Strategic analysis of the water system impacts of data centre development in Greater London and the Thames Basin

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22.5.26

Summary

- Data centres require cooling to work efficiently, which can be delivered using water or with air conditioning. The scale and speed of data centre rollout currently envisaged for the coming years presents challenges with both approaches. Our modelling suggests that it will not be possible to use water cooling for all planned data centres in the Thames Basin given the limitations of the water system.
- Using water for cooling data centres can greatly increase stress on water systems. If all currently planned data centres for London and the South East went ahead and were designed to use 'evaporative cooling', this could require 10% of London's current water supply. Total demand during hot weather could be equivalent to the amount of water flowing through the Thames in Teddington in one day.
- An alternative approach is to use water for cooling and then release it, for example into waterways, though the impact on water temperatures needs to be controlled to avoid unwanted impacts on aquatic life.
- Given these challenges, many developers are instead proposing to use air conditioning for cooling. This, however, comes with its own problems, increasing data centres' energy consumption (which is already likely to be large) by as much as a third and therefore exacerbating the energy and emissions challenges associated with data centre rollout.
- Reuse of waste heat is desirable in principle but faces various practical barriers which have so far prevented widespread implementation of this approach.
- To deliver data centres sustainably, it is essential to consider the variability of both air temperature and water availability. This study models, for illustration, an approach under which a relatively water-efficient approach to cooling is adopted, heat is discharged into London's sewer system until wastewater reaches 27°C (to prevent technical problems) and on very hot days the system switches to dry cooling.
- Delivering an approach like this would require high-level cooperation between the relevant authorities, however, including Thames Water. Currently there is no process in place for considering the cumulative impact of data centre proposals in terms of the water system, or for facilitating coordination between regulators.

The problem

Data centre expansion in the UK is set to have a significant impact on UK power and water networks, with some anslyses anticipating a 20% increase in national energy demand[1]. This is especially pronounced in Greater London and the Thames Basin, which have so far attracted the majority of investment for data centres[2]. While the power demand is mostly derived from running the server hardware, cooling can represent up to 30% of the total electrical load. Both air and water can be used to cool these data centres, but water options tend to consume less power, especially during hot periods, since water has a higher capacity to absorb heat than air. Water can be partially heated or evaporated in this process. It can also be used to move part of the excess heat cheaply to homes or agriculture[3,4,5]. However, this typically has some downsides: any evaporated water is lost for other uses; infrastructure upgrades may be needed to cope with the hot water or to transport it to where it is needed, and warm water may have environmental impacts if released into natural water bodies.

This leads to a situation where using water for cooling is likely to transfer part of the environmental problem from the power system onto the water system. While energy-related CO_2 emissions are reduced and electricity bills lowered, water availability – to households, for example – may be reduced, and water infrastructure may need to be upgraded. Striking the right balance in this situation requires systems thinking and an integrated approach to the water-power nexus. This report tries to address this challenge. It highlights the structural limitations of current cooling approaches, as well as the potential limits of the regional water system in coping with the heat that would come from cooling data centres. It also highlights the underlying potential for energy reuse through cooperative approaches. Taking London as a case study and using a model of the hydrology of the Thames River, it showcases the importance of studying water and power systems in an integrated way to balance environmental conservation with industrial growth.

Methodology

Our analysis began by estimating the overall demand for data centres in the Thames Basin; this area was selected as it represents the primary hydrological unit likely to be affected in the UK and must be evaluated as a single entity. We then identified the primary cooling options currently available to the industry and used these to develop seven scenarios to illustrate the water demand impacts. Most of these scenarios are presented for illustrative purposes and should not be treated as likely development alternatives, but rather as comparative benchmarks. We performed two types of analysis. A basic thermal mass evaluation was carried out of the effects of the basic scenarios (numbers 1-7) on the water and power systems. For scenario number 7, which combines water and power systems at its core, we then carried out a dynamic simulation using the Water Systems Integrated Model (WSIMOD) developed by

Imperial College London[6], which helps us see the benefits of a combined, strategic approach. Finally, we considered the implications of the results for strategic planning and infrastructure resilience.

The analysis

Power and water demand from data centres

The UK data centre market is concentrated in the South East, with approximately 80% of the nation's total capacity located in Greater London and the Thames Basin. The pipeline of proposed projects could, we estimate, add 2.8 GW of power demand in the near term (see Annex), which would need to be topped up with an extra 20%-30% of power for cooling, depending on the technology used. This growth is driven by high-density AI workloads, which require significantly higher power intensity than traditional cloud storage. For comparison, these 2.8GW would be able to supply 4-5 million households with all their electricity needs.

Heat dissipation is necessary for data centres because the heat produced by the chips could otherwise either damage the chip or reduce its performance. The processes of heat removal and internal reuse are constantly improving thereby increasing the computing output of data centres. However, even after these processes, the initial 2.8GW of power will all eventually become heat, which needs to be rejected into an external sink, whether this is water or air. The extra power needed to deliver cooling means that in total the 2.8GW will transform into a final 3.5GW of heat. This will need to be transferred either into the atmosphere (in the form of hot air or heat latent in water vapour) or into the water system (in the form of warm water at around 40°C). The following sections explain the approaches for delivering this cooling.

Data centre cooling options

i. *Evaporative:* very water-intensive, but highly energy-efficient, where the heat goes into water to make it evaporate, dramatically reducing the electrical power needed for cooling. While some facilities still use this system, currently planned data centres are avoiding it given its intense water requirement,
ii. *Adiabatic, optimised*: the current industry "go-to" system. The heat finds its way to the air with the help of water evaporation. It operates in dry mode for 97% of the year in the UK, using water only when temperatures exceed 21-23°C. However, its peak water demand occurs during summer heatwaves, which poses a problem and a limit to its scalability, since this is the time when water is more scarce. As a result, some operators are being forced to go back to a fully-dry mode system, which uses substantially more electricity and suffers disproportionately from extreme heat situations.
iii. *Fully dry:* very energy-intensive. This method relies on mechanical compressors and fans without any water assistance. While it eliminates on-site water use, it

creates a significant strain on the power grid and may end up being the forced fallback for adiabatic systems if water restrictions are imposed. Power demands during extreme heatwaves increase substantially.

iv. *Reject into water*: utilising a water body as a heat sink. In this case, the receiving water is warmed up, but remains on site. This is more stable than air-based systems and provides a consistent year-round sink at 10°C–15°C. It reduces the need for mechanical refrigeration but requires careful management of the thermal impact on the river or the wastewater system that receives the heat. While warm summer months can see temperatures of receiving water bodies rise, thus reducing efficiency, these variations are less extreme than air temperatures. The receiving water body can be the river Thames, canals or docks (some projects are looking into these options) or, as we shall discuss in this report, the Thames water sewage system. During dry months, this carries a larger amount of water than the river Thames itself and, as a result, has a larger capacity to accept heat with the wastewater network potentially dissipating heat[7]. Wastewater treatment plants can dissipate heat and also benefit during cold months form warmer effluent if temperatures are controlled[8].

v. *Heating reuse:* the most sustainable option. It involves capturing waste heat and "upgrading" it via heat pumps for residential, social or agricultural use. Water reuse is limited by the proximity of the data centre to the heat demand, however, and is less efficient in hot weather, which coincides with domestic heating demand being at its lowest. Even a well-insulated home needs 30-50% less hot water in the warm months compared to winter, when maximum reuse occurs. Public buildings such as swimming pools and hospitals have a more consistent hot water demand, but currently only 1-2 % of data centre heat is being reused.

Other options, such as heat rejection into bedrock, exist, but are not in full deployment yet and have not been included in this analysis.

Scenario development

To illustrate the implications of different technology choices, we assume the entire 2,800 MW regional pipeline adopts the cooling strategies described above, as well as some hybrid approaches.

1. **Exclusive evaporative:** All facilities use open-loop cooling towers (Op i).
2. **Exclusive optimised adiabatic:** All facilities use seasonal water misting (Op ii).
3. **Exclusive Fully Dry:** All facilities use air-cooled chillers/refrigerants (Op iii).
4. **50/50 Mix:** A split between adiabatic (Op ii) and dry systems (Op iii), which is most akin to current, real-worldproposals.
5. **Exclusive water body rejection:** All facilities reject heat into the water system (Op iv), either the river, or the sewer network.
6. **Exclusive heat reuse**: Heat from all facilities is reused in houses or agriculture (Op v).

7. **Balanced combination approach:** Power and water systems are combined into a single approach, assuming that the most efficient method is used according to water and air temperature, as well as water volume in the Thames. Heat is discharged to foul (Op iv), capped when the temperature reaches 27°C. Remaining heat is first drawn to the optimised adiabatic, which runs dry for days with temperatures below 25°C. On hotter days, water is drawn only when the Thames runs with above 1,000 million m3/day, otherwise dry cooling takes place. This constraint of the Thames discharge is studied in this scenario only since the model allows for this detailed analysis. Since a large proportion of treatment plants in London are located close to the estuary, discharge is likely to be in the tidal area. Seawater mix is likely to help dilute the effluent and reduce impact but detailed modelling of this is not included in this study.

Scenarios 1-6 are evaluated using a basic mass-balance approach. Scenario 7 is done using WSIMOD. In all cases, it is important to emphasise that this approach shows an averaged evaluation of the system. Since some of these data centres can constitute a substantial proportion of the demand, their concentrated effects are likely to be disproportionately large in particular areas and therefore potentially worse than assumed in this study.

Results

The following points outline the main outcomes of developing numeric mass calculations for Scenarios 1-6 and WSIMOD for Scenario 7 (Figures 1 and 2 in Annex 1)

- Scenario 1 (Evaporative): achieves high energy efficiency with a total power consumption of ~28.2 million MWh annually. However, peak summer water demand reaches ~195 million litres per day, approximately 10% of London's total daily supply. During extreme summer heat waves, the figures could grow so much that they could be comparable to the entire flow of the Thames River, which can be as low as 300 million litres per day. Storage capacity for this scenario would require the construction of major reservoirs around the city of London.
- Scenario 2 (Adiabatic): consumes ~29.4 million MWh annually. Water use is minimal for 9 months but spikes to ~135 million litres per day during heatwaves, which is not very different from Scenario 1. Similar to Scenario 1, storage capacity for this scenario would require the construction of major reservoirs.
- Scenario 3 (Fully Dry): the most disruptive to the power grid, requiring ~44.1 million MWh annually. During a 35°C peak, the cooling electrical load alone can reach 2,550 MW.
- Scenario 4 (Mixed): a balanced infrastructure profile requiring ~36.7 million MWh annually. This reduces peak-day water demand but adds nearly 1.5 GW of electrical

load to the grid compared to Scenario 5. Water demand is still large and likely to require the construction of a large reservoir.

- Scenario 5 (Rejection to water bodies): the most energy-efficient for the grid, with a total consumption of ~27.1 million MWh. It eliminates potable water use but injects a continuous 3,200 MW thermal load into the water network. In the case of using the river as a heat sink, that thermal load could, theoretically, heat the water by as much as 80°C, making it undeliverable[i]. Rejecting this heat into the sewer network raises wastewater temperatures by 14°C to 16.5°C on average. This range of temperatures, even if it took place in a homogeneous, non-concentrated manner across the entire system, would pose problems of potential odour and corrosion on sewers as well as severe operational problems on wastewater treatment plants, especially during summer.
- Scenario 6 (full reuse): the most sustainable system. It would provide heating for around 2 million people during winter, provided that this amount of homes (or greenhouse equivalents) are newly built near the data centres, or a similar number of homes are upgraded. It would still require heavy water-cooling during summer due to excess heat not being used.
- Scenario 7 (balanced combination): We used a daily simulation to evaluate this scenario using WSIMOD on a daily basis. The results are shown in timeseries in Figure 2 below.
    - Water in the sewer system is very frequently at its warmest limit (27°C), meaning that other systems need to enter into play. The effects of this water being discharged into the wastewater has the positive side-effect of increasing treatment efficiency. Timeseries 2 shows how keeping water warm (27°C) keeps ammonia (red line) lower than what would otherwise be without intervention (black).
    - Looking at the type of cooling active (timeseries 3), rejecting water into the wastewater (cheapest) is used all of the time actively at different intensities (black), with adiabatic only being turned on 50% of the time and dry cooling around 10%. During the warmest period, wastewater is contributing around 10-15% to the overall mix of cooling demand.
    - Looking at the flows (timeseries 4), water is only pumped 6% of the time when the Thames flow is larger than 1,000m3/day (purple line). This would assume there is no need to build a new reservoir.
    - The power and water consumption figures shown in Figure 1 are for the peak demand. It assumes that 15% of the load is taken by wastewater in Scenario 5, and the remaining one is taken by the mix outlined in Scenario 4.

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[i] It should be noted that these values assume a theoretical transfer of heat from the data centre to the water. However, achieving such high temperatures is not possible in practice, considering that warm water from the data centres is likely to be at 40°C. This means that the Thames itself does not have the actual volume required to accept the heat discharge.

Conclusions

There is no feasible way to cool all the datacentres planned for 2030 in the Thames Basin with water, in the absence of substantial infrastructure improvements (notably reservoirs). Scenarios 1 and – to a lesser extent – 2, which rely on water to cool during summer, would draw unacceptable flows from the Thames during hot months, or require building some of the largest reservoirs of the country, which suggests they are not realistic. Scenario 4 (mixed Op ii and Op iii), currently often seen as the most favourable approach in practice, poses a similar challenge of water shortage, although to a more limited extent (with a smaller reservoir required).

Options for exclusively rejecting heat into water bodies (Scenario 5) are equally undesirable since the Thames does not have enough water holding capacity, or the heat in Thames water sewers would pose significant challenges (14°C to 16.5°C), even if assuming there are no concentrated discharges. More sustainable options, such as linking the cooling to district heating, can only address part of the problem and still discharge large quantities of heat during summer.

Scenario 7 (combined power and water into a single system) is the most energy efficient option that could be deliverable in practice (with a 10-20% energy reduction compared to Scenario 4). It is likely to be even more favourable if combining this with the district heating option (Op v), since this technology will reduce further heat discharge. One caveat is that we did not, in our modelling, consider the concentrated effects of discharge or distance to the treatment plants, which may increase negative effects. Moreover, the effects of warm discharge into the Thames Estuary are yet to be evaluated, and coordination challenges will remain between companies and stakeholders. Nevertheless, the numbers showcase the benefit of integrated thinking when compared with a traditional, siloed approach.

A combined systems thinking approach, where we pair data centres with the entire water system, including its infrastructure and natural water bodies, could help to deliver a pathway for growth that is socially and environmentally acceptable and operationally resilient. This relates to the point introduced at the start – environmental burdens perhaps need to be partially shared between power and water systems. However, for this scenario to be delivered, coordination between power and water suppliers is required at a high level, as well as with other stakeholders and regulators.

Annex 1 - Thermal Calculations

This annex outlines the lumped thermal estimates used to quantify the infrastructure load.

1. **Thermal Rejection Capacity of Wastewater:**

Using the heat transfer formula $Q = \dot{m} \cdot C_p \cdot \Delta T$, we can calculate the capacity of London's wastewater stream.

- Thames Water daily treated flow: ~4.7 billion litres ($4.7 \times 10^9 \text{ kg/day}$).
- Wastewater specific heat capacity: $\approx 4.184 \text{ kJ/kg°C}$.
- A modest 5°C rise in the temperature of this entire stream provides a cooling capacity of **~1,138 MW**. To handle the full 3,200 MW reject load, the 4.7 billion litres would experience a total rise of **~14.1°C**.

2. **Latent Heat of Vaporization (Water Demand):**

Thermodynamic calculations for evaporative cooling rely on the phase change of water.

- Latent heat of vaporization: $\approx 2,257 \text{ kJ/kg}$.
- Theoretical minimum: 1.595 litres of water evaporated per kWh of heat removed.
- Applying the industry average WUE of 1.8 L/kWh for the 2.8 GW IT load ($24.5 \text{ million MWh/year}$), the peak day evaporation is estimated at ~121 million litres, with total makeup (including blowdown) reaching ~195 million litres.

3. **Electrical Power Demand for Cooling:**

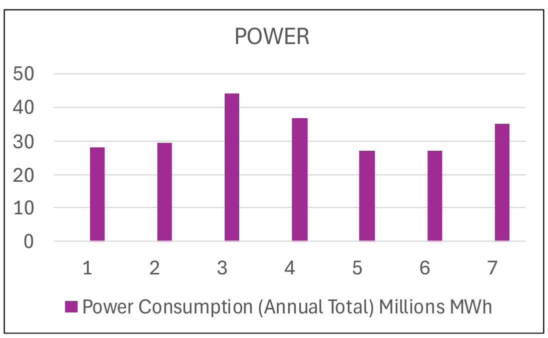
- **Adiabatic EER:** ~75 (dry mode) vs. ~4 (mechanical mode).
- **Cooling Load:** 100% of IT power is treated as heat rejection. For a 2.8 GW IT load, the auxiliary power for pumps/fans is modelled at ~400 MW, resulting in a total thermal load of **3,200 MW**.

4. **Scenario definition combining**

- If we were 100% adiabatic, we would need to dissipate E heat energy, and this would require, on a >25C day, 135 million litres (Figure 1).
- Thermal discharged into foul is W, removing most of the load.
- So we need to actually dissipate E - W.
- The amount of water, A, needed is scaled linearly so:

- A = (E-W) * 135 million litres / E
- Thames draw is limited to those days when flow > 1000 million litres. Otherwise dry cooling will be triggered. As result we may not actually be able to meet A.
- We draw down to 1000 million litres and then stop, giving a real abstraction of A'. and a heat energy dissipated by adiabatic:
  - (E-W)*A'/A
- The amount of energy needed to be dissipated by dry cooling is thus:
  - E - W - (E-W)*A'/A

	Scenario	Power Consumption (Annual Total)	Water Consumption (Peak summer Day)	Thermal Load into Foul (Peak Summer day)	Constraint
		Millions MWh	million l		
1	**Fully Evaporative**	28.2	195.6	Negligible	A large reservoir near London is required (Top 2 in the UK)
2	**Optimised Adiabatic**	29.4	135	Zero (Closed-loop)	A large reservoir near London is required (Top 2 in the UK)
3	**Fully Dry System**	44.1	Zero	Zero	Power demand equivalent to an extra million people
4	**Currently consensus Mix (50/50)**	36.7	67.5	Zero	Power demand for 800K people and reservoir (top 20 in UK)
5	**Heat Rejection to Foul**	27.1	Zero (Potable)	3,200 MW (Constant)	Add +16C to all foul or +80C to Thames
6	**District heat though Foul**	27.1	Zero (Potable)	2,000 MW (Summer)	Add +10C to all foul or +50C to Thames
7	**Balanced combination**	35.26	57.375	480MW	10-20% reduction from current consensus



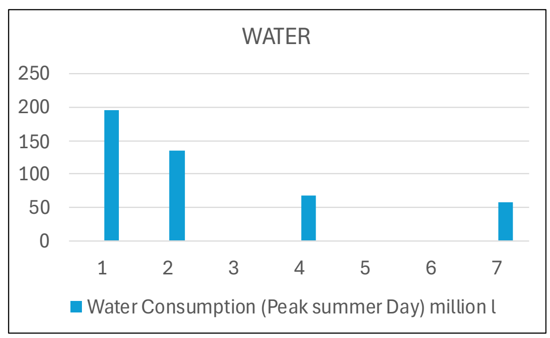


Figure 1: Overall numbers for Scenarios

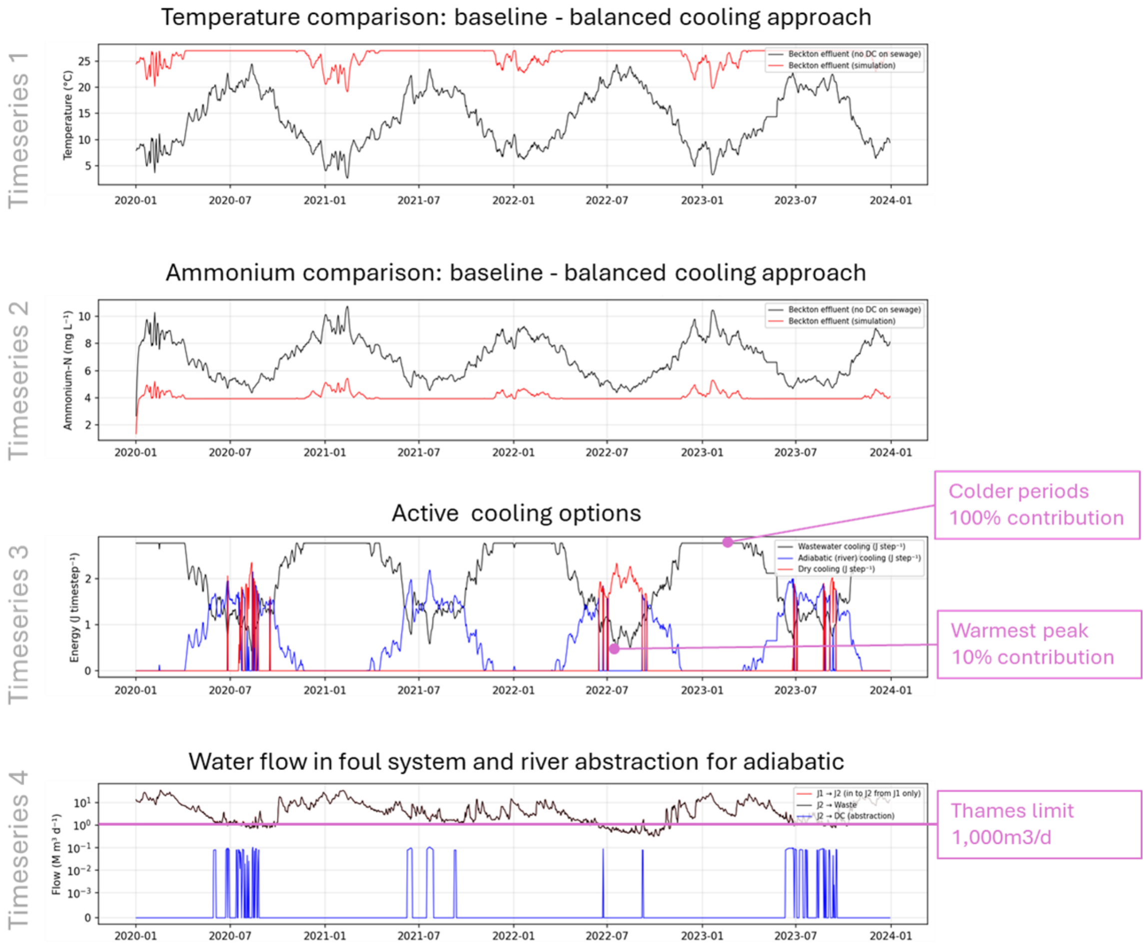


Figure 2: Daily WSOIMOD results for Scenario 7

Annex 2 - Full list of data centres

The 2,800 MW IT load estimate for the Greater London area and Thames Basin is justified by the following identified project pipeline:

Developer	**Location**	**Proposed Capacity (MW)**	**Status**
Digital Reef	East Havering	600	Planning
Ada Infrastructure	Royal Docks	210	Groundbroken
Global Technical Realty	Southall	180	Approved
VIRTUS	Stockley Park / Slough	175	Planned
Tritax Big Box	Slough	147	Planning
CloudHQ	Didcot	101 - 300	Approved
Amazon AWS	Didcot A	150 - 200	Planning
CyrusOne	Southall	100	Planning
Colt DCS	Hayes	97 (Expansion)	Under Construction
Microsoft	Park Royal	60 - 100	Under Construction
Other Regional Hubs	Regional Cluster	~800	Operational/Expansion
Total Pipeline	**Regional**	**~2,800 MW**	

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