AquatorGA: Integrated optimisation for reservoir operation using Multiobjective Genetic Algorithms

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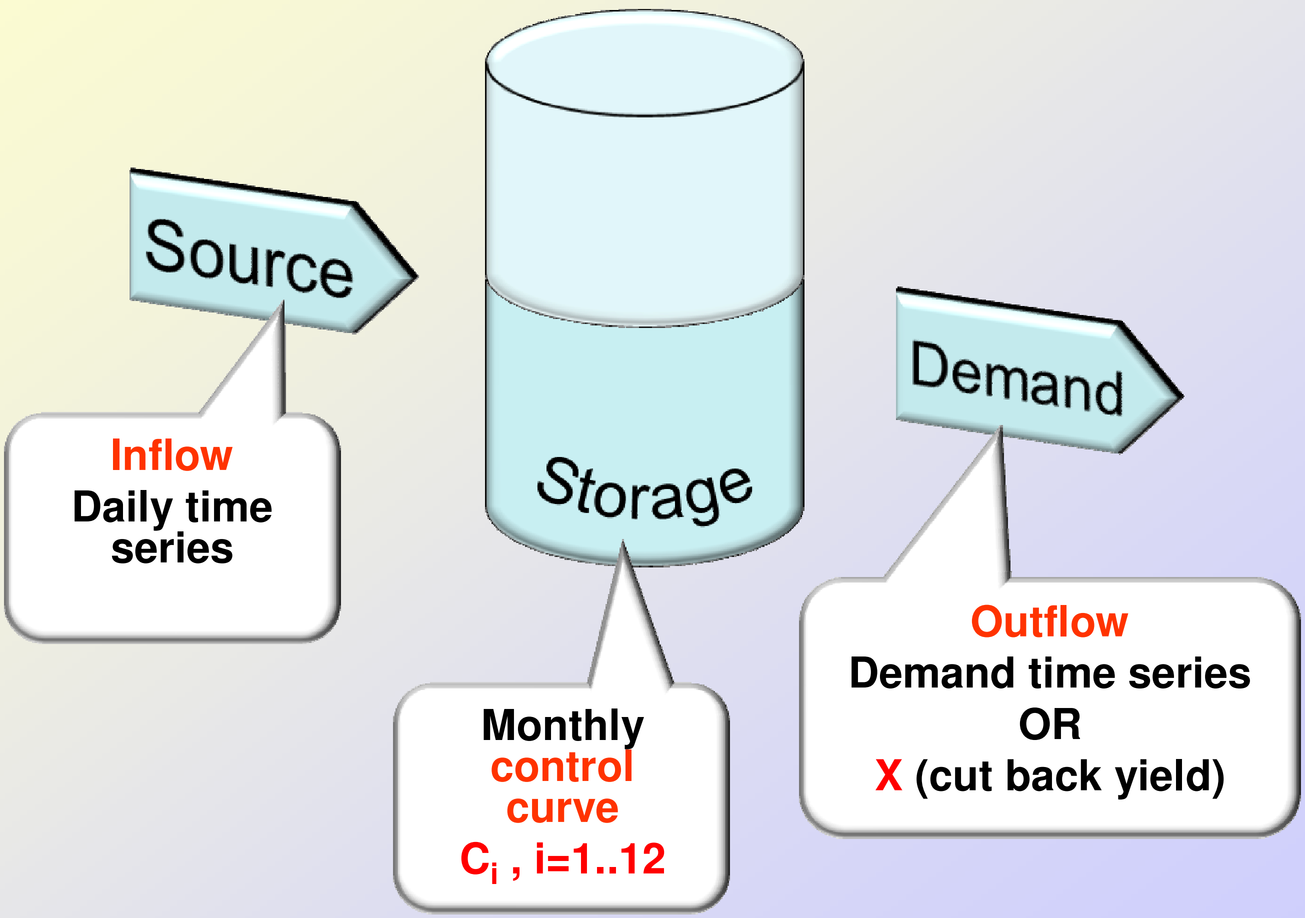
What is this presentation about?

- AQUATOR: (OXSCISOFT)
  - ❑Water supply system simulation software
  - ❑In use by several UK water companies
- Genetic Algorithms (GA): (University of Exeter-CWS)
  - ❑Genetic Algorithms software for optimisation (generic software)
- Project Objective: Linking and integrating GA and AQUATOR, applying them for the optimisation of single and multiple reservoir systems →AquatorGA
  - ❑3 case studies (2 single + 1 multiple reservoirs)

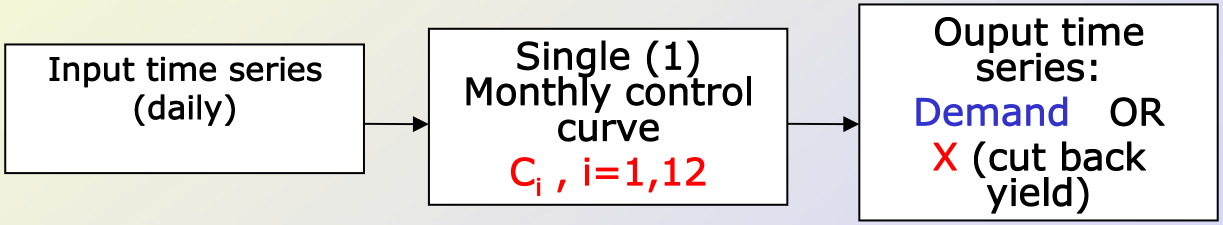
History of the project

- Single reservoir system optimisation project with UU
  - Presented at the previous annual meeting (September Stirling 2008)
  - December 2008-Completed
  - Successful
  - AquatorGA installed at UU (2 test case studies)
- Since then
  - Moving to multiple reservoir systems
  - Scottish Method for Deployable Output added
  - Fife system (3 reservoirs)
  - To be presented today…

Single reservoir system

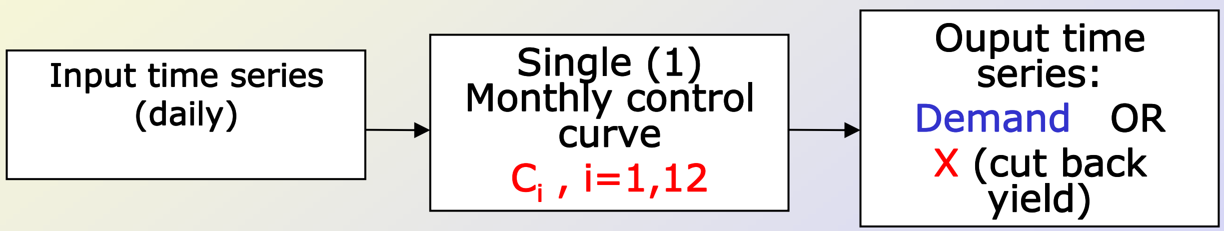


Single reservoir system



- Single reservoir
- No spills /No energy costs taken into account (gravity fed)
- Target: Maximising yield (water volume) AND No deficits
- Decision variables (Unknowns): X and C_i, i=1,12
- Initial optimal solution given by UU

Single reservoir system



- Control curve (monthly) C_i , i=1,12
- Ci % of max water volume (reservoir capacity)
- If storage > Ci → Outflow= Demand
- If storage < Ci → Outflow= X (cutback yield)
- If storage < minimum → deficit (To be avoided)

Genetic Algorithms (GA)

- Optimisation method suitable
  - For "hard" problems (non-linear/discrete/non convex)
  - For "difficult" decision variables
  - For "strange" constraints
  - For discrete search space/variables
  - For one (single) or more (multi-) objective problems
  - Directed random search
- Based on Darwinian evolution principles ("Survival of the fittest")
- Solutions can be reproduced (repeatable)

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Optimising using Genetic Algorithms

- Decision variables (unknowns): (Multiple control curves now possible)
  - X (cutback yield)
  - Ci, i=1,12 (monthly control curve components)
- Total: 13 unknowns = string of 13 decision variables for 1 control curve
- 13*2=26 unknowns = string of 26 decision variables for 2 control curves, …3*13=39 for 3 control curves….
- All in one step!
- AND being able to include desirable shape constraints…
- AQUATOR (simulator) treated as "black box"

Objectives for the shape of the control curve

- Smooth curve
- Magnitude of change in consecutive months → *DC*
- *Objective: minimising DC*

- OR

- "Steady" curve
- Number of changes in a year> significant *step* → *NC*
- *Objective: minimising NC*

Multi-objective GA for single reservoir system

➢Objective function (1): max V (Yield/total Water Volume supplied water over the simulation period)

➢AND

➢Objective function (2): min NC (number of changes in the control curve in a year)

➢OR

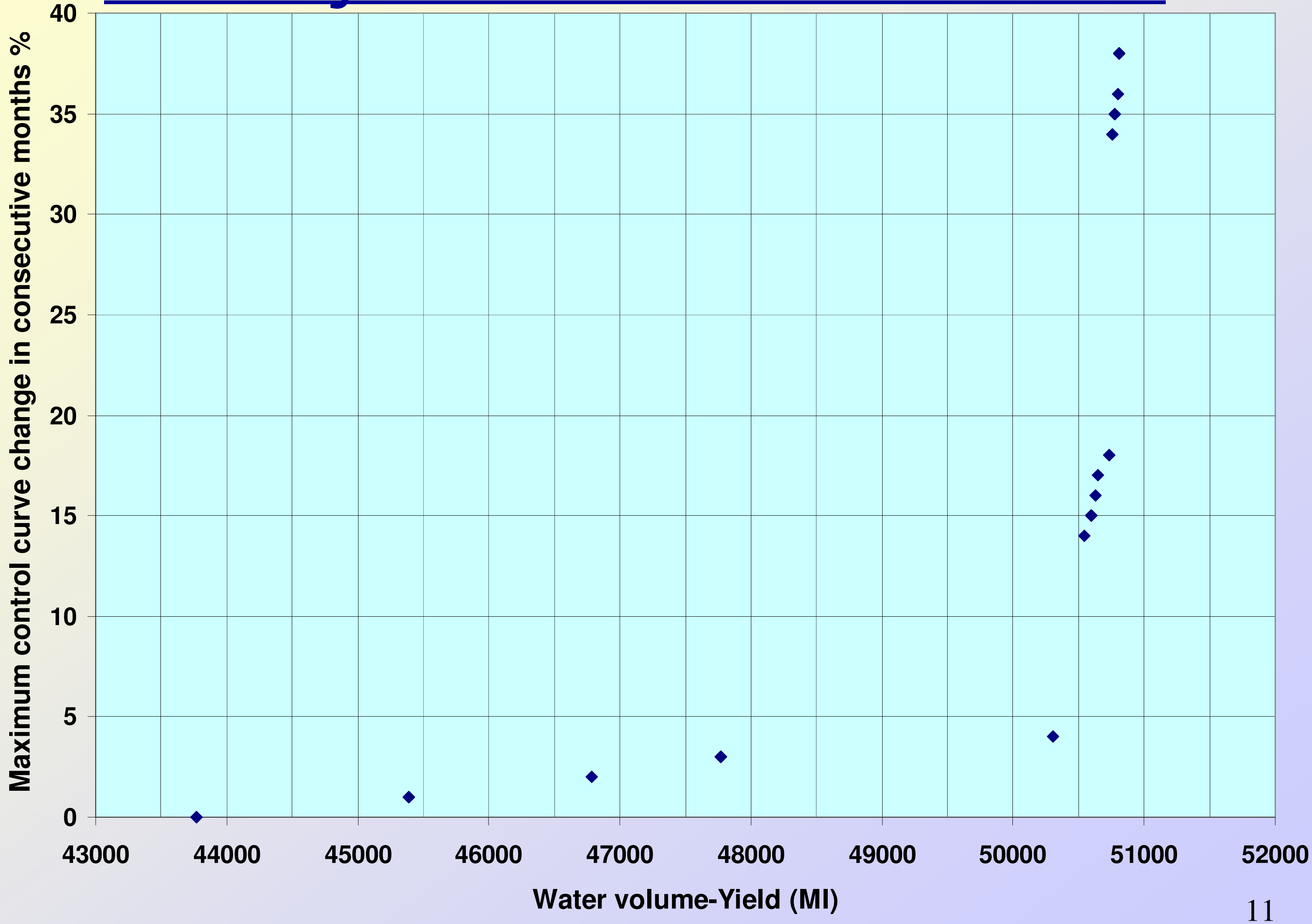
➢Objective function (3): min DC (magnitude of changes in the control curve for consecutive months)

➢Constraints: No supply deficits (SD=0) / failures (NF=0), limits to the number of changes in a year, control curve discretisation step… (any other)

➢No single winner: Multiple optimal solutions

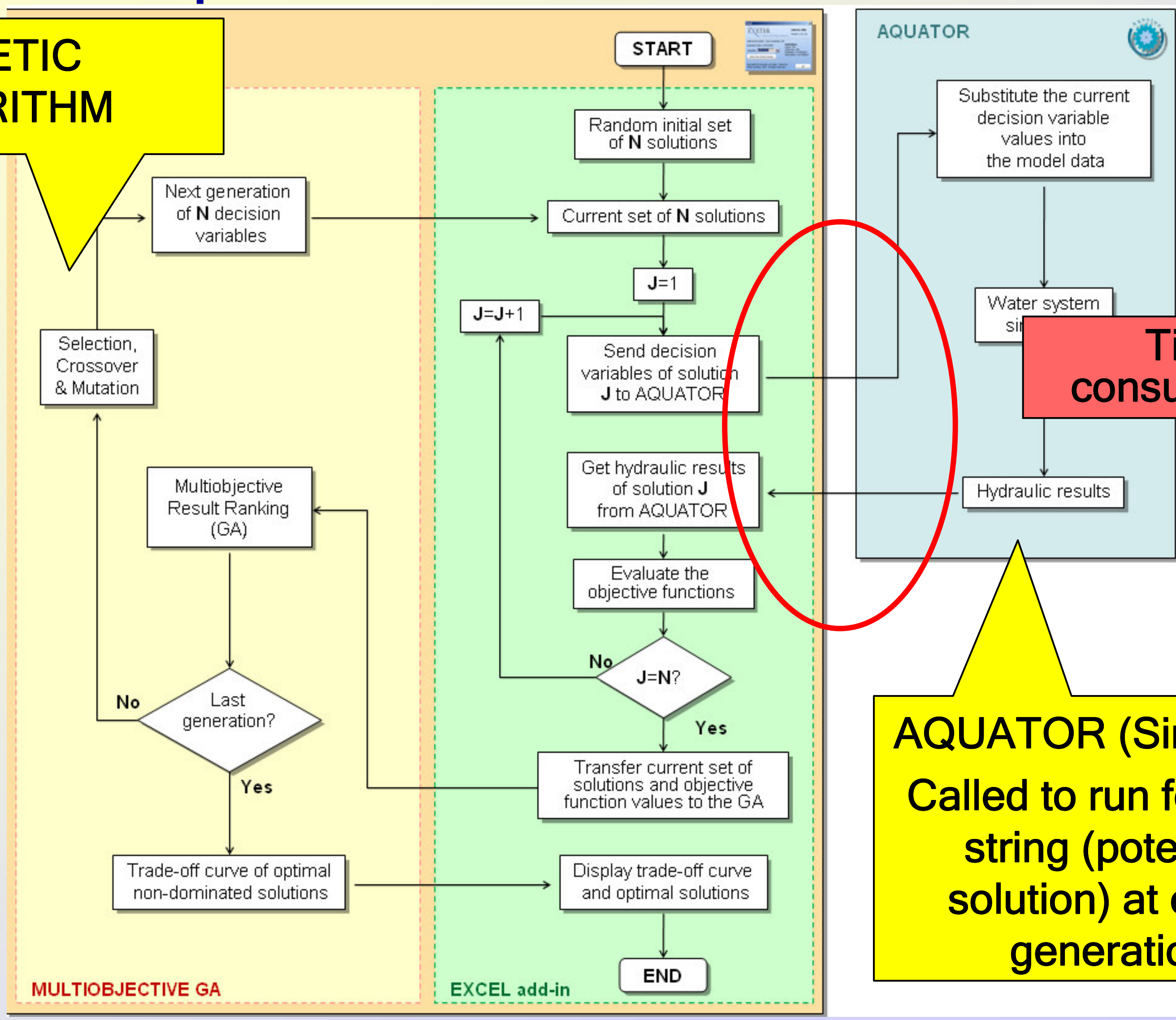
•Trade-off curve of non-inferior solutions (Pareto points)

Multiobjective GA-Trade-off curve



Implementation Structure

GENETIC ALGORITHM



Time consuming!!!

AQUATOR (Simulator)
Called to run for each string (potential solution) at every generation

AquatorGA

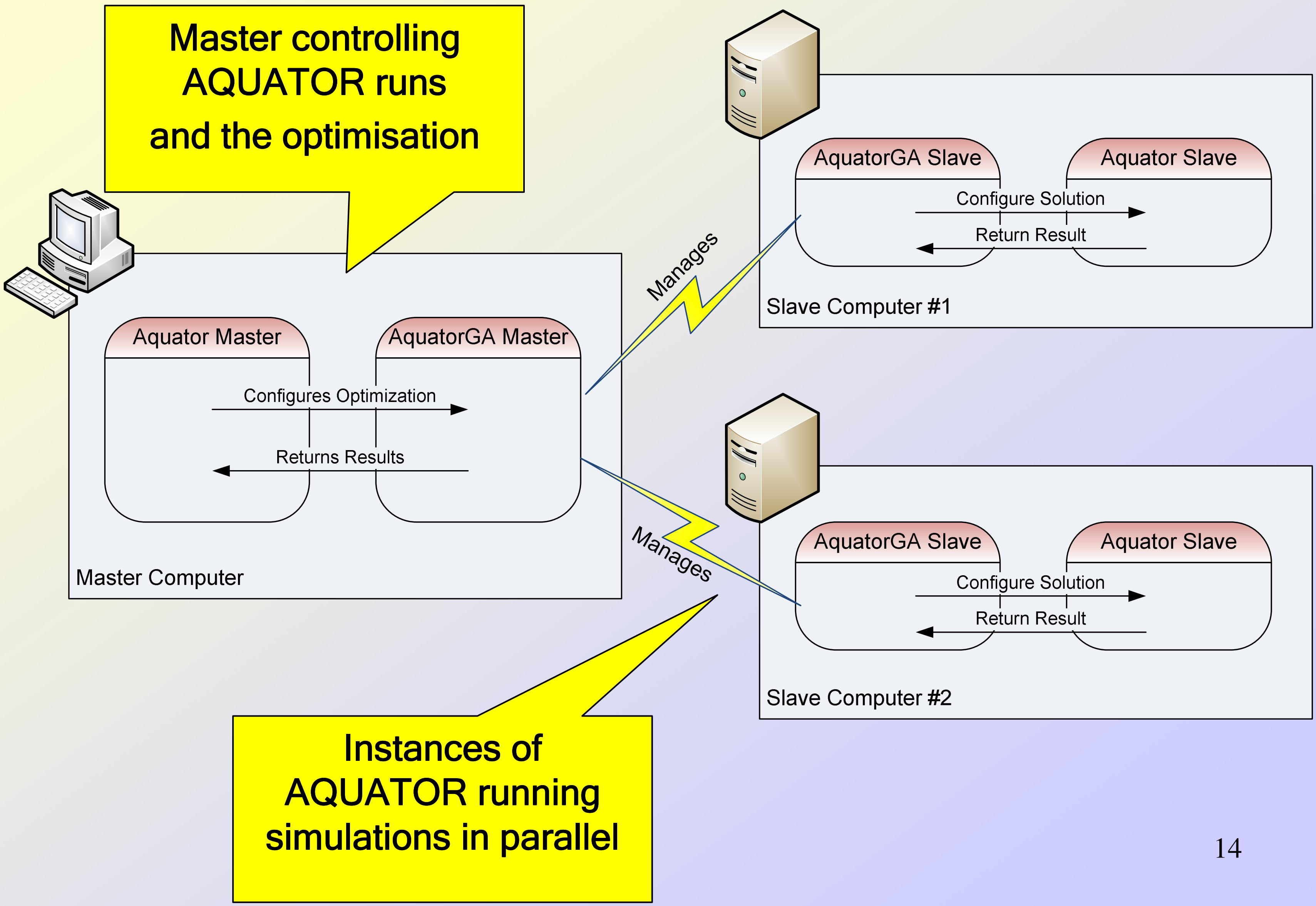
Problem:

- Runtime needed (thousands of generations/AQUATOR simulations) → distribution to computers in parallel

AND Reducing the time by

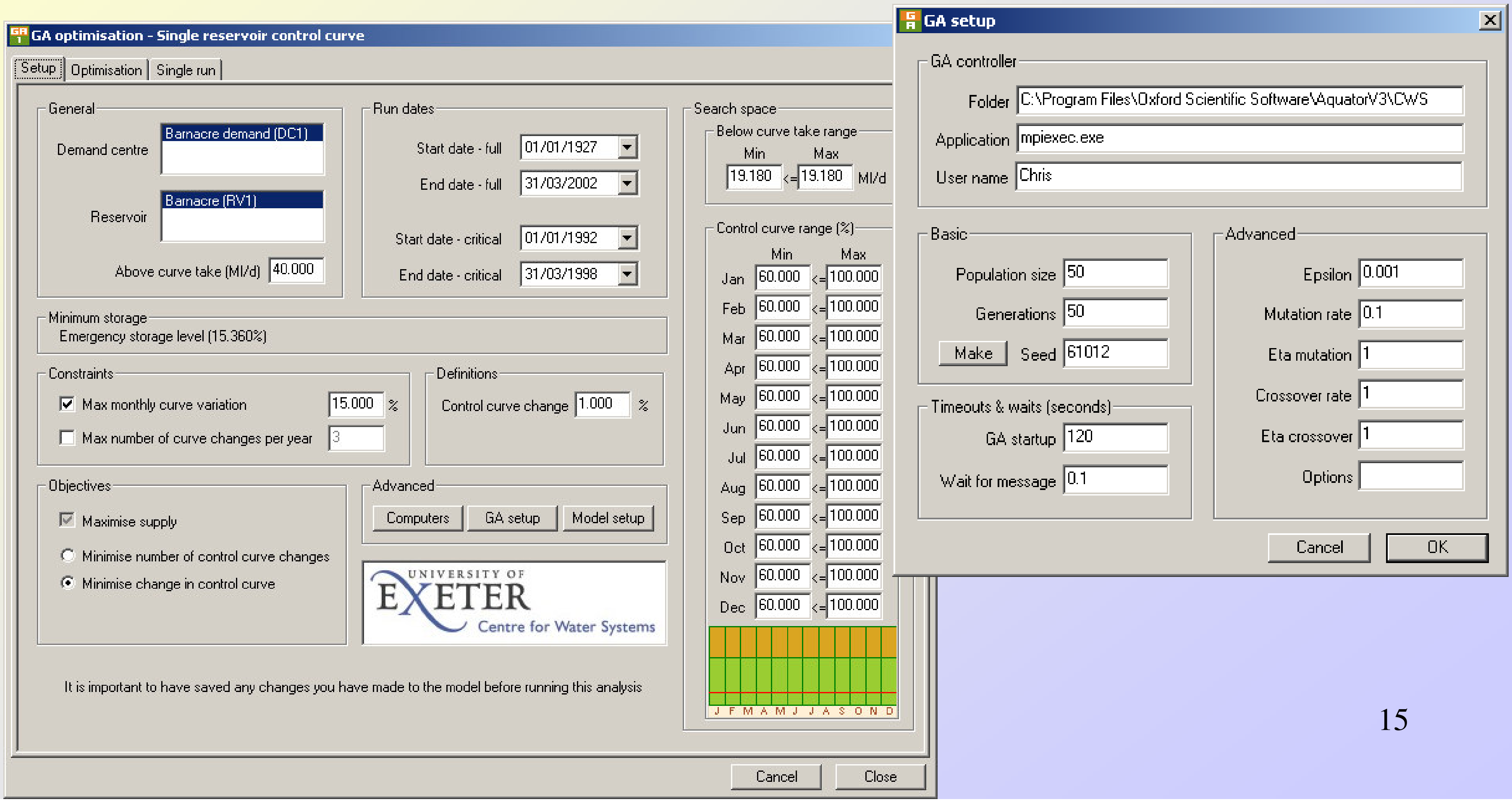
- Critical period concept
  - Optimising for a short critical period
  - Validating for full period
- Improving the GA …
  - Improving the algorithm
  - Larger population (100-250)
  - ‘Near optimal’ results in 150-300 generations (instead of 3000) in under 1 hour for a single reservoir system

Distributed computing for AquatorGA

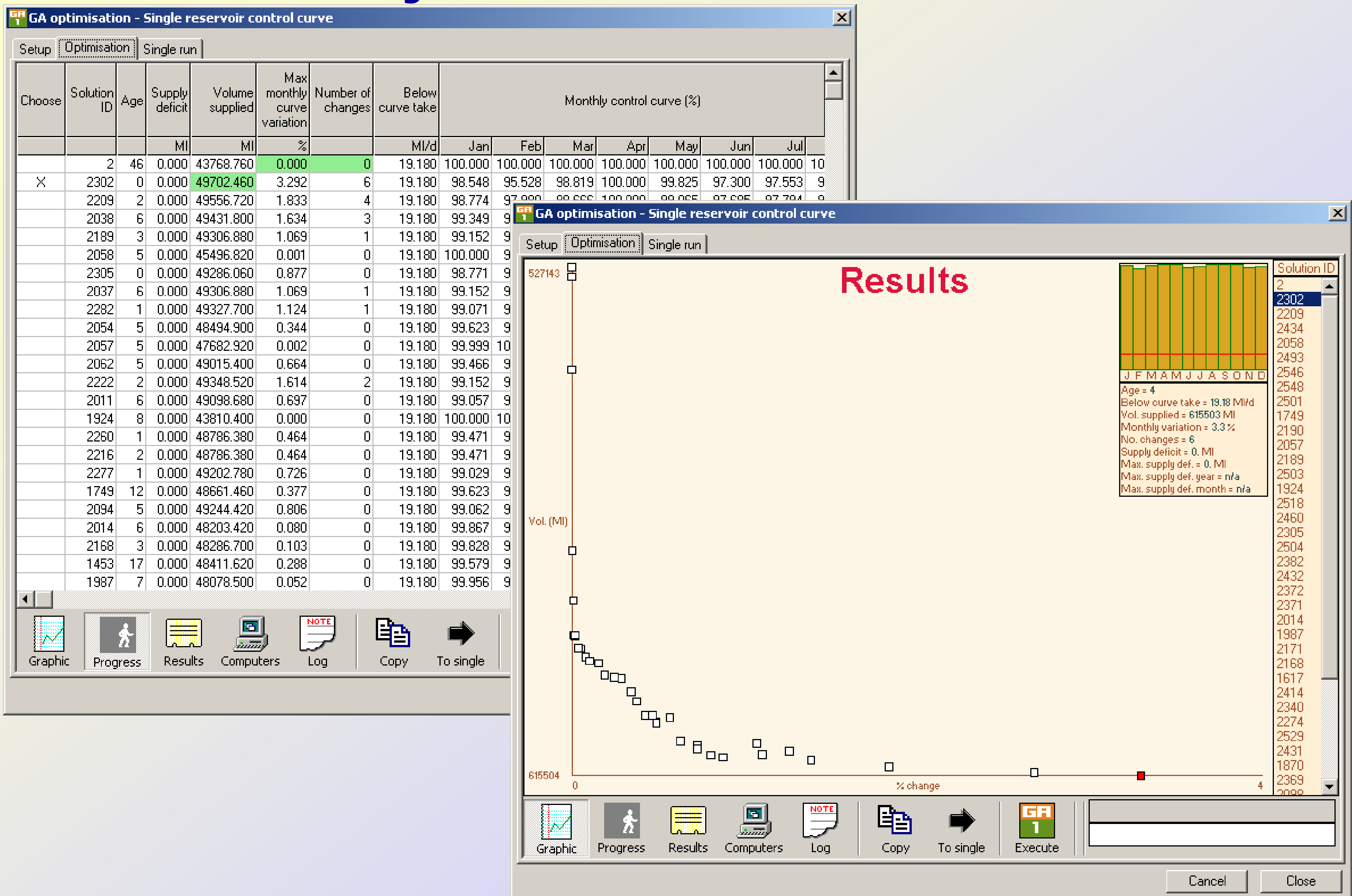


AquatorGA - Integration

- GA Optimisation developed as add-in to AQUATOR
- Activated through AQUATOR (AquatorGA)
- Optimisation set up by the user (menus in AQUATOR)

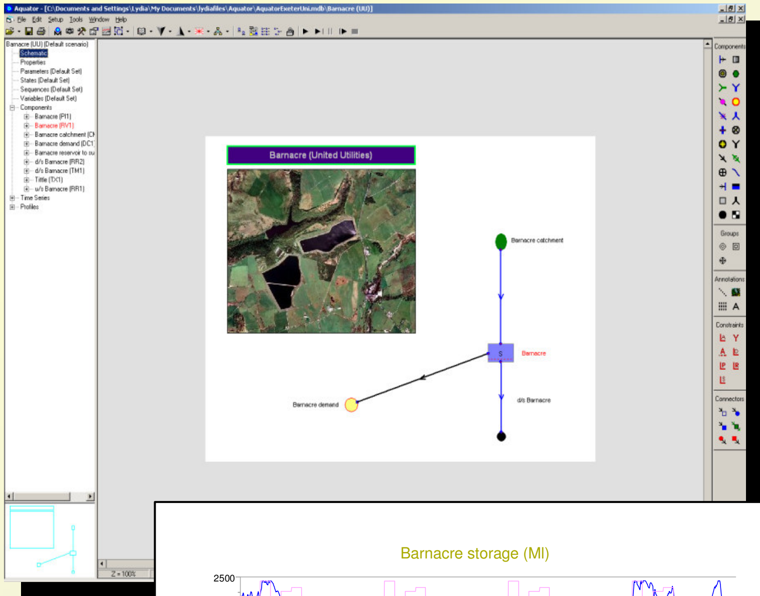


Multiobjective GA-Trade-off curve



Choose	Solution ID	Age	Supply deficit	Volume supplied	Max monthly curve variation	Number of changes	Below curve take	Monthly control curve (%)							
			Ml	Ml	%		Ml/d	Jan	Feb	Mar	Apr	May	Jun	Jul	
	2	46	0.000	43768.760	0.000	0	19.180	100.000	100.000	100.000	100.000	100.000	100.000	100.000	10
X	2302	0	0.000	49702.460	3.292	6	19.180	98.548	95.528	98.819	100.000	99.825	97.300	97.553	9
	2209	2	0.000	49556.720	1.833	4	19.180	98.774							
	2038	6	0.000	49431.800	1.634	3	19.180	99.349	9						
	2189	3	0.000	49306.880	1.069	1	19.180	99.152	9						
	2058	5	0.000	45496.820	0.001	0	19.180	100.000	9						
	2305	0	0.000	49286.060	0.877	0	19.180	98.771	9						
	2037	6	0.000	49306.880	1.069	1	19.180	99.152	9						
	2282	1	0.000	49327.700	1.124	1	19.180	99.071	9						
	2054	5	0.000	48494.900	0.344	0	19.180	99.623	9						
	2057	5	0.000	47682.920	0.002	0	19.180	99.999	10						
	2062	5	0.000	49015.400	0.664	0	19.180	99.466	9						
	2222	2	0.000	49348.520	1.614	2	19.180	99.152	9						
	2011	6	0.000	49098.680	0.697	0	19.180	99.057	9						
	1924	8	0.000	43810.400	0.000	0	19.180	100.000	10						
	2260	1	0.000	48786.380	0.464	0	19.180	99.471	9						
	2216	2	0.000	48786.380	0.464	0	19.180	99.471	9						
	2277	1	0.000	49202.780	0.726	0	19.180	99.029	9						
	1749	12	0.000	48661.460	0.377	0	19.180	99.623	9						
	2094	5	0.000	49244.420	0.806	0	19.180	99.062	9						
	2014	6	0.000	48203.420	0.080	0	19.180	99.867	9						
	2168	3	0.000	48286.700	0.103	0	19.180	99.828	9						
	1453	17	0.000	48411.620	0.288	0	19.180	99.579	9						
	1987	7	0.000	48078.500	0.052	0	19.180	99.956	9						

1st case study: Barnacre system



- 1st test case study (2006-2008)
- Inflows daily time series 1927-2002
- Optimisation carried out for the critical period (1992-1998) to reduce the computational time for AQUATOR
- Checking (automatically) for the whole period after optimisation
- Several Combinations of objectives tried
- Initial "*Best solution*" provided by UU for comparison

Selected Solutions for Barnacre

1992-1998	Original UU	Smooth curve	Smooth curve	Smooth curve	Min changes	Min changes	Max yield
					1 change	2changes	
max dC%	6.90	1.00	2.00	3.00	13.45	42.28	38.00
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Rate A	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Rate B=X	19.1800	19.12898	19.03226	19.00012	19.18536	19.18536	19.12691
Jan	92.60	97.00	94.00	93.00	86.55	57.72	60.00
Feb	99.50	98.00	96.00	92.00	86.55	57.72	60.00
Mar	100.00	99.00	96.00	95.00	100.00	100.00	98.00
Apr	100.00	100.00	98.00	98.00	100.00	100.00	100.00
May	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun	100.00	100.00	100.00	100.00	86.55	86.55	100.00
Jul	100.00	100.00	100.00	100.00	86.55	86.55	100.00
Aug	100.00	100.00	100.00	100.00	86.55	86.55	100.00
Sep	96.30	100.00	100.00	99.00	86.55	86.55	100.00
Oct	91.50	99.00	98.00	97.00	86.55	86.55	89.00
Nov	88.80	98.00	96.00	94.00	86.55	86.55	74.00
Dec	89.80	98.00	96.00	91.00	86.55	86.55	94.00
Failures	0	0	0	0	0	0	0
Deficit	0	0	0	0	0	0	0
Volume	48203	49580	50288	50330	49297	50796	50807
Volume increase %	0.00	2.86	4.32	4.41	2.27	5.38	5.40

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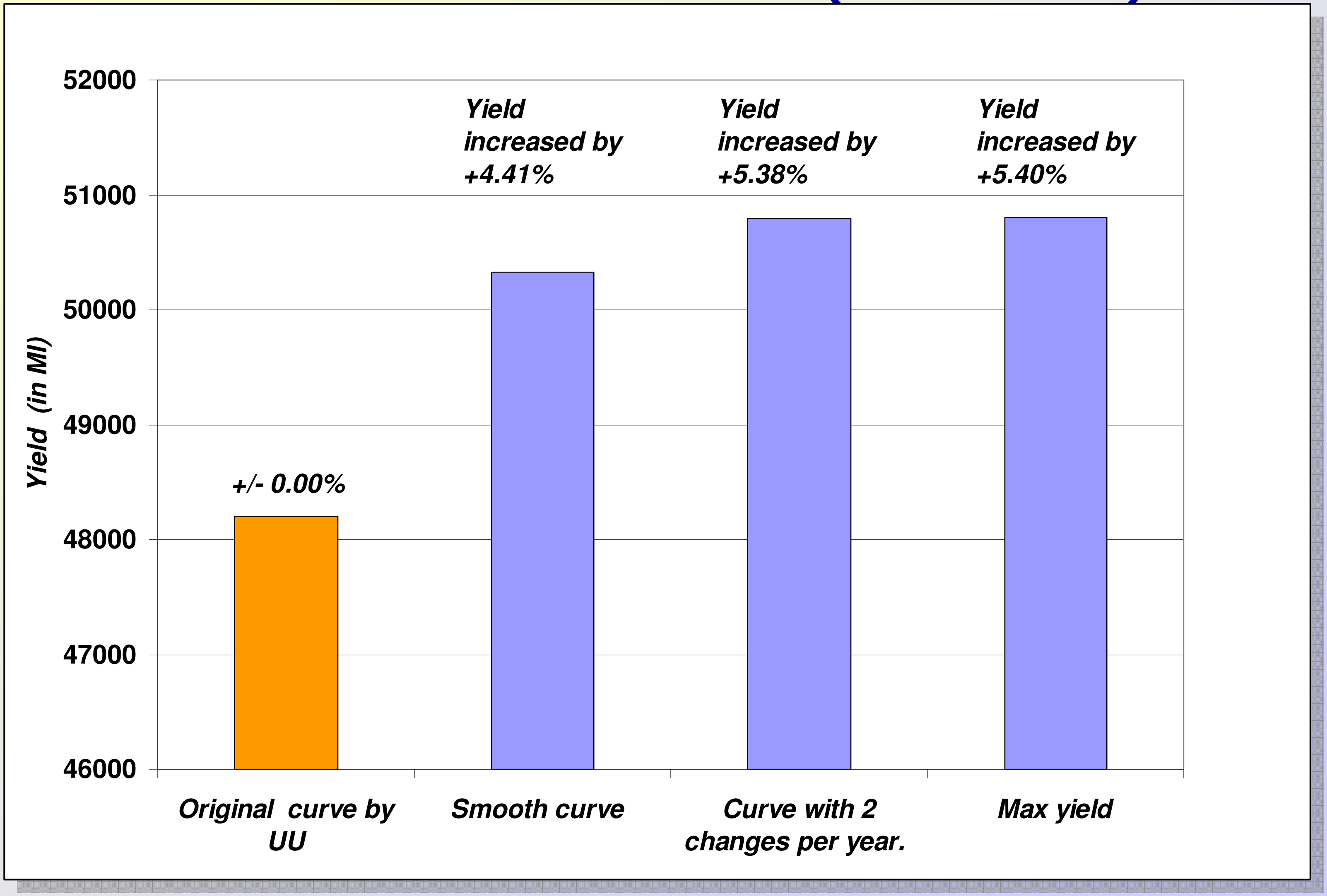
Different control curves (Barnacre)



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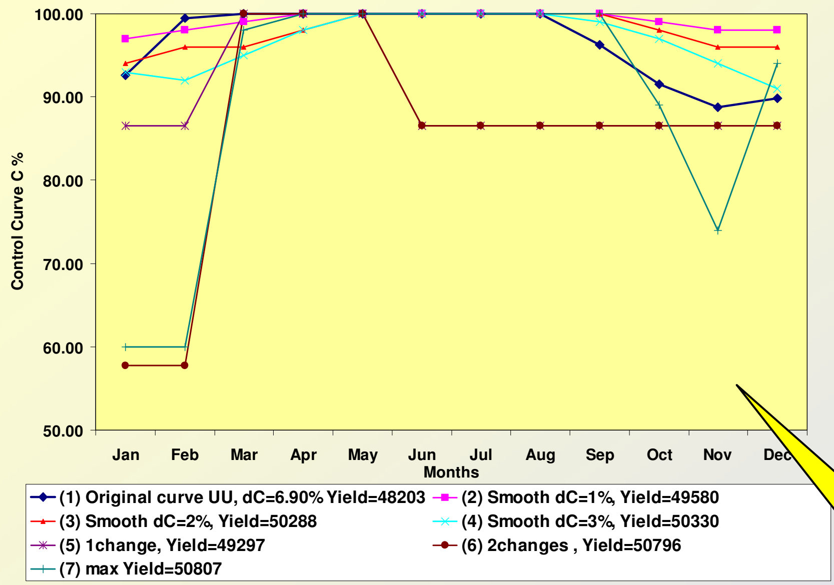
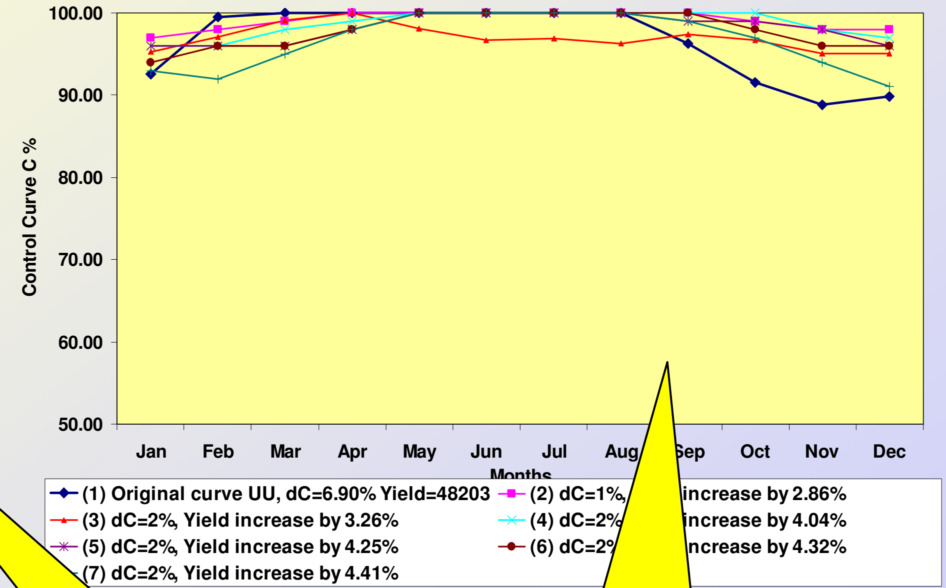
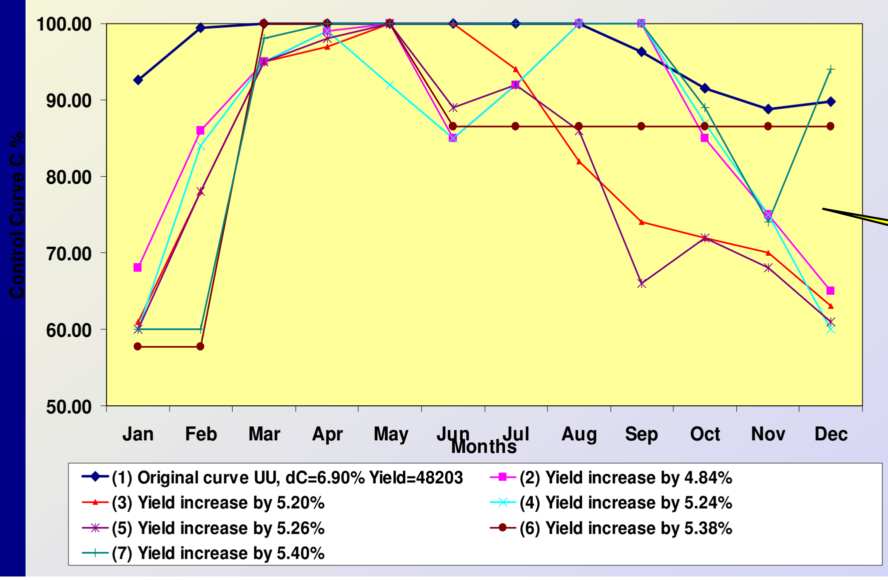


Steady curves

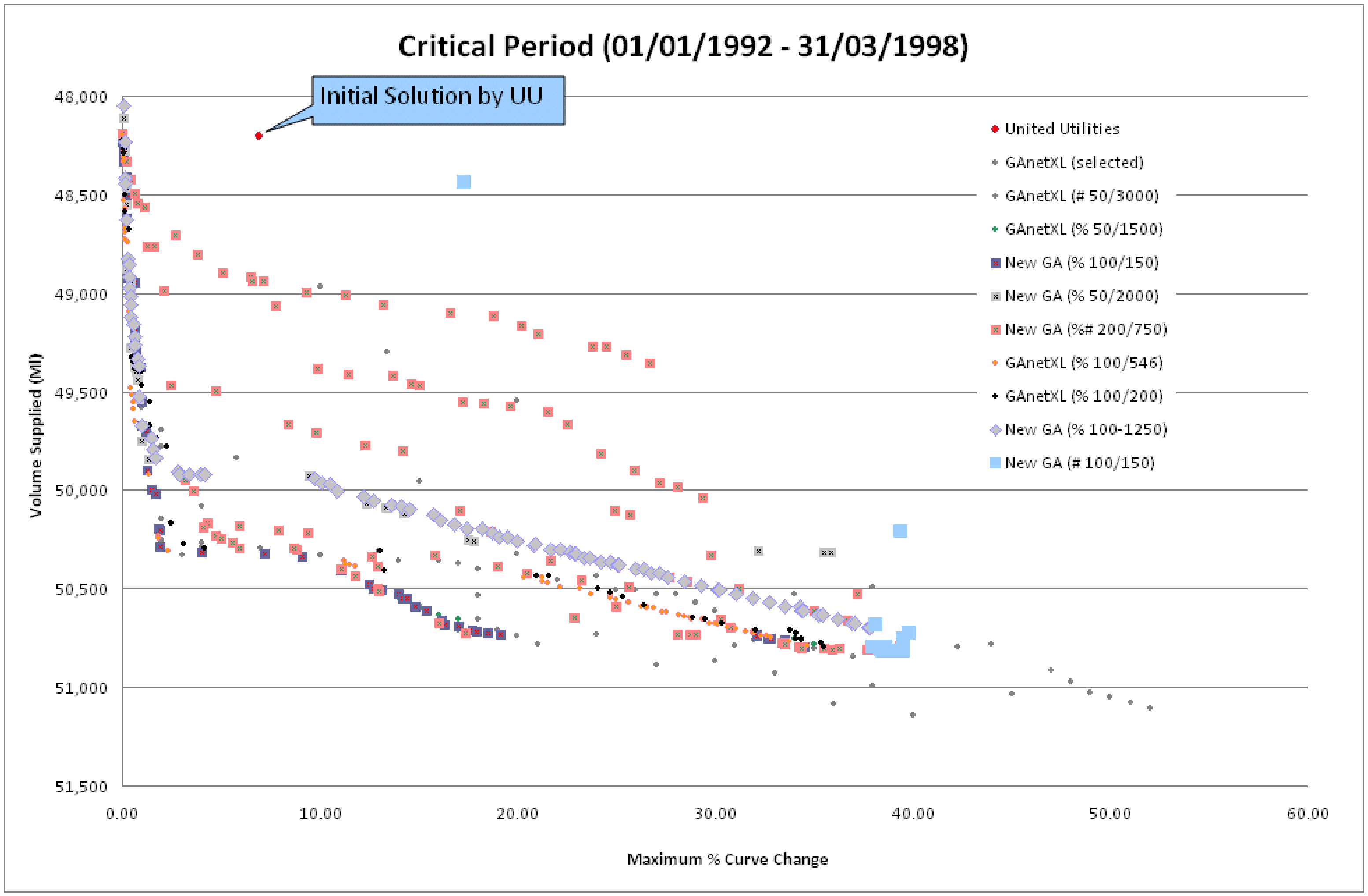


Smooth curves

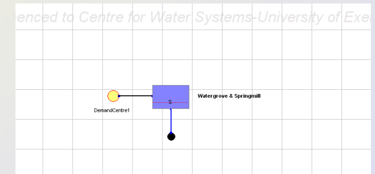


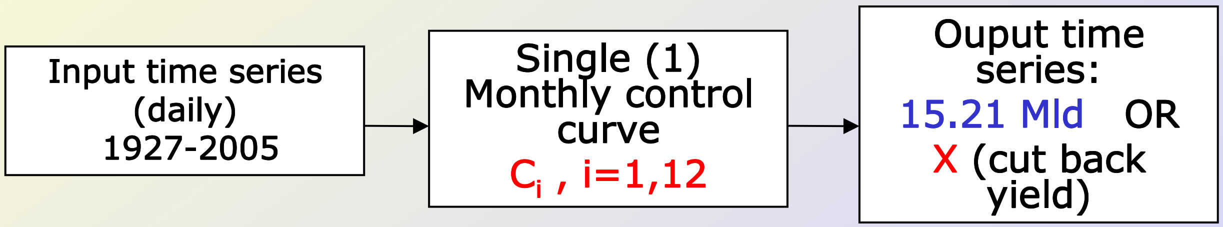
Maximum yield

Multiobjective GA-trade-off curves (Barnacre)



2nd case study: Watergrove & Springmill



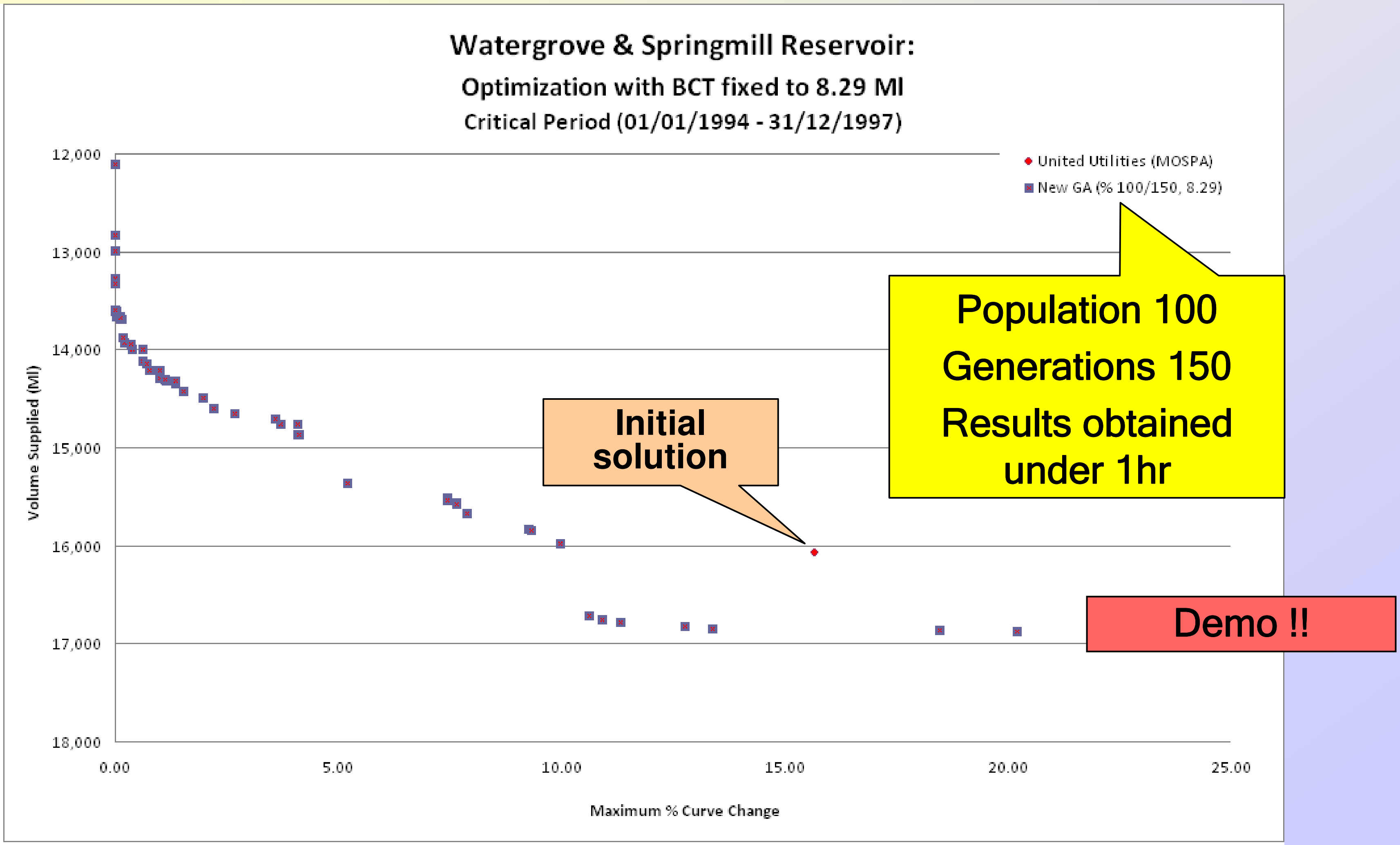


- Single reservoir
- Spills /No energy costs taken into account (gravity fed)
- Target: Maximising yield (water volume) AND No deficits
- Decision variables (Unknowns): X and C_i, i=1,12
- Initial optimal solution given by UU (*X fixed at UU request*)

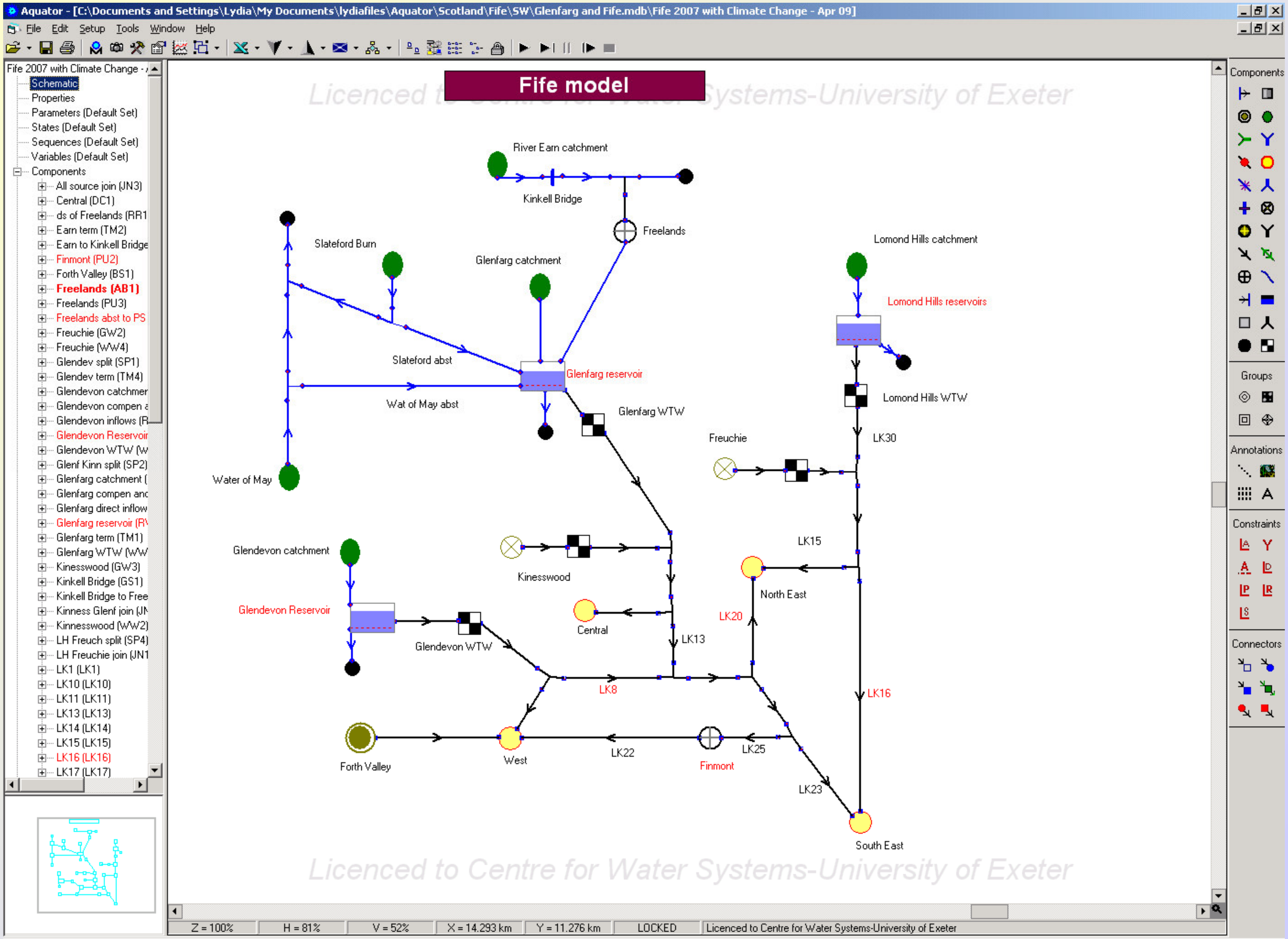
Selected Solutions for W&S

1993-1997	Original UU	Smoother curve	Smoother curve	Smoother curve	Smoother curve	Max yield	Max yield
max dC%	15.67	10.90	11.32	12.77	13.38	18.48	20.21
		(2)	(3)	(4)	(5)	(6)	(7)
Rate A	15.21	15.21	15.21	15.21	15.21	15.21	15.21
Rate B=X	8.2900	8.29000	8.29000	8.29000	8.29000	8.29000	8.29000
Jan	72.24	68.47	68.47	62.60	66.73	51.17	49.37
Feb	84.92	77.89	76.98	69.48	69.26	69.65	69.58
Mar	92.99	84.08	84.08	82.26	82.63	87.68	82.44
Apr	97.16	94.80	94.90	94.96	95.33	95.34	95.33
May	100.00	90.57	91.19	91.19	89.44	89.44	91.23
Jun	98.66	87.55	87.55	87.55	86.25	86.83	84.57
Jul	87.76	76.96	76.24	75.48	76.37	76.28	75.95
Aug	72.09	68.03	66.88	66.94	67.13	66.85	66.85
Sep	60.30	58.35	58.35	58.62	57.45	57.56	57.43
Oct	52.53	55.70	55.70	55.98	54.24	52.85	54.18
Nov	54.77	50.10	50.10	49.94	49.54	49.54	49.54
Dec	61.64	57.57	57.91	57.63	53.76	50.90	58.12
Failures		0	0	0	0	0	0
Deficit		0	0	0	0	0	0
Volume	16077	16748	16783	16824	16852	16866	16880
Volume increase %		4.18	4.39	4.65	4.82	4.91	4.99
Volume full period	371165	390659	391171	391662	392901	392597	393226
Volume increase % full period		5.25	5.39	5.52	5.86	5.77	5.94

Trade-off curve for W&S/Critical period



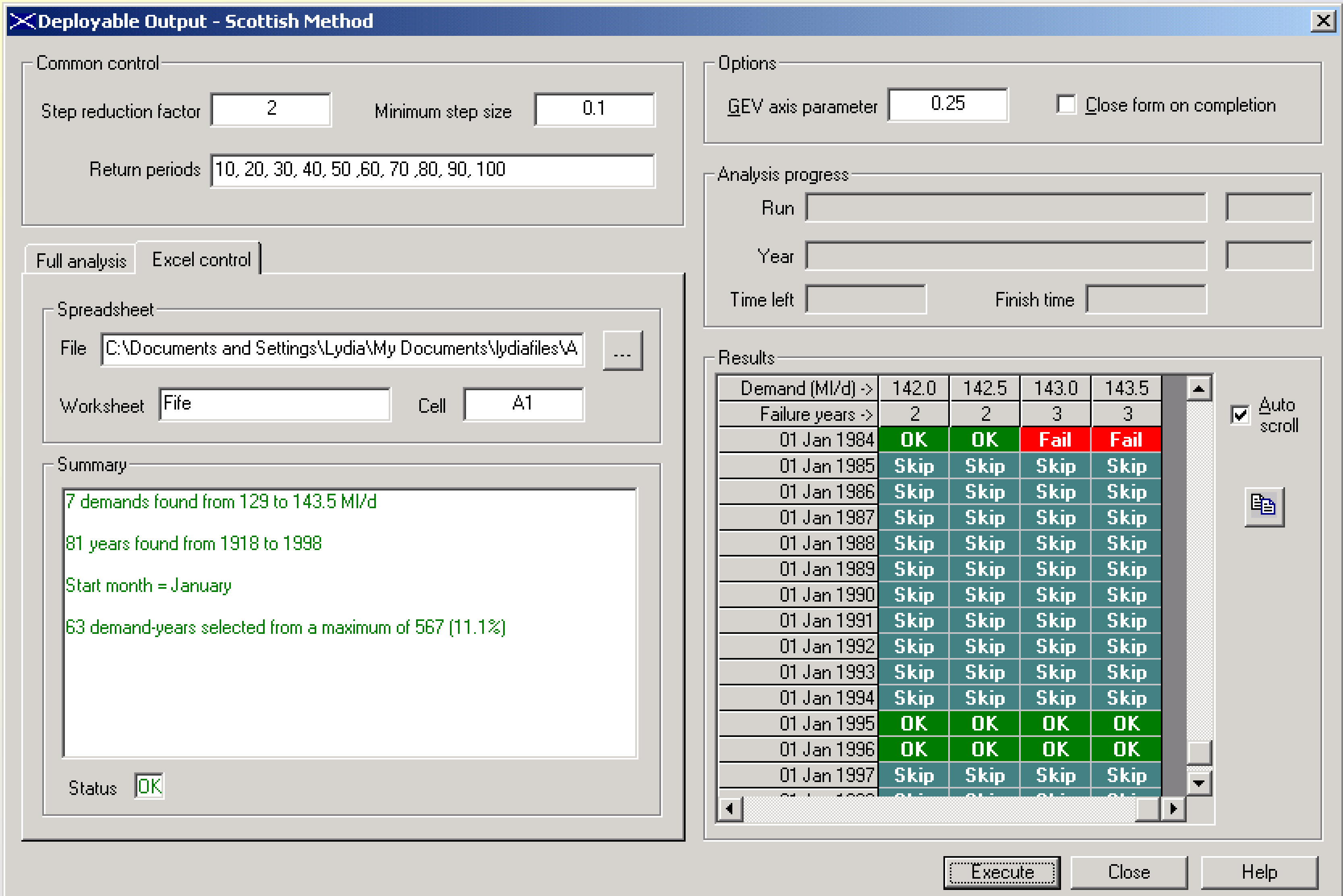
3rd case study: Fife system



Fife system

- 3rd case study: Fife system. Multiple reservoirs (3)
- Three control curves (Ci, i=1,12). In total 3*12=36 decision variables (unknowns)
- Optimisation in one step (Ci simultaneously for all reservoirs), system as a whole
- Daily input time series (1918-1998) 81 years
- Scottish method of Deployable Output (DO) as primary objective (maximise DO) for a return period T=40 years
- Supply Deficits > 0, because DO for T=40 between 2 and 3 years of failure (NF) for N=81 years
- Initial solution provided by OSS for comparison: Deployable Output DO=136.2 Mld -computational step 1 Mld (or 135.9 Mld- computational step 0.5 Mld)

Deployable Output in AQUATOR



Fife system

- Deployable Output (DO) as primary objective (maximise DO)
- →Additional time consuming computations. Testing different demands for the same (Ci) set of potential solutions, in order to compute the DO for T=40 years.
- Optimisation carried out for 9 critical years (non consecutive) to reduce the computational time needed.
- With 9 years, 15-20 min for a single DO simulation to run in AQUATOR, with a computational step of 1Mld for the DO!
- Specific methods to overcome the computational problem for the GA have been adopted, including parallelisation…
- Efficiency of different configurations for the GA and the objective functions have been tried…
- Not a trivial problem: Days or weeks to run for a single optimisation… (10 days in July, down to 36 hours now)

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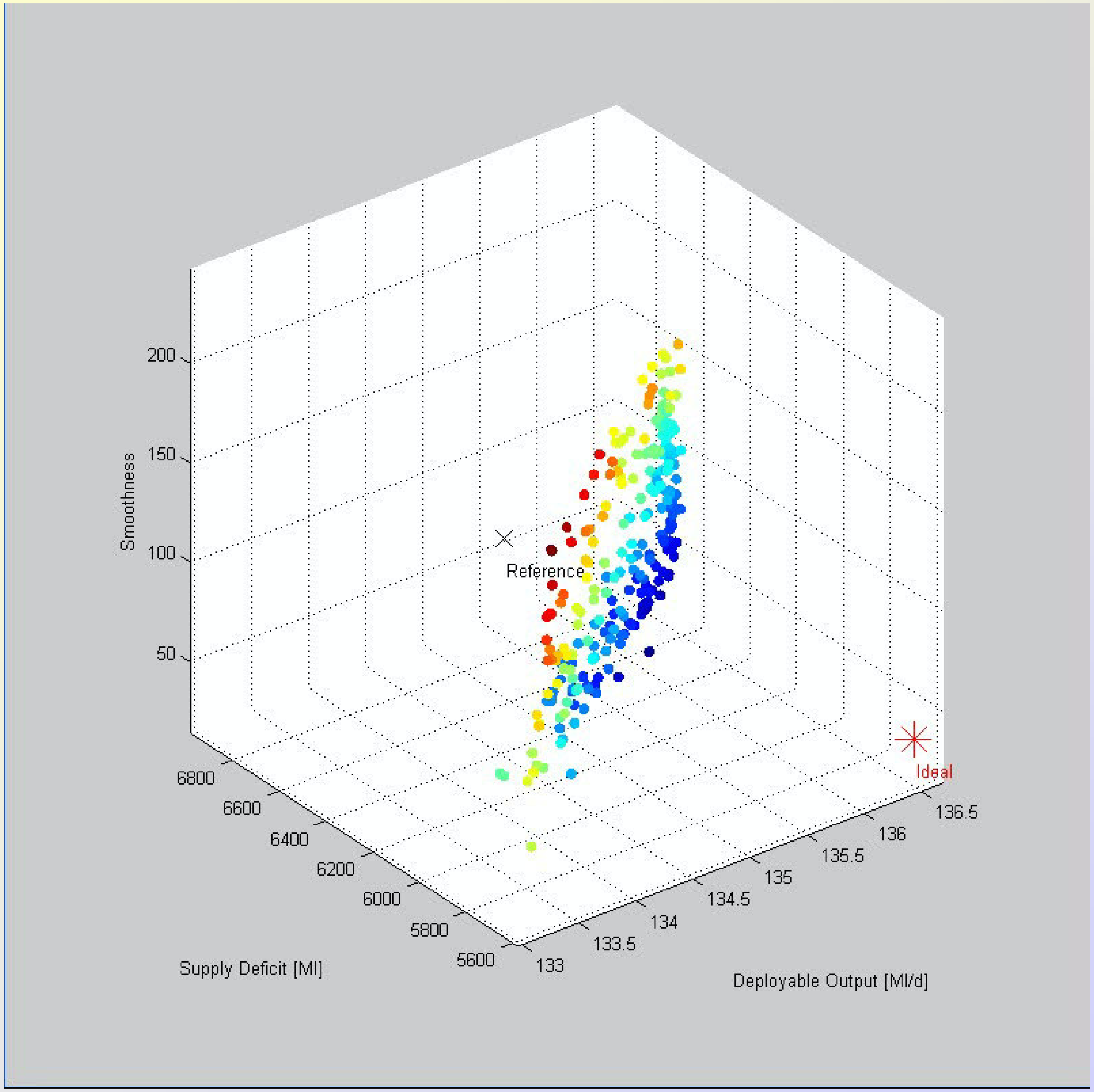
Fife system: Objective functions

- (1): max DO (Deployable Output for return period T=40 years- between NF=2 and NF=3 failure years)
- (2): min DC (magnitude of changes in the control curve for consecutive months taken as a sum of the 3 reservoirs)
- (3): min (DCmax) (the maximum monthly change in the control curve for consecutive months in all 3 reservoirs)
- (4): min (SD) (supply deficit). SD>0 in all cases, because the DO for T=40 relates to computations with 2 or 3 failure years (NF)
- Other objective functions tried (e.g. cost) but proved inefficient or unsuitable.
- Specific computational method introduced to the GA for estimating the DO for T=40 quicker.

Fife system: Trade-off –Pareto curves



Pareto "surface" for three objectives

1.max DO

Deployable Output (Mld)

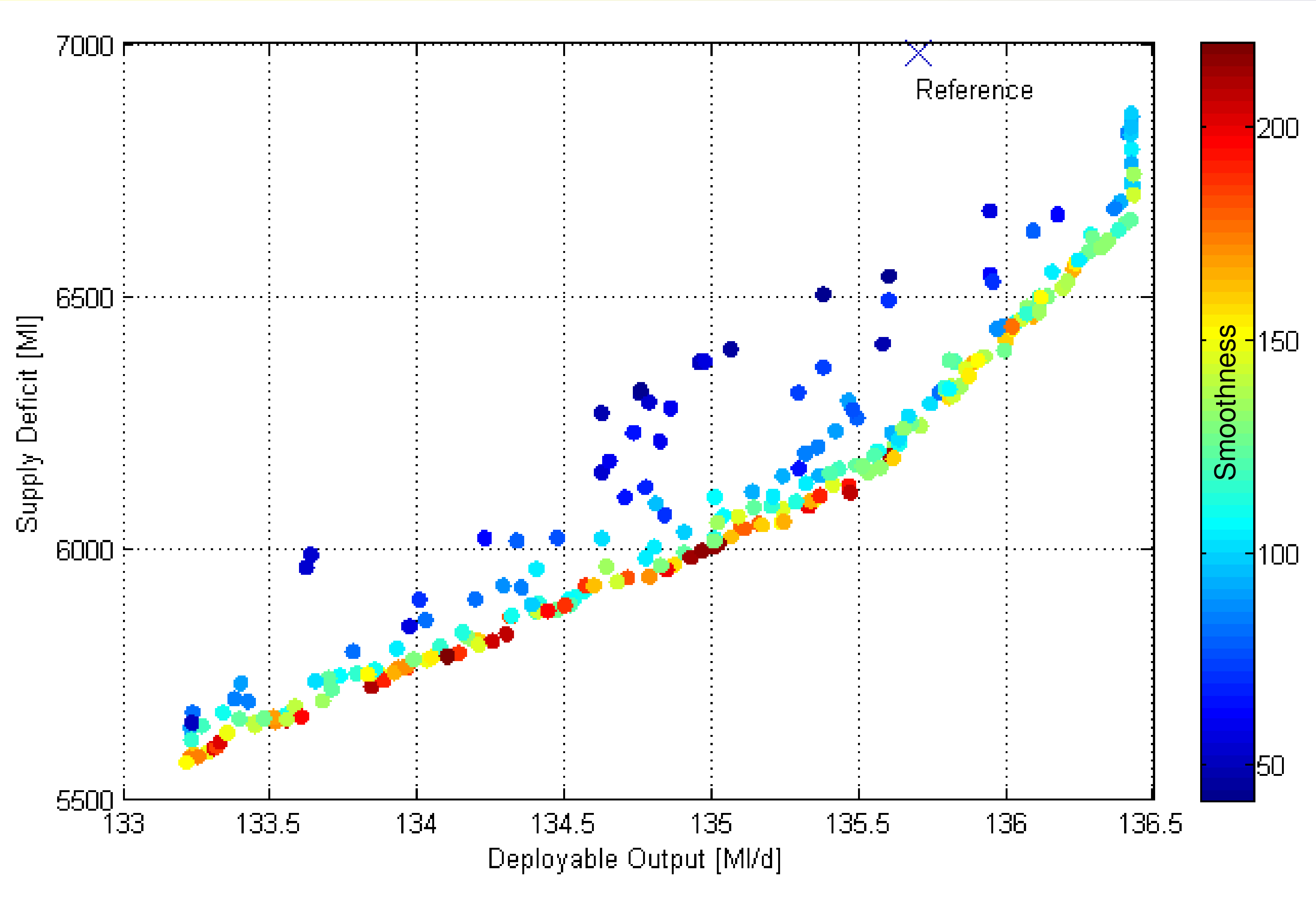
2.min DC

(total magnitude of change at all three control curves)

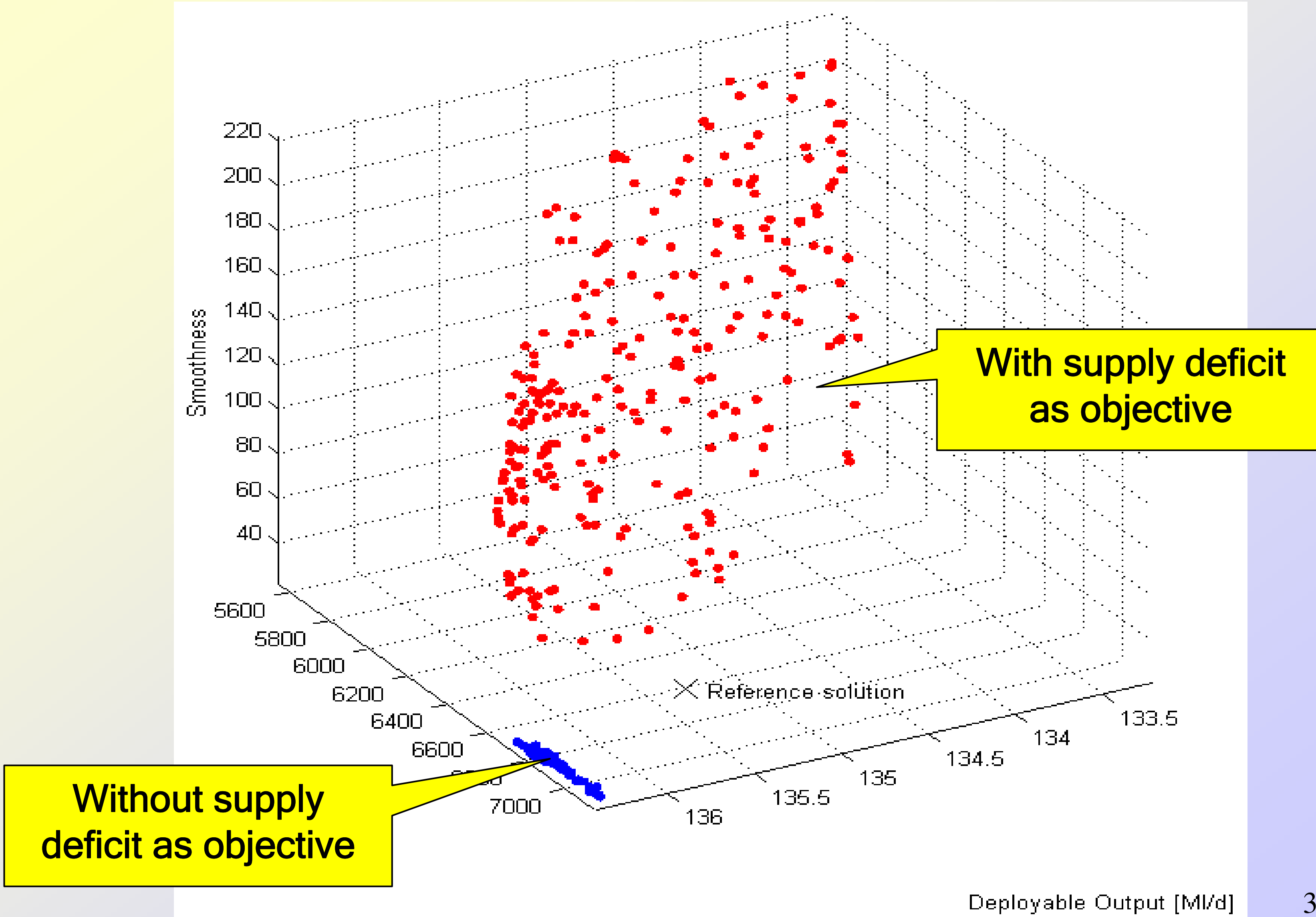
2.min SD

Supply deficit (Ml)

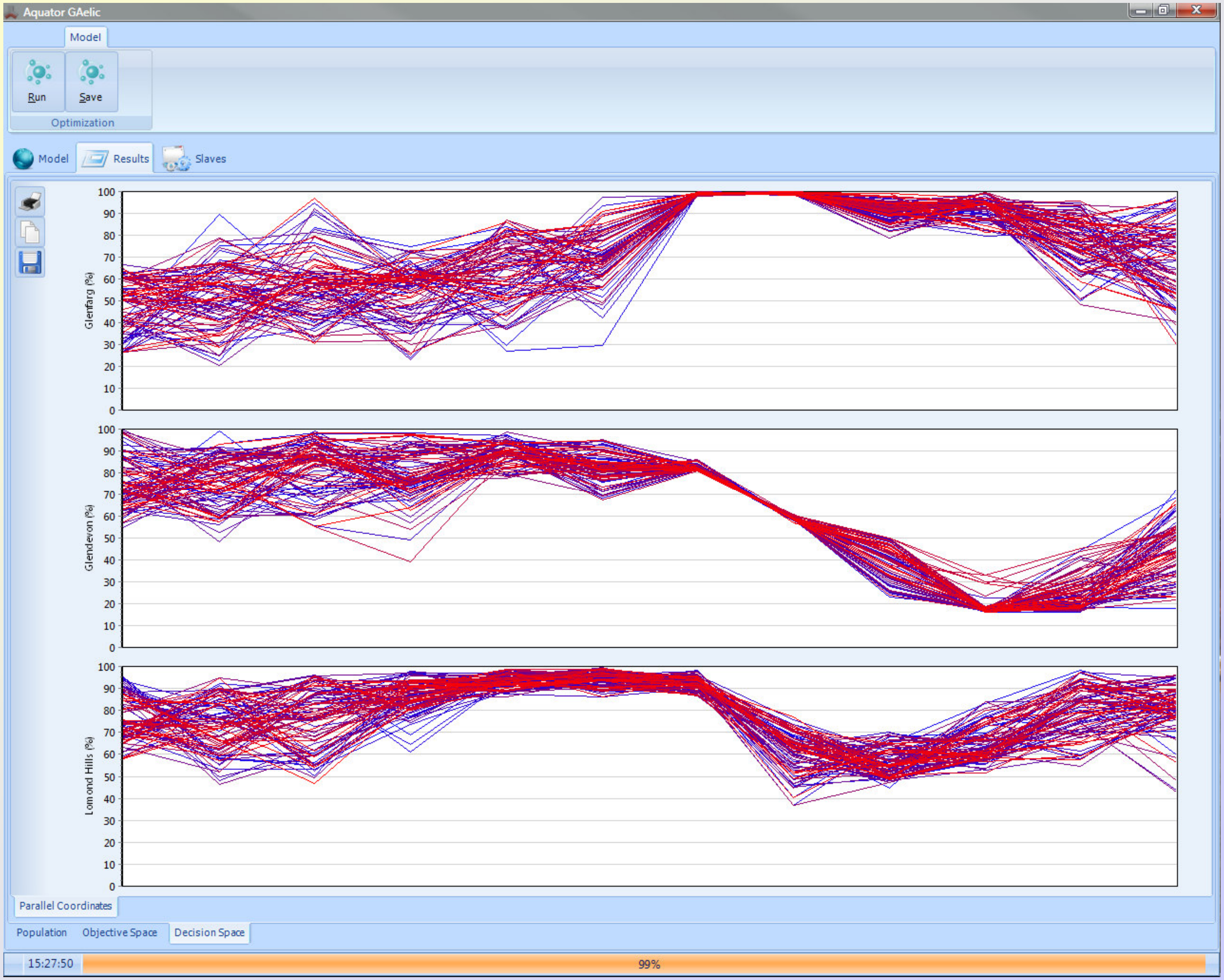
Fife system: Trade-off curves



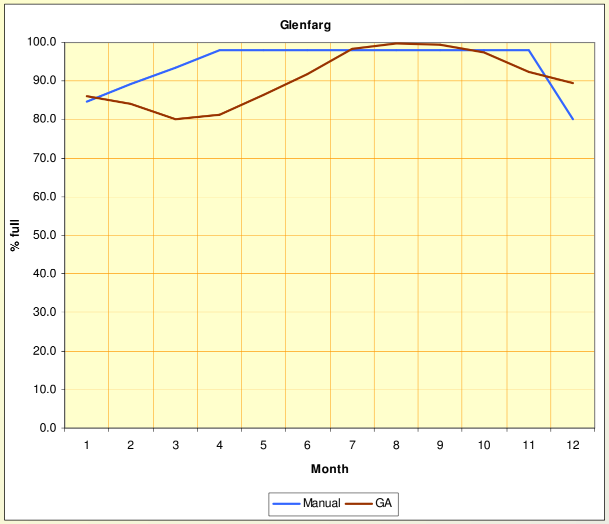
Pareto optimal solutions

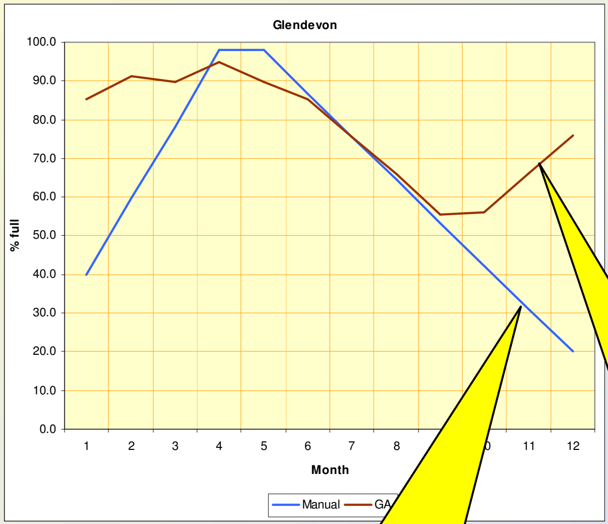


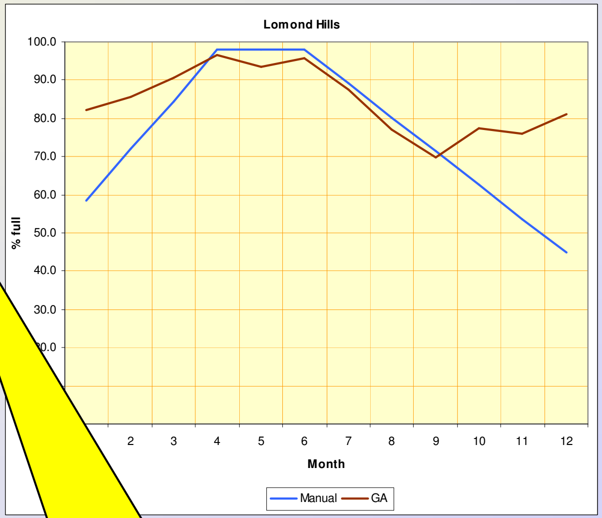
Control curves optimal decision space



Control curves for the 3 reservoirs







Manual solution (reference)

AquatorGA solution

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Aquator
OXFORD SCIENTIFIC SOFTWARE

Thank you for your attention!

Demo available…

Paper:
Vamvakeridou-Lyroudia, L.S., Morley M.S., Bicik J., Green C., Smith M. and Savic, D.A. (2009). AquatorGA: Integrated optimisation for reservoir operation using multiobjective genetic algorithms, in "Integrating Water Systems", Proc. 10th Int. Conf. on Computing and Control for the Water Industry CCWI 2009, 1-3 Sept 2009 University of Sheffield, UK, pp 493-500

Website:
http://centres.exeter.ac.uk/cws/projects/water-resources-management/165-ga-aquator