APPENDIX D:

Supply forecast

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1. Introduction

This appendix details the modelling and assessments undertaken as part of the Supply Forecast element of Jersey Water's WRDMP24. It includes the assessments undertaken to derive an estimate of the reliable source yield ("deployable output") of the raw water supply system.

This appendix sets out:

- A summary of the hydrological modelling undertaken in support of this WRDMP24 including: a review of the catchments in Jersey and the available data; and detail on the rainfall-runoff methodology and results.
- A summary of the water resource modelling undertaken as part of WRDMP24 including: a description of Jersey Waters sources and assets; a summary of the development and validation of the Pywr Water Resources model; and the methodology and results of the deployable output assessment.
- Descriptions of our assessment of the impact of climate change, process losses and outage; culminating in presentation of the water available for use figures.

2. Hydrological Modelling

The Jersey raw water system primarily comprises surface water sources, which means an accurate understanding of the associated flow regimes – in this case using hydrological modelling – is critical for ensuring a resilient and secure water supply. This section outlines how catchment inflow datasets have been generated to inform this WRDMP.

An understanding of historical flow regimes can come from observed streamflow records alone. However, with the Jersey system, a scarcity of long-term records meant hydrological models were required to construct a library of reliable flow estimates over the historically observed period (e.g. 1995-2023). Furthermore, hydrological models allow for flow regimes to be simulated under different climate conditions – e.g. beyond those which have been recorded or observed. This was done here with the simulation of stochastic baseline and climate change scenario flows. Stochastic flow series such as this are key inputs for modelling the supply system as a whole and they allow for stress-testing of the system under a range of conditions.

The hydrological assessment primarily involved development and calibration of an open-source GR6J rainfall-runoff model against a key streamflow record followed by transposition of this model to the other catchments across the island. The transposed models were then used to produce daily timeseries of catchment inflows (both historical and stochastic series) for input into the new water resources model (See section 3). Additional hydrological modelling focussed on the development of a water balance model for the Grands Vaux reservoir system, which was used to inform validation of the rainfall-runoff model.

The output from this assessment was the production of a new suite of rainfall-runoff models and simulated catchment inflows.

2.1 Catchment summary

The Jersey supply system comprises six main raw water storage reservoirs. As well as direct runoff from their respected impounded catchments, the reservoirs can be fed by a combination of the following indirect sources:

- Various surface water catchments with pumped abstractions in place.

  - This includes two minor impounding reservoirs (La Hague and Le Mourier) from which flows are directed to other (i.e. main) reservoirs.
- Groundwater abstracted from the St Ouen's wellfield and the Tesson borehole.
- Transfers between reservoirs.
- And, when required, flows from the La Rosiere desalination plant.

This assessment has modelled all the surface water source catchments (both direct and indirect) that make up the system. It has also modelled an additional eight sub-catchments where streamflow monitoring sites are established, which are either located upstream of reservoirs or near pumped abstraction sites. The resulting 31 components are summarised in Table 2-1 below and mapped in Figure 2-1.

Longer-term (i.e. at least 20 years in length, without excessive gaps) continuous streamflow monitoring only exists for two catchments (the Grands Vaux and La Hague streams), and the latter of these presents a significantly altered flow regime. As such, the Grands Vaux stream catchment has been the primary focus of this study. This long and relatively reliable record presented the best opportunity for successful calibration (and validation) of a rainfall-runoff model. Furthermore, the catchment aligns closely with the Trinity catchment which was used in previous rainfall-runoff modelling work (MWH, 2006).

The previously modelled Trinity catchment was the subject of a detailed hydrological and hydrogeological study carried out by CEH Wallingford/British Geological Survey (on behalf of the Jersey Public Works Department) in the mid-1990s (MWH, 2006). As a result of this, there was a wealth of hydrological data available (e.g. streamflows, rainfall, PET) over this period. This is presumably why it was selected by MWH for their model calibration. It would have been ideal to re-model this catchment in this assessment; however, from discussions with Jersey Water it appears the monitoring stations were not established long term and have since been removed with historical manual measurement of v-notches being undertaken. This, therefore, left the Grands Vaux stream catchment as the best candidate for rainfall-runoff model calibration. New stream flow monitoring stations have been installed in 2023 so will be available for the future.

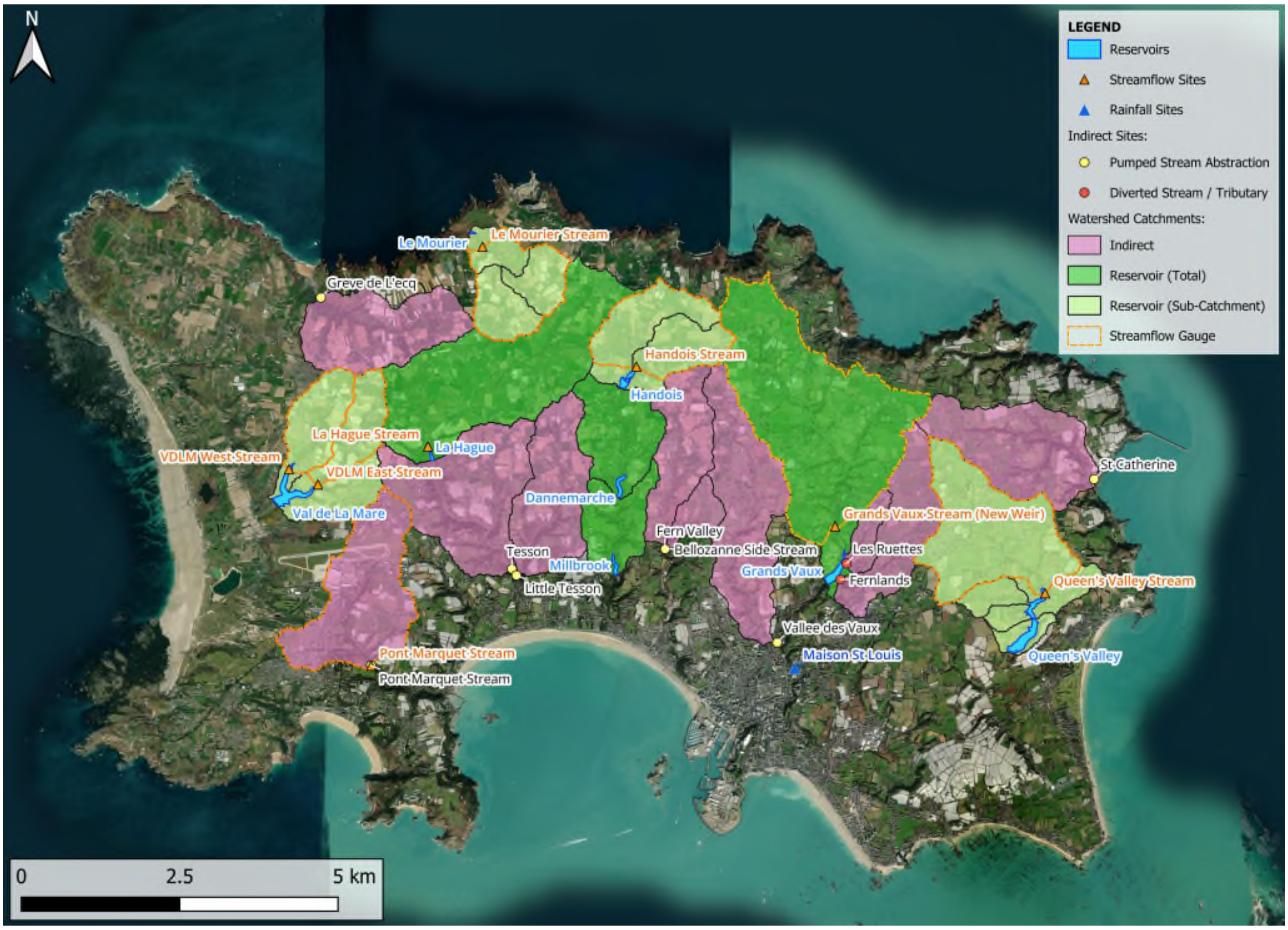

Figure 2-1 - Map of modelled surface water catchments and key site locations

Table 2-1 - Summary of surface water catchments assessed

Reservoir System	Catchment	Type	Catchment Area (km^2)	Rainfall scaling factor	Description
Grands Vaux	Grands Vaux Stream[1]	Gauged sub-catchment	6.802	1.060	Subset of Grands Vaux reservoir catchment.
	Grands Vaux Reservoir	Direct	7.216	1.054	Direct reservoir inflow (excluding Fernlands and Les Ruettes)
	Fernlands	Diverted sub-catchment	2.013	1.036	Subset of Grands Vaux reservoir catchment. Typically diverted away from reservoir, except in ad-hoc drought conditions.
	Les Ruettes (aka Paul Mill Stream)	Diverted sub-catchment	0.474	1.010	Subset of Grands Vaux reservoir catchment. Assumed to be always diverted away from reservoir.
	Vallee des Vaux	Indirect	3.435	1.085	Run-of-river source pumped into Grands Vaux reservoir.
Queen's Valley	Queen's Valley Stream	Gauged sub-catchment	3.579	1.080	Subset of Queen's Valley reservoir catchment.
	Queen's Valley Reservoir (Upper)	Direct sub-catchment	4.327	1.077	Direct reservoir inflow (excluding side stream)
	Queen's Valley Reservoir (Side Stream)	Direct sub-catchment	0.408*	1.058	Subset of Queen's Valley upper reservoir catchment
	Queen's Valley Reservoir (Lower)	Direct sub-catchment	0.350*	1.054	Direct reservoir (lower) inflow
	St Catherine	Indirect	3.031	1.048	Run-of-river source pumped into Queen's Valley reservoir.
Handois	Handois Stream	Gauged sub-catchment	2.307	1.090	Subset of Handois reservoir catchment.
	Handois Reservoir (West)	Direct sub-catchment	1.485	1.089	Direct reservoir inflow (western side).
	Handois Reservoir (East)	Direct sub-catchment	1.173	1.086	Direct reservoir inflow (eastern side).
Dannemarche	Dannemarche Reservoir	Direct	1.843*	1.060	Direct reservoir inflow (downstream of Handois).

Millbrook	Millbrook Reservoir	Direct	1.289*	1.041	Direct reservoir inflow (downstream of Dannemarche).
	Fern Valley	Indirect	0.531	1.052	Run-of-river source pumped into Millbrook reservoir.
	Bellozanne Side Stream	Indirect	1.887	1.061	Same as above
Val de la Mare	Val de la Mare West Stream	Gauged sub-catchment	1.197	1.066	Subset of Val de la Mare reservoir catchment.
	Val de la Mare East Stream	Gauged sub-catchment	1.018	1.065	Subset of Val de la Mare reservoir catchment.
	Val de la Mare Reservoir (West)	Direct sub-catchment	1.334	1.023	Direct reservoir inflow (western side).
	Val de la Mare Reservoir (East)	Direct sub-catchment	2.001	1.043	Direct reservoir inflow (eastern side).
	Pont Marquet Stream	Gauged indirect	3.324	1.088	Run-of-river source (with gauge alongside) pumped into Val de la Mare reservoir.
	Greve de L'Ecq	Indirect	2.674	1.083	Run-of-river source pumped into Val de la Mare reservoir.
La Hague[2]	La Hague Stream	Gauged sub-catchment	5.111	1.091	Subset of La Hague reservoir catchment.
	La Hague Reservoir	Direct	5.432	1.091	Direct reservoir inflow.
	Tesson	Indirect	3.658	0.946	Run-of-river source (downstream of La Hague reservoir) pumped back up into reservoir.
	Little Tesson	Indirect	2.495	0.984	Run-of-river source pumped into Tesson Stream.
Le Mourier[3]	Le Mourier Stream	Gauged sub-catchment	1.957	0.942	Subset of Le Mourier reservoir catchment.
	Le Mourier Reservoir (Upper West)	Direct sub-catchment	0.824	0.958	Direct reservoir inflow (upper western quadrant).
	Le Mourier Reservoir (Upper East)	Direct sub-catchment	0.716	0.932	Direct reservoir inflow (upper eastern quadrant).

	Le Mourier Reservoir (Lower)	Direct sub-catchment	0.542	1.037	Direct reservoir inflow (lower half).

1. New Weir site.
2. Minor impounding reservoir. Flows are directed either to Handois Reservoir or Val de la Mare Reservoir.
3. Minor impounding reservoir. Flows are directed either to Handois Reservoir or Val de la Mare Reservoir (via La Hague).

2.1.1 Topography and catchment delineation

Jersey's surface water source catchments are all located on a raised plateau of land that makes up the majority of the island's landform. The entire north coast is bounded by a wall of high, steep cliffs, along which the top of the plateau is formed (Fiona Fyfe Associates, 2020). Moving inland, the plateau generally tilts to the south, with most of the source catchments draining the same way. The exceptions being in the northwest (where the Le Mourier, Greve de L'ecq and Val de la Mare catchments drain to the north and west) and northeast corner (where the St Catherine catchment drains to the east). The gentle slopes of the plateau are bisected by deep valleys carved out by the various streams (Fiona Fyfe Associates, 2020). To the south, southeast, and west the plateau and valleys come to an end along an escarpment which represents an ancient coastline – now pushed back by blown deposits of sand to form a relatively flat, low-lying coastal plain (Government of Jersey, 1999). While much of the island's urbanisation is located on this lower plain, all the water supply catchments sit behind the escarpment on the upper plateau.

Catchment areas have been delineated based on 1m topographic contours provided by Jersey Water. These contours were used to derive a 3D digital elevation model (DEM) which was, in turn, used to generate watershed areas and flow paths to the various sites of interest (e.g. streamflow gauges, reservoir spillways, raw abstraction sites, etc.). The resulting catchments boundaries can be seen in Figure 2-2, and the derived catchment areas can be found in Table 2-1. Together, the catchments form a contiguous area that covers almost 45% of the island's surface area.

Looking specifically at Grands Vaux, the direct reservoir catchment area is estimated to be 7.22 km^2, which is in general agreement with the catchment area of 7.16 km^2 quoted in a recent flood study for the reservoir (CCH, 2023). The diverted Fernlands and Les Ruettes stream sub-catchment areas have been estimated at 2.01 and 0.47 km^2, respectively, which also align with those presented in the 2023 flood study (2.09 and 0.46 km^2, respectively). The calibration catchment used in this study terminates at the Grands Vaux New Weir gauging site, which is located approximately 500m upstream of the reservoir, with a catchment area of 6.80 km^2 (equating to 94% of the reservoir's direct catchment). These catchments are presented in more detail in Figure 2-3.

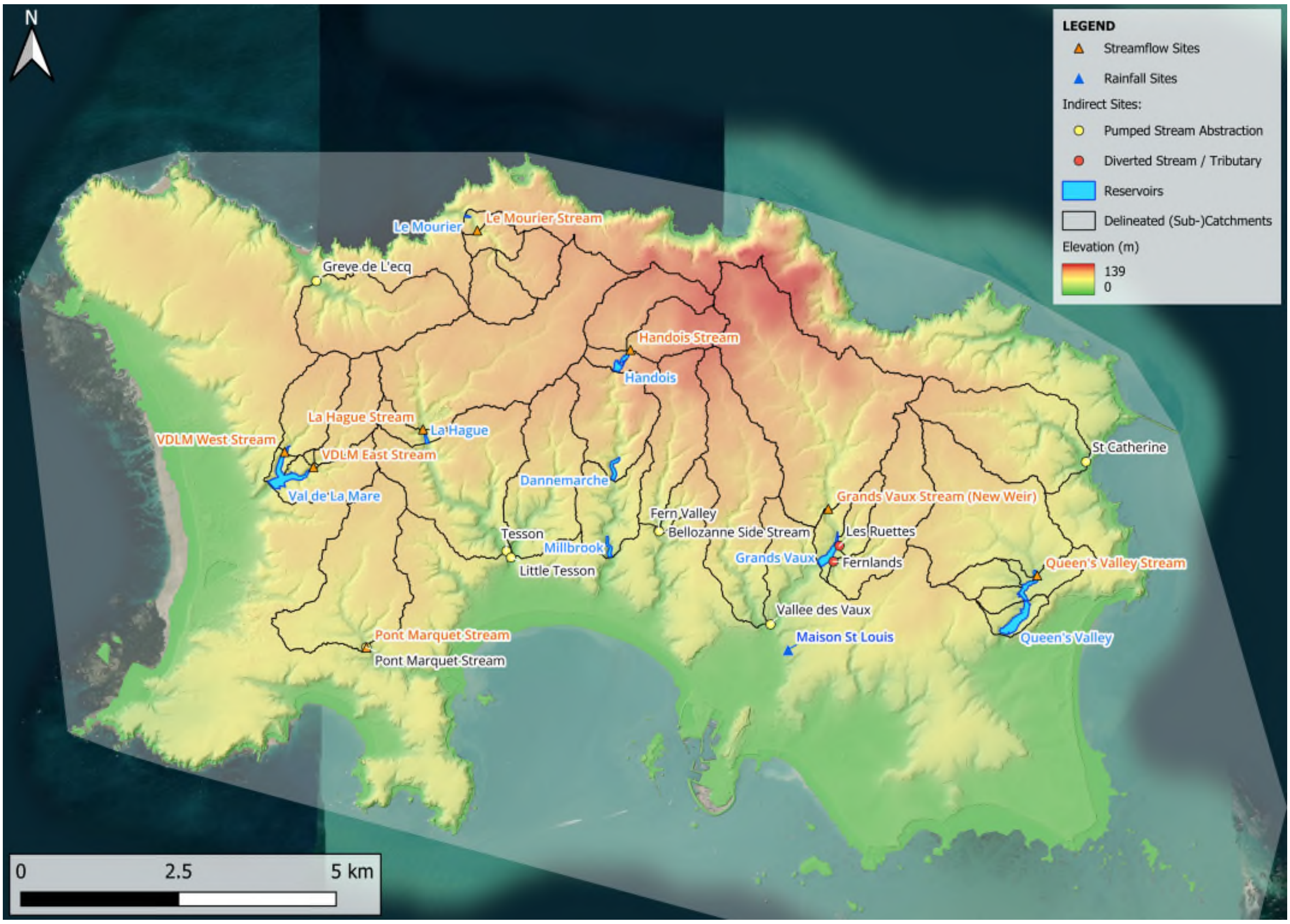

Figure 2-2 - Map of digital elevation model (DEM) derived from 1 m topographic contours

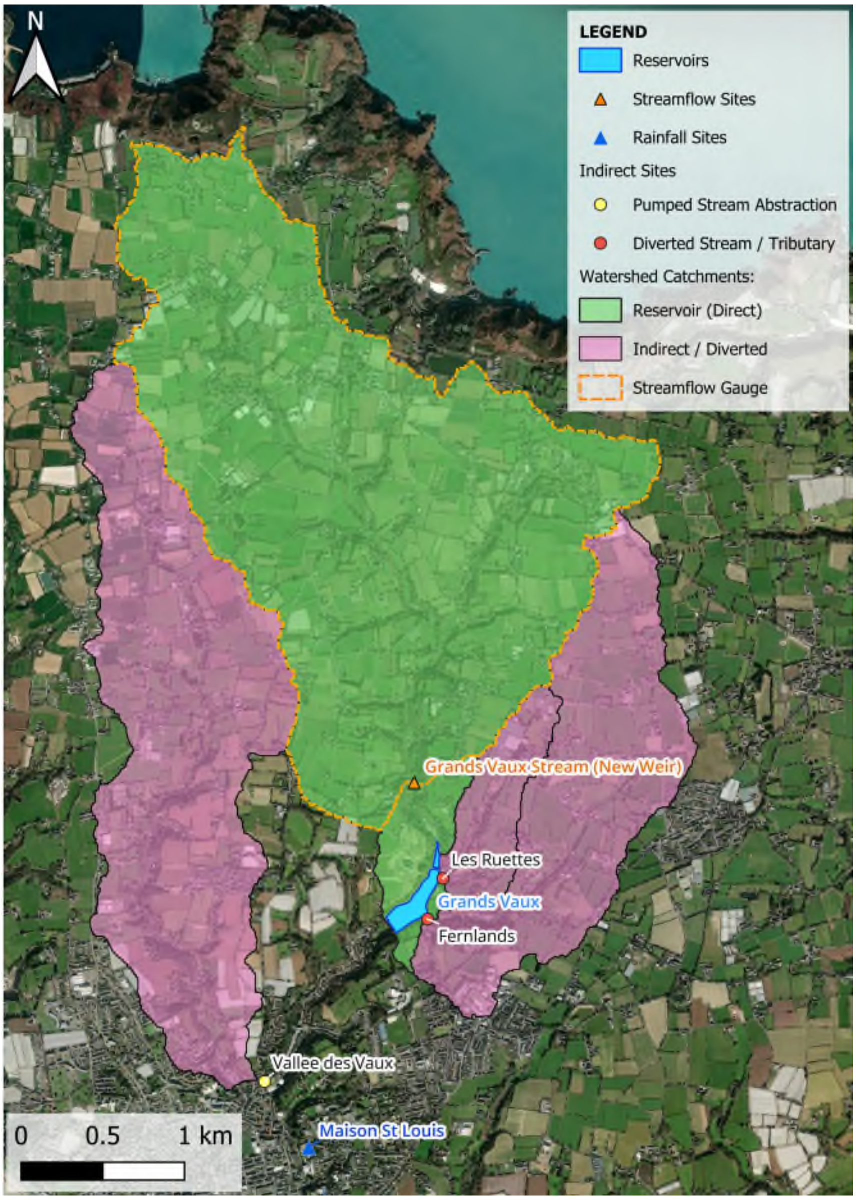

Figure 2-3 - Map of modelled surface water catchments and key site locations for Grands Vaux Reservoir

2.1.2 Landcover and geology

A summary of the land cover breakdown for the island is presented in Table 2-2. This is based on 2023 data originally published by the Government of Jersey across each of its 12 parish areas. The parish areas have been grouped here to align, as much as possible, with the reservoir watersheds. The source catchments mostly overlap with the northern, north-eastern, central west, and western parishes. For reference, a map of the parish area groupings is shown in Figure 2-4. The data in Table 2-2 indicates that the source catchments have a consistent proportion of pervious surfaces (approximately 80%), although the specific land cover type (e.g. cultivated versus natural environment) varies slightly (by ±5%). This consistency suggests that transposition of a rainfall-runoff model across the various catchments is reasonable.

As a cross check, a review of aerial imagery (dated 2019-2021[1]) was conducted for the Grands Vaux New-Weir sub-catchment. Land use across this sub-catchment appears to be predominantly for agricultural purposes (e.g. as pasture, growing crops, or even greenhouse-type buildings), scattered with both residential industrial buildings and lots. An approximate land cover breakdown for this calibration catchment is presented in Table 2-3, which suggests that approximately 87% of the catchment is pervious. However, this is likely an over-estimate as, unlike in Table 2-2, minor roads and small buildings were not included in the measured impervious areas.

While land use is relatively consistent across the source catchments, the underlying geology does vary somewhat. Figure 2-5 presents maps of both the solid (i.e. bedrock) geology and drift geology (i.e. superficial deposits). These differences are noted and might help explain potential discrepancies in simulated flows when the Grands Vaux calibration is transposed to other catchments. However, given the lack of high-quality streamflow records across the island (especially on the western side, where the geology varies more), the options for capturing these differences in our modelling are limited at present.

Table 2-2 - Land cover breakdown[1] (originally by parish) for Jersey (adapted from Government of Jersey, 2023)

Parish area	Built environment[2]	Inland water	Total Impervious	Cultivation	Natural environment[3]	Misc.[4]	Total Pervious
Northern[5]	17%	0%	17%	62%	20%	2%	83%
North-eastern[6]	19%	0%	19%	63%	16%	1%	80%
Central west[7]	19%	1%	20%	64%	15%	2%	80%
Western[8]	19%	2%	21%	55%	19%	7%	80%
South-western[9]	30%	0%	30%	23%	38%	9%	70%
South-eastern[10]	37%	1%	38%	47%	8%	7%	62%
All	**25%**	**1%**	**75%**	**52%**	**18%**	**5%**	**26%**

1. Note: All percentages are rounded independently so may not appear to total 100%.
2. Built environment includes: man-made surfaces such as buildings, roads, swimming pools, gardens, glasshouses.
3. Natural environment includes: woodlands, dunes, grassland, cliffs, shrub.
4. Miscellaneous includes: intertidal, parks, golf courses, cemeteries, quarries, sports fields.
5. Northern represents average of following parishes: St John & Trinity.
6. North-eastern represents St Martin parish.
7. Central west represents average of following parishes: St Mary & St Lawrence.
8. Western represents average of following parishes: St Ouen & St Peter.
9. South-western represents St Brelade parish.
10. South-eastern represents average of following parishes: St Helier, St Saviour, Grouville, & St Celement.

[1] Maxar (Vivid) imagery captured on Mar 28 2019 and Apr 25 2021, accessed via the ESRI World Imagery map service.

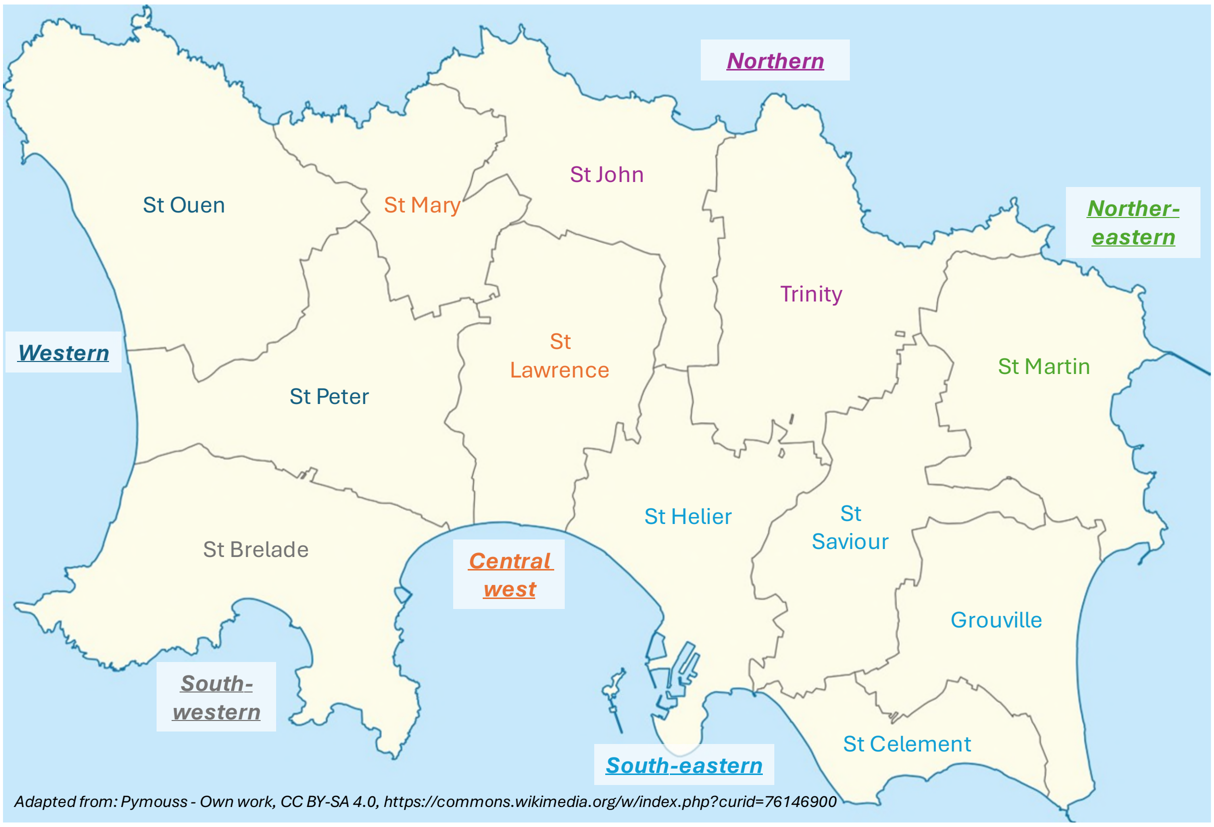

Figure 2-4 - Parishes of Jersey, grouped by characteristic land cover

Table 2-3 - Land cover breakdown for Grands Vaux New Weir catchment based on 2019-2021 aerial imagery

Land use category	Area (km^2)	Proportion of catchment
Greenhouses	0.1	2%
Buildings	0.8	11%
Sub-Total Impervious	**0.9**	**13%**
Shrubland, woodland, riparian margins	0.6	8%
Agriculture	5.4	79%
Sub-Total Pervious	**5.9**	**87%**

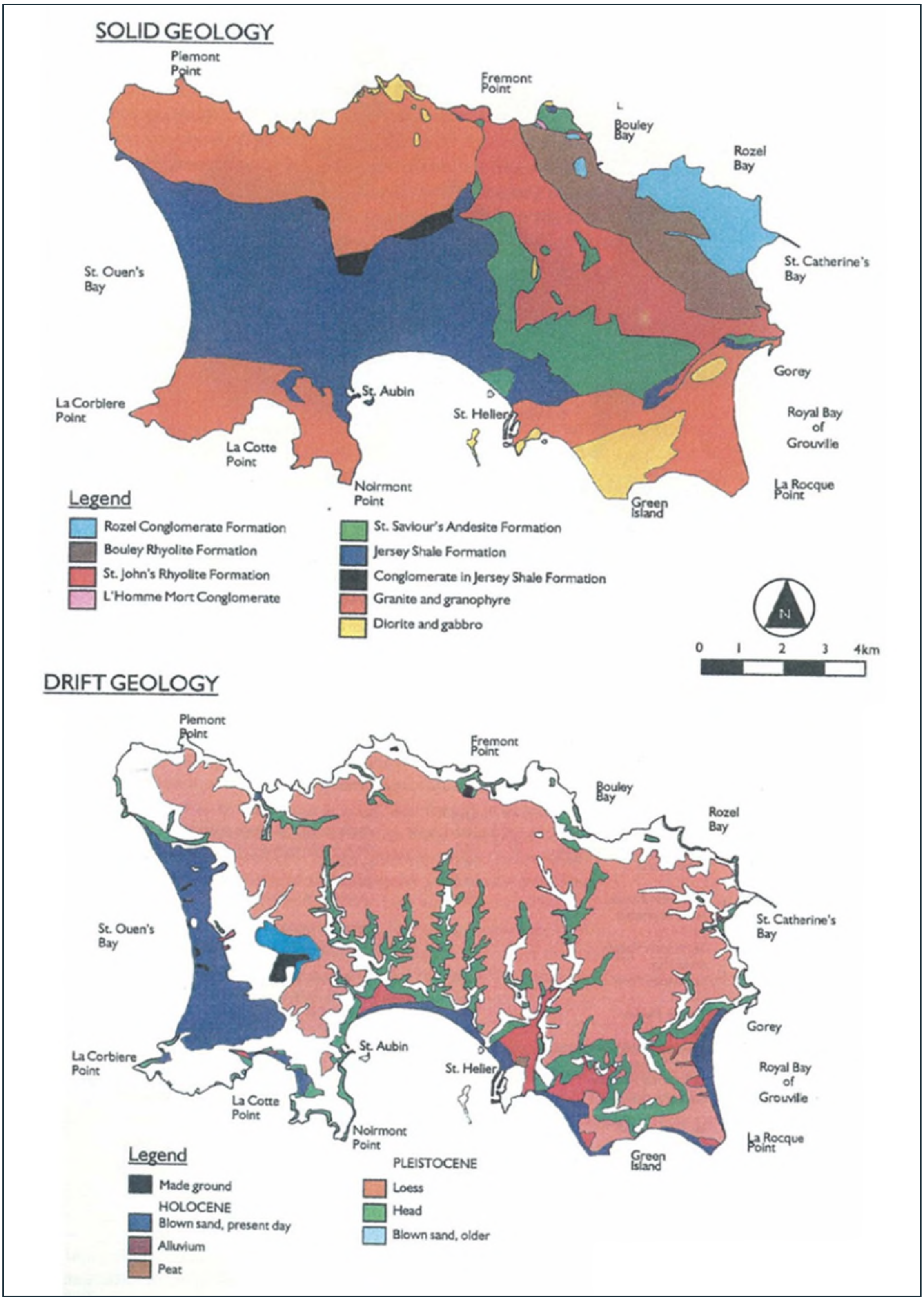

Figure 2-5 - Simplified geological map of Jersey (source: Renouf, 1985)

2.1.3 Artificial influences

From discussion with Jersey Water, it appears that many of the (sub-)catchments analysed in this study contain upstream surface water and/or groundwater abstractions by other water users. As such, the catchments are likely to have altered flow regimes. However, as far as we have been made aware, there is no monitoring data available which captures these abstracted volumes. Altered flow regimes can be challenging to model, and so ideally the target streamflow records are naturalised before model calibration. However, without any upstream abstraction data, the streamflow records were unable to be naturalised in this assessment. If abstraction records (ideally at a daily resolution) are recorded or become available in the future, we would recommend that a naturalisation (identifying and excluding upstream influences) of key streamflow records (e.g. at the Grands Vaux Stream gauge) be considered in future hydrological studies.

2.2 Available data

Various hydrological datasets have been provided by Jersey Water for this study. These include:

- Daily rainfall from 1995 to 2023 at eight Jersey Water sites as well as a long-term daily record (from 1894 to 2024) at the Jersey Met site at Maison St. Louis.
- Daily temperature from 1994 to 2023 at two Jersey Water sites as well as a long-term daily record (from 1894 to 2024) at the Jersey Met site at Maison St. Louis.
- Daily streamflows from 1995 to 2023 (although with varying levels of completeness) at eight Jersey Water sites as well as hourly streamflows for part of 2024 from new automatic gauge sites located adjacent or nearby to seven of the eight legacy sites.
- Daily pumped abstraction volumes (from indirect catchment sites and the reservoirs themselves).

2.2.1 Rainfall

Rainfall (also referred to as precipitation) is a key input into any rainfall-runoff model.

As mentioned above, daily rainfall records were provided for the eight gauges maintained by Jersey Water. These records provided useful context but were not explicitly employed in the rainfall-runoff modelling. Rather, the daily record at Maison St. Louis maintained by Jersey Met was primarily used for the following reasons:

- It presented a longer-term dataset (spanning over 120 years) with no gaps.
- To align with the stochastic weather generation process (which also used the Maison St. Louis record).

Table 2-4 - Summary of Daily Rainfall Records Received

<table>
<tr><th>Source / Data Owner</th><th>Site</th><th>Period Covered</th><th>Record Length</th><th>Record Completeness[1]</th><th>Quality[2]</th></tr>
<tr><td rowspan="8">Jersey Water</td><td>Grands Vaux[3]</td><td rowspan="8">01-Jan-1995 – 31-Oct-2023</td><td rowspan="8">28.8 years</td><td rowspan="8">> 94%</td><td rowspan="8">Good</td></tr>
<tr><td>Handois[3]</td></tr>
<tr><td>Queen's Valley[3]</td></tr>
<tr><td>Val de la Mare[3]</td></tr>
<tr><td>Millbrook[3]</td></tr>
<tr><td>Augres</td></tr>
<tr><td>Greve de Lecq</td></tr>
<tr><td>St. Catherine</td></tr>
<tr><td rowspan="2">Jersey Met</td><td>Maison St. Louis</td><td>01-Jan-1894 – 30-Jun-2024</td><td>124.3 years</td><td>100%</td><td>Good</td></tr>
<tr><td>Airport</td><td>01-Jan-1983 – 31-Jul-2018</td><td>35.6</td><td colspan="2">n/a</td></tr>
</table>

1. Proportion of record with data (i.e. not gaps).

2. Assessed based on completeness.
3. Located at/near reservoir.

In an effort to capture the spatial variability in rainfall across the island, the Maison St. Louis record was scaled for each (sub-)catchment before being input into the rainfall-runoff models. These scaling factors were derived from isohyets mapped by MWH in their 2006 report (see Figure 2-6), where the isohyets were based on mean annual rainfall from 1971 to 1991. The resulting scaling factors ranged from 93.2% to 109.1% and were applied uniformly to the daily rainfall at Maison St. Louis.

The process for estimating/deriving the scaling factors was as follows:

- Firstly, the isohyets were converted the to a gridded form, covering the entire island.
- Then, the average of gridded values across each of the catchment areas was calculated
- The catchment average values were then compared to the value cited for the Maison St. Louis site (834 mm/yr) and a linear scaling factor calculated as

$$factor = catchment\ average \div Maison\ St. Louis\ average$$

Note: The spatial variability captured in the MWH isohyets was sense-checked against the pattern seen in the 1995 to 2023 records across the various Jersey Water sites The two data sources were found to align reasonably well, with the proportion of average rainfall seen at each site (relative to average rainfall at Maison St. Louis) varying by only ±5% (refer Table 2-5 below).

Note: The final rainfall scaling factors applied to each (sub-)catchment is presented as part of Table 2-5.

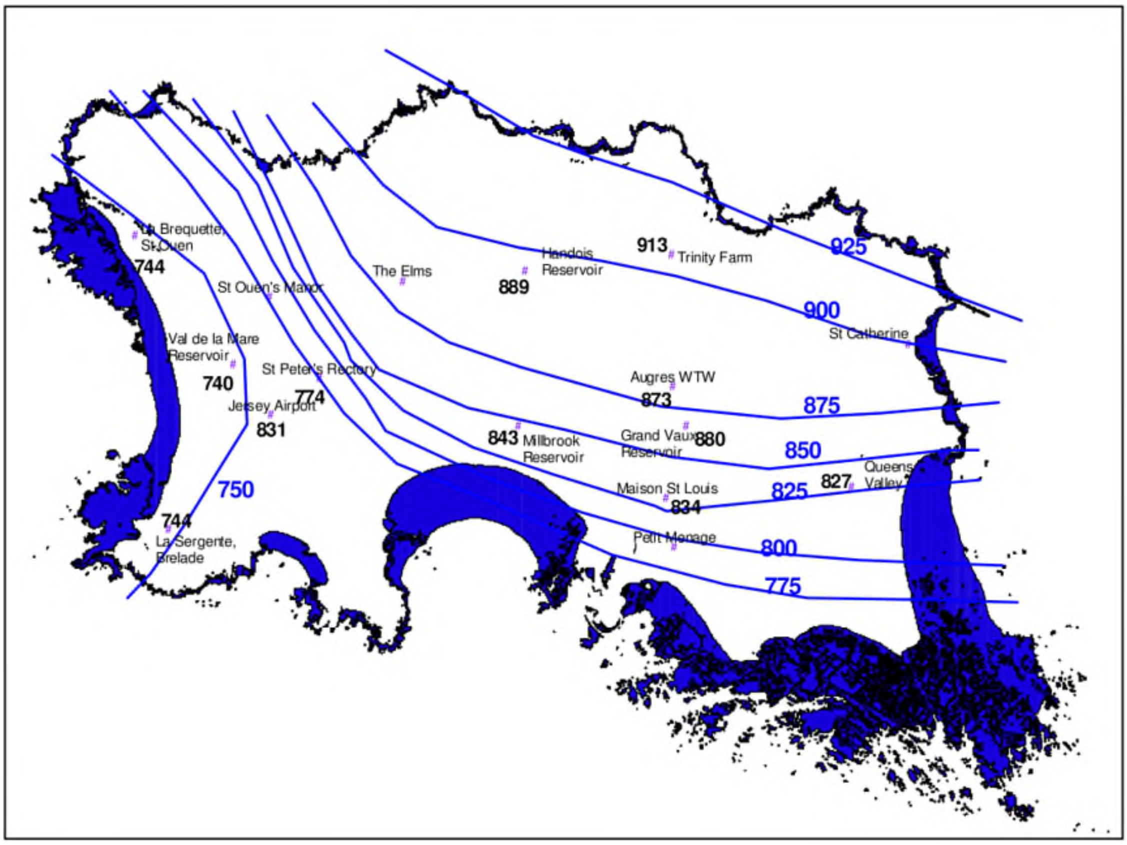

Figure 2-6 - Jersey 1970-1991 Annual Average Rainfall (Source: MWH, 2006, Figure 5-6)

Table 2-5 – Comparison of mean annual rainfall estimates and corresponding scaling factors

Site	Mean Annual Rainfall (mm/yr)		Proportion of Maison St. Louis [1]	
	1970-1991 [2]	1995-2023 [3]	1970-1991	1995-2023
Handois	889	1097.9	107%	110%
Millbrook	843	1058.7	101%	106%
Augres	873	1064.8	105%	107%
Val de la Mare	740	886.7	89%	89%
Grands Vaux	880	1051.8	106%	106%
Queen's Valley	827	997.4	99%	100%
Greve de Lecq	850	968.7	102%	97%
St. Catherine	900	1081.6	108%	109%
Station Average	850.3	1026.0	102%	103%
Maison St. Louis	**834**	**996.9**	**100%**	**100%**

1. Blue shading indicates sites with higher annual rainfall than Maison St Louis, red shading indicates vice versa.
2. Source: MWH, 2006, Figure 5-6.
3. Only hydrological years with less than 5% gaps included in the average. Across all the Jersey Water rainfall sites, this equated to 1/10/1997-30/09/2001 & 1/10/2019-30/09/2023.

2.2.2 Temperature

Temperature is not typically a key input into rainfall-runoff models, however in the absence of any potential evapotranspiration records, temperature became a significant requirement of this assessment.

As mentioned above, daily temperature records were provided for two gauges maintained by Jersey Water. Initially, these were the only temperature records available. Careful review of these records uncovered a major anomaly in the records prior to 2005. This matter was documented in a technical note issued in April 2024 (AtkinsRéalis, 2024). This review also sought to correct the anomaly so that the records could be reliably used in this study. However, a long-term record from Jersey Met was subsequently obtained and so this was used instead.

Table 2-6 - Summary of Daily Temperature (Min and Max) Records Received

Source / Data Owner	Site	Period Covered	Record Length	Record Completeness[1]	Quality[2]
Jersey Water	Handois[3] Millbrook[3]	12-Apr-1994 – 31-Oct-2023	29.6	n/a	Poor[4]
Jersey Met	Maison St. Louis	01-Jan-1894 – 29-Feb-2024	124.3 years	100%	Good

1. Proportion of record with data (i.e. not gaps).
2. Assessed based on completeness and apparent reliability.
3. Located at/near reservoir.
4. Major anomaly in the records prior to 2005.

2.2.3 Streamflows

Observed streamflows are required to calibrate and validate any rainfall-runoff model, as they represent the variable the models are attempting to predict.

Jersey Water maintain a network of streamflow monitoring sites across the island (see Table 2-7). However, these vary in terms of both data quality and quantity. Daily streamflows have been measured for many decades, and these records have been provided from 1995 onwards. In 2024, Jersey Water began installing and implementing a continuous monitoring system. Where available, these streamflow records were also provided – noting that continuous gauges had not yet been installed at every site. These two sources of streamflow data are referred to as the “old” and “new” gauge networks, respectively.

A qualitative assessment of each of the records received is presented in Table 2-7. This table also outlines which records were used in the rainfall-runoff model calibration and validation. Some of the records were used only with caution in the validation stages. This was limited to qualitative review, say, of how simulated and observed hydrographs aligned during periods when the records appeared more reliable.

Table 2-7 - Summary of Jersey Water streamflow records received

<table>
<tr><th>Stream Site</th><th>Gauge Network</th><th>Resolution</th><th>Period Covered</th><th>Record Length</th><th>Record Completeness[1]</th><th>Quality[2]</th><th>Notes</th><th>Status / Conclusion</th></tr>
<tr><td rowspan="2">Grands Vaux[3]</td><td>Old</td><td>Daily</td><td>01-Jan-1995 – 26-Apr-2024</td><td>29.3 years</td><td>71%</td><td>Good</td><td rowspan="2">▪ Relatively complete old record but some capped high flows
▪ Well aligned with the new record</td><td rowspan="2">Both records used in GR6J calibration & validation</td></tr>
<tr><td>New</td><td>Hourly</td><td>04-Mar-2024 – 25-Jun-2024</td><td>3.7 months</td><td>100%</td><td>Good</td></tr>
<tr><td rowspan="2">Handois</td><td>Old</td><td>Daily</td><td>01-Jan-1995 – 07-Jul-2002</td><td>7.5 years</td><td>76%</td><td>Moderate</td><td rowspan="2">▪ Incomplete / short old record, with some capped high flows
▪ No overlap with new record
▪ But new record aligns well with Grands Vaux</td><td rowspan="2">Both records used in validation</td></tr>
<tr><td>New</td><td>Hourly</td><td>25-Jan-2024 – 25-Jun-2024</td><td>5.0 months</td><td>100%</td><td>Good</td></tr>
<tr><td rowspan="2">Queen's Valley</td><td>Old</td><td>Daily</td><td>01-Mar-1995 – 05-Oct-2009</td><td>14.6 years</td><td>66%</td><td>Moderate</td><td rowspan="2">▪ Incomplete old record with capped high flows and potentially altered flow regime
▪ No overlap with new record
▪ But new record aligns well with Grands Vaux</td><td rowspan="2">▪ Old record used with caution in validation
▪ New record used with slightly more confidence</td></tr>
<tr><td>New</td><td>Hourly</td><td>08-Apr-2024 – 25-Jun-2024</td><td>2.6 months</td><td>100%</td><td>Good</td></tr>
<tr><td rowspan="2">La Hague</td><td>Old</td><td>Daily</td><td>01-Jan-1995 – 26-Apr-2024</td><td>29.3 years</td><td>67%</td><td>Moderate</td><td rowspan="2">▪ Relatively complete old record, but some capped high flows and “stepped” in latter period
▪ Aligned new record, but with “steps” present</td><td rowspan="2">Both records used with caution in validation</td></tr>
<tr><td>New</td><td>Hourly</td><td>27-Feb-2024 – 25-Jun-2024</td><td>3.9 months</td><td>100%</td><td>Moderate</td></tr>
<tr><td>Le Mourier</td><td>Old</td><td>Daily</td><td>22-Aug-1995 – 26-Apr-2024</td><td>28.7 years</td><td>49%</td><td>Poor</td><td>▪ Patchy (i.e. incomplete) old record, with rather unstable (e.g. fluctuating) flow regime
▪ No new gauge</td><td>Old record used with caution in validation</td></tr>
<tr><td rowspan="2">Pont Marquet</td><td>Old</td><td>Daily</td><td>01-Sep-1995 – 31-Dec-2001</td><td>6.3 years</td><td>83%</td><td>Moderate</td><td rowspan="2">▪ Incomplete old record with capped high flows
▪ No overlap with new record
▪ New record sits relatively low compared to other sites</td><td rowspan="2">▪ Old record used in validation
▪ New record also used, with slightly less confidence</td></tr>
<tr><td>New</td><td>Hourly</td><td>29-Mar-2024 – 25-Jun-2024</td><td>2.9 months</td><td>100%</td><td>Moderate</td></tr>
</table>

VDLM East	Old	Daily	03-Apr-1995 – 24-Dec-2003	8.7 years	58%	Poor	▪ Incomplete old record with <u>some</u> capped high flows ▪ Old gauge located downstream of a pumped abstraction input, rendering it unrepresentative of natural flow regime ▪ No overlap with new record ▪ New record aligns well with Grands Vaux & and Handois sites	▪ Old record disregarded ▪ New record used, with <u>more confidence</u>
	New	Hourly	28-Feb-2024 – 25-Jun-2024	3.9 months	100%	Good		
VDLM West	Old	Daily	03-Apr-1995 – 26-Apr-2024	29.1 years	50%	Poor	▪ Old record incomplete with capped high flows, very "stepped" in second half, and unstable flow regime ▪ New record appears inconsistent	Both records disregarded
	New	Hourly	04-Mar-2024 – 25-Jun-2024	3.6 months	100%	Poor		

1. Proportion of record with data (i.e. not gaps).
2. Assessed based on completeness and apparent reliability of flow regime captured.
3. Confirmed to be New Weir location in email from Jersey Water dated 01-May-2024.

2.2.4 Pumped abstraction

Pumped abstraction records were utilised in the development of a water balance model of the Grands Vaux reservoir system.

Daily records were provided for some 19 sites, the following of which were pertinent to the Grands Vaux reservoir system - and therefore used in this study:

- Pumped abstraction from Vallee des Vaux Stream into Grands Vaux reservoir
- Pumped abstraction from Grands Vaux reservoir into production (sent to Augres WTW)
- Pumped abstraction from Grands Vaux reservoir into Queen's Valley Reservoir.

A preliminary review of these records indicated that they contained significant gaps (15-18%). These gaps are highlighted in Figure 2-7, Figure 2-8 and Figure 2-9.

Note: No additional analysis was done to attempt to fill these gaps or QA the records any further as this fell outside the scope of this study.

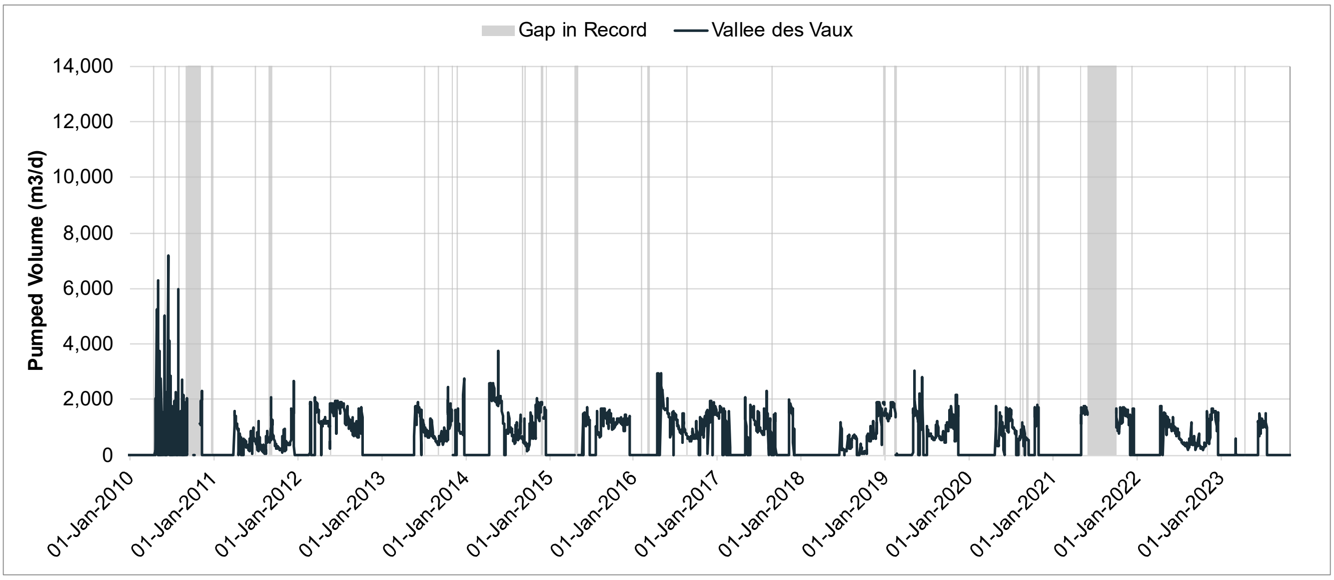

Figure 2-7 – Pumped abstraction (2010-2023) from Vallee des Vaux Stream with gaps in grey

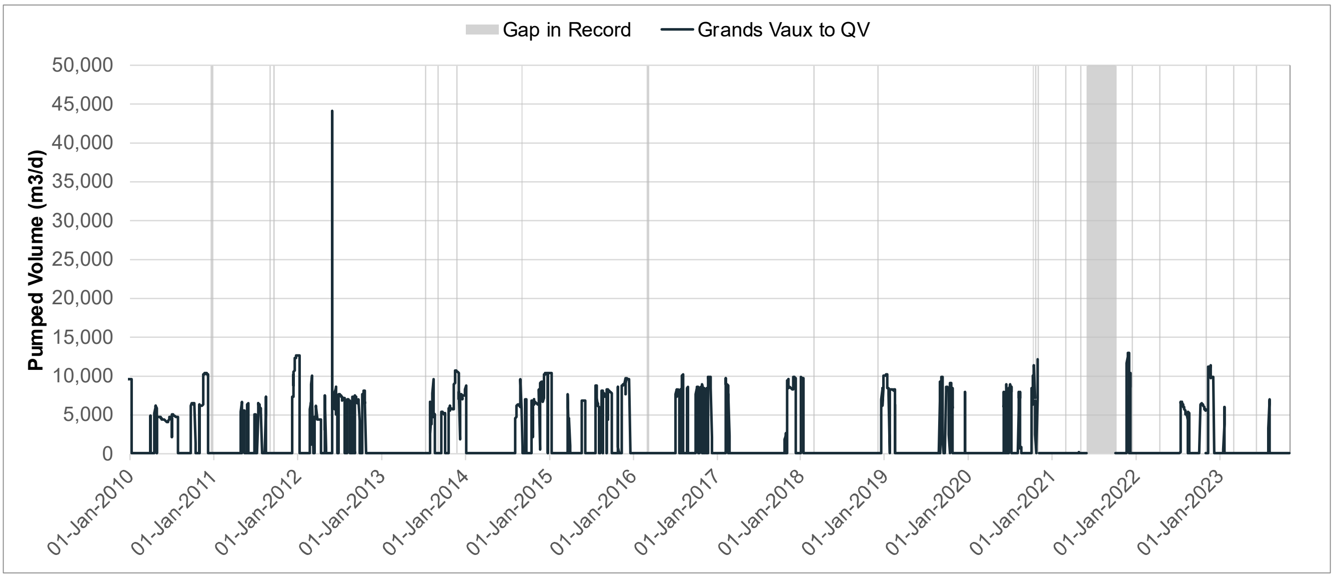

Figure 2-8 – Pumped abstraction (2010-2023) from Grands Vaux to Queen's Valley with gaps in grey

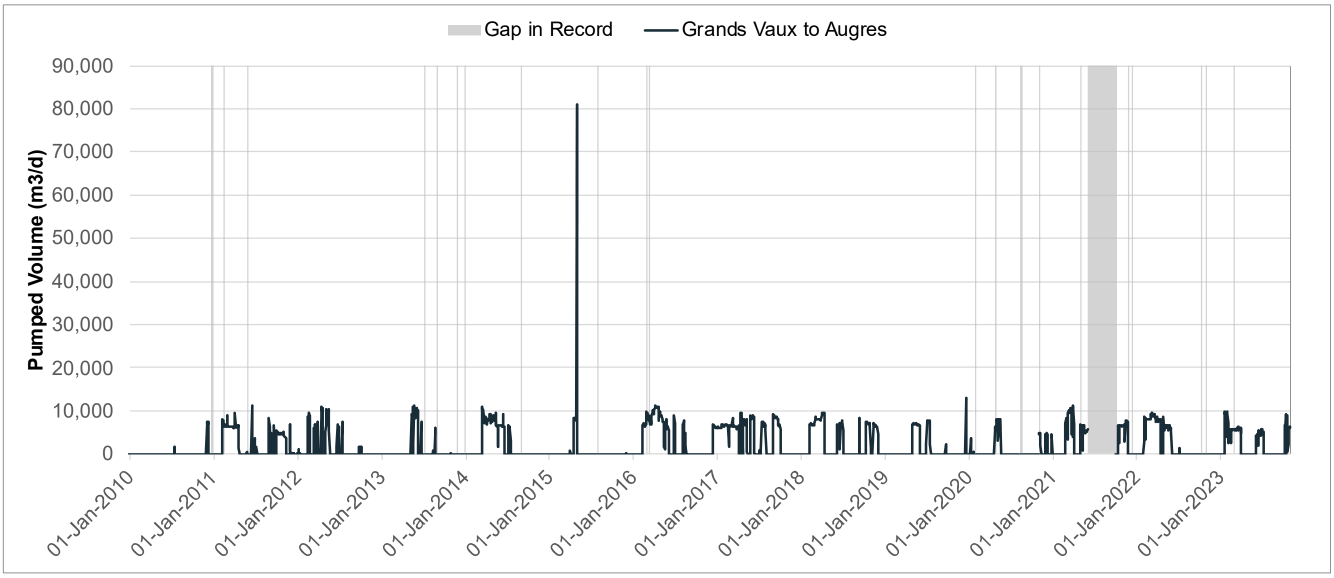

Figure 2-9 – Pumped abstraction (2010-2023) from Grands Vaux to Augres WTW with gaps in grey

2.2.5 Reservoir operations

Reservoir water level and storage records were also utilised in the development of a water balance model of the Grands Vaux reservoir system. Daily records were provided spanning January 1995 through October 2023.

The storage record was primarily used to calculated changes in reservoir storage (a critical component of the water balance). It was also used, alongside the water level record, to estimate the reservoir surface area on each day and then calculate direct rainfall and evaporation from the reservoir surface (a secondary component of the water balance).

2.2.5.1 Reservoir rating curve modifications

To calculate the reservoir surface area on any given day required a rating curve linking either storage or water level to surface area. Such a curve did not exist for the Grands Vaux reservoir, however a rating curve linking storage to water level was provided by Jersey Water.

The storage-elevation curve provided did not cover the full range of reservoir storage. Specifically, the curve did not extend below 24,321.1 m^3. To ensure the water balance model could simulate conditions below this level, the storage-elevation curve was extrapolated using a second order polynomial fitted equation for determining storage based on water level (refer Figure 2-11) and a fourth order polynomial for vice versa (refer Figure 2-12).

This was used to estimate a relationship between storage and surface area by calculating changes in storage and water level at each step of the rating curve (assuming a simplified cross section at each step, refer Figure 2-10) as per the following equation:

$$Derived\ surface\ area_i\ (m^2) = \frac{|\Delta Storage|\ (m^3)}{|\Delta Elevation|\ (m)} = \frac{|Storage_{i+1} - Storage_i|}{|Elevation_{i+1} - Elevation_i|}$$

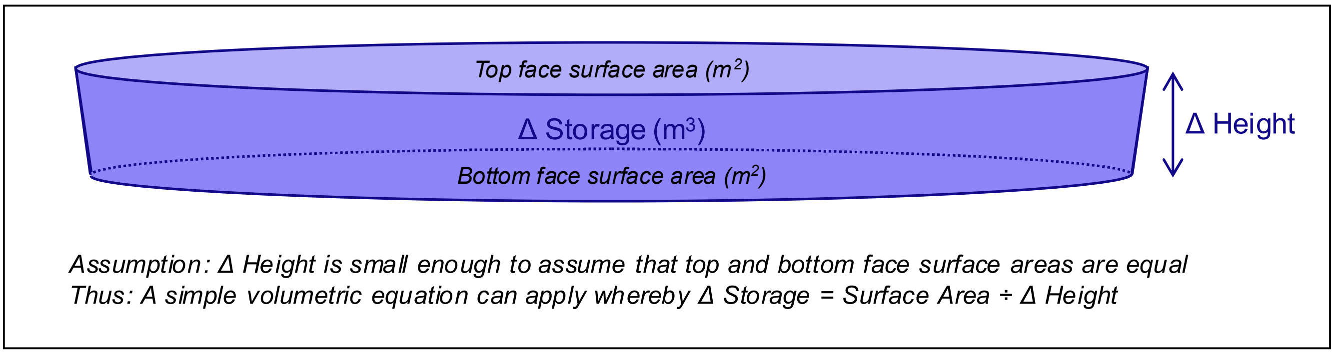

Figure 2-10 – Conceptual model of reservoir cross section at each step of a rating curve

With all these components put together, a surface area vs elevation relationship was derived as shown in Figure 2-13 (refer to the black line). Noting that the raw relationship presented significant noise which was smoothed out using another second order polynomial fitted equation (refer to the pink line). This fitted equation was used in the water balance model to estimate reservoir surface area given observed water levels.

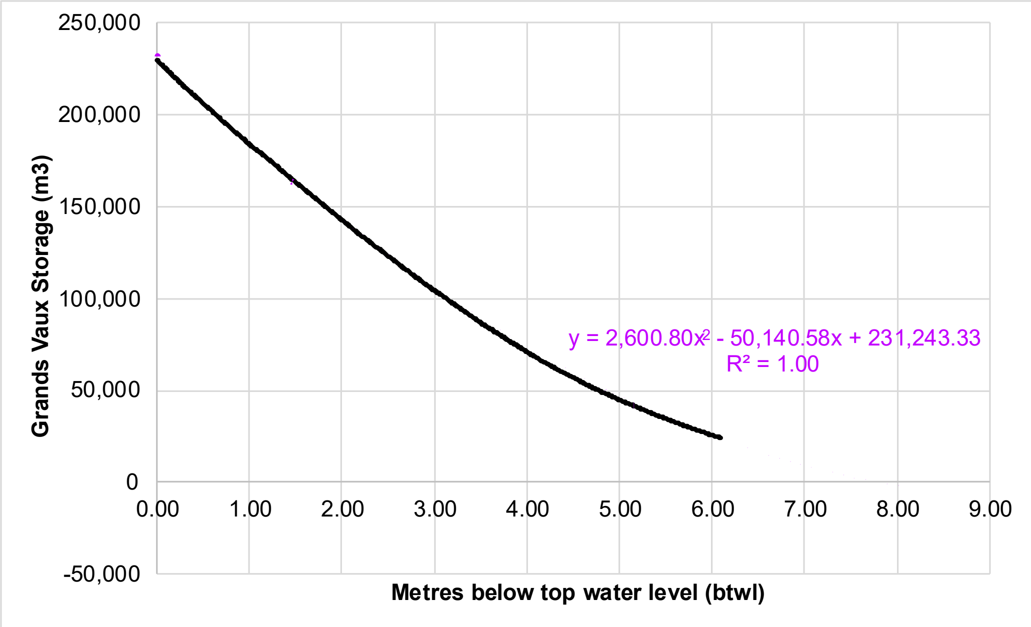

Figure 2-11 – Grands Vaux reservoir storage vs elevation curve (black) with polyfit extrapolation (pink)

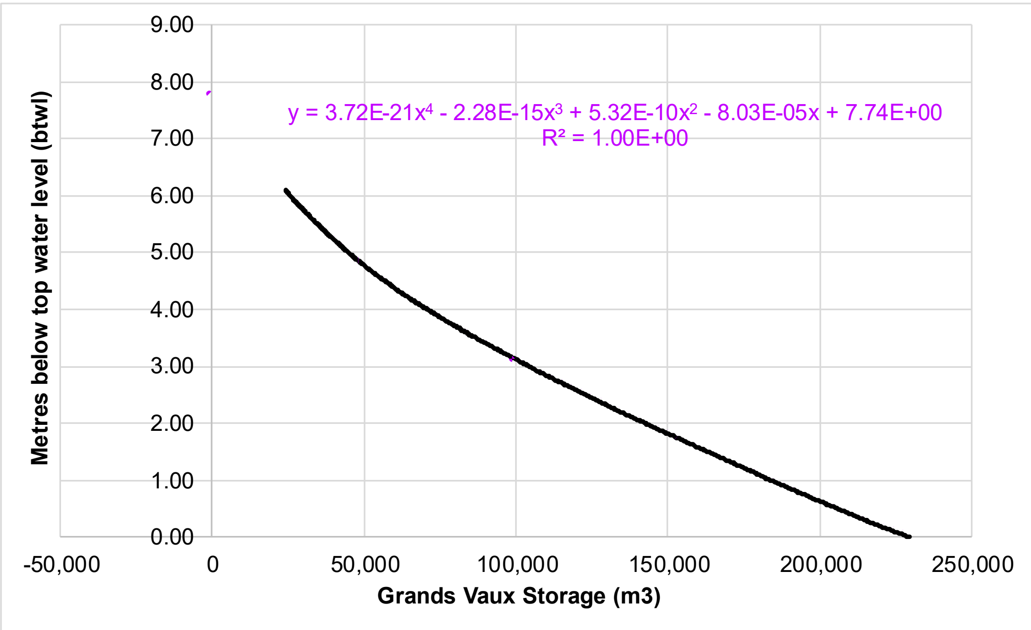

Figure 2-12 – Grands Vaux reservoir elevation vs storage curve (black) with polyfit extrapolation (pink)

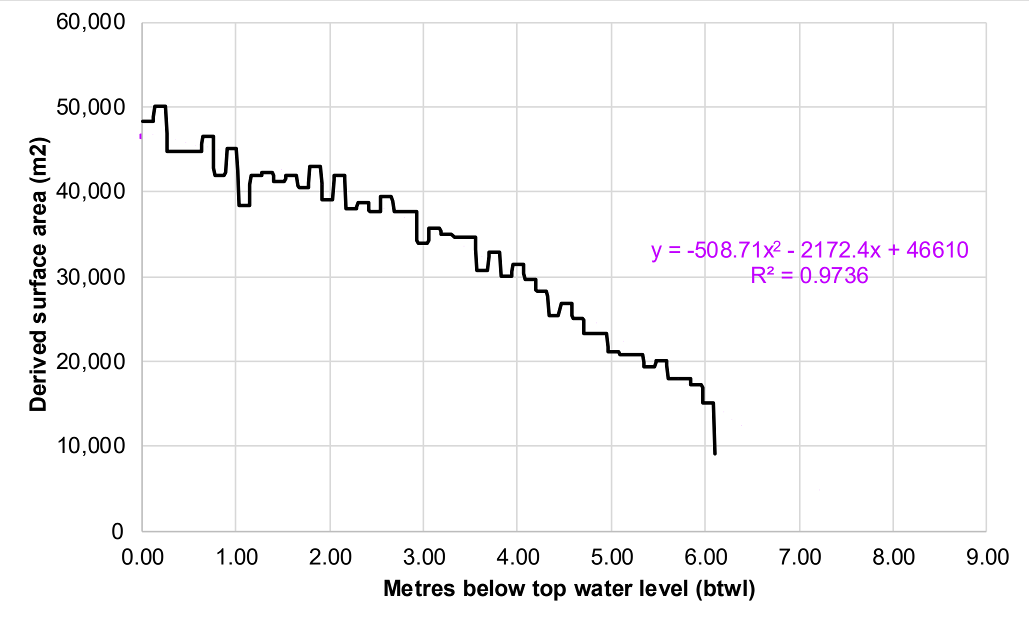

Figure 2-13 – Grands Vaux reservoir derived surface area vs elevation (black) with polyfit smoothing and extrapolation (pink)

2.3 PET derivation

Potential evapotranspiration (PET) is the other critical input for rainfall-runoff models as it represents what is often the largest outflux of water from a catchment, aside from runoff itself. PET is a theoretical measure of how much water would be evaporated (and transpired by vegetation) by the catchment surface (i.e. the land cover and soil) if there was sufficient water available (e.g. from precipitation and soil moisture). Being a theoretical parameter, it cannot be directly measured. Instead, it is estimated based on other measured meteorological parameters (such as temperature, solar radiation, humidity, and wind speed).

There are multiple methods for calculating PET and these vary in terms of input parameters required. For example, the commonly used Penman-Monteith equation requires inputs including solar radiation, vapour pressure, relative humidity and wind speed. The Penman-Monteith equation was used to derive PET for the previous hydrological study (MWH, 2006) as these meteorological variables were measured at the Trinity weather station in the mid-1990s. This is not the case for the weather stations utilised in this study (e.g. Maison St. Louis) and so a different method was required.

Our assessment has utilised another commonly used method, the Oudin equation, as it only requires mean daily temperature and latitude. Although a less detailed (and arguably less precise) method than, say, the Penman-Monteith equation, studies have found the Oudin equation outperforms others when employed in rainfall-runoff modelling applications (Flores et al., 2021).

The Oudin equation is written as follows (Oudin et al., 2005):

$PET = \frac{R_e}{\lambda\rho}\frac{T_a+5}{100}$ if $T_a + 5 > 0$

$PET = 0$ otherwise

Where PE is the rate of potential evapotranspiration (mm/day), Re is extraterrestrial radiation (MJ/m^2/day), depending only on latitude and Julian day, λ is the latent heat flux (taken equal to 2.45 MJ/kg), ρ is the density of water (kg/m^3) and Ta is mean daily air temperature (°C). PE is therefore a single function of the Julian day for a given location (Oudin et al., 2005).

Using the PE_Oudin function included in the airGR package in R, the daily temperature record at Maison St. Louis was used to derive a corresponding daily PET dataset. Note: the latitude of the site was assumed to be 49.1907 decimal degrees.

Unlike with rainfall, no scaling was applied to PET (to transpose it from the Maison St. Louis site to the catchments of interest). This decision was driven by the following factors:

- Over the relatively small area of Jersey, PET is not expected to vary significantly.
- There were no spatially varying PET datasets available to inform any scaling.

In order to sense-check the Oudin derived PET record it was plotted against the record produced by MWH utilising the Penman-Monteith method. This can be seen in Figure 2-14 which shows monthly PET values for the two methods from 1990 through 2007. Note: The MWH record was pulled from the HYSIM export files provided by Jersey Water[2]. This plot indicates that the Oudin method generally produces PET estimates with a greater range (higher peaks and lower troughs), but on average the two methods align well. This provided reasonable confidence that the Oudin method was fit for purpose in this application.

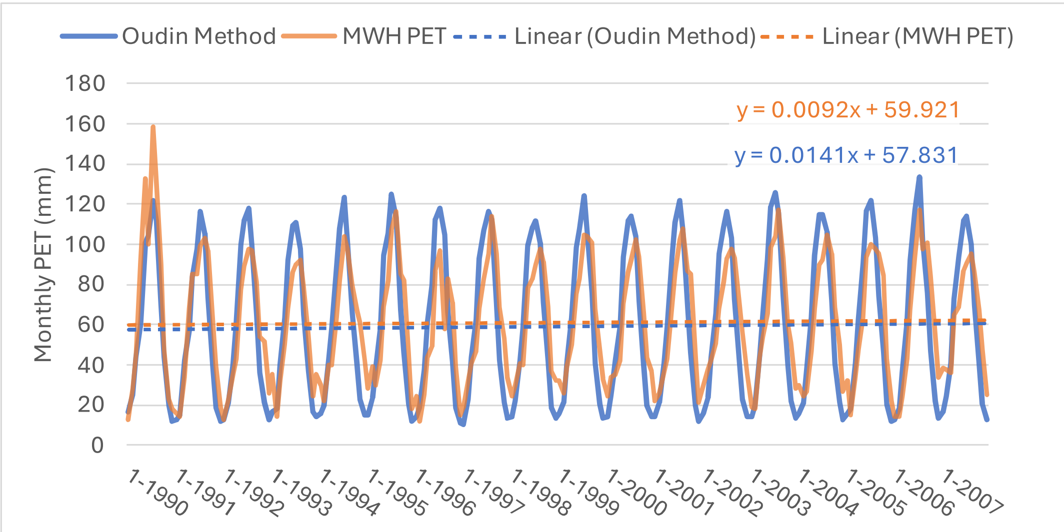

Figure 2-14 – Comparison of derived PET records, Oudin (used here) vs. Penman Monteith (used by MWH in 2006 analyses)

2.4 Rainfall-runoff modelling

A rainfall-runoff model was utilised to produce daily streamflow series for all the relevant surface water source catchments. The GR6J model (Génie Rural à 6 paramètres Journalier; Pushpalatha et al., 2011) was adopted in this assessment. GR6J is increasingly used in the UK for water resources applications (UK Hydrological Outlook, 2025) due to its simplicity, relative accuracy, and open-source deployment. As such, it was adopted in this study.

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[2] Refer to 'Grand Vaux Rainfall-PET Perturb calcs v2.0.xlsx'.

2.4.1 The GR6J model

The GR6J model is a conceptual lumped hydrological model. The inputs to the model are spatially averaged catchment daily precipitation and potential evapotranspiration. In the model, the water balance is controlled by a soil moisture reservoir and a conceptual groundwater exchange function. The routing procedure of the module includes two flow components routed by two unit-hydrographs, a non-linear store and an exponential store, with a total of six parameters (Table 2-8). The structure of the model is illustrated in Figure 2-15, and a detailed description of the model routines is given in Pushpalatha et al. (2011).

GR6J, as implemented by the original model developers, is an open-source model freely available from https://odelaigue.github.io/airGR/index.html. The model is part of a collection of hydrological models provided in the "airGR" modelling suite for the R software programme (Coron et al., 2017, Coron et al., 2023).

Table 2-8 - GR6J Model Parameters

Parameter	Name	Units	Description
X1	Production store capacity	mm	Non-linear production storage capacity
X2	Inter-catchment exchange coefficient	mm/d	Groundwater exchange coefficient
X3	Route store capacity	mm	Non-linear routing store capacity
X4	Unit hydrograph time constant	d	Time parameter for unit hydrograph routing
X5	Inter-catchment exchange threshold	-	Threshold parameter for water exchange with groundwater (threshold for change in F sign)
X6	Coefficient for emptying exponential store	mm	Exponential routing store capacity

Source: Coron et al. (2023)

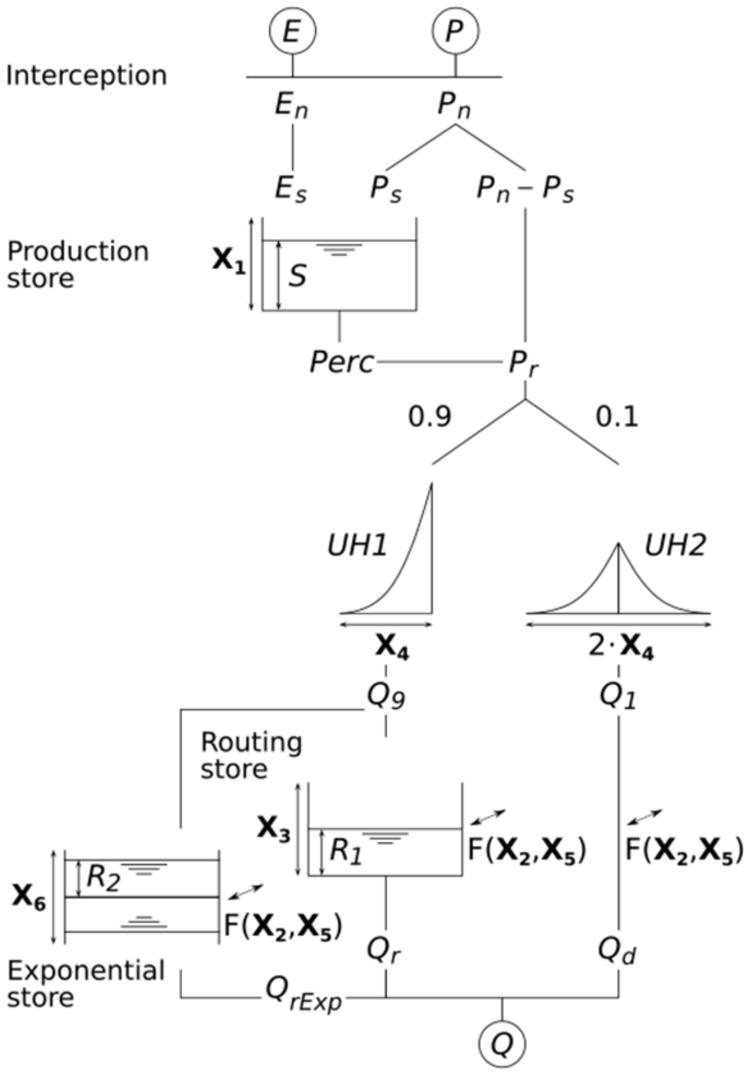

Figure 2-15 - Schematic representation of the GR6J model (where E = potential evapotranspiration, P = precipitation, and Q = streamflow). Source: Coron et al. (2023).

2.4.2 Calibration and validation set up

The airGR package includes an automatic calibration procedure which has been employed in this assessment. Using this procedure, one can specify a number of error metrics with which to drive the calibration (i.e. that the procedure will seek to minimise) and an observed streamflow record for the model performance to be evaluated against. The procedure will then proceed to perform a steepest descent local search algorithm on GR6J's six parameters until an optimal set of parameter values is found (subject to user-defined initial conditions for the parameter values, user-defined bounds on the parameter values, and a built-in threshold for termination of the search algorithm).

The following two error metrics were used to drive the auto calibration in this assessment, with each metric given equal weighting:

- Nash-Sutcliffe Efficiency (NSE) score on sorted flows.
- NSE on the natural log of flows.

The NSE score is a commonly used statistical measure in hydrological studies as an estimate of 'goodness of fit' between modelled and observed flows on any given day in a record (Nash and Sutcliffe, 1970). Calculating the NSE score on sorted flows serves to match the flow regime as a whole – i.e. not simply matching instantaneous flows). Conversely, calculating the NSE score on the natural log of flows reduces the relative emphasis put on higher flows – i.e. serving to prioritise matching low flows, which are of greater importance than high flows for water resources applications.

Calibration and validation of the Grands Vaux stream GR6J model was primarily informed by the longer streamflow record presented in the "old gauge network". However, due to significant data gaps, the first two years (1995 and 1996) of this record were dropped. The remaining record was then split approximately 50/50 into calibration and validation periods, with each period spanning at least 13 hydrological years. The calibration dataset was used to drive the local search algorithm, and the validation dataset was used to independently test any optimal parameter sets found. While it can be tempting to utilise as much observed data as is available for model calibration, setting aside part of the data for validation allows for the model's performance to be assessed and verified on a separate, unseen dataset. This helps to avoid overfitting a model to the exact conditions seen in the calibration period. Note: Rather than splitting the record exactly down the middle, the calibration period was selected such that it included only full hydrological years. This was to help ensure the calibration was optimised on the full flow regime, rather than inadvertently skewing it to flow conditions that would otherwise be overrepresented in the period.

In addition: While one might have favoured more recent data for model calibration (because it captures the latest state of the catchment), in this case the first half of the streamflow record was selected for model calibration. This is because the more recent data was much more sparse. For example, from April 2005 onwards, data stopped being collected on Sundays and Mondays. This alone represents an almost 30% reduction in datapoints.

The "new gauge network" record was appended to provide additional validation data.

Altogether, this resulted in the following calibration-validation breakdown:

- Calibration period = 1-Oct-1997 to 30-Sep-2010 (13 full hydrological years)
- Validation period = 1-Oct-2010 to 30-Jun-2024 (13 full hydrological years plus a further 9 months)

2.4.3 Grands Vaux stream calibration

Table 2-9 presents the calibrated GR6J model parameters for the Grands Vaux stream catchment. Meanwhile, Figure 2-16 presents a visual summary of the calibrated model and Table 2-10 provides a summary of various performance metrics across the calibration and validation periods.

Looking at the flow timeseries comparison in Figure 2-16 (refer middle plot), one can see that the calibration presents a good fit for recession and baseflow conditions. This is also reflected in the very closely matching Q90 metrics seen in Table 2-10. However, the model does appear to miss a lot of the peak flows, especially the smaller 'flashy' peaks that occur during recession periods. These peaks in flow could potentially be linked to localised rainfall events that have not been captured in the Maison St. Louis record. Note: Various tests were carried out to attempt to improve the simulation of these spate flows (e.g. testing higher rainfall scaling factors, calibrating to more local rainfall gauges, testing alternative parameter sets, etc.). None of these tests proved successful and so were discarded.

Despite missing the 'flashier' flows, a look at the key metrics presented in Table 2-10 reveals that the calibrated model performs very well over both the calibration and validation periods, with NSE scores greater than 0.8 and percentage biases within 10%. Overall, we consider this to be a good model fit, especially given the data limitations (e.g. significant gaps present in the observed streamflow record). This is further emphasised in Figure 2-17 which presents a comparison of flow duration curves (FDCs) between observed and simulated flows. Also included in this figure is a FDC representing the previously calibrated HYSIM rainfall-runoff model

(MWH, 2006). This dataset has been pulled from HYSIM exports provided by Jersey Water[3]. The HYSIM FDC sits lower than both the observed and GR6J curves, which aligns with findings from MWH in 2006: *"For Grands Vaux, the simulated streamflows are generally lower than the gauged operational values."* This suggests that the new rainfall-runoff model presents an improvement over the previous HYSIM model, with the GR6J simulated curve matching the observed flow regime very closely across both the calibration and validation periods.

Note: In water resources applications with impounded storage, a comparison of cumulative flows is a valuable exercise. However, in this case, due to the significant gaps in the observed streamflow record, such a comparison was not possible.

Table 2-9 - GR6J model parameters for the Grands Vaux stream calibration

Parameter	Description	Suggested range	Calibrated value
X1	Production store capacity (mm)	9 to 2,000	40.01
X2	Intercatchment exchange coefficient (mm/d)	-4.0 to 5.0	-0.5211
X3	Routing store capacity (mm)	0 to 500	333.3
X4	Unit hydrograph time constant (d)	0.5 to 6.0	1.653
X5	Intercatchment exchange threshold (-)	-4.0 to 4.0	-0.09704
X6	Coefficient for emptying exponential store (mm)	0 to 20	28.43
P Factor	Scaling factor applied to precipitation	n/a	1.08
PET Factor	Scaling factor applied to potential evapotranspiration	n/a	1

Table 2-10 - Performance summary for the Grands Vaux stream GR6J calibration

Metric	Dataset	Calibration period	Validation period
Mean flow (m^3/s)	Observed	0.079	0.084
	Simulated	0.076	0.09
	Difference	*-3.8%*	*+7.1%*
Q90 (m^3/s)	Observed	0.013	0.012
	Simulated	0.013	0.012
	Difference	*0.0%*	*0.0%*
NSE	-	0.839	0.817
NSE (log flows)	-	0.900	0.871
Percentage bias[1]	-	1.2%	8.2%

1. Percentage bias is a measure of the average tendency of the simulated flows to be larger or smaller than the observed ones. Low-magnitude values indicate accurate model simulation (with 0% indicating a perfect match). Positive values indicate overestimation bias, while negative values indicate model underestimation bias.

[3] Refer to 'Grand Vaux HYSIM output comparison.xls'. Note: runoff (mm/d) data used. It has been trimmed to the calibration period and scaled based on catchment area to be equivalent to Grands Vaux stream catchment (MWH 2006 reservoir sub-catchment area of 7.19 km^2 compared to stream catchment of 6.851 km^2.

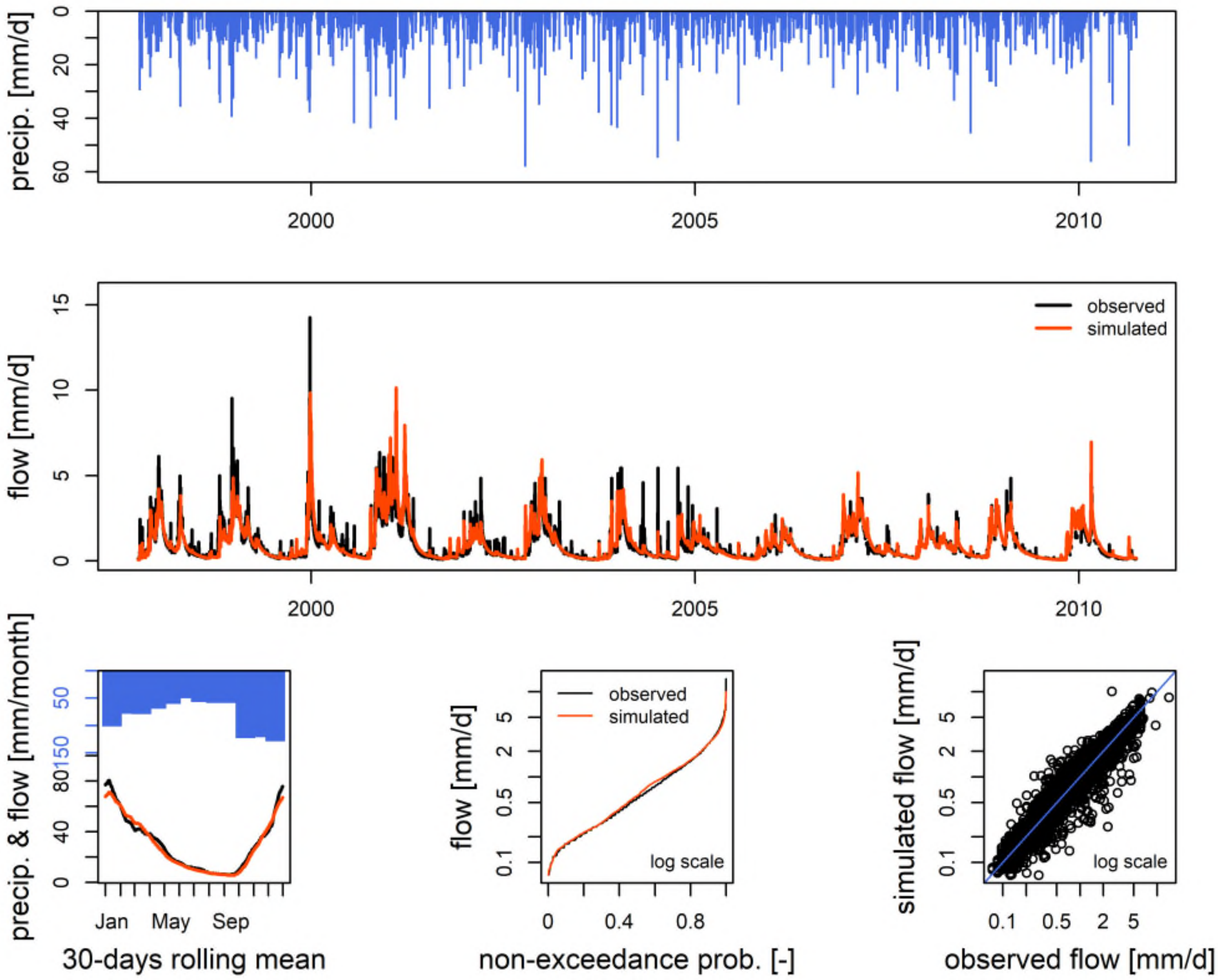

Figure 2-16 - GR6J calibration summary for Grands Vaux stream catchment

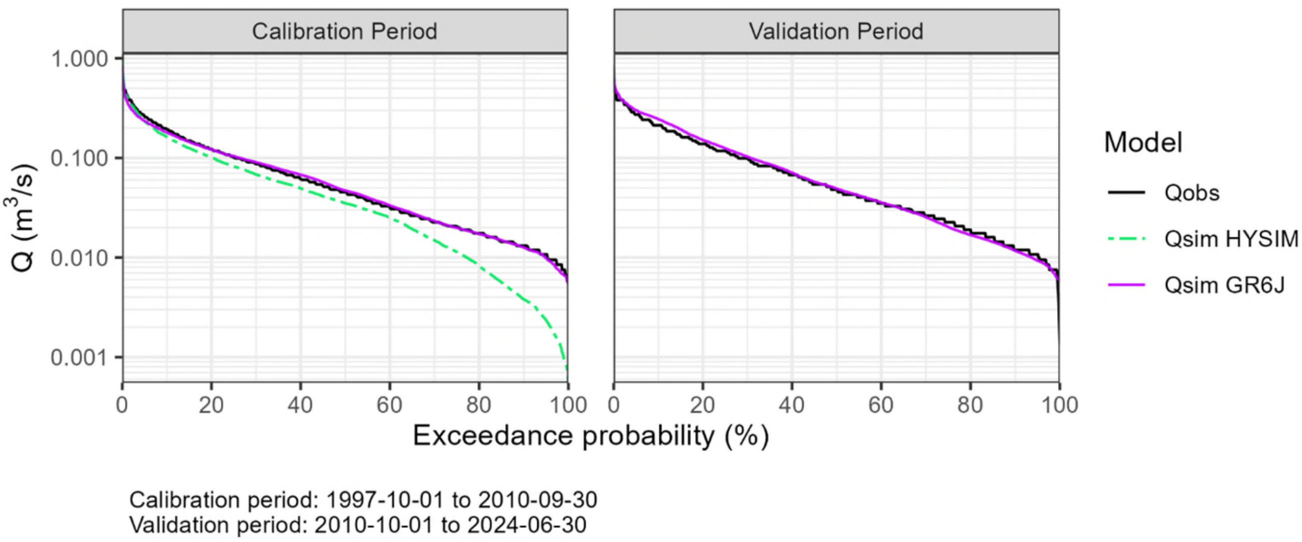

Figure 2-17 - Flow duration curve comparison for Grands Vaux stream, observed in black, HYSIM simulated in green, and GR6J simulated in purple Model transposition

2.4.4 Model transposition

The general approach for model transposition has been to take the successfully calibrated Grands Vaux stream GR6J parameter set and apply it to the other 30 catchments. The only input parameters to vary between the catchments is the precipitation scaling factor and catchment area.

In the case of sub-catchments with their own streamflow gauges, some bespoke calibrations were explored. However, only two of these alternative calibrations presented potential improvements in simulated flows. For the sake of simplicity and consistency, the decision was made to proceed with the original approach and apply the transposed Grands Vaux calibration everywhere.

A record of the GR6J parameter set applied in this assessment can be found in Table 2-9.

2.5 Grands Vaux reservoir water balance

A trial water balance model was developed for the Grands Vaux system in the hopes that it could help validate the rainfall-runoff model outputs. The Grands Vaux reservoir was selected to align with the Grands Vaux stream calibration catchment. It was also prioritised over the other reservoir systems because it was the simplest system within Jersey Water's integrated network, and therefore with the best chance of being modelled successfully.

Two approaches were tested:

1. Simulating the storage response with GR6J inflows plugged in (and comparing against observed storage)
2. Back-calculating catchment inflows (and comparing against GR6J inflows).

Table 2-11 outlines the various component inflows and outflows of the system and how they were (or were not) included in the water balance model.

In the first approach, the simulated storage model saw the reservoir emptying too often (see Figure 2-18) which suggests some input(s) to the system are missing. This most likely stems from the measured abstraction inputs which presented significant gaps from 2002 to 2009. This is further emphasised with the results looking more realistic from 2010 onwards, although the simulated reservoir is still not consistently refilling enough (or at the right times).

In the second approach, the back-calculated catchment inflows present a similar general pattern (refer Figure 2-19). The derived inflows are very noisy throughout the series (which is not uncommon in water balances driven by changes in observed water levels). However, as with approach 1, they are much more stable from 2010 onwards. A 30-day moving average suggests the derived inflows align quite well with GR6J modelled flows. However, the model misses high flow periods (when the dam is spilling) which means only recession and baseflow periods can be compared to the GR6J modelled flows.

All in all, the water balance model outputs were found to be noisy and unreliable in many periods. As such, it provided limited benefit towards validating the GR6J model. However, alignment between the water balance and GR6J simulations were observed in some key periods/sequences. This suggests a cautious pass in terms of GR6J validation.

Table 2-11 - Summary of inputs and outputs to the Grands Vaux reservoir system

Component	Input or Output	Measured?	Details	Included in Water Balance Model?
Grands Vaux Stream direct catchment runoff	Input	✗	Calculated via GR6J (approach 1) or back-calculated (approach 2).	✓
Vallee des Vaux Stream indirect catchment runoff	Input	✓	Daily record provided by Jersey Water.	✓
Abstraction for production (sent to Augres WTW)	Output	✓	Daily record provided by Jersey Water.	✓
Abstraction to Queen's Valley Reservoir	Output	✓	Daily record provided by Jersey Water.	✓
Direct lake surface rainfall	Input	✗	Calculated based on lake surface area.	✓
Direct lake surface evaporation	Output	✗	Calculated based on lake surface area.	✓
Fernland's Stream "drought source" inflow	Input	✗	Calculated as proportion of Grands Vaux Stream catchment inflow.	✓
Dam spill flows	Output	✗	Neither measured nor calculated.	✗
Pumped inflow from Queen's Valley	Input	✗	Not routinely used.	n/a
Compensation releases	Output	✗	No minimum release requirements.	n/a

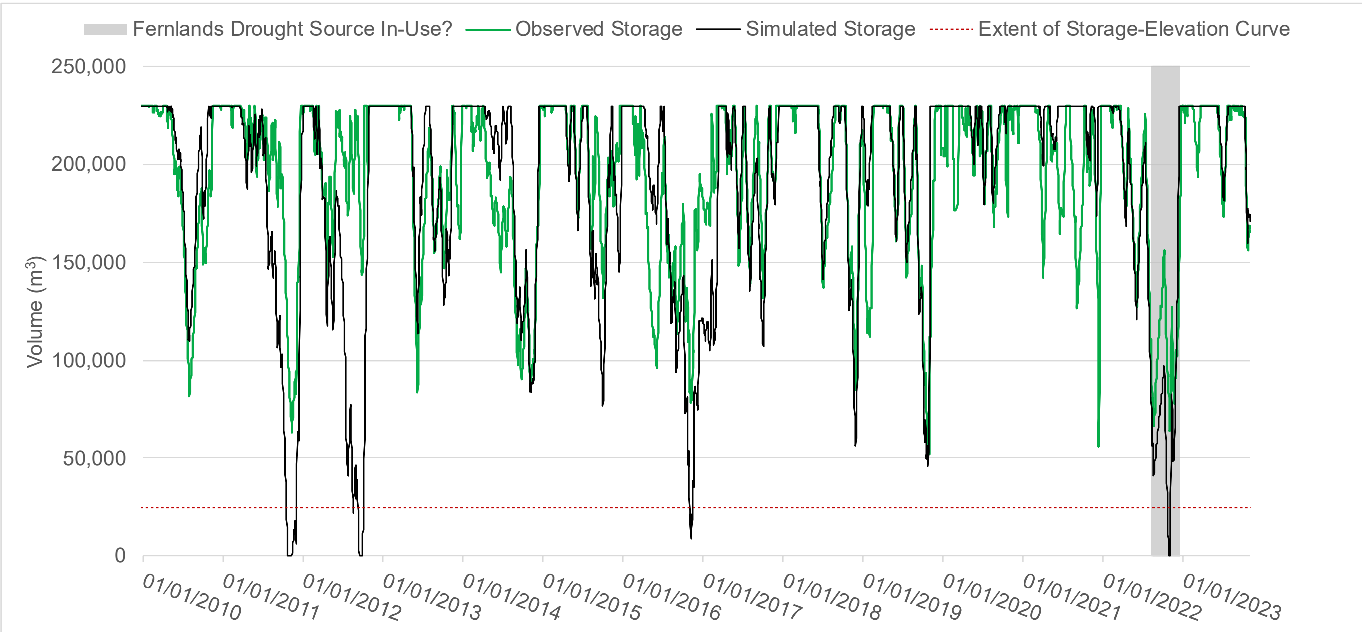

Figure 2-18 - Grands Vaux water balance simulated storage (black) versus observed storage (green)

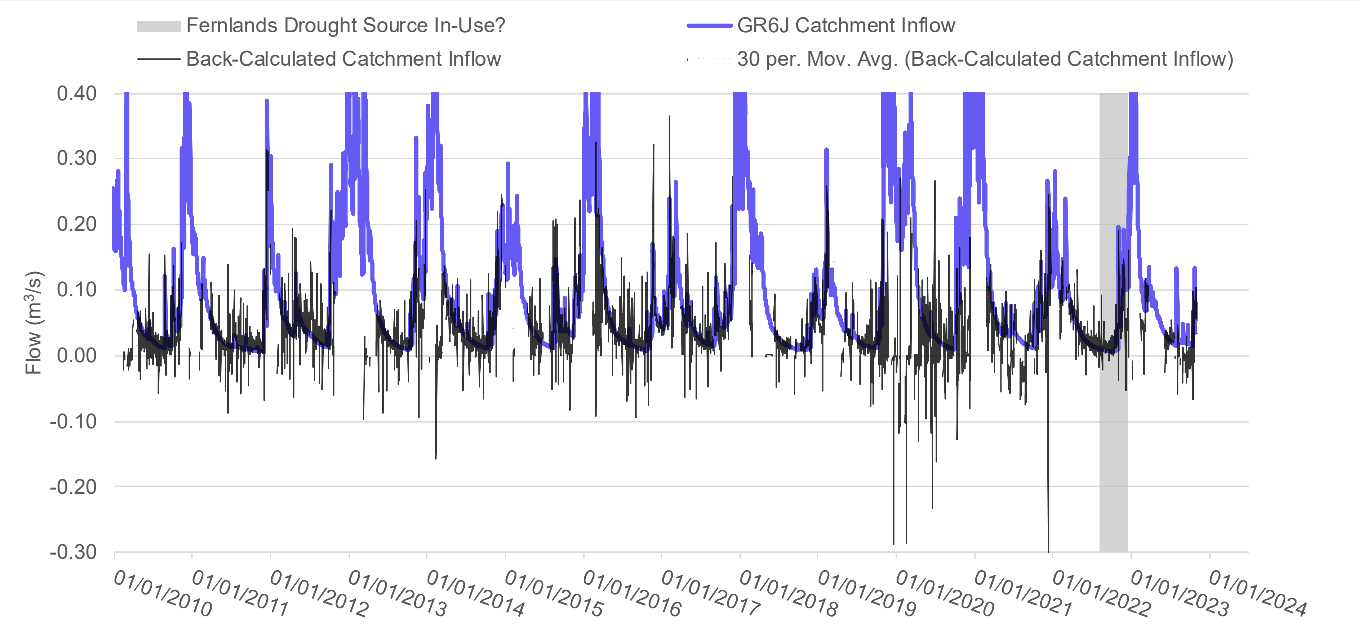

Figure 2-19 - Grands Vaux water balance derived inflows (black) versus GR6J flows (blue)

2.6 Catchment inflow generation

Once the calibration and transposition of the GR6J models was finalised, these parameter sets (refer Table 2-10) were used to simulate stochastic flow series for each of the required inflow points, for both the baseline and climate change perturbed scenarios. This process involved:

- Applying the derived climate change impact factors (refer to Appendix B of the WRDMP document set) to the baseline stochastic rainfall and temperature series (see Appendix C).
- Converting the baseline and perturbed temperature series into PET (using the Oudin equation).
- Scaling the baseline and perturbed rainfall series to each of the 31 catchments.
- Finally, simulating catchment runoff in GR6J using the calibrated and transposed parameter sets to produce a total of 403 daily timeseries datasets (13 climate scenarios × 31 catchments), each spanning 19,600 years (98-year series × 200 stochastic sequences).

The resulting series of inflows are summarised in Figure 2-20, which compares monthly rainfall and simulated flows across the 13 stochastic scenarios employed.

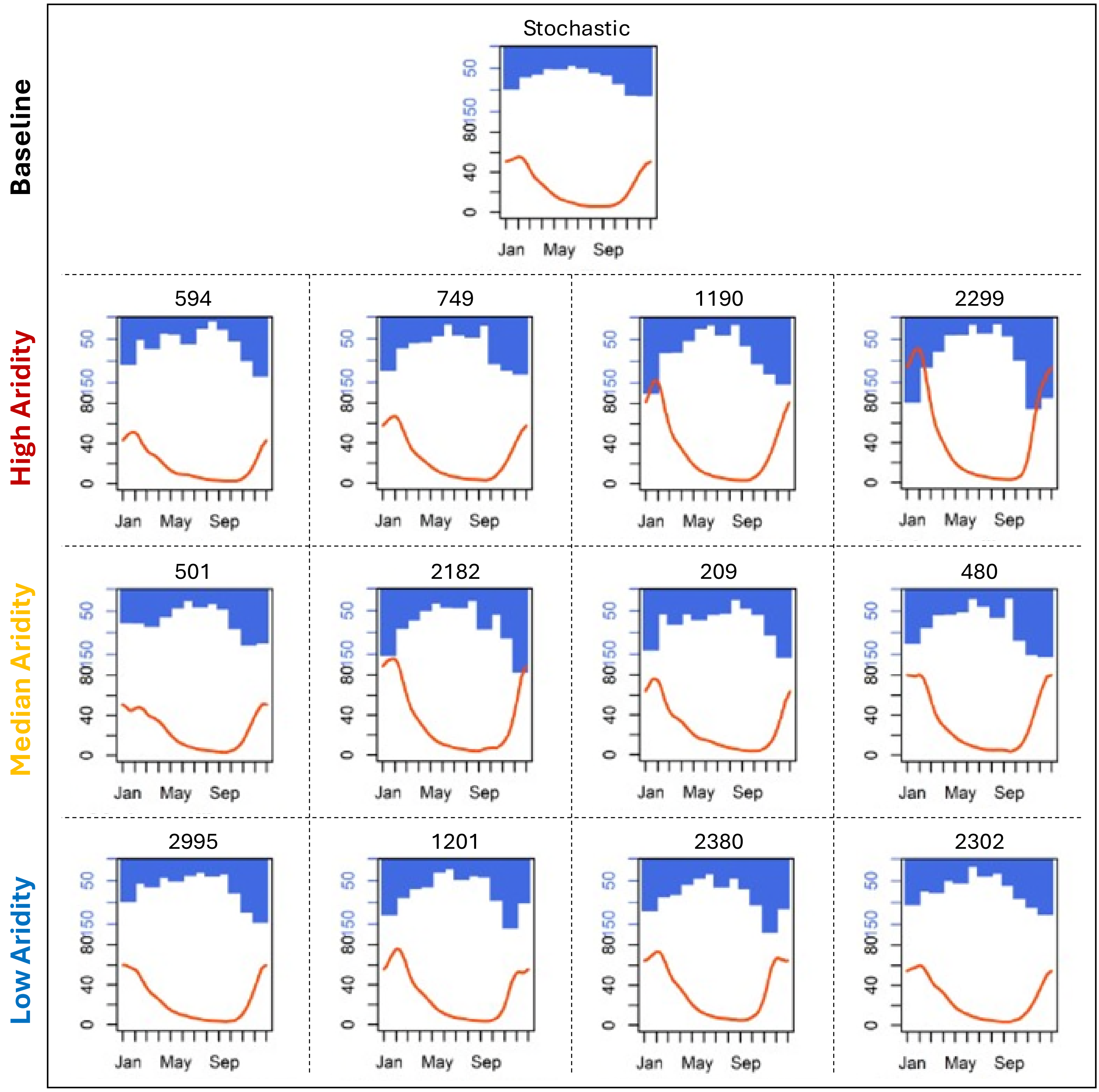

Figure 2-20 - Stochastic inflow summary for Grands Vaux stream catchment; blue bars denote average monthly rainfall (mm/month), and red lines present 30-day rolling mean flow (mm/month)

2.7 Recommendations for future hydrological assessments

We recommend that the GR6J model be re-calibrated when more streamflow data from the new gauge network becomes available (at least a year's worth, although closer to five years would be ideal). If reliable records are obtained across the gauged network, we would suggest calibrating a model for each of the reservoir systems (i.e. rather than transposing the Grands Vaux Stream model).

Furthermore, if any records or analysis of upstream abstractions are to become available in the future, we would recommend a naturalisation of key streamflow records (e.g. at the Grands Vaux Stream gauge) be considered in future hydrological studies.

We would also recommend that water balance models be developed for the other reservoir systems if the various inputs and outputs start to be captured. Similarly, the Grands Vaux water balance model could be refined if the data capture in and around it improves.

3. Water Resource Modelling

3.1 Summary of Sources and Assets

The Jersey Water raw water sources and raw water storage assets that have been considered in this supply forecast assessment are summarised in this section.

The raw water supply system comprises a series of interlinked raw water storage and impounding reservoirs. It consists of eight impounding reservoirs and their direct catchments, a number of pumped surface water catchments as described in Section 2, six boreholes and the La Rosière desalination plant.

3.1.1 Reservoirs

The total raw water storage available to Jersey Water is 2714 Ml.

The reservoirs are fed by a combination of indirect water sources and their direct catchments. The reservoirs can be broadly grouped into four sub-systems: Val de la Mare; Water Works Valley (containing Handois, Dannemarche and Millbrook reservoirs); Grands Vaux; and Queen's Valley. There are not currently any compensation flow release requirements at any of the reservoirs. Historically a compensation flow requirement was in place at Queen's Valley reservoir of 50,000 gallons / day however this has been removed from the system. There are also two smaller reservoirs at La Hague and Les Mourier.

The minimum capacity / "Dead Water" is approximately 10% of the total storage volume. This water is assumed to be unavailable for water resource planning purposes, based on the risk that the water stored at the very bottom of storage reservoirs in drought conditions may be of poor quality (e.g. high sediment content and therefore not feasible to treat to drinking quality water standards) and/or it may not be possible to physically abstract it from the bottom of the reservoir. A summary of the capacity and minimum volumes of the impounding reservoirs is presented in Table 3-1.

Table 3-1 - Storage and minimum capacities of Jersey Water's raw water reservoirs

Reservoir	Maximum Capacity (Ml)	Minimum Capacity / Dead Water (Ml)
Queen's Valley	1193	119.3
Val de la Mare	939	93.9
Grand Vaux	230	22.7
Handois	187	19
Dannemarche	93	9
Millbrook	54	4
Les Mourier	9	0

La Hague	9	0
Total Storage		**2714**

3.1.2 Abstraction, Pump and Water Treatment Works capacities

Both La Hague and Les Mourier are supplied by direct stream catchments. La Hague also receives water from Tesson borehole and the Little Tesson and Tesson streams. Water at La Hague can be pumped to Handois Reservoir or Val de la Mare Reservoir. Water at Les Mourier Reservoir can be pumped to Handois Reservoir or La Hague Reservoir. Water from the Val de la Mare, Grand Vaux and Queen’s Valley systems are blended and used interchangeably in the raw water “header” tanks at Mont Gavey, which supplies Handois Water Treatment Works (WTW), and Beechfield, which supplies Augrès WTW. Mont Gavey and Beechfield tanks provide a short-term buffer for fluctuations in pump rates from the raw water pumping stations. The Val de la Mare system is the predominant supply to Handois WTW and the Grands Vaux and Queen’s Valley systems are the predominant supplies to Augrès WTW. Handois WTW has a maximum treatment capacity of 28 Ml/d and Augrès WTW has a maximum treatment capacity of 20 Ml/d. Table 3-2 presents the abstraction and pump capacities within Jersey Water’s raw water network.

Table 3-2 - Abstraction and Pump capacities

Abstraction / Pump	Capacity (Ml/d)
Queen's Valley	24.48
Val de la Mare	24.48
Grand Vaux	12.96
La Hague	8.40
Millbrook	6.48
Tesson Pump Station	5.33
St Catherine's	4.32
Fern Valey	3.91
Les Mourier	3.72
Greve de L'Ecq	3.12
Vallee des Vaux	2.76
Pont Marquet	2.45

3.1.3 Boreholes

There are five boreholes within the St. Ouen’s wellfield; two of which are currently out of service due to the presence of contaminants from fire-fighting foam historically used at the airport. There is also a small borehole at Tesson. Little is known about these groundwater sources apart from their maximum pumping capacity and operational usage since 1995. It is not known how reliable these sources are during a notable drought although the yield of the St. Ouen’s wellfield is previously quoted to have a reliable yield of 1.8 Ml/d . Under current operating conditions, taking account of the water quality constraints at the St Ouen’s boreholes, the maximum reliable deployable output for the St. Ouen’s boreholes and Tesson boreholes is assumed to be 1.0 Ml/d and 0.09 Ml/d, respectively.

3.1.4 Desalination

La Rosière desalination plant can supply either 5.4 Ml/d (one treatment stream) or 10.8 Ml/d (two treatment streams) and is used when the other water sources need supplementing. The operation of the desalination plant is triggered based on the volume of storage that is available across the whole island. Additionally it may be operated to improve water quality if required.

3.2 Pywr Model Development

In the previous WRDMP21 four spreadsheet-based water balance and storage models were developed to assess the yield of Jersey Water's raw water sources using the following groupings:

- Val de la Mare Reservoir, stream intakes including La Hague, Les Mourier, Greve de L'Ecq, Pont Marquet, Tesson and Little Tesson, St. Ouen's and Tesson boreholes and La Rosière desalination plant
- Waterworks Valley (Handois, Dannemarche and Millbrook reservoirs) and associated stream intakes including Bellozanne \ Fern Valley.
- Grands Vaux Reservoir and associated stream intake at Vallee de Vaux
- Queen's Valley Reservoir and associated stream intake at St. Catherine Stream.

The models allowed the simulation of historic storage between 1901 and 2007 based on the available storage capacity, an input sequence of flow data for the source catchments and an assumed annual demand profile for water placed on the supply system. For each of the four storage systems, the model considered raw water storage and the surface water sources as a 'lumped' storage and source model rather than explicitly considering the individual storage reservoirs and sources (and the transmission links between them) separately. There are limitations in this approach, principally that the operational constraints between the lumped individual sources and storages may not be accurately reflected.

Therefore as part of this WRDMP24 we have developed a full water resource model of the raw water supply system including network capacity and connection constraints. This water resource model has been developed in the Python for Water Resources (Pywr) software. A Pywr model allows us to: forecast the supply capabilities of the system against a wide range of drought events, effectively test the supply options, and assess the deployable output (DO) of the system for a variety of return periods (e.g. 1in200 years, 1in500 years etc.) and under a range of potential climatic conditions, in line with the most recent Water Resources Planning Guidelines.

Pywr was selected as the software for the water resource model for the following reasons:

- It is fast enough to handle large stochastic datasets and the large numbers of scenarios and function evaluations required by advanced decision making methodologies and to support deployable output assessments including a 1in500 return period; and
- It is readily extendable as it uses the Python programming language to define complex operational rules and control model runs and therefore any bespoke functionality required could be developed and included.

3.2.1 Model Components

The Pywr model has been developed to represent the raw water assets described in Section 3.1. A schematic of the Pywr model is shown in Figure 3-1. This section describes how the different components of the raw water system have been represented in the Pywr model.

Raw water reservoirs

Raw water reservoirs have been represented using the 'Reservoir' node type in Pywr. Maximum and minimum volumes have been assigned as described in Table 3-1. Each reservoir has been assigned a piecewise cost curve that considers the current storage volume against a linear control curve. The control curve does not represent an explicit control curve utilised by Jersey Water but is instead utilised to balance relative 'health' between the reservoirs across the network. When an individual storage is below this curve it becomes relatively more expensive from a resource state position and vice-versa when above the control curve. In general the penalty cost assigned to a reservoir is always negative so that the model tries to keep the reservoir full however the model will not choose to fill reservoirs at the detriment of meeting demand.

Service reservoirs

The Mont Gavey and Beechfield header tanks have been represented as 'Link' nodes. Although there will be a small amount of storage in these tanks it is assumed to be nominal for the purposes of this water resource modelling.

Water Treatment Works (WTWs)

The Augres and Handois WTW nodes have been represented as 'PiecewiseLink' nodes. Piecewise nodes have been used as they allow a split cost depending on the volume of flow through the works. This allows better balancing between the WTWs, as the relative cost of the works increases as output increases, seen in the model validation (Section 3.3). 5% of the demand supplied by the WTWs is attributed to process loss, however this is recaptured and fed back into Dannemarche reservoir as Jersey Water have previously invested in comprehensive treatment and recycling facilities for the wash-water from the WTW processes so that they do not lose any raw water resource.

Boreholes

The St. Ouens and Little Tesson boreholes have been represented using 'Input' nodes. These nodes are constrained by maximum flow constraints. Additionally the St. Ouens boreholes are constrained so that they cannot be operated unless the desalination plant is also in operation. This is to ensure the protection of water quality as the St. Ouens boreholes are impacted by higher PFAS concentrations and require blending.

Catchments

Direct and indirect catchments have been represented using 'Catchment' nodes. Flows have been set to the outputs of the hydrological modelling (Section 2). Where a catchment does not flow directly into a reservoir (indirect catchments) each catchment connects to a termination 'Output' node to allow non-abstracted flow to leave the model at each timestep, these termination nodes are unconstrained. Each of these catchments is also connected to an abstraction node to control flow into the model. Where catchments flow directly into a reservoir (direct catchments) these are connected straight in the reservoir, however in most cases a bypass link is also present reflecting the ability to divert catchment flow around the reservoir if required for the protection of water quality or other reasons.

Abstractions

Abstraction from indirect catchments to their appropriate reservoirs has been represented by 'Link' nodes. These links contain capacity constraints. The capacities of these abstractions are captured in Table 3-2.

Desalination plant

The La Rosiere desalination plant has been represented using an 'Input' node. The node can input 0, 5.4 or 10.8 Ml/d into the system depending on the position of the total raw water storage across the island compared to two control curves with greater volumes being available the lower the island storage position. This reflects how Jersey Water operate the desalination plant and the option to run its two input streams independently or in conjunction. These values are fixed so an output of 7 Ml/d for example is not available, in this case 10.8 Ml/d would be used and the excess requirement stored in the reservoirs for future use. Additionally a 'hold' has been placed on the desalination so that once it is triggered it remains operational for a minimum of 30-days. This is both a better reflection of the operational approach and also is used to prevent 'hunting' behaviour which can occasionally be observed in water resource models as relative costs switch priority on a daily timestep.

Network

The model network in Pywr is constructed through a combination of 'Link' nodes and 'Edges'. Where a capacity constraint is required, for example due to a constraining pipe size, then a Link node is used. These constraints are captured in Table 3-2 alongside the abstraction constraints. If only directionality is concerned then an edge is suitable. In any case, edges are required to allow flow between the nodes and therefore around the model.

Drought response & Demand Savings

Alongside the operation of the desalination plant when total island storage reduces below our trigger curves, we have also included representation of Temporary Use Bans (TUBs) and Non-Essential Use Bans (NEUBs) within the Pywr model. TUBs and NEUBs are applied as a demand reduction factor to the modelled demand node. The demand reduction factors associated with each formal intervention are:

- TUBs: 3% during October - May (i.e. 97% of demand remains) and 8% during June – September (92% of the demand remains).
- NEUBs: 4.5% during October - May (95.5% of demand remains), 9.5% during June & August – September (90.5% of the demand remains) and 10.5% during July (89.5% of the demand remains).

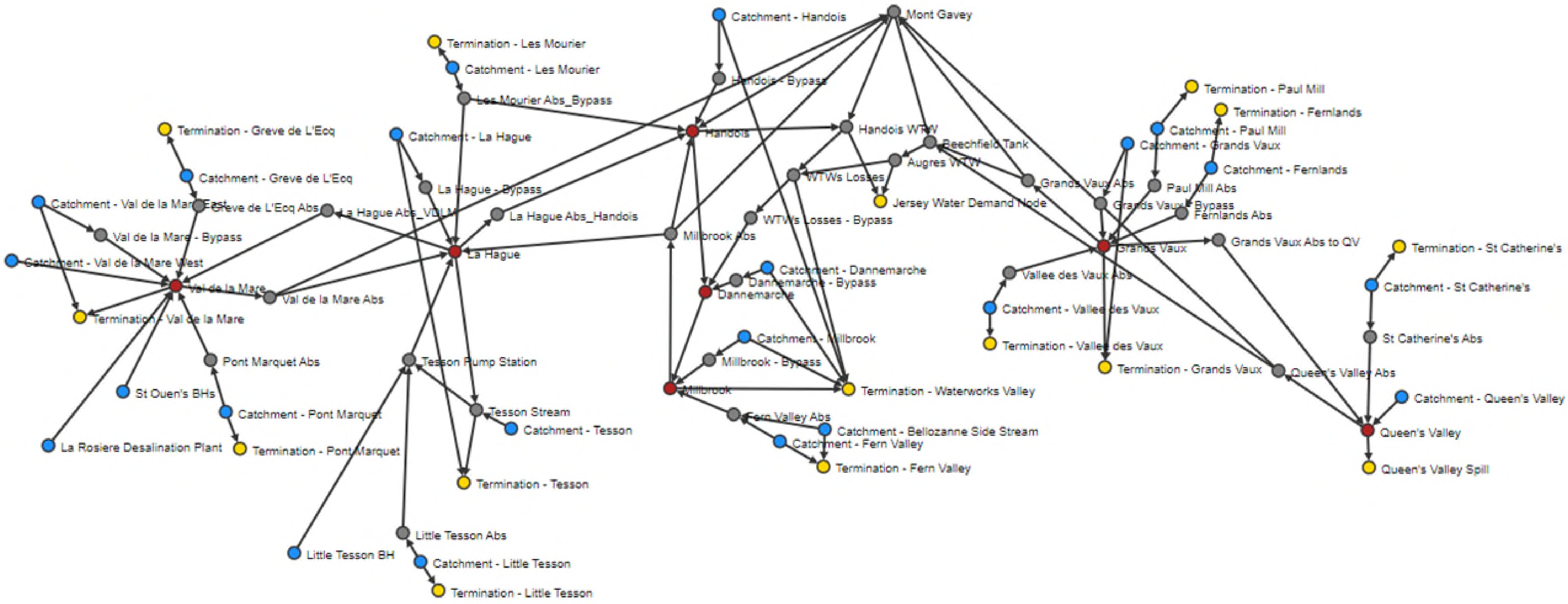

Figure 3-1 - Pywr Model Schematic. Red nodes indicate storage, blue nodes are inputs, yellow nodes are outputs and grey nodes hold additional constraint data and act to form the network.

3.3 Pywr Model Validation

The Pywr model has been validated against an observed dataset for the period 2012 – 2024. This section summarises the model validation and indicates a good fit between the Pywr model and the observed dataset. There are a number of known differences between the model and how we have operated our system historically which are discussed in this section, however the model reflects our current operational rules and understanding. We have validated the model at a number of key locations across the network including:

- The largest reservoirs (Grands Vaux, Val de la Mare and Queen's Valley) and total water resource storage across the island
- The output from the La Rosiere Desalination plant
- The output from the two WTWs and the volume of supply provided to the demand centre

Figure 3-2, Figure 3-3 and Figure 3-4 present the Pywr modelled storage and the observed dataset for each of the three largest reservoirs in the supply system: Grands Vaux, Val de la Mare and Queen's Valley. As well as being the largest in terms of storage, the location of these reservoirs covers the breadth of the island and the water resources network so provide good locations to undertaken model validation. The plots indicate a good alignment between the Pywr model and the observed dataset particularly at Val de la Mare and Queen's Valley, the two largest storages. The fit at Grand Vaux is also reasonable and the magnitude and timing of peaks and troughs in storage is good. Within water resource modelling the smaller reservoirs are generally more challenging to align and provide a significantly diminishing return in terms of validation and therefore focus has been given to the larger reservoirs.

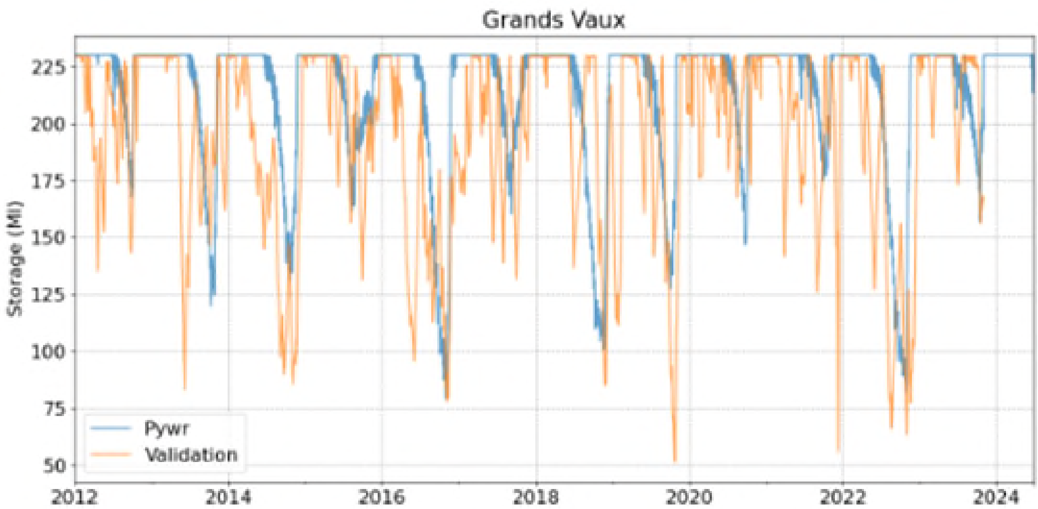

Figure 3-2 - Pywr modelled storage and the observed storage dataset provided for model validation for Grands Vaux Reservoir (Ml).

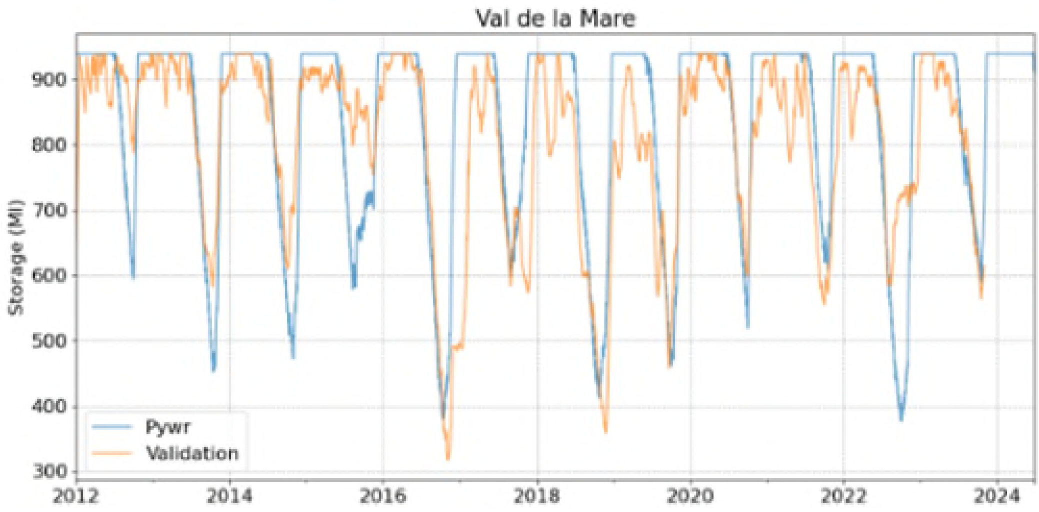

Figure 3-3 - Pywr modelled storage and the observed storage dataset provided for model validation for Val de la Mare Reservoir (Ml).

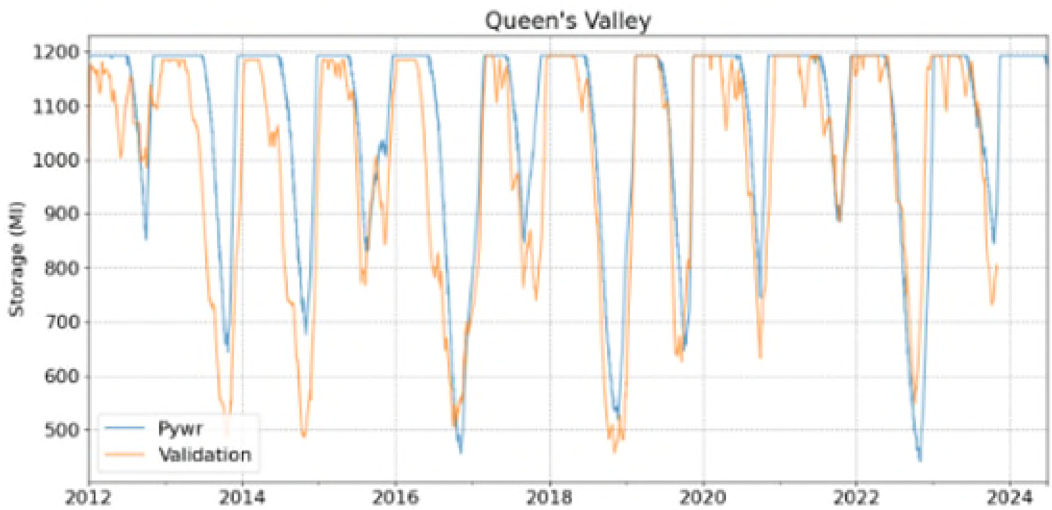

Figure 3-4 - Pywr modelled storage and the observed storage dataset provided for model validation for Queen's Valley Reservoir (Ml).

We have also compared the total raw water storage across the island, the outputs of the Pywr model are compared to the observed dataset in Figure 3-5. This is a significant metric for model validation as it encompasses both the large and small reservoirs and we use total island storage as a trigger for drought responses and operation of the La Rosiere desalination plant. The plot indicates a very good fit between the Pywr model and validation dataset with the magnitude and timings of storage recession and refill aligning well.

There are two periods of notable difference between the modelled and the observed dataset that have been further investigated. These are the drawdown period in 2019, where Pywr outputs have a greater storage volume than the observed dataset, and then the drawdown in 2022 where the inverse is observed and the Pywr model experiences a much greater drawdown than was observed. In 2019 the difference can be explained by an increased use of the La Rosiere desalination plant as seen in Figure 3-6. The Pywr model has been set up to trigger the desalination plant once total storage drops below a trigger curve, however there have been some known reliability issues with the desalination plant historically and therefore it may not have been available during that period. In 2022 the difference is explained by the use of TUBs. Jersey Water decided to implement

TUBs ahead of crossing the trigger curve to protect supplies in the face of an impending drought, however the model did not cross the trigger curve, consequently a difference in storage is observed.

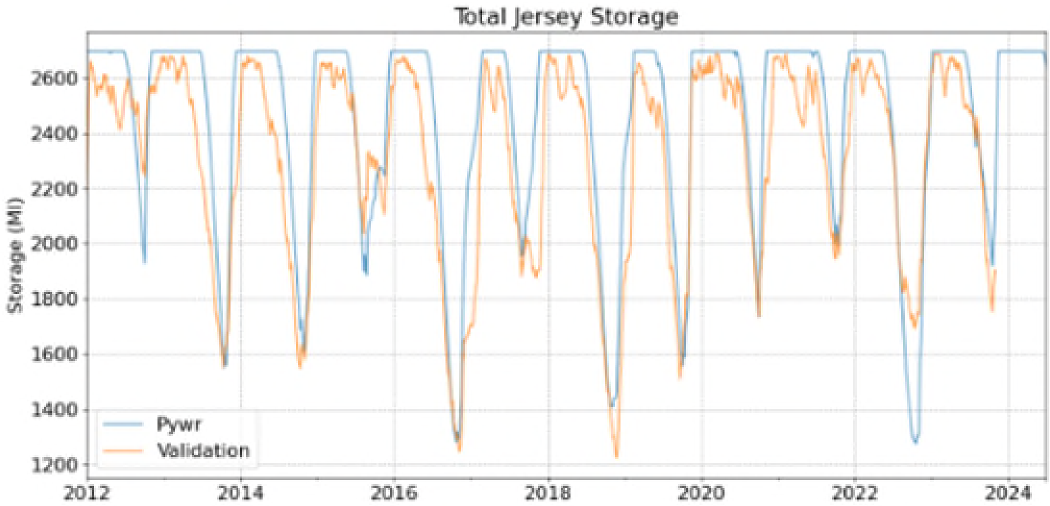

Figure 3-5 - Pywr modelled storage and the observed storage dataset provided for model validation for total storage across the island (Ml).

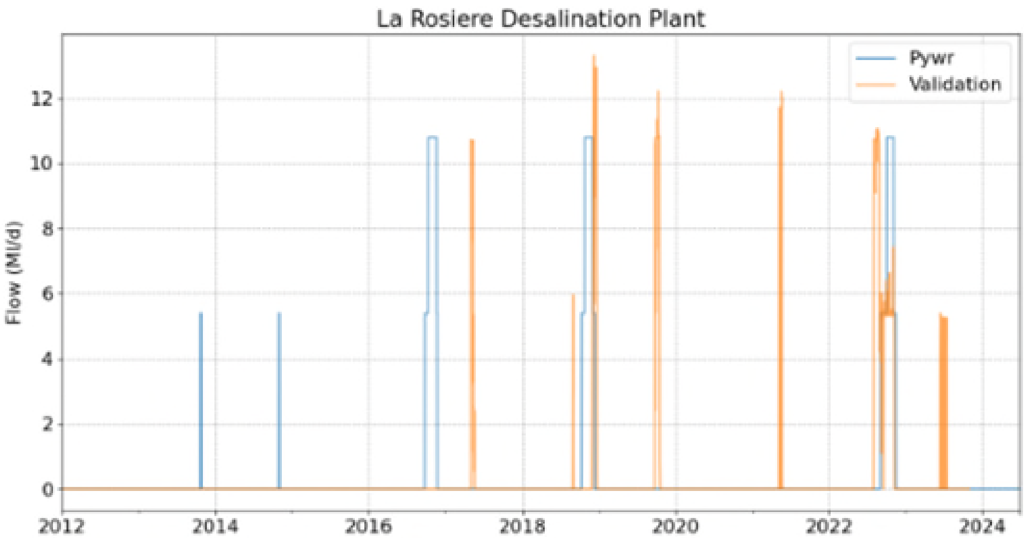

Figure 3-6 - Pywr modelled output and the observed output dataset provided for model validation for La Rosiere Desalination Plant (Ml/d).

Figure 3-7 and Figure 3-8 present the modelled and observed output for Augres and Handois WTWs. The Pywr model has been set up to attempt to supply a monthly profile and balance utilisation between the sources. Jersey Water operate the treatment works together in a similar balance, however the validation data is presented at a daily timestep. A generally good alignment between the model and the validation dataset is observed, while minor differences in the balancing of the two works act to cancel out any deviation as seen in the total supplied to the model's demand node (Figure 3-9).

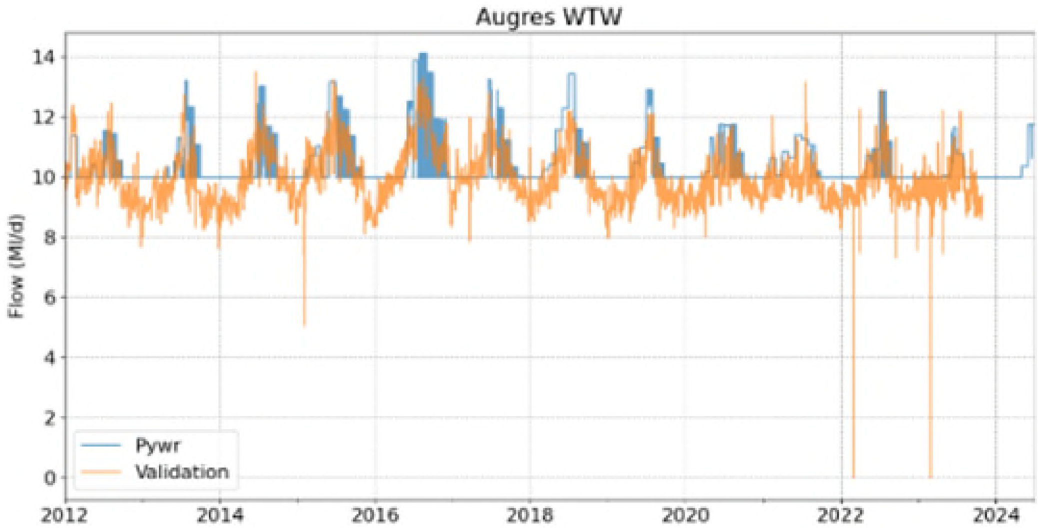

Figure 3-7 – Pywr modelled output and the observed output dataset provided for model validation for Augres WTW (Ml/d).

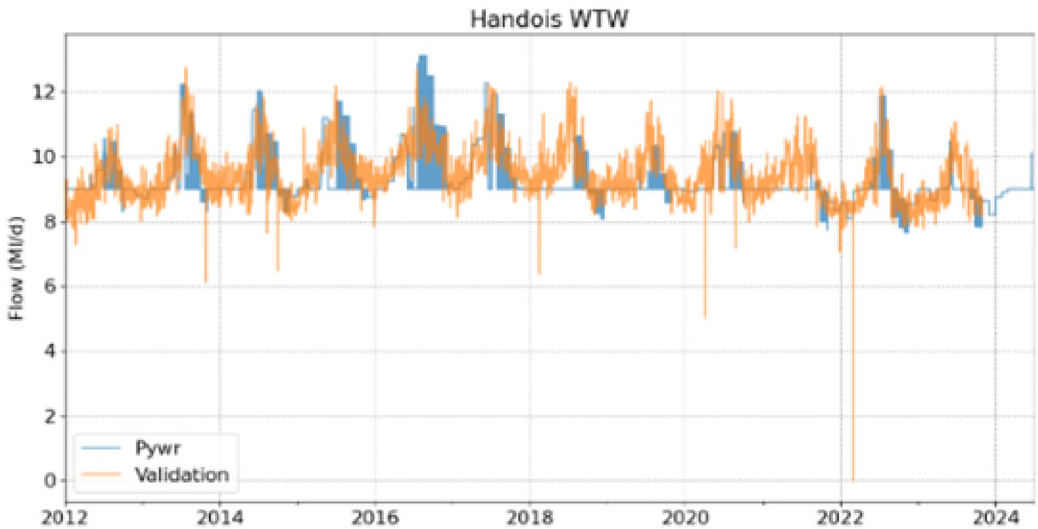

Figure 3-8 – Pywr modelled output and the observed output dataset provided for model validation for Handois WTW (Ml/d).

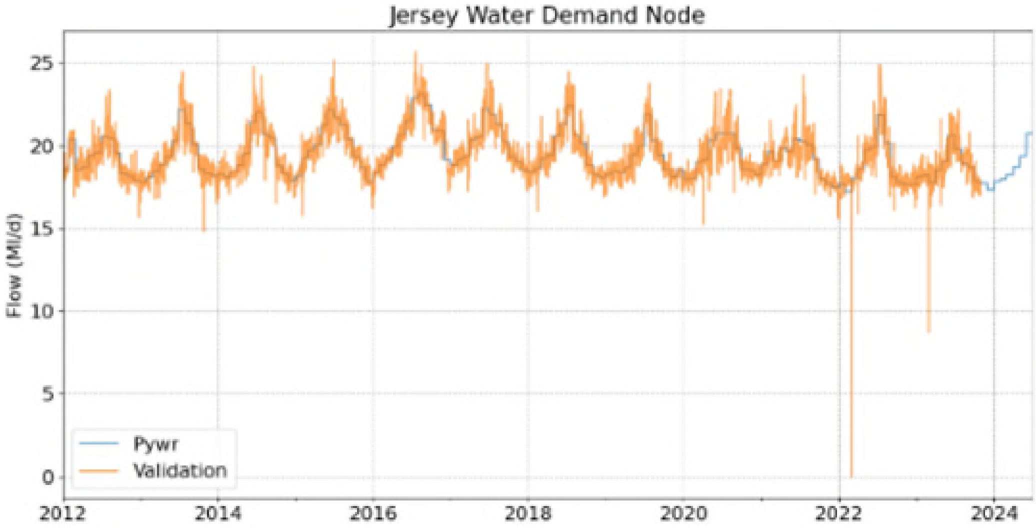

Figure 3-9 – Pywr modelled supply and the observed supply dataset provided for model validation for Jersey Water demand (Ml/d). Note, missing validation data in early 2022 and early 2023.

3.4 Deployable Output Assessment

3.4.1 Previous Assessment (WRDMP21)

The previous storage models utilised in WRDMP21 calculated deployable output (DO) as 20.46 Ml/d; this is equivalent to a dry year annual demand that results in the predicted total Jersey Water reservoir storage reducing to the Emergency Storage level during the worst historic drought on record. This event was estimated to have a return period of 1 in 191 years which was calculated using the Gringorten method[4].

3.4.2 WRDMP24 Assessment

We have reassessed Deployable Output (DO) as part of this WRDMP24 using the Pywr model. The results are presented in Table 3-3. Additionally the DO by return period curve is plotted in full in Figure 3-10. The DO assessment follows the 'Scottish' method and is in line with UK best practice. In the Scottish method, simulated demand is steadily increased to understand the point at which deficits occur at the demand centre. At each level of demand the frequency of deficits is recorded and used to determine the return period of a given system output until we have assessed the DO at all the required return periods, up to a 1 in 500-year drought. Therefore, the return period of the DO is driven by modelled supply-demand failures, rather than the return period of rainfall events or the storage levels of the reservoirs. Given the integrated nature of the water supply system, the whole of Jersey is considered as a single water resource zone for the purposes of supply demand balance assessments and planning, and therefore the DO has been assessed at a system-wide level. Demand restrictions, in the form of TUBs and NEUBs, have been included in the baseline DO assessment.

Table 3-3 - Deployable Output Summary Table

Return Period	NYAA (1in2)	DYAA (1in10)	1in100	1in200	1in500

[4] Gringorten, I. I. (1963), A plotting rule for extreme probability paper, *J. Geophys. Res.*, 68(3), 813–814, doi:10.1029/JZ068i003p00813.

Deployable Output (DO) (Ml/d)	31.51	25.84	20.38	19.38	18.38

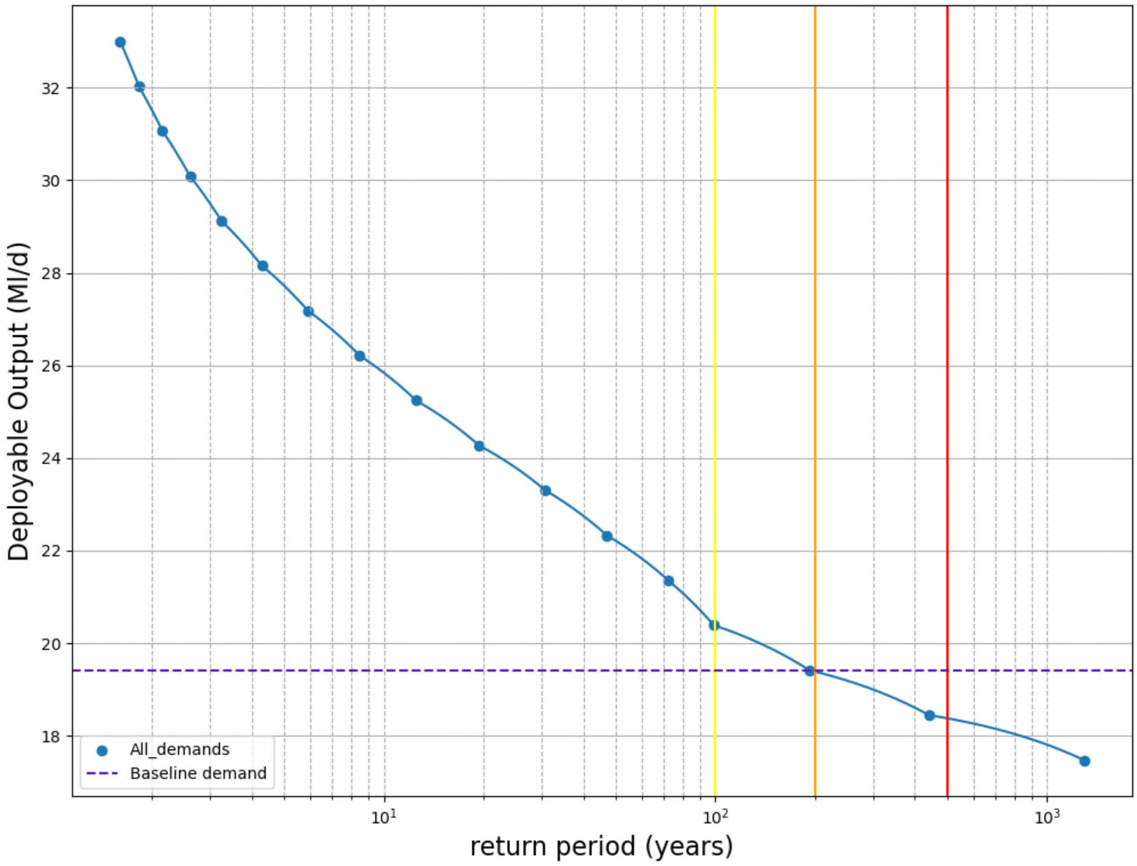

Figure 3-10 - Deployable Output by return period for the Baseline Stochastic Assessment (yellow line is 1in100-year, orange line is 1in200-year, and red line is 1in500-year return period position)

3.5 Climate Change Deployable Output Impact Assessment

In accordance with best practice (such as the England & Wales Water Resource Planning Guidelines) Jersey Water recognises the importance of assessing, reporting and planning for the potential impact of climate change on deployable output. The previous assessment for WRDMP21 was based on UK Climate Change projections released in 2009 (known as UKCP09). As part of the update for WRDMP24 we have adopted the latest industry best practice by using the most up-to-date climate change projections for the UK (known as UKCP18).

As described in the Climate Change appendix of the main WRDMP documentation (Appendix B) a two-step sampling methodology was undertaken to determine the Climate Change scenarios. This included an initial ranking approach based on an aridity index and drought durations relevant to Jersey Water's system followed by a manual sub-selection from 30 to 12 samples using expert judgement. Table 3-4 summarises these selected scenarios.

Table 3-4 - Sub-sample of UKCP18 probabilistic projections (RCP8.5) and their associated Climate Model

Climate Model	UKCP18 probabilistic ID	Aridity	Temperature (°C)	Precipitation (% change)
CC01	**2299**	**High aridity**	**4.9**	**14**
CC01	**2995**	**Low aridity**	**1.4**	**-13**
CC02	**2380**	**Low aridity**	**1.8**	**12**
CC03	**2182**	**Median aridity**	**3.2**	**10**
CC04	**1190**	**High aridity**	**4.0**	**2**
CC05	**480**	**Median aridity**	**2.9**	**4**
CC06	**1201**	**Low aridity**	**2.0**	**-2**
CC07	**209**	**Median aridity**	**3.0**	**-2**
CC09	**501**	**Median aridity**	**3.0**	**-12**
CC10	**749**	**High aridity**	**4.3**	**-10**
CC11	**2995**	**Low aridity**	**1.4**	**-13**
CC12	**594**	**High aridity**	**3.6**	**-21**

These 12 possible Climate Change (CC) futures have been assessed and the DO impact quantified from running the UKCP18 probabilistic data through the Pywr model. Each future consists of 19,600 years of daily stochastic weather data which is assessed using the Pywr Water Resources model. The assessment follows the same Scottish DO methodology approach as use in the baseline assessment described previously. The futures selected represent a spread of CC scenarios in the 2070s, which cover a range of temperature increases and rainfall patterns which vary the magnitude and timing of temperature and precipitation. Consequently, the impacts of climate change include both drier futures, in which available water resources could decrease, and wetter futures, where increased winter rainfall could lead to increased supply availability. Climate change could therefore hold a positive or negative long term impact and our assessment must account for this range of possibilities. Table 3-5 presents a summary of the impacts of climate change on DO.

Table 3-5 – Deployable Output impact by 2070, by drought return period, across the Climate Change scenarios.

CC scenario	2070's NYAA (1in2) DO impact	2070's DYAA (1in10) DO impact	2070's 1in100 DO impact	2070's 1in200 DO impact	2070's 1in500 DO impact
CC01	-2.08	0.74	2.82	2.85	2.07
CC02	0.97	1.60	2.13	1.90	1.51
CC03	-0.96	0.25	1.34	0.84	0.73
CC04	-1.92	0.02	1.25	0.82	0.60
CC05	-1.50	0.16	1.07	0.79	0.57
CC06	-1.96	-0.28	0.36	0.29	0.27

CC07	-1.68	-0.75	-0.28	-0.32	-0.15
CC08	-2.25	-1.09	-0.58	-0.45	-0.31
CC09	-2.55	-1.66	-1.09	-0.99	-0.76
CC10	-3.40	-1.82	-1.13	-1.04	-0.92
CC11	-3.90	-2.32	-1.38	-1.18	-0.98
CC12	-5.84	-4.03	-2.81	-2.36	-1.96

The impacts on DO in the 2070s have been scaled back through the planning period to 1990 (i.e. the mid-range of the baseline period). Both a linear and non-linear scaling approach were considered alongside whether there may be any justification to delay the impacts of climate change across the planning period. Following some analysis and review the AtkinsRéalis non-linear scaling equation[5] with no delayed impacts was selected. Figure 3-11 provides a visual representation of the impact on DO in each year of the planning period at the 1in500-year return period and demonstrates this scaling.

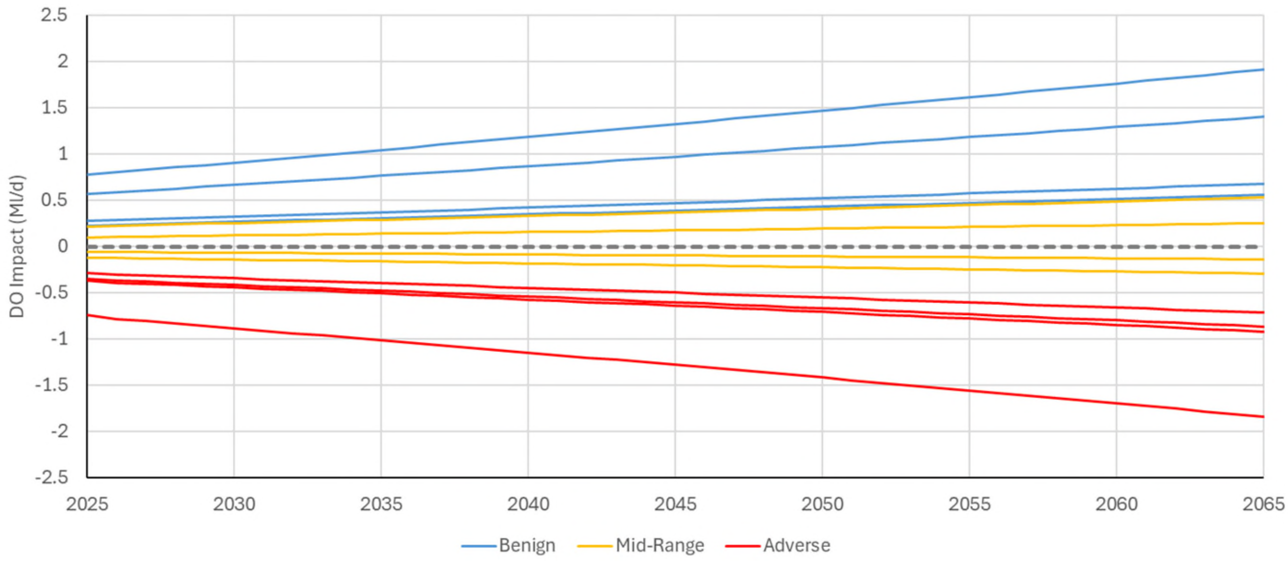

Figure 3-11 – 1in500-year Deployable Output impact across the Climate Change scenarios, scaled through the planning period (from the 2070's to the 1990).

3.6 Outage

An outage allowance has been included in our assessment of Water Available for Use (WAFU), in accordance with best practice. Outage is an allowance for events that could lead to the temporary loss of output from supply sources. It can relate to planned (i.e. planned maintenance of sources) or unplanned events (such as power failure or short term pollution incidents). Jersey Water's outage risks are assessed as being at the lower end of the scale compared to many other UK water companies: this reflects the very high maintenance standards and rapid response times to asset failures for the raw water supply and WTW assets, because of their critical importance to water supply security. In view of Jersey's isolated position, Jersey Water must operate a critical spares retention policy to avoid potential delivery delays (particularly in bad weather) and they have also

[5] Regional Water Resources Planning: Climate Data Tool Operation Framework for Implementing the EA supplementary guidance on climate change, AtkinsRéalis, 2021

invested in standby arrangements for key assets so that any outages that may arise can be quickly addressed to minimise potential impacts to customers.

In discussion with Jersey Water staff, outage impacts have been assessed to be effectively zero for the storage assets. This is because temporary loss of our storage assets would not impact the ability to meet peak supply requirements before the outage can be resolved and the storage reconnected to the supply network. Therefore, we have only considered the desalination plant in our outage assessment as the supply lost during a desalination outage event cannot be recovered. Although Jersey water have made recent investments (for example, spare High Pressure Motors, Replacement Couplings, Dry Standby Quarry Pool Pump) in the desalination plant, which will improve resilience and the ability to maintain full output, it is unrealistic to assume that there could be zero outage allowance at this source.

Through assessment of the operation of the desalination plant since WRDMP21, a 12.5% outage allowance has been estimated for the La Rosiere plant. This equates to an outage allowance for planning purposes of 1.35 Ml/d which has been included in the supply demand balance assessments.

3.7 Process Losses

Process losses occur between the point of abstraction and the point at which water enters the supply network and accounts for the loss of water during the treatment process. Losses can occur at both groundwater and surface water sources. Jersey Water have previously invested in comprehensive treatment and recycling facilities for the water treatment works (WTW) processes so that they do not lose raw water resources. Therefore, as in WRDMP21, there is no allowance for raw water system losses or WTW losses in the supply assessment.

3.8 Water Available for Use (WAFU)

Water Available For Use (WAFU) across the supply system is calculated as the deployable output minus estimated climate changes impacts on DO minus an allowance for outage – i.e. it represents what can be supplied to customers during droughts, and project over time represents the supply forecast. Table 3-6 provides an example of the WAFU calculations for the most adverse climate change future (CC12) for the 1in500-year return period drought. This same calculation has been undertaken for each drought return period, each climate change impact scenario, and in each year of the planning period. Full WAFU tables are provided in Appendix A to this document. Figure 3-12 presents a visualisation of the results for the 1in500-year return period.

Table 3-6 - An illustrative WAFU calculation using the most adverse climate change future (CC12) for the 1in500-year return period.

Water Available for Use Component (Ml/d)	2025	2045	2065
Baseline Deployable Output (1in500)	18.38	18.38	18.38
Scaled Climate Change impact (CC12)	-0.74	-1.28	-1.84
Raw water and Water Treatment Works Losses	Assumed as 0		
Outage allowance	-1.35	-1.35	-1.35

Water Available for Use (Ml/d)	**16.29**	**15.75**	**15.19**

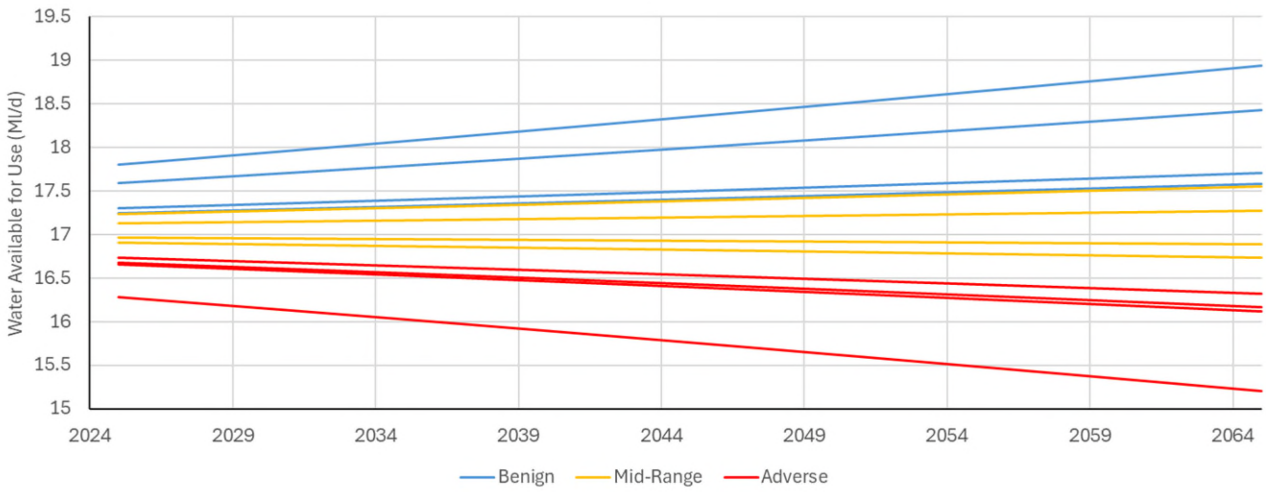

Figure 3-12 - Water Available for Use across the range of CC scenarios for the 1in500-year return period, across the planning period.

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Appendix A. WAFU Tables (Ml/d)

A.1 Normal Year Annual Average

NYAA	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	CC12
2025	29.38	30.53	29.80	29.44	29.60	29.43	29.53	29.32	29.20	28.88	28.69	27.97
2026	29.36	30.54	29.79	29.41	29.58	29.40	29.51	29.29	29.17	28.84	28.65	27.89
2027	29.33	30.55	29.78	29.39	29.56	29.38	29.49	29.26	29.14	28.80	28.60	27.82
2028	29.30	30.57	29.77	29.37	29.54	29.35	29.46	29.23	29.10	28.75	28.54	27.74
2029	29.28	30.58	29.75	29.34	29.52	29.33	29.44	29.20	29.07	28.71	28.49	27.67
2030	29.25	30.59	29.74	29.32	29.50	29.30	29.42	29.17	29.04	28.66	28.44	27.59
2031	29.22	30.60	29.73	29.29	29.48	29.28	29.40	29.14	29.01	28.62	28.39	27.51
2032	29.19	30.62	29.72	29.26	29.46	29.25	29.38	29.11	28.97	28.57	28.34	27.44
2033	29.17	30.63	29.70	29.24	29.44	29.22	29.35	29.08	28.94	28.53	28.29	27.36
2034	29.14	30.64	29.69	29.21	29.42	29.20	29.33	29.05	28.90	28.48	28.24	27.28
2035	29.11	30.66	29.68	29.19	29.40	29.17	29.31	29.02	28.87	28.44	28.19	27.20
2036	29.08	30.67	29.67	29.16	29.38	29.15	29.29	28.99	28.84	28.39	28.13	27.13
2037	29.06	30.68	29.65	29.14	29.36	29.12	29.26	28.96	28.80	28.35	28.08	27.05
2038	29.03	30.70	29.64	29.11	29.34	29.09	29.24	28.93	28.77	28.30	28.03	26.97
2039	29.00	30.71	29.63	29.08	29.32	29.07	29.22	28.90	28.73	28.26	27.98	26.89
2040	28.97	30.72	29.61	29.06	29.30	29.04	29.20	28.87	28.70	28.21	27.92	26.81
2041	28.94	30.73	29.60	29.03	29.28	29.01	29.17	28.84	28.66	28.16	27.87	26.73
2042	28.91	30.75	29.59	29.01	29.26	28.99	29.15	28.81	28.63	28.12	27.82	26.65
2043	28.89	30.76	29.58	28.98	29.24	28.96	29.13	28.78	28.59	28.07	27.76	26.57
2044	28.86	30.77	29.56	28.95	29.22	28.93	29.10	28.75	28.56	28.02	27.71	26.49
2045	28.83	30.79	29.55	28.93	29.20	28.91	29.08	28.72	28.52	27.98	27.66	26.41
2046	28.80	30.80	29.54	28.90	29.18	28.88	29.06	28.68	28.49	27.93	27.60	26.33
2047	28.77	30.82	29.52	28.87	29.16	28.85	29.03	28.65	28.45	27.88	27.55	26.25
2048	28.74	30.83	29.51	28.85	29.14	28.82	29.01	28.62	28.42	27.83	27.49	26.17
2049	28.71	30.84	29.50	28.82	29.12	28.80	28.99	28.59	28.38	27.79	27.44	26.09
2050	28.68	30.86	29.48	28.79	29.09	28.77	28.96	28.56	28.35	27.74	27.38	26.01
2051	28.66	30.87	29.47	28.77	29.07	28.74	28.94	28.53	28.31	27.69	27.33	25.92
2052	28.63	30.88	29.46	28.74	29.05	28.71	28.92	28.49	28.27	27.64	27.27	25.84
2053	28.60	30.90	29.44	28.71	29.03	28.69	28.89	28.46	28.24	27.60	27.22	25.76
2054	28.57	30.91	29.43	28.68	29.01	28.66	28.87	28.43	28.20	27.55	27.16	25.67
2055	28.54	30.92	29.41	28.66	28.99	28.63	28.84	28.40	28.17	27.50	27.11	25.59

2056	28.51	30.94	29.40	28.63	28.97	28.60	28.82	28.37	28.13	27.45	27.05	25.51
2057	28.48	30.95	29.39	28.60	28.95	28.58	28.80	28.33	28.09	27.40	27.00	25.42
2058	28.45	30.97	29.37	28.57	28.92	28.55	28.77	28.30	28.06	27.35	26.94	25.34
2059	28.42	30.98	29.36	28.55	28.90	28.52	28.75	28.27	28.02	27.30	26.88	25.26
2060	28.39	30.99	29.35	28.52	28.88	28.49	28.72	28.24	27.98	27.25	26.83	25.17
2061	28.36	31.01	29.33	28.49	28.86	28.46	28.70	28.20	27.95	27.21	26.77	25.09
2062	28.33	31.02	29.32	28.46	28.84	28.43	28.67	28.17	27.91	27.16	26.72	25.00
2063	28.30	31.04	29.30	28.43	28.82	28.41	28.65	28.14	27.87	27.11	26.66	24.92
2064	28.27	31.05	29.29	28.41	28.79	28.38	28.63	28.11	27.83	27.06	26.60	24.83
2065	28.24	31.07	29.28	28.38	28.77	28.35	28.60	28.07	27.80	27.01	26.54	24.75

A.2 Dry Year Annual Average

DYAA	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	CC12
2025	24.77	25.09	24.59	24.50	24.55	24.39	24.21	24.08	23.87	23.81	23.62	22.98
2026	24.78	25.11	24.59	24.50	24.55	24.38	24.20	24.07	23.85	23.79	23.59	22.93
2027	24.79	25.13	24.59	24.50	24.56	24.38	24.19	24.05	23.83	23.76	23.56	22.87
2028	24.80	25.16	24.60	24.50	24.56	24.38	24.18	24.04	23.81	23.74	23.53	22.82
2029	24.81	25.18	24.60	24.50	24.56	24.37	24.17	24.03	23.79	23.72	23.50	22.77
2030	24.82	25.20	24.60	24.50	24.56	24.37	24.16	24.01	23.76	23.69	23.47	22.72
2031	24.83	25.22	24.61	24.50	24.56	24.36	24.15	24.00	23.74	23.67	23.44	22.67
2032	24.84	25.24	24.61	24.50	24.57	24.36	24.14	23.98	23.72	23.64	23.41	22.61
2033	24.85	25.26	24.61	24.50	24.57	24.36	24.13	23.97	23.70	23.62	23.38	22.56
2034	24.86	25.28	24.62	24.51	24.57	24.35	24.12	23.96	23.68	23.60	23.35	22.51
2035	24.87	25.30	24.62	24.51	24.57	24.35	24.11	23.94	23.65	23.57	23.32	22.45
2036	24.88	25.32	24.62	24.51	24.58	24.35	24.10	23.93	23.63	23.55	23.29	22.40
2037	24.89	25.34	24.63	24.51	24.58	24.34	24.09	23.91	23.61	23.52	23.26	22.34
2038	24.90	25.37	24.63	24.51	24.58	24.34	24.08	23.90	23.59	23.50	23.23	22.29
2039	24.91	25.39	24.63	24.51	24.58	24.33	24.07	23.88	23.57	23.47	23.20	22.24
2040	24.92	25.41	24.64	24.51	24.58	24.33	24.06	23.87	23.54	23.45	23.16	22.18
2041	24.93	25.43	24.64	24.51	24.59	24.33	24.05	23.85	23.52	23.42	23.13	22.13
2042	24.94	25.45	24.64	24.51	24.59	24.32	24.04	23.84	23.50	23.40	23.10	22.07
2043	24.95	25.47	24.65	24.51	24.59	24.32	24.03	23.82	23.48	23.38	23.07	22.02
2044	24.96	25.50	24.65	24.51	24.59	24.31	24.02	23.81	23.45	23.35	23.04	21.96
2045	24.97	25.52	24.66	24.51	24.59	24.31	24.01	23.79	23.43	23.33	23.01	21.91
2046	24.98	25.54	24.66	24.51	24.60	24.31	24.00	23.78	23.41	23.30	22.97	21.85
2047	24.99	25.56	24.66	24.51	24.60	24.30	23.99	23.76	23.38	23.27	22.94	21.79

2048	25.00	25.58	24.67	24.51	24.60	24.30	23.98	23.75	23.36	23.25	22.91	21.74
2049	25.01	25.61	24.67	24.51	24.60	24.29	23.97	23.73	23.34	23.22	22.88	21.68
2050	25.02	25.63	24.67	24.51	24.61	24.29	23.96	23.72	23.31	23.20	22.84	21.62
2051	25.03	25.65	24.68	24.51	24.61	24.29	23.95	23.70	23.29	23.17	22.81	21.57
2052	25.04	25.67	24.68	24.51	24.61	24.28	23.94	23.69	23.27	23.15	22.78	21.51
2053	25.05	25.70	24.68	24.51	24.61	24.28	23.93	23.67	23.24	23.12	22.75	21.45
2054	25.06	25.72	24.69	24.51	24.61	24.27	23.92	23.65	23.22	23.10	22.71	21.40
2055	25.07	25.74	24.69	24.51	24.62	24.27	23.90	23.64	23.20	23.07	22.68	21.34
2056	25.08	25.77	24.69	24.51	24.62	24.27	23.89	23.62	23.17	23.04	22.65	21.28
2057	25.10	25.79	24.70	24.51	24.62	24.26	23.88	23.61	23.15	23.02	22.61	21.22
2058	25.11	25.81	24.70	24.51	24.62	24.26	23.87	23.59	23.13	22.99	22.58	21.17
2059	25.12	25.83	24.71	24.51	24.63	24.25	23.86	23.58	23.10	22.97	22.55	21.11
2060	25.13	25.86	24.71	24.51	24.63	24.25	23.85	23.56	23.08	22.94	22.51	21.05
2061	25.14	25.88	24.71	24.51	24.63	24.25	23.84	23.55	23.05	22.91	22.48	20.99
2062	25.15	25.90	24.72	24.51	24.63	24.24	23.83	23.53	23.03	22.89	22.45	20.93
2063	25.16	25.93	24.72	24.51	24.64	24.24	23.82	23.51	23.01	22.86	22.41	20.87
2064	25.17	25.95	24.72	24.52	24.64	24.23	23.81	23.50	22.98	22.83	22.38	20.82
2065	25.18	25.97	24.73	24.52	24.64	24.23	23.80	23.48	22.96	22.81	22.35	20.76

A.3 1 in 100 Year Return Period

1IN100	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	CC12
2025	20.09	19.83	19.53	19.50	19.43	19.16	18.92	18.81	18.61	18.60	18.50	17.97
2026	20.12	19.85	19.55	19.51	19.44	19.17	18.92	18.80	18.60	18.59	18.49	17.93
2027	20.16	19.88	19.56	19.53	19.46	19.17	18.91	18.79	18.59	18.57	18.47	17.90
2028	20.20	19.91	19.58	19.54	19.47	19.18	18.91	18.78	18.57	18.56	18.45	17.86
2029	20.23	19.94	19.60	19.56	19.48	19.18	18.91	18.78	18.56	18.54	18.43	17.82
2030	20.27	19.96	19.62	19.58	19.50	19.19	18.90	18.77	18.54	18.53	18.42	17.79
2031	20.31	19.99	19.63	19.59	19.51	19.19	18.90	18.76	18.53	18.52	18.40	17.75
2032	20.34	20.02	19.65	19.61	19.53	19.20	18.89	18.75	18.52	18.50	18.38	17.71
2033	20.38	20.05	19.67	19.63	19.54	19.20	18.89	18.75	18.50	18.49	18.36	17.68
2034	20.42	20.08	19.69	19.64	19.56	19.20	18.89	18.74	18.49	18.47	18.34	17.64
2035	20.46	20.11	19.70	19.66	19.57	19.21	18.88	18.73	18.47	18.46	18.32	17.60
2036	20.49	20.13	19.72	19.68	19.58	19.21	18.88	18.72	18.46	18.44	18.31	17.56
2037	20.53	20.16	19.74	19.69	19.60	19.22	18.88	18.71	18.44	18.43	18.29	17.53
2038	20.57	20.19	19.76	19.71	19.61	19.22	18.87	18.71	18.43	18.41	18.27	17.49
2039	20.61	20.22	19.78	19.73	19.63	19.23	18.87	18.70	18.41	18.40	18.25	17.45

2040	20.64	20.25	19.79	19.74	19.64	19.23	18.86	18.69	18.40	18.38	18.23	17.41
2041	20.68	20.28	19.81	19.76	19.66	19.24	18.86	18.68	18.38	18.36	18.21	17.37
2042	20.72	20.31	19.83	19.78	19.67	19.24	18.86	18.67	18.37	18.35	18.19	17.34
2043	20.76	20.34	19.85	19.79	19.69	19.25	18.85	18.67	18.35	18.33	18.17	17.30
2044	20.80	20.37	19.87	19.81	19.70	19.25	18.85	18.66	18.34	18.32	18.16	17.26
2045	20.84	20.39	19.89	19.83	19.72	19.26	18.84	18.65	18.32	18.30	18.14	17.22
2046	20.88	20.42	19.90	19.85	19.73	19.26	18.84	18.64	18.31	18.29	18.12	17.18
2047	20.92	20.45	19.92	19.86	19.74	19.27	18.84	18.63	18.29	18.27	18.10	17.14
2048	20.96	20.48	19.94	19.88	19.76	19.27	18.83	18.63	18.28	18.26	18.08	17.10
2049	21.00	20.51	19.96	19.90	19.77	19.28	18.83	18.62	18.26	18.24	18.06	17.06
2050	21.03	20.54	19.98	19.92	19.79	19.28	18.83	18.61	18.25	18.22	18.04	17.02
2051	21.07	20.57	20.00	19.93	19.80	19.29	18.82	18.60	18.23	18.21	18.02	16.99
2052	21.11	20.60	20.02	19.95	19.82	19.29	18.82	18.59	18.22	18.19	18.00	16.95
2053	21.15	20.63	20.04	19.97	19.84	19.30	18.81	18.59	18.20	18.18	17.98	16.91
2054	21.19	20.66	20.06	19.99	19.85	19.30	18.81	18.58	18.19	18.16	17.96	16.87
2055	21.23	20.69	20.07	20.00	19.87	19.31	18.81	18.57	18.17	18.14	17.94	16.83
2056	21.27	20.72	20.09	20.02	19.88	19.32	18.80	18.56	18.15	18.13	17.92	16.79
2057	21.32	20.75	20.11	20.04	19.90	19.32	18.80	18.55	18.14	18.11	17.90	16.75
2058	21.36	20.79	20.13	20.06	19.91	19.33	18.79	18.54	18.12	18.10	17.88	16.71
2059	21.40	20.82	20.15	20.08	19.93	19.33	18.79	18.53	18.11	18.08	17.86	16.66
2060	21.44	20.85	20.17	20.09	19.94	19.34	18.78	18.53	18.09	18.06	17.84	16.62
2061	21.48	20.88	20.19	20.11	19.96	19.34	18.78	18.52	18.08	18.05	17.82	16.58
2062	21.52	20.91	20.21	20.13	19.97	19.35	18.78	18.51	18.06	18.03	17.80	16.54
2063	21.56	20.94	20.23	20.15	19.99	19.35	18.77	18.50	18.04	18.01	17.78	16.50
2064	21.60	20.97	20.25	20.17	20.01	19.36	18.77	18.49	18.03	18.00	17.76	16.46
2065	21.64	21.00	20.27	20.18	20.02	19.36	18.76	18.48	18.01	17.98	17.74	16.42

A.4 1 in 200 Year Return Period

1IN200	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	CC12
2025	19.11	18.75	18.35	18.34	18.33	18.14	17.91	17.87	17.66	17.64	17.59	17.14
2026	19.14	18.77	18.36	18.35	18.34	18.15	17.91	17.86	17.65	17.63	17.58	17.11
2027	19.18	18.80	18.37	18.36	18.35	18.15	17.91	17.85	17.64	17.62	17.56	17.08
2028	19.22	18.82	18.38	18.37	18.36	18.15	17.90	17.85	17.62	17.60	17.55	17.05
2029	19.25	18.85	18.39	18.38	18.37	18.16	17.90	17.84	17.61	17.59	17.53	17.02
2030	19.29	18.87	18.41	18.40	18.38	18.16	17.89	17.84	17.60	17.57	17.52	16.99
2031	19.33	18.90	18.42	18.41	18.39	18.17	17.89	17.83	17.58	17.56	17.50	16.96

2032	19.37	18.92	18.43	18.42	18.40	18.17	17.88	17.82	17.57	17.55	17.48	16.93
2033	19.40	18.95	18.44	18.43	18.41	18.17	17.88	17.82	17.56	17.53	17.47	16.90
2034	19.44	18.97	18.45	18.44	18.42	18.18	17.88	17.81	17.54	17.52	17.45	16.87
2035	19.48	19.00	18.46	18.45	18.43	18.18	17.87	17.81	17.53	17.51	17.44	16.84
2036	19.52	19.02	18.47	18.46	18.44	18.19	17.87	17.80	17.52	17.49	17.42	16.81
2037	19.56	19.05	18.48	18.47	18.45	18.19	17.86	17.79	17.51	17.48	17.41	16.77
2038	19.59	19.07	18.50	18.48	18.47	18.19	17.86	17.79	17.49	17.46	17.39	16.74
2039	19.63	19.10	18.51	18.49	18.48	18.20	17.85	17.78	17.48	17.45	17.37	16.71
2040	19.67	19.13	18.52	18.50	18.49	18.20	17.85	17.78	17.46	17.44	17.36	16.68
2041	19.71	19.15	18.53	18.52	18.50	18.20	17.85	17.77	17.45	17.42	17.34	16.65
2042	19.75	19.18	18.54	18.53	18.51	18.21	17.84	17.76	17.44	17.41	17.33	16.61
2043	19.79	19.20	18.55	18.54	18.52	18.21	17.84	17.76	17.42	17.39	17.31	16.58
2044	19.83	19.23	18.56	18.55	18.53	18.22	17.83	17.75	17.41	17.38	17.29	16.55
2045	19.87	19.26	18.58	18.56	18.54	18.22	17.83	17.75	17.40	17.36	17.28	16.52
2046	19.91	19.28	18.59	18.57	18.55	18.22	17.82	17.74	17.38	17.35	17.26	16.48
2047	19.95	19.31	18.60	18.58	18.56	18.23	17.82	17.73	17.37	17.33	17.25	16.45
2048	19.99	19.33	18.61	18.59	18.57	18.23	17.81	17.73	17.36	17.32	17.23	16.42
2049	20.03	19.36	18.62	18.61	18.58	18.24	17.81	17.72	17.34	17.31	17.21	16.38
2050	20.07	19.39	18.63	18.62	18.60	18.24	17.81	17.71	17.33	17.29	17.20	16.35
2051	20.11	19.41	18.65	18.63	18.61	18.24	17.80	17.71	17.31	17.28	17.18	16.32
2052	20.15	19.44	18.66	18.64	18.62	18.25	17.80	17.70	17.30	17.26	17.16	16.28
2053	20.19	19.47	18.67	18.65	18.63	18.25	17.79	17.70	17.29	17.25	17.15	16.25
2054	20.23	19.50	18.68	18.66	18.64	18.26	17.79	17.69	17.27	17.23	17.13	16.22
2055	20.27	19.52	18.69	18.68	18.65	18.26	17.78	17.68	17.26	17.22	17.11	16.18
2056	20.31	19.55	18.71	18.69	18.66	18.27	17.78	17.68	17.24	17.20	17.10	16.15
2057	20.35	19.58	18.72	18.70	18.67	18.27	17.77	17.67	17.23	17.19	17.08	16.12
2058	20.39	19.60	18.73	18.71	18.69	18.27	17.77	17.66	17.21	17.17	17.06	16.08
2059	20.43	19.63	18.74	18.72	18.70	18.28	17.76	17.66	17.20	17.16	17.05	16.05
2060	20.47	19.66	18.75	18.73	18.71	18.28	17.76	17.65	17.19	17.14	17.03	16.01
2061	20.51	19.69	18.77	18.75	18.72	18.29	17.75	17.64	17.17	17.13	17.01	15.98
2062	20.55	19.71	18.78	18.76	18.73	18.29	17.75	17.64	17.16	17.11	16.99	15.95
2063	20.60	19.74	18.79	18.77	18.74	18.29	17.75	17.63	17.14	17.10	16.98	15.91
2064	20.64	19.77	18.80	18.78	18.75	18.30	17.74	17.62	17.13	17.08	16.96	15.88
2065	20.68	19.80	18.82	18.79	18.77	18.30	17.74	17.62	17.11	17.07	16.94	15.84

A.5 1 in 500 Year Return Period

1IN500	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	CC12
2025	17.80	17.60	17.30	17.25	17.24	17.13	16.97	16.91	16.74	16.68	16.66	16.29
2026	17.83	17.62	17.31	17.26	17.25	17.13	16.97	16.91	16.73	16.67	16.65	16.26
2027	17.86	17.64	17.32	17.27	17.26	17.14	16.97	16.90	16.72	16.66	16.63	16.24
2028	17.88	17.66	17.33	17.28	17.26	17.14	16.97	16.90	16.71	16.64	16.62	16.21
2029	17.91	17.67	17.34	17.28	17.27	17.14	16.96	16.89	16.70	16.63	16.61	16.19
2030	17.94	17.69	17.35	17.29	17.28	17.15	16.96	16.89	16.69	16.62	16.60	16.16
2031	17.96	17.71	17.36	17.30	17.28	17.15	16.96	16.89	16.68	16.61	16.58	16.14
2032	17.99	17.73	17.37	17.31	17.29	17.15	16.96	16.88	16.67	16.60	16.57	16.11
2033	18.02	17.75	17.38	17.31	17.30	17.16	16.96	16.88	16.66	16.58	16.56	16.09
2034	18.05	17.77	17.39	17.32	17.31	17.16	16.96	16.87	16.65	16.57	16.54	16.06
2035	18.07	17.79	17.40	17.33	17.31	17.16	16.95	16.87	16.64	16.56	16.53	16.03
2036	18.10	17.81	17.41	17.34	17.32	17.17	16.95	16.87	16.63	16.55	16.52	16.01
2037	18.13	17.83	17.42	17.35	17.33	17.17	16.95	16.86	16.62	16.53	16.50	15.98
2038	18.16	17.85	17.43	17.35	17.34	17.17	16.95	16.86	16.61	16.52	16.49	15.95
2039	18.18	17.88	17.44	17.36	17.34	17.18	16.95	16.85	16.60	16.51	16.48	15.93
2040	18.21	17.90	17.45	17.37	17.35	17.18	16.94	16.85	16.59	16.50	16.46	15.90
2041	18.24	17.92	17.46	17.38	17.36	17.19	16.94	16.85	16.58	16.48	16.45	15.87
2042	18.27	17.94	17.47	17.39	17.37	17.19	16.94	16.84	16.57	16.47	16.44	15.85
2043	18.30	17.96	17.48	17.39	17.38	17.19	16.94	16.84	16.56	16.46	16.42	15.82
2044	18.33	17.98	17.49	17.40	17.38	17.20	16.94	16.83	16.55	16.45	16.41	15.79
2045	18.35	18.00	17.50	17.41	17.39	17.20	16.93	16.83	16.54	16.43	16.40	15.77
2046	18.38	18.02	17.51	17.42	17.40	17.20	16.93	16.82	16.53	16.42	16.38	15.74
2047	18.41	18.04	17.52	17.43	17.41	17.21	16.93	16.82	16.52	16.41	16.37	15.71
2048	18.44	18.06	17.53	17.44	17.42	17.21	16.93	16.82	16.51	16.40	16.36	15.68
2049	18.47	18.08	17.54	17.44	17.42	17.22	16.93	16.81	16.49	16.38	16.34	15.66
2050	18.50	18.10	17.55	17.45	17.43	17.22	16.92	16.81	16.48	16.37	16.33	15.63
2051	18.53	18.13	17.56	17.46	17.44	17.22	16.92	16.80	16.47	16.36	16.32	15.60
2052	18.56	18.15	17.57	17.47	17.45	17.23	16.92	16.80	16.46	16.34	16.30	15.57
2053	18.59	18.17	17.58	17.48	17.45	17.23	16.92	16.79	16.45	16.33	16.29	15.55
2054	18.62	18.19	17.59	17.49	17.46	17.23	16.91	16.79	16.44	16.32	16.27	15.52
2055	18.64	18.21	17.60	17.49	17.47	17.24	16.91	16.78	16.43	16.30	16.26	15.49
2056	18.67	18.23	17.61	17.50	17.48	17.24	16.91	16.78	16.42	16.29	16.25	15.46
2057	18.70	18.26	17.62	17.51	17.49	17.25	16.91	16.78	16.41	16.28	16.23	15.43
2058	18.73	18.28	17.63	17.52	17.50	17.25	16.91	16.77	16.40	16.26	16.22	15.41

2059	18.76	18.30	17.64	17.53	17.50	17.25	16.90	16.77	16.39	16.25	16.20	15.38
2060	18.79	18.32	17.65	17.54	17.51	17.26	16.90	16.76	16.38	16.24	16.19	15.35
2061	18.82	18.34	17.67	17.55	17.52	17.26	16.90	16.76	16.36	16.22	16.18	15.32
2062	18.85	18.36	17.68	17.56	17.53	17.27	16.90	16.75	16.35	16.21	16.16	15.29
2063	18.88	18.39	17.69	17.56	17.54	17.27	16.90	16.75	16.34	16.20	16.15	15.26
2064	18.91	18.41	17.70	17.57	17.54	17.27	16.89	16.74	16.33	16.18	16.13	15.24
2065	18.94	18.43	17.71	17.58	17.55	17.28	16.89	16.74	16.32	16.17	16.12	15.21