ATKINS

Member of the SNC-Lavalin Group

Water Resources Management Planning

Groundwater Deployable Output Review

SES Water

Aug 2022

5197934_060

Notice

This document and its contents have been prepared and are intended solely as information for SES Water and use in relation to WRMP24

Atkins Limited assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 27 pages including the cover.

Document history

Document title: Groundwater Deployable Output Review

Document reference: 5197934_060

Revision	Purpose description	Origin-ated	Checked	Reviewed	Author-ised	Date
Rev 1.0	Draft	VC	KW	SCW	SCW	May 21
Rev 2.0	Final	VC	KW	SCW	SCW	Aug 22

Contents

Tables

Figures

1. Introduction

As part of its water resources management plan (WRMP) SES Water is required to calculate the total amount of water it can reliably supply over the course of a design drought which is called the deployable output (DO). For the Company's 2024 WRMP (WRMP24), the calculation of DO has been updated to reflect the current source constraints and revised design drought conditions.

This report documents the steps undertaken to update the baseline DO for SES Water's groundwater sources and the impact of climate change on DO.

2. Baseline DO assessment

2.1. Assessment overview

The DO assessment relates groundwater levels to abstraction rates in order to determine the reliable source output available over the course of a design drought. The peak DO (PDO) represents the available source output during the period of peak water supply 'strain', when demand is highest, whilst the minimum DO (MDO) represents the available source output during the period of lowest resource availability.

The DO assessment is based on three components: source constraints, the relationship between groundwater levels and abstraction, and the initial hydrogeological conditions. For this WRMP, focus has been given to updating the source constraints and revising the initial hydrogeological conditions to enable the DO of different drought severities to be calculated.

The process for calculating the DO is as follows:

- Stochastic climatic datasets are used in combination with lumped parameter models to calculate groundwater levels at two aquifer-specific reference observation boreholes (OBH), Chipstead and Riverhead, for a range of drought severities.
- These drought groundwater levels are scaled to SES Water's abstraction sources as rest water levels (i.e. water levels without pumping) and the relationship between groundwater levels and abstraction (as determined by pumping tests / operational data), termed the 'drought curve', downshifted by this amount.
- The source DO is calculated based on the intersection of the drought curve with the most constraining source constraint.

The following sources are unavailable for use within the planning period and have therefore been excluded from the DO assessment: Secombe Centre, Fetcham boreholes, The Clears, Pains Hill and Duckpit Wood.

2.2. Resource constraints

Accurate constraint evaluation is important for robust DO assessments; bringing the assessments up to date and / or reducing the uncertainty associated with the existing constraint information improves the confidence in the resultant DO values. Using the data provided by SES Water and the Environment Agency, a targeted set of tasks identified during a review in 2016 have been undertaken. In addition, cross checks on group licence constraints, treatment works capacities and pump capacities have been conducted and new data incorporated. The results of this work and implications on the DO assessment are set out in Table 2-1. The following key points are noted:

- The review of historical abstraction rates identified a number of sources that did not pump at the reported WRMP19 PDO during the recent droughts of 2012 and 2018. In most of these instances, outputs during these periods was slightly lower that the WRMP19 PDO but in some cases they were slightly higher. In the main, the differences between the actual rates pumped and the PDO are small (typically less than 0.5 Ml/d) and it is not clear whether the actual abstraction rate is a reflection of demand or of an overstated/understated DO (e.g. actual pump output may be lower than recorded nominal pump capacity when pumping lifts are that much greater during drought). Unless explicit evidence was available that recorded output constraint capacity was incorrect, the DO assessments have not been updated to limit PDO to 2012 / 2018 abstraction rates.
- Distribution network constraints have not been considered or applied to the source DOs
- Elmer and Leatherhead sources are now listed on the same licence. However, due to the complexities of these sources the DO assessment has been undertaken separately as per previous WRMPs.

- The DO source assessment spreadsheets have been cleaned to remove information that has been superseded. However, further work is recommended to streamline and unify these documents to ensure the assessments are clear and auditable.

Table 2-1 - Review of infrastructure constraints

Group	Source	Task	Result	Outcome for DO assessment	Other change made to DO constraints
North Downs Chalk	Cheam	(1) Check the elevation of the adit roof. (2) Check how high above the adit roof the minimum PWL needs to be. (3) Check whether output exceeds 12 Ml/d (e.g. with 3 rather than only 2 BHs operating) during the 2012 / 2018 droughts.	(1) Adit elevation (floor) is 42.35 mbGL (0.5 mAOD). Adit height is 1.8 m. Adit roof is 2.3 m.[1] (2) DAPWL to be 1 m above adit roof (more consistent reference point than adit floor). (3) Cheam daily abstraction is ~12 Ml/d in late 2011-early 2012 (WHI minima in March 2012) and in late-2017. This is consistent with WRMP19 PDO assessment of 12 Ml/d.	DAPWL reduced by 0.2 m, from 3.5maOD to 3.3 maOD (set at 1m above adit roof) Confidence 12 Ml/d can be achieved during drought (depending on drought severity)	-
	Cheam Park	None	-	-	-
	Springclose Lane	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is 2 Ml/d[2] (2) Abstraction may decline during drought; during 2012 drought abstraction reduces from 2 Ml/d to 1.7 Ml/d. However, due to periods of non-pumping, there is limited data to assess abstraction during drought period (Nonsuch Park minima in March 2012). There was limited abstraction during the second half of 2017, but abstraction between December 2017 and January 2018 also declines from 2 Ml/d to 1.85 Ml/d.	No change to pump capacity of 2 Ml/d. This may be a slight overstatement (~0.3 Ml//d) of capacity in drought.	-
	Langley Park	(1) Obtain details of Jul 16 pump replacement (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is reported as 1.9 Ml/d[2]. However, this data source also notes that a new pump was due to be installed July 2016. There was no change in stated pump capacity between WRMP14 and WRMP19. No further information available. (2) Daily abstraction is slightly less than pump capacity (1.9 Ml/d, WRMP19 PDO constraint) during droughts (~1.5 Ml/d 2012 and 1.7 Ml/d in 2017).	Pump capacity of 1.9 Ml/d assumed. This may be a slight overstatement (~0.2 Ml//d) of capacity in drought.	-
	Nonsuch Park	(1) Check whether BH1 and BH2 pumps are both 9.6 Ml/d and why they can't pump together - is this just to avoid licence breach of 12 Ml/d or hydrogeological (2004 CRT suggested 11-12 was viable for 3 weeks but HSI said radial flow model thought >8Ml/d not viable for 3 months)	(1) Pump capacity is (BH1) 9.6 Ml/d and (BH2) 9.6 Ml/d[2]. Boreholes can only run individually but no further information available on the justification. Daily abstraction was ~5 Ml/d during 2012 and 2017 droughts (limited by annual average licence)	No change to DO assessment	-
	Sutton	(1) Check whether Operations have had any turbidity issues when pumping during 2012 / 2018 droughts (or before) and at what PWLs.	(1) No turbidity issues identified from spot sampled raw data (from BH1-4) during 2012 and 2017 drought (turbidity remained below 0.95 NTU)[3]. Abstraction during this time was typically between 2 and 3.5 Ml/d. There was one failure from BH2 during 2015 (4 NTU), however this appears to be a deviation from the trend.	No change to DO assessment	-
	Sutton Court Road	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is 1.95 Ml/d[2]. (2) Abstraction may decline during drought: during 2012 drought abstraction reduces from 1.4 Ml/d to 1.1 Ml/d (Nonsuch Park minima in March 2012) which is less than the WRMP19 PDO (1.5 Ml/d, constrained by pump cut out). There is no abstraction during late 2017.	No change to DO assessment. This may be an overstatement of DO by ~0.4 Ml/d. However, no evidence is available to confirm this.	-
Woodmansterne	Chipstead	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is 5 Ml/d[2]. (2) Daily abstraction was ~4 Ml/d during 2012 drought (Well House Inn minima in March 2012) which is less than the WRMP19 PDO (5 Ml/d, constrained by pump capacity). The source has been out of supply in recent years including 2018.	No change to DO assessment	-
	Holly Lane	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is 6.5 Ml/d[2]. (2) Total daily abstraction ~6.3 Ml/d during 2012 drought (Holly Lane minima in April 2012). This is slightly less than the pump capacity (0.2 Ml/d). There was no abstraction during 2017.	No change to pump capacity of 6.5 Ml/d. This may be a slight overstatement (~0.2 Ml//d) of capacity in drought.	Apportioned licence adjusted to account for Outwood Lane coming online.

Group	Source	Task	Result	Outcome for DO assessment	Other change made to DO constraints
	Woodmansterne	None	-	-	
	Outwood Lane	(1) Check source is operational and if so, pump duty	(1) Source became operational from mid-July 2019. Pump capacity is 5 Ml/d[4].	New DO assessment required for this new source	New DO assessment created
	Smitham	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum) (3) Check whether pump is slightly throttled as new pump database suggests	(1) Pump capacity is 5.85 Ml/d[2]. (2) Daily abstraction ~4 Ml/d during 2012 drought (Woodcote minima in April 2012) and consistently 4.5 Ml/d during late-2017 drought period which is less than the WRMP19 PDO (5.7 Ml/d, constrained by licence) but no evidence this is due to drought constraints. (3) Uncertain; pump could be throttled but the abstraction rate could also be a reflection of demand.	No change to DO assessment.	'-
Hackbridge	Hackbridge and Goatbridge	(1) Check current Wandle Laundry aggregation agreement and recent Wandle Laundry abstraction to identify how much to deduct from Hackbridge licence	(1) The 2016 licence change simplified the conditions slightly. The licence stipulates 30 day rolling and annual abstraction constraints based on the volume recharged during the preceding winter. There are constraints relating to the Hackbridge, Goatbridge and, not yet commissioned, Bishopsford Rd boreholes, with aggregate totals for the group, for Goatbridge with Wandle Laundry and the group with Wandle laundry. SES Water could potentially recharge 730 Ml between 1 November and 31 March. However, recent years the recharge volume is more typically within the 280-350 Ml constraint band stipulated on the licence. This reduced recharge is partly due to the cost of operating the recharge scheme (in most years the high recharge volumes are not required). SES Water also tries to avoid recharging before December to avoid any potential impact on the sensitive trout spawning season[5] The Wandle laundry licence volume reduced in August 2016 to 3 Ml/d daily peak and 1.133 Ml/d annual average. Wandle Laundry is entitled to take its maximum licensed volume, although abstraction is more typically ~0.4 Ml/d Due to the proximity of Oaks to Hackbridge, recharge water is dominantly fed from Oaks. However the recharged water can be obtained from a number of sources; raw water from Oaks and Woodcote combines with Cheam (North Downs Chalk) group sources at Cheam WTW, with an offtake for Hackbridge recharge before the treatment plant. In previous DO assessment iterations, the recharged water has been assigned to Cheam group.	Update Hackbridge DO assessment with the assumption of: - Up to 350 Ml recharge - Wandle Laundry can abstract up to the licence The following contingent licence constraints are therefore assumed: - 16 Ml/d daily peak, 13.87 Ml/d 30 day rolling, up to 8.57 Ml/d annual average Update Cheam DO assessment with the assumption: - 730 Ml recharge (conservative assessment) thereby reducing the annual Cheam group licence to 11300 Ml/yr - Abstraction in winter increases to cover supply and recharge requirements, with a reduction in the remaining months to ensure licence limits are honoured (29.56 Ml/d).	'-
Unconfined Chalk	Oaks	(1) Check that 9.4 Ml/d abstraction can be achieved and PWLs during 2012 / 2018 droughts	(1) Abstraction during 2012 drought slightly declined from 8.5 Ml/d to 7.8 Ml/d (Well House Inn minima in March 2012). This is less than the WRMP19 PDO assessment (9.9 Ml/d, constrained by pump capacity – BH1 + BH2/3 + Oaks Park). This difference is suspected to be due to historical usage but is unconfirmed. Pump capacity is (BH1) 3.62 Ml/d, (BH2) 5 Ml/d, (BH3) 5 Ml/d.[2] Oaks Park is currently disused whilst awaiting a new flow meter, but is assumed to come back online within the planning period. As such it has not been excluded from the site pump capacity.[8]	Output during drought may be slightly overstated (0.78 Ml/d, excluding Oaks Park which is currently offline).	Inclusion of Abstraction Incentive Mechanism constraint: - average abstraction limited to 7 Ml/d when Well House Inn is less than 89 m aOD. Apportioned equally across Oaks and Woodcote based

Group	Source	Task	Result	Outcome for DO assessment	Other change made to DO constraints
	Woodcote	(1) Check source is operational and if so, pump duty (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity[2] is 4.6 Ml/d. (2) Abstraction has decreased since the early 2000s when abstraction was ~4.85 Ml/d. During 2012/2017 abstraction was 4.6 – 4.7 Ml/d.	No change to pump capacity. Pump capacity may be slightly under reported, but this rate is reflective of what can be achieved during drought conditions	on similar historical abstraction rates - peak abstraction limited to 12 Ml/d when Well House Inn is less than 89 m aOD. Apportioned across Oaks and Woodcote 7.4 Ml/d vs 4.6 Ml/d based on Woodcote pump constraint of 4.6 Ml/d.
Kenley	Kenley	(1) Confirm whether pumps have been lowered (thought to have happened in 2012)	(1) Pump cut out levels significantly changed during WRMP19, which is believed to be reflective of the pumps being lowered.	No change to pump cut off – change already captured in assessment.	'-
	Purley	(1) Check depth of pumps and pump cutouts and what happened with pumps/riser in 2012 (notes in BH construction records in WRMP14 file 50)	(1) Depth to suction pump: BH5: 84 m, BH6: 82 m, BH7: 42 m. These were updated in WRMP19	No change to pump cut off – change already captured in assessment.	'-
Mole Valley	Fetcham Springs	(1) Review total spring flow since 2006 (particularly 2012 / 2018 droughts) (2) Review augmentation requirements and 1in50 yr adjustment	(1) Spring abstraction between 2006 and 2009 is ~9 Ml/d. During the 2011-2012 drought abstraction between ~0 and ~12.5 Ml/d. (Well House Inn minima in March 2012). SES Water does not record total spring flow; the Fetcham spring flows into a sump, from which SWS Water abstract a portion with the remainder overflowing into the River Mole at Mole Lane[8]. (2) WRMP19 slightly updated the DO assessment. In WRMP14, the DO was calculated as: mean total springflow of peak week abstraction during 2006 and two weeks either side (PDO) / minimum average monthly total calculated springflow in 2006 (MDO) minus 0.5 Ml/d allowance for flow to Fetcham Ponds (offtake is downstream of meter to Elmer WTW and flow is not metered) all multiplied by 90% to make arbitrary allowance for a 1:50 yr drought total springflow. It was noted that there were insufficient total springflow data to allow prediction of springflow reduction from OBH groundwater level record. In WRMP19, the assessment was updated to remove the 10% reduction to represent 1:50 yr drought on the basis that there were insufficient data to link groundwater levels with spring flow and that abstraction was predominantly demand driven. SES Water does not record total spring flow, and therefore it is not possible to review whether a relationship exists between DO and climate. However, it should be noted that the current assessment (based on WRMP14) is based estimated total spring flow in 2006 (rather than abstraction as reported in WRMP19); total spring flow was estimated for 2006 based on a limited number of spot flow measurements of spring overflow.	Clarity that that the 2006 data are estimated total spring flow.	Minor correction to the mean total springflow for 13/5/06 - 16/6/07.
	Elmer & Young	None	-	-	

Group		Source	Task	Result	Outcome for DO assessment	Other change made to DO constraints
		Leatherhead	(1) Check pump configuration and operational constraints. ((2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Reported pump capacity is (BH7) 11.53 Ml/d, (BH8) 12.96 Ml/d, (BH9) 17.5 Ml/d, (BH10) 11.53 Ml/d[2]. Abstraction data confirms that one borehole is normally operated, but higher outputs can be reached. Whilst there are theoretically no constraints on pump configuration, SES Water estimate a maximum flow would be 45 Ml/d. Typically, only 2 pumps are run together due to water quality constraints, but this general practice rather than a configuration constraint.[9] Current DO assumption is that up to 3 boreholes can pump at one time. (2) Daily abstraction ~14 Ml/d during 2012 drought (Well House Inn minima in March 2012). BH7: 13 Ml/d, BH8: 10.8 Ml/d, BH9: 18 Ml/d, BH10: 14 Ml/d (pumps operating individually). During late 2017, only BH7 was operating (5.5 Ml/d). Where pump capacity is greater than abstraction, it is unclear whether this is due to lower demand rather than incorrect pump capacity.	No change to DO assessment. Some uncertainty over pump capacity, with recent abstraction at BH7 being 8 Ml/d less than the reported pump capacity. However, no evidence that the pump has been changed and capacity reduced.	Updated Elmer WTW capacity (84 Ml/d). Not apportioned as this constraint does not constrain abstraction from the sources that feed this WTW.
Lower Greensand		Dorking	None	-	-	
	Sub group	Buckland	None	-	-	
		Clifton's Lane	None	-	-	
	Sub group	Warwick Wold	None	-	-	
		Brewer Street	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is (BHB) 1.1 Ml/d, and (BHC) 3.2 Ml/d[2]. (2) Abstraction may slightly decline during drought; abstraction reduced from 1.26 Ml/d (slightly above the BHB pump capacity) to 1.08 Ml/d (approximate to the pump capacity) (Pendell Farm Hythe and Folkestone March 2012 minima). Similarly, in 2017 abstraction declined from 3.5 to 3.3 Ml/d.	No change to pump capacity. Pump capacity at BHB may be slightly under reported, but this rate is reflective of what can be achieved during drought conditions	
	Godstone sub group	Bletchingley	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum) (3) Check whether Ops tweak VSDs to prevent 3.5Ml/d.	(1) Pump capacity was designed to be 3.5 Ml/d. However, pump capacity is actually 3 Ml/d. (1) Daily abstraction is ~3 Ml/d during 2012 drought (Riverhead minima in April 2012) which is equivalent to the actual pump capacity. In 2017 abstraction is more variable around 2-2.5 Ml/d, but no evidence that this reduced rate is not due to demand.	Pump capacity reduced by 0.5 Ml/d to 3 Ml/d.	Godstone WTW treatment capacity (16 Ml/d) apportioned across group to ensure PDO is within this. Apportioned based on other constraining features to maximise abstraction potential.
		North Park	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum) (3) Check what pumps can operate together (2007 DO calculated that all 3 can theoretically)	(1) Pump capacity is (BHA) 1.8 Ml/d (BHB) 1 Ml/d (BHC) 1.8 Ml/d (2) North Park daily abstraction is ~1 Ml/d during 2012 drought (March 2012 Pendell Farm Hythe and Folkestone minima) which is comparable to the pump capacity from BHC. There was no abstraction during late 2017. However, abstraction in early 2017 and during 2018 shows a general slight decline of ~0.1 Ml/d over the period of operation (to ~1.8 Ml/d). (3) There may be water quality blending constraints across the wider group. However, Godstone WTW feeds an isolated WRZ and thus reduction in abstraction below the PDO is likely to be related to demand[7]	No change to DO assessment	
		Godstone	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum) (3) If PDO is not reached, is this due to the actions of the Ops team	(1) Pump capacity is 2.8 Ml/d[2]. (2) Daily abstraction is ~1.9 Ml/d declining to 1.8 Ml/d during 2012 drought (Riverhead minima in April 2012) which is less than the WRMP19 PDO assessment (2.6 Ml/d, constrained by site daily licence). Although historically abstraction has been greater (2.6 Ml/d) rates have been falling since 2000. Assumed that the pump capacity is still correct and lower abstraction rates due to	No change to DO assessment	

Group		Source	Task	Result	Outcome for DO assessment	Other change made to DO constraints
				demand. Daily abstraction is reasonably constant at 1.7 Ml/d in late-2017. (3) Godstone WTW feeds an isolated WRZ and thus reduction in abstraction below the PDO is likely to be related to demand[7].		
		Flower Lane	None	-	-	
	Westwood subgroup	Water Lane	(1) Check installed pump capacity (2) Check 2012 output (drought conditions) (3) Check water quality constraints	(1) Pump capacity is 2 Ml/d[2]. (2) Daily abstraction is ~ 1.5 Ml/d during 2012 drought (Riverhead minima in March 2012) which is less than the pump capacity (WRMP19 PDO constraint). There was minimal abstraction during 2017. (3) Water quality constraints - pesticide issue at Water Lane B. Volume from Water Lane B should be no more than 55% of total treated flow at Westwood WTW. Iron and manganese are at a significant level in Water Lane B.[6]	DO assessment updated with apportioned Westwood WTW capacity (55% of 8 Ml/d = 4.44 Ml/d)	
		South Green	(1) Check installed pump capacity (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) Pump capacity is 2.3 Ml/d[2] (2) Total daily abstraction ~1.8 Ml/d during 2012 drought (Riverhead minima in April 2012) which is less than the WRMP19 PDO assessment (2.2 Ml/d, constrained by licence) but no evidence this is due to drought constraints. There was no abstraction for a period in 2017, but generally abstraction over 2017-2018 is ~1.8 Ml/d.	No change to DO assessment	
		Westwood	(1) Check if any new PWLs with which to confirm shape and position of drought curve. (2) Check output & PWLs in during the 2012 / 2018 droughts (GWL minimum)	(1) No groundwater level data have been made available (2) Total daily abstraction ~2 Ml/d during the 2012 drought, depending on the combination of boreholes used (Riverhead minima in April 2012) which is less than the WRMP19 PDO assessment (5.6 Ml/d, constrained by DAPWL). The daily abstraction during 2017-2018 was highly variable and so no clear evidence PDO can't be achieved. Pump capacity is (BH4) 2 Ml/d, (BH5) 4.1 Ml/d, (BH6) 2.8 Ml/d, and (BH7) 2.8 Ml/d.[2]	No change to DO assessment	

Data sources:
[1] Cheam No.1 borehole record.pdf, provided by SES Water in WRMP14
[2] Borehole data mar 2017.xls, provided by SES Water
[3] Sutton_Sources_TurbidityData.txt, provided by SES Water
[4] pers comm. email from Alison Murphy SES Water, 20/08/2020
[5] Initial environmental assessment discussion minute notes, attended by SES Water, Environment Agency and Atkins, 20 August 2020
[6] pers comm, email on 02/09/2020, Rob Baldry, SES Water
[7] pers comm. email on 09/09/2020 Alison Murphy, SES Water
[8] pers comm. email on 15/09/2020 Laura Taylor, SES Water
[9] Pers comm. email on 25/11/20 Liam Ahearne, SES Water

2.2.1. Impact of updating resource constraints

Table 2-2 and Table 2-3 compare the reported WRMP14 1:50 year and WRMP19 Worst Drought on Historical Record (WDHR) DO values respectively with those calculated using the updated resource constraints. The initial water levels have not been updated for this assessment to enable a direct comparison with the previous data. These tables demonstrate that whilst MDO is relatively similar between the assessments, the constraint update results in an impact on PDO for these drought scenarios in the region of +/- 10 Ml/d.

Table 2-2 - Difference in DO from WRMP14 1:50 due to change in resource constraints

Source group	MDO (Ml/d)			PDO (Ml/d)			Comment
	WRMP14	Updated	Difference	WRMP14	Updated	Difference	
North Downs Chalk	29.35	28.59	-0.76	41.38	42.62	1.24	WRMP change to Sutton pump cut off
Woodmansterne group	29.45	34.57	5.12	34.82	35.31	0.49	Outwood Lane pump capacity increased. Holly Lane change in constraint to DAPWL
Hackbridge	8.47	8.57	0.10	17.20	13.87	-3.33	Change in recharge assumptions
Unconfined chalk	9.10	7.00	-2.10	14.00	12.00	-2.00	AIM added
North Downs Chalk	22.79	22.79	0.00	24.90	41.28	16.38	Kenley and Purley constraints significantly altered in WRMP19 (pumps lowered)
Mole valley	50.34	50.50	0.16	68.45	68.79	0.34	Fetcham boreholes removed
Lower Greensand	37.43	34.83	-2.60	40.25	36.15	-4.10	WRMP19 updates to pump capacity / cut off at Bletchingley, Brewer Street Warwick Wold, Westwood). Godstone WTW constraint added
Total	186.93	186.85	-0.08	241.00	250.02	9.02	

Table 2-3 - Difference in DO from WRMP19 WDHR due to change in resource constraints

Source group	MDO (Ml/d)			PDO (Ml/d)			Comment
	WRMP19	Updated	Difference	WRMP19	Updated	Difference	
North Downs Chalk	29.29	30.13	0.84	47.85	47.92	0.07	Apportioned licence constraint for Cheam updated
Woodmansterne group	31.81	32.21	0.40	33.68	33.60	-0.08	Apportioned licence constraint for Holly Lane
Hackbridge	8.47	8.57	0.10	17.20	13.87	-3.33	Change in recharge assumptions
Unconfined chalk	9.10	7.00	-2.10	14.52	12.00	-2.52	AIM added

Source group	MDO (Ml/d)			PDO (Ml/d)			Comment
	WRMP19	Updated	Difference	WRMP19	Updated	Difference	
North Downs Chalk	22.79	22.79	0.00	41.28	41.28	0.00	No change
Mole valley	51.43	50.50	-0.93	69.92	68.79	-1.13	Fetcham boreholes removed (0.98 Ml/d)
Lower Greensand	36.70	36.74	0.04	44.69	39.14	-5.55	Godstone WTW constraint added
Total	189.59	187.93	-1.66	269.14	256.59	-12.55	

2.3. Initial hydrogeological conditions

2.3.1. Reference OBHs

As noted in Section 2.1, the source DO assessments are based on a relationship between groundwater level and abstraction determined from historical test pumping and/or operational data: the drought curve. This drought curve is downshifted by downshifting its rest water level origin to represent droughts of different severities. The method for determining the degree of downshift uses a scaling approach developed for WRMP14 that compares groundwater level fluctuations between key index boreholes and nearby observation boreholes. The scaling methodology accounts for the lack of a long-term groundwater level record at the abstraction boreholes.

In previous WRMPs, three key reference OBHs were used; Well House Inn OBH, Ashtead Park Freeman's School OBH and Riverhead OBH. For WRMP24 this has been rationalised to Chipstead OBH and Riverhead OBH for the following reasons:

- The Environment Agency has switched from using Well House Inn OBH to Chipstead OBH to monitor regional aquifer groundwater level trends as it has been interpreted that the former does not exhibit the full extent of severe drought recession to be considered representative of the wider North Downs Chalk aquifer and Atkins (2020a) recommended that SES Water also uses Chipstead OBH (rather than Well House Inn OBH) as the drought trigger borehole.
- Ashtead Park Freeman's School OBH has a limited duration historical record compared to Well House Inn (and Chipstead) OBH. To allow for long time series stochastic analysis, all Chalk source DOs have been scaled to Chipstead OBH.
- Atkins (2020a) recommended the use of Riverhead OBH as a dedicated Lower Greensand drought reference and trigger borehole.

2.3.2. Lumped parameter models

Lumped parameter models for the two reference OBHs, Chipstead OBH and Riverhead OBH have been generated. These follow similar assumptions to the Well House Inn and Riverhead models used in WRMP19. To enable an assessment of the DO sensitivity caused by switching from the reference OBH from Well House Inn to Chipstead OBH a lumped parameter model of Well House Inn has also been developed.

These models have been developed in VBA and are designed to accommodate stochastic climatic sequences. The climatic data sequences in these models use the Environment Agency's 'North Downs-South London' hydrometric area rather than the 'South London' area used in WRMP19 in order to better reflect the catchments being modelled. The models have been calibrated to the period 1998-2018.

Calibration of the three lumped parameter models is presented below. The r^2 values for the linear relationship between modelled and observed groundwater levels for Well House Inn, Chipstead and Riverhead are 0.924, 0.904 and 0.819 respectively.

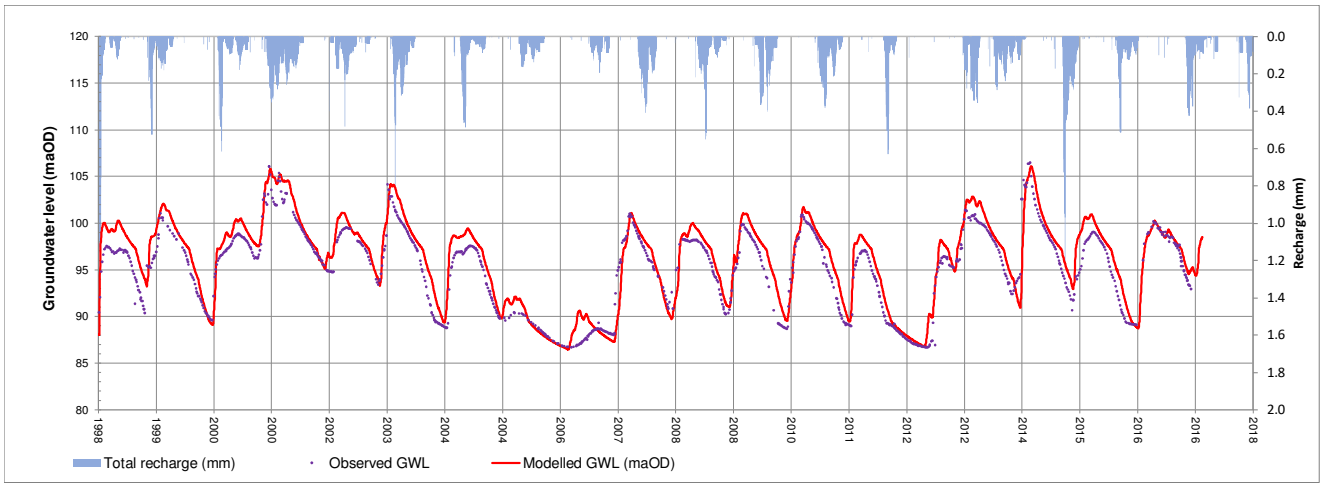

Figure 2-1 - Calibration to Well House Inn OBH groundwater levels

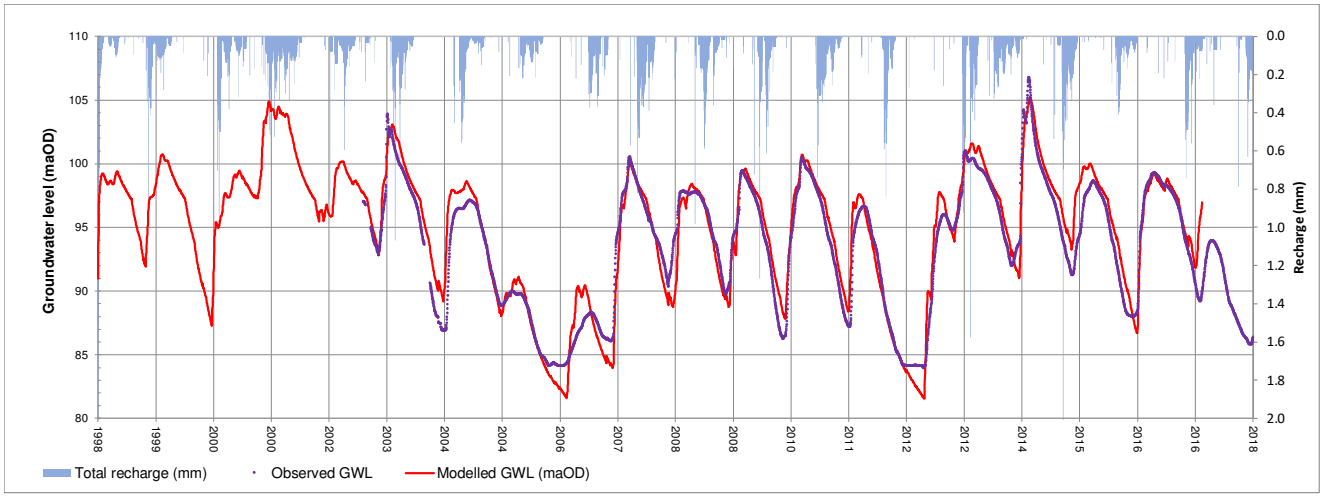

Figure 2-2 - Calibration to Chipstead OBH groundwater levels

Although calibration of the model to observed groundwater levels is reasonably good, it should be noted that Chipstead OBH logged data fails to capture the deepest part of the groundwater level recession; groundwater levels fall below the transducer level (estimated at 84.6 maOD) until it was lowered in 2017 and although several manual dips appear to corroborate the 2006 logged minimum groundwater levels, these are considered to be rather suspect and no manual dips were taken during the 2012 groundwater level minimum. It is therefore not possible to verify model calibration during these key periods of low groundwater level, thus creating uncertainty.

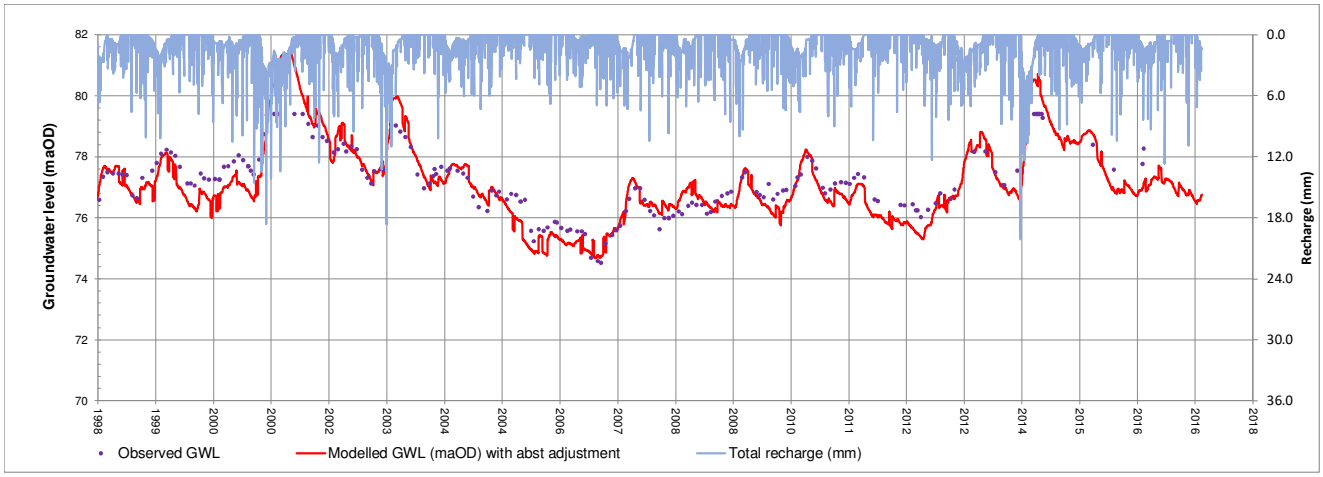

Figure 2-3 - Calibration to Riverhead OBH groundwater levels

There is relatively low confidence in the Riverhead model. A reasonable fit is achieved between modelled and observed data for the model calibration period (1998 – 2016). However, when hindcast, the model is unable to replicate the lower groundwater level recessions observed during the 1990s droughts (Figure 2-4). It is unclear if the observed recession is abstraction related; prior to 1997 there was significantly more abstraction from Thames Water's adjacent Sundridge and Brasted sources, but various abstraction impact investigations have been inconclusive as to the impact these sources had on groundwater levels. As the lumped parameter model remains the best tool available to assess the DO of SES Water's Lower Greensand sources and because these sources are relatively insensitive to the rest water level conditions, the Riverhead model has been used with caution within the DO assessments.

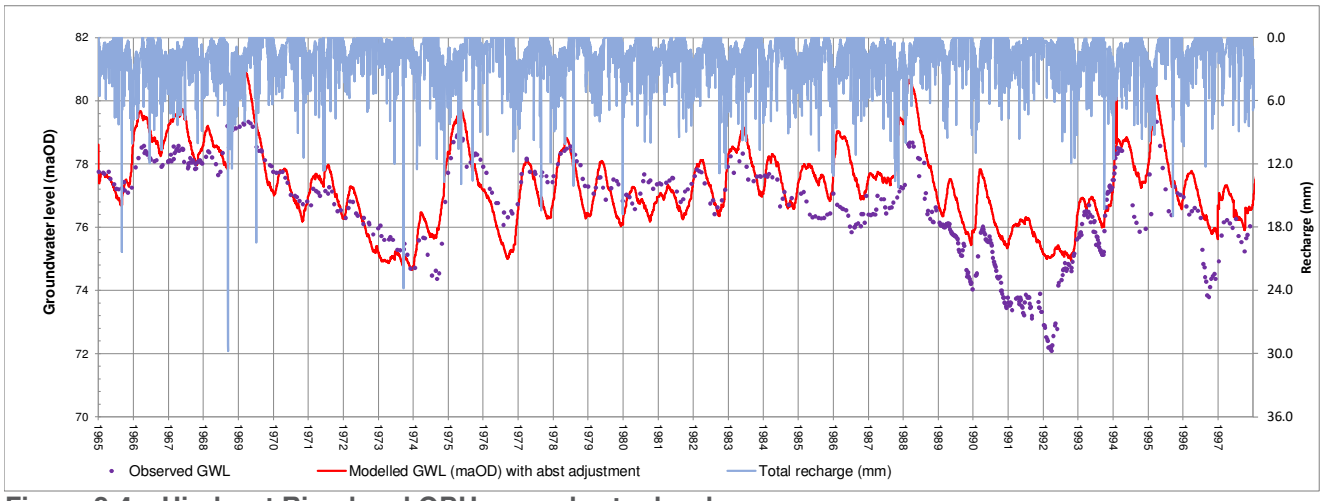

Figure 2-4 – Hindcast Riverhead OBH groundwater levels

2.3.3. Stochastic analysis

Stochastic climatic datasets, comprising 400 x 48-year timeseries (equivalent to 19,200 years) of daily data, have been applied to the lumped parameter models to generate rest groundwater levels at the reference OBHs for a range of drought severities. These stochastic datasets have been provided by Water Resources South East (WRSE) enabling a consistent approach to be taken across water companies in the region.

For SES Water's area, the stochastic rainfall is based on Dorking rain gauge and the PE dataset is WRSE's Thames South London dataset. These stochastic datasets have been factored based on the relationship between the original historical timeseries underlying the stochastic data and the datasets used for calibration of the lumped parameter models to ensure they are appropriate for use in the models. The historical data underlying the stochastic data are slightly different to that used to calibrate the lumped parameter model. This is because they represent slightly different areas. Thus, if the stochastic data was not appropriately adjusted, the results would include the inherent impact of changing the historical climatic sequence.

The modelled groundwater level output has been analysed to determine groundwater levels at the reference OBHs for a 1 in 200-year and 1 in 500-year return period for both an annual minimum (for minimum DO, MDO,

determination) and July minimum (for peak DO, PDO, determination) frequency. These results are presented in Table 2-4 and Figure 2-5.

As discussed above, Well House Inn is believed to under-represent the full extent of groundwater recession during severe droughts. This is reflected in the difference in groundwater levels between this OBH and Chipstead OBH (approximately 6 m difference for a modelled 1:200-year drought event).

The rest groundwater levels generated using the new stochastics are similar to those used in WRMP19 (shown in brackets in Table 2-4) but consistently slightly lower.

Table 2-4 – Index borehole groundwater levels for different drought severities

	Well House Inn OBH	Chipstead OBH	Riverhead OBH
1:200-year (annual minimum)	85.02 (85.46)	79.15	74.41 (74.62)
1:200-year (July)	85.68 (86.47)	80.17	74.53 (75.12)
1:500-year (annual minimum)	84.73	78.59	74.29
1:500-year (July)	85.32	79.50	74.38

Values in brackets are the numbers used in WRMP19

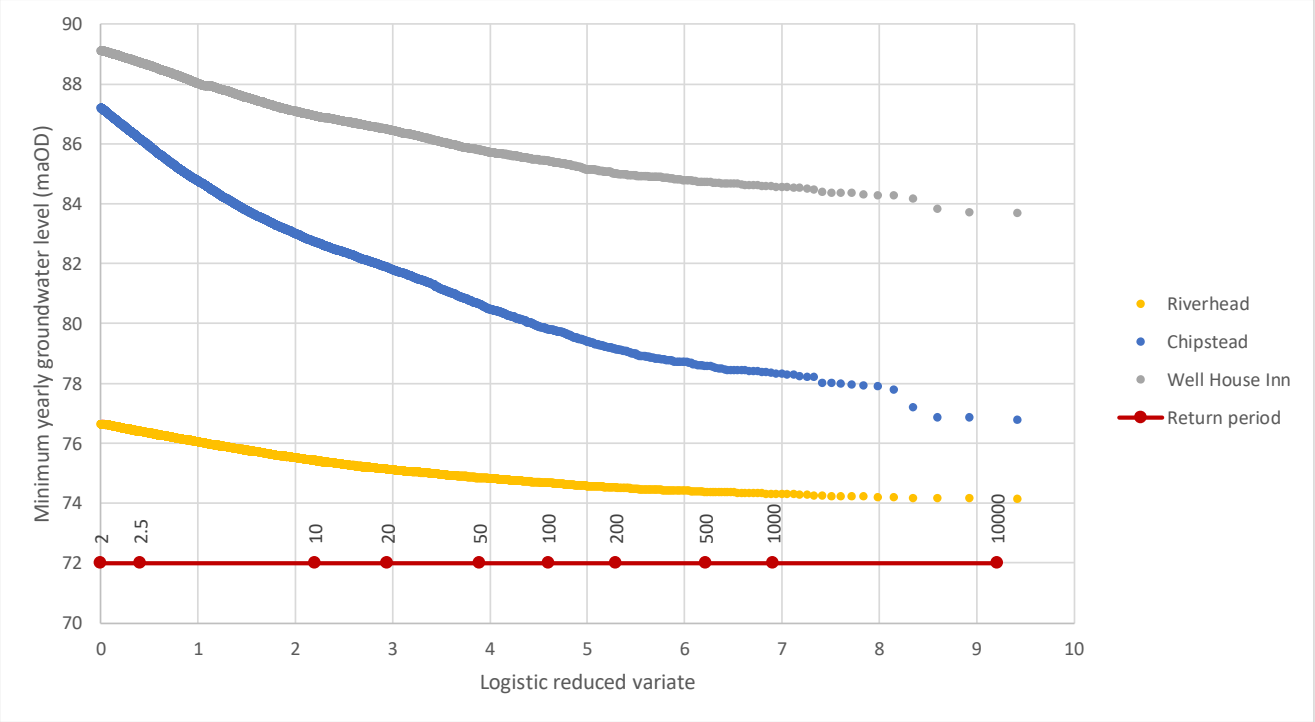

Figure 2-5 - Return period analysis at index boreholes

2.3.4. Scaling methodology

Water levels at the index boreholes are scaled in order to represent SES Water's sources. This scaling approach, developed in WRMP14, is described as follows:

"This scaling operation comprises a simple comparison of the mean annual water level fluctuation of the nearest appropriate observation borehole to a source with the mean annual fluctuation of the signature borehole for the ARU [Aquifer Resource Unit]. This ratio is then multiplied by the difference between the signature borehole 1 in 50 year [or other return period] annual minimum and the groundwater level recorded in this observation borehole at the same (or similar) time as the data used to define the source drought curve was collected. The source drought curve is then downshifted by this amount." (Atkins, 2013)

The ratio used to adjust the water level is set out in Table 2-5. These ratios have been updated from WRMP14 to represent changes in the selected reference OBHs.

For Chipstead and Kenley abstraction sources, where there was a good relationship between the representative OBH borehole and the reference OBH, WRMP14 used a linear regression equation rather than the scaling operation to calculate the downshift amount. These relationships, which were developed with Well House Inn OBH, have been adjusted to represent change in reference OBH to Chipstead OBH.

As noted above, the scaling methodology uses the reference OBH water level on the same (or similar) time as the source rest water level. Groundwater level data are only available for Chipstead OBH from 2002, however, many of the sources use rest water levels from a date that precedes this. In these instances, a linear regression with Well House Inn has been used to estimate the level at Chipstead OBH. The relationship has been developed excluding the groundwater levels during extreme droughts, which are believed to not be represented at Well House Inn. The source rest water levels are typically outside of these extreme drought periods.

$$Chipstead\ OBH = 1.0311 * Well\ House\ Inn - 3.493,\ R^2 = 0.98$$

Table 2-5 - Water level adjustments applied to operational / analytical drought curves

Group		Source	Nearest representative OBH	Index OBH	Downshifting adjustment ratio[5]
North Downs Chalk		Cheam	Nonsuch Park	Chipstead[3]	0.43 (4.7/11)
		Cheam Park	Nonsuch Park	Chipstead[3]	0.43 (4.7/11)
		Springclose Lane	Nonsuch Park	Chipstead[3]	0.43 (4.7/11)
		Langley Park	St Philomena's	Chipstead[3]	0.33 (3.6/11)
		Nonsuch Park	Nonsuch Park	Chipstead[3]	0.43 (4.7/11)
		Sutton	St Philomena's	Chipstead[3]	0.33 (3.6/11)
		Sutton Court Road	St Philomena's	Chipstead[3]	0.33 (3.6/11)
Woodmansterne		Chipstead	Well House Inn	Chipstead[3]	Regression equation (R^2 = 0.93): Chipstead RWL = 1.6879*(Well House Inn WL) - 71.0941 Regression equation (R^2 = 0.98): Well House Inn = (Chipstead OBH+3.493) / 1.0311
		Holly Lane	Well House Inn	Chipstead[3]	0.68 (7.5/11)
		Woodmansterne	Well House Inn	Chipstead[3]	0.68 (7.5/11)
		Outwood Lane	Well House Inn	Chipstead[3]	0.68 (7.5/11)
		Smitham	Well House Inn	Chipstead[3]	0.68 (7.5/11)
Hackbridge		Hackbridge and Goatbridge	Beddington STW	Chipstead[3]	0.19 (2.1/11)
Unconfined Chalk		Oaks	Woodcote	Chipstead[3]	0.27 (3/11)
		Woodcote	Woodcote	Chipstead[3]	0.27 (3/11)
Kenley		Kenley	Rose & Crown	Chipstead[3]	Regression equation (R^2 = 0.91): Kenley RWL = 1.3762*Chipstead -54.488
		Purley	Purleybury	Chipstead[3]	0.31 (3.4/11)
Mole Valley		Fetcham Springs	Ashtead Park Freeman's School	Chipstead[4]	n/a
		Elmer & Young	Ashtead Park Freeman's School	Chipstead[4]	0.28 (3.1/11)
		Leatherhead	Ashtead Park Freeman's School	Chipstead[4]	0.28 (3.1/11)
Lower Greensand		Dorking	Riverhead[1]	Riverhead	1 (1.4/1.4)
	Sub group	Buckland	Riverhead[2]	Riverhead	1 (1.4/1.4)
		Clifton's Lane	Riverhead	Riverhead	1 (1.4/1.4)
	Sub group	Warwick Wold	Riverhead[2]	Riverhead	1 (1.4/1.4)
		Brewer Street	Riverhead[2]	Riverhead	1 (1.4/1.4)
	Godstone sub group	Bletchingley	Riverhead[2]	Riverhead	1 (1.4/1.4)
		North Park	Riverhead[2]	Riverhead	1 (1.4/1.4)
		Godstone	Riverhead[2]	Riverhead	1 (1.4/1.4)
		Flower Lane	Riverhead[2]	Riverhead	1 (1.4/1.4)
	Westwood sub group	Water Lane	Black Eagle Brewery	Riverhead	1.071 (1.5/1.4)
		South Green	Black Eagle Brewery	Riverhead	1.071 (1.5/1.4)
		Westwood	Black Eagle Brewery	Riverhead	1.071 (1.5/1.4)

[1] Reigate Heath is the nearest representative OBH but data and datum is unreliable. No adjustment made to Riverhead index borehole as a precautionary approach.
[2] Pendall Farm thought to be the nearest representative OBH but insufficient source water level data to confirm. No adjustment made to Riverhead index borehole as a precautionary approach.
[3] Previous WRMPs used Well House Inn
[4] Previous WRMPs used Ashtead Park Freeman's School
[5] Representative OBH mean annual water level range / index borehole mean annual water level range

2.4. DO algorithm

Polynominal equations have been derived for the individual source DO drought curves and these along with source constraints and stochastic rest water levels have been incorporated into a source DO calculating algorithm within one Excel spreadsheet. Whilst this algorithm spreadsheet is currently of basic functionality and can be developed further, it will aid efficiencies in future DO assessments and make comparisons between different scenarios easier.

2.5. Baseline DO assessment results

The individual source DOs have been calculated by applying the updated constraints and stochastic rest groundwater levels to the DO algorithm. The results of this assessment are presented in Table 2-6. This assessment uses Chipstead OBH and Riverhead OBH as reference OBHs and calculates the MDO from annual minima statistics and the PDO using minimum water levels in July, the period of peak demand. Results have been presented for a 1:200-year and 1:500-year return period.

Table 2-6 demonstrates there is very little difference in DO between the 1 in 200-year and 1 in 500-year drought events suggesting relatively little reduction in resilience within the groundwater sources from severe to extreme droughts.

Table 2-6 - DO results summary

	1: 200-year	1:500-year
MDO (Ml/d)	182	181
PDO (Ml/d)	247	245

Table 2-7 - Individual source DO and constraints

Group	Site	Annual average licence (Ml/d)	1:200-year				1:500-year			
			MDO (Ml/d)	Constraint	PDO (Ml/d)	Constraint	MDO (Ml/d)	Constraint	PDO (Ml/d)	Constraint
North Downs Chalk	Cheam	18.23	8.29	DAPWL	10.63	DAPWL	8.18	DAPWL	10.42	DAPWL
	Cheam Park		1.06	DAPWL	1.16	DAPWL	1.04	DAPWL	1.14	DAPWL
	Springclose Lane		2.00	Pump capacity	2.00	Pump capacity	2.00	Pump capacity	2.00	Pump capacity
	Langley Park		1.90	Pump capacity	1.90	Pump capacity	1.90	Pump capacity	1.90	Pump capacity
	Nonsuch Park		5.00	Licence	12.00	Licence	5.00	Licence	12.00	Licence
	Sutton	22.79	8.45	DAPWL	12.19	DAPWL	8.35	DAPWL	11.90	DAPWL
	Sutton Court Road		0.64	Pump cut off	1.14	Pump cut off	0.63	Pump cut off	1.13	Pump cut off
	(Cheam group)	*32.96*	27.34		41.03		27.11		40.49	
Woodmansterne	Chipstead		1.21	DAPWL	1.92	DAPWL	1.00	DAPWL	1.64	DAPWL
	Holly Lane		5.91	DAPWL	6.50	Pump capacity	5.74	DAPWL	6.50	Pump capacity
	Woodmansterne		13.72	DAPWL	14.68	DAPWL	13.59	DAPWL	14.51	DAPWL
	Outwood Lane		3.02	Licence	3.02	Licence	3.02	Licence	3.02	Licence
	Smitham		5.68	Daily peak licence	5.68	Licence	5.68	Daily peak licence	5.68	Licence
	(Woodmansterne group)	*29.55*	29.54		31.80		29.03		31.35	
Hackbridge	Hackbridge and Goat Bridge	9.01	8.57	Licence	13.87	Licence	8.57	Licence	13.87	Licence
Unconfined chalk	Oaks		3.50	Average AIM (apportioned)	7.40	Peak AIM (apportioned)	3.50	Average AIM (apportioned)	7.40	Peak AIM (apportioned)
	Woodcote		3.50	Average AIM (apportioned)	4.60	Pump capacity	3.50	Average AIM (apportioned)	4.60	Pump capacity
	(Woodcote group)	*9.10*	7.00		12.00		7.00		12.00	
North Downs Chalk	Kenley		17.74	Apportioned licence	22.08	Pump capacity	17.74	Apportioned licence	22.08	Pump capacity
	Purley		5.05	Apportioned licence	19.20	Pump capacity	5.05	Apportioned licence	19.20	Pump capacity
	(Kenley group)	*22.79*	22.79		41.28		22.79		41.28	
Mole valley	Fetcham Springs	13.68	8.33	Average total spring flow Sep 2006 minus 0.5Ml/d allowance for flow to Fetcham Pond	10.83	Mean total spring flow for 13/5/06 - 16/6/07 minus 0.5M/d allowance for return to Fetcham Pond	8.33	Average total spring flow Sep 2006 minus 0.5Ml/d allowance for flow to Fetcham Pond	10.83	Mean total spring flow for 13/5/06 - 16/6/07 minus 0.5M/d allowance for return to Fetcham Pond
	Elmer & Young		14.25	Apportioned licence	17.05	Apportioned licence	14.25	Apportioned licence	17.05	Apportioned licence
	Leatherhead		27.92	Apportioned licence	40.91	Apportioned licence	27.92	Apportioned licence	40.91	Apportioned licence
	(Leatherhead group)	*42.17*	42.17		57.96		42.17		57.96	
Lower Greensand	Dorking	11.82	11.82	Licence	11.82	Licence	11.82	Licence	11.82	Licence
	Buckland		1.40	Water Quality	1.40	Water Quality	1.40	Water Quality	1.40	Water Quality
	Cliftons Lane		0.88	Apportioned licence	1.16	DAPWL	0.88	Apportioned licence	1.12	DAPWL
	(Buckland group)	2.28	2.28		2.56		2.28		2.52	
	Warwick Wold		3.24	DAPWL	3.22	Apportioned WTW	3.22	DAPWL	3.22	Apportioned WTW
	Brewer Street		2.42	Pump cut off	2.42	Apportioned WTW	2.41	Pump cut off	2.42	Apportioned WTW
	(Warwick Wold group)	*6.85*	5.66		5.64		5.64		5.64	
	Bletchingley	3.50	2.03	Pump cut off	2.02	Apportioned WTW	2.02	Pump cut off	2.02	Apportioned WTW

Group	Site	Annual average licence (Ml/d)	1:200-year				1:500-year			
			MDO (Ml/d)	Constraint	PDO (Ml/d)	Constraint	MDO (Ml/d)	Constraint	PDO (Ml/d)	Constraint
	North Park		3.50	Apportioned licence	3.50	Apportioned WTW	3.50	Apportioned licence	3.50	Apportioned WTW
	Godstone		2.48	Apportioned licence	2.48	Apportioned WTW	2.48	Apportioned licence	2.48	Apportioned WTW
	Flower Lane		2.00	Apportioned licence	2.37	Apportioned WTW	2.00	Apportioned licence	2.37	Apportioned WTW
	(Godstone group)	*7.98*	7.98		8.34		7.98		8.35	
	Water Lane		2.00	Pump capacity	2.00	Pump capacity	2.00	Pump capacity	2.00	Pump capacity
	South Green		2.18	Licence	2.18	Licence	2.18	Licence	2.18	Licence
	Westwood		2.60	DAPWL	3.21	DAPWL	2.59	DAPWL	3.08	DAPWL
	(Westwood group)	*6.85*	6.78		7.39		6.77		7.26	
	Total		182.27		246.54		181.50		245.38	

DAPWL = Deepest advisable pumping water level, WTW = Water treatment works, AIM = Abstraction incentive mechanism

2.5.1. DO sensitivity

To understand the influence of the component changes, DO has been calculated for a number of scenarios:

- Using Well House Inn OBH and Riverhead OBH as reference OBHs;
- Using Chipstead OBH and Riverhead OBH as reference OBHs;
- Using annual groundwater level minima return period statistics for 1 in 200/500-year scenarios as rest water levels to determine MDO and PDO
- Using July groundwater level minima return period statistics for 1 in 200/500-year scenarios as rest water levels to determine PDO

Table 2-8 presents a summary of the calculated DOs for a 1 in 200-year return period for each of these scenarios compared to those reported in WRMP19. The values used in WRMP14 are also presented for reference, but it should be noted that these reflect a 1 in 50-year event. Commentary is provided to explain the differences between the final DO and the WRMP19 values.

Due to the uncertainty in calibration of the Riverhead lumped parameter model, additional sensitivity analysis has been undertaken for the Lower Greensand sources. Changing the Riverhead 1:200-year water level by +/- 1 m results in a 0.56 Ml/d change in DO of the Lower Greensand sources. This demonstrates that the DO for SES Water's Lower Greensand sources is relatively insensitive to climatic conditions.

Table 2-8 - DO assessment results for 1:200-year return period

	1 in 50-year	1 in 200-year					Explanation
	Reported WRMP14	Reported WRMP19	Using WHI & Riverhead as index boreholes	Using Chipstead & Riverhead as index boreholes	Using Chipstead & Riverhead as index boreholes & specific July RWL	Difference with reported WRMP19	
MDO (Ml/d)	*186.9*	188.7	188.9	**182.3**	n/a	(6.4)	• Change from WHI to Chipstead OBH = 6.5 Ml/d (Chipstead ABS reduces by 3.5 Mld) • No Fetcham = 0.92 Ml/d • AIM applied to Oaks and Woodcote = 2 Ml/d • Different rest water level = ~0.5 Ml (WHI ~73 cm lower, Riverhead ~33 cm lower) • WRMP19 excluded Outwood lane = 3 Ml/d increase
PDO (Ml/d)	*241.0*	265.5	252.0	244.9	**246.5**	(19.0)	• Change from WHI to Chipstead OBH = 7 Ml/d (Chipstead ABS reduces by 3.5Mld) • Specific July RWL for return periods = 1 Ml/d increase • No Fetcham = 0.95 Ml/d • AIM applied to Oaks and Woodcote = 2.5 Ml/d • Change in Hackbridge assumptions = 3.3 Ml/d • Change in Bletchingly pump capacity = 0.5 Ml/d • Application of Godstone WTW capacity = 3 • Different rest water level ~5.5 Ml/d (WHI ~80 cm lower, Riverhead ~60 cm lower, Sutton reduces by 2Ml/d and Westwood by 2 Ml/d) • WRMP excluded Outwood lane = 3 Ml/d increase

WHI = Well House Inn
Bold text = DO values for WRMP24

3. Climate change impact on DO

The impact of climate change on groundwater DO has been assessed using the 1 in 500-year DO as the baseline (Section 2) and a suite of UKCP18 scenarios.

3.1. Climate change DO assessment

The climate change scenarios have been identified by WRSE. These include 12 Regional Climate Model (RCM) scenarios and 28 Global Climate Model (GCM) scenarios. The climate change data have been provided in the form of monthly factors generally representing percentage change from baseline, the exception being the GCM PE factors which are a direct factor. Whilst the GCM factors are spatially concurrent across the entire SES Water supply area, the RCM factors have been generated for specific areas: Chipstead OBH is located within the 'South London' and Riverhead OBH within the 'Eden' WRSE areas.

The climate change factors have been applied to perturb the stochastic PET and rainfall datasets used in the Chipstead and Riverhead OBH lumped parameter models The lumped parameter models have been run for each climate change scenario, frequency analysis undertaken and the DO determined, following the methodology set out in Section 2. The results are presented compared to the baseline 1 in 500-year DO.

3.2. Climate change DO results

The results of the climate change DO assessment are summarised in Table 3-1 in comparison to the 1 in 500-year baseline. A detailed source breakdown is shown in Table 3-2 and Table 3-3 for the RCM and GCM scenarios respectively.

In general, the impact of climate change on the 1 in 500-year DO baseline is relatively small.

Table 3-1 - DO climate change results summary

	MDO			PDO		
	DO total (Ml/d)	DO impact (Ml/d)*	DO impact (%)	DO total (Ml/d)	DO impact (Ml/d)*	DO impact (%)
1 in 500 year baseline	181.50	-	-	245.38	-	-
RCM scenarios						
Min CC DO	180.63	-0.87	0%	244.60	-0.78	0%
Max CC DO	182.45	0.95	1%	248.33	2.95	1%
GCM scenarios						
Min CC DO	179.42	-2.08	-1%	242.74	-2.64	-1%
Max CC DO	182.82	1.32	1%	250.05	4.67	2%

*climate change scenario minus baseline. Negative indicates reduction in DO

Table 3-2 – RCM climate change scenarios – impact compared to 1 in 500 year baseline

		Baseline 1 in 500-year DO (Ml/d)	Difference from 1 in 500-year baseline (Ml/d)*											
			Sc1	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	Sc10	Sc11	Sc12	Sc13	Sc15
Minimum	North Downs Chalk	27.11	-0.30	-0.03	-0.28	-0.09	0.35	0.11	-0.04	-0.27	-0.09	-0.02	-0.13	0.40
	Woodmansterne group	29.03	-0.47	0.01	-0.44	-0.10	0.52	0.27	-0.01	-0.43	-0.10	0.03	-0.17	0.52
	Hackbridge	8.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Unconfined chalk	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Kenley/Purley	22.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mole valley	50.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lower Greensand	36.50	-0.10	-0.07	-0.14	-0.08	0.02	-0.08	-0.12	-0.13	-0.13	0.01	-0.17	0.03
	Total	**181.50**	**-0.87**	**-0.09**	**-0.86**	**-0.28**	**0.88**	**0.30**	**-0.17**	**-0.83**	**-0.33**	**0.02**	**-0.47**	**0.95**
Peak	North Downs Chalk	40.49	-0.34	0.12	-0.34	0.13	1.12	0.54	0.31	-0.27	0.04	0.35	0.06	1.37
	Woodmansterne group	31.35	-0.26	0.10	-0.26	0.10	1.01	0.44	0.25	-0.21	0.03	0.28	0.05	1.29
	Hackbridge	13.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Unconfined chalk	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Kenley/Purley	41.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mole valley	68.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lower Greensand	37.60	-0.12	-0.04	-0.18	-0.06	0.26	-0.02	-0.12	-0.15	-0.16	0.22	-0.20	0.29
	Total	**245.38**	**-0.71**	**0.18**	**-0.78**	**0.18**	**2.39**	**0.96**	**0.43**	**-0.63**	**-0.08**	**0.85**	**-0.09**	**2.95**

*climate change scenario minus baseline. Negative indicates reduction in DO.

Table 3-3 – GCM climate change scenarios – impact compared to 1 in 500 year baseline

			Difference from 1 in 500 yr baseline (Ml/d)*																											
		Baseline 1 in 500 DO (Ml/d)	GCM sc HadGEM3-GC3.05-r001i1p00000	GCM sc HadGEM3-GC3.05-r001i1p00605	GCM sc HadGEM3-GC3.05-r001i1p00834	GCM sc HadGEM3-GC3.05-r001i1p01113	GCM sc HadGEM3-GC3.05-r001i1p01554	GCM sc HadGEM3-GC3.05-r001i1p01649	GCM sc HadGEM3-GC3.05-r001i1p01843	GCM sc HadGEM3-GC3.05-r001i1p01935	GCM sc HadGEM3-GC3.05-r001i1p02123	GCM sc HadGEM3-GC3.05-r001i1p02242	GCM sc HadGEM3-GC3.05-r001i1p02305	GCM sc HadGEM3-GC3.05-r001i1p02335	GCM sc HadGEM3-GC3.05-r001i1p02491	GCM sc HadGEM3-GC3.05-r001i1p02832	GCM sc HadGEM3-GC3.05-r001i1p02868	GCM sc bcc-csm1-r1i1p1	GCM sc CCSM4-r1i1p1	GCM sc CESM1-BGC-r1i1p1	GCM sc CanESM2-r1i1p1	GCM sc CMCC-CM-r1i1p1	GCM sc CNRM-CM5-r1i1p1	GCM sc EC-EARTH-r1i1p1	GCM sc ACCESS1-3-r1i1p1	GCM sc HadGEM2-ES-r1i1p1	GCM sc IPSL-CM5A-MR-r1i1p1	GCM sc MPI-ESM-MR-r1i1p1	GCM sc MRI-CGCM3-r1i1p1	GCM sc GFDL-ESM2G-r1i1p1
Minimum	North Downs Chalk	27.11	-0.43	-0.72	-0.65	-0.12	-0.30	-0.50	-0.10	-0.19	-0.52	-0.61	-0.52	-0.48	-0.43	-0.25	0.01	0.43	0.05	-0.06	0.07	0.07	0.37	0.36	0.67	-0.30	0.02	-0.25	0.05	-0.02
	Woodmansterne group	29.03	-0.70	-1.19	-1.08	-0.15	-0.47	-0.83	-0.11	-0.27	-0.85	-1.01	-0.86	-0.78	-0.70	-0.38	0.09	0.52	0.16	-0.04	0.20	0.21	0.52	0.52	0.52	-0.48	0.11	-0.38	0.15	0.02
	Hackbridge	8.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Unconfined chalk	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Kenley/Purley	22.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mole valley	50.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lower Greensand	36.50	-0.13	-0.17	-0.23	-0.04	-0.08	-0.19	-0.02	-0.07	-0.13	-0.17	-0.18	-0.10	-0.20	-0.10	-0.05	0.07	-0.03	-0.06	0.01	-0.01	0.08	0.06	0.13	-0.07	-0.01	-0.12	-0.02	-0.04
	Total	**181.5**	**-1.26**	**-2.08**	**-1.96**	**-0.32**	**-0.85**	**-1.52**	**-0.23**	**-0.52**	**-1.50**	**-1.78**	**-1.56**	**-1.36**	**-1.33**	**-0.73**	**0.06**	**1.01**	**0.18**	**-0.15**	**0.27**	**0.27**	**0.96**	**0.93**	**1.32**	**-0.85**	**0.12**	**-0.75**	**0.17**	**-0.04**
Peak	North Downs Chalk	40.49	-0.52	-1.43	-1.04	-0.01	-0.36	-0.63	0.19	-0.05	-0.57	-0.94	-0.82	-0.43	-0.55	-0.20	0.33	0.86	0.23	-0.06	0.41	0.21	0.96	0.97	1.92	-0.28	0.28	-0.36	0.13	0.24
	Woodmansterne group	31.35	-0.38	-0.94	-0.73	-0.01	-0.27	-0.46	0.15	-0.04	-0.42	-0.66	-0.59	-0.32	-0.40	-0.15	0.27	0.74	0.18	-0.04	0.33	0.16	0.84	0.86	2.03	-0.21	0.22	-0.27	0.10	0.19
	Hackbridge	13.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Unconfined chalk	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Kenley/Purley	41.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mole valley	68.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lower Greensand	37.60	-0.20	-0.27	-0.33	0.05	-0.11	-0.23	0.12	-0.01	-0.11	-0.22	-0.24	-0.12	-0.25	-0.07	0.03	0.29	0.01	-0.08	0.14	0.14	0.34	0.31	0.72	-0.06	0.11	-0.15	0.00	0.02
	Total	**245.38**	**-1.10**	**-2.64**	**-2.10**	**0.03**	**-0.73**	**-1.32**	**0.45**	**-0.11**	**-1.10**	**-1.82**	**-1.65**	**-0.86**	**-1.21**	**-0.42**	**0.64**	**1.88**	**0.42**	**-0.18**	**0.88**	**0.52**	**2.13**	**2.14**	**4.67**	**-0.54**	**0.60**	**-0.78**	**0.23**	**0.46**

*climate change scenario minus baseline. Negative indicates reduction in DO

4. References

Aecom, 2018, Water Supply – Deployable Output and Climate Change Impact Assessment Report, SES Water's draft Water Resource Management Plan 2019 Appendix A

Atkins, 2013, Sutton & East Surrey Water plc, Review of Groundwater Source Deployable Outputs for 2014 Water Resource Management Plan

Atkins 2020a, Drought Plan - OBH review technical note for SES Water

Atkins 2020b, Groundwater Assessment Framework

Victoria Crellin
Atkins Limited
The Axis
10 Holliday Street
Birmingham
B1 1TF

Direct: +44 (0)1372 756813
victoria.crellin@atkinsglobal.com