Spring 6-12-2014

Modeling and Optimization Workshop

Vito Primavera
EnginSoft

Key partner in Design Process Innovation

modeFRONTIER

Getting to know the investigated phenomena and manage them according to its own wishes

WBTR, 12/06/2014

Ing. Vito Primavera, EnginSoft SpA

Workshop Goal

modeFRONTIER

Getting to know the investigated phenomena and Manage them according to its own wishes

… but what does it mean?

- Realize the behaviour of the physical phenomena behind our applications
- Assess which are the truly important parameters affecting our phenomenon
- Plan experimental campaigns and/or build up accurate numerical models able to enwrap the driving forces embedded into the phenomenon
- Perform multi-disciplinary and multi-objective optimization at the aim to get the best performances
- Make clear our final decisions with respect ourselves and others
- Maximize efficiency and effectiveness of whole technical & decisional process

Workshop Agenda

modeFRONTIER

Getting to know the investigated phenomena and Manage them according to its own wishes

Overview & Applications

- modeFRONTIER Intro
- History Cases & Theoretical Backgrounds
  1. Exploring Design Alternatives for DG5 Schemes Assisted by modeFRONTIER
  2. Using modeFRONTIER to calibrate slow soil runoff and wetting parameters for area drainage models in InfoWorks CS
  3. Multi-Objective Optimization of a Complex Water Distribution Network)
- Questions & Answers

ENGIN SOFT

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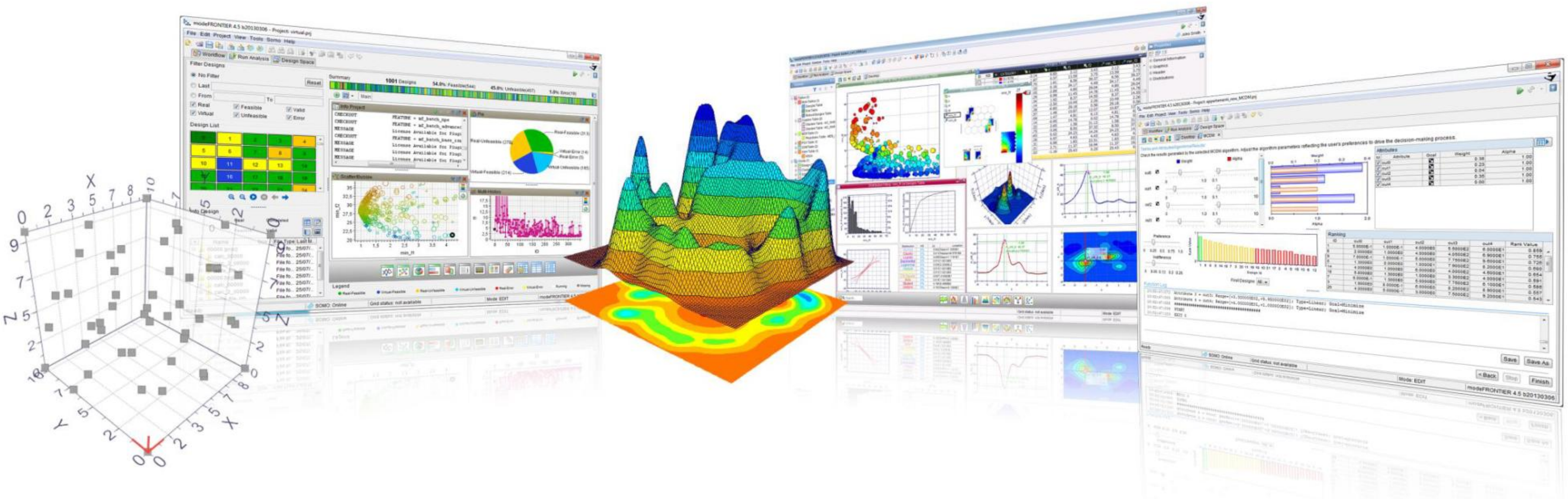
Multi-Objective Optimization and Design Environment

modeFRONTIER



modeFRONTIER is an integration platform for multi-objective and multi-disciplinary optimization. It provides a seamless coupling with third party engineering tools, enables the automation of the design simulation process, allow to perform advanced data mining, and facilitates analytic decision making

modeFRONTIER Assessing

Based on an **innovative idea**

1995-1998 EU Project "*Open System for Collaborative Design Optimization Using Pareto* **Frontier***s*"

1999-2002: ES.TEC.O. and **modeFRONTIER v1.0 Multi-Objective Design Environment** came to life

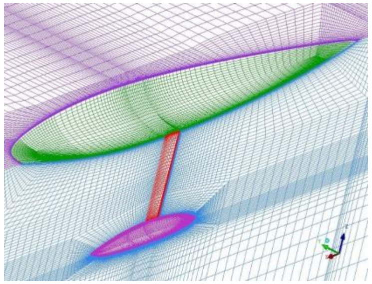
Formula 1
Ferrari (Italy)

OUTCOME:

Truly Multi-Objective Optimization, together with **Process Integration,** goes out of the mathematics guru's lab and - thanks to **some radical innovations** - is applied to **any, real-world, engineering design area**

Strollers
GRACO (US)

America's Cup Class
Yacht Bulb



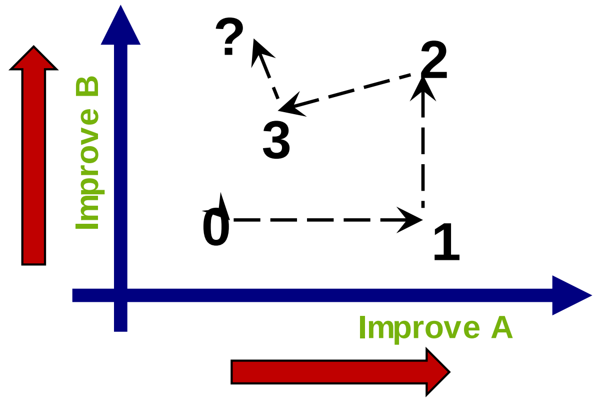
The “philosophy” behind modeFRONTIER: optimization

”traditional” way:

Set-up of a design process | TRIAL | Error | TRIAL | Error | TRIAL …

Design 0 1 2 3 …

time



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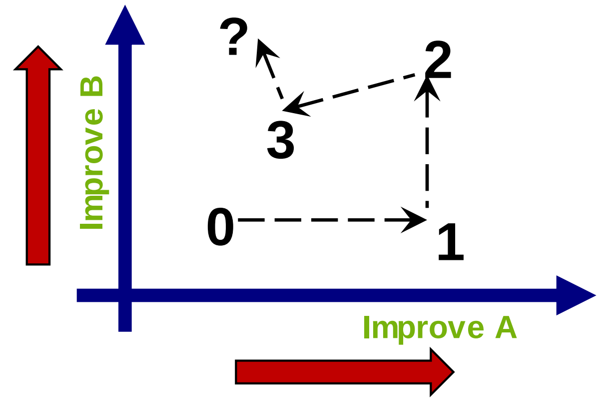
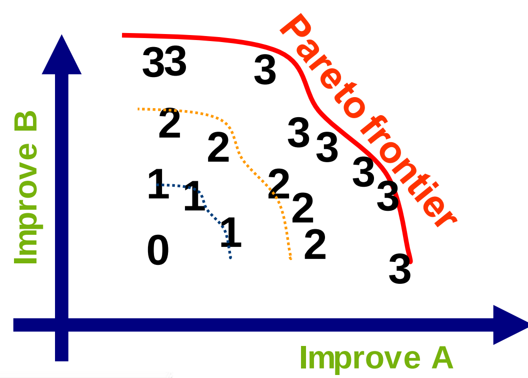


The modeFRONTIER way :

Workflow Set-up | TRIAL Error TRIAL Error TRIAL Error | Decision Making Tools

0 1 2 3…

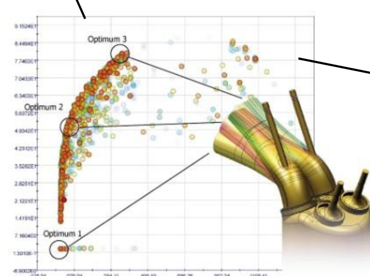


= Sooner, better, more"robust" design

modeFRONTIER

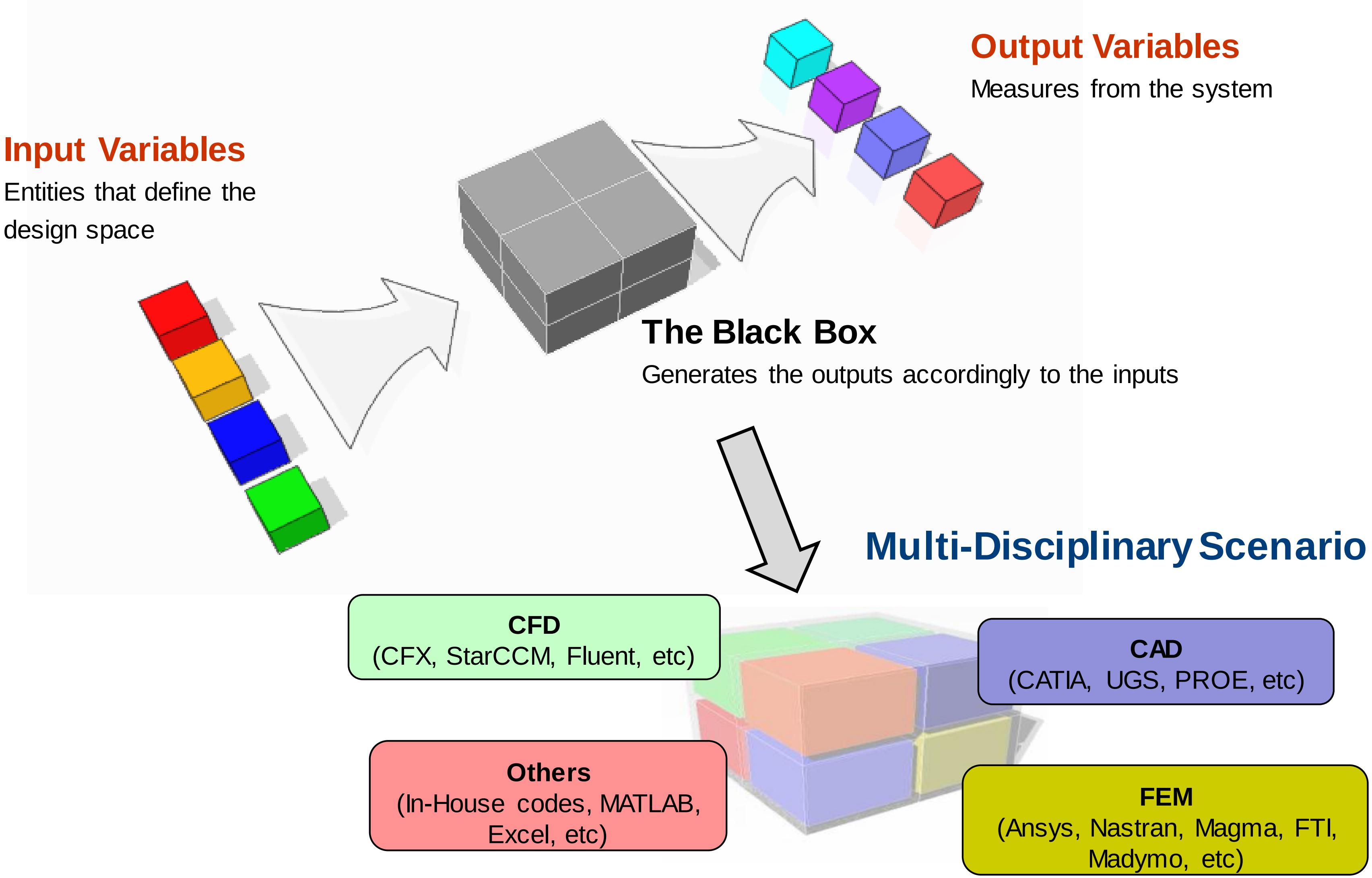
automated process integration (data flow) +

smart looking for better performances (logic flow)

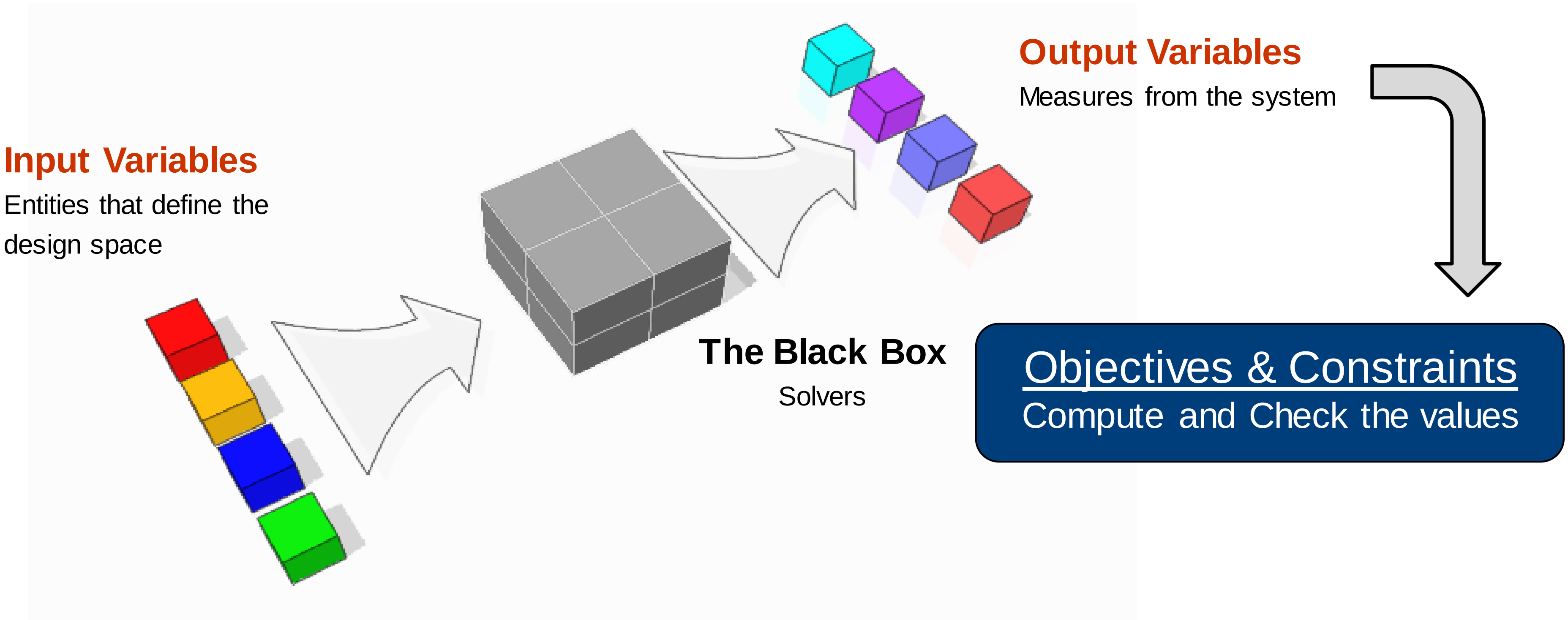


… and with effective pictures of "what-if"
➔ scenarios analysis

Process Integration: automated data flow

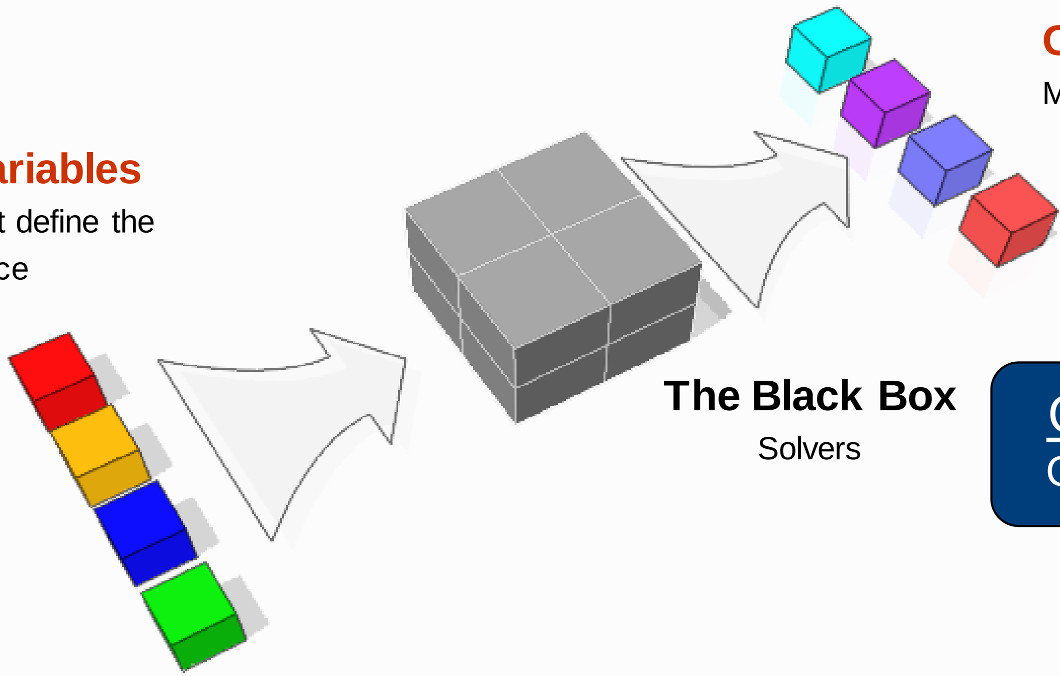


Smart Search & Evaluation of Solutions: logic flow – "brain"



Smart Search & Evaluation of Solutions: logic flow – “brain”

Input Variables
Entities that define the design space



The Black Box
Solvers

Output Variables
Measures from the system

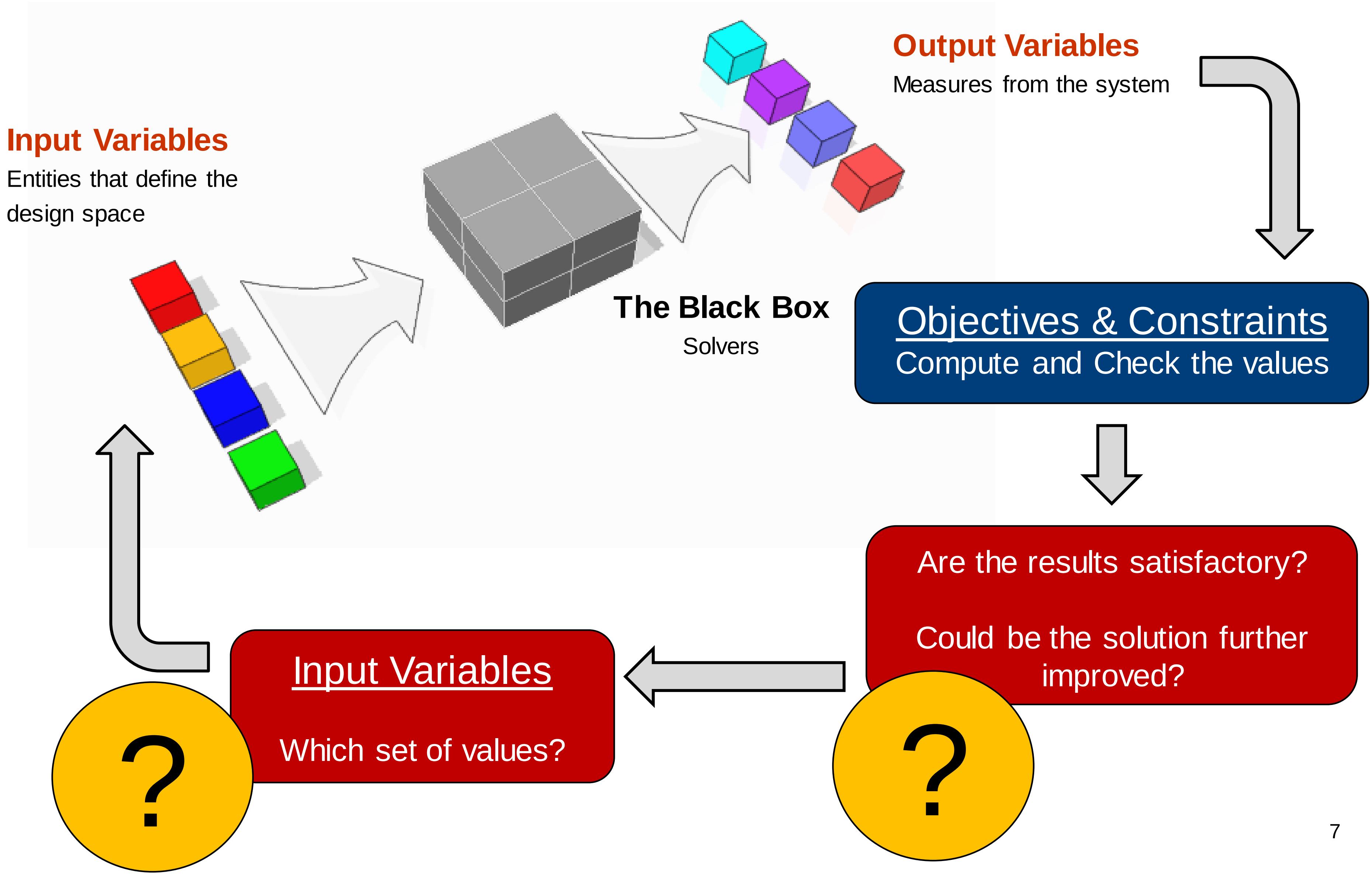
Objectives & Constraints
Compute and Check the values

Are the results satisfactory?

Could be the solution further improved?

?

Smart Search & Evaluation of Solutions: logic flow – “brain”



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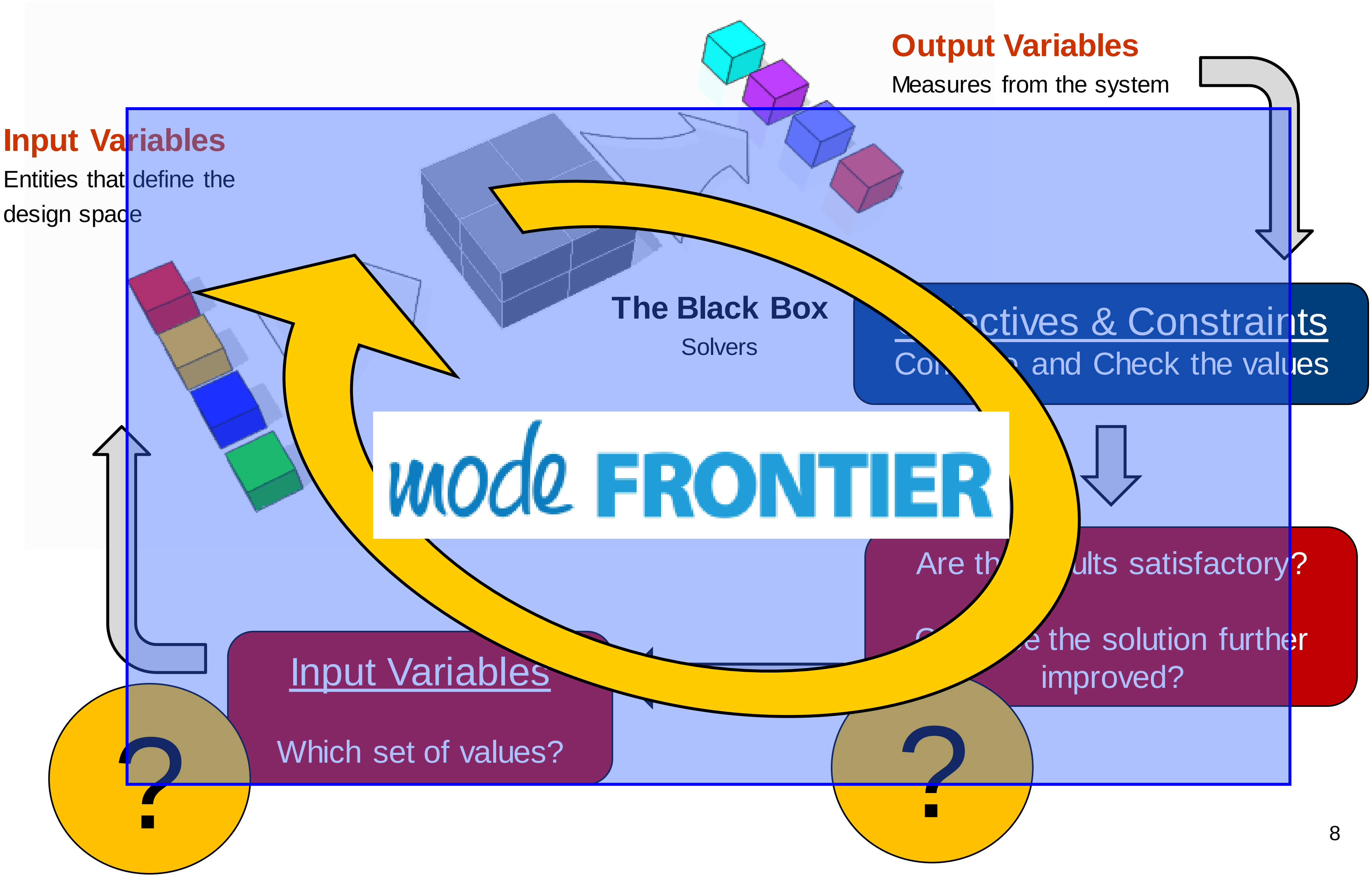
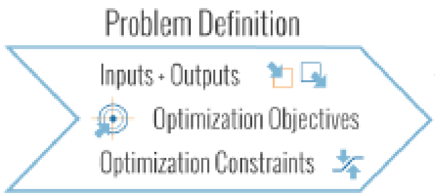


How modeFRONTIER is helping you

1. Process integration and clear definition of the problem ➔ workflow



How modeFRONTIER is helping you

1. Process integration and clear definition of the problem ➔ workflow
2. Numerical Optimization Algorithms (coupled with DOE) + RSM techniques (meta-modeling) help the designer to explore completely new solutions/refine in the most fast way the already good ones

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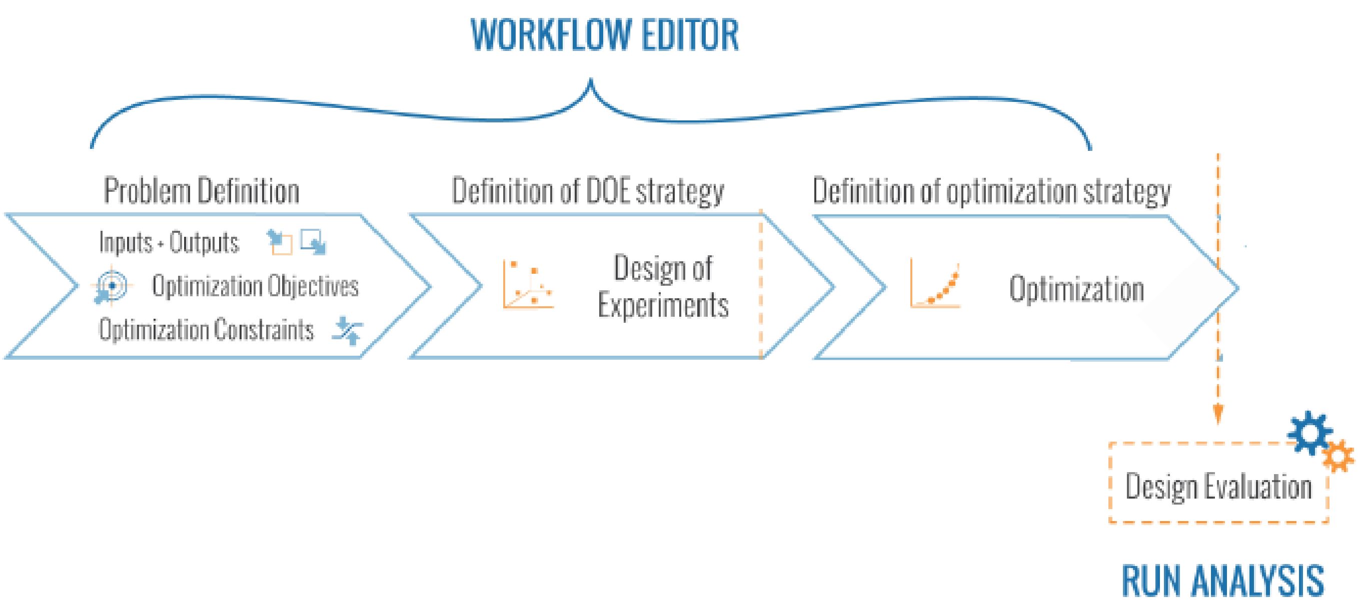
1. Process integration and clear definition of the problem ➔ workflow
2. Numerical Optimization Algorithms (coupled with DOE) + RSM techniques (meta-modeling) help the designer to explore completely new solutions/refine in the most fast way the already good ones
3. Complete automation of the loop ➔ 100% Hardware/Software resources exploiting



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1. Process integration and clear definition of the problem ➔ workflow
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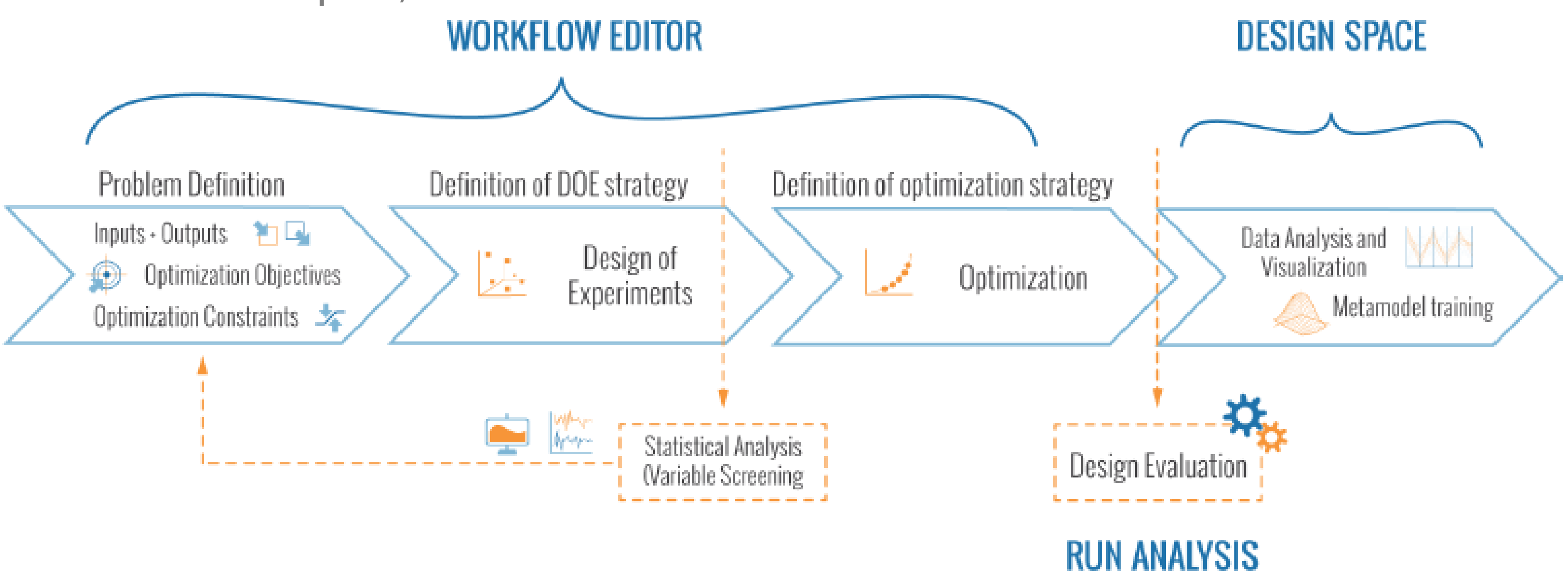
3. Complete automation of the loop ➔ <u>100% Hardware/Software resources exploiting</u>
4. Data mining (statistics, graphical data post-processing, …) + decision making, automatic report, …



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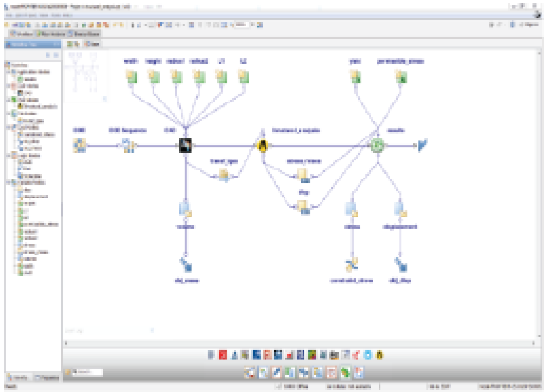
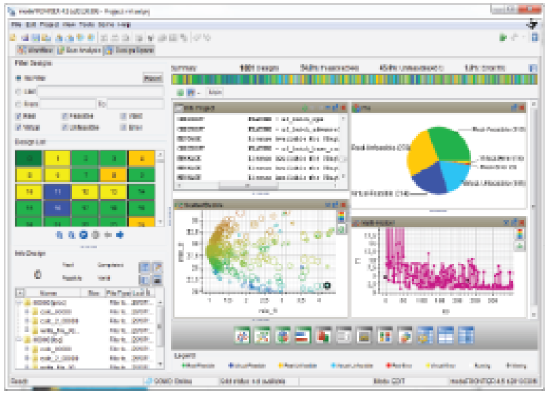
How modeFRONTIER is helping you

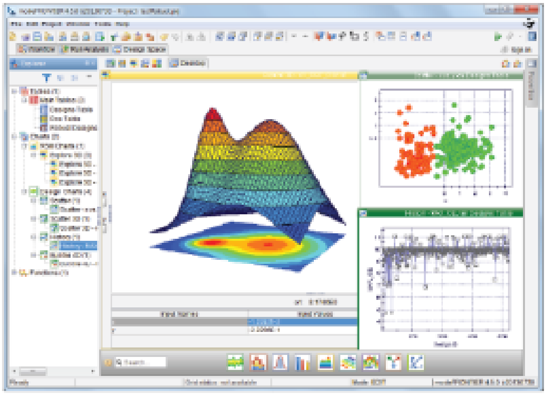
INTEGRATION AND PROCESS AUTOMATION



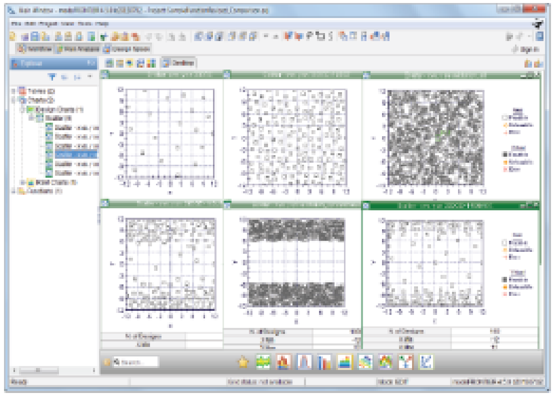
OPTIMIZATION



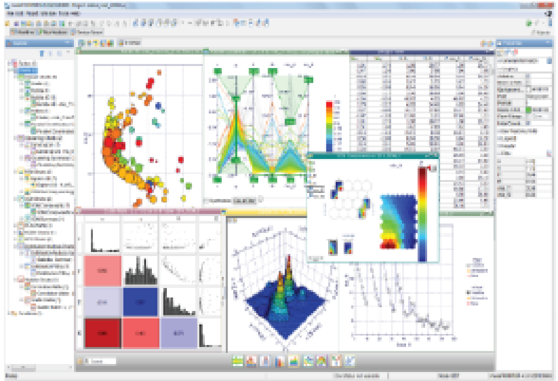
ROBUST DESIGN AND RELIABILITY



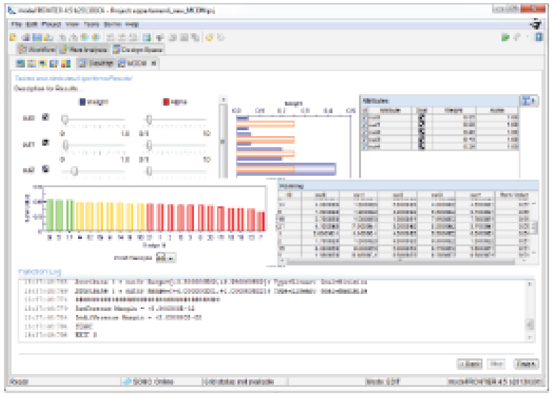
DESIGN SPACE EXPLORATION



ANALYTICS AND VISUALIZATION



DECISION MAKING



How modeFRONTIER is helping you - 1 – workflow: basic bricks

Any problem to be investigated has to build-up exploiting the data and logic “bricks”:

Free parameters ➔ to be changed to improve the proposed solution, that is defined completely by means of them (“**input variables**”). They have some reasonable variability limits (***range***) and a list of values that they can assume (i.e.: every real number, just integer values or just few values out of a catalog ***within the range***)

Tools ➔ programs or measures, that allow us to evaluate the behavior of our proposed solutions (“**solver**”)

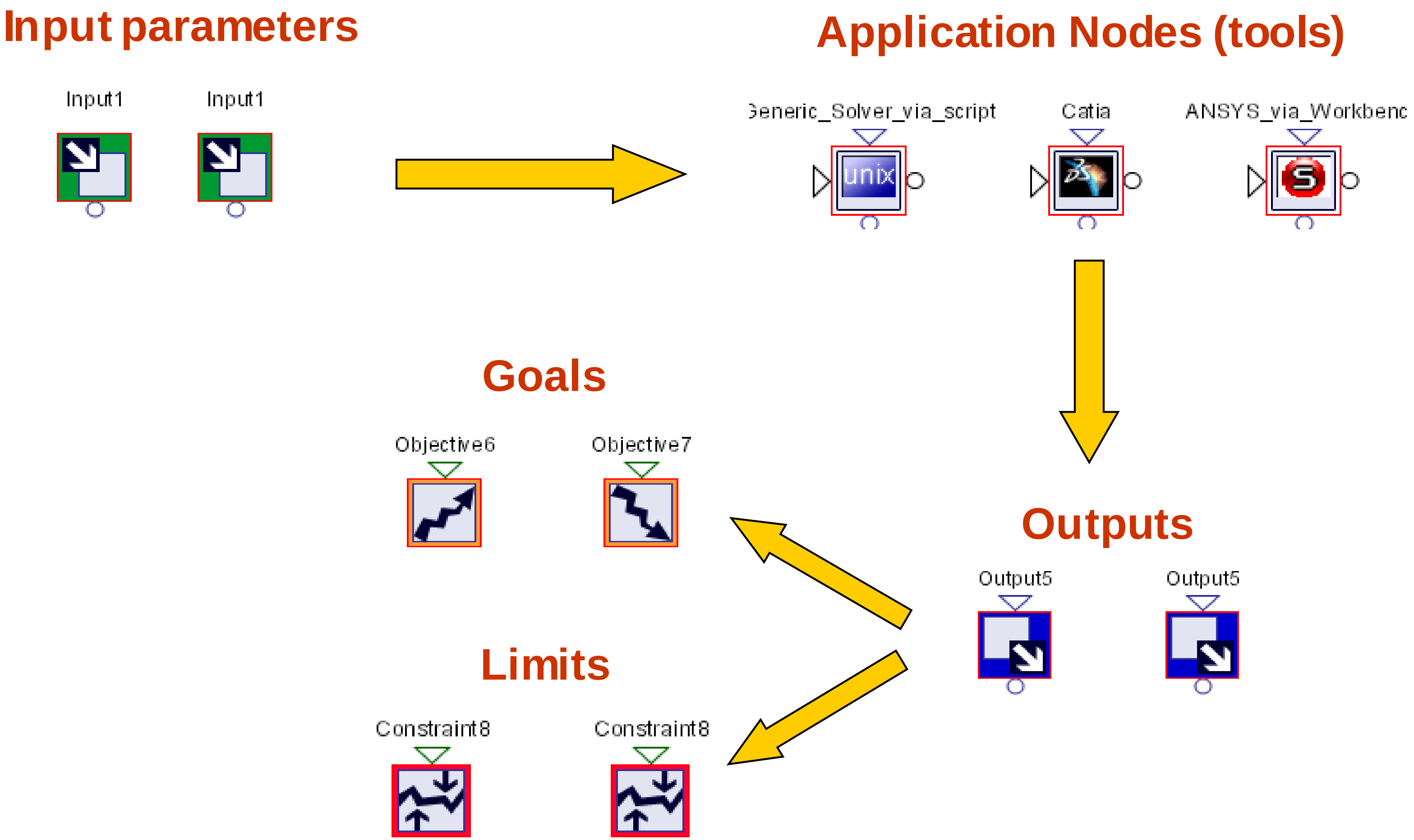
Outputs ➔ results that are describing the behavior of the proposed solution, produced by our “solver” (“**output variables**”)

Goals ➔ to achieve – more than one, also not strictly concordant – that could be expressed like functions of the obtained “outputs” (“**objectives**”)

Limits ➔ to be strictly respected, in terms of free parameters values and/or output values (“**constraints**”)

How modeFRONTIER is helping you - 1 – workflow: graphical approach

Any problem to be investigated has to build-up exploiting the data and logic "bricks":

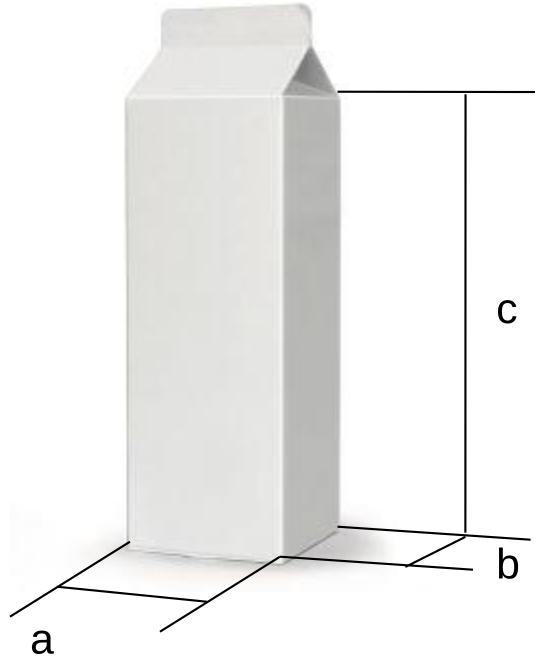


How modeFRONTIER is helping you - 1 – workflow: graphical approach

Simple Problem – Milk Box

Consider a Milk Box with edges of length a, b, c.
2 opposing-objective problem:

- minimize S/V ratio (minimize Thermal Dispersion)
- minimize also the area of the base 'ab' of the solid



How modeFRONTIER is helping you - 1 – workflow: graphical approach

Simple Problem – Milk Box

3 INPUT VARIABLES	*Lengths of 3 edges of a box (a,b,c)*
SOLVER	*Unix - bc*
2 OUTPUT VARIABLES	*box volume* *box ext. surface*
2 OBJECTIVES	*min. S/V* *min surf. for "ab" base*
1 CONSTRAINT	*minimum volume limit*

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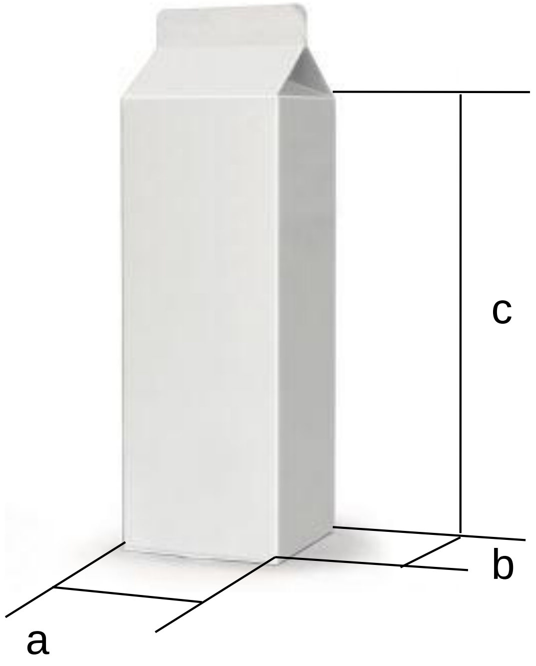

How modeFRONTIER is helping you - 1 – workflow: graphical approach

Simple Problem – Milk Box

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2 OBJECTIVES	***min. S/V min surf. for "ab" base***
1 CONSTRAINT	***minimum volume limit***

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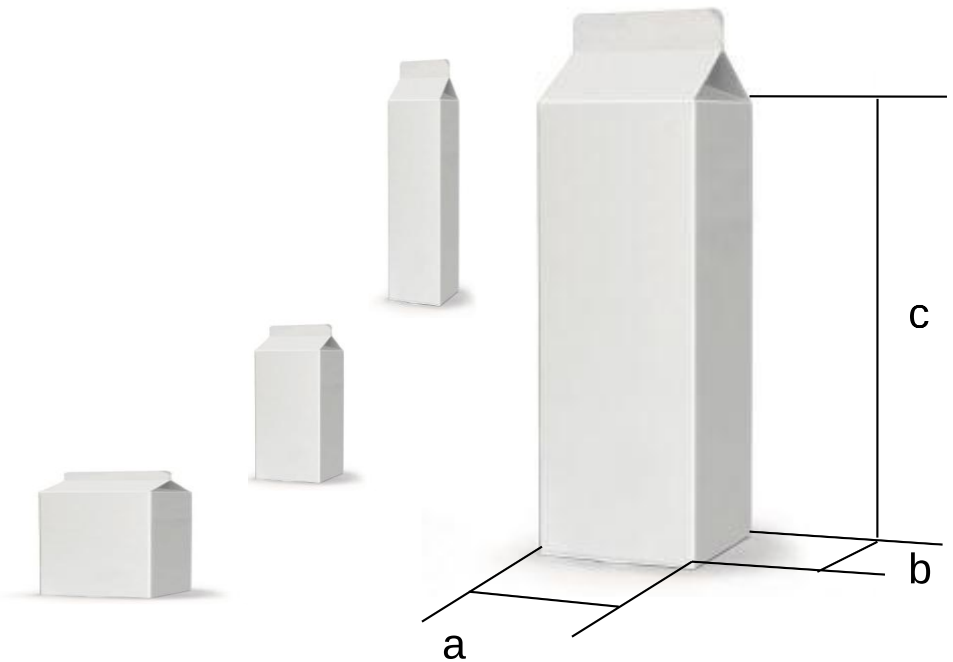

- Min S/V leads to the biggest Box possible within the assigned "a","b","c" bounds
- Min area of the "ab" base leads to small "plant-sized" shapes

How modeFRONTIER is helping you - 1 – workflow: graphical approach

Simple Problem – Milk Box

3 INPUT VARIABLES	***Lengths of 3 edges of a box (a,b,c)***
SOLVER	***Unix - bc***
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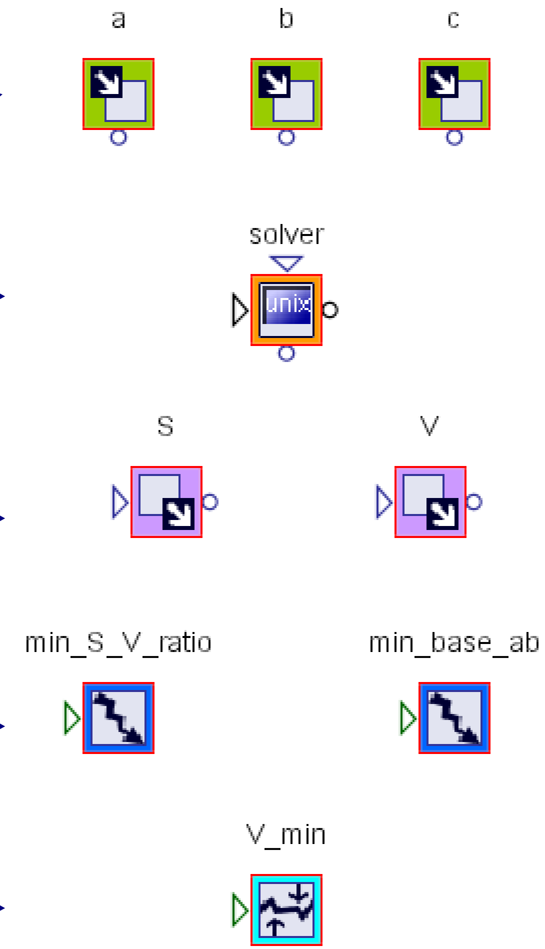
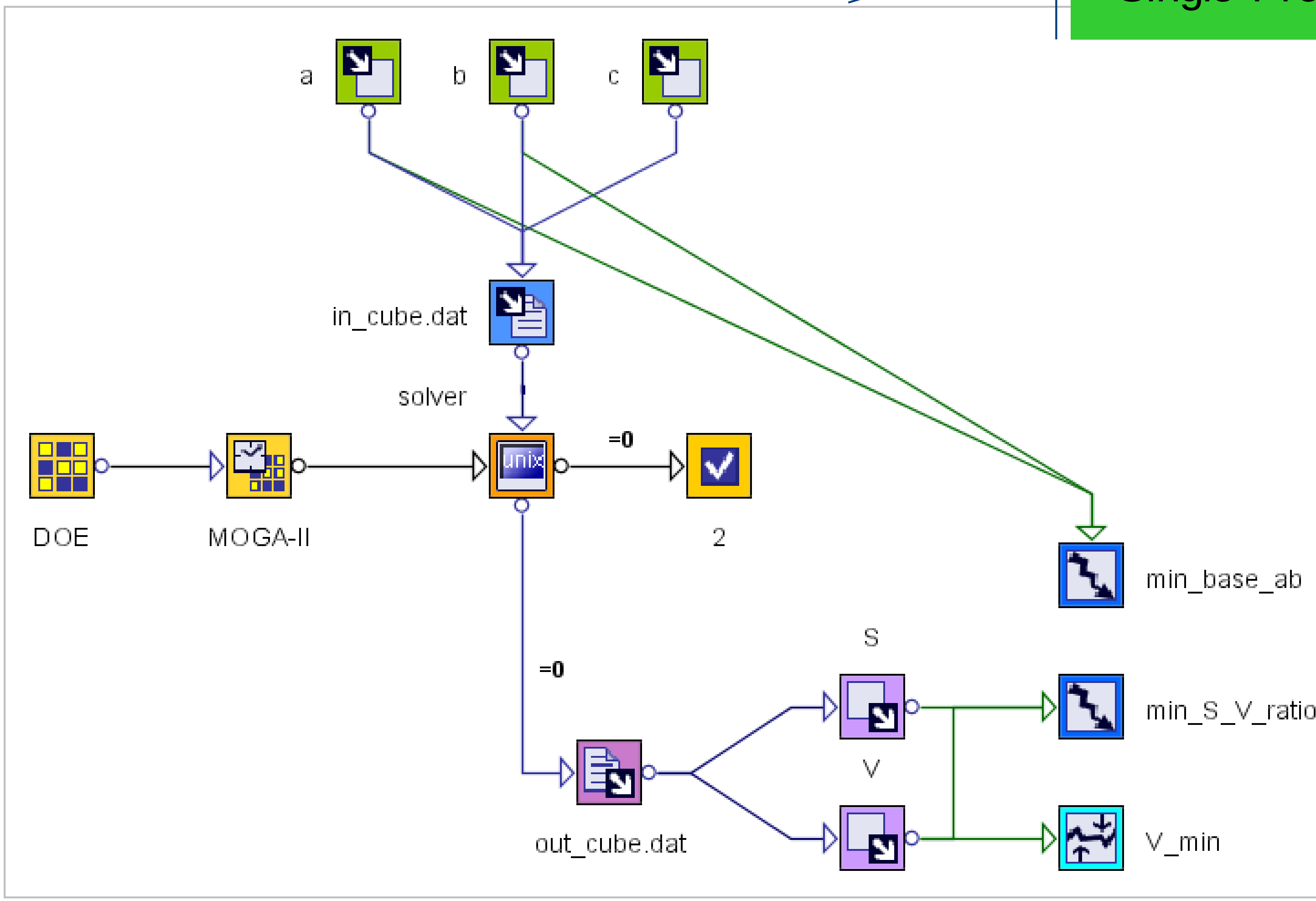


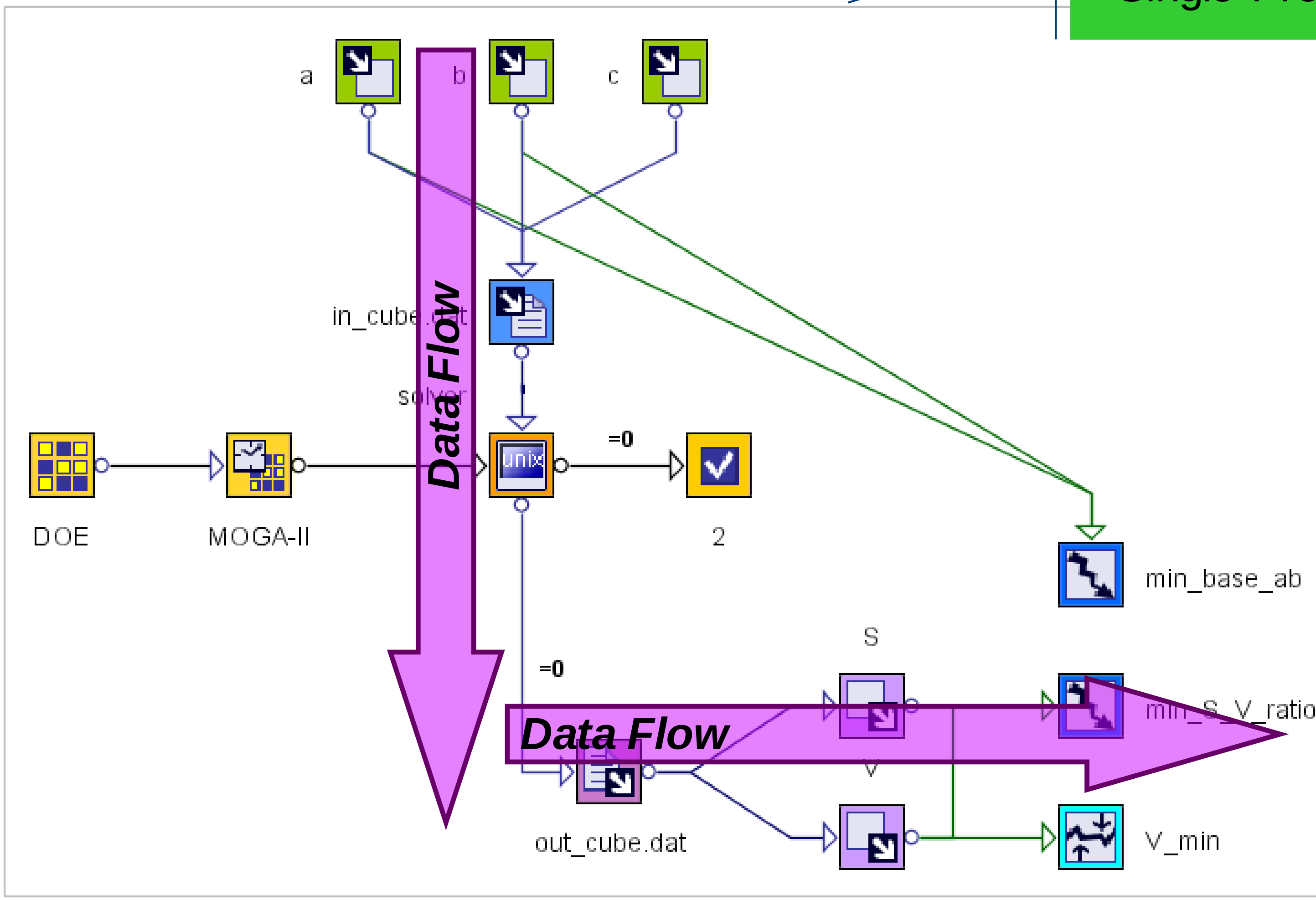
How modeFRONTIER is helping you - 1 – workflow definition

• Single-Process Integration



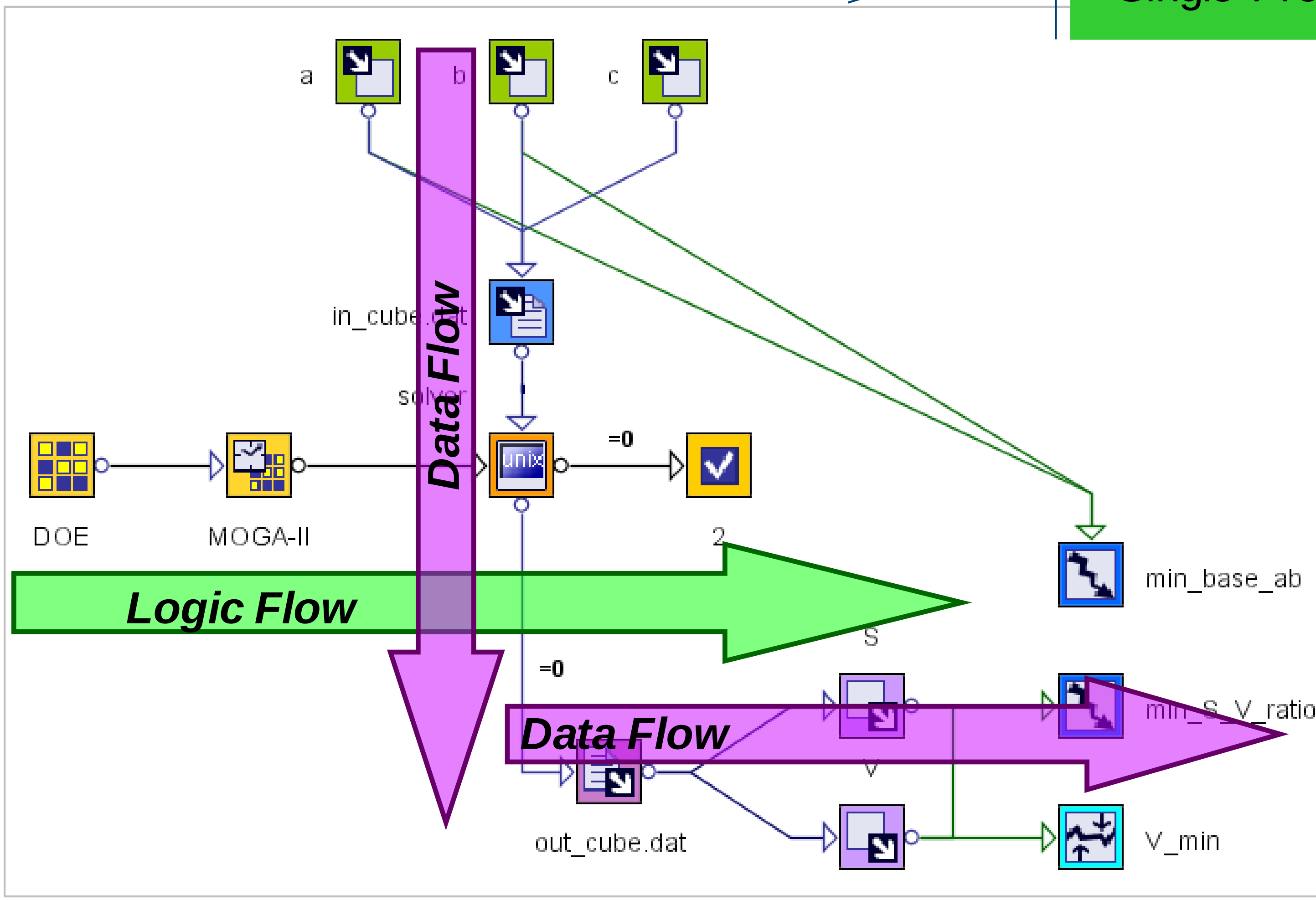
How modeFRONTIER is helping you - 1 – workflow definition

• Single-Process Integration



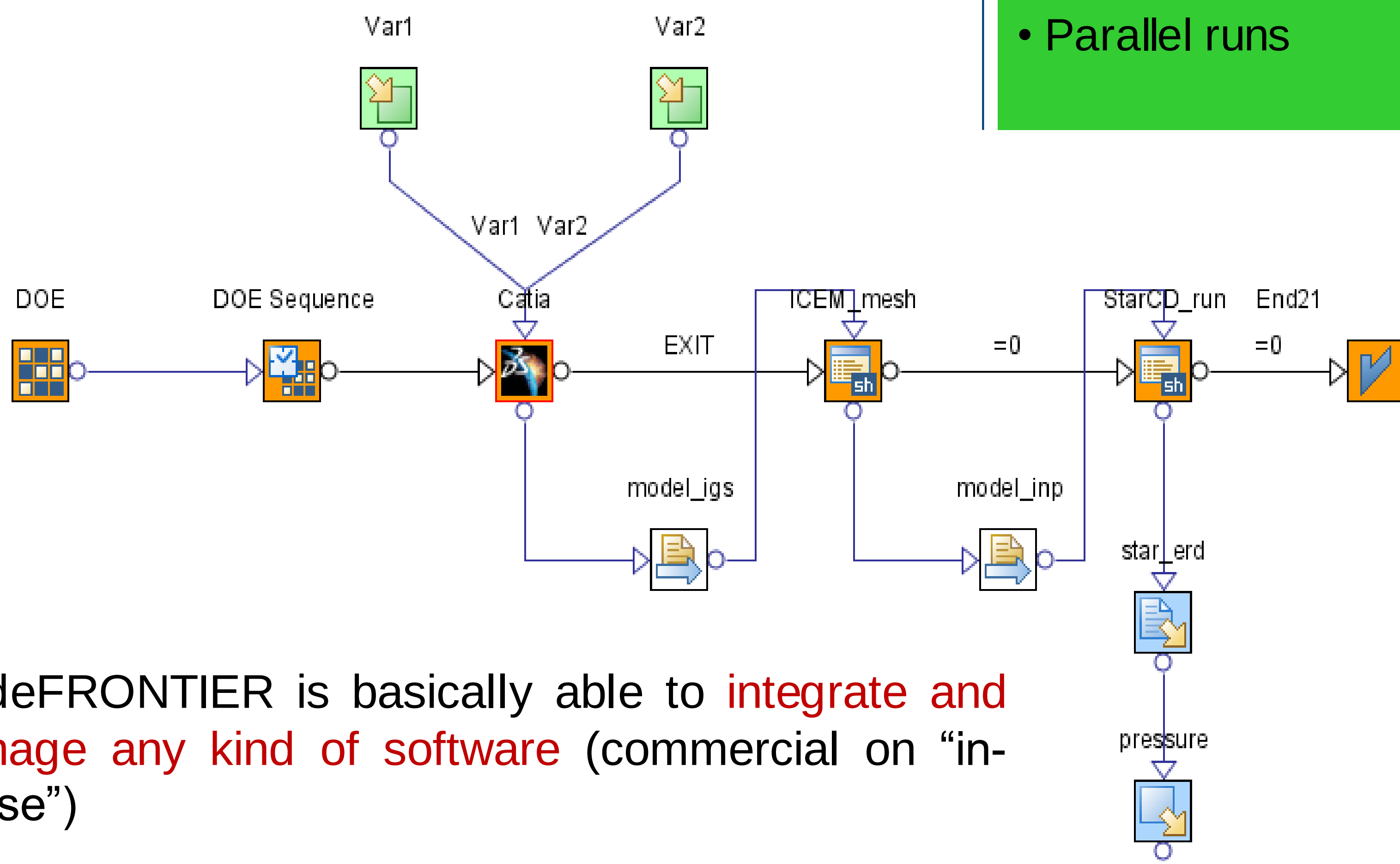
How modeFRONTIER is helping you - 1 – workflow definition

- Single-Process Integration



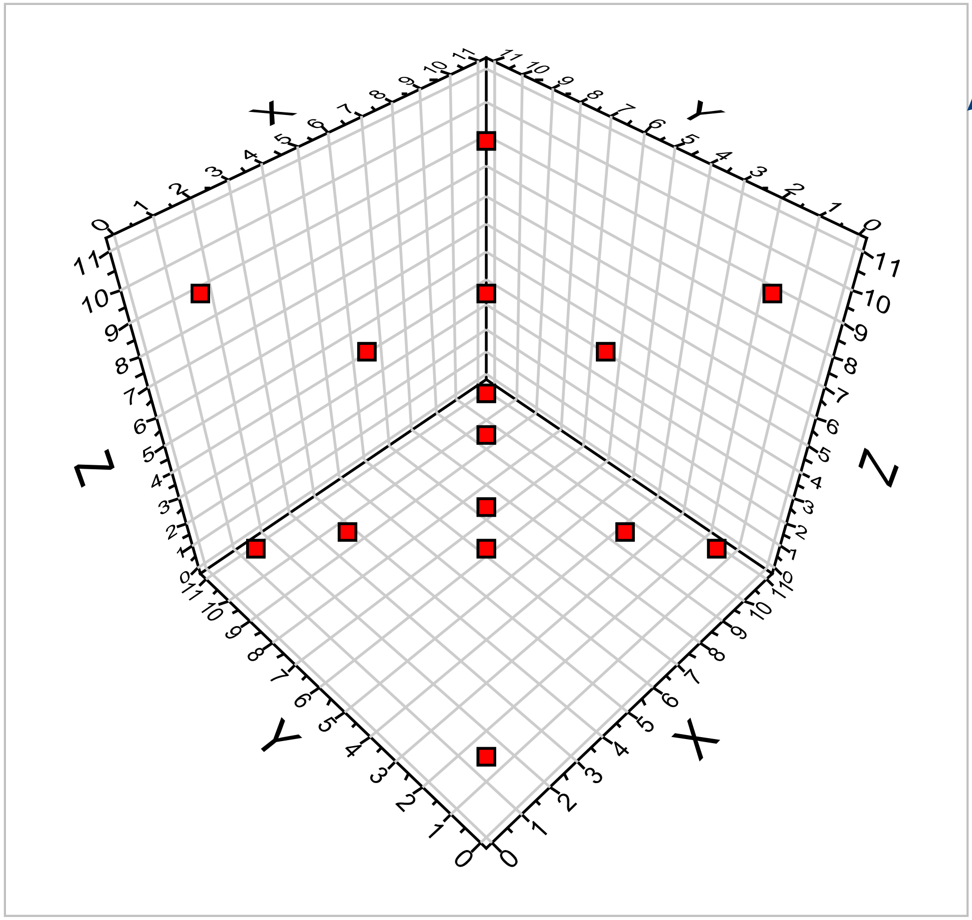
How modeFRONTIER is helping you - 1 – workflow definition

- Multi-Process Integration
- Software dedicated nodes
- Parallel runs



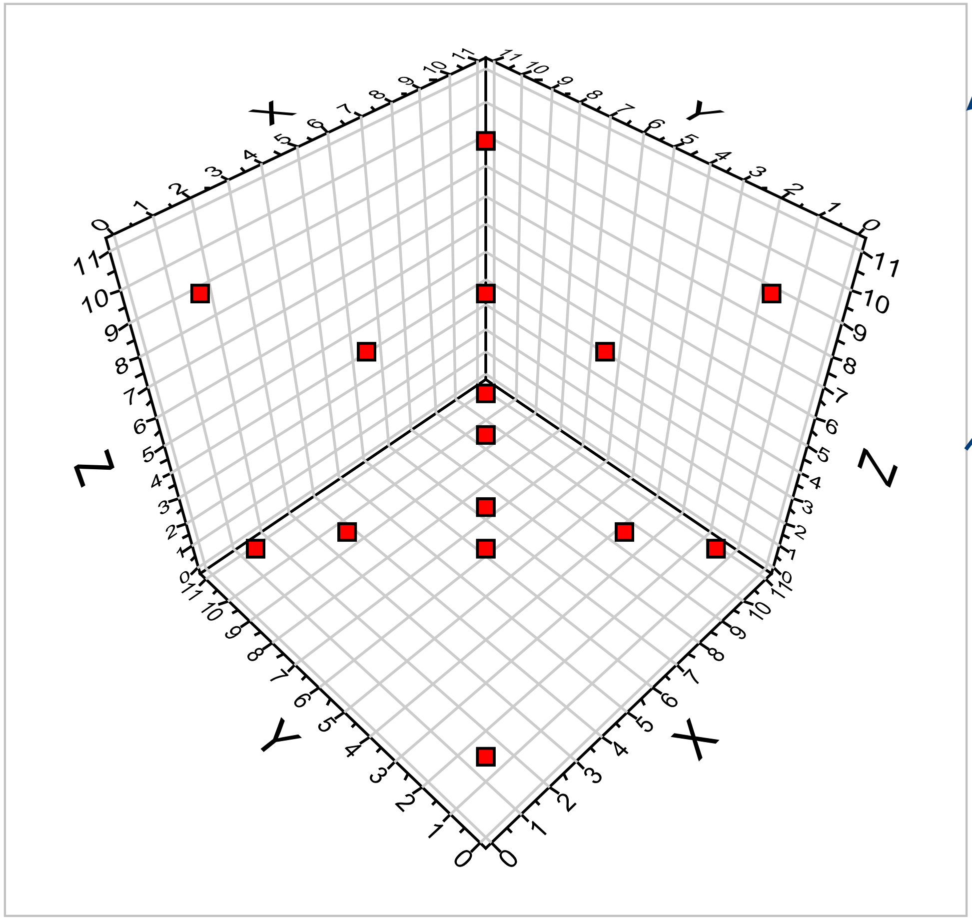
modeFRONTIER is basically able to integrate and manage any kind of software (commercial on "in-house")

How modeFRONTIER is helping you - 2 – whole exploration of design space



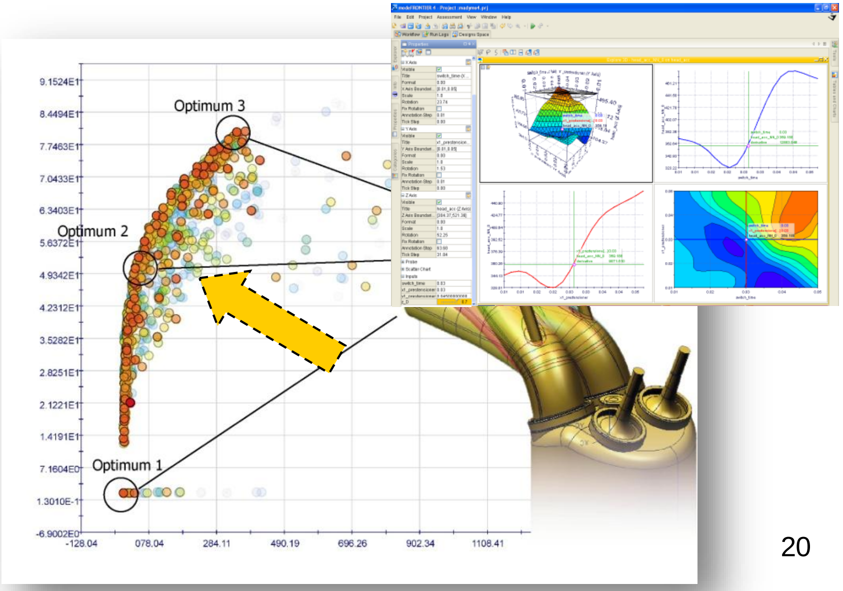
- Design Of Experiments (DOE) ➔ initial "picture"

How modeFRONTIER is helping you - 2 – whole exploration of design space



- Design Of Experiments (DOE) ➔ initial “picture”

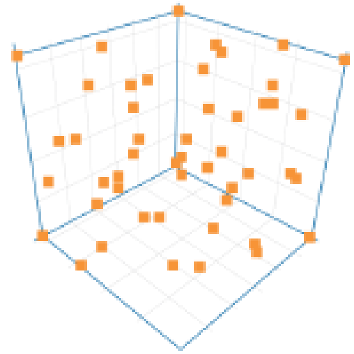
- Optimization Algorithms (with strategy wizard)



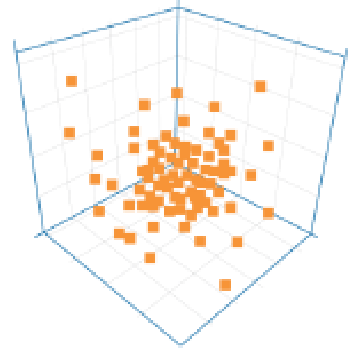
How modeFRONTIER is helping you - 2 – DOEs

DOE methods:

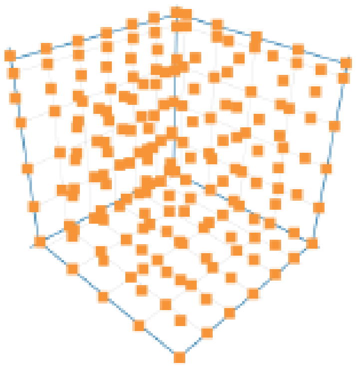
- **Space Filler DOEs** serve as the starting point for a subsequent optimization process or a database for response surface training



- **Statistical DOEs** are useful for creating samplings for the sensitivity analysis thus allowing in-depth understanding of the problem by identifying the sources of variation



- **Robustness and reliability DOEs** help create a set of stochastic points for robustness evaluation

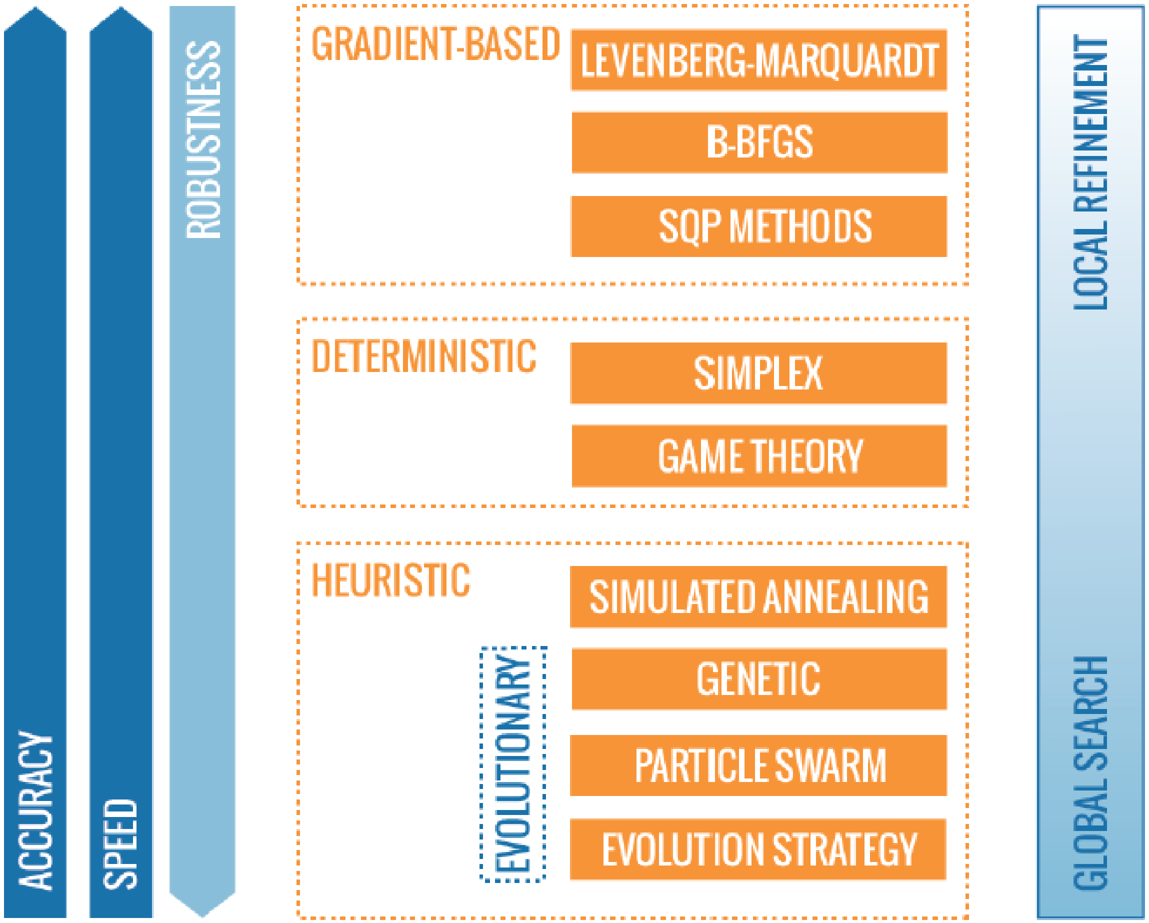


- **Optimal Designs DOEs** are special purpose techniques used for reducing the dataset in a suitable way

How modeFRONTIER is helping you - 2 – Optimization Algorithms

Complete array of optimization algorithms covering deterministic, stochastic and heuristic methods for single and multi-objective problems.

Beside the traditional methods, modeFRONTIER provides fine-tuned hybrid algorithms combining the strengths of single approaches.



How modeFRONTIER is helping you - 2 – multi-objective problems

“false” multi objective solution

$$\begin{cases} \min \ f_i(x_k) \\ g_c(x_k) \le 0 \end{cases}$$

i = 1, n objectives
k = 1, n variables
c = 1, n constraints

Transform a multi-objective optimization problem into an equivalent single one. The solution (one solution) depends on the choice of the parameter values.

$$\begin{cases} \min \ h\ (x_k) = \sum_{i=1}^{nobj} \alpha_i f_i(x) \\ g_c(x_k) \le 0 \end{cases}$$

Arbitrarily chosen

How modeFRONTIER is helping you - 2 – multi-objective problems

“true” multi objective solution

$$\begin{cases} \min \; f_i(x_k) \\ g_c(x_k) \leq 0 \end{cases}$$

i = 1, n objectives
k = 1, n variables
c = 1, n constraints

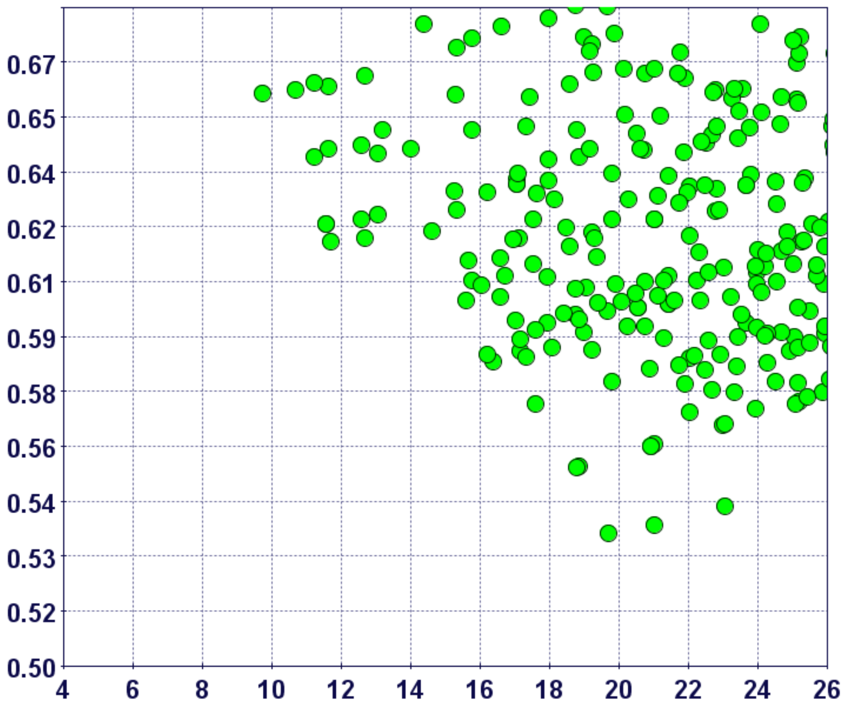
set of optimal solutions usually known as **Pareto Frontier**

Pareto Frontier: do not exist solutions with better values for all the objectives ➔ not dominated solutions

How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives

f1,
to be
minimized

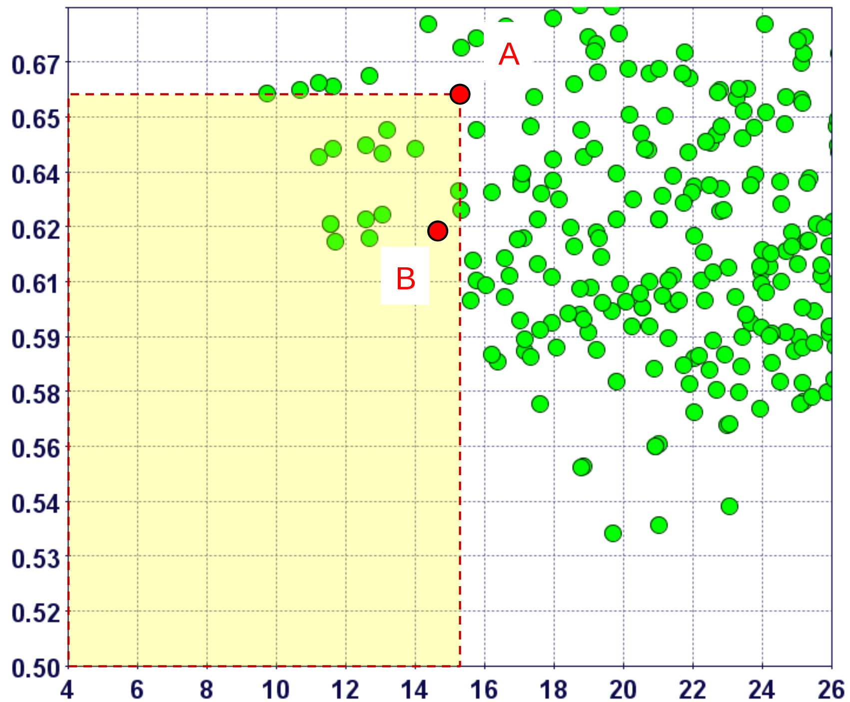


f2, to be minimized

How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives

f1,
to be
minimized



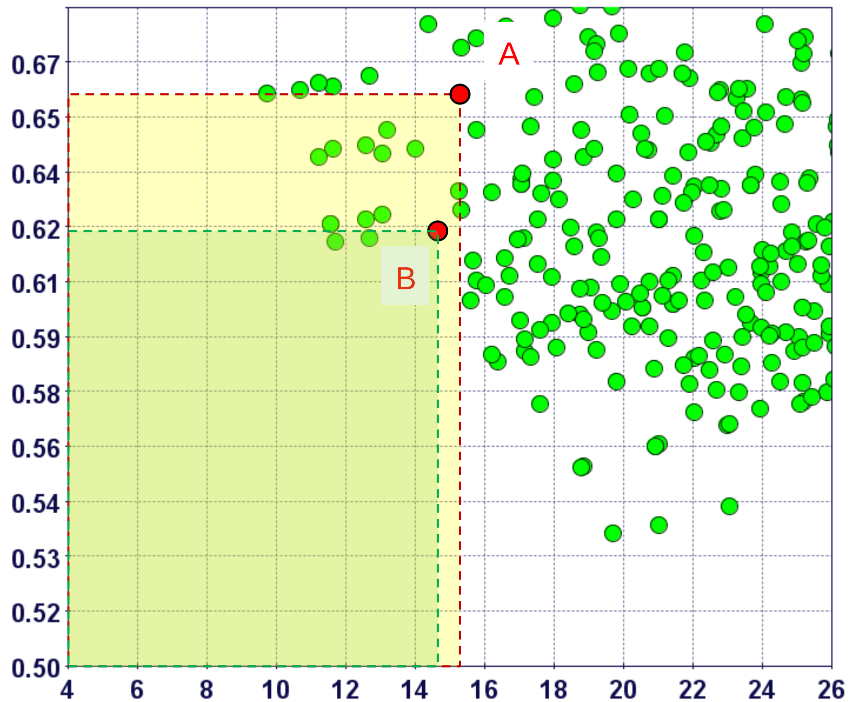
f2, to be minimized

How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives

A dominated by B

f1, to be minimized

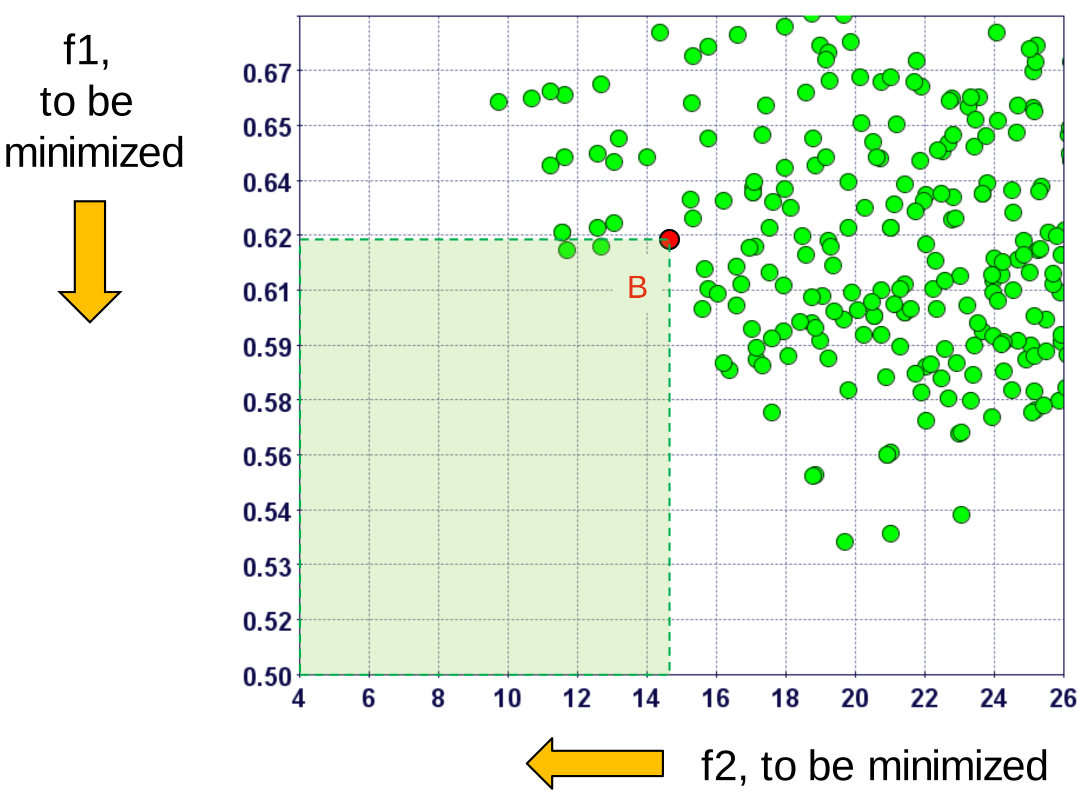


f2, to be minimized

How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives

A dominated by B



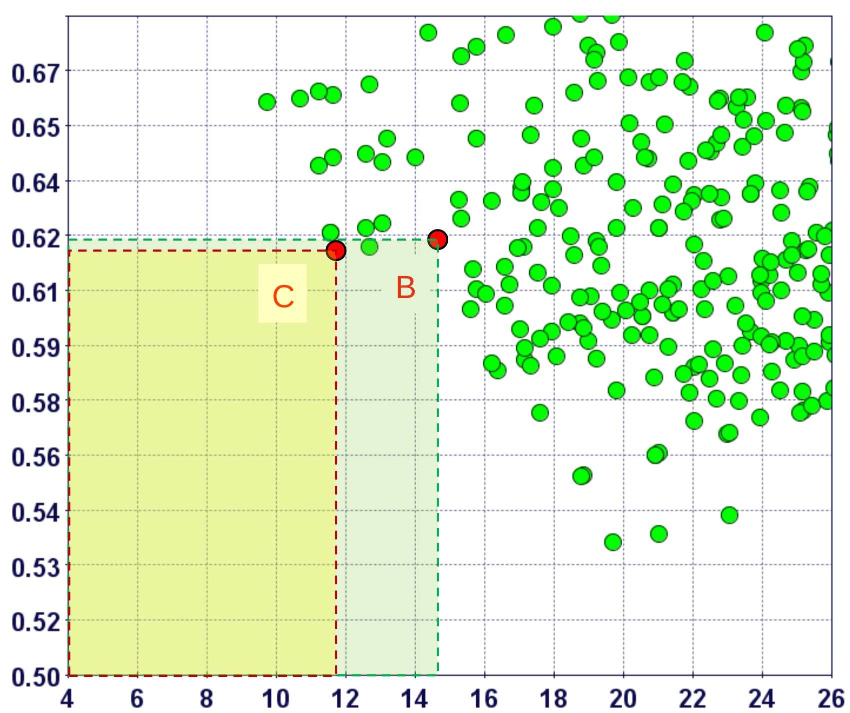
How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives

A dominated by B

B dominated by C

f1, to be minimized

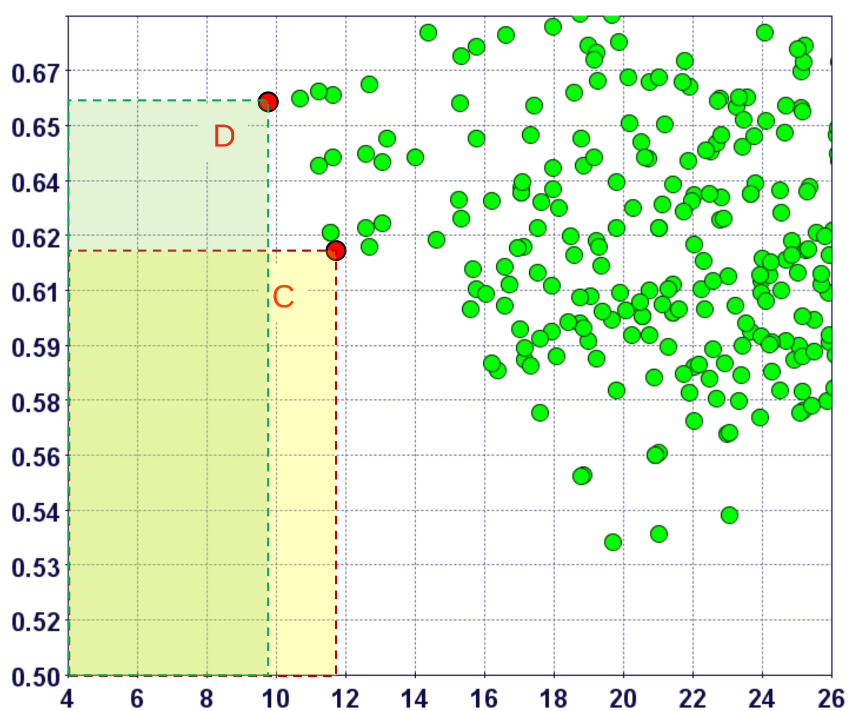


f2, to be minimized

How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives

f1,
to be
minimized



f2, to be minimized

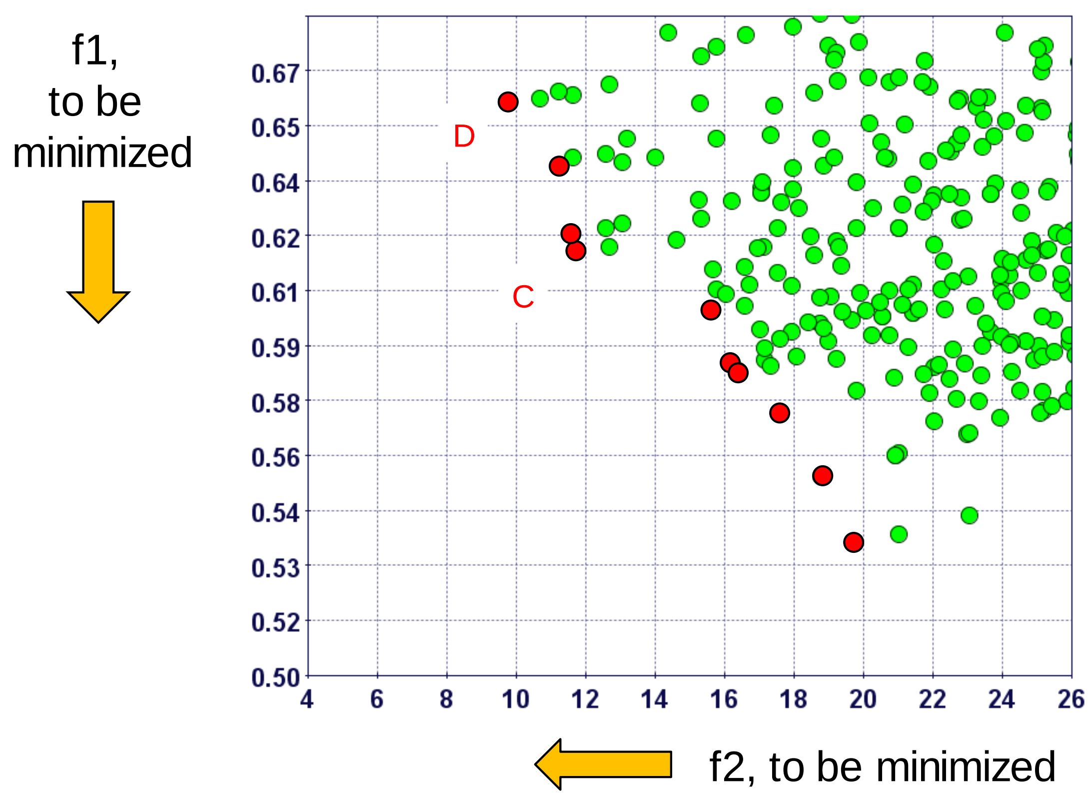
A dominated by B

B dominated by C

D and C are <u>not</u> dominated

How modeFRONTIER is helping you - 2 – More about Pareto Frontier

Pareto Frontier set: different trade-off between objectives



A dominated by B

B dominated by C

D and C are not dominated

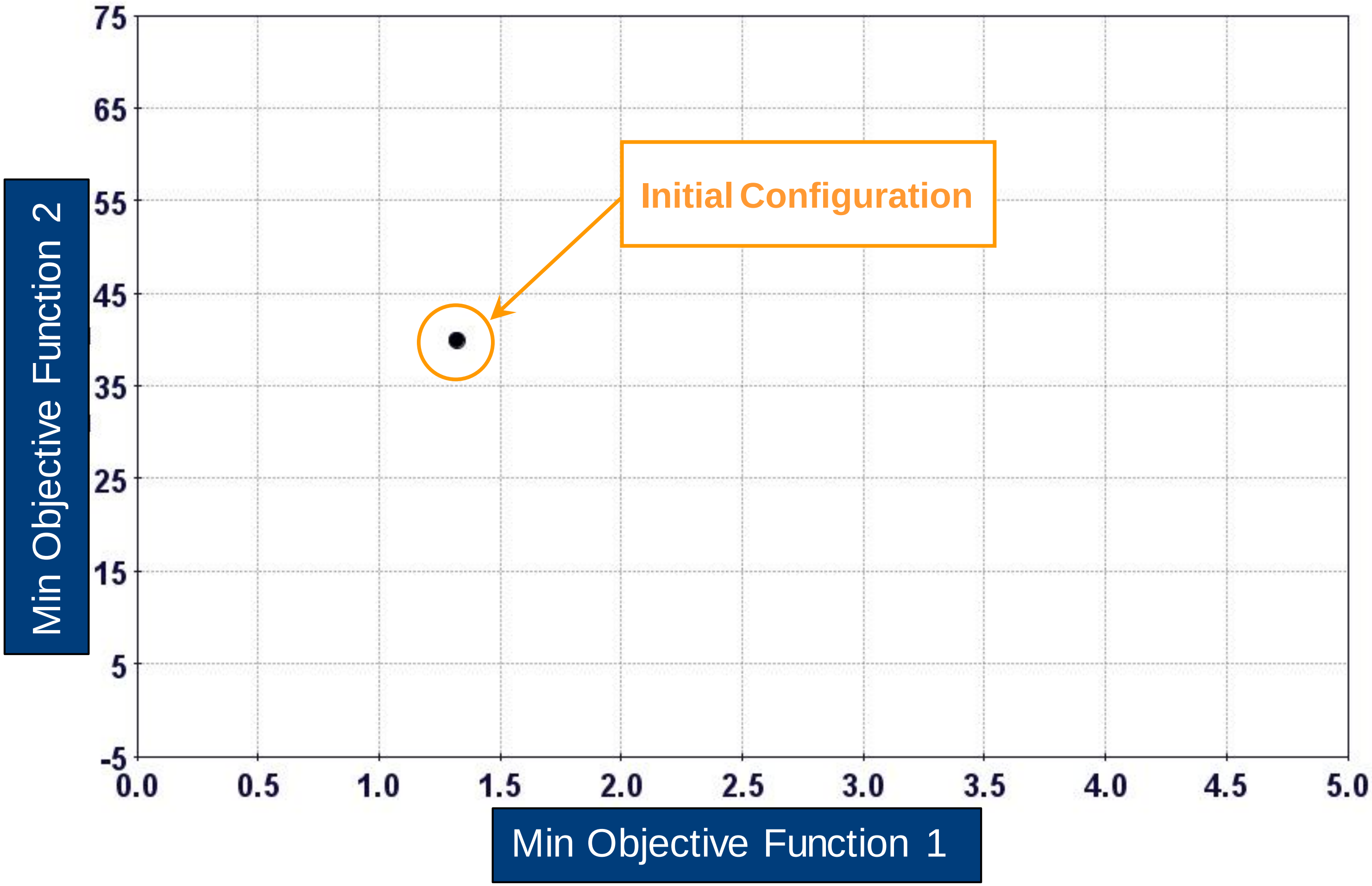
● Pareto Frontier

f1 → single point
f1,f2 → curve
f1,f2,f3 → 3D surface

n functions → n-dim surface

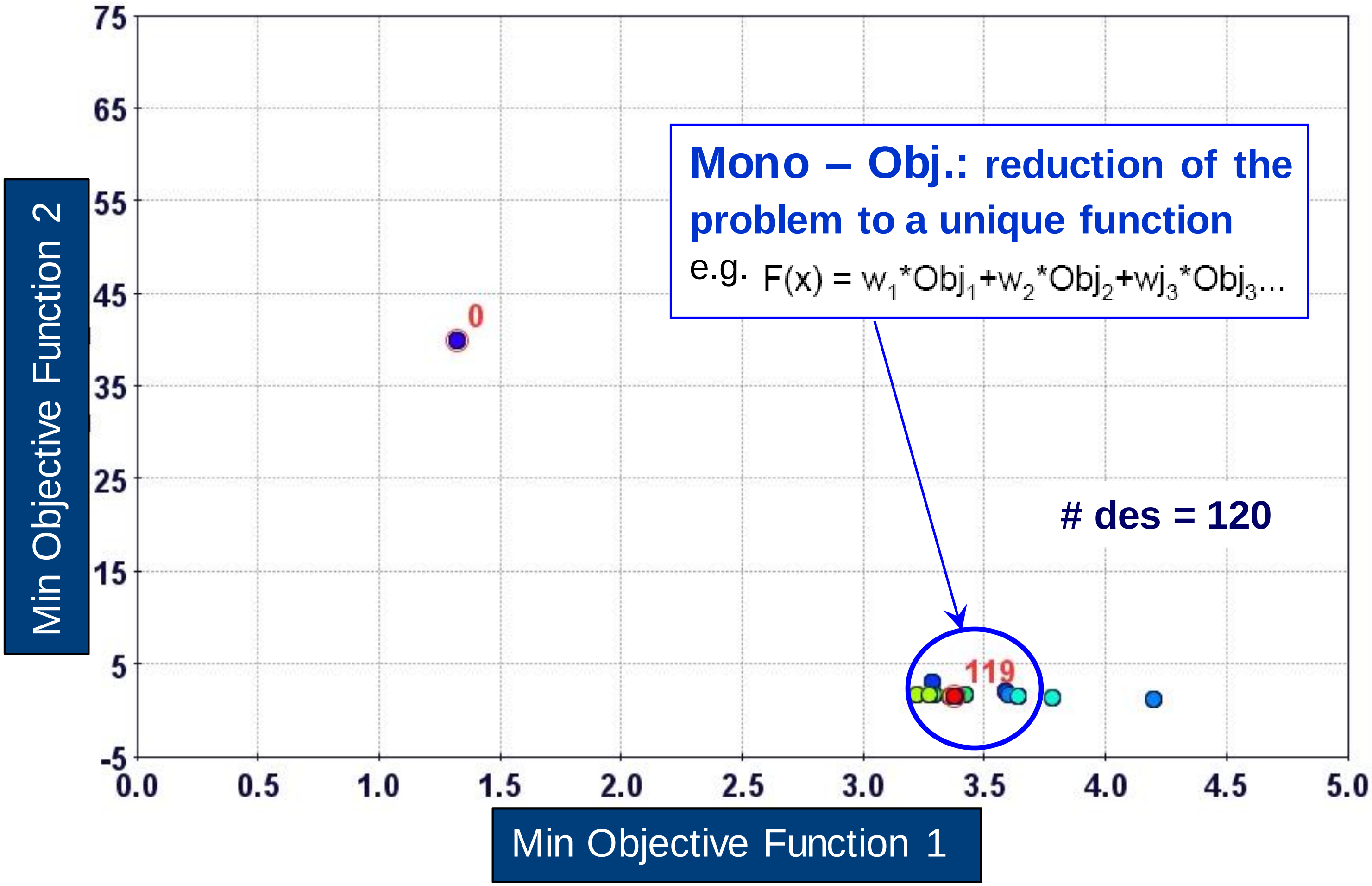
How modeFRONTIER is helping you - 2 – exploration

Simple Problem – Milk Box



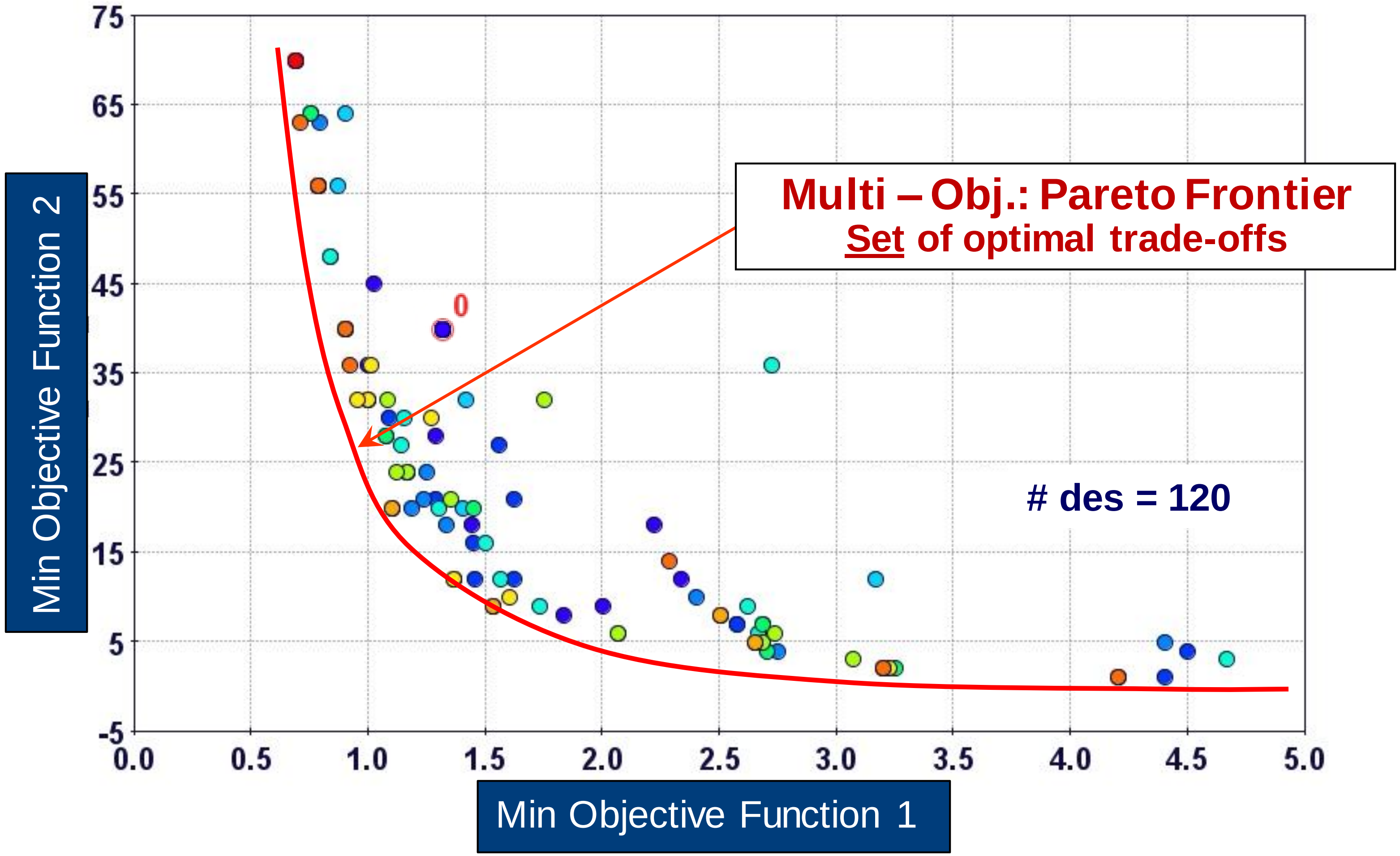
How modeFRONTIER is helping you - 2 – weight function

Simple Problem – Milk Box



How modeFRONTIER is helping you - 2 – Pareto Frontier

Simple Problem – Milk Box



How modeFRONTIER is helping you - 2 – DOEs + Optimization Algorithms + RSM

RSM (Response Surface Methodology), or meta-modeling, is a valid strategy which serves as a surrogate for heavy simulation processes, allowing engineers to fast-run the classic optimization process, and/or only experimental data are available (no numerical model does exist)

How modeFRONTIER is helping you - 2 – DOEs + Optimization Algorithms + RSM

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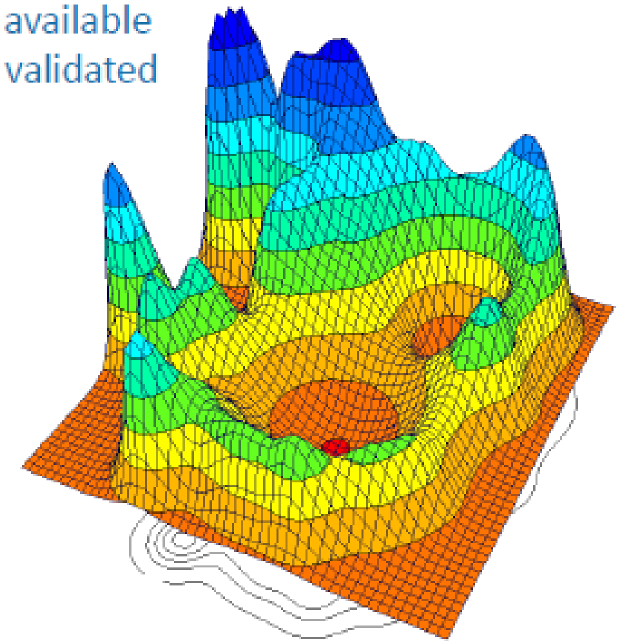
How does it work in modeFRONTIER?

1. RSMs are **trained** from an available database of real designs and validated one against another.

2. The best model is used to **compute** the outputs of the system; this process is called **virtual optimization**.

3. The best designs obtained through virtual optimization are then **evaluated by the real solver**



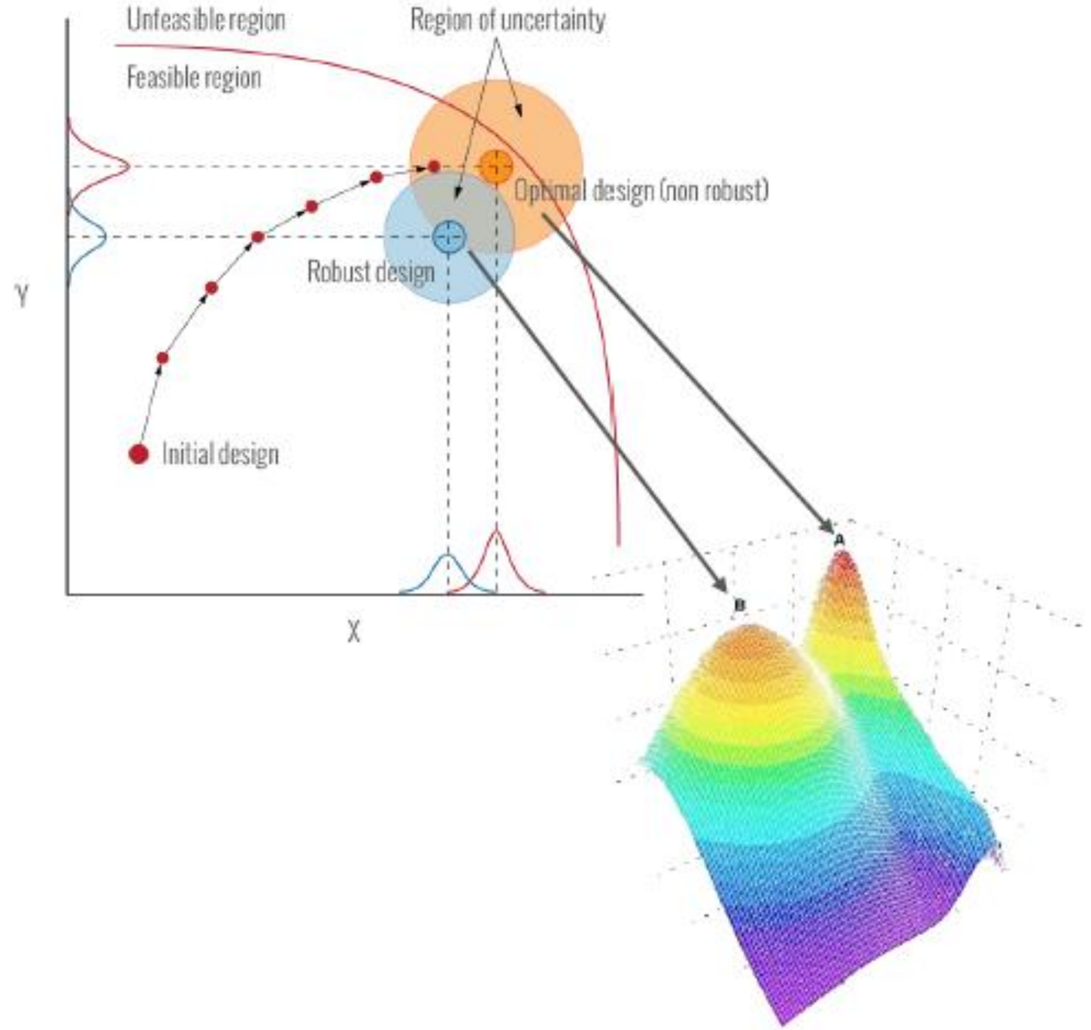
Main advantages

- ✓ perform thousands of design evaluations in short time
- ✓ accelerate the optimization step
- ✓ use small amounts of data efficiently
- ✓ smart exploitation of available computational resources

How modeFRONTIER is helping you - 2 – Robust Design and Reliability of Optimum

The input parameters uncertainty is reflected in the outputs of the system

modeFRONTIER multi-objective robust design optimization (MORDO) algorithms generate a scatter of samples (noise factors) around the design, in order to verify how sensitive the design is to variations, i.e. whether the values of the outputs are still within the user-defined limits



How modeFRONTIER is helping you - 3 – automating the workflow

Working days | holidays

2/3

Working hour | Meal, home,sleep

1/2

designing | Other works

1/2

calculate | others

1/2

Calculate 1/12 | Others 11/12

Without mF, calculations have to be run one by one, a lot of time is not used

Conversely, once the workflow is set in mF, the calculations run automatically and the **available time is fully used**

Calculate 12/12

How modeFRONTIER is helping you - 4 – Data Mining, Robust Design, …

“Question”

What do numerical and/or experimental data mean?

<ID>	D2	B2	Beta1	Beta2	Height_wheel	Blade_shape	Wrapping	Blades	DeltaP	efficiency
0	5.30E+01	1.10E+01	3.30E+01	1.50E+01	0.00E+00	1.50E+00	9.00E+01	1.10E+01	2.34E+04	6.05E-01
1	5.70E+01	1.20E+01	1.90E+01	1.90E+01	0.00E+00	1.30E+00	5.50E+01	1.10E+01	3.34E+04	5.59E-01
2	5.75E+01	6.00E+00	1.30E+01	3.50E+01	0.00E+00	1.20E+00	7.50E+01	1.10E+01	2.73E+04	5.33E-01
3	5.90E+01	7.00E+00	2.50E+01	1.30E+01	0.00E+00	1.30E+00	6.50E+01	9.00E+00	2.76E+04	5.59E-01
4	5.60E+01	7.00E+00	2.10E+01	1.90E+01	0.00E+00	1.30E+00	7.00E+01	9.00E+00	2.41E+04	5.65E-01
5	5.50E+01	8.00E+00	3.10E+01	1.10E+01	0.00E+00	1.50E+00	8.00E+01	1.10E+01	2.03E+04	5.91E-01
6	5.40E+01	9.00E+00	3.30E+01	3.90E+01	0.00E+00	1.30E+00	7.50E+01	9.00E+00	2.59E+04	5.21E-01
7	5.40E+01	6.00E+00	1.50E+01	2.70E+01	0.00E+00	1.30E+00	6.00E+01	1.10E+01	2.19E+04	5.64E-01
8	5.75E+01	8.00E+00	1.70E+01	2.10E+01	0.00E+00	1.50E+00	9.00E+01	1.10E+01	2.65E+04	5.81E-01
9	5.90E+01	6.50E+00	1.70E+01	3.70E+01	0.00E+00	1.30E+00	5.50E+01	1.10E+01	3.12E+04	5.24E-01
10	5.70E+01	1.00E+01	2.90E+01	1.50E+01	0.00E+00	1.30E+00	6.50E+01	9.00E+00	3.05E+04	NaN
11	5.75E+01	1.10E+01	3.10E+01	2.90E+01	0.00E+00	1.10E+00	9.00E+01	9.00E+00	3.47E+04	4.91E-01
12	5.30E+01	1.10E+01	3.30E+01	1.10E+01	0.00E+00	1.50E+00	9.00E+01	1.10E+01	2.18E+05	6.11E-01
13	5.80E+01	7.00E+00	2.50E+01	1.30E+01	0.00E+00	1.30E+00	6.50E+01	9.00E+00	NaN	NaN
14	5.50E+01	8.00E+00	3.30E+01	4.10E+01	0.00E+00	1.20E+00	7.00E+01	9.00E+00	2.71E+04	5.26E-01
15	5.45E+01	1.00E+01	2.10E+01	2.10E+01	0.00E+00	1.30E+00	6.50E+01	1.10E+01	NaN	NaN
16	5.90E+01	6.50E+00	2.10E+01	3.70E+01	0.00E+00	1.30E+00	5.50E+01	1.10E+01	3.10E+04	5.24E-01
17	5.50E+01	1.10E+01	2.90E+01	1.10E+01	0.00E+00	1.50E+00	5.50E+01	1.10E+01	2.65E+04	6.05E-01
18	5.90E+01	6.00E+00	1.50E+01	3.70E+01	0.00E+00	1.30E+00	5.50E+01	1.10E+01	3.02E+04	5.28E-01
19	5.70E+01	8.00E+00	1.70E+01	3.70E+01	0.00E+00	1.30E+00	9.00E+01	1.10E+01	3.01E+04	5.24E-01
20	5.70E+01	6.50E+00	1.70E+01	3.70E+01	0.00E+00	1.30E+00	6.50E+01	9.00E+00	2.69E+04	5.38E-01
21	5.75E+01	8.00E+00	1.70E+01	1.90E+01	0.00E+00	1.50E+00	9.00E+01	1.10E+01	2.61E+04	5.79E-01
22	5.35E+01	1.10E+01	3.10E+01	2.90E+01	0.00E+00	1.10E+00	9.00E+01	9.00E+00	2.75E+04	4.89E-01

How modeFRONTIER is helping you - 4 – Data Mining, Robust Design, …

“Question”

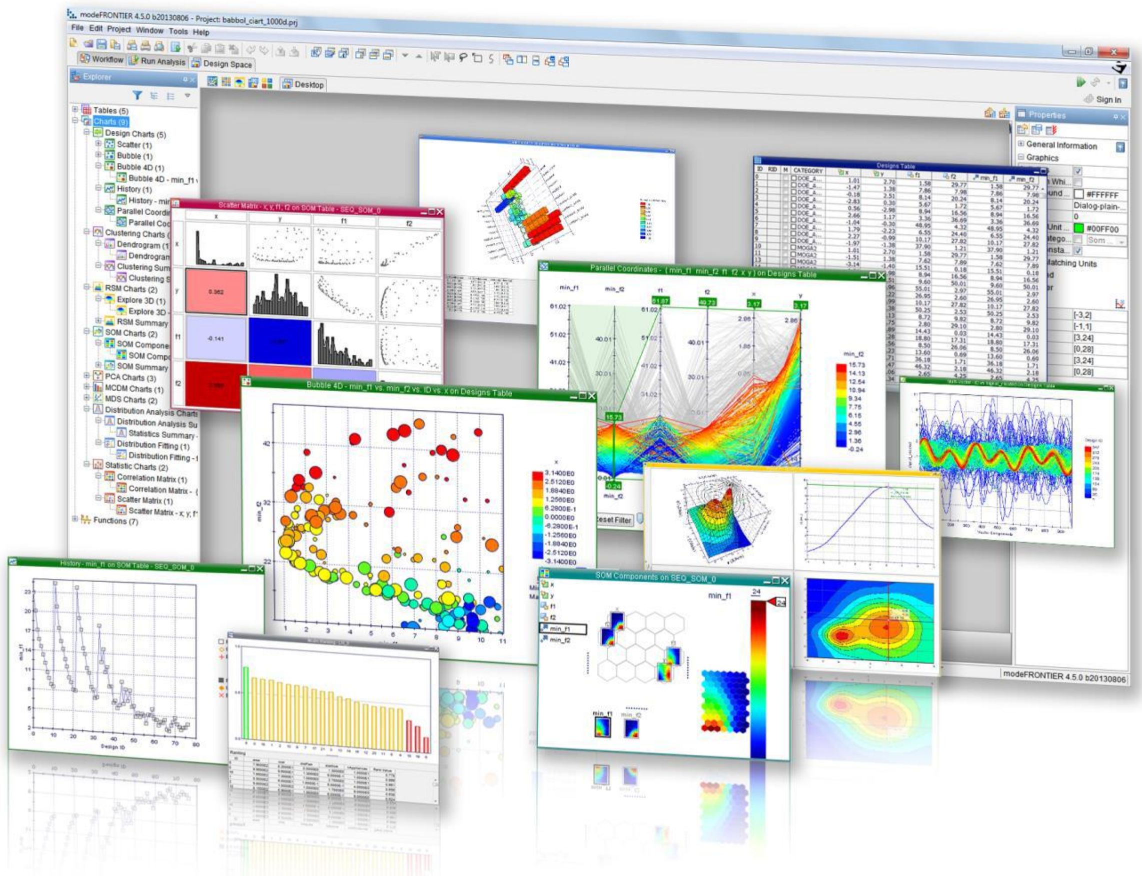
What do numerical and/or experimental data mean?

- How can we analyse in a efficient way the available data?
- Which are the relationship between the input variables, objectives, and constraints?
- Which are the most important design variables?
- Can we reduce the variables space?
- What is the best design space region to address for the optimization process?
- What is a reasonable number of objectives or constraints to assess?

How modeFRONTIER is helping you - 4 – Data Mining, Robust Design, …

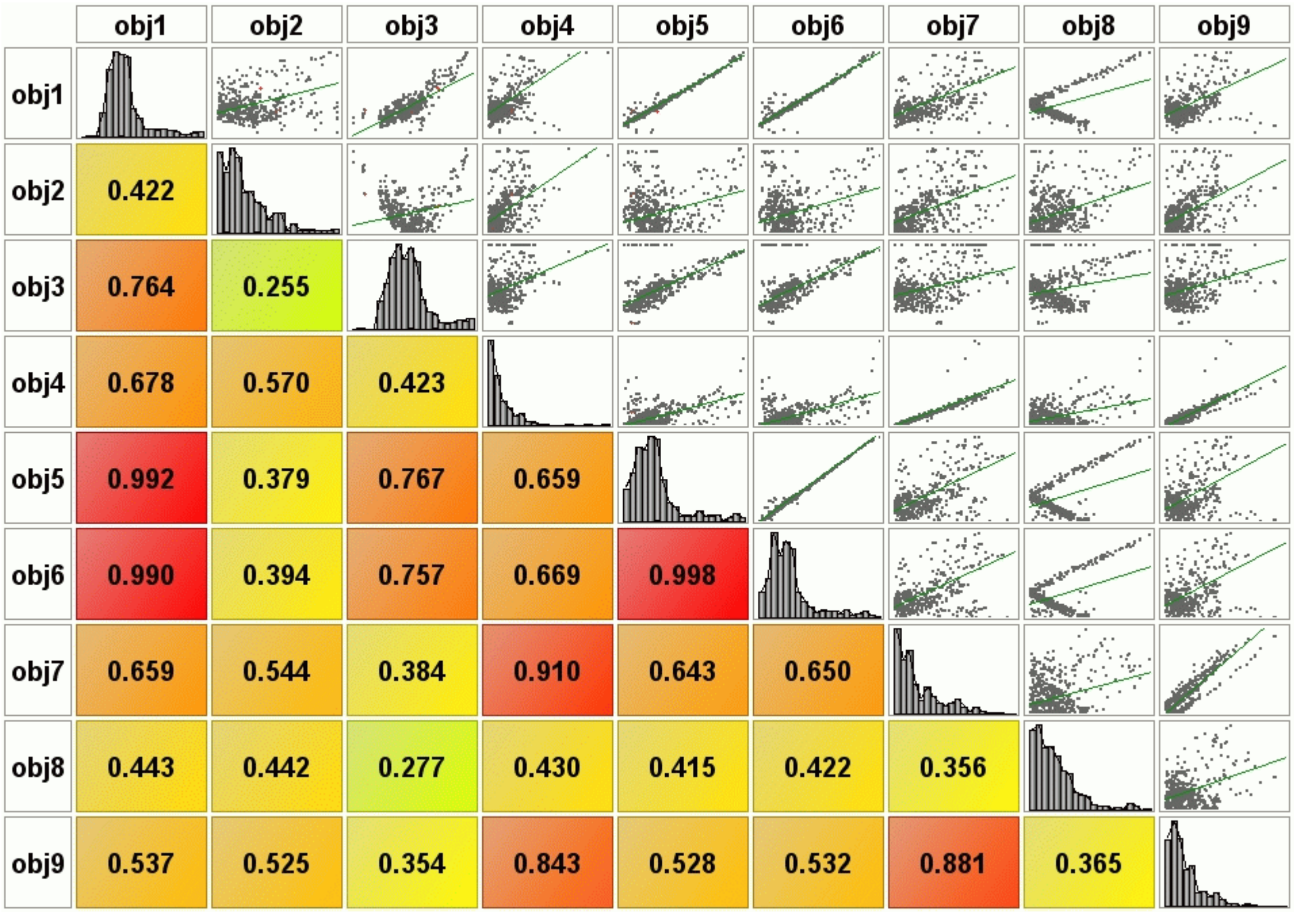
modeFRONTIER provides a complete and comprehensive environment for data analysis and visualization, enabling statistical assessment of complex datasets.

Its sophisticated post-processing tools, such as Sensitivity Analysis, Multi-Variate Analysis, and Visual Analysis, allow results from multiple simulations to be visualized in a meaningful manner and key factors to be identified



How modeFRONTIER is helping you - 4 – Statistical Analyses (… some tools)

Correlation Matrix (or **Scatter Matrix**) quantifies the linear correlation between variables (both input-output, input-input and output-output)



- Only statistical DOE designs (no optimization)
- First-order correlation:
  1 ➔ full correlation
  0 ➔ no correlation

Reduce objectives number

How modeFRONTIER is helping you - 4 – Statistical Analyses (… some tools)

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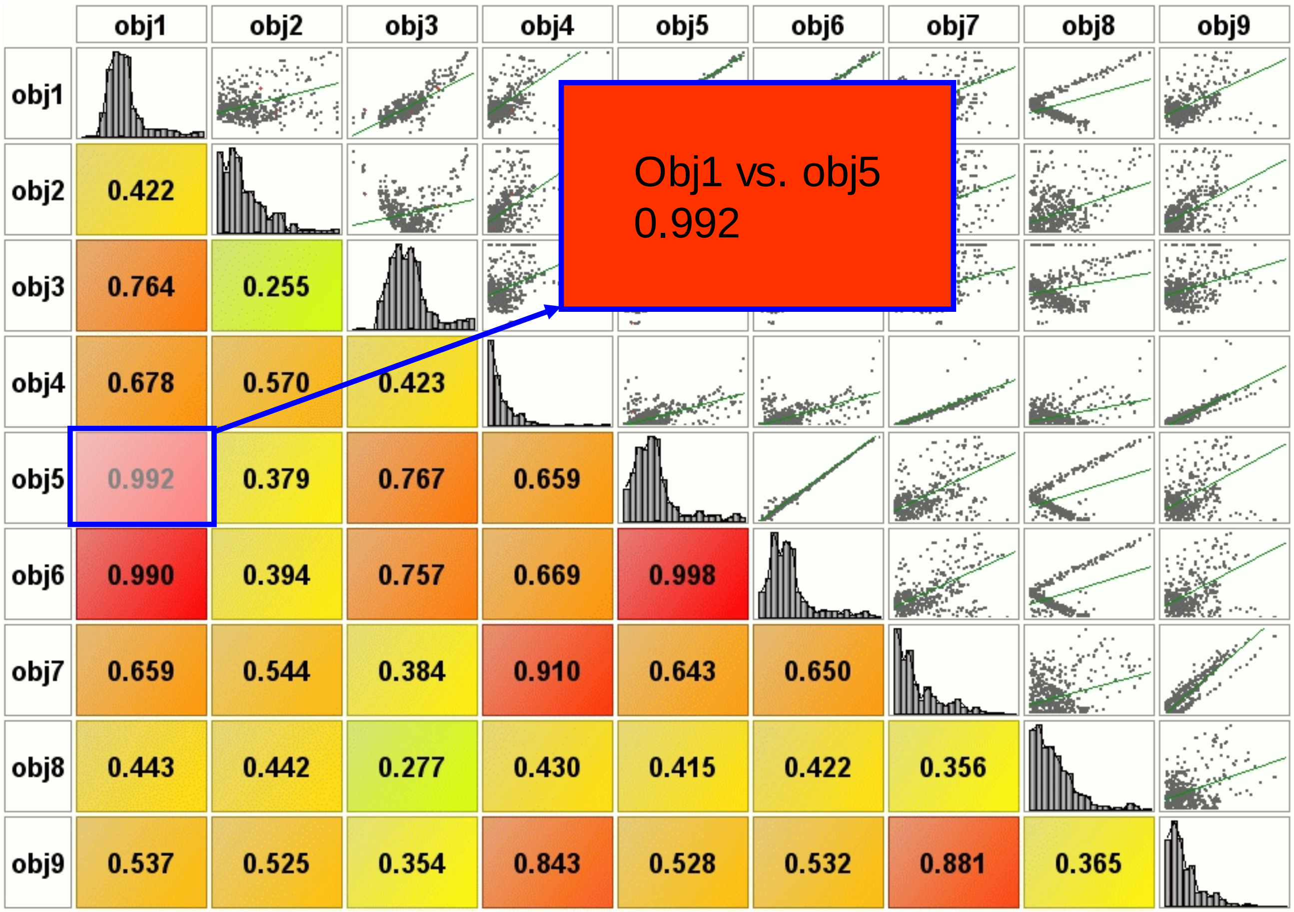

	obj1	obj2	obj3	obj4	obj5	obj6	obj7	obj8	obj9
obj1									
obj2	0.422								
obj3	0.764	0.255							
obj4	0.678	0.570	0.423						
obj5	0.992	0.379	0.767	0.659					
obj6	0.990	0.394	0.757	0.669	0.998				
obj7	0.659	0.544	0.384	0.910	0.643	0.650			
obj8	0.443	0.442	0.277	0.430	0.415	0.422	0.356		
obj9	0.537	0.525	0.354	0.843	0.528	0.532	0.881	0.365	

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How modeFRONTIER is helping you - 4 – Statistical Analyses (… some tools)

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	obj1	obj2	obj3	obj4	obj5	obj6	obj7	obj8	obj9
obj1									
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obj7	0.659	0.544	0.384	0.910	0.643	0.650			
obj8	0.443	0.442	0.277	0.430	0.415	0.422	0.356		
obj9	0.537	0.525	0.354	0.843	0.528	0.532	0.881	0.365	

Obj1 vs. obj5
0.992

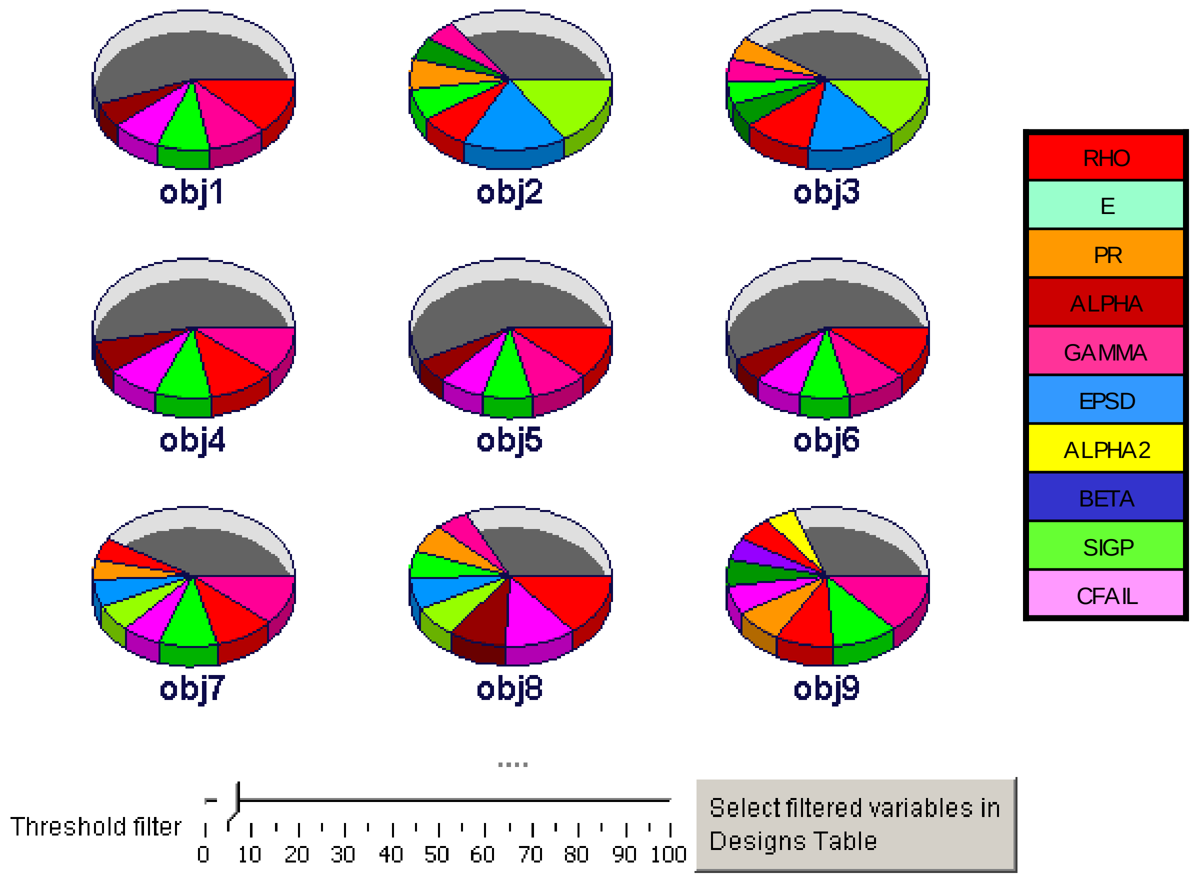
- Only statistical DOE designs (no optimization)
- First-order correlation:
  1 ➔ full correlation
  0 ➔ no correlation

Reduce objectives number

Obj 8 ➔ no correlation

How modeFRONTIER is helping you - 4 – Statistical Analyses (… some tools)

t-Student Chart allows to perform a sensitivity analysis with the aim to highlight the most important input variables in respect of the objective functions.



Every pie chart is an objective and the slices are the input variables

How modeFRONTIER is helping you - 4 – Statistical Analyses (… some tools)

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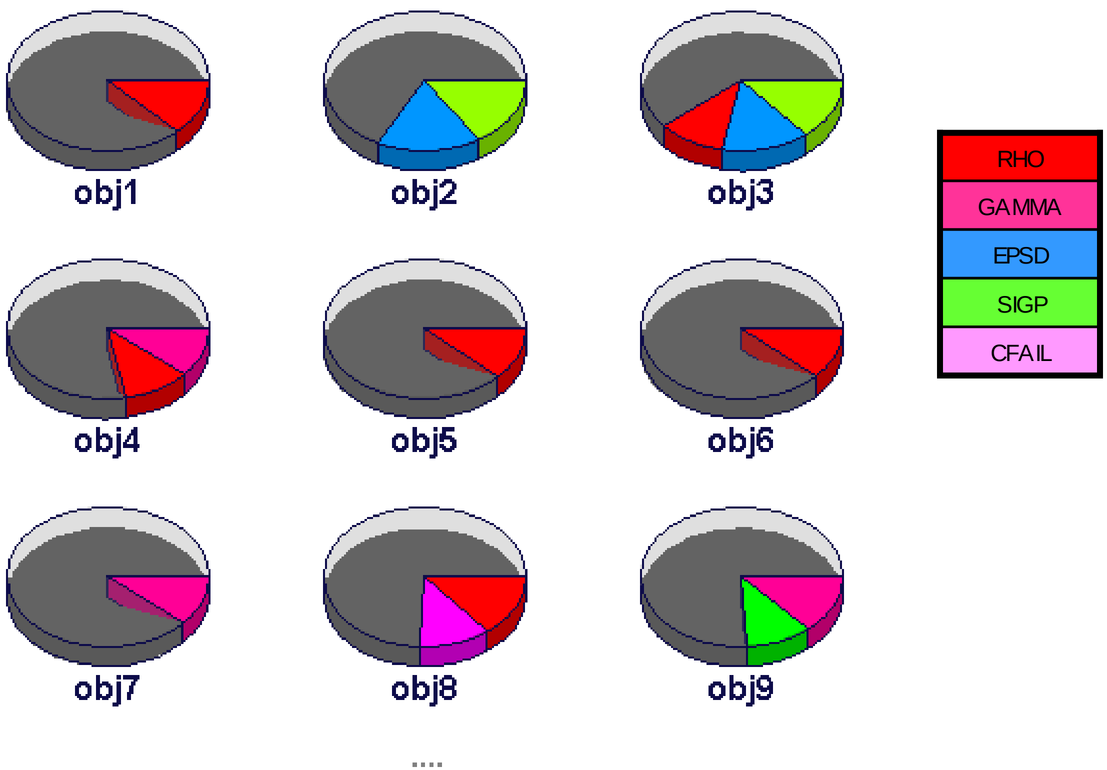
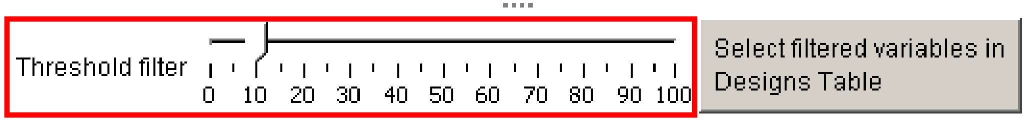




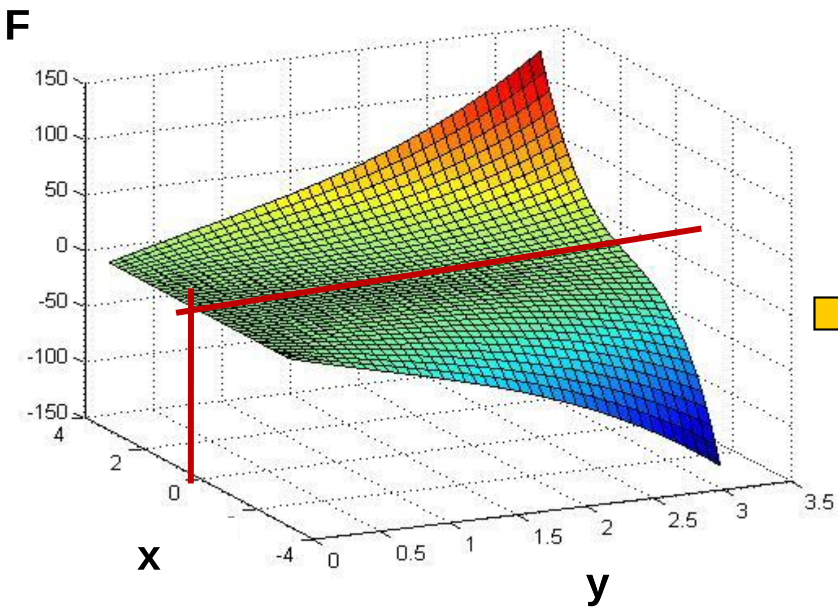
threshold filter

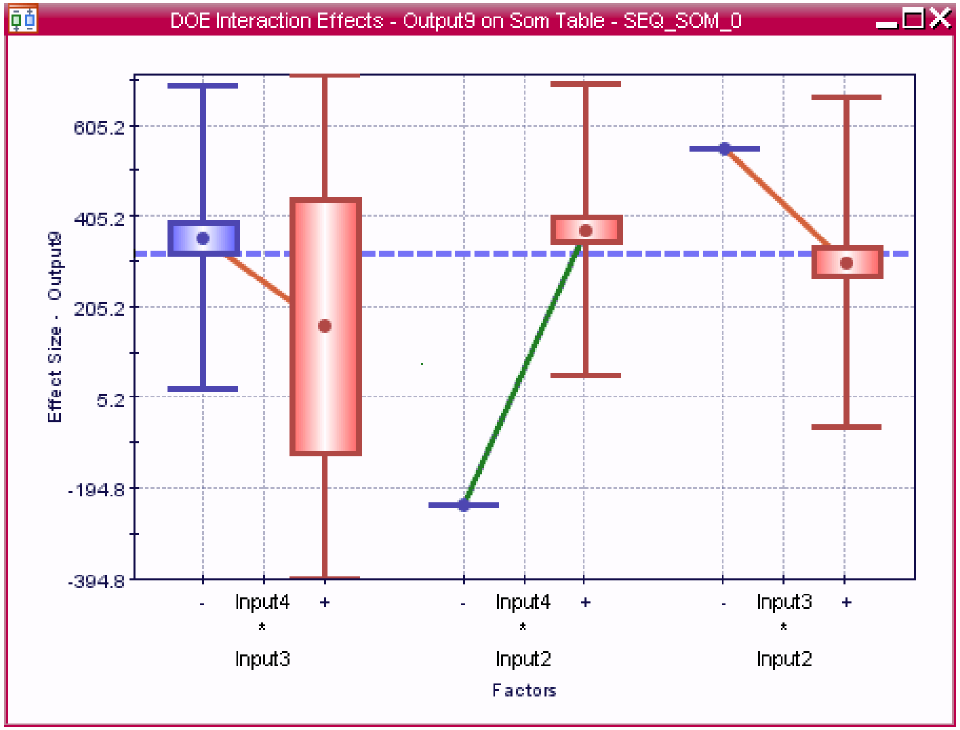
Reduce number of the design parameters

How modeFRONTIER is helping you - 4 – Statistical Analyses (… some tools)

Interaction btw variables ➔ first-order interaction effects F=F(x*y)

DOE Interaction Effects chart shows if the interaction of two variables (e.g. x*y) has an effect on the output (while main effect is 0 for both)





How modeFRONTIER is helping you - 4 – Multivariate Analysis - SOM (… some tools)

SOM (Self Organizing Maps) → statistical tool for multivariate analysis

If the number of variables is high (more than 4 or 5), it becomes prohibitive to plot all the information by classical 2-dimensional charts. SOMs:

- project high-dimensional data space into low-dimensional space (usually 2D)

- put "similar" data samples to nearby cells

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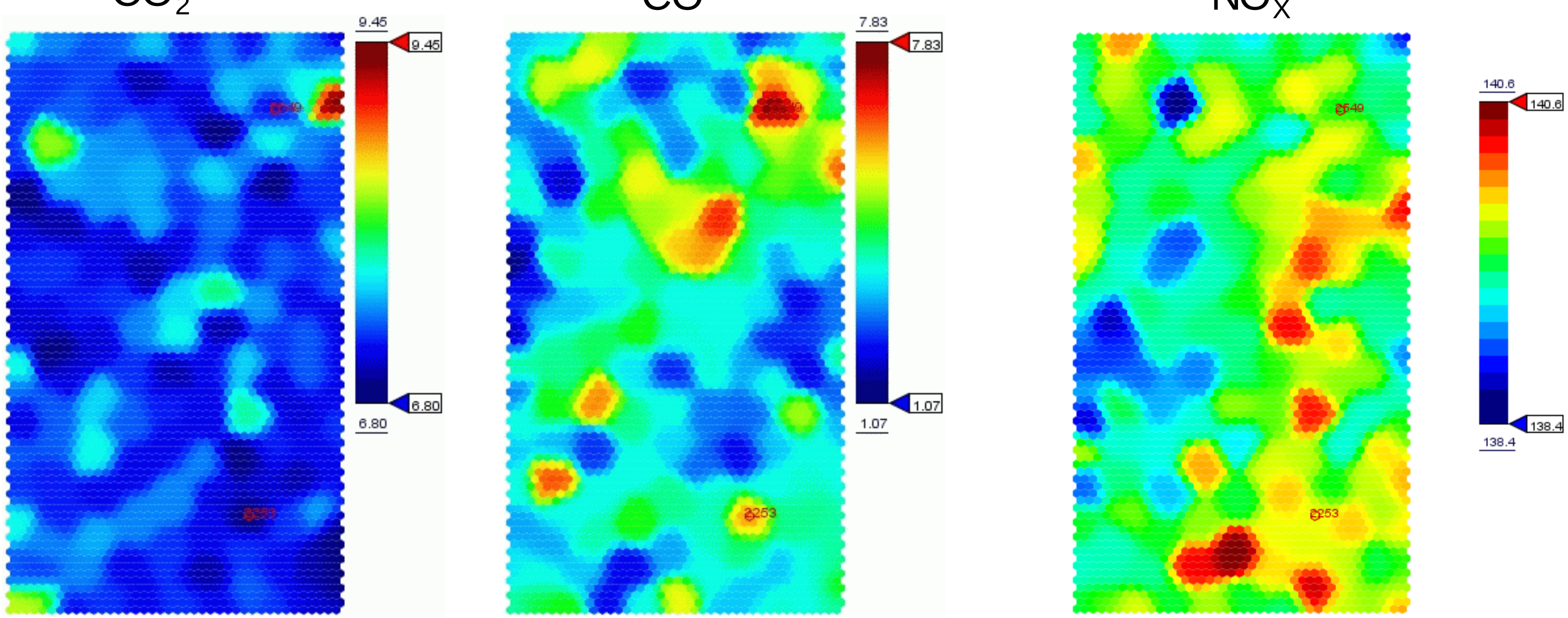
CO_2 CO NO_X



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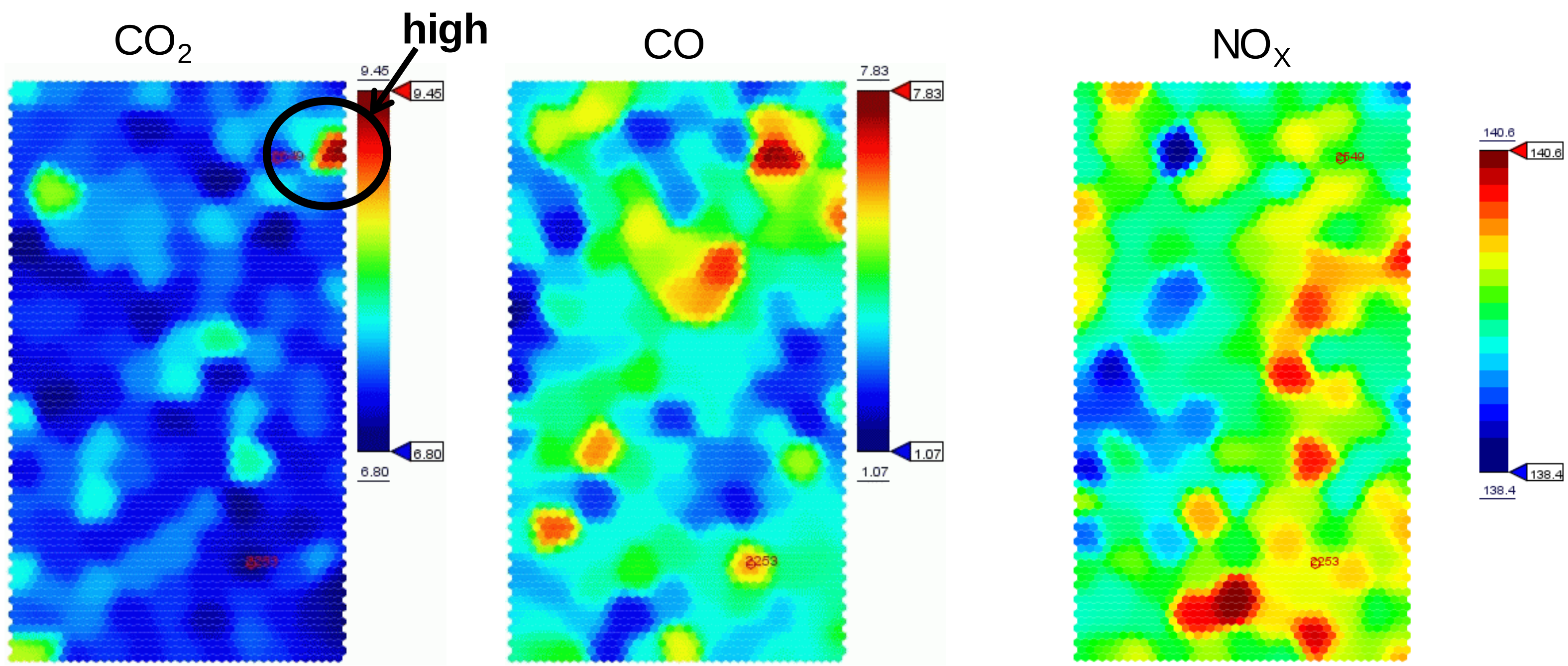

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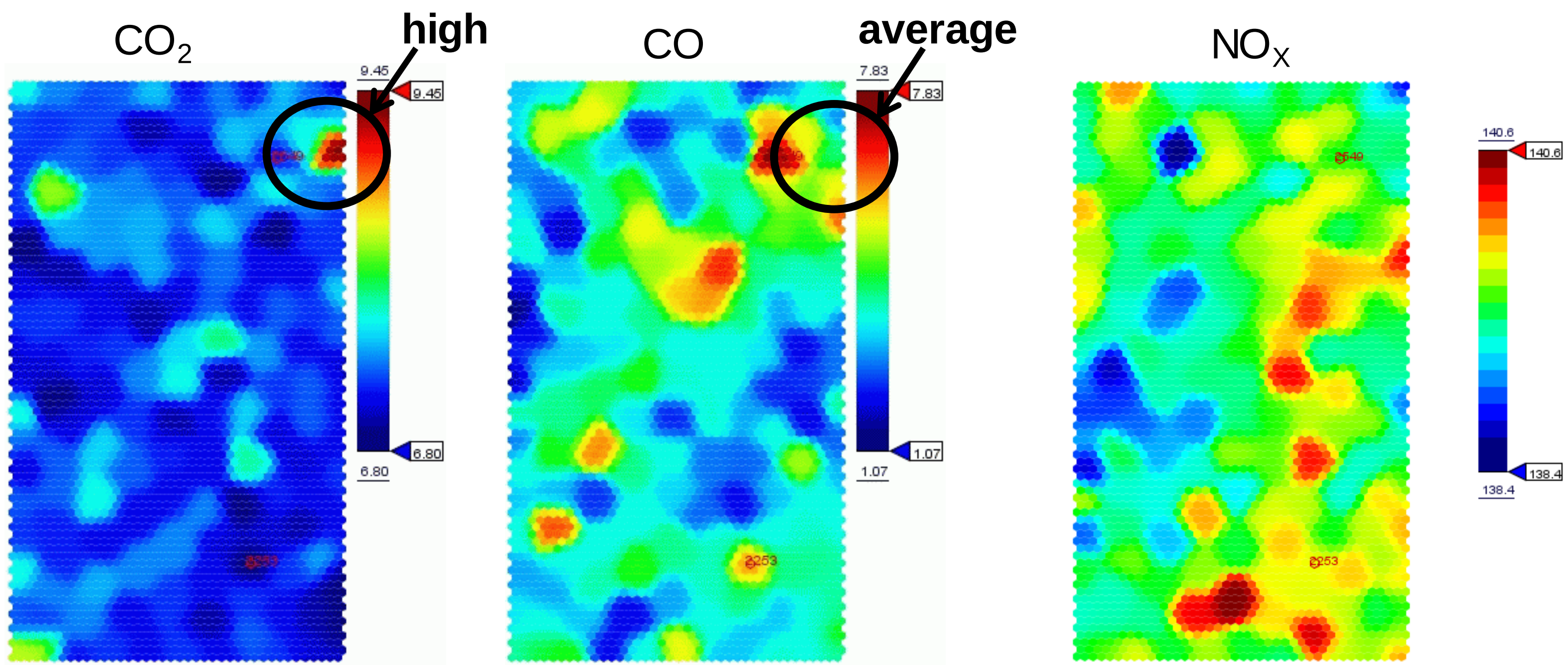

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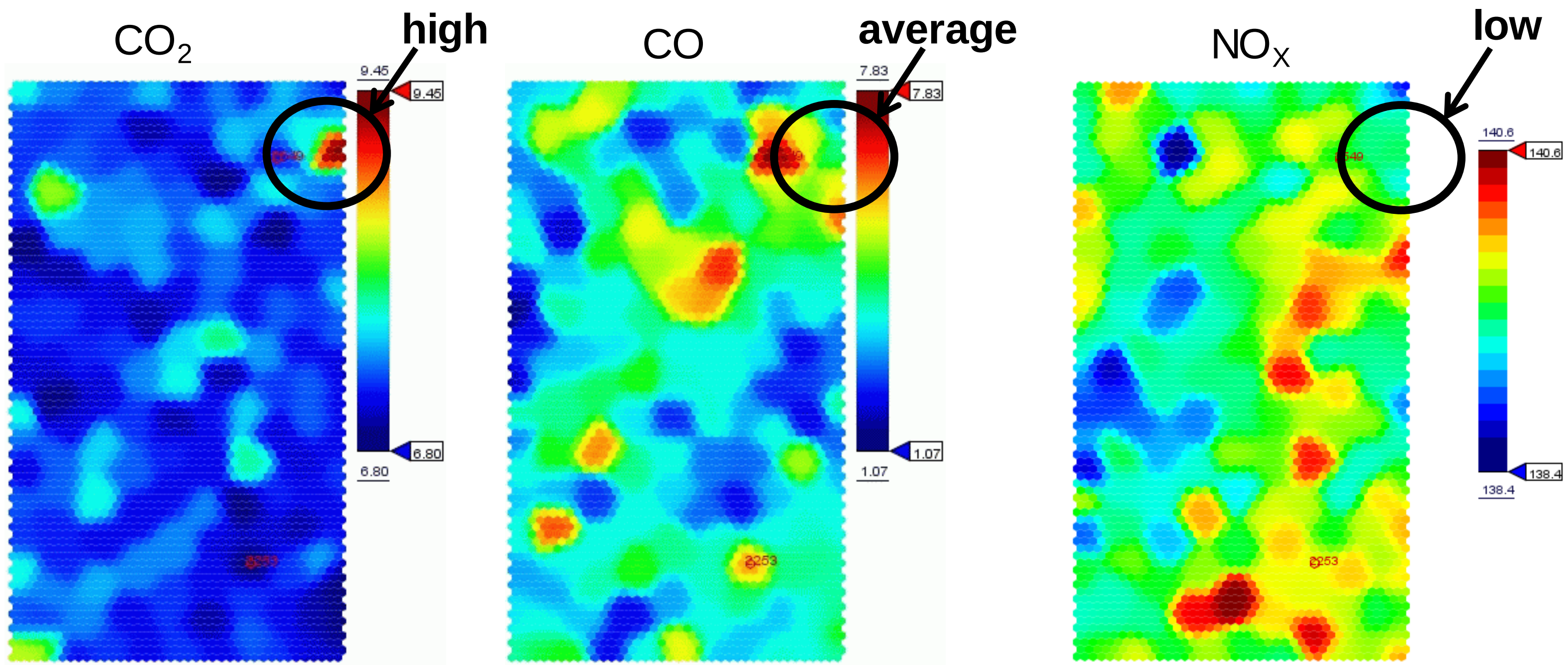


modeFRONTIER

…some applications

Application Fields

Aerospace
CFD/Structural interaction on 3d wing
Flap Splitting and Wing Setting analysis
Shape analysis of airfoil profile
Ramjet-Powered Missile analysis
Supersonic Transport Airplane studies

Water Industry, Distribution Networks, ...
Drainage and flooding risk assessment
Efficient management of water and wastewater distribution networks
Multi-Objective Optimization of Water Distribution Network

Turbomachinery
Centrifugal Compressor 3D analysis
Axial Turbine 3D analysis
Axial Compressor 3D analysis
Turbine single stage 2D steady and unsteady analysis
Turbine 2 stages 2D unsteady analysis

Powertrain Optimization
Inlet ducts 3D analysis
Water Jacket 3D analysis
Exhaust ducts 3D analysis
Whole engine 1D analysis
(CFD and Cooling Manifolds applications)

Experimental Application
Washing Machine experimental assessment
Burners Modelling and prediction studies

Combustion
Burners Pre-mixer analysis for a Gas Turbine
Complex Chemistry reactions

Power plants and Heat Exchange cases
Heat Exchanger for Domestic Boilers analysis
Axisymmetric Fin designing for Heat Exchangers
Evaporator geometry analysis
Domestic Refrigerator thermal analysis

Multibody, Crash, Structural, Vibro-Acustics
Automotive braking system analysis
Vehicle Comfort-Handling analysis
Racing Vehicle Suspension set-up analysis
Vacuum Bell analysis
Electro-Magnetic Actuator analysis
Frontal Frame crash analysis

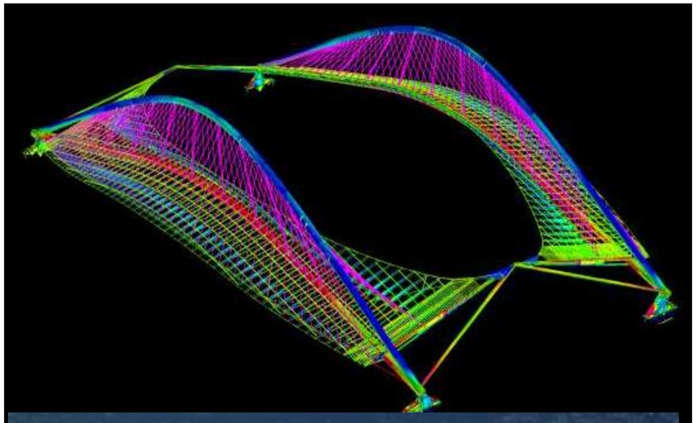
Manufacturing
Injection Molding analysis for automotive components
Metal Casting analysis
Metal sheet forming and thermo-forming analysis

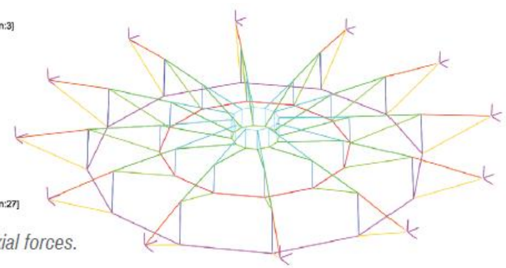
Marine
Ship hull design
Wave wash minimisation analysis
Stabilising fin analysis
3D full ship study
Ship structure optimisation

Architectural: roof of stadium (Olympic Stadium of Athens, Georgia Dome in Atlanta)

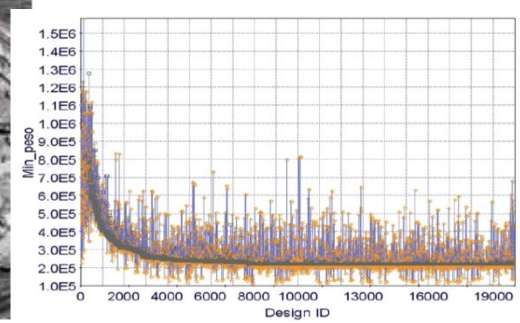
- modeFRONTIER was used to determine the exact amount of <u>pre-stress in cables</u> (input variables) such to achieve the <u>final post-tensions</u> (objective) determined through measurements

- the FE model integrated with modeFRONTIER to compute each configuration tensions is Straus7

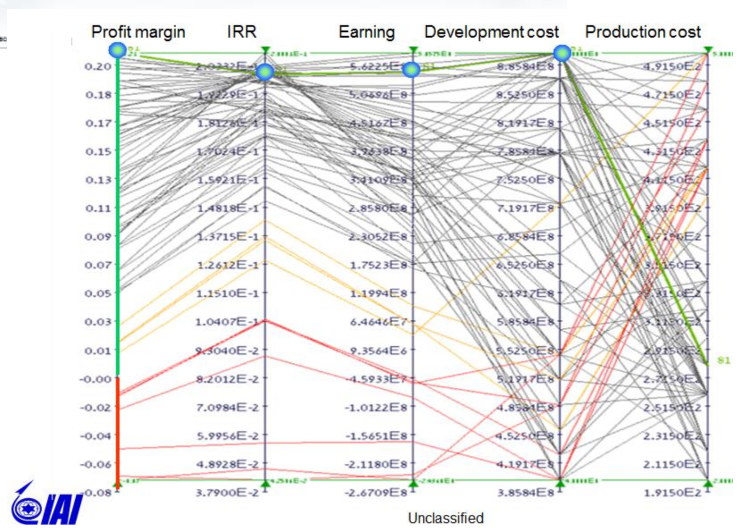




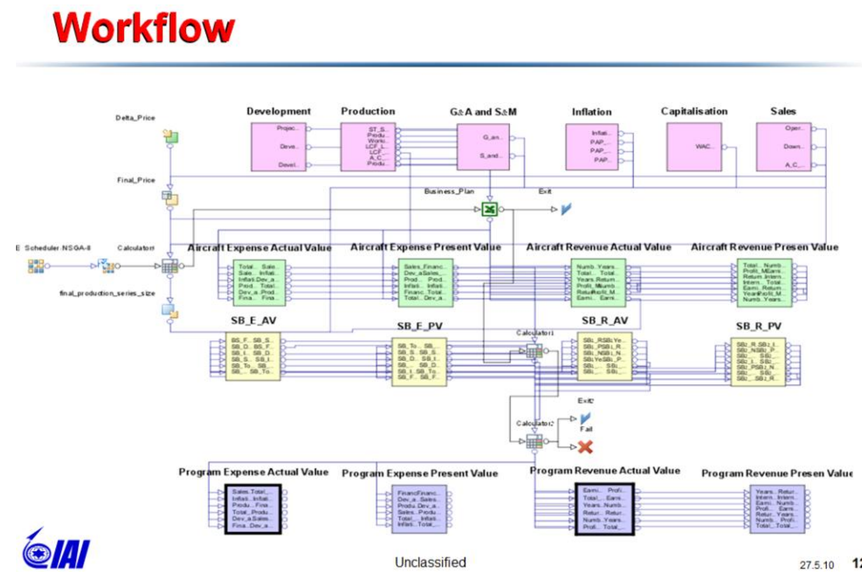
(b) Final axial forces.

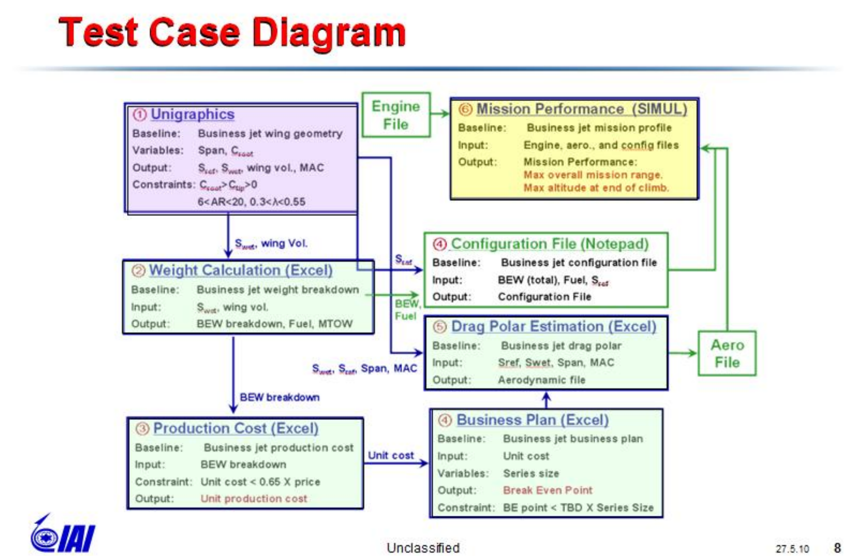


MultiDisciplinary Example: Engineering and Cost Multi-disciplinary Optimization



Full presentation available within modeFRONTIER International Users' Meeting proceedings, 2010



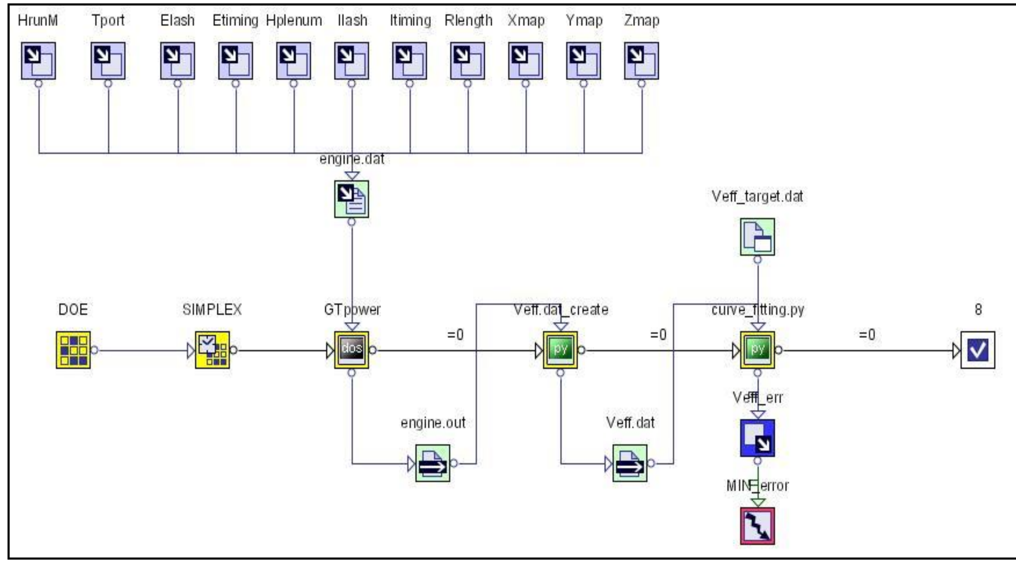


Automotive: Numerical Model Calibration

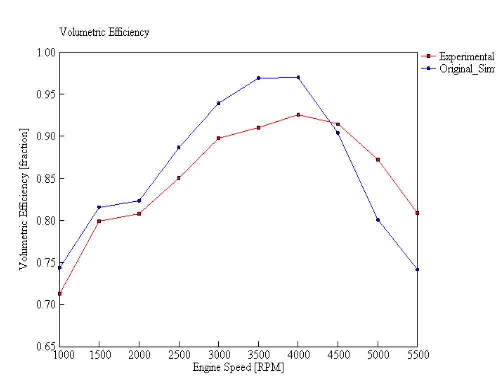
- A GT-Power model is used for a calibration

- experimental data (volume efficiency vs. rpm chart) is available and GT-Power model parameters (HT coefficients, valves timing, etc..) have to be set to match the curve

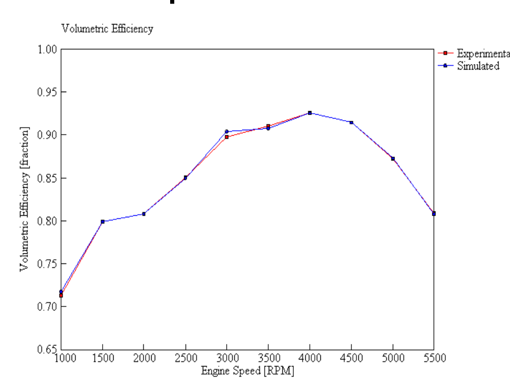
- the optimisation objective is the minimisation of mean squared distance between experimental and numerical curves



Initial model



Optimised model



Automotive: numerical model calibration

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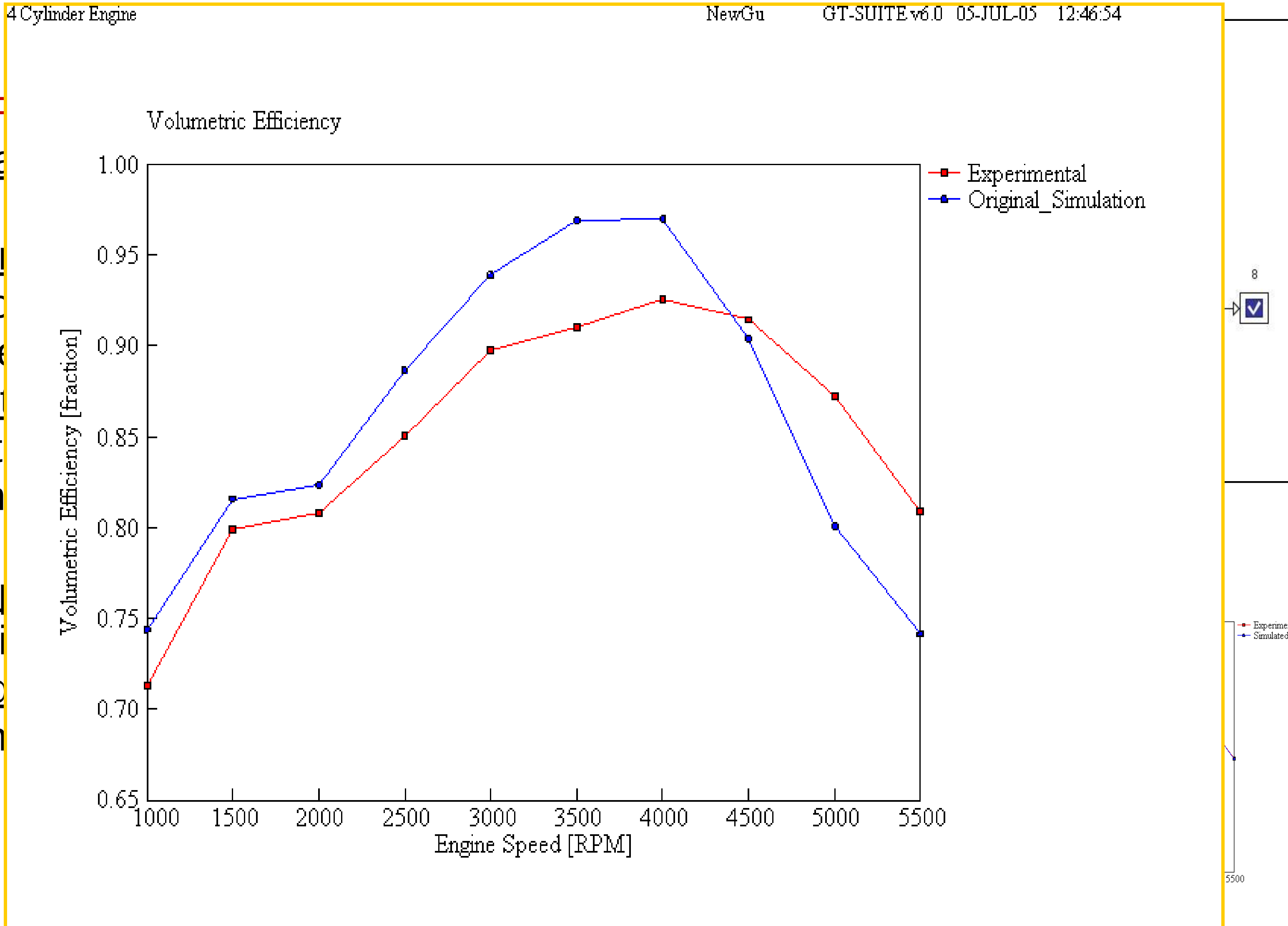

Automotive: numerical model calibration

• A GT-P
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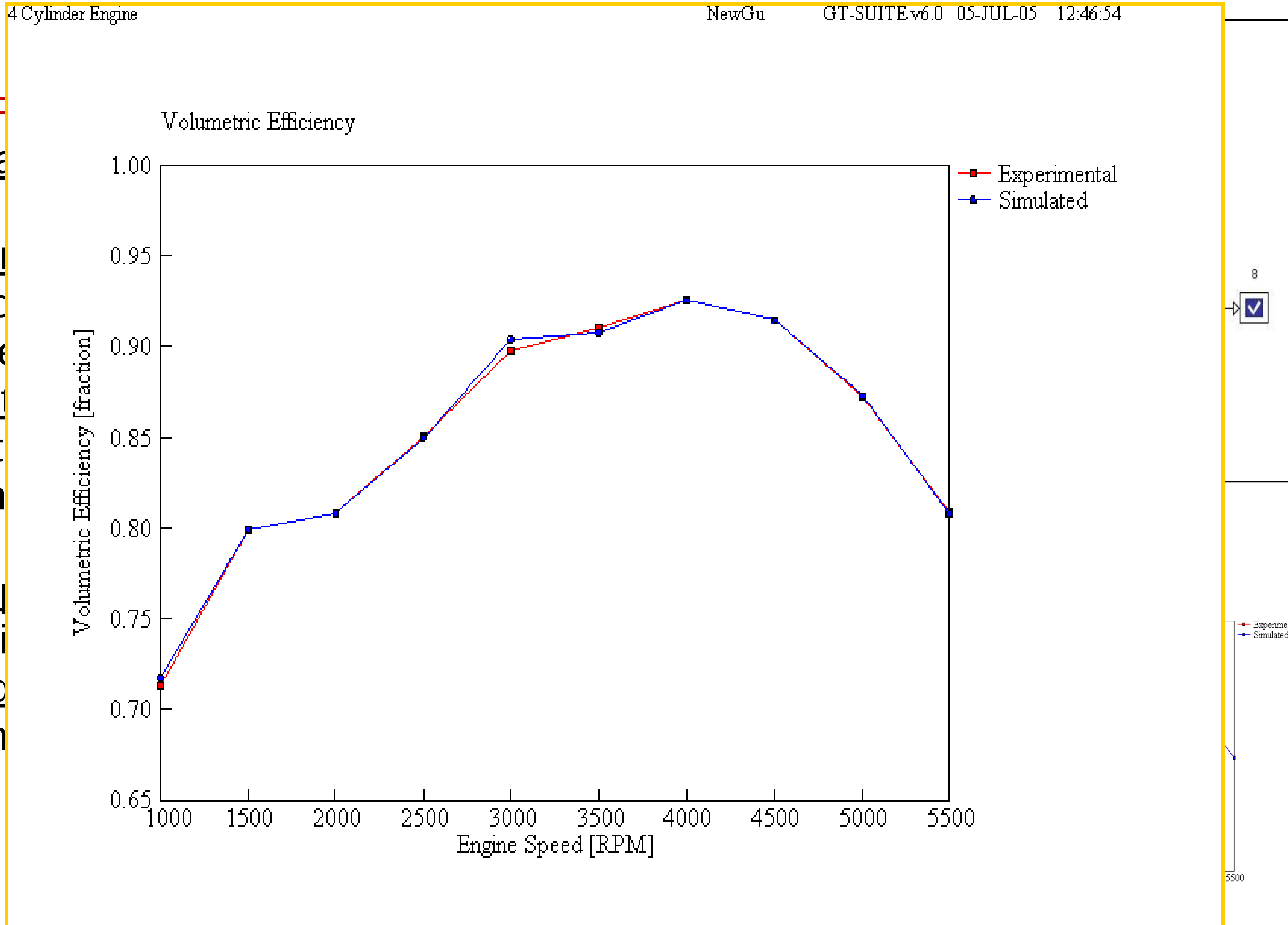
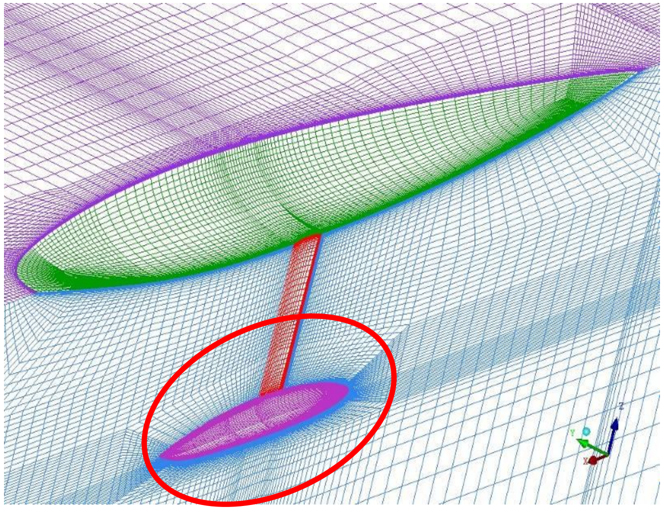
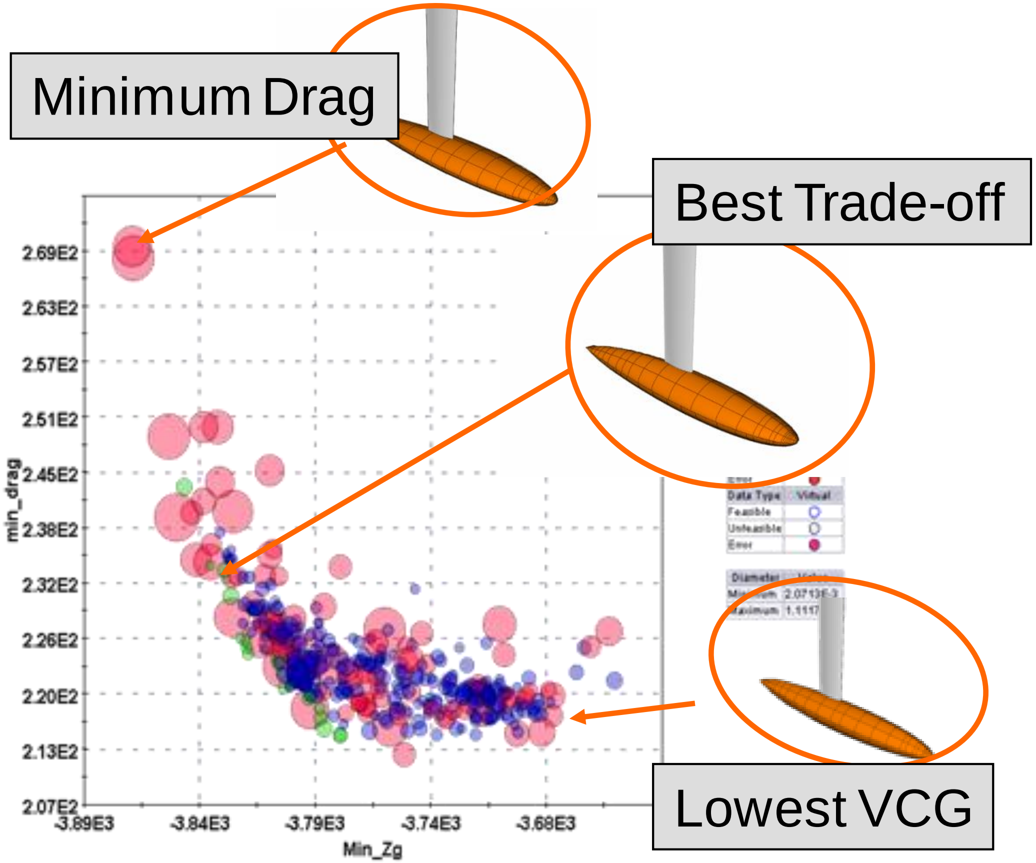


America's Cup Class Yacht Bulb





An initial ellipsoid is modified with Bezier curves (CATIA v5), and scaled to the target volume.
Mesh by ICEM and CFD by CFX5

Optimization goals:

- minimum drag
- lowest center of gravity

ENGIN SOFT

Key partner in Design Process Innovation

Thanks for your time!

Vito Primavera
v.primavera@enginsoft.it

Key partner in Design Process Innovation

Exploring Design Alternatives for DG5 Schemes Assisted by modeFRONTIER

modeFRONTIER coupled to InfoWorks CS

David Moseley, John Barnes (ES UK), Vito Primavera (ES Italy)

Abstract

- This activity will demonstrate the following:
  - ✓ How modeFRONTIER can be applied to DG5 (register for flooding problems) flood alleviation
  - ✓ How automated techniques and smart optioneering can propose a range of optimal scheme alternatives
  - ✓ How alternative designs are created, flooding quantified, and costs calculated
  - ✓ How designs are tested against multiple Design Storms and Time Series Rainfall (TSR) evaluation
  - ✓ The incorporation of cost models to permit direct financial comparison of alternatives, and the systematic assessment of every monitored performance attribute under every storm condition, providing robust auditing of all possible design requirements

Background

- EnginSoft UK set up a Steering Group (SG) to allow the Water Industry to drive the development of a software platform (based on InfoWorks CS and modeFRONTIER) addressed to meet the expectation and requirements of the experts in the field
- Several meetings have been held and the outcome of the of those meetings has directly influenced the functionality of the Interface
- Furthermore, the SG members have requested certain case studies be conducted and reported in order to jointly test the software and verify its capability
- This paper was carried out on one of the models provided by one of the members or the SG
- The following Companies have active members in the Steering Group:
  - Anglian Water, Southern Water, Yorkshire Water, Wessex Water
  - Atkins Global, Clear, Pick Everard, Mott MacDonald, MWH Global, Remwater, Innovyze

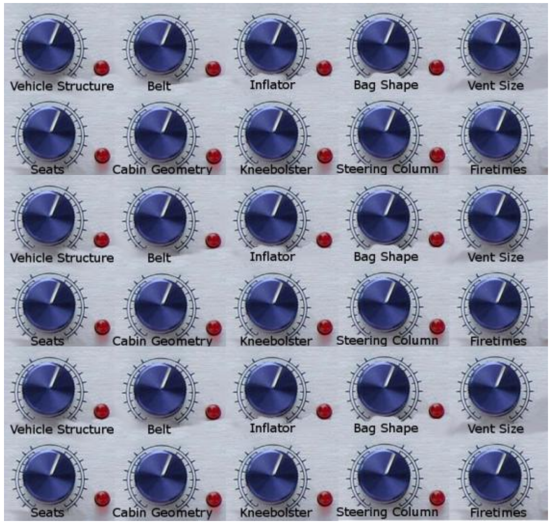
Outline

- Automated techniques:
  - ✓ The new design process
  - ✓ Application to a real-world problem
- Smart optioneering:
  - ✓ The control of input parameters
  - ✓ The collection of data
  - ✓ Data mining
  - ✓ Solution delivery

Automated Techniques

Generic design process

Design Decisions



Generic design process

Design Decisions

Product / Process

InfoWorks™ CS

Generic design process

Design Decisions

Product / Process

Performance

InfoWorks™ CS

Generic design process

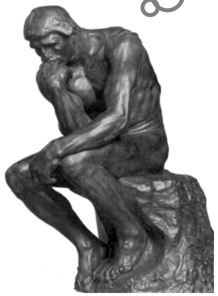
Design Decisions

Product / Process

Performance

InfoWorks™ CS

How do I best fulfil the design requirements?



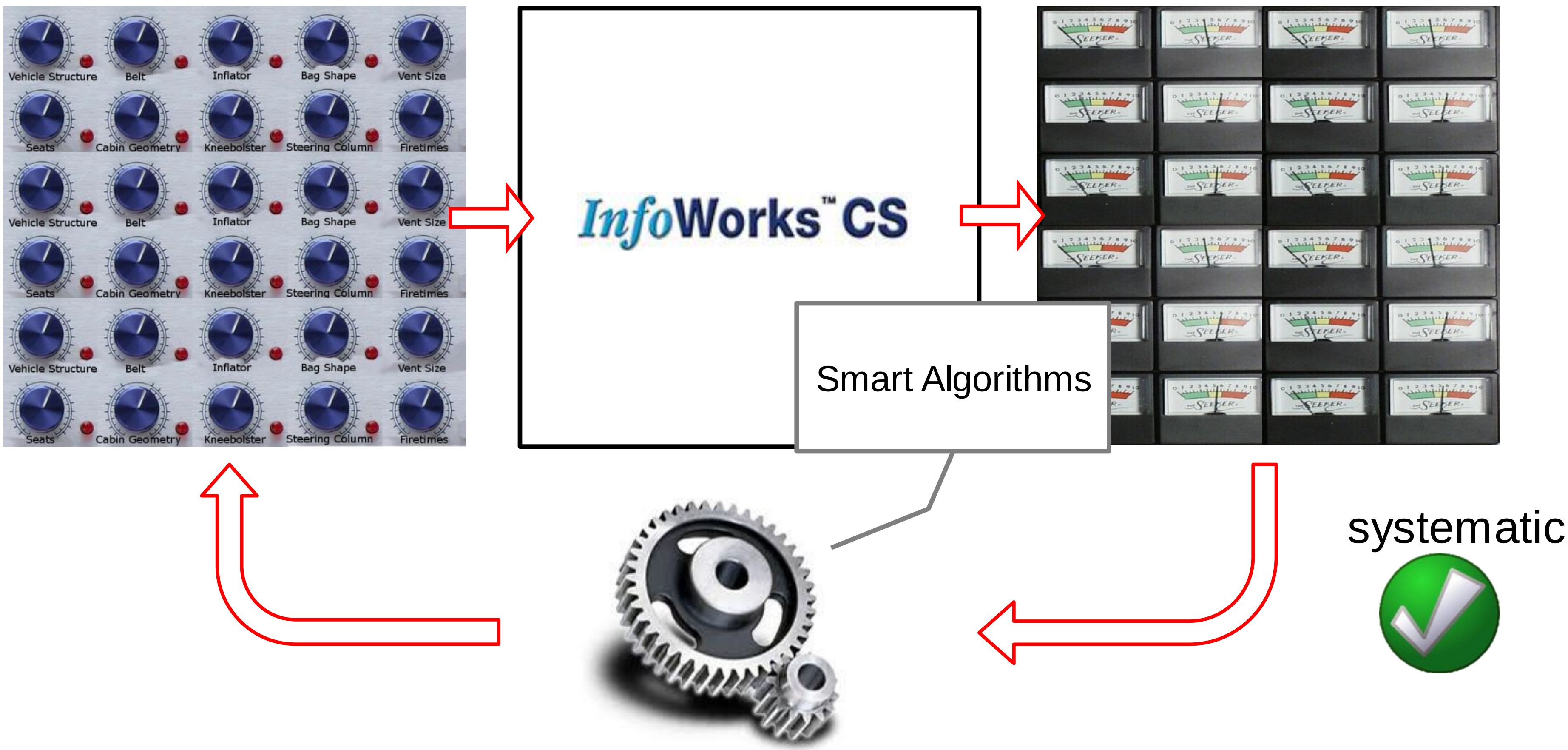
heuristic

Generic design process

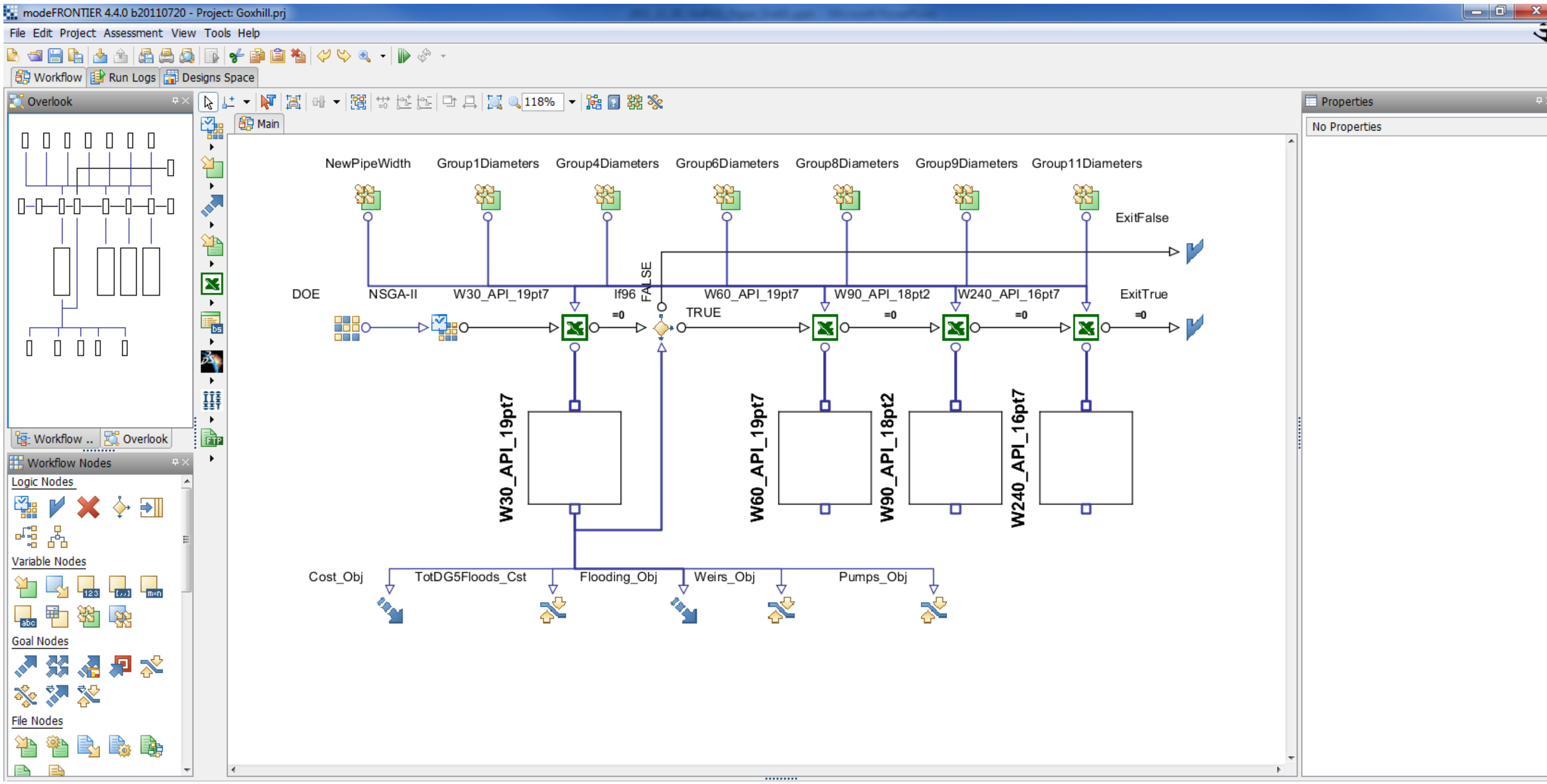
Design Decisions

Product / Process

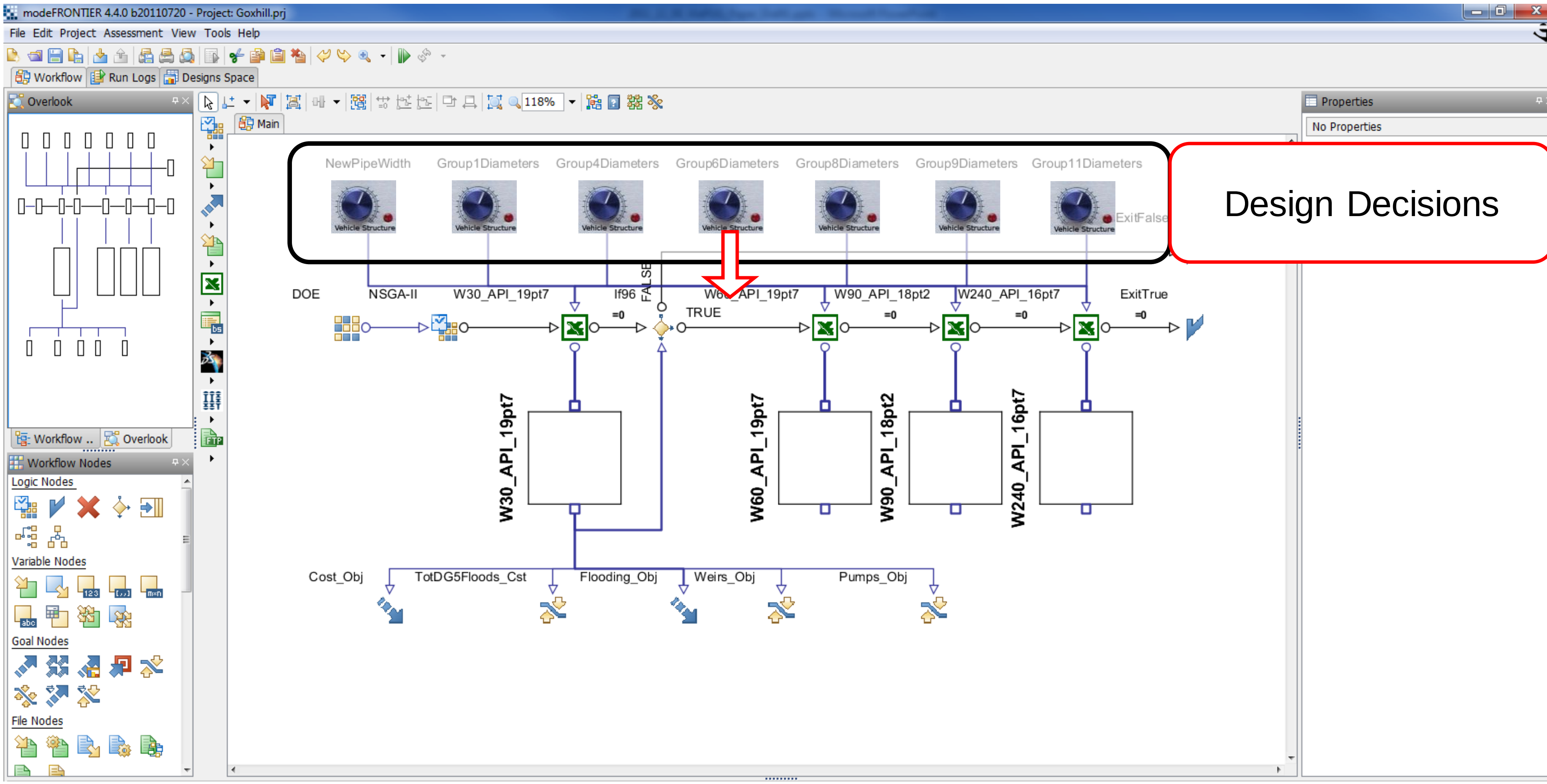
Performance



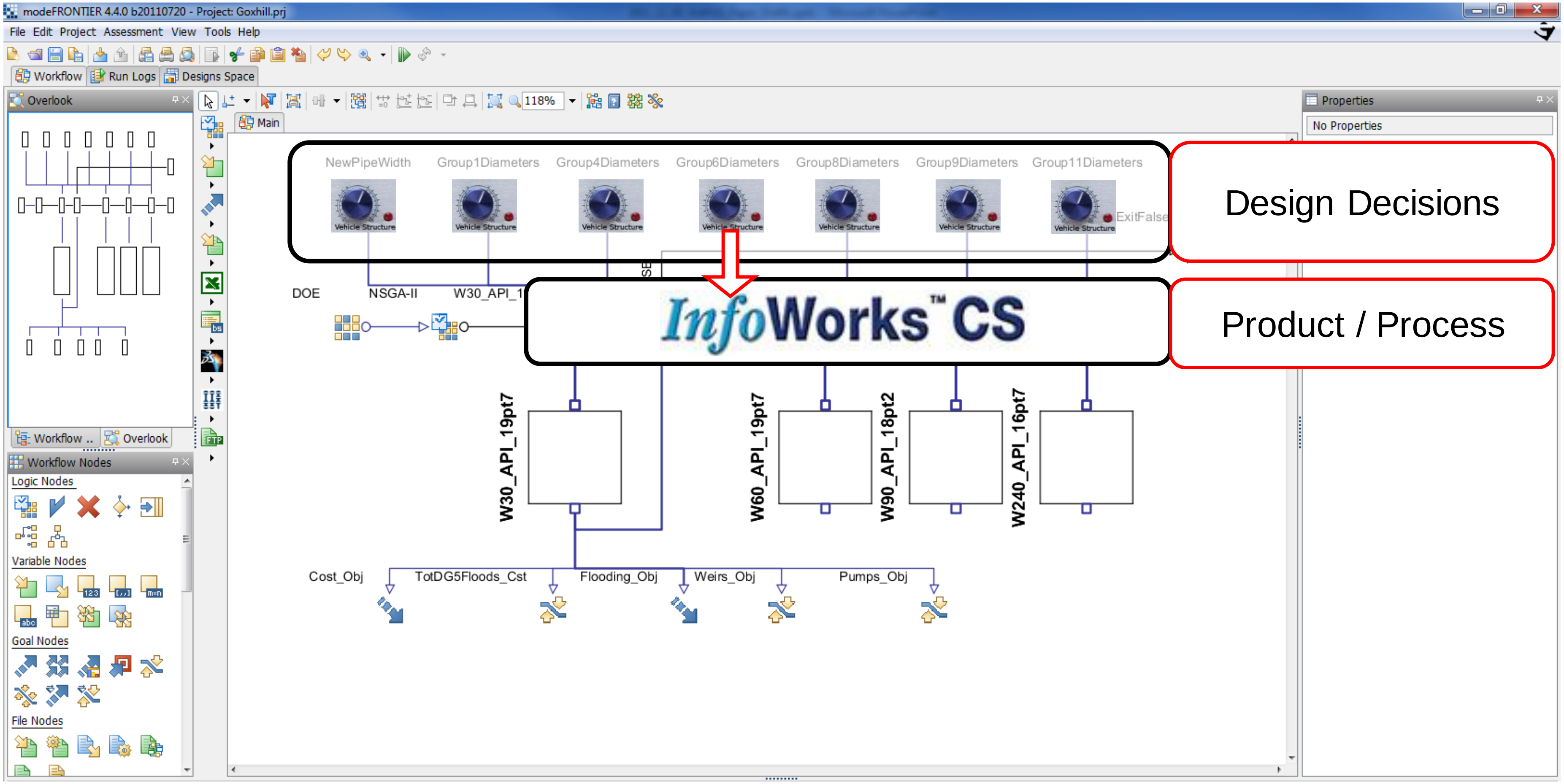
modeFRONTIER design process



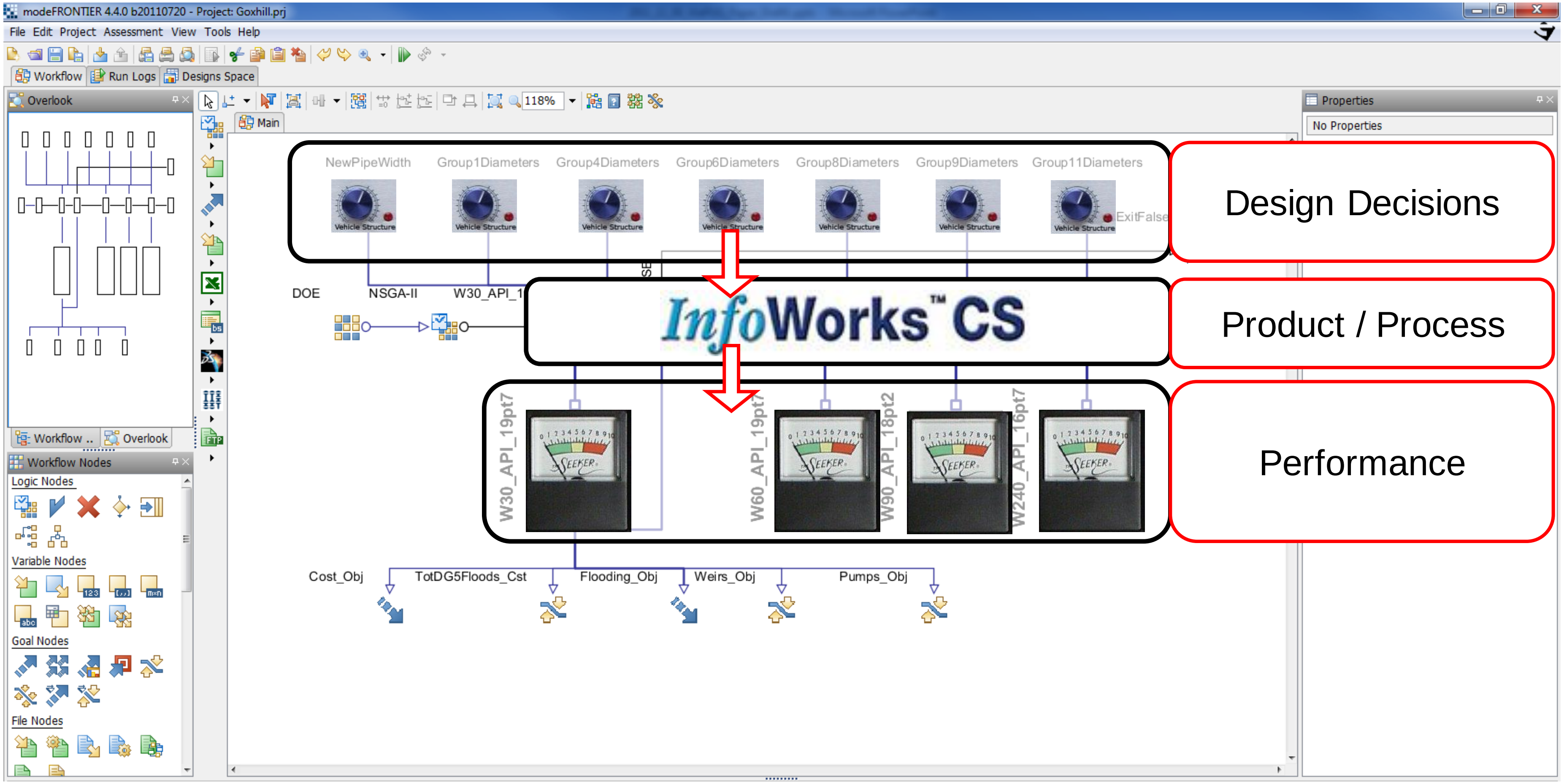
modeFRONTIER design process



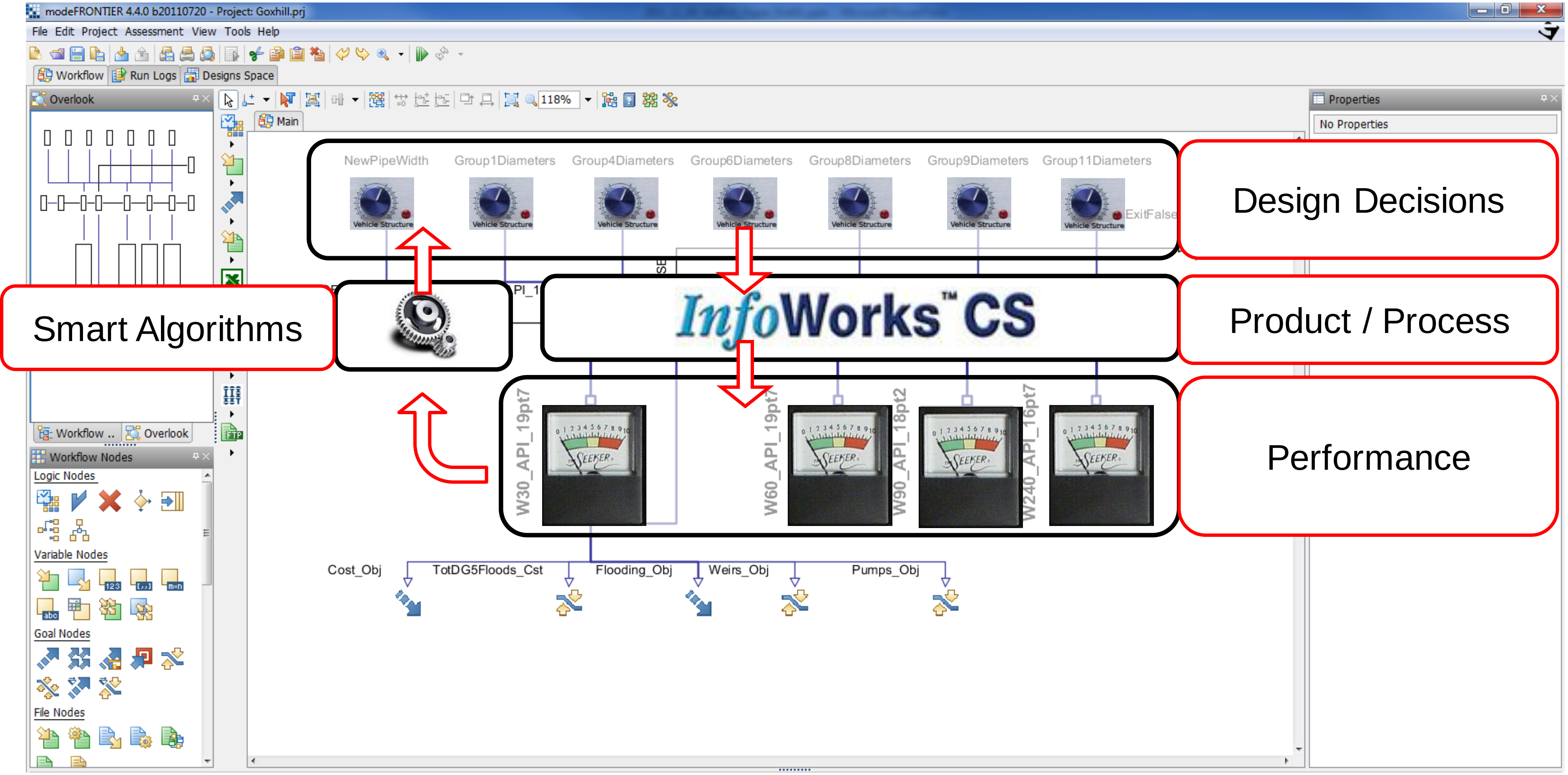
modeFRONTIER design process



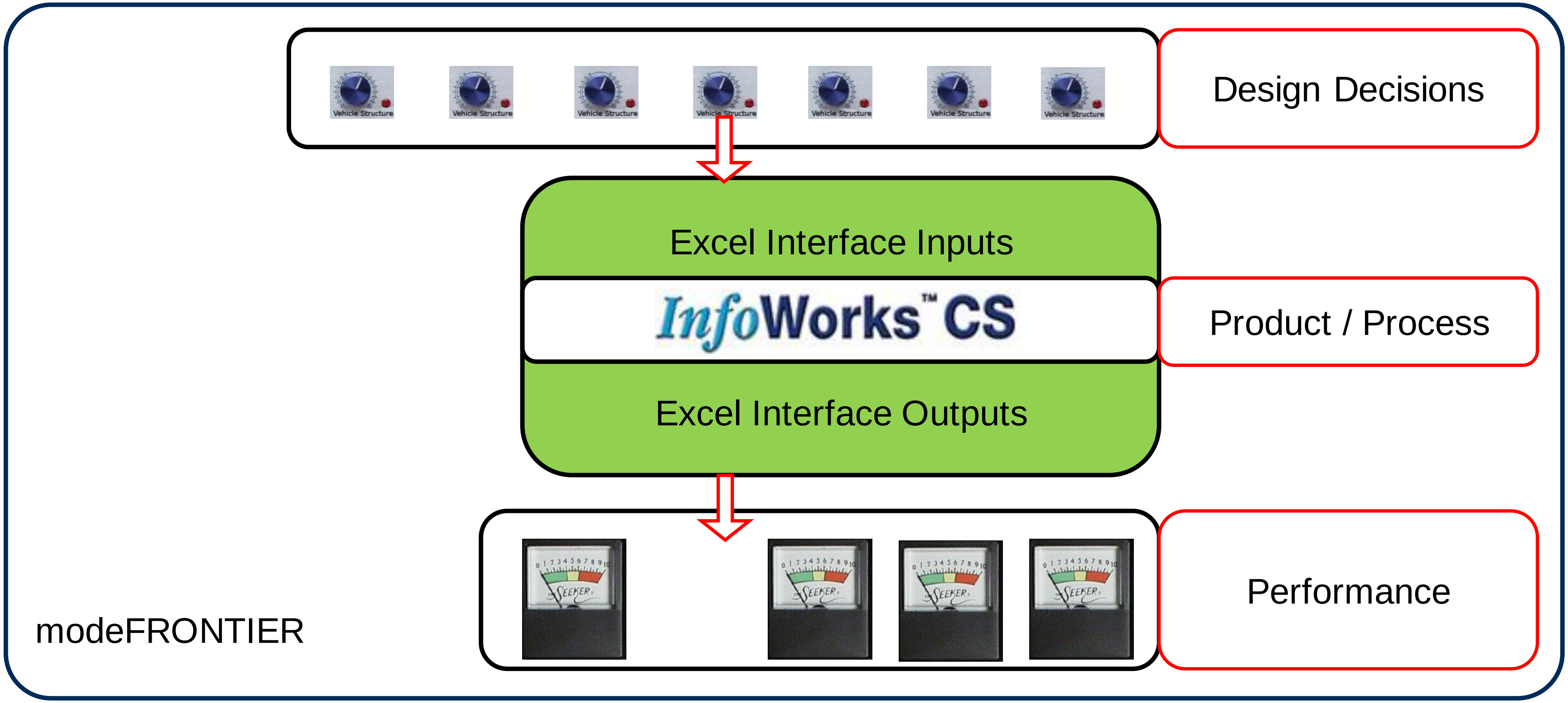
modeFRONTIER design process



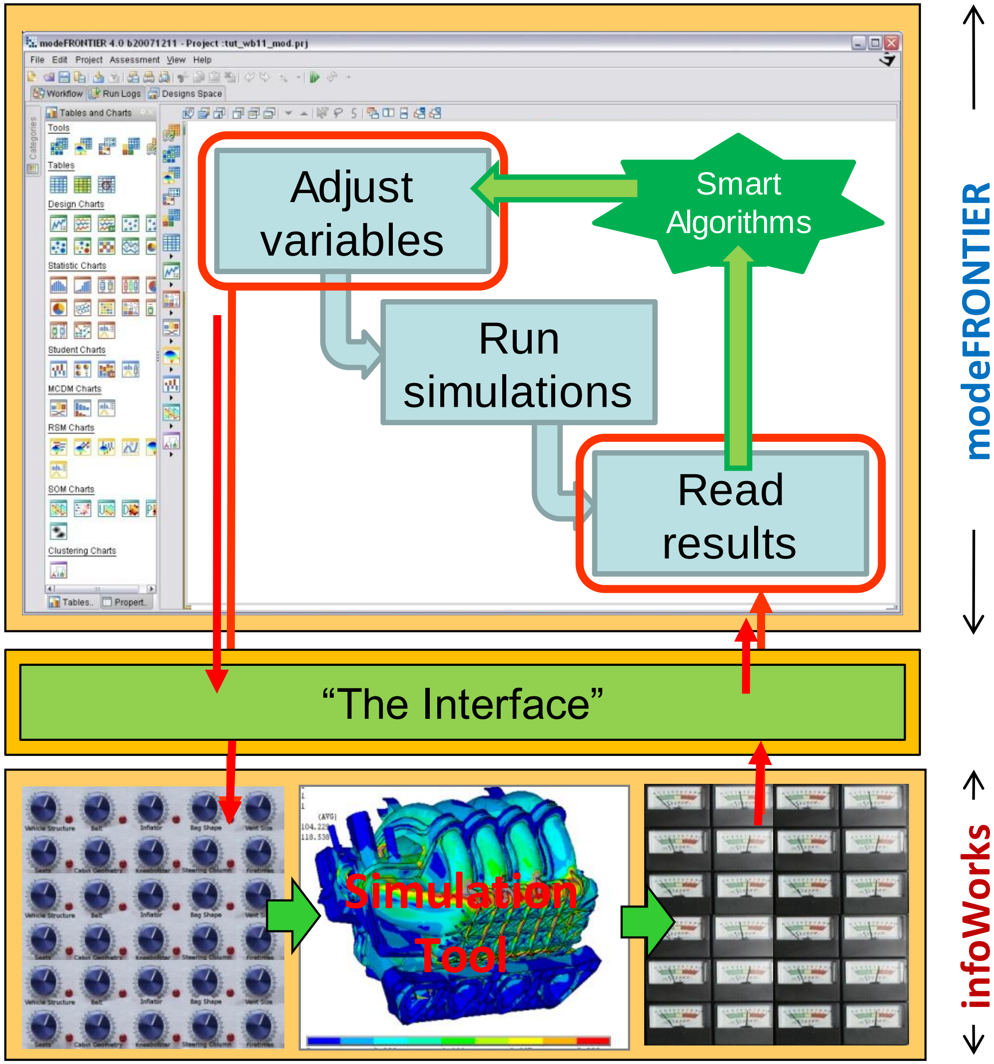
modeFRONTIER design process



modeFRONTIER design process



Interface for InfoWorks CS



- The Interface is a layer (in the form of a spreadsheet) between modeFRONTIER and InfoWorks CS that enables InfoWorks CS to be run automatically
- modeFRONTIER carries out sequential InfoWorks simulations adjusting input variables and evaluating improvements to verification fits from each run

Application: Sewerage at Thorpe-le-Soken (UK)

Thorpe-le-Soken (UK): small village with a number DG5 flood locations

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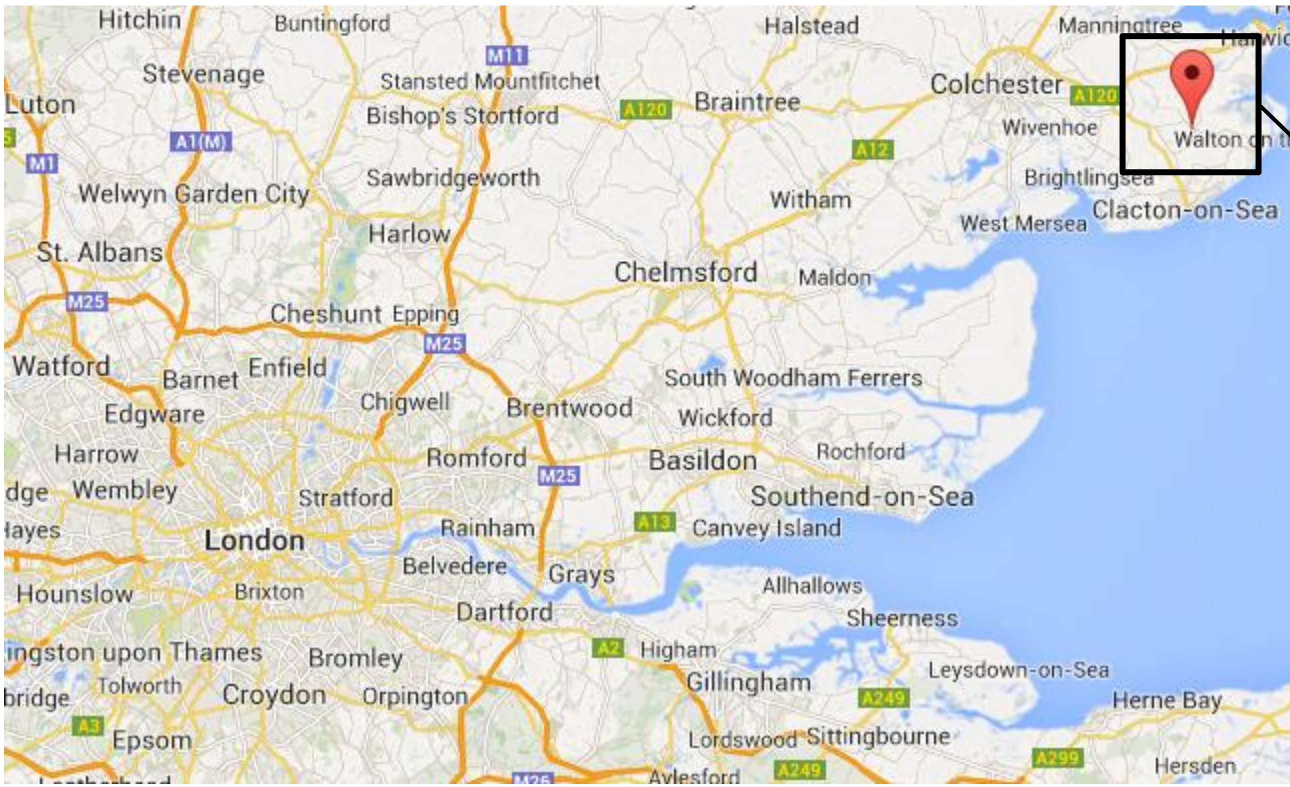

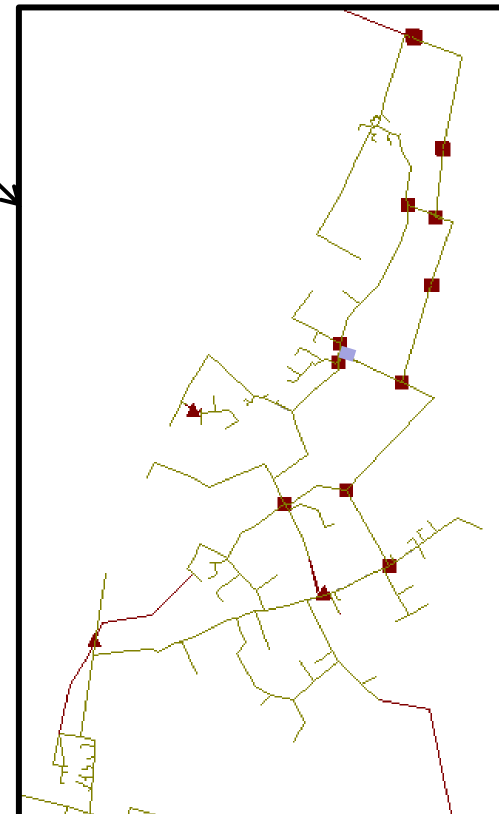

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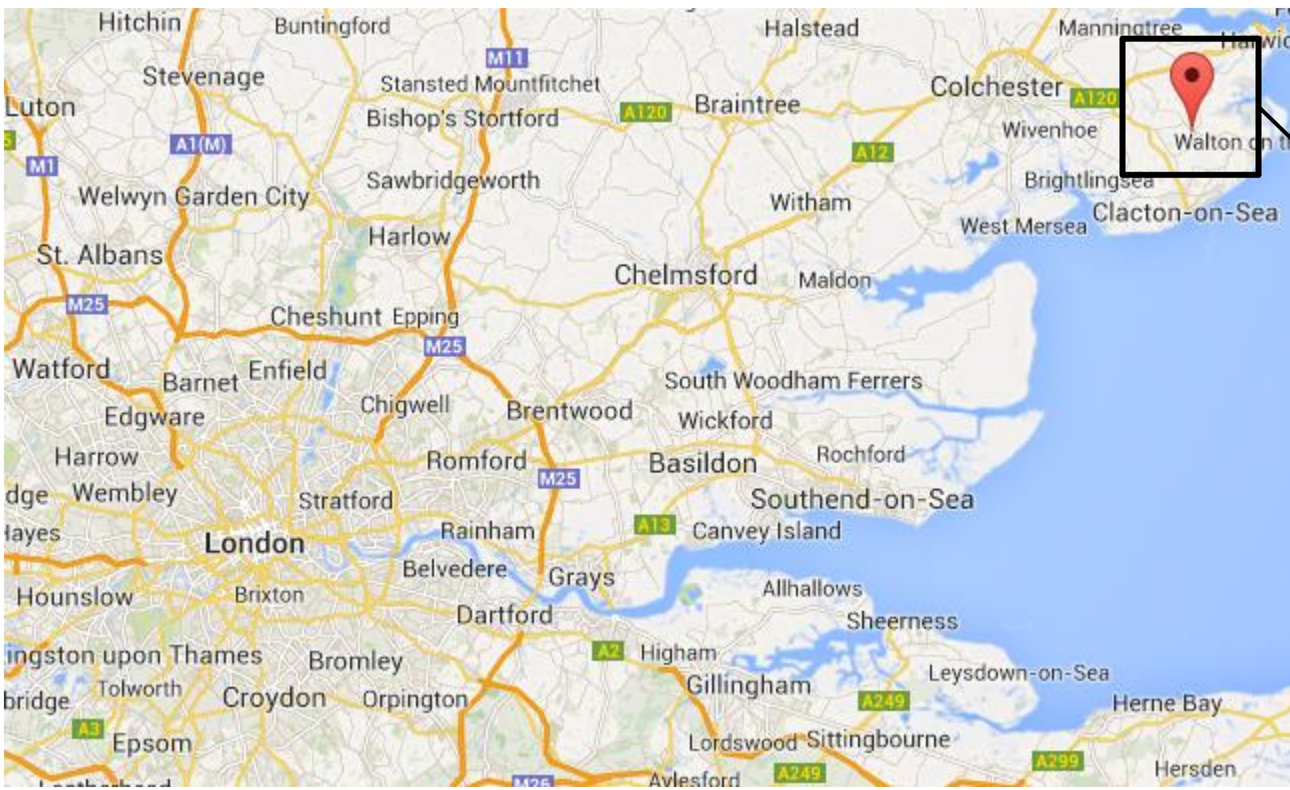

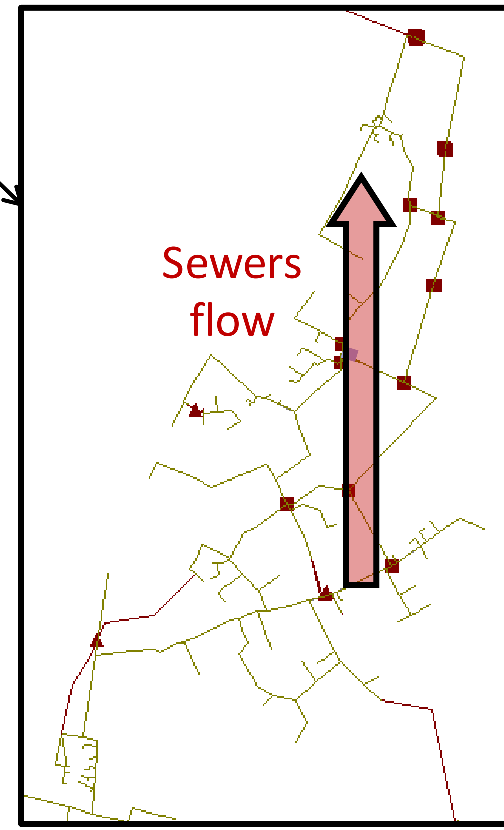

Application: Sewerage at Thorpe-le-Soken (UK)

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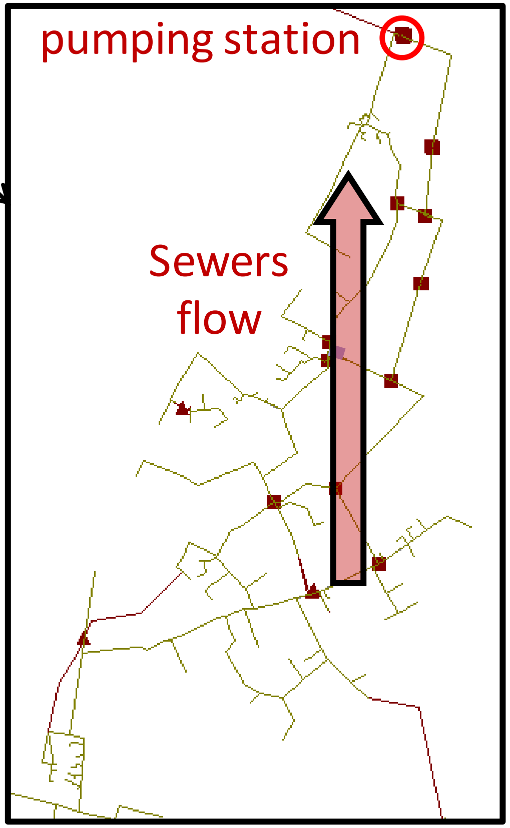


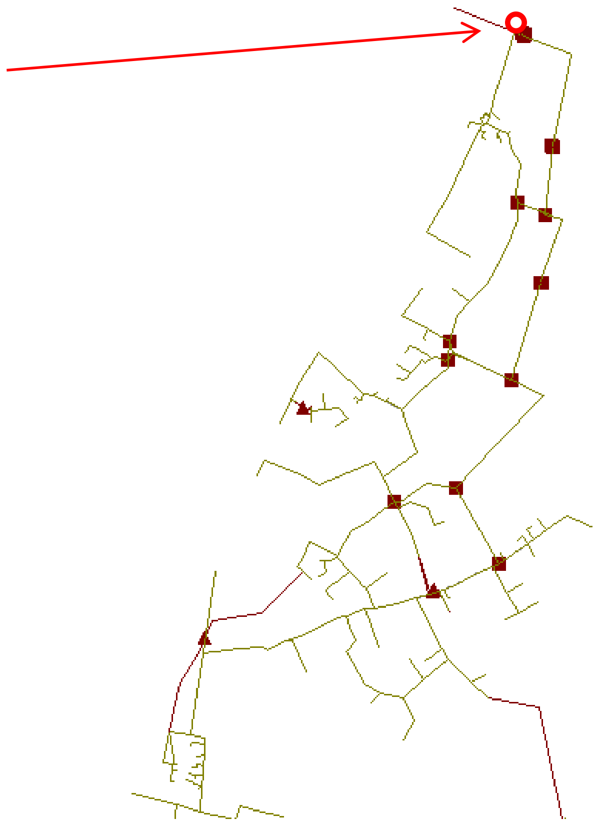
Application: InfoWorks CS Model @ Thorpe-le-Soken (UK)

InfoWorks™ CS

Product / Process

Application: InfoWorks CS Model @ Thorpe-le-Soken (UK)

Overflow at the pumping station could not exceed 4 spills per year

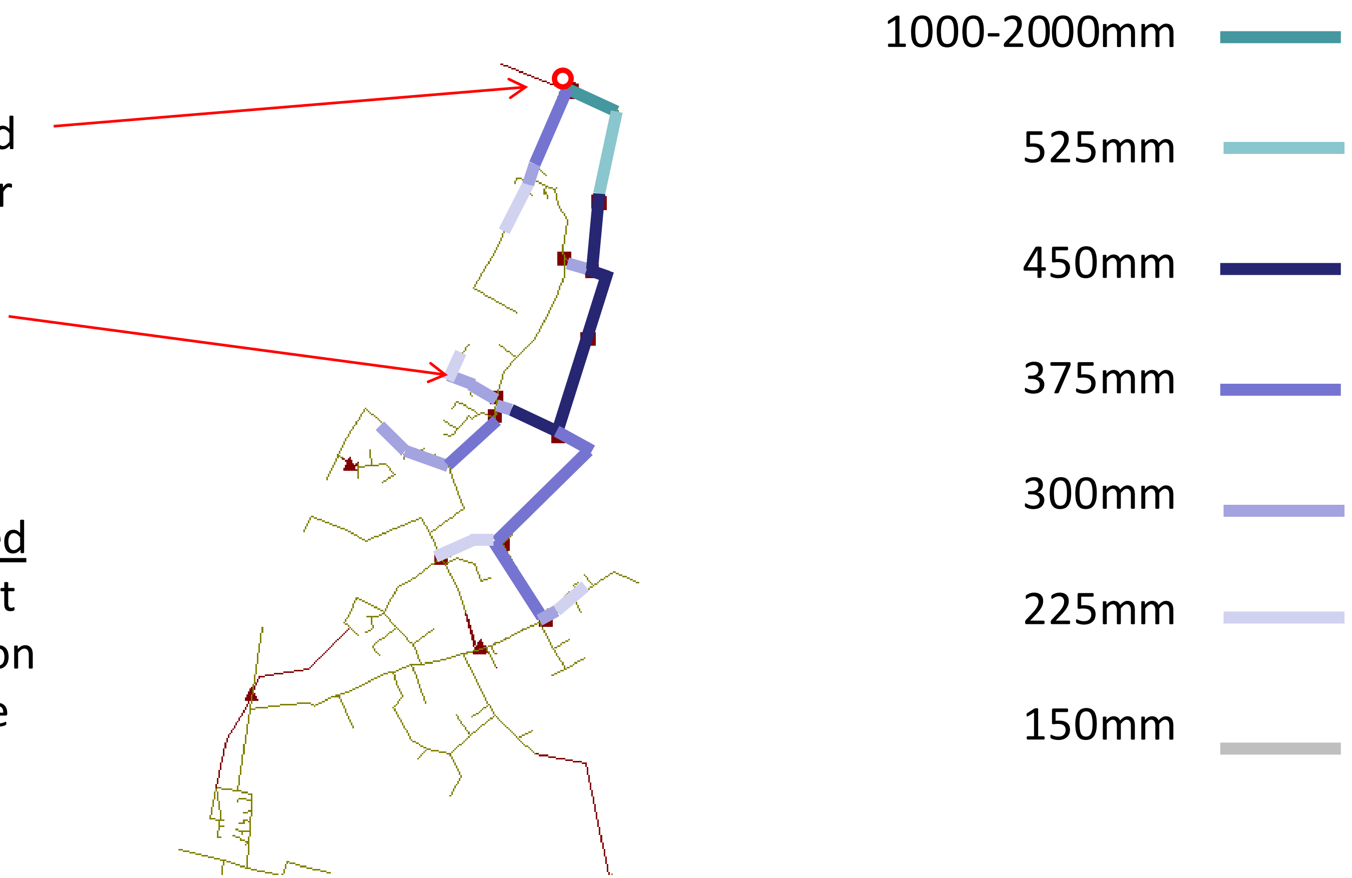


Application: InfoWorks CS Model @ Thorpe-le-Soken (UK)

Overflow at the pumping station could not exceed 4 spills per year

New and upgraded pipes

A <u>manually engineered solution</u> was looked at that had a combination of new pipes and pipe upgrades
(colour intensity ➔ major upgrading)



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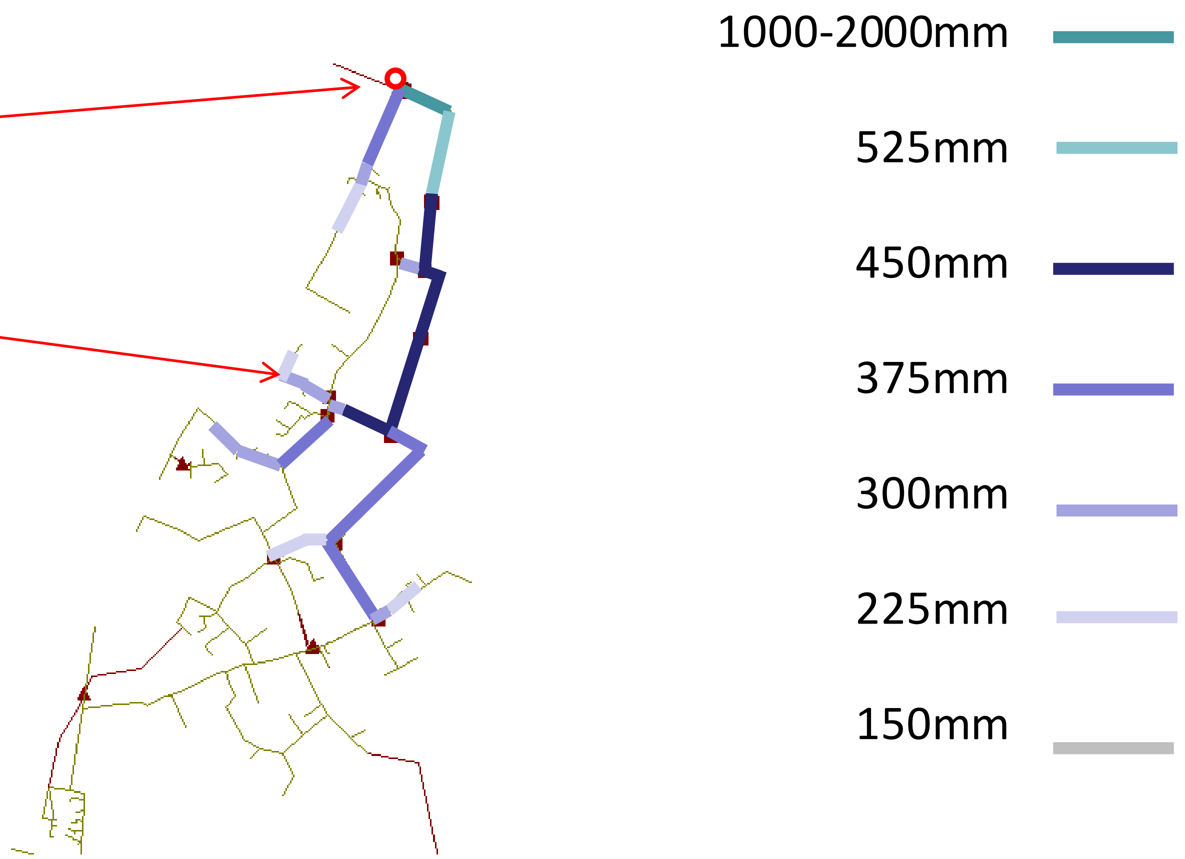
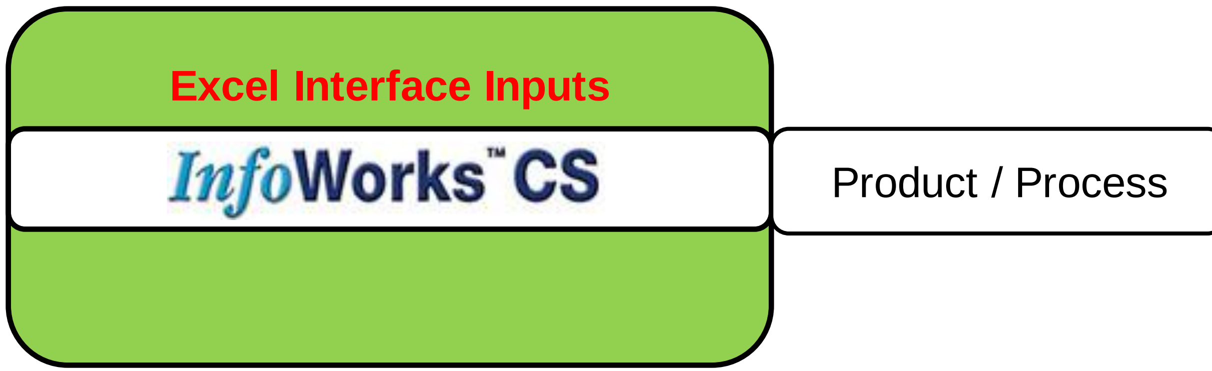


Q1: how reduce the cost?
Q2: what other solutions with storages?

Application: Interface with Optioneering Extension



Application: Interface with Optioneering Extension

Infoworks / modeFRONTIER Interface
Optioneering Mock-Up

Inputs Panel

Selected Base Run (Event 1):	>CG~GoxhillMF>RUNG~Run Group Nadia Solution>RUN~Opt-5 mF;Winter x 1; 30min;
Selected Base Run (Event 2):	- only one event selected -
Selected Base Run (Event 3):	- only one or two events selected -
Implied Network:	>CG~GoxhillMF>NET~Option 5 - Collector sewer Culvert storage option_2

The created Run will be named by the time of its creation, extended by the contents of the cells below:

User String to Add: _OptionStudy_ID_ User ID to Add: 132

Example Run Name: opt_2010_02_08_22:55:25_OptionStudy_ID_132

During Verification, the user string is specified on the mFLinks pages instead!

Choose Parameters to Modify

Object Type	Object Name	Parameter Name	Parameter Value	Status
conduit	Joint.2	conduit_width	300.	Everything OK

Add the parameter selected above to the list below [Add Parameter] [Auto-Add Parameters]

x Delete any parameters marked "x" from the list below [Delete Parameter(s)] [Clear Whole List] [Check List Validity]

List of Selected Parameters

Mark	Object Type	Object Name	If Link, Which Suffix?	Parameter Name	Original Value	Modified Value

Application: Interface with Optioneering Extension

Infoworks / modeFRONTIER Interface
Optioneering Mock-Up

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Select inputs from drop down menus

Application: Interface with Optioneering Extension

Infoworks / modeFRONTIER Interface
Optioneering Mock-Up

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Selected Base Run (Event 1):	>CG~GoxhillMF>RUNG~Run Group Nadia Solution>RUN~Opt-5 mF;Winter x 1; 30min;
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List of Selected Parameters

Mark	Object Type	Object Name	If Link, Which Suffix?	Parameter Name	Original Value	Modified Value

Click button to add an input variable

Application: Interface with Optioneering Extension

Infoworks / modeFRONTIER Interface
Optioneering Mock-Up

Inputs Panel

Selected Base Run (Event 1): >CG~GoxhillMF>RUNG~Run Group Nadia Solution>RUN~Opt-5 mF;Winter x 1; 30min;
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x Delete any parameters marked "x" from the list below [Delete Parameter(s)] [Clear Whole List] [Check List Validity]

List of Selected Parameters

Mark	Object Type	Object Name	If Link, Which Suffix?	Parameter Name	Original Value	Modified Value
	conduit	Joint	2	conduit_width	300.	400

The input is added to the list

Application: Interface with Optioneering Extension

Infoworks / modeFRONTIER Interface
Optioneering Mock-Up

Inputs Panel

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Selected Base Run (Event 2):	- only one event selected -
Selected Base Run (Event 3):	- only one or two events selected -
Implied Network:	>CG~GoxhillMF>NET~Option 5 - Collector sewer Culvert storage option_2

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Choose Parameters to Modify

Object Type	Object Name	Parameter Name	Parameter Value	Status
conduit	Joint.2	conduit_width	300.	Everything OK

Add the parameter selected above to the list below [Add Parameter] [Auto-Add Parameters]

x Delete any parameters marked "x" from the list below [Delete Parameter(s)] [Clear Whole List] [Check List Validity]

List of Selected Parameters

Mark	Object Type	Object Name	If Link, Which Suffix?	Parameter Name	Original Value	Modified Value
	conduit	Joint	2	conduit_width	300.	400

The current value in the model is shown

Application: Interface with Optioneering Extension

Infoworks / modeFRONTIER Interface
Optioneering Mock-Up

Inputs Panel

Selected Base Run (Event 1): >CG~GoxhillMF>RUNG~Run Group Nadia Solution>RUN~Opt-5 mF;Winter x 1; 30min;
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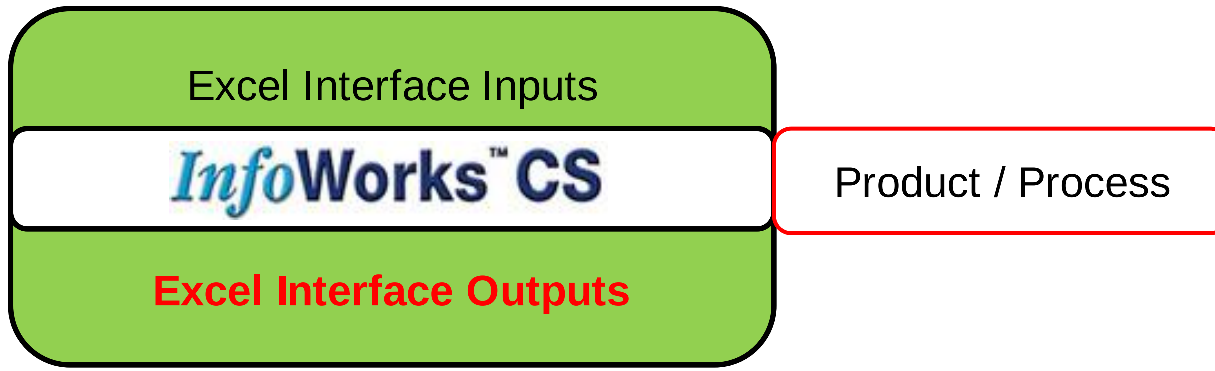
List of Selected Parameters

Mark	Object Type	Object Name	If Link, Which Suffix?	Parameter Name	Original Value	Modified Value
	conduit	Joint	2	conduit_width	300.	400

The automated modeFRONTIER process will change the value in the InfoWorks model by updating this cell

Application: Cost Model



Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

						Calculate Flooding Constraints			Calculate Pipe Cost	
Flood Type	Conduit Ref	US Node	Suffix	DS Node	US/DS?	Target (m)	Flooding Value (m)	Ground Type	Unit Cost (£)	Total Cost (£)
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA10216501	US	0	0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0	Highway		
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0	Highway		
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Conn_Bentpenny	US	0	0	Highway		
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_1TR_MH002	US	0	0	Highway		
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_1TR_MH003	US	0	0	Highway		
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Flood Type	Ref	US Node	Suffix	DS Node	US/DS?	Calculate Flooding Constraints: Target (m)	Flooding Value (m)	Ground Type	Calculate Pipe Cost: Unit Cost (£)	Total Cost (£)
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
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USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0	Highway		
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0	Highway		
		1	1	Conn_Bentpenny	US	0	0	Highway		
			1	PS_1TR_MH002	US	0	0	Highway		
			1	PS_1TR_MH003	US	0	0	Highway		
			1	PS_4TR_MH001	US	0	0	Highway		
			1	GOXTSP	US	0	0	Highway		
			1	PS_4TR_MH001	US	0	0	Highway		

Set whether a manhole is a DG5 location

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Target

Set the flooding target

Flood Type	Conduit Ref	US Node	Suffix	DS Node		Target	…nstraints …ng Value	Calculate Pipe Cost Ground Type	Unit Cost (£)	Total Cost (£)
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry				0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts				0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdaleho				0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank				0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA10216501	US	0	0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0	Highway		
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0	Highway		
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Conn_Bentpenny	US	0	0	Highway		
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_1TR_MH002	US	0	0	Highway		
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_1TR_MH003	US	0	0	Highway		
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

ENGIN SOFT

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Flooding Value

						Ca		culate Pipe Cost		
Flood Type	**Conduit Ref**	**US Node**	**Suffix**	**DS Node**	**US/DS?**	**Ta (r**		**e**	**Unit Cost (£)**	**Total Cost (£)**
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA1			0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Con			0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DU			0	Highway		
Flood	Joint.1	Joint	1	TA1			0	Highway		
DG5	Junct1.1	Junct1	1	TA1			0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0	Highway		
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0	Highway		
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Conn_Bentpenny	US	0	0	Highway		
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_1TR_MH002	US	0	0	Highway		
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_1TR_MH003	US	0	0	Highway		
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

Has the manhole flooded?

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Flood Type	Conduit Ref	US Node	Suffix	DS Node	US/DS?	Calculate Flooding Target (m)	Floo (m)	Ground Type		Cost Total Cost (£)
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA10216501	US	0	0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA1		0	0	Highway		
USFlood	mhp4.2	mhp4	2	Con		5	0	Highway		
DG5	mhp5.1	mhp5	1	TA1		0	0	Highway		
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Con		0	0	Highway		
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_		0	0	Highway		
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_		0	0	Highway		
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

Set whether the pipe is under a road?

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Flood Type	Conduit Ref	US Node	Suffix	DS Node	US/DS?	Calculate Flooding Constraints Target (m)	Flooding Value (m)	Ground Type	Calcula… U (£	Total Cost
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US					
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US					
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US					
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US					
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	[illegible]				
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	[illegible]	[illegible]	[illegible]	[illegible]	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA10216501	US	0	0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0	Highway		
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0	Highway		
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Conn_Bentpenny	US	0	0	Highway		
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_1TR_MH002	US	0	0	Highway		
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_1TR_MH003	US	0	0	Highway		
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

What is the cost of upgrading this pipe upgrade?

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Flood Type	Conduit Ref	US Node	Suffix	DS Node	US/DS?	Calculate Flooding Constraints Target (m)	Flooding Value (m)	Ground Type	Calculate Pipe Cost Unit Cost (£)	Total Cost (£)
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA10216501	US	0	0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0			
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0			
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0			
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0	Highway		
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Conn_Bentpenny	US	0	0	Highway		
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_1TR_MH002	US	0	0	Highway		
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_1TR_MH003	US	0	0	Highway		
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
Worst Flood Depth	0.11272
No. Failed Constraints	7
Pipe Cost	947034.08
Flood Constraint Group 0	0.00422
Flood Constraint Group 1	0.00000
Flood Constraint Group 2	0.00000
Flood Constraint Group 3	0.00000
Flood Constraint Group 4	0.00000
Flood Constraint Group 5	0.00000
Flood Constraint Group 6	0.03626
Flood Constraint Group 7	0.11272
Flood Constraint Group 8	0.00000
Flood Constraint Group 9	0.00302
Flood Constraint Group 10	0.00000
Flood Constraint Group 11	0.00000
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

Summary of cost

ENGIN SOFT

Key partner in Design Process Innovation

Application: Cost Model

Inputs

User Defined Outputs (Flood Depth)

Flood Type	Conduit Ref	US Node	Suffix	DS Node	US/DS?	Calculate Flooding Constraints			Calculate Pipe Cost	
						Target (m)	Flooding Value (m)	Ground Type	Unit Cost (£)	Total Cost (£)
USFlood	Conn_Bartonvilla.1	Conn_Bartonvilla	1	Conn_Velindre	US	0.063	0	Highway		
USNoFlood	Conn_Bentpenny.1	Conn_Bentpenny	1	TA09217002	US	0	0	Highway		
USNoFlood	Conn_Elms.1	Conn_Elms	1	TA10207701	US	0	0	Highway		
USNoFlood	Conn_Galatia.1	Conn_Galatia	1	Conn_Grainthorpe	US	0	0	Highway		
USNoFlood	Conn_Goathouse.1	Conn_Goathouse	1	Conn_Elms	US	0	0	Highway		
USNoFlood	Conn_Grainthorpe.1	Conn_Grainthorpe	1	Conn_Bartonvilla	US	0	0	Highway		
USNoFlood	Conn_Haddonfarm.1	Conn_Haddonfarm	1	Conn_Goathouse	US	0.08895	0	Highway		
DG5	Conn_Highthorne.1	Conn_Highthorne	1	NEWMH09	US	0	0	Highway	318.93	4369.35
DG5	Conn_Langdale.1	Conn_Langdale	1	Conn_Thorncottage	US	0	0	Highway	221.05	8974.51
DG5	Conn_NorthFerry.1	Conn_NorthFerry	1	Conn_RseCotts	US	0	0	Highway	350.91	1614.20
DG5	Conn_NorthFerry2.1	Conn_NorthFerry2	1	TA10224601	US	0	0	Highway	269.06	3121.14
DG5	Conn_RseCotts.1	Conn_RseCotts	1	Conn_Sunnybank	US	0	0	Highway	350.91	1824.74
DG5	Conn_Rusdalehouse.1	Conn_Rusdalehouse	1	TA10224602	US	0	0	Highway	221.05	2895.72
DG5	Conn_Sunnybank.1	Conn_Sunnybank	1	TA10225701	US	0	0	Highway	418.33	17737.27
Flood	Conn_Thebungalow.1	Conn_Thebungalow	1	TA10213403	US	0.07349	0	Highway		
DG5	Conn_Thepaddock.1	Conn_Thepaddock	1	TA10224601	US	0	0	Highway		
DG5	Conn_Thorncottage.1	Conn_Thorncottage	1	TA10216501	US	0	0	Highway	269.06	5300.56
USFlood	Conn_Velindre.1	Conn_Velindre	1	Conn_Bentpenny	US	0.00448	0	Highway		
USFlood	GOXTSP.2	GOXTSP	2	DUMMY_GOXTSP	DS	3.9255	0	Highway		
Flood	Joint.1	Joint	1	TA10223010	US	0.15568	0	Highway		
DG5	Junct1.1	Junct1	1	TA10223010	US	0	0	Highway	389.83	24715.40
DG5	MH3.1	MH3	1	mhp1	US	0	0	Highway		
DG5	mhp1.2	mhp1	2	Junct1	US	0	0	Highway		
DG5	mhp2.2	mhp2	2	TA10216501	US	0	0	Highway		
DG5	mhp3.1	mhp3	1	TA10211904	US	0	0	Highway		
USFlood	mhp4.2	mhp4	2	Conn_Galatia	US	0.10766	0	Highway		
DG5	mhp5.1	mhp5	1	TA10212901	US	0	0			
USNoFlood	PS_1BPTR_MH001.1	PS_1BPTR_MH001	1	Conn_Bentpenny	US	0	0			
USNoFlood	PS_1TR_MH001.1	PS_1TR_MH001	1	PS_1TR_MH002	US	0	0			
USNoFlood	PS_1TR_MH002.1	PS_1TR_MH002	1	PS_1TR_MH003	US	0	0			
USNoFlood	PS_1TR_MH003.1	PS_1TR_MH003	1	PS_4TR_MH001	US	0	0	Highway		
USNoFlood	PS_4TR_MH001.1	PS_4TR_MH001	1	GOXTSP	US	0	0	Highway		
USNoFlood	PS_4TR_MH002.1	PS_4TR_MH002	1	PS_4TR_MH001	US	0	0	Highway		

Summary of floods

Outputs

Collated Outputs for modeFRONTIER

Description	Value
No. DG5 Floods	2
No. Worse Floods	1
No. New Floods	0
No. Floods At New Pipes	0
No. US Worse Floods	4
No.Worse Weirs	0
Total Flooding Depth	0.15622
Ave. Flooding Depth	0.022317143
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Flood Constraint Group 9	0.00302
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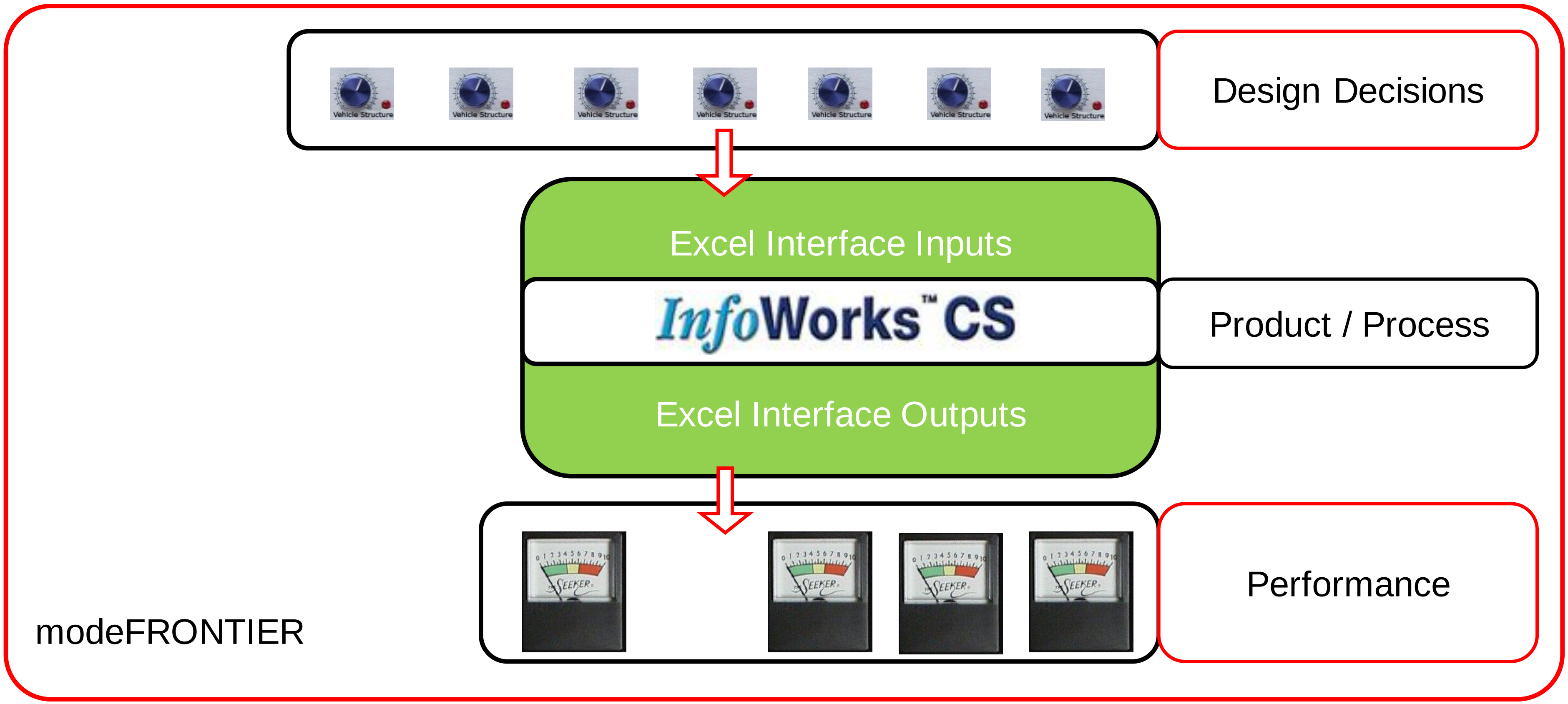
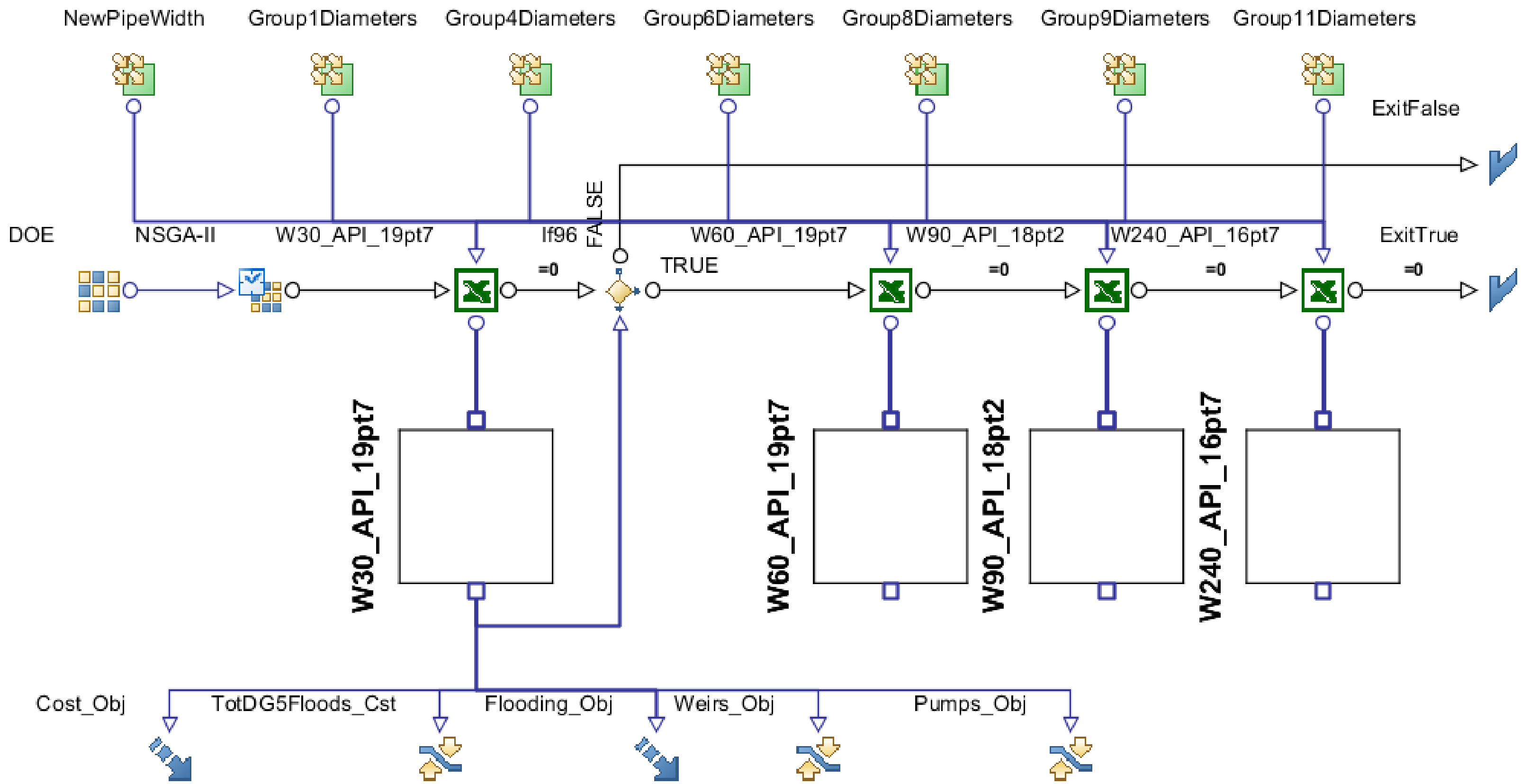
Flood Constraint Group 12	0.00000
Worse Weir	0.00000
Total Cost	947034.08
Tot. DG5 Flood	0.1490
Tot. Worse Floods	0.0030
Tot. New Flood	0.0000
Tot. Floods At New Pipes	0.0000
Tot. US Worse Floods	0.0042
Pump Volume	0.0000

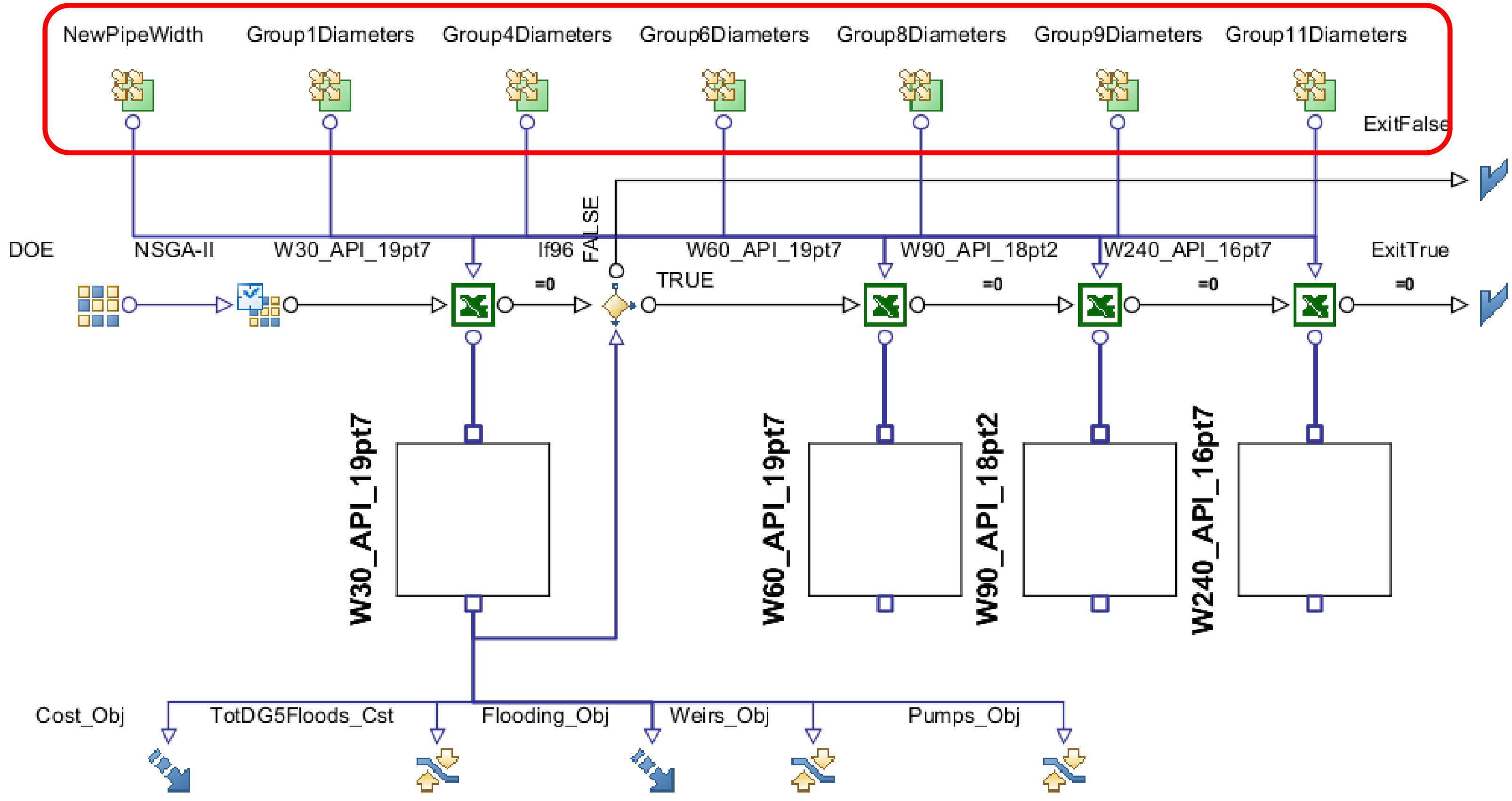
Application: modeFRONTIER Workflow



Application: modeFRONTIER Workflow

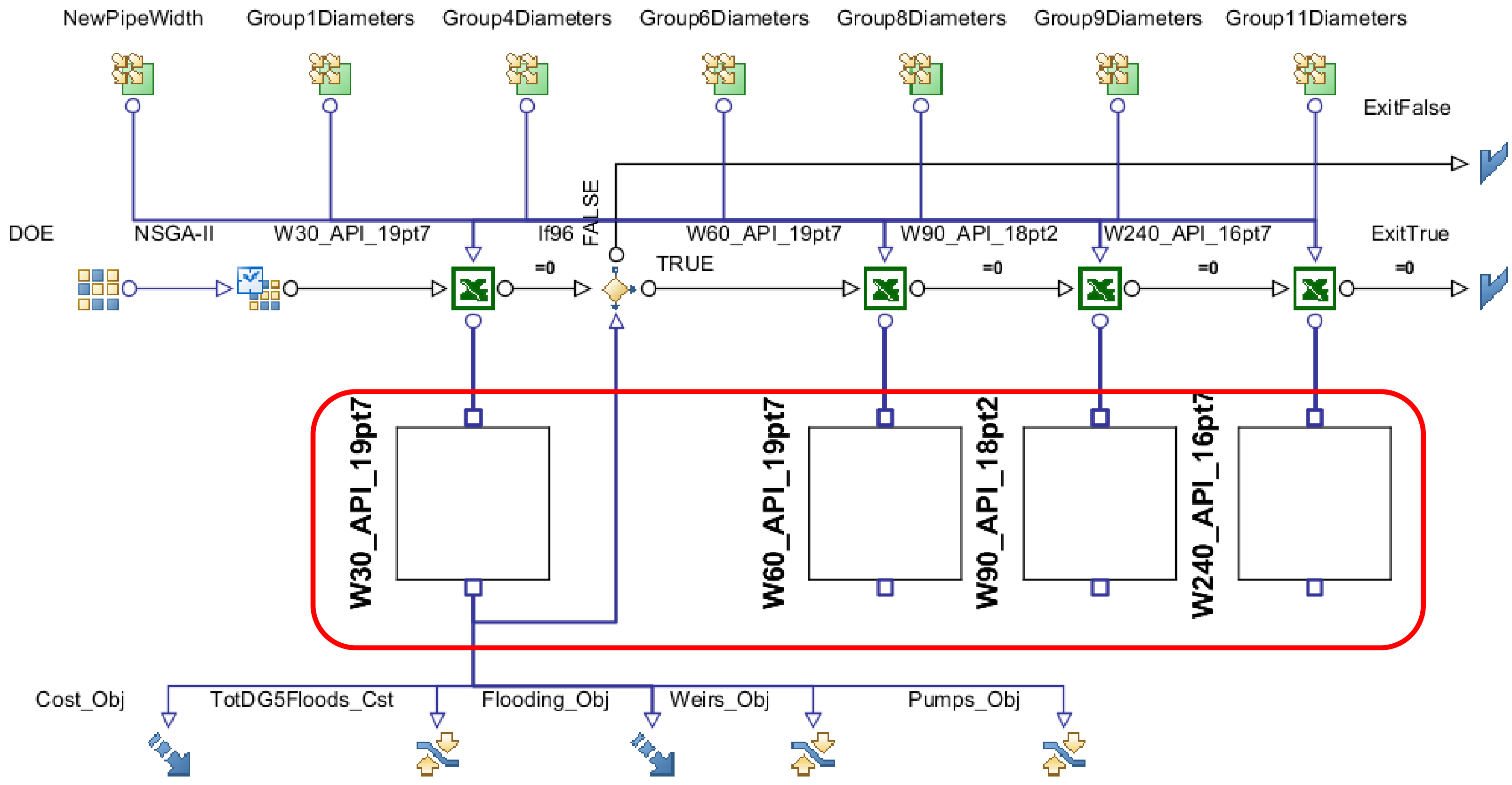


Application: modeFRONTIER Workflow



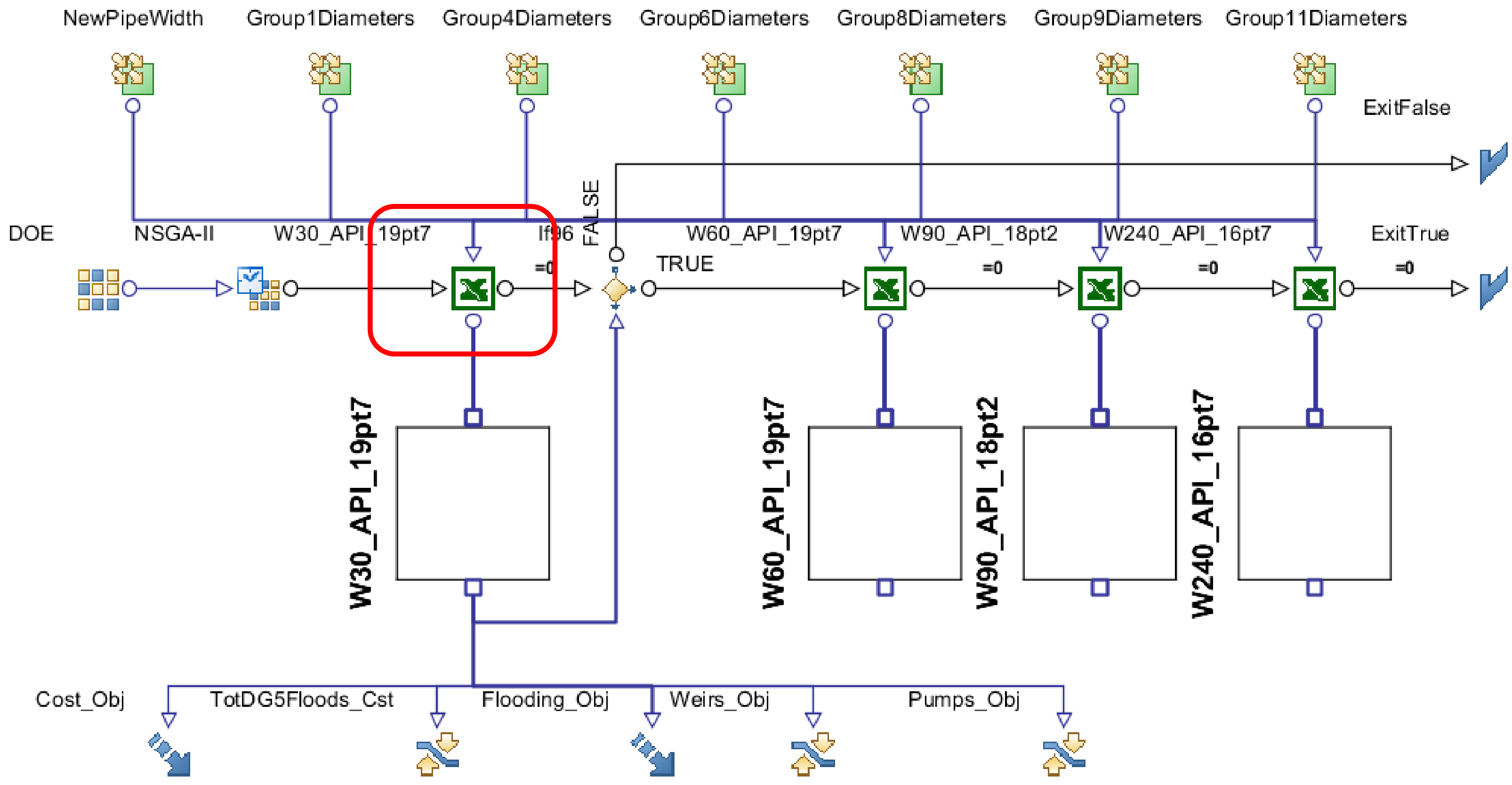
Inputs to be changed are setup in modeFRONTIER

Application: modeFRONTIER Workflow



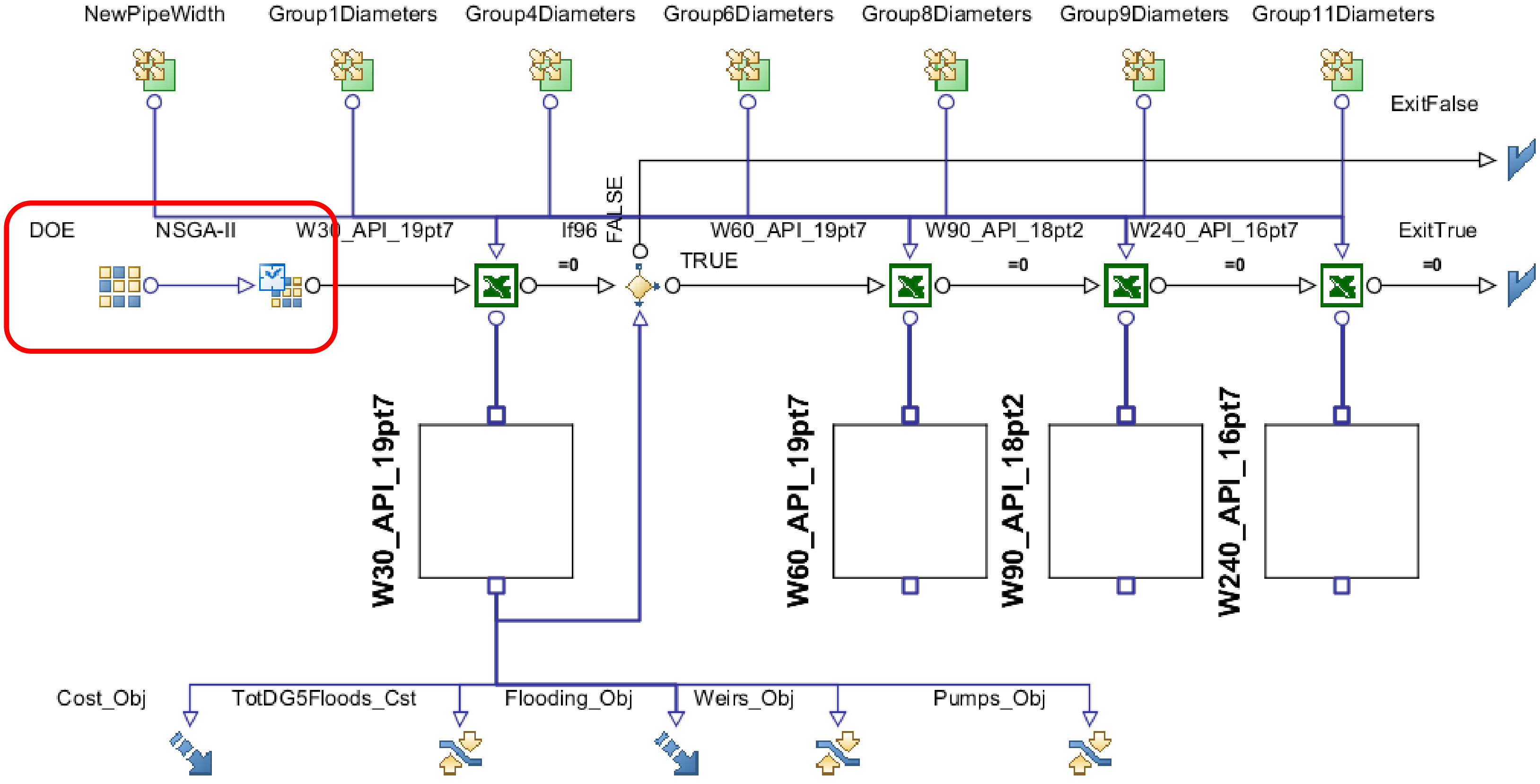
Outputs to be monitored are setup in modeFRONTIER

Application: modeFRONTIER Workflow



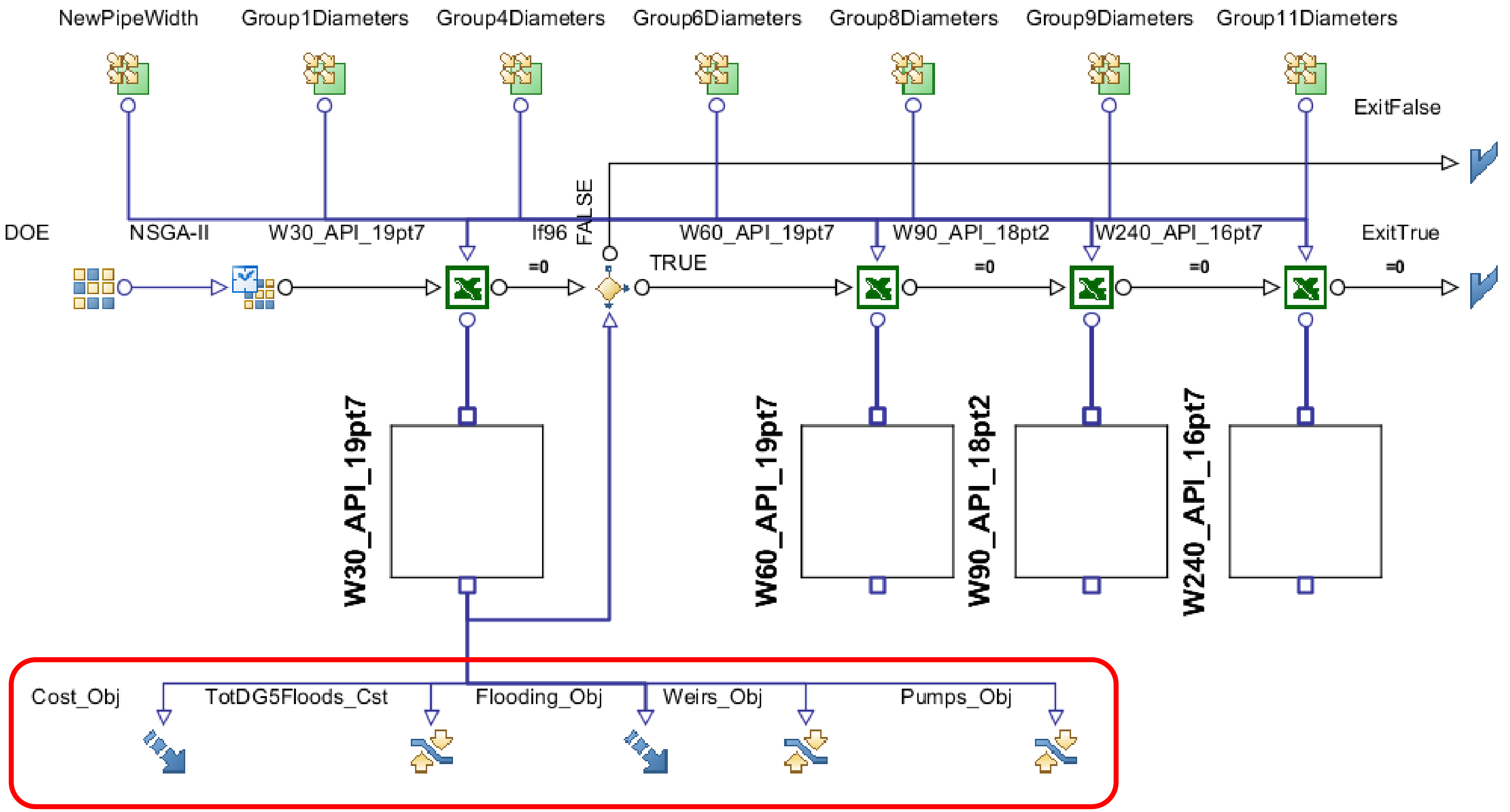
Variables are linked to InfoWorks CS via the Excel interface

Application: modeFRONTIER Workflow



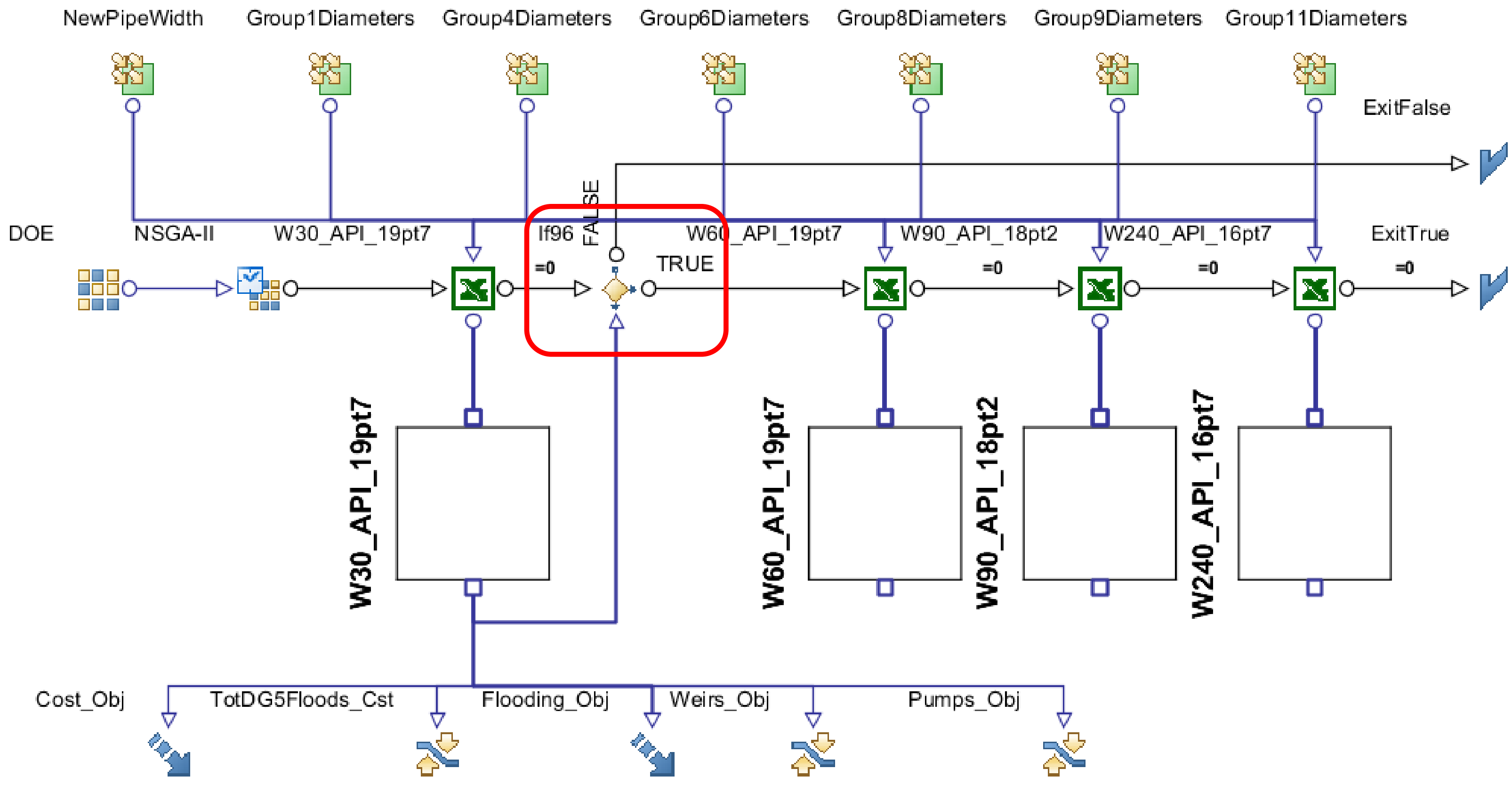
Designs are scheduled according to a smart algorithm

Application: modeFRONTIER Workflow



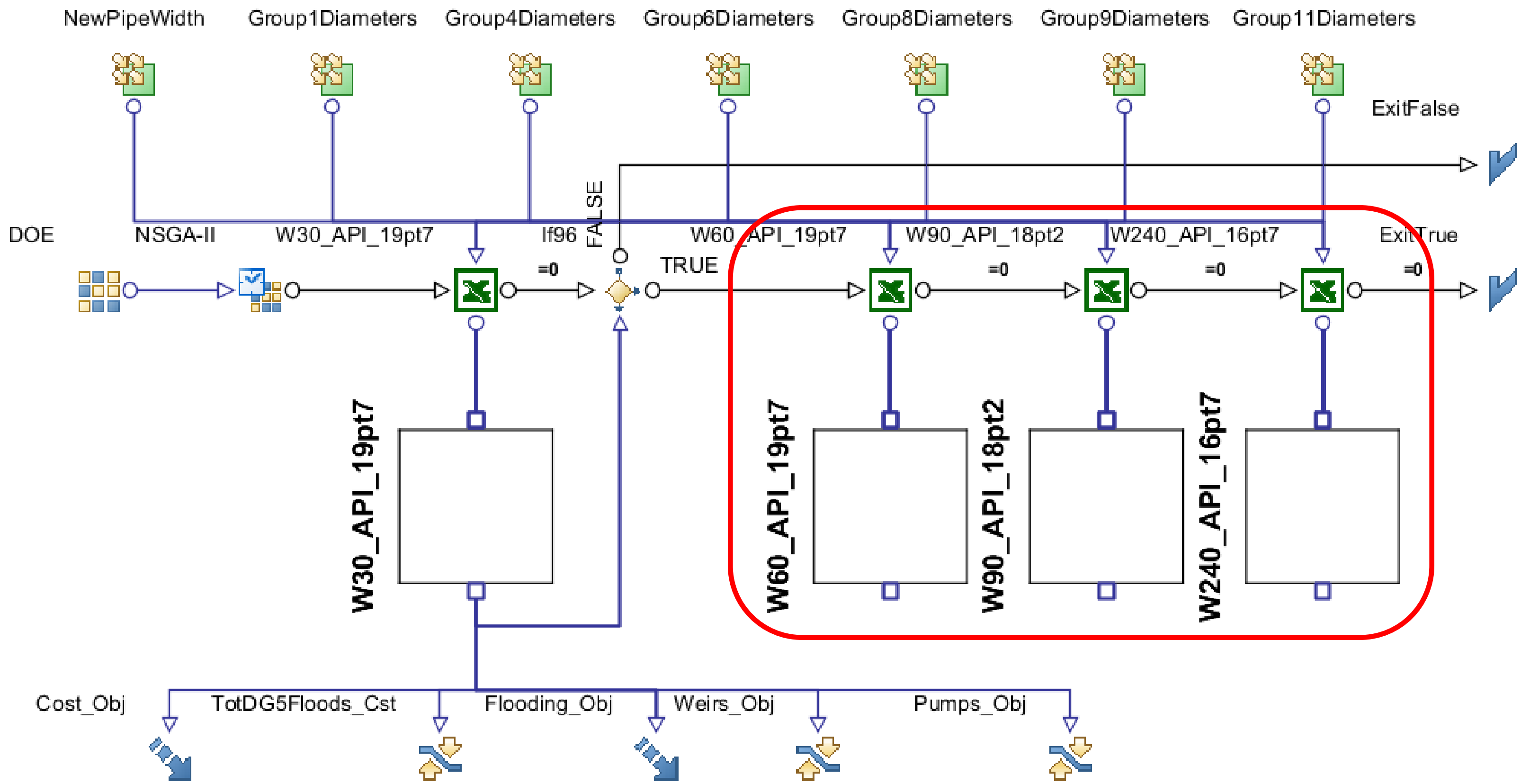
Cost and flooding are minimised while DG5 manholes, weir levels and pumps must be below a target value

Application: modeFRONTIER Workflow



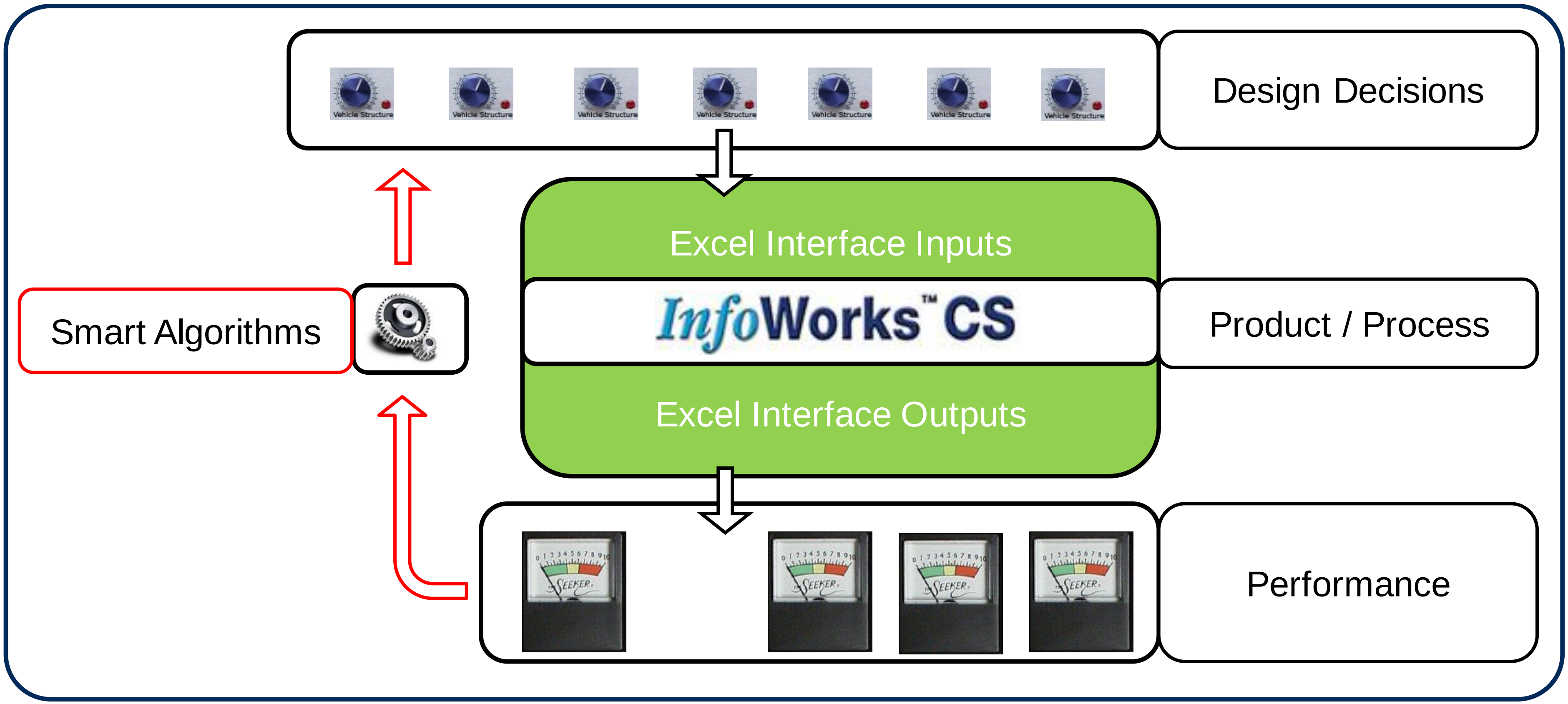
If the critical storm passes cost and flooding criteria then the other design storms will be assessed

Application: modeFRONTIER Workflow

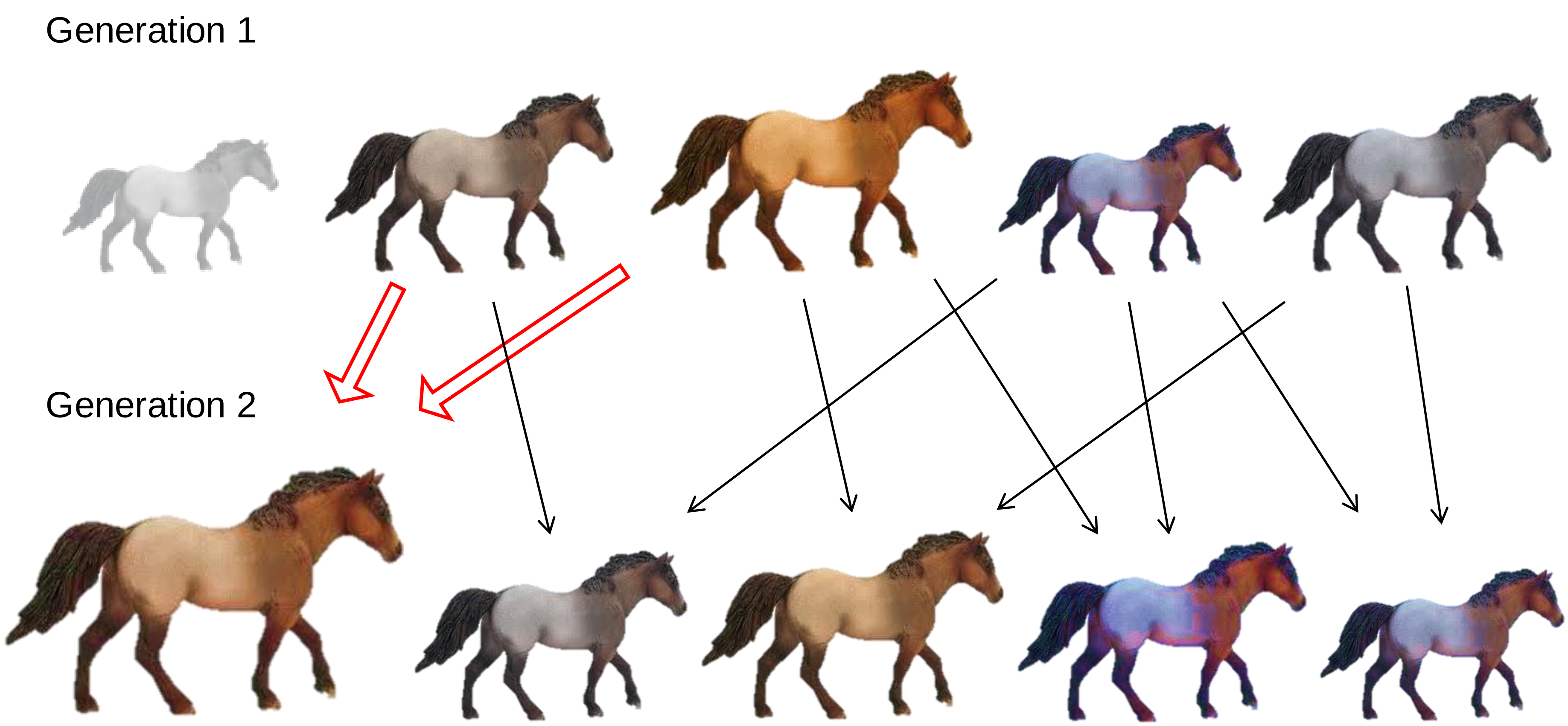


The design storms are run

Application: Smart Algorithms

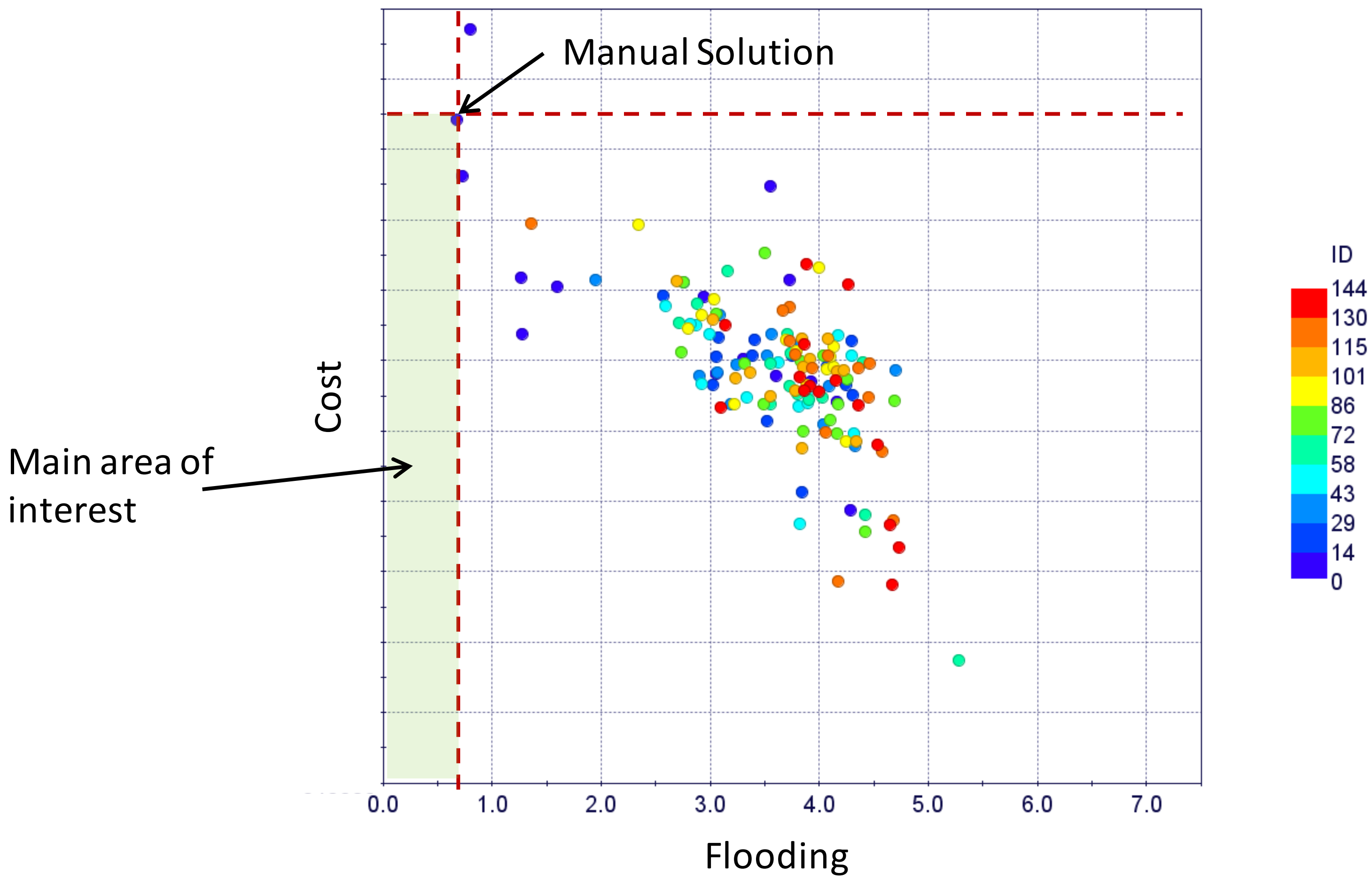


Application: Smart Algorithms

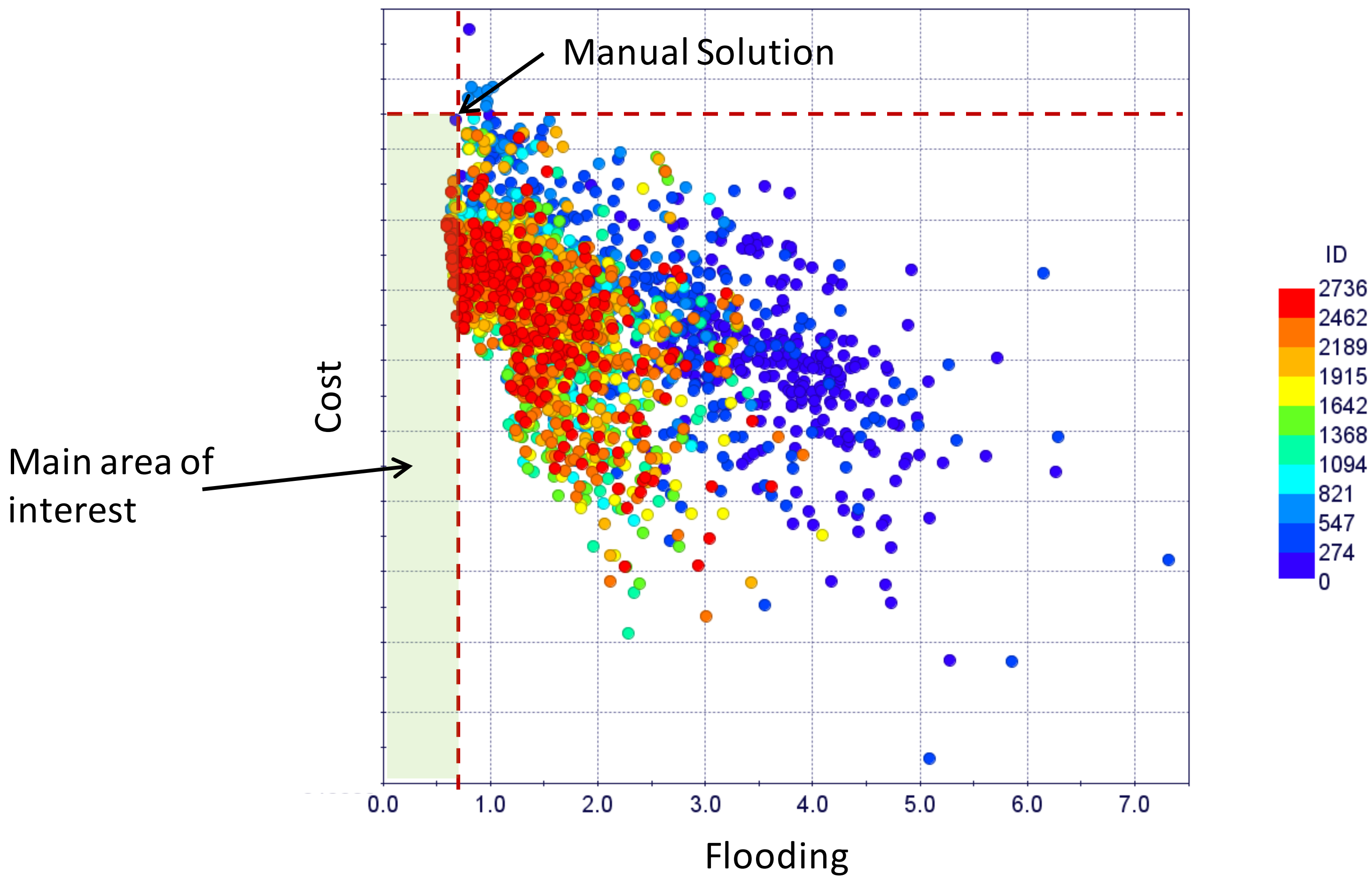


Smart Optioneering [1]:
only pipe upgrades

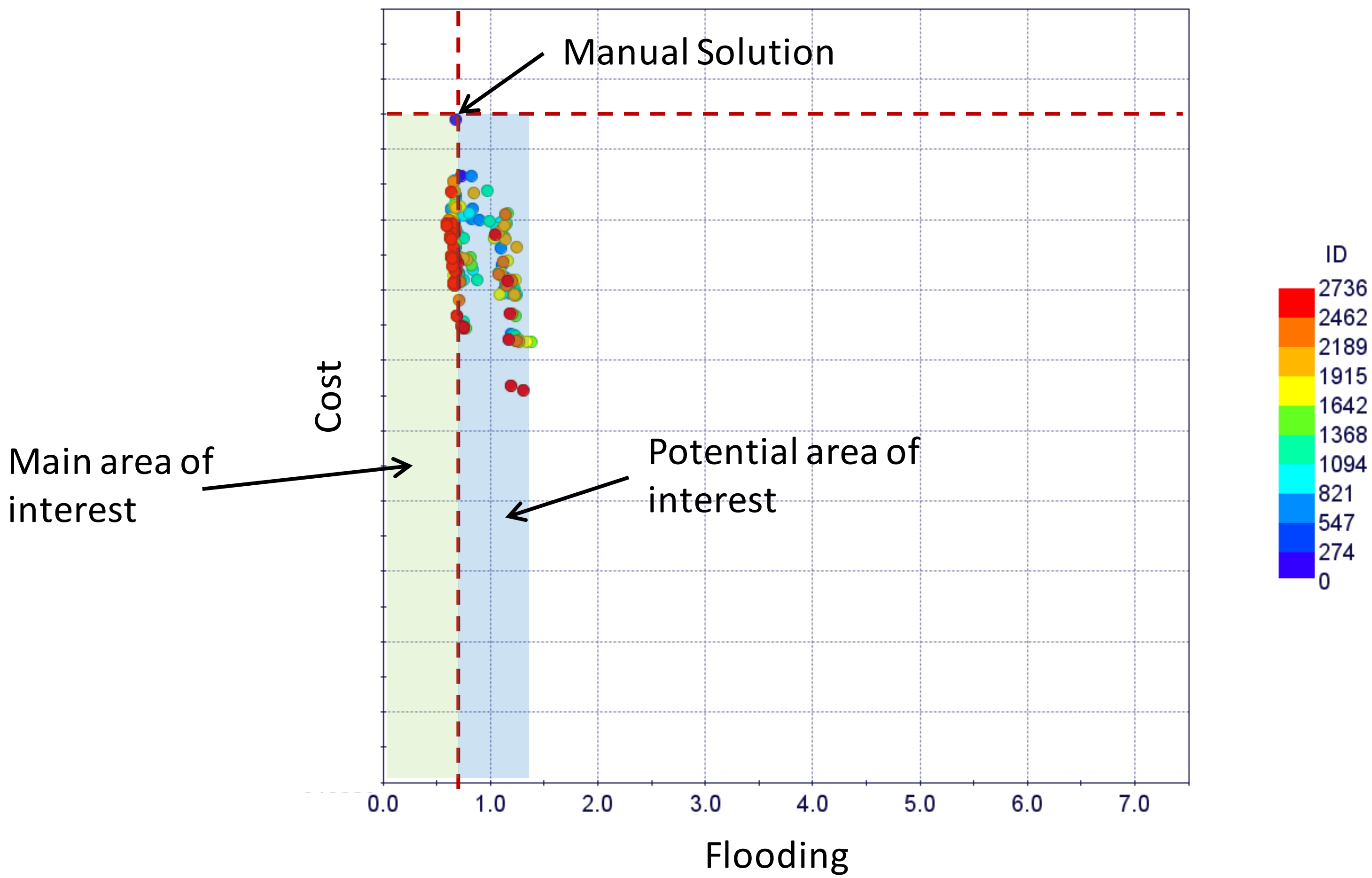
Global Results



Global Results

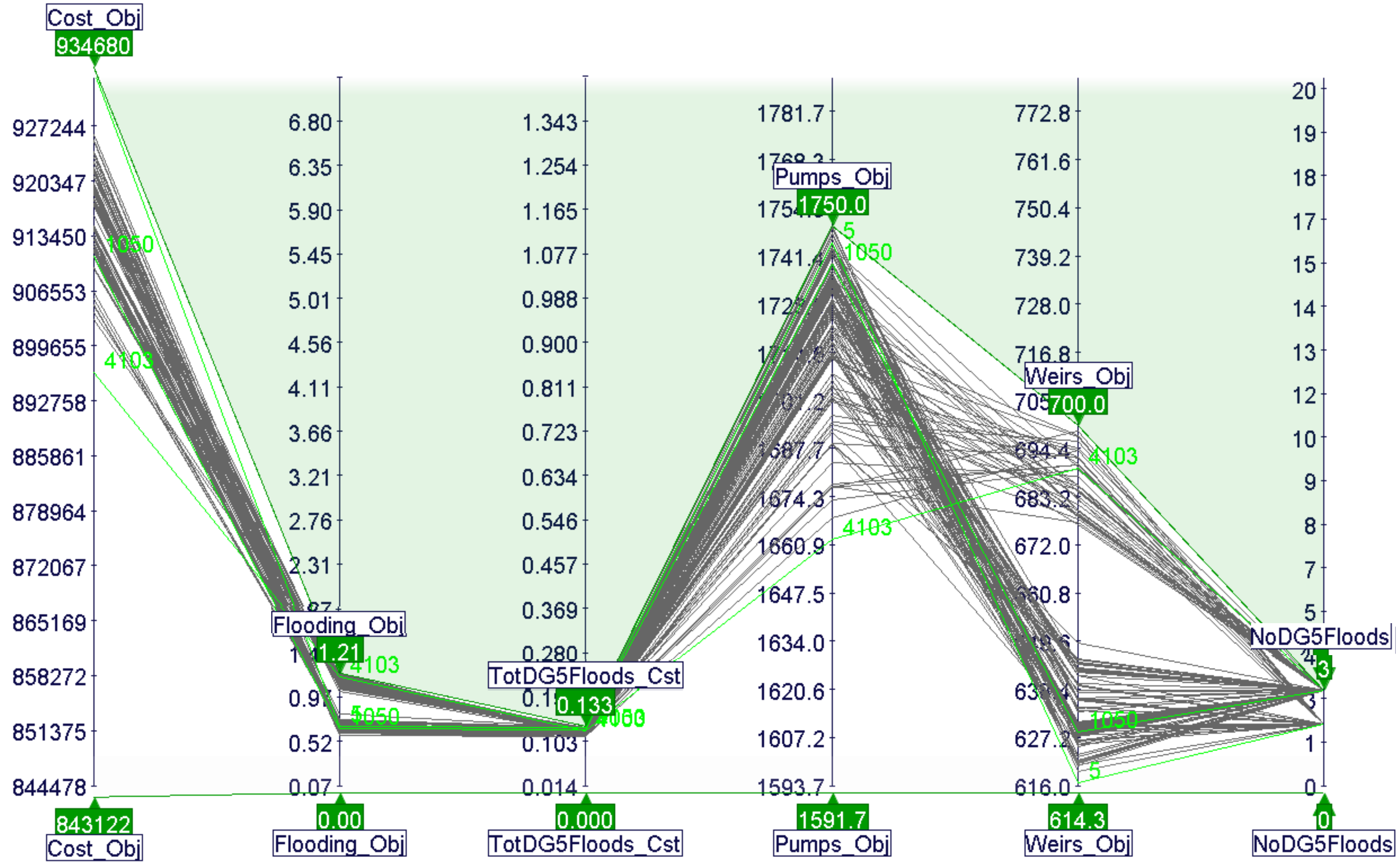


DG5 Compliant Results



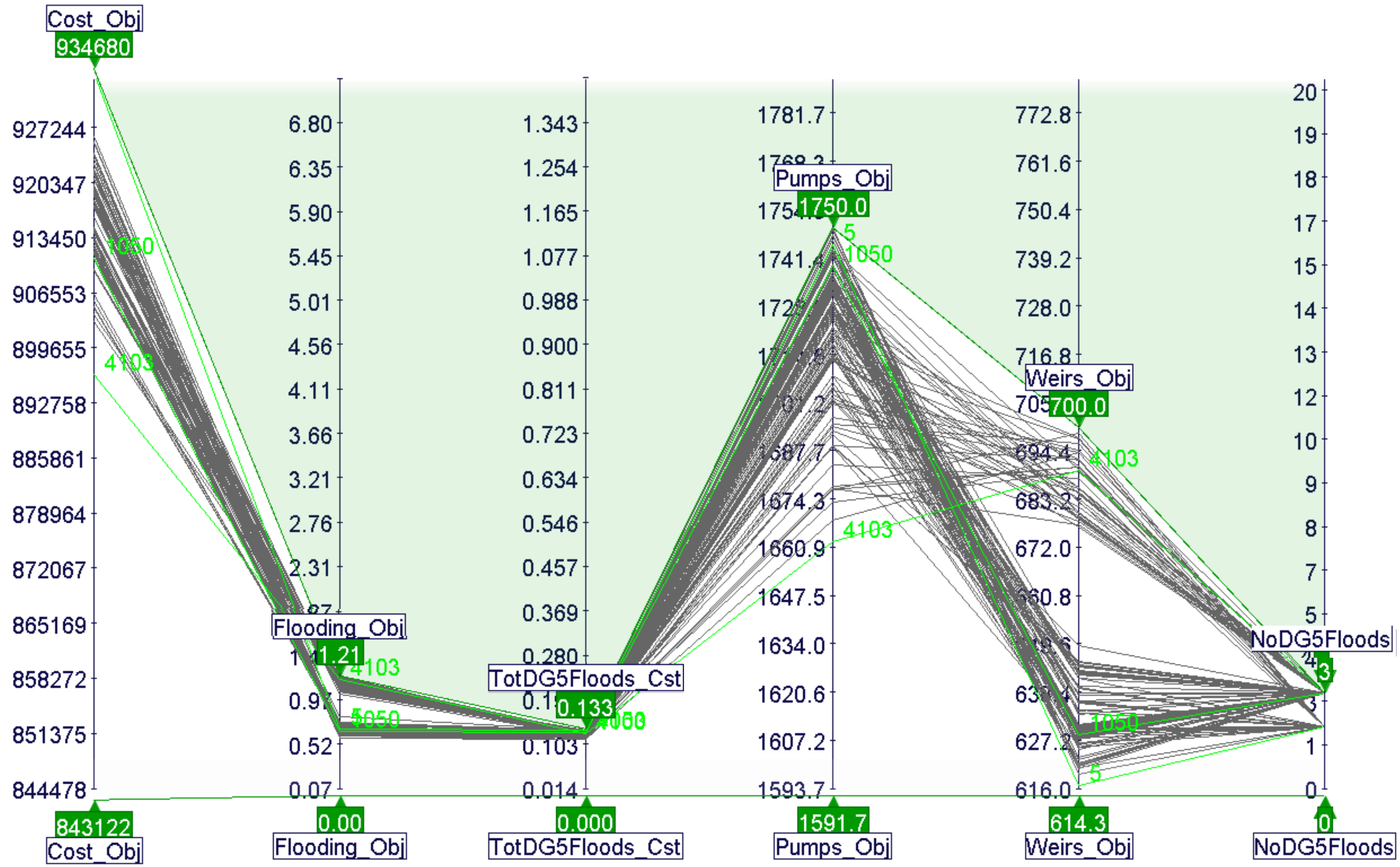
Filtering Results: Axis Parallel Chart

Results:



Filtering Results: Axis Parallel Chart

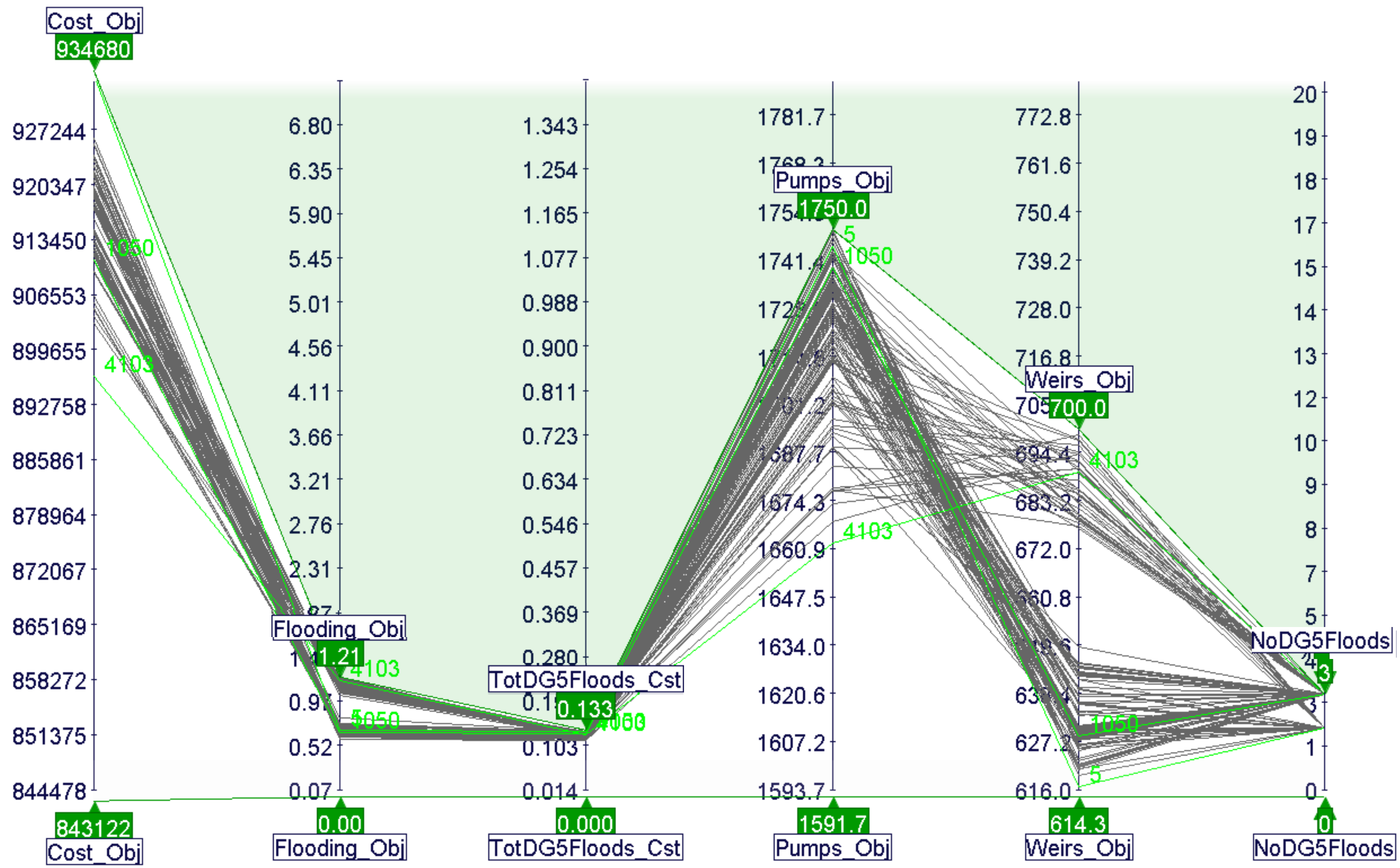
Results:



Tota cost of solution

Filtering Results: Axis Parallel Chart

Results:

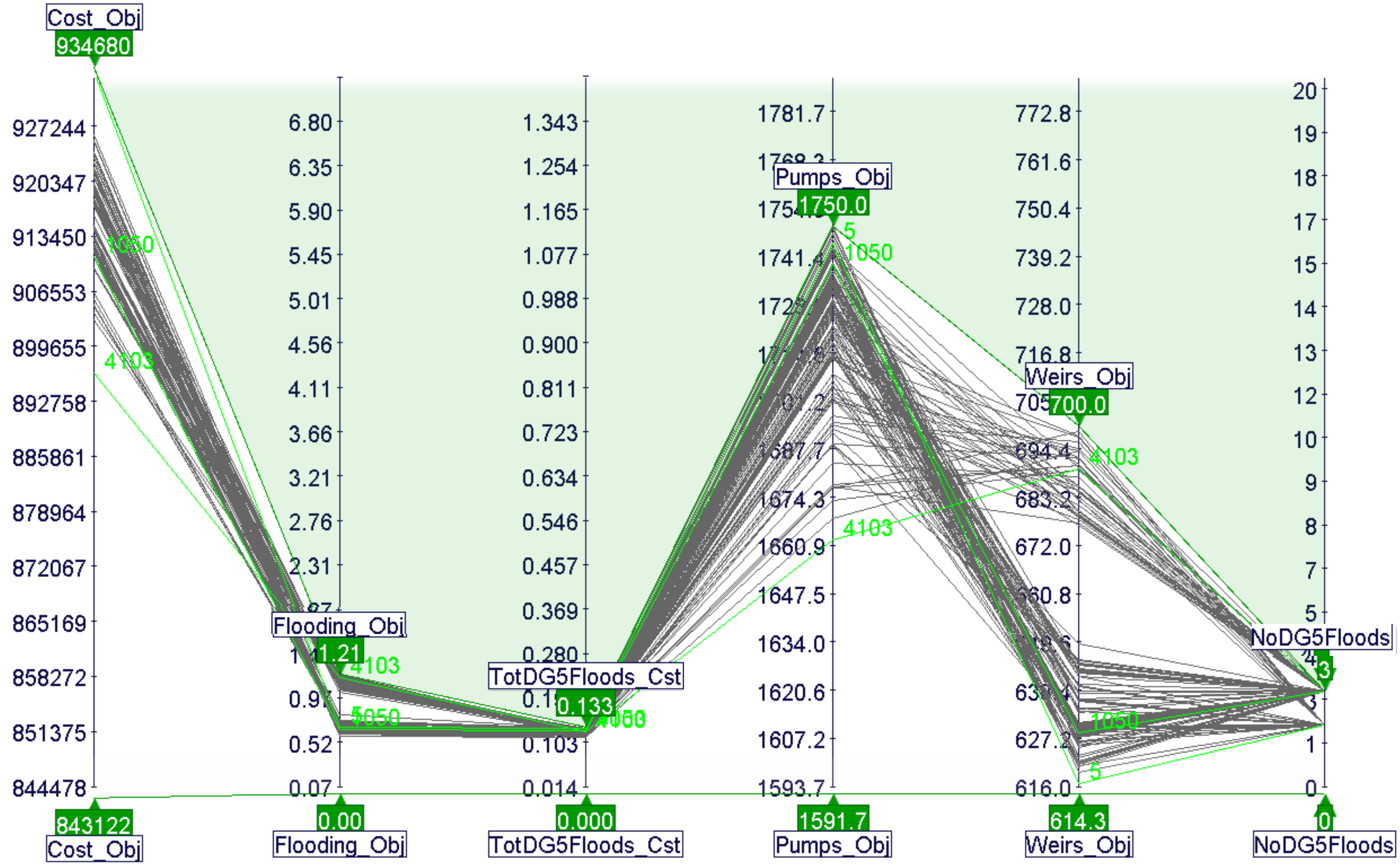


Tota cost of solution

DG5 +
Non DG5 floods

Filtering Results: Axis Parallel Chart

Results:



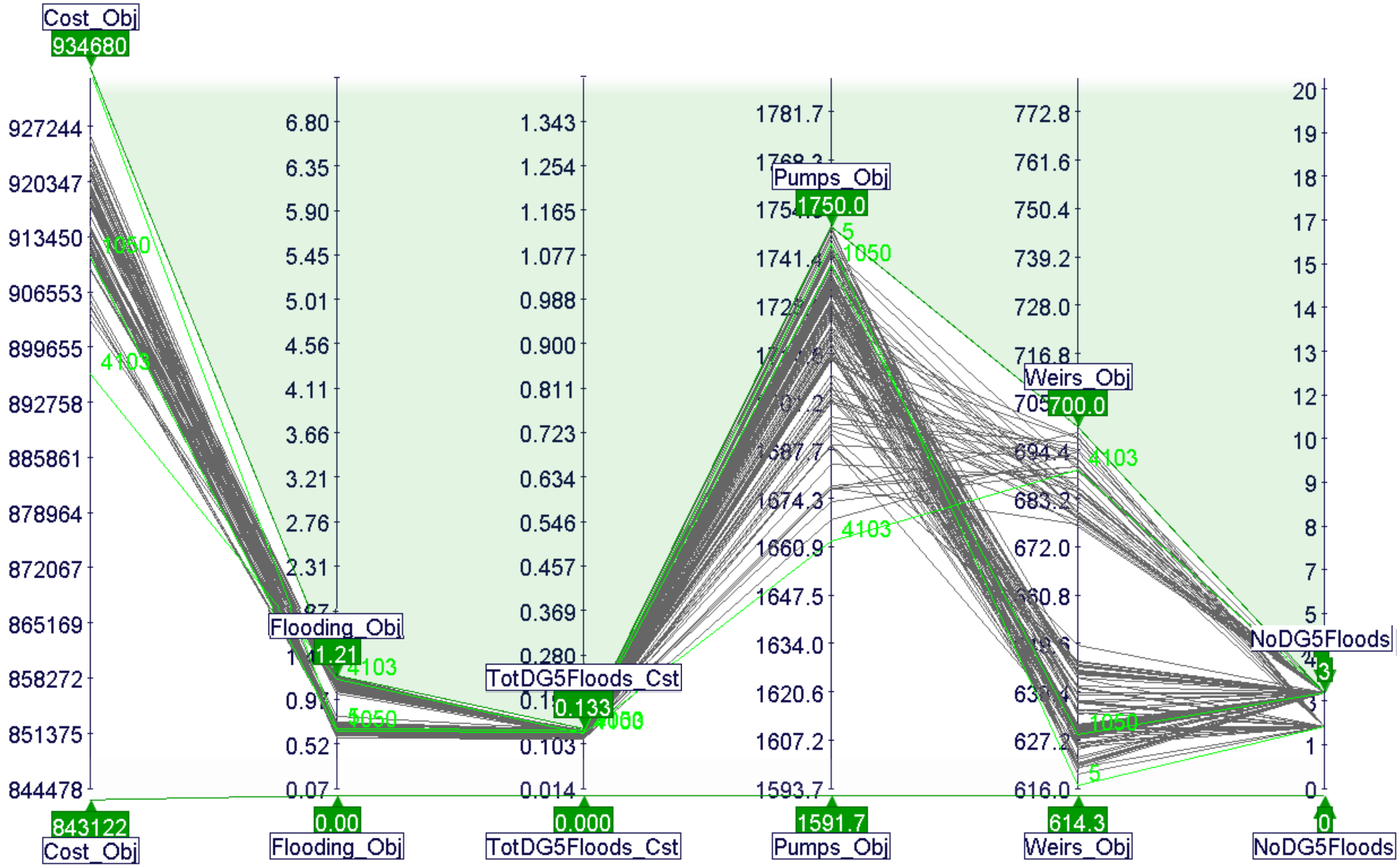
Tota cost of solution

DG5 + Non DG5 floods

DG5 flood

Filtering Results: Axis Parallel Chart

Results:



Tota cost of solution

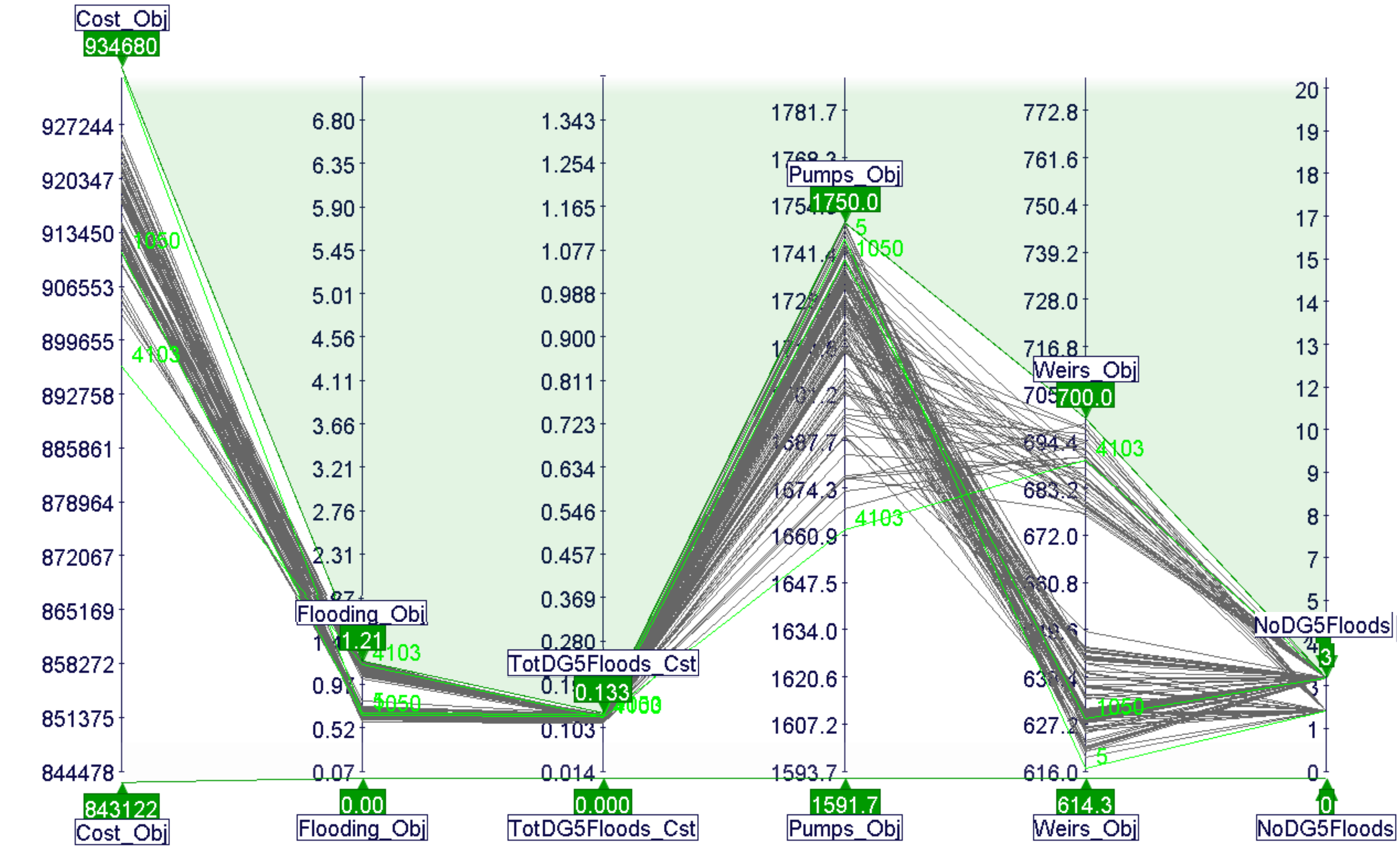
DG5 + Non DG5 floods

DG5 flood

Volume of water pumped for treatment

Filtering Results: Axis Parallel Chart

Results:



Tota cost of solution

DG5 + Non DG5 floods

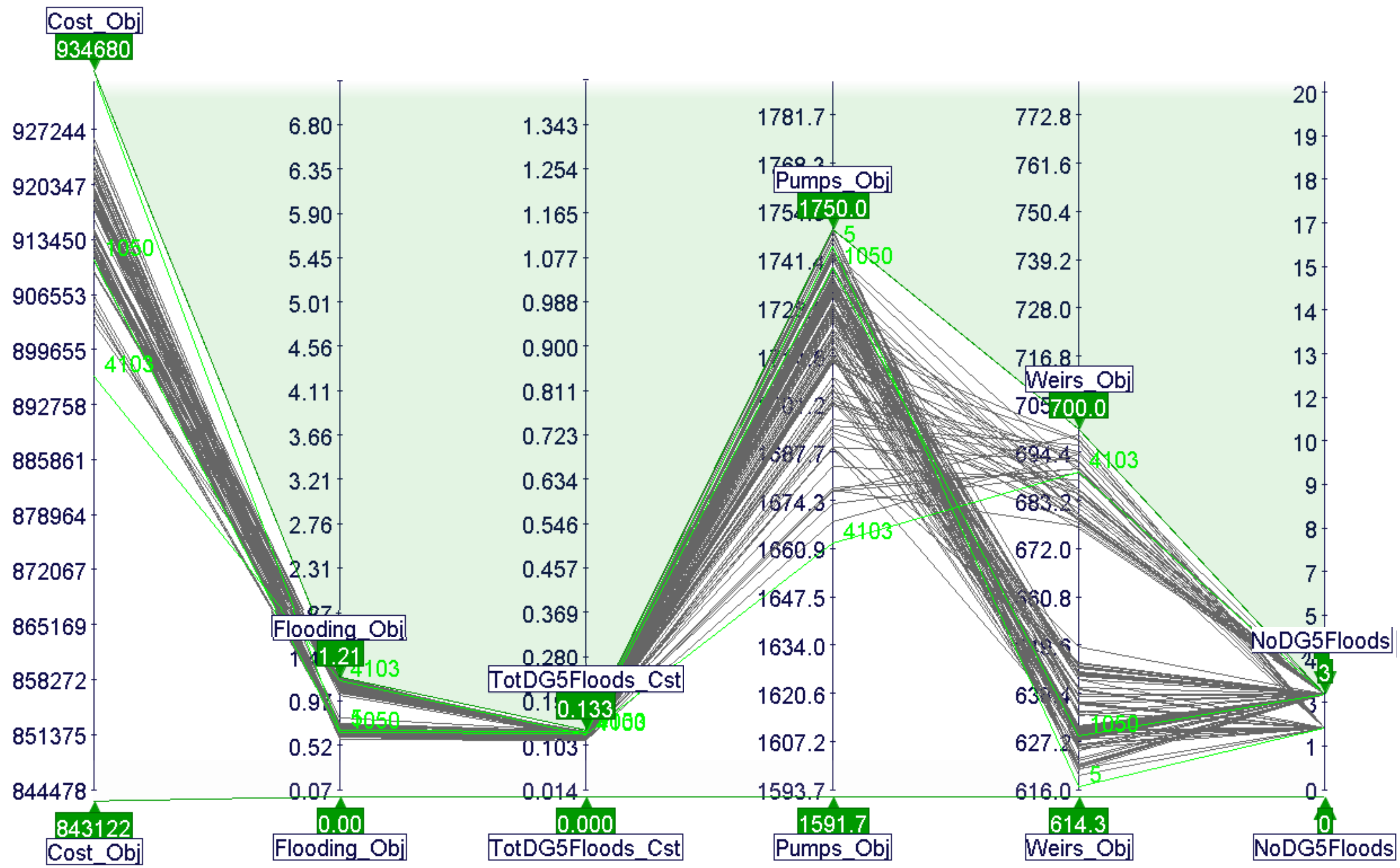
DG5 flood

Volume of water pumped for treatment

Volume of water spilt to the water course

Filtering Results: Axis Parallel Chart

Results:



Tota cost of solution | DG5 + Non DG5 floods | DG5 flood | Volume of water pumped for treatment | Volume of water spilt to the water course | # DG5 floods

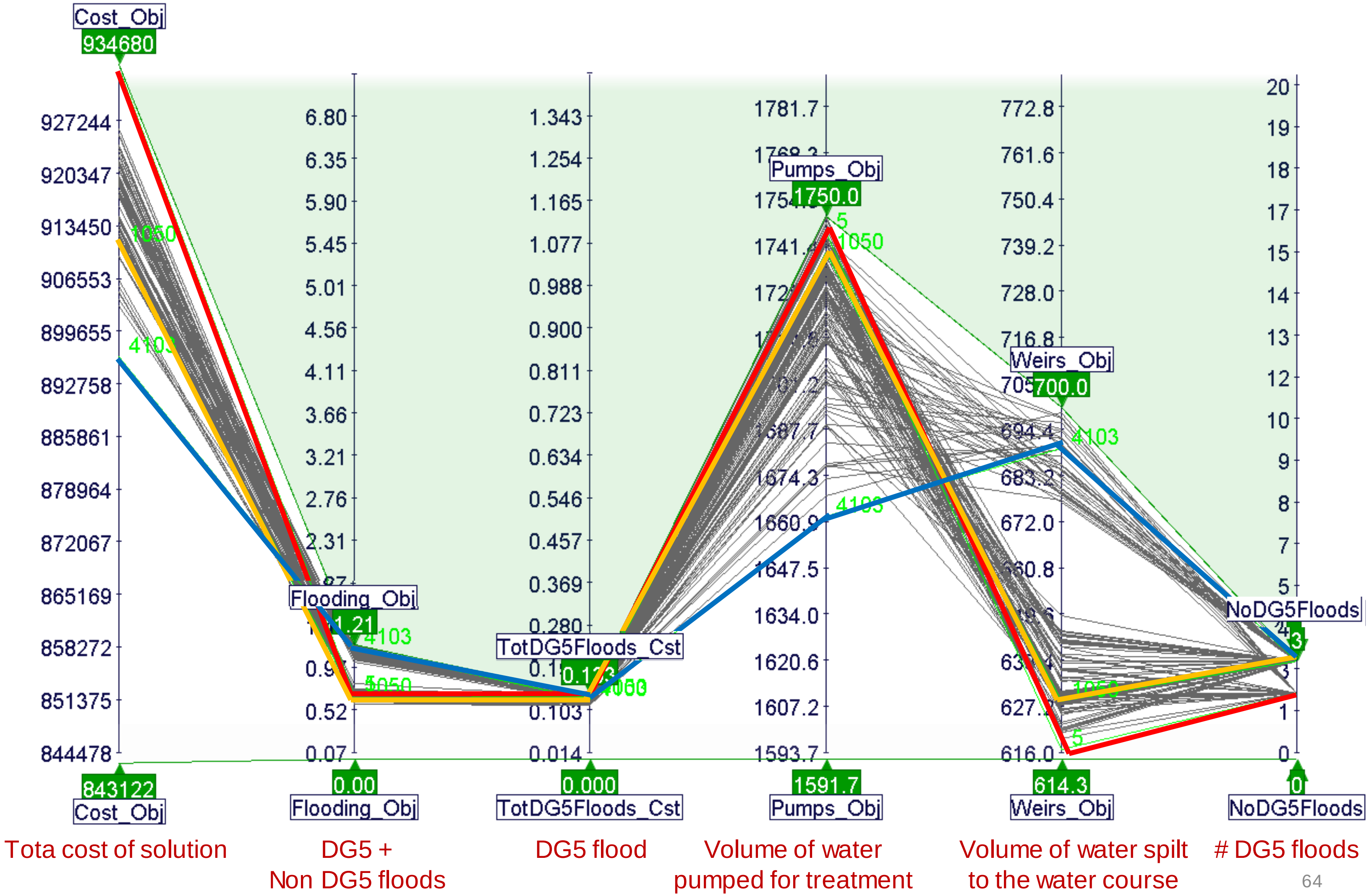
Filtering Results: Axis Parallel Chart

Results:

Manual

Solution 1

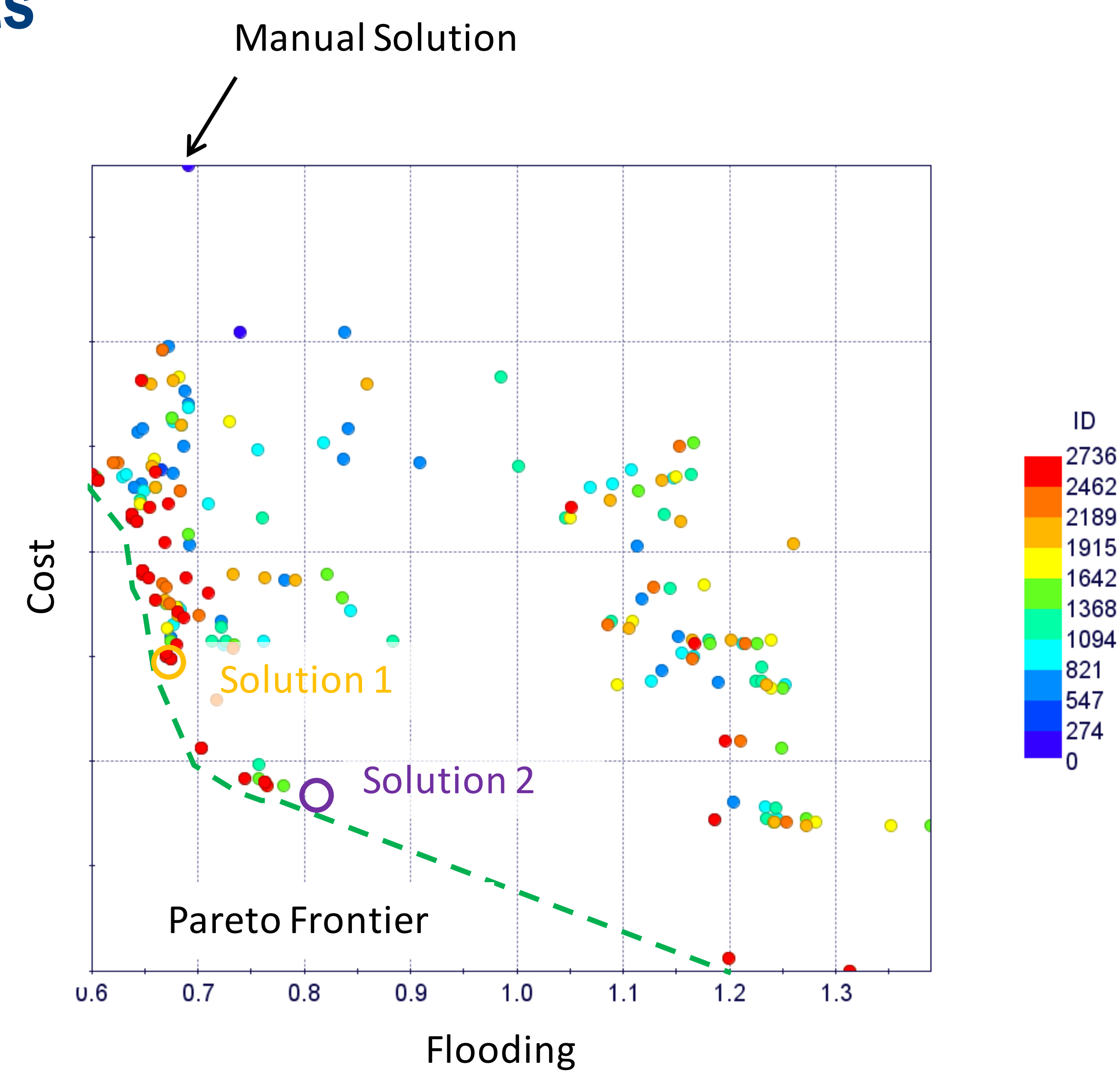
Solution 2



Detailed Results

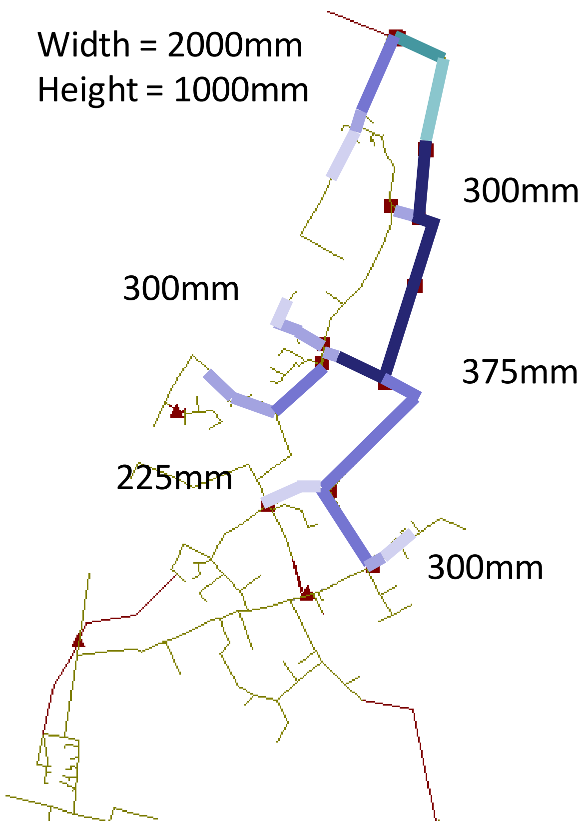
Results:

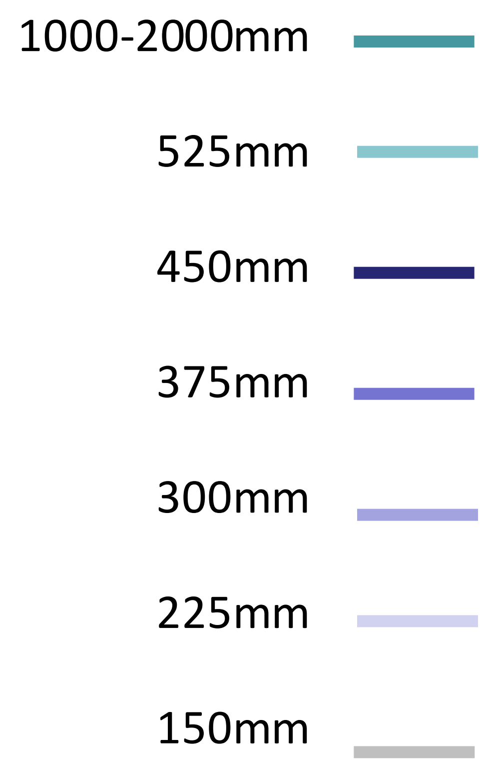
Two solutions have been chosen from the Pareto Front to assess Time Series Rainfall (TSR)



Design Solution 1

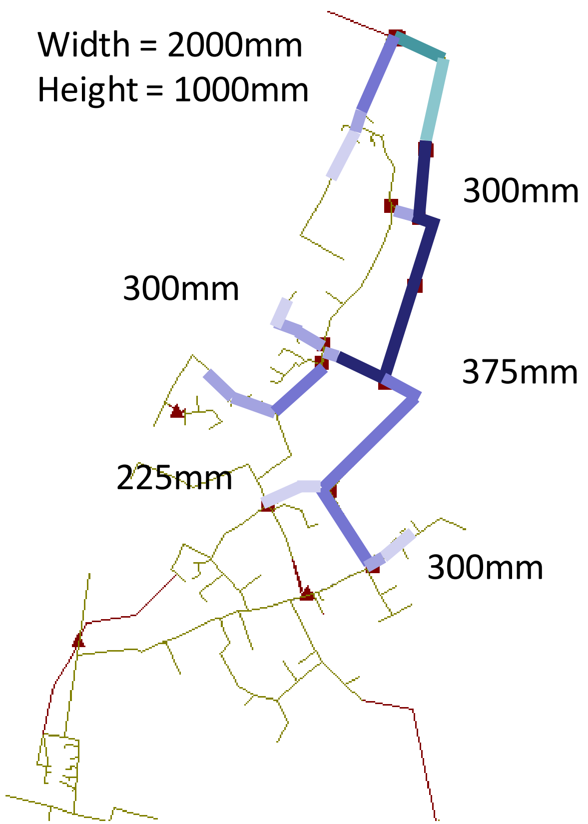
Manual Solution:



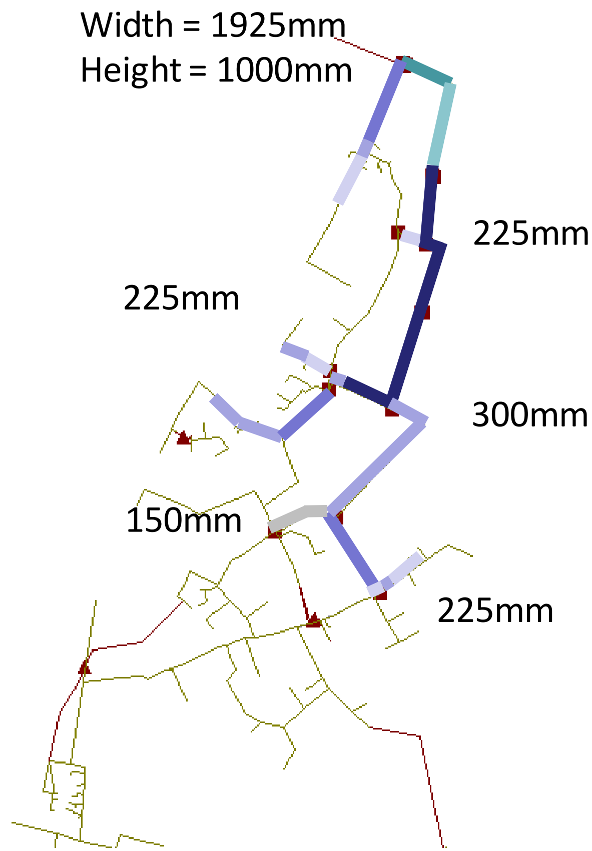


Design Solution 1

Manual Solution:

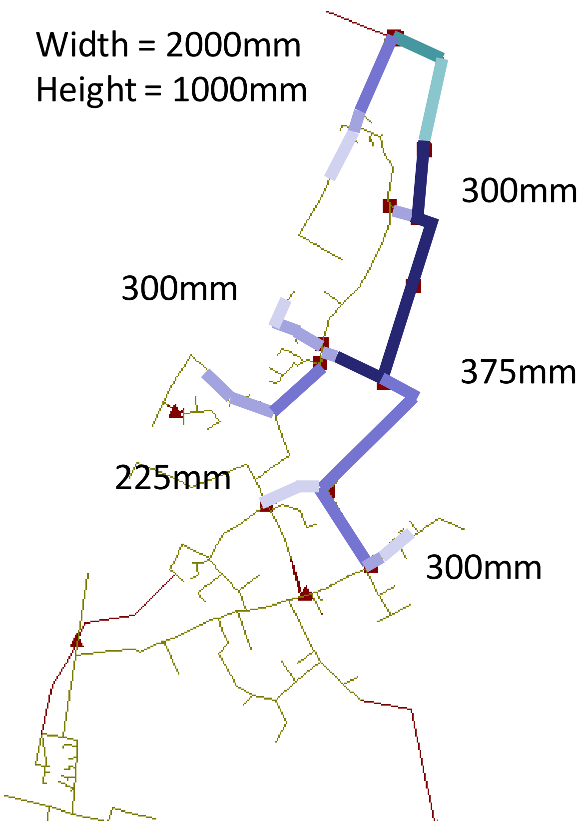


mF Solution 1:

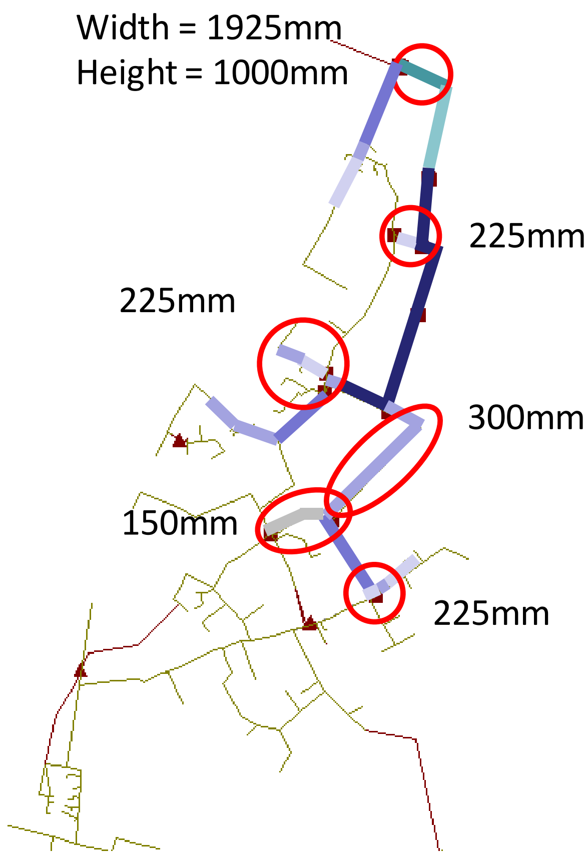


Design Solution 1

Manual Solution:

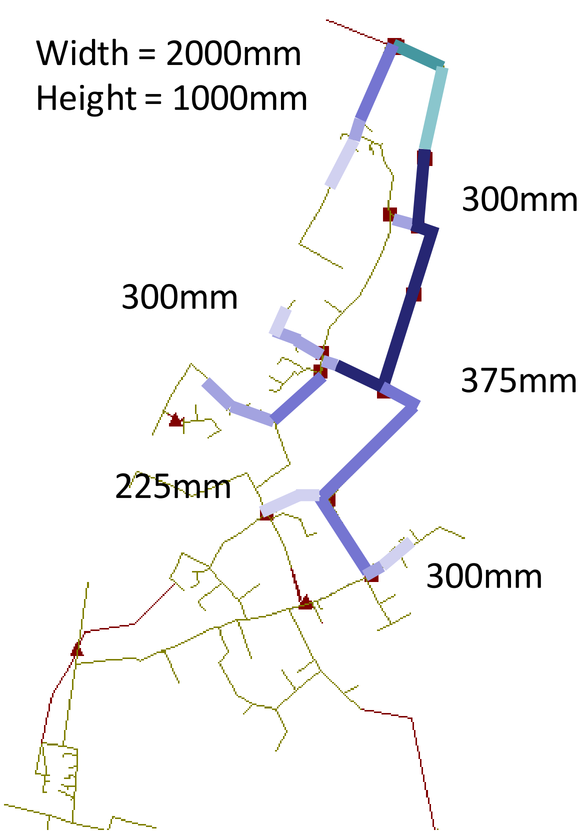


mF Solution 1:

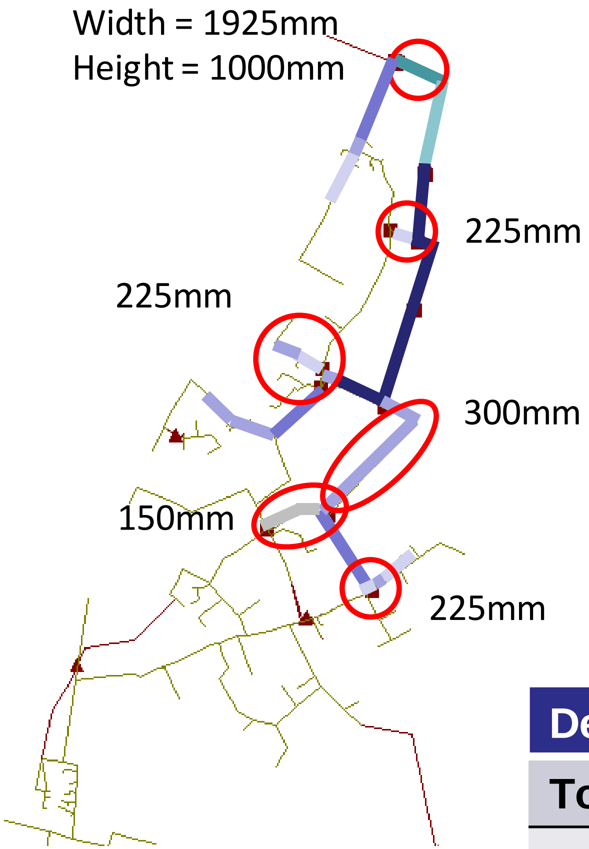


Design Solution 1

Manual Solution:



mF Solution 1:



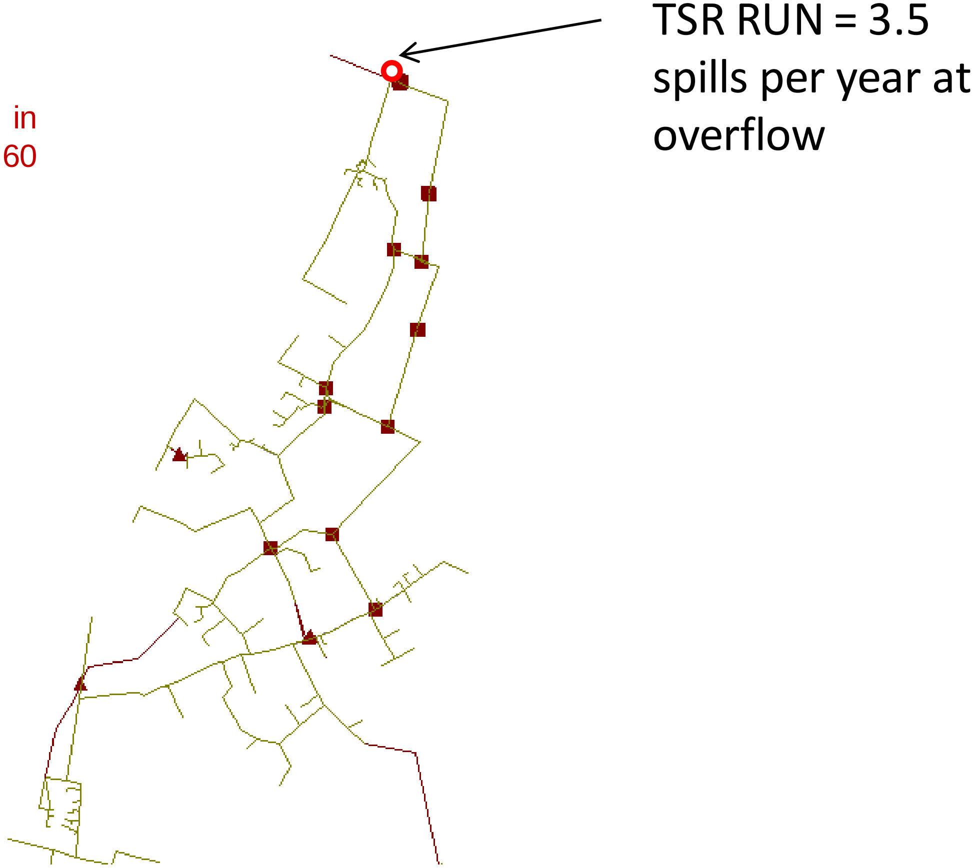
- 1000-2000mm
- 525mm
- 450mm
- 375mm
- 300mm
- 225mm
- 150mm

Description	Cost
Total Cost	**£910,983**
Saving	£23,000 (2.5%)

Design Solution 1: Flooding

Critical Flooding (2 locations) vs. TSR

TSR example:
M30-60 = expected depth of rainfall in millimetres (mm) from a storm lasting 60 minutes with a return period of 30 years

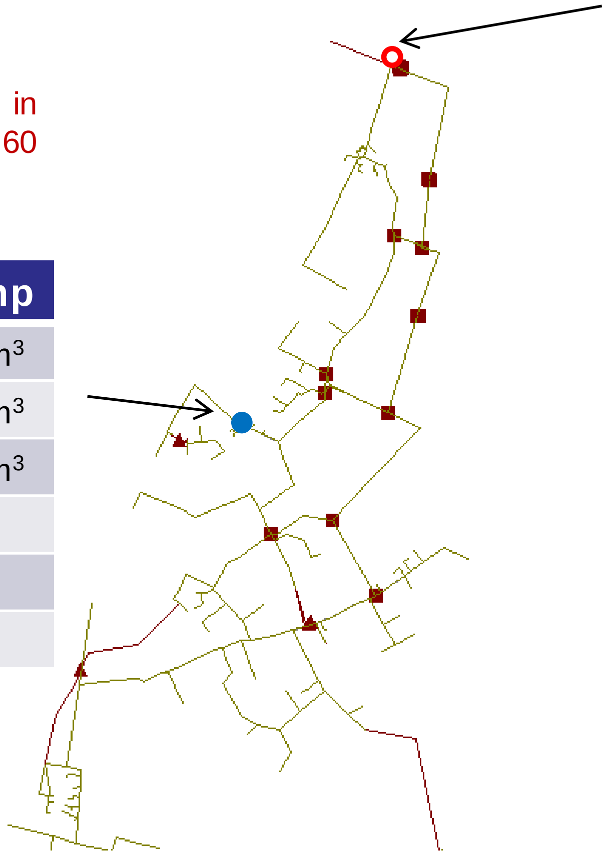


Design Solution 1: Flooding

Critical Flooding (2 locations) vs. TSR

TSR example:
M30-60 = expected depth of rainfall in millimetres (mm) from a storm lasting 60 minutes with a return period of 30 years

Storm	Manual	mF	Comp
M30-30	0.6m^3	0.1m^3	-0.5m^3
M30-60	6.0m^3	3.6m^3	-2.4m^3
M30-120	6.5m^3	3.2m^3	-3.3m^3
M30-240	0.0m^3	0.0m^3	-
M30-480	0.0m^3	0.0m^3	-
M30-720	0.0m^3	0.0m^3	-



TSR RUN = 3.5 spills per year at overflow

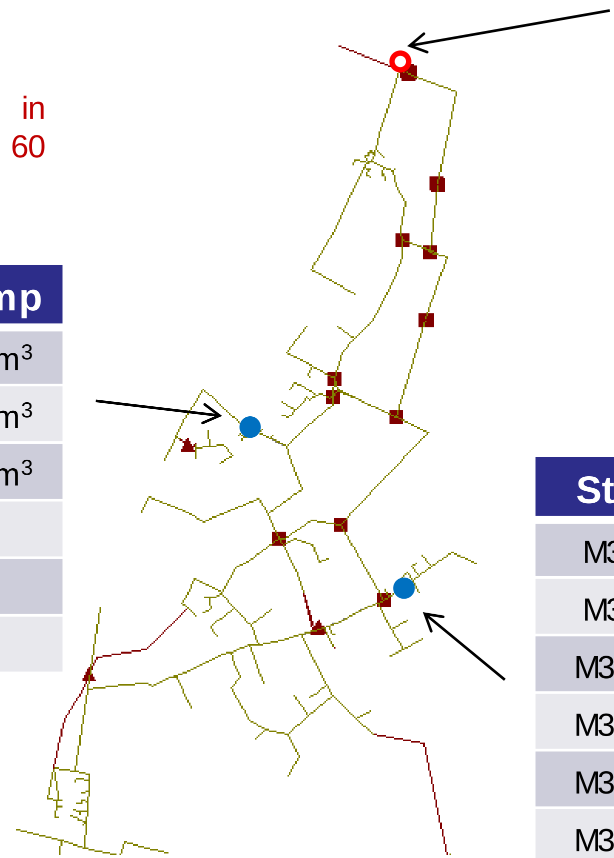
Design Solution 1: Flooding

Critical Flooding (2 locations) vs. TSR

TSR example:
M30-60 = expected depth of rainfall in millimetres (mm) from a storm lasting 60 minutes with a return period of 30 years

Storm	Manual	mF	Comp
M30-30	0.6m^3	0.1m^3	-0.5m^3
M30-60	6.0m^3	3.6m^3	-2.4m^3
M30-120	6.5m^3	3.2m^3	-3.3m^3
M30-240	0.0m^3	0.0m^3	-
M30-480	0.0m^3	0.0m^3	-
M30-720	0.0m^3	0.0m^3	-

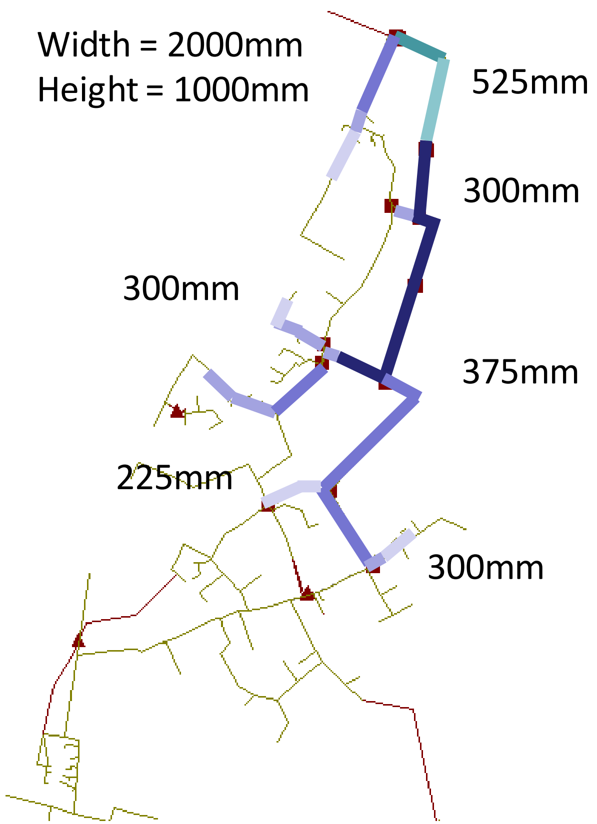
TSR RUN = 3.5 spills per year at overflow



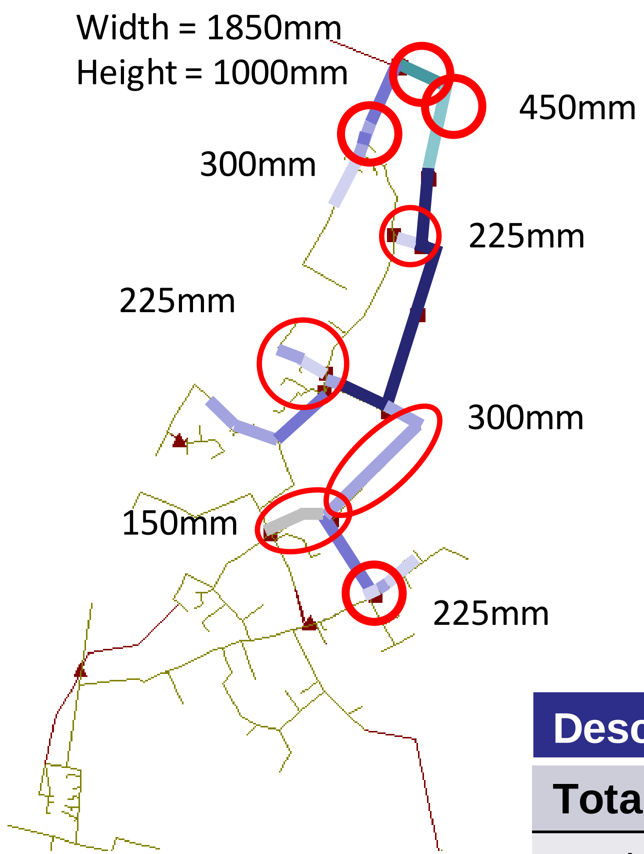
Storm	Manual	mF	Comp
M30-30	6.1m^3	6.3m^3	+0.2m^3
M30-60	7.6m^3	8.3m^3	+0.7m^3
M30-120	5.8m^3	7.0m^3	+1.2m^3
M30-240	0.0m^3	1.3m^3	+1.3m^3
M30-480	0.0m^3	0.0m^3	0.0m^3
M30-720	0.0m^3	0.0m^3	0.0m^3

Design Solution 2

Manual Solution:



mF Solution 2:



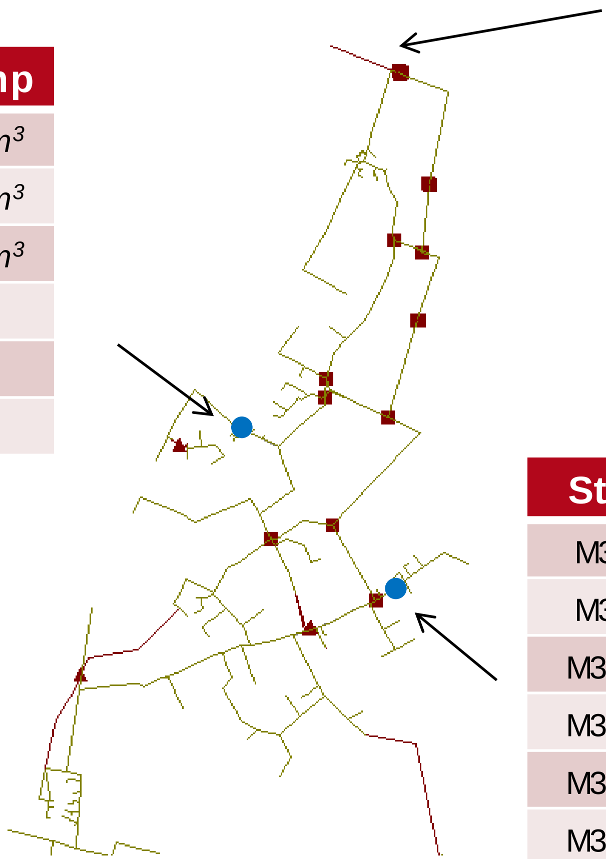
Description	Cost
Total Cost	**£904,790**
Saving	£30,000 (3.2%)

Design Solution 2: Flooding

Critical Flooding (2 locations) vs. TSR

Storm	Manual	mF	Comp
M30-30	$0.6m^3$	$0.1m^3$	$-0.5m^3$
M30-60	$6.0m^3$	$3.6m^3$	$-2.4m^3$
M30-120	$6.5m^3$	$3.3m^3$	$-3.2m^3$
M30-240	$0.0m^3$	$0.0m^3$	-
M30-480	$0.0m^3$	$0.0m^3$	-
M30-720	$0.0m^3$	$0.0m^3$	-

TSR RUN = 3.9 spills per year at overflow



Storm	Manual	mF	Comp
M30-30	$6.1m^3$	$6.3m^3$	$+0.2m^3$
M30-60	$7.6m^3$	$8.3m^3$	$+0.7m^3$
M30-120	$5.8m^3$	$7.0m^3$	$+1.2m^3$
M30-240	$0.0m^3$	$1.4m^3$	$+1.4m^3$
M30-480	$0.0m^3$	$0.0m^3$	$0.0m^3$
M30-720	$0.0m^3$	$0.0m^3$	$0.0m^3$

Smart Optioneering [2]: with Storage Options

Urban Flood Prevention

Input variables

- 50 Pipe diameters
- 6 Storage volumes
- 8 New manhole options

Output variable

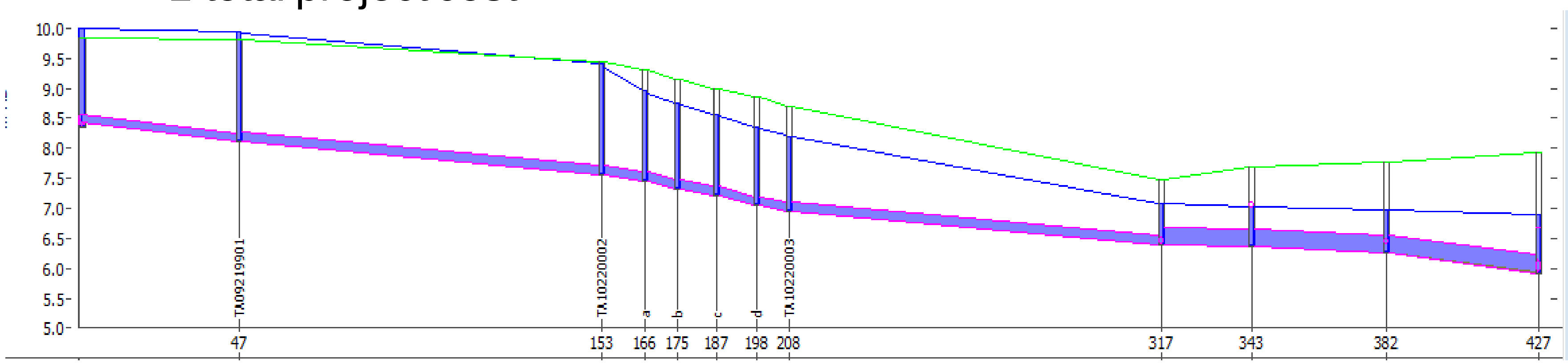
- 100 flood volumes
- 1 total project cost

Objective

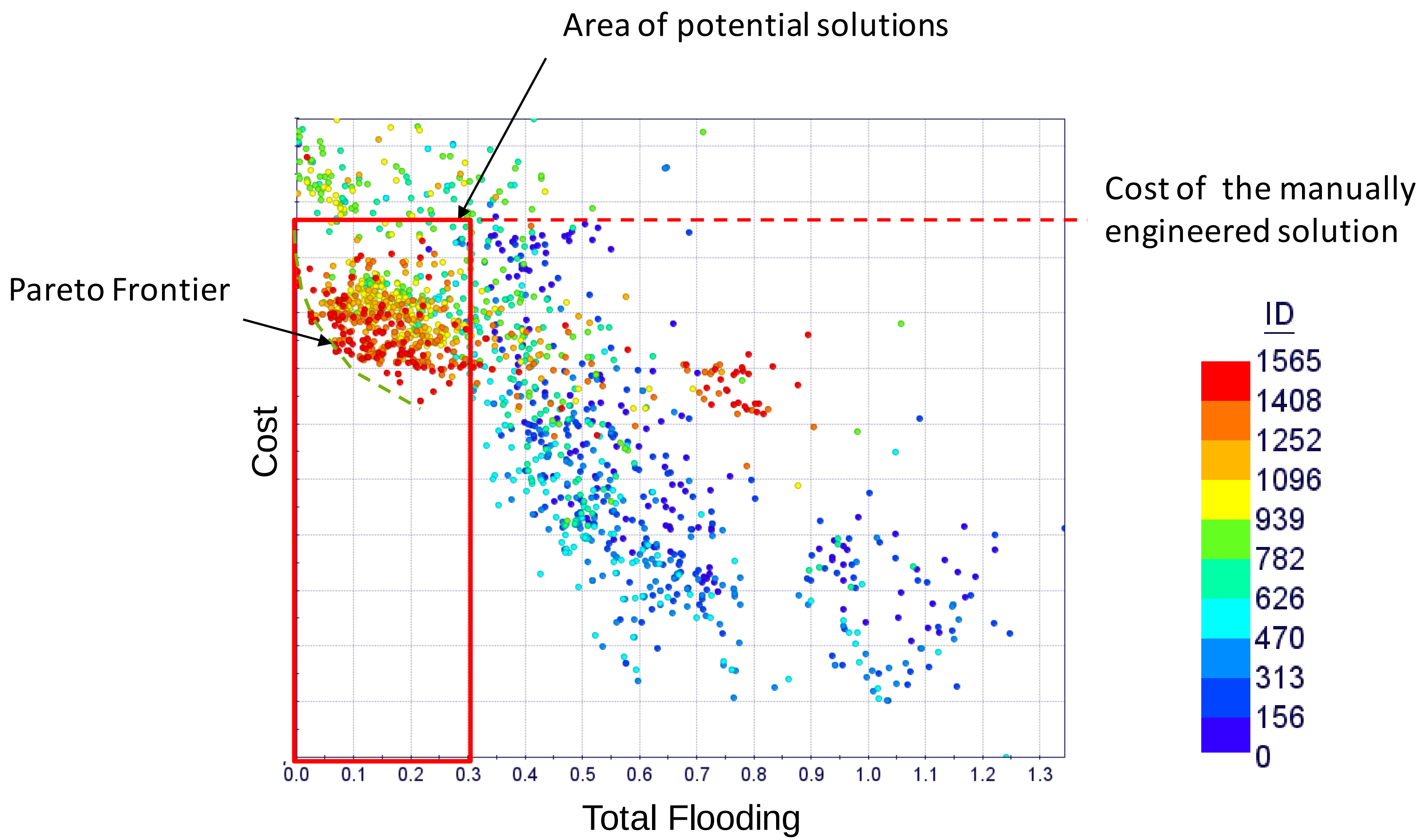
- Minimise Cost and Flooding

Optimisation Strategy

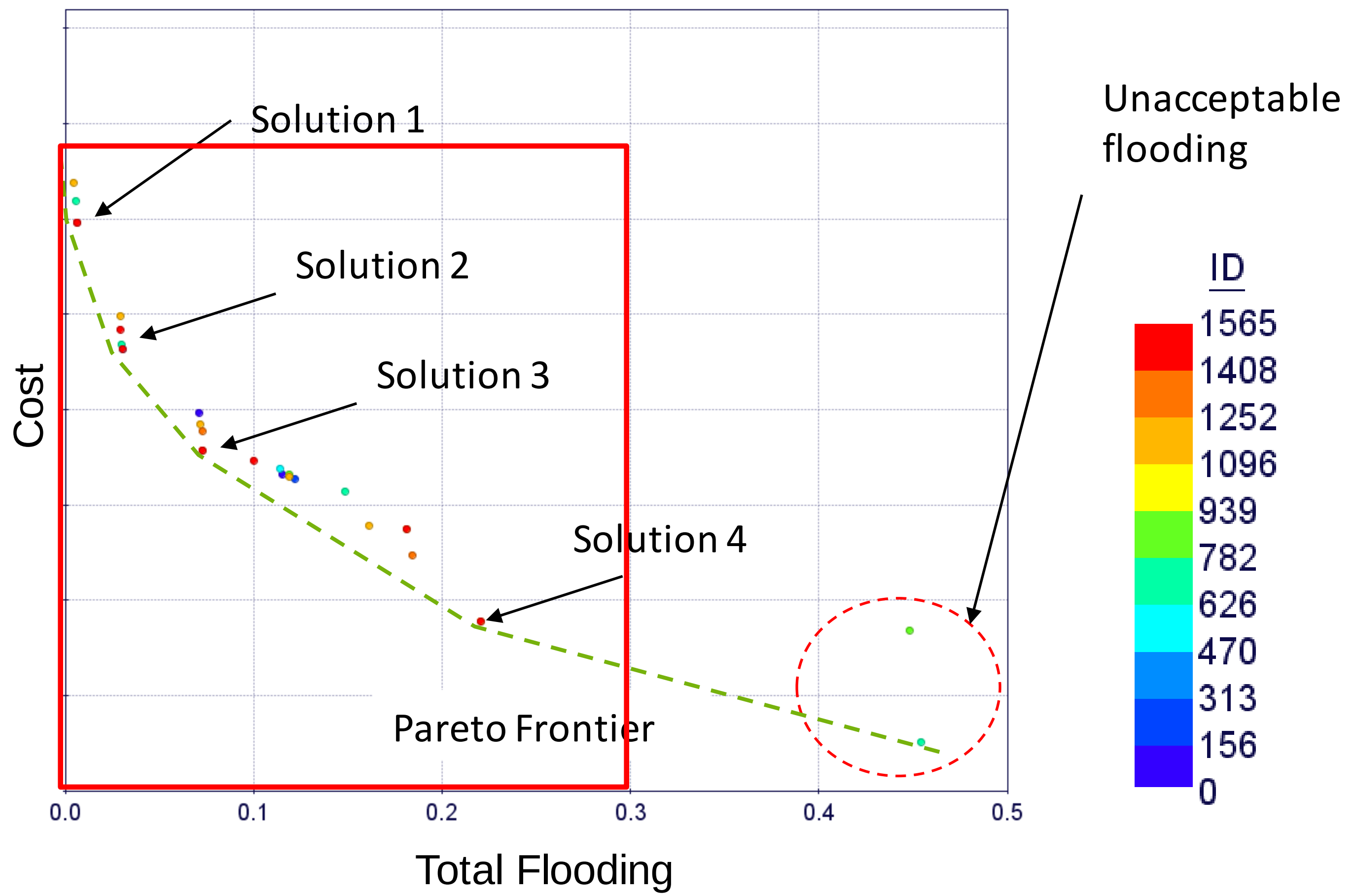
- Multi-Objective
- MOGA-II / NSGA-II with MFGA



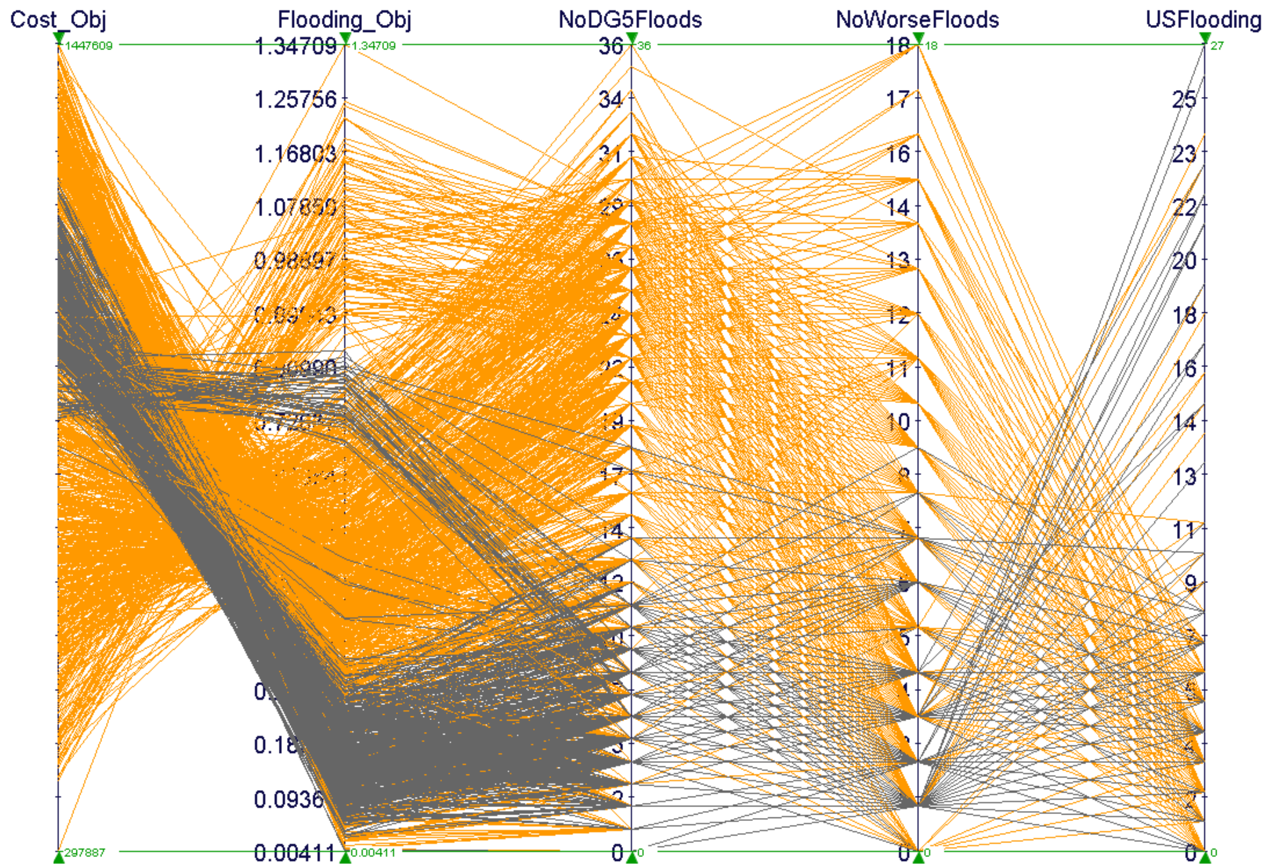
Urban Flood Prevention



Urban Flood Prevention

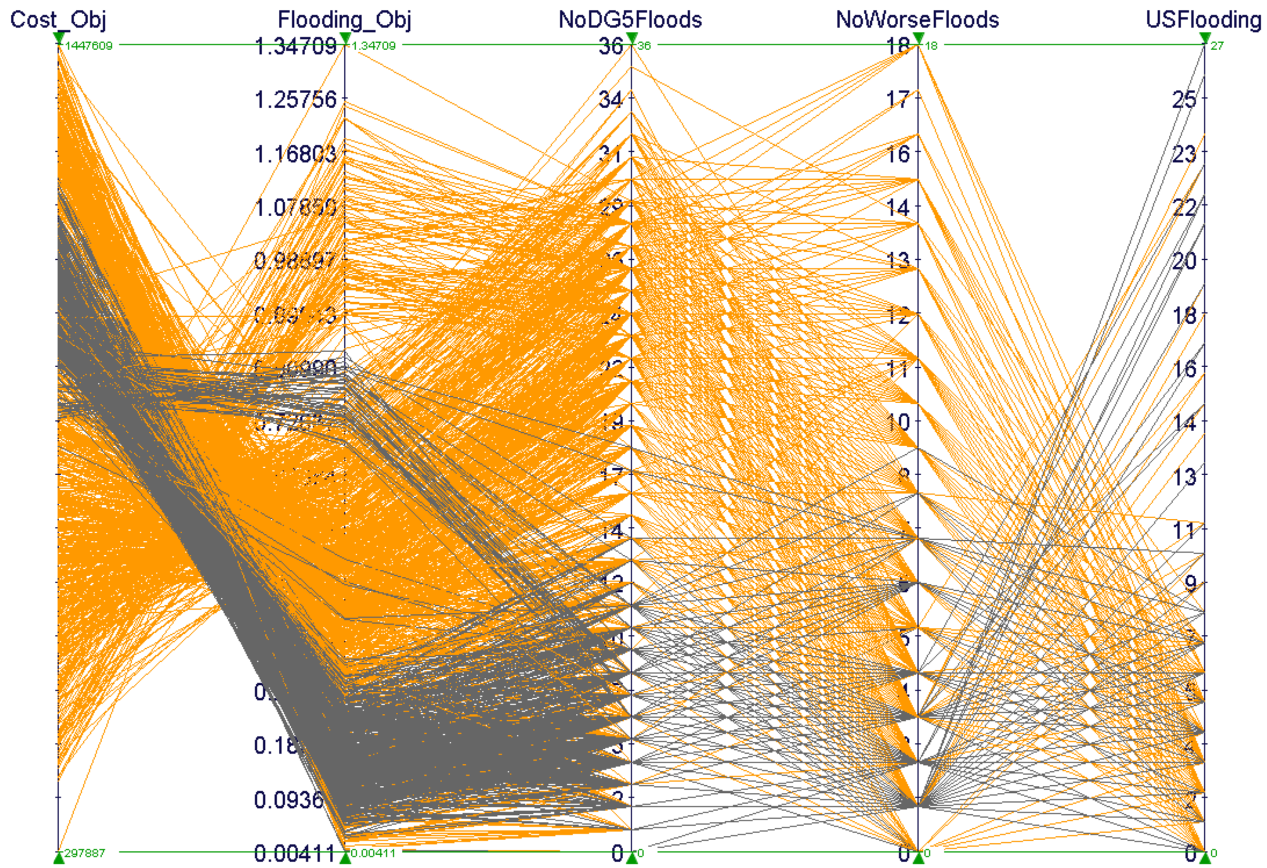


Urban Flood Prevention



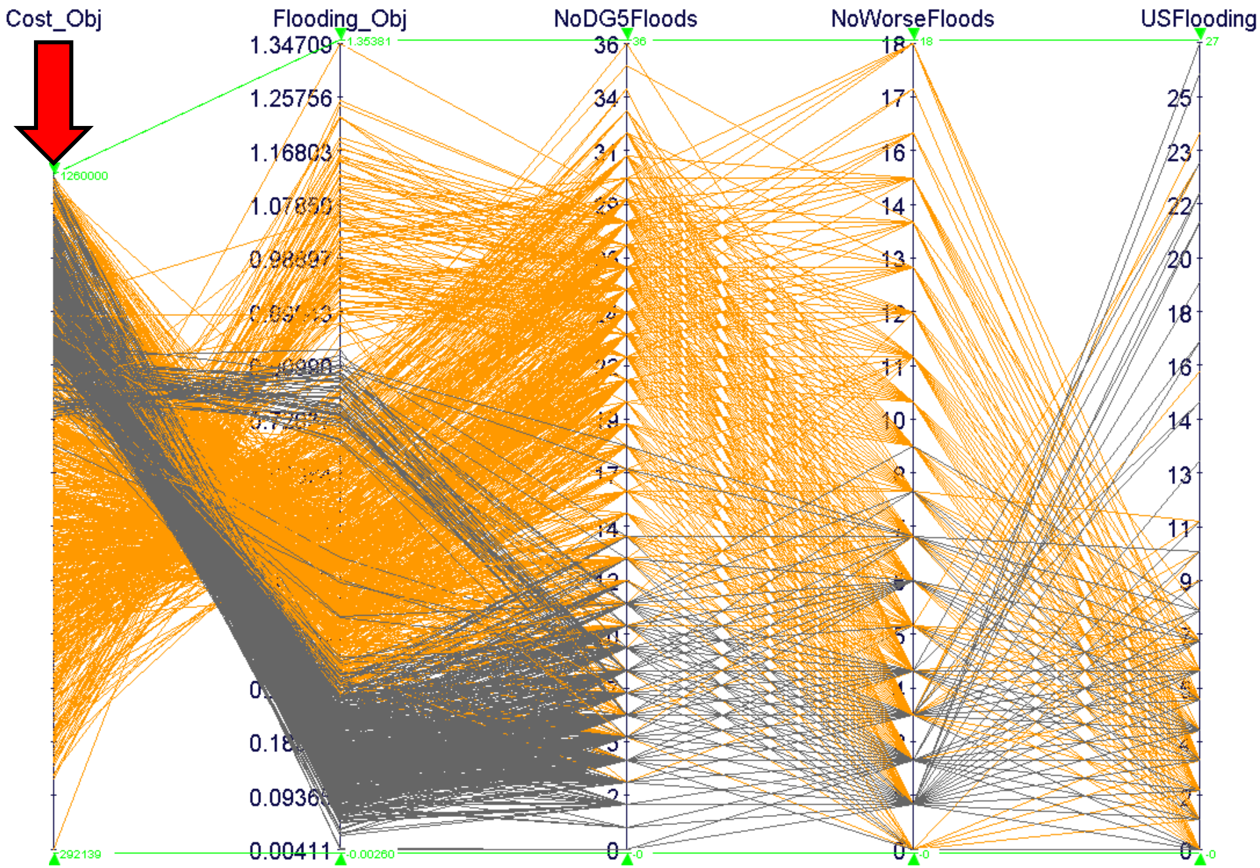
Urban Flood Prevention

Most Important Floods → **Least Important Floods**



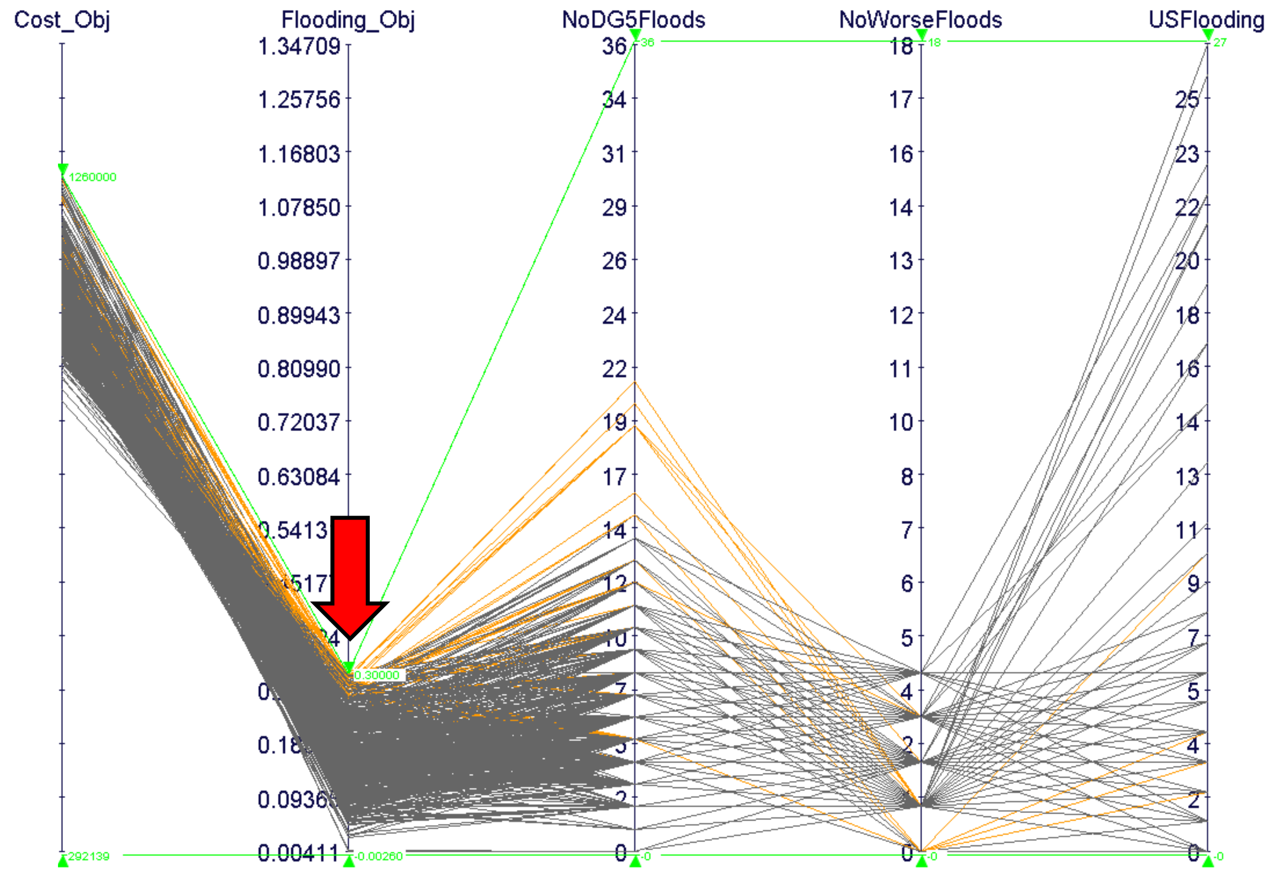
Urban Flood Prevention

Most Important Floods → **Least Important Floods**



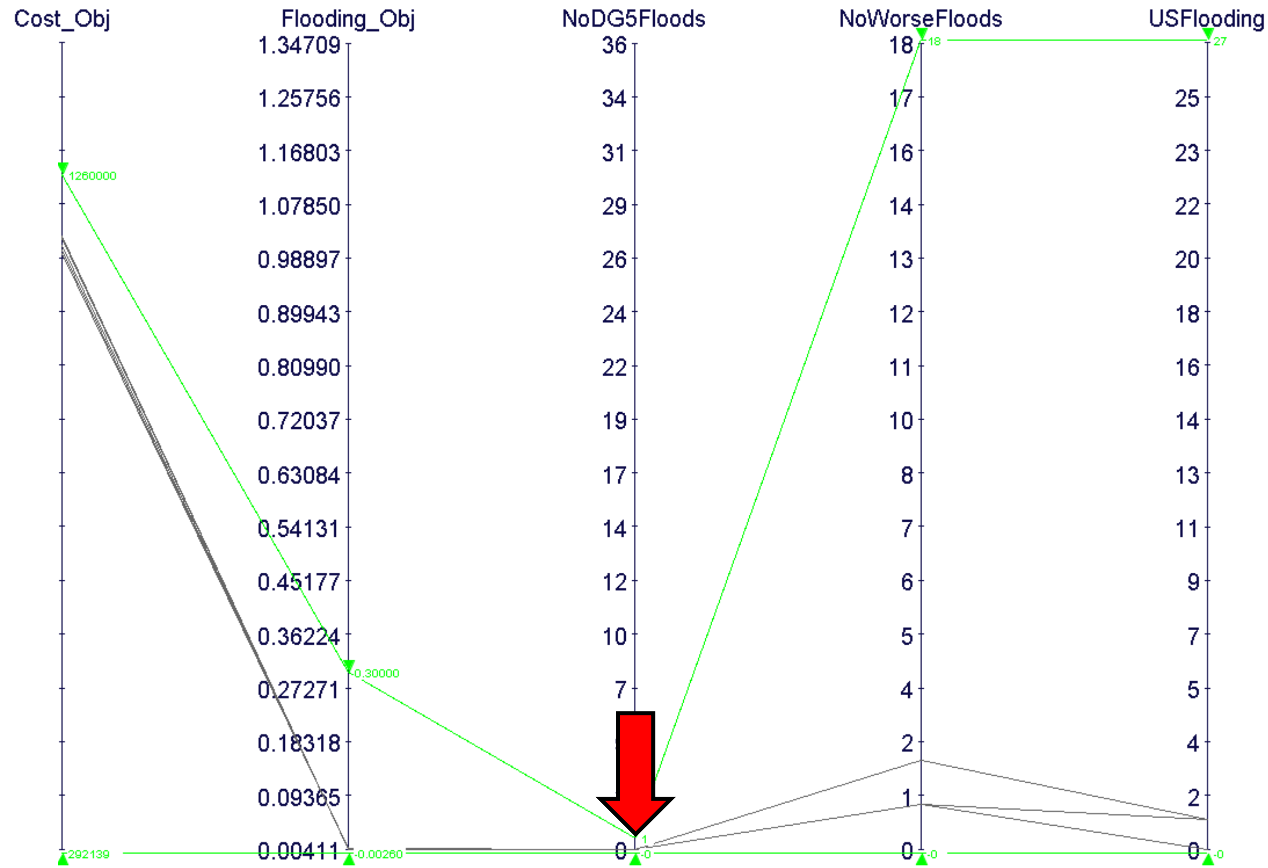
Urban Flood Prevention

Most Important Floods → Least Important Floods



Urban Flood Prevention

Most Important Floods → Least Important Floods



Urban Flood Prevention

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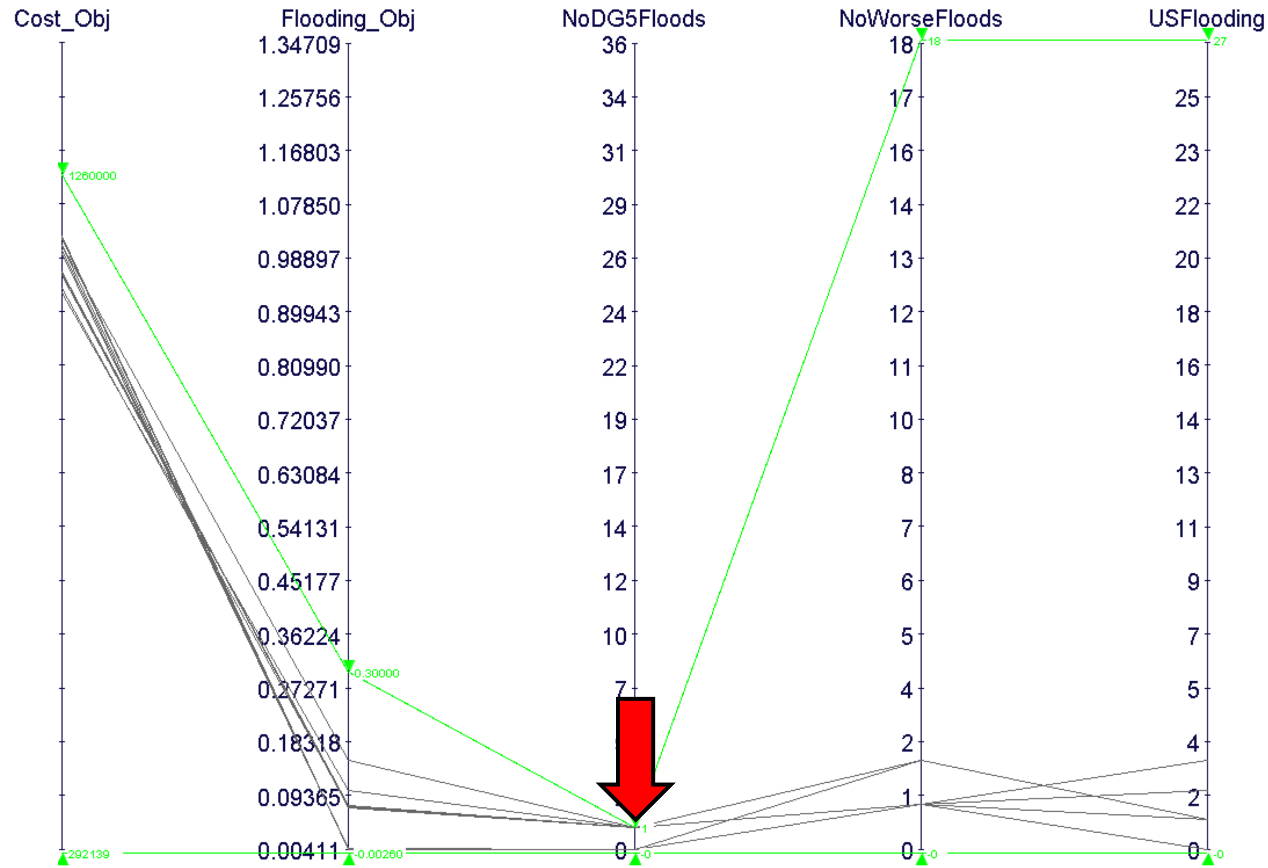

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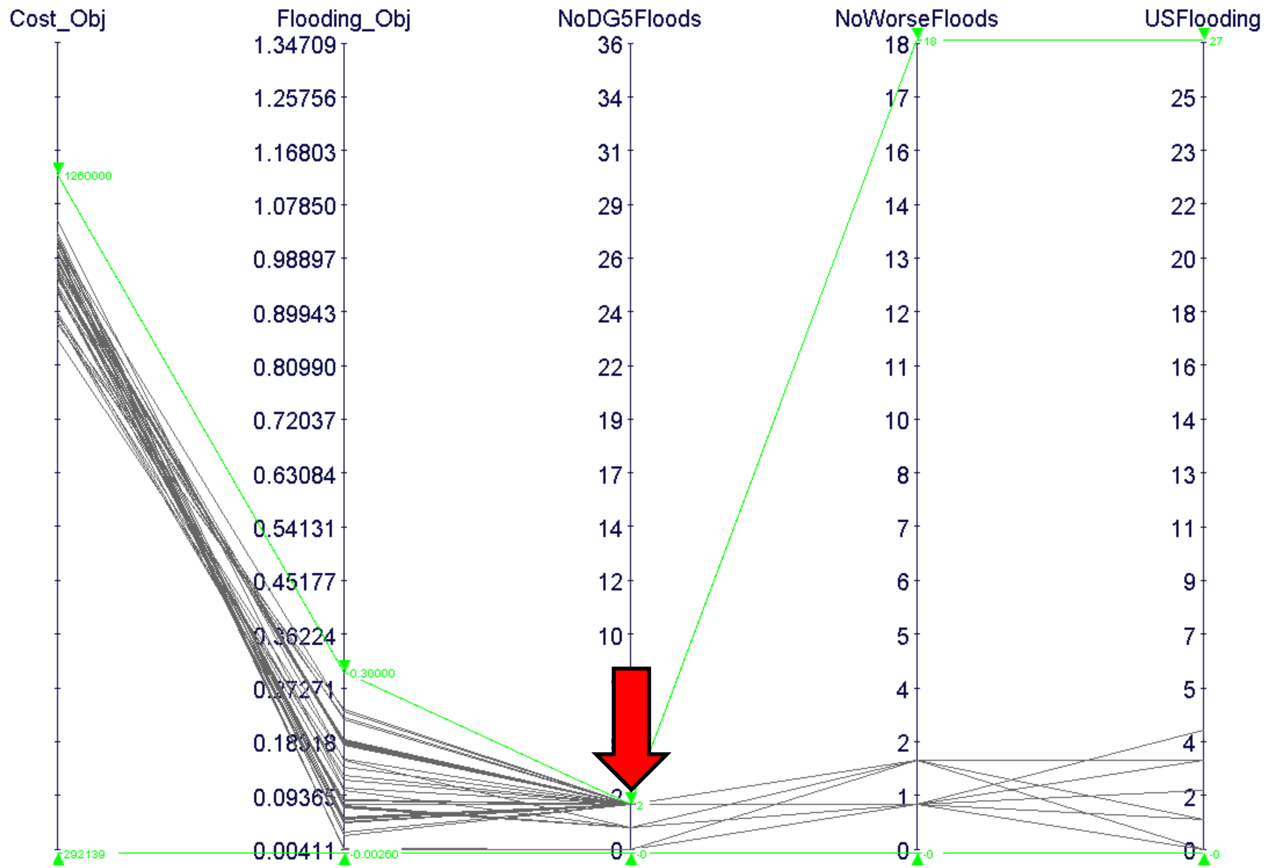

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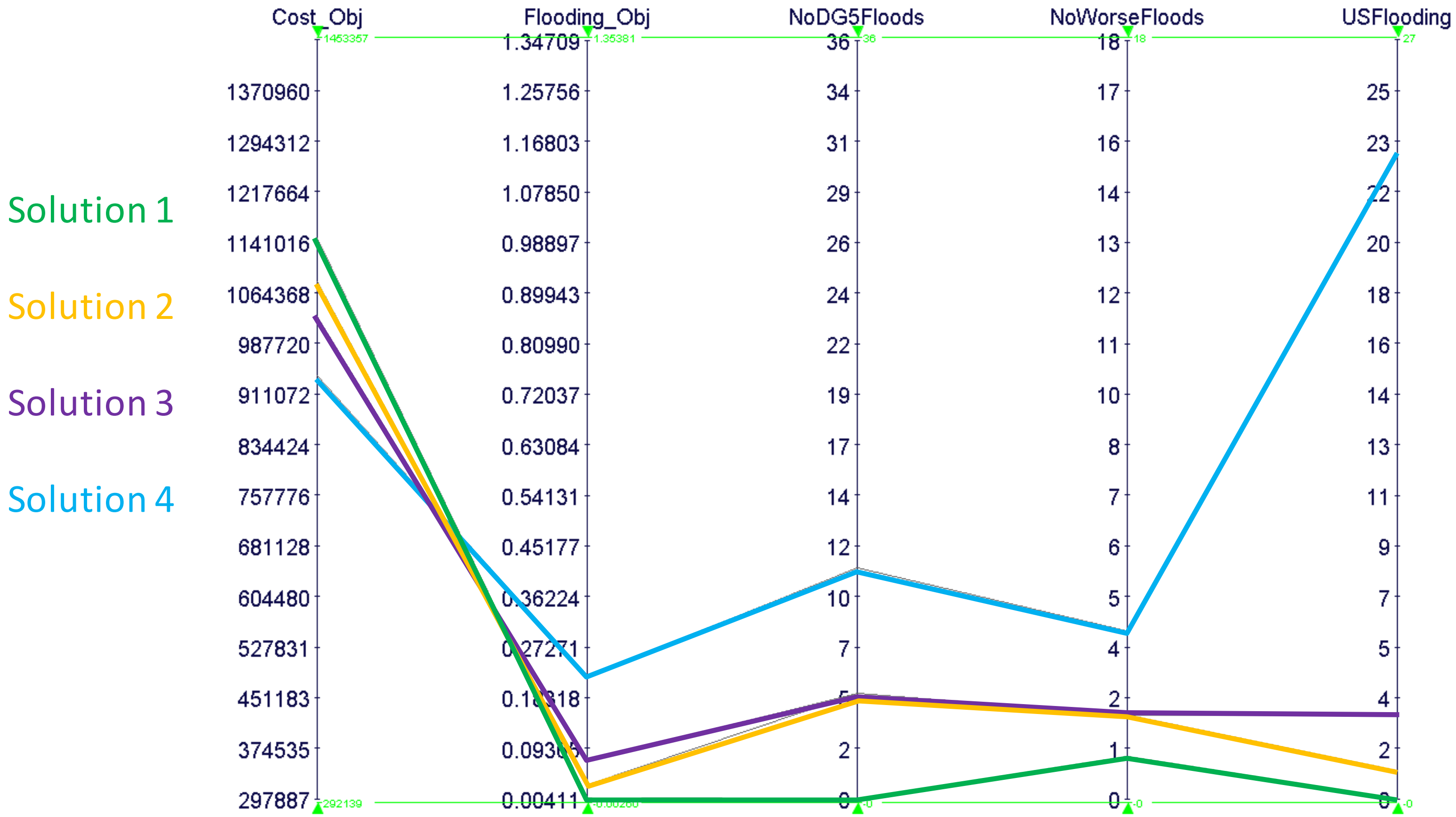

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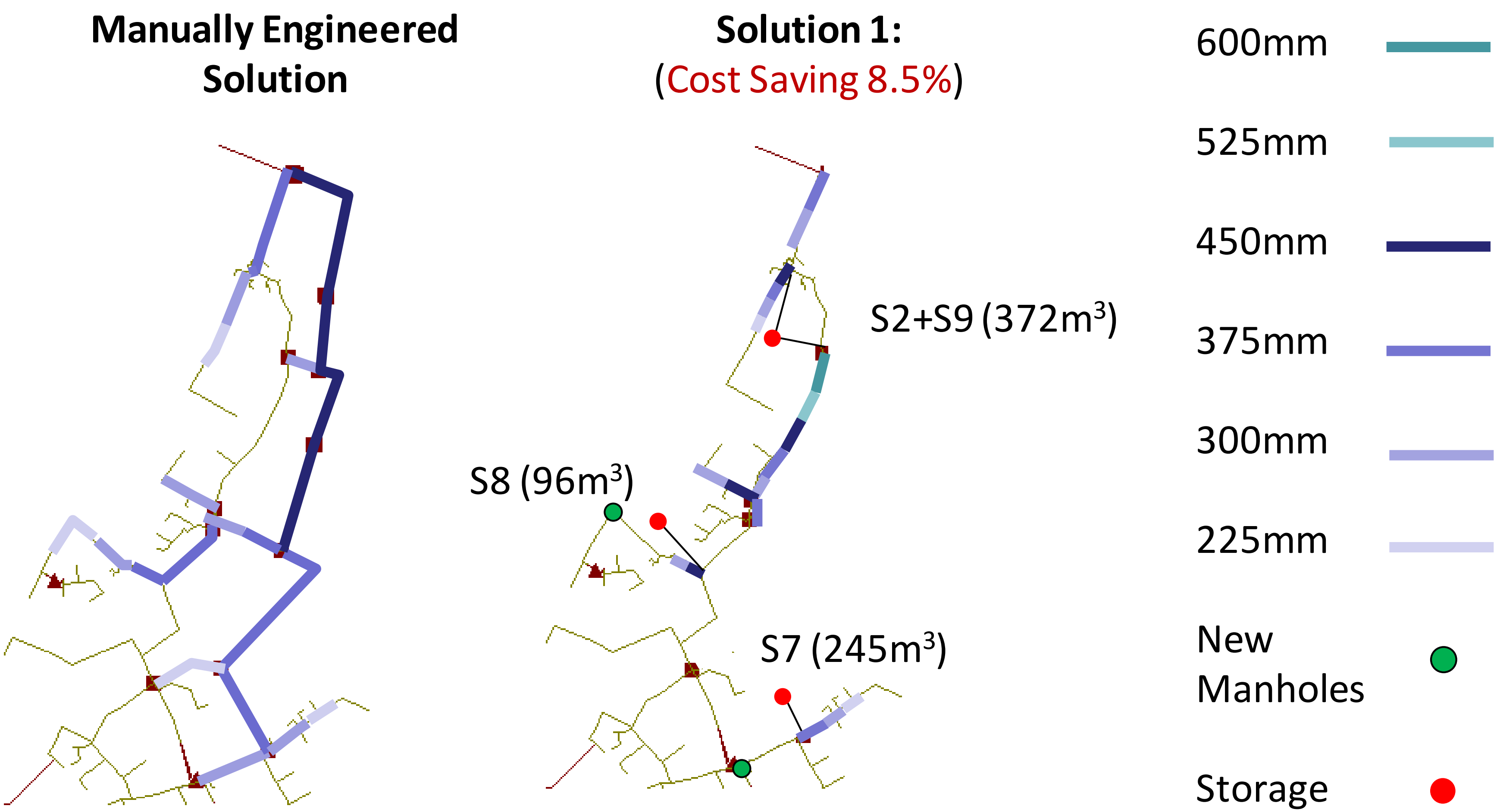

Recap From the last SGM (Steering Group Meeting)

We have shown that…

- ✓ We can advance the Pareto Frontier beyond a manually engineered solution
- ✓ A theme of solutions can be explored (for example: pumped storage vs. upgraded pipes)
- ✓ Designs can be explored upfront at the design stage and give clear objective direction to the project
- ✓ A cost-model can be implemented to assess cost-effectiveness
- ✓ The problem can be reduced to a single objective optimisation of cost

Executive Summary

- Advanced automated design optimisation has been carried out using modeFRONTIER coupled to InfoWorks CS

- Optimisation has been limited to downgrading pipe diameters to a manually engineered solution – This gives "a like for like comparison"

- modeFRONTIER has identified two key solutions:
  - ✓ Solution 1 shows a cost reduction of 2.5% (£23,000)
  - ✓ Solution 2 shows a cost reduction of 3.2% (£30,000)

- A greater cost reduction (8.5%) has also been identified using modeFRONTIER by exploring new design themes. However, this saving is based on a cost model that requires further refinement

- This is approximately one weeks work to obtain these solutions

Conclusion

Solution 1

- 2.5% cost saving of £23,000
- Comparable DG5 flooding performance to manual solution
- TSR compliant (3.5 spills a year)

Solution 2

- 3.2% cost saving of £30,000
- Comparable DG5 flooding performance to manual solution
- TSR compliant (3.9 spills a year)

Using modeFRONTIER to calibrate slow soil runoff and wetting parameters for area drainage models in InfoWorks CS

David Searby (Wessex Water)
David Moseley (EnginSoft UK)
Vito Primavera (EnginSoft Italy)

Topic Background - Calibration of what?

- **Total flow in <u>sewer collection systems</u> is the sum of:**

1. **"dry-weather" flow** ➔ 2 standard components
   - **base flow** (wastewater from residential, commercial, and industrial areas released to the sanitary sewer system)
   - **ground water flow** (groundwater infiltration - GWI - that enters sewer system through defective pipes, pipe joints, breaks, … irrespective of rainfall availability)

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- **ground water flow** (groundwater infiltration - GWI - that enters sewer system through defective pipes, pipe joints, breaks, … irrespective of rainfall availability)

2. rainfall-derived inflow and infiltration (RDII) ➔ rainfall-driven flow that makes its way to the collection system

- **RDII** is the main cause of sewer overflows ➔ every water authority needs to control&predict RDII ➔ reliable mathematical drainage models are "welcome" ➔ drainage models calibration vs. monitored data

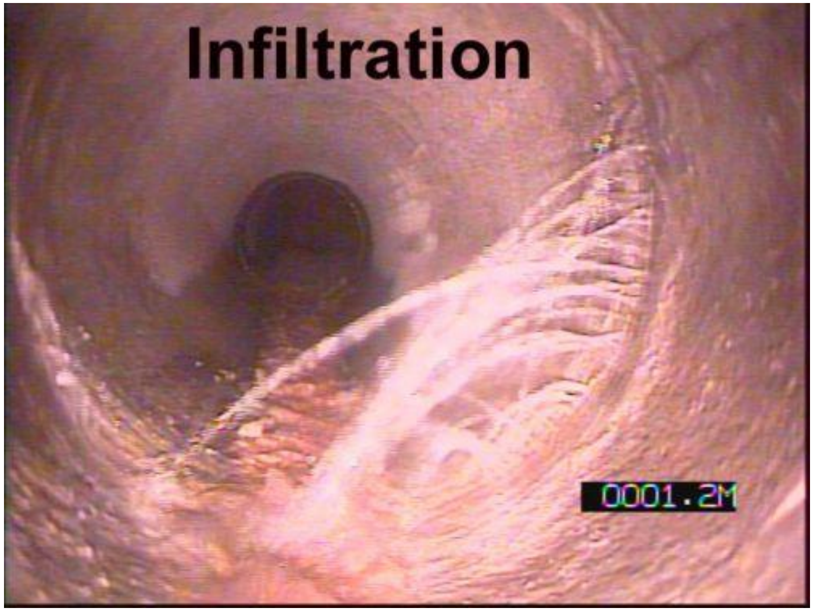
Calibration of slow runoff in INFOWORKS CS - Outline

- Need for tools for Calibration
- The tools: modeFRONTIER and the InfoWorks Interface
- Method for Slow Runoff Calibration
- Examples
- Conclusions and next steps

Introduction:

Wessex Water Perspective

- Programme of modelling for AMP5 (Asset Management Plans, where "5" means runs from April 2010 to March 2015)
- Looking (as ever…) to minimise capital spend ➔ tendency to use storage solutions
- Understanding more important post rainfall inflows ("slow runoff")

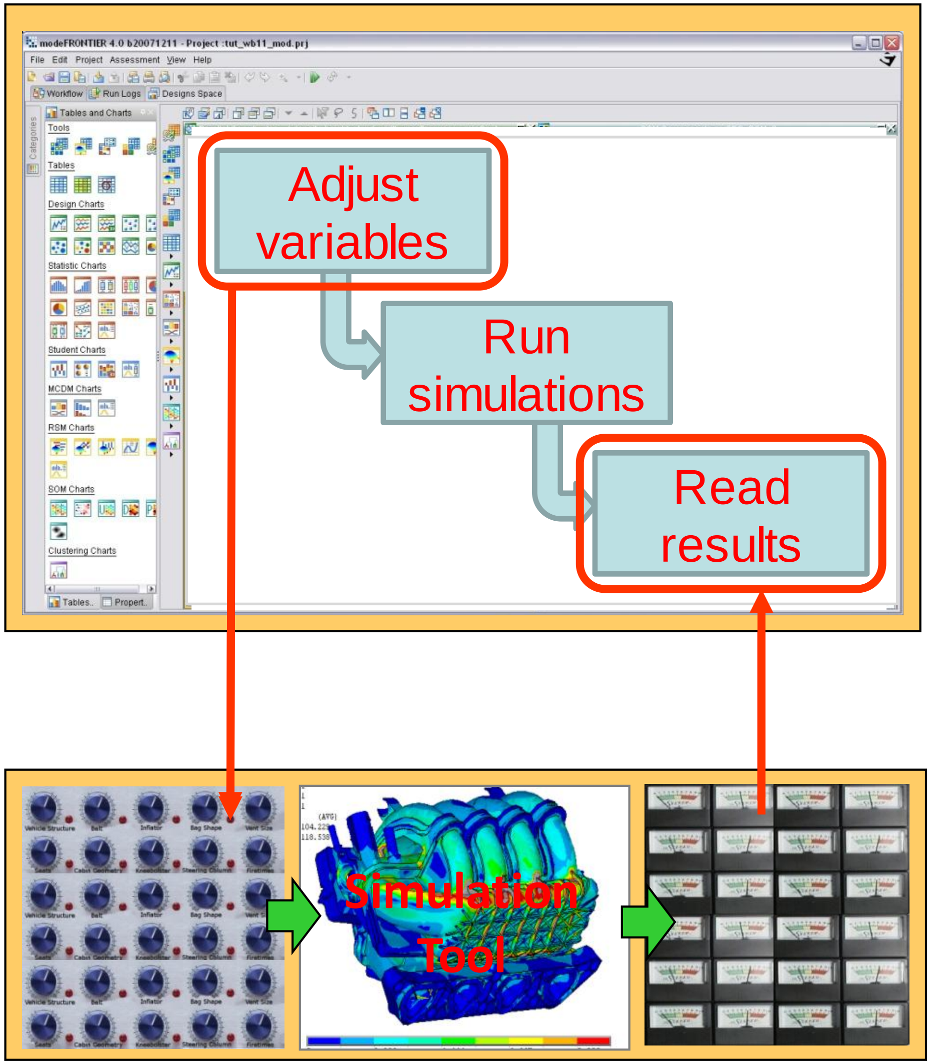


Need for tools

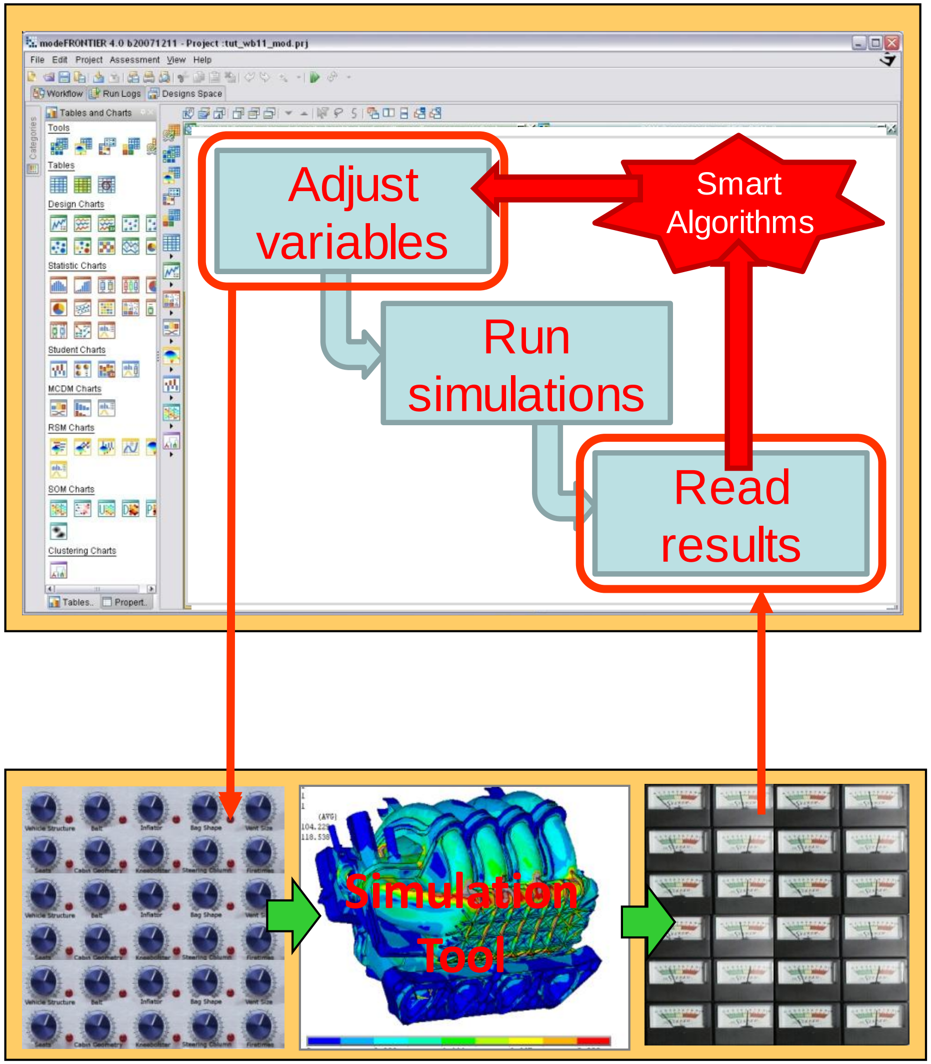
- Tools: New UK, GIM (soil and ground store) - All essentially empirical
- Calibration parameters unmeasurable
- Essentially a “force fitting” exercise
- Time consuming – in one case one monitor fit using GIM ground store took two weeks due to seasonal variation in ground water table

modeFRONTIER

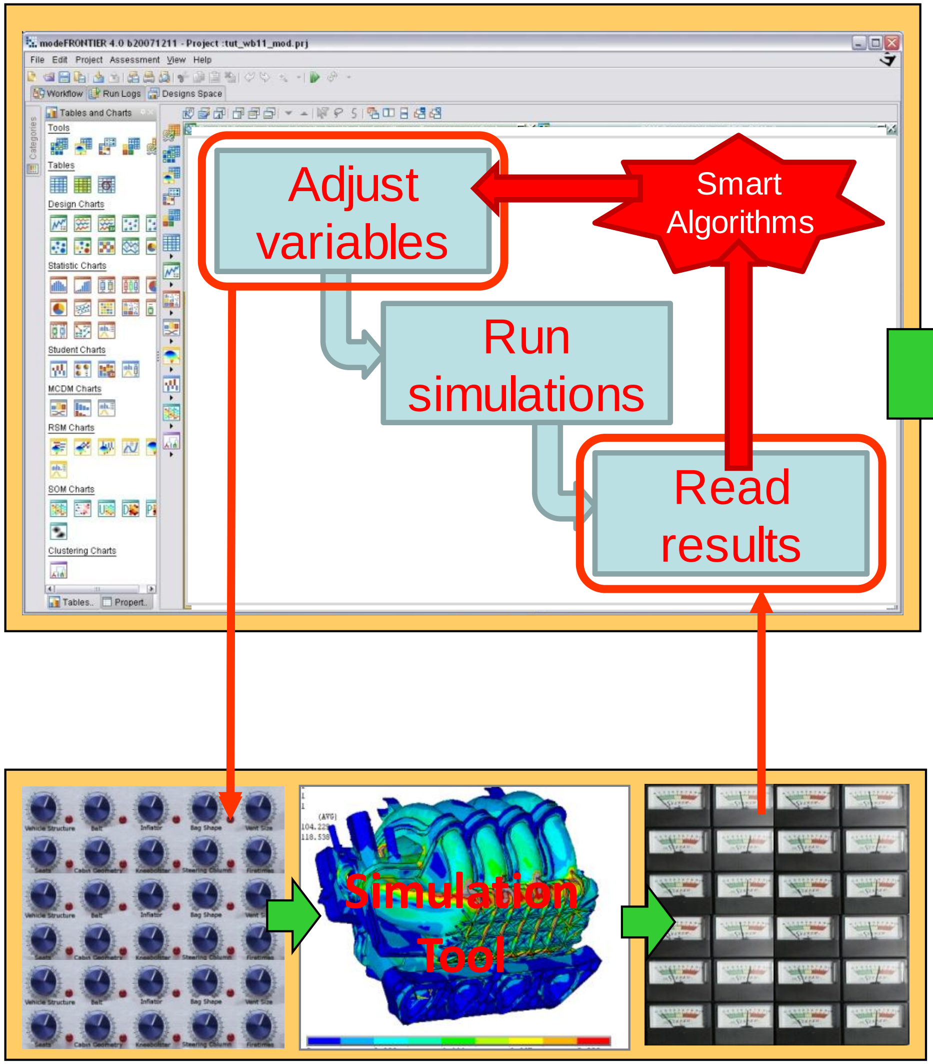
modeFRONTIER



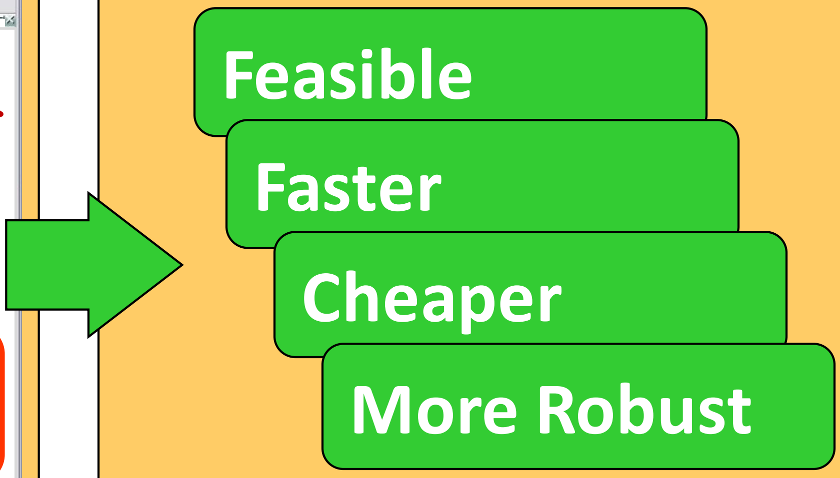
modeFRONTIER



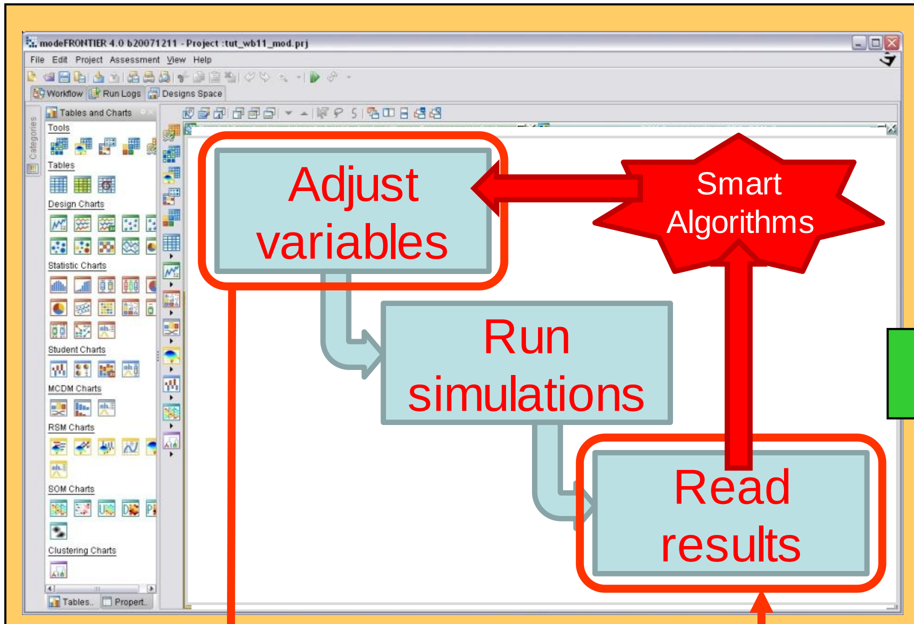
modeFRONTIER



design process & outcome …

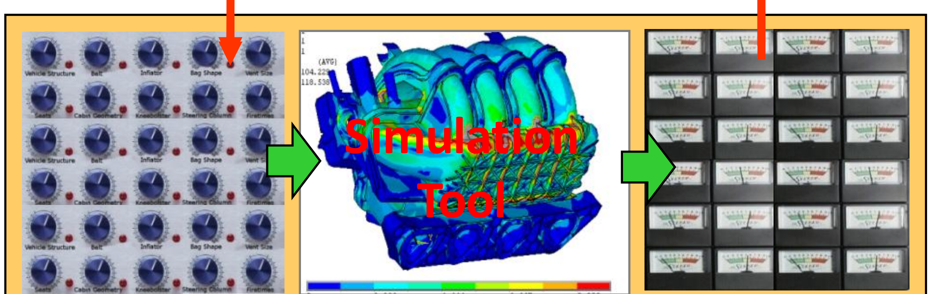


modeFRONTIER

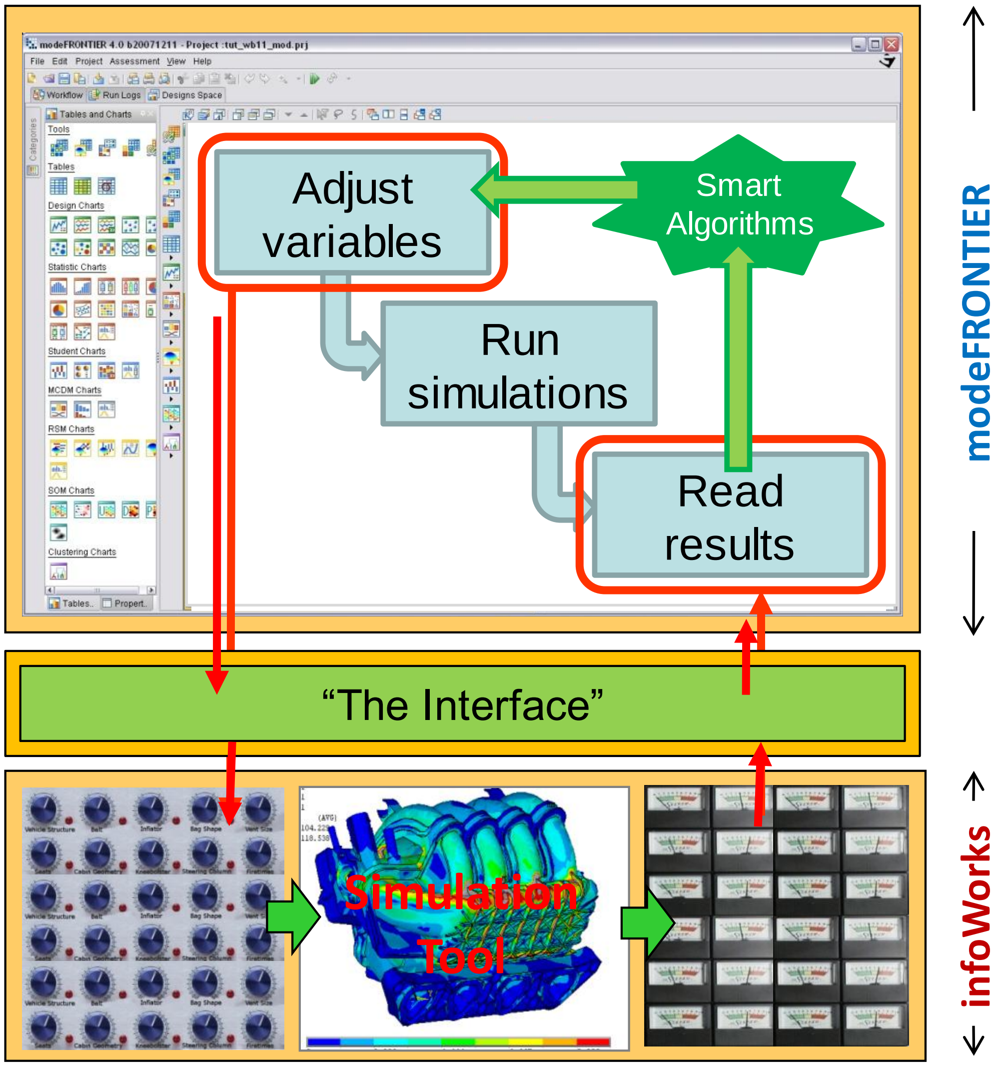


design process & outcome …

- **Feasible**
- **Faster**
- **Cheaper**
- **More Robust**

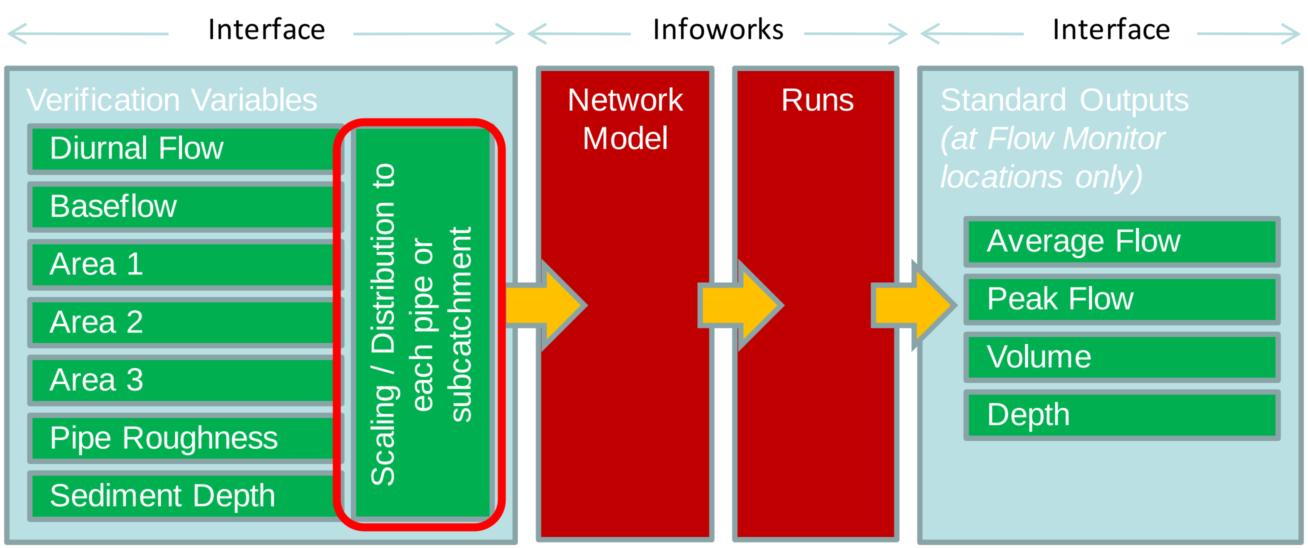


the Interface for InfoWorks CS



- The Interface is a layer (in the form of a spreadsheet) between modeFRONTIER and InfoWorks CS that enables InfoWorks CS to be run automatically
- modeFRONTIER carries out sequential InfoWorks simulations adjusting input variables and evaluating improvements to verification fits from each run

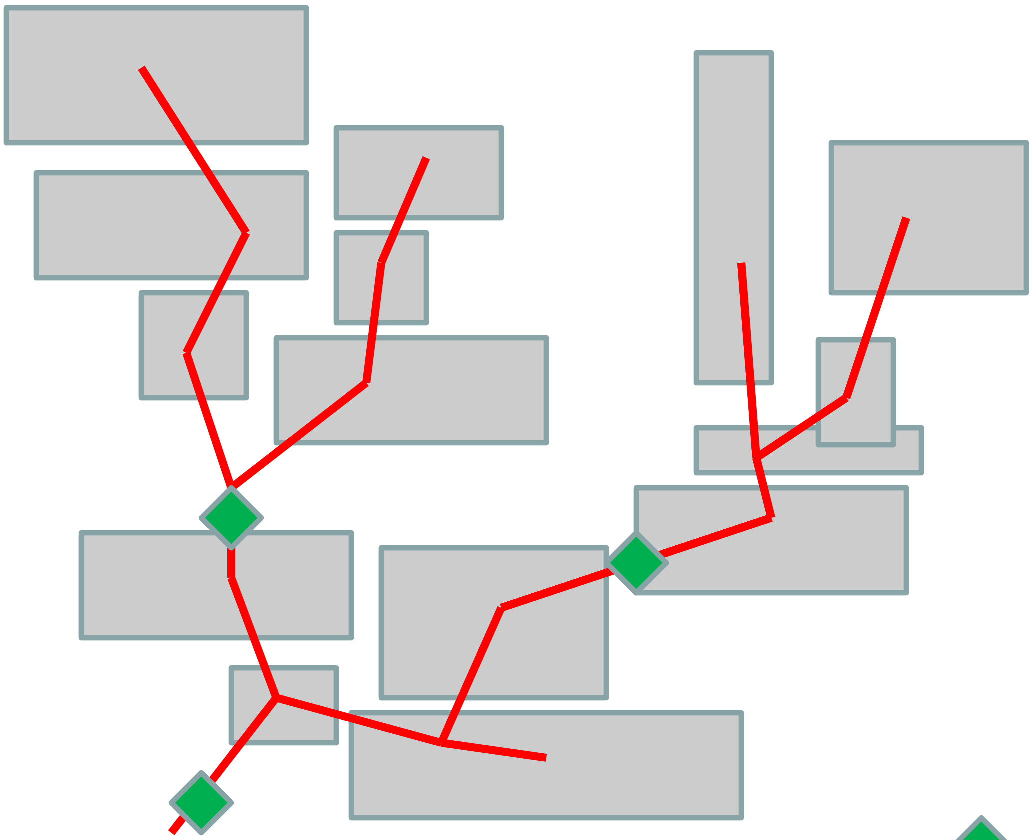
Interface Functionality



Grouped sub-catchment mode:

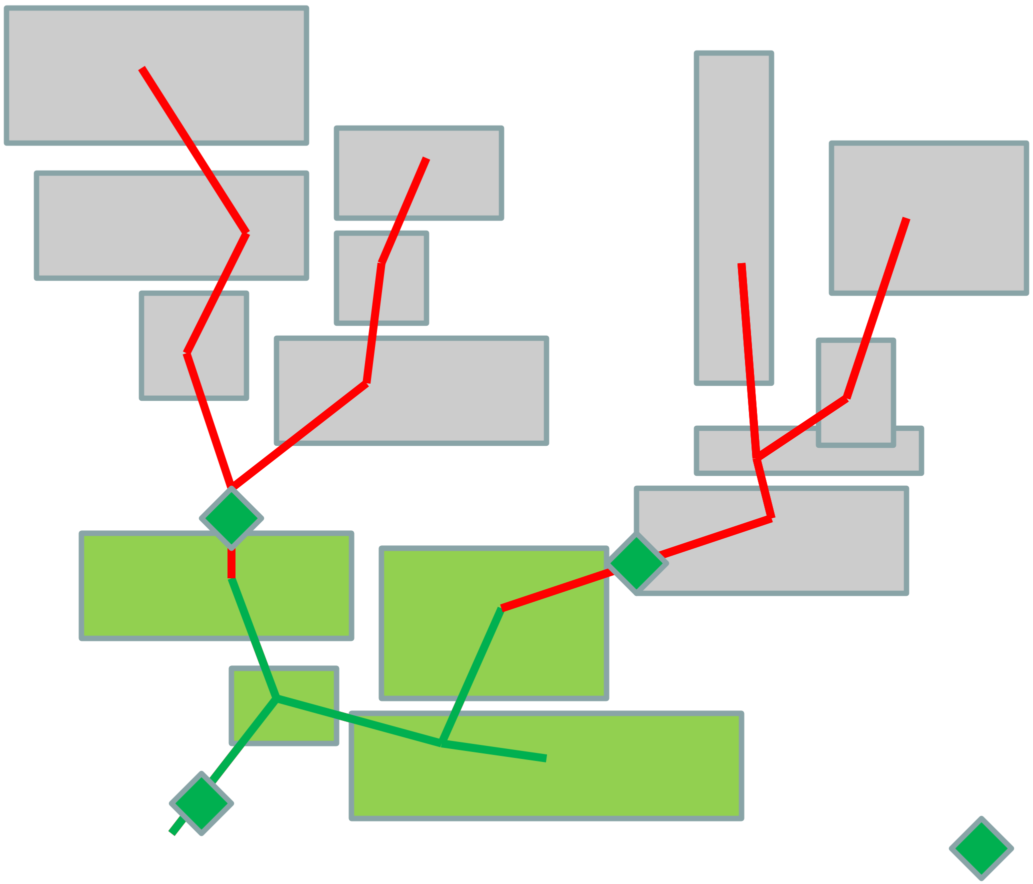
- it permits changes to be made to <u>specific features</u> of the network model
- the contents of the model are automatically <u>grouped by flow monitor</u> and changes are made to these groups

Subcatchment Collections



- Interface automatically builds <u>subcatchment collections</u> based on the topology of the network and the location of the Flow Monitors

Subcatchment Collections



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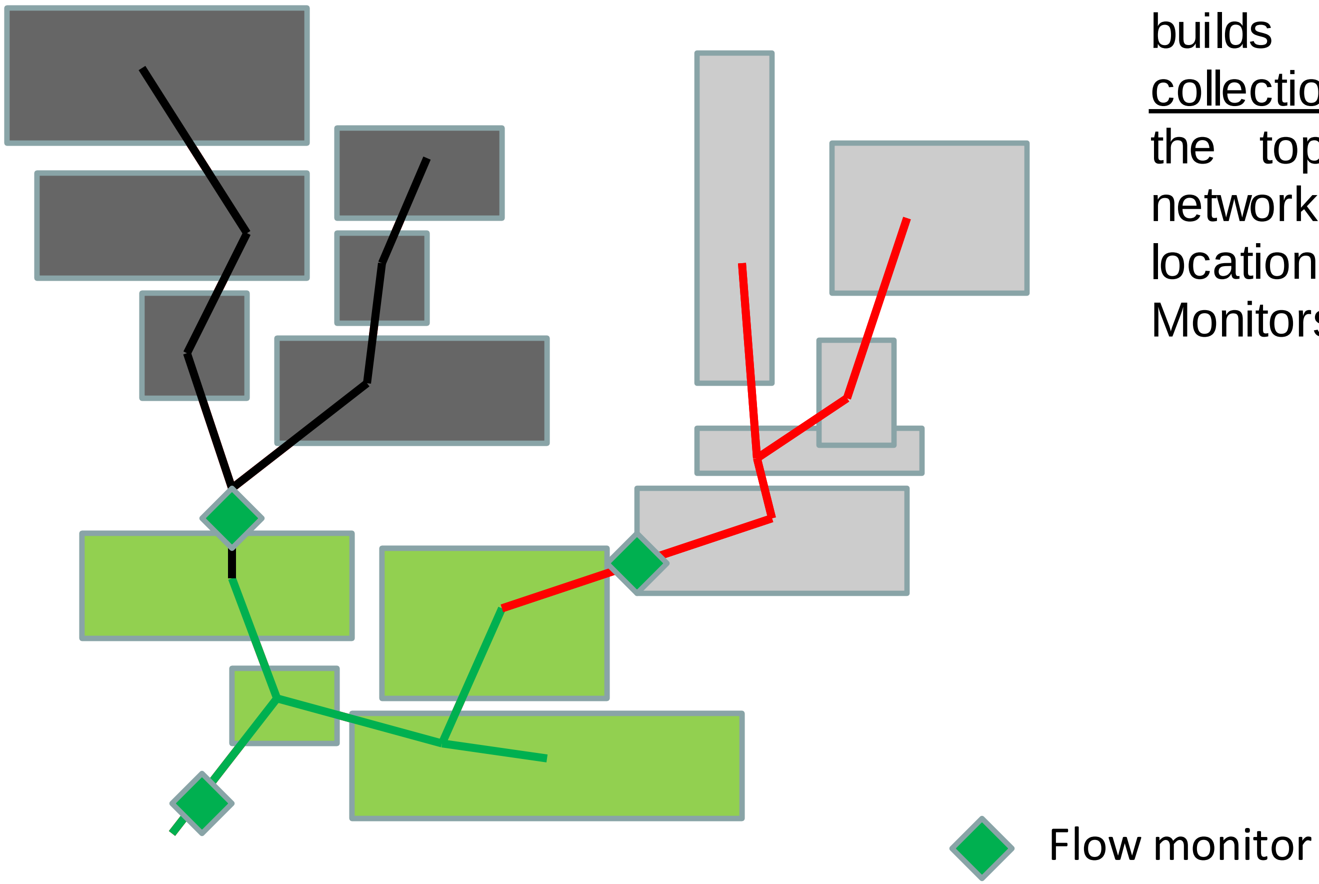
Flow monitor

Subcatchment Collections



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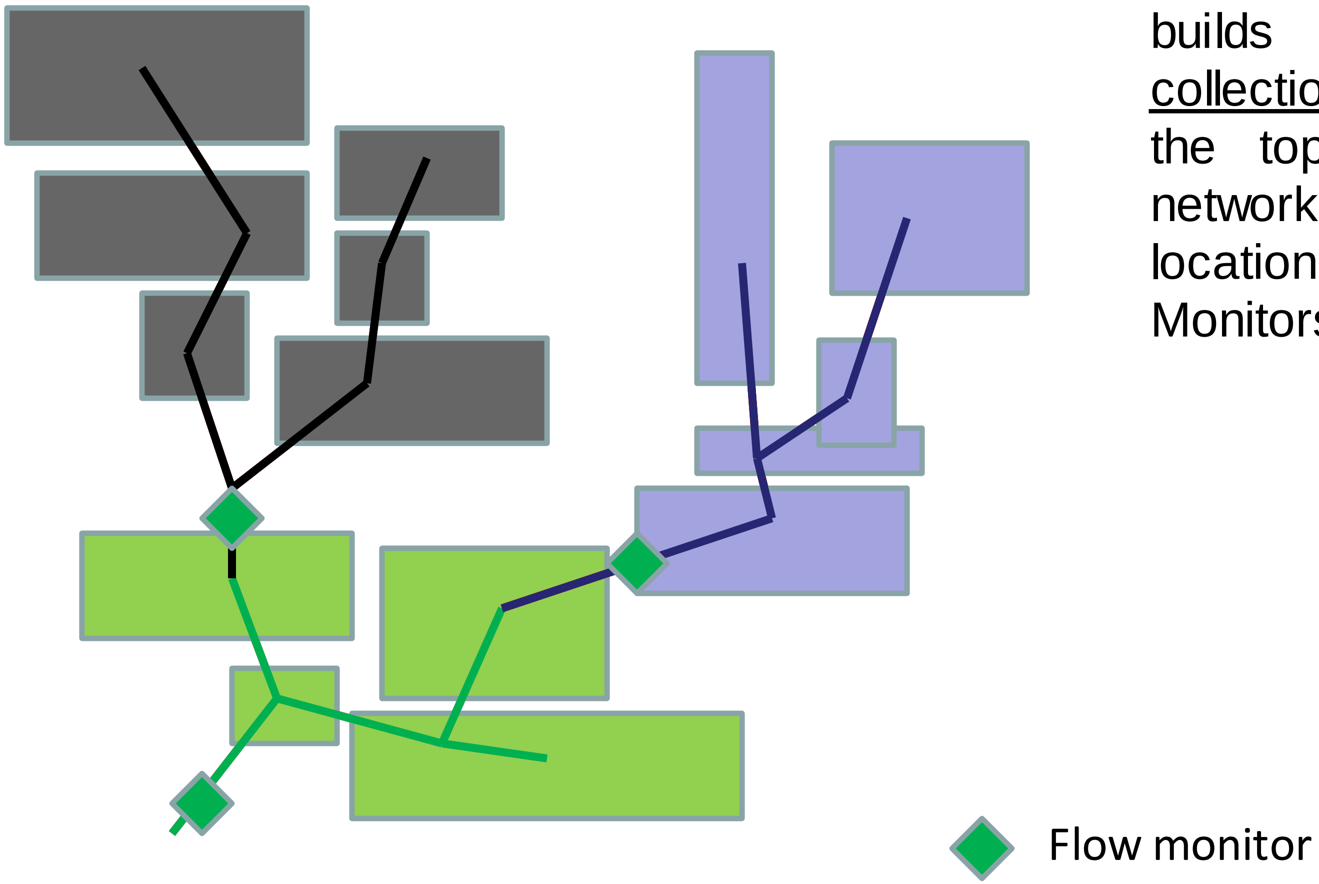
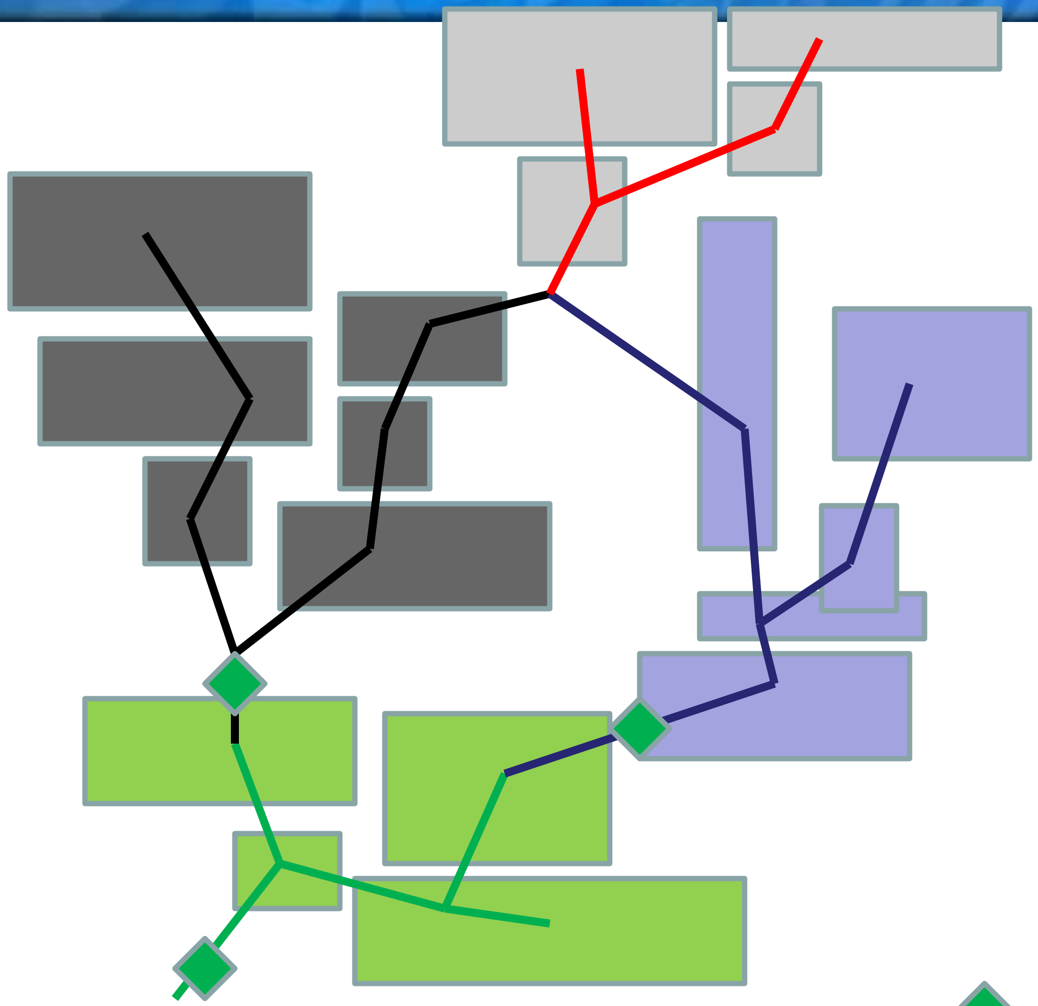
Subcatchment Collections



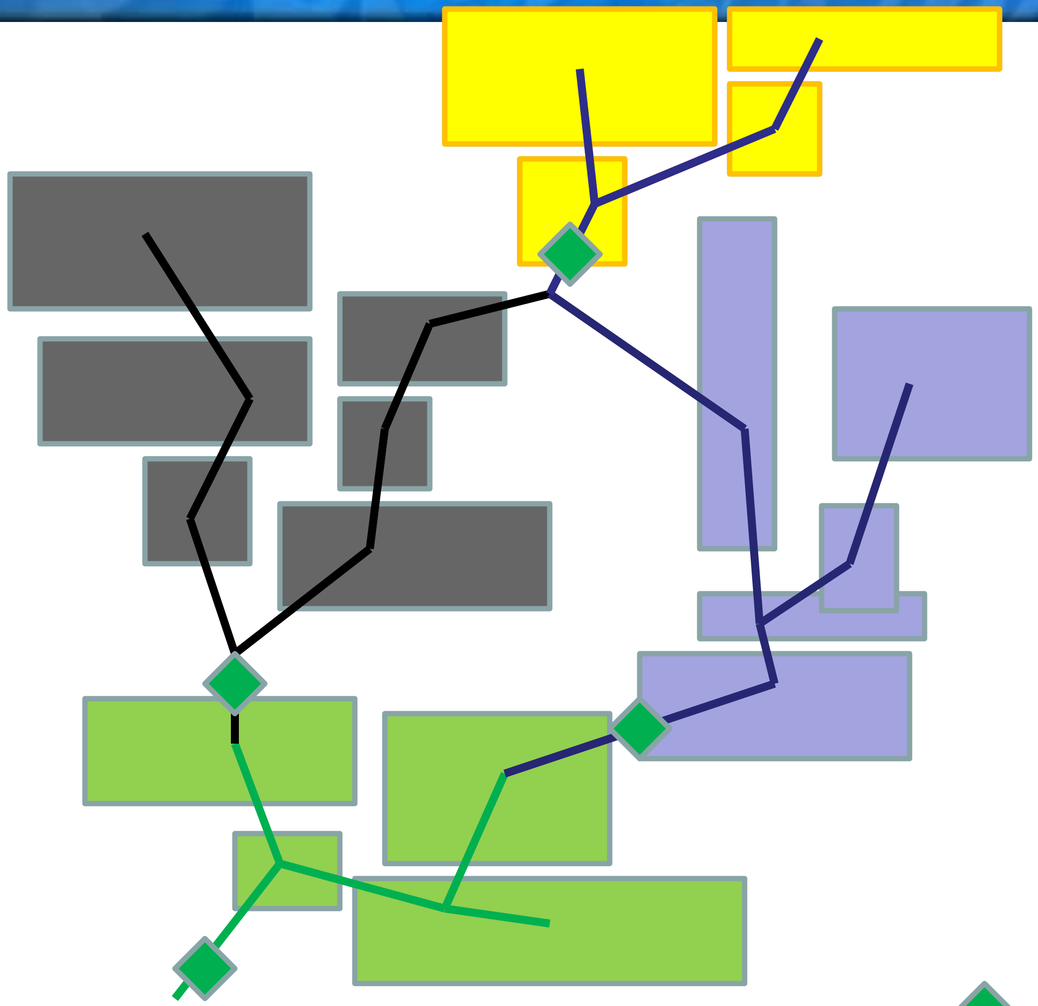
- Interface automatically builds <u>subcatchment collections</u> based on the topology of the network and the location of the Flow Monitors

Bifurcations



- The Interface deals with bifurcations by creating artificial flow monitor locations at their root
- Of course, no flow monitor data exists for these locations

Bifurcations



- The Interface deals with bifurcations by creating artificial flow monitor locations at their root
- Of course, no flow monitor data exists for these locations

Verification Interface Parameters

- Parameters available for adjustment (input) and monitoring (output):

Phase	Controls	**Targets** (WaPUG)

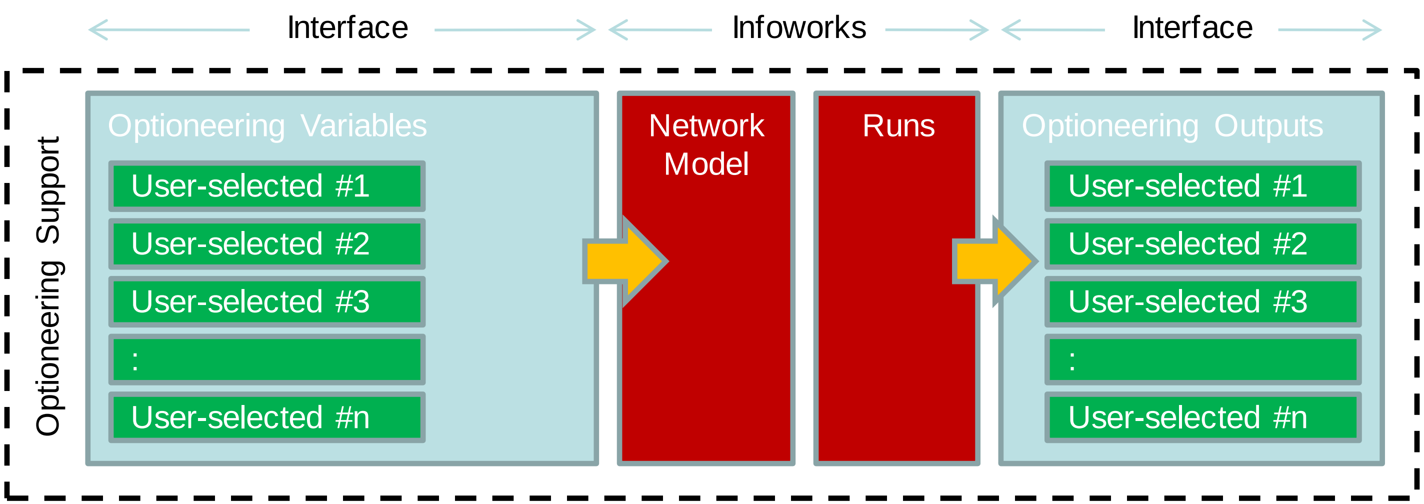
Dry Day	• Baseflow
	  • (pro-rata by area within each subcatchment collection)
	• Population
	  • (in proportion to original population within each subcatchment collection)
		• Night flow period mean
		• Peak flow
		• Volume

Storm	• Scaled
	  • Area 1
	  • Area 2
	  • Area 3
	  • Sediment Depth
	  • Pipe Roughness
		• Peak Flow
		• Time of Peak Flow
		• Peak Depth
		• Volume

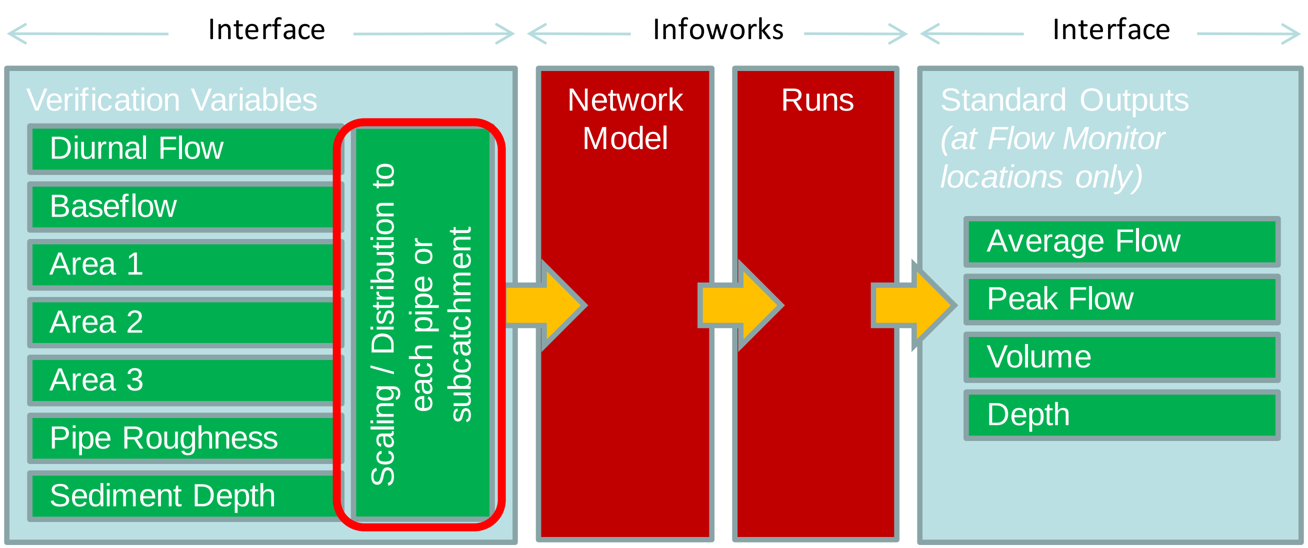
(note: the user specifies the limits within which any parameter may be adjusted)

Interface Functionality vs. Optioneering Extension

- The primary purpose for this extension is to permit the <u>arbitrary modification of InfoWorks models</u> to allow entirely user-defined objectives and studies
- In this Optioneering mode exactly the same process is used without reference to the grouping of subcatchment collections to provide this control

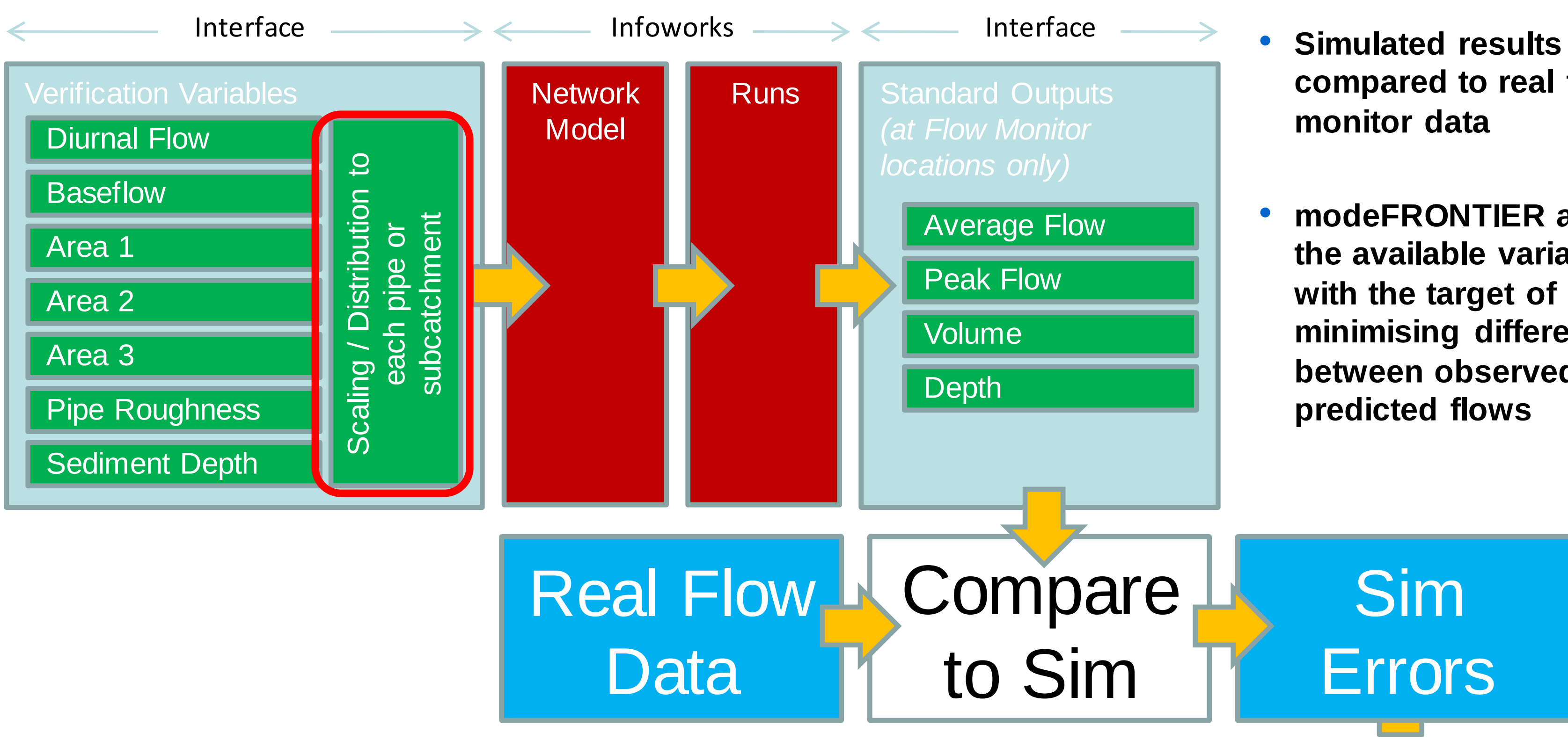


Interface coupled with modeFRONTIER



- **Simulated results are compared to real flow monitor data**
- **modeFRONTIER adjusts the available variables with the target of minimising differences between observed and predicted flows**

Interface coupled with modeFRONTIER



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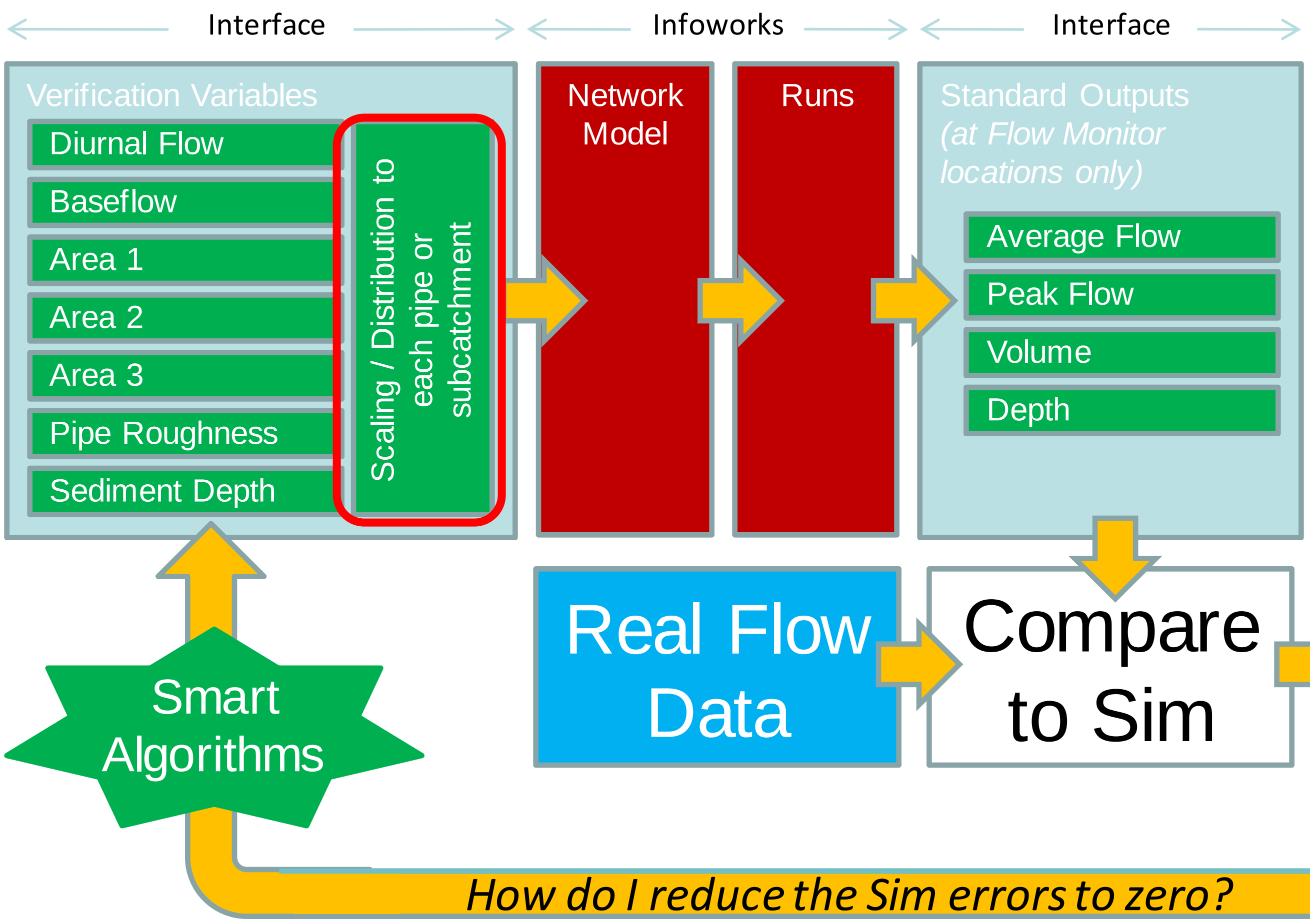


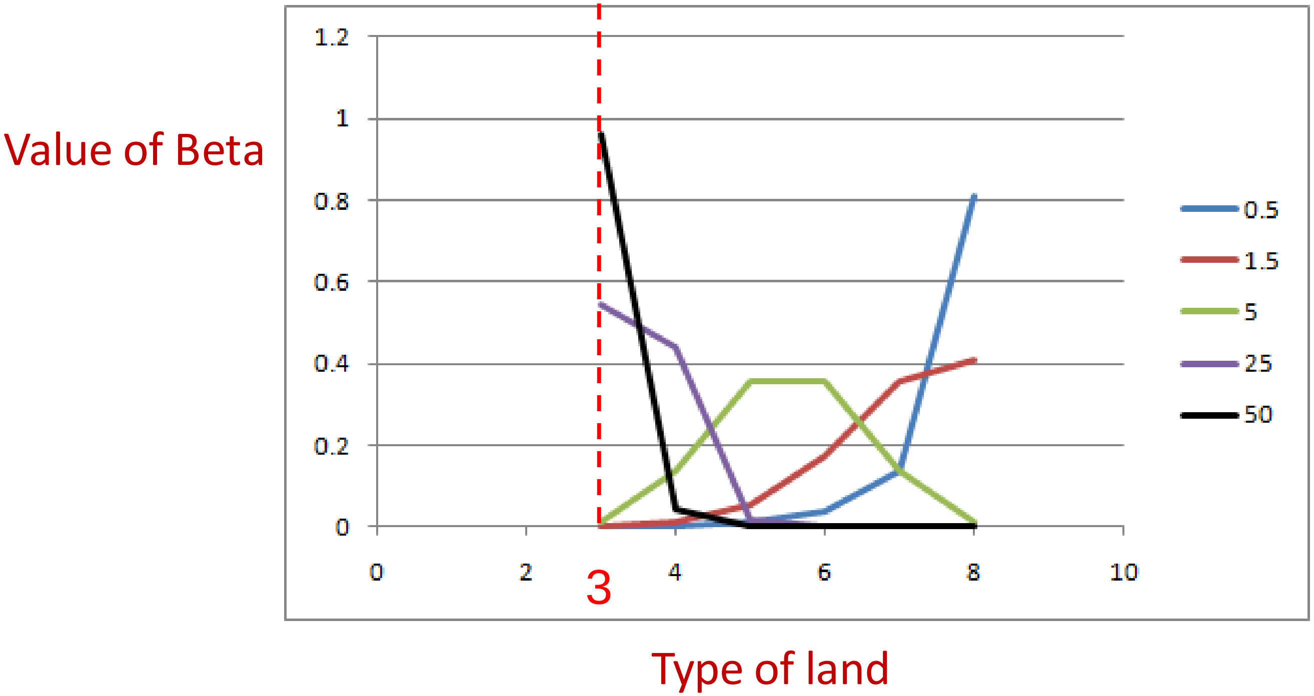
- **Simulated results are compared to real flow monitor data**
- **modeFRONTIER adjusts the available variables with the target of minimising differences between observed and predicted flows**

How can the Slow Runoff Parameters be Adjusted? Methods

- **Two methods were considered**
  1. **Define a unique "Land Use" for groups of subcatchments associated with each flow monitor**
     - For each Land Use, define its own unique Runoff for sub-area 3
     - Tune the parameters of the Runoff definition
  2. **Define a common "Land Use" for all subcatchments affected by slow runoff**
     - For this Land Use, define a series of increasingly-slow Runoff definitions for sub-areas 3 to 8
     - Redistribute the subcatchment land in sub-area 3 among the sub-areas 3 to 8
     - The redistribution pattern should be common to groups of subcatchments associated with each flow monitor

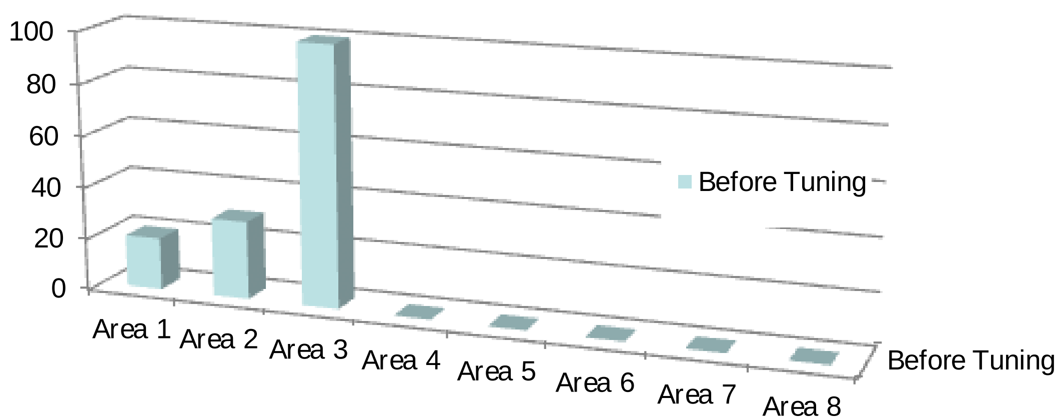
How can the Slow Runoff Parameters be Adjusted? 2nd Method selected

- For each subcatchment, the land was redistributed by multiplying the original sub-area 3 with a redistribution function, which uses a single parameter “beta” which ranges from 100 (no change) to 0 (all the area moved to the “slowest” response)



How can the Slow Runoff Parameters be Adjusted? 2nd Method selected

- For a particular subcatchment, the method may be represented visually as shown below:



- Roof and road (areas 1 and 2) assessed using OS data and evaluation of disposal route
- Permeable/slow runoff represented by up to 6 runoff surfaces (3-8) with increasing RRVs
- modeFRONTIER adjusts total amount and "mix" of areas 3-8

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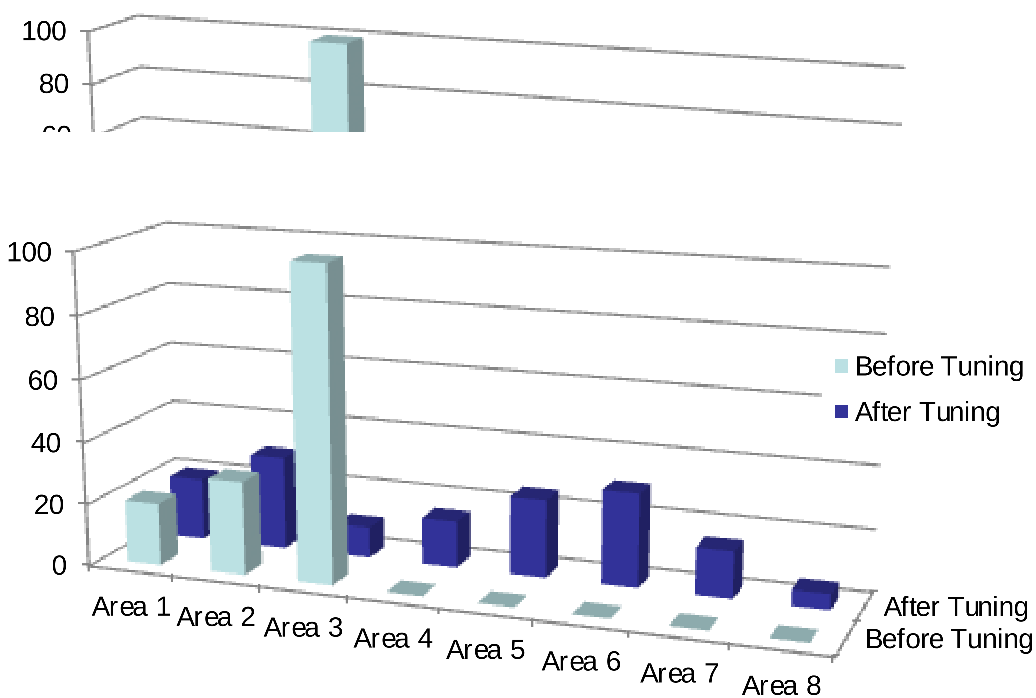

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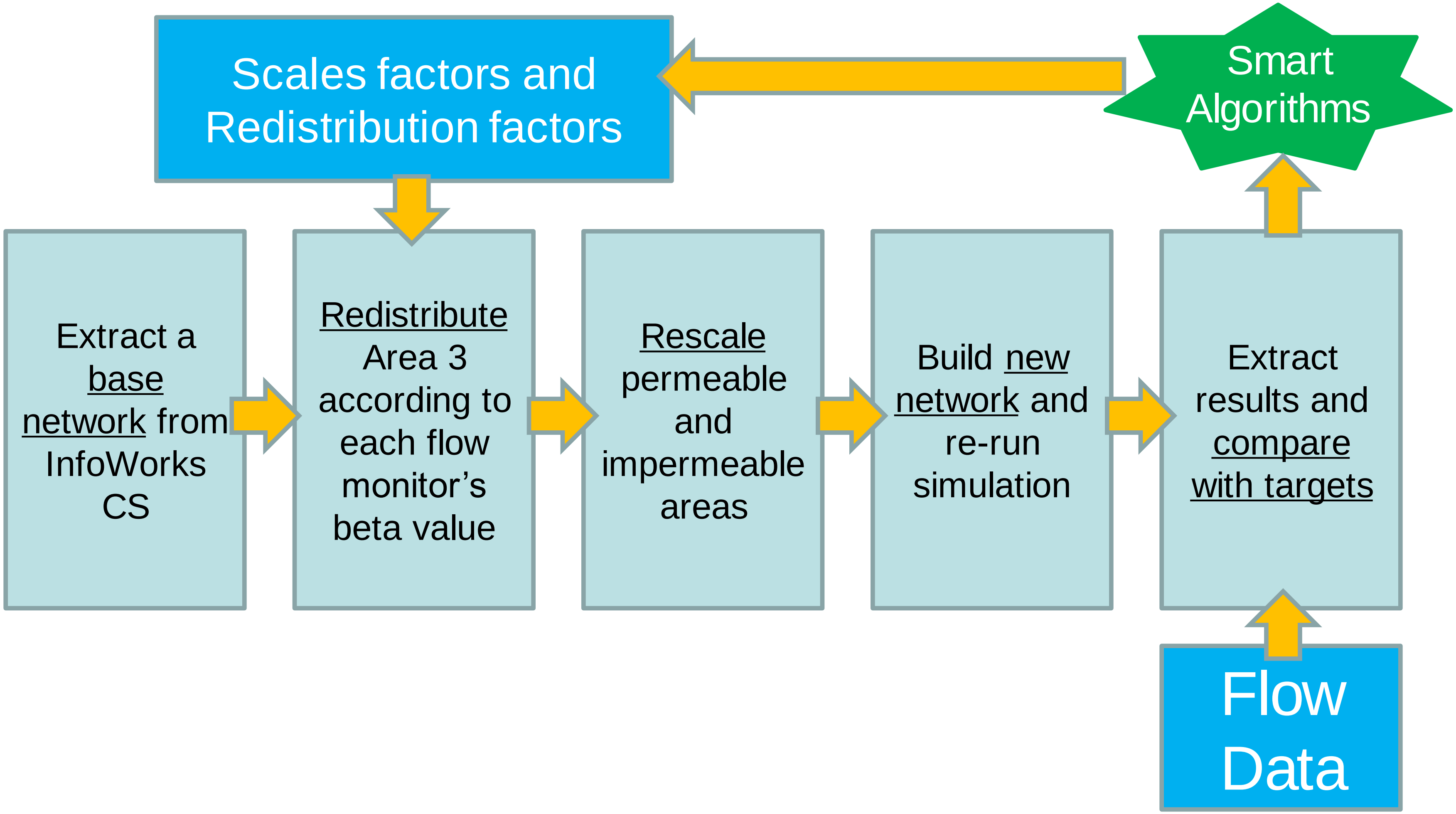
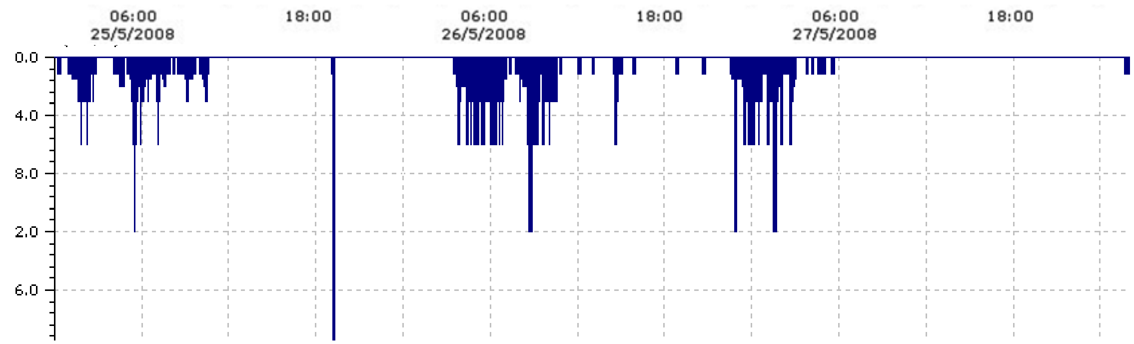
The modeFRONTIER Process Flow



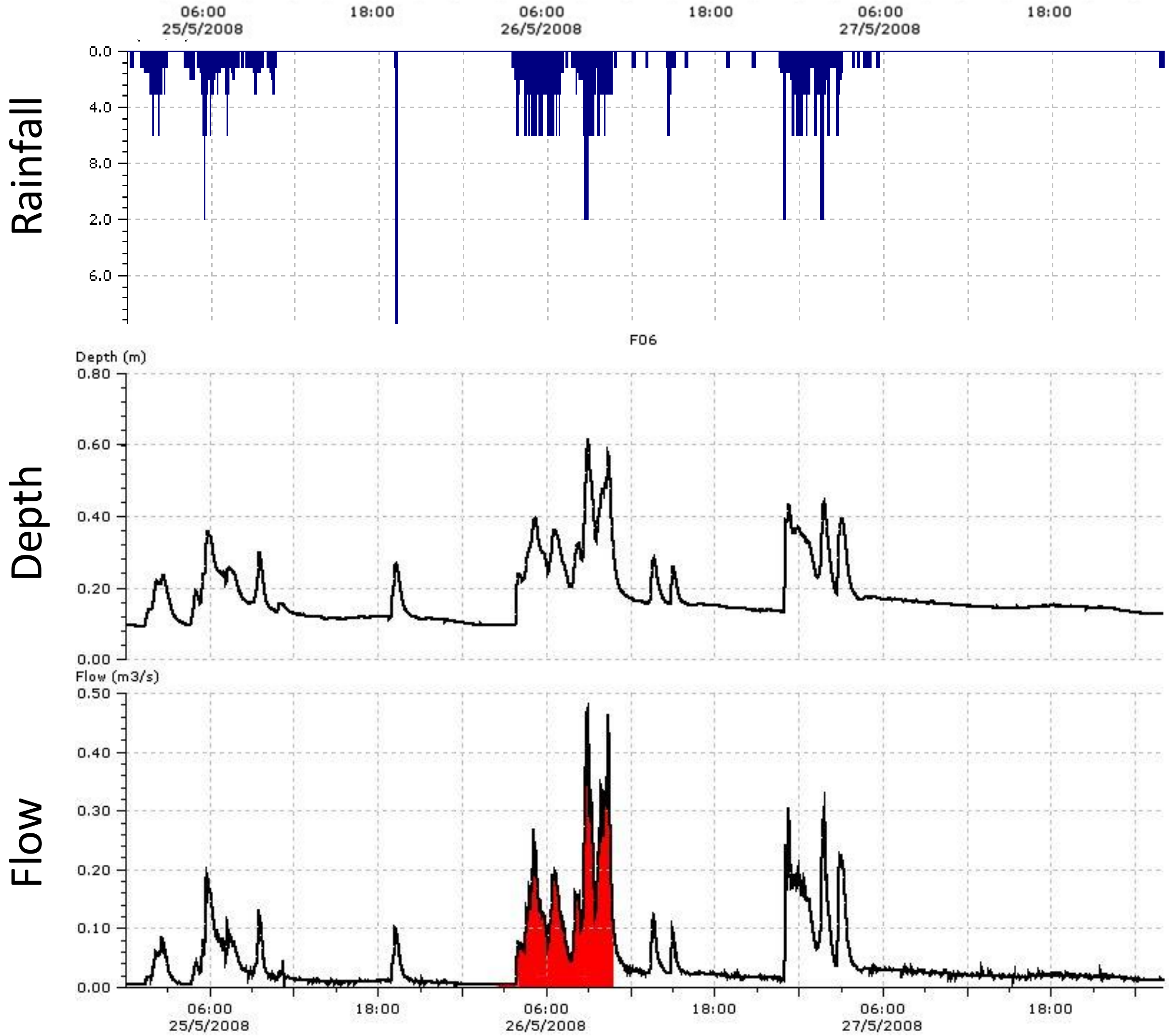
Selecting targets for modeFRONTIER

Rainfall



Selecting targets for modeFRONTIER

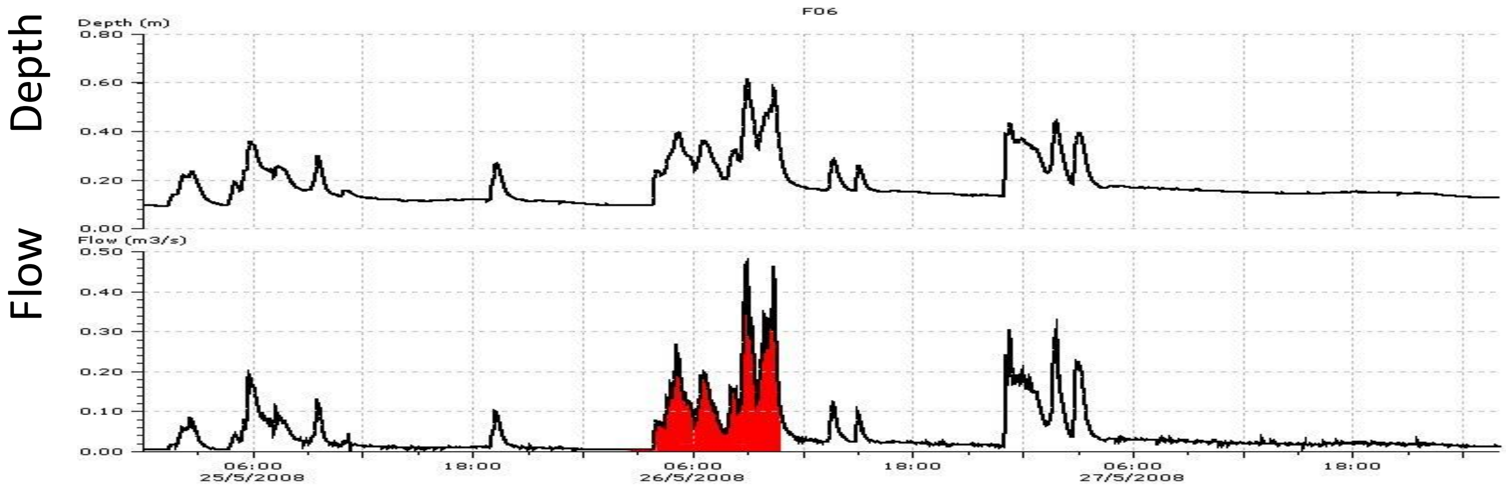
a YTL company



Flow Monitor 06

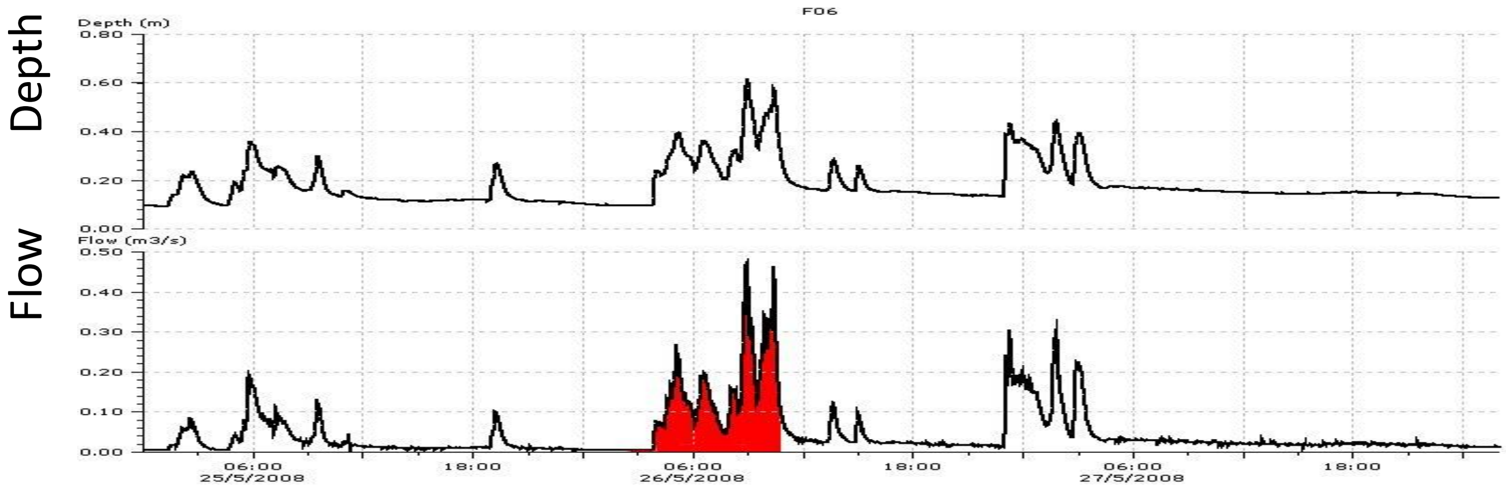
Selecting targets for modeFRONTIER

DS end of conduit AB123456



Selecting targets for modeFRONTIER

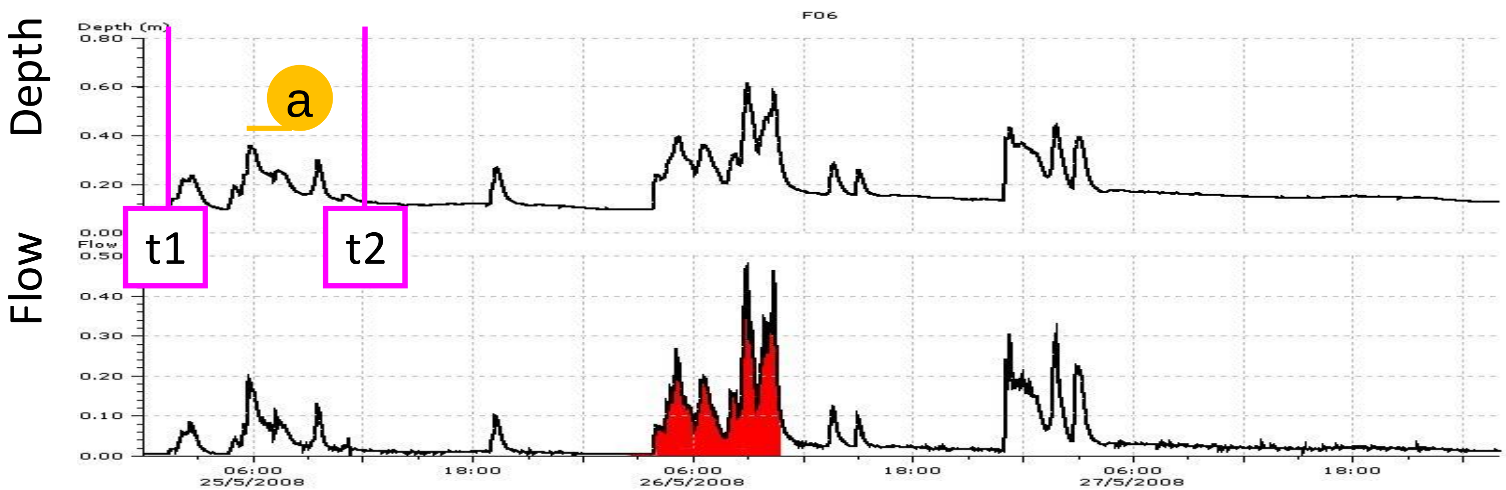
DS end of conduit AB123456



Network Location	Result Type	Window Start	Window End	=	Result Value

Selecting targets for modeFRONTIER

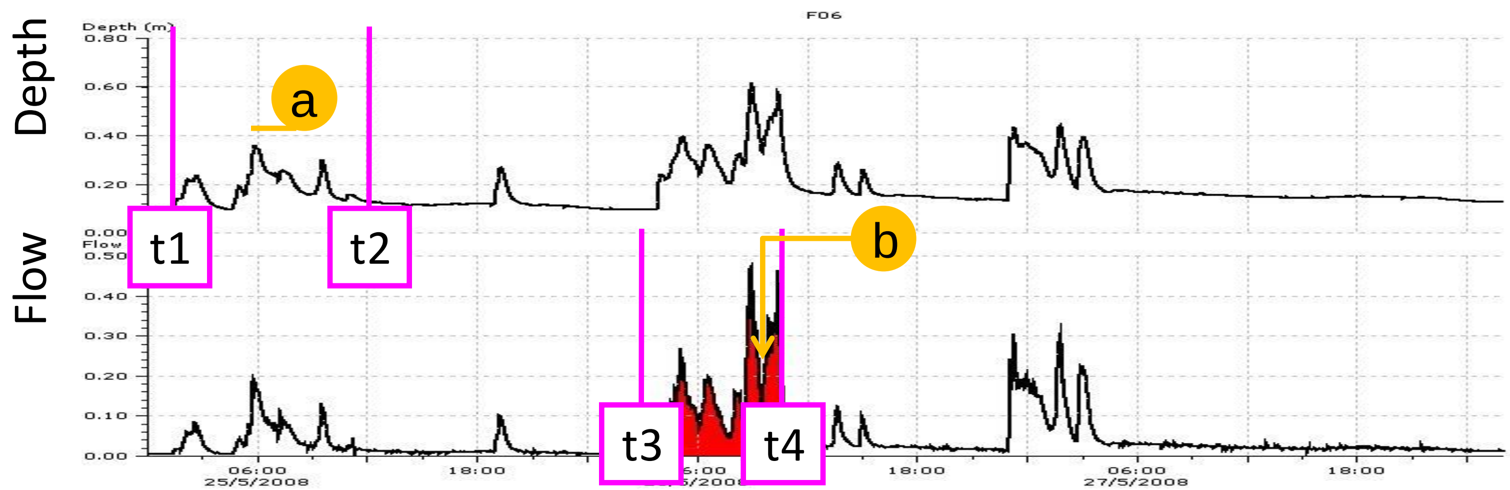
DS end of conduit AB123456



Network Location	Result Type	Window Start	Window End	=	Result Value
Link AB123456 (DS)	Peak Depth	t1	t2	=	Depth “a”

Selecting targets for modeFRONTIER

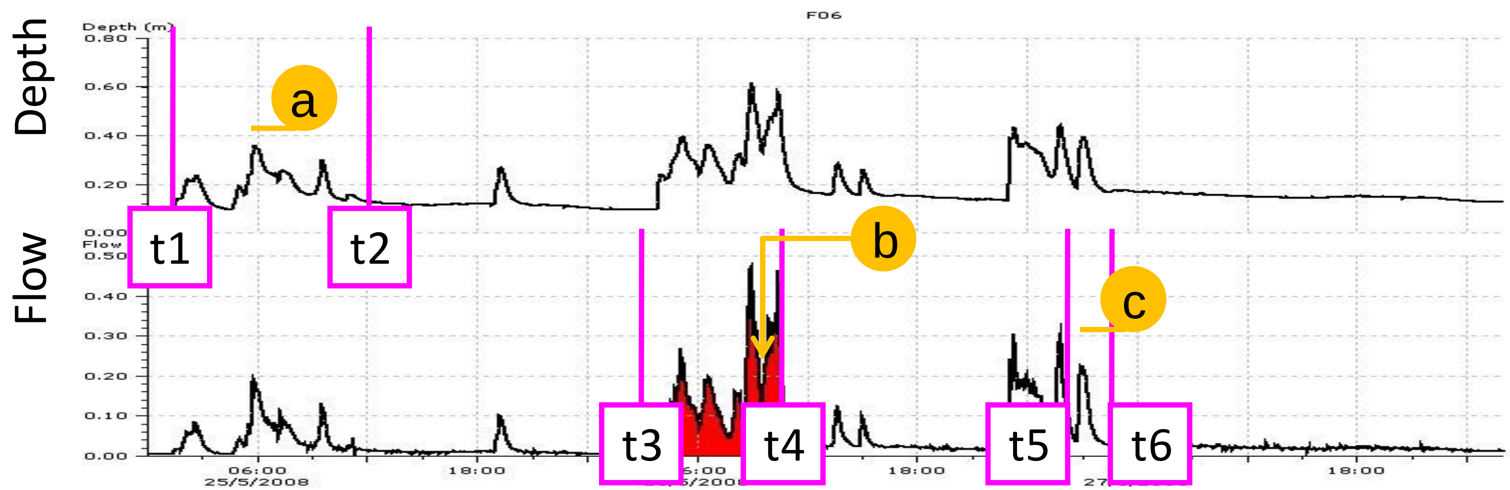
DS end of conduit AB123456



Network Location	Result Type	Window Start	Window End	=	Result Value
Link AB123456 (DS)	Peak Depth	t1	t2	=	Depth "a"
Link AB123456 (DS)	Volume	t3	t4	=	Volume "b"

Selecting targets for modeFRONTIER

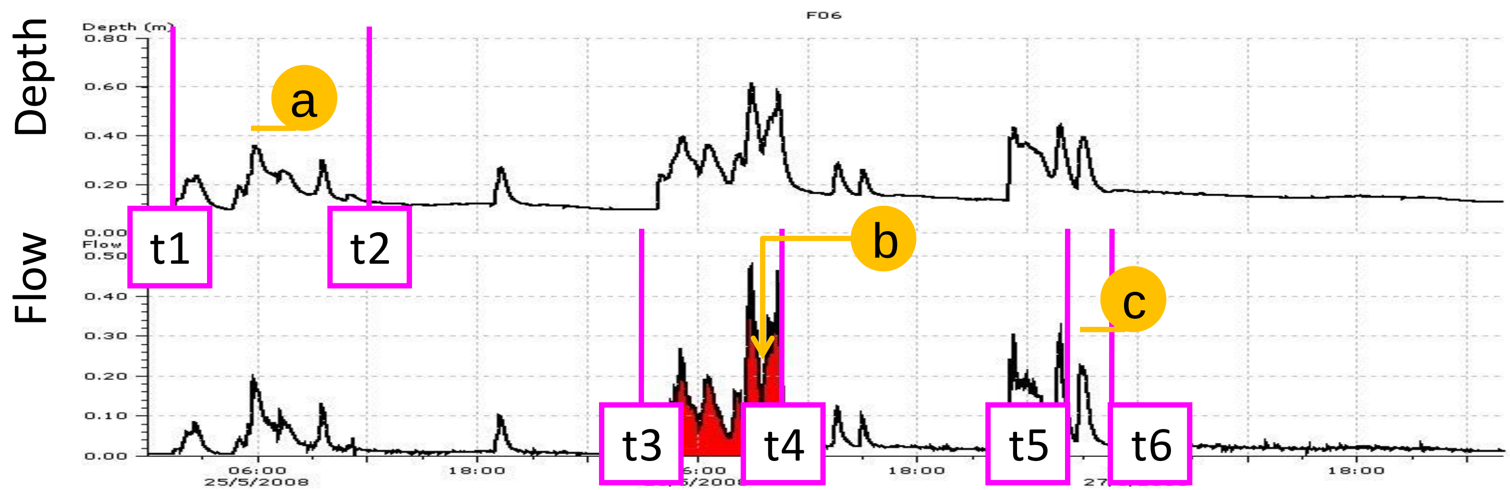
DS end of conduit AB123456



Network Location	Result Type	Window Start	Window End	=	Result Value
Link AB123456 (DS)	Peak Depth	t1	t2	=	Depth “a”
Link AB123456 (DS)	Volume	t3	t4	=	Volume “b”
Link AB123456 (DS)	Peak Flow	t5	t6	=	Flow “c”

Selecting targets for modeFRONTIER

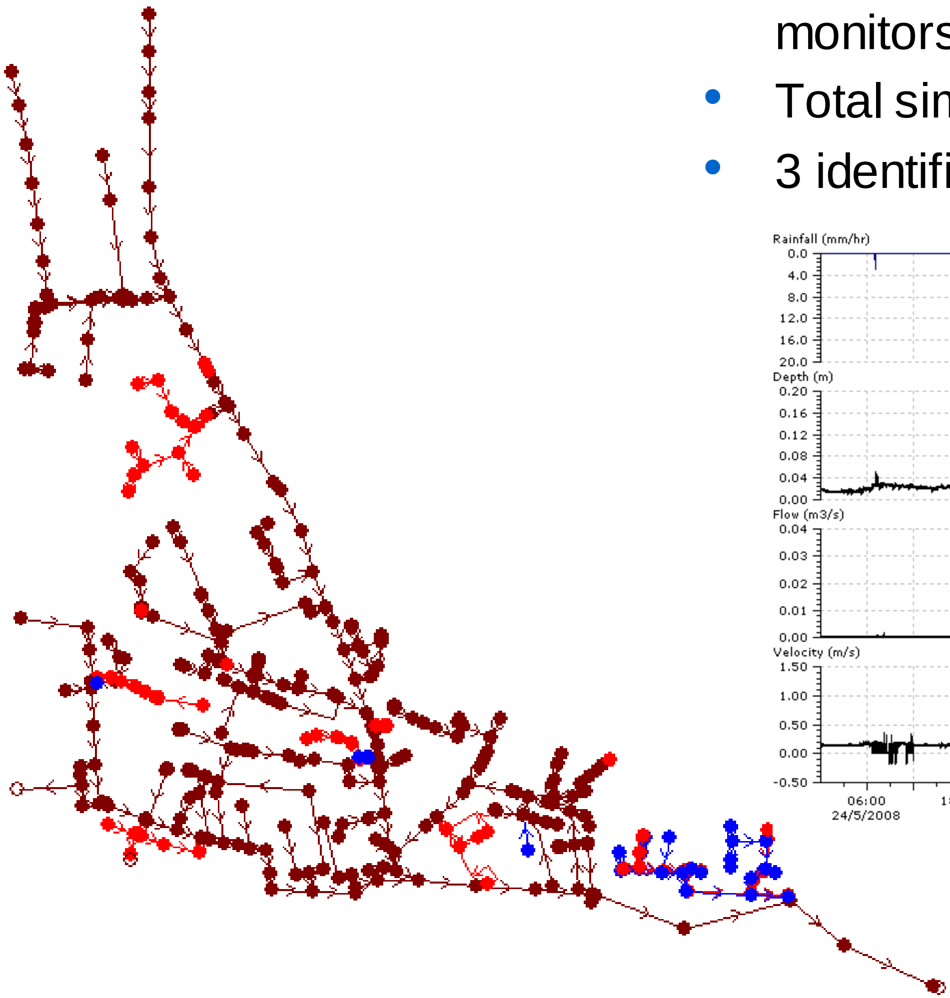
DS end of conduit AB123456



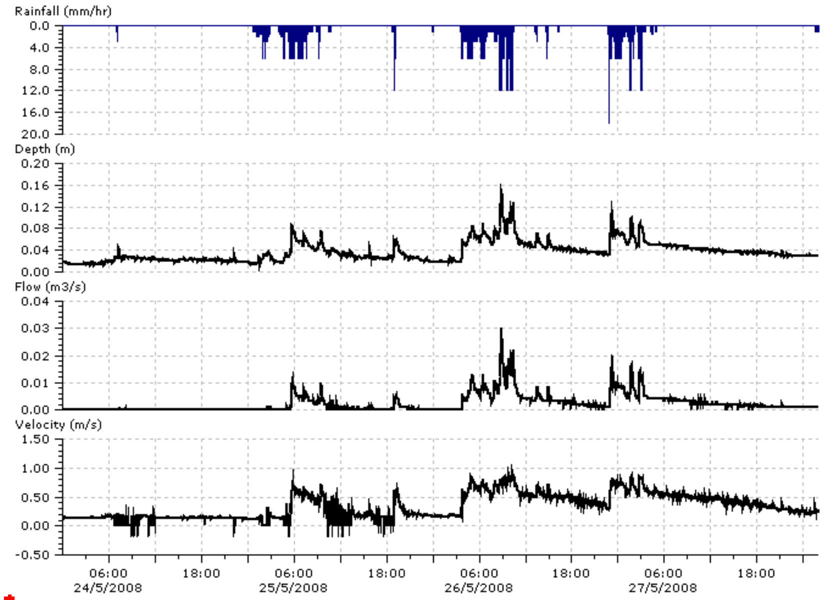
Network Location	Result Type	Window Start	Window End	=	Result Value
Link AB123456 (DS)	Peak Depth	t1	t2	=	Depth “a”
Link AB123456 (DS)	Volume	t3	t4	=	Volume “b”
Link AB123456 (DS)	Peak Flow	t5	t6	=	Flow “c”

- The user selects a results location, type and a time window
- The interface extracts the result value from the simulation
- Multiple targets must be set along a simulation history to characterise slow runoff
- Different confidence levels can be applied to different monitors

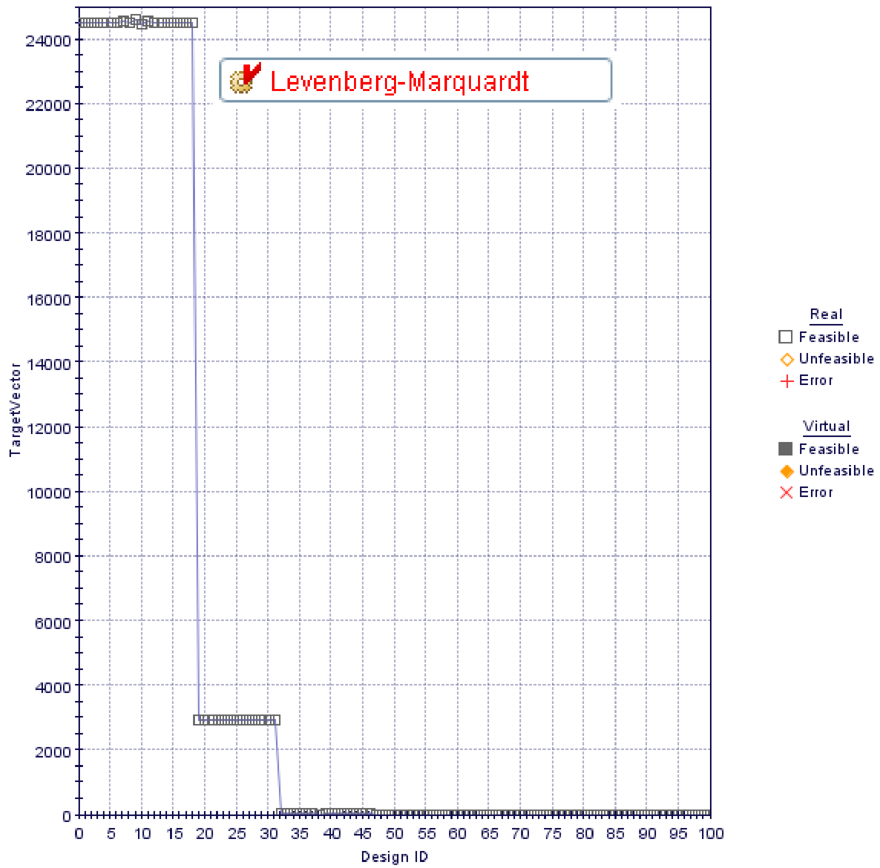
Example: Chosen Network



- 350 subcatchments, 346 nodes, 3 flow monitors (FM5, FM6, FM16)
- Total simulation time 3.5 days
- 3 identified event periods

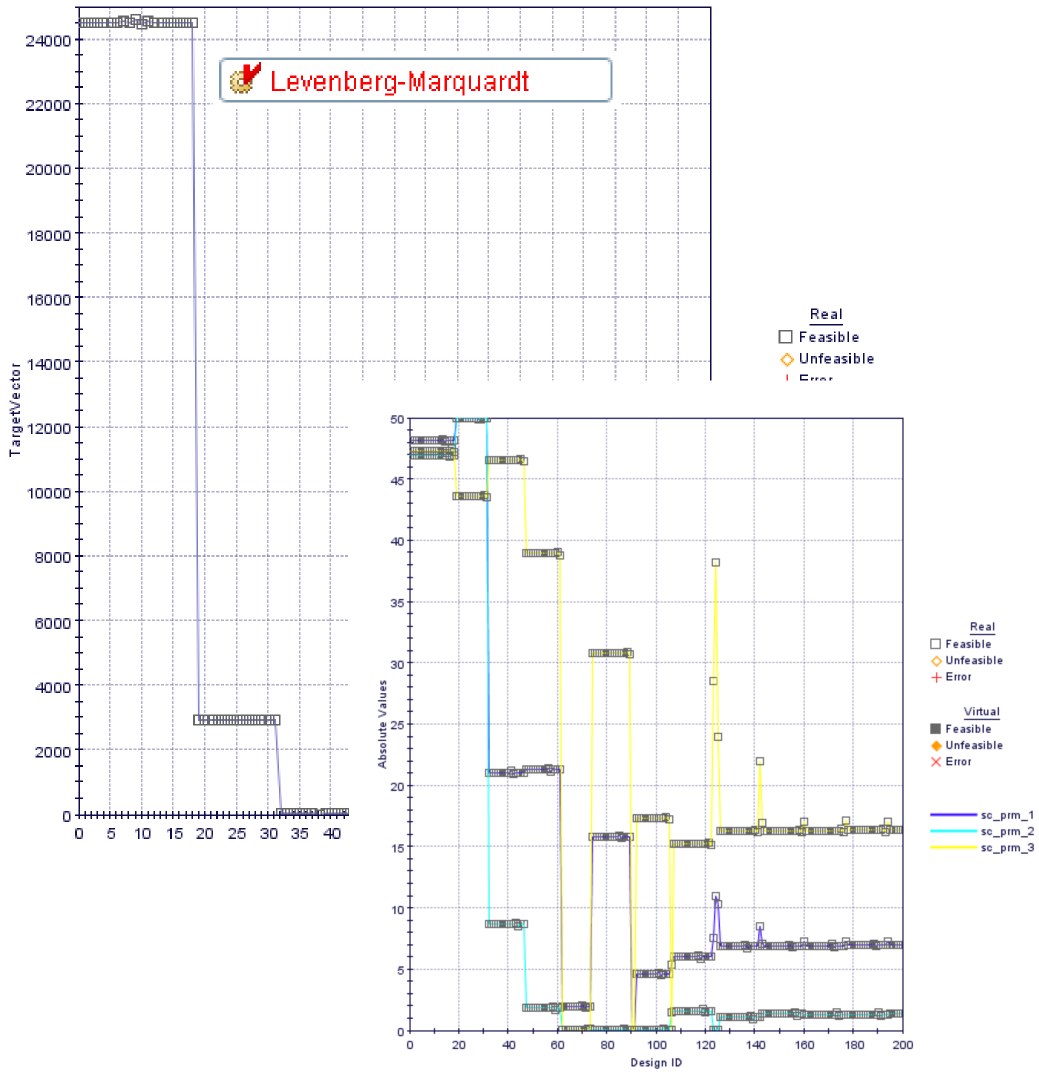


Example: Progress to Convergence



- The error between the simulation and the chosen targets quickly reduces
  - The steps show modeFRONTIER moving from exploration phases (flat regions) to adjustment phases (sudden improvements given by a gradient algorithm)

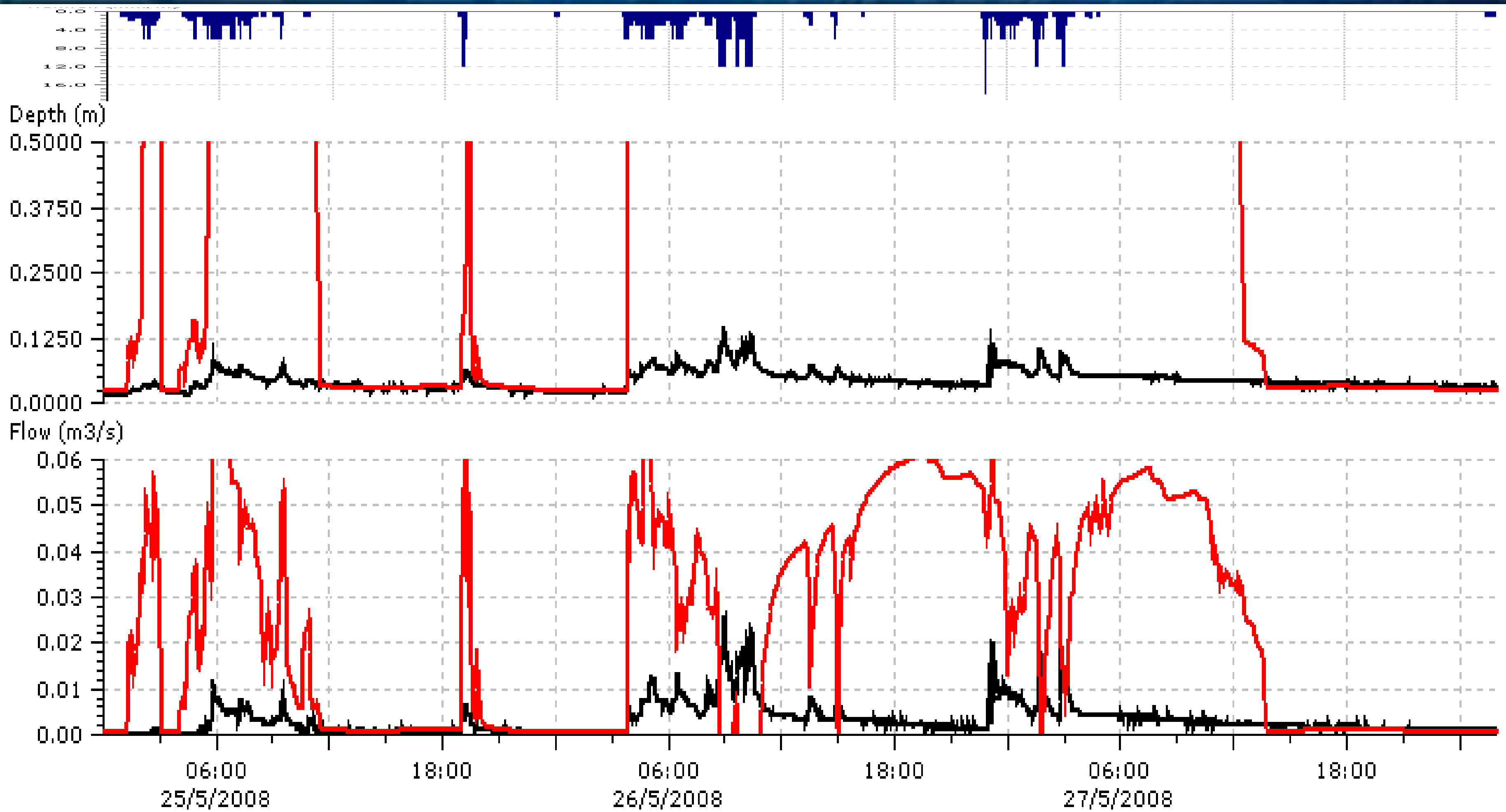
Example: Progress to Convergence



- The error between the simulation and the chosen targets quickly reduces
  - The steps show modeFRONTIER moving from exploration phases (flat regions) to adjustment phases (sudden improvements given by a gradient algorithm)
- modeFRONTIER adjust the beta parameter and scale factors for each group of subcatchments
  - this graph shows the progressive tuning of the permeable area (an example)

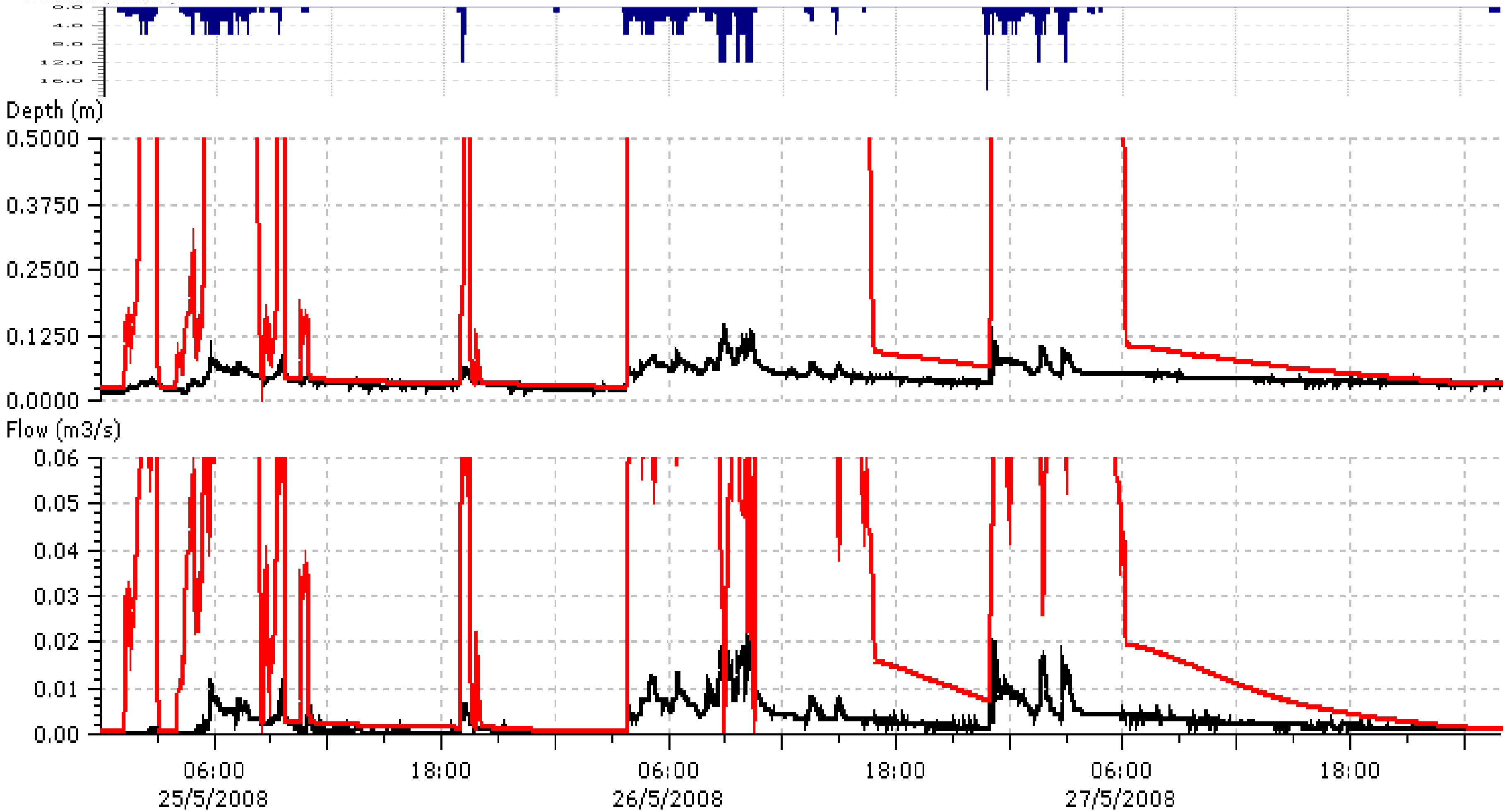
Animation of Flow Monitor 5 Progress – omit first fit – too high

a YTL company



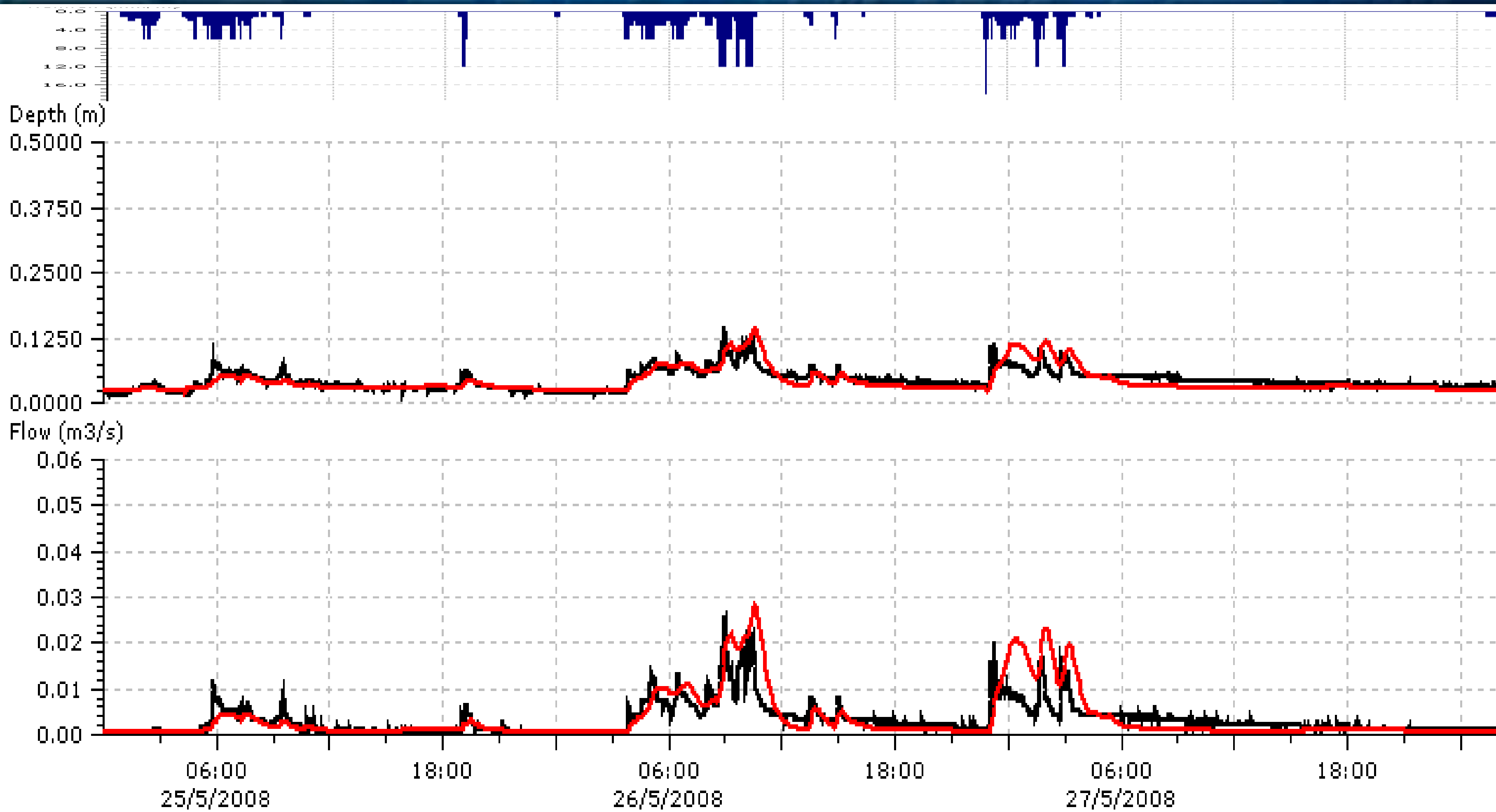
Flow Monitor 05

Animation of Flow Monitor 5 Progress – omit first fit – too high



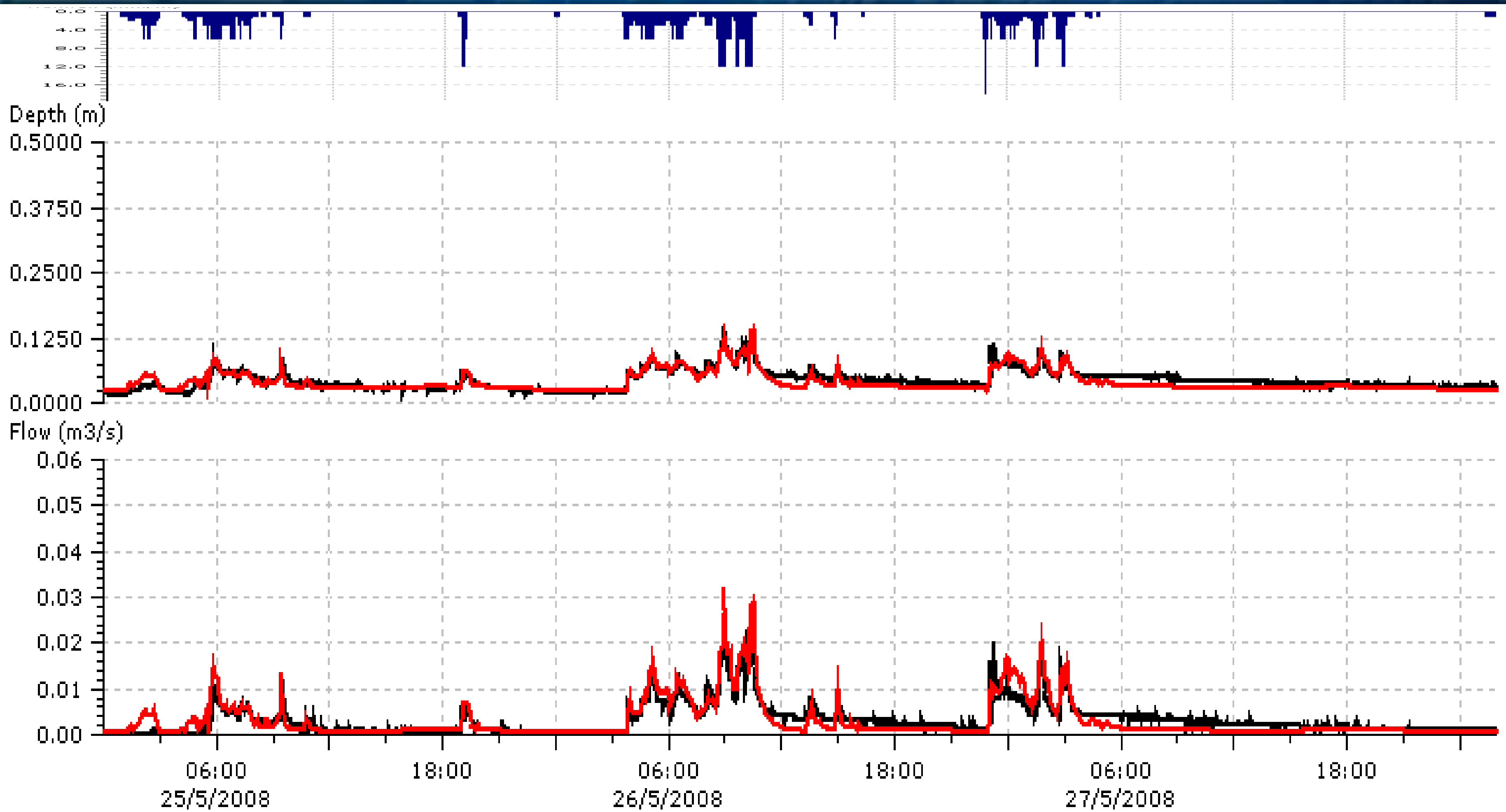
Flow Monitor 05

Animation of Flow Monitor 5 Progress – omit first fit – too high



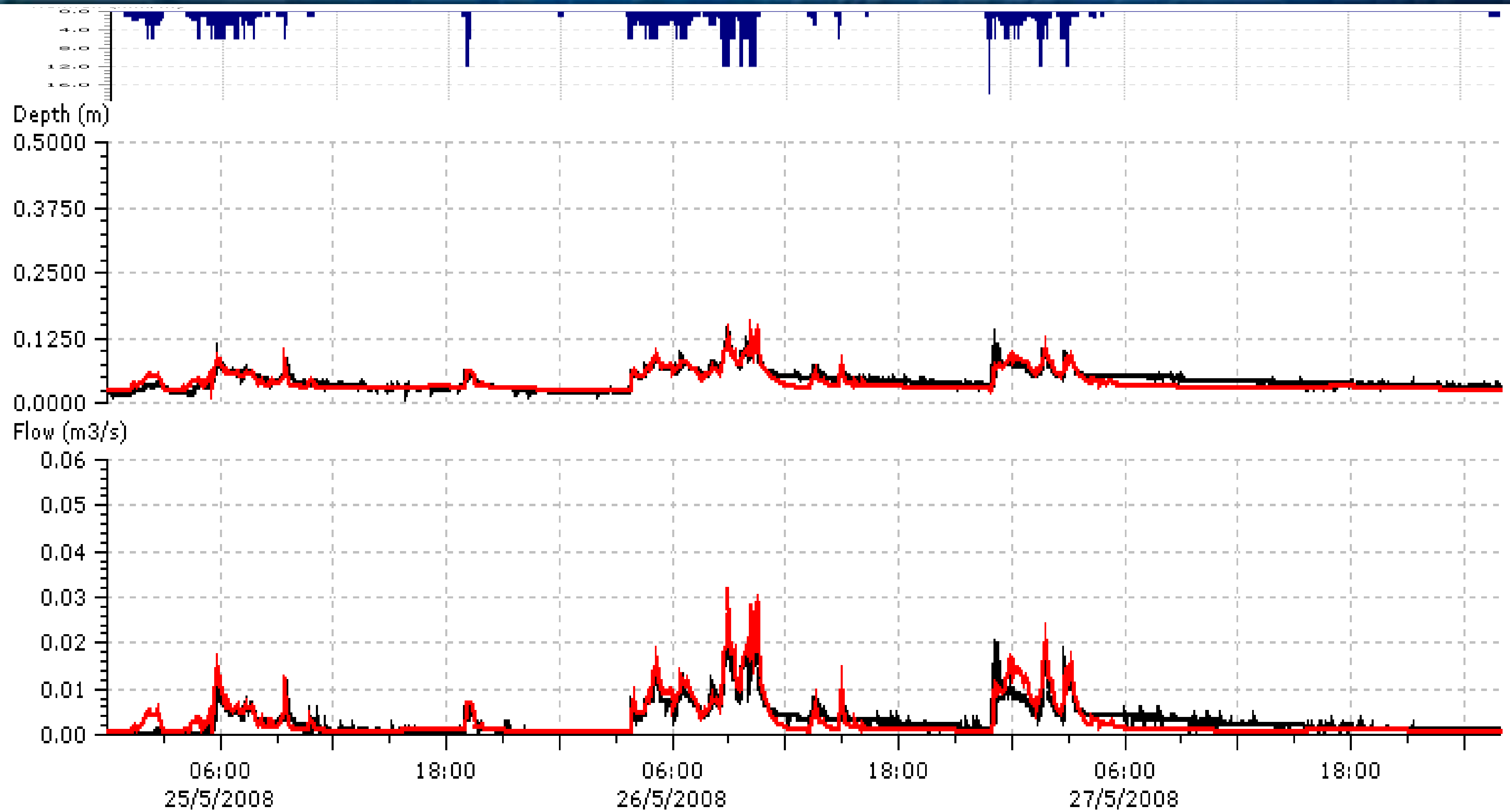
Flow Monitor 05

Animation of Flow Monitor 5 Progress – omit first fit – too high



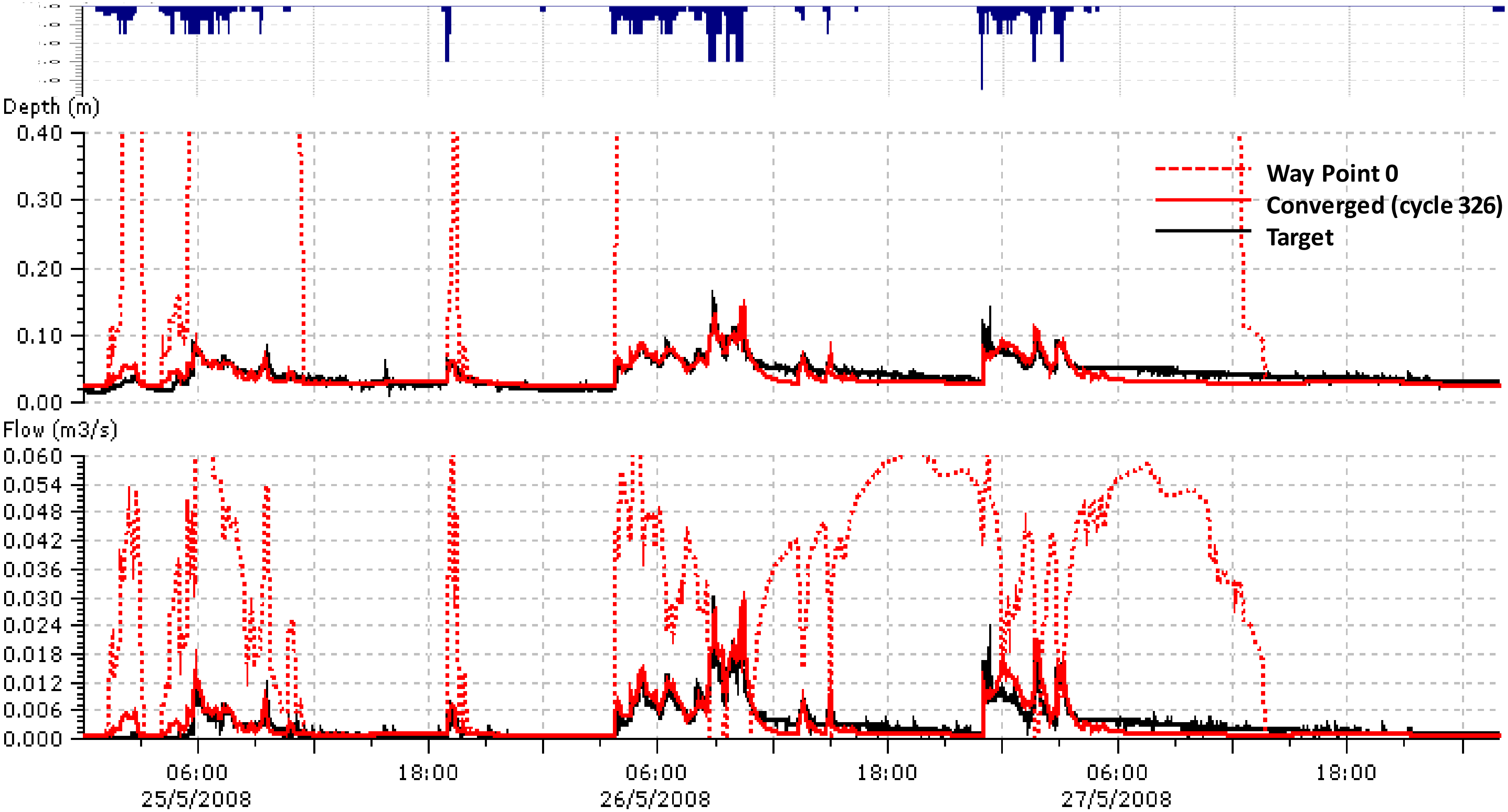
Flow Monitor 05

Animation of Flow Monitor 5 Progress – omit first fit – too high



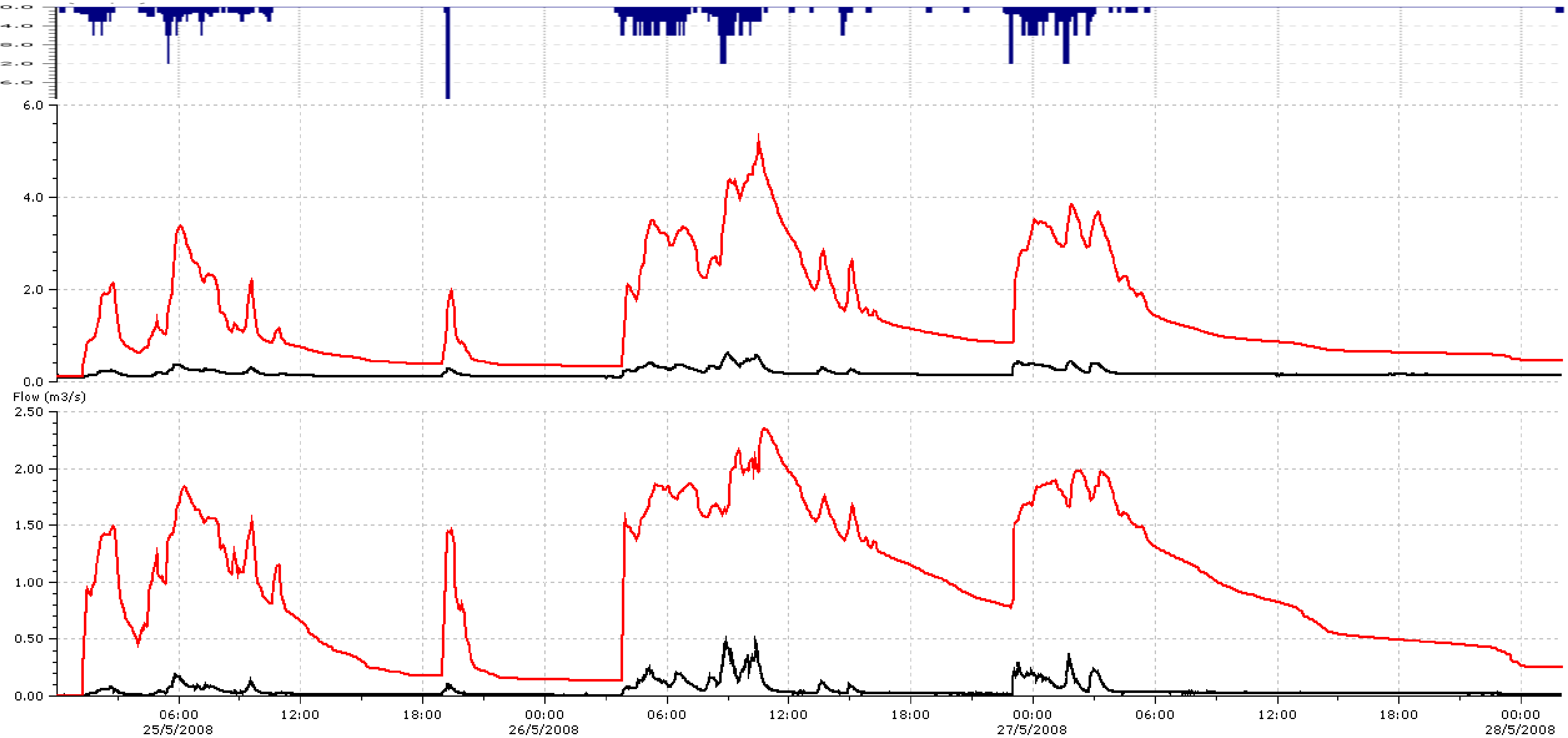
Flow Monitor 05

Animation of Flow Monitor 5 Progress – omit first fit – too high



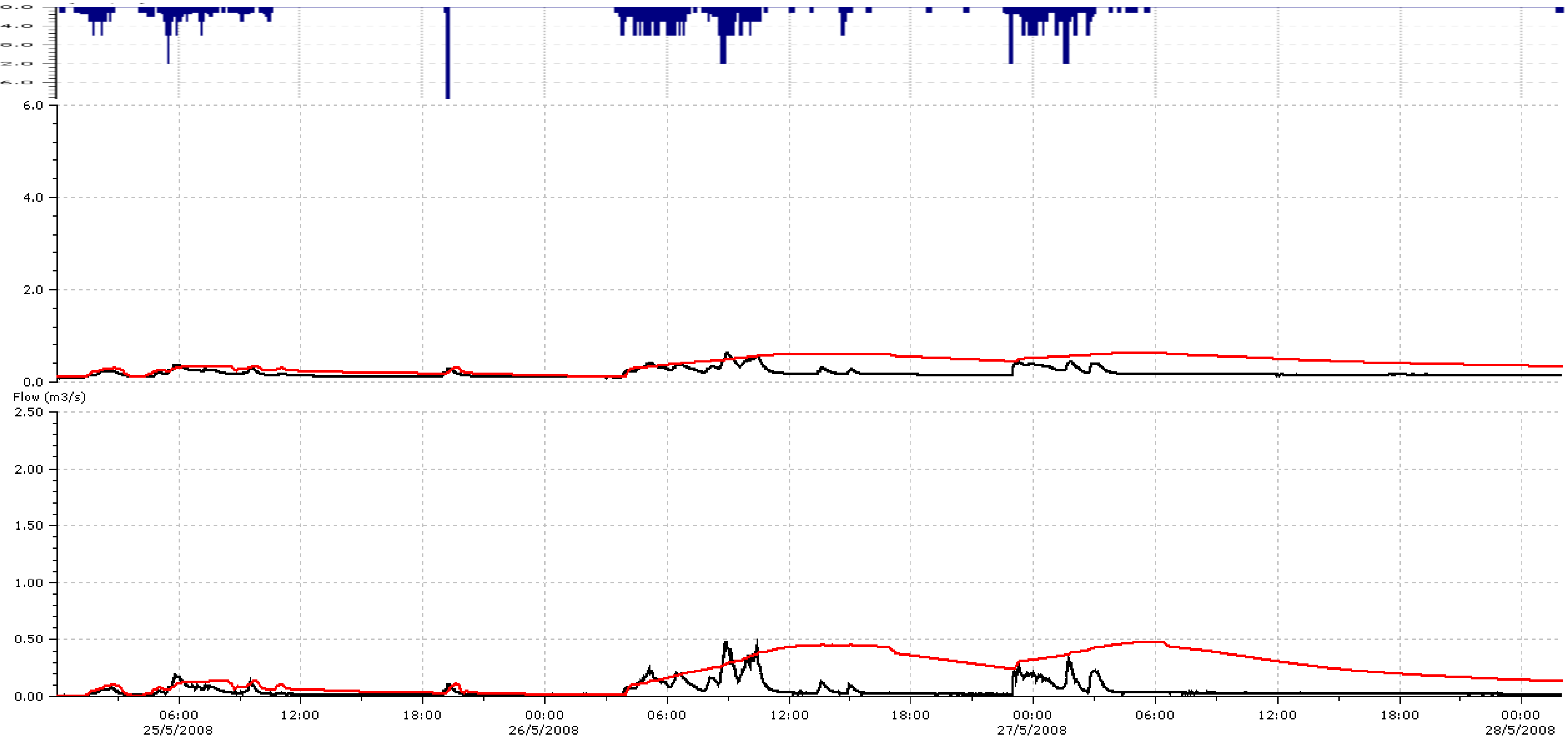
Flow Monitor 05

Animation of Flow Monitor 6 Progress



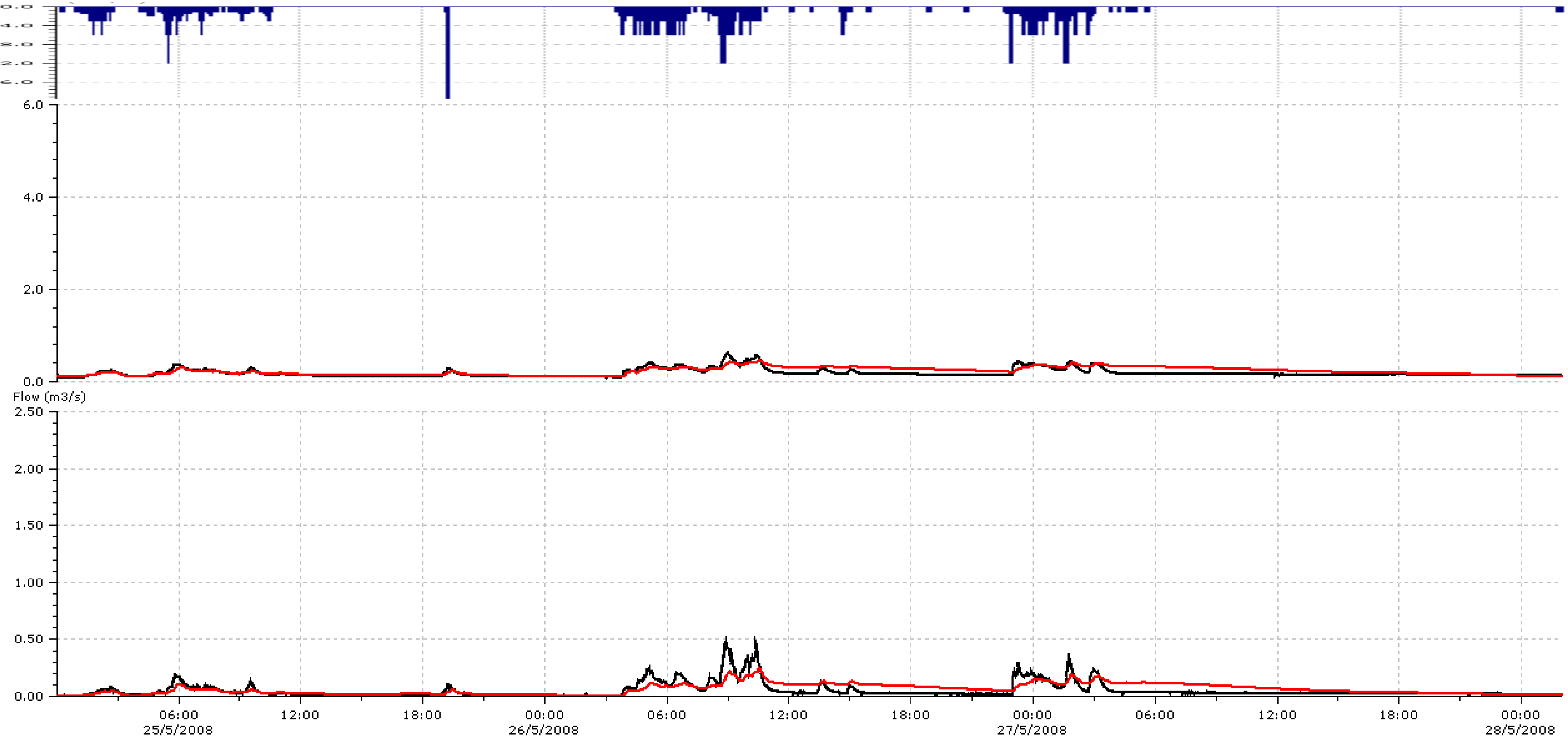
Flow Monitor 06

Animation of Flow Monitor 6 Progress



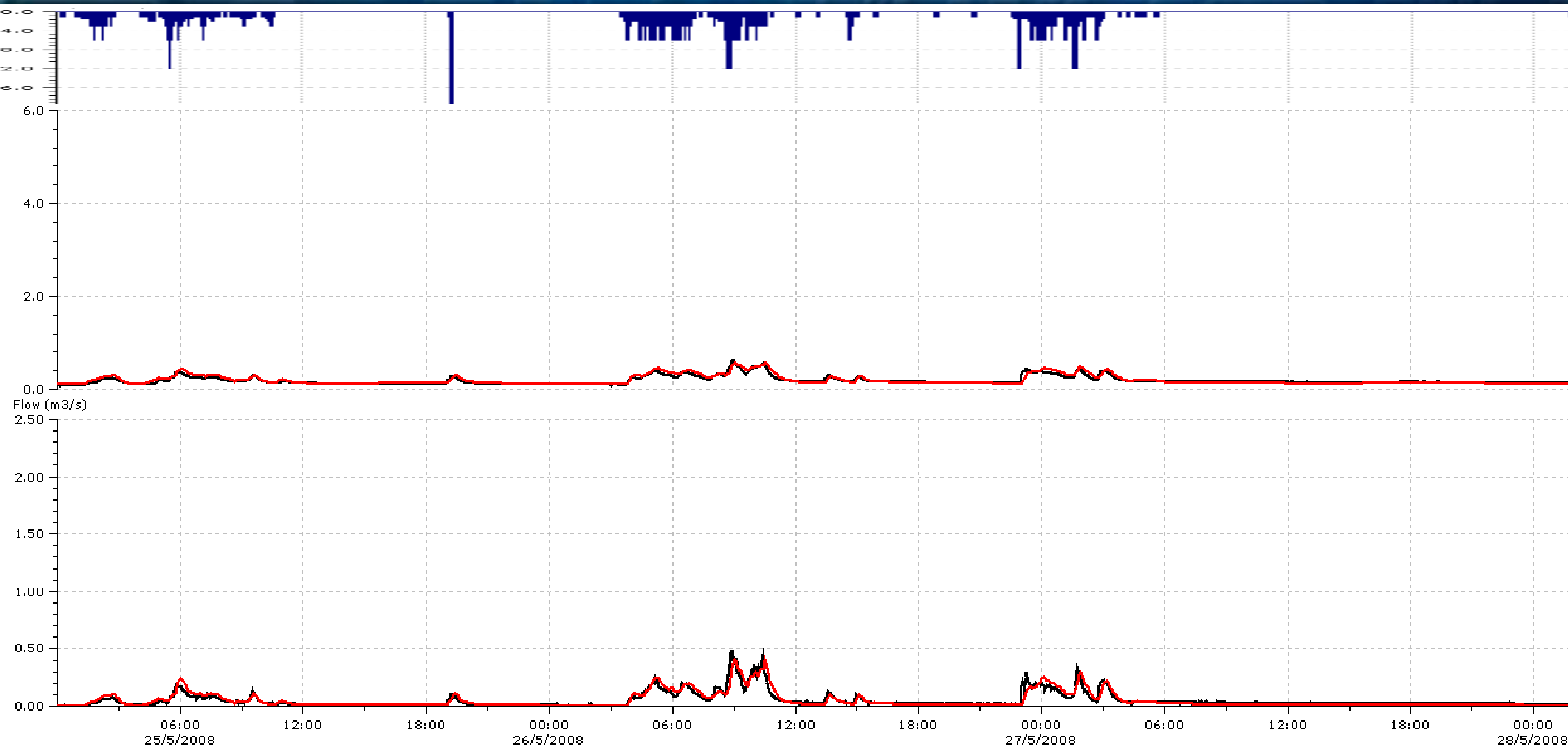
Flow Monitor 06

Animation of Flow Monitor 6 Progress



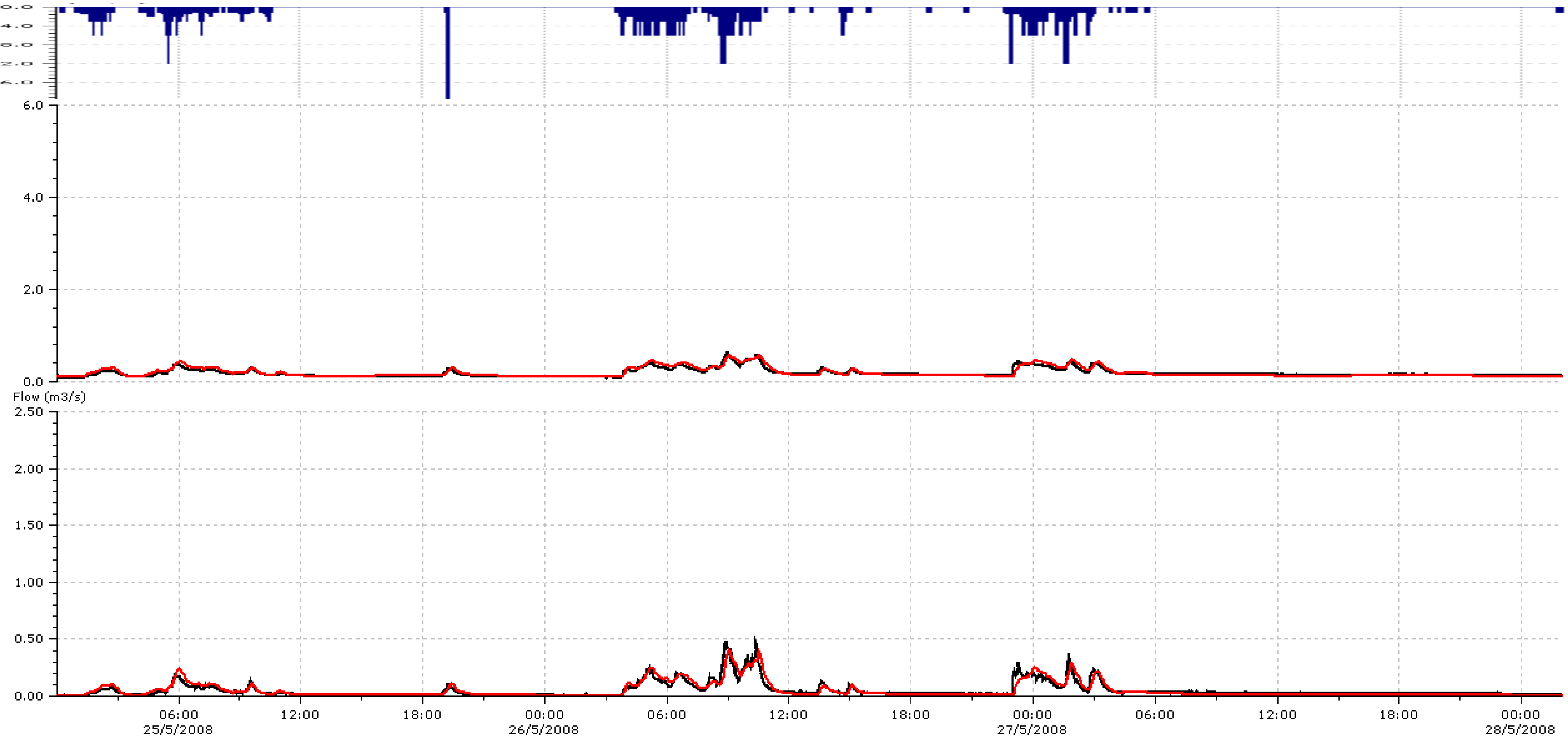
Flow Monitor 06

Animation of Flow Monitor 6 Progress



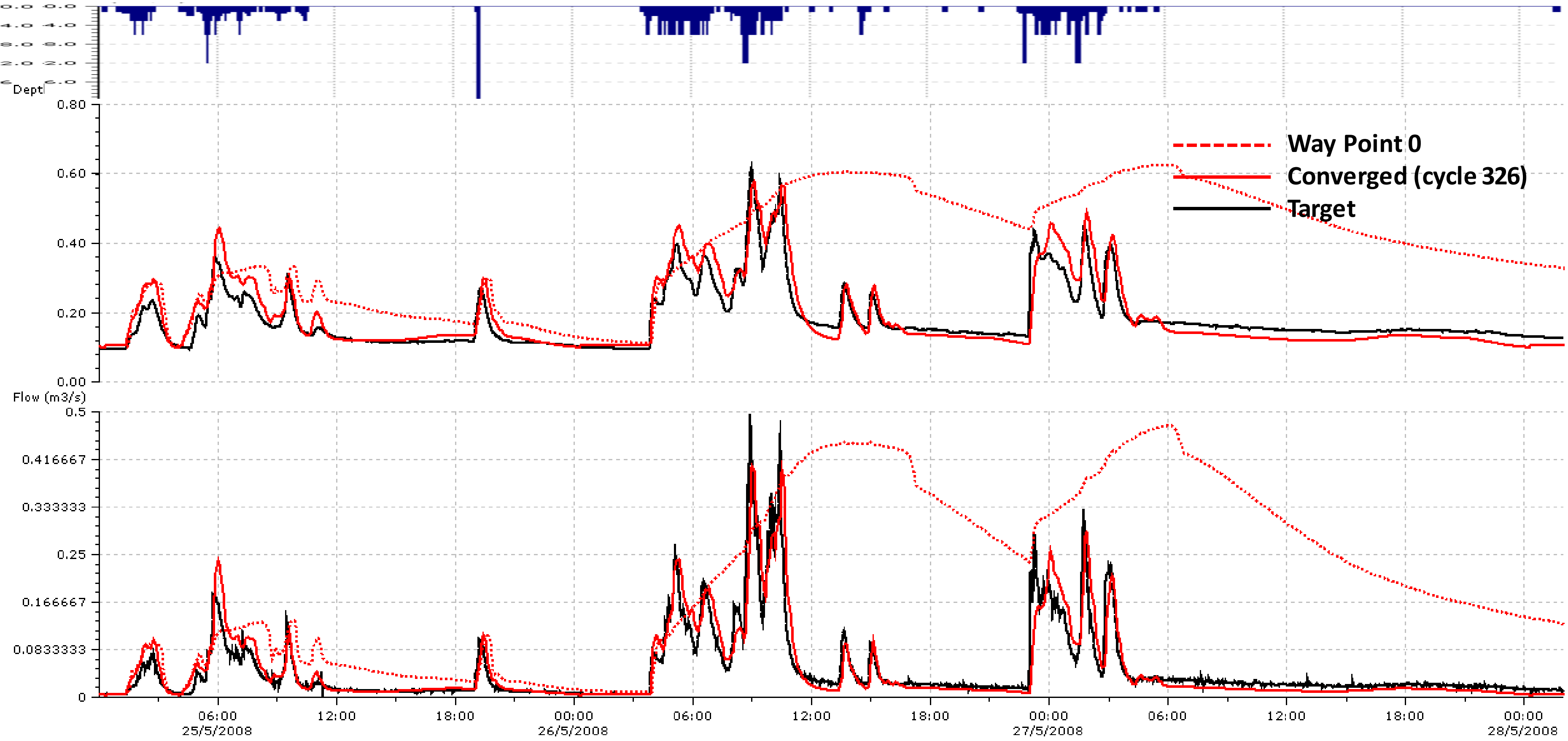
Flow Monitor 06

Animation of Flow Monitor 6 Progress



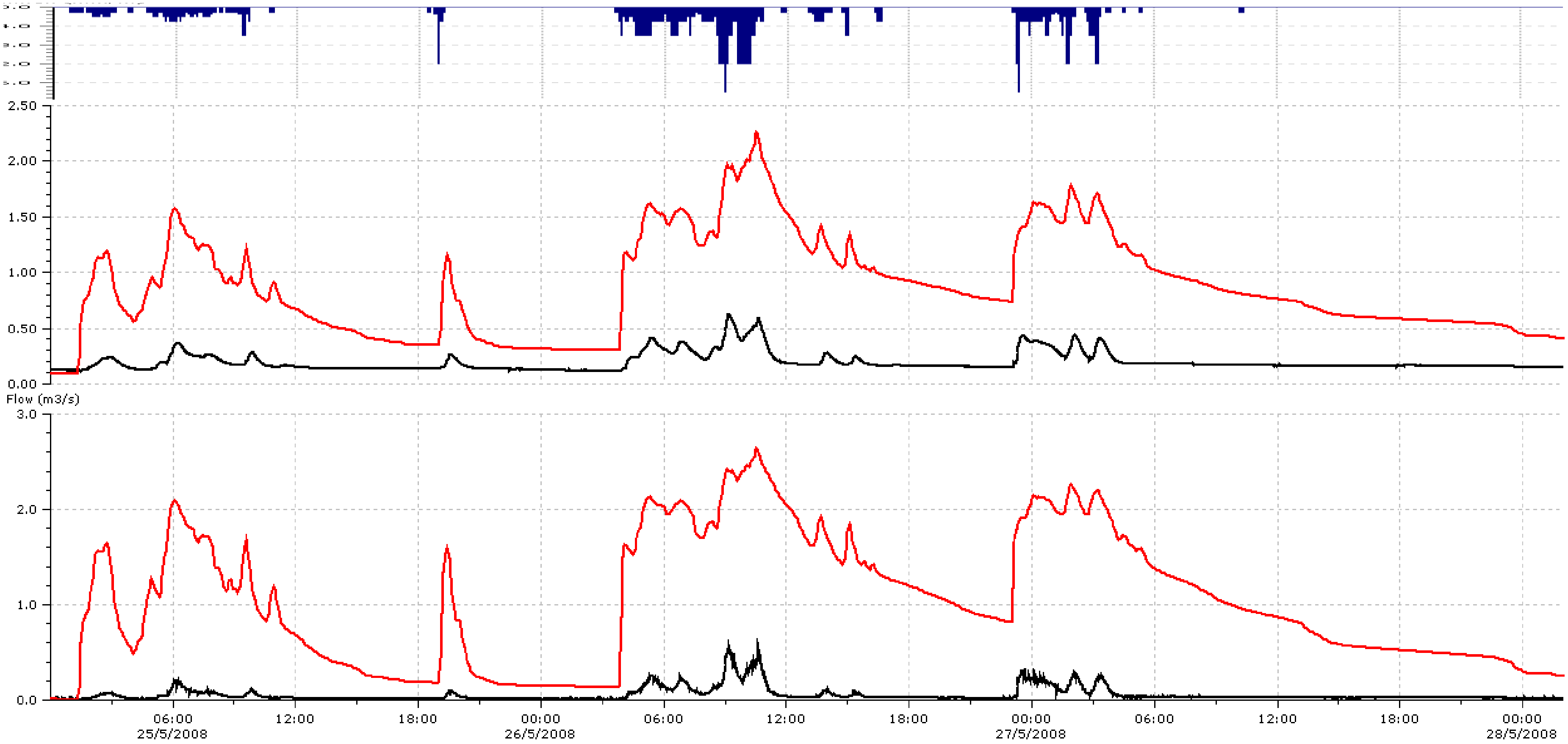
Flow Monitor 06

Animation of Flow Monitor 6 Progress



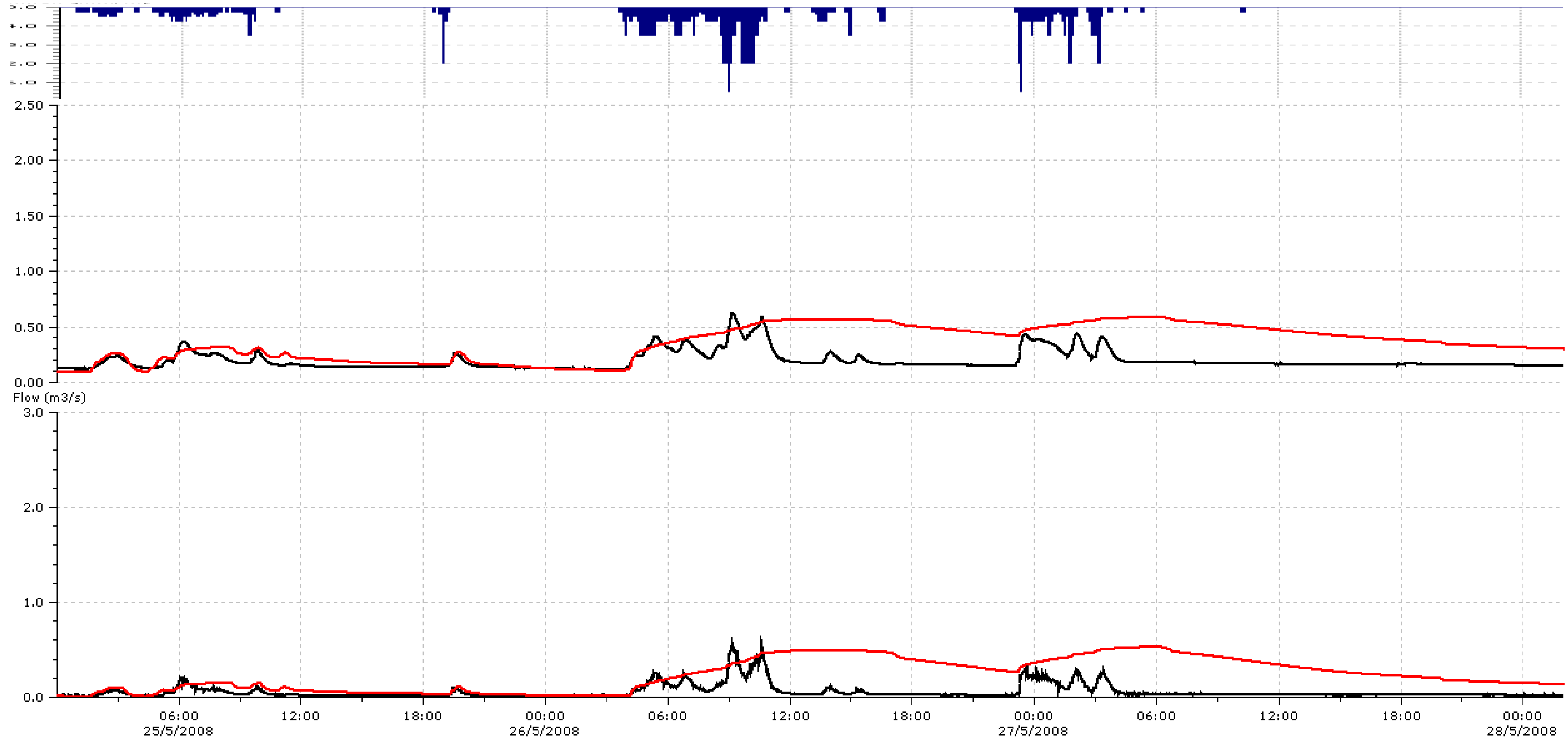
Flow Monitor 06

Animation of Flow Monitor 16 Progress



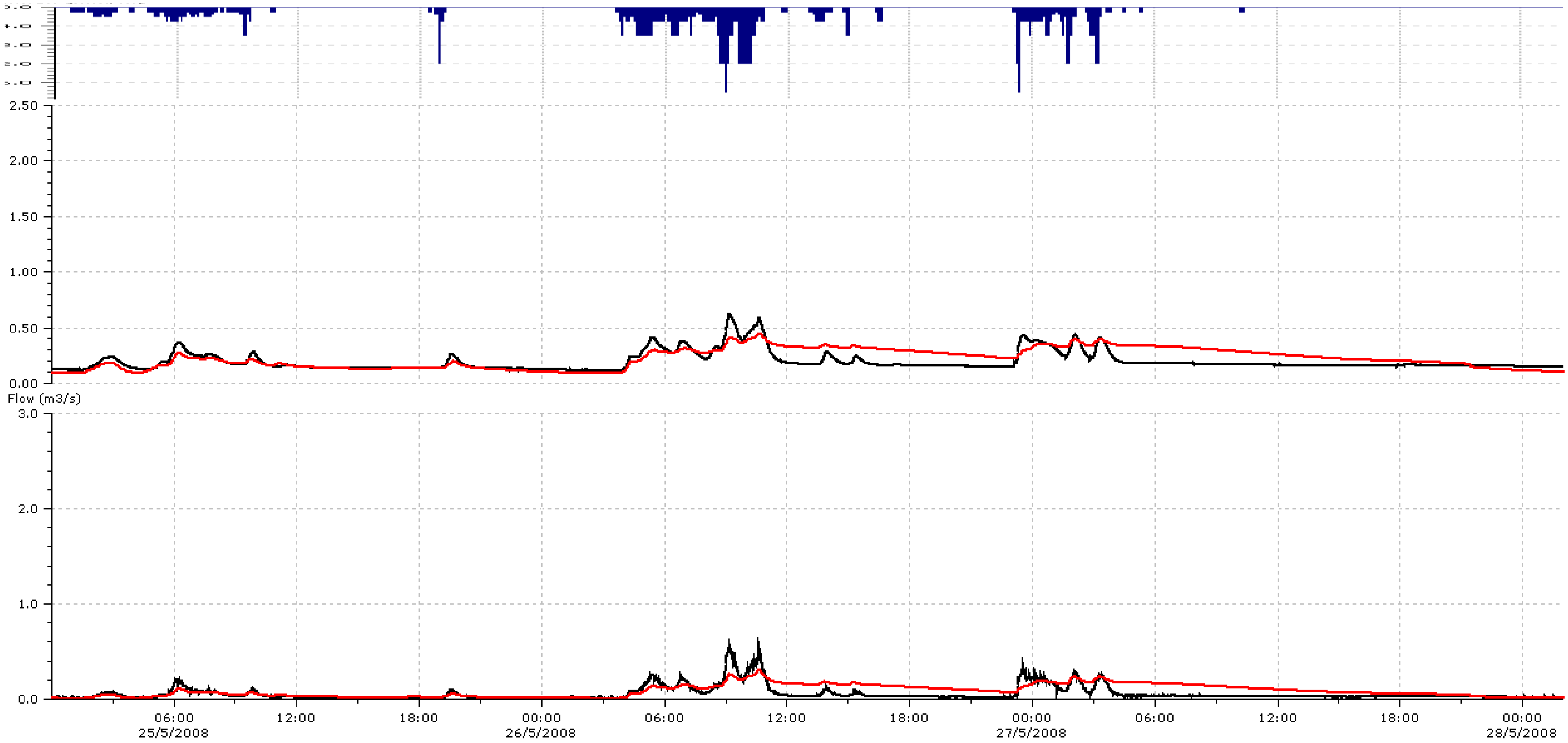
Flow Monitor 16

Animation of Flow Monitor 16 Progress



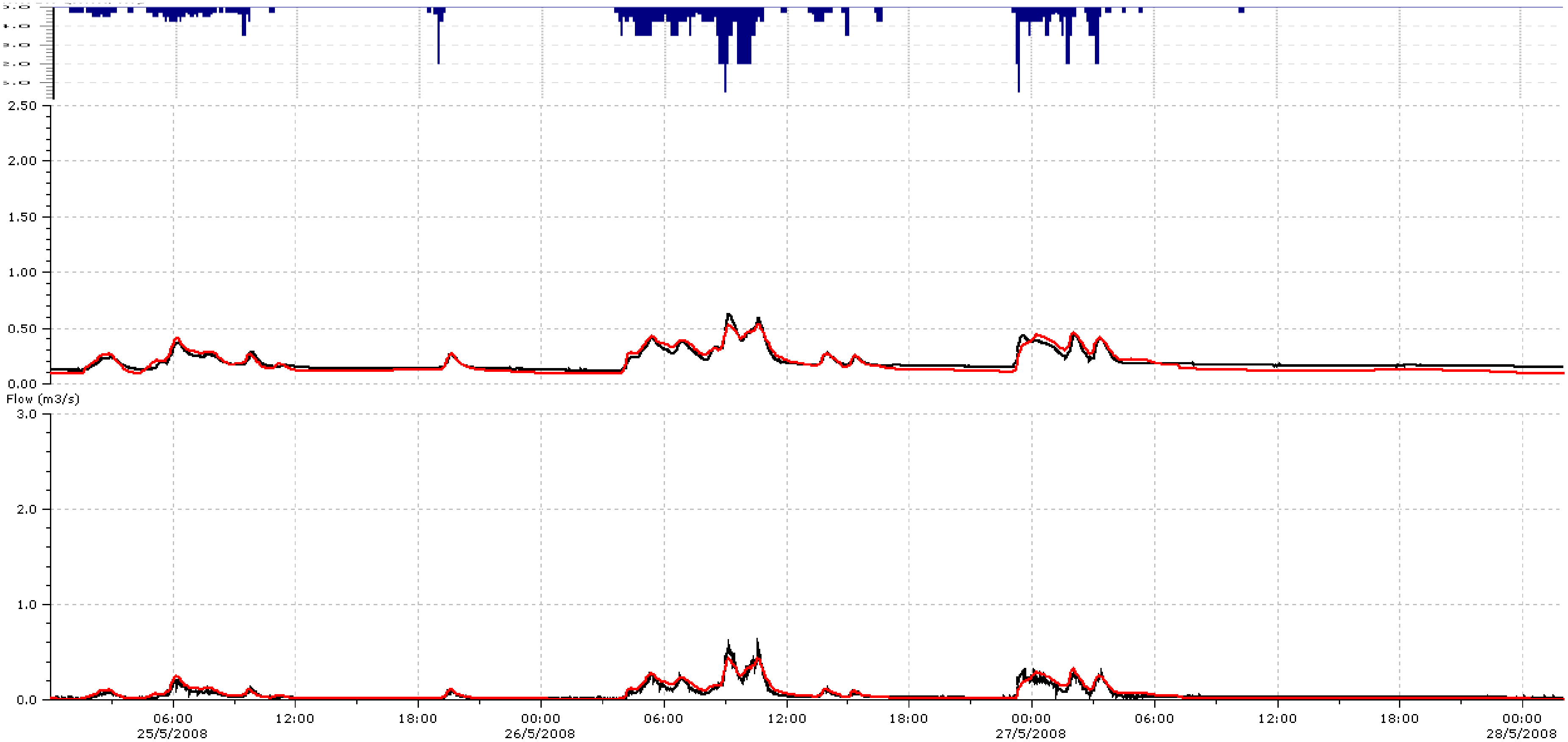
Flow Monitor 16

Animation of Flow Monitor 16 Progress



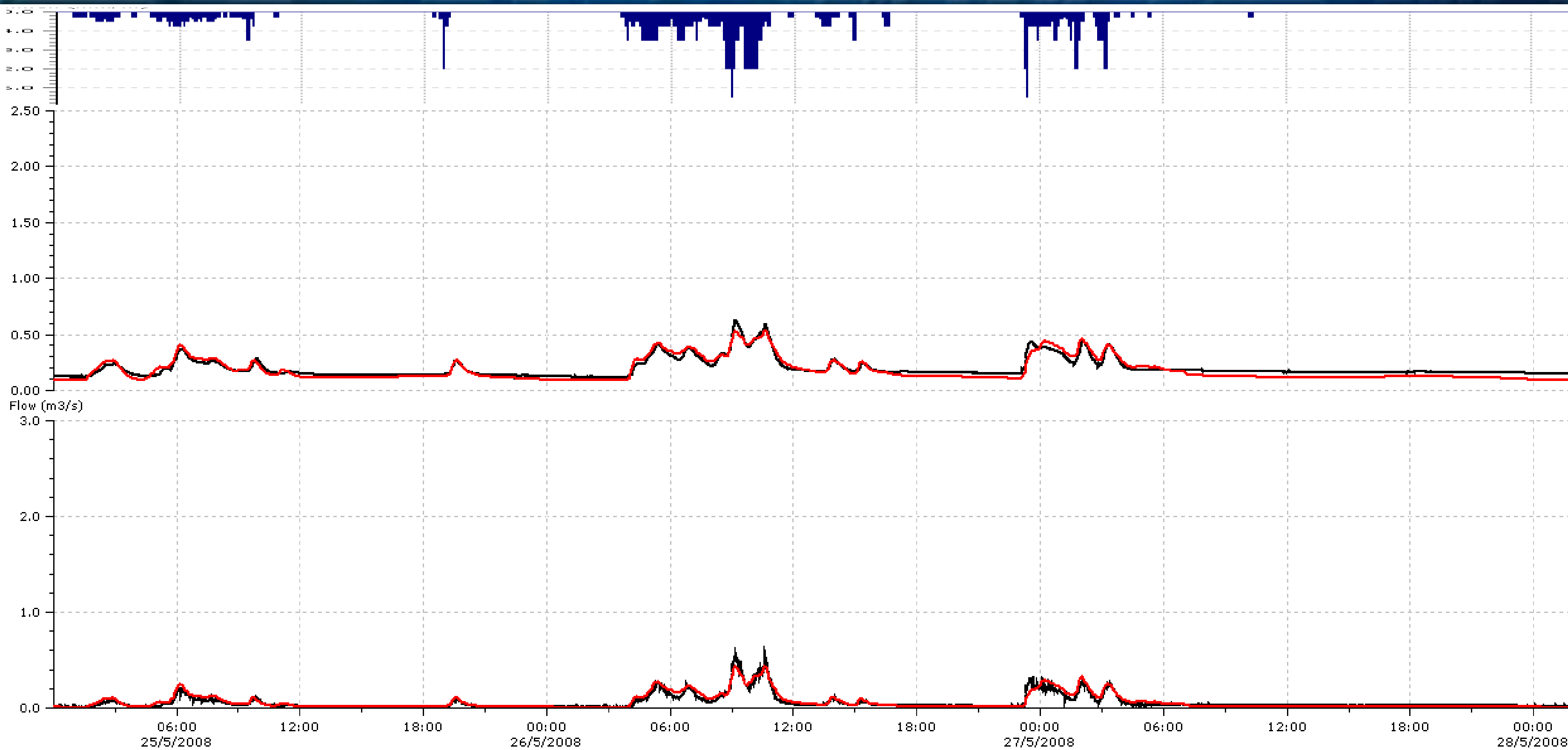
Flow Monitor 16

Animation of Flow Monitor 16 Progress



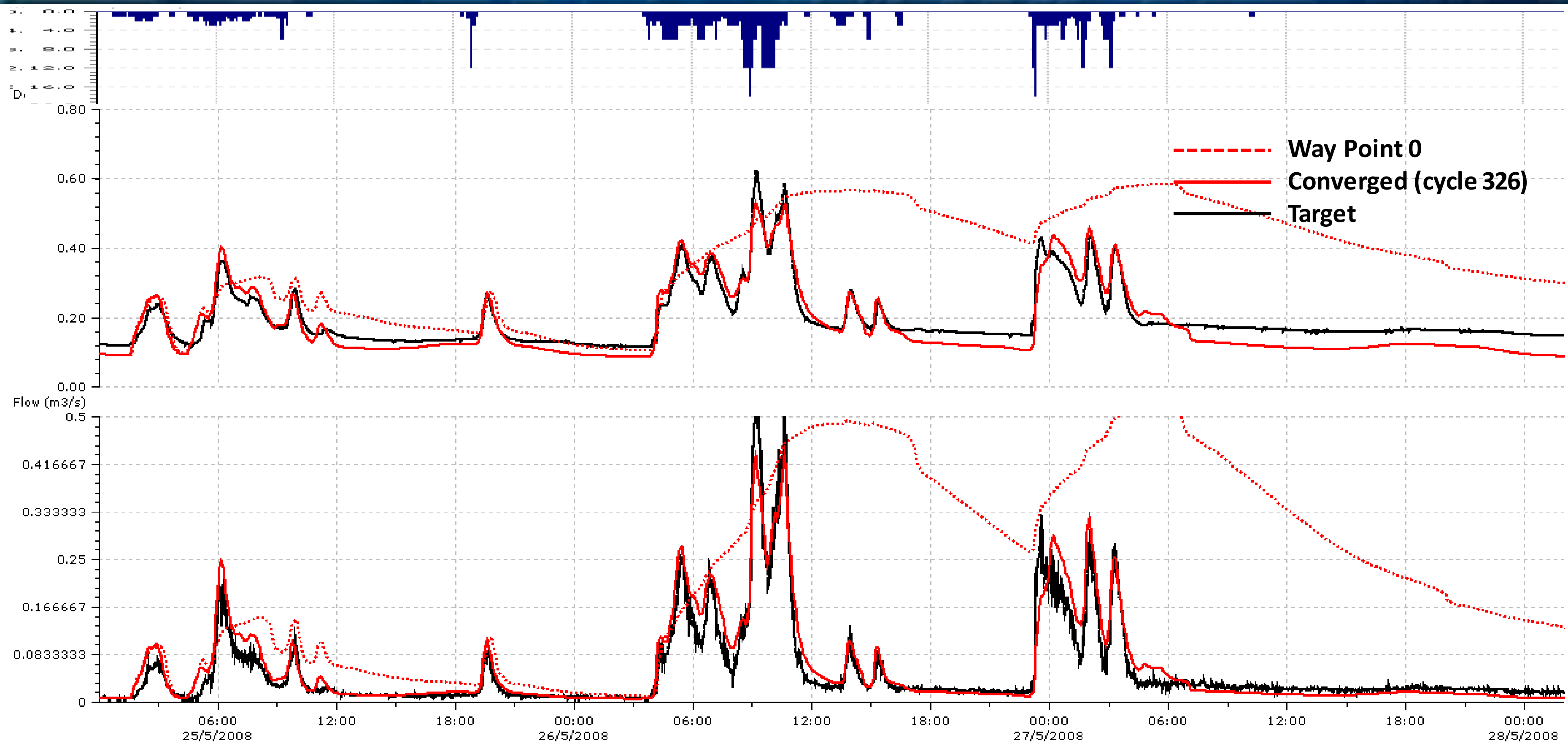
Flow Monitor 16

Animation of Flow Monitor 16 Progress



Flow Monitor 16

Animation of Flow Monitor 16 Progress



Flow Monitor 16

Summary of Features

- Integration of InfoWorks CS in modeFRONTIER (mfi4IWCS) is able to:
  - Automate InfoWorks CS runs
  - Support verification (calibration)
  - Assist with optimisation solutions ('smart' optioneering)

Summary of Benefits

- The benefits of using InfoWorks CS + modeFRONTIER:
  - Greater software/hardware utilisation since you can run InfoWorks 24/7 in unattended mode
  - Substantial reduction in time to verify model (up to 50%)
  - Valuable diagnostic information available to help engineer understand why certain FM's are not calibrating (at an early stage of the project)
  - Ability to calibrate slow run-off and ground water infiltration
  - Ability to optimise the solution phase and therefore realise significant capital savings
  - Advanced reporting tools offer a greater in-sight into the solutions therefore enhancing learning

Key partner in Design Process Innovation

Multi-Objective Optimization of a Complex Water Distribution Network

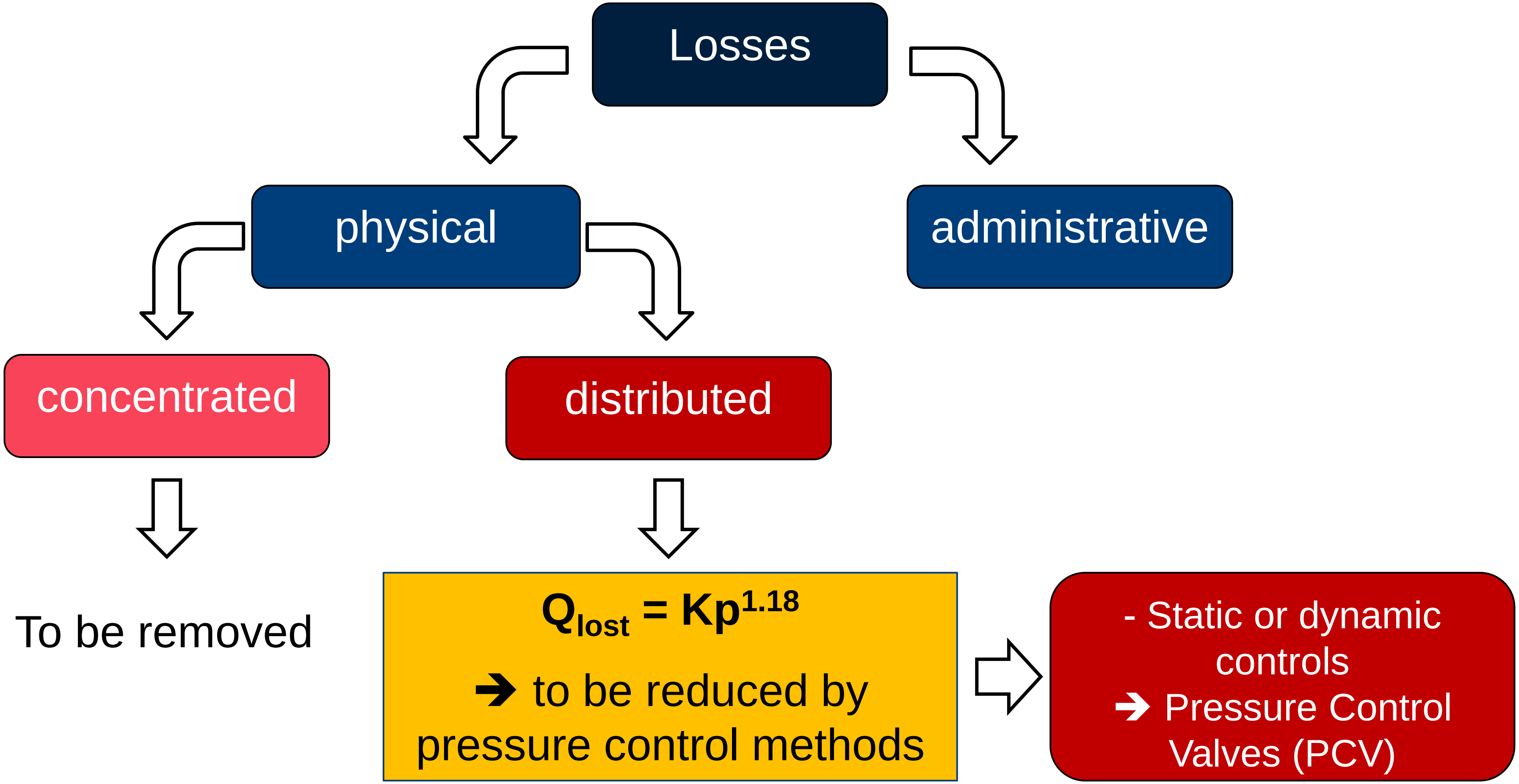
Vito Primavera, EnginSoft Italy

Activity Description & Goals

A water distribution network, with known topology, is given

- Management of network needs to take into account several parameters → not deterministic parameters (demands on different time periods, pipes roughness, emergencies, …)
- Crucial problem → management of losses

Activity Description & Goals



Activity Description & Goals

Losses

The current activity is aimed to:

1. Pressure minimization
2. Costs minimization (i.e. number of PCVs)

At same time, minimum demands have to be guaranteed at each network node

Activity Description & Goals

The activity has been divided into the following phases:

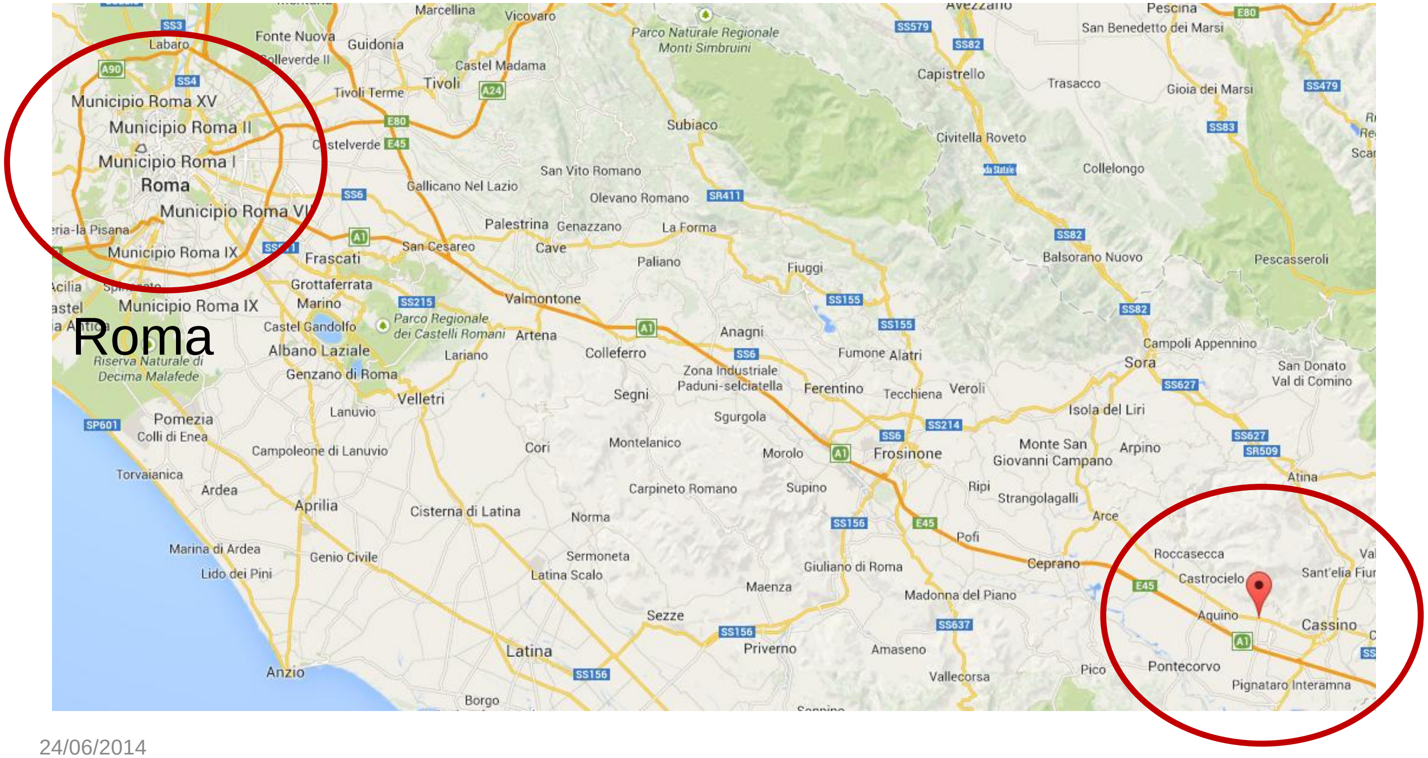
- Phase_01 ➔ selection of positions and minimum number of valves, in respect of all the time periods (scenarios);
- Phase_02 ➔ determination of the optimum opening degree of the positioned valves, for every scenario
- Phase_03 ➔ determination of the found solution robustness in respect of pipes roughness and node demands.

The software tools used for the numerical analyses are:

- the water distribution network solver EPAnet2, freeware tool to calculate the parameters characterizing an hydraulic network
- in-house utilities written in C++, used to dynamically update various characteristics of the network analyzed by EPANet2
- the multi-objective design and optimization environment modeFRONTIER. This tool has been used for both network optimization and data post-processing.

Hydraulic Network: Piedimonte San Germano's

- The activity took into account a real water distribution network → Piedimonte San Germano, characterized by a high percentage of distributed losses due to loads usually larger in respect of the service



Piedimonte San Germano

Hydraulic Network: Piedimonte San Germano's

- Networks characteristics:

  30 nodes

  42 pipes

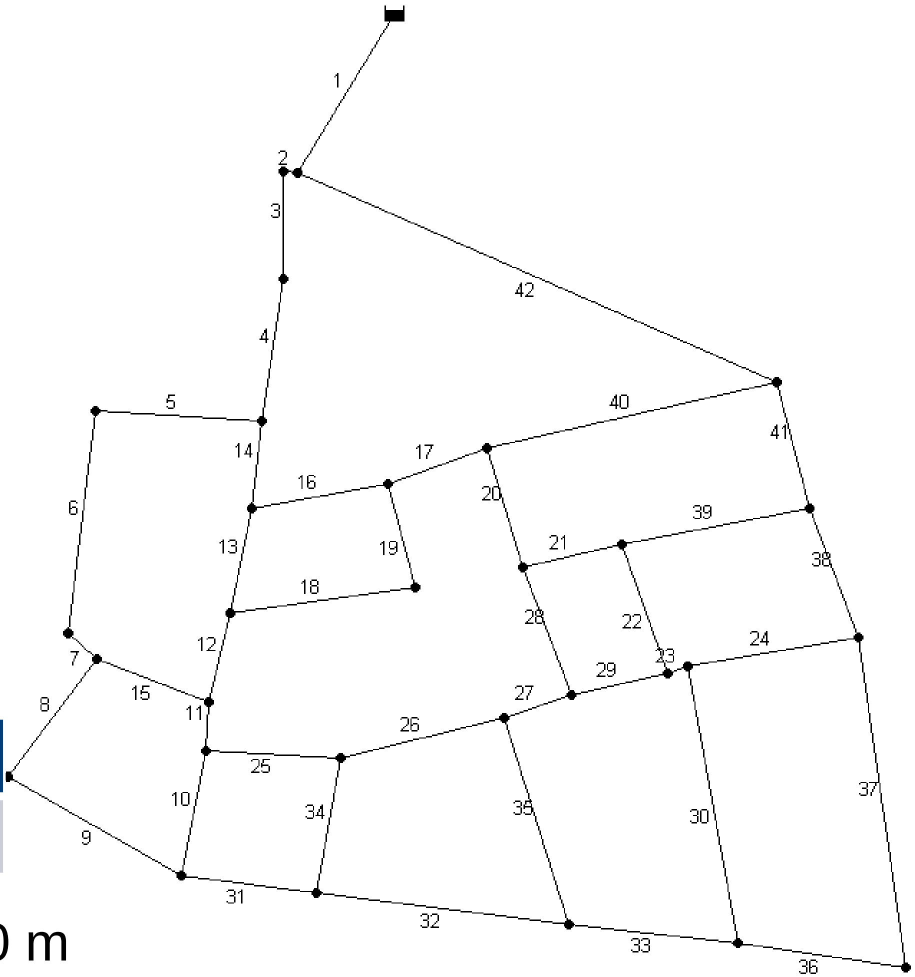
  12 chains

  1 tank node

- Starting network configuration:
  - Valves n° = 0
  - $\sum_{1}^{30} p_i =$

03:00	06:00	07:00	09:00
1658 m	1543 m	1222 m	1065 m

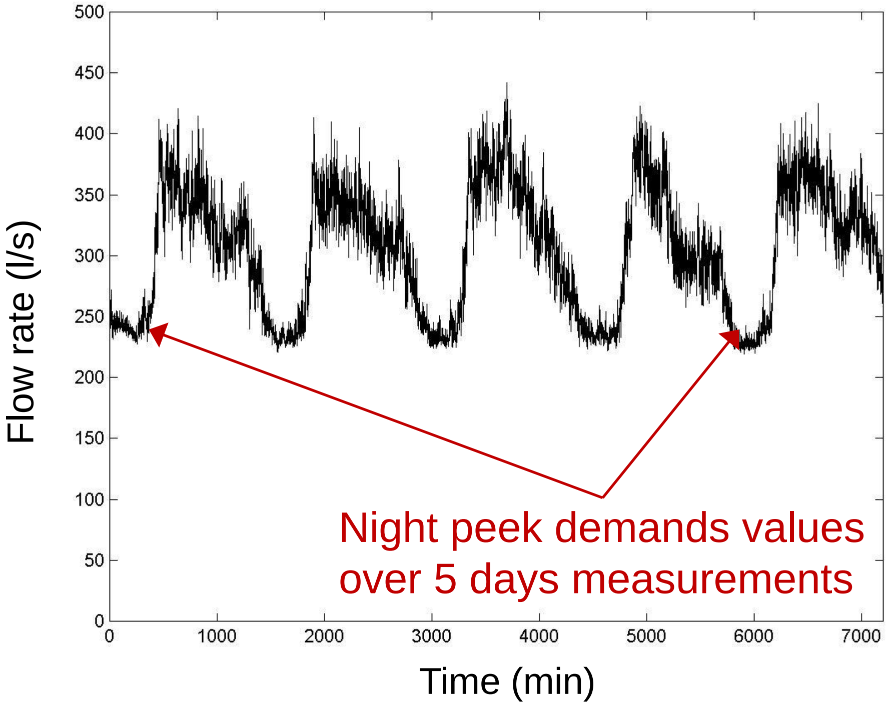
  - Tank node ➔ prevalence = 180 m



Hydraulic Network: Piedimonte San Germano's

- Networks characteristics: the presence of high water losses is demonstrated by the high demands during the night-time ➔ their values can't be justified by number and typology of the consumers.

7th network node



Demands (l/s) @ 4 scenarios: 03:00, 06:00, 07: 00, 09:00

Node	Ore 03:00	Ore 06:00	Ore 07:00	Ore 09:00
1	0	0	0	0
2	0.612	0.468	0.612	0.72
3	0.972	0.684	0.972	1.08
4	0.108	0.072	0.108	0.144
5	0	0	0	0
6	0.792	0.612	0.792	0.9
7	0.036	0	0.036	0.036
8	3.168	2.376	3.168	3.456
9	3.24	3.24	3.24	3.24
10	0.396	0.288	0.396	0.396
11	0.036	0.036	0.036	0.036
12	0.36	0.288	0.36	0.396
13	1.296	0.864	1.296	1.476
14	0.108	0.072	0.108	0.144
15	0.18	0.144	0.18	0.216
16	0.432	0.36	0.432	0.468
17	0	0	0	0
18	0.9	0.72	0.9	1.008
19	0.972	0.72	0.972	1.08
20	0.612	0.468	0.612	0.72
21	0.36	0.18	0.36	0.396
22	0.432	0.324	0.432	0.468
23	0.216	0.144	0.216	0.216
24	0.54	0.396	0.54	0.612
25	0.252	0.18	0.252	0.252
26	0.252	0.18	0.252	0.288
27	0.216	0.144	0.216	0.216
28	2.088	1.512	2.088	2.268
29	1.152	0.864	1.152	1.332
30	0.576	0.396	0.576	0.684

Phase 01

Phase 01 – Description

Phase_01 ➔ positioning of the optimal minimum number of valves with respect to all 4 frame time scenarios. modeFRONTIER workflow relies on:

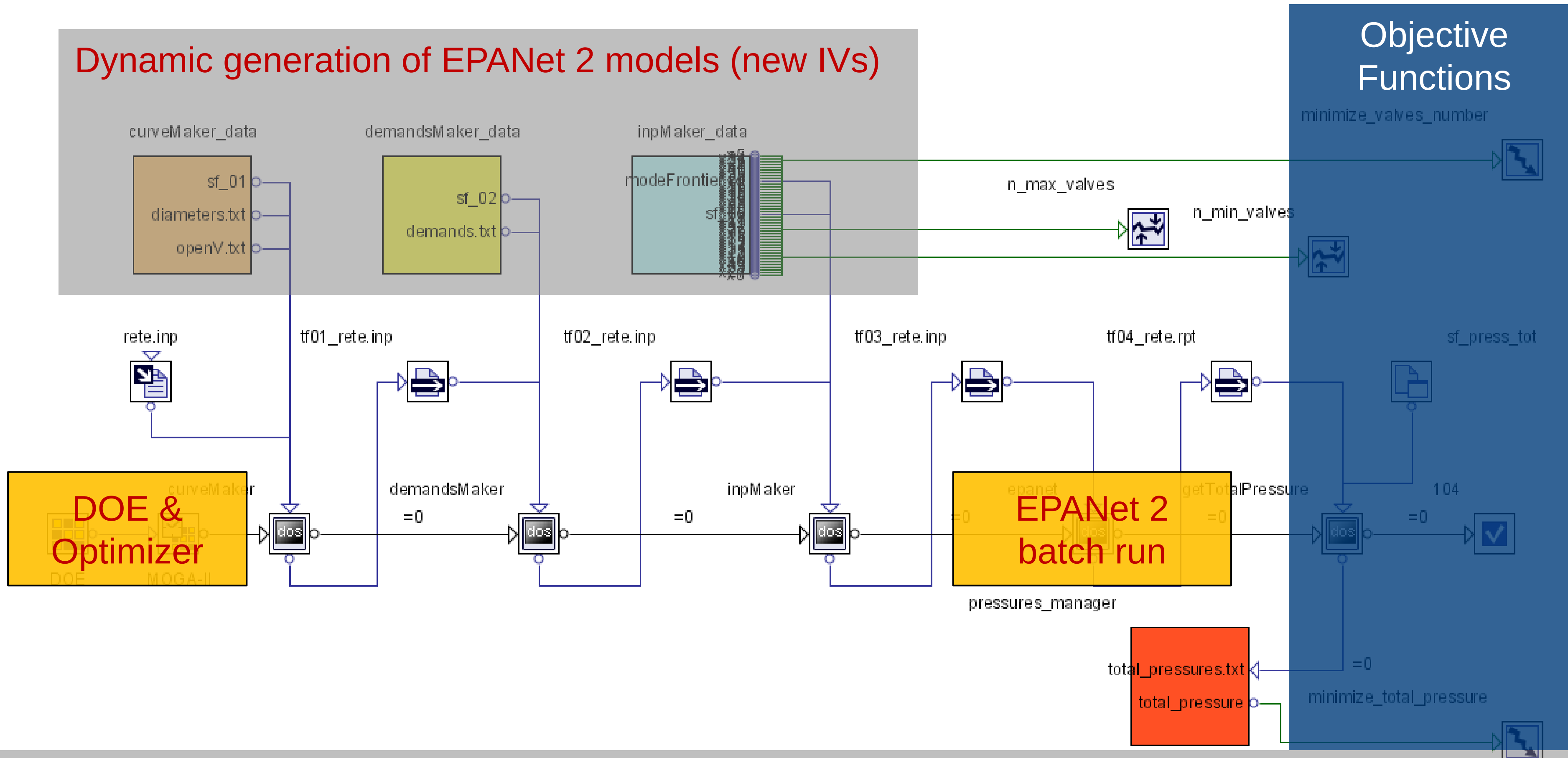
- Input Variables: valves number, position and opening degree
  - on_off_valves = 42 binary variables, where 0/1 means valve not inserted/inserted
  - openV = 42 variables related to opening degree of the corresponding valve (0, 5, 10, 20, 30, 50, 95 %)
  - set_demands = variable setting randomly which one of the 4 possible scenarios has to be considered for the current simulation
- Output Variables: nodes pressure
  - nodes pressure = pressure at 30 nodes
  - flag = variable checking if the given solution is balanced

Phase 01 – Description

Phase_01 → positioning of the optimal minimum number of valves with respect to all 4 frame time scenarios. modeFRONTIER workflow relies on:

- Objectives:
  - minimize_total_pressure = objective node minimizing network total pressure
  - minimize_valves_number = objective node minimizing the total valves number
- Constraints:
  - pressure_constraints = 30 constraints verifying the correspondent node pressure belongs to a specified range (10 m < p < 70 m)

Phase 01 – modeFRONTIER workflow



Design parameters
Input variables: 88

Design goals
Objectives: 2
Constraints: 30

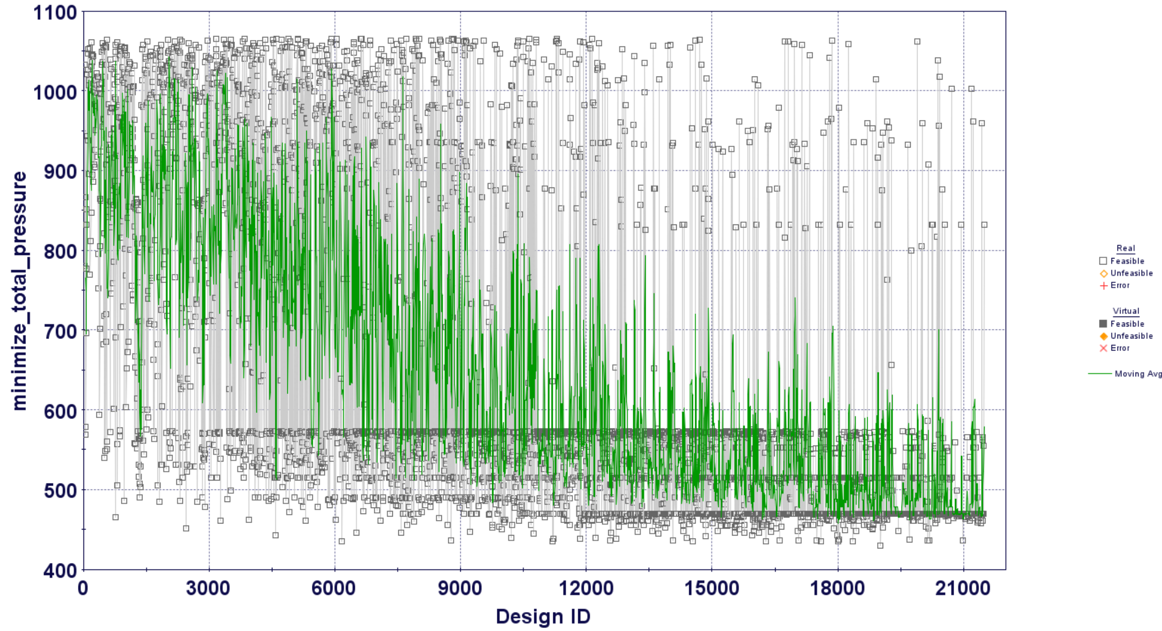
Optimization's set-up data
Sampling phase
DOE: 1500 SOBOL

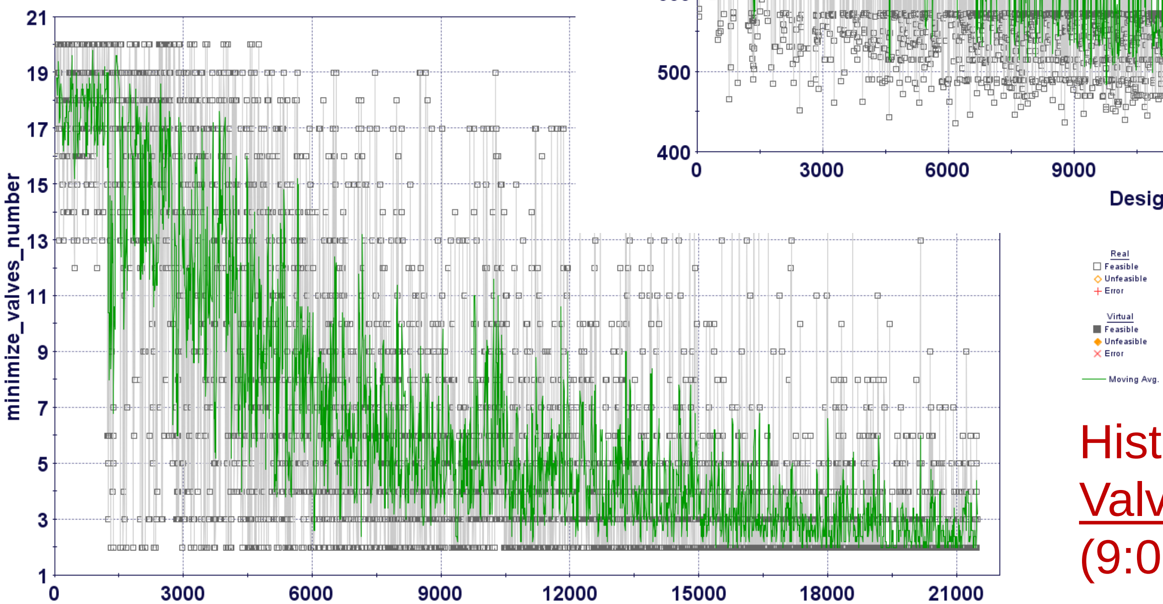
Exploration phase
Algorithm: MOGA II

CPU time
Number of analyses: 21000
CPU time required: ca. 20 h

Phase 01 – Results: Solutions Convergence (e.g. 9:00 am)

History Chart:
Total Pressure vs. design
(9:00 a.m.)

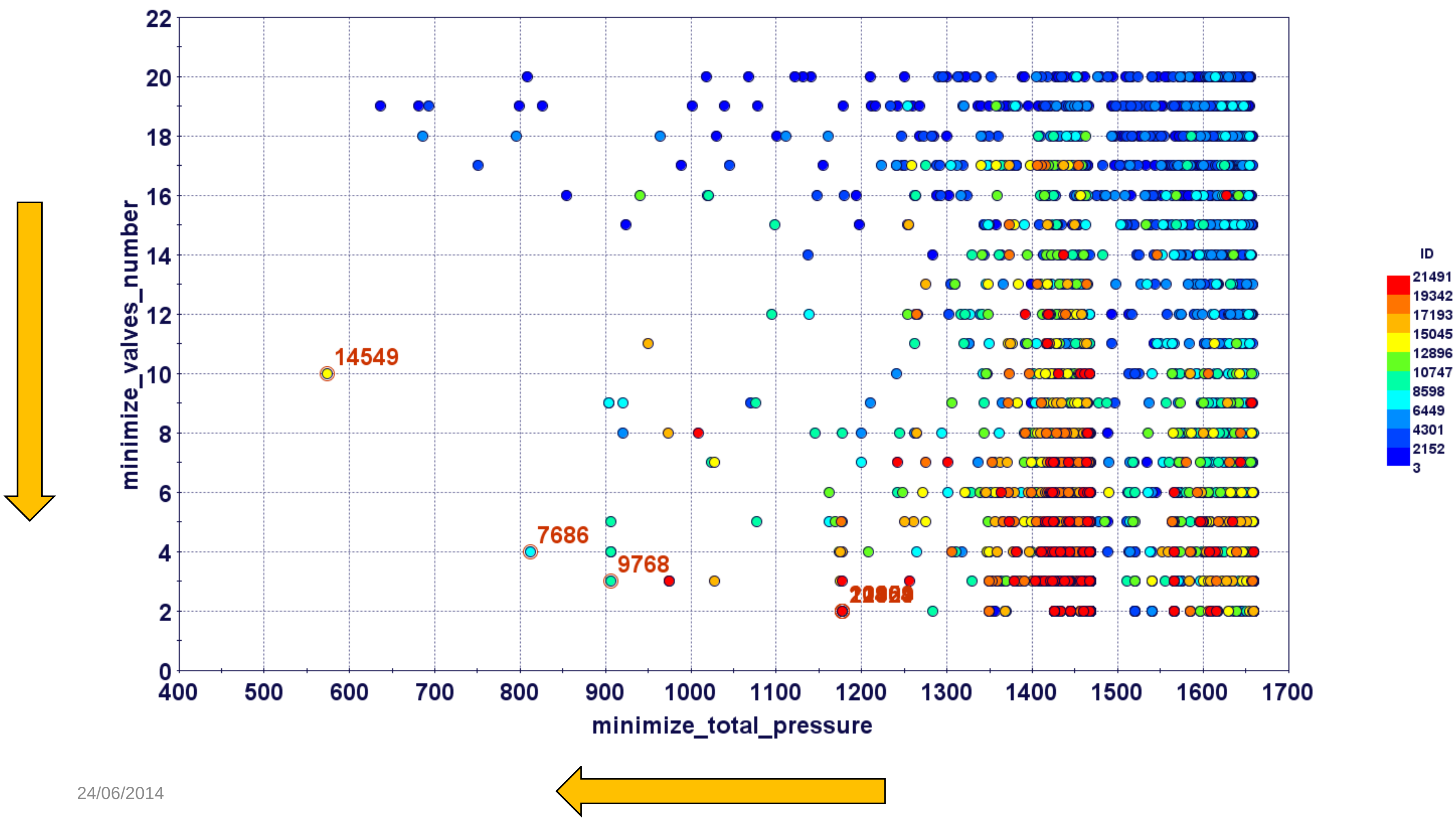




History Chart:
Valves Number vs. design
(9:00 a.m.)

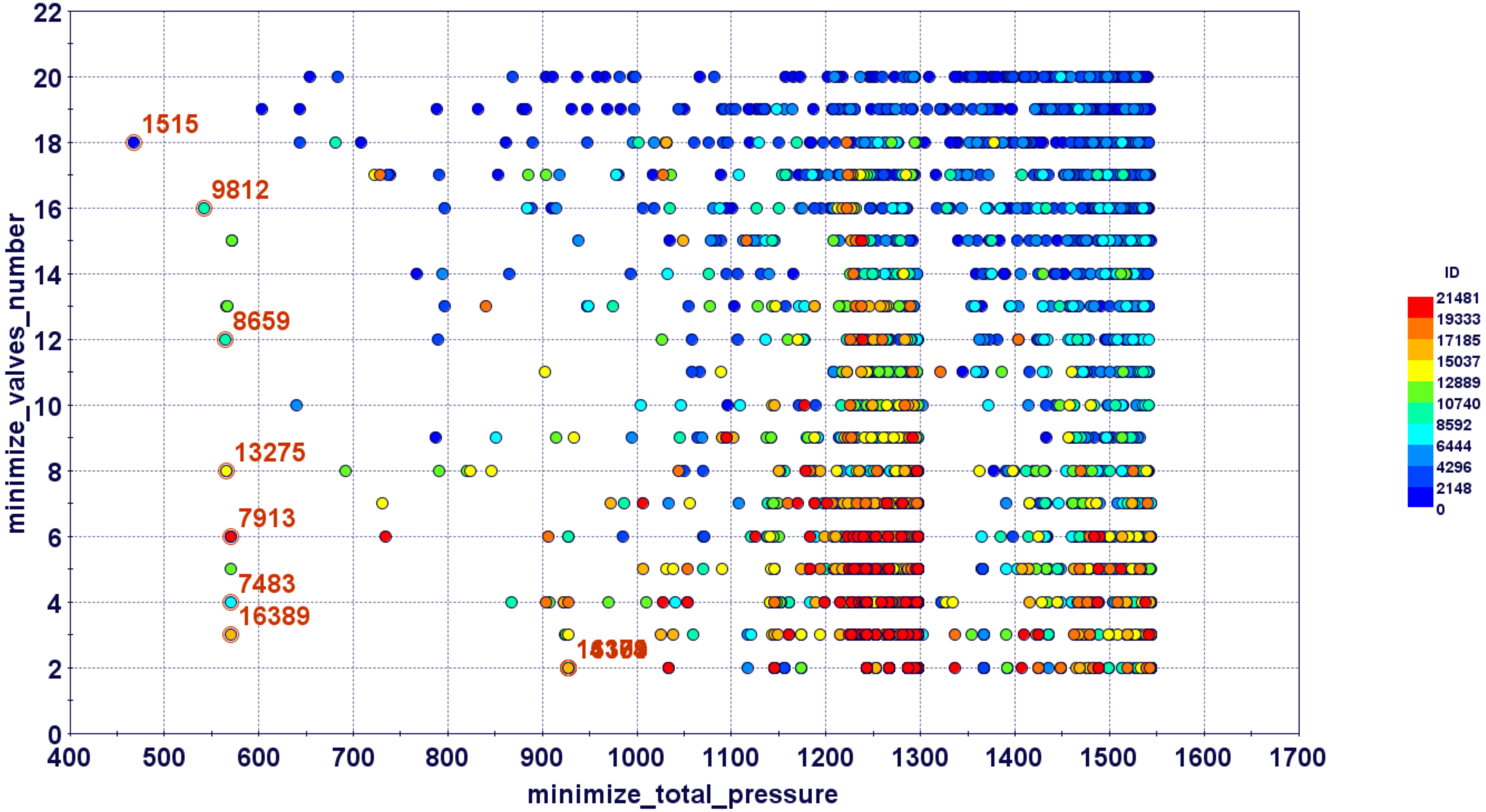
Phase 01 – Results: Pareto Designs @ 03:00 am scenario

Selected designs ➔ best trade-off vs. 2 objective functions @ 03:00 am



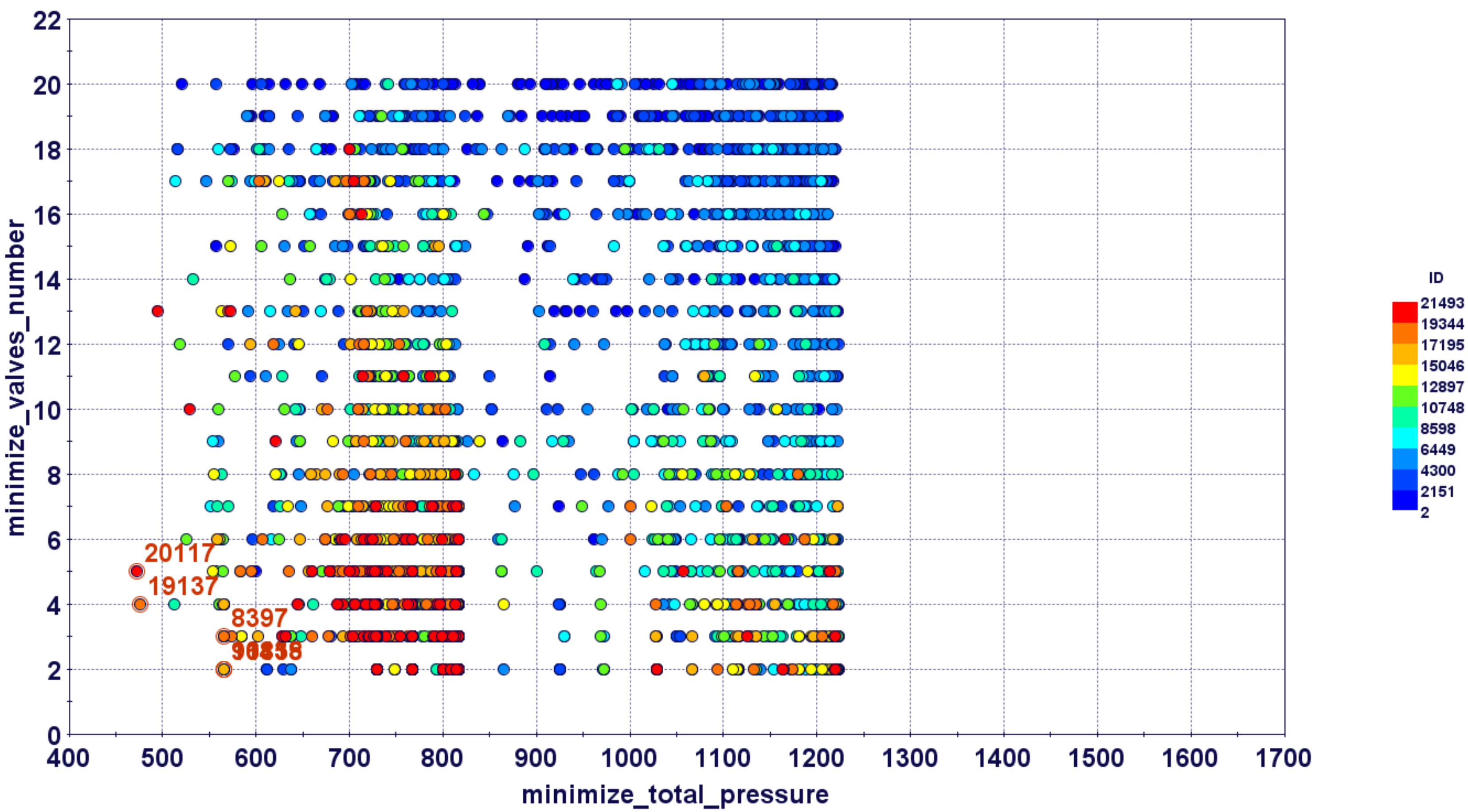
Phase 01 – Results: Pareto Designs @ 06:00 am scenario

Selected designs ➔ best trade-off vs. 2 objective functions @ 06:00 am



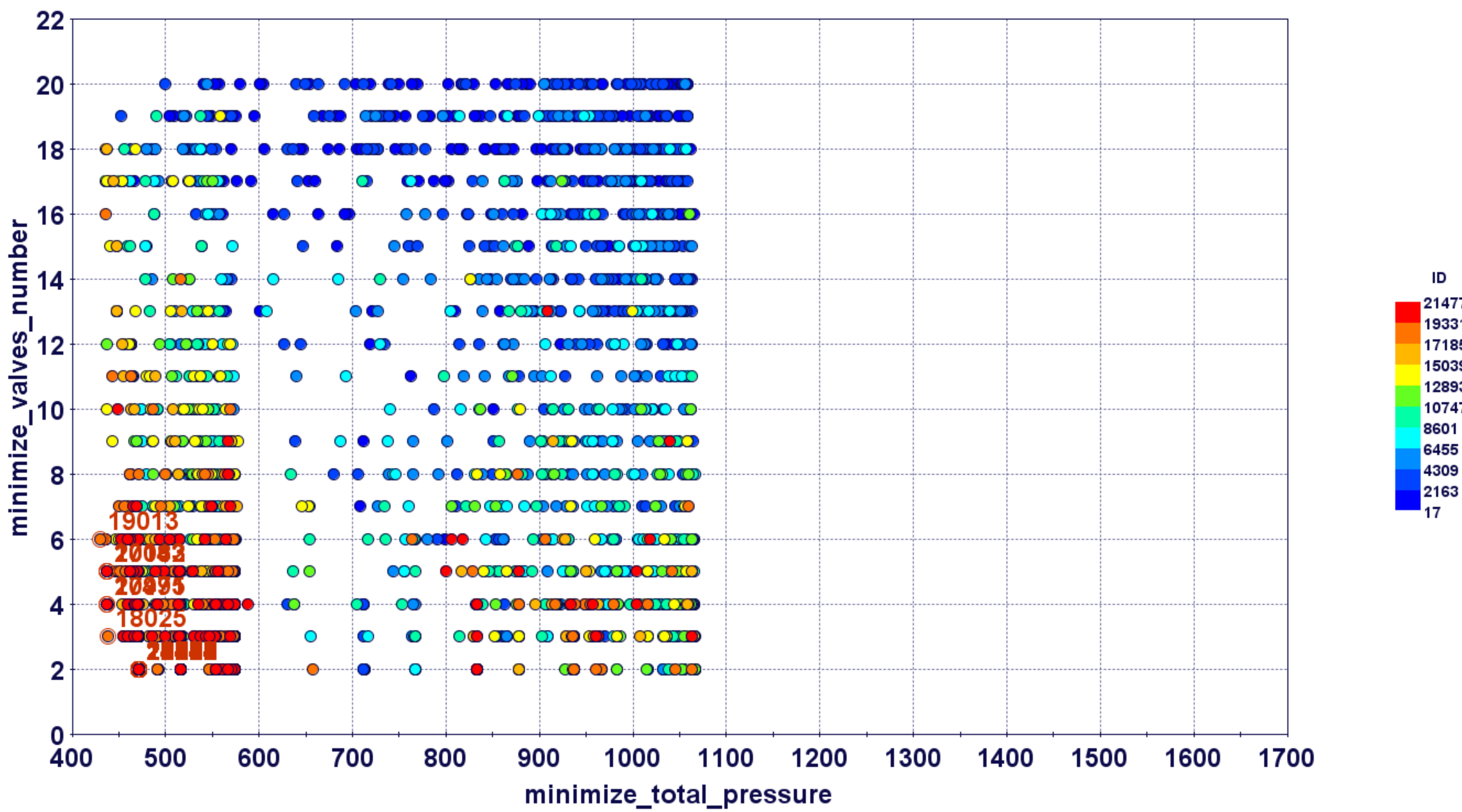
Phase 01 – Results: Pareto Designs @ 07:00 am scenario

Selected designs ➔ best trade-off vs. 2 objective functions @ 07:00 am



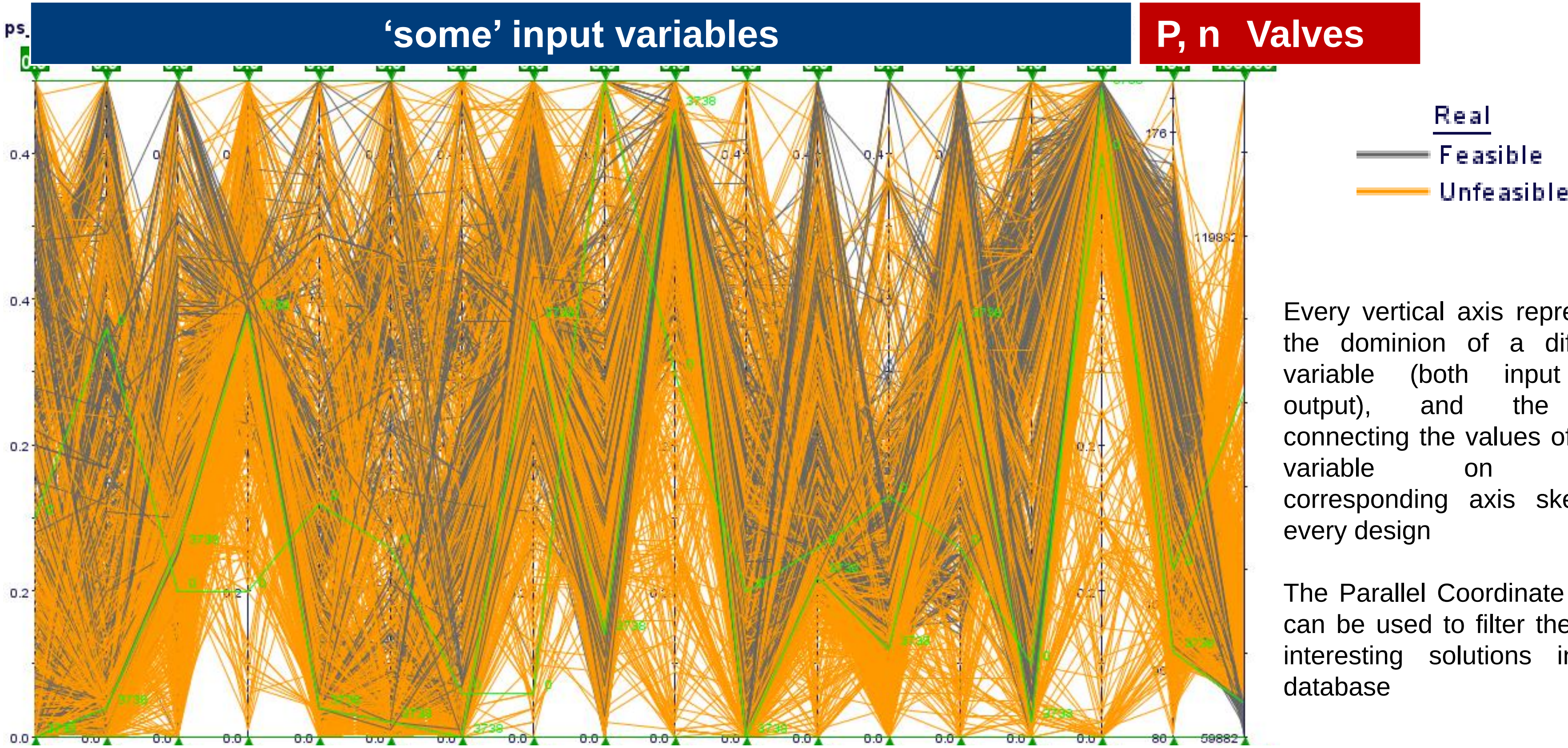
Phase 01 – Results: Pareto Designs @ 09:00 am scenario

Selected designs ➔ best trade-off vs. 2 objective functions @ 09:00 am



Phase 01 – Results: Getting to to Know the Best

- Parallel Coordinate Charts ➔ filtering out the OFs, best designs survive

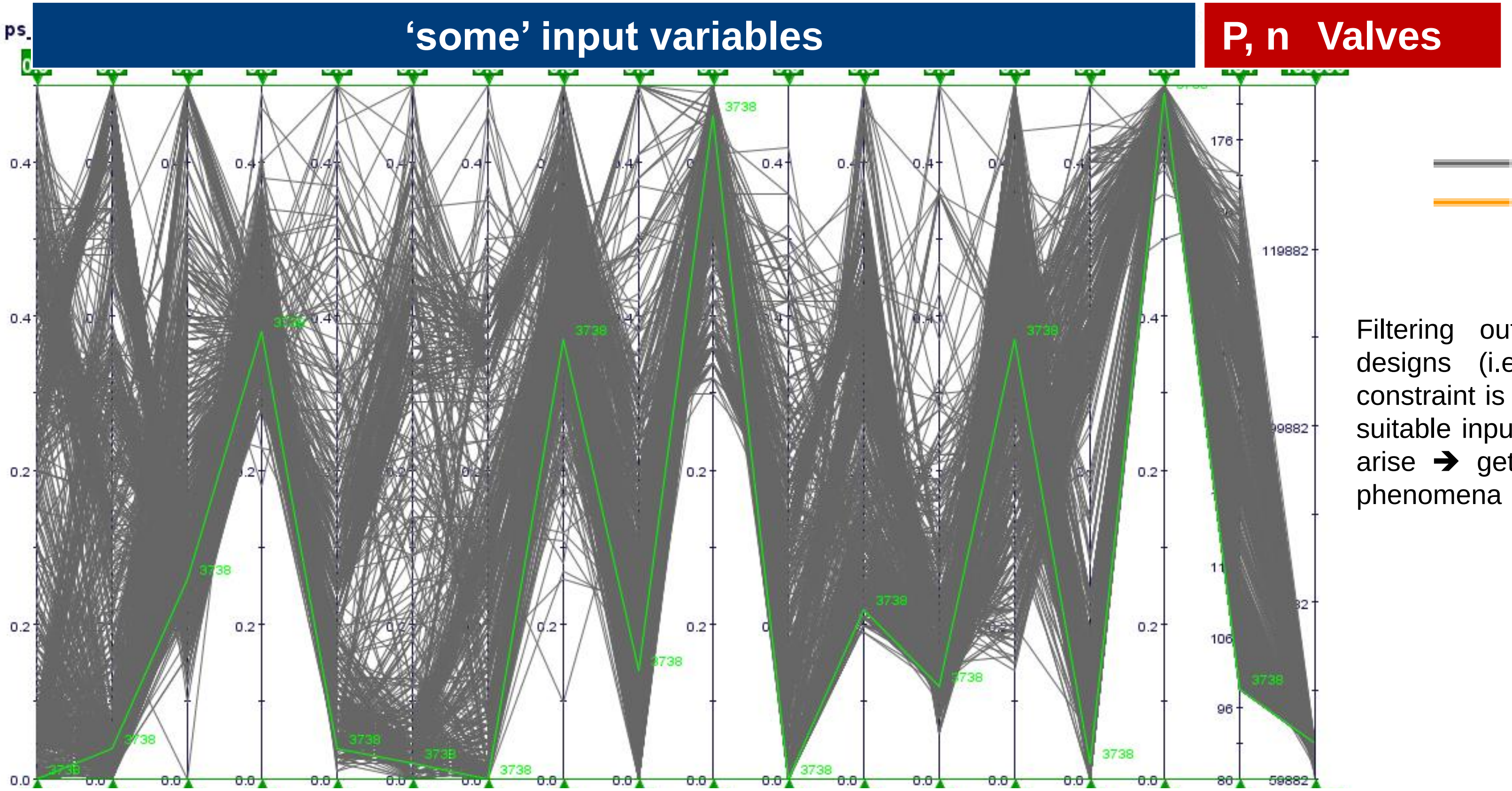


Every vertical axis represents the dominion of a different variable (both input and output), and the line connecting the values of each variable on each corresponding axis sketches every design

The Parallel Coordinate Chart can be used to filter the most interesting solutions in the database

Phase 01 – Results: Getting to to Know the Best

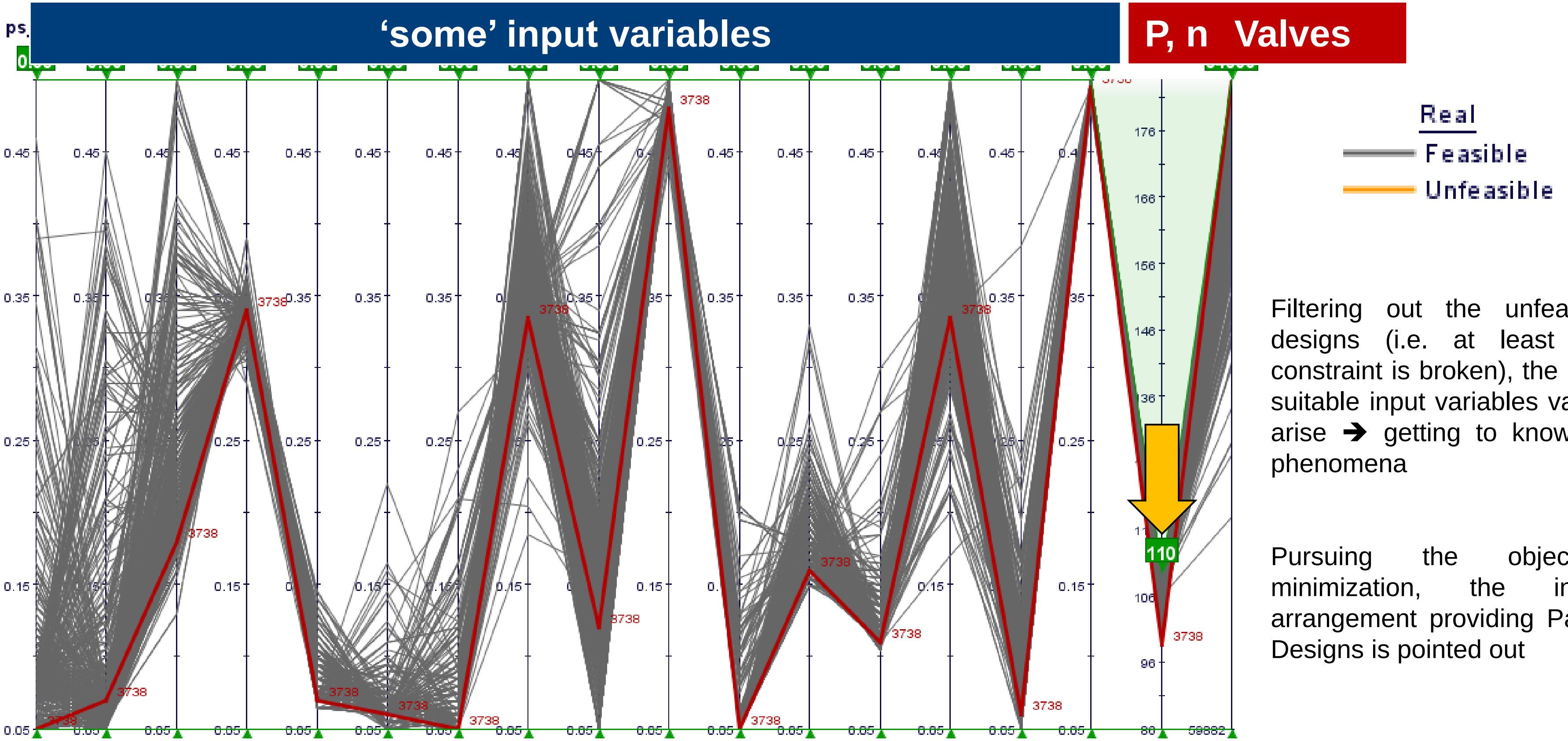
- Parallel Coordinate Charts ➔ filtering out the OFs, best designs survive



Filtering out the unfeasible designs (i.e. at least one constraint is broken), the most suitable input variables values arise ➔ getting to know the phenomena

Phase 01 – Results: Getting to to Know the Best

- Parallel Coordinate Charts ➔ filtering out the OFs, best designs survive



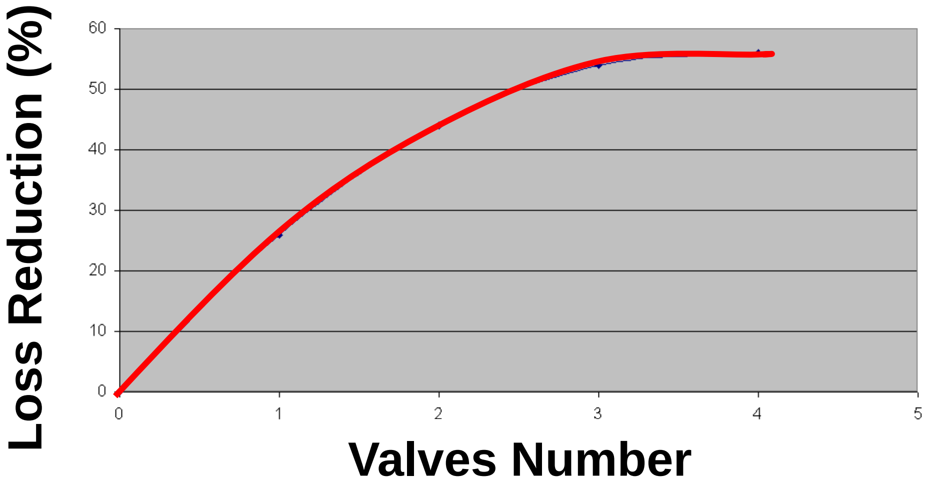
Filtering out the unfeasible designs (i.e. at least one constraint is broken), the most suitable input variables values arise ➔ getting to know the phenomena

Pursuing the objectives minimization, the inputs arrangement providing Pareto Designs is pointed out

Phase 01 – Results: Selection of Best

- The Post Processing Analysis highlight how the minimum of nodes prevalence sum is almost reached for 3-4 valves number → configurations providing the lowest hydraulic losses

- At management purpose, it is necessary to balance between the losses costs and the costs of actions taken to minimize losses themselves → during the analysis phase, configurations for 1, 2, 3 and 4 valves have been examined



Phase 01 – n° Valves = 1

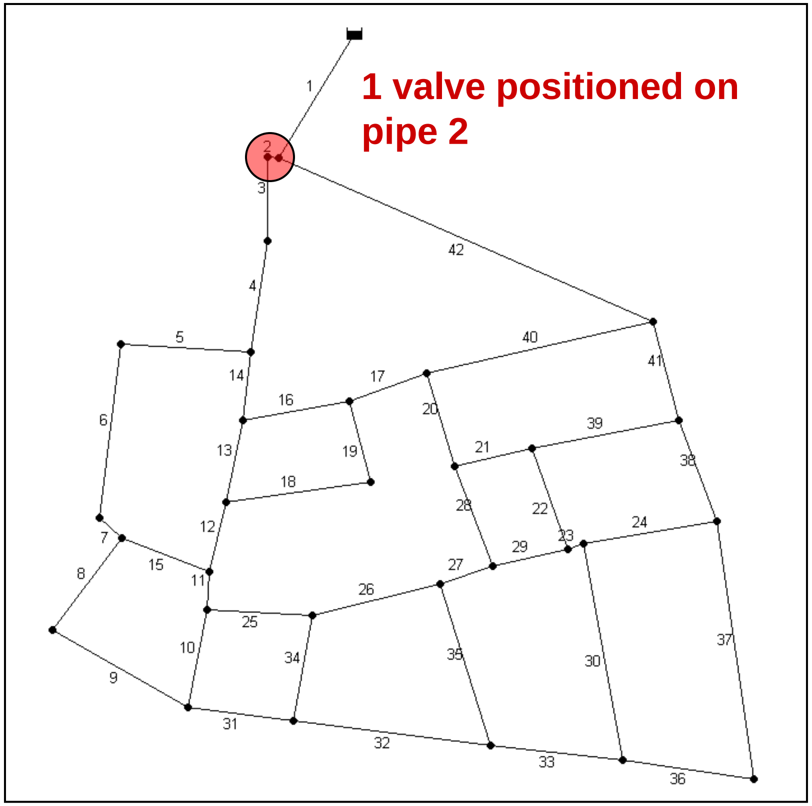
- Network configuration:

- Valves n° = 1

- $\sum_{1}^{30} p_i =$

ORE 03:00	ORE 06:00	ORE 07:00	ORE 09:00
1287.80 mt	1070.10 mt	796.16 mt	864.67 mt

Average percentage of loads reduction: 26 %



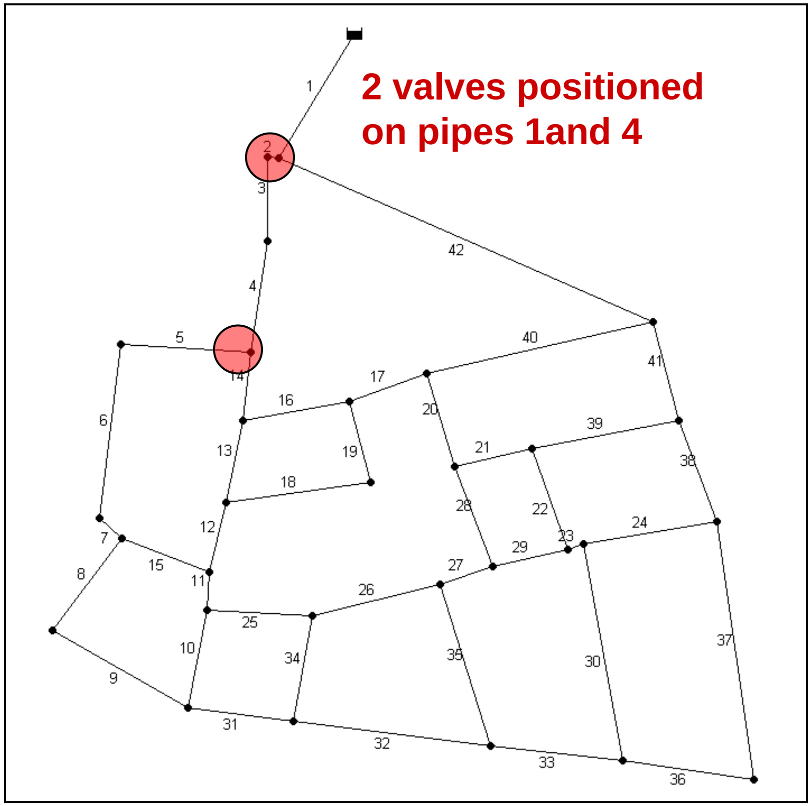
Phase 01 – n° Valves = 2

- Network configuration:

- Valves n° = 2

- $$\sum_{1}^{30} p_i =$$

ORE 03:00	ORE 06:00	ORE 07:00	ORE 09:00
1177.00 mt	926.71 mt	565.12 mt	490.43 mt



Average percentage of loads reduction: 44 %

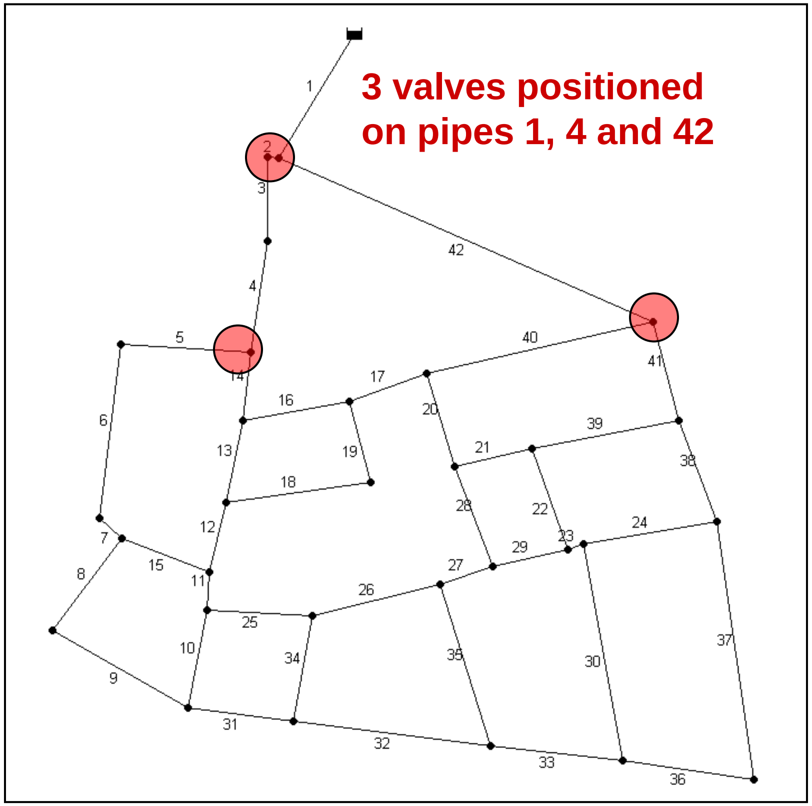
Phase 01 – n° Valves = 3

- Network configuration:

- Valves n° = 3

- $\sum_{1}^{30} p_i =$

ORE 03:00	ORE 06:00	ORE 07:00	ORE 09:00
905.13 mt	569.31 mt	583.68 mt	460.23 mt



Average percentage of loads reduction: 54 %

Phase 01 – n° Valves = 4

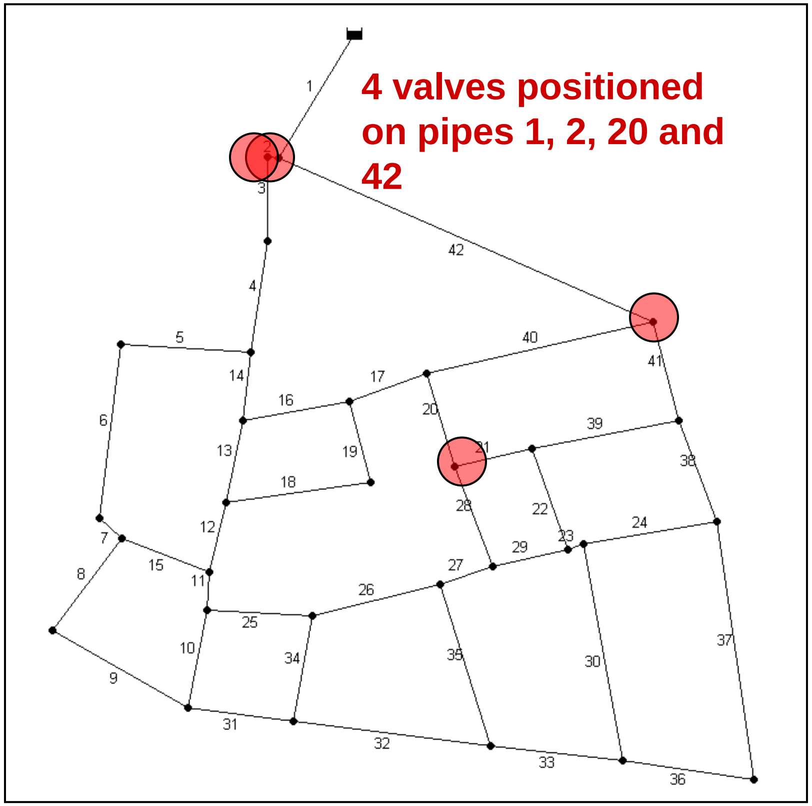
- Network configuration:

- Valves n° = 4

- $\sum_{1}^{30} p_i =$

ORE 03:00	ORE 06:00	ORE 07:00	ORE 09:00
835.63 mt	659.66 mt	475.09 mt	465.04 mt

Average percentage of loads reduction: 56 %



Phase 01 – Summary

The following table highlights the network total pressures at 4 different time shifts taken into account:

- The percentage trend of the losses reduction decreases with the increasing of the valves number, showing plateau trend
- The optimum valves number to be introduced is equal to 4, positioned on pipes 1, 2, 20 and 42

		03:00	06:00	07:00	09:00	Average Pressure / *Average Reduction*
0 Valves	Pression (mt)	1658.60	1543.10	1222.20	1065.40	1372.33
	% Reduction	*0 %*	*0 %*	*0 %*	*0 %*	*0 %*
1 Valve	Pression (mt)	1287.80	1070.10	796.16	864.67	1004.68
	% Reduction	*22 %*	*30 %*	*35 %*	*18 %*	*26 %*
2 Valves	Pression (mt)	1177.00	926.71	565.12	490.43	789.82
	% Reduction	*29 %*	*40 %*	*53 %*	*54 %*	*44 %*
3 Valves	Pression (mt)	905.13	569.31	583.68	460.23	629.59
	% Reduction	*45 %*	*63 %*	*52 %*	*57 %*	*54 %*
4 Valves	Pression (mt)	835.63	659.66	475.09	465.04	608.86
	% Reduction	*49 %*	*57 %*	*61 %*	*56 %*	*56 %*

Phase 02

Phase 02 – Description

Phase_02 → looking for the best opening degrees for the optimum configuration coming from Phase_01 for every scenario

- Input Variables: valves opening degree (0, 5, 10, 15, 20, 30, 50, 95 %)

- Output Variables: nodes pressure

- Objective Functions: minimize network loads sum for every given scenario

- Constraints: prevalence on nodes encompassed in the range of 10 – 70 m (service conditions)

NOTE: modeFRONTIER workflow remains the same one (IV switched to constants)

Phase 02 – Summary Results

- Optimization process
  - DOE: from 20 to 50 SOBOL designs, depending on valves number
  - Optimization Algorithm: MOGA II (Multi-Objective Genetic Algorithm)

- Depending on the valves number, the optimization process convergence has taken from circa 1200 designs (2 hrs analysis time, 4 valves) to a number of 8 designs (1 valve)

- Optimization is mono-objective, being the valves opening degree definition the only requirement (but multiple pressure constraints management)

- Results ➔ the performance are almost the same vs. Phase_01's, so the 1st optimization has been performed efficiently

Phase 02 – Summary Results

- Optimization process

		03:00	06:00	07:00	09:00	Average Pressure / *Average Reduction*
0 Valves	Pression (mt)	1658.60	1543.10	1222.20	1065.40	1372.33
	% Reduction	*0%*	*0%*	*0%*	*0%*	*0%*
1 Valve	Pression (mt)	1287.80	1070.10	796.16	864.67	1004.68
	% Reduction	*22%*	*30%*	*35%*	*18%*	*26%*
2 Valves	Pression (mt)	1177.00	926.71	565.12	490.43	789.82
	% Reduction	*29%*	*40%*	*53%*	*54%*	*44%*
3 Valves	Pression (mt)	811.28	569.31	537.51	460.23	594.58
	% Reduction	*51%*	*63%*	*56%*	*57%*	*57%*
4 Valves	Pression (mt)	644.99	659.66	472.24	459.94	559.21
	% Reduction	*61%*	*57%*	*61%*	*57%*	*59%*

- Results ➔ the performance are almost the same vs. Phase_01's, so the 1st optimization has been performed efficiently

Phase 03

Phase 03 – Description

- Phase_03 → looking for the more robust solutions in respect of the non-deterministic parameters → variables subject to a probabilistic distribution represent an important problem for the system performances

- A stochastic distribution has been assigned to those variables with oscillating values in time or with an unknown value at all

- This phase has been carried out through the MORDO (Multi Objective Robust Design Optimization) module available into modeFRONTIER → it allows to carry out optimization analyses, searching for the solutions which are least sensible to some given stochastic parameters

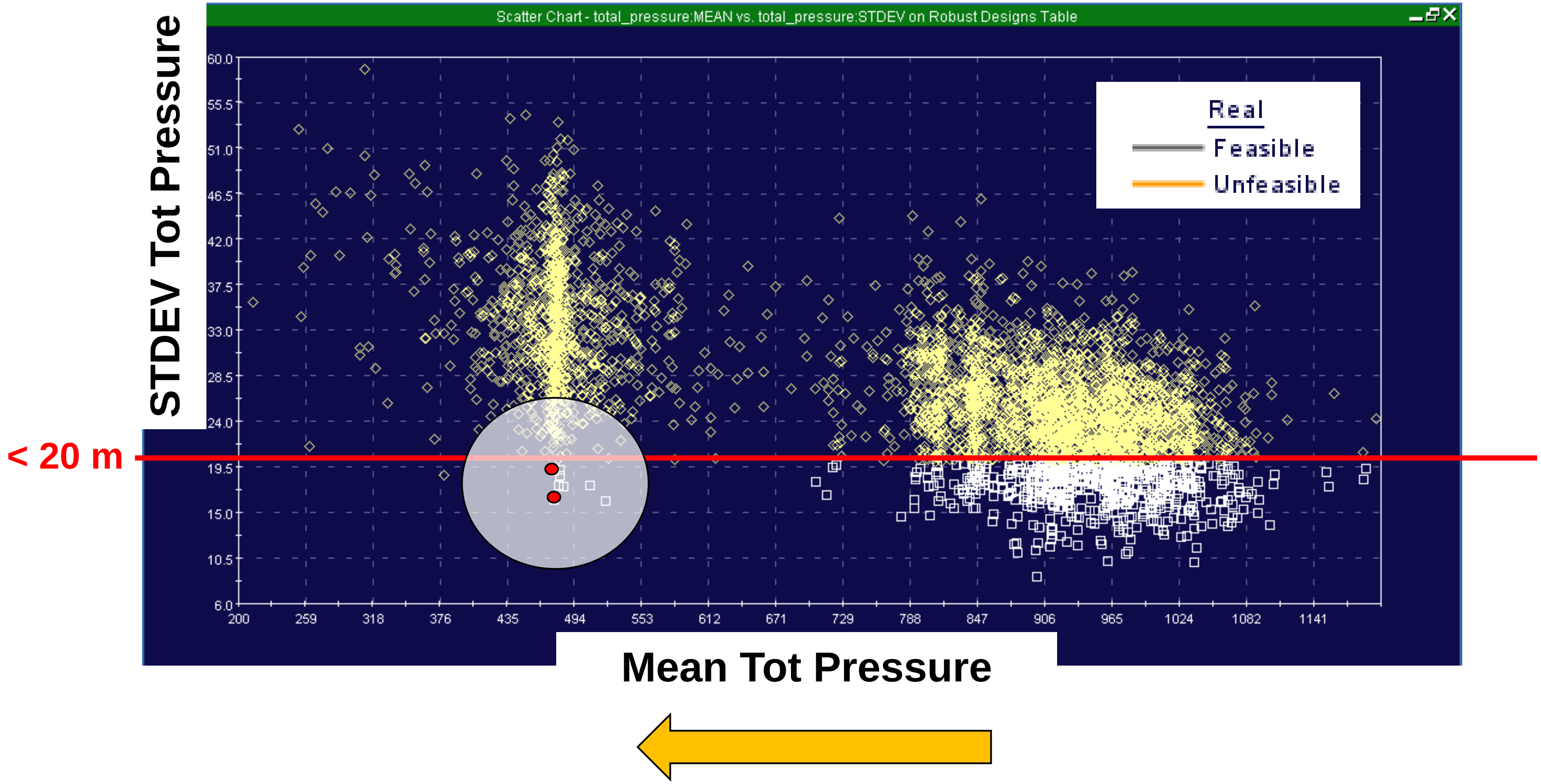
Phase 03 – Description

- The 4 valves – 9:00 a.m. scenario has been investigated, since that is the time frame with the highest demands → highest probability of demands variations. Following are the project parameters:
  - stochastic input variables: nodes demand and pipes roughness, with a definition domain comprehended in a range of 10 % of the associated nominal value. A Gauss Distribution sampling of 15 values has been given to every nominal value
  - deterministic input variables: valves opening degree (0, 5, 10, 15, 20, 30, 50, 95 %)
  - output variables: nodes pressure
  - objectives: minimizing the mean value of the network prevalence sum, calculated on the 15 designs associated to the normal distribution
  - constraints: prevalence on nodes encompassed in the range of 10 – 70 m (service conditions) and pressures standard deviation < 20 m
- Optimization Process → 50 SOBOL + MOGA II

  Convergence has taken circa 4000 designs (7 hrs CPU time)

Phase 03 – Looking for Best Results

- Scatter Chart → Standard Deviation of Tot Pressure vs. Mean Tot Pressure



Phase 03 – Looking for Best Results

- Phase_03 ➔ Optimum Configurations: id 2934, id 4157

These tables show the configurations of the 2 optimal solutions highlighted in the previous chart.

4 VALVES - 09:00 Scenary (Des. 2934)		
Valve n.	Position	Open Degree
1	Pipe 01	10%
2	Pipe 02	50%
3	Pipe 20	10%
4	Pipe 42	Closed
Total Mean Pressure (mt):		475.74
Standard Deviation (mt):		19

4 VALVES - 09:00 Scenary (Des. 4157)		
Valve n.	Position	Open Degree
1	Pipe 01	10%
2	Pipe 02	50%
3	Pipe 20	5%
4	Pipe 42	Closed
Total Mean Pressure (mt):		475.88
Standard Deviation (mt):		16

The 2 solutions reached both a pressure mean value very similar to Phase_02 values, and a standard deviation good “enough” to assure them to be robust solutions.

Phase 03 – Results Comparison vs. Phase 02

- Phase_03 ➔ checking robustness of Phase_02 best solution ➔ by comparing Phase_02 and Phase_03 results, it has been easy to point out similarities ➔ Phase_02 optimal solution, id 4120, becomes more robust by simply modifying the opening degree of one of its 4 valves (positioned on pipe 20) ➔ id 4157

4 VALVES - 09:00 Scenary (Des. 4120)		
Valve n.	Position	Open Degree
1	Pipe 01	10%
2	Pipe 02	50%
3	Pipe 20	Closed
4	Pipe 42	Closed
Total Mean Pressure (mt):		473.48
Standard Deviation (mt):		37

Phase_02 optimum configuration

4 VALVES - 09:00 Scenary (Des. 4157)		
Valve n.	Position	Open Degree
1	Pipe 01	10%
2	Pipe 02	50%
3	Pipe 20	5%
4	Pipe 42	Closed
Total Mean Pressure (mt):		475.88
Standard Deviation (mt):		16

Phase_03 optimum configuration

Summary

- A fully automatized procedure has been implemented by integrating freeware EPANet 2 hydraulic software tool into modeFRONTIER

- A Multi-Objective optimization has been performed taking into account multiple and several free parameters. The results coming from provide the best trade-off solutions (Pareto Solutions), so the more suitable configurations can be selected according its own requirements

- Robustness of the solutions has been evaluated in respect of typical stochastic parameters of water hydraulic networks