Pindari destratification – numerical modelling of operational procedures to balance power requirements

WRL TR 2024/05, July 2024

By F C Chaaya and B M Miller

FINAL

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1 Introduction

Cold water pollution downstream of thermally stratified reservoirs is a complex issue with a range of ecological, environmental and social impacts. Despite a recognition of cold water pollution in NSW for almost two decades, it remains an issue downstream of many large storage dams. An international literature review undertaken by the UNSW Sydney Water Research Laboratory (WRL) investigated causes and impacts of, and options for mitigating cold water pollution (Chaaya and Miller, 2022). This review highlighted artificial destratification via bubble plumes as the only mitigation option capable of addressing both cold water pollution and other water quality impacts caused by reservoir stratification. The successful application of bubble plume destratification in large storage reservoirs was found to be limited, primarily due to the significant operational costs at larger scales. As such, renewable energy and optimised operational procedures are considered a necessity for feasible artificial destratification via bubble plumes in large reservoirs.

Given the limited successful application of bubble plume destratification in large reservoirs, especially in NSW, a pilot trial destratification system is recommended to demonstrate feasibility. WRL was previously engaged by the NSW Department of Primary Industry – Fisheries (DPI Fisheries) to investigate and recommend a NSW dam at which to undertake these destratification trials. Pindari Dam located on the Severn River (Figure 1-1), one of eight high-priority dams outlined as part of the previous cold water pollution mitigating works in NSW (NSW Cold Water Pollution Interagency Group, 2012), was deemed the most appropriate.

WRL was engaged by DPI Fisheries to undertake a number of tasks to support the design of the proposed Pindari Dam bubble plume artificial destratification trials. These have been summarised in the following reports:

- WRL TR2022/04 (Chaaya and Miller, 2023a) – initial investigation into Pindari's existing cold water pollution issues, existing data availability and suitability for a trial
- WRL TR2022/19 (Chaaya and Miller, 2023b) – providing recommendations for a monitoring network
- WRL TR2023/05 (Chaaya and Miller, 2024) – conceptual design of compressor and pneumatic (distribution and diffuser pipelines) components, and operational design

This report presents the results from the numerical modelling undertaken to understand the impacts of various proposed operational scenarios to refine the power requirements of a long-term installation. The following sections present these results:

- Section 2 summarises model setup and results from modelling idealised conditions and basic operational procedures
- Section 3 summarises model setup and the results of long-term scenario modelling based on the operational scenarios presented as part of a concurrent investigation into power refinement

This modelling was undertaken concurrently to an external investigation by KOMO Energy (engaged separately by DPI Fisheries). The results from this modelling provided power estimates to assist with their development of power refinement scenarios for the Pindari Dam destratification project.

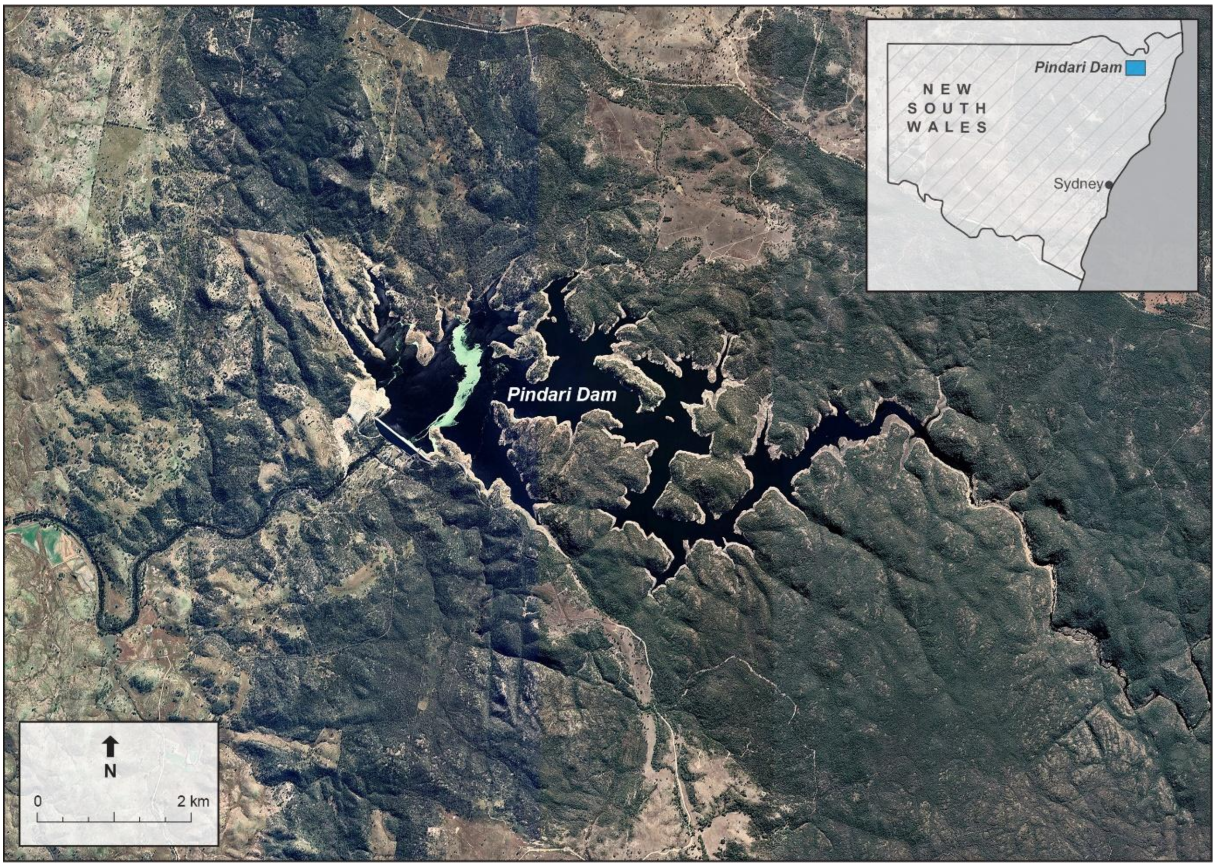

Figure 1-1 Pindari Dam location

1.1 AEM3D numerical modelling

Numerical modelling of artificial destratification in Pindari Dam was undertaken in AEM3D (Hydronumerics, 2024), which is used to simulate natural stratification and artificial destratification processes in a three-dimensional reservoir environment.

The model reservoir bathymetry, input meteorological and input hydrological data were adapted from the model files provided by the Australian Rivers Institute of Griffith University as part of a previous modelling study of Pindari Dam (Prentice *et al.*, 2021). Input meteorological and hydrological data provided by the Australian Rivers Institute were verified against the WaterNSW and BOM data from which it was sourced.

The model bathymetry provided, including the location of the diffuser as a boundary condition, was not modified for the idealised scenario modelling. The location of the diffuser and vertical layer structure were varied for the long-term scenario modelling (discussed in Section 3).

2 Idealised scenario modelling

WRL had previously proposed a range of air flowrates between 500 to 2,500 L/s (Chaaya and Miller, 2023a) as an initial conceptual working range to ensure Pindari Dam could be destratified under all conditions. WRL undertook further sensitivity testing of the model parameters and basic operational procedures under daily repeating idealised meteorological conditions (Appendix A) to assess the destratification implications of basic power refinement scenarios. This idealised modelling was used to further refine these flowrates to a target flowrate which provided KOMO Energy with an indicative power requirement for their assessments.

The operational procedures in the idealised scenarios were:

- Continuous operation (24 hours per day) with varied flow rates
- Intermittent operation between 8am and 4pm (8 hours per day)
- Operation with 1 hour of down time (demand management scheme)

The model was run for 90 days under idealised conditions, including:

- Initial water temperature of 14 °C, to represent conditions prior to the onset of stratification
- Meteorological conditions representative of summer conditions repeating daily
- Low wind speed, which did not provide any significant mixing energy or evaporative cooling
- No inflows or outflows
- Full storage level

These idealised conditions were selected to represent the "worst case" for destratification. As such, the results of modelling can be considered conservative. While these conditions do not represent realistic long-term variability in meteorological and hydrological conditions, it is important to understand the potential worst-case conditions for a long-term installation. If a system is under-designed, it may not have the capacity (i.e. air flowrate) to break stratification under extreme conditions. WRL has recommended (Chaaya and Miller, 2024) the use of variable speed drive (VSD) compressors specifically to facilitate varied flowrates based on current meteorological and hydrological conditions. These should, however, be capable of destratification in the worst-case scenario.

In terms of meteorological conditions over the 90-day modelling period, moderate summer conditions (air temperatures between 22 and 32 °C with a total daily solar radiation of 30 MJ) and low wind speeds best represent the worst-case scenario. While extreme summer conditions (higher air temperature and solar radiation) will result in additional stratification potential, it is unlikely that these would be sustained over the 90 days the system was modelled. A reservoir at full storage requires the most destratification energy input (i.e. air flowrate) due to the volume of water being destratified and the larger surface area through which surface heating enters. Inflows add mixing energy to the reservoir, and periods with no inflows will require additional destratification energy.

2.1 Continuous operation

Continuous operation with a range of fixed air flowrates was modelled to determine an appropriate maximum requirement flow rate for consideration in power refinement scenarios. This modelling, for the purposes of power refinement, should be considered conservative as the conditions modelled represent an extended period (90 days) or worst-case conditions under which to destratify. Variations in meteorological conditions, mixing inflows and varying water levels would reduce the air flowrate required to maintain a destratified reservoir, and thus lower the power requirements.

Figure 2-1 demonstrates the effects of varied flow rates over a period of 30, 60 and 90 days with continuous destratification operation on a full Pindari Reservoir. The starting condition on Day 0 was a uniform temperature from the surface to the bed of 14 ˚C. These scenarios represent conditions where the heat is entering the reservoir faster than any destratification airflow can fully mix it.

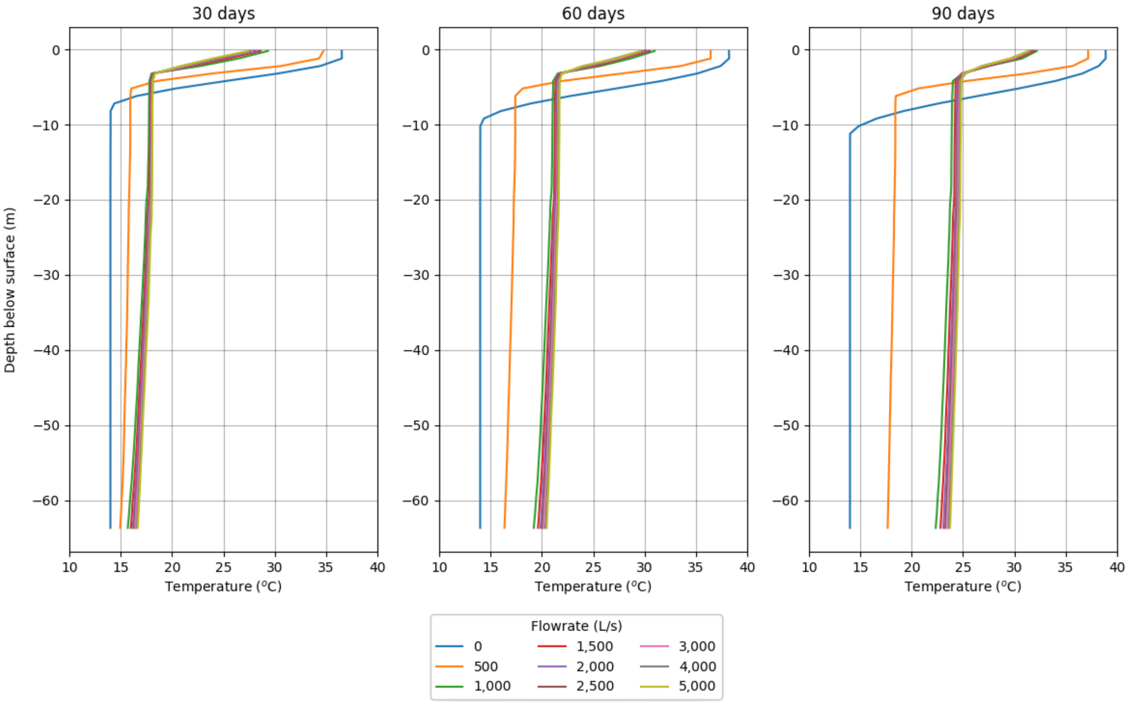

Figure 2-1 Varied flowrates through continuous operation over 30 (left), 60 (middle) and 90 (right) days under idealised summer conditions

Table 2-1 shows the resulting bed temperatures for each of the air flowrates modelled and the change from the no-destratification (0 L/s) case after 90 days.

Table 2-1 Bed temperatures following 90 days of modelling destratification under idealised Summer conditions

Air flowrate (L/s)	Bed temperature (°C)	Increase to bed temperature from no destratification case (°C)
0	14.0	0.0
500	17.7	3.7
1,000	22.3	8.3
1,500	22.8	8.8
2,000	23.1	9.1
2,500	23.3	9.3
3,000	23.4	9.4
4,000	23.6	9.6
5,000	23.7	9.7

After 90 days of idealised summer conditions, while the reservoir was not fully destratified, the following observations can be made:

- Air flow of 500 L/s was found to be capable of increasing the temperature at the bed of the reservoir by 3.5 °C above the zero airflow case
- Increasing the airflow up to 1,000 L/s provided additional heating to the bed, increasing temperature at the bed by 8 °C above the zero airflow case
- Increasing the airflow above 1,000 L/s was found to provide additional heat at the bed, but with significantly less return as flows increased

The idealised modelling demonstrated that a maximum air flowrate of 1,000 L/s would be suitable for destratifying Pindari Dam. A maximum achievable air flowrate less than this may be incapable of effectively destratifying the water column in the worst-case scenario. Air flowrates higher than this would provide significantly diminished returns based on their scaling power requirements and energy consumption. A compressor of approximately 400 kW power would be capable of achieving this air flowrate. This power requirement will vary with varying compressor pressure ratings, manufacturers, choice of variable or fixed speed (flowrate) compress and air flowrates in the case of a variable speed drive (VSD) compressor.

2.2 Intermittent operation

Intermittent operation of an artificial destratification system (8 hours per day between 8am and 4pm) represents a solar-friendly scenario, where a bubble plume system would only operate while solar energy was available.

Bubble plume destratification theory (Schladow, 1992) suggests that destratification occurs as a result of the work (water displaced by the mechanical energy introduced) done by a bubble plume. The work is linearly proportional to both the flowrate and the durations, indicating that intermittent operation for 8 hours per day (a third of the total time for a continuous operating day) would require three times the air flowrate of a continuously operated system to maintain the equivalent work input.

To assess this intermittent operation, two scenarios were run comparing 2,500L/s continuous with 7,500 L/s between 8am and 4pm. A 2,500 L/s base flow rate was based on the modelling undertaken in a precursor study (Chaaya and Miller, 2023a) of Pindari Dam, which indicated an upper limit of 2,500 L/s as a requirement to break established stratification. Given the unknown implication of an 8 hour per day intermittent operation, the 2,500 L/s and linearly scaled 7,500 L/s was used to ensure destratification would occur.

Figure 2-2 shows the results of testing continuous (2,500 L/s) and intermittent (7,500 L/s) under the same conditions for 90 days.

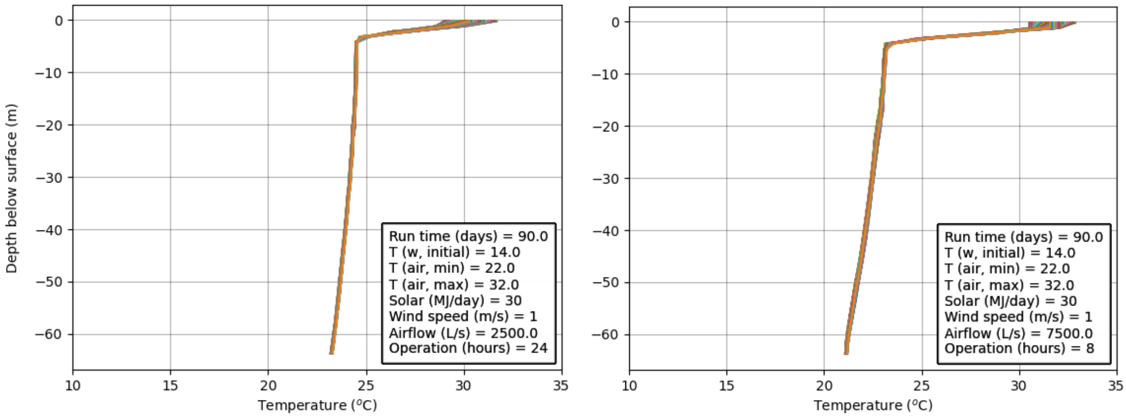

Figure 2-2 Continuous 2,500 L/s (left) and intermittent 7,500 L/s (right) operation under idealised Summer conditions

Following the results provided in an initial memo (*M20221215_WRL2022049*), an additional idealised 90-day scenario was run to demonstrate the effects of scaling the proposed 1,000 L/s continuous air flowrate to a 3,000 L/s intermittent 8 hour per day air flow rate. Figure 2-3 presents these results.

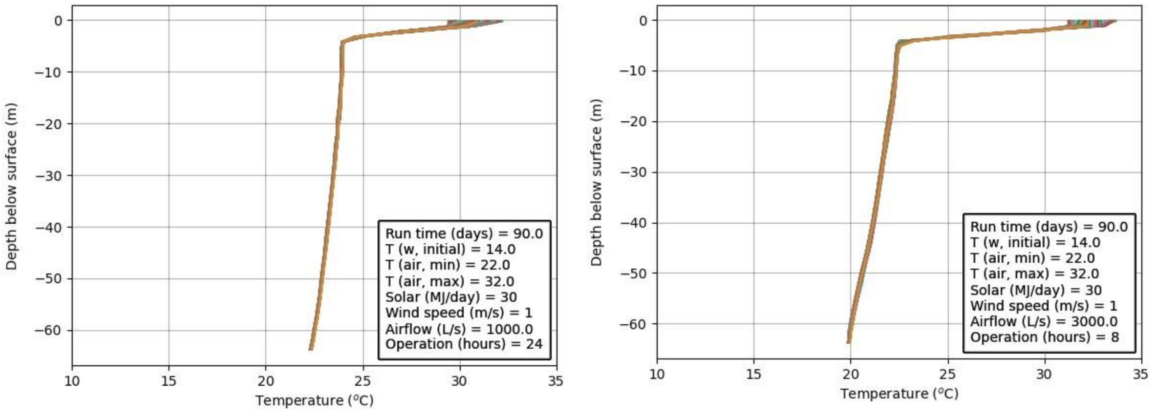

Figure 2-3 Continuous 1,000 L/s (left) and intermittent 3,000 L/s (right) operation under idealised Summer conditions

These results demonstrate that continuous operation was more effective than a scaled intermittent operation. As such, an intermittent operation needs higher scaled flows than simply the time ratio. On this basis, an air flowrate of 3,750 L/s (equivalent to 1,500 kW power requirement) was used for the 8 hour per day intermittent operation scenarios in the long-term modelling undertaken (Section 3).

2.3 Demand management operation

An initial demand management scheme was proposed by KOMO Energy in which operation would intermittently be ceased for up to 60 minutes to provide negative demand. This was modelled with both continuous and intermittent operations by ceasing operation for 1 hour at 12 noon every day. Operation was ceased at 12 noon to represent the worst-case scenario for stratification effects (peak solar radiation). Figure 2-4 shows the results of the 24 and 23 hour per day operation at 1,000 L/s over 90 days.

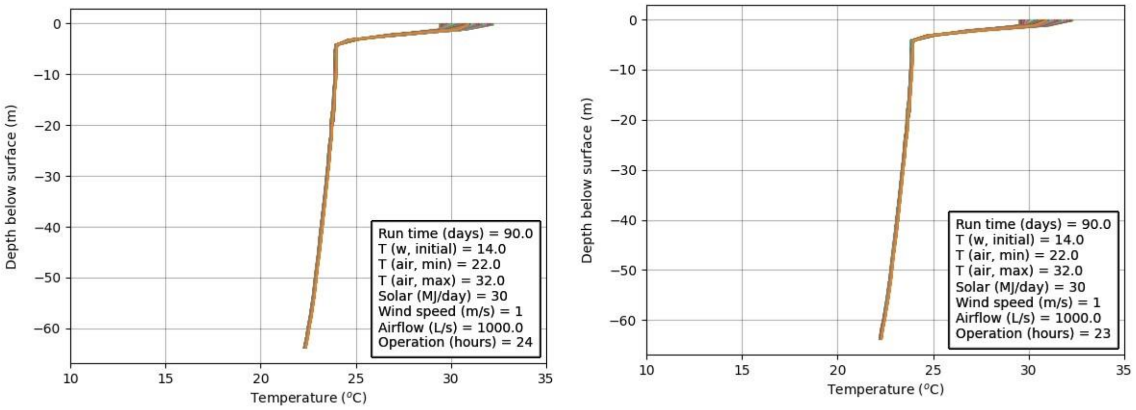

Figure 2-4 Continuous operation (left) and 23 hour per day demand management operation (right) at 1,000 L/s

This modelling demonstrated minimal difference in the resulting bed temperatures after 90 days between the cases with and without 1 hour of ceased operation. Based on the idealised testing, it would be operationally feasible to implement a demand management scheme under which operations were ceased for 1 hour per day.

3 Long-term modelling

The results of the idealised modelling outlined in Section 2 were provided to DPI Fisheries and KOMO Energy as a memo (*M20221215_WRL2022049*) at the end of 2022. Based on these results, KOMO Energy prepared an array of power procurement and refinement options that could be utilised for a long-term destratification installation at Pindari Dam. From these, five key operational strategies were identified and modelled to test their effectiveness for destratifying Pindari Dam over a long-term period under a range of hydrological and meteorological conditions. Table 3-1 summarises the six scenarios tested, including a base case scenario with no operational destratification.

Table 3-1 Summary of the long-term operational scenarios modelled

Scenario	Komo Scenario	Operation	Airflow (L/s)	Description
0	-	No destratification	0	Base case with no destratification.
1	5A	Continuous (24 hr/day)	1,000	Continuous operation.
2	6-2	Intermittent (8 hr/day)	3,750	Intermittent operation representing the 1,500 kW power requirement recommendation. Operated from 8am to 4pm where solar energy would be available.
3	1A	Intermittent (20 hr/day)	1,690	Operated continuously except for the period between 4.30pm and 8:30pm to avoid peak periods. The 1,690 L/s flow rate is linearly interpolated between the continuous case (1,000 L/s) and the intermittent case (3,750 L/s) based on 20 hours of operation.
4	1B	Intermittent (20 hr/day weekdays) (24 hr/day weekend)	1,690 (weekdays) 1,000 (weekends)	Similar operation to Scenario 3 with continuous operation on Saturday and Sunday. The air flowrate is reduced from 1,690 L/s to 1,000 L/s for these days.
5	2A	Intermittent (8 hours/day)	3,750	Intermittent operation for the 8 hours per day (as with Scenario 2), operated overnight from 9pm to 5am.

3.1 Model Configuration

3.1.1 Modelling period

Each scenario was run for a 5 year period from 1 July 2015 to 30 June 2020. This period was chosen as it included:

- A variety of meteorological conditions, including sustained periods of high temperatures
- Variations in the reservoir water level, including a sustained period of full supply level

Timeseries of relevant meteorological and hydrological data for the modelling period is available in Appendix B

3.1.2 Destratification period

Destratification was operated in each model scenario from 1 September to 30 April for each of the 5 years modelled. Outside of this period (in the cooler months), no destratification was applied.

3.1.3 Model bathymetry

As with the idealised modelling, the model bathymetry for the long-term scenarios was adapted from the 50 x 50 m Pindari bathymetry provided by the Australian Rivers Institute (Prentice *et al.*, 2021).

WRL updated the model mesh to have 1 m vertical layers throughout the entire water column.

The model bathymetry with the diffuser location is available in Figure 3-2. The diffuser was applied as 1,000 m long with 150 ports for all scenarios. Figure 3-2 also shows the locations where data was extracted for the following discussion, referred to as:

- Location A – profile adjacent to the existing offtake tower location
- Location B – location upstream of the main body of the reservoir and diffuser

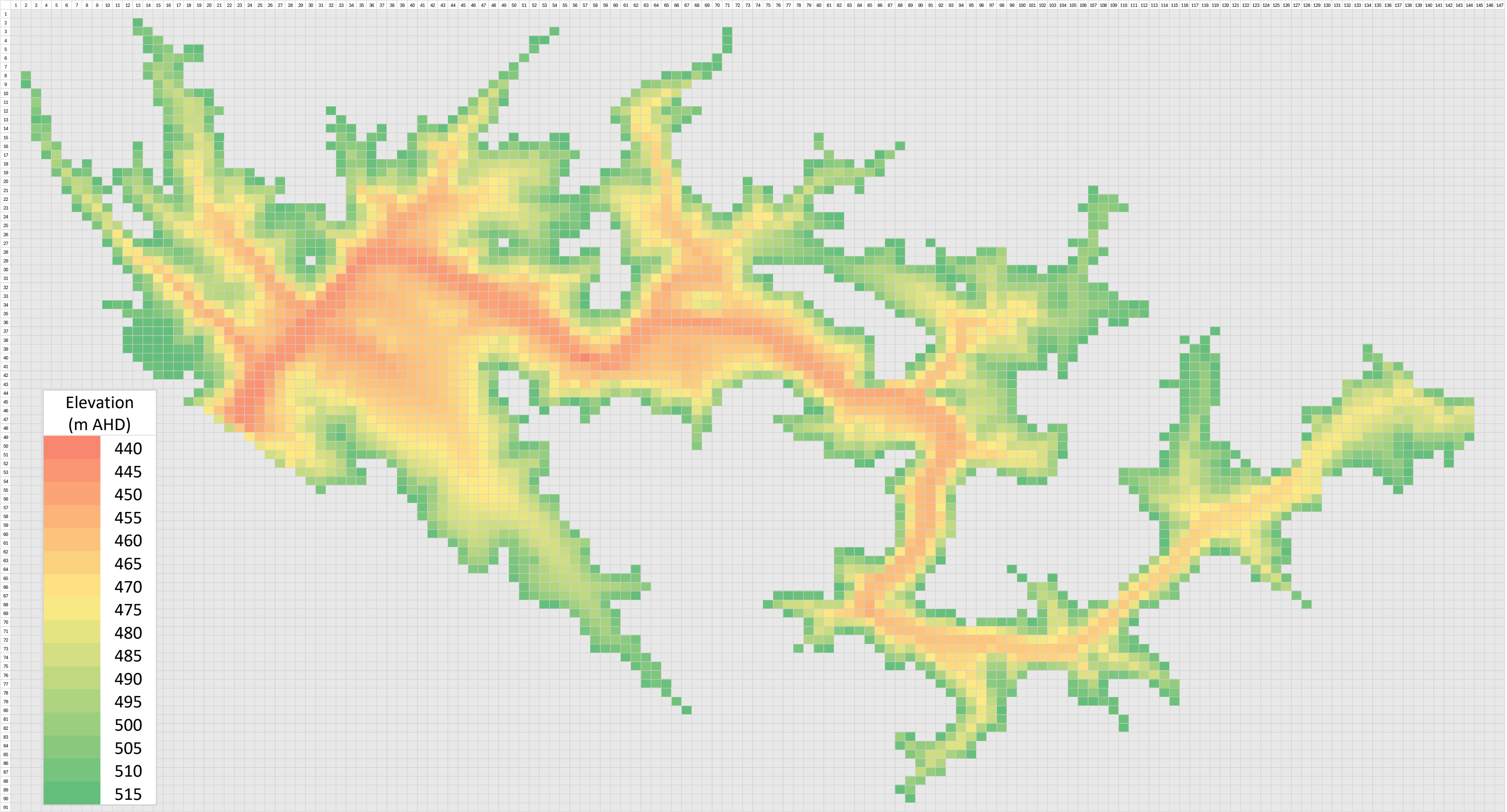

Figure 3-1 Reservoir bathymetry

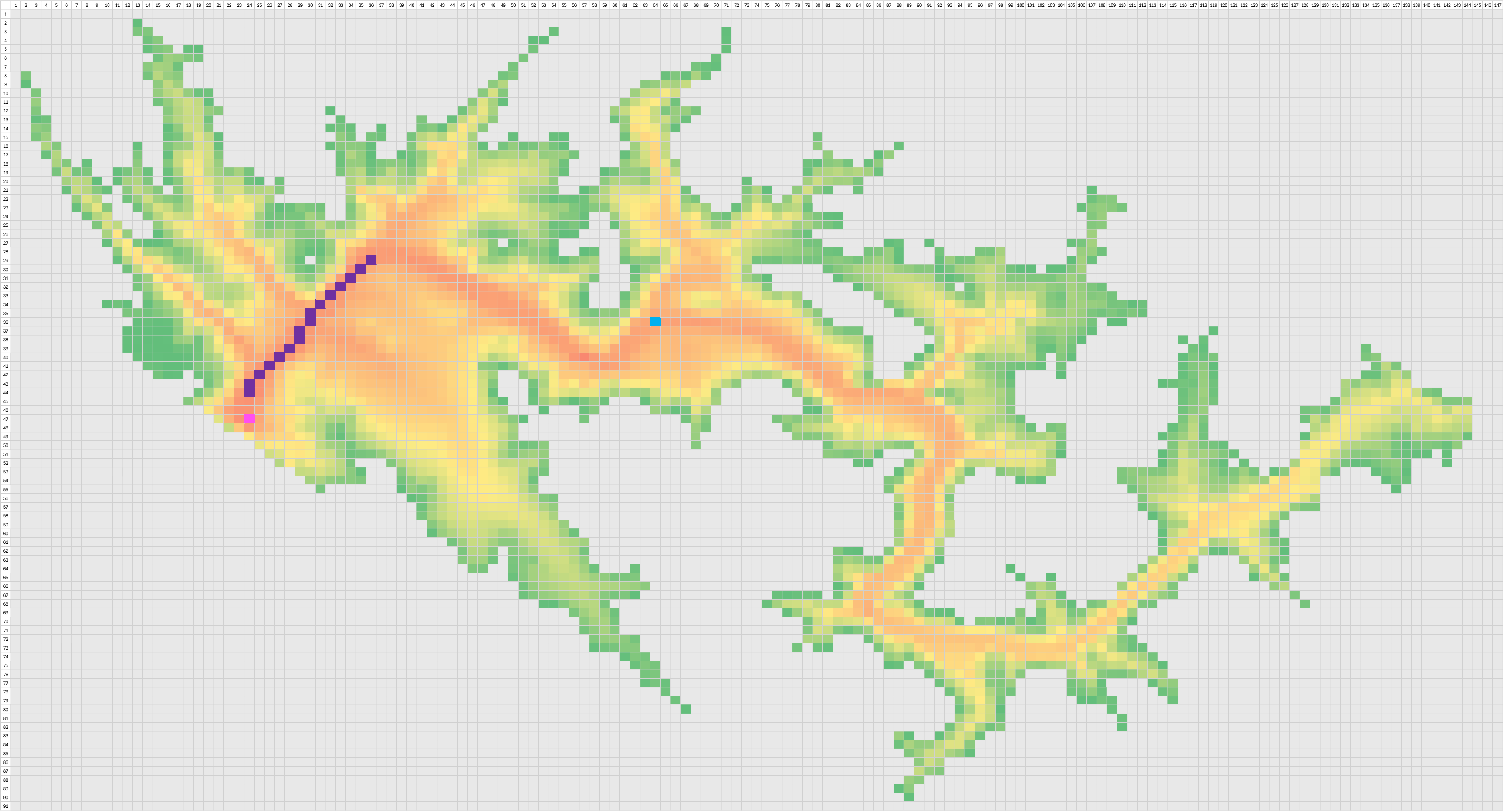

Figure 3-2 Reservoir bathymetry with long-term modelling diffuser location (purple), near-offtake results profile location (Location A, pink) and upstream results profile location (Location B, blue)

3.2 Model results

Two primary goals were considered when assessing the effectiveness of each of the destratification operation scenarios:

- Mitigating cold water pollution
- Effective reservoir-wide destratification

Mitigation of cold water pollution is achieved by increasing the temperature of the water released. Based on the review of ecological temperature thresholds by Michie et al. (2023), DPI Fisheries has proposed that a release temperature threshold of 20 °C should be achieved and maintained to mitigate the impacts of cold water pollution.

To quantify the increase in release water temperatures in the model results, the bed temperature from the profile nearest to the existing offtake tower (Figure 3-2, hereby referred to as Location A) was extracted for each scenario. If the release temperature threshold is achieved in the lowest part of the water column (i.e. the bed), extraction from any part of the water column should effectively mitigate cold water pollution.

Figure 3-3 shows the bed temperature at this location for each scenario over the 5-year modelling period, the proposed 20 °C temperature threshold and the reservoir water level.

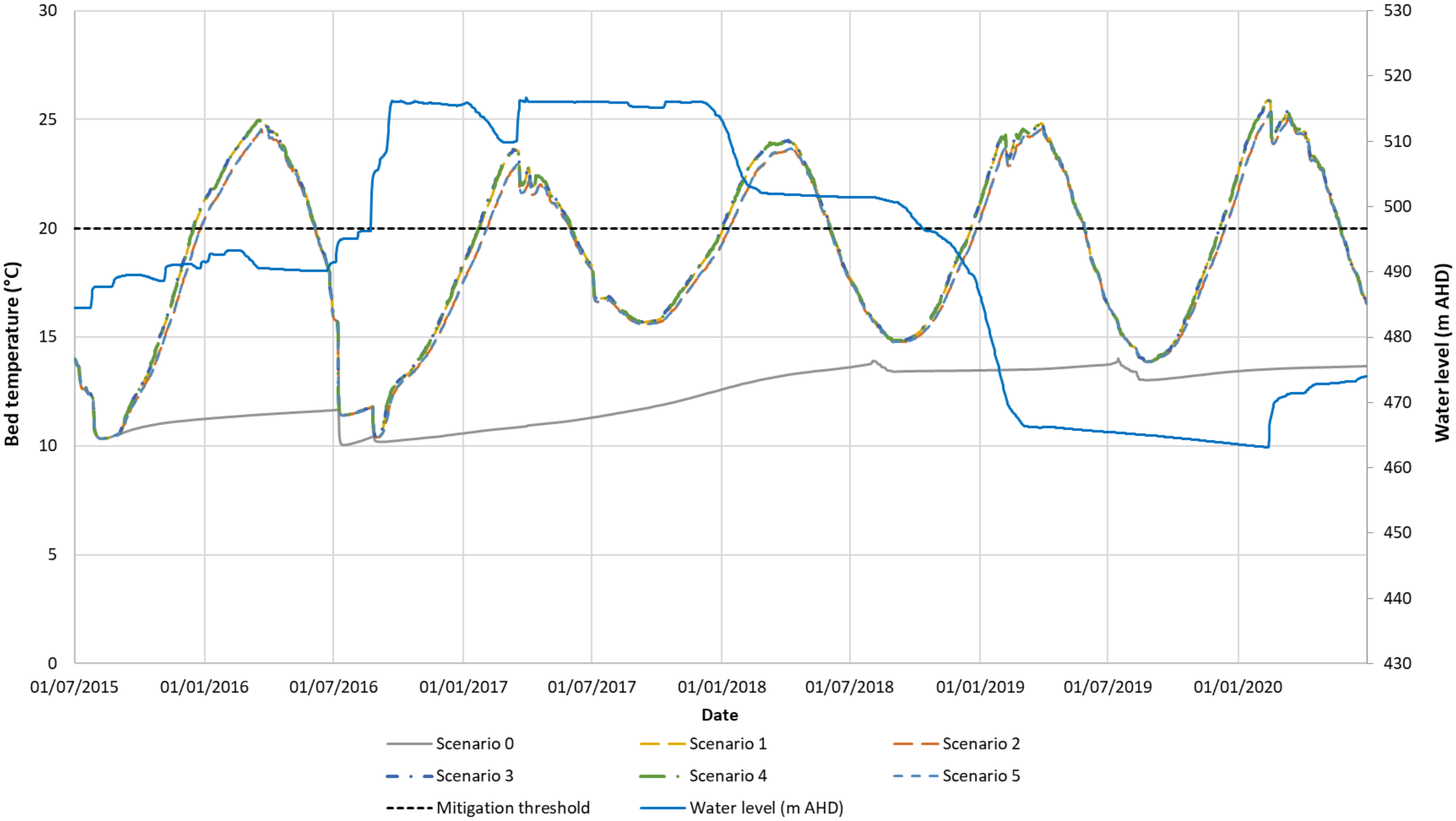

Figure 3-3 Bed temperature at Location A over 5 year modelling period for each scenario, 20 °C threshold and reservoir water level

Figure 3-3 demonstrates the effectiveness of each of the five destratification operational strategies (Scenario 1 to 5) in mitigating cold water pollution by increasing the bed temperature near the offtake tower in Pindari Dam. Scenario 2 and 5 (8 hour per day intermittent operation) resulted in marginally lower bed temperatures (no greater than 1 °C) in the peak of summer than Scenario 1, 3 and 4 (continuous or 20 hour per day operation), however the bed temperatures achieved are still considered to be an effective mitigation of cold water pollution. Additionally, all operations were able to maintain bed temperatures above 20 °C for the duration of the Summer period once this temperature was achieved.

As such, each of the operational strategies tested resulted in similar near bed temperatures near the offtake.

Figure 3-4 demonstrates the measured upstream and downstream temperatures, and release flows over the 5-year modelling period, along with the bed temperatures for Scenario 0 and 1. Scenarios 0 and 1 best represent the likely with and without destratification operational scenarios (i.e. continuous) for the Pindari destratification trial.

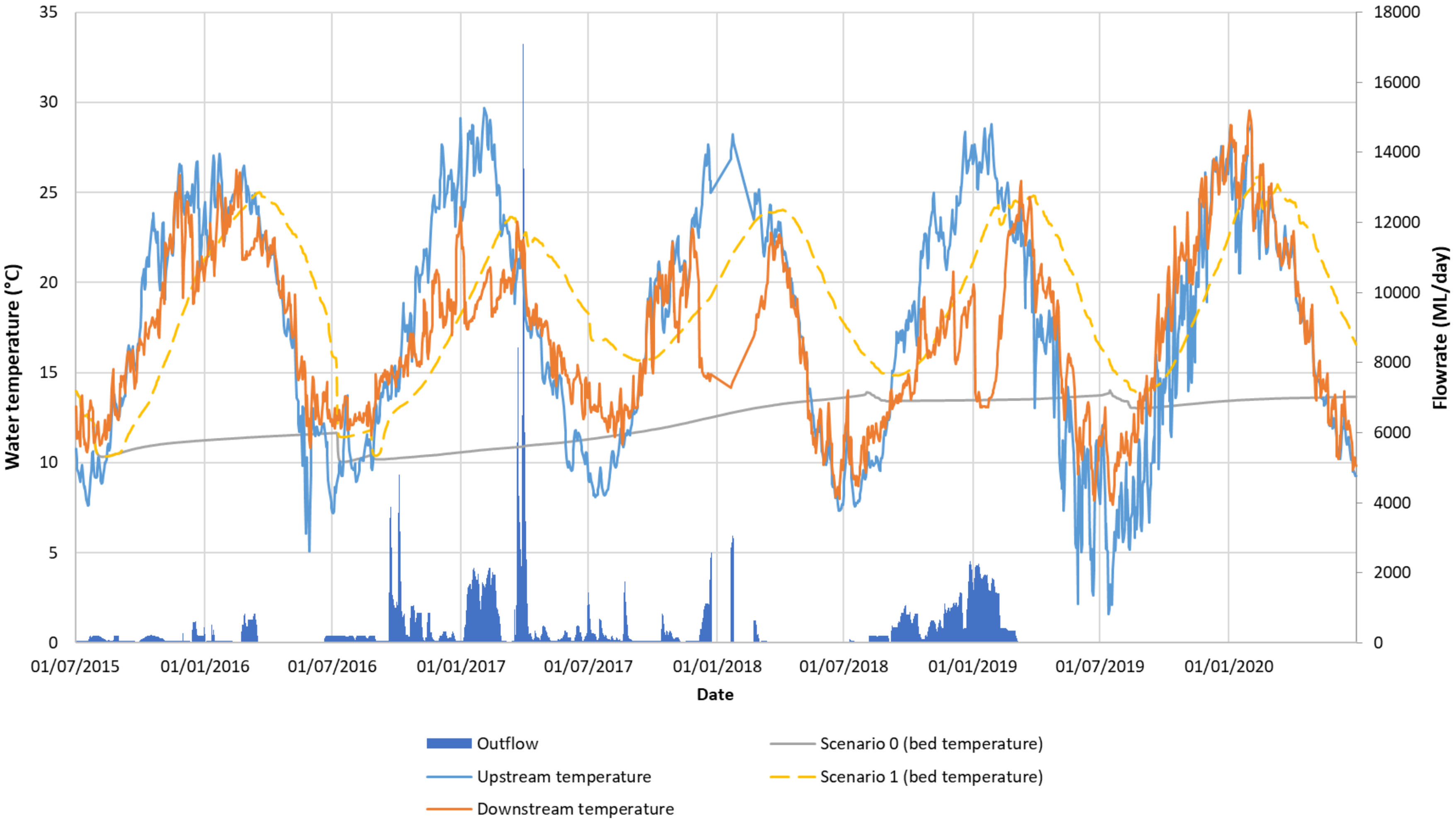

Figure 3-4 Bed temperature at Location A for Scenario 0 and 1, upstream and downstream river temperature and outflows over 5 year modelling period

Assessment of whether the near bed temperatures could be further raised was made by assessing the reservoir-wide destratification through comparison of the surface and bed temperatures.

Figure 3-5 and Figure 3-6 shows the difference in surface and bed temperatures at locations A and B (Figure 3-2) for each 5 year scenario modelled. Figure 3-7 and Figure 3-8 shows the difference between 5 m below the surface and the bed.

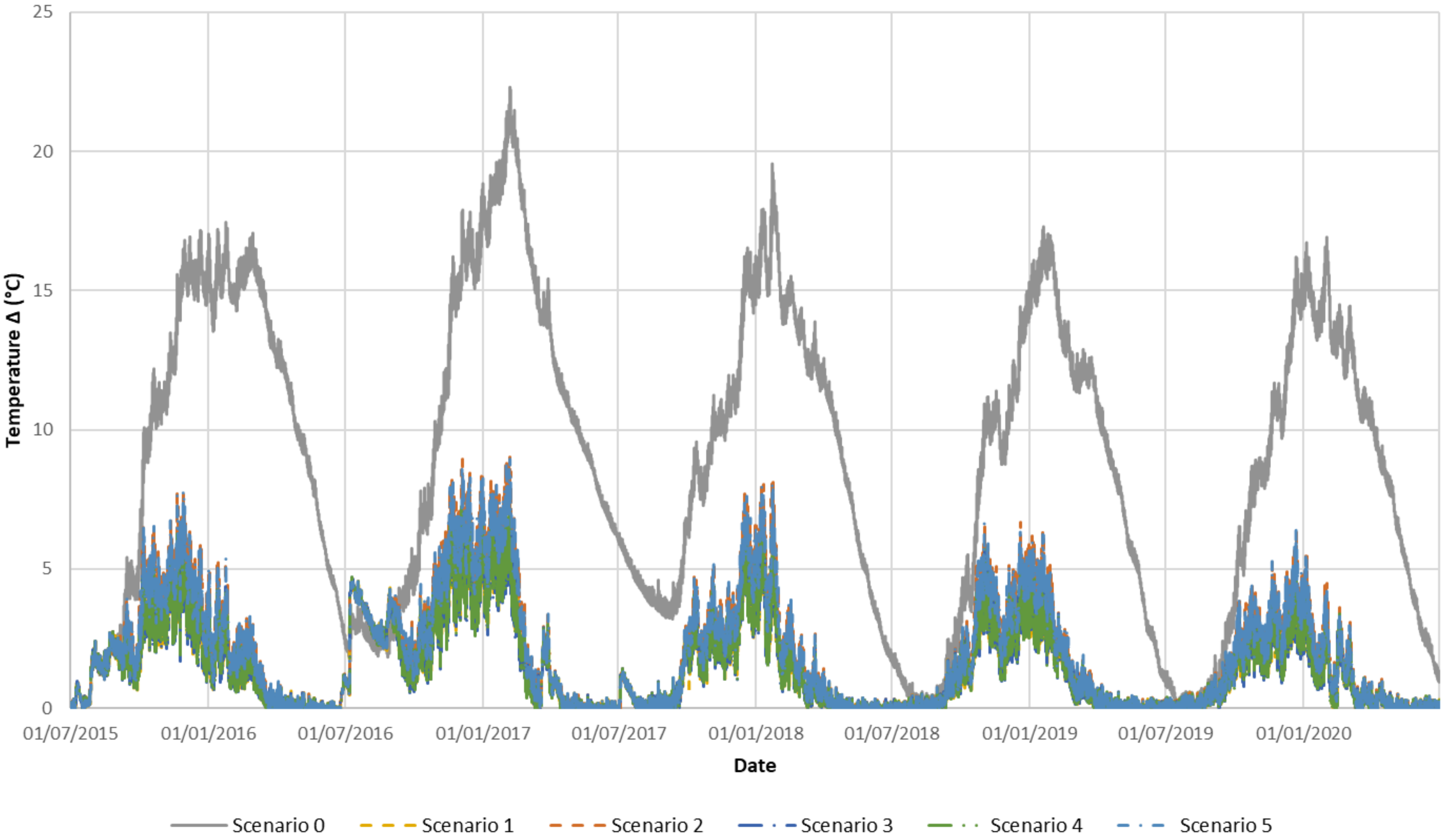

Figure 3-5 Location A, difference (Δ) between surface and bed temperature for 5 year modelled scenarios

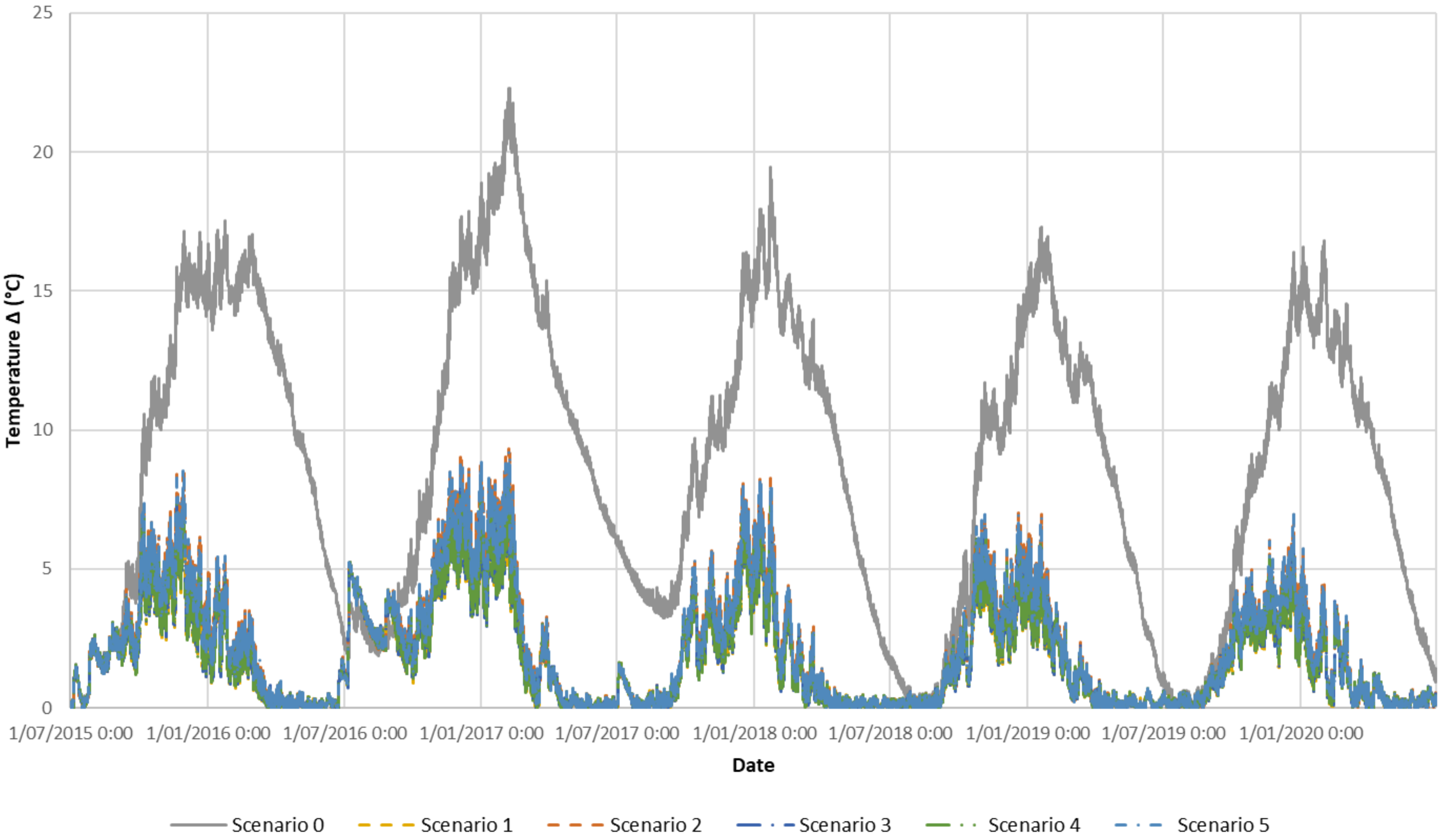

Figure 3-6 Location B, difference (Δ) between surface and bed temperature for 5 year modelled scenarios

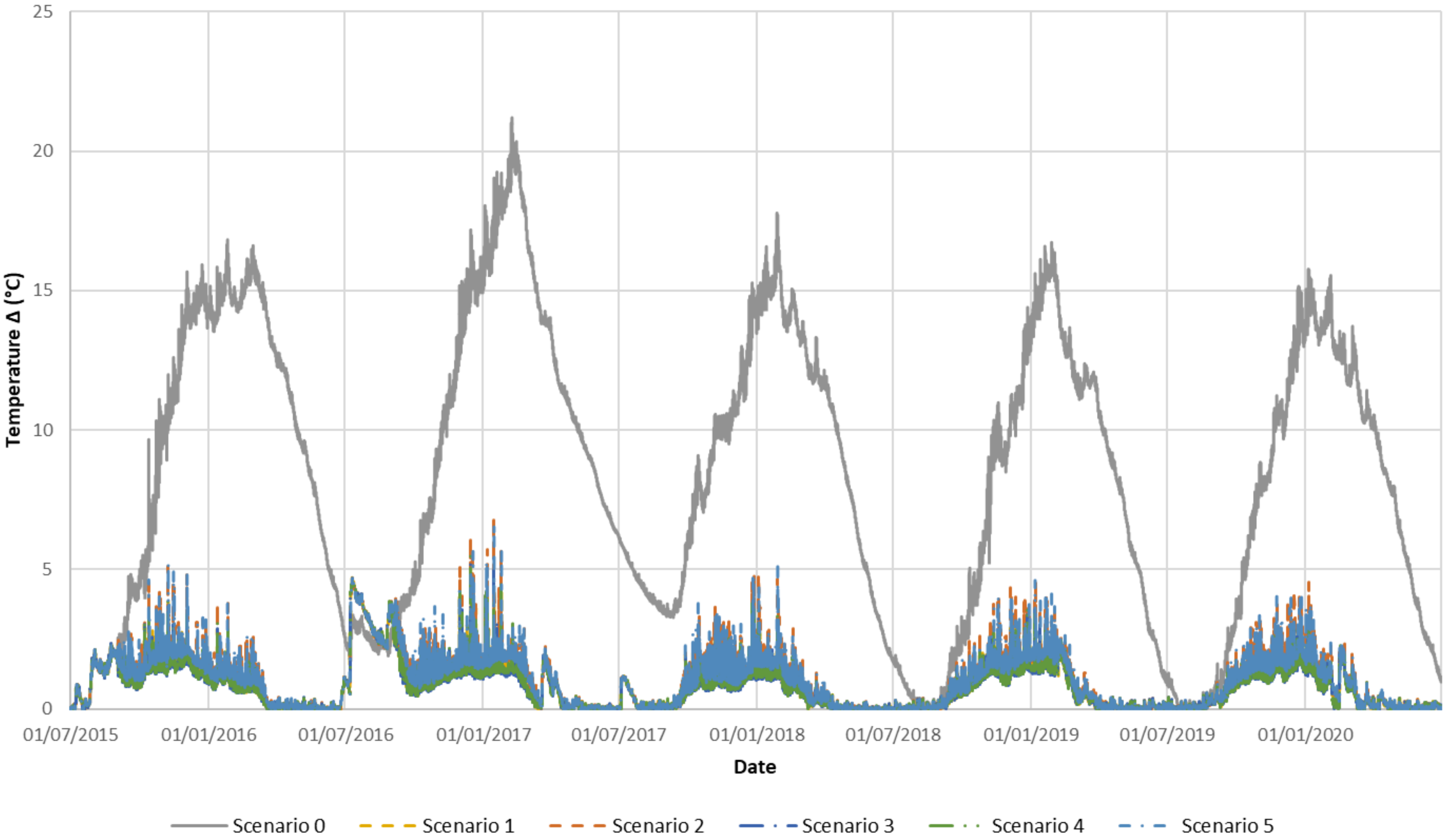

Figure 3-7 Location A, difference (Δ) between temperature 5 m below surface and bed temperature for 5 year modelled scenarios

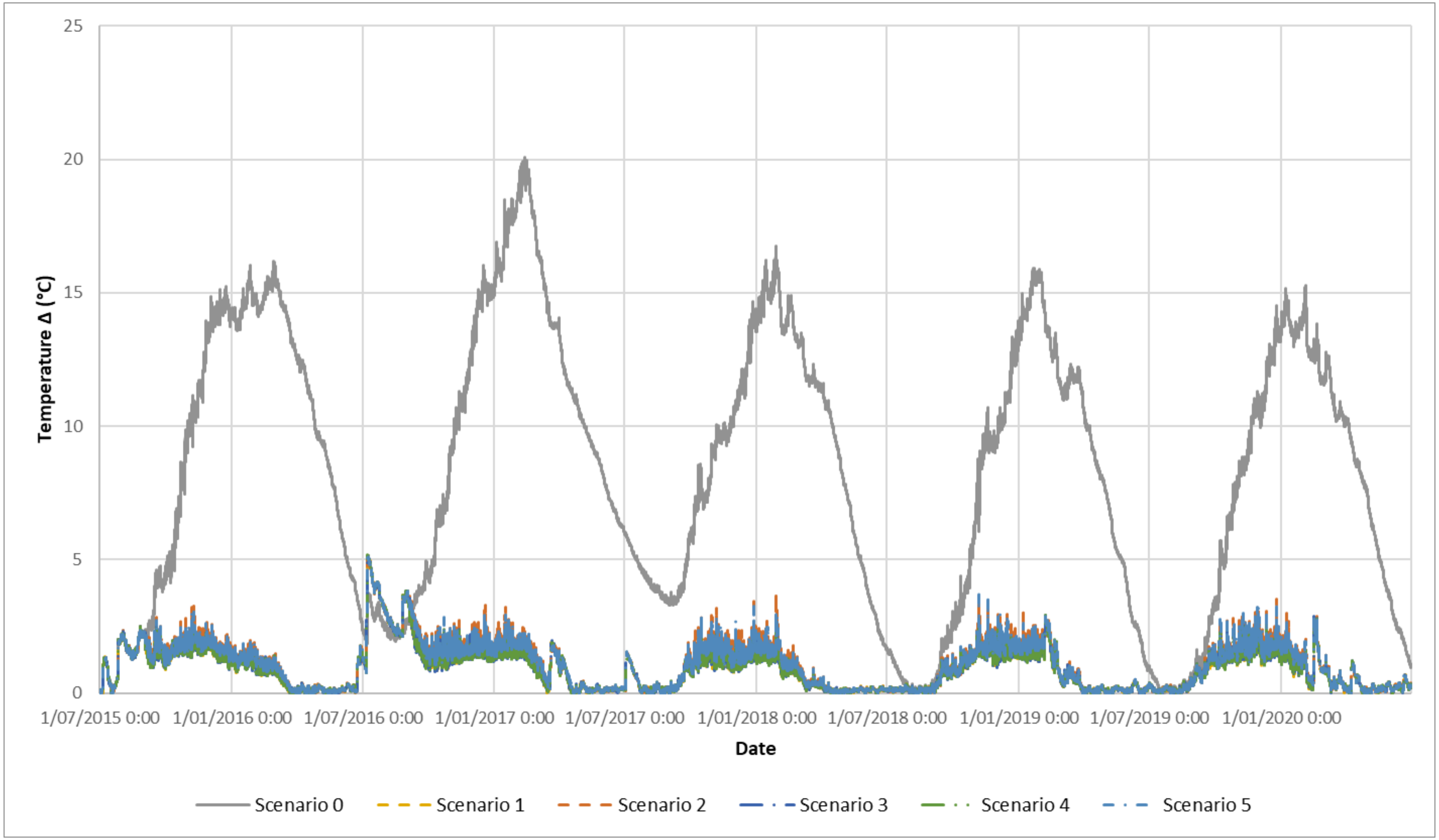

Figure 3-8 Location B, difference (Δ) between temperature 5 m below surface and bed temperature for 5 year modelled scenarios

The results demonstrate sustained periods of temperature differences greater than 2 °C through the hottest periods of the year (in particular, through the 2016/2017 Summer period in which the hottest sustained days were observed). This is due to the micro-stratification occurring at the surface of the model due to the sustained heat entering the reservoir surface layers through solar radiation and increased air temperatures.

This result was not observed when comparing the bed to 5 m below the surface where micro-stratification effects were less prominent. In this part of the water column, a temperature difference of less than 2 °C was maintained consistently with spiking temperature differences.

Table 3-2 shows, for Location A and B for all scenarios, a breakdown of the percentage of time between 1 September and 30 April (i.e. the destratification operation period) over the 5 year modelling period that a temperature difference of less than 2 °C was observed. The table includes the temperature difference between the bed and both the surface, and 5 m below the surface.

Table 3-2 Percentage of time between 1 September to 30 April that more or less than 2 °C temperature difference occurs

		Temperature difference between bed and surface (% of time)		**Temperature difference between bed and 5 m below surface (% of time)**	
Scenario	**Location**	> 2 °C	<= 2 °C	> 2 °C	<= 2 °C
0	**A**	97%	3%	96%	4%
0	**B**	97%	3%	96%	4%
1	**A**	44%	56%	4%	96%
1	**B**	55%	45%	4%	96%
2	**A**	58%	42%	14%	86%
2	**B**	62%	38%	16%	84%
3	**A**	44%	56%	3%	97%
3	**B**	55%	45%	4%	96%
4	**A**	45%	55%	4%	96%
4	**B**	55%	45%	4%	96%
5	**A**	58%	42%	14%	86%
5	**B**	61%	39%	13%	87%

With regards to mitigating cold water pollution, Table 3-3 shows the date the bed temperature at location A exceeded and fell below the 20 °C threshold for each scenario for each of the 5 years modelled.

Table 3-3 Date bed temperatures at location A exceeded (> 20 °C) and fell below (< 20°C) the 20°C threshold for each scenario and year modelled

		Dates					
Year	**Scenarios**	**0**	**1**	**2**	**3**	**4**	**5**
2015/2016	**> 20 °C**	-	15/12/2015	25/12/2015	15/12/2015	15/12/2015	25/12/2015
	< 20 °C	-	05/06/2016	04/06/2016	05/06/2016	05/06/2016	04/06/2015
2016/2017	**> 20 °C**	-	22/01/2017	02/02/2017	20/01/2017	21/01/2017	02/02/2017
	< 20 °C	-	01/06/2017	30/05/2017	01/06/2017	01/06/2017	30/05/2017
2017/2018	**> 20 °C**	-	02/01/2018	11/01/2018	30/12/2017	01/01/2018	10/01/2018
	< 20 °C	-	03/06/2018	01/06/2018	03/06/2018	03/06/2018	01/06/2018
2018/2019	**> 20 °C**	-	18/12/2018	26/12/2018	18/12/2018	18/12/2018	26/12/2018
	< 20 °C	-	29/05/2019	28/05/2019	28/05/2019	28/05/2019	28/05/2019
2019/2020	**> 20 °C**	-	05/12/2019	12/12/2019	04/12/2019	05/12/2019	11/12/2019
	< 20 °C	-	24/05/2020	23/05/2020	24/05/2020	24/05/2020	23/05/2020

Figure 3-9 to Figure 3-20 presents timeseries of the profile results extracted from locations A and B for each of the scenarios modelled.

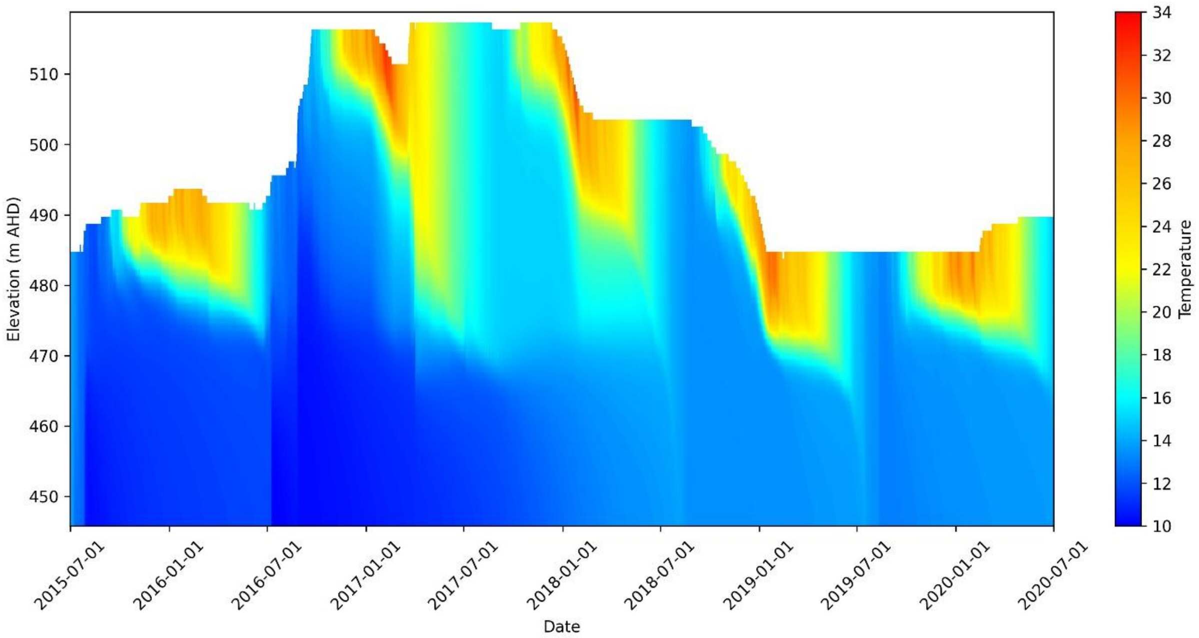

Figure 3-9 Scenario 0 – Location A temperature profile over 5 year modelling period

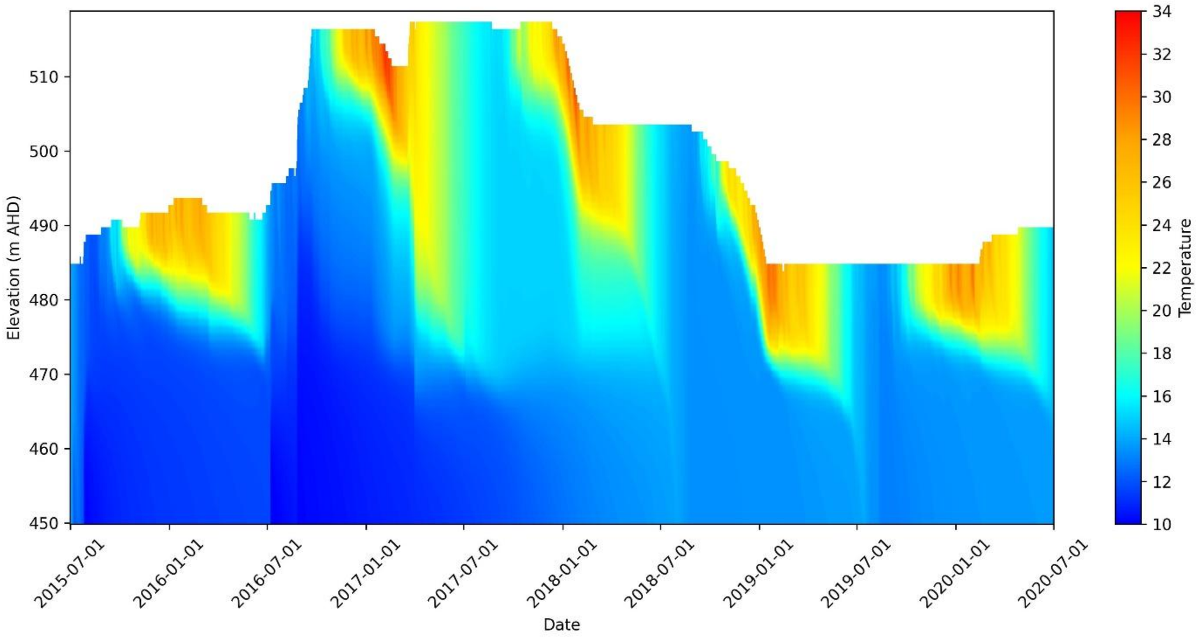

Figure 3-10 Scenario 0 – Location B temperature profile over 5 year monitoring period

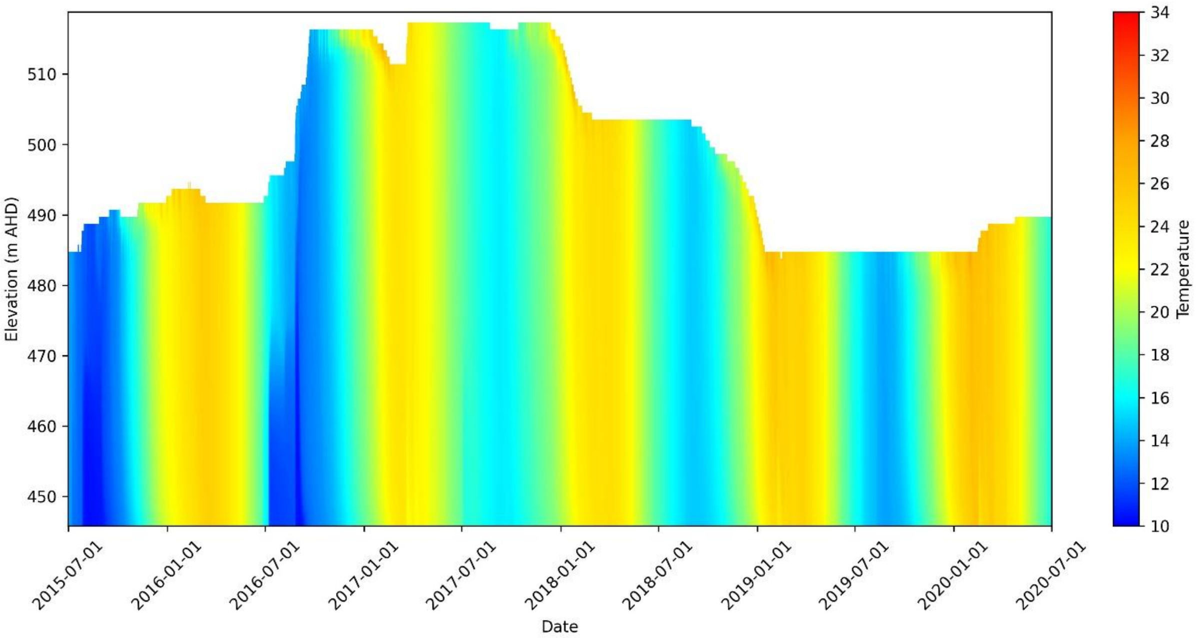

Figure 3-11 Scenario 1 – Location A temperature profile over 5 year modelling period

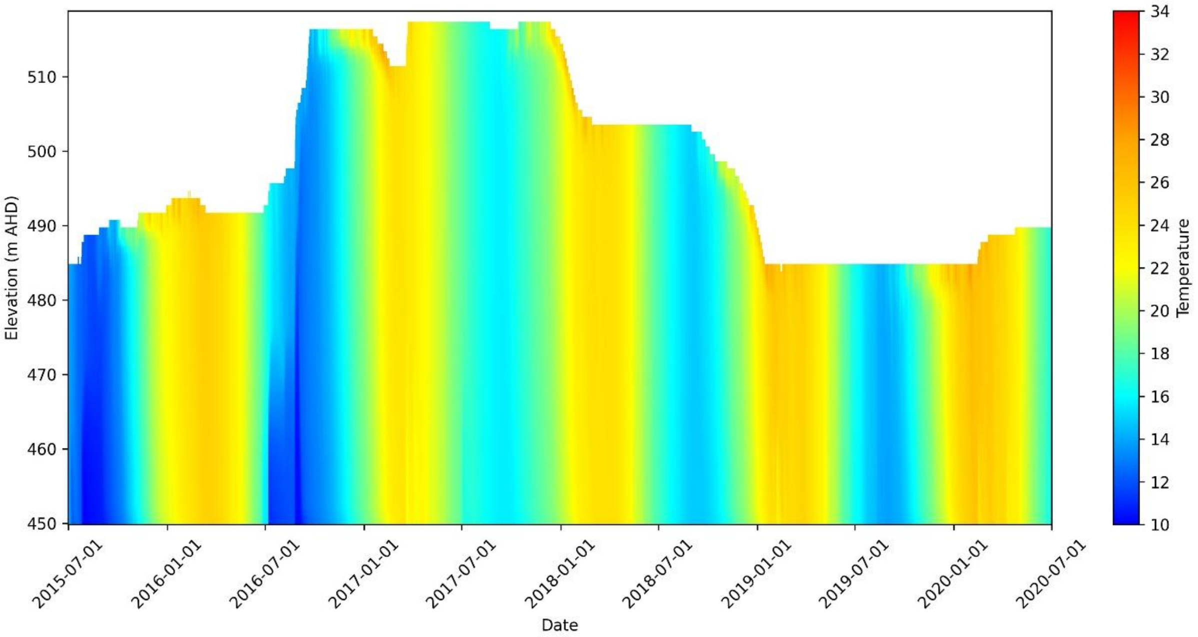

Figure 3-12 Scenario 1 – Location B temperature profile over 5 year monitoring period

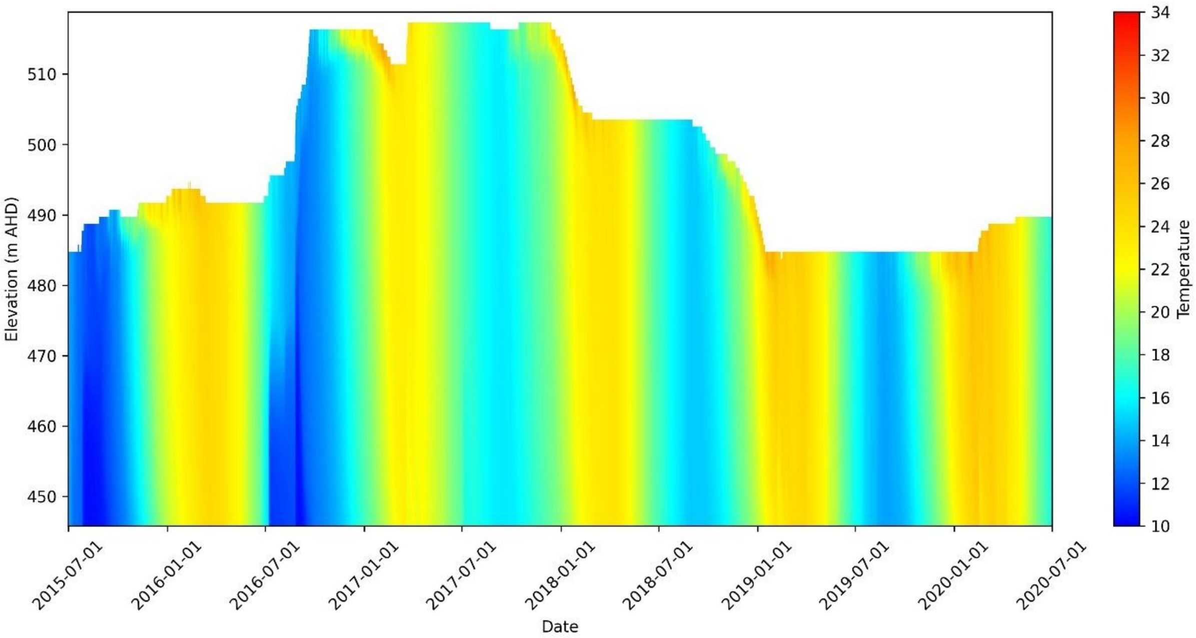

Figure 3-13 Scenario 2 – Location A temperature profile over 5 year modelling period

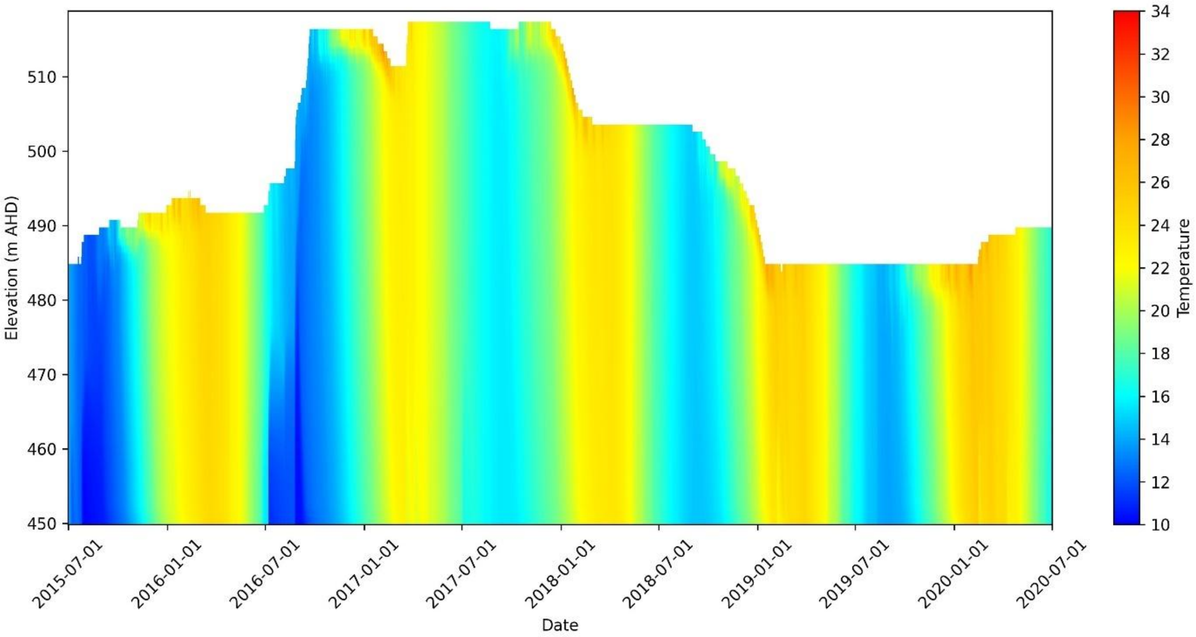

Figure 3-14 Scenario 2 – Location B temperature profile over 5 year monitoring period

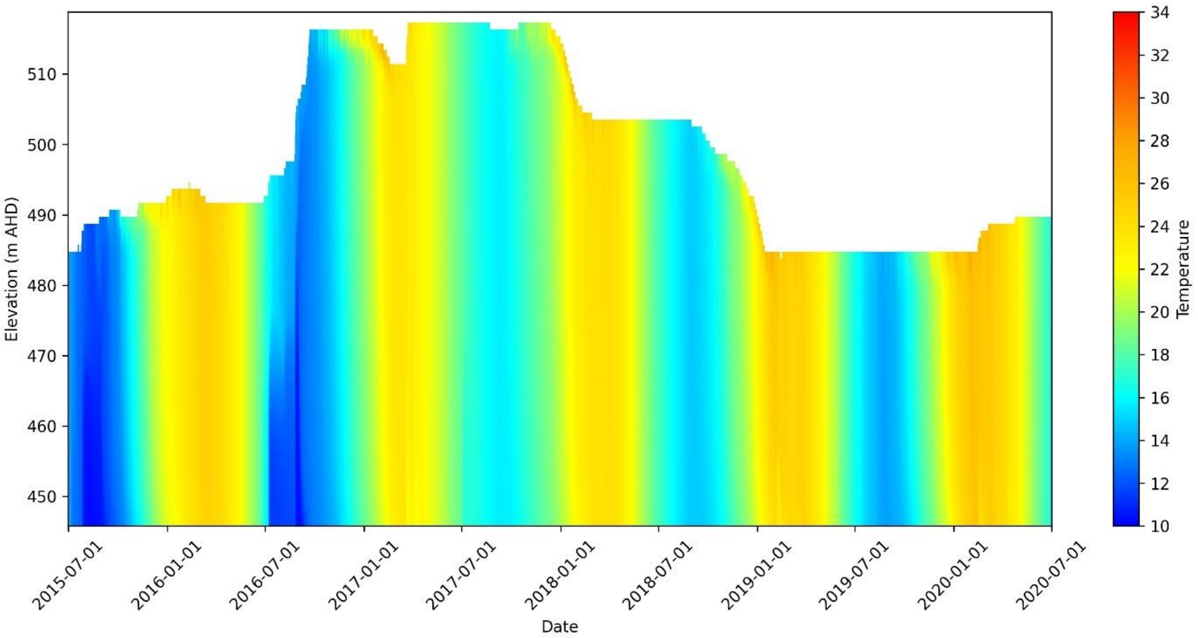

Figure 3-15 Scenario 3 – Location A temperature profile over 5 year modelling period

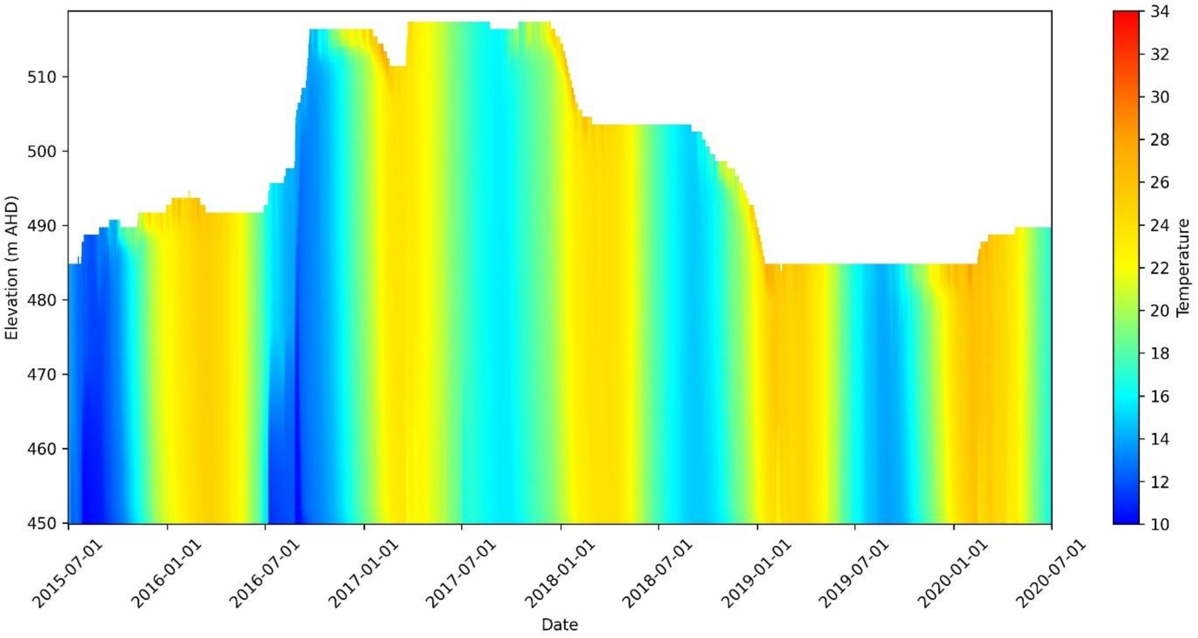

Figure 3-16 Scenario 3 – Location B temperature profile over 5 year monitoring period

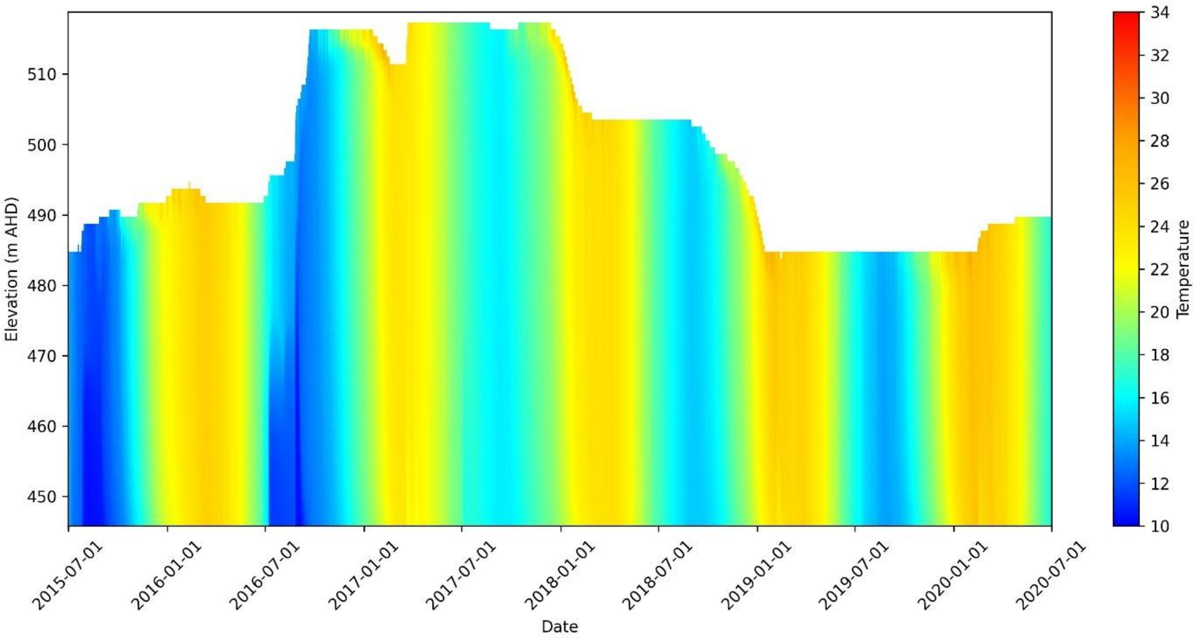

Figure 3-17 Scenario 4 – Location A temperature profile over 5 year modelling period

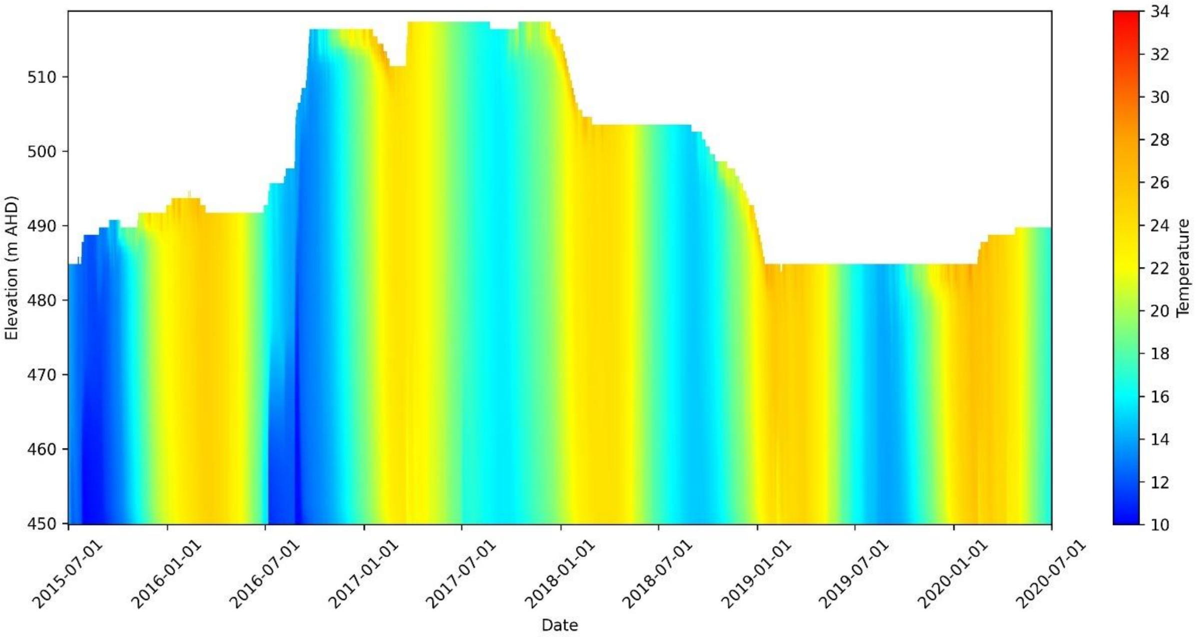

Figure 3-18 Scenario 4 – Location B temperature profile over 5 year monitoring period

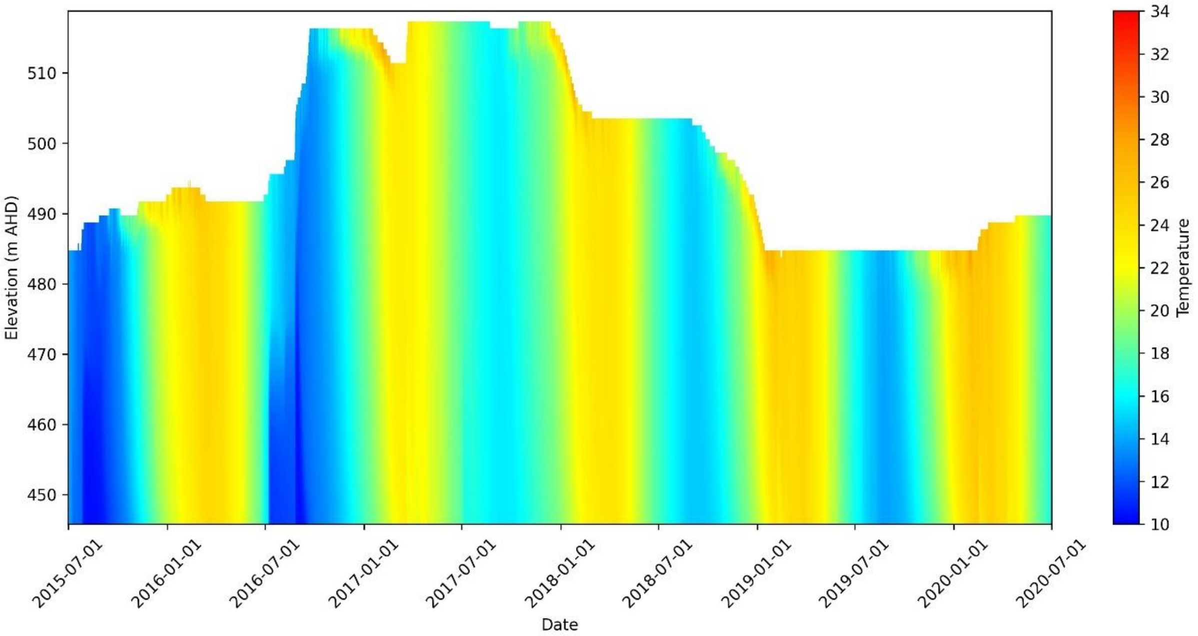

Figure 3-19 Scenario 5 – Location A temperature profile over 5 year modelling period

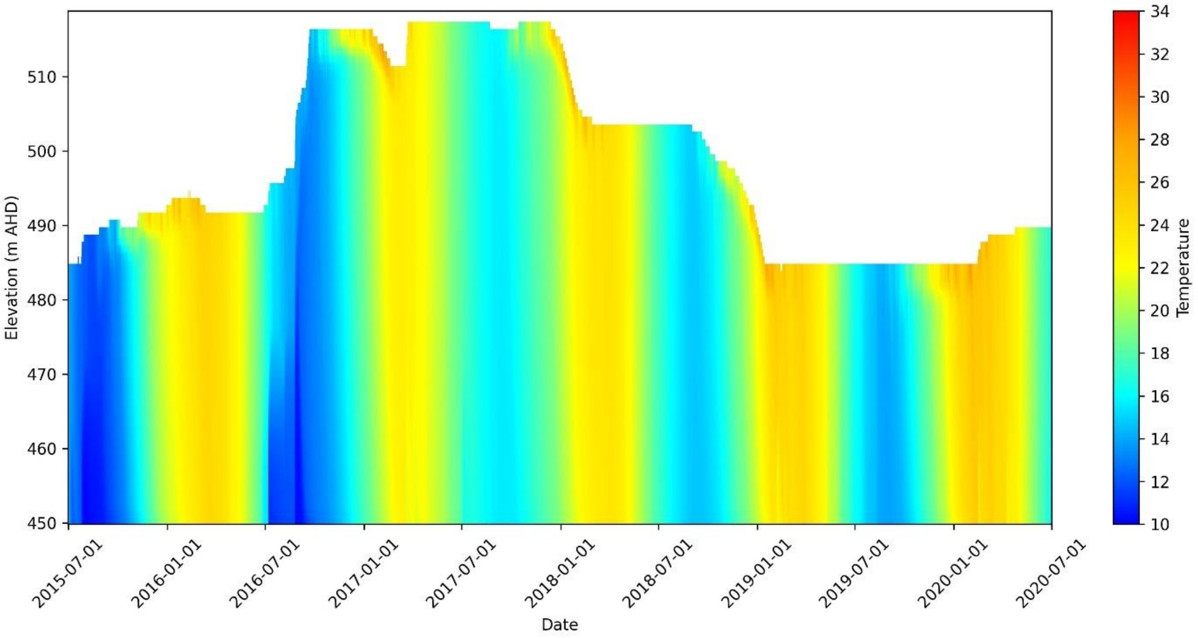

Figure 3-20 Scenario 5 – Location B temperature profile over 5 year monitoring period

4 Discussion

The proposed operational scenarios resulted in similar near bed temperatures. All operational strategies were able to raise the near bed temperature by approximately 12 °C at the peak of summer, compared to the base case with no artificial destratification operation. Additionally, all strategies were able to increase the bed temperature above the proposed 20°C threshold. An increase to bed temperature near the existing offtake (Location A) would result in a reduction in cold water pollution downstream of Pindari Dam, regardless of the depth from which water is withdrawn.

Differences between bed and surface temperatures in two locations (Location A and B) for each of the operational scenarios demonstrated a reservoir-wide destratification effect. While some microstratification persisted through the peak summer conditions, the temperature profiles below these surface layers were shown to be near-isothermal.

The base recommended flowrate of 1,000 L/s was found to be adequate when operated for an entire season through variable meteorological and hydrological conditions. The results also demonstrate the viability of varied operational strategies, including 8 hour per day intermittent operation and operation outside of peak times, as a means of refining the ongoing operating costs through sustainable power infrastructure.

This modelling study did not consider dynamic operating scenarios with lower flowrates corresponding to the dynamic in-reservoir and meteorological conditions. The initial idealised modelling demonstrated the diminishing returns when operating above 1,000 L/s under consistent worst-case conditions. Savings on operational costs may be further realised if the limit of diminishing returns is understood over a range of conditions.

The modelling undertaken in this study assumed that destratification operation was initiated before the onset of stratification. The modelling did not consider scenarios in which the artificial destratification system would be required to break established stratification (e.g. a system breakdown or mid-summer installation and commissioning). Further modelling would be required to assess the effectiveness of the recommended 1,000 L/s air flowrate in this scenario

Numerical modelling results presented in this study are based on limited model validation. To effectively refine dynamic operational strategies for a long-term Pindari destratification system, pre- and post-destratification data from a trialled system would be required.

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Appendix A Idealised daily summer meteorological conditions

Time	Wind speed (m/s)	Temperature (°C)	Relative humidity (%)	Solar radiation (W/m²)	Atmospheric pressure (kPa)	Rainfall (mm/day)	Clouds
0:00	1	24.5	25%	0	101325	0	0
1:00	1	23.7	25%	0	101325	0	0
2:00	1	22.8	25%	0	101325	0	0
3:00	1	22.0	25%	0	101325	0	0
4:00	1	22.8	25%	0	101325	0	0
5:00	1	23.7	25%	0	101325	0	0
6:00	1	24.5	25%	0	101325	0	0
7:00	1	25.3	25%	318.3	101325	0	0
8:00	1	26.2	25%	578.7	101325	0	0
9:00	1	27.0	25%	781.2	101325	0	0
10:00	1	27.8	25%	925.9	101325	0	0
11:00	1	28.7	25%	1012.7	101325	0	0
12:00	1	29.5	25%	1041.7	101325	0	0
13:00	1	30.3	25%	1012.7	101325	0	0
14:00	1	31.2	25%	925.9	101325	0	0
15:00	1	32.0	25%	781.2	101325	0	0
16:00	1	31.2	25%	578.7	101325	0	0
17:00	1	30.3	25%	318.3	101325	0	0
18:00	1	29.5	25%	0	101325	0	0
19:00	1	28.7	25%	0	101325	0	0
20:00	1	27.8	25%	0	101325	0	0
21:00	1	27.0	25%	0	101325	0	0
22:00	1	26.2	25%	0	101325	0	0
23:00	1	25.3	25%	0	101325	0	0

Appendix B Modelling data

Modelling data was provided by the Australian Rivers Institute and prepared as per their modelling report (Prentice et al., 2021).

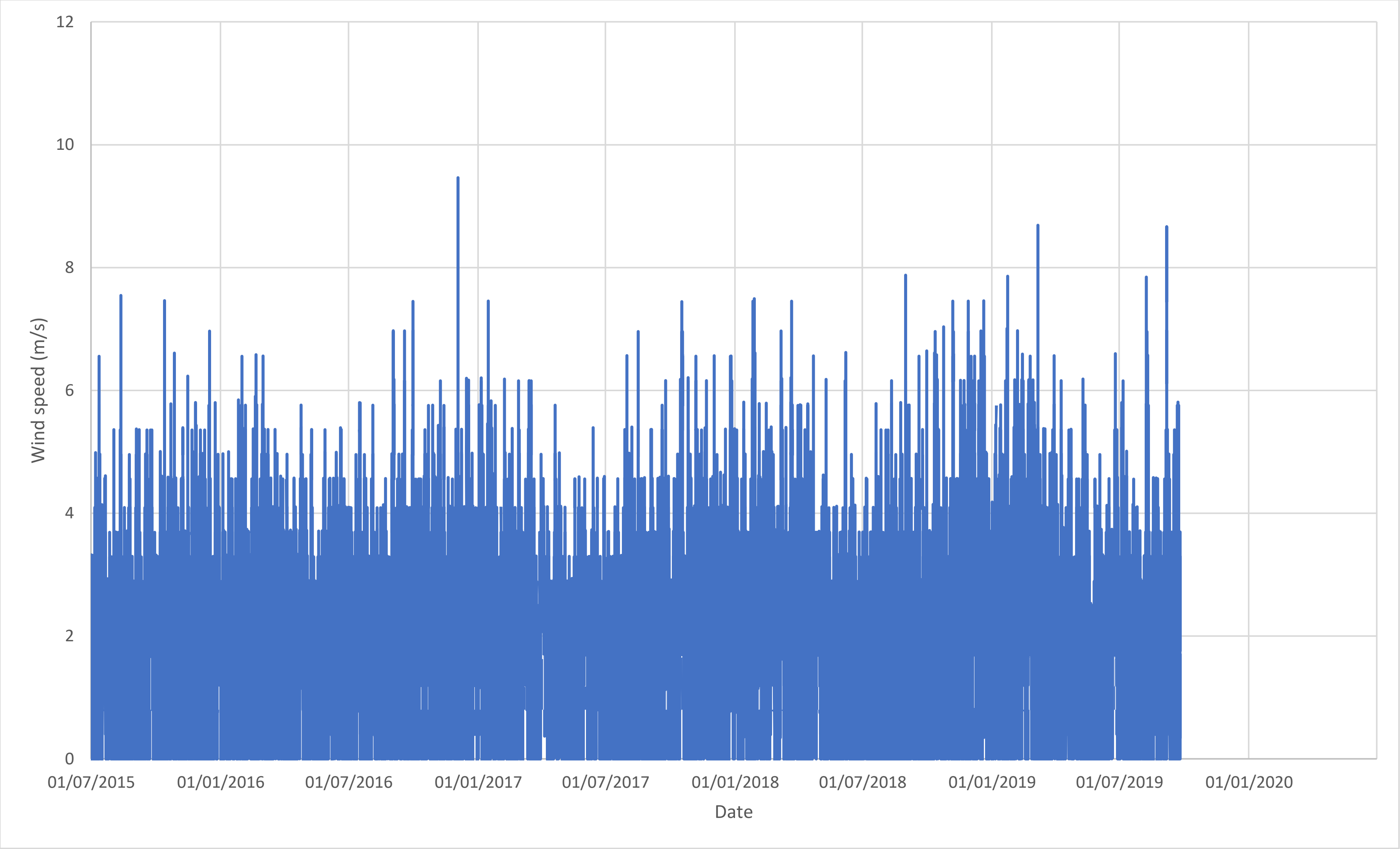

Figure B-5-1 Wind speed over modelling 5 year period

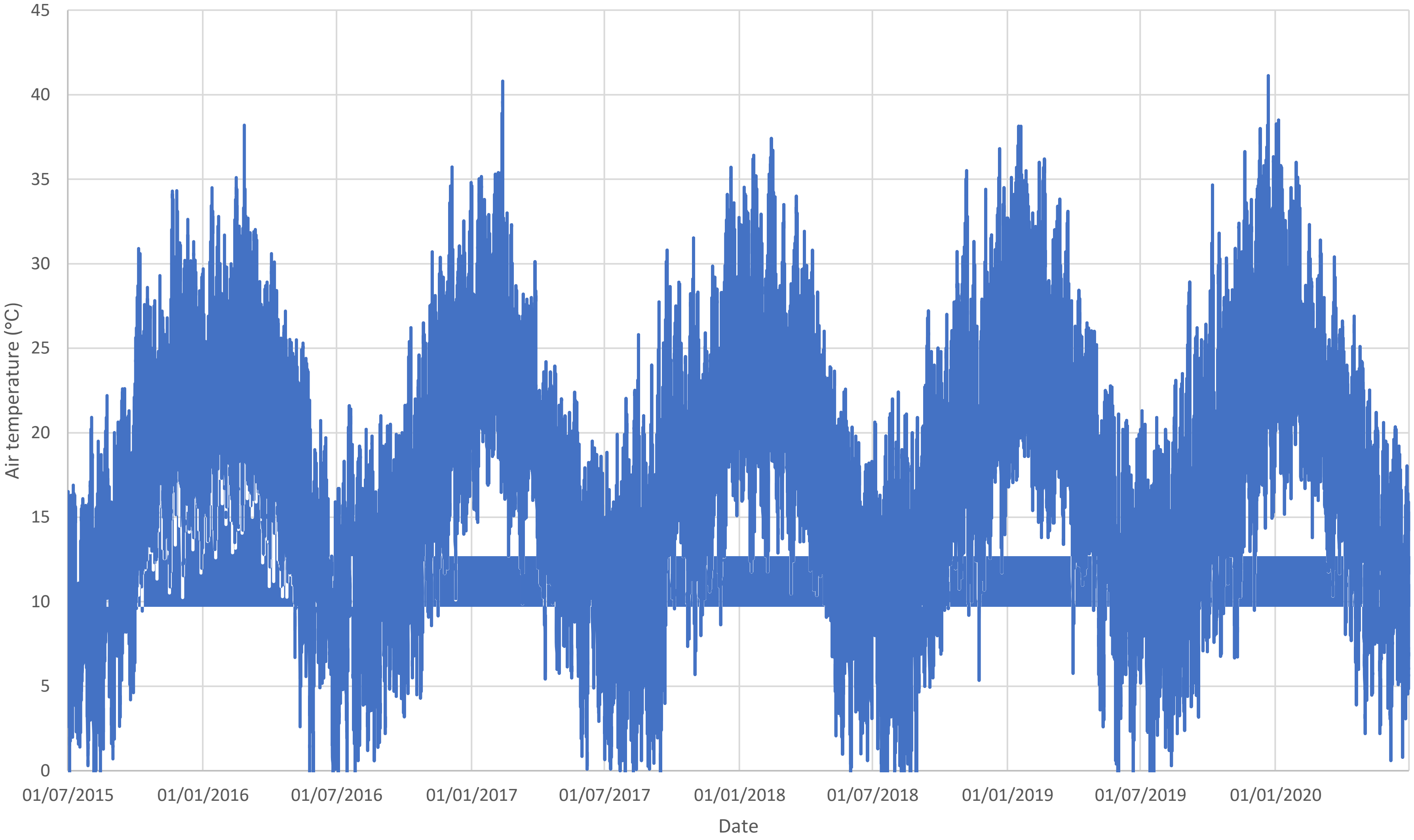

Figure 5-2 Air temperature over 5 year modelling period

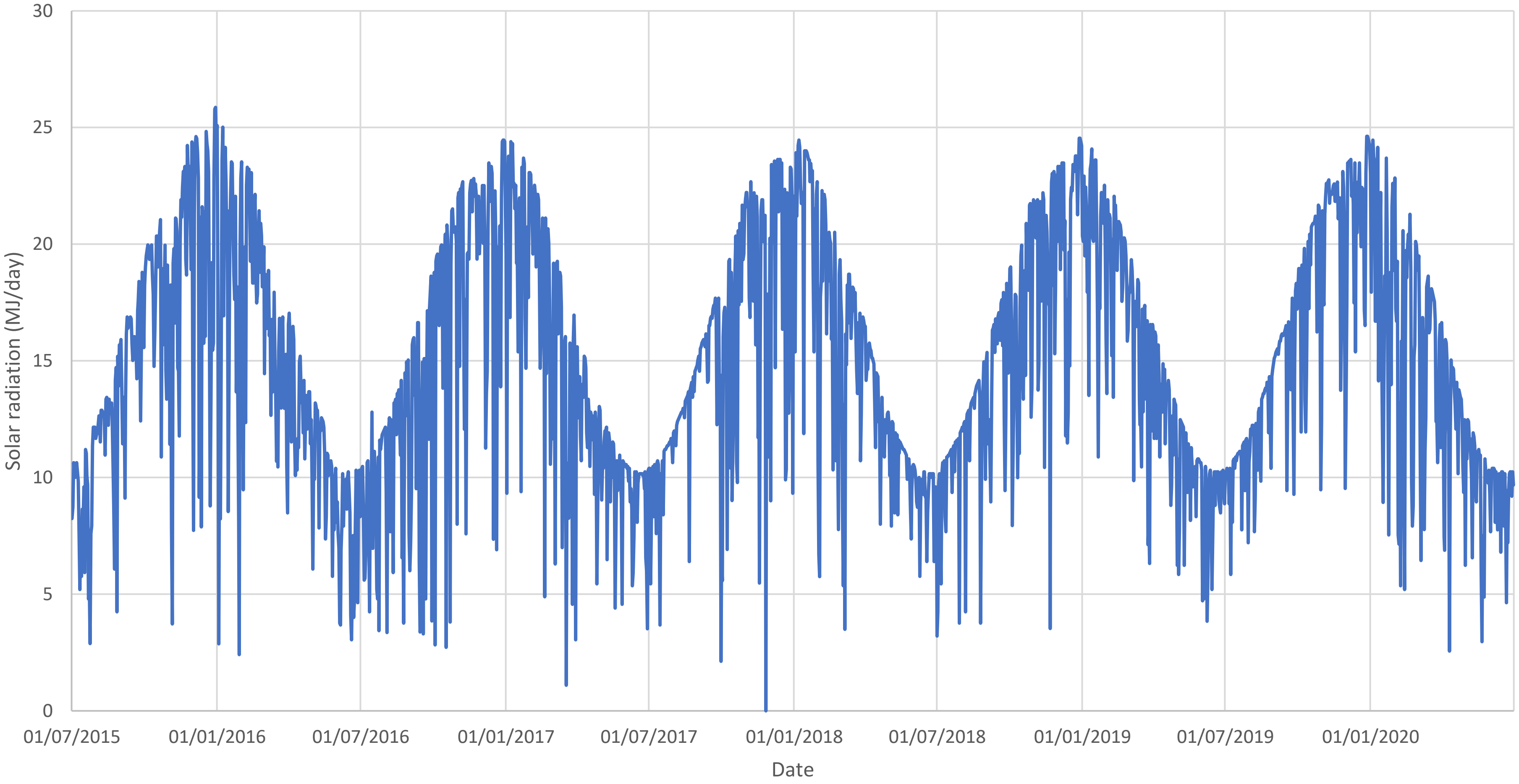

Figure 5-3 Solar radiation over 5 year modelling period

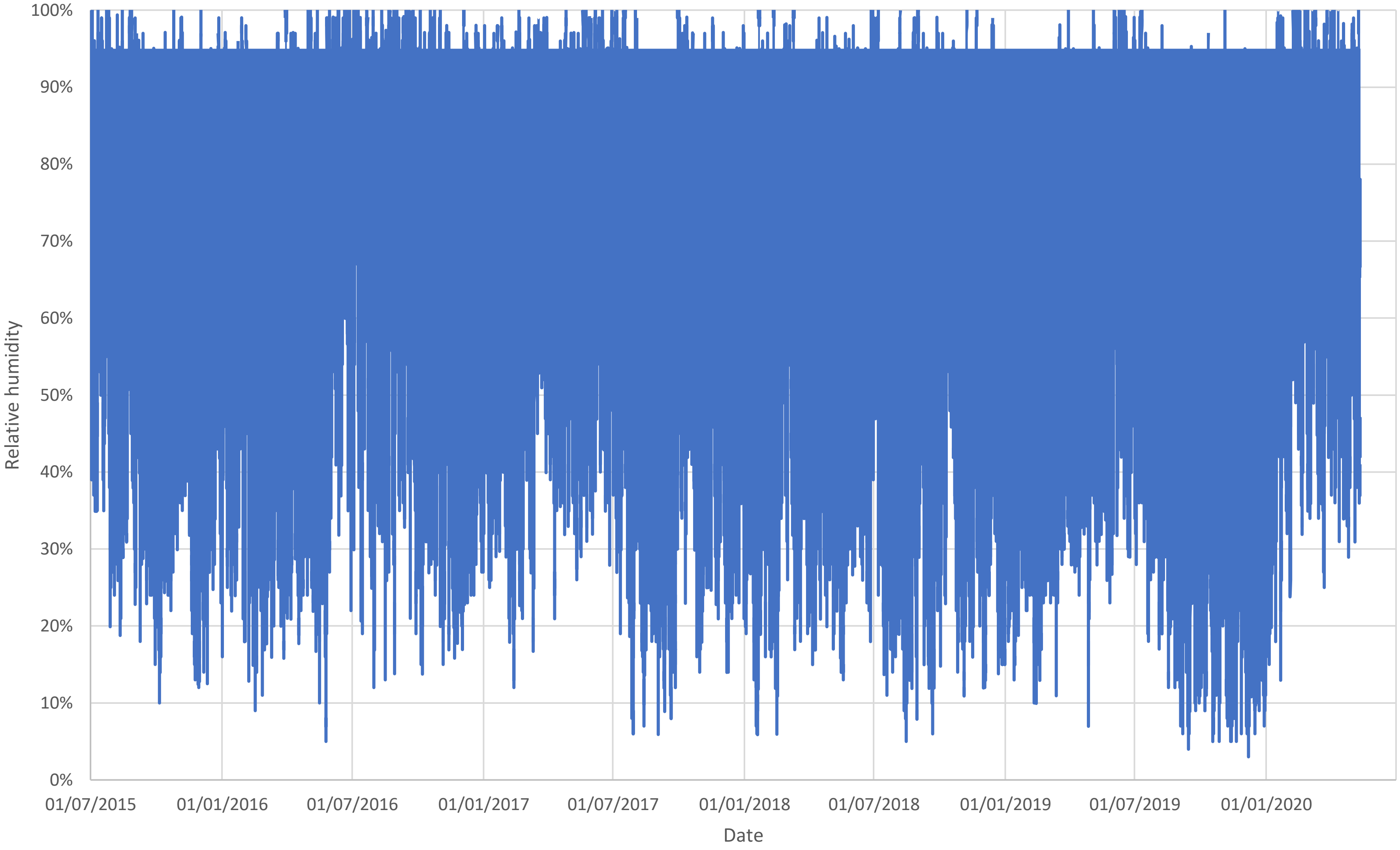

Figure 5-4 Relative humidity over 5 year modelling period

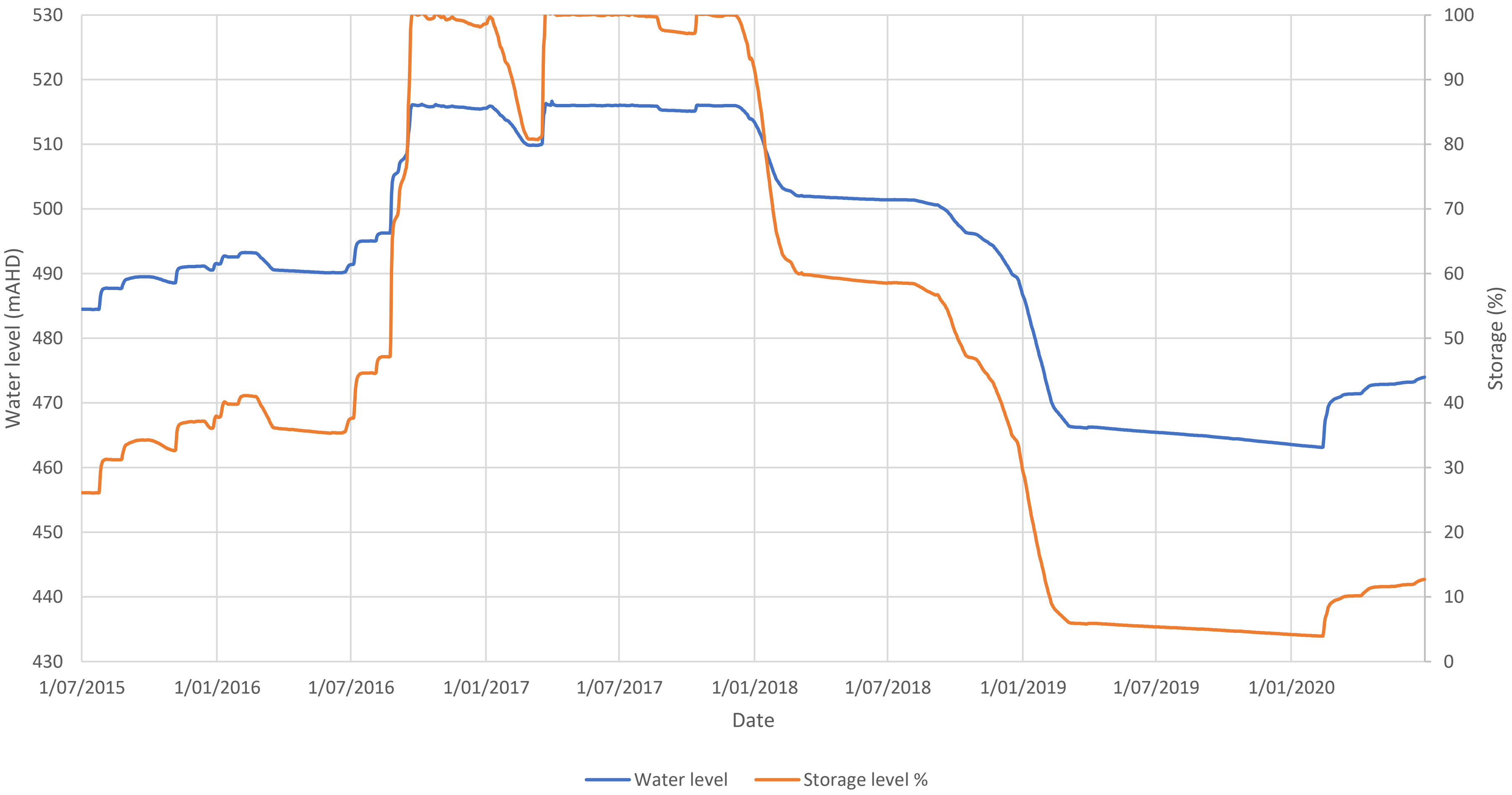

Figure 5-5 Reservoir water level and storage level over 5 year modelling period

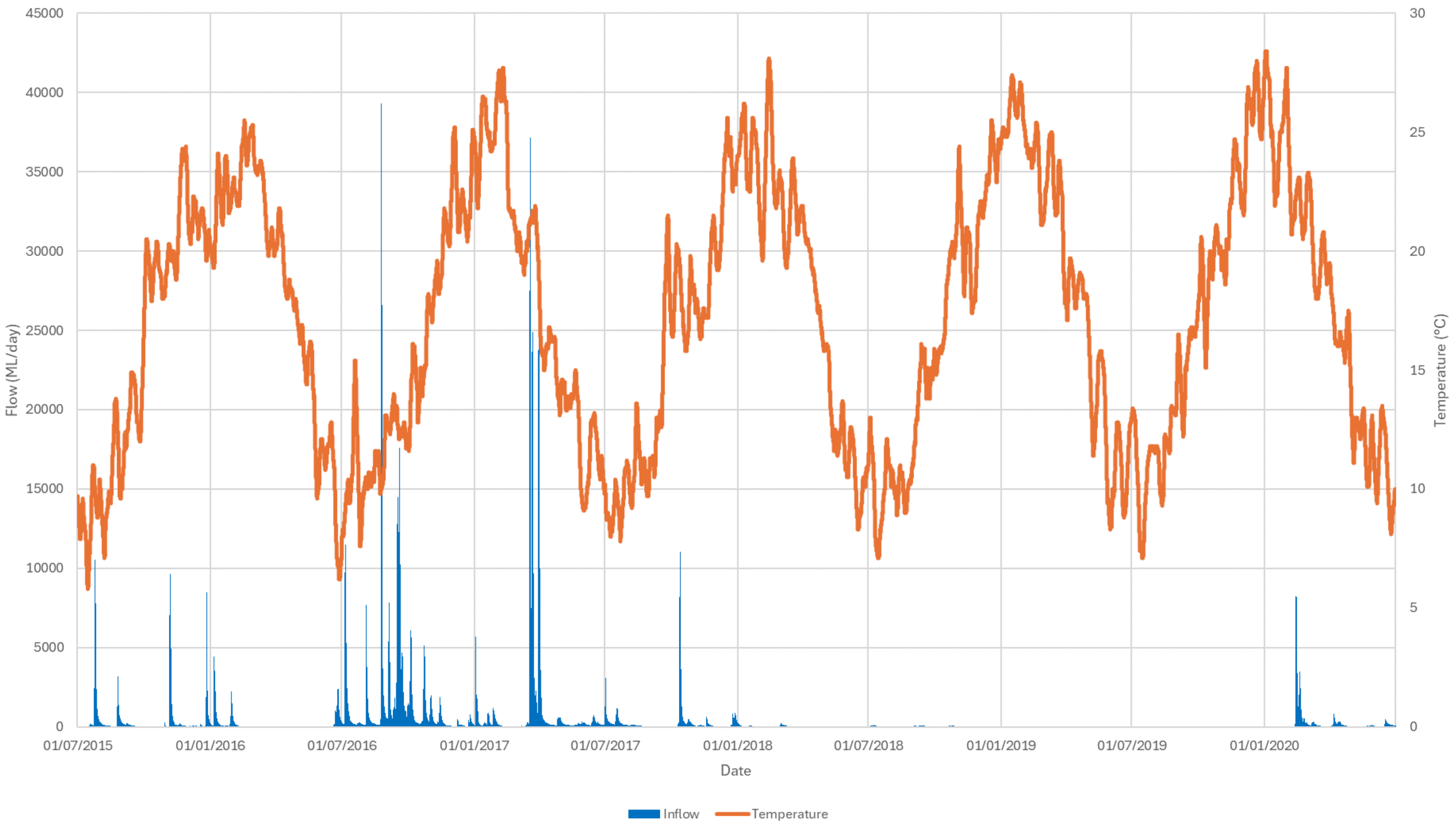

Figure 5-6 Boundary inflows and temperatures over 5 year modelling period

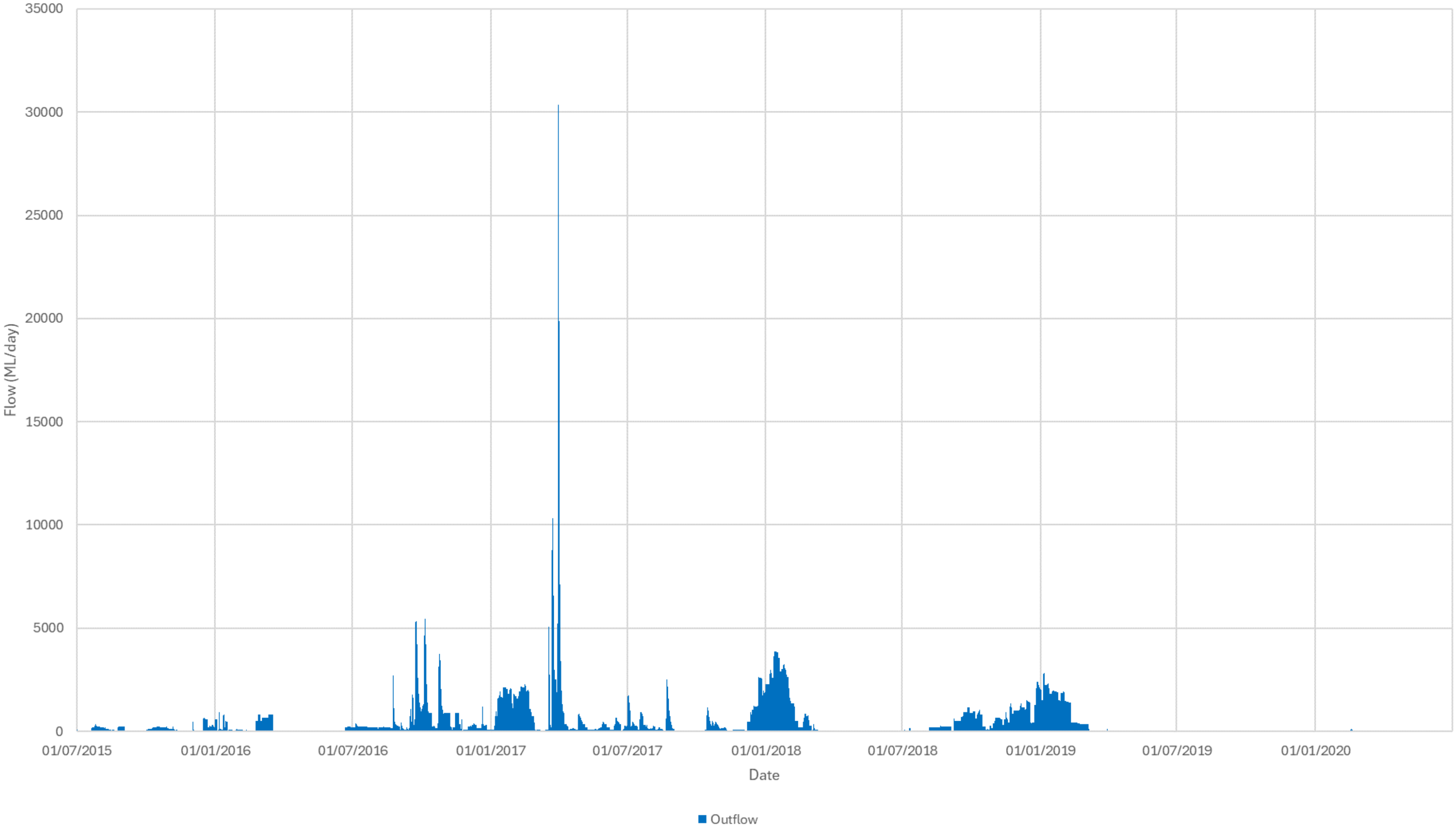

Figure 5-7 Boundary outflows over 5 year modelling period

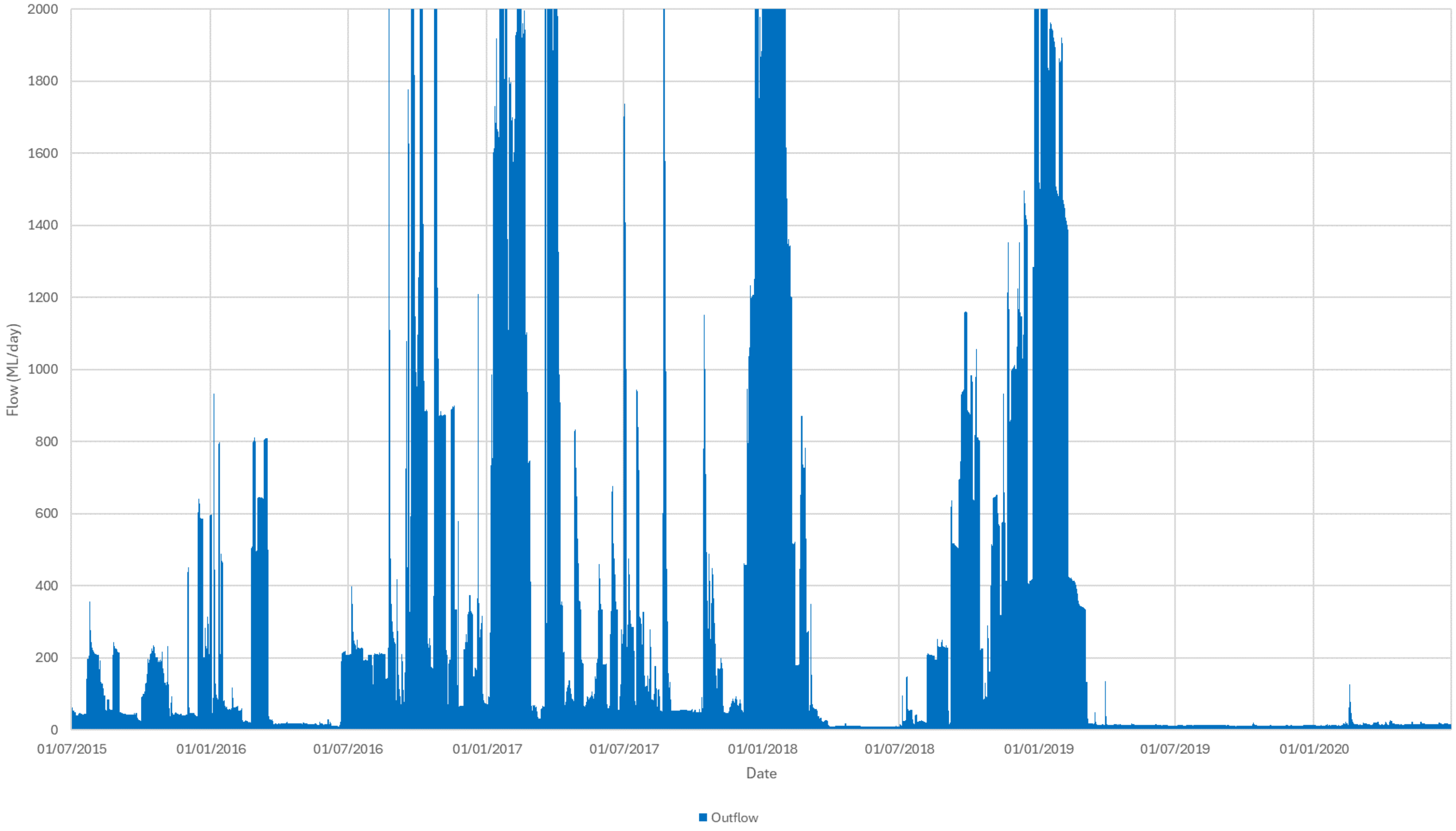

Figure 5-8 Boundary outflows (< 2,000 ML/day) over 5 year modelling period