Water Resources

Lower Thames Control Diagram & Deployable Output Optimisation

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Aquator User Group Meeting, Worcester College Oxford, 12th October 2016

Presentation Overview

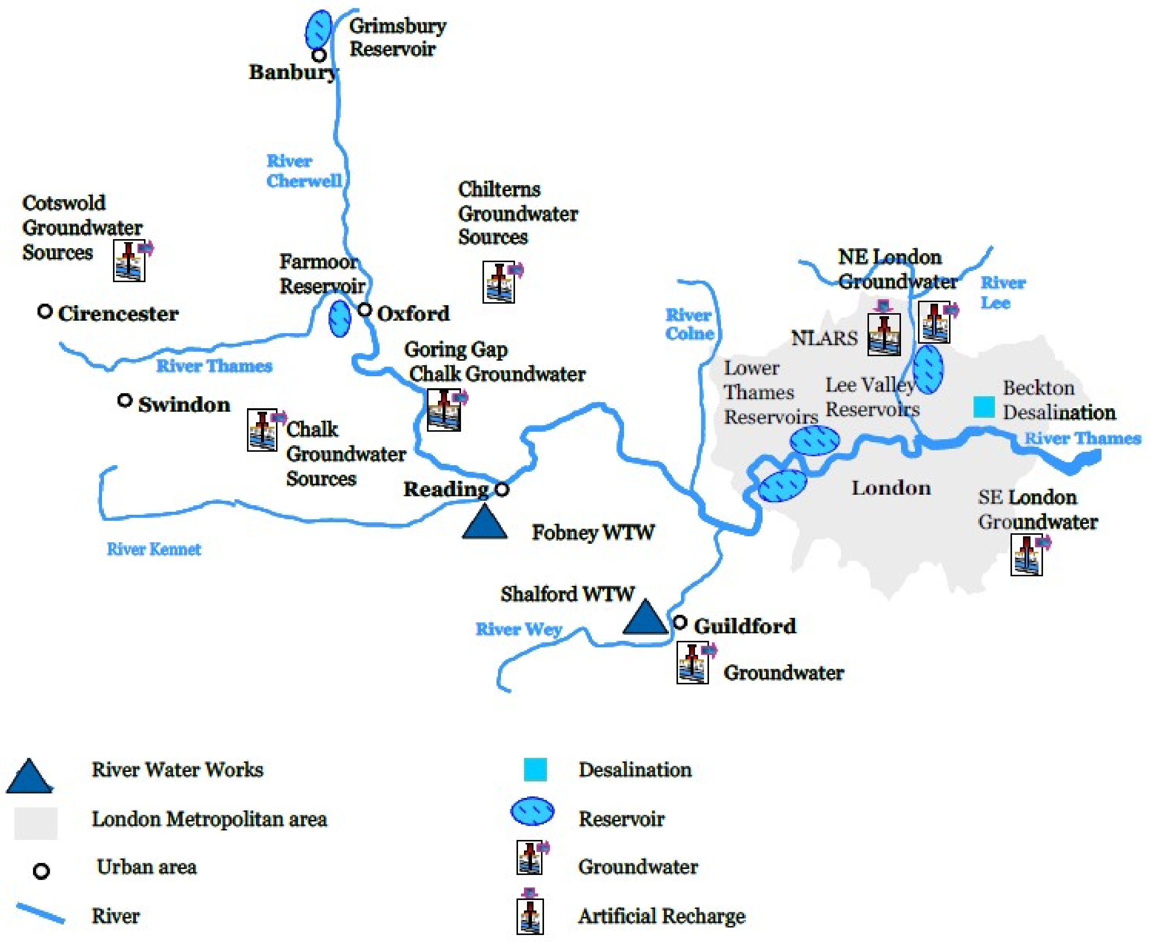
- London's Water Resources *(KM)*
  - Deployable Output
  - WARMS 2
- Introduction to the LTCD *(KM)*
- Optimising the LTCD (*MM*)
  - Defining the problem
  - Solving the problem
  - Results
- Conclusions *(KM)*

London's Water Resources & Deployable Output

Kevin Mountain

Water Strategy & Planning, Thames Water Utilities Ltd

Water Resources in the Thames Catchment

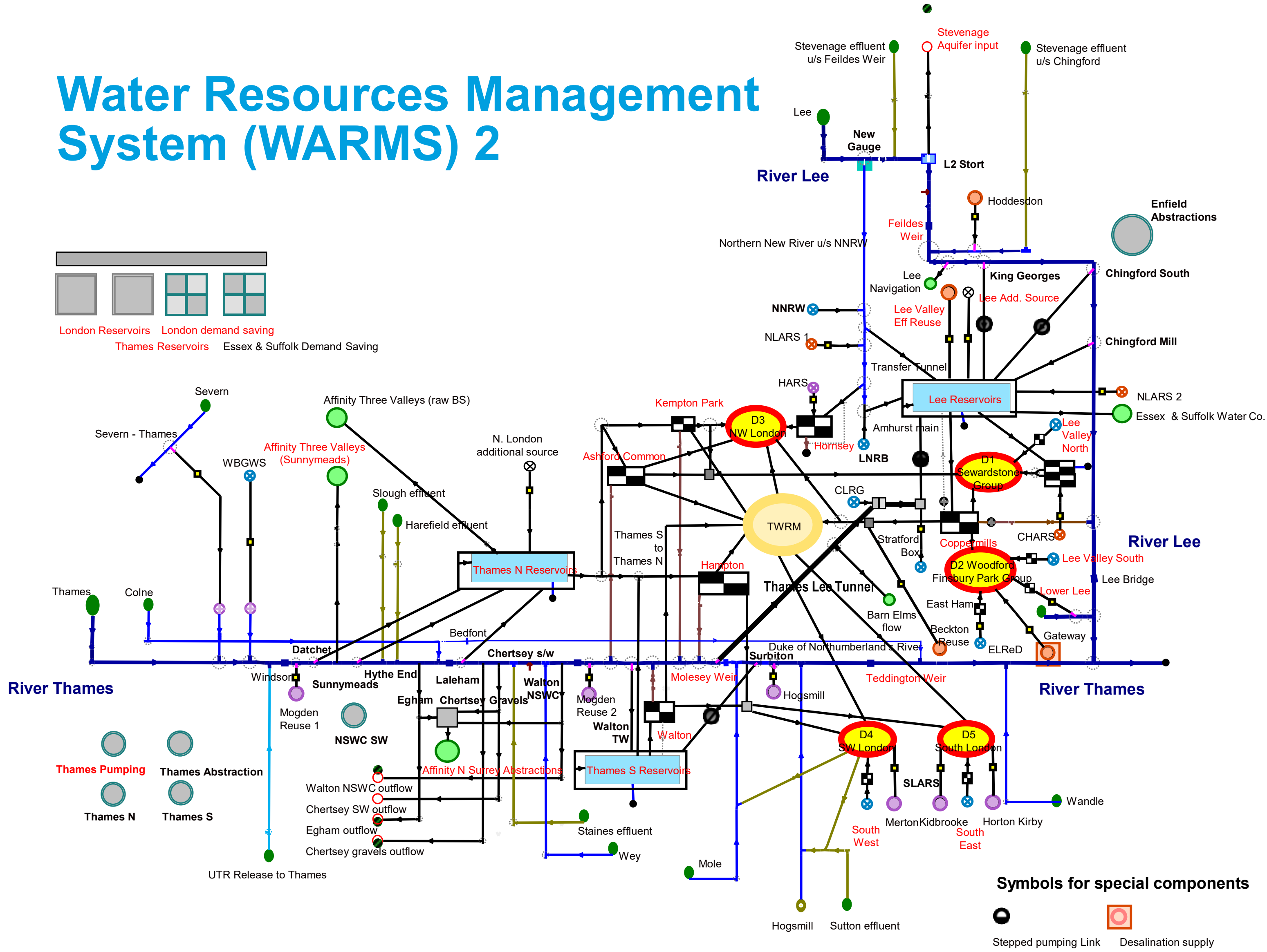


London’s Water Resources

• Raw Water Reservoirs	**19**
• Raw Water Intakes	**10**
• Groundwater sources	**>50**
• Strategic schemes *(Gateway, NLARS, etc.)*	**7**
• Water Trading agreement *(nPower = Didcot)*	**1**
• Bulk Supply Raw Water Exports *(E&S reduced)*	**2**
• Bulk Supply Treated Water Exports	**2**
• Bulk Supply Imports	**zero**
• Major water treatment works	**7**

Thames Water

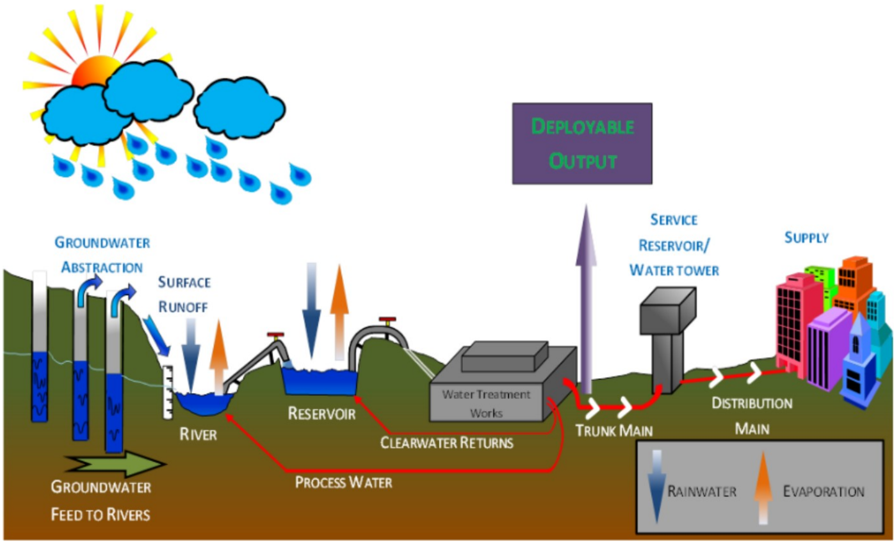
Water Resources Management System (WARMS) 2



Deployable Output: Definition

Our measure of Water Resources is Deployable Output (DO) & is defined as the output of a commissioned source or group of sources or of a bulk supply for a given level of service as constrained by:

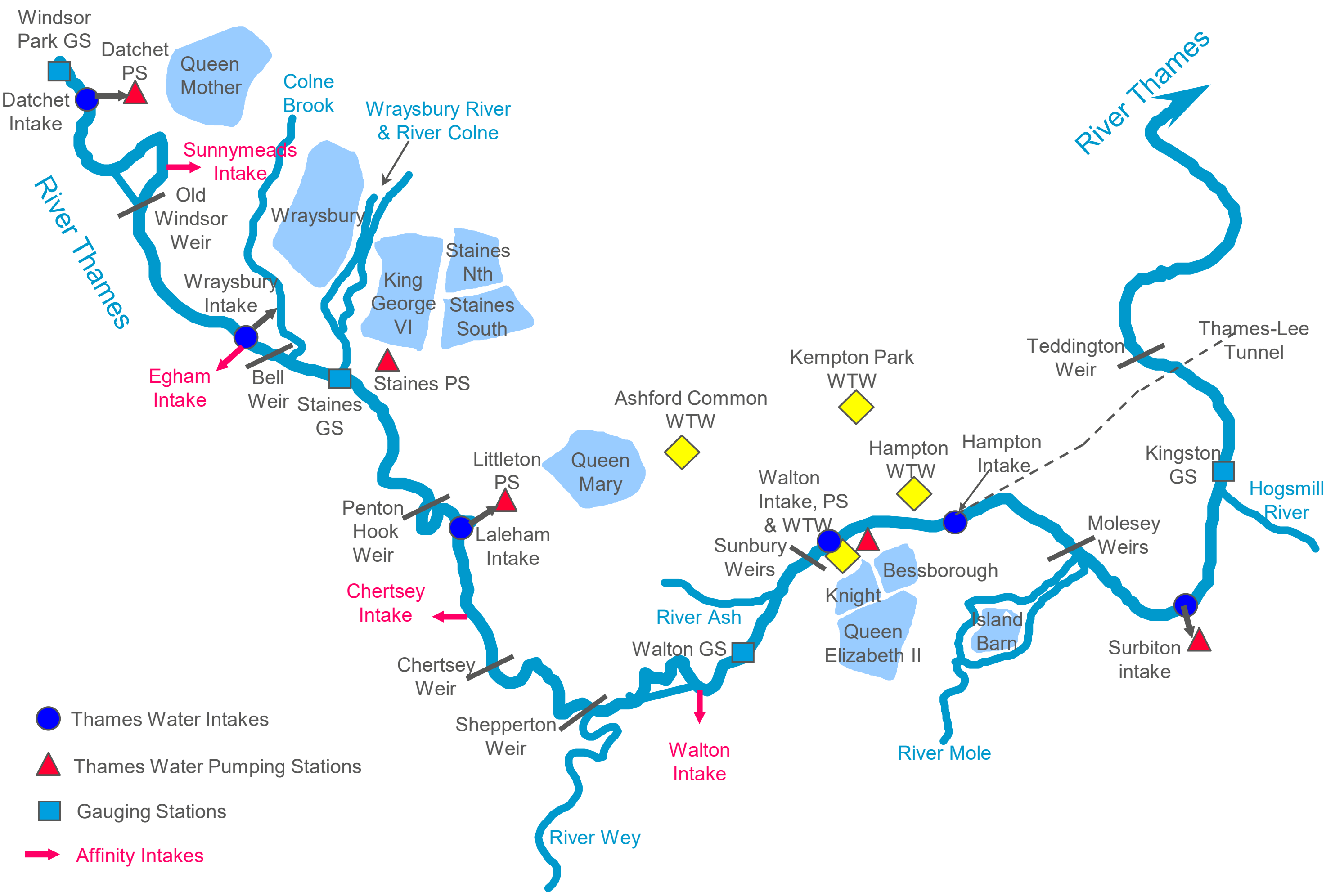
- Environment
- Licence
- Operating Agreement
- Pumping plant
- Well/aquifer properties
- Raw water mains
- Transfer and/or output main
- Treatment capability
- Water quality



WARMS2 Assumptions

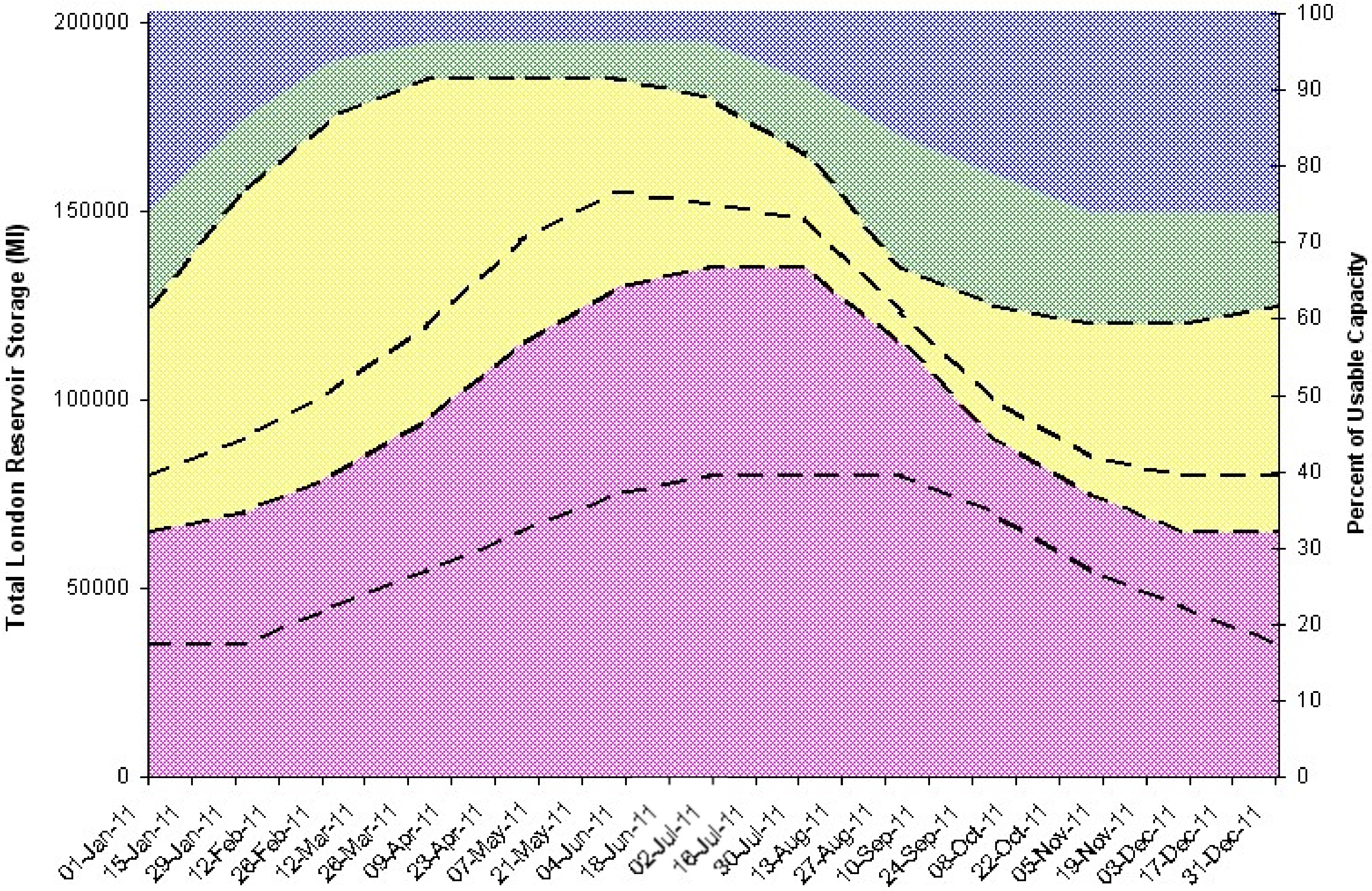
- Hydrology of Thames & Lee catchments derived from rainfall-runoff models using EA rainfall and PET data *(common usage)*
- Current Lower Thames Control Diagram *(LTCD – explained shortly)*
- Section 20 Agreement with the EA; any amendment needs negotiation
- Abstraction licences and source deployable outputs
- Demands and seasonal demand distribution
- Principal links
- Effluent returns
- Reservoir capacities
- WTWs capabilities
- Process water losses
- Strategic schemes; NLARS, WBGWS, Gateway, Stratford Box, ELRED

The Lower Thames Stored Water System

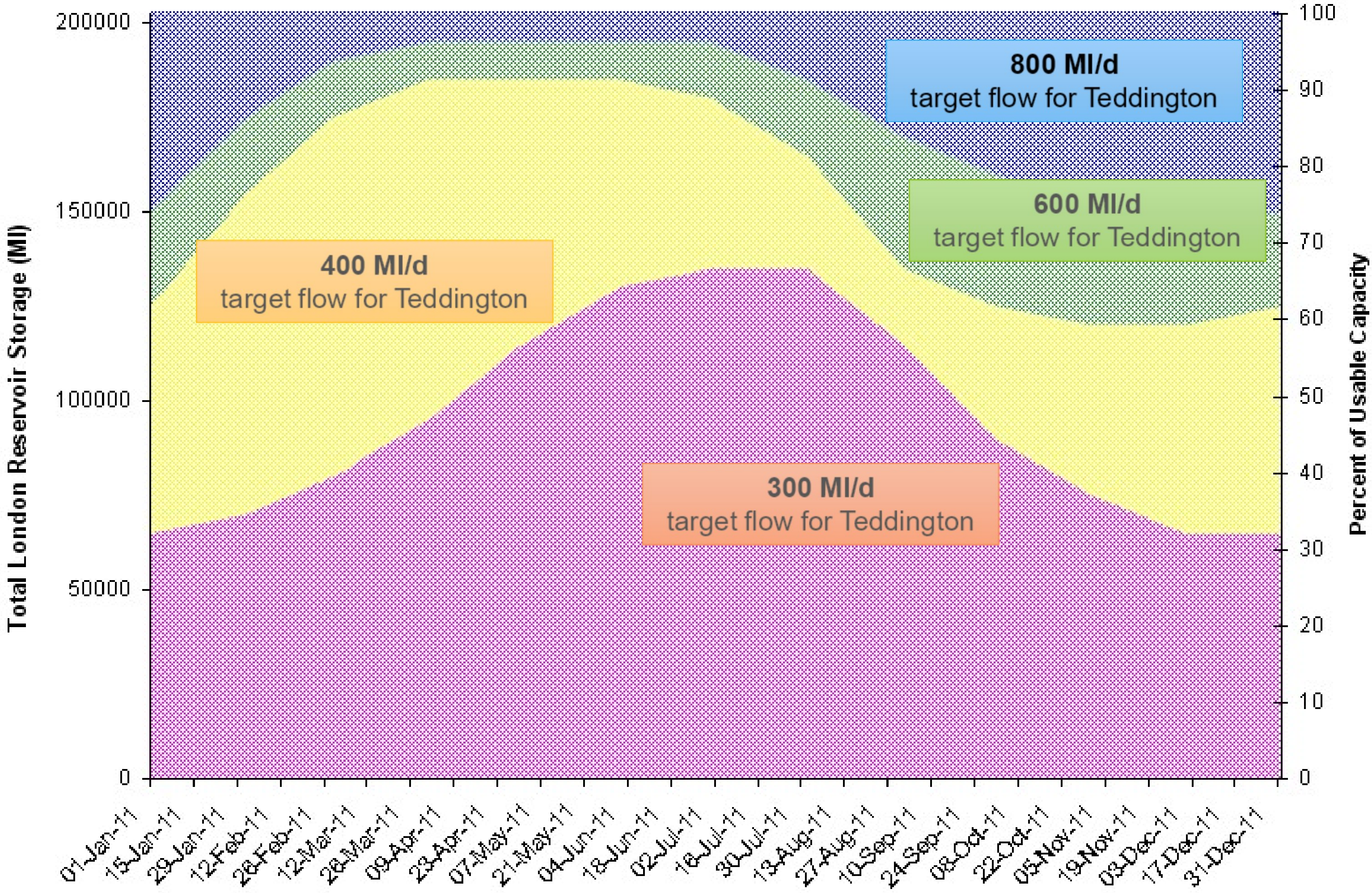


Introduction to the Lower Thames Control Diagram

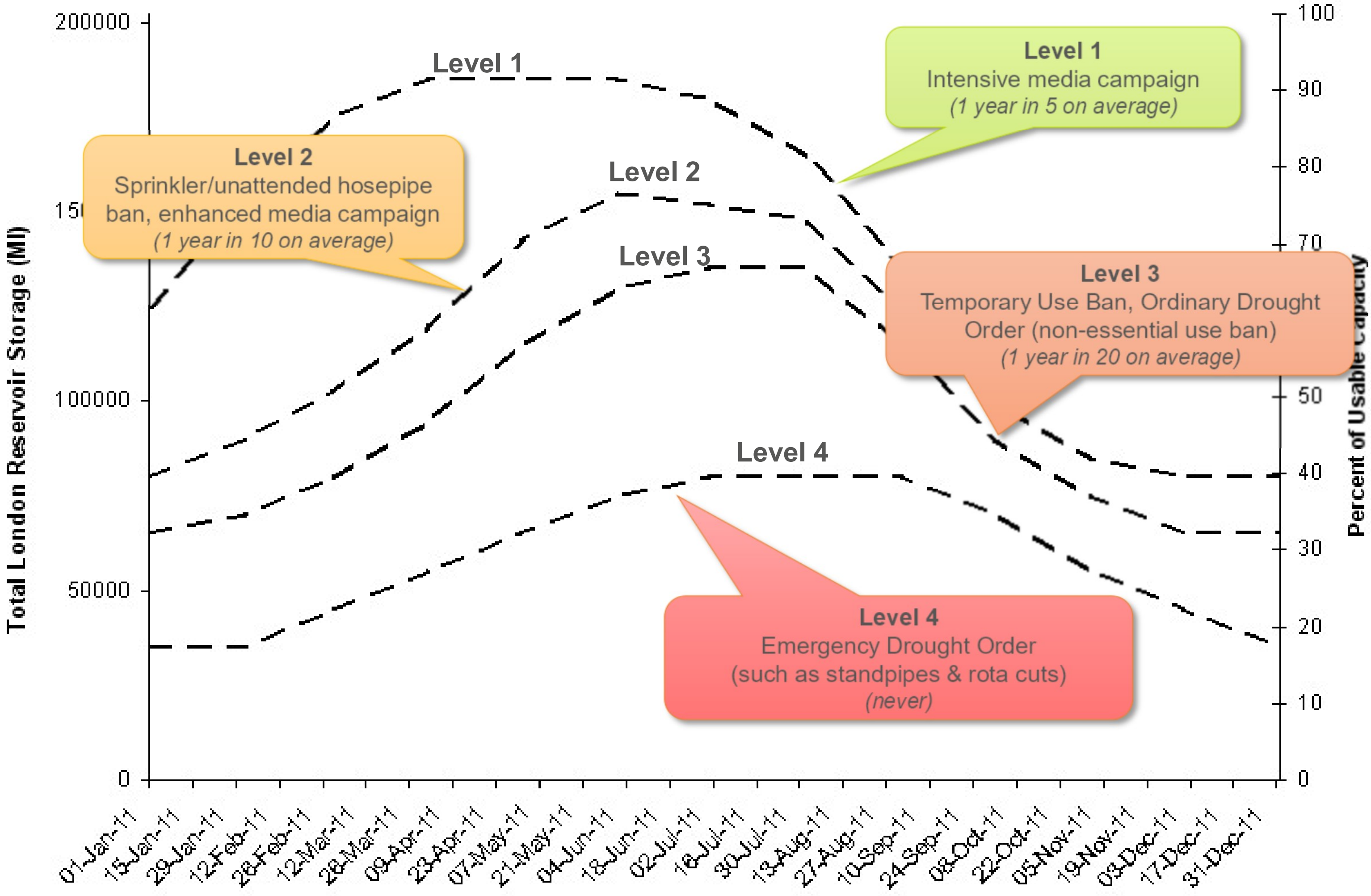
Lower Thames Control Diagram (LTCD) *(pre-2016)*



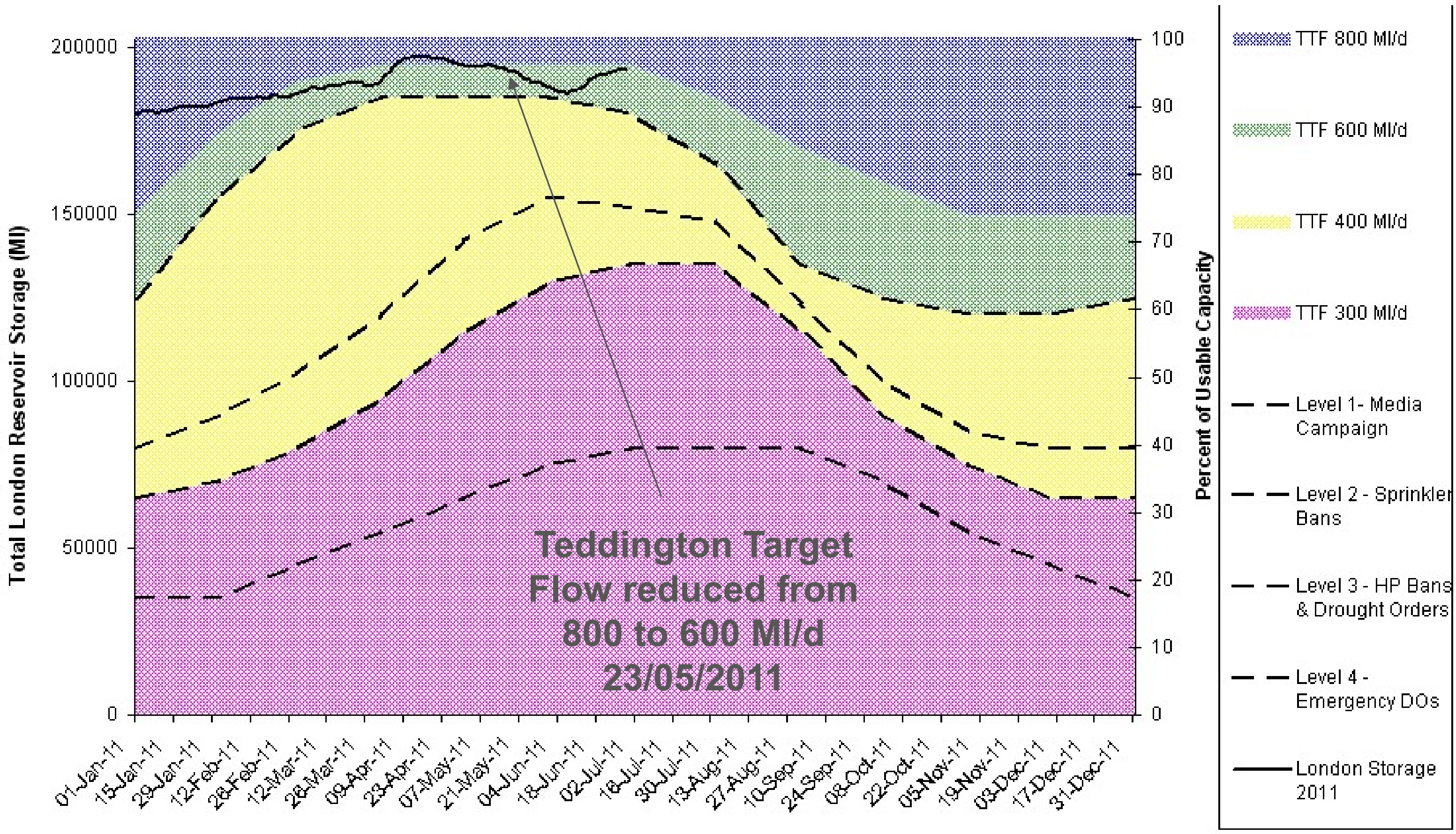
LTCD – Teddington Target Flows *(TTF)*



LTCD – Levels of Restrictions on Customers



LTCD with London 2011 Storage



Calculation of London's Deployable Output

1. The model is run to calculate London reservoir storage for each day from 1920 to date with a given demand.

2. The number of times the storage falls below the Level of restriction curves is calculated on an "Event" basis and compared against the number permitted.

3. Number of "Events" permitted in the 100 year record is:

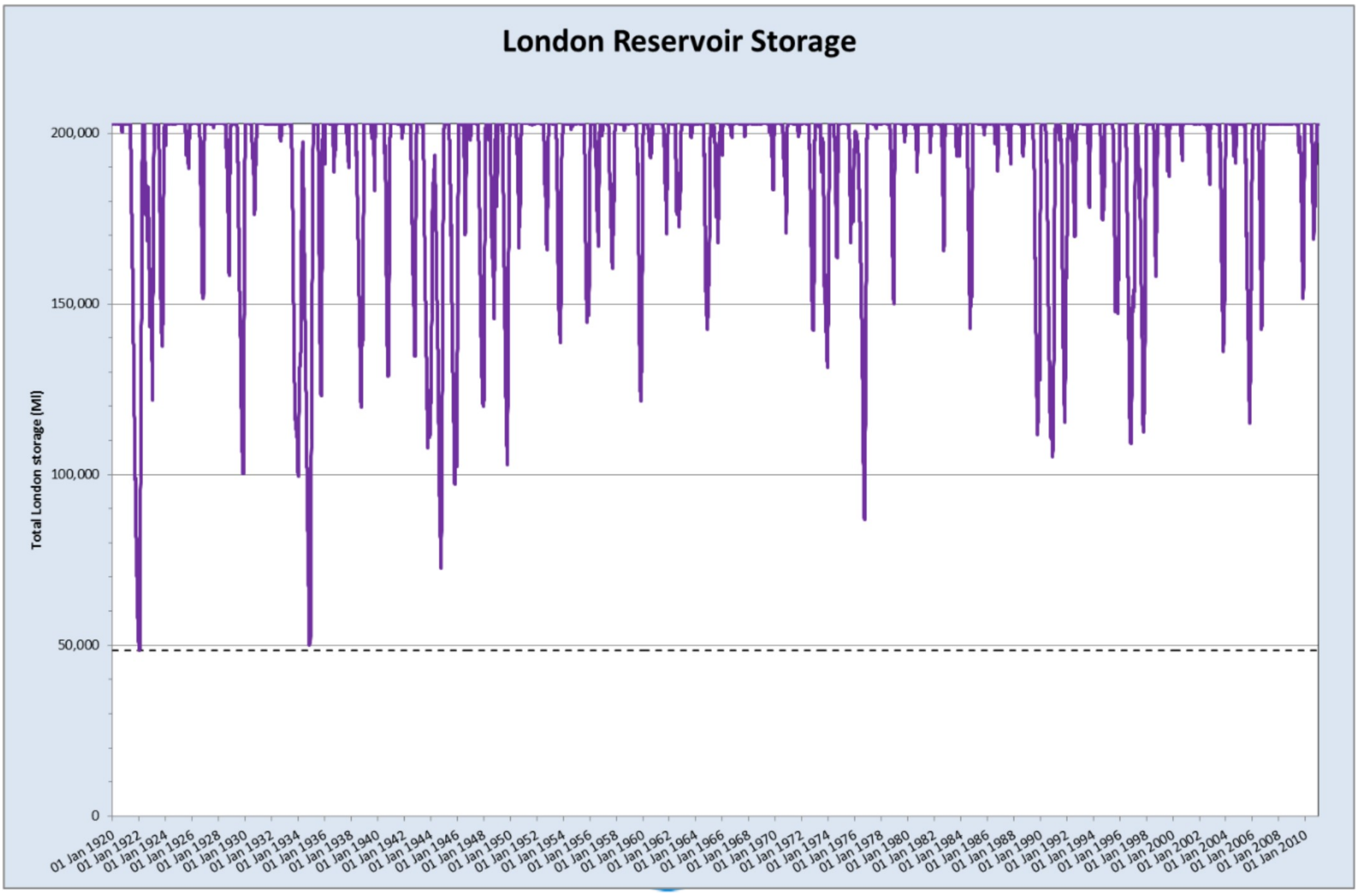
   Level 1 = **20** Level 2 = **10**

   Level 3 = **5** Level 4 = **Never**

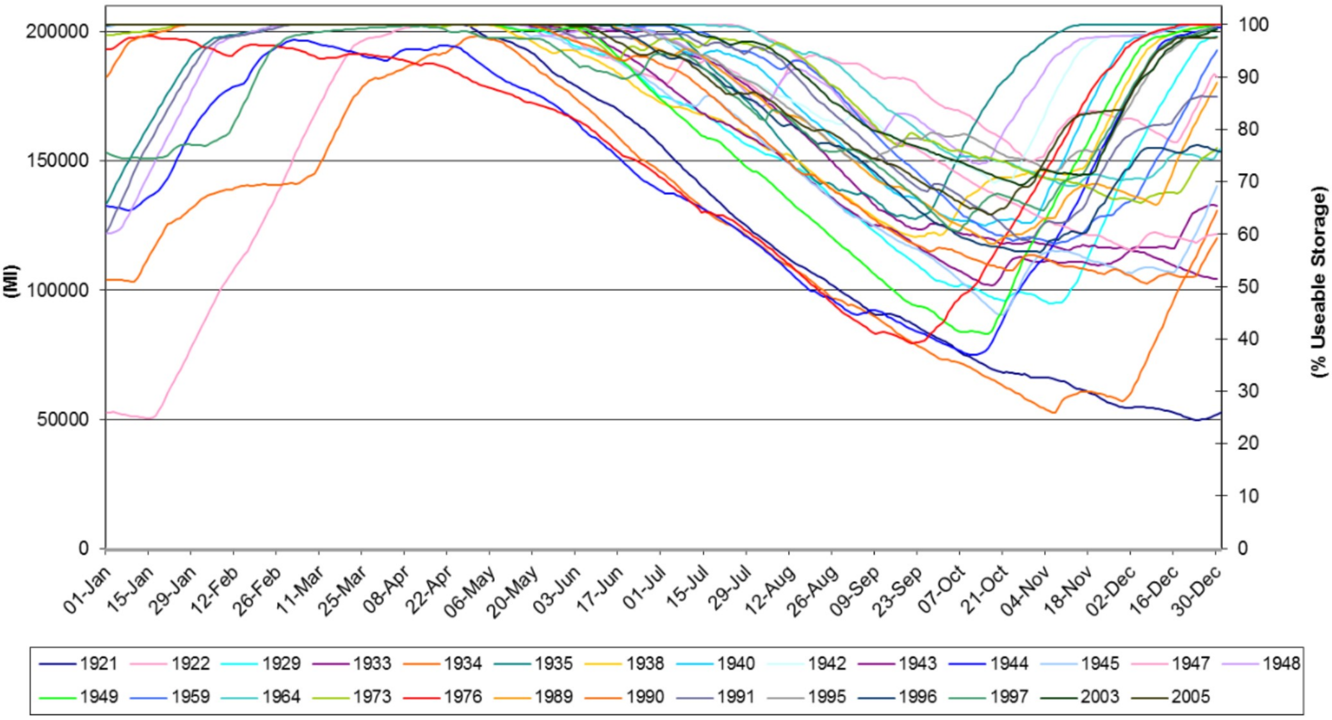
4. The model is automatically run again with a change in demand so as to maximise the demand whilst meeting the Level of Service.

5. The DO is the maximum demand the system can support whilst meeting the requirements of the Level of Service.

Calculation of London's Deployable Output *(cont'd)*



London Reservoir Storage for Selected Years



Optimising the LTCD

Defining the problem

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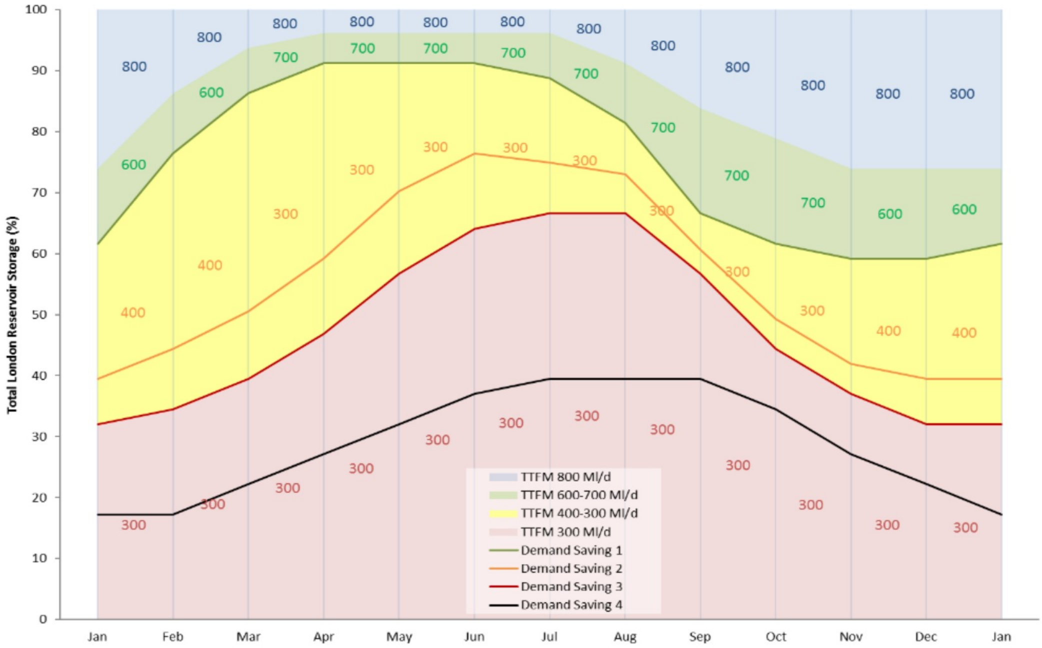
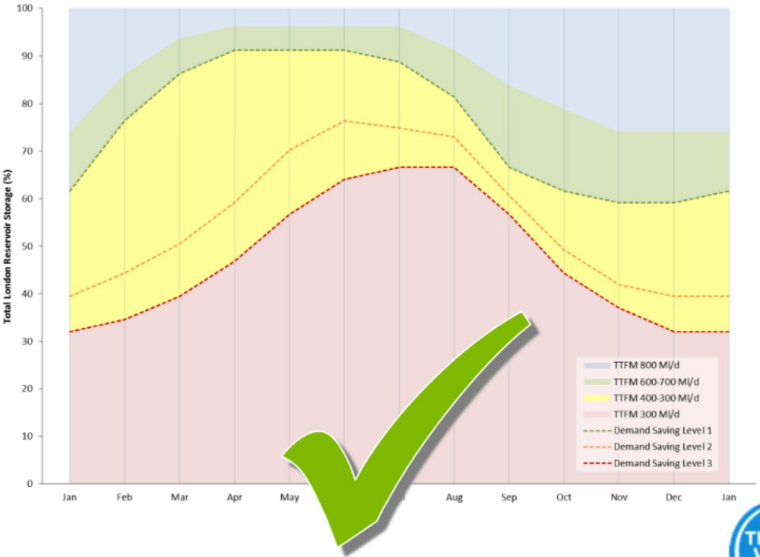
Starting Position

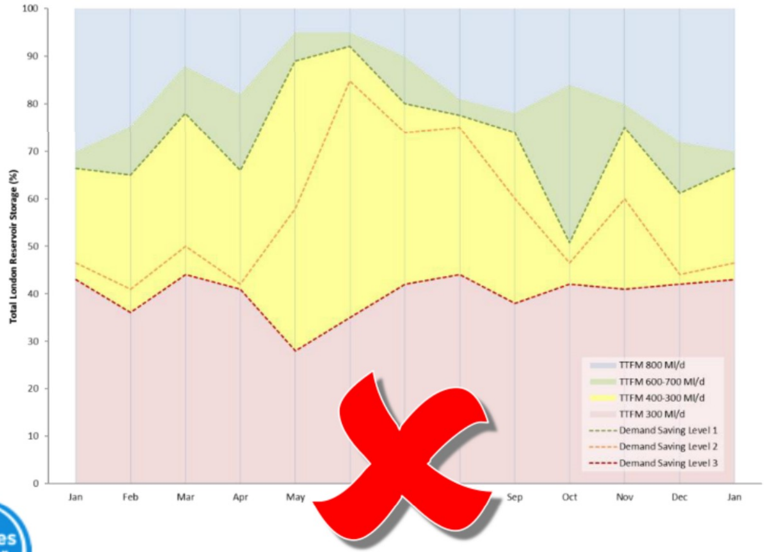
- Assume Useable Capacity of 202,828 Ml
- Teddington Target Flow Matrix *(TTFM)* as EA scenario 2:



Objectives

- Maximise Deployable Output
- Minimise Curve Complexity
  (making curves acceptable to practitioners)





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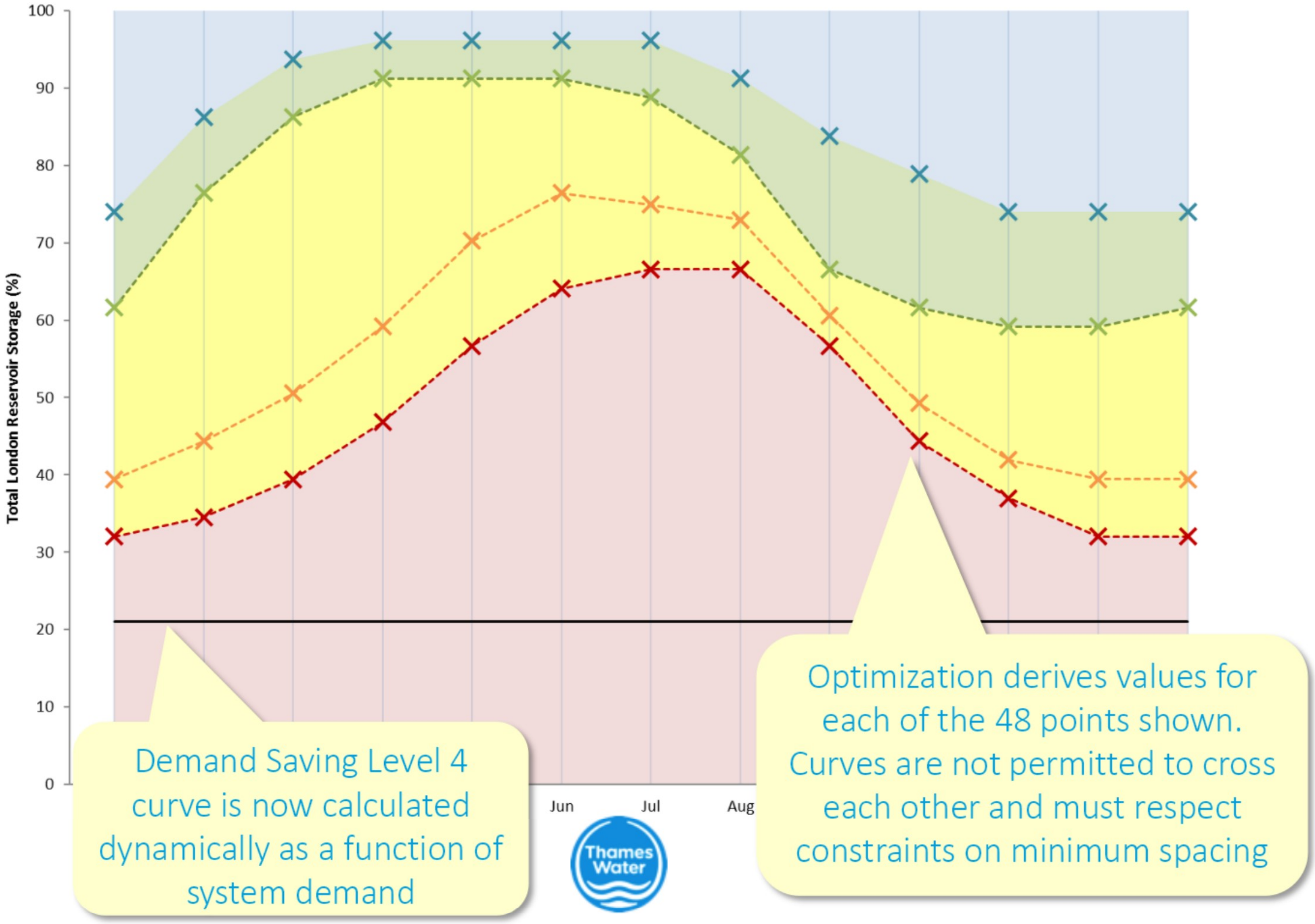
Decision Variables



Constraints and Criteria

- Level of Service (LoS) maintained at:
  - Level 1: *1-in-5 years*
  - Level 2: *1-in-10 years*
  - Level 3: *1-in-20 years*
  - Level 4: *never*
- Impact of Flood & Water Management Act 2010:
  - minimum number of **14 days** from Level 1 to Level 2
  - minimum number of **56 days** from Level 2 to Level 3
- TTFM – Band 1 to Band 2 line no higher than the current 800/600 TTF line, 195,000 Ml or 3.86% of useable capacity.

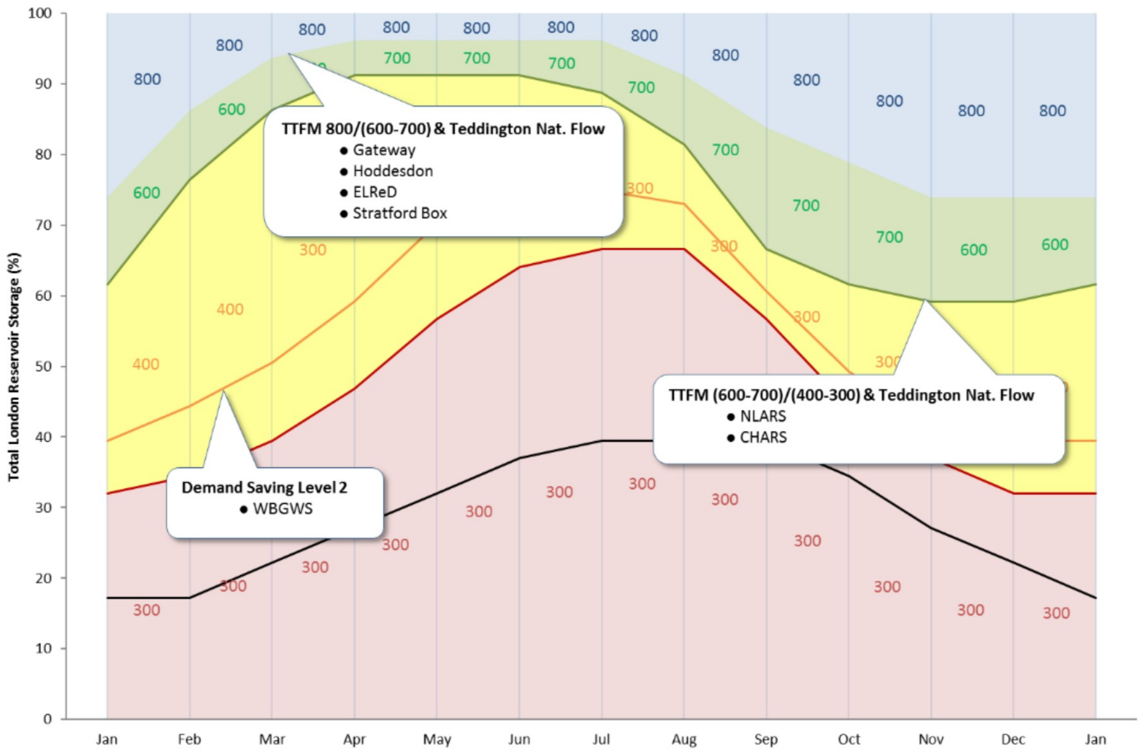
Thames Water

Constraints and Criteria *(cont'd)*

- Level 1 LoS line = TTFM Band 2 / TTFM Band 3 line.
- Level 3 LoS line = TTFM Band 3 / TTFM Band 4 line.
- Flow threshold band widths should be at least **3.5%** of the total London storage.
- A "dynamic" Level 4 LoS line based on the demands on the reservoir system in the simulation, equivalent to 30 days storage.
- There must be **no** failures reported during the model run.

Constraints and Criteria *(cont'd)*

- Water resource scheme triggers are also "dynamic" in that they use the lines on the LTCD within their trigger configuration.



Optimising the LTCD

Solving the problem

Genetic Algorithms & Aquator

Developed GA optimization in 2008 firstly for single reservoir control curves and then multiple curves for multiple, conjunctive reservoirs

Latest version runs with AquatorXM

Has been used on projects for:

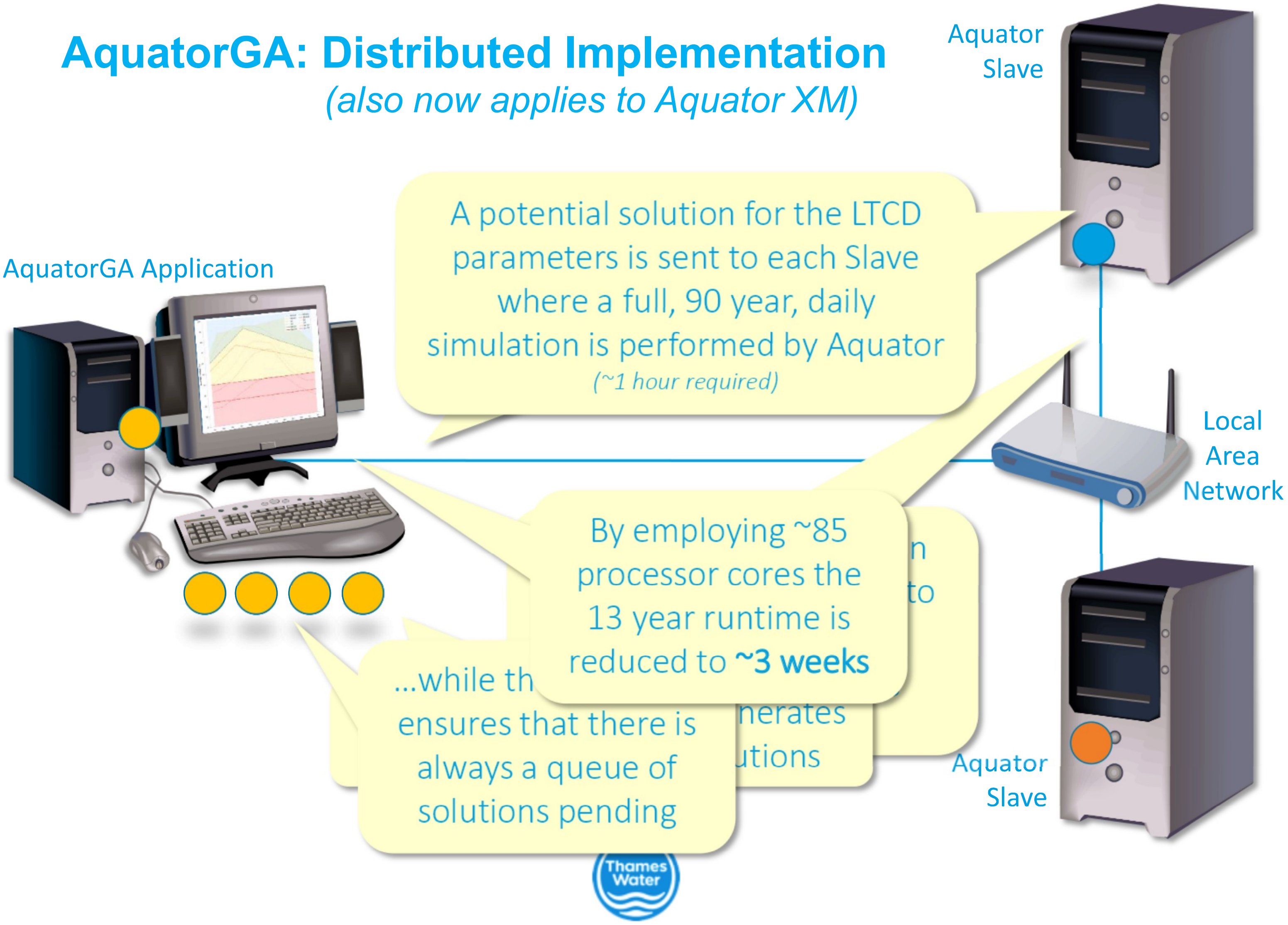
- United Utilities
- Thames Water
- Dŵr Cymru Welsh Water
- Scottish Water

Problem Complexity

- Genetic Algorithms are adept at handling problems of *extreme* complexity and with a *variety* of constraints
- **2.8 × 10^{158}** different solutions of the LTCD problem
  - *281,474,976,710,656,000,000,000,000,000,000,000,000,000, 000,000,000,000,000,000,000,000,000,000,000,000,000,000, 000,000,000,000,000,000,000,000,000,000,000,000,000,000, 000,000,000,000,000,000,000,000,000,000,000*
- Using the Genetic Algorithm approach, this search space was sampled and evaluated using just **120,000** solutions
- Each solution takes **~1 hour** to simulate on a reasonably fast PC
  - Still **over 13 years** to run the optimization on a single PC

AquatorGA: Distributed Implementation

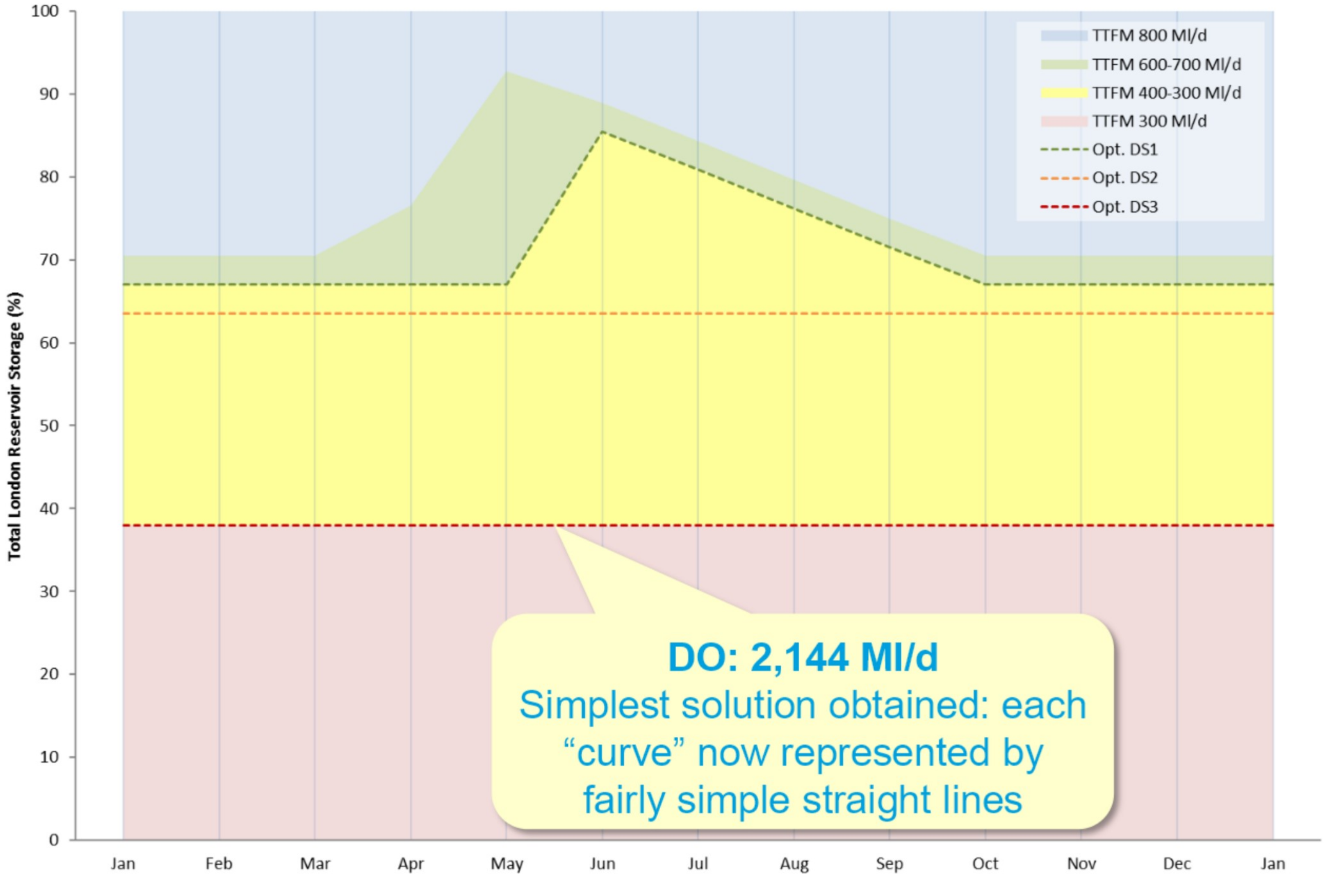
(also now applies to Aquator XM)



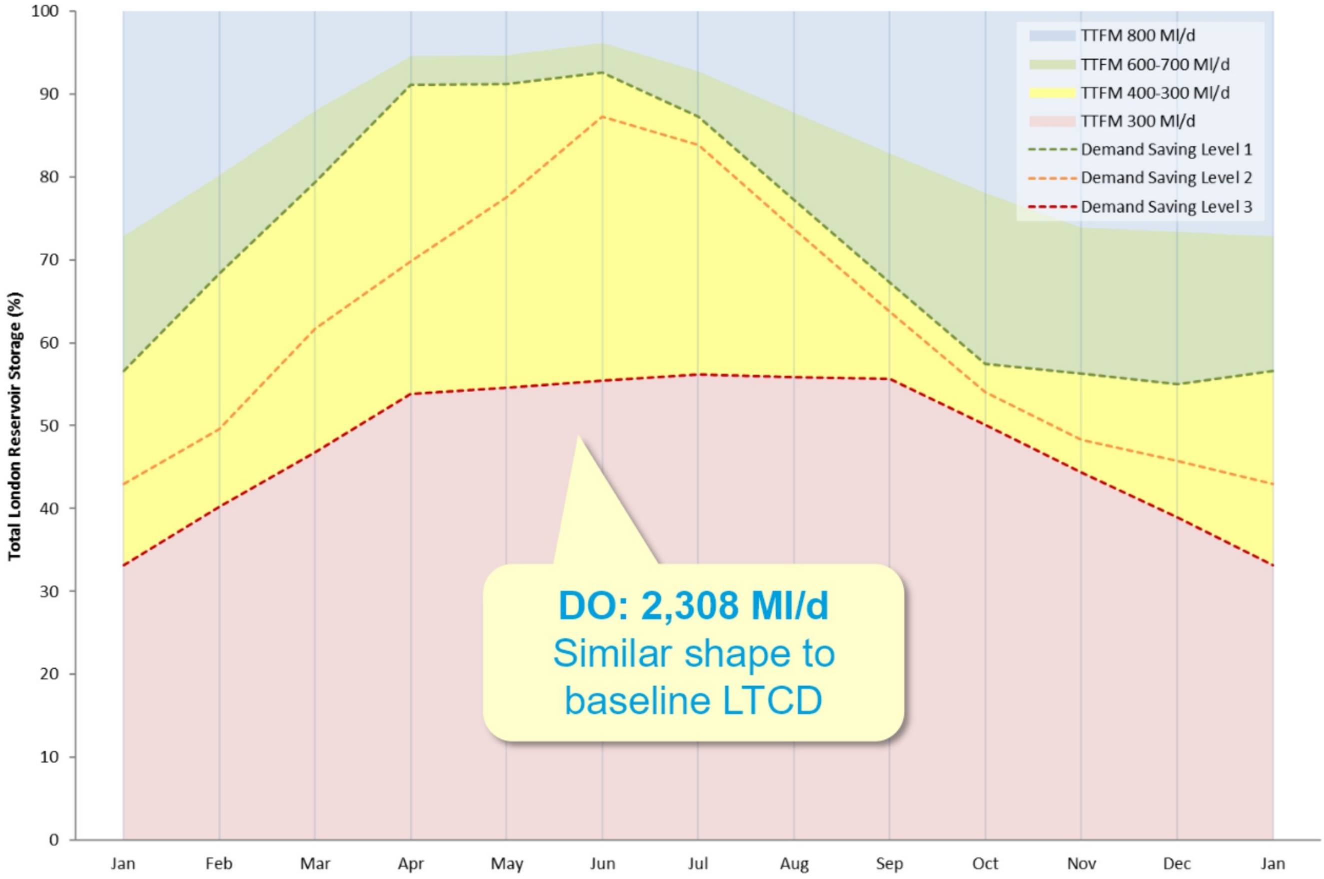
Optimising the LTCD

Results

Example Results *(least complex, lowest DO)*



Example Results *(most complex, highest DO)*

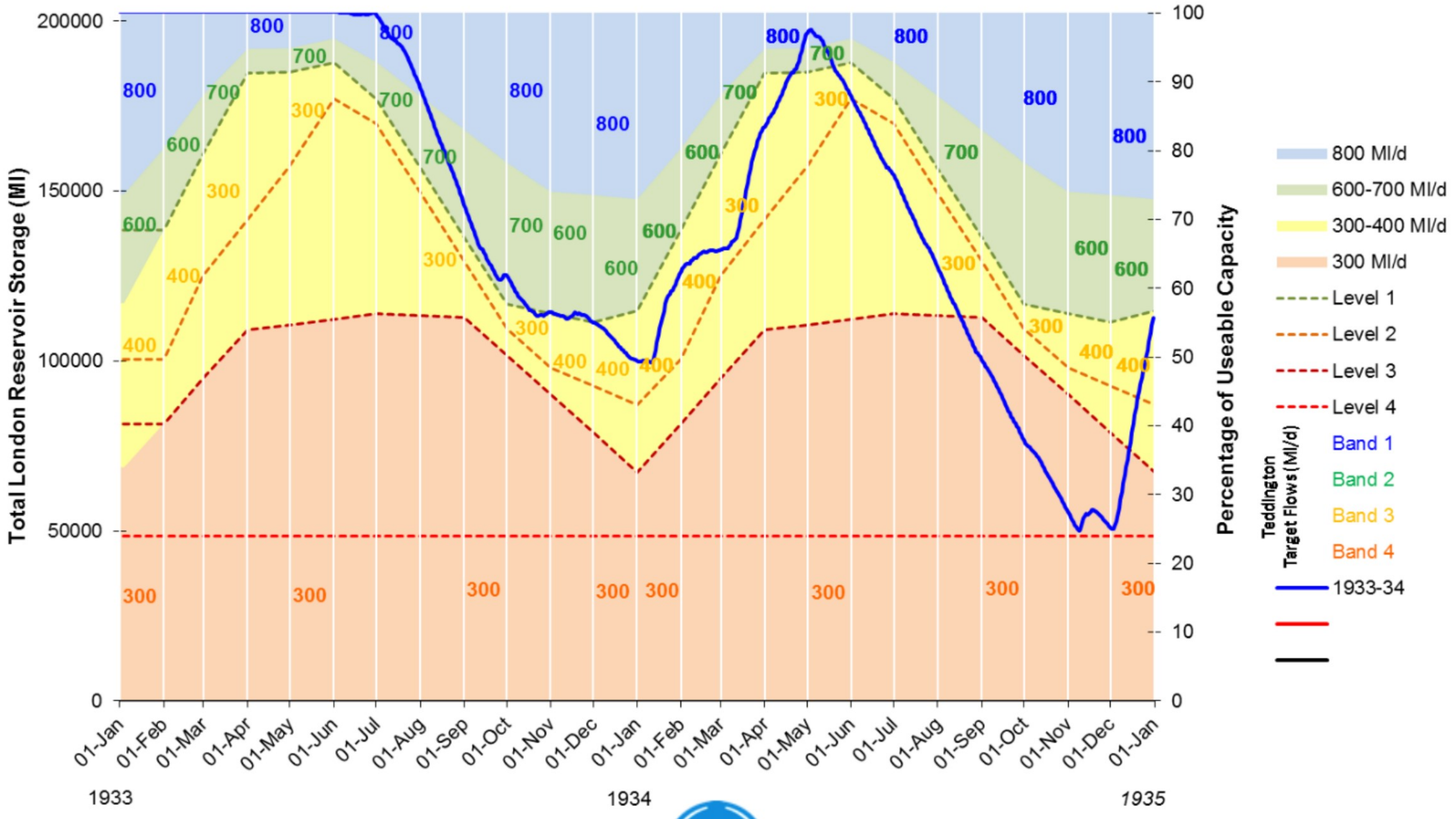


Summary of Results

LTCD	DO	Improvement
Original	2,285* Ml/d	n/a
Optimized *(simple)*	2,144 Ml/d	-141 Ml/d = -6.2%
Optimized *(complex)*	2,308 Ml/d	+23 Ml/d = 1.0%

** The original LTCD violates the constraint requiring 56 days to elapse between triggering Demand Saving Levels 2 and 3 when run for the entire historical data set. The DO of the baseline when considering that constraint is ~2,086 Ml/d.*

New LTCD vs Historical Drought 1933-1935



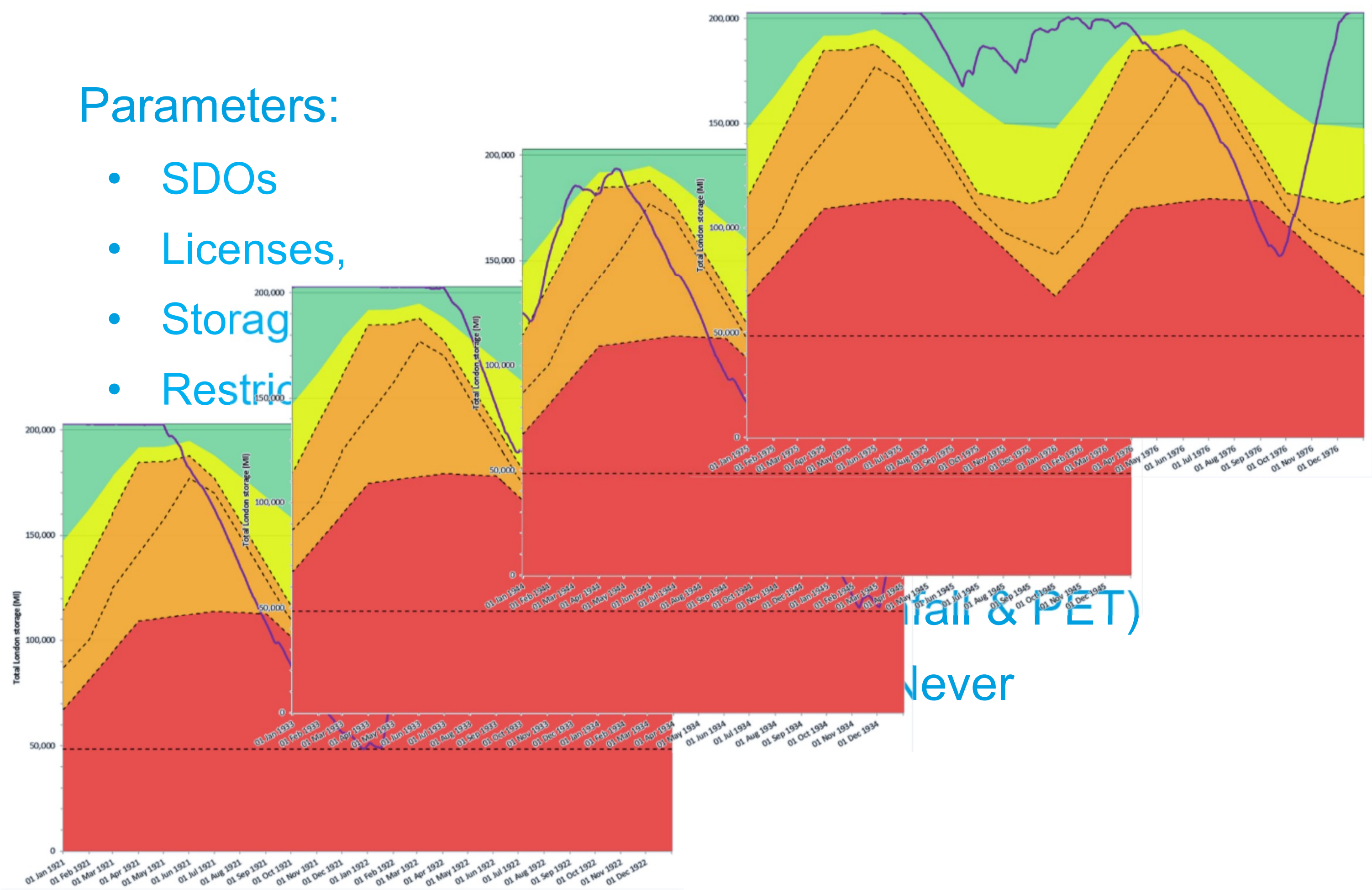
WARMS2 Calculation of Deployable Output (DO)

Parameters:

- SDOs
- Licenses,
- Storag
- Restric

fall & PET)

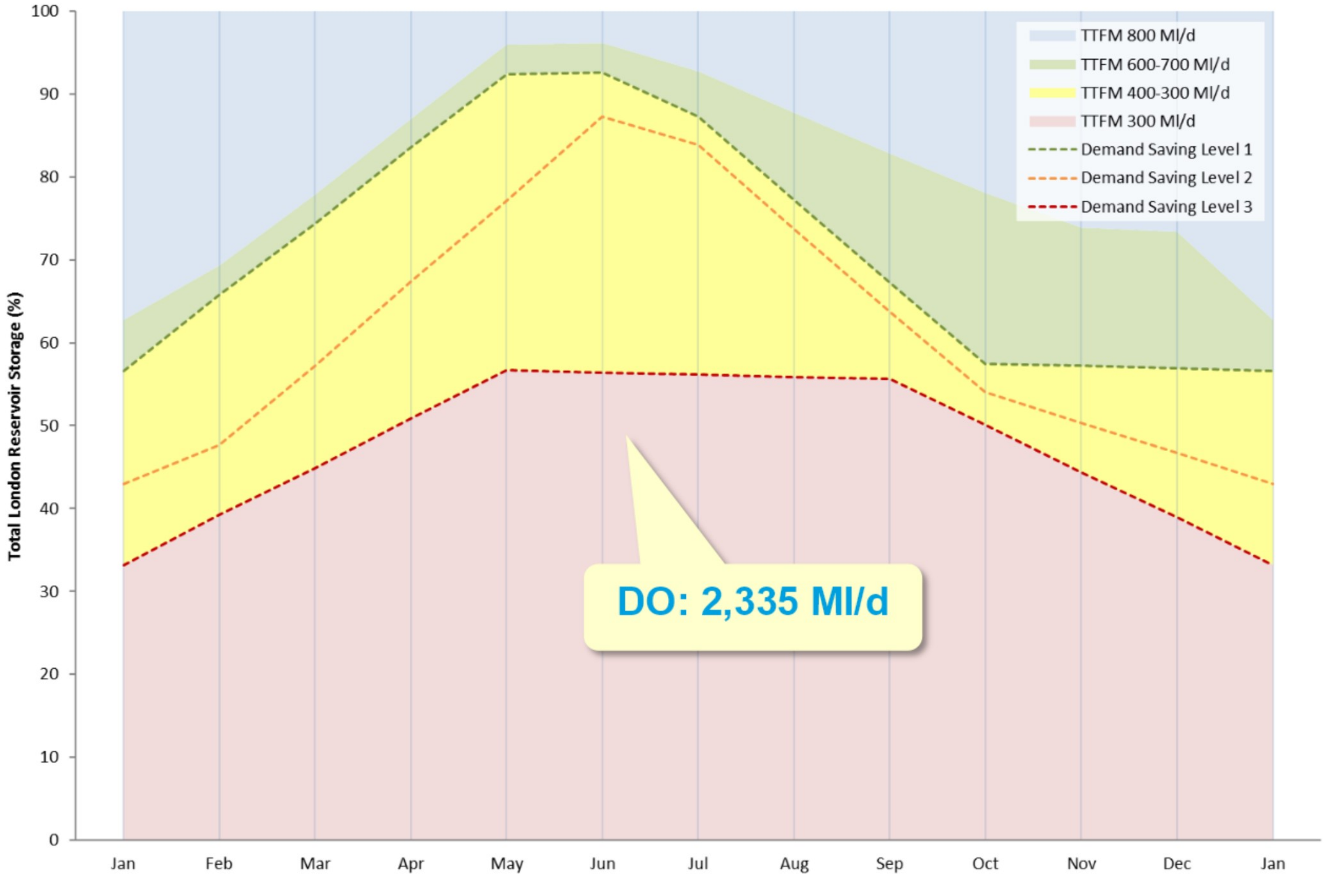
Never



LTCD Optimisation – Increased Storage

- The total reservoir storage capacity of the London system has increased by extracting aggregate from one of the reservoirs.
- This has resulted in a net increase in capacity of **~6,000 Ml** *(approximately 3% of the total storage).*
- The operational infrastructure would need to be upgraded to take advantage of this additional volume of water.
- The optimization was re-run to investigate the effect this would have on the DO of the system as a whole.

Example Results *(most complex, highest DO)*



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Optimized *(simple)*	2,144 Ml/d	-141 Ml/d = -6.2%
Optimized *(complex)*	2,308 Ml/d	+23 Ml/d = 1.0%
Additional Storage	2,335 Ml/d	+27 Ml/d = 1.2%

*As can be seen, the introduction of this additional storage – a relatively cheap operation – has allowed significant **additional** flexibility in the operation of the system as a whole, resulting in a **further** improvement of **1.2%** in DO being realised by the optimization.*

Conclusions

Water Resources Briefing

- Teddington Target Flow Matrix introduced to LTCD
- LTCD Optimisation Results of:
  +23 Ml/d (1.0%) and **+27 Ml/d** (1.2%)
- Agreed with the Environment Agency
  - Yet to be formally adopted
- AR16 DO 2305 Ml/d

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