Supporting material for CityWat: variables and parameters

Barnaby Dobson and Ana Mijic, Imperial College London, UK

# Summary

In this document we list all the parameters and state variables in CityWat for our model of London’s water cycle. We provide units and sources of information for parameters and inputs. We also provide parameter values.

# State variables

All state variables are defined on a given day, t.

|  |  |  |
| --- | --- | --- |
| Symbol | Description | Unit |
| adist,t | Water sent from freshwater treatment works direct to distribution | Ml/d |
| aFWTW,t | River abstraction direct to freshwater treatment | Ml/d |
| agw,t | Groundwater abstractions direct to freshwater treatment | Ml/d |
| arwh,t | Abstraction from rainwater harvesting storage to supply outdoor demand | Ml/d |
| aS,t | River abstraction direct to supply reservoirs | Ml/d |
| atarg,t | Maximum allowable and beneficial river abstraction | Ml/d |
| Cphosphorus,t | Concentration of phosphorus in the river downstream of effluent discharge | mg/l |
| Ddist,t | Treated water required by distribution network from service reservoirs | Ml/d |
| DFWTW,t | Demand at freshwater treatment works | Ml/d |
| Dh,base,t | Baseline demand | Ml/d |
| Dh,eff,t | Effective demand required by consumers from distribution network | Ml/d |
| Dh,tot,t | Total water demand on a given day | Ml/d |
| Idist,t | Total water supplied to the distribution network | Ml/d |
| Ih,rain,t | Amount of demand supplied by precipitation | Ml/d |
| Isewer,eff,t | Total effluent received by sewers | Ml/d |
| Isewer,target,t | Total effluent sent towards sewers | Ml/d |
| IWWTW, t | Input to wastewater treatment works | Ml/d |
| IWWTW,max,t | Maximum possible input to wastewater treatment works on a given day | Ml/d |
| LFWTW,t | Processing losses during freshwater treatment | Ml/d |
| LORt | Level of restrictions | - |
| LWWTW, t | Processing losses during wastewater treatment | Ml/d |
| montht | Month | - |
| MRFt | Minimum required flow | Ml/d |
| OFWTW,t | Output of freshwater treatment works | Ml/d |
| OFWTW,targ,t | Maximum beneficial freshwater treatment output | Ml/d |
| Og,t | Volume of pluvial flooding over greenspaces | Ml/d |
| Oh,t | Volume of effluent released from houses | Ml/d |
| Oimperm,t | Volume of runoff from impermeable surfaces to sewers | Ml/d |
| Omanhole,t | Water sent to sewers but spilled at manholes due to lack of capacity | Ml/d |
| Oreuse,t | Amount of treated effluent sent upstream for re-abstraction | Ml/d |
| Orwh,t | Spill from rainwater harvesting served rooves to sewers | Ml/d |
| Osewer,t | Total water output by sewers | Ml/d |
| Ountreated,t | Untreated effluent discharged to river | Ml/d |
| OWWTW, t | Treated effluent discharged into river from wastewater treatment | Ml/d |
| Pg,t | Total rainfall on greenspaces | mm |
| Pimperm,t | Total rainfall on impermeable spaces | mm |
| Prwh,t | Precipitation on rooves served by rainwater harvesting | mm |
| Qd,t | Flow downstream of abstractions | Ml/d |
| Rraw,t | Proportion of the river flow downstream of effluent discharge that is raw river water (i.e. not effluent) | - |
| Rreduction,t | Percentage to reduce demand by due to water use restrictions | - |
| Rtreated,t | Proportion of the river flow downstream of effluent discharge that is treated effluent | - |
| Runtreated,t | Proportion of the river flow downstream of effluent discharge that is untreated effluent | - |
| SDres,t | Storage in service reservoirs | Ml |
| Sg,t | Volume of water stored on greenspaces at end of timestep | Ml |
| Sg,targ,t | Total volume of water on greenspaces | Ml |
| Simperm,t | Volume of water stored on impermeable surfaces at end of timestep | Ml |
| Simperm,targ,t | Total volume of water on impermeable surfaces | Ml |
| SS,t | Storage in supply reservoirs | Ml |
| Sstorm,t | Volume of water stored in storm tanks at end of timestep | Ml |
| udist,t | Water released from service reservoirs to the distribution network | Ml/d |
| uDres,t | Release from freshwater treatment works to service reservoirs | Ml/d |
| uFWTW,t | Release from supply reservoirs to freshwater treatment | Ml/d |
| uFWTW,targ,t | Target release from supply reservoirs to freshwater treatment | Ml/d |

# Parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Symbol | Description | Unit | Value | Source |
| acap | Max river abstraction on a given day | Ml/d | 5,000 | Max change in historic storage (Waterfutures, 2020) plus max water demand (Environment Agency, 2019) |
| Agarden | Area of gardens in London | km2 | 350 |  |
| agw,targ | The target daily abstraction from groundwater sources | Ml/d | 300 |  |
| Aroof | Total roof area of London | km2 | 160 |  |
| Atotal | Area of London | km2 | 1,000 |  |
| aupstream | Constant daily abstraction upstream of London abstractions | Ml/d | 500 |  |
| Cphosphorus,raw | Concentration of phosphorus in raw river water | mg/l | 0.2 | Averaged from (Bowes et al., 2017) |
| Cphosphorus,treated | Concentration of phosphorus in treated effluent | mg/l | 2 |  |
| Cphosphorus,untreated | Concentration of phosphorus in untreated effluent | mg/l | 5 |  |
| Dhousehold | Per household consumption per day | l/d | 360 | (Environment Agency, 2019) |
| Dnon\_household | Total water demand not in households | Ml/d | 375 | (Environment Agency, 2019) |
| Eg | Total evapotranspiration over London’s greenspaces | mm | 1.5 | (est – average) |
| Eimperm | Total evapotranspiration over London’s impermeable surfaces | mm | 1.5 | (est – average) |
| Isewer,cap | Sewer input capacity | Ml/d | 10,000 |  |
| IWWTW,max | Maximum possible input to wastewater treatment works | Ml/d | 6,000 | (FOI-request, 2018) |
| Nhouseholds | Number of households covered by the model | - | 3.5e6 |  |
| OFWTW,max | Maximum possible output of freshwater treatment works | Ml/d | 3,000 | (est – round value greater than max water demand (Environment Agency, 2019)) |
| OFWTW,min | Minimum allowable output of freshwater treatment works | Ml/d | 1,500 | (est – round value less than min water demand (Environment Agency, 2019)) |
| Oreuse,max | Maximum amount of treated effluent that may be reused | Ml/d | Depends on option |  |
| PAED | Precipitation below which abstraction effluent-dilution cannot take place | mm | Depends on option |  |
| Rh,consumed | Proportion of indoor water use that is consumed | - | 0.1 |  |
| Rimperm | Proportion of area that is impermeable | - | 0.53 | (Mayor of London’s Office, 2020) |
| Rleak,dist | Proportion of distribution throughput that becomes leaked water | - | 0.2 | (Environment Agency, 2019) |
| Rleak,FWTW | Proportion of freshwater treatment input that becomes leaked water | - | 0.02 | (Thames Water, 2019) |
| Rleak,sewer | Proportion of sewer input that becomes leaked | - | 0.2 |  |
| Rleak,WWTW | Proportion of wastewater treatment input that is lost during processing | - | 0.1 |  |
| Rrain | Proportion of demand satisfiable by rainfall | - | 0.08 | (est - (Environment Agency, 2019) shows that 4% of water consumption is on external use, given that rainfall is greater than evaporation on about 50% of days, we double 4% to get the demand satisfiable by rainfall) |
| Rreuse | Proportion of treated effluent that can be reused | - | 0.15 | (est – max available effluent of Thames Water reuse options listed in (Thames Water, 2019) is around 15% of total treatment capacity) |
| Rrwh | Proportion of outdoor demand (and of roof area) served by rainwater harvesting | - | Depends on option |  |
| SAED | Supply reservoir storage below which abstraction effluent-dilution cannot take place | Ml | Depends on option |  |
| SDres,cap | Storage capacity in service reservoirs | Ml | 10,000 | Difference between given storage capacity and plotted storage capacity in (Mortazavi‐Naeini et al., 2019) |
| Sg,cap | Storage capacity of water on greenspaces | Ml | 80,000 | (est - 170mm attenuation over area) |
| Simperm,cap | Storage capacity of water on impermeable surfaces | Ml | 2350 | (est - 5mm attenuation over area) |
| Srwh,cap | Storage capacity of rainwater harvesting tanks | Ml | Depends on option |  |
| Ss,cap | Storage capacity in supply reservoirs | Ml | 194,755 | (Mortazavi‐Naeini et al., 2019) |
| Sstorm,cap | Storage capacity of water in storm tanks | Ml | 2,000 |  |
| ΔFWTW,max | Maximum rate of change of output of freshwater treatment works | Ml/d | 500 |  |
| ΔWWTW,max | Maximum possible rate of change of input to wastewater treatment works | Ml/d | 1,000 |  |

## Input data

|  |  |  |  |
| --- | --- | --- | --- |
| Symbol | Description | Units | Source |
| Pt | Total precipitation over London over a given day | mm | (Hollis et al., 2019) |
| Qa,t | Average flow over a given day upstream of abstractions | Ml/d | (Centre for Ecology and Hydrology, 2020) |

# References

Bowes, M., Armstrong, L., Wickham, H., Harman, S., Gozzard, E., Roberts, C., & Scarlett, P. (2017). *Weekly water quality data from the River Thames and its major tributaries (2009-2013)[CEH Thames Initiative]*.

Centre for Ecology and Hydrology. (2020). National River Flow Archive. Retrieved March 11, 2020, from https://nrfa.ceh.ac.uk/

Environment Agency. (2019). *Revised Draft Water Resources Management Plan 2019 Supply-Demand Data at Company Level 2020/21 to 2044/45*. Retrieved from https://data.gov.uk/dataset/fb38a40c-ebc1-4e6e-912c-bb47a76f6149/revised-draft-water-resources-management-plan-2019-supply-demand-data-at-company-level-2020-21-to-2044-45#licence-info

FOI-request. (2018). Data request - wastewater treatment information. Retrieved March 11, 2020, from https://www.whatdotheyknow.com/request/capacity\_of\_londons\_sewage\_treat

Hollis, D., McCarthy, M., Kendon, M., Legg, T., & Simpson, I. (2019). HadUK-Grid—A new UK dataset of gridded climate observations. *Geoscience Data Journal*, *6*(2), 151–159. https://doi.org/10.1002/gdj3.78

Mayor of London’s Office. (2020). Green cover of London. Retrieved March 11, 2020, from https://www.london.gov.uk/what-we-do/environment/parks-green-spaces-and-biodiversity/green-infrastructure-maps-and-tools#acc-i-54375

Mortazavi‐Naeini, M., Bussi, G., Elliott, J. A., Hall, J. W., & Whitehead, P. G. (2019). Assessment of risks to public water supply from low flows and harmful water quality in a changing climate. *Water Resources Research*, 2018WR022865. https://doi.org/10.1029/2018WR022865

Thames Water. (2019). *Water Resources Management Plan*. Reading.

Waterfutures. (2020). Historic reservoir storage. Retrieved March 11, 2020, from http://waterfutures-eastlondon.org.uk/index.html