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Tamar Lake Inc. Destratification Scenarios

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Synopsis:	**Scenarios executed using the implementation of Tamar Lake operational strategies to reduce thermal stratification using the existing three-dimensional hydrodynamic, sediment transport and water quality numerical model of the Tamar estuary.**

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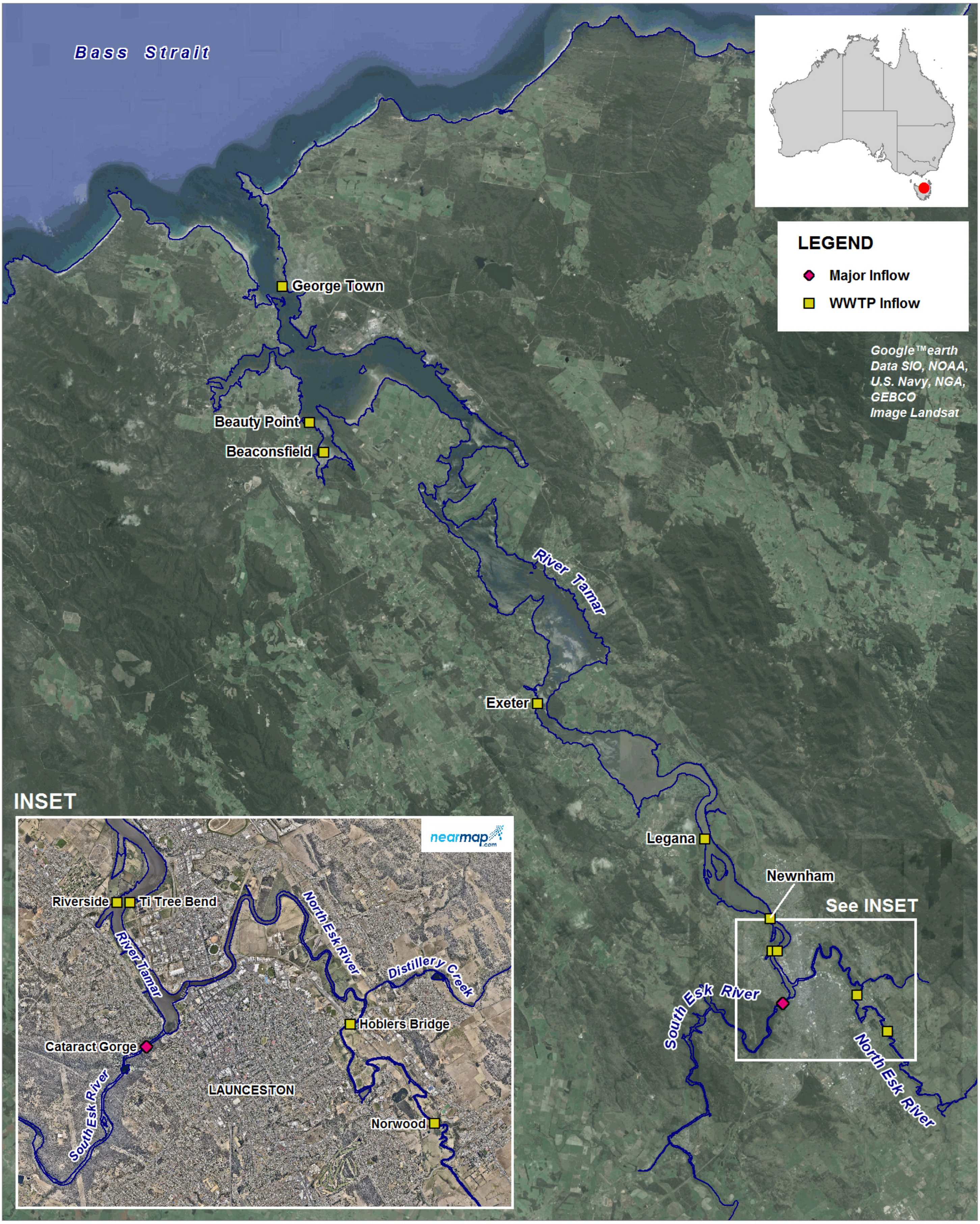
1 Introduction

The Tamar Estuary (see locality map, Figure 1-1), situated in Tasmania's North, is a complex environmental system driven by a number of key processes. The system receives major inflows from the North and South Esk rivers as well as direct inflows from surrounding catchments. Flows from the South Esk are contained by the Trevallyn Dam from which flows are also directed through the Trevallyn Hydro-electric station and downstream tailrace. Complex siltation and scour processes dominate the system and play an important part in controlling estuarine water quality, which has most recently received Ecosystem Health Assessment Program (EHAP) scores of A- to D.

BMT WBM Pty Ltd has previously constructed a three dimensional (3D) hydrodynamic, sediment transport and water quality model of the Tamar Estuary on behalf of NRM North. Tamar Lake Inc. (TLI) subsequently commissioned the execution of several scenarios using this model. TLI proposes the installation of a barrage just south of the Rowella area to create a 60km long freshwater lake.

In previous studies, the barrage was permitted to release water twice per day on the ebbing tides, using flow controls and artificial structures. Several scenarios were simulated to represent a release over the upper and lower two meters of the water column. Controls were also set in place to adjust this flow to be greater or lesser if the water level upstream of the barrage either exceeded 1mAHD or fell below 0.8m AHD.

To date, studies have suggested that if a lake was to be created via construction of a barrage, it would experience severe thermal stratification regardless of release depth, and that this in turn would have a significant and detrimental impact on ambient and downstream water quality. As a result, Tamar Lake Inc. has requested that BMT WBM undertake further modelling works to examine impacts on thermal stratification if barrage operational rules are related directly to the strength of lacustrine thermal stratification. This report describes those investigations and their outcomes.



Title:
Locality Map

Figure: 1-1

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2 Methodology

In previous TLI studies, model predictions were presented for two scenarios which were undertaken to compare water quality within the Tamar Estuary under different 'developed case' conditions. The first of these included 'as is' conditions with wastewater treatment plant (WWTP) discharges entering the model from their current locations and loads and the second with discharges configured in accordance with the Launceston Sewage Infrastructure Plan (LSIP).

The barrage control rules in these previous scenarios allowed a release twice per day on ebbing tides, using flow controls and artificial structures. Ebb-tide flows were defined so as to achieve a daily balance with incoming catchment flows. Controls were set in place to adjust this flow to be greater or lesser if the water level upstream of the barrage either exceeded 1m AHD or fell below 0.8m AHD. Flows were applied either over the top or bottom two meters of the water column.

For this study the TUFLOW FV model used for previous TLI investigations was again deployed (Figure 2-1). In this study however, rules were applied within the model such that release mechanisms were triggered by 'on the fly' examination of bottom dissolved oxygen concentrations behind the barrage.

Utilising this model capability three scenarios were executed using an agreed set of barrage control rules (commissioned 14/06/2016).

Two scenarios were set up to compare results from previous scenarios. A third scenario was executed to incorporate the water quality improvement plan (WQIP) which aims to reduce the total loads entering the estuary via the catchments. The three scenarios simulated under this first set of control rules were:

(1) Updated barrage configuration (i.e. with release rules based on DO) using current wastewater treatment plant (WWTP) configurations

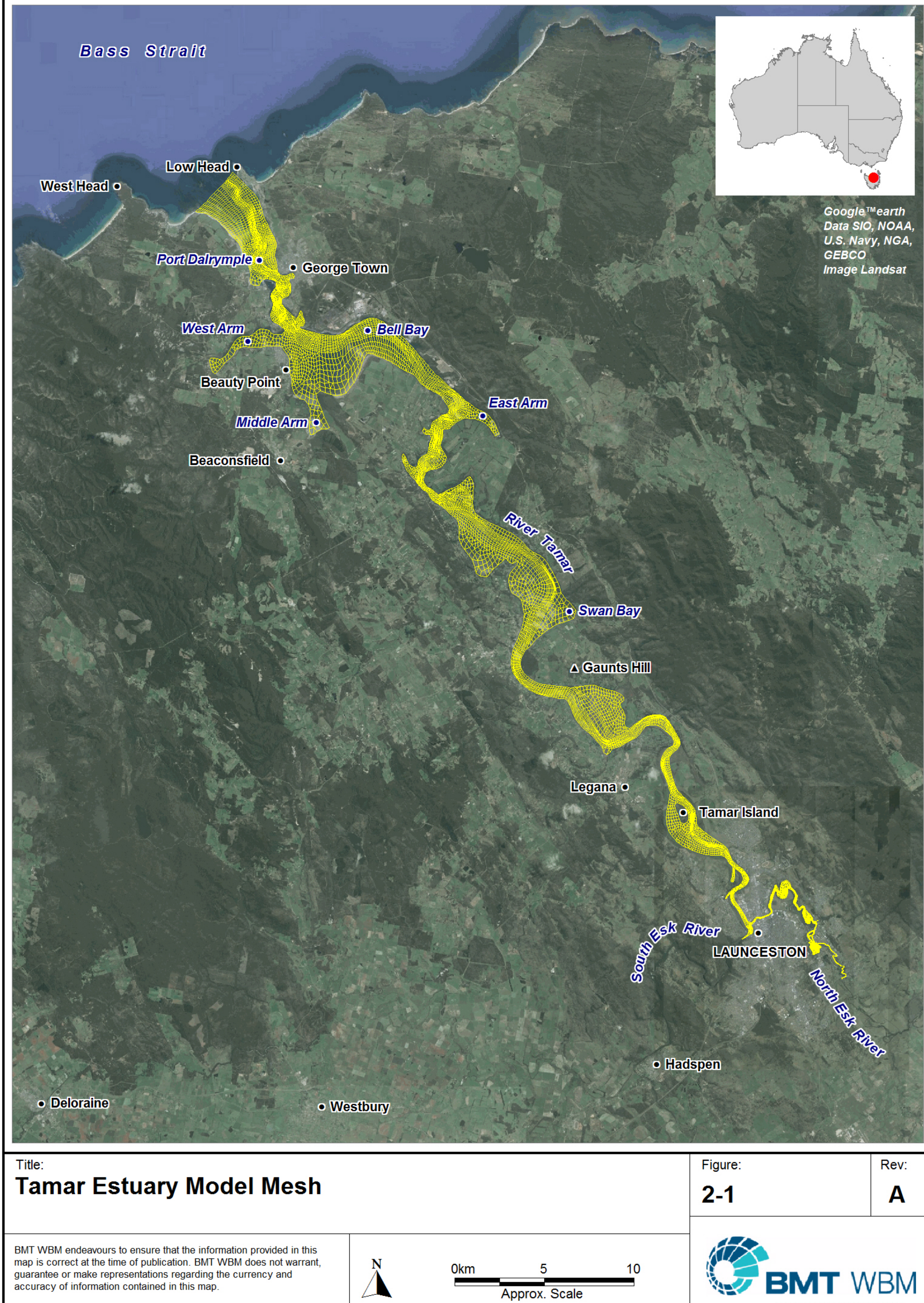
(2) Updated barrage configuration using the Launceston swage infrastructure plan (LSIP) WWTP configuration

(3) Updated barrage configuration using LSIP WWTP configuration and catchment inflows with reduced nutrient loads as specified in the WQIP.

Subsequent to this, a fourth scenario was established similarly to Scenario 3 however incorporated a revised set of barrage controls (commissioned 17/07/2017).

(4) Updated barrage configuration using LSIP WWTP configuration and catchment inflows with reduced nutrient loads as specified in the WQIP with revised control rules

Once scenarios were executed predictions were then extracted for the four scenarios at TEER EHAP (Figure 2-2) sites throughout the Tamar Estuary. This method of data extraction is the same to that undertaken in previous works. This section describes the model setup in further detail.



Title:
Tamar Estuary Model Mesh

Figure: 2-1

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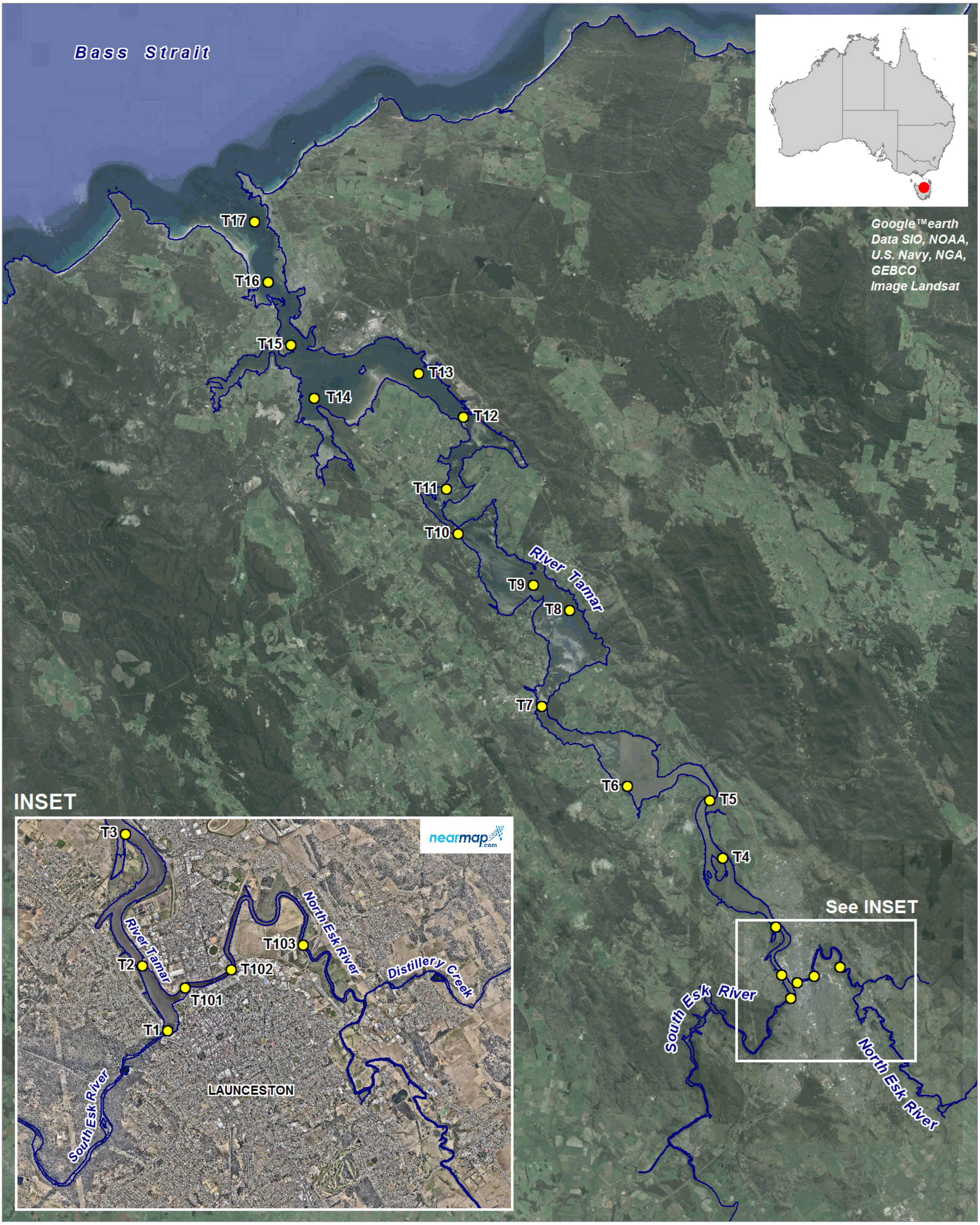

Title:

TEER EHAP Locations

Figure: 2-2

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2.1 Model Description

2.1.1 Barrage control rules

For the first three scenarios control rules were implemented based on the strength of upstream lacustrine thermal stratification as follows:

- A limit set on the lowest level the lake could reach of -1.0m AHD.
- A pipe was included in the base of the dam at the lowest level with a maximum outflow capacity of 200m^3/s.
- Up until the dissolved oxygen (saturated) percentage at the lower levels of the lake reached 80%, the barrage operated as normal with the releases twice per day through the flood gates.
- When the dissolved oxygen percentage fell below 80%, the flood gates remained closed and the stop valve in the bottom pipe opened to allow some of the cold, deoxygenated layers of bottom water within the lake to be released downstream continuously at any time during tidal cycles.
- If the dissolved oxygen percentage fell below 50%, the top level barrage gates opened on the ebb tides to reduce the level in the lake as far as is necessary to remove the threat of algal blooms, but no lower than -1.0m AHD.

For the fourth scenario the control rules were modified from those above as follows:

- A limit set on the lowest level the lake could reach of 0.0m AHD.
- When the dissolved oxygen percentage fell below 80%, the flood gates remained closed and the stop valve in the bottom pipe opened to allow some of the cold, deoxygenated layers of bottom water within the lake to be released downstream twice per day
- If the dissolved oxygen percentage fell below 50%, the top level barrage gates opened on the ebb tides to reduce the level in the lake as far as is necessary to remove the threat of algal blooms, but no lower than 0.0m AHD.
- Normal gate operation resumed if dissolved oxygen percentage reached 80% at the trigger site.

The sample point from which these dissolved oxygen and water levels are measured is approximately 700m upstream of the barrage as indicated in Figure 1-1. The extent deoxygenation at this given sample point would indicate a worst case scenario as it is located in a deeper section of the proposed lake compared to the surrounding area.

2.1.2 Initial Conditions

Initial conditions for Tamar Lake Scenarios 1-3 were established using the same approach as outlined in the Tamar Estuary 3D Modelling report (BMT WBM 2015). This initialisation process for both the hydrodynamic and AED[2] models allowed the information at the TEER EHAP sites to be interpolated between sites and provide a complete coverage throughout the model domain. This warmup period is not represented in results. Initial conditions for Tamar Lake Scenario 4 were established to ensure that dissolved oxygen levels within the lake were at 100% when the reporting simulation period began.

2.1.3 Catchment inflows

For the first two scenarios, inflows entering the model from the North and South Esk, the Trevallyn tailrace and flows entering directly from surrounding sub-catchments remained unchanged from previous TLI scenarios. For the final two scenarios, the following reductions were made to nutrient loads entering the model from the catchments in accordance with the WQIP:

- 17% for Total Nitrogen (TN);
- 27% for Total Phosphorus (TP);
- 6% for Total Suspended Solids (TSS); and
- 24% for Enterococci (ENT).

2.1.3.1 WWTPs

For the first scenario, treatment plants were incorporated into the model using data provided by TasWater for current flows and loads. These flows and loads are the same as those used in the NRM North, Tamar Estuary 3D model. The second, third and fourth scenarios incorporated the implementation of the LSIP. Under the LSIP scenario the six decommissioned WWTPs were removed and flows and loads were redirected to the New Northern WWPT which is proposed to be constructed alongside the existing plant at Ti-Tree Bend (Figure 1-1). Flows and loads from Ti-Tree Bend remained unchanged for the second scenario in accordance with the LSIP.

2.1.4 Nutrient Sediment Flux

For the purposes of TLI scenarios, sediment flux parameters were applied upstream of the barrage that were more representative of a lake system. These sediment flux parameters are detailed in the Tamar Lake Scenarios report (BMT WBM, 2016).

2.1.5 Time period

To capture seasonal variability for each scenario the model was simulated over a winter to winter period. The timeframe used was 01/07/2010 to 01/07/2011.

2.2 Scenarios

The scenarios and their corresponding inputs are presented below in Table 2-1.

Table 2-1 Scenarios

Scenario	Scenario ID	Catchments	WWTPs
As current	1	Unchanged	Unchanged
LSIP applied	2	Unchanged	LSIP
LSIP and WQIP applied	3	WQIP	LSIP
LSIP and WQIP applied (modified trigger dependencies)	4	WQIP	LSIP

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3 Results

3.1 Presentation

Data extracted for each of the four scenarios have been presented in three different formats: box and whisker plot, timeseries and profile view contour plots. Each of these formats are described below.

3.1.1 Box and Whisker Plots

Box and whisker plots are presented for both surface and bottom layer concentrations for both summer and winter time periods. An example box and whisker plot is presented in Figure 3-1. This plot represents the surface (top layer) DO percentage in for each of the reporting locations as well as the water quality objective (WQO) as outlined by NRM North (2016).

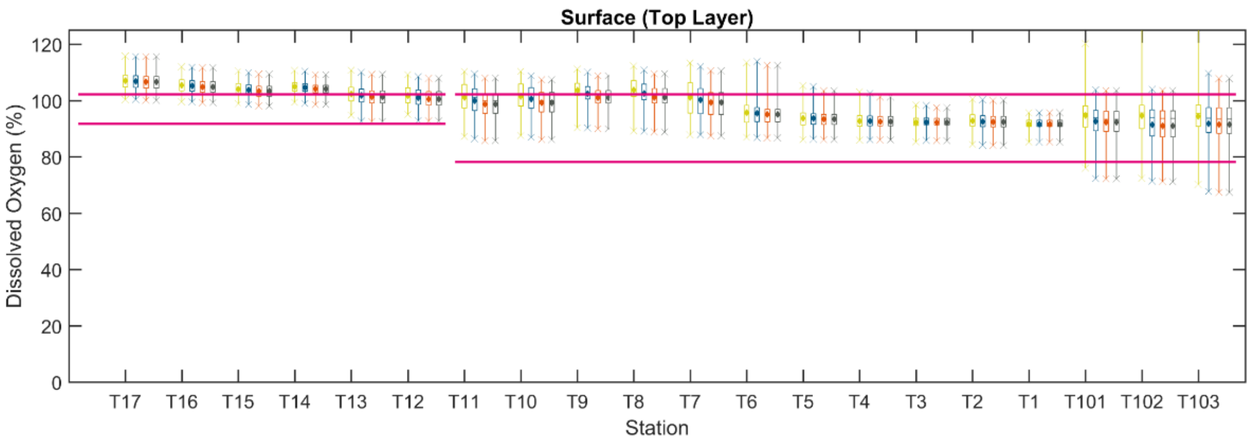

Figure 3-1 Example box and whiskers plot

3.1.2 Thalweg Contour Plots

For each of the four scenarios a thalweg contour plot is presented. These plots indicate the concentration in DO from the mouth of the Tamar through to Homereach. These plots reflect concentrations at a single point in time (01/01/2011). An example thalweg contour plot is presented below in Figure 3-2.

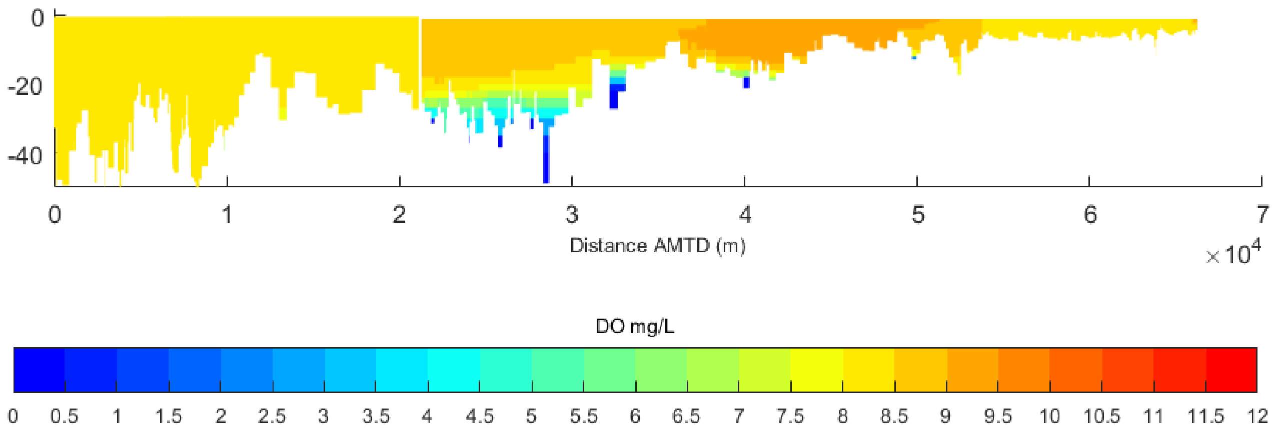

Figure 3-2 Example thalweg contour plot

3.1.3 Timeseries Plots

An example timeseries plot is presented in Figure 3-3, which shows results for DO percentage at the sample point location. The blue line indicates DO (% saturation) at the top layer whilst the orange line indicates DO (% saturation) at the bottom layer. These result shave also been presented for the water level at the same location.

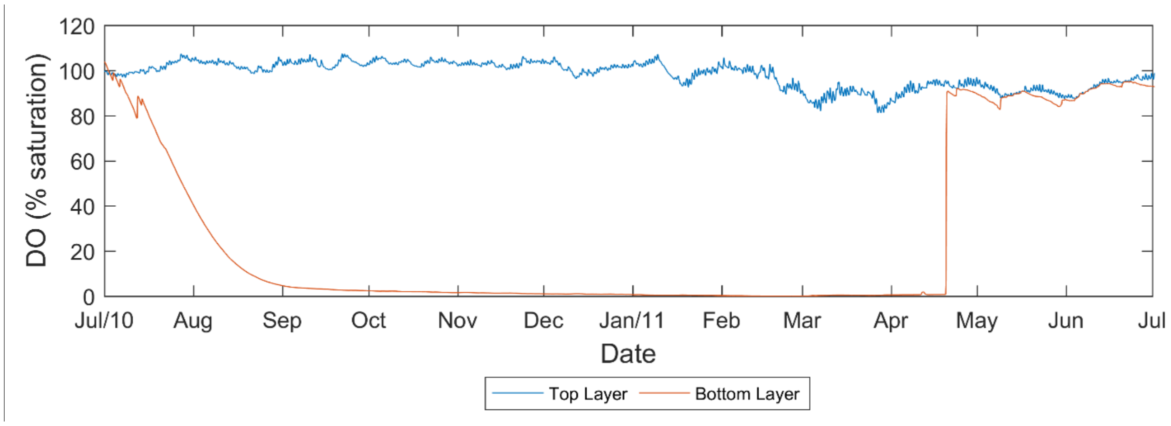

Figure 3-3 Example timeseries plot

3.2 Temperature

3.2.1 Summer

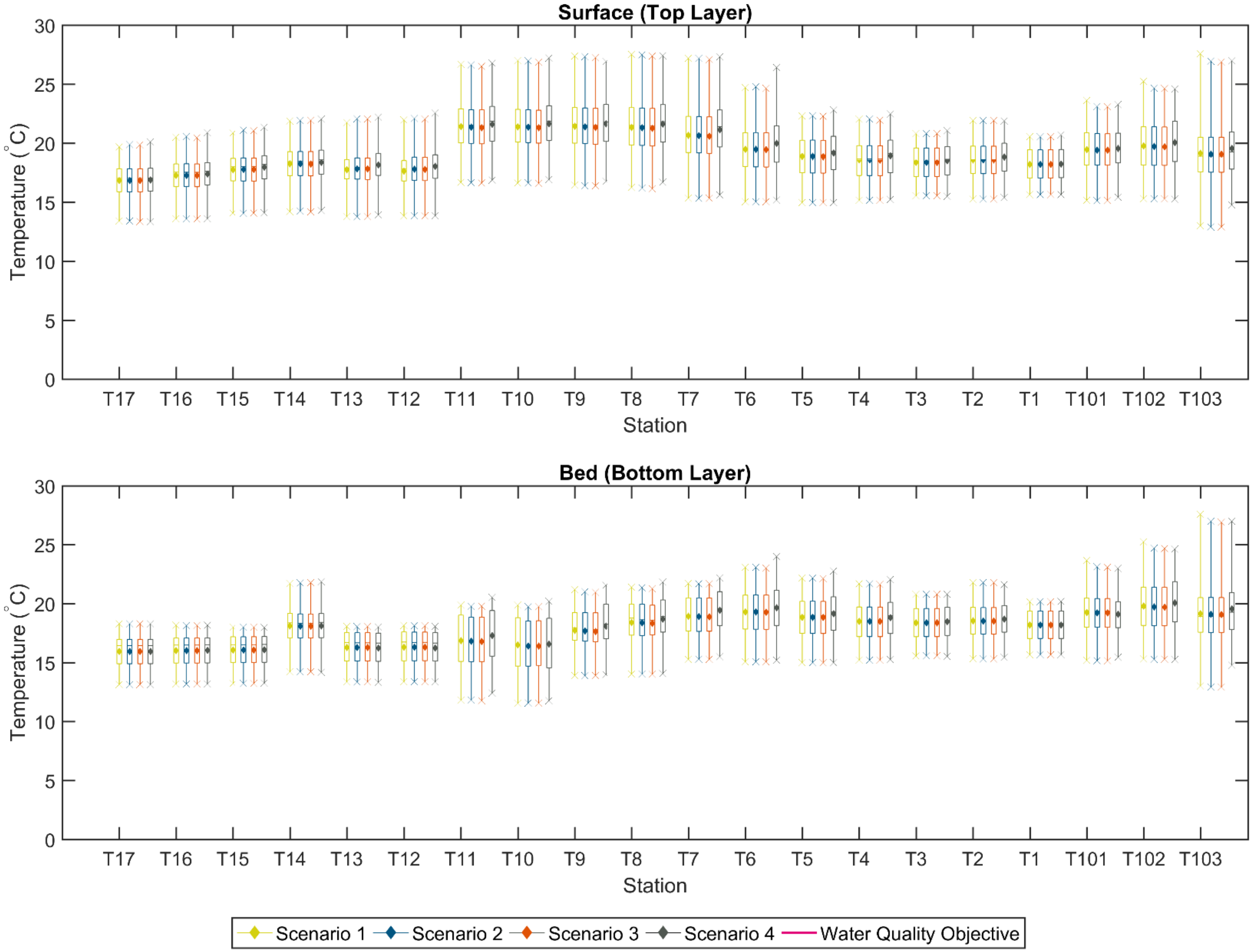

Figure 3-4 Temperature - Summer

3.2.2 Winter

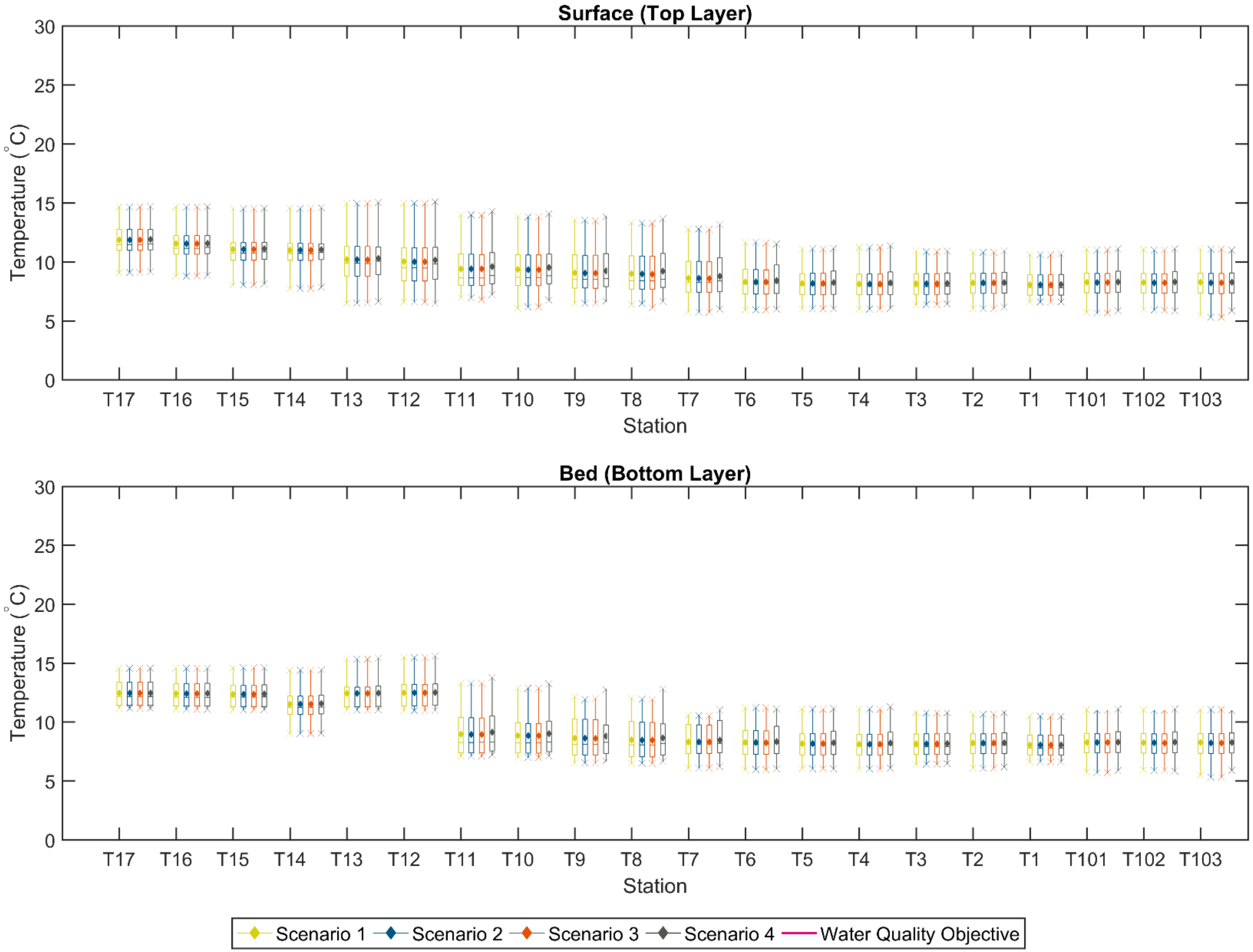

Figure 3-5 Temperature - Winter

3.3 Salinity

3.3.1 Summer

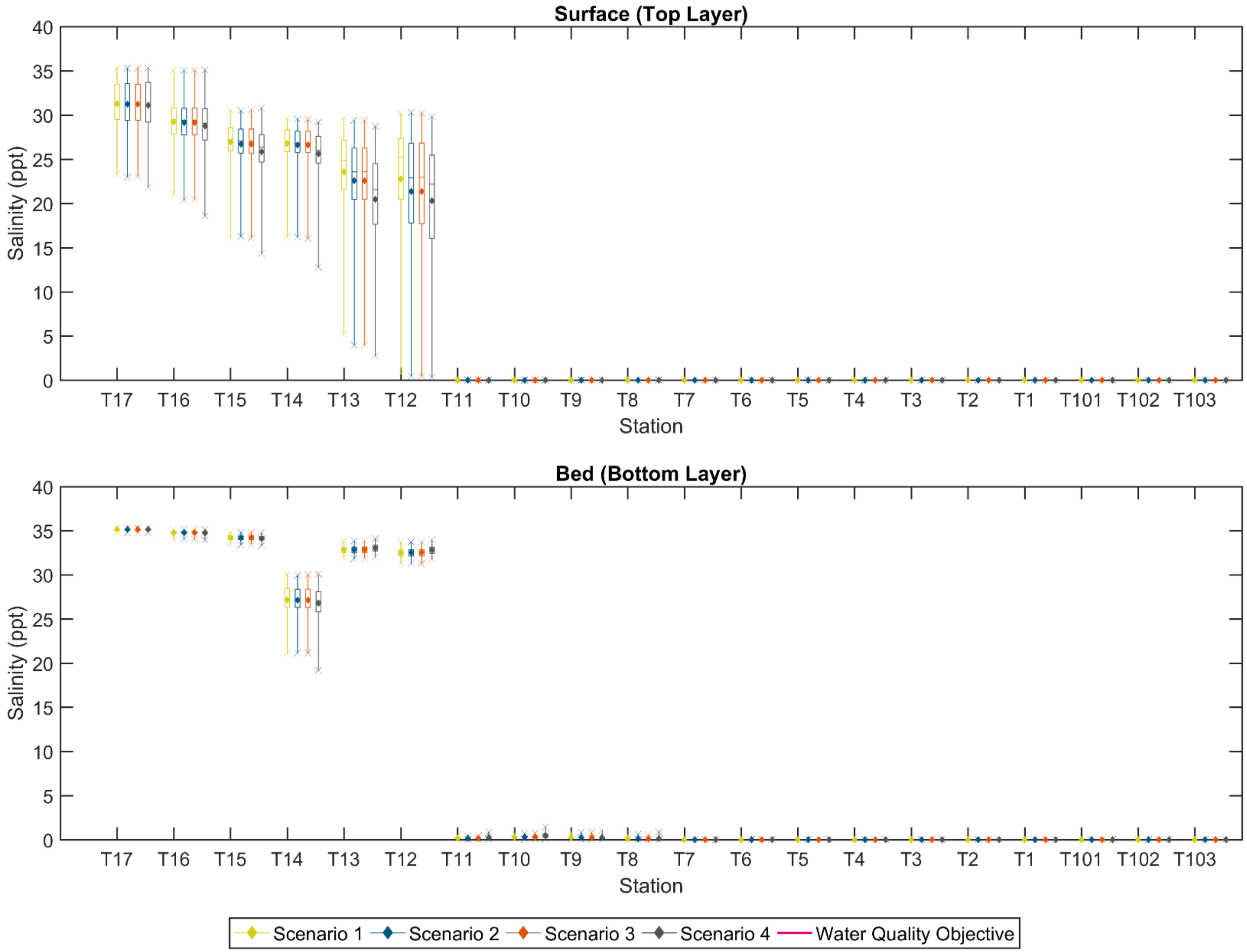

Figure 3-6 Salinity - Summer

3.3.2 Winter

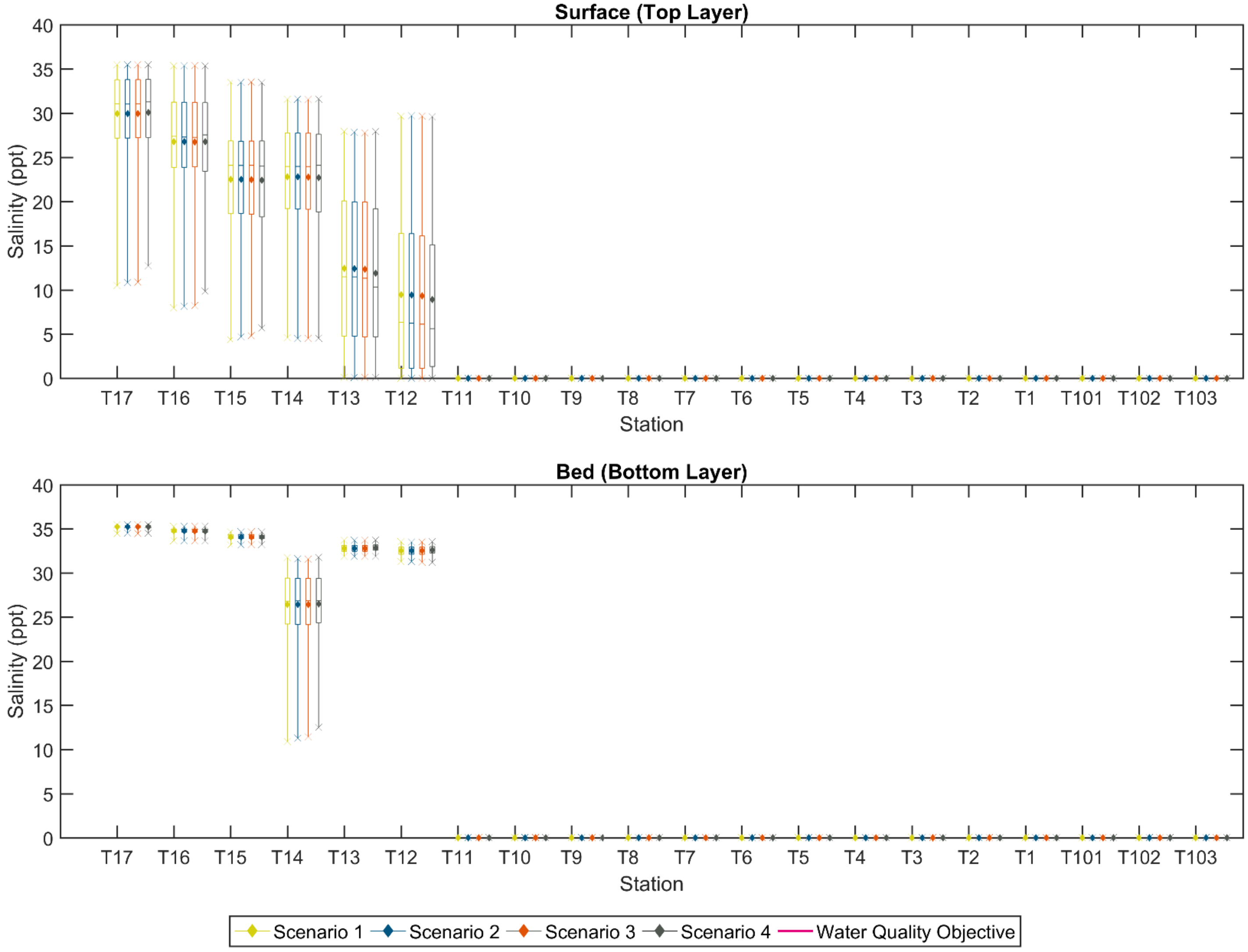

Figure 3-7 Salinity - Winter

3.4 TSS

3.4.1 Summer

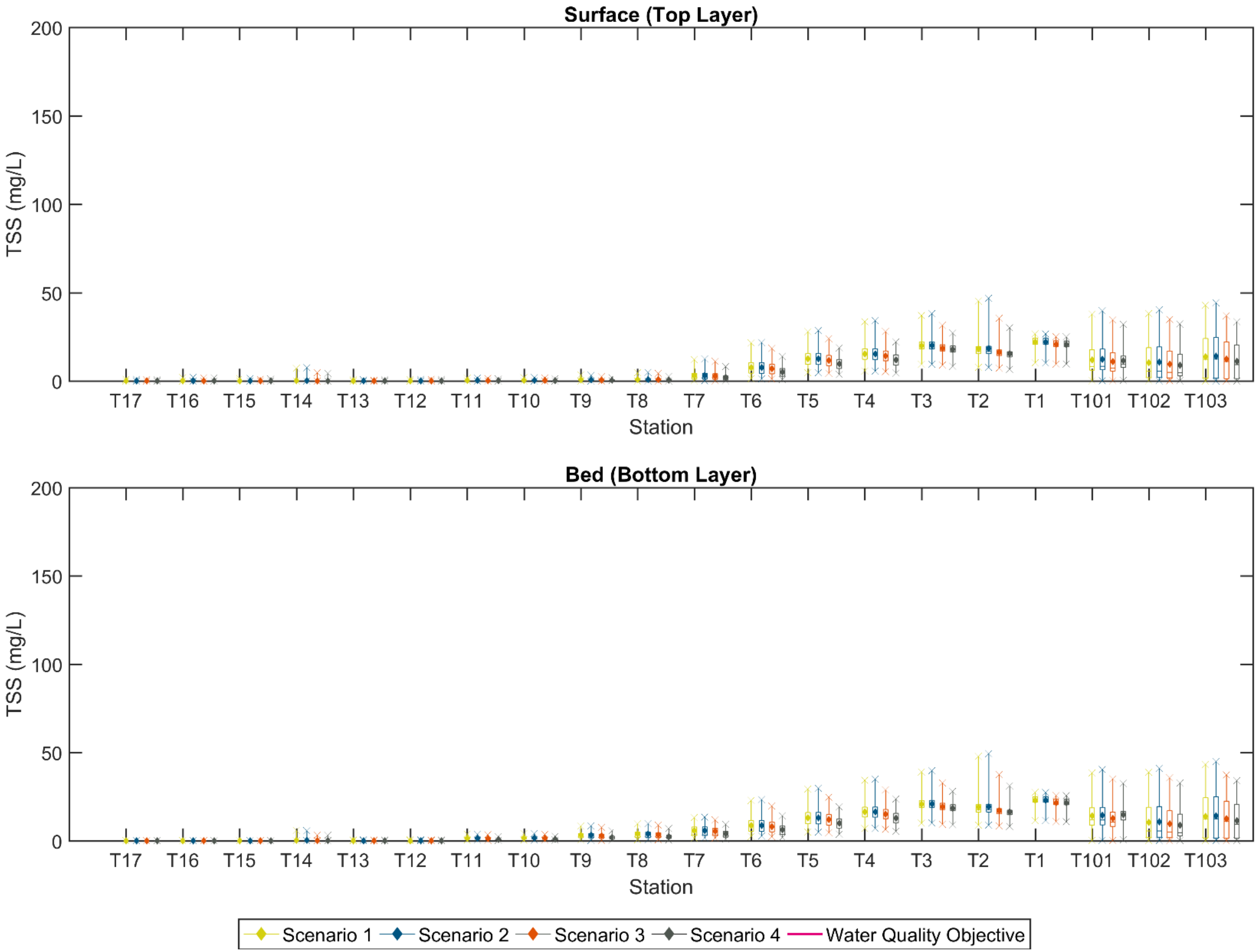

Figure 3-8 TSS - Summer

3.4.2 Winter

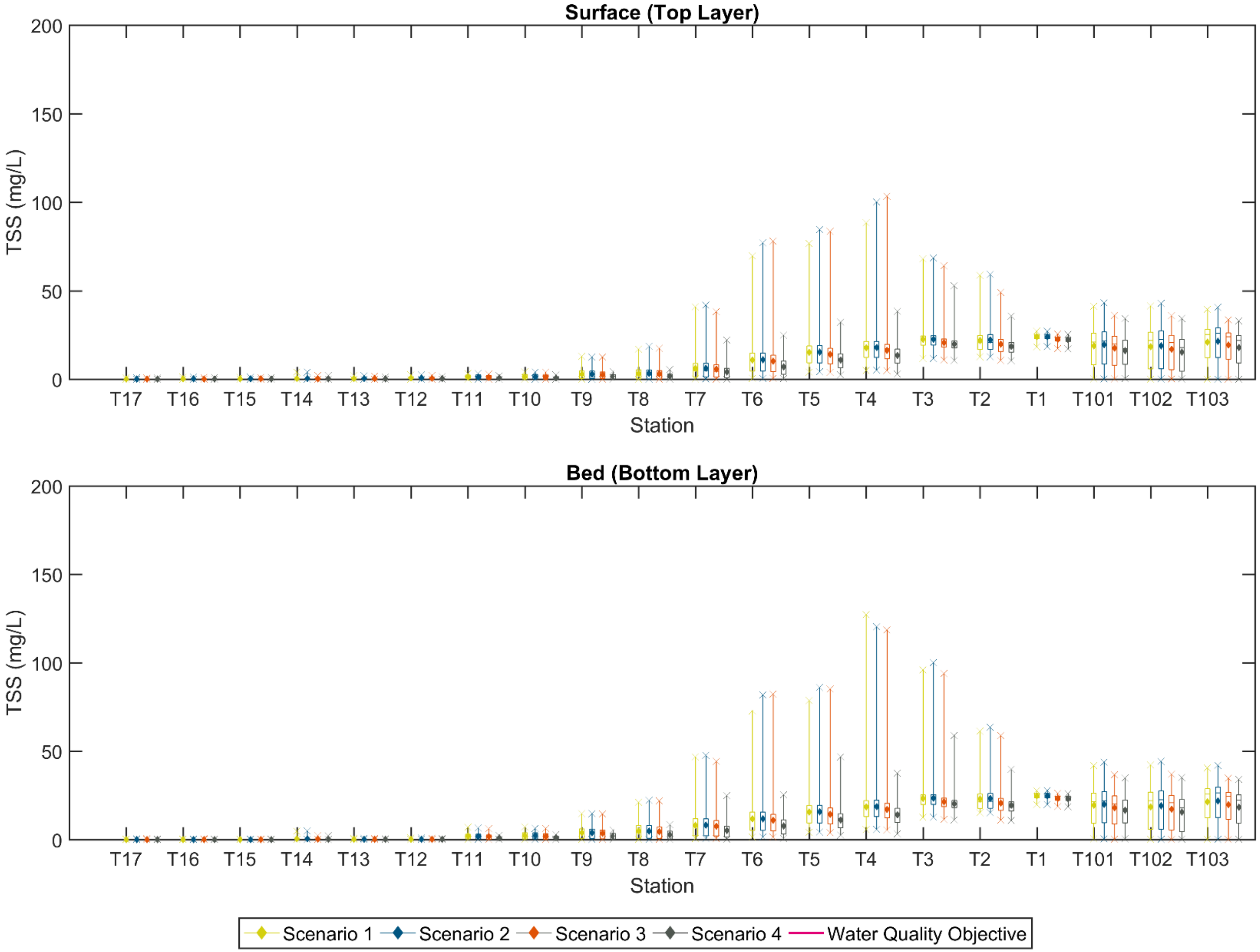

Figure 3-9 TSS - Winter

3.5 Dissolved Oxygen (% saturation)

3.5.1 Summer

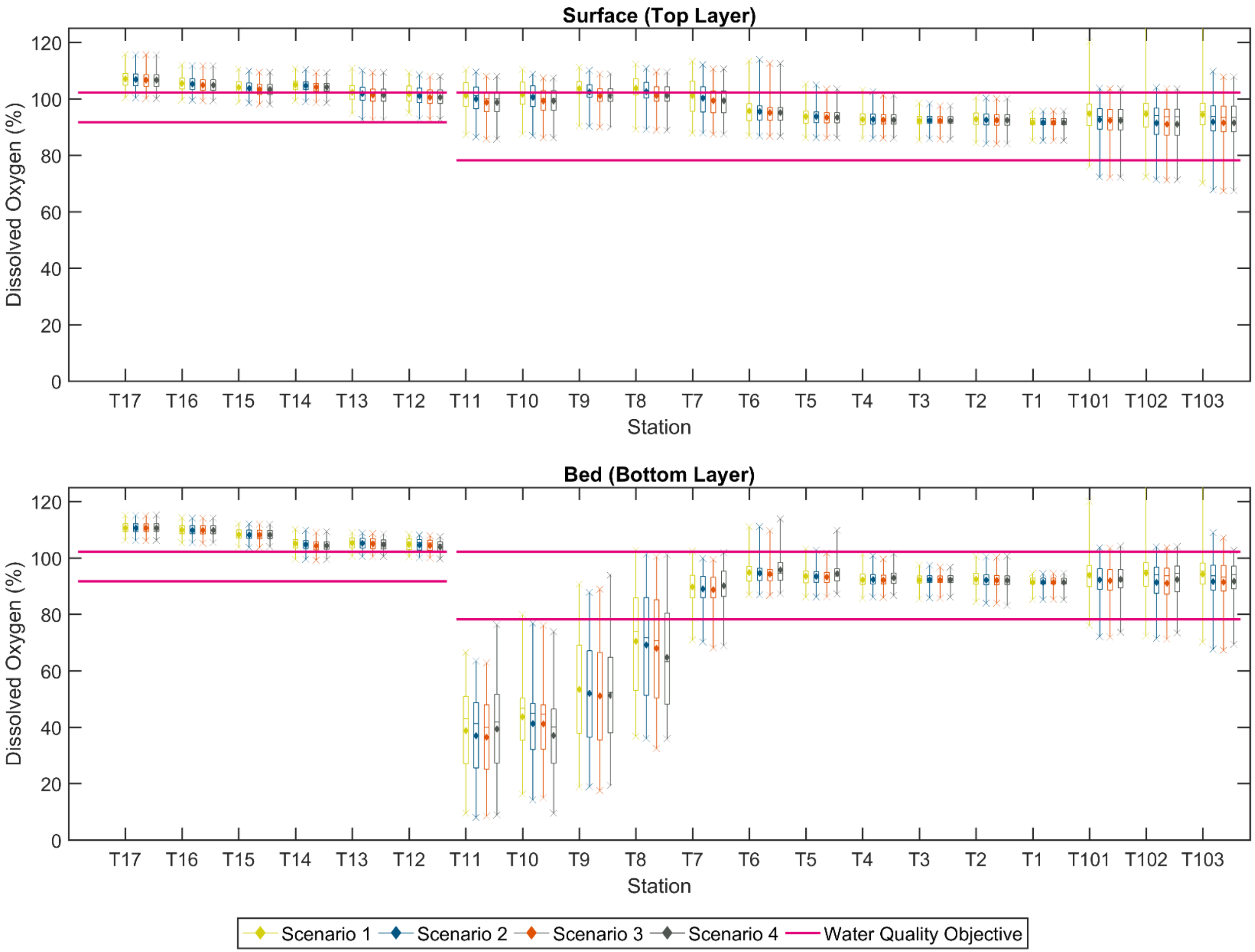

Figure 3-10 DO - Summer

3.5.2 Winter

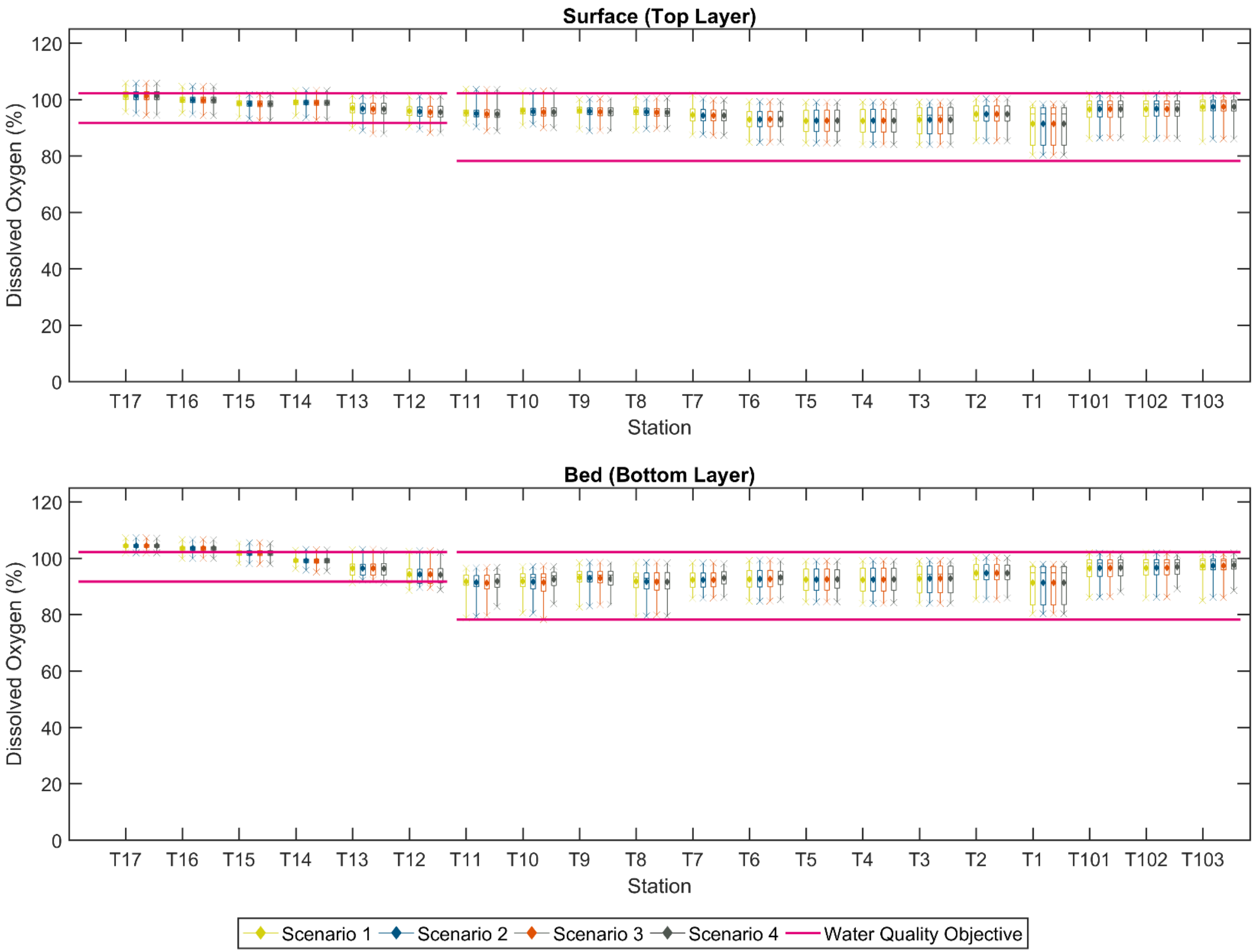

Figure 3-11 DO - Winter

3.6 Nitrate

3.6.1 Summer

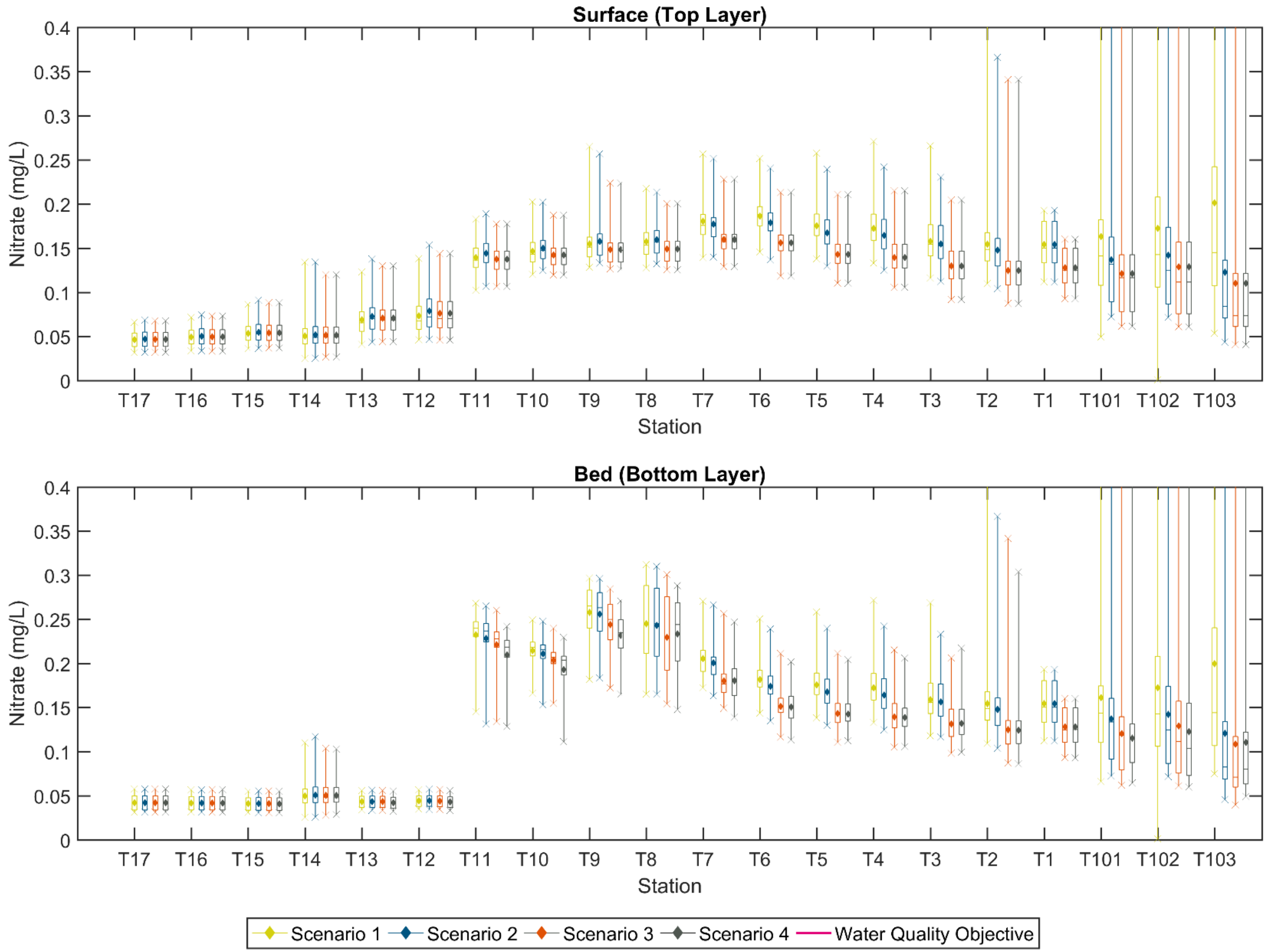

Figure 3-12 Nitrate - Summer

3.6.2 Winter

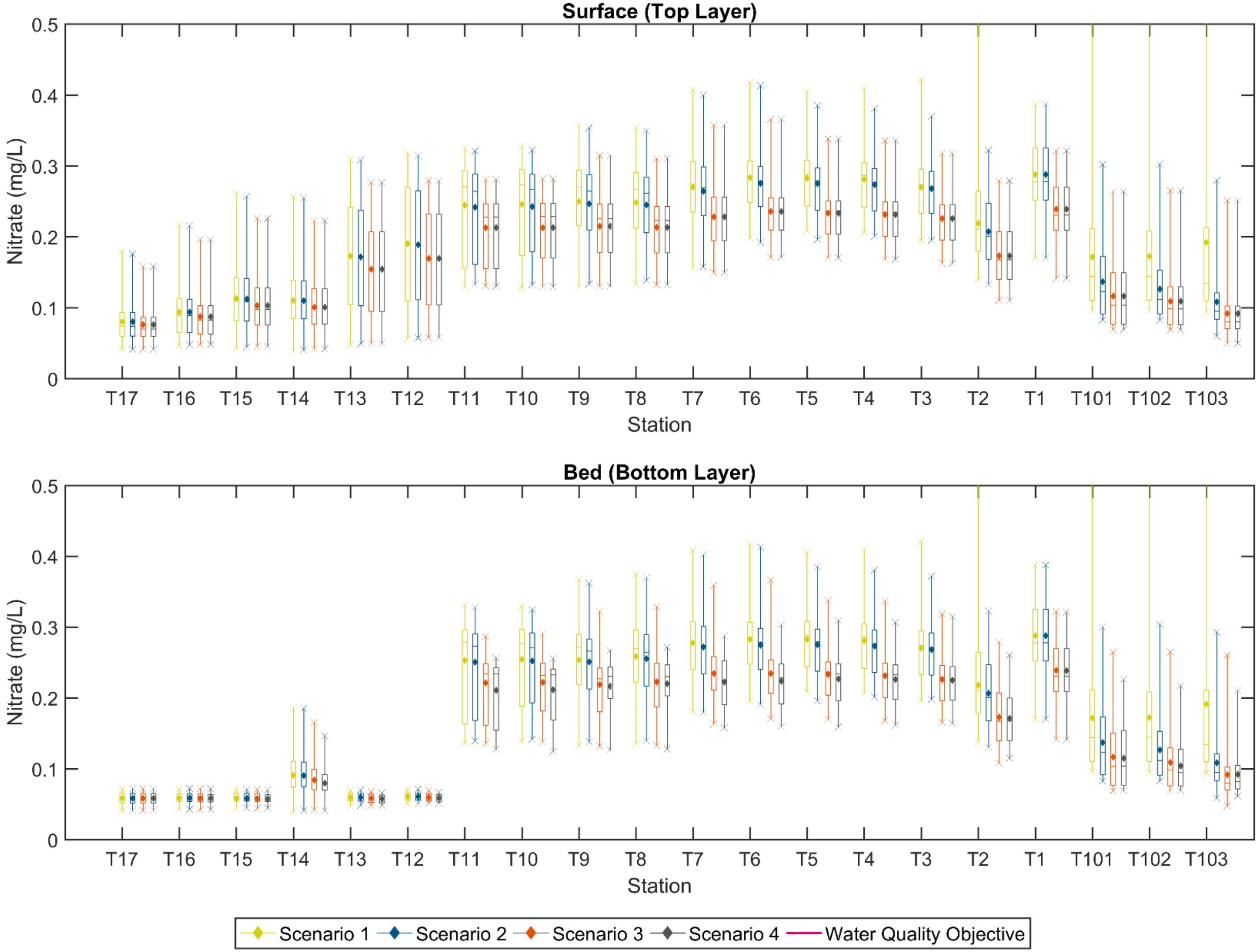

Figure 3-13 Nitrate - Winter

3.7 Ammonia

3.7.1 Summer

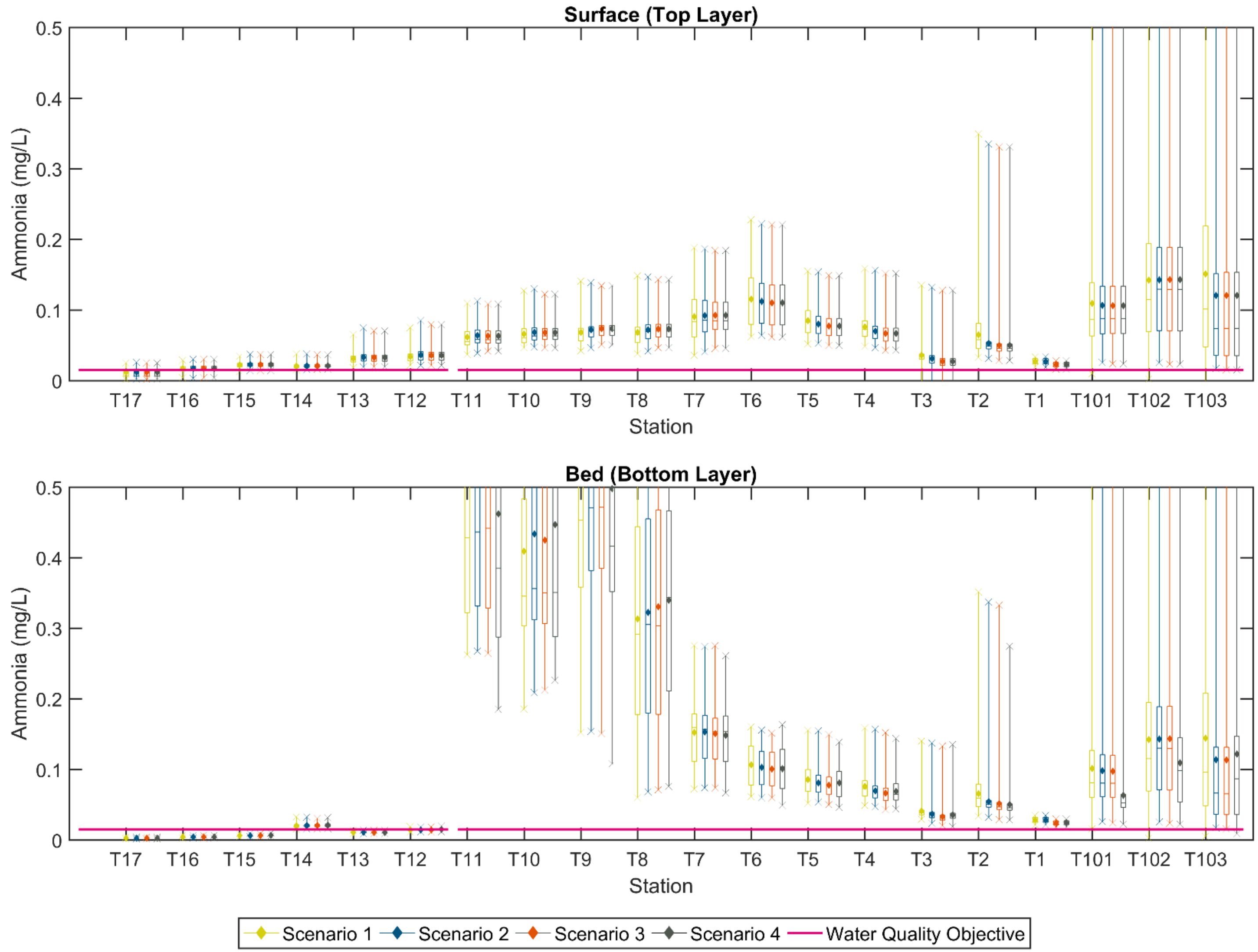

Figure 3-14 Ammonia - Summer

3.7.2 Winter

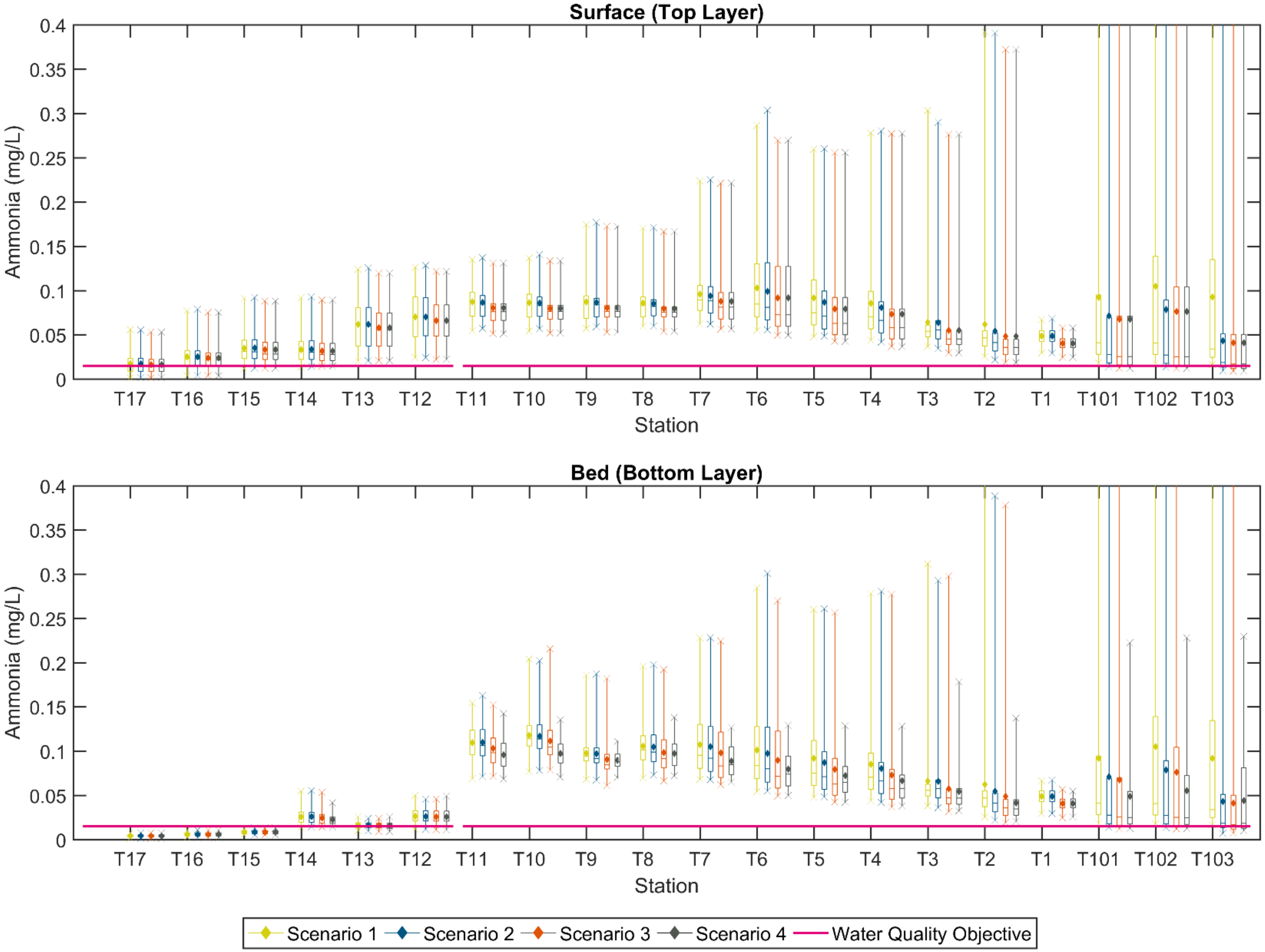

Figure 3-15 Ammonia - Winter

3.8 Total Nitrogen

3.8.1 Summer

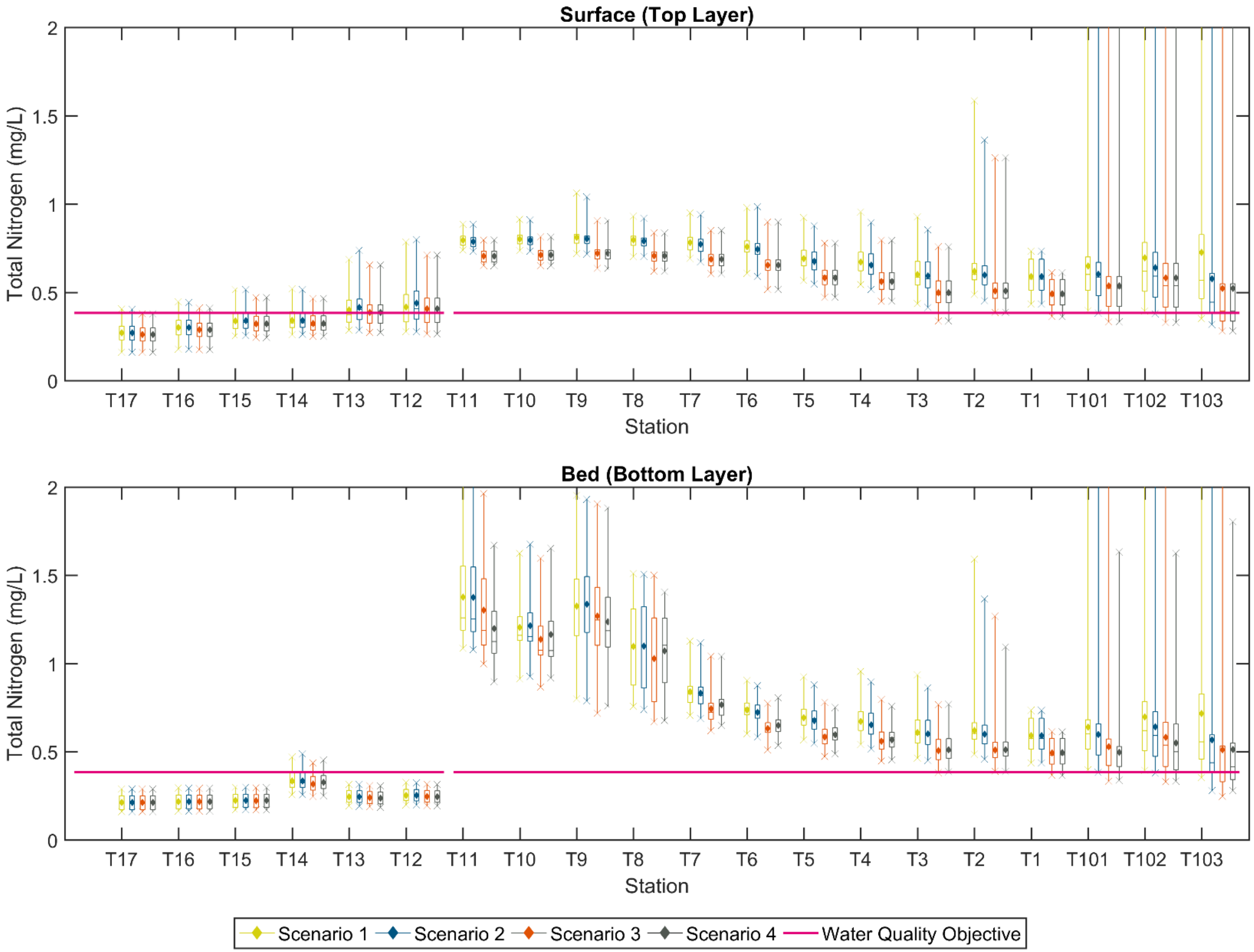

Figure 3-16 TN - Summer

3.8.2 Winter

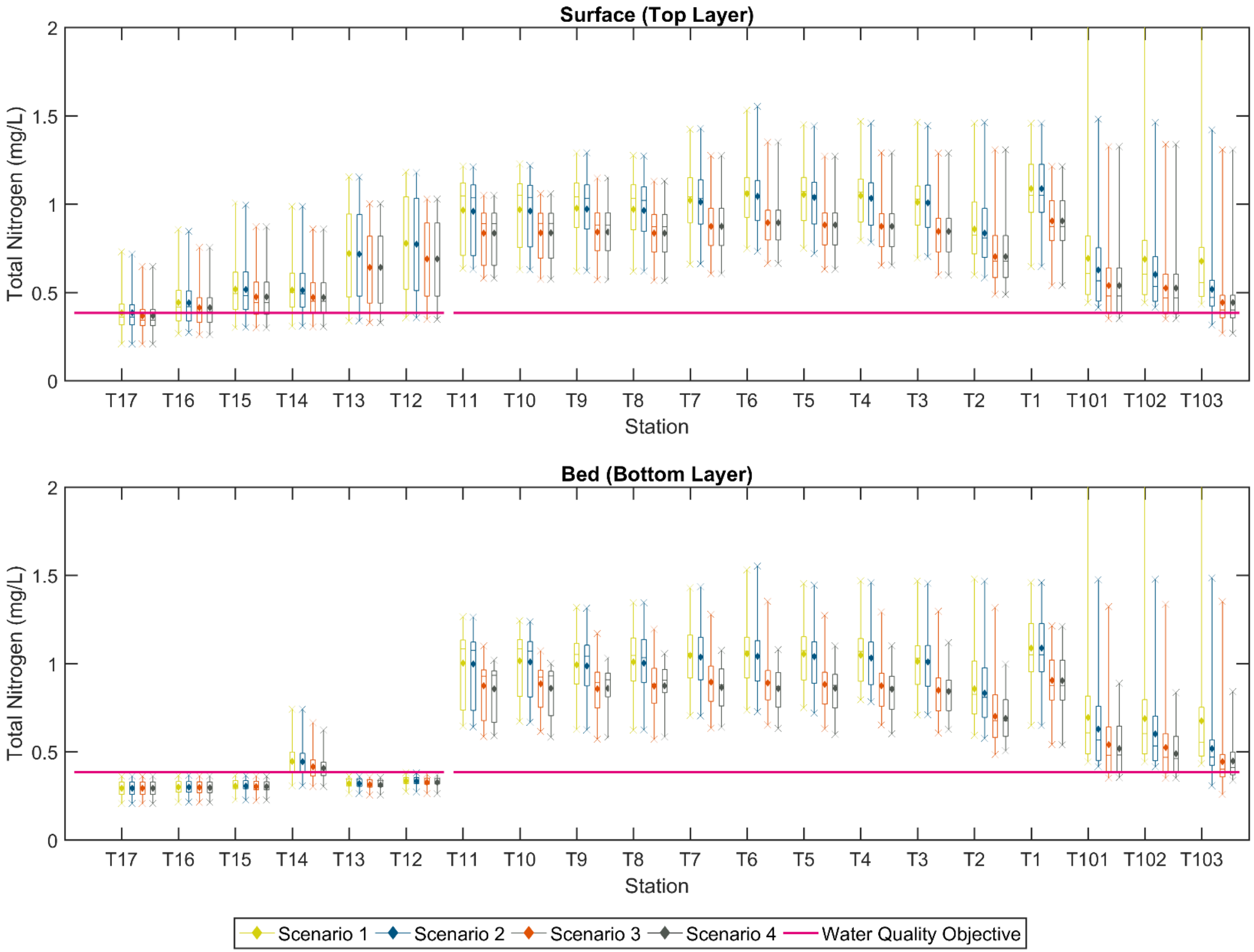

Figure 3-17 TN - Winter

3.9 FRP

3.9.1 Summer

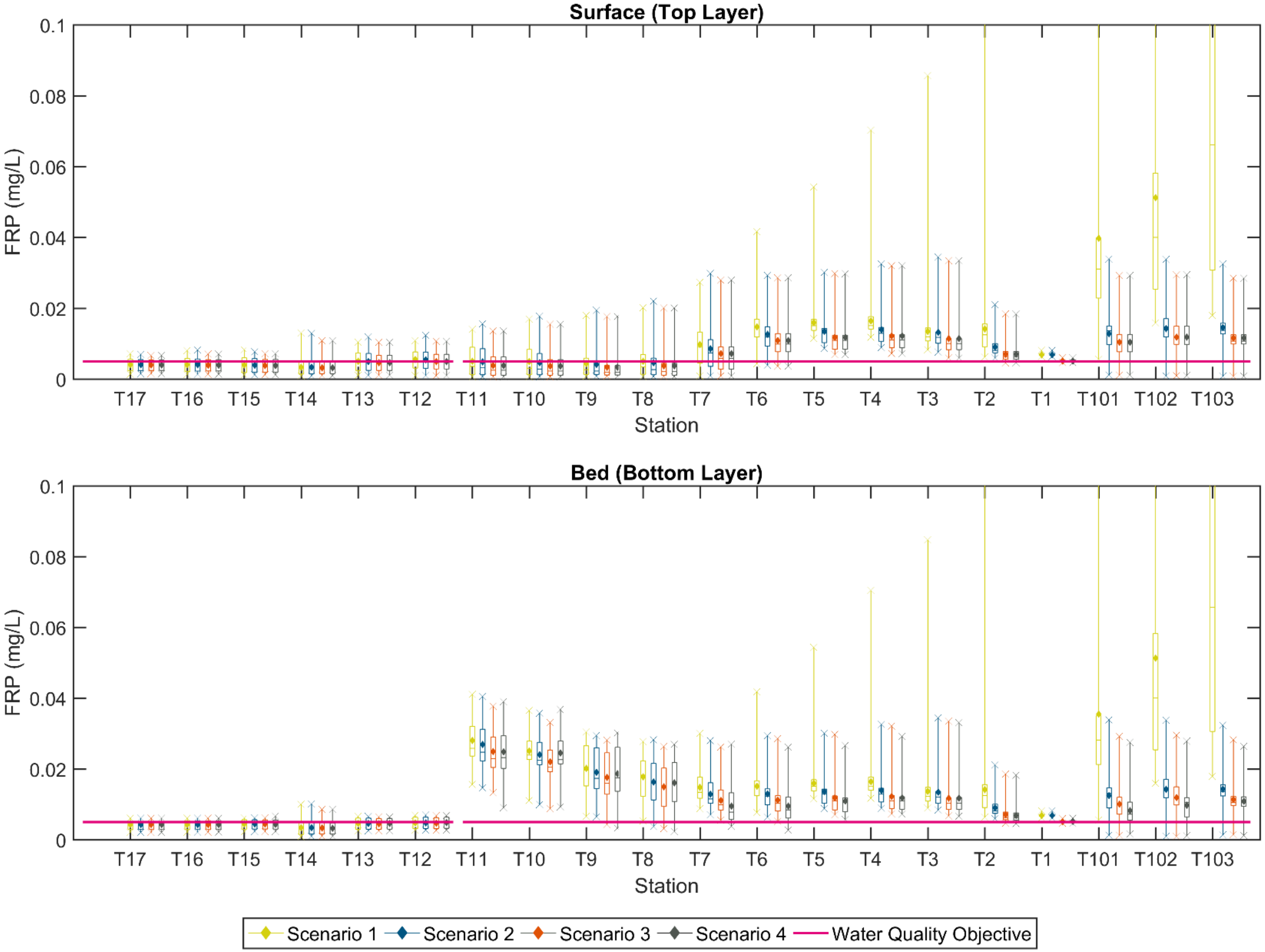

Figure 3-18 FRP - Summer

3.9.2 Winter

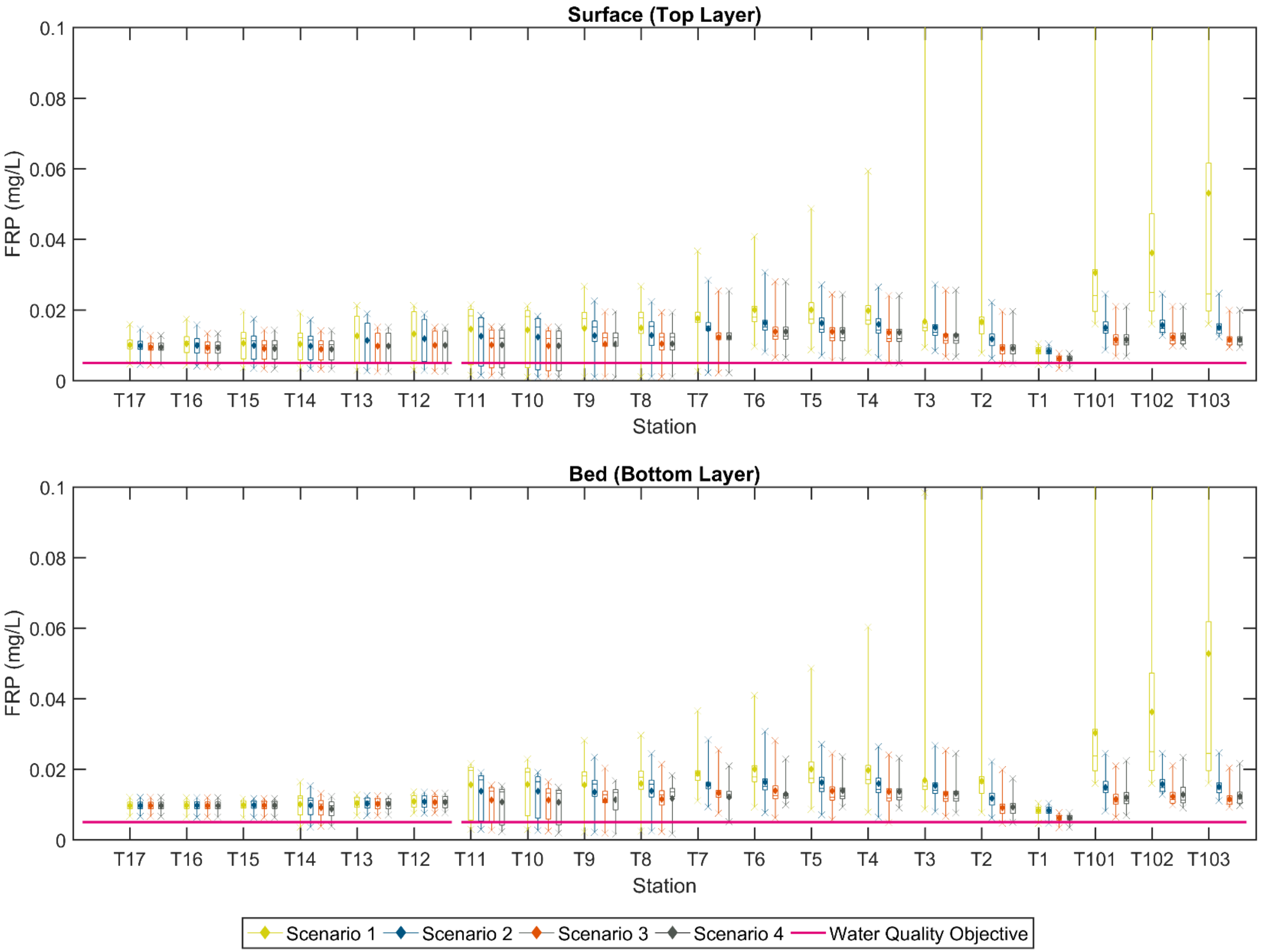

Figure 3-19 FRP - Winter

3.10 Total Phosphorus

3.10.1 Summer

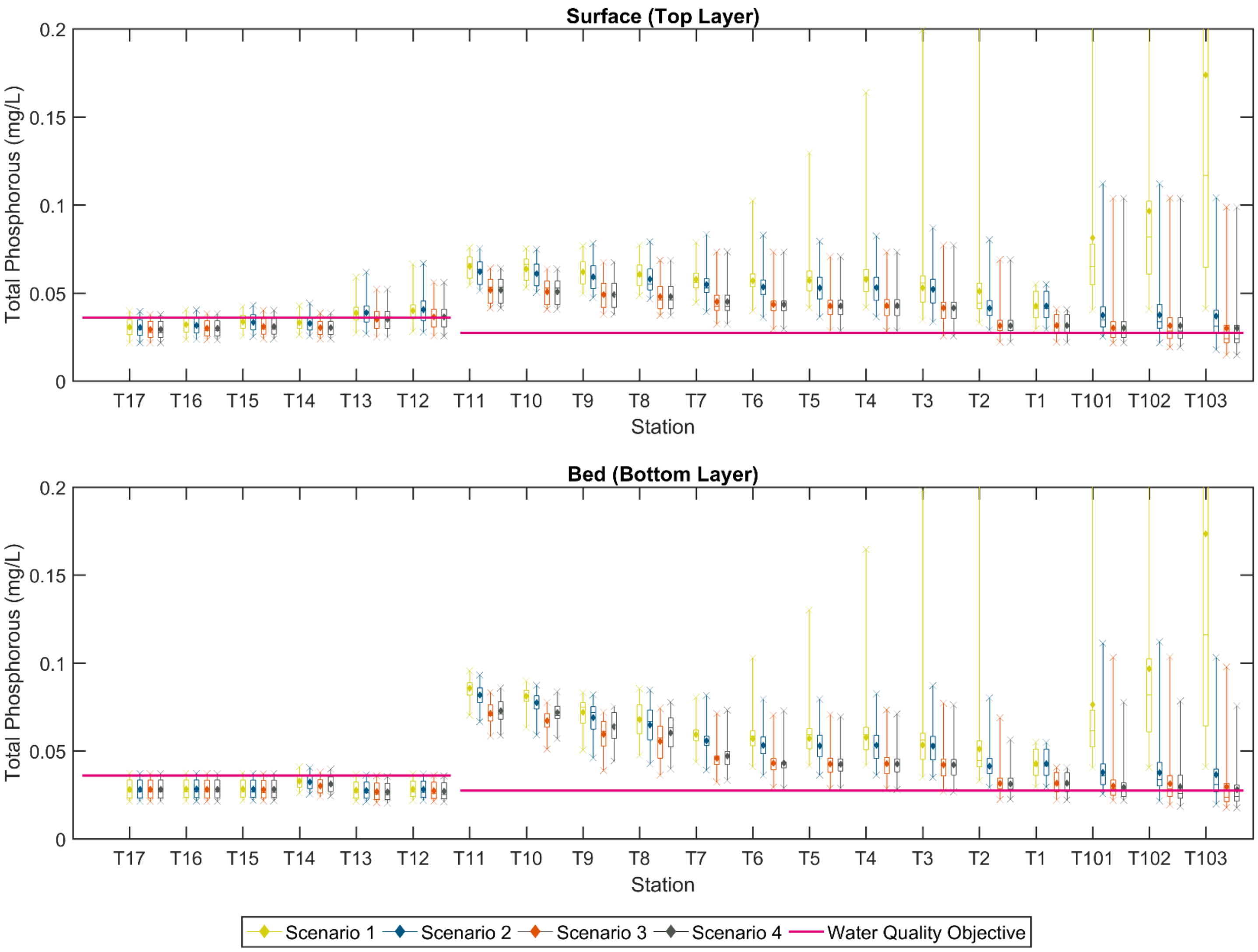

Figure 3-20 TP - Summer

3.10.2 Winter

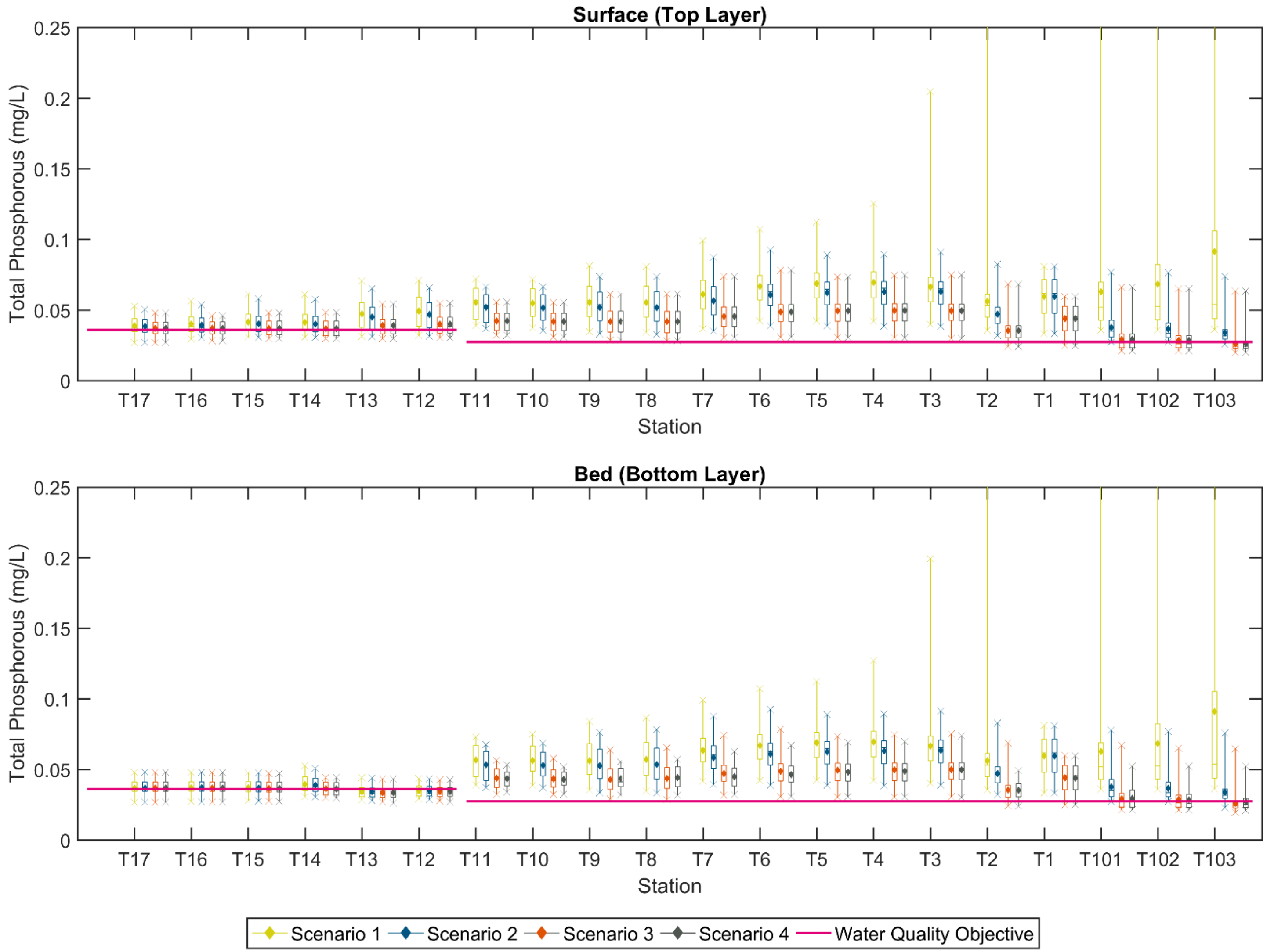

Figure 3-21 TP - Winter

3.11 Chlorophyll-a

3.11.1 Summer

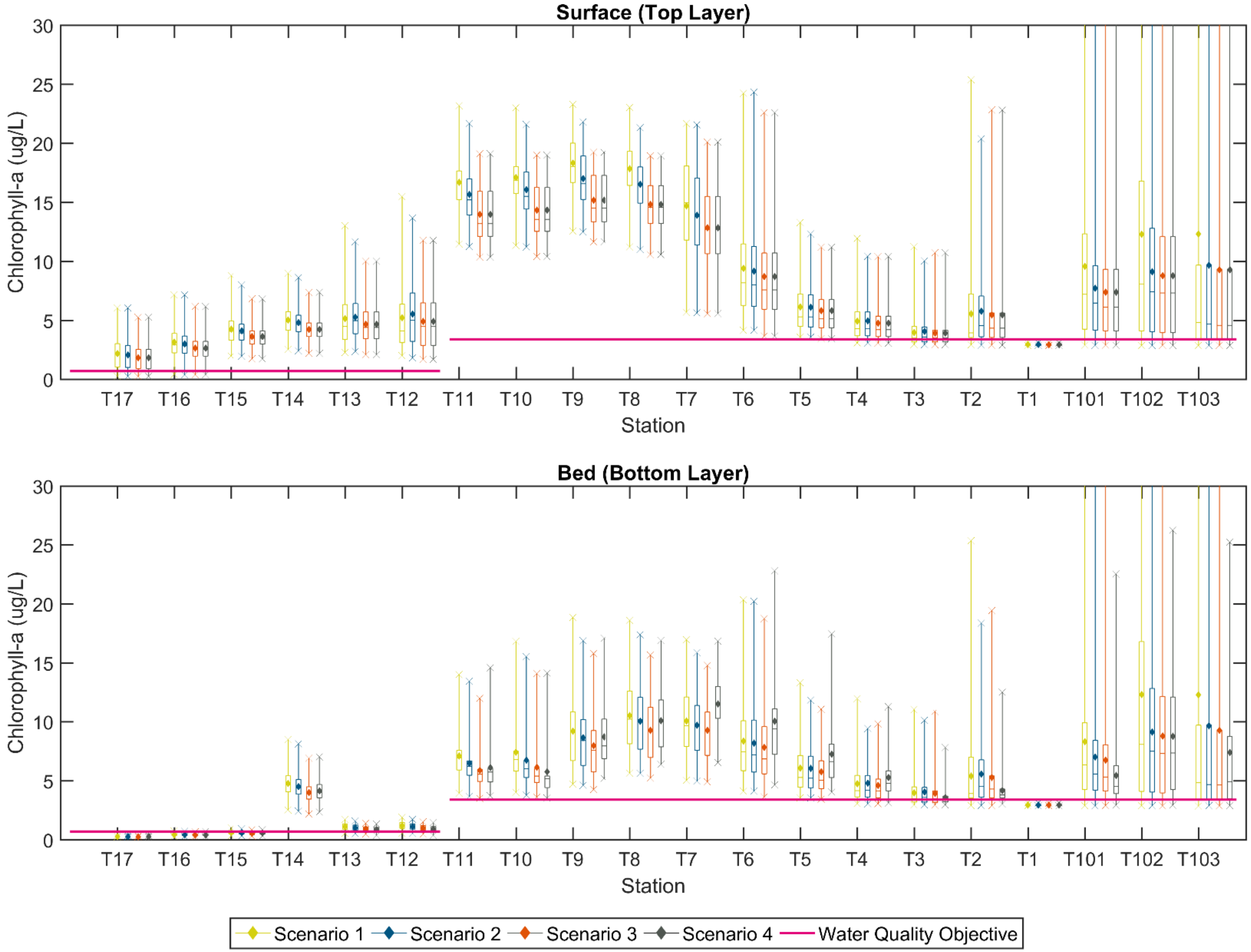

Figure 3-22 Chl-a - Summer

3.11.2 Winter

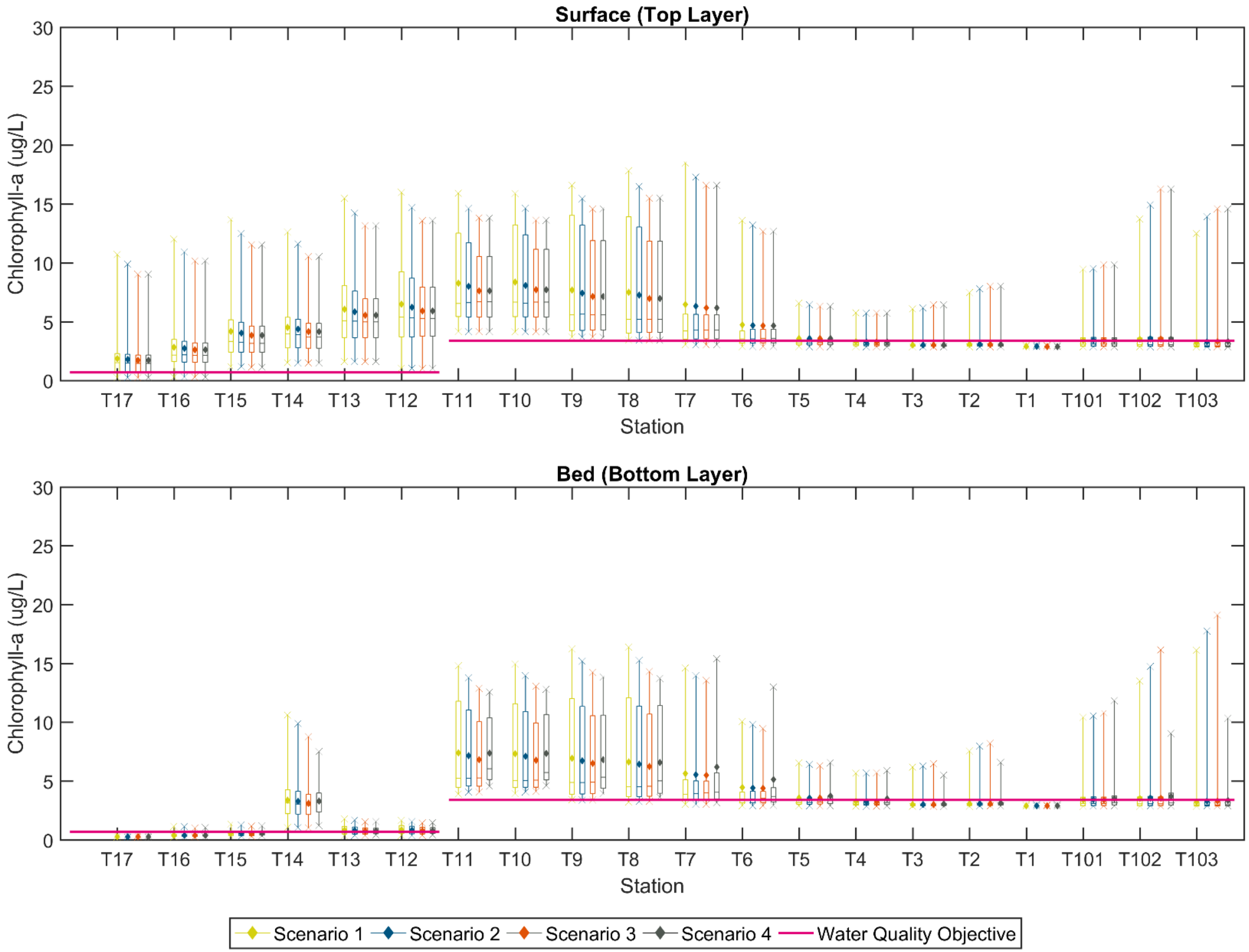

Figure 3-23 Chl-a - Winter

3.12 Enterococci

3.12.1 Summer

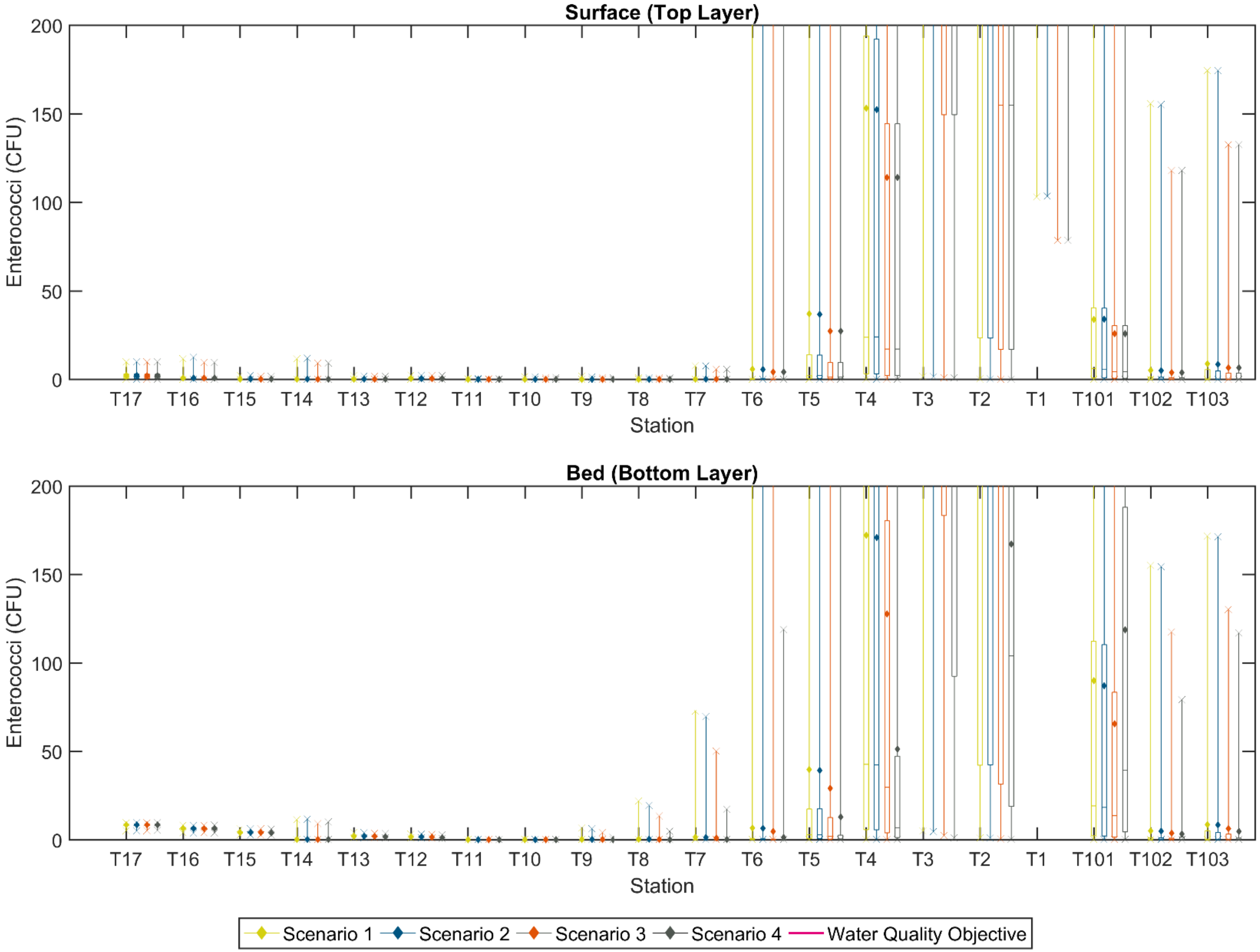

Figure 3-24 ENT - Summer

3.12.2 Winter

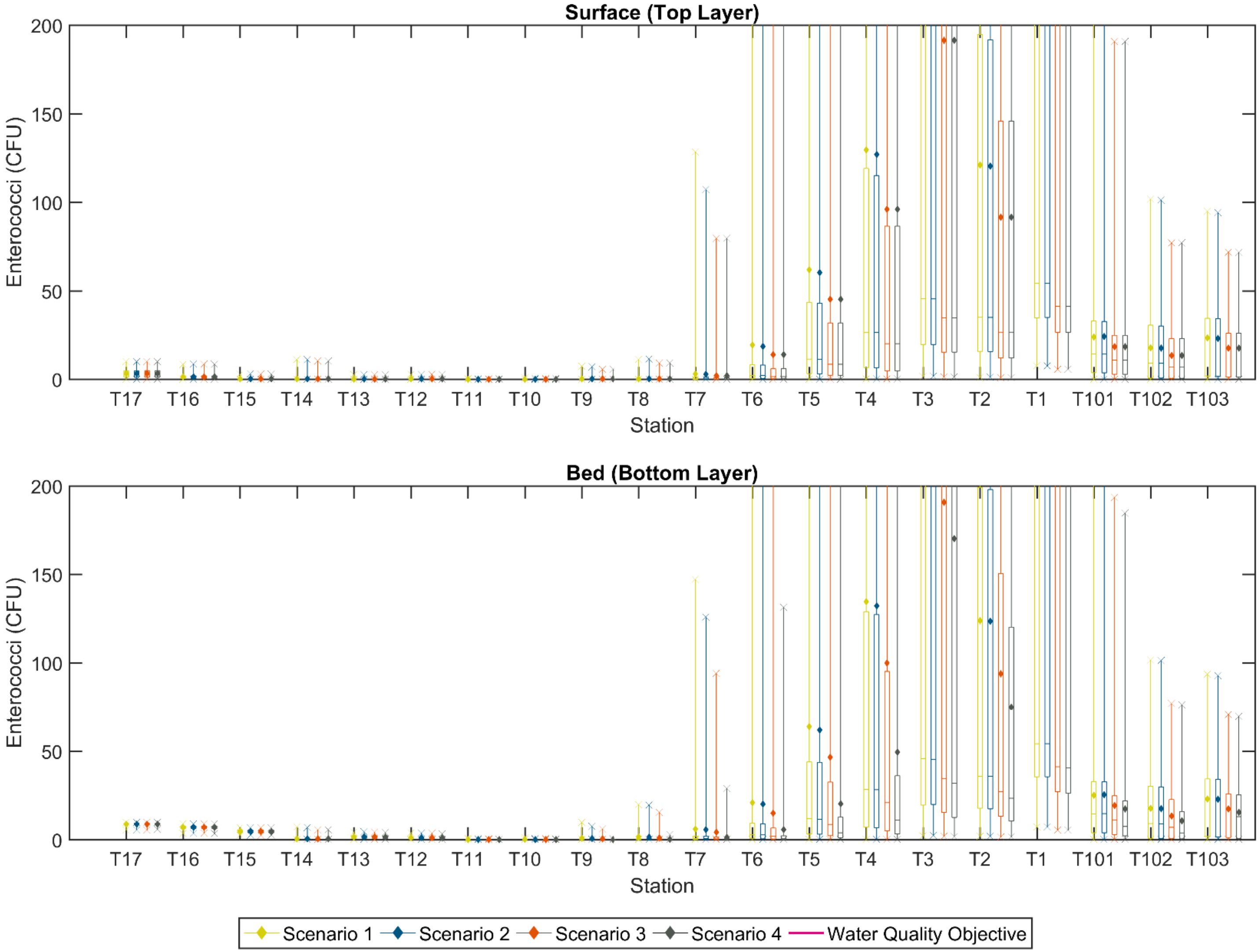

Figure 3-25 ENT - Winter

3.13 Profile view contour comparison

3.13.1 DO (mg/L)

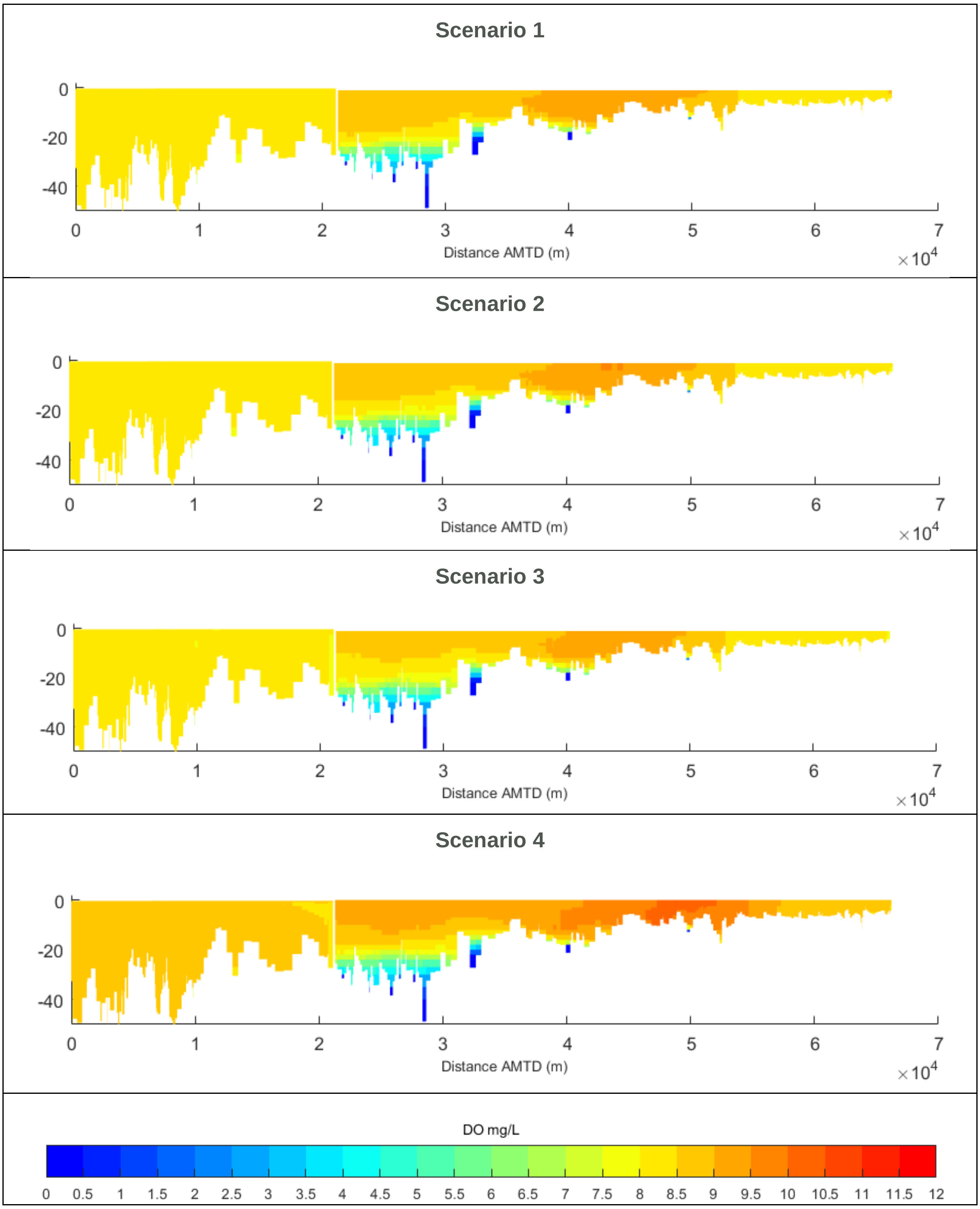

Figure 3-26 DO (mg/L) Profile view contour plots

3.14 Timeseries

3.14.1 DO (% saturation)

Note that Scenarios 1-3 incorporate one month warm up period prior to presentation of results in which the DO percent saturation at the trigger point reduced to approximately 40%. Scenario 4 was updated to reflect a DO percent saturation of 100% when the reporting simulation began.

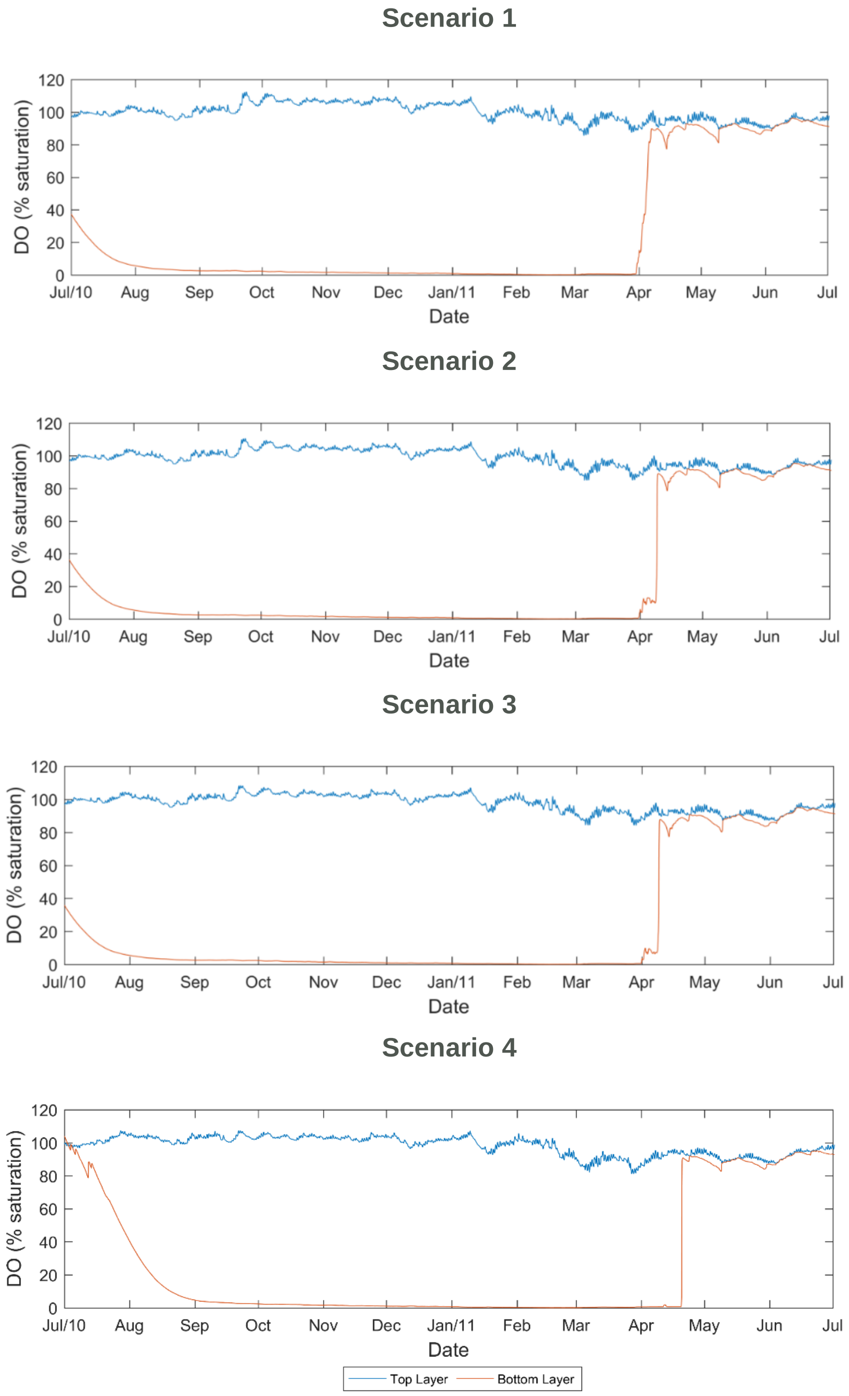

Figure 3-27 DO (%) timeseries

3.14.2 Water Level

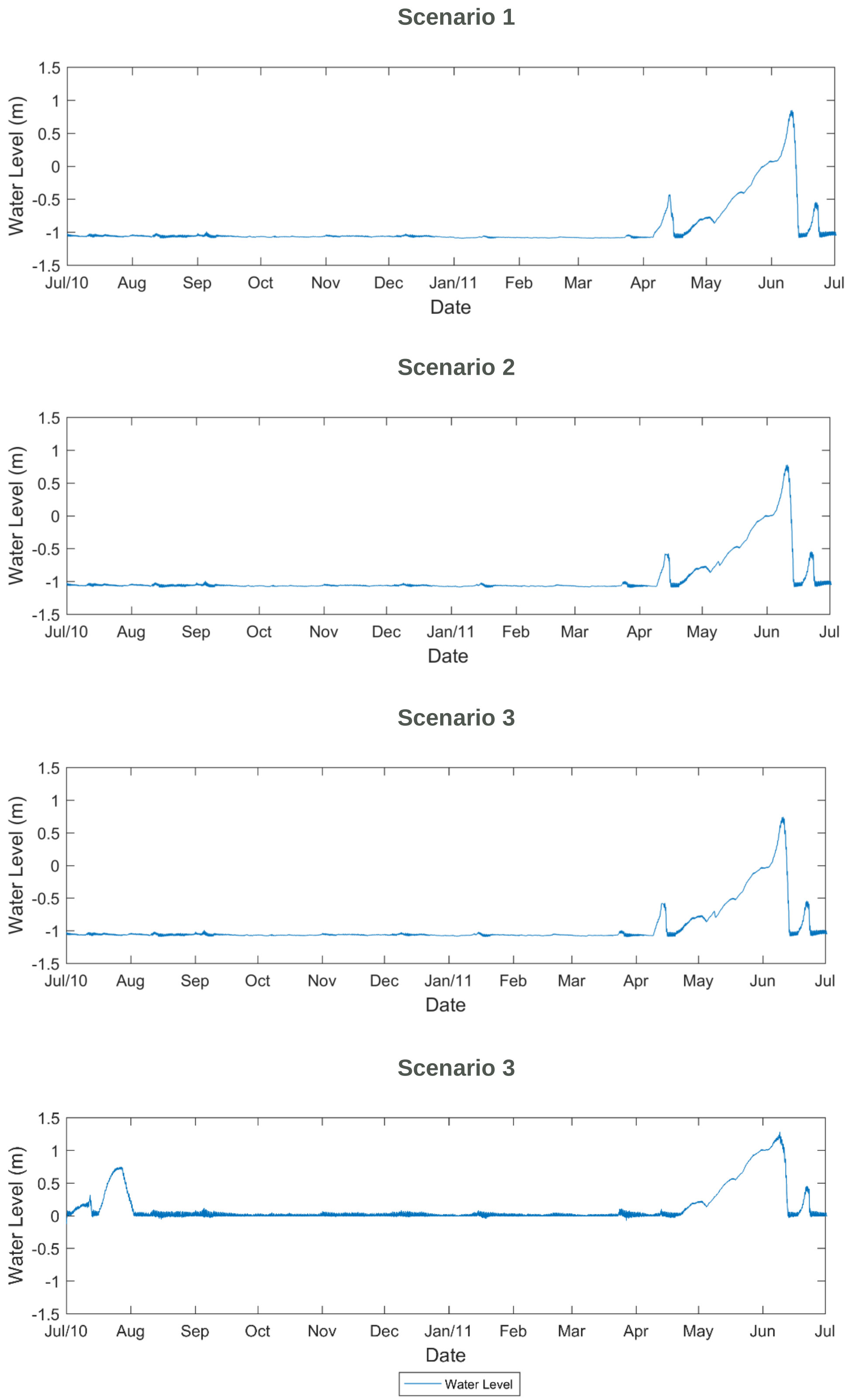

Figure 3-28 Water Level Timeseries Discussion

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3.15 Environmental impacts

The inclusion of discharge controls based on the extent of lacustrine deoxygenation has very marginally improved ambient water quality, when compared to previous TLI scenarios. This improvement is not significant in terms of making any material difference to lake health, with strong summertime thermal stratification and consequential DO reductions at depth still occurring across a large section of the lake. For example, at station T11, DO is predicted at the bottom layer to reach as low as 10% for scenario 1, and other locations within the model domain show bottom waters becoming completely anoxic for extended periods (Figure 3-27). These summertime low oxygen conditions result in the release of bioavailable nutrients from the sediments which then cause extensive algal activity.

As such, despite the execution of a large number of scenarios that examine a variety of barrage discharge controls, the following outcomes remain:

- Summertime thermal stratification persists in the proposed lake, which is the fundamental driver of water quality issues within the lake
- Associated depletion of dissolved oxygen at depth, with the development of ecologically toxic anoxic waters still occurs
- Remineralisation of organic matter within and on top of the sediments persists
- Supply of nutrients to the water surface where their abundance, together with light and warm temperatures still leads to significant primary production and algal activity. This algal activity could include blooming of any number of species, including those harmful to humans. Other Australian reservoirs of similar sizes and depths to the proposed Tamar Lake have regularly reported the presence of potentially toxic blue green algae (such as *Cylindrospermopsis Raciborskii*, with its associated toxin cylindrospermopsin) under summertime conditions similar to those predicted by the modelling reported here.

In addition to the above, the pipe structure and control rules considered here introduce the risk of moving large volumes of poorly oxygenated water from upstream of the barrage to the downstream receiving environments. The system therefore would act as a conduit for delivering low DO water from upstream of the barrage to downstream receiving environments. Low DO water is an acute toxicant to aquatic fauna and flora, and as such these releases present an additional and significant environmental hazard to the region.

In summary, outcomes from this study show that the proposed Tamar Lake barrage arrangement, under all scenarios considered, presents a significant environmental threat to the area. This threat is driven primarily by persistently depressed seasonal lacustrine dissolved oxygen concentrations at depth, which in turn result from the onset and maintenance of summertime thermal stratification and elevated algal activity. Based on Australian experiences of similar lakes, it is possible that this algal activity could include blooming of potentially toxic species. This could then see the proposed Tamar Lake present a human health threat, over and above the broader environmental threats discussed in this report.

3.16 Potential future investigations

BMT WBM has undertaken a large number of simulations of proposed Tamar Lake configurations using the fully three dimensional TUFLOW FV model. This model was used so that detailed spatial and temporal features of the proposed lake could be investigated. Now that these detailed investigations are complete, a further query has been raised regarding how/if the magnitude, composition and duration of summertime algal blooms might be investigated over longer temporal scales, and under varying summer weather conditions.

Two potential options exist for investigating the proposed Tamar Lake.

3.16.1 Extend the TUFLOW FV model

TUFLOW FV, although three dimensional and detailed, can be executed over a decadal period. Indeed, BMT WBM has affected such simulations for several clients including Sydney Water, where the entire Hawkesbury Nepean river system from Pheasants Nest and Broughtons Pass (~200 m AHD) to the ocean boundary at Barrenjoey was simulated. This TUFLOW FV model was calibrated over a 2 year period, but then one hundred (100) ten-year simulations were executed and provided to Sydney Water as part of the commission.

Naturally, this is no small undertaking, but it is possible and TLI may wish to consider extending the existing TUFLOW FV model to encompass a decadal simulation, with variable summer meteorology. This would provide the highest quality outcome, and the model would need no additional calibration or validation. The obvious disbenefit is that this approach is computationally intensive and scenarios would take some time (likely several days to a week each) to complete.

3.16.2 One dimensional model

Prior to the wider adoption of three dimensional models such as TUFLOW FV, one dimensional lake models were used extensively throughout academia and consulting. These models simulate only the vertical dimension, and treat the simulated lake as a series of horizontally homogeneous layers. These layers do capture the lake volume accurately (they follow a hypsometric curve) and each computes its own hydrodynamic and water quality quantities. Vertical mixing and stratification processes are simulated, as is light and all relevant water quality processes.

The key advantage of one dimensional models is that they have a small computational overhead and so can easily be run for periods up to or exceeding 100 years. BMT WBM has undertaken such simulations in the past for various domestic customers. Of course, the meteorological forcing over this 100 years can comprise a mixture of real and synthesised data in order to capture the desired range of climatic conditions, as is sought by TLI. The key disadvantage of one dimensional models is that they cannot resolve lateral lacustrine processes such as intrusions or meteorological processes such as sheared wind or radiative fields. In the context of TLIs enquiry however, this is most likely a second or third order issue.

An example one dimensional model is the General Lake Model. It has been co-developed by AED at the University of Western Australia. AED also developed the water quality model used in the existing Tamar Lake TUFLWO FV model deployed in this study.

4 References

BMT WBM 2015. **Tamar Estuary 3D Modelling**. Prepared for NRM North. Ref. no. R.B20921.001.04.

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