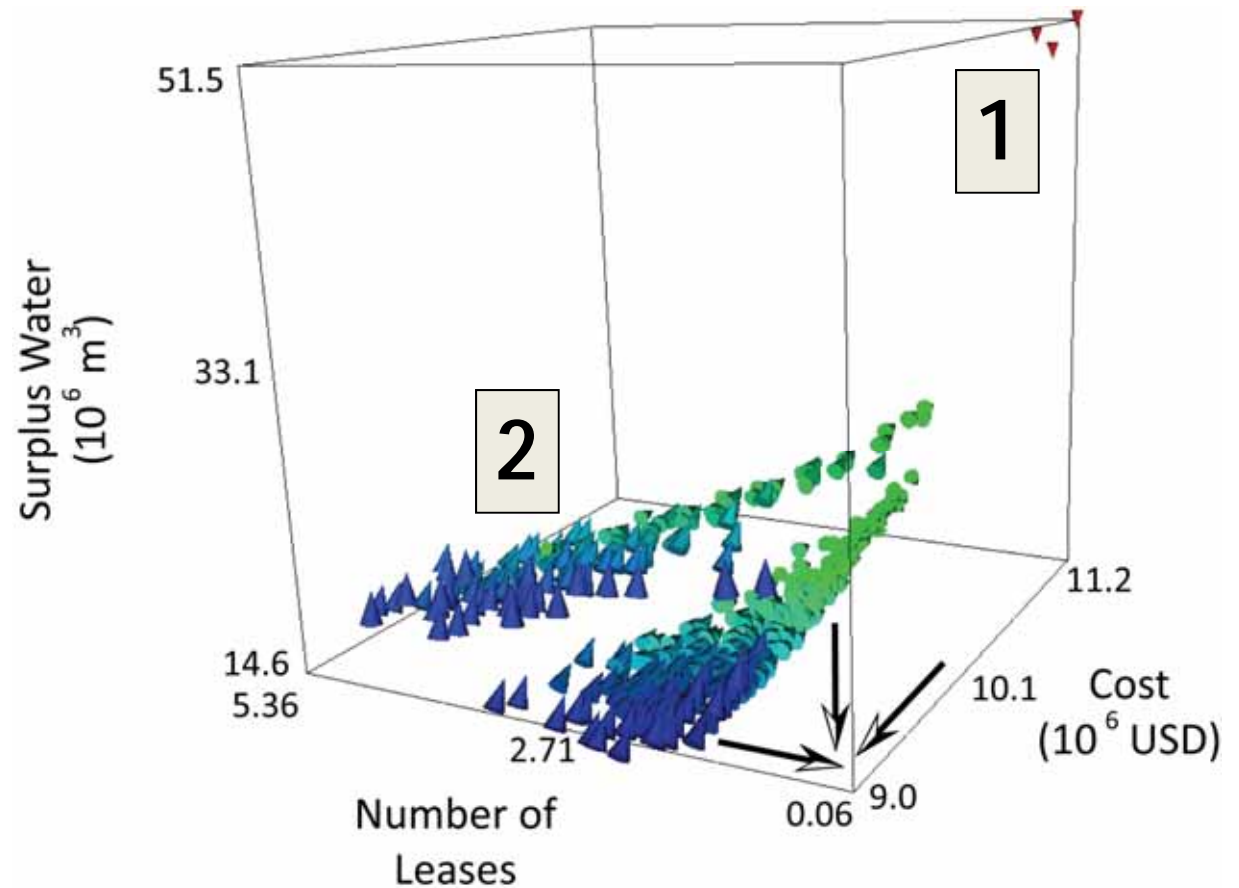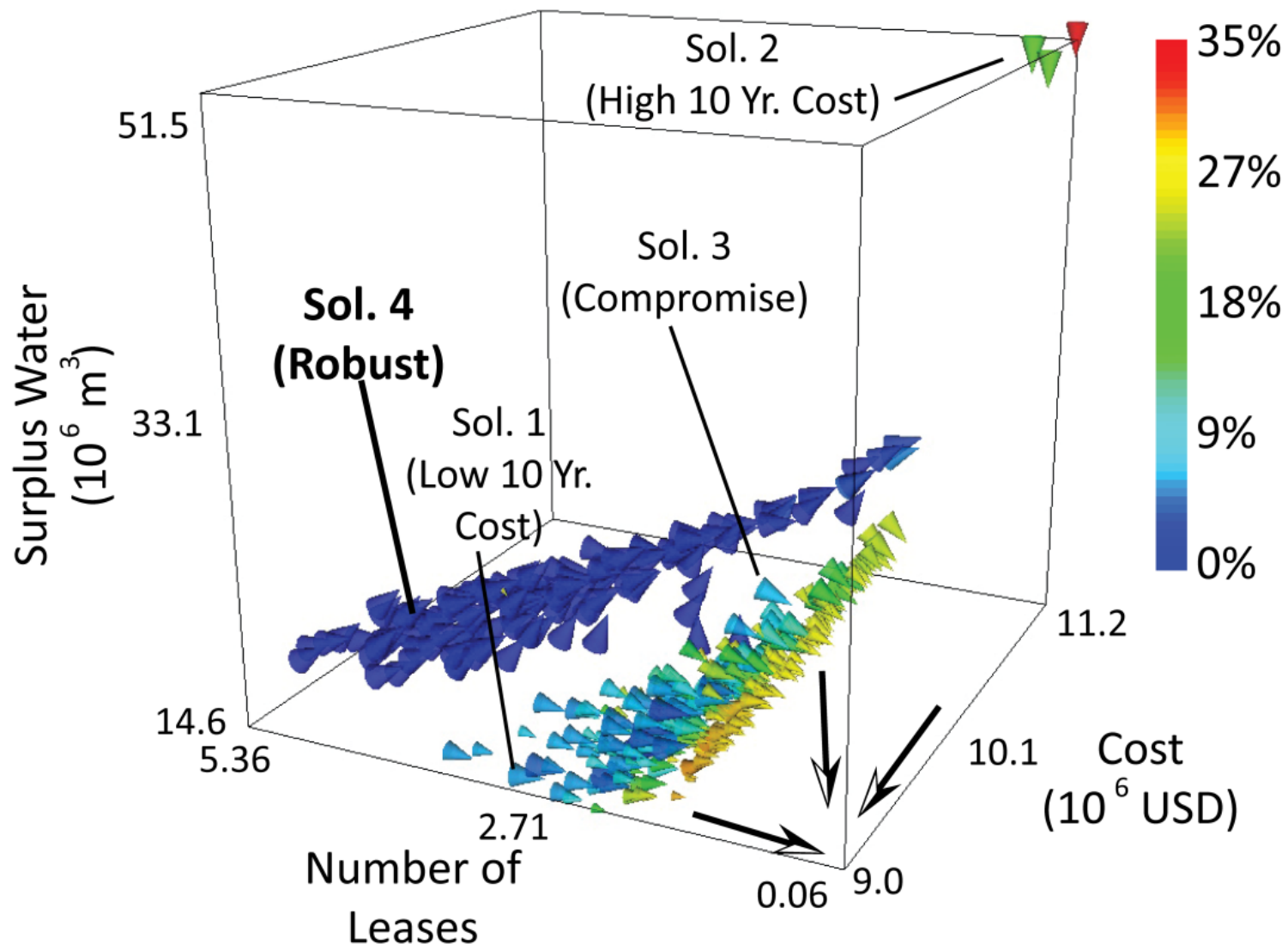
An approach to robustness

- **Traditional scenario analysis**
  - Make assumptions about important factors
  - Evaluate performance
- **Robust Decision Making**
  - Ensembles of plausible factors
- **Which tradeoff solutions have large deviations under the assumed scenarios?**

Color: Percent Deviation in **Critical Reliability**

Operating a single reservoir

Decision Maker Concern	Problem Formulation
How much to spill/release?	**Decision Variables:** Operating Strategy
How uncertain are flow projections? How do conditions upstream affect my decisions?	Running multiple data streams through RiverWare
How to balance downstream power needs with my own targets?	**Objectives:** Reliability of competing demands

Regional Planning

Decision Maker Concern	Problem Formulation
Does my water pricing accurately reflect my future financial responsibility?	**Decision Variables:** Pricing schemes; **Objectives:** Financial risk
What is the best adaptation strategy?	**Decision Variables:** Size/capacity/location of new infrastructure or plans
How resilient is my existing infrastructure?	**Objectives:** Reliability, resilience, vulnerability

Regulations

Decision Maker Concern	Problem Formulation
Are we doing enough to protect the environment and water quality?	**Objectives:** Env. Flow; **Constraints:** Limits flow target violations
What is effect of transboundary issues? Existing compacts?	**Simulation:** Adding uncertainty to deliveries; **Objectives:** Modeling different stakeholder concerns

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Thanks! Questions?

References

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