An Advanced Optimisation Based Approach for Wastewater Network Planning

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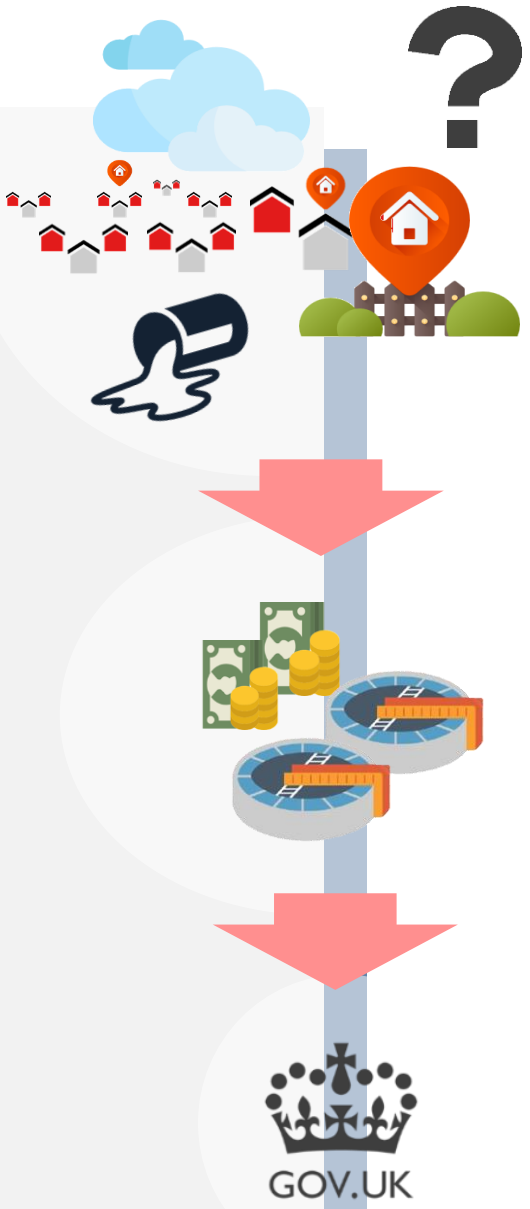
THE INTERNATIONAL ASSOCIATION FOR THE ENGINEERING MODELLING, ANALYSIS, AND SIMULATION COMMUNITY.

1. UK Water Industry Challenges
2. Advanced Optimisation Methodology
3. Example Results & Interactive Reporting
4. Outcomes & Benefits

CHALLENGE

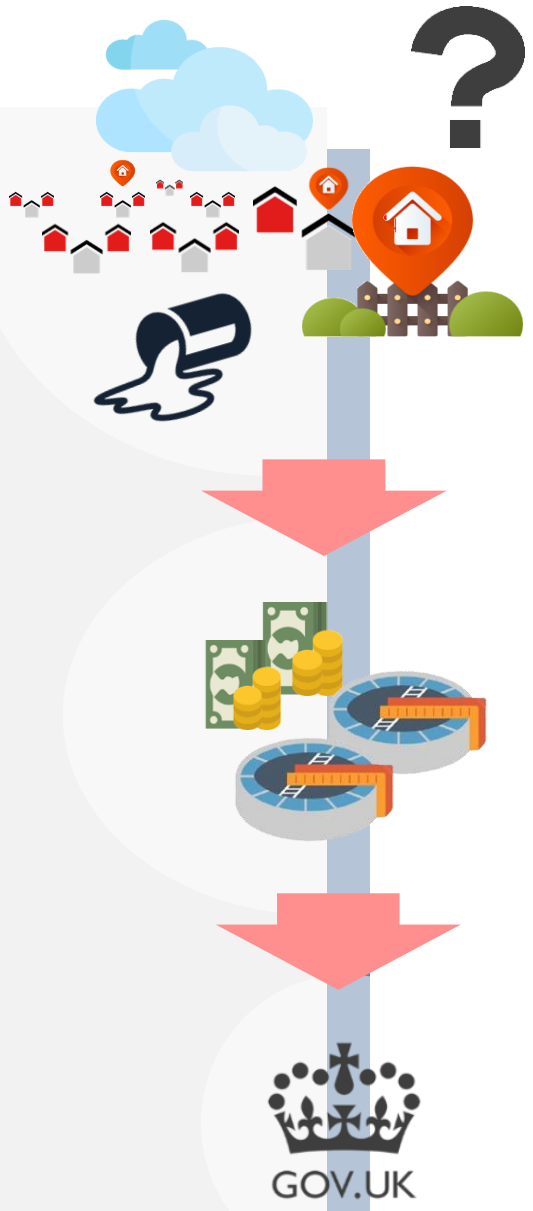
Industry Background

- **Step change in demands** placed on wastewater networks necessitates **efficient investment** in **upgrades**
  - CSO spills reduced to 10/yr
  - Maintain flood risk & wks capacity in face of climate change
- Insufficient **modelling resource** available
- Manual approaches offer limited confidence



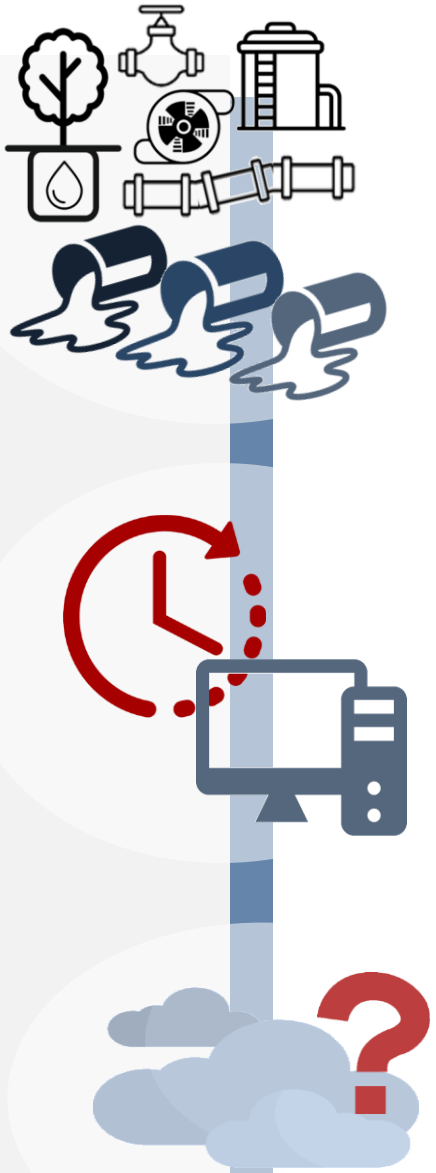
Study Objectives

- Inform **“Price Review”** 5yr business plan
- Create holistic network solutions to meet all performance needs:
  - Ensure treatment works compliance
  - Minimise flood risk across the catchment
  - CSO spills reduced to 10/yr
- Using network upgrades:
  - Pipe upsizes
  - Pump upgrades
  - Storage tanks
  - Groundwater infiltration removal
  - Runoff area disconnection via Sustainable Drainage Solutions (SuDS).
- Analysis based on 1D hydraulic models



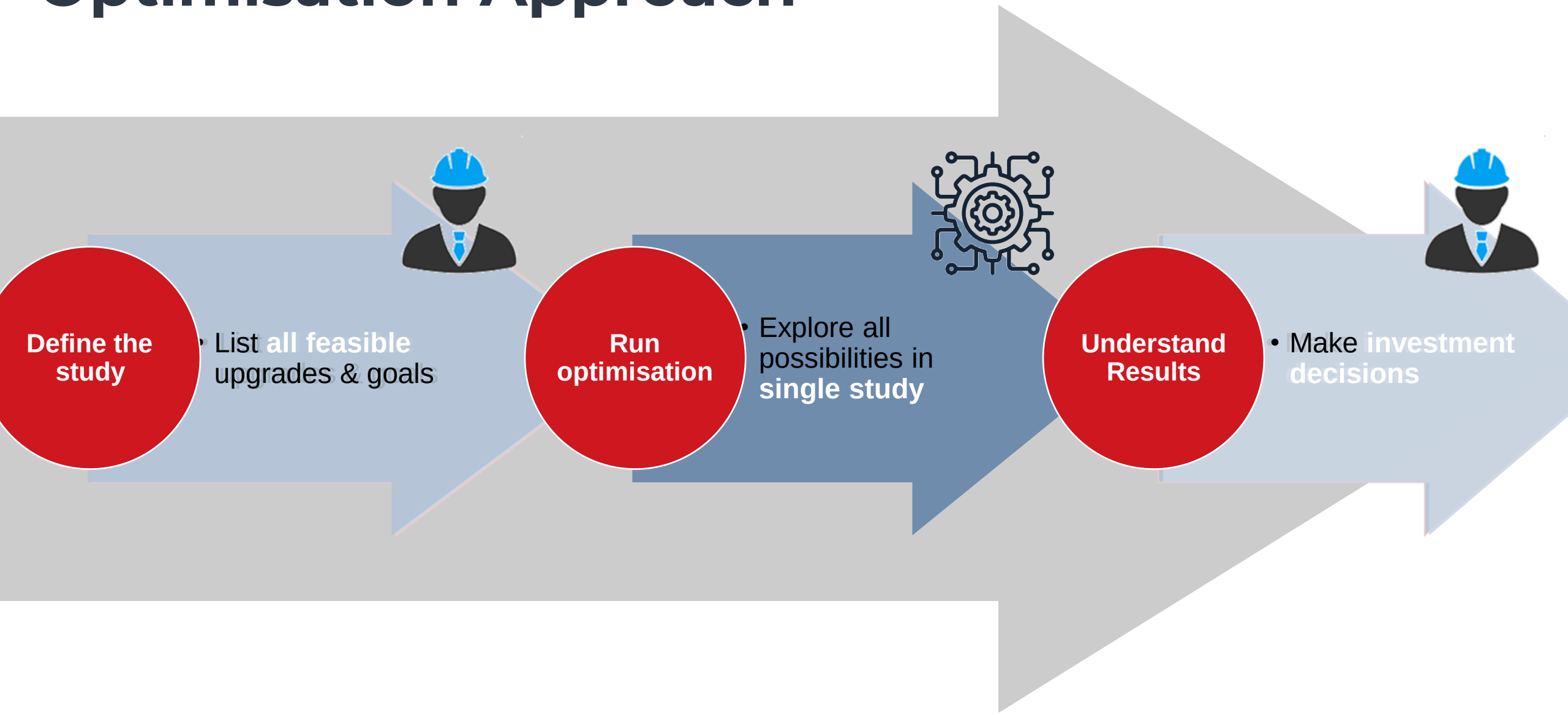
Technical Challenges

- High **dimensionality**
  - 10,000s individual upgrades possible
  - 10,000s individual flood risk points
  - Up to 100 CSOs per catchment
- Long simulation **runtimes**
  - 1 to 10 years of simulation used for CSO spill count
- **High uncertainty** in solution requirements
  - Changing regulatory requirements
  - Unknown boundary conditions



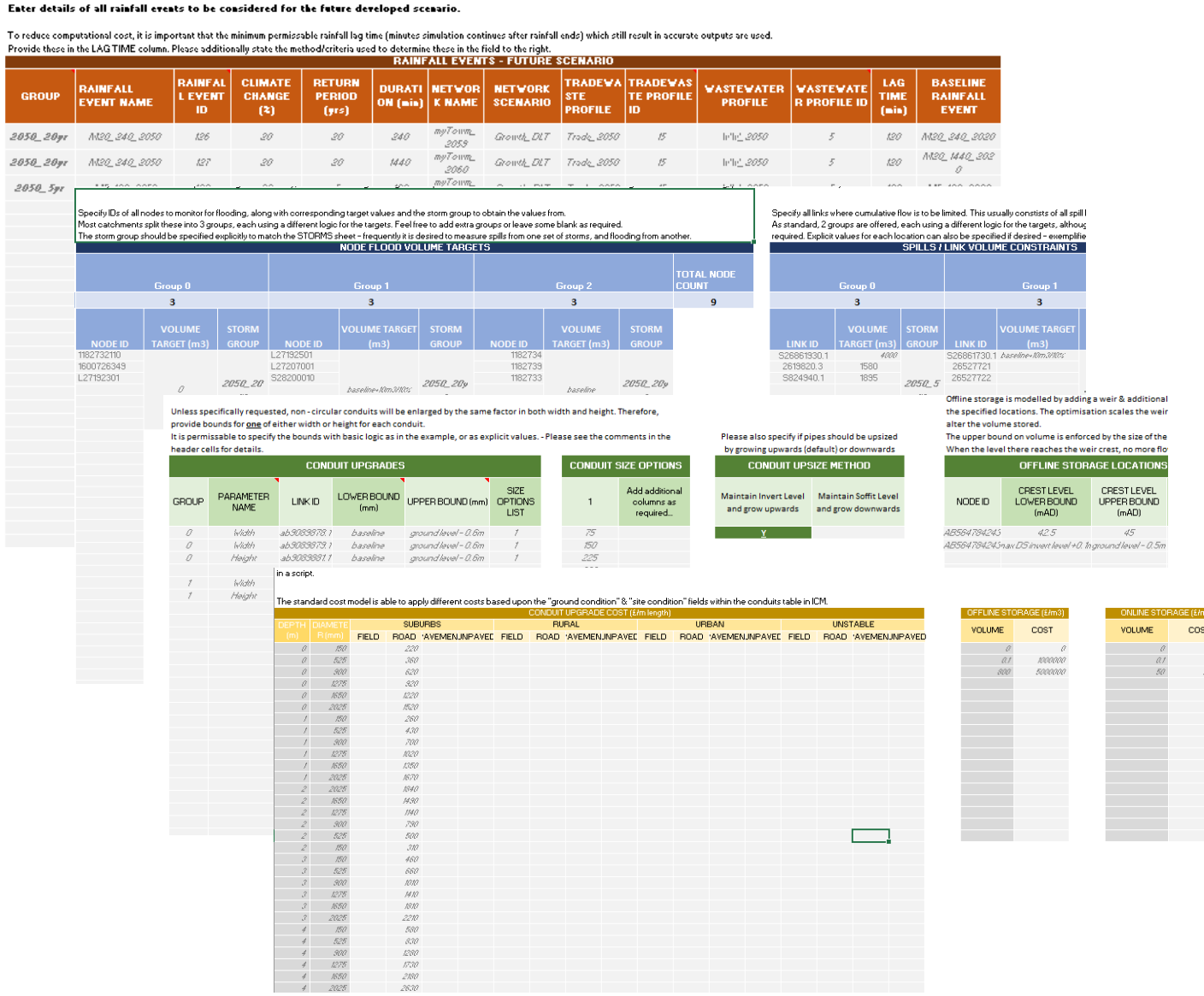
METHODOLOGY

Optimisation Approach



Define The Problem

- Optimisation **proforma** completed by water company or consultant
- Captures domain knowledge in **robust, auditable** way



Enter details of all rainfall events to be considered for the future developed scenario.

To reduce computational cost, it is important that the minimum permissable rainfall lag time (minutes simulation continues after rainfall ends) which still result in accurate outputs are used.
Provide these in the LAG TIME column. Please additionally state the method/criteria used to determine these in the field to the right.

RAINFALL EVENTS - FUTURE SCENARIO

GROUP	RAINFALL EVENT NAME	RAINFALL EVENT ID	CLIMATE CHANGE (%)	RETURN PERIOD (yrs)	DURATION (min)	NETWORK NAME	NETWORK SCENARIO	TRADEWASTE PROFILE	TRADEWASTE PROFILE ID	WASTEWATER PROFILE	WASTEWATER PROFILE ID	LAG TIME (min)	BASELINE RAINFALL EVENT
2050_20yr	M30_240_2050	126	20	30	240	myTown_2059	Growth_DLT	Trade_2050	15	InfIn_2050	5	120	M30_240_2020
2050_20yr	M30_240_2050	127	20	30	1440	myTown_2060	Growth_DLT	Trade_2050	15	InfIn_2050	5	120	M30_1440_2020
2050_5yr						myTown_							

Specify IDs of all nodes to monitor for flooding, along with corresponding target values and the storm group to obtain the values from.
Most catchments split these into 3 groups, each using a different logic for the targets. Feel free to add extra groups or leave some blank as required.
The storm group should be specified explicitly to match the STORMS sheet - frequently it is desired to measure spills from one set of storms, and flooding from another.

NODE FLOOD VOLUME TARGETS

Group 0			Group 1			Group 2			TOTAL NODE COUNT
3			3			3			9
NODE ID	VOLUME TARGET (m3)	STORM GROUP	NODE ID	VOLUME TARGET (m3)	STORM GROUP	NODE ID	VOLUME TARGET (m3)	STORM GROUP	
1182732110			L27192501			1182734			
1600726349			L27207001			1182739			
L27192301			S28200010			1182733			
0		2050_20	baseline+10m3/l0s:		2050_20y	baseline		2050_20y	

Specify all links where cumulative flow is to be limited. This usually constists of all spill l
As standard, 2 groups are offered, each using a different logic for the targets, althou
required. Explicit values for each location can also be specified if desired - exemplifie

SPILLS / LINK VOLUME CONSTRAINTS

Group 0			Group 1	
3			3	
LINK ID	VOLUME TARGET (m3)	STORM GROUP	LINK ID	VOLUME TARGET (m3)
S26861930.1	4000		S26861730.1	baseline+10m3/l0s:
2619820.3	1580		26527721	
S824340.1	1835	2050_5	26527722	

Unless specifically requested, non-circular conduits will be enlarged by the same factor in both width and height. Therefore, provide bounds for **one** of either width or height for each conduit.
It is permissable to specify the bounds with basic logic as in the example, or as explicit values. - Please see the comments in the header cells for details.

CONDUIT UPGRADES

GROUP	PARAMETER NAME	LINK ID	LOWER BOUND (mm)	UPPER BOUND (mm)	SIZE OPTIONS LIST
0	Width	ab50836878.1	baseline	ground level - 0.6m	1
0	Width	ab50836879.1	baseline	ground level - 0.6m	1
0	Height	ab50836881.1	baseline	ground level - 0.6m	1
1	Width				
1	Height				

CONDUIT SIZE OPTIONS

1	Add additional columns as required...
75	
150	
225	

Please also specify if pipes should be upsized by growing upwards (default) or downwards

CONDUIT UPSIZE METHOD

Maintain Invert Level and grow upwards	Maintain Soffit Level and grow downwards
Y	

Offline storage is modelled by adding a weir & additional
the specified locations. The optimisation scales the weir
alter the volume stored.
The upper bound on volume is enforced by the size of the
When the level there reaches the weir crest, no more flo

OFFLINE STORAGE LOCATIONS

NODE ID	CREST LEVEL LOWER BOUND (mAD)	CREST LEVEL UPPER BOUND (mAD)
AB564784243	42.5	45
AB564784243nav.DS invert level +0.1m ground level - 0.5m		

in a script.

The standard cost model is able to apply different costs based upon the "ground condition" & "site condition" fields within the conduits table in ICM.

CONDUIT UPGRADE COST (£/m length)

DEPTH (m)	DIAMETER (mm)	SUBURBS				RURAL				URBAN				UNSTABLE			
		FIELD	ROAD	AVEMEN	JNPAVED	FIELD	ROAD	AVEMEN	JNPAVED	FIELD	ROAD	AVEMEN	JNPAVED	FIELD	ROAD	AVEMEN	JNPAVED
0	150		220														
0	525		360														
0	900		620														
0	1275		920														
0	1650		1220														
0	2025		1520														
1	150		260														
1	525		430														
1	900		700														
1	1275		1020														
1	1650		1350														
1	2025		1670														
2	2025		1840														
2	1650		1490														
2	1275		1140														
2	900		790														
2	525		500														
2	150		310														
3	150		460														
3	525		660														
3	900		1010														
3	1275		1410														
3	1650		1810														
3	2025		2210														
4	150		580														
4	525		830														
4	900		1280														
4	1275		1730														
4	1650		2190														
4	2025		2630														

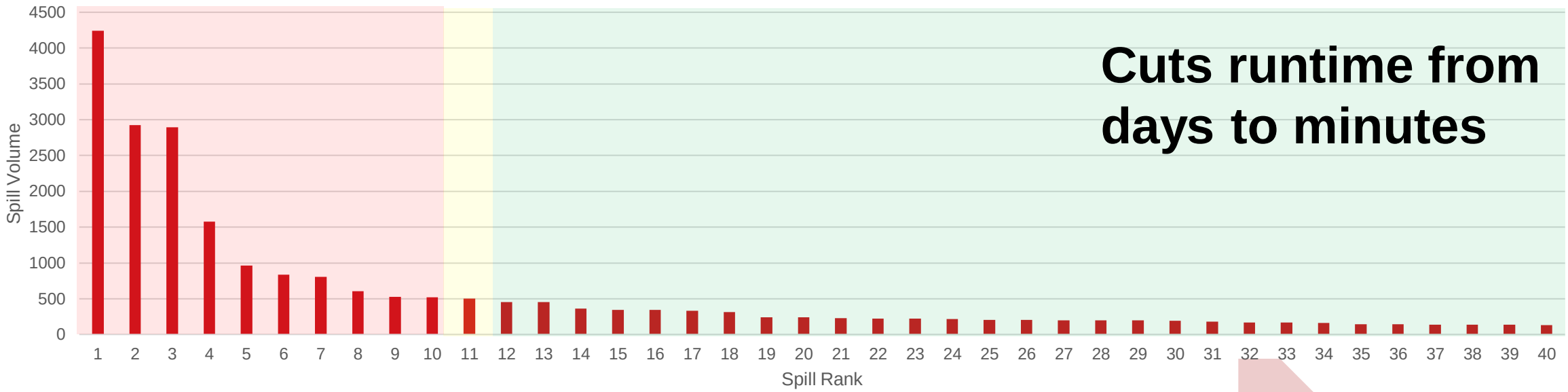
OFFLINE STORAGE (£/m3)

VOLUME	COST
0	0
0.1	10000000
800	50000000

ONLINE STORAGE (£/m

VOLUME	COS
0	
0.1	
30	

Determine Extract Events



Cuts runtime from days to minutes

Rank spills from full period

- Find 11th ranked spill

Excel VBA Tool

- Minimise deviation from 11th spill across all CSOs

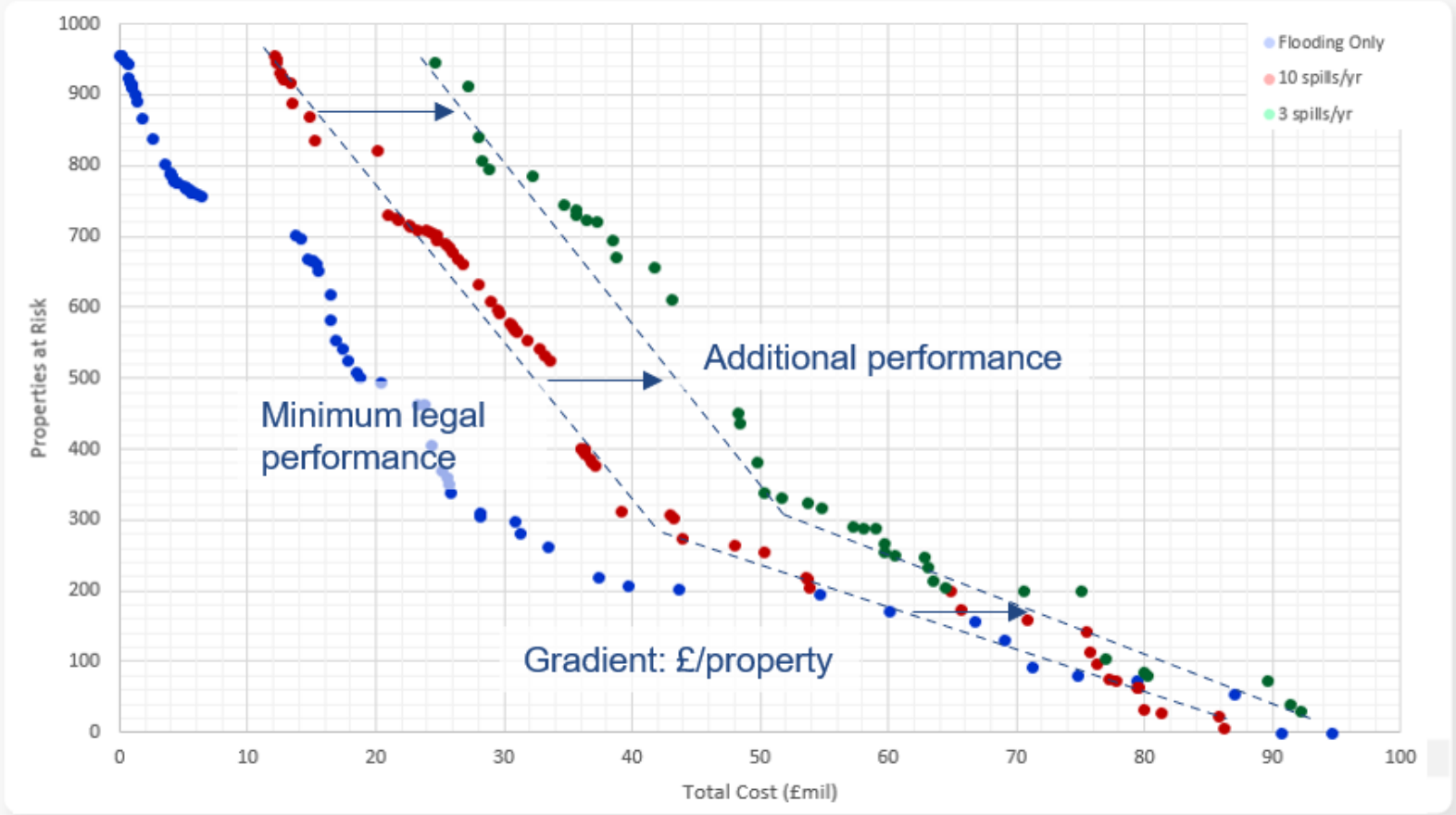
Validate on “Bookend” runs

Run Optimisation

- **Multi-objective** optimization
  - *Minimise Cost*
  - *Minimise Flood detriment*
  - *Minimise FFT (dry-day wks inflow)*
- Additional **constraints**
  - *Max cost & flooding bounds*
  - *10 spills/yr at each location*
  - *Storm tank utilisation*
- **Advanced** algorithm
  - **Essential** due to long simulation times
  - Avoids **wasted capital outlay**

EXAMPLE RESULTS

Cost Vs Properties at Risk Scatter Graph



Info
Help
C M P
Cost v Perf
Des Map
Heat Map
Cost Cont
Perf Cont
Des Table

X Axis Zoom Slider

0

Y Axis Zoom Slider

Selector

Highlight :

PR Pareto Only

True

ID

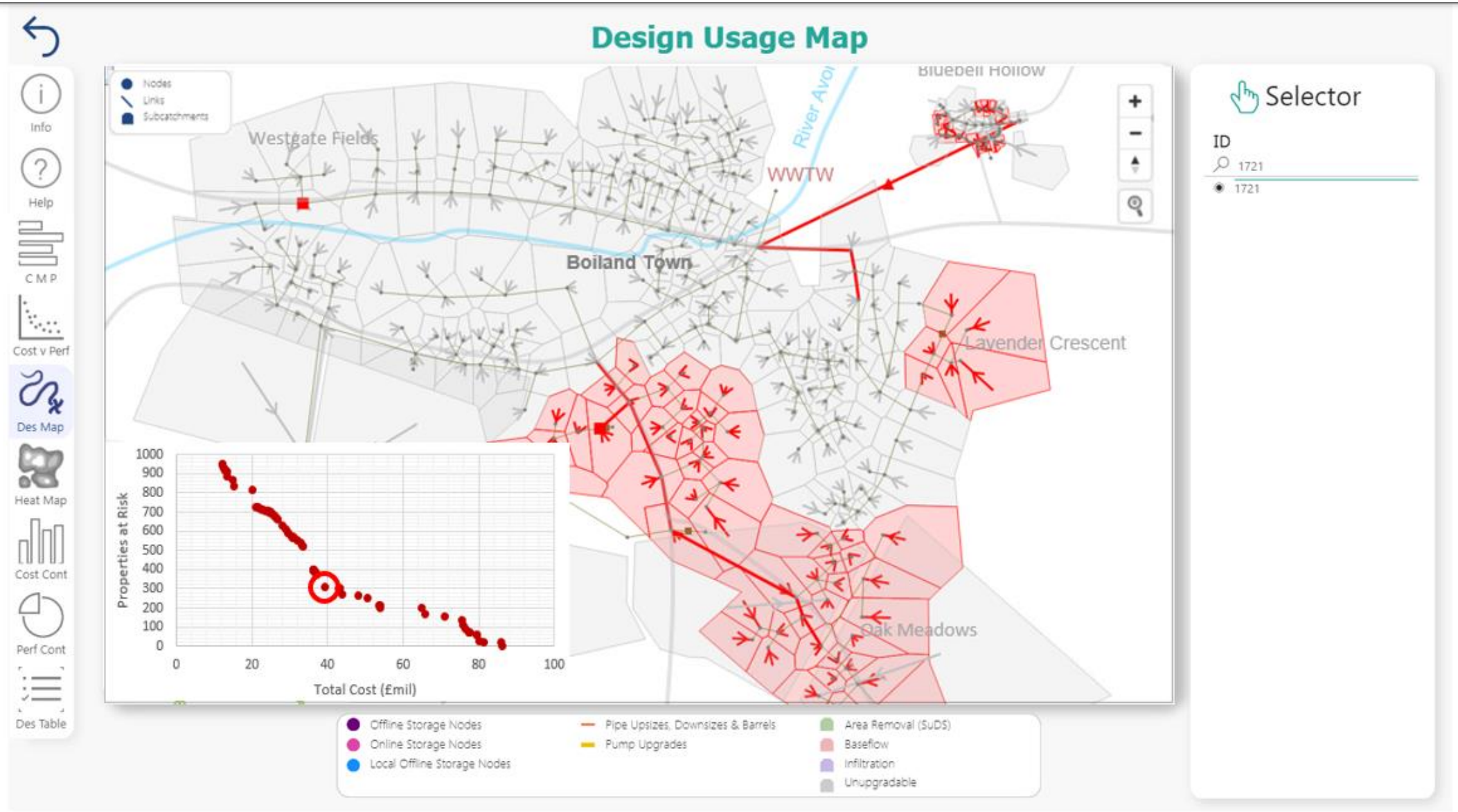
All

Background :

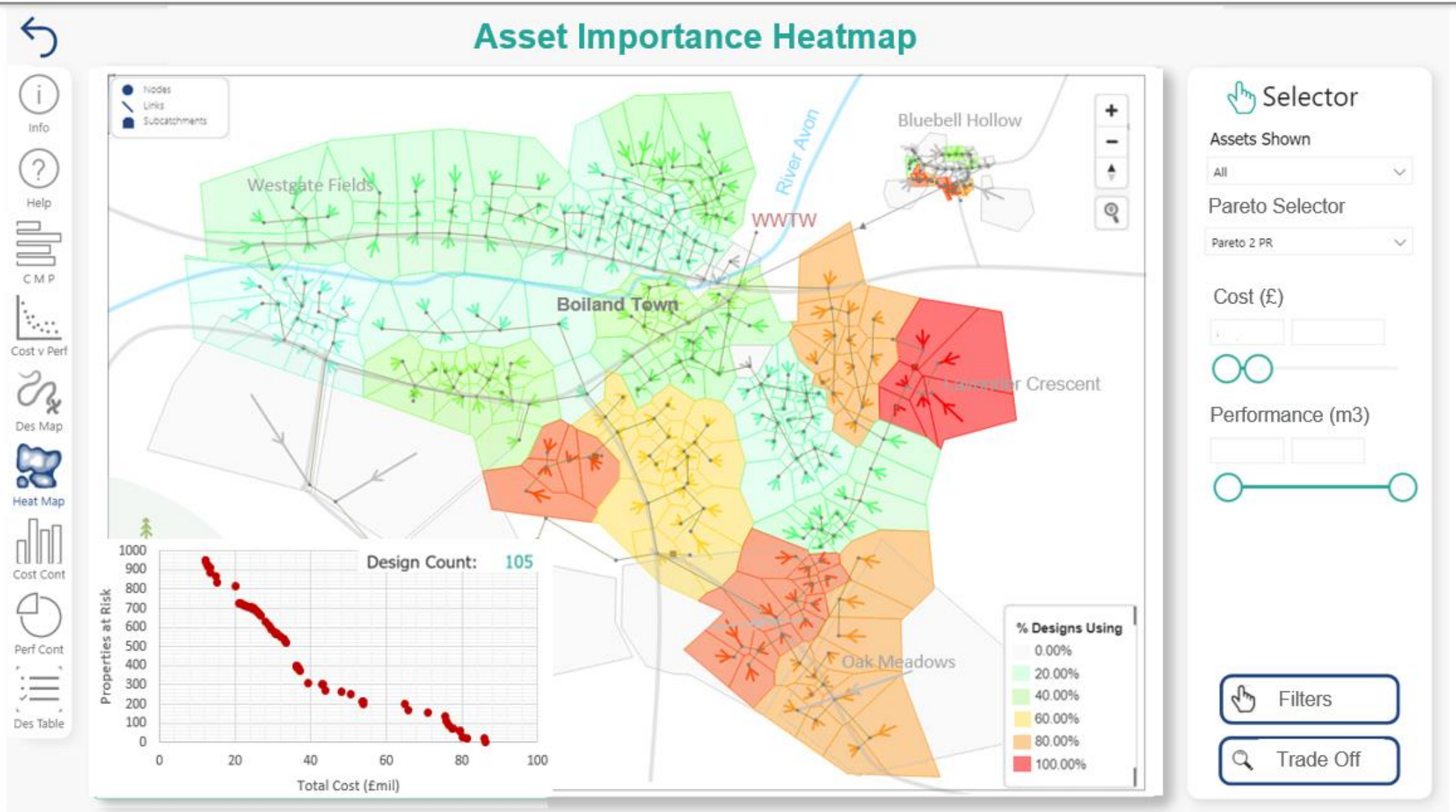
PR Pareto Only Background

True

Asset Filter


Design Usage Map
Info
Help
C M P
Cost v Perf
Des Map
Heat Map
Cost Cont
Perf Cont
Des Table
Nodes
Links
Subcatchments
Westgate Fields
River Avon
Bluebell Hollow
WWTW
Boiland Town
Lavender Crescent
Oak Meadows
Properties at Risk
Total Cost (£mil)
Selector
ID
1721
1721
Offline Storage Nodes
Online Storage Nodes
Local Offline Storage Nodes
Pipe Upsizes, Downsizes & Barrels
Pump Upgrades
Area Removal (SuDS)
Baseflow
Infiltration
Unupgradable

Asset Importance Heatmap




Cost Vs Properties at Risk Scatter Graph
Close Asset Filters
Info
Help
C v M
C v P
C C C
P C C
A H M
Properties at Risk
Total Cost (£mil)
0
100
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
Asset Filter 1
Asset - Area Removal Scaling (Attribute (gro...
Asset Filter 2
Asset - Conduit Scaling (Attribute (groups)) ...
Asset Filter 3
Output - Storm Flood (Attribute (groups)) + ...
Asset Filter 4
All
Asset Filter 5
All
Asset Filter 6
All
Asset Filter 7
All
Asset Filter 8
All
X Axis Zoom Slider
Y Axis Zoom Slider
Volume View
Volume Detail

OUTCOMES

Benefits

- **Confidence** in optimal solution
  - **No further “what ifs”**
  - **Holistic,** detailed solutions – **Lower risk**
  - **Fair** consideration of innovative, **sustainable** options
- Workflow & Dataset forms a **company asset**
  - Provides **head-start** for detailed design
  - Supports **region-wide** investment decisions
  - Enables **collaborative planning**
- Greater level of solution possible
- Speed

Transferable Concepts

- **Pro-forma** document for auditable problem definition
- **Proxy metrics** combined with **back-check** of optimal results.
- Application of multi-objective optimisation to **high-dimensional** problem.
- **Heatmaps** averaging over optimal designs
- Filtering datasets **after optimization run**