CRC for Water Sensitive Cities

Integrated optimisation of pump operations in systems with a variety of alternative water sources

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Business
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Outline

- Introduction
- The POAWS Optimisation Toolkit
- Summary of the Orange Supply System
- Results
- Conclusions

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Introduction

Why optimisation?

- Many possible solutions
- Find better solutions than with just engineering judgement

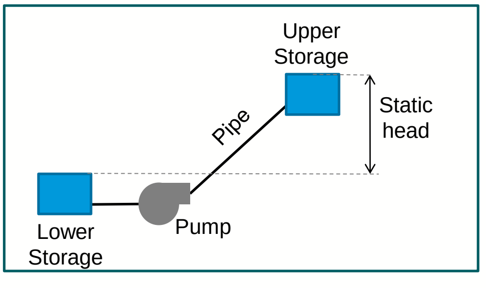
Why use alternative water sources?

- Stormwater, groundwater, imported water, desalination, and others
- Water security
- Environmental benefits
- Social benefits

Introduction

How are alternative water sources more complex?

- Hydraulic considerations for accurate energy costs ➡ Hydraulic solvers

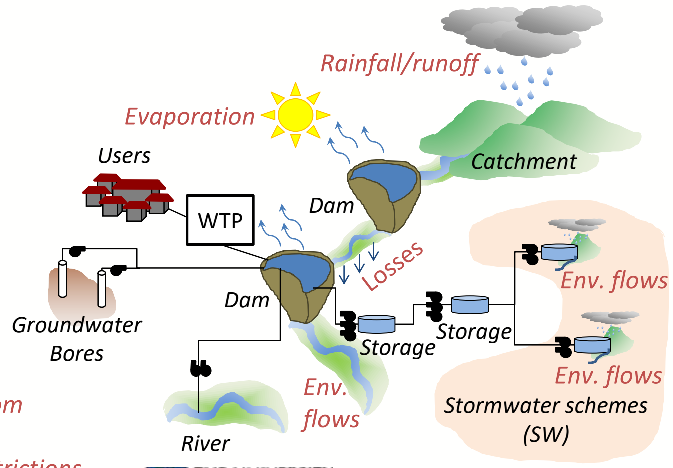


- Pipe flows,
- Pump power
- Multi-pattern electricity tariff

Introduction

How are alternative water sources more complex?

- Additional components are not simulated in hydraulic models



... + Limits on extractions from water sources and water restrictions

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The POAWS Optimisation Toolkit

Pumping Operation for Alternative Water Sources Tool (POAWS)

- **Optimisation**
  Multi-objective Genetic Algorithm Optimisation Algorithm (NSGA-II)

- **Hydraulic solver**
  EPANET (for hydraulics)

- **Additional processes**
  Mass balance models to take into account

- **Four Excel Spreadsheets (to easily use the software)**

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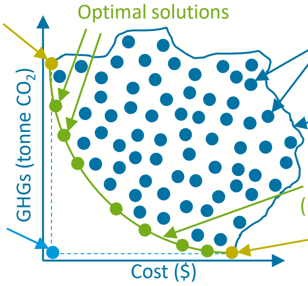
The POAWS Optimisation Toolkit

Multi-objective Optimisation Algorithm NSGA-II

based on analogy with natural evolution → best solutions survive and evolve

Trade-offs between objectives



Other objectives (minimisation of Spill, maximisation of Environmental flows)

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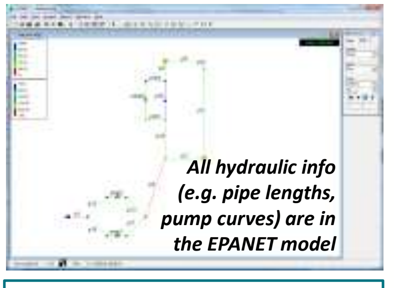
The POAWS Optimisation Toolkit A New Development

Hydraulic Solver EPANET

[Free download @ https://www.epa.gov/water-research/epanet](https://www.epa.gov/water-research/epanet)



All types of pump controls can be optimised

- Time-based (e.g. patterns)
- Simple Controls based on one condition (e.g. tank trigger levels)
- Rule-based controls* →

  E.g. optimising tank trigger levels based on day of the week and/or time of the day

Example of Rule-based controls
RULE 1
IF SYSTEM DAYTIME >= MONDAY
AND SYSTEM DAYTIME < SATURDAY
AND SYSTEM CLOCKTIME > 7 AM
AND SYSTEM CLOKTIME < 11 PM
AND TANK 1 LEVEL BELOW 3.0
AND TANK 2 LEVEL BELOW 2.5
THEN PUMP 1 STATUS IS OPEN

* Capability of optimising rule-based controls and controlling pumps based on the day of the week has been added during the *CRC for Water Sensitive Cities* project.

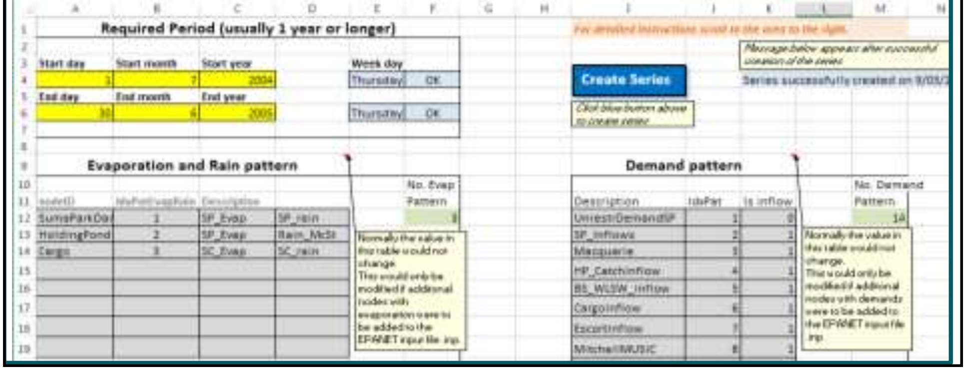
The POAWS Optimisation Toolkit

4 Excel Spreadsheets

The POAWS Optimisation Toolkit

4 Excel Spreadsheets

- **AllData.xlsm**
  Selection of different years (dry/wet) of daily inflows, evap., etc.



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4 Excel Spreadsheets

- **AllData.xlsm**
  Selection of different years (dry/wet) of daily inflows, evap., etc.
- **CreateNetFile.xlsm**
  Additional data for evap./rainfall, env. flows, etc..

The POAWS Optimisation Toolkit

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  Data for optimisation (e.g. objectives, constraints, decision variables)

The POAWS Optimisation Toolkit

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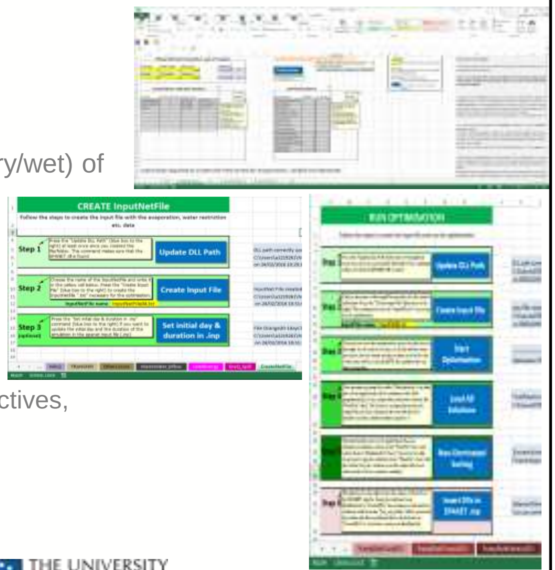

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- **AnalyseSol.xlsm**

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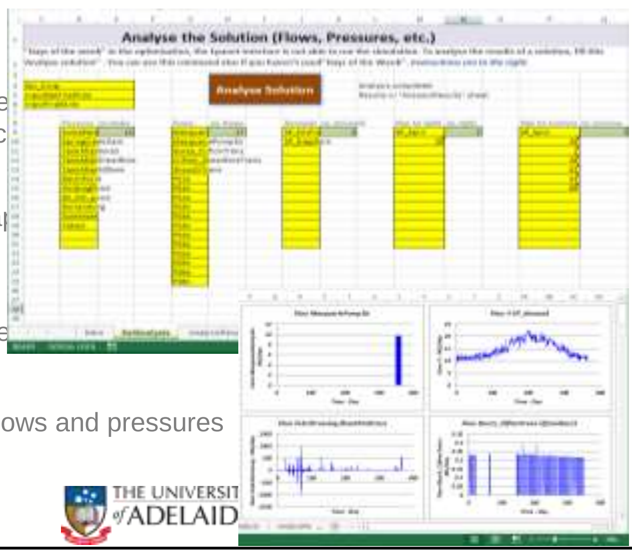
The POAWS Optimisation Toolkit

4 Excel Spreadsheets



- **AllData.xlsm**
  Selection of different ye
  daily inflows, evap., etc
- **CreateNetFile.xlsm**
  Additional data for eva
  etc..
- **InterfaceOpti.xlms**
  Data for optimisation (e
- **AnalyseSol.xlsm**
  Analysis and plots of flows and pressures of a specific solution

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Summary of Orange Supply System Model

Water Sources for Suma Park Dam

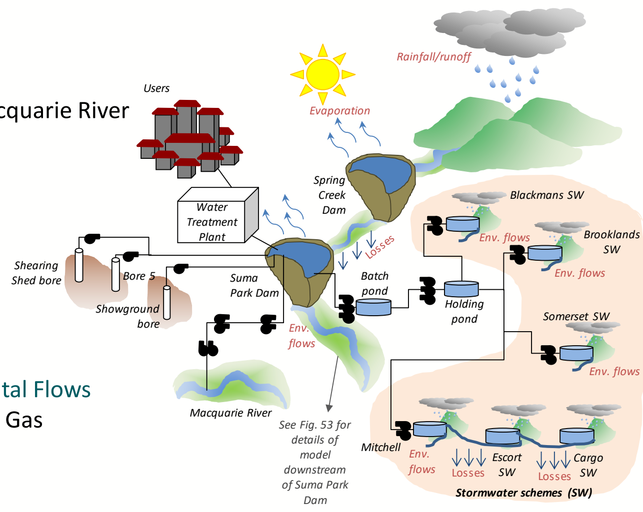
- Catchment water
- Groundwater
- Stormwater
- Pumped water for Macquarie River (Inter-basin transfer)

Possible Objectives

(Individual or Multiple):

- Minimise Cost
- Minimise Spill *(from Suma Park Dam and Holding Pond)*
- Maximise Environmental Flows
- Minimise Greenhouse Gas Emissions

Orange Supply System



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Summary of Orange Supply System Model

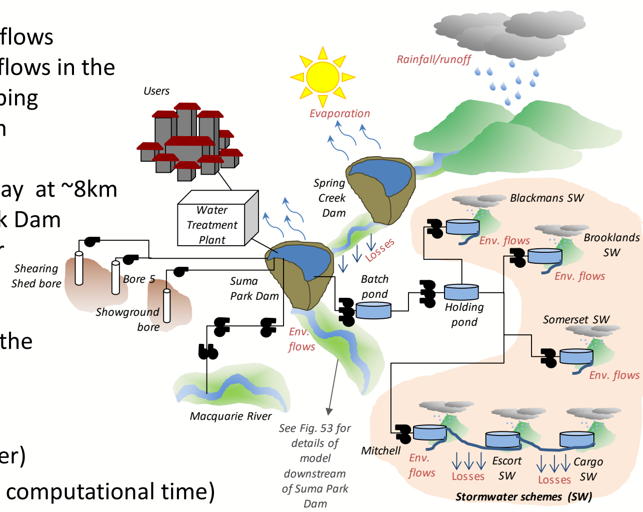
Constraints

- Minimum environmental flows
- Minimum and maximum flows in the Macquarie River for pumping
- Maximum extraction from groundwater bores
- Minimum flow 1.75 ML/day at ~8km downstream of Suma Park Dam
- Possibility of having water restrictions (and, if so, for how long)
- Target level at the end of the simulation

Other info

- Duration = 1 year (or longer)
- Time step = 1 day (to save computational time)

Orange Supply System



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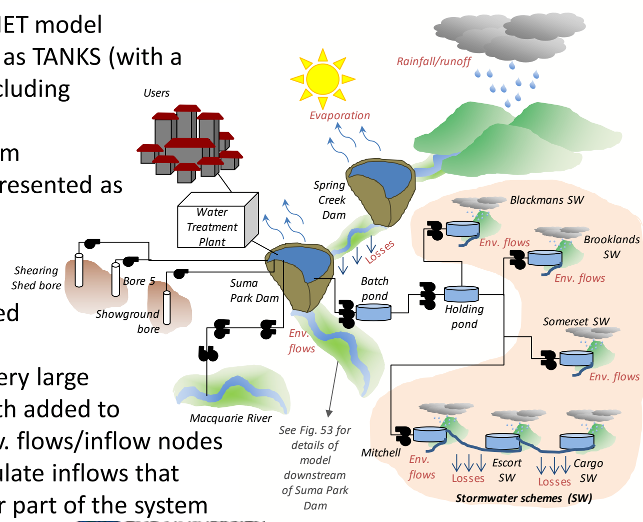
Summary of Orange Supply System Model

Modelling

- Hydraulic info as in EPANET model
- All storages represented as TANKS (with a height-volume curve) including groundwater bores
- Evaporation and minimum environmental flows represented as demands at nodes
- Inflows represented as negative demands
- Fictitious reservoirs added to keep track of spill
- Additional 'pipes' with very large diameter and short length added to connect evaporation/env. flows/inflow nodes
- Additional nodes to simulate inflows that depend on flows in other part of the system (Transfer losses)

Orange Supply System



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Summary of Orange Supply System Model

Costs

- Only operational costs affected by pumping
- Can be changed in Excel Interface Files

Pumps	Off-peak tariff (10 PM – 7 AM weekday & entire weekend)	Peak tariff (7 AM – 10 PM weekday)
Stormwater schemes and groundwater source	7.3364 cent/kWh	13.5664 cent/kWh
Macquarie River	4.0355 cent/kWh	5.6628 cent/kWh
Macquarie River Power Demand Charge	185.81 cent/kVA	812.96 cent/kVA

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Summary of Orange Supply System Model

Decision Variables (DVs): Tank Trigger Levels

RULE 6
IF NODE MacquarieUS DEMAND > -5000.0000
AND NODE MacquarieUS DEMAND < -108.0000
AND SYSTEM DAYTIME >= SATURDAY
OR SYSTEM DAYTIME < MONDAY
AND NODE SumaParkDam LEVEL < **15.8600**
THEN LINK MacquariePump1a STATUS IS OPEN

RULE 36
IF NODE BatchPond LEVEL < **4.4500**
AND NODE HoldingPond LEVEL > 0.1000
AND SYSTEM DAYTIME >= MONDAY
AND SYSTEM DAYTIME < SATURDAY
THEN LINK PS2b STATUS IS OPEN

These will be changed by the algorithm
(Options and DVs are defined in Excel interface)

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Summary of Orange Supply System Model

Decision Variable Choice Tables: Tank Trigger Levels

Macquarie Pumps depend on the level of Suma Park Dam				Bore Pumps and PS3 (from Batch pond) depend on the level of Suma Park Dam				PS2 depends on the level of Batch Pond		PS1, PS4, PS5, PS6 depend on the level of Holding Pond	
No.	Value (m)	No.	Value (m)	No.	Value (m)	No.	Value (m)	No.	Value (m)	No.	Value (m)
1	0.072	22	11.172	1	0.072	22	11.172	1	0	1	0
2	0.108	23	11.591	2	0.108	23	11.591	2	0.23	2	0.375
3	0.144	24	11.997	3	0.144	24	11.997	3	0.46	3	0.75
4	0.180	25	12.391	4	0.180	25	12.391	4	0.69	4	1.125
5	0.855	26	12.775	5	0.855	26	12.775	5	0.92	5	1.5
6	1.719	27	13.149	6	1.719	27	13.149	6	1.15	6	1.875
7	2.534	28	13.511	7	2.534	28	13.511	7	1.38	7	2.25
8	3.308	29	13.866	8	3.308	29	13.866	8	1.61	8	2.625
9	4.039	30	14.215	9	4.039	30	14.215	9	1.84	9	3
10	4.739	31	14.555	10	4.739	31	14.555	10	2.07	10	3.375
11	5.408	32	14.890	11	5.408	32	14.890	11	2.3	11	3.75
12	6.050	33	15.221	[illegible]	[illegible]	[illegible]	[illegible]	12	2.53	12	4.125
13	6.662	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	2.76	13	4.5
14	7.240	35	15.857	[illegible]	[illegible]	[illegible]	[illegible]	14	2.99	14	4.875
15	7.793			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	[illegible]
[illegible]	[illegible]			16	8.326	37	16.427	[illegible]	[illegible]	16	[illegible]
[illegible]	[illegible]			17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17	6
[illegible]	[illegible]			18	[illegible]	39	17.000	[illegible]	[illegible]	18	[illegible]
[illegible]	[illegible]			19	9.821			[illegible]	[illegible]	19	6.75
[illegible]	[illegible]			20	10.288			[illegible]	[illegible]	[illegible]	[illegible]
21	10.738			21	10.738			21	4.6	21	7.5

Max Level correspond to 100% Suma Park

Max Level correspond to 90% Suma Park

Max Level of Batch Pond

Max Level of Holding Pond

Example of Optimisation Results

Average (2004/05), Wet (1991/92) and Dry (1957/58) year

(from Draft of the Decision Support Tool)

Genetic Algorithm Parameters

(Computational times for 1 seed: ~ 1h:30min)

- Population Size = 50 solutions
- Number of generations = 100
- Prob. of crossover = 0.8
- Probability of mutation = 0.02 (~ 1/No.DVs, No.DVs =68)

Initial conditions:

- Suma Park Level = 16m (max 17m) & Spring Creek Dam = 10m (max 10.6m)
- Full licence of groundwater available
- Various initial levels for stormwater scheme storages
- Target level for Suma Park = 16m
- No water restrictions allowed

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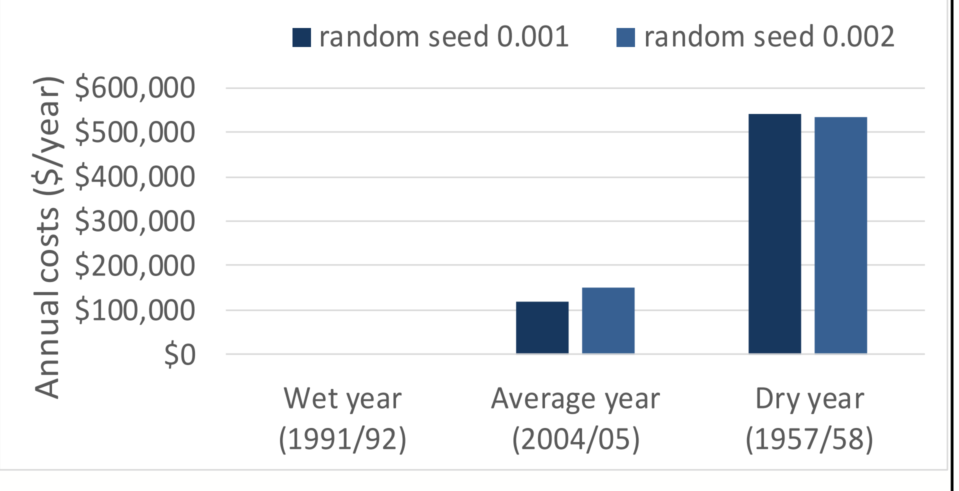
Example of Optimisation Results

Minimisation of Pumping Costs (single objective)



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Example of Optimisation Results

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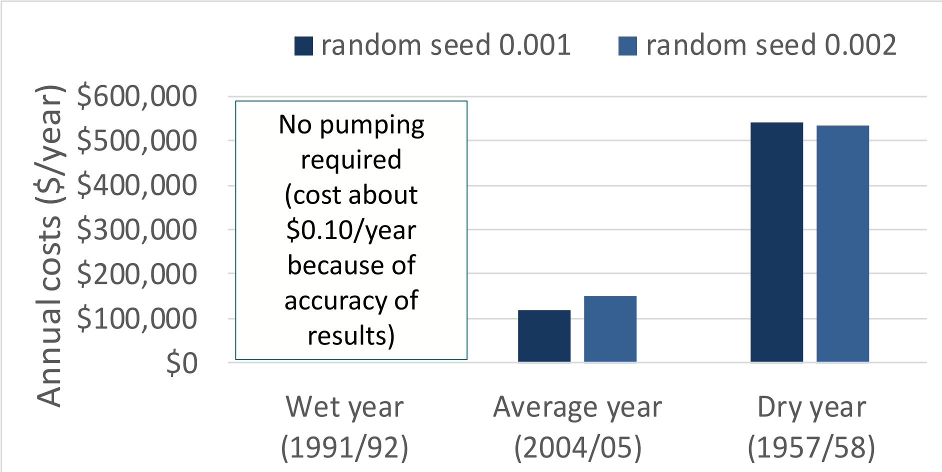

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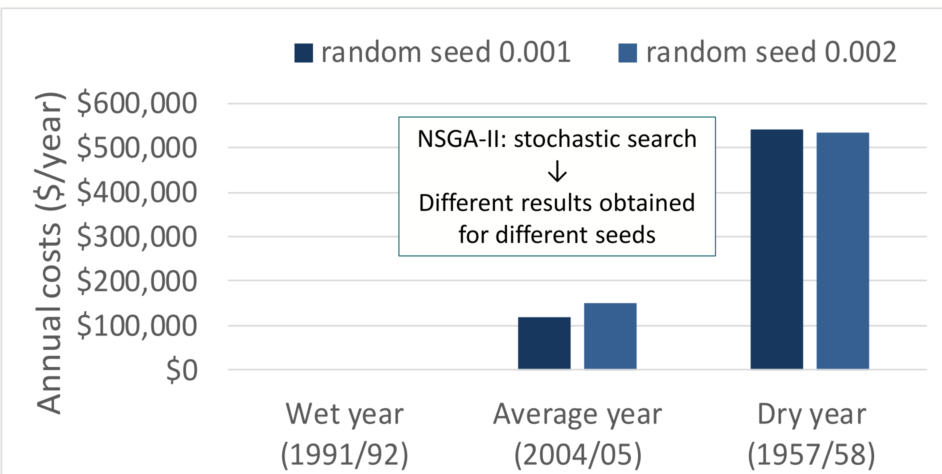
Example of Optimisation Results

Minimisation of Pumping Costs (single objective)



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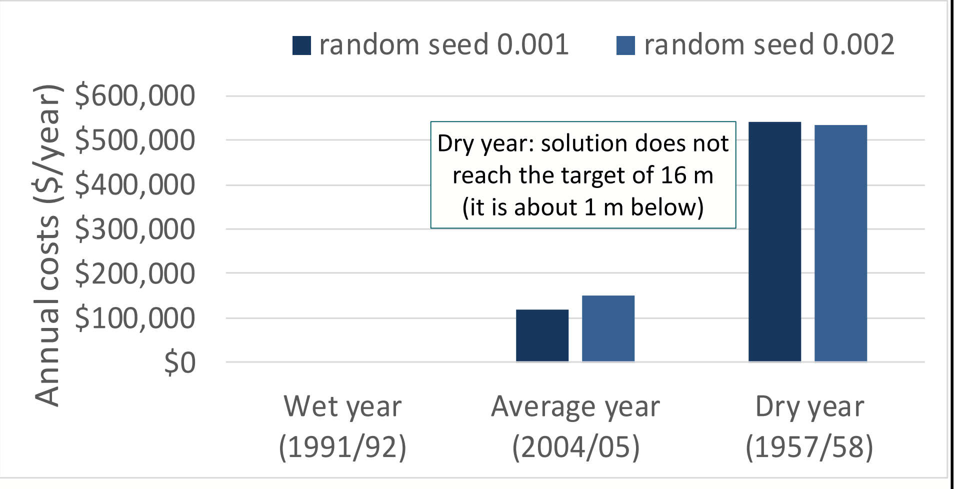
Example of Optimisation Results

Minimisation of Pumping Costs (single objective)



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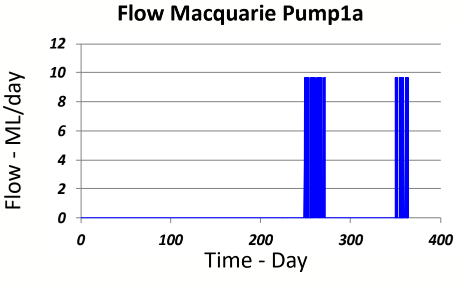
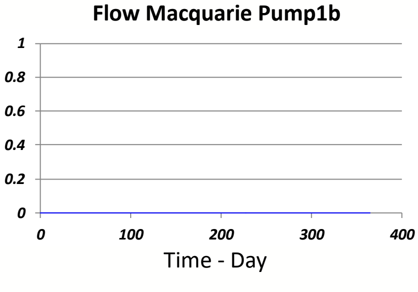
Example of Optimisation Results

Minimisation of Pumping Costs (single objective)

Average year (2004/05)

- Only one pump is switched on to save on electricity demand charge





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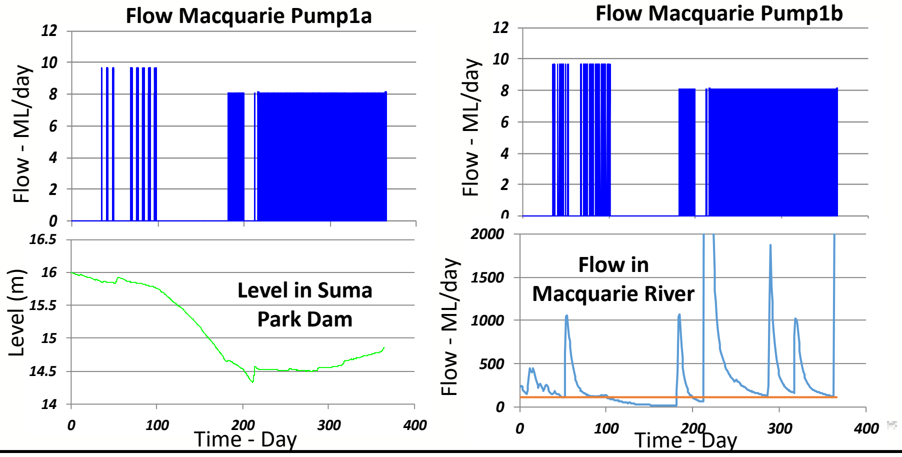
Example of Optimisation Results

Minimisation of Pumping Costs (single objective)

Dry year (1957/58)

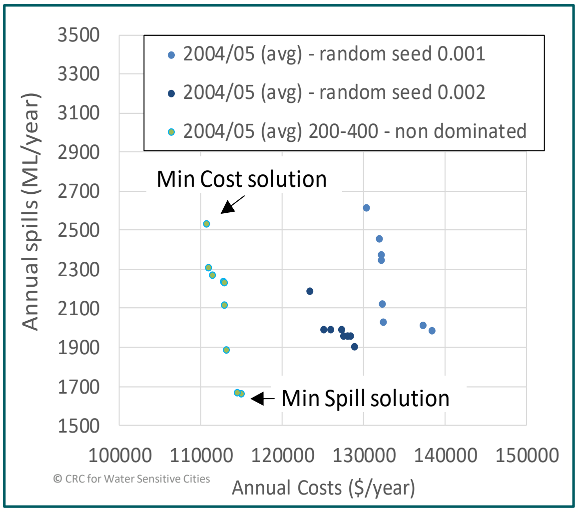
- More pumping from both pumps
- Limit on minimum of 108 ML/day in the River and minimum level Suma Park Dam for pumping are satisfied



Example of Optimisation Results

Minimisation of Pumping Costs and Spill (2 objectives)

Average year (2004/05)



- Trade-off between costs and spills
- (Pop =200, Gen=400 to improve results)
- Non-dominated solutions of multiple seeds can be found automatically

Example of Optimisation Results

Minimisation of Pumping Costs and Spill (2 objectives)

Comparison of minimum cost solution and minimum spill solution for the Average year (2004/05)

Objectives and Water sources	Min. Cost Solution	Min. Spill Solution
Costs ($/year)	110,706	141,955
Spill (ML/year)	2,537	1,165
Macquarie (ML/year)	210	212
Groundwater (ML/year)	444	266
Stormwater (ML/year)	1,307	2,112

- Similar pumping volume from Macquarie River
- More groundwater used in minimum cost solution (cheaper source)
- More stormwater used in the minimum spill solution

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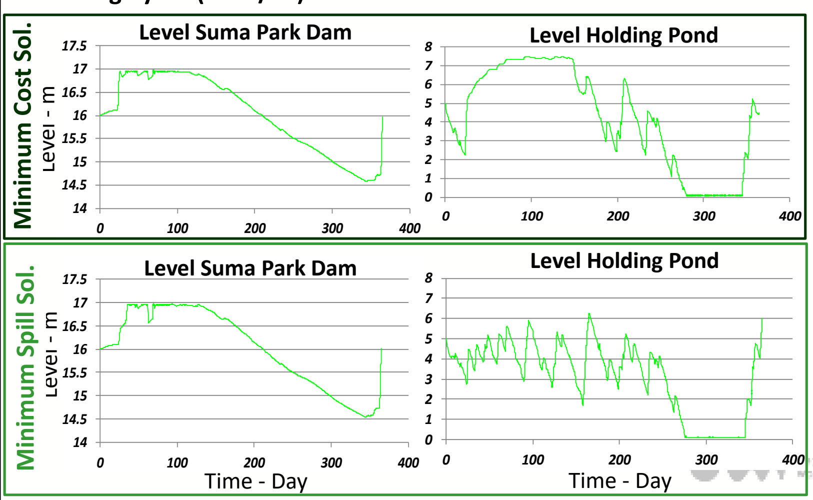
Example of Optimisation Results

Minimisation of Pumping Costs and Spill (2 objectives)

Comparison of minimum cost solution and minimum spill solution for the Average year (2004/05)



Using stormwater allows the holding pond to be emptier when there are natural inflow to the pond

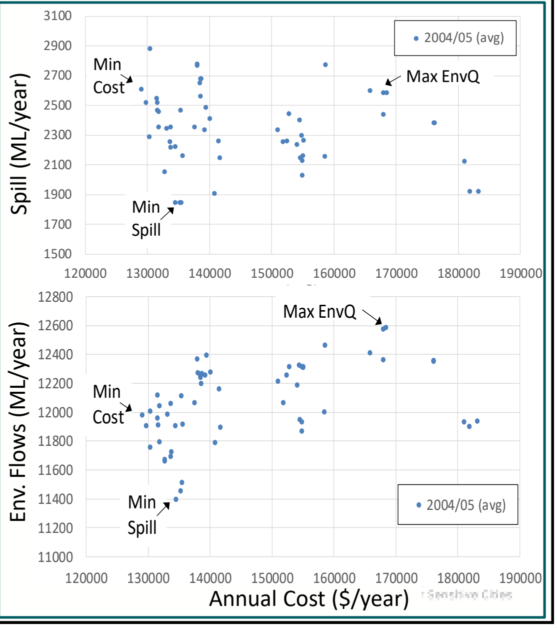
Example of Optimisation Results

Minimisation of Pumping Costs & Spill and Maximisation of Environmental Flows

(3 objectives)

Average year (2004/05)

- Trade-offs among the objectives



Conclusions

Summary

- Multi-objective optimisation algorithm (NSGA-II) has been linked to hydraulic solver (EPANET2) integrated with mass-balance processes to optimise pump operations of systems with alternative water sources
- Different years (wet, average, dry) have been optimised, taking into account different objectives (pumping costs, spill, environmental flows) and constraints (e.g. minimum environmental flows and target levels)
- Input data can be changed in Excel spreadsheets (and model components can be changed in EPANET)

Example of Preliminary Results applied to the Orange Supply System

- To minimise pumping costs, a combination of water sources (Groundwater, Macquarie River water and Stormwater) is used
- More stormwater is used to minimise spill
- Less stormwater is used to increase environmental flows

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Thank you!

Acknowledgments:

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