

Limerick WWTP Upgrade and Regional Bioresource Centre

Appendix 16.3 - Modelling Report

June 2026



Formerly JB Barry Partners who became part of Egis in 2023

REPORT

Modelling report for Bunlicky WWTP Upgrade

Client: Uisce Éireann

Reference: BH6548-RHD-XX-XX-RP-X-0001

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Executive Summary

The aim of this study is to assess whether the proposed upgrade of the Bunlicky wastewater treatment plant (WWTP) complies with the WFD conservation status objectives of the receiving water bodies and the conservation objectives of any protected Natura 2000 sites, as defined in the Surface Waters Regulations 2009 in the receiving waterbodies. The Bunlicky WWTP provides secondary treatment to domestic and non-domestic wastewater from the Limerick City Agglomeration. In the proposed upgrade, the WWTP design capacity is proposed to increase from 130,000 PE to 285,000 PE (and allow provision to increase to 325,000 PE).

The receiving waterbodies are Limerick Dock (Shannon River), Upper Shannon Estuary and Maigue Estuary. These waterbodies are designated as Special Areas of Conservation (SAC), Special Protection Areas (SPA), proposed Natural Heritage Areas (NHA) and WFD Transitional Waterbodies. The latest available WFD status (2019-2024) of Limerick Dock was 'Poor', Upper Shannon Estuary was 'Poor' and Maigue Estuary was 'Moderate'. Agriculture has been identified as the most significant pressure on water quality in the Upper Shannon Estuary and Maigue Estuary.

The calibrated and validated model was applied to assess three key water quality parameters (BOD, DIN, and MRP) in the baseline situation and for several WWTP upgrade scenarios, including improved treatment standards. The study investigated the impact of these upgrades on water quality under summer and winter conditions to determine if the changes were acceptable.

In addition to the upgrade of Bunlicky WWTP, this study also considered the cumulative impact of two other large WWTP upgrade projects:

- Castletroy WWTP, increase of capacity from 45,000 PE to 81,000 PE within 25-year growth;
- Shannon Town WWTP with a capacity of 28,000 PE.

Both the effect of the Bunlicky WWTP upgrade alone, and the combined effect of the three WWTP upgrades, were considered in this study. All three plants discharge to the River Shannon and Shannon Estuary. In addition to this, a scenario with improved water treatment for BOD and MRP at the Bunlicky WWTP was analysed for the summer conditions to simulate the worst-case scenario of the plume dispersion, which results from a combination of the highest level of the WWTP upgrade and low discharge of the Shannon River.

The extent of the mixing zones for different water quality parameters was determined based on statistical analysis of model results across the spring-neap tidal cycle for the baseline situation and different WWTP upgrade scenarios. The following conclusions can be drawn from the analysis:

- **BOD:** The study area is characterized by a high status based on indicative water quality (WQ) for BOD. In the baseline situation, the extent of the BOD mixing zone with good and moderate EQS status is limited to the area in close proximity to the outfall. However, all WWTP upgrade scenarios result in a significant expansion of these mixing zones. In the summer period, the length of the mixing zone with good EQS status increases from 110 to 270-290 meters (0.1 to 0.3% of the estuary), while the length of the mixing zone with moderate EQS status increases from 70 to 110 meters (0.07 to 0.1%). In the winter period, the extent of the mixing zones with good and moderate EQS status is similar to the summer period, at 290 (0.3%) and 130 (0.1%) meters, respectively.
- **DIN:** For DIN, a large part of the study area is characterized by a good EQS status in both summer and winter conditions under the baseline scenario. As no DIN EQS is defined for WFD Transitional Waters, this status is based on indicative water quality thresholds for DIN in WFD Coastal Waters. With the WWTP upgrade, the length of the good EQS status zone expands slightly in summer conditions, while a moderate EQS status zone emerges near the outfall. However, the length of

this moderate EQS status zone is minimal, reaching a maximum of 80 meters (0.08% of the estuary). In winter conditions, there are no notable changes in indicative WQ status following the WWTP upgrade.

- **MRP:** For MRP, a large part of the study area shows MRP background concentrations are already elevated, resulting in 'Moderate' indicative WQ status for MRP in summer conditions. In winter conditions, the area generally shows a 'Good' indicative WQ status with only moderate indicative WQ status within 350 m near the outfall under the baseline scenario. In the WWTP upgrade scenarios, only summer scenarios show a notable increase (> 0.060 mg/l corresponding to a 'Moderate' WQ status in the absence of background MRP), with impacts extending from approximately 2.5 km upstream to 8 km downstream (11% of the estuary). This leads to an expansion of the 'Moderate' WQ status, from 16 to 18.5 km (16 to 18% of the estuary) in the summer conditions and from 350 to 1,100 m (0.3 to 1%) in the winter conditions. Reduction of MRP concentrations at the outfall following the EPA licence review improved the water quality status of the study area during summer conditions, changing it from predominantly moderate to good, with moderate status observed only in the immediate vicinity of the outfall.

Overall, the Bunlicky WWTP upgrade is expected to increase concentrations of all analysed water quality parameters, with the highest increases occurring near the outfall. However, the overall impact on water quality within the study area remains limited: DIN largely complies with EQS for a transitional water, with only minor and localised 'Moderate' EQS status near the outfall (up to 130 m), while BOD shows localised 'Moderate' status up to 80 m, resulting in limited non-compliance. In contrast, MRP is already predominantly non-compliant under baseline conditions (up to 16 km) and further deteriorates under all upgrade scenarios (up to 18.5 km). This reflects a cumulative deterioration rather than the introduction of new impact areas. Without elevated background concentrations, the additional load would result in 'Moderate' water quality conditions extending from around 2.5 km upstream to 8 km downstream (11% of the estuary).

The upgrade of Bunlicky WWTP is designed to sustain development and protect water quality, therefore it will be able to meet better treatment standards for MRP and BOD than the current licence. In this upgrade scenario with improved treatment standards, the length of the BOD mixing zone is significantly reduced, and the MRP mixing zone shows a marked improvement in status from 'Moderate' to 'Good' indicative WQ status compared to the current situation .

Acronyms

BOD	Biological Oxygen Demand
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DWF	Dry Weather Flow
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
ELV	Emission Limit Values
EQS	Environmental Quality Standards
FM	Flexible Mesh
IW	Irish Water
NHA	Natural Heritage Areas
PE	Population Equivalent
PSU	Practical Salinity Unit
SAC	Special Areas of Conservation
SPA	Special Protection Areas
SWO	Stormwater Overflow
TON	Total Organic Nitrogen
TP	Total Phosphorus
UÈ	Uisce Èireann
WFD	Water Framework Directive
WQ	Water Quality
WWDL	Wastewater Discharge License
WWTP	Wastewater Treatment Plant

1 Introduction

1.1 Project definition and objective

J.B. Barry and Partners Ltd. were appointed by Uisce Éireann (UÉ), formerly known as Irish Water (IW), to progress the Gate 2 Planning and Detailed Design Stage for the upgrade of the Bunlicky wastewater treatment plant (WWTP). The Bunlicky WWTP is located to the west of Limerick and releases its effluent on the Shannon Estuary (Figure 1-1). J.B. Barry appointed HaskoningDHV (since 2025 Haskoning) to execute a modelling study for this assessment which follows a tiered assessment, as outlined in the UÉ Technical Standards for Marine Modelling IW-TEC-100-015 (Uisce Éireann, 2022).

The Bunlicky WWTP provides secondary treatment to domestic and non-domestic wastewater from the Limerick City Agglomeration. The present Bunlicky WWTP was constructed in 2000 and designed for 130,000 PE. Now, a significant upgrade is planned to increase the capacity to 285,000 PE (with allowance for a further upgrade to 325,000 PE).

The increase in outfall discharge from the upgraded Bunlicky WWTP could potentially lead to a decrease in the water quality of the receiving water, as the concentrations of suspended sediment and dissolved substances may exceed the Environmental Quality Standards (EQS) of the Water Framework Directive (WFD) as defined in the Surface Waters (amendment) Regulations 2019 (European Union Environmental Objectives (Surface Waters) (AMENDMENT) regulations 2019, Statutory Instruments No. 77 of 2019). However, the upgrade project is designed to sustain development and protect water quality, and the upgraded WWTP will be able to meet better treatment standards for MRP and BOD than the current license.

The receiving WFD waterbody is Limerick Dock (Shannon River), with adjacent WFD waterbodies Upper Shannon Estuary and Maigue Estuary. These three WFD waterbodies are designated as Special Areas of Conservation (SAC), Special Protection Areas (SPA) and proposed Natural Heritage Areas (NHA). The WFD status of 2019-2024 of Limerick Dock is 'Poor', Upper Shannon Estuary is 'Poor' and Maigue Estuary is 'Moderate'.

The main objective of this study is to evaluate the potential impact of the existing and proposed discharges and whether this results in the exceedance of the EQS in the receiving water for the upgrade of Bunlicky WWTP and a combined upgrade of Bunlicky WWTP, Castletroy WWTP and Shannon Town WWTP. The following water quality parameters have been assessed:

- Dissolved Inorganic Nitrogen (DIN);
- Molybdate Reactive Phosphorus (MRP);
- Biochemical Oxygen Demand (BOD).

No designated bathing water and shellfish areas are located in the vicinity of the Bunlicky WWTP or in the model domain. Therefore, bacteria concentrations are not considered.



Figure 1-1: Location of the Bunlicky WWTP upstream of the Shannon Estuary, showing Bunlicky WWTP (red square), the present outfall pipe (red circle), and Corcanree Main Lift Pumping Station (blue triangle).

1.2 Summary of Model Development

HaskoningDHV undertook a tiered assessment for the Bunlicky WWTP upgrade in the Model Scoping report (HaskoningDHV, 2021), as outlined in Uisce Éireann's Technical Standards for Marine Modelling IW-TEC-100-015 (Uisce Éireann, 2022). The screening assessment of the existing and proposed outfall discharges of Bunlicky WWTP revealed that the WFD EQS for BOD and MRP/OP are exceeded in the vicinity of the discharge location, both in the present situation, as well as in the future situation, after the upgrade of the WWTP. The modelling approach was determined from the findings of Stage 1 (scoping study including tiered assessment (HaskoningDHV, 2021)) and Stage 2 (Surveys and SIR (HaskoningDHV, 2022)) to account for the spatial and temporal variations in the tidal currents, river flow, and plume dispersion.

To provide input for the construction, calibration and validation of the numerical model, a survey campaign over a 35-day period from the end of September 2021 to the beginning of November 2021 was organised. During these surveys, data describing bathymetry, meteorology, hydrology, currents and water quality were collected. The obtained survey data in combination with existing data from other sources was considered sufficient and suitable as presented in the Survey Interpretive Report (HaskoningDHV, 2022). The survey data showed that a three-dimensional model is required to accurately reproduce the vertical variations in current velocity, salinity and water temperature, and accurately predict the effluent dispersion from the upgraded Bunlicky WWTP outfall.

A 3D hydrodynamic and water quality model in the Flexible Mesh (FM) version of MIKE 21/3 modelling software was constructed, calibrated, and validated using approaches set out in Uisce Éireann's Technical Standards Marine Modelling (Uisce Éireann, 2022) for hydrodynamics, temperature and salinity. Model calibration and validation results are presented in the Model Calibration Report (HaskoningDHV, 2023). Overall, the hydrodynamic model was able to reproduce the observed water level, currents, water temperature, and salinity.

The water quality model showed that it was able to reproduce the observed BOD, DIN, and MRP. This means that the water quality model is suitable for modelling the dispersion of Bunlicky WWTP effluent in the present situation and the future situation with an upgraded WWTP.

This document presents the simulation results for the existing and proposed discharges of the Bunlicky WWTP upgrade with the calibrated and validated numerical model. The water quality within the receiving waters is evaluated against the EQS.

1.3 Model scenarios

The present Bunlicky WWTP was constructed in 2000 and designed for 130,000 PE. Now, a significant upgrade is planned to increase the capacity to 285,000 PE, with allowance for a further upgrade to 325,000 PE. Both upgrades are simulated in this study.

In addition to Bunlicky WWTP, two other major WWTPs, being Castletroy WWTP and Shannon Town WWTP, discharge into the Shannon Estuary or Shannon River and are planned to be upgraded in the future. The Shannon Town WWTP with a capacity of 28,000 PE. Castletroy WWTP is planned to be upgraded from c. 35,000 PE to 77,500 PE in 10 years and to 81,000 PE within 25 years.

It is expected that the ELV concentrations will be adjusted following an EPA license review and Environmental Impact Assessment (EIA), where BOD is reduced from 25 to 20 mg/L and MRP is reduced from 6.5 to 1 mg/L. These ELV concentrations were applied to the model for only the summer conditions and discharges corresponding to the development status code C05 to simulate the worst-case scenario of the plume dispersion, which results from a combination of the highest level of the WWTP upgrade and low discharge of the Shannon River.

In order to predict the effects of the proposed WWTP upgrades, the existing situation and multiple future scenarios with modelled WWTP discharge concentrations based on future EPA revised ELVs and capacities are modelled. The simulated modelling scenarios are listed in Table 1-1. The codes for the modelling scenarios are defined as:

- **Above Ground Scheme Code** - the asset location and types of treatment for continuous discharges:
 - A: Existing situation: baseline with current discharges and ELV concentrations;
 - C: Upgraded treatment with existing outfall: increased PE with current and ELVs concentrations as stated below.
- **Development Status Code** - the population load on the system based on the epoch and development status of the area:
 - 01: Existing situation with a 130,000 PE and current ELV concentrations.
 - 02: Upgrade of Bunlicky WWTP to 285,000 PE and current ELV concentrations;
 - 03: Upgrade of Bunlicky WWTP to 325,000 PE and current ELV concentrations;
 - 04: Combined upgrade of Bunlicky WWTP to 285,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and current ELV concentrations;
 - 05: Combined upgrade of Bunlicky WWTP to 325,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and current ELV concentrations.
 - 06: Combined upgrade of Bunlicky WWTP to 325,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and lowered ELV concentrations for BOD and MRP for Bunlicky WWTP.
- **Season** - the conditions of the receiving waters and discharge rates and quality:
 - s: summer;
 - w: winter.

Table 1-1: Modelling scenario codes.

Nr	Code	Above Ground Scheme Code	Development Status Code							Season
			01	02	03	04	05	06	Description	
1	A01s	Existing situation (A)	✓						Existing situation with a 130,000 PE and current ELV concentrations	Summer (s)
2	A01w	Existing situation (A)	✓						Existing situation with a 130,000 PE and current ELV concentrations	Winter (w)
3	C02s	Upgraded treatment with existing outfall (C)		✓					Upgrade of Bunlicky WWTP to 285,000 PE and current ELV concentrations	Summer (s)
4	C02w	Upgraded treatment with existing outfall (C)		✓					Upgrade of Bunlicky WWTP to 285,000 PE and current ELV concentrations	Winter (w)
5	C03s	Upgraded treatment with existing outfall (C)			✓				Upgrade of Bunlicky WWTP to 325,000 PE and current ELV concentrations	Summer (s)
6	C03w	Upgraded treatment with existing outfall (C)			✓				Upgrade of Bunlicky WWTP to 325,000 PE and current ELV concentrations	Winter (w)
7	C04s	Upgraded treatment with existing outfall (C)				✓			Combined upgrade of Bunlicky WWTP to 285,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and current ELV concentrations	Summer (s)
8	C04w	Upgraded treatment with existing outfall (C)				✓			Combined upgrade of Bunlicky WWTP to 285,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and current ELV concentrations	Winter (w)
9	C05s	Upgraded treatment with existing outfall (C)					✓		Combined upgrade of Bunlicky WWTP to 325,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and current ELV concentrations.	Summer (s)
10	C05w	Upgraded treatment with existing outfall (C)					✓		Combined upgrade of Bunlicky WWTP to 325,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and current ELV concentrations	Winter (w)
11	C06s	Upgraded treatment with existing outfall (C)						✓	Combined upgrade of Bunlicky WWTP to 325,000 PE and Castletroy WWTP to 81,000 PE within 25-year growth, and Shannon Town WWTP of 28,000 PE and lowered ELV concentrations for BOD and MRP for Bunlicky WWTP	Summer (s)

2 Model description

This chapter describes the numerical hydrodynamic and water quality model, as well as the setup for scenario modelling for the winter and summer seasons (January and August). The summer and winter conditions are based on the available information in the Model Scoping report (HaskoningDHV, 2021).

2.1 Modelling software

In the modelling study, the MIKE model software package is used. MIKE is developed by Danish Hydraulic Institute (DHI) and is a widely and worldwide applied model software package. It was designed for simulating hydrodynamics, waves, sediment dynamics and water quality in coastal, estuarine, and riverine environments.

From the analysis of the vertical distribution of salinity and water temperature, it became clear that the flows near the Bunlicky WWTP outfall are stratified (HaskoningDHV, 2021). This means that a 3-dimensional modelling approach is required to simulate the effluent dispersion. Therefore, the three-dimensional MIKE 3 is applied.

The MIKE 3 model consists of a number of modules, each with a specific objective. The modules relevant for this study are:

- MIKE 3 HD for simulation of the three-dimensional hydrodynamics.
- MIKE 3 MT for advection and diffusion of dissolved substances and dye tracing.
- MIKE 3 Particle Tracking for drogue tracking.

The Flexible Mesh version of MIKE 3 is used, which provides a high degree of flexibility in computational grid resolution to optimize the balance between level of detail and computational time.

2.2 Model domain

The model domain can be seen in Figure 2-1. The downstream boundary of the model domain is located at Shannon Airport, the upstream boundaries at the Ardnacrusha Dam and upstream of Castletroy. The downstream boundary is chosen such that a water level measurement location is nearby (for boundary condition generation) and the distance to the Shannon Town WWTP is sufficiently large to ensure its effluent plume remains within the model domain. The upstream boundaries are chosen at the approximate tidal limit and to include Castletroy WWTP. Additionally, the boundary in the original River Shannon was chosen so that Castletroy WWTP can be included in the model as a point source, enabling modelling of the future upgraded WWTP. The contribution from the Groody River, Blackwater River and Mulkear are included in the upstream boundary of the original River Shannon.

Relevant tributaries to the estuary (see also Figure 2-1) are included in the model domain up to the location where a water quality monitoring location is present and thus a trustworthy water quality boundary condition can be derived. For the Mague River, this entails including it up to the Carraigh West monitoring point, for the Owenagarney River up to the N18 bridge.

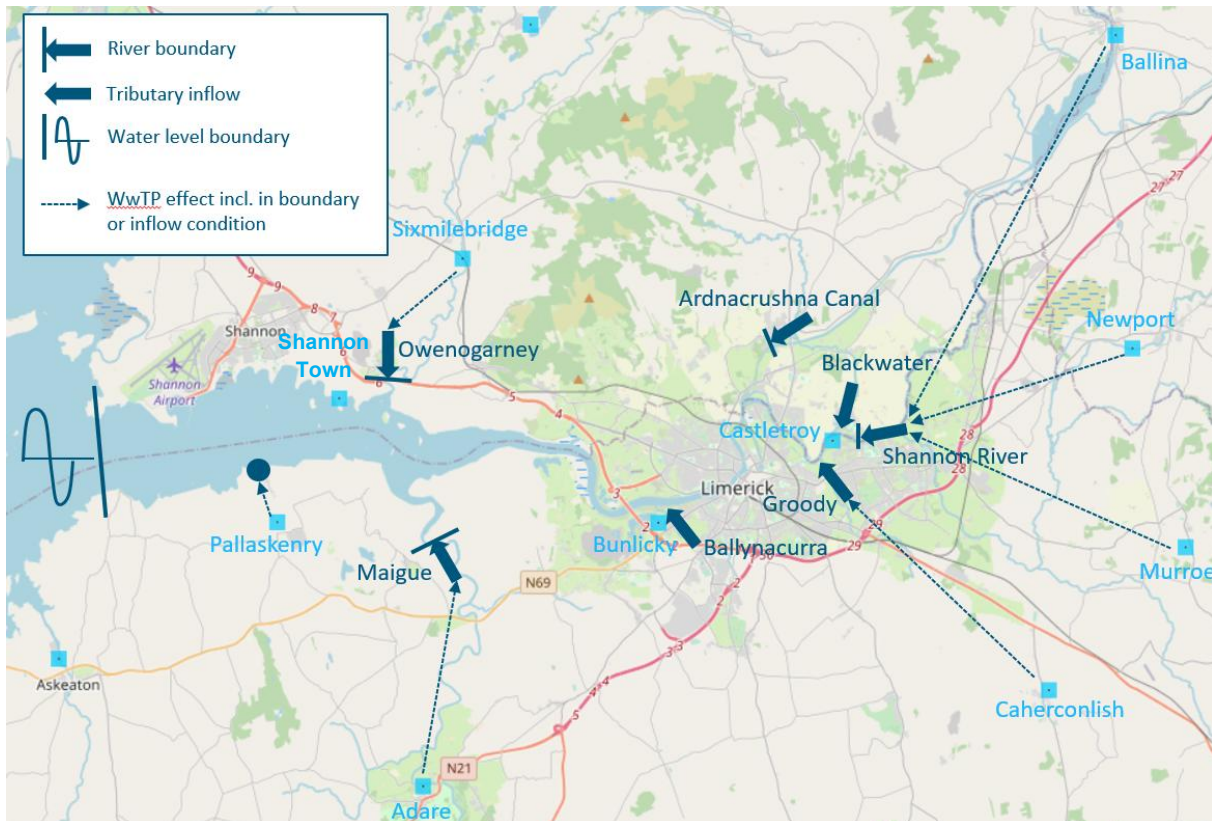


Figure 2-1: Model domain for the Marine Modelling Study.

2.3 Bathymetry

The model bathymetry is shown in Figure 2-2 and Figure 2-3. This model bathymetry is based on the survey data. The relatively steep channel banks upstream of Limerick Dock were not captured correctly in the resolution of the DTM and model bathymetry. The bed level along the channel banks upstream of Limerick Dock were manually corrected to account for the relatively steep channel banks, which would otherwise result in an underestimation of the water depth near the channel banks and thus underestimation of the tidal discharge. The datum on which the bathymetry is based is Malin Head Ordnance Datum (m OD).

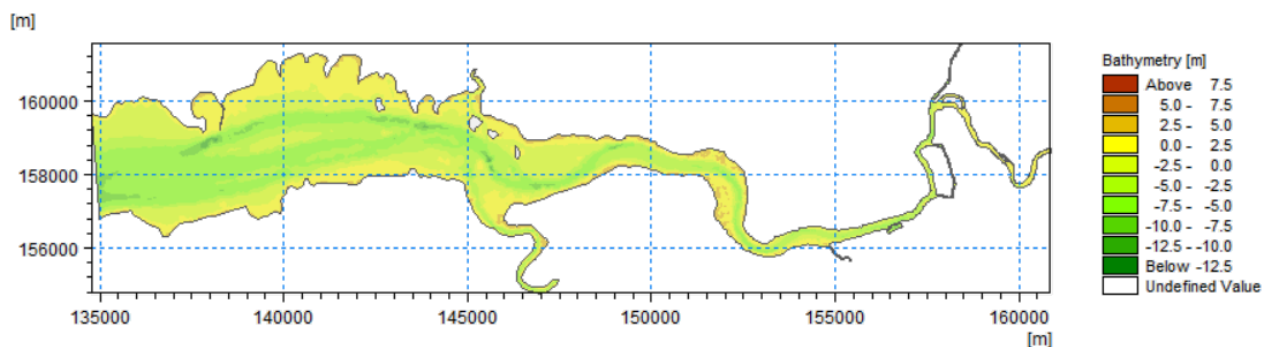


Figure 2-2: Bathymetry in the MIKE model

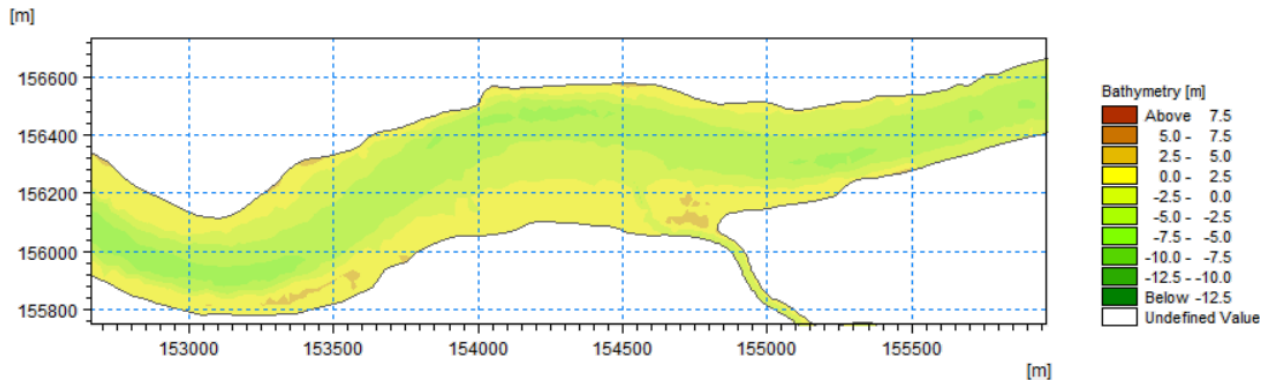


Figure 2-3: Detail of the model bathymetry around Bunlicky WWTP outfall.

2.4 Computational grid

The total computational grid is shown in Figure 2-4. It is an unstructured triangular grid with spatially variable grid resolution. The grid resolution depends on the channel width and the area of interest: narrow channels such as upstream and in Limerick have small grid cells and a high grid resolution to simulate the discharge accurately (Figure 2-5), and the grid resolution at the Bunlicky WWTP outfall is also relatively high to accurately capture the outfall plume dispersion (Figure 2-6). The wide downstream area has a relatively low grid resolution with large grid cells (Figure 2-7).

The vertical model resolution was based on a discretisation in layers of varying thicknesses known as sigma layers. The model developed contained 5 layers with an equidistant distribution independent of variations in water depth and water level. An amount of 5 layers was selected to adequately resolve the vertical gradients in temperature and salinity.

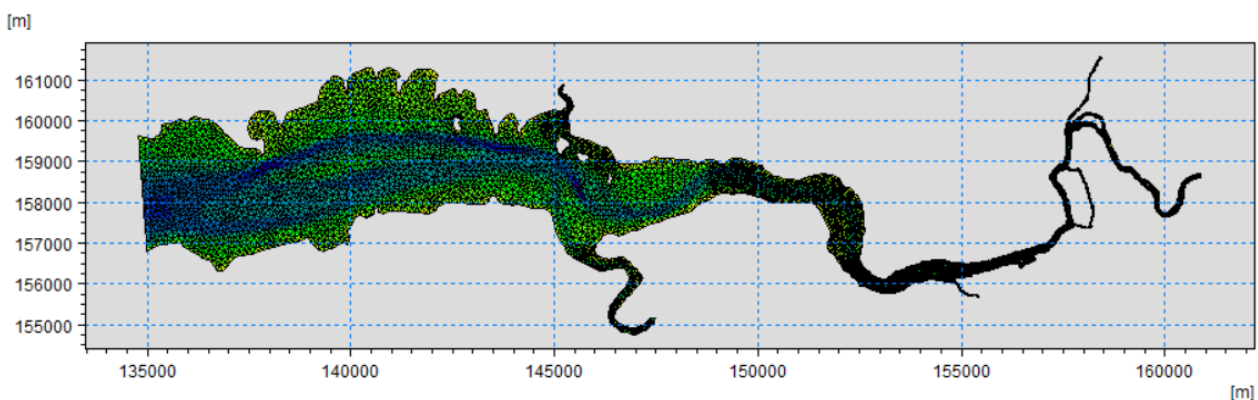


Figure 2-4: Total computational grid

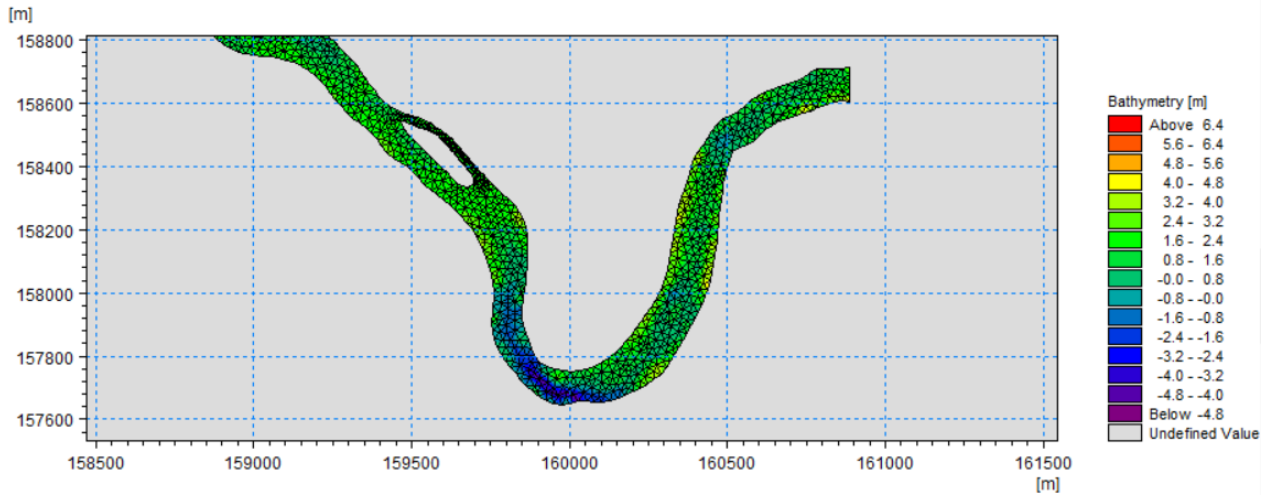


Figure 2-5: Detail of computational grid around the upstream model boundary

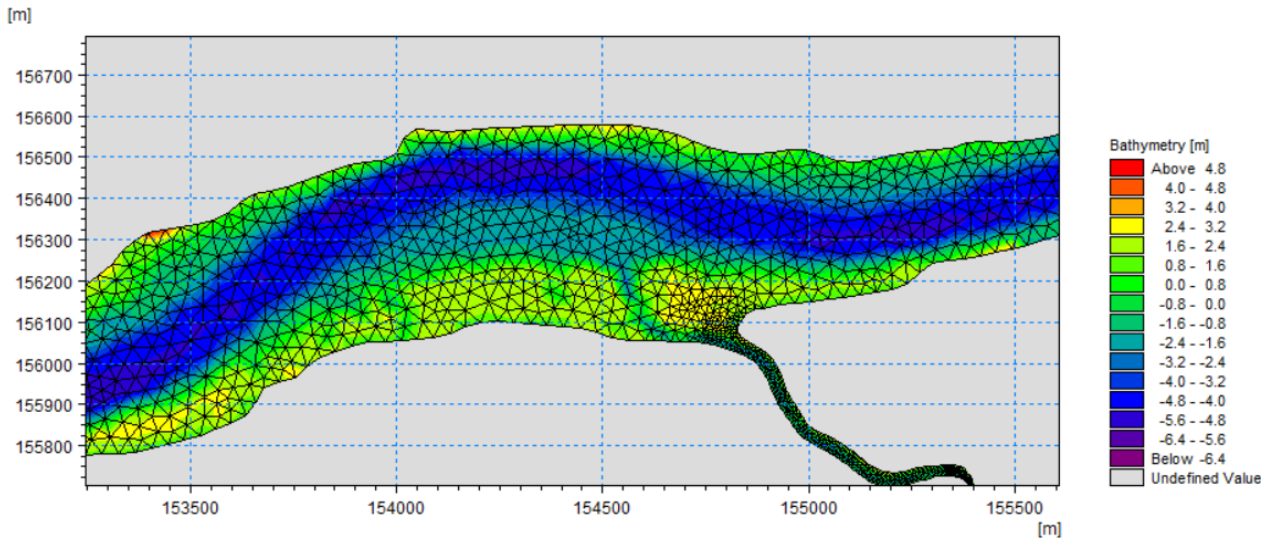


Figure 2-6: Detail of computational grid around Bunlicky WWTP outfall

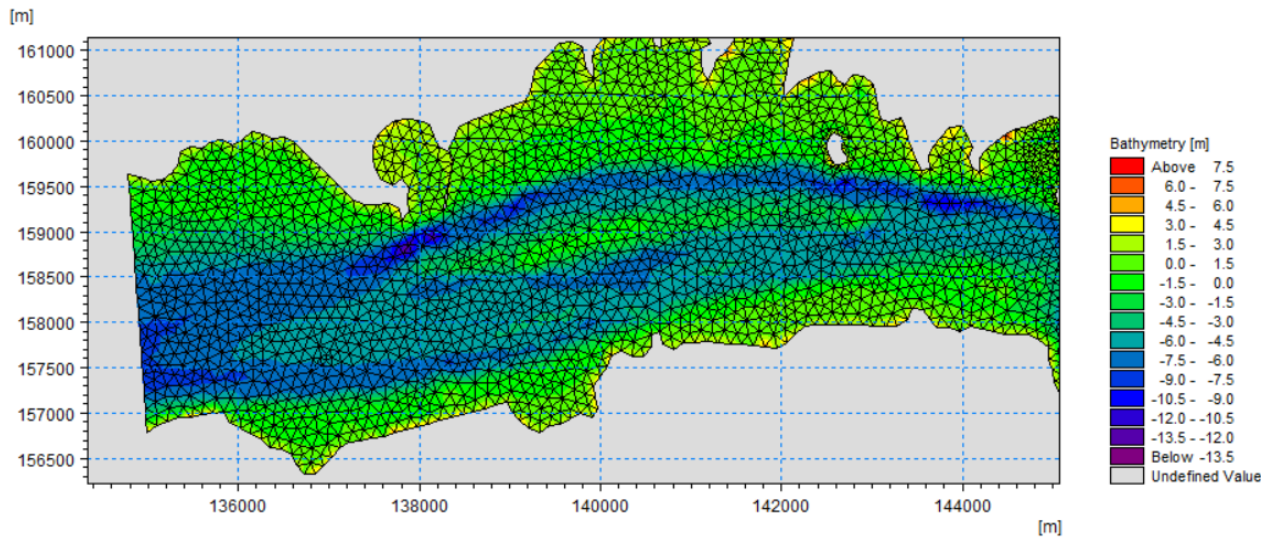


Figure 2-7: Detail of computational grid around the downstream model boundary

2.5 Hydrodynamic model setup

2.5.1 Boundary conditions

At the downstream boundary near Shannon Airport, a water level timeseries of the astronomical tide is imposed. Further, all river inflows are set at Q95 for summer and Q30 for winter conditions.

Only the river tributaries with a Q30 discharge larger than 0.49 m³/s, which is the Dry Weather Flow (DWF) of Bunlicky WWTP, are included in the model. These tributaries are Blackwater River, Groody River, Maigue River, Owenogarney River, and Ballinacurra Creek. Table 2-1 gives the Q30 and Q95 flow rates for the rivers and tributaries that discharge on the Shannon Estuary within the model domain. Tributaries with Q30 discharges smaller than 0.49 m³/s have limited influence on the flow patterns as they are smaller than the current DWF of Bunlicky and are trivial compared to the discharge of Shannon River, the three larger tributaries and tidal discharge.

The imposed discharge at the upstream boundary of the Shannon River is derived from measured discharges at Parteen Weir together with the discharges from the tributaries that join the Shannon River, being the Mulkear, Blackwater River, and Groody River.

At the upstream boundary at Ardnacrushna Dam, a variable discharge was applied in the calibrated model. The discharge variation is necessary to produce the abrupt surge in current speed during the upstream propagation of the flood. For this discharge, a Q30 outflow of 280 m³/s from the Ardnacrushna Dam was applied and temporally adjusted by reducing the discharge to 185 m³/s during rising tide to increase the upstream propagation of the flood, and by increasing the discharge to 385 m³/s during falling tide to reproduce the ebb current. This discharge timeseries boundary condition specified at Ardnacrushna Dam is consistent with the ESB reported daily average flows during winter conditions.

Table 2-1: Q30 and Q95 discharge rates applied at the boundaries within the model domain.

Boundary	Q30 discharge [m ³ /s]	Q95 discharge [m ³ /s]
Ardnacrushna Canal	185 - 385	6.3
Shannon River (Parteen Weir, the Mulkear, Blackwater River, Groody River)	31.08	13.15
Ballinacurra Creek	0.80	0.10
Owenogarney River	5.60	0.50
Maigue River	18.87	2.11

2.6 Water quality model setup

2.6.1 Boundary conditions

The water quality, salinity, and water temperature boundary conditions can be found in Table 2-2. The values of the downstream (Shannon Airport) and upstream boundaries (Ardnacrusha Canal and Shannon River) were derived from available EPA monitoring stations. Data for the period of 2013-2020 was evaluated and summer and winter average values were determined. For the tributaries that discharge on the Shannon Estuary, no monitoring stations were available and therefore average values from the survey campaign (September to November 2021) were used for the water quality and salinity for both the summer and winter conditions. The water temperature is set to 15°C in summer and 8°C in winter.

Table 2-2: Water quality, salinity, and temperature boundary conditions.

Boundary	Source	Summer					Winter				
		BOD [mg/l]	MRP [mg/l]	DIN [mg/l]	S [PSU]	T [°C]	BOD [mg/l]	MRP [mg/l]	DIN [mg/l]	S [PSU]	T [°C]
Shannon Airport	Monitoring station SN340 Beagh Castle (TW19004 123SN3001)	<1	0.034	0.30	18	15	<1	0.034	0.89	18	8
Ardnacrusha Canal	Monitoring station Parteen Bridge (RS25S750900)	<1	0.006	1.13	<1	15	<1	0.030	1.39	<1	8
Shannon River*	Monitoring station Shannon Bridge (RS25S012561)	1.20	0.013	1.46*	<1	15	1.19	0.026	2.64*	<1	8
Ballinacurra Creek	Survey campaign	1.43	0.038	1.10	<1	15	1.43	0.038	1.10	<1	8
Owenogarney River	Survey campaign	0.76	0.024	0.60	<1	15	0.76	0.024	0.60	<1	8
Maigue River	Survey campaign	0.95	0.057	1.12	1	15	0.95	0.057	1.12	1	8

*DIN at Shannon River is based on the measured ammonium and ammonium/ Total Oxidised Nitrogen (TON) = Nitrate + Nitrite ratio found at Ardnacrusha Dam where DIN is calculated by the sum of ammonium and TON.

2.6.2 WWTP outfalls

In addition to Bunlicky WWTP, two other major WWTPs, being Castletroy WWTP and Shannon Town WWTP, discharge into the Shannon Estuary or Shannon River and are planned to be upgraded in the future. The ELV concentrations and discharges for these three WWTP outfalls are given in Table 2-3.

The discharge is provided for the six Development Status Code of the simulations as defined in Section 1.3 (Table 1-1). The modelled WWTP discharge concentrations are based on current ELVs from the Wastewater Discharge Licenses (WWDL) or from future EPA revised ELVs. The WWTP discharge used for modelling is the DWF multiplied by a Peaking Factor. The value used for the Peaking Factor is 1.5 (as selected in consultation with UÈ in the Model Scoping report (HaskoningDHV, 2021)).

It is expected that the ELV concentrations will be adjusted following an EPA licence review and EIA where BOD is reduced from 25 to 20 mg/l and MRP is reduced from 6.5 to 1 mg/l. The concentration of DIN remained at the same level of 30 mg/l.

The salinity of the effluent from the WWTPs is set to 0 PSU. The water temperature is set to 10 °C in winter and 20 °C in the summer.

Table 2-3: WWTP outfall water quality concentrations and discharges specified for the six Development Status Code.

Discharge (DWF * 1.5) [m³/day]	
	05

	101,560
	15,866
	9,648

¹ In Development Status Code 6 BOD is reduced from 25 to 20 mg/l.

² In Development Status Code 6 MRP is reduced from 6.5 to 1 mg/l.

³ No MRP ELV defined, therefore the same concentration as for Bunlicky WWTP is applied. This assumes no phosphorus removal in the process.

⁴ In Development Status Code 4 and 5 MRP concentration is reduced to 0.5 mg/l.

⁵ The design PE of the Shannon Town WWTP is 28,000, while the current AER reports a peak week load of 15,183 PE. To be conservative, the design capacity is applied for both the existing and future scenario.

3 Environmental Quality Standard (EQS)

EQS values are defined in the Surface Water (Amendment) Regulations 2019 and implemented by the WFD. The WFD Water Quality Standards for a transitional waterbody, such as Limerick Dock, Upper Shannon Estuary and Maigue Estuary, are listed in Table 3-1 for BOD and MRP.

DIN is a non-regulatory target standard for the WFD transitional waterbodies. For coastal water bodies, the threshold DIN concentration is determined by interpolation based on median salinity. The median salinity around Bunlicky WWTP is below 1 psu, so the concentration of 2.6 mg/l required for obtaining a 'Good' EQS status was considered as the reference for analysing water quality at this location.

For DIN and MRP, the status was based on the median concentration. For BOD, the status was based on the concentration below which 95% of the data were found (or in other words, the concentration that is exceeded by 5% of the dataset).

Table 3-1: Transitional and coastal waterbody EQS (Surface Water (Amendment) Regulations 2019)

EQS	Transitional Waterbody		Coastal Waterbody	
	'Good' status	'High' status	'Good' status	'High' status
BOD	<= 4.0 mg/l (95%ile)	<= 3.0 mg/l (95%ile)	N/A	N/A
DIN	N/A	N/A	(0 psu) <= 2.6 mg/l (median) (34.5 psu) <= 0.25 mg/l (median)	(0 psu) <= 1.0 mg/l (median) (34.5 psu) <= 0.17 mg/l (median)
MRP	(0-17 psu) <= 0.060 mg/l (median) (>17-35 psu) <= 0.060-0.040 mg/l (median)	(0-17 psu) <= 0.030 mg/l (median) (>17-35 psu) <= 0.030-0.025 mg/l (median)	N/A	N/A

4 Results

4.1 Presentation of the results

The results of the water quality model scenarios (existing and future discharge environment) are presented in this chapter as contoured map plots. These maps show the spatial variation of the analysed water quality parameters for summer and winter seasons based on their depth average concentrations over a spring-neap tidal cycle.

The water quality model was run for two consecutive spring-neap tidal cycles. The first of these cycles was designated as a model spin-up period and the analysis was only performed on the data from the second spring-neap tidal cycle.

The water quality parameters are presented in the following plots:

- **Concentration Plots** – present the concentration in mg/l in each grid cell over the model domain. The concentration represents the relevant statistical measure required under the specific parameter EQS, e.g. 95th percentile for BOD, median for DIN and MRP. These plots provide an overview of the distribution of concentration of each parameter around Bunlicky WWTP.
- **Indicative Quality Plots** – present contours of the indicative EQS class in each model cell. Indicative quality is determined by comparing the modelled concentration with the relevant statistical EQS threshold to determine its class (e.g. 1='High', 2='Good', 3='Moderate') for 95th percentile for BOD, and median for DIN and MRP and delineate the class boundaries (Table 3-1). The mixing zone is delineated as EQS status 'Moderate' and 'Good'. These plots provide an indication of the extent of the mixing zone where the EQS is not met for each of the water quality parameters. The EQSs published in the Surface Water Regulations Ireland (amended 2019) do not provide thresholds for 'Poor' or 'Bad' class, therefore, the plots present only 'High' (blue), 'Good' (green) and 'Moderate' (yellow) classes.
- **Delta Plot** – present the change in the concentration of water quality parameters between the WWTP upgrade scenarios (C02 – C06) and the baseline situation (A01).

The full overview of the plots presenting model results for different water quality parameters and WWTP scenarios is given in Table 4-1. For every model scenario (baseline situation A01 and upgrade scenarios C02 – C06) and both summer and winter conditions, detailed maps showing the concentration patterns and the EQS status close to the Bunlicky WWTP outfall are given. In addition to this, for the baseline situation (A01) and the upgrade scenario C02, maps showing the overview of the entire model area are provided. As similar results were observed for the other upgrade scenarios (C03 – C06) these overview maps are not provided.

In addition to the contoured map plots, tables with the length of the mixing zone, the areas classified as 'Good' and 'Moderate' EQS, are provided for each water quality parameter. The length was measured from the corresponding concentration contours, the length parameter corresponds to the total extent of the mixing zone along the deepest channel line.

Table 4-1: Overview of model result plots for different water quality parameters.

Water quality parameter	Season	Section	Model scenario	Area	Plot
BOD 95%ile	Summer	4.2.1.1	A01s	Entire model	Figure 4-1
			A01s	Bunlicky WWTP	Figure 4-2
			C02s	Entire model	Figure 4-3
			C02s	Bunlicky WWTP	Figure 4-4
			C03s	Bunlicky WWTP	Figure 4-5
			C04s	Bunlicky WWTP	Figure 4-6
			C05s	Bunlicky WWTP	Figure 4-7
			C06s	Bunlicky WWTP	Figure 4-8
	Winter	4.2.1.2	A01w	Entire model	Figure 4-9
			A01w	Bunlicky WWTP	Figure 4-10
			C02w	Entire model	Figure 4-11
			C02w	Bunlicky WWTP	Figure 4-12
			C03w	Bunlicky WWTP	Figure 4-13
			C04w	Bunlicky WWTP	Figure 4-14
			C05w	Bunlicky WWTP	Figure 4-15
DIN 50%ile	Summer	4.2.2.1	A01s	Entire model	Figure 4-16
			A01s	Bunlicky WWTP	Figure 4-17
			C02s	Entire model	Figure 4-18
			C02s	Bunlicky WWTP	Figure 4-19
			C03s	Bunlicky WWTP	Figure 4-20
			C04s	Bunlicky WWTP	Figure 4-21
			C05s	Bunlicky WWTP	Figure 4-22
	Winter	4.2.2.2	A01w	Entire model	Figure 4-23
			A01w	Bunlicky WWTP	Figure 4-24
			C02w	Entire model	Figure 4-25
			C02w	Bunlicky WWTP	Figure 4-26
			C03w	Bunlicky WWTP	Figure 4-27
			C04w	Bunlicky WWTP	Figure 4-28
			C05w	Bunlicky WWTP	Figure 4-29
MRP 50%ile	Summer	4.2.3.1	A01s	Entire model	Figure 4-30
			A01s	Bunlicky WWTP	Figure 4-31
			C02s	Entire model	Figure 4-32
			C02s	Bunlicky WWTP	Figure 4-33
			C03s	Bunlicky WWTP	Figure 4-34
			C04s	Bunlicky WWTP	Figure 4-35
			C05s	Bunlicky WWTP	Figure 4-36
			C06s	Bunlicky WWTP	Figure 4-37
	Winter	4.2.3.2	A01w	Entire model	Figure 4-38
			A01w	Bunlicky WWTP	Figure 4-39
			C02w	Entire model	Figure 4-40
			C02w	Bunlicky WWTP	Figure 4-41

			C03w	Bunlicky WWTP	Figure 4-42
			C04w	Bunlicky WWTP	Figure 4-43
			C05w	Bunlicky WWTP	Figure 4-44

4.2 Mixing zone assessment

4.2.1 BOD

Section 4.2.1.1 (Figure 4-1 to Figure 4-8) shows the modelling results for the BOD depth-average concentration in the summer conditions. In the existing situation (A01s), the concentration of BOD throughout the estuary is generally below 2 mg/l, which corresponds to 'High' EQS status (Figure 4-1). An area of increased concentrations up to 10 mg/l can be found near the existing Bunlicky WWTP outfall. The mixing zone with 'Good' EQS status extends approximately 110 m in the streamwise direction, and the area with 'Moderate' status extends over approximately 70 m (Figure 4-2)

In the scenarios with the upgrade of Bunlicky WWTP (C02s – C05s), the ambient BOD concentration, concentration not influenced by the Bunlicky WWTP, in the estuary increases by around 0.7 mg/l for all upgrade scenarios and remains within 'High' EQS status (Figure 4-3). An increase in BOD concentration of more than 2.5 mg/l is observed only near the WWTP outfall, which leads to the increase in the extent of the zone with 'Moderate' EQS status to 120 m. The streamwise extent of the 'Good' EQS status zone also increases from 110 m in the existing situation to 270-290 m in the upgrade scenarios (Figure 4-4 to Figure 4-7).

In the scenario with the combined upgrades of the WWTPs (C06s) and reduced BOD concentration at the outfall, the situation improves compared to other upgrade scenarios as the increase in the background BOD concentration is lower (around 0.5 mg/l) and the area with 'Good' EQS status in this case only extends over 170 m in the streamwise direction compared to 290 m in the scenario C05 (Figure 4-8).

Section 4.2.1.2 (Figure 4-9 to Figure 4-15) shows the modelling results for the BOD depth-average concentration in the winter conditions. In the existing situation (A01w), BOD concentration is around 0.7 mg/l, which results in 'High' EQS status throughout the entire estuary (Figure 4-9 and Figure 4-10).

In all the upgrade scenarios (C02w – C05w), the BOD concentration increase of more than 0.25 mg/l is observed only within approximately 2 km around the Bunlicky outfall. The area with 'Good' EQS status is limited to approximately 290 m around the outfall, while 'Moderate' status is observed within a 130 m stretch of the estuary in all of the considered scenarios (Figure 4-11 to Figure 4-15).

Table 4-2: BOD mixing zone length (along the deepest channel line).

Season	Model scenario	Mixing zone length		Relative of total length Shannon Estuary (~100km)	
		EQS status: Good	EQS status: Moderate	EQS status: Good	EQS status: Moderate
Summer	A01s	110 m	70 m	0.1%	0.1%
	C02s	270 m	120 m	0.3%	0.1%
	C03s	270 m	120 m	0.3%	0.1%
	C04s	270 m	120 m	0.3%	0.1%
	C05s	290 m	120 m	0.3%	0.1%
	C06s	170 m	120 m	0.2%	0.1%
Winter	A01w	-	-	-	-
	C02w	290 m	130 m	0.3%	0.1%
	C03w	290 m	130 m	0.3%	0.1%
	C04w	290 m	130 m	0.3%	0.1%
	C05w	290 m	130 m	0.3%	0.1%

4.2.1.1 Summer conditions

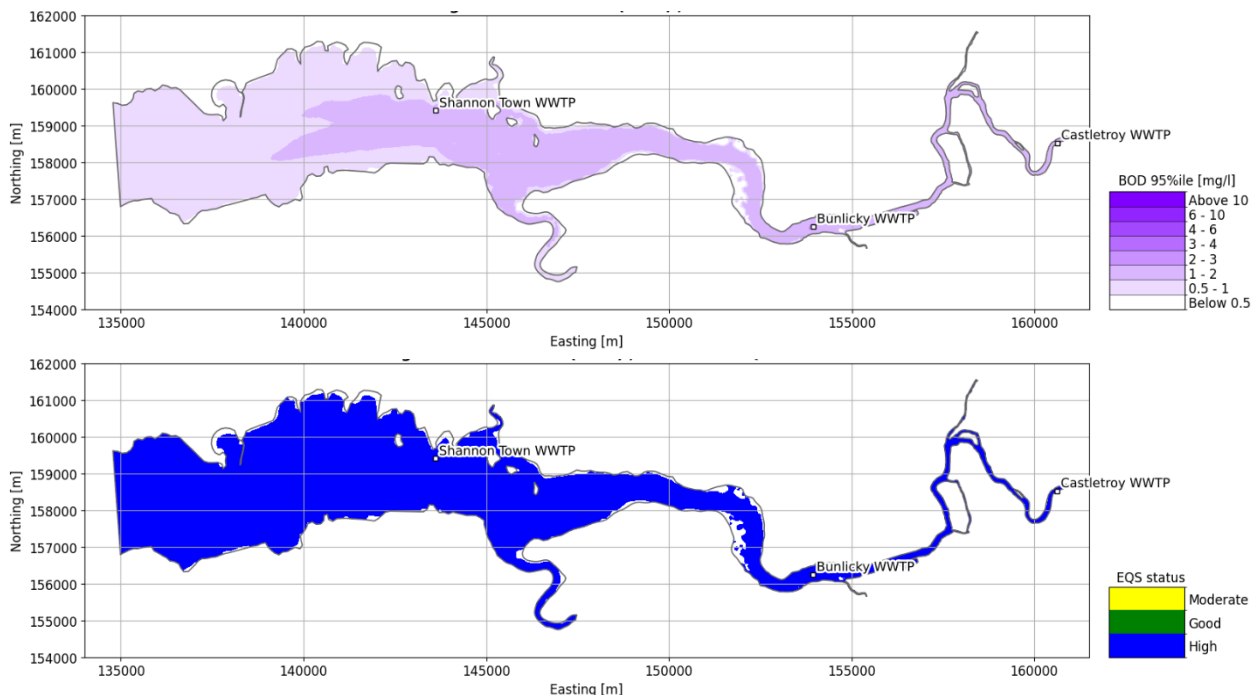


Figure 4-1: Depth-average concentration of BOD 95%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (summer), full estuary overview.

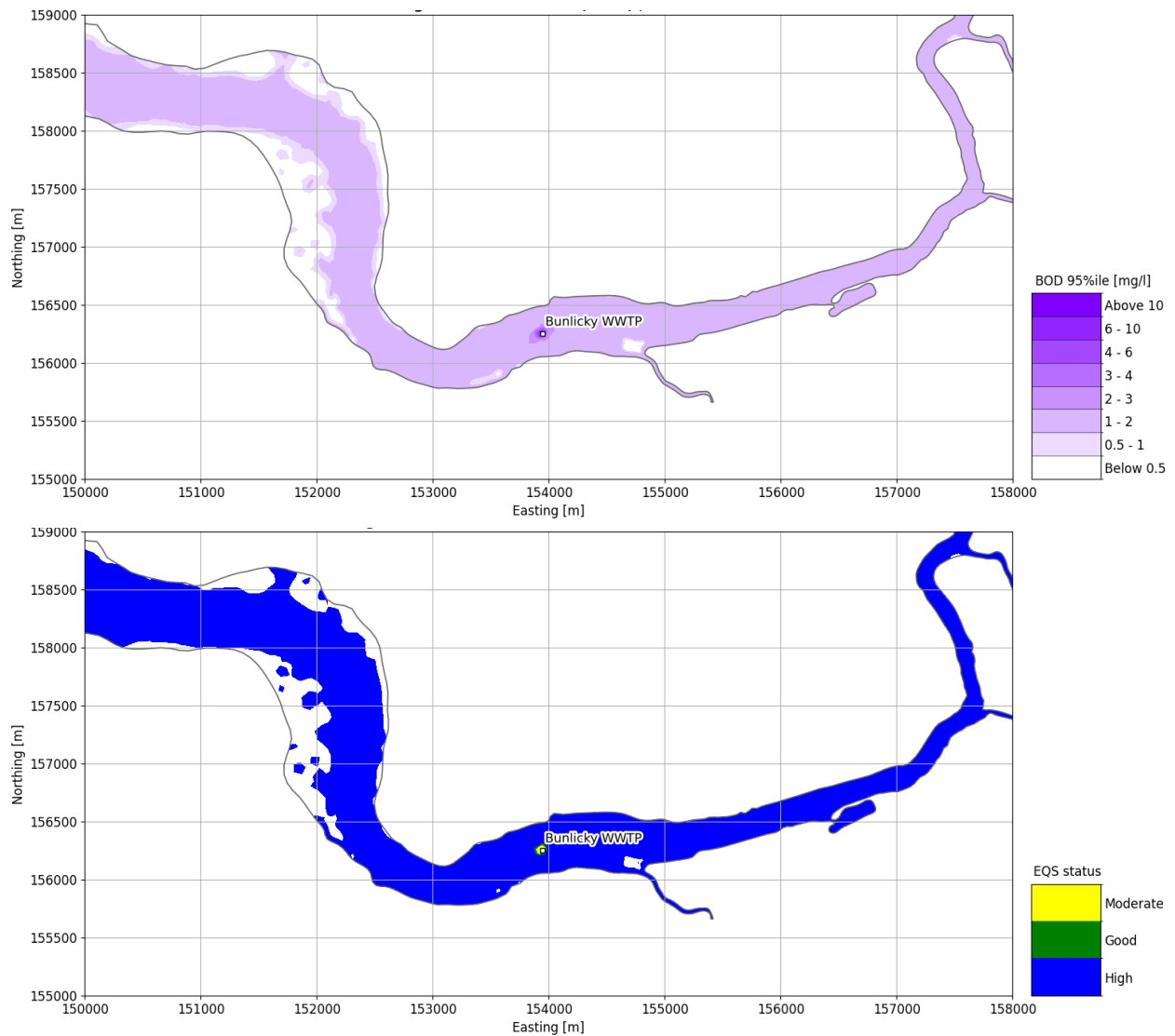


Figure 4-2: Depth-average concentration of BOD 95%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (summer).

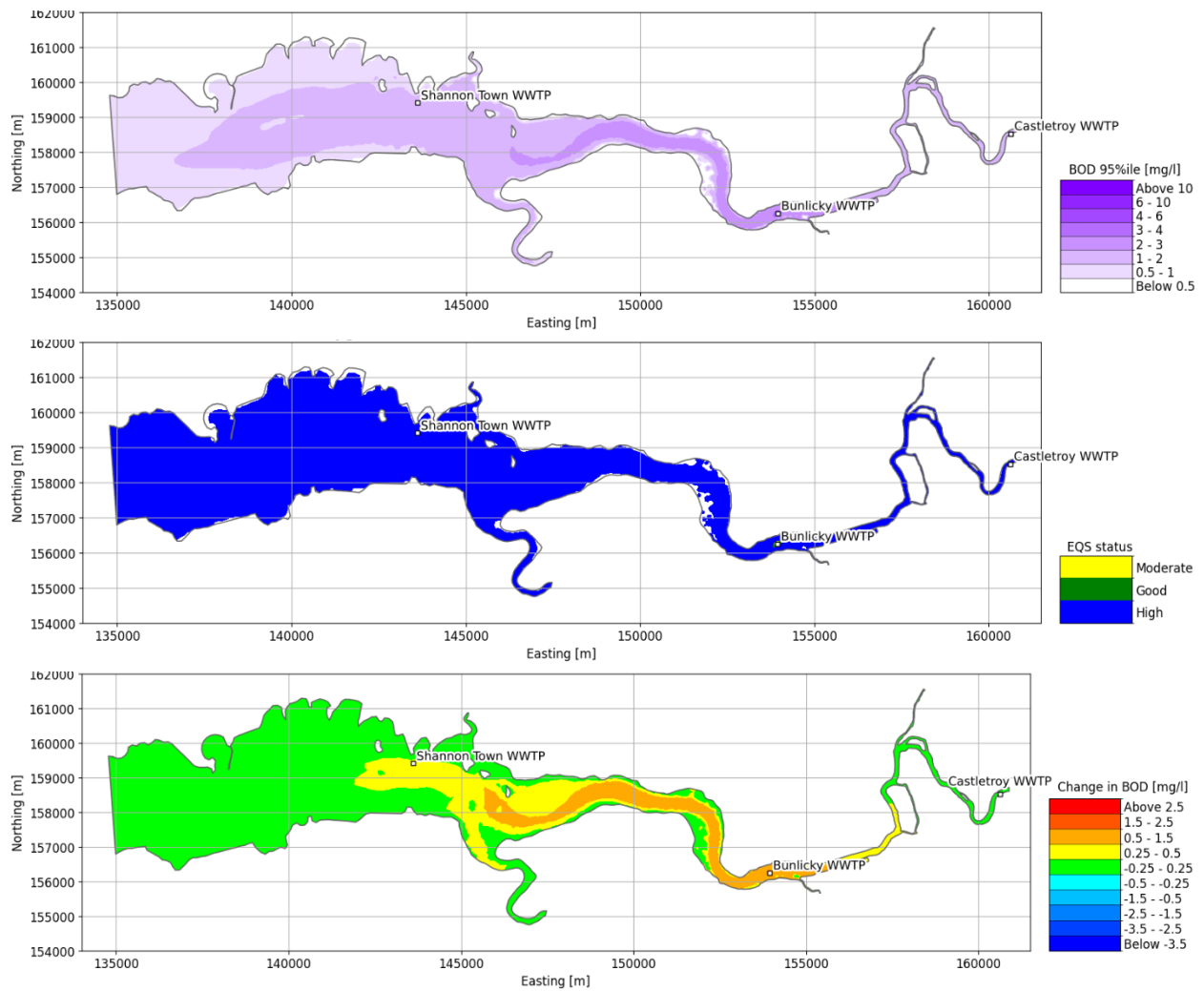


Figure 4-3: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (summer), full estuary overview.

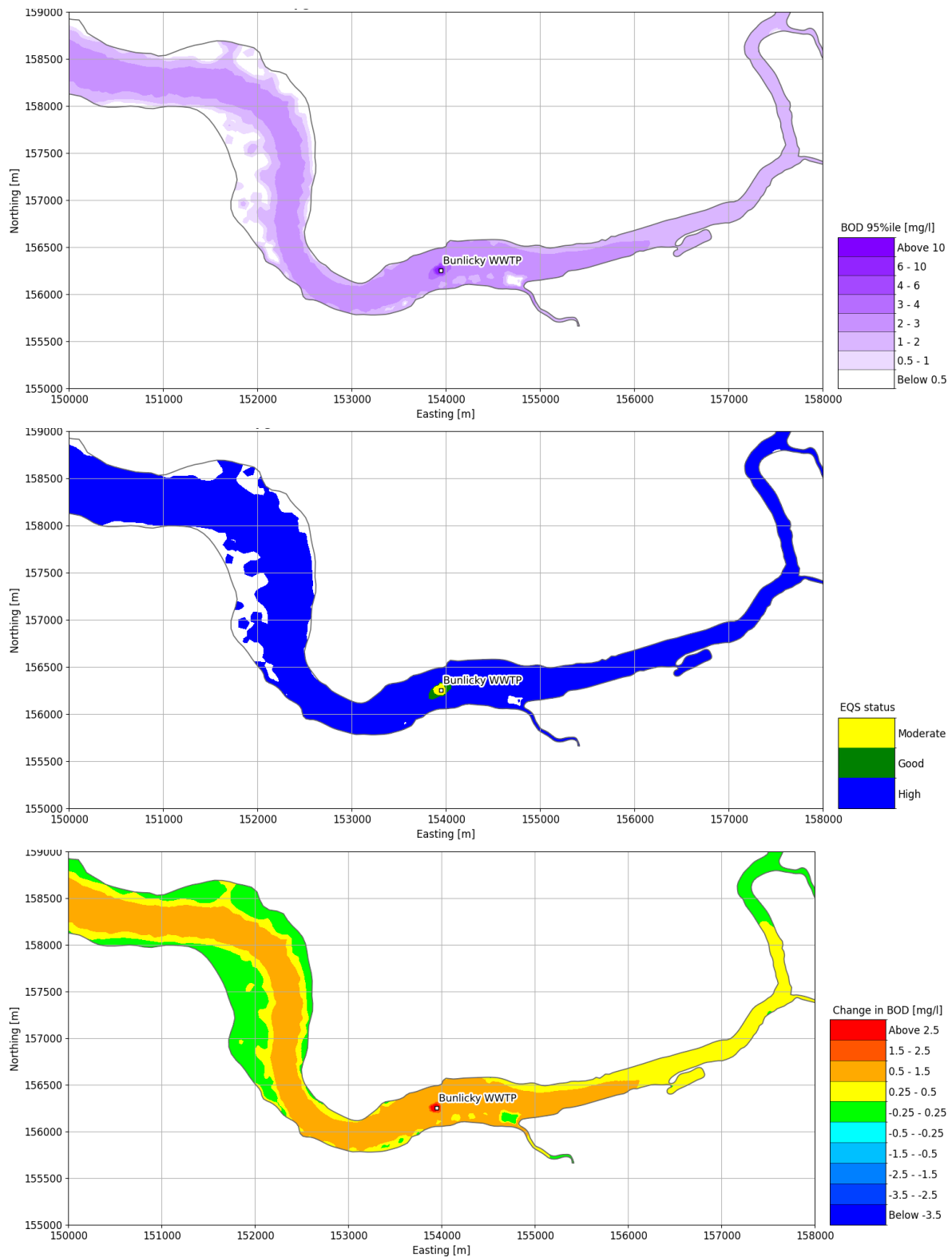


Figure 4-4: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (summer).

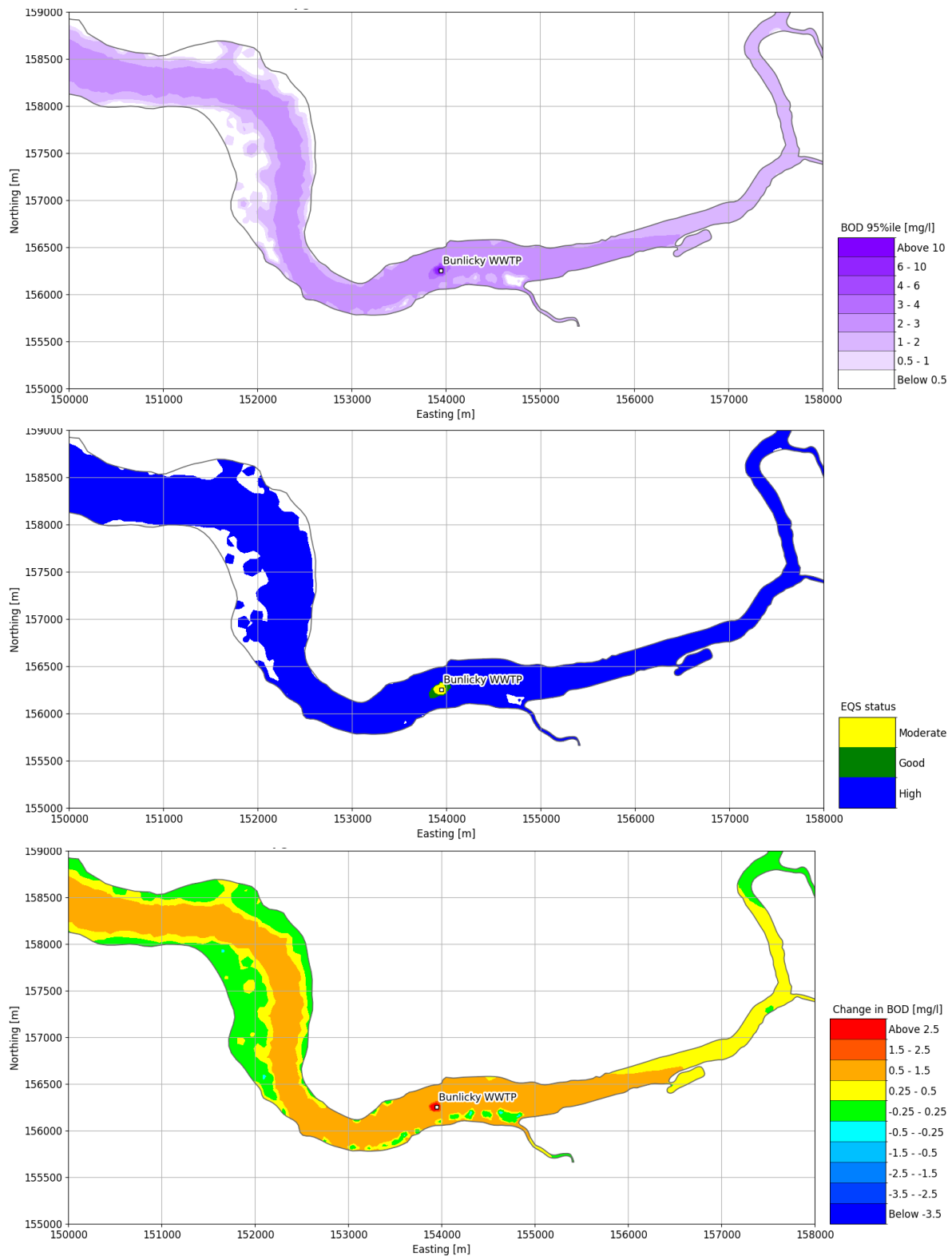


Figure 4-5: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C03 (summer).

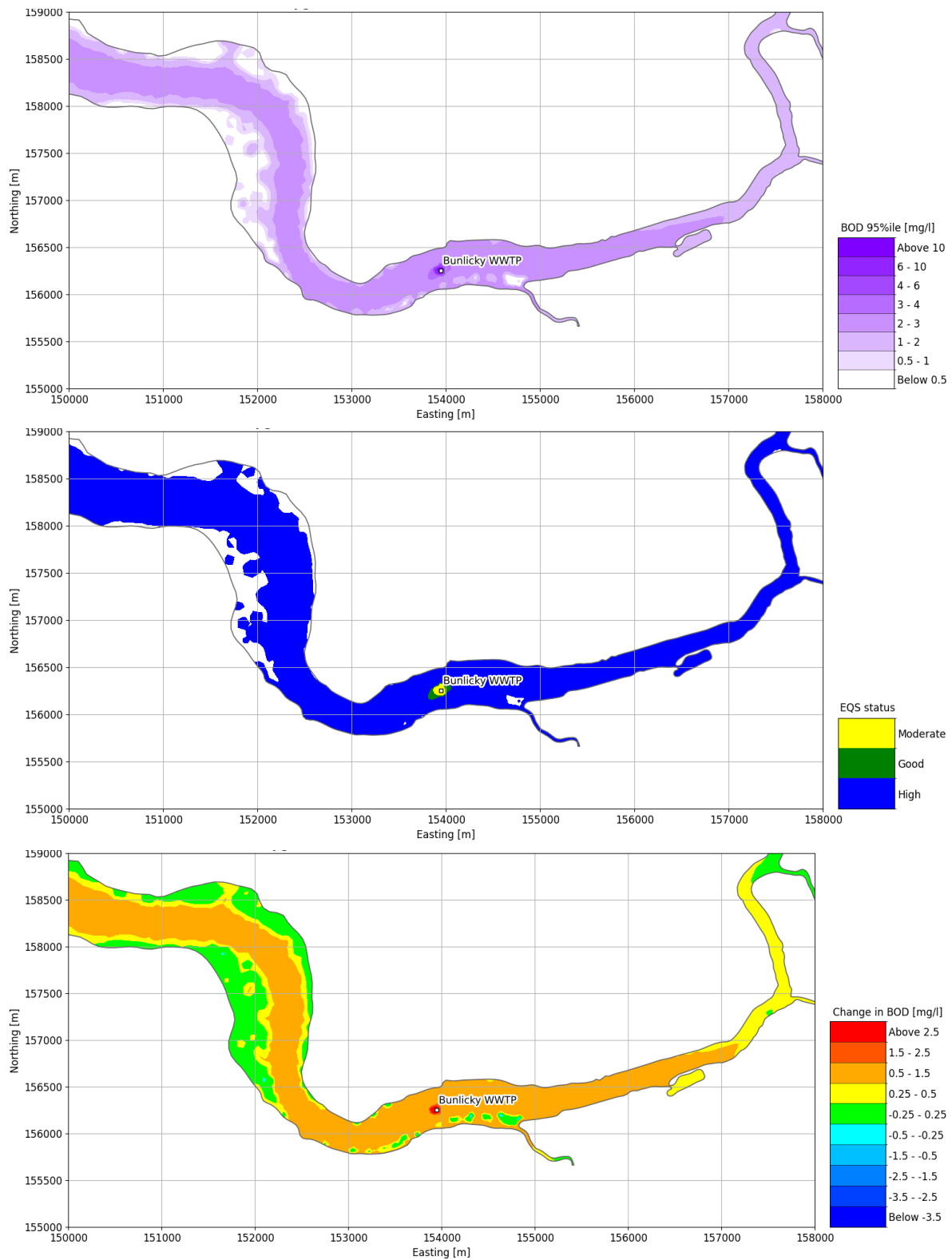


Figure 4-6: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C04 (summer).

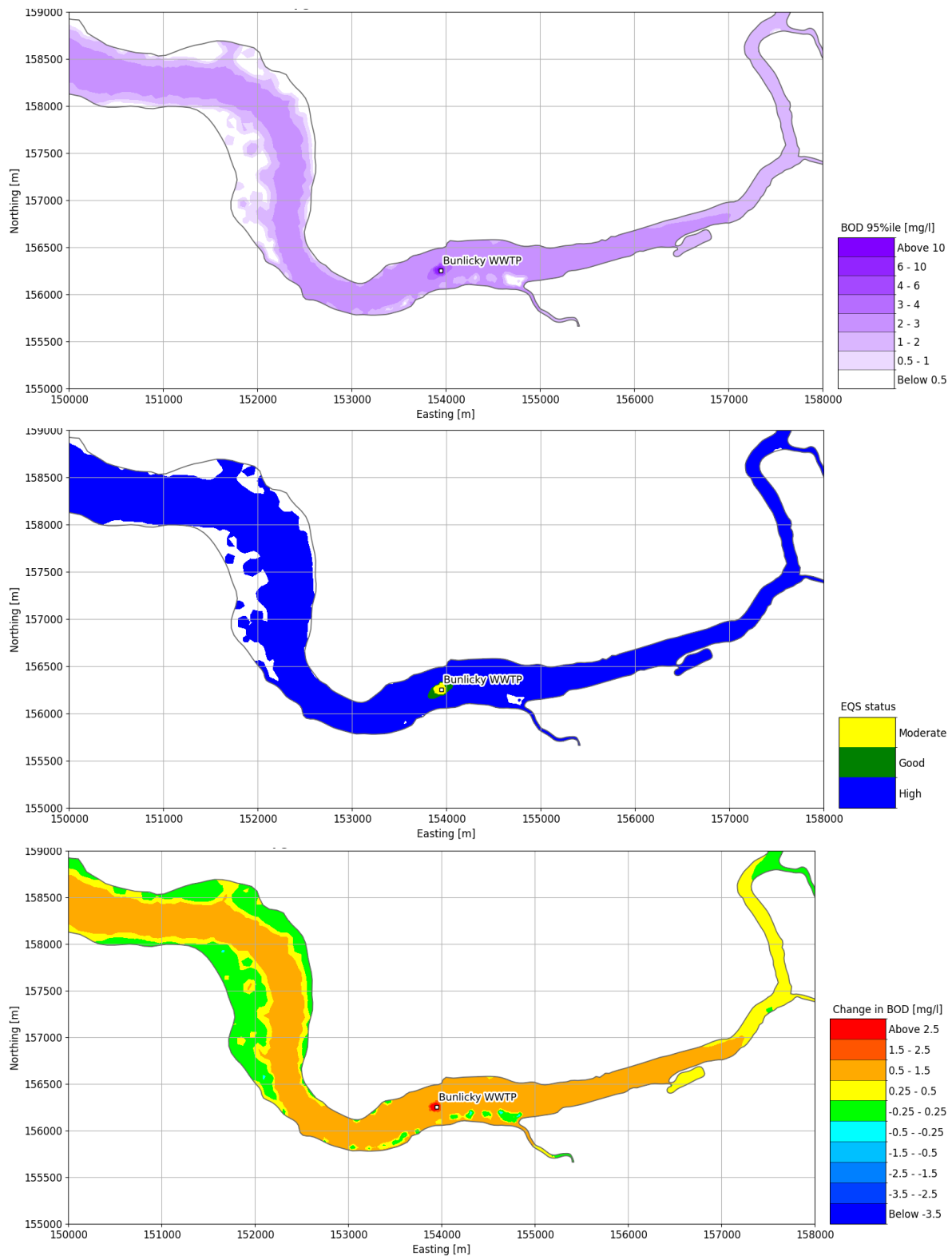


Figure 4-7: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C05 (summer).

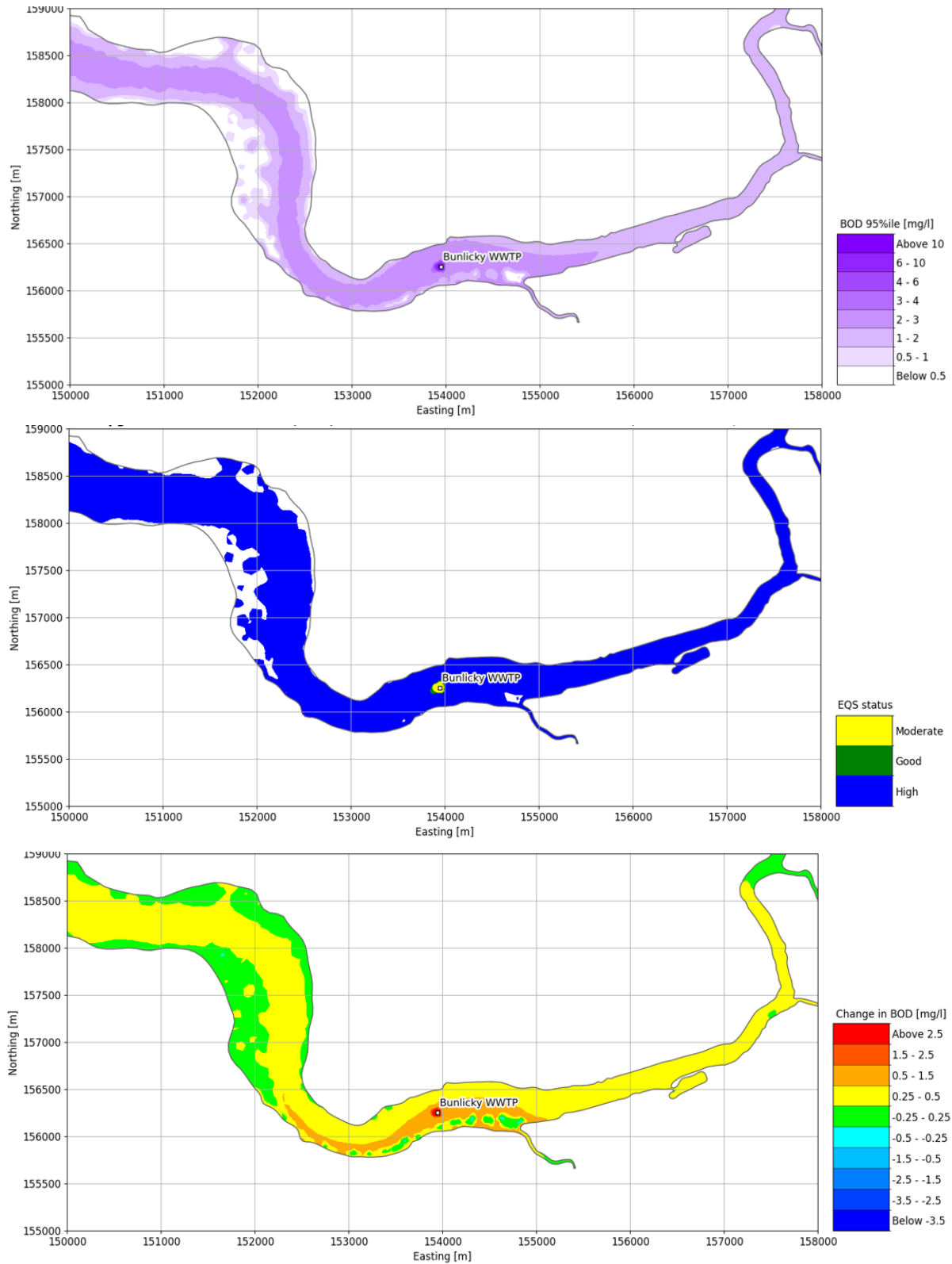


Figure 4-8: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C06 (summer).

4.2.1.2 Winter conditions

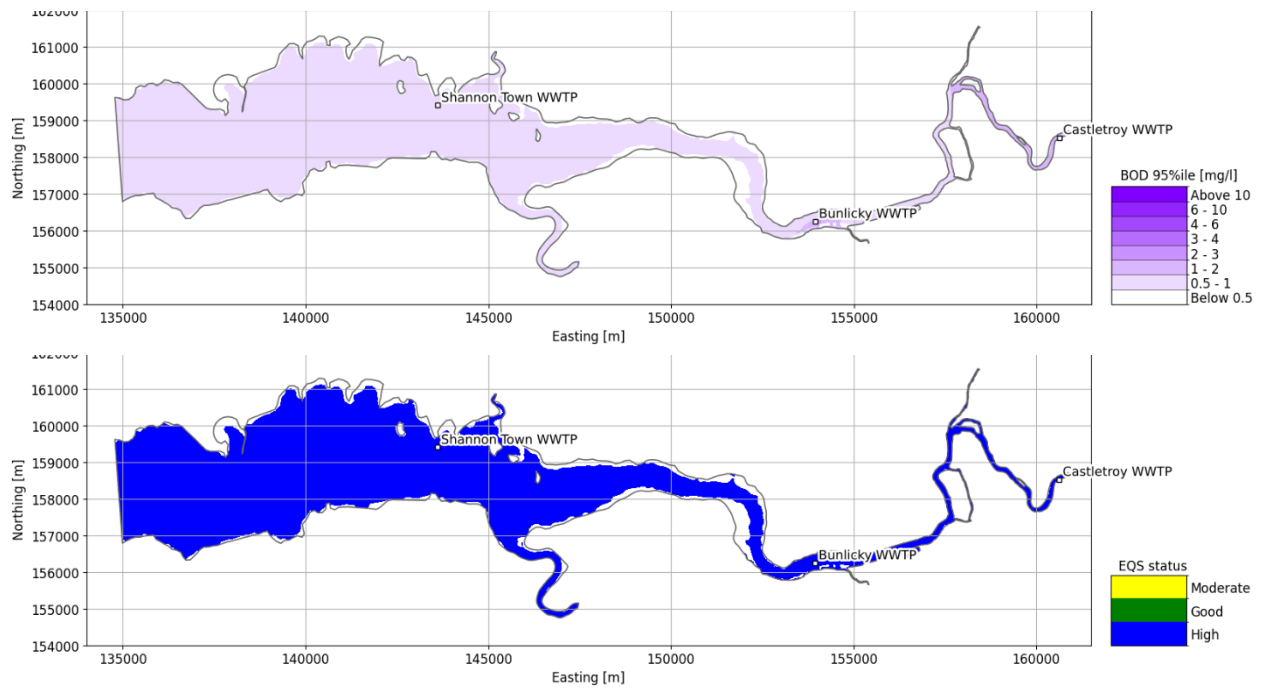


Figure 4-9: Depth-average concentration of BOD 95%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (winter), full estuary overview.

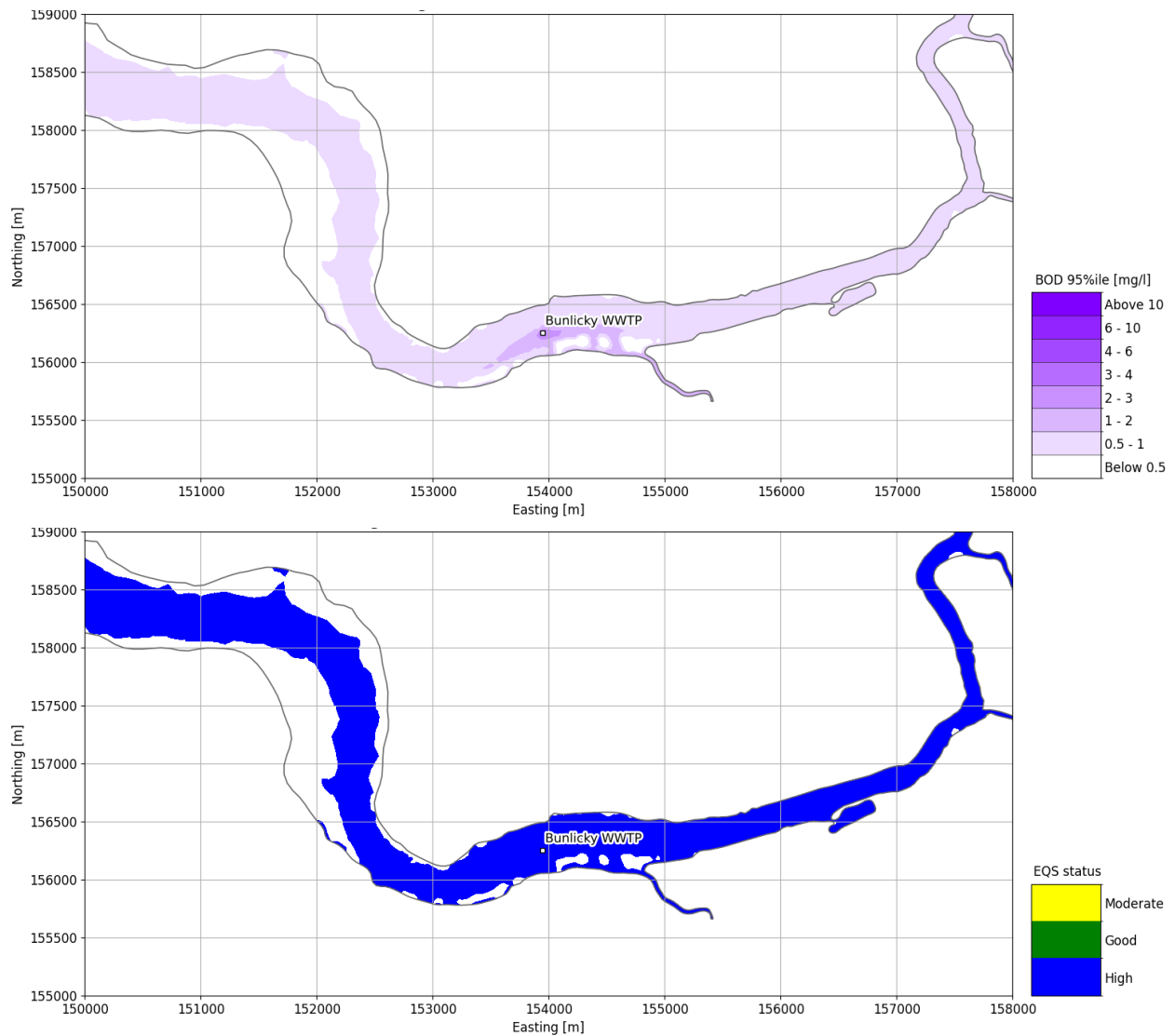


Figure 4-10: Depth-average concentration of BOD 95%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (winter).

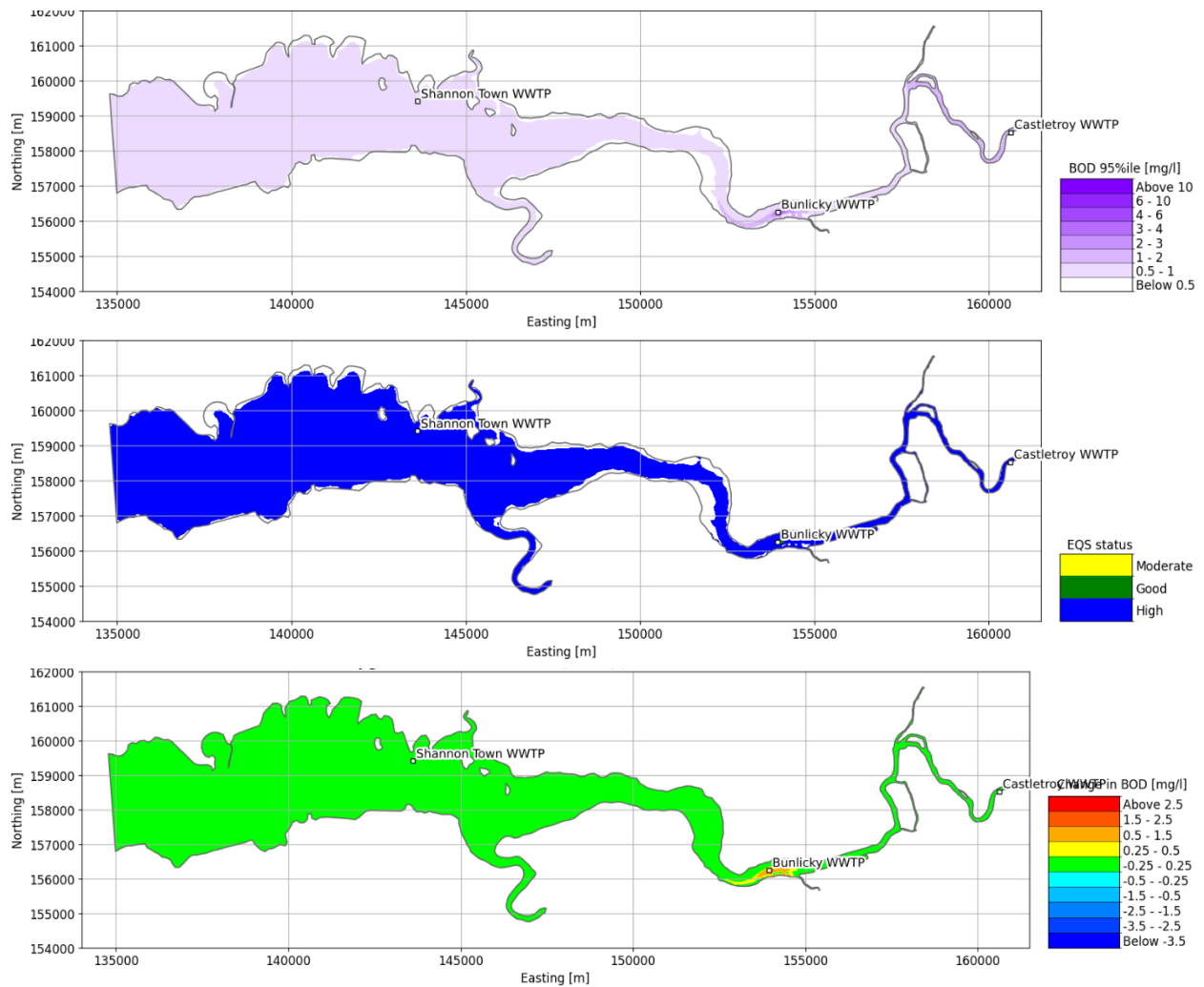


Figure 4-11: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (winter), full estuary overview.

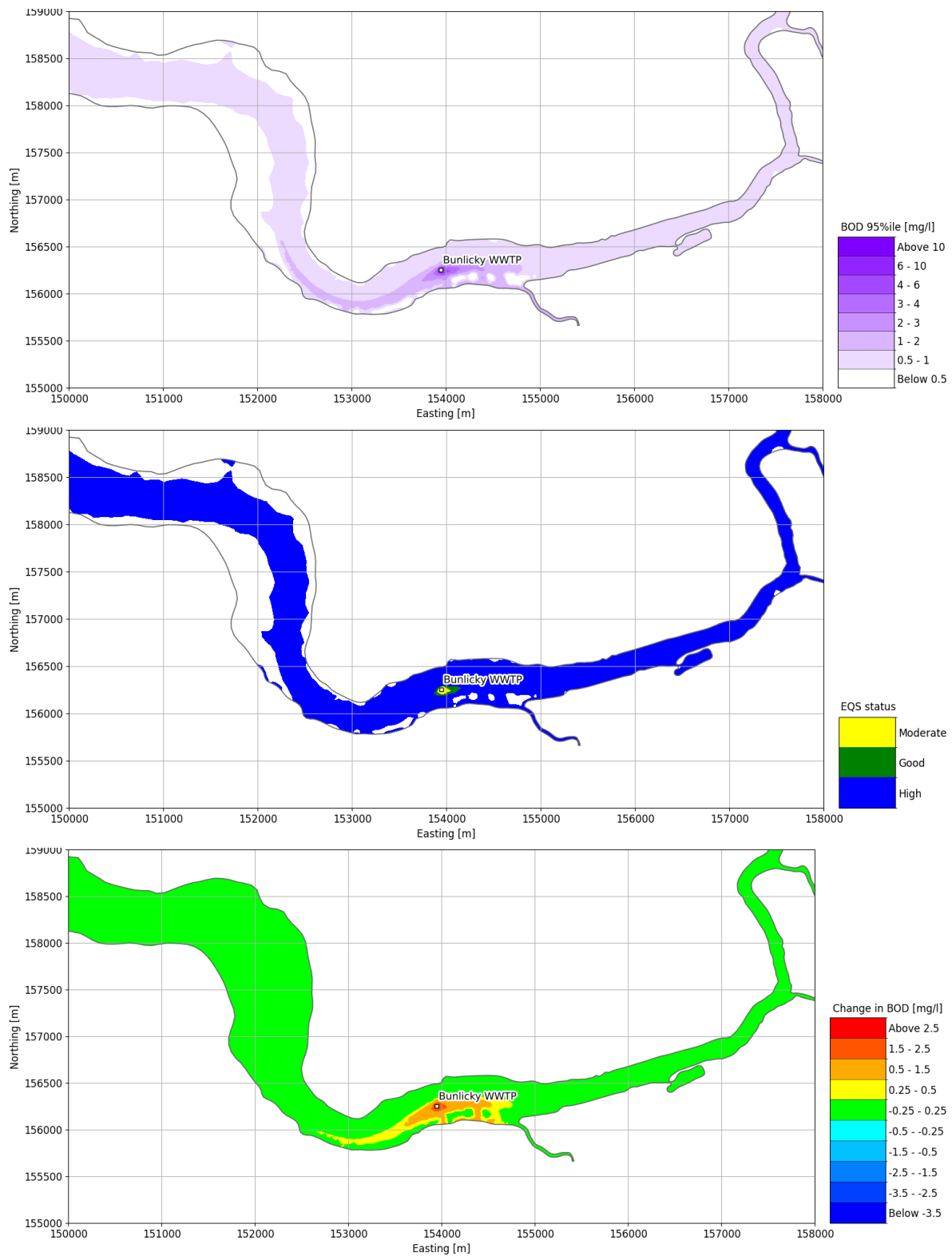


Figure 4-12: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (winter).

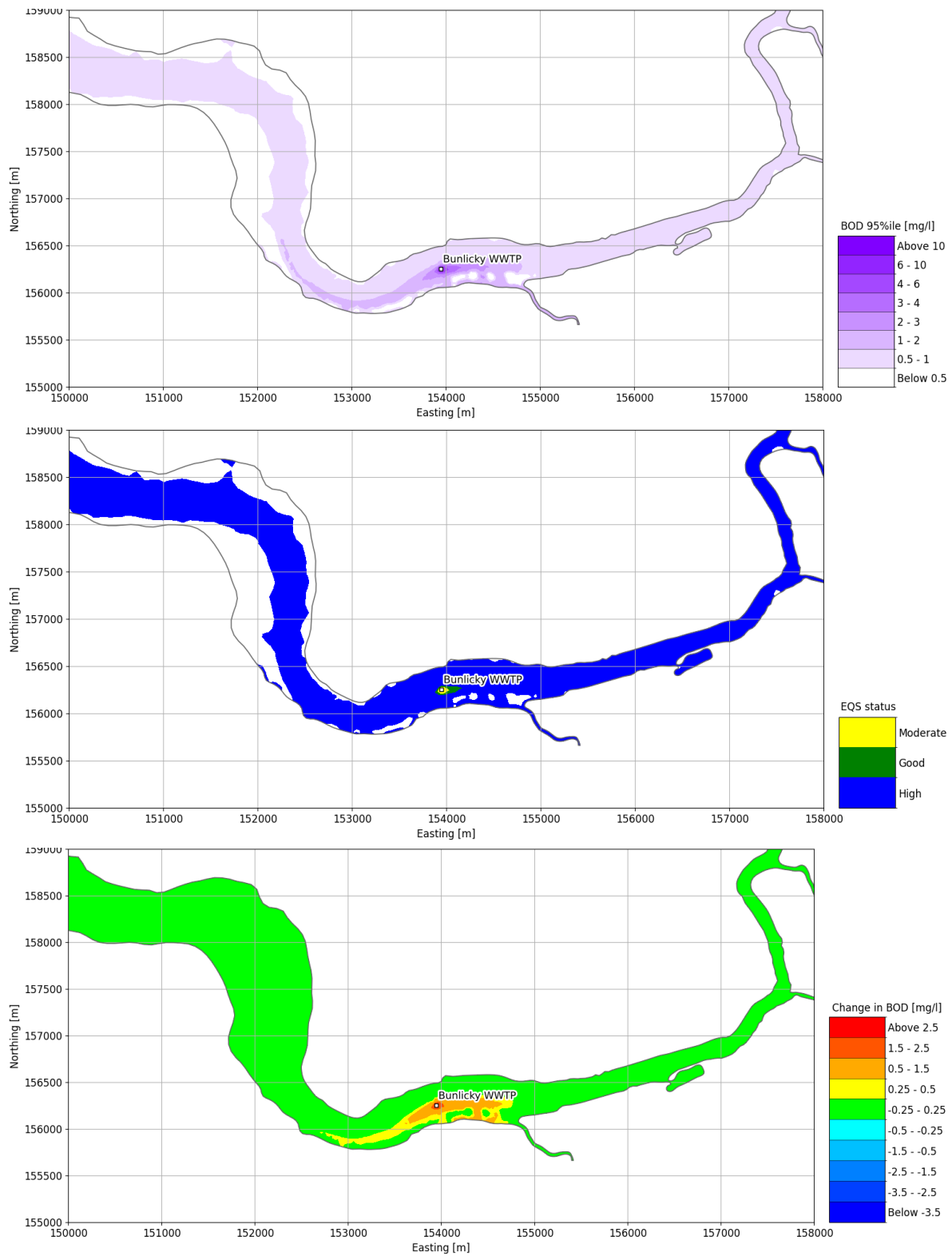


Figure 4-13: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C03 (winter).

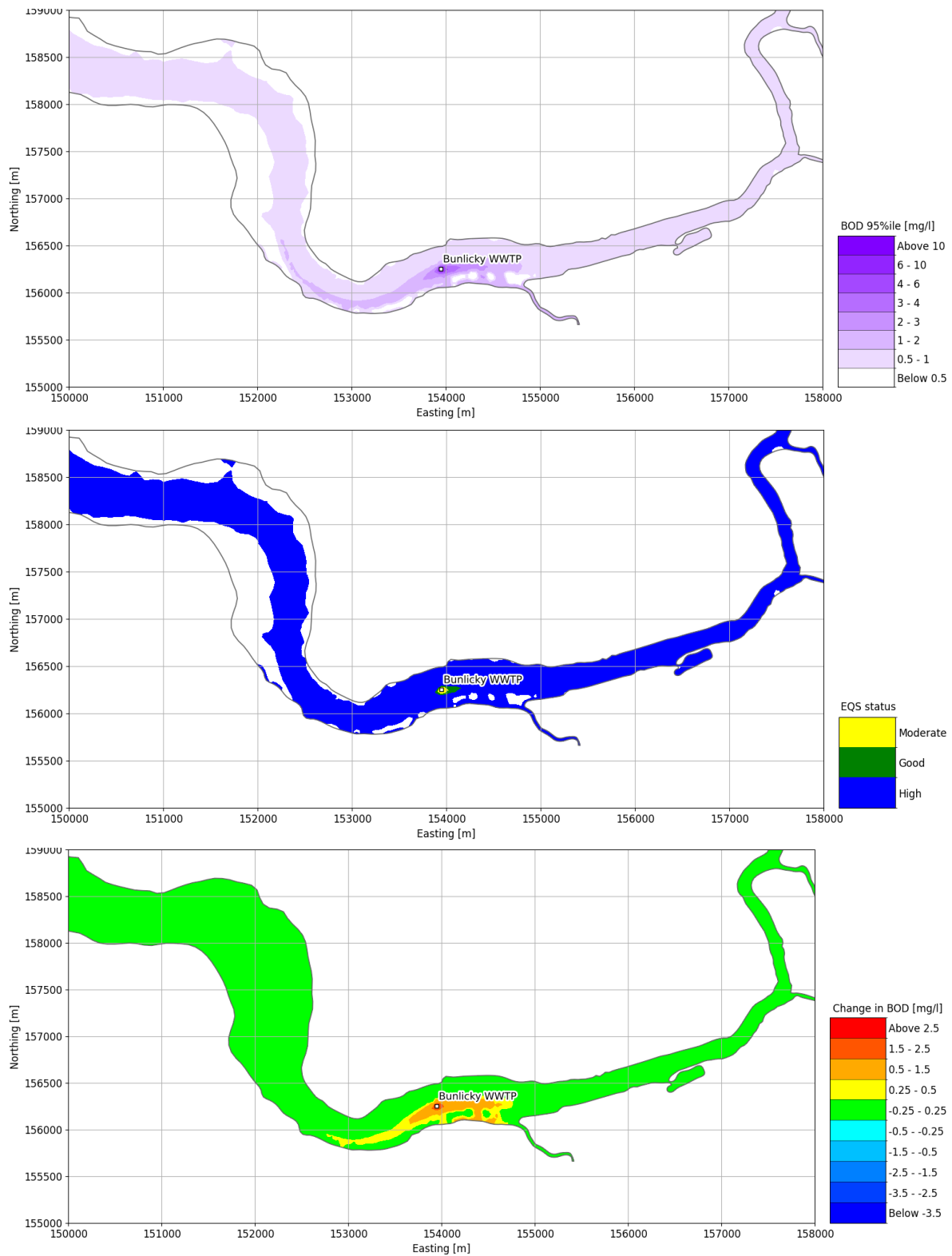


Figure 4-14: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C04 (winter).

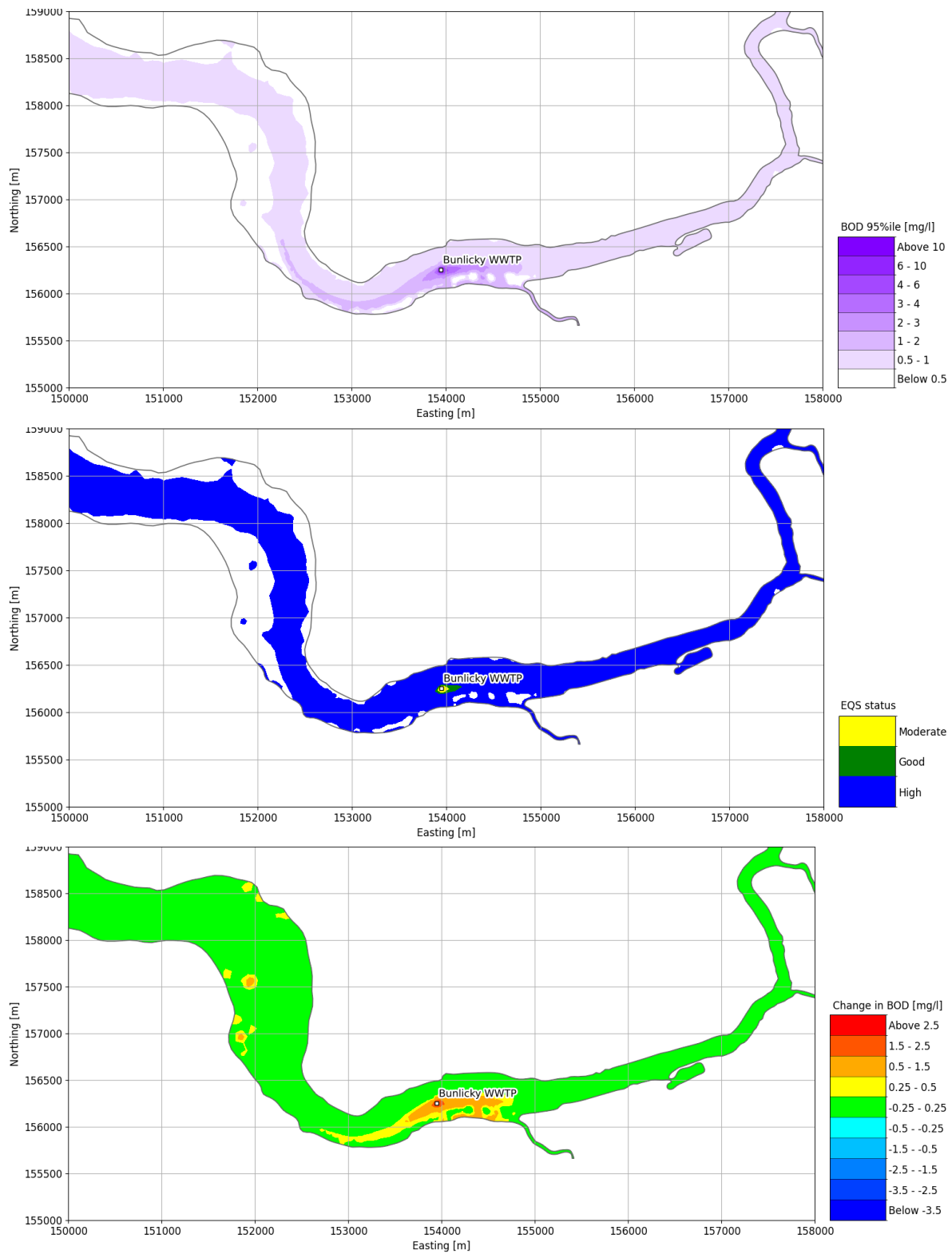


Figure 4-15: Depth-average concentration of BOD 95%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C05 (winter).

4.2.2 DIN

Section 4.2.2.1 (Figure 4-16 to Figure 4-22) shows the modelling results for the DIN depth-average concentration in the summer conditions. Figure 4-16 shows that modelled DIN concentrations in the region are within the non-regulatory DIN EQS target for Good Status, extending approximately 8 km downstream of the outfall and all the way to the upstream boundary. The maximum DIN concentration of around 1.9 mg/l is observed near the Bunlicky WWTP outfall and the threshold for 'Moderate' EQS status is not exceeded in the current situation (Figure 4-17).

In the scenarios with the upgrade of Bunlicky WWTP (C02s – C05s), DIN concentrations near the outfall discharge exceed the non-regulatory DIN EQS target for Good Status of 2.6 mg/l at 0 psu. The extent of the mixing zone with 'Moderate' EQS status however is limited to the distance of 50 to 80 m around the outfall depending on the scenario (Figure 4-19 to Figure 4-22). Further away from the outfall DIN concentration increases by around 0.35 – 0.55 mg/l and the extent of the area with 'Good' EQS status in all upgrade scenarios increases from around 8 to 10 km downstream of the outfall (Figure 4-18).

Section 4.2.2.2 (Figure 4-23 to Figure 4-29) shows the modelling results for the DIN depth-average concentration in the winter conditions. It can be seen that in the existing situation (A01w), a large section of the study area is also characterised by 'Good' EQS status with a downstream boundary extending approximately 18 km downstream from Bunlicky WWTP outfall (Figure 4-23). The threshold for 'Moderate' EQS status in the winter condition is not exceeded with the maximum DIN concentration near the outfall only reaching 1.9 mg/l (Figure 4-24).

In all the WWTP upgrade scenarios (C02w – C05w), DIN concentration near the outfall increases by approximately 0.4 mg/l and still does not exceed the threshold for 'Moderate' EQS status. In general, the concentration increases due to the WWTP upgrade in all scenarios only affects a 2 km stretch downstream of the outfall (Figure 4-26 to Figure 4-29). As a result, the downstream boundary for the 'Good' EQS status also does not change compared to the existing situation (Figure 4-25).

Table 4-3: DIN mixing zone length (along the deepest channel line).

Season	Model scenario	Mixing zone length		Relative of total length Shannon Estuary (~100km)	
		EQS status: Good	EQS status: Moderate	EQS status: Good	EQS status: Moderate
Summer	A01s	>8 km	-	8.0%	-
	C02s	>10 km	50 m	10.0%	0.1%
	C03s	>10 km	70 m	10.0%	0.1%
	C04s	>10 km	70 m	10.0%	0.1%
	C05s	>10 km	80 m	10.0%	0.1%
Winter	A01w	> 18 km	-	18.0%	-
	C02w	> 18 km	-	18.0%	-
	C03w	> 18 km	-	18.0%	-
	C04w	> 18 km	-	18.0%	-
	C05w	> 18 km	-	18.0%	-

4.2.2.1 Summer conditions

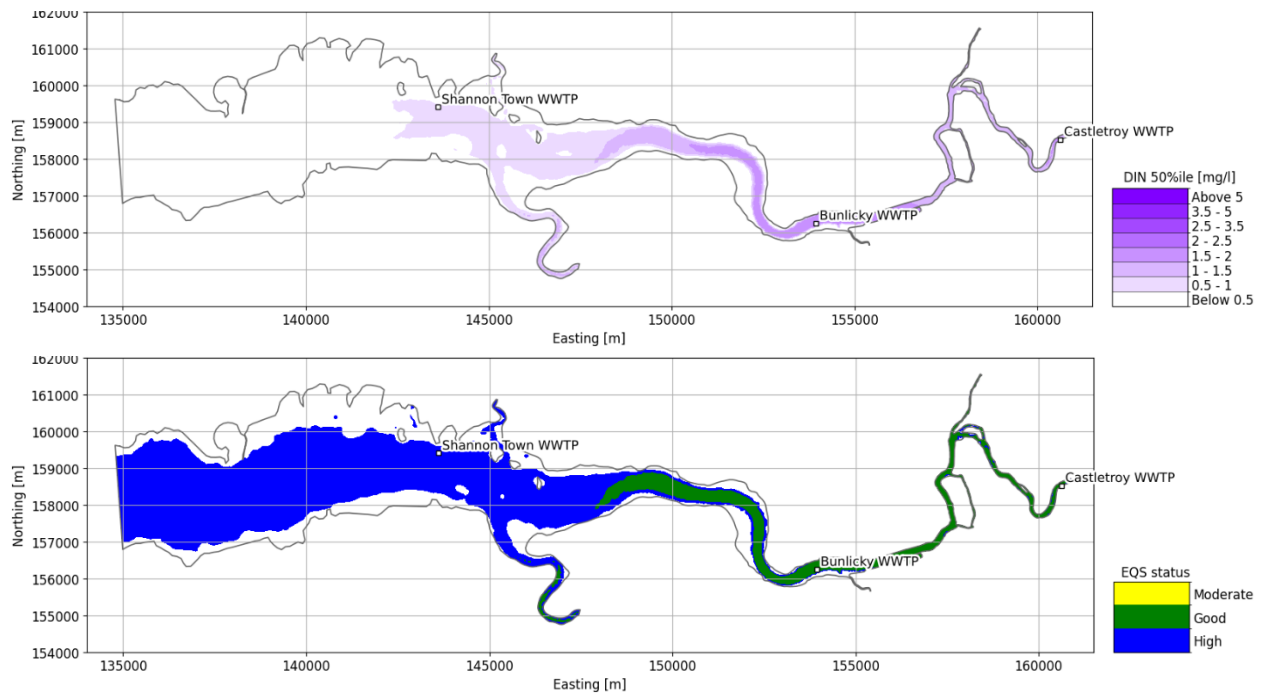


Figure 4-16: Depth-average concentration of DIN 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (summer), full estuary overview.

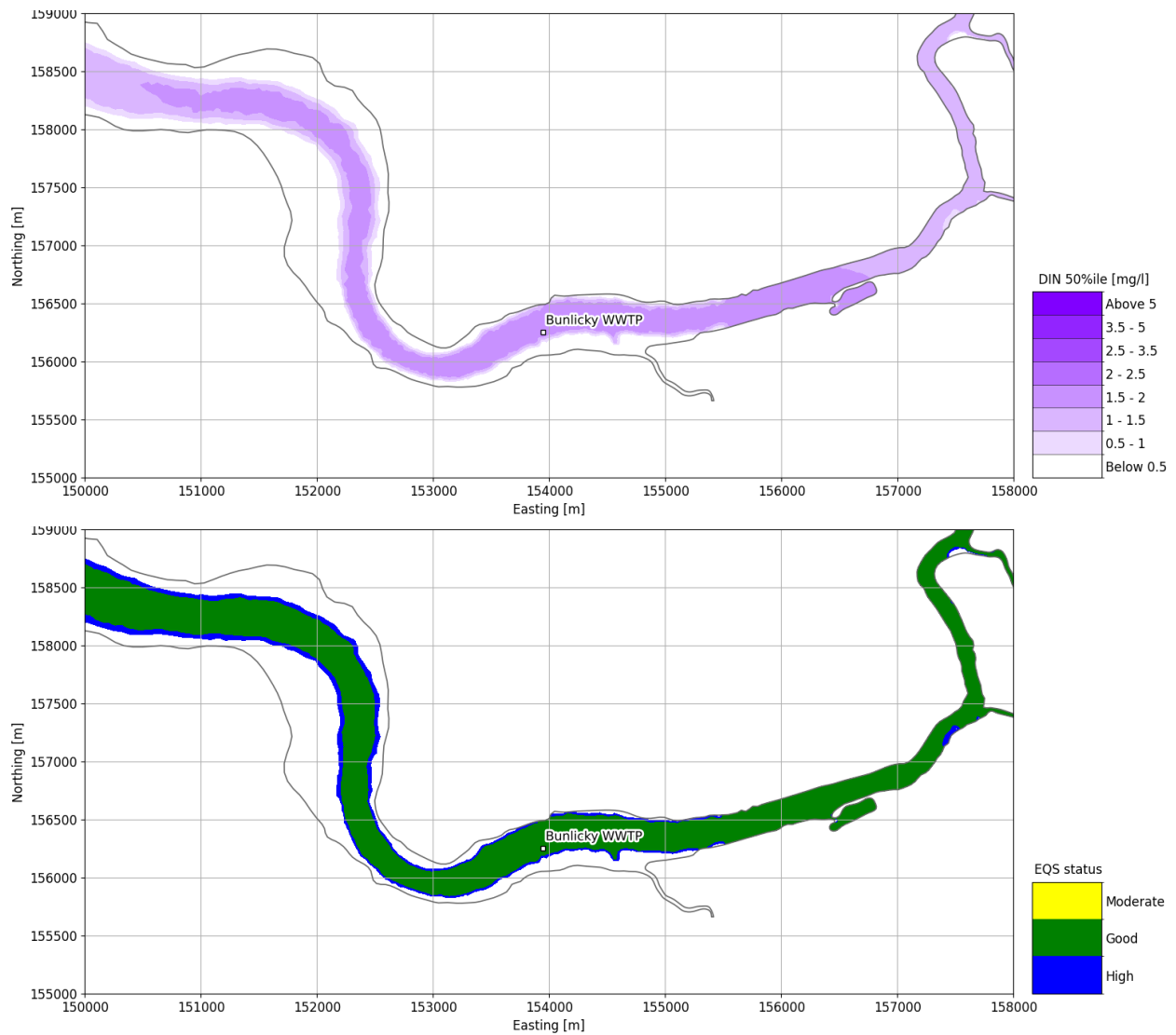


Figure 4-17: Depth-average concentration of DIN 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (summer).

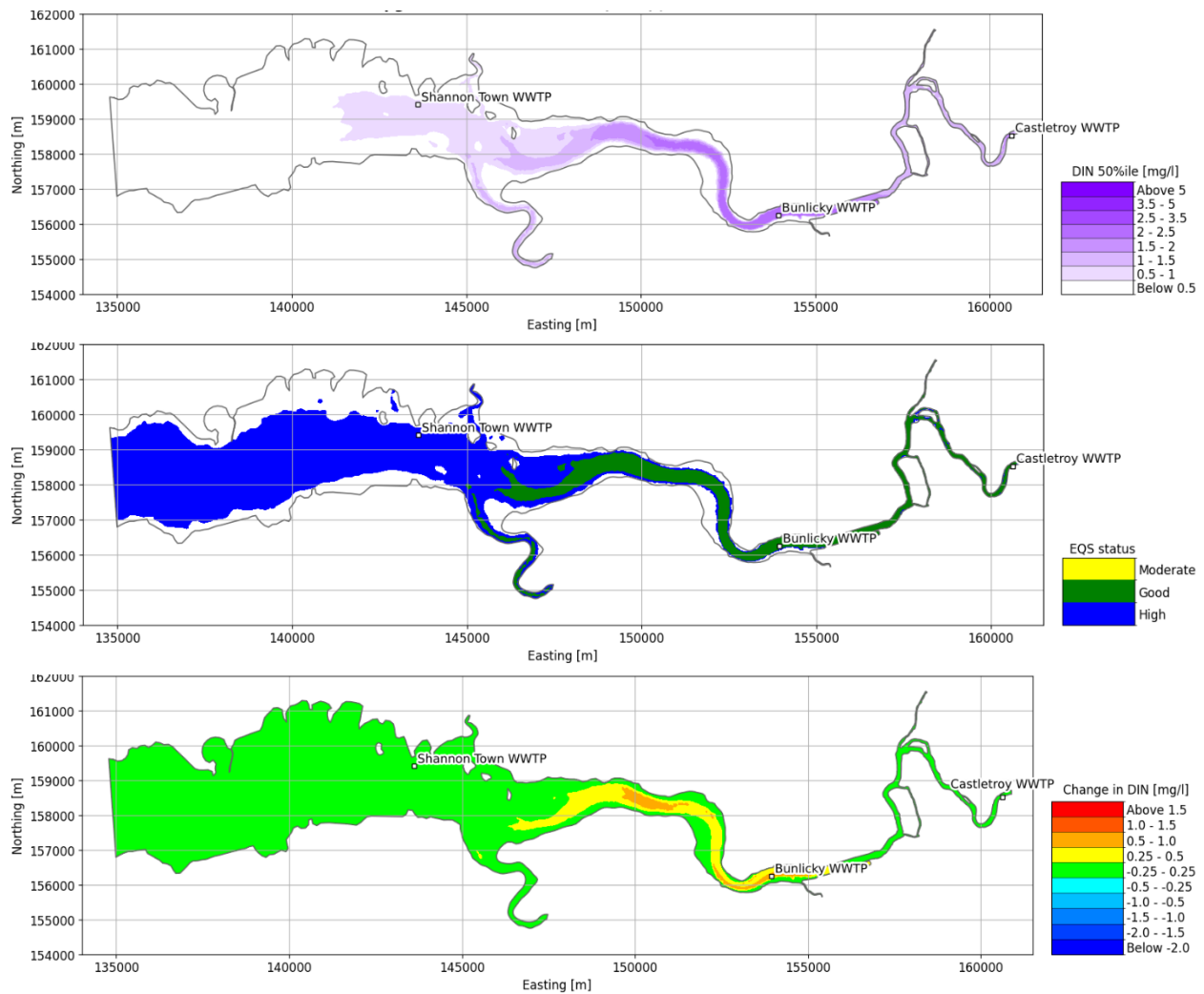


Figure 4-18: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (summer), full estuary overview.

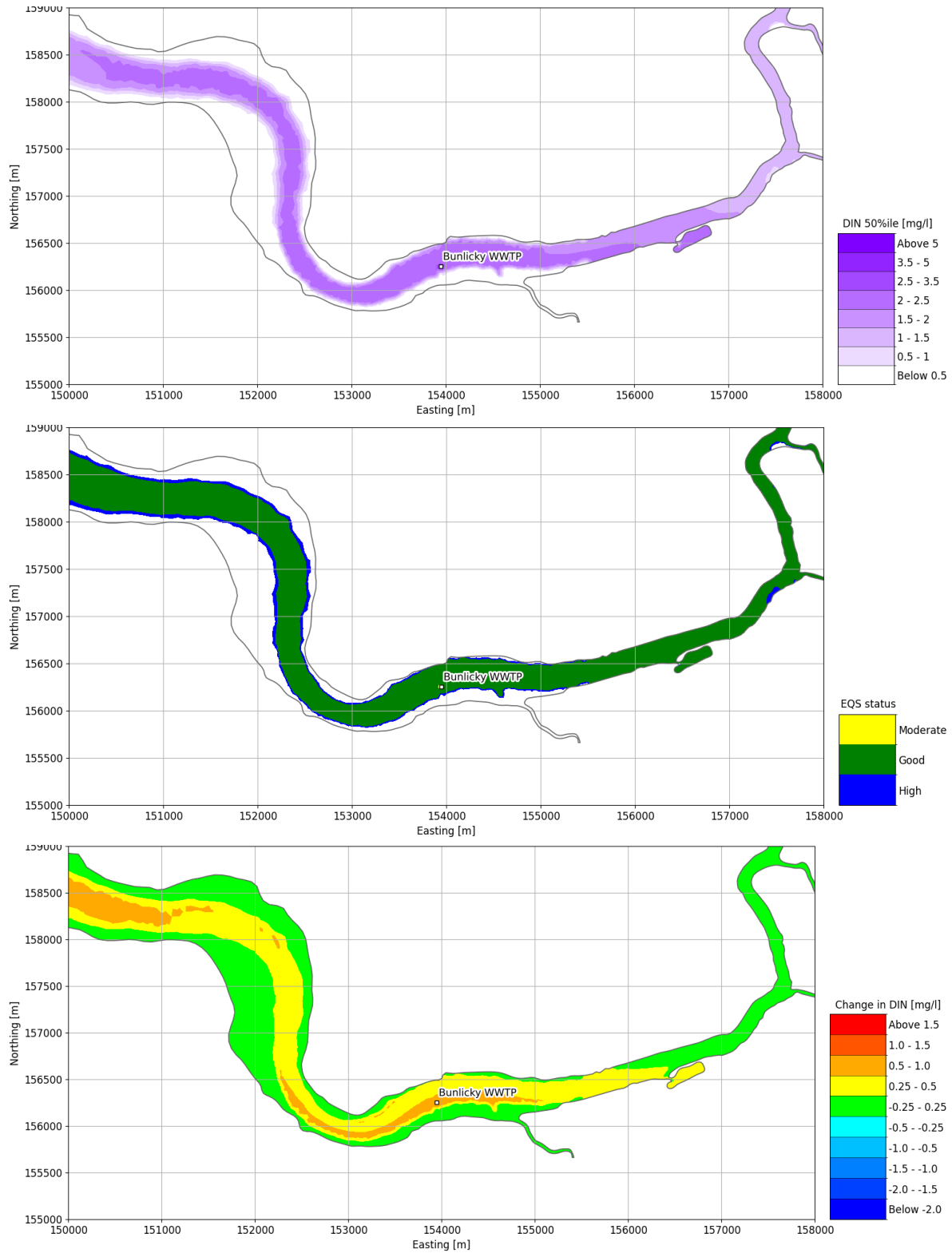


Figure 4-19: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (summer).

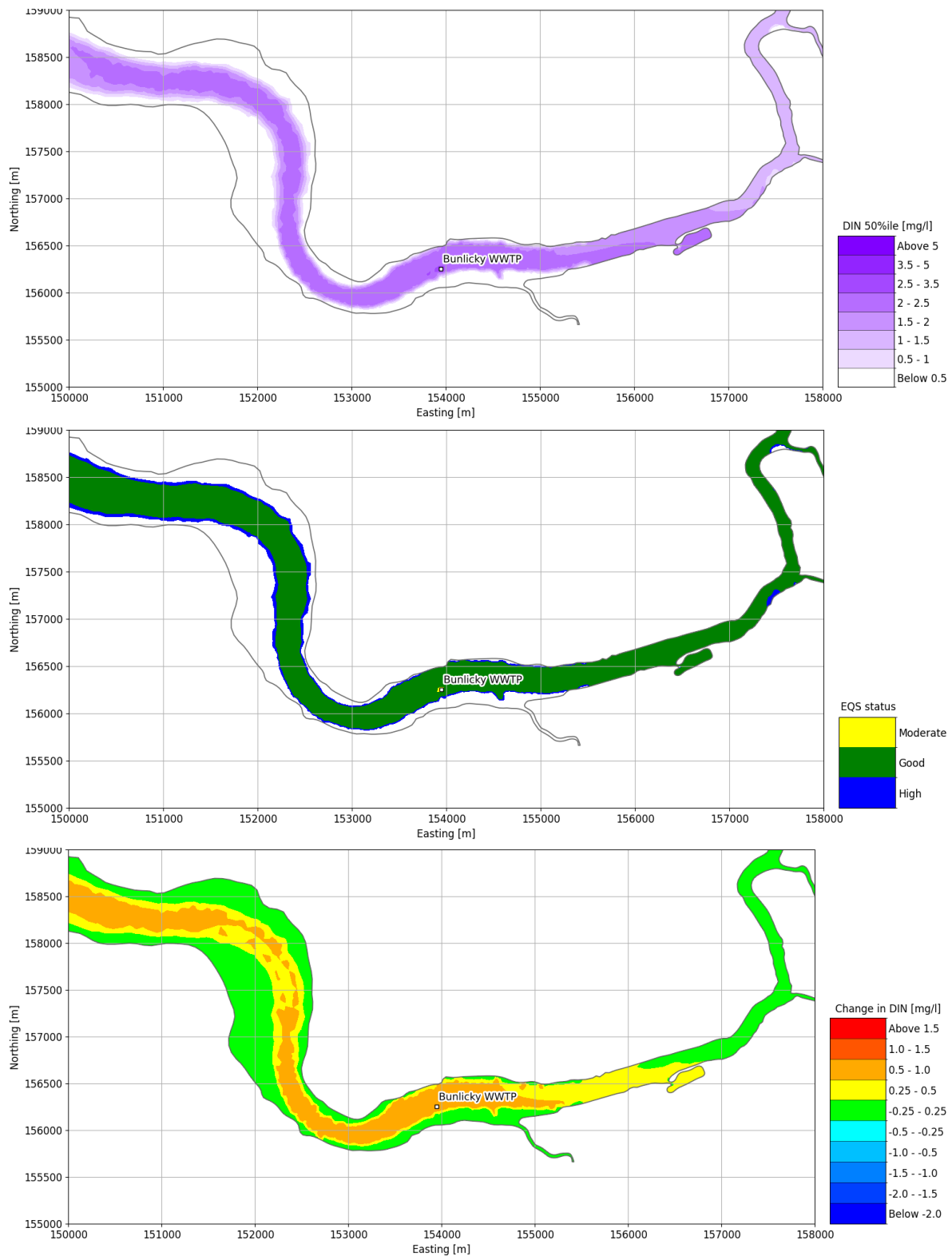


Figure 4-20: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C03 (summer).

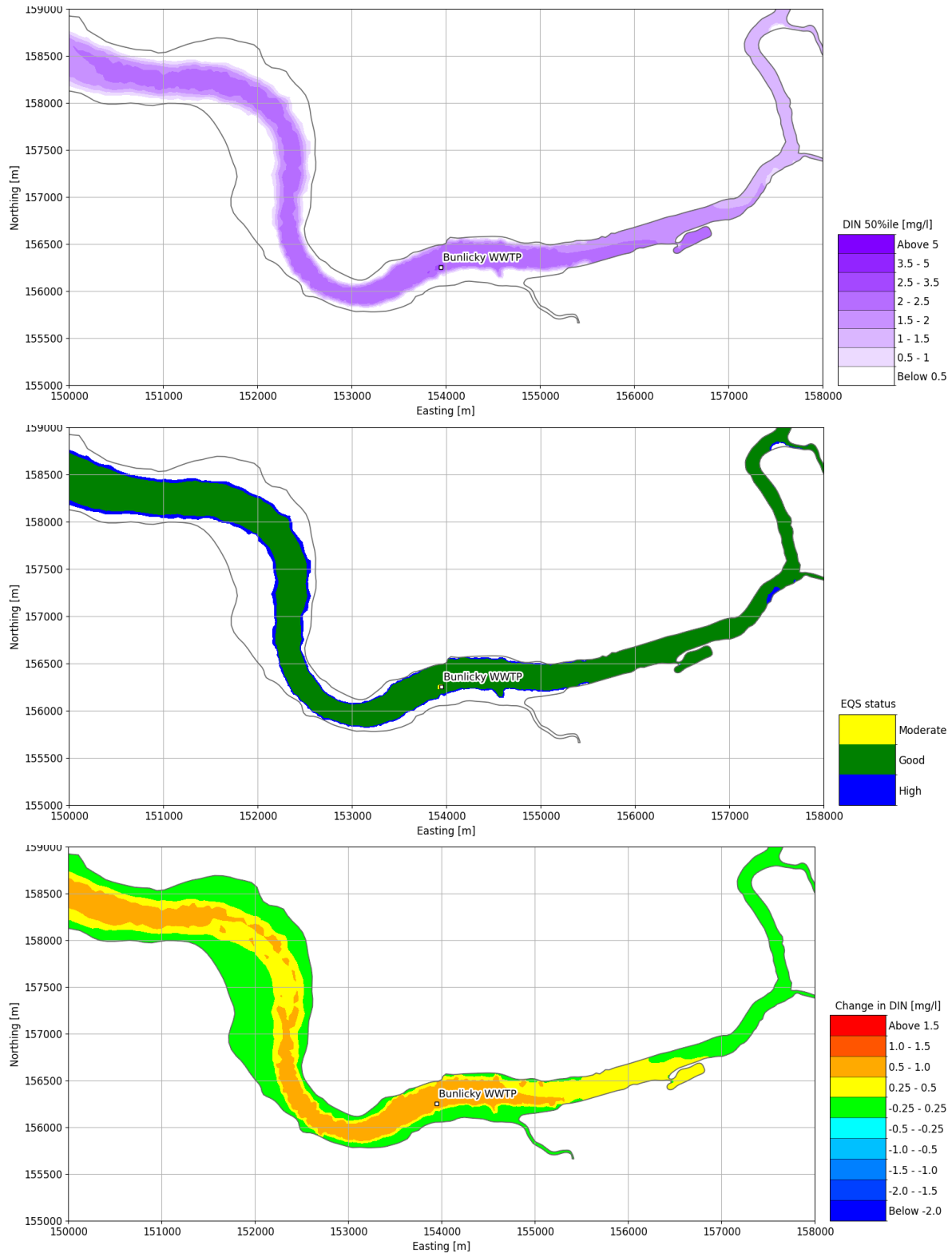


Figure 4-21: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C04 (summer).

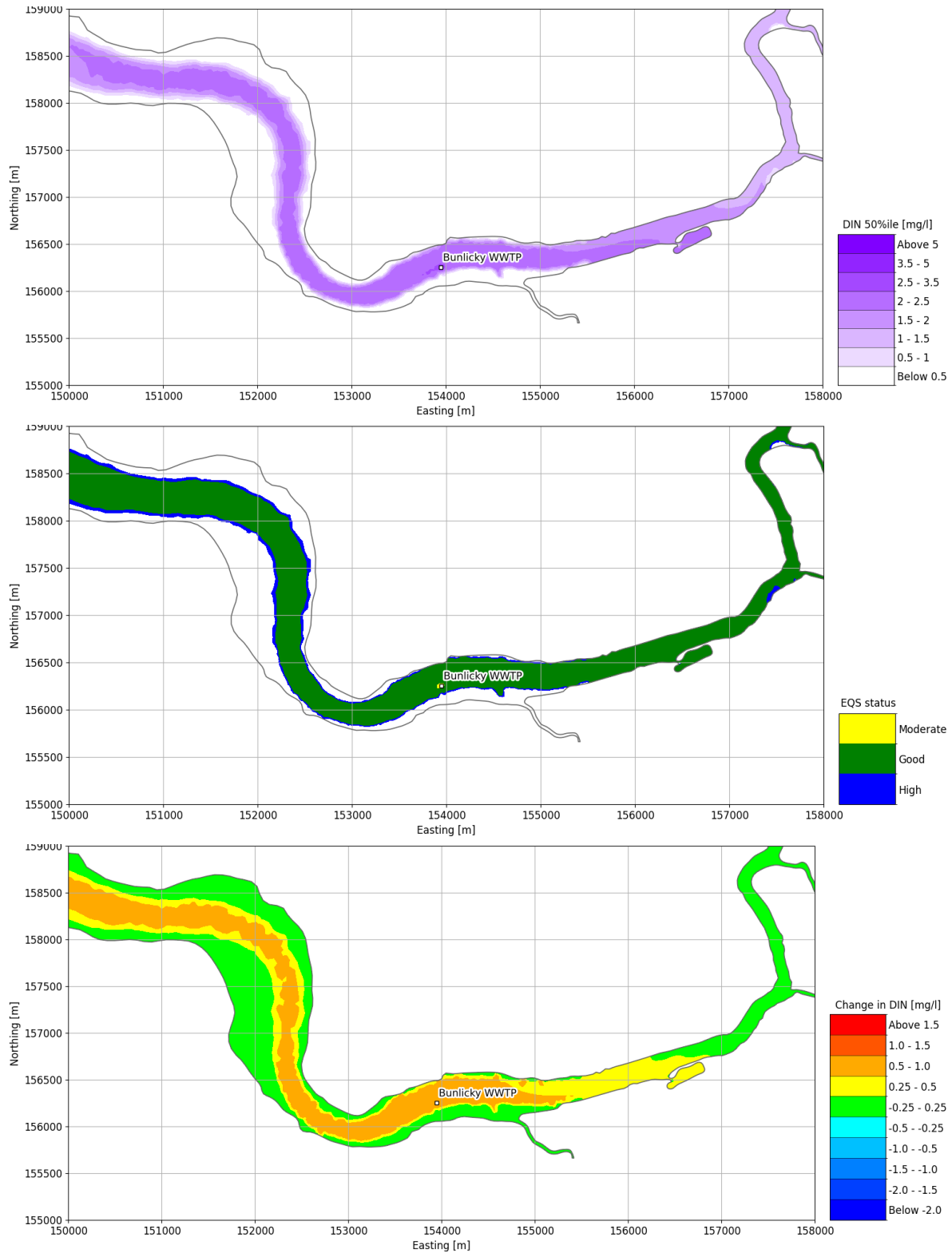


Figure 4-22: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C05 (summer).

4.2.2.2 Winter conditions

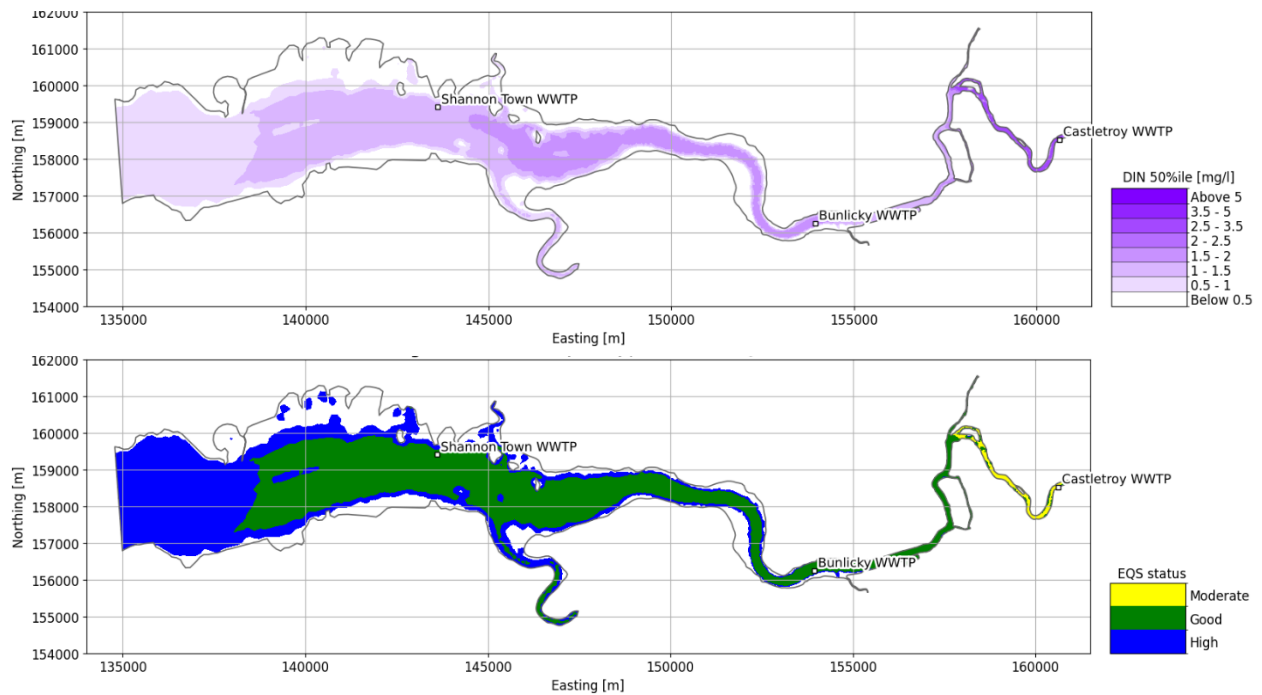


Figure 4-23: Depth-average concentration of DIN 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (winter), full estuary overview.

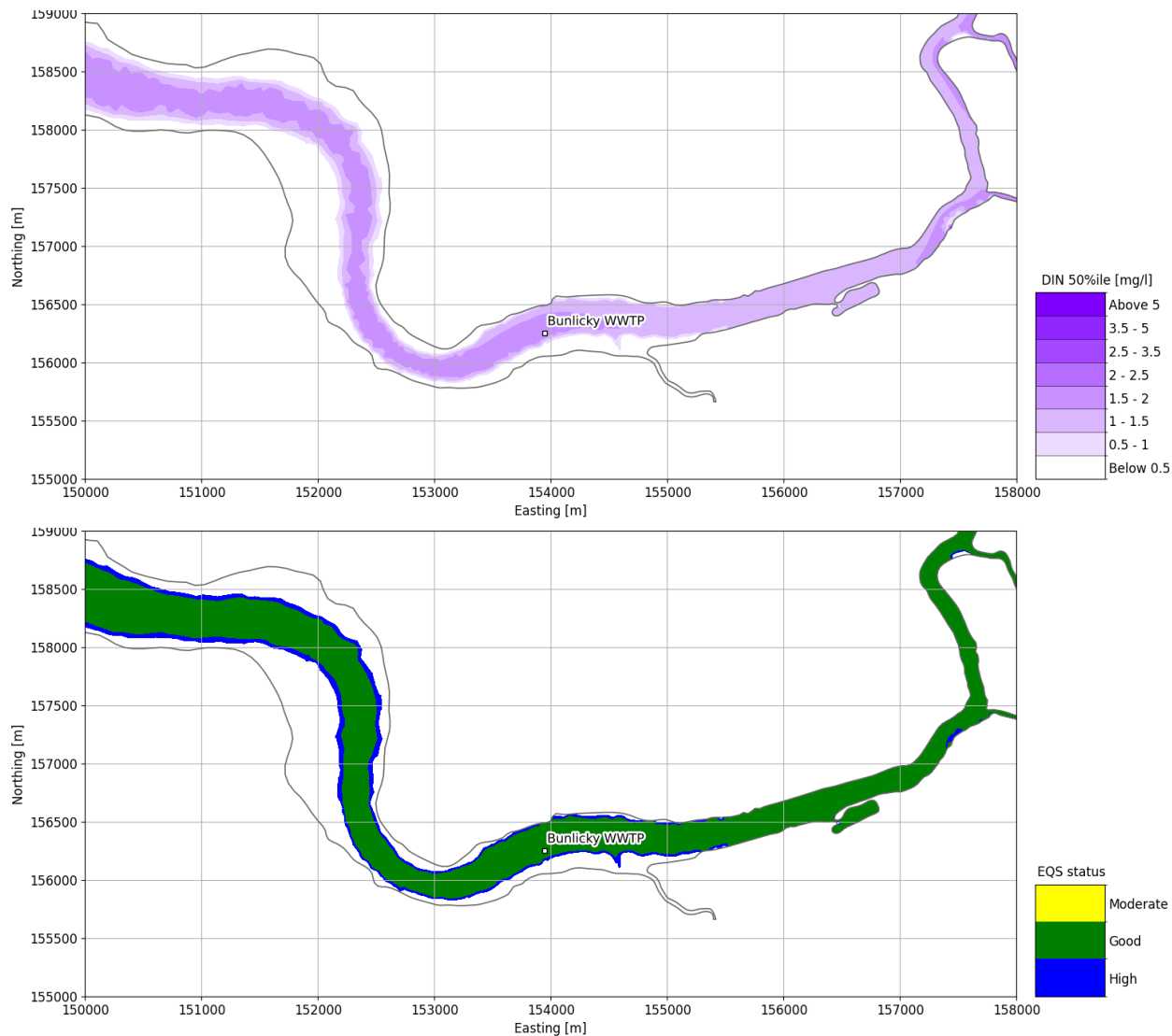


Figure 4-24: Depth-average concentration of DIN 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (winter).

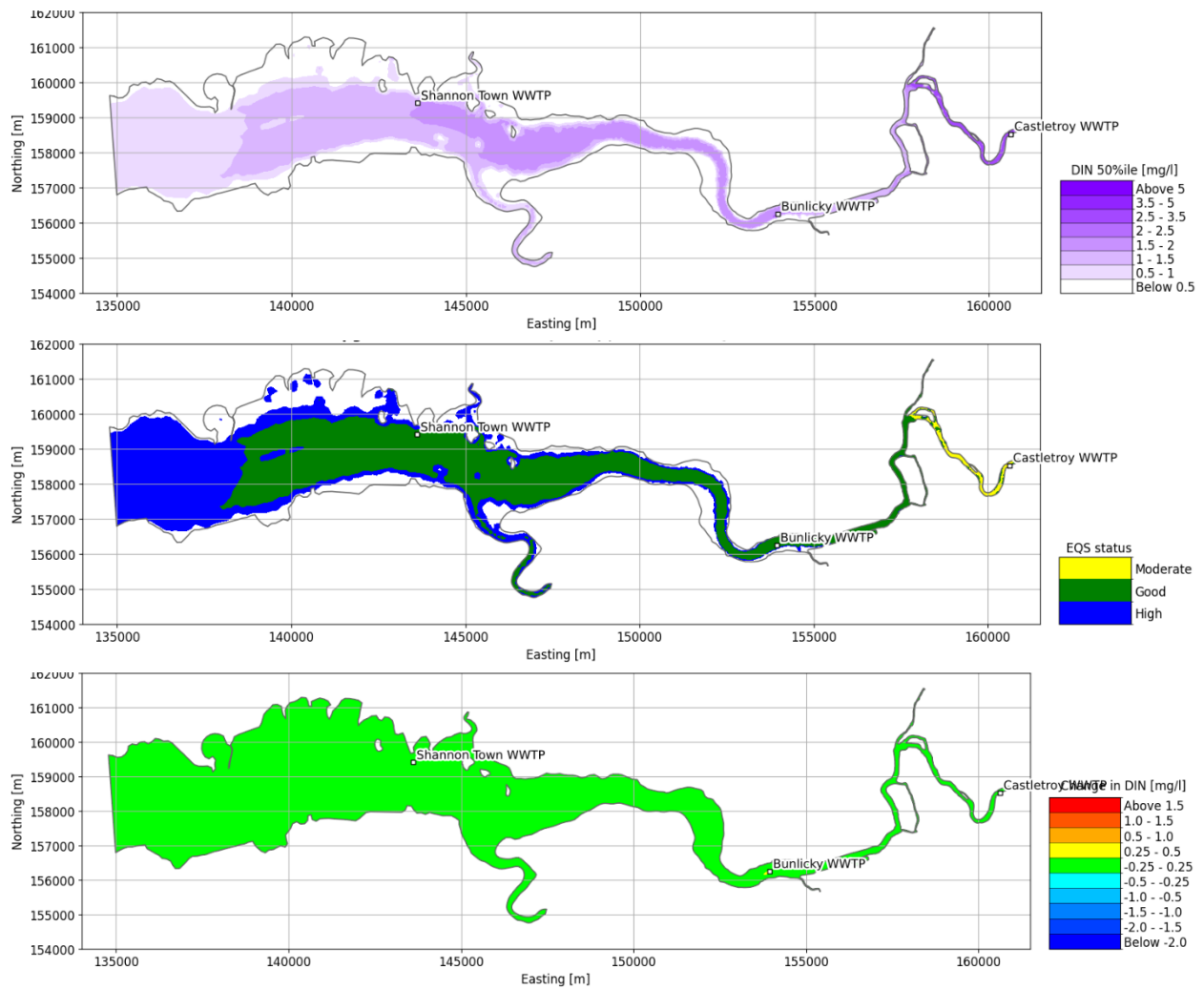


Figure 4-25: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (winter), full estuary overview.

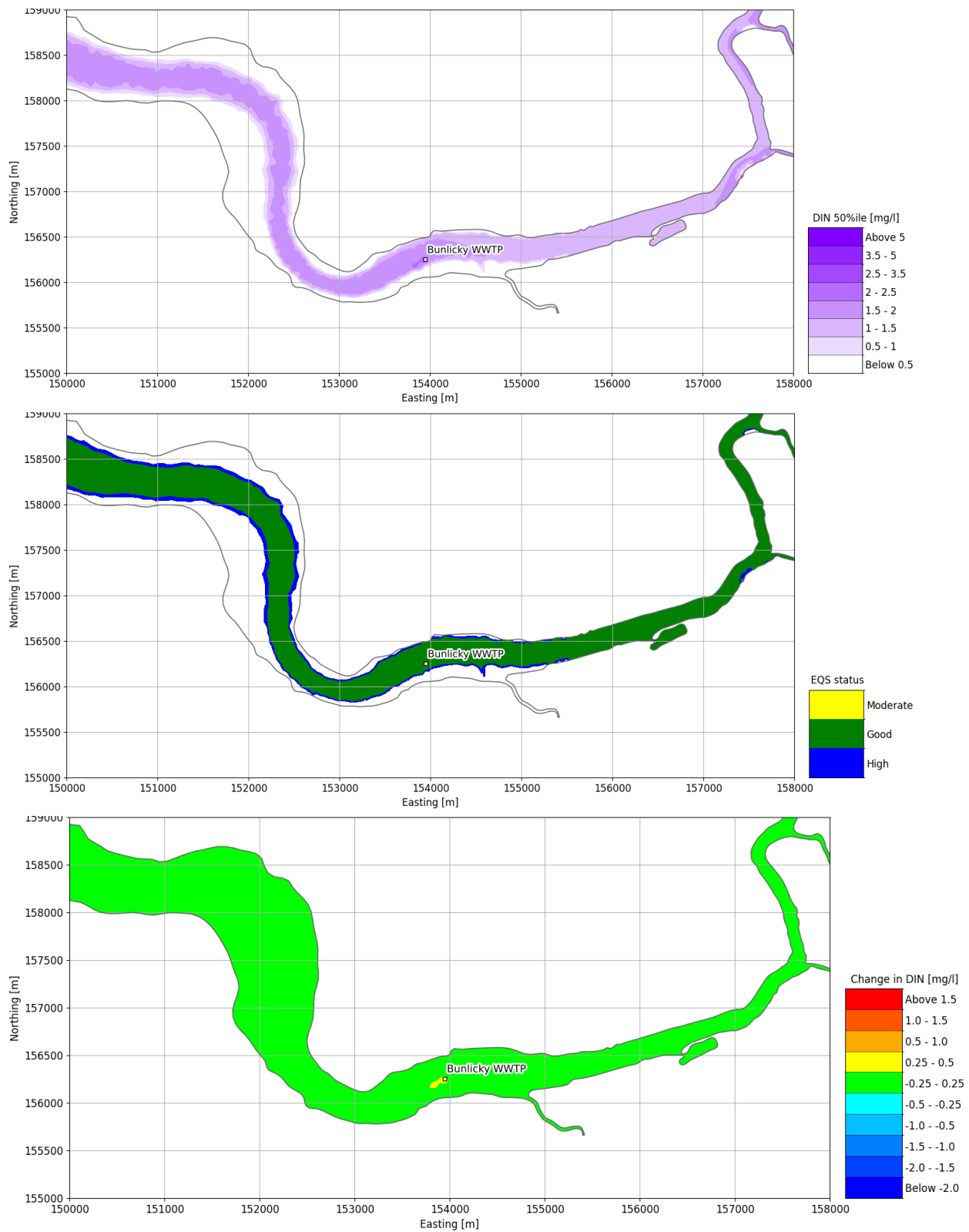


Figure 4-26: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (winter).

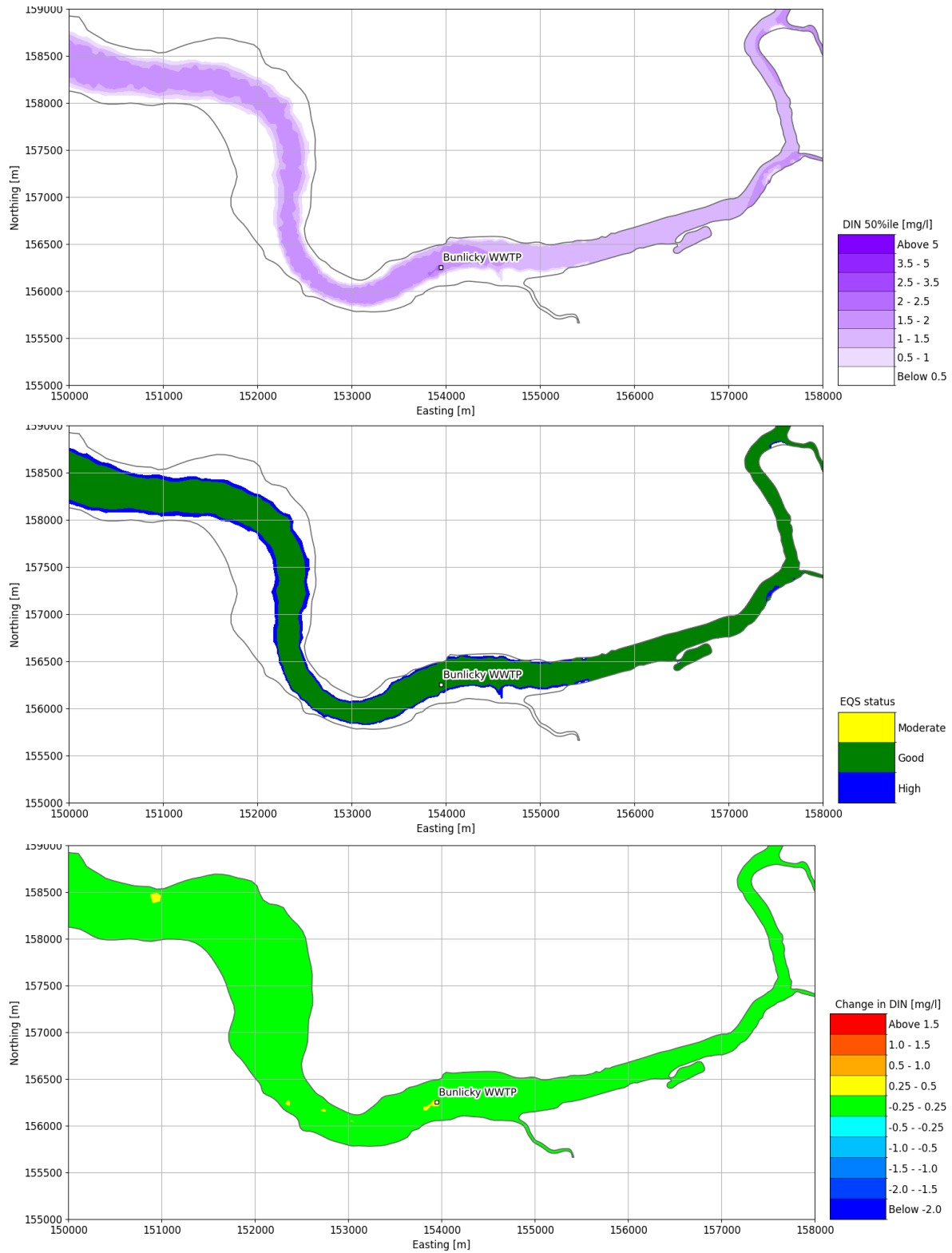


Figure 4-27: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C03 (winter).

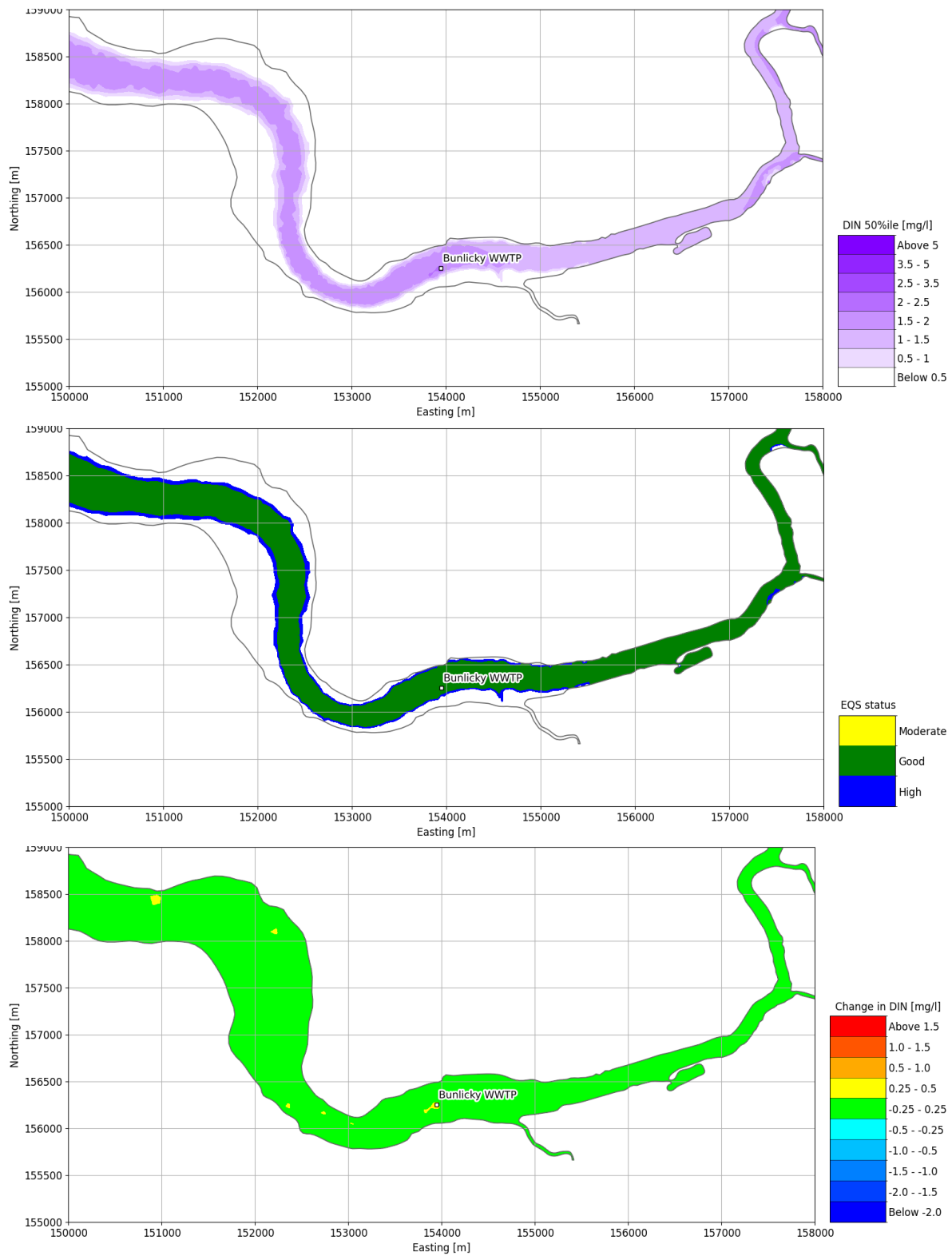


Figure 4-28: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C04 (winter).

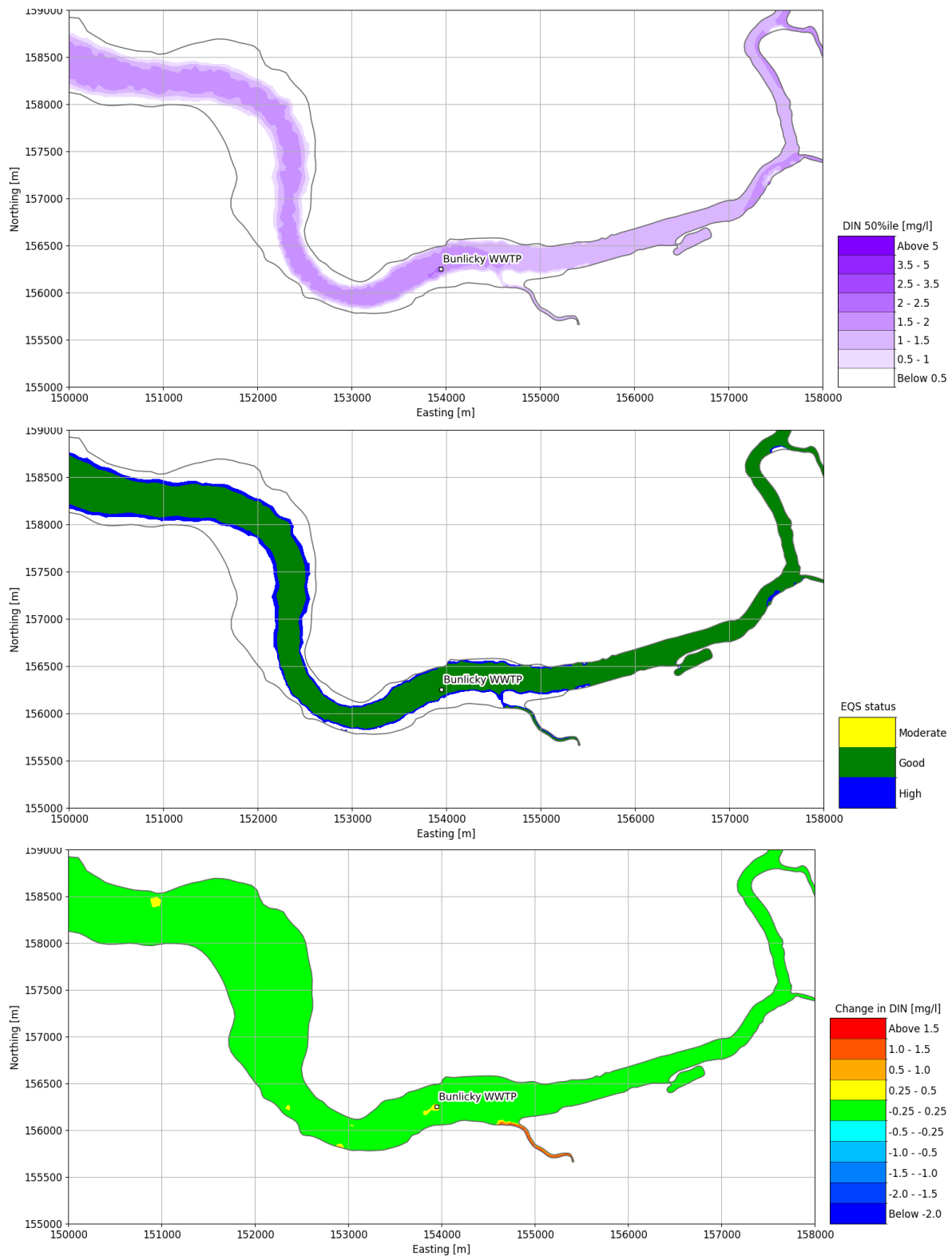


Figure 4-29: Depth-average concentration of DIN 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C05 (winter).

4.2.3 MRP

Section 4.2.3.1 (Figure 4-30 to Figure 4-37) shows the modelling results for the MRP depth-average concentration in the summer conditions. In the existing situation (A01s), the concentrations in the region are predicted to have Moderate indicative WQ status for MRP. This area extends from approximately 2.5 km upstream to 13.5 km downstream of the Bunlicky WWTP outfall. The zone with 'Good' indicative WQ status spans 25.5 km from the downstream boundary of the model to around 4 km upstream of the outfall (Figure 4-30). Maximum MRP concentration at the outfall itself in the existing situation reaches 0.16 mg/l (Figure 4-31).

In the scenarios with the Bunlicky WWTP upgrade (C02s – C05s), MRP concentration near the outfall increases by up to 0.18 mg/l above background concentrations, reaching a cumulative concentration of 0.34 mg/l (Figure 4-33 to Figure 4-36). An increase in concentration of more than 0.060 mg/l, corresponding to a 'Moderate' WQ status in the absence of background MRP, extends from approximately 2.5 km upstream to around 8 km downstream. As a result the mixing zone length with 'Moderate' indicative WQ status increases from 16 km to around 18.5 km, extending 3 km upstream and 15.5 km downstream from the outfall (Figure 4-32).

In the scenario with the combined upgrades of the WWTPs (C06s) and reduced MRP ELV concentration at the outfall, the condition improves significantly, maximum MRP concentration near the outfall decreases by about 0.09 mg/l compared to the existing situation, to 0.07 mg/l (Figure 4-37). The extent of the mixing zone with 'Moderate' indicative WQ status in this case is limited to only 510 m around the outfall. The extent of the 'Good' indicative WQ status zone, however, does not change significantly.

Section 4.2.3.2 (Figure 4-38 to Figure 4-44) shows the modelling results for the MRP depth-average concentration in the winter conditions. In the existing situation (A01w), most of the estuary is also characterized by 'Good' indicative WQ status, which extends over approximately 23 km (Figure 4-38). Maximum MRP concentration near the outfall reaches 0.1 mg/l, but the extent of the mixing zone with Moderate MRP indicative WQ status is limited to around 350 m (Figure 4-39).

In the upgrade scenarios (C02w – C05w), MRP concentration near the outfall increases by about 0.1 mg/l above background concentrations. An increase in concentration of more than 0.060 mg/l, corresponding to a 'Moderate' WQ status in the absence of background MRP, is not observed. However, the cumulative impact increases the extent of the mixing zone 'Moderate' EQS compared to the existing situation from 350 m to around 1100 m (Figure 4-41 to Figure 4-44). The change in concentration is observed only within approximately 2 km from the outfall and most of the estuary remains within 'Good' EGS status in all the scenarios (Figure 4-40).

Table 4-4: MRP mixing zone length (along the deepest channel line).

Season	Model scenario	Mixing zone length		Relative of total length Shannon Estuary (~100km)	
		EQS status: Good	EQS status: Moderate	EQS status: Good	EQS status: Moderate
Summer	A01s	25.5 km	16 km	25.5%	16.0%
	C02s	25.7 km	18.5 km	25.7%	18.5%
	C03s	25.9 km	18.5 km	25.9%	18.5%
	C04s	25.9 km	18.5 km	25.9%	18.5%
	C05s	25.9 km	18.5 km	25.9%	18.5%
	C06s	25.2 km	510 m	25.2%	0.5%

Winter	A01w	23 km	350 m	23.0%	0.4%
	C02w	23 km	1.1 km	23.0%	1.1%
	C03w	23 km	1.1 km	23.0%	1.1%
	C04w	23 km	1.1 km	23.0%	1.1%
	C05w	23 km	1.1 km	23.0%	1.1%

4.2.3.1 Summer conditions

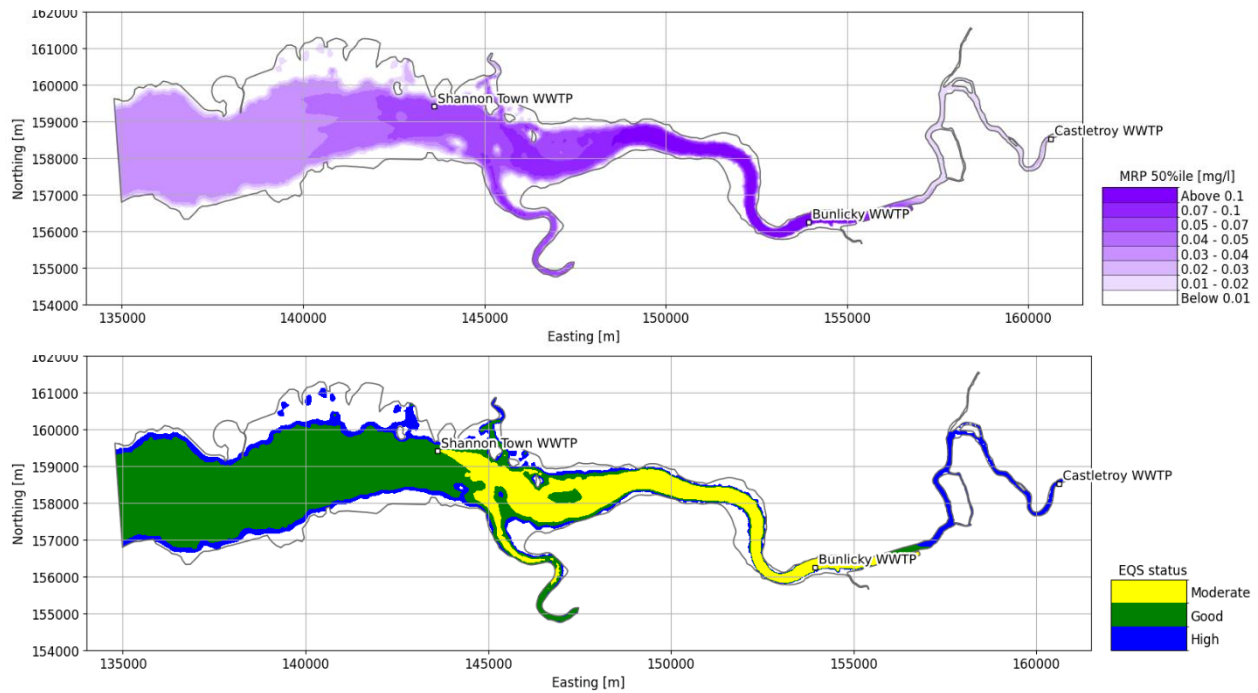


Figure 4-30: Depth-average concentration of MRP 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (summer), full estuary overview.

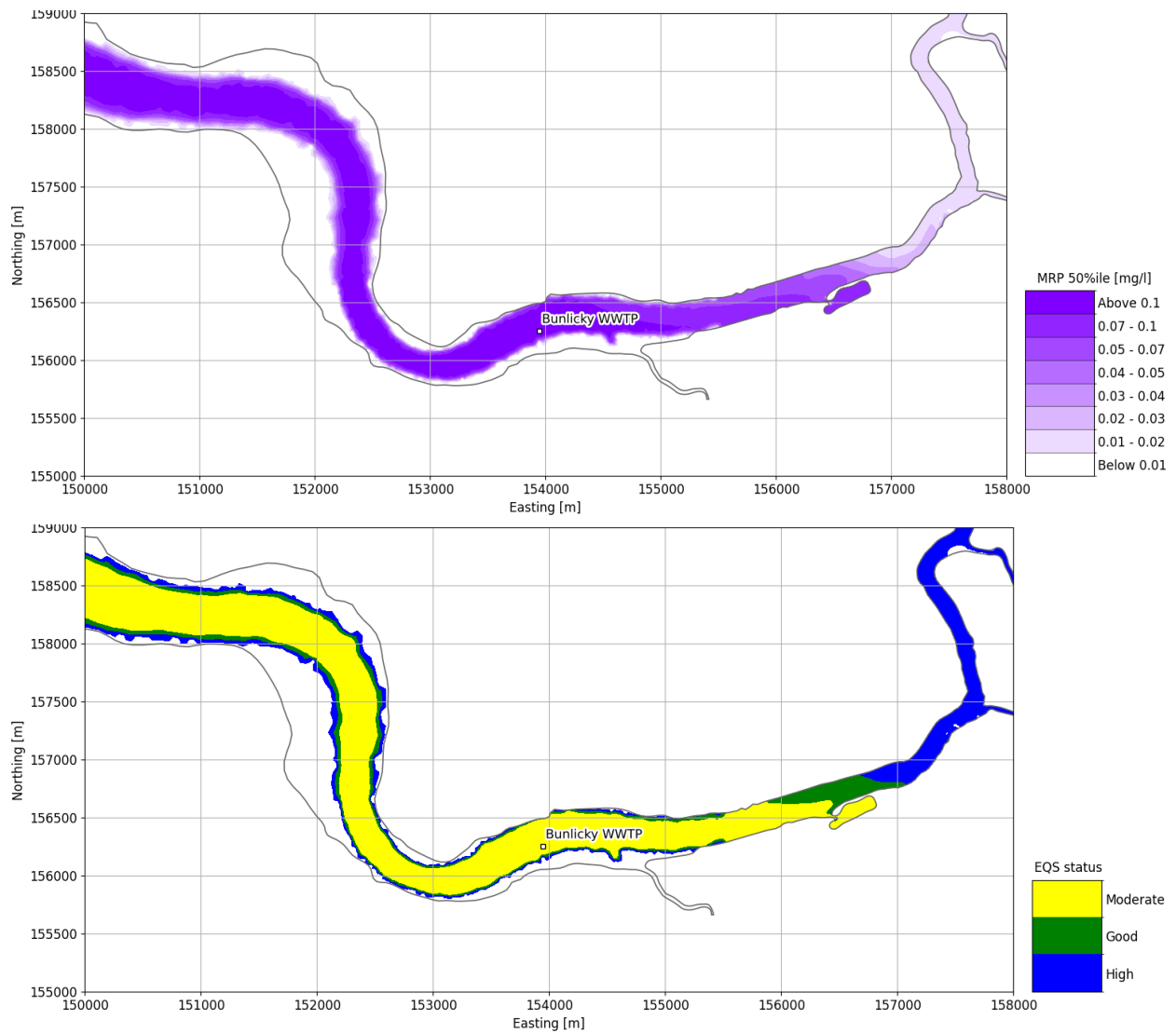


Figure 4-31: Depth-average concentration of MRP 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (summer).

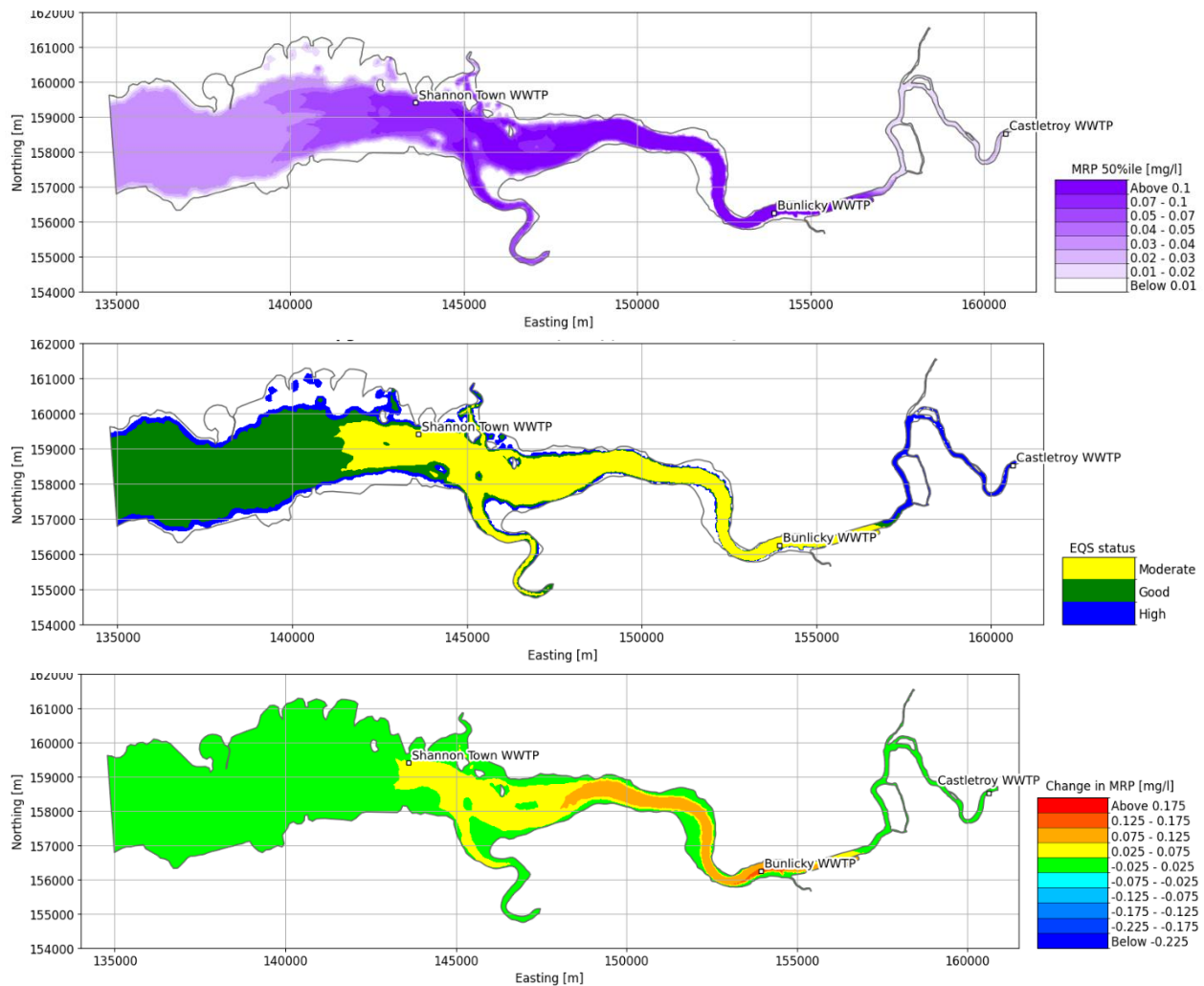


Figure 4-32: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (summer), full estuary overview.

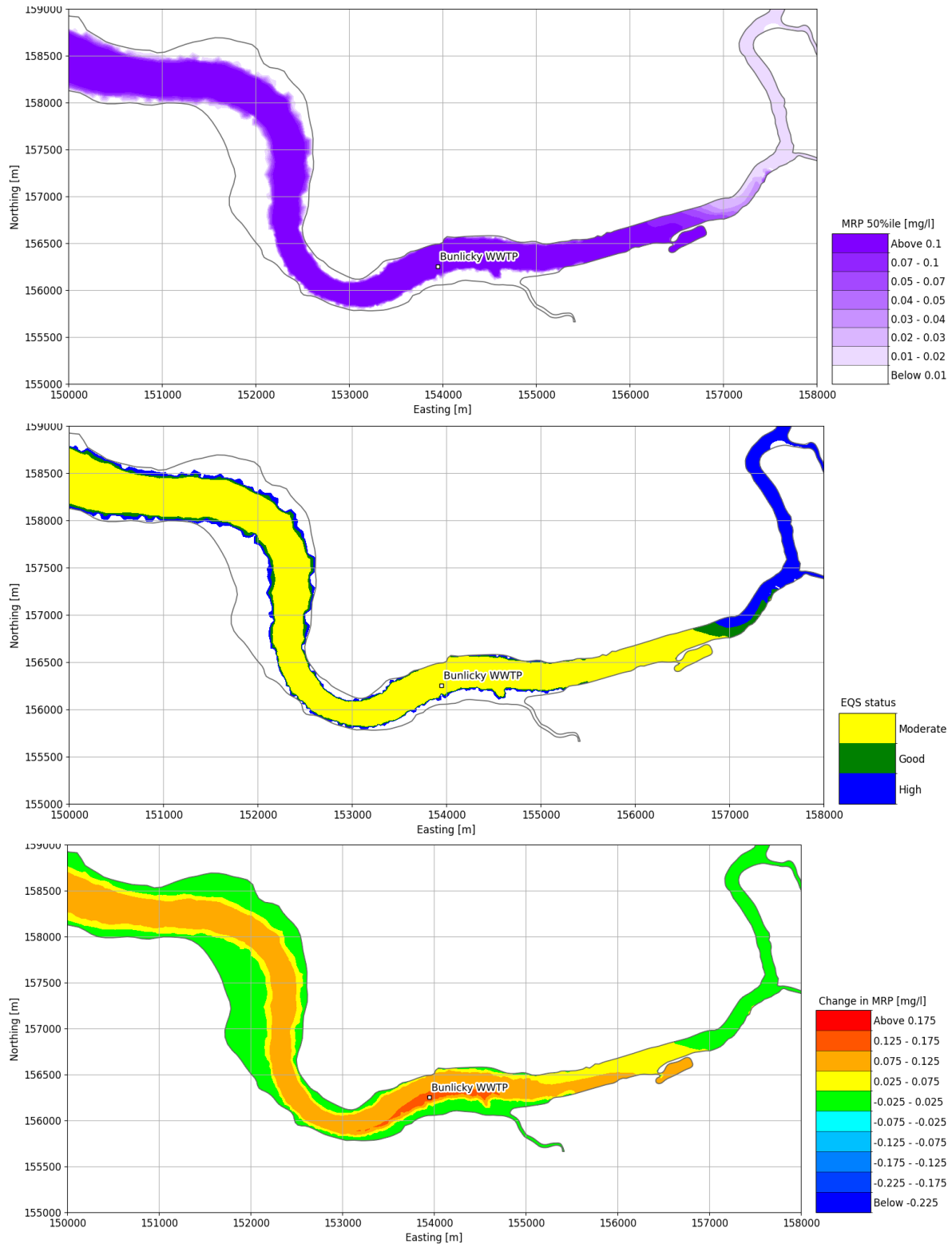


Figure 4-33: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (summer).

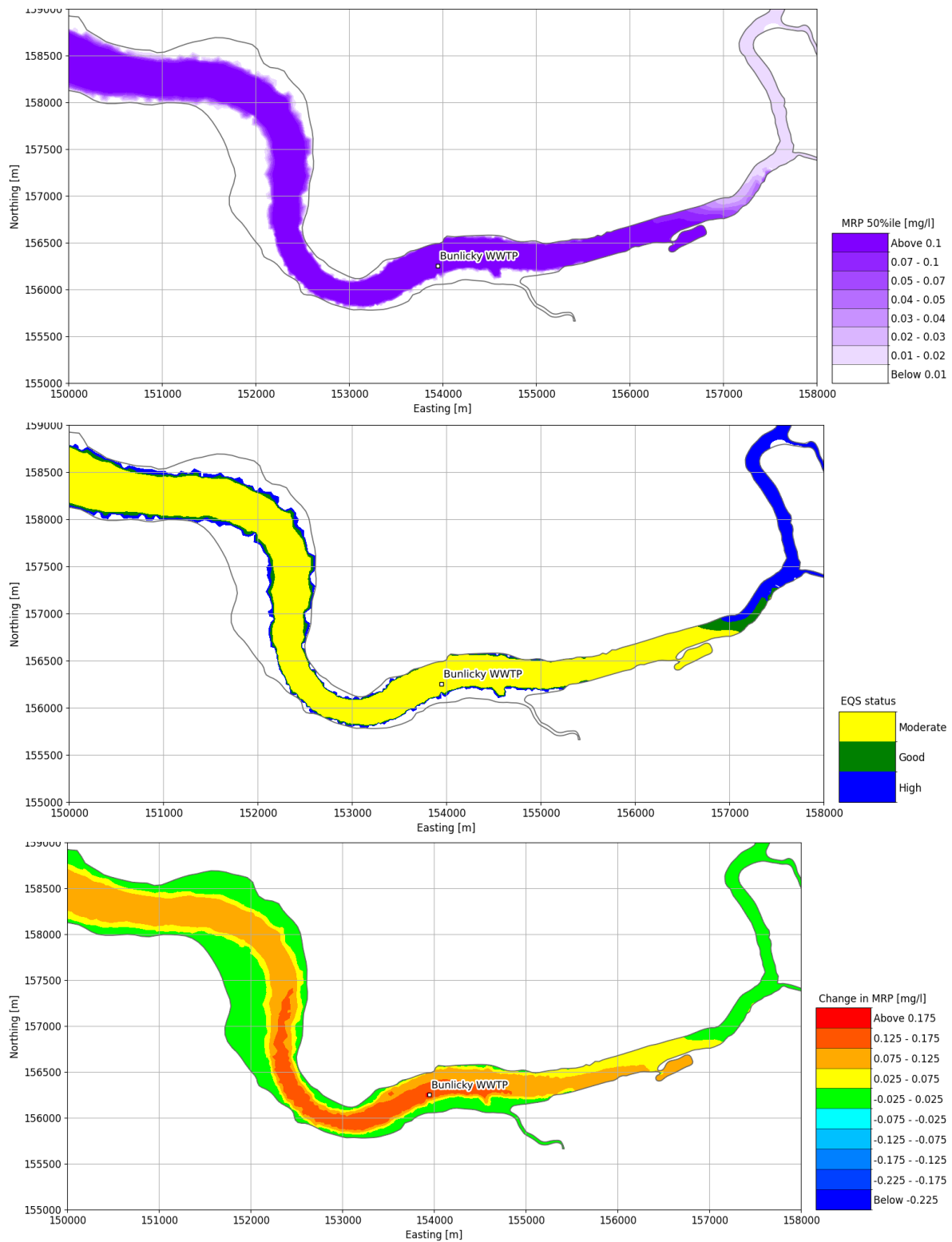


Figure 4-34: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C03 (summer).

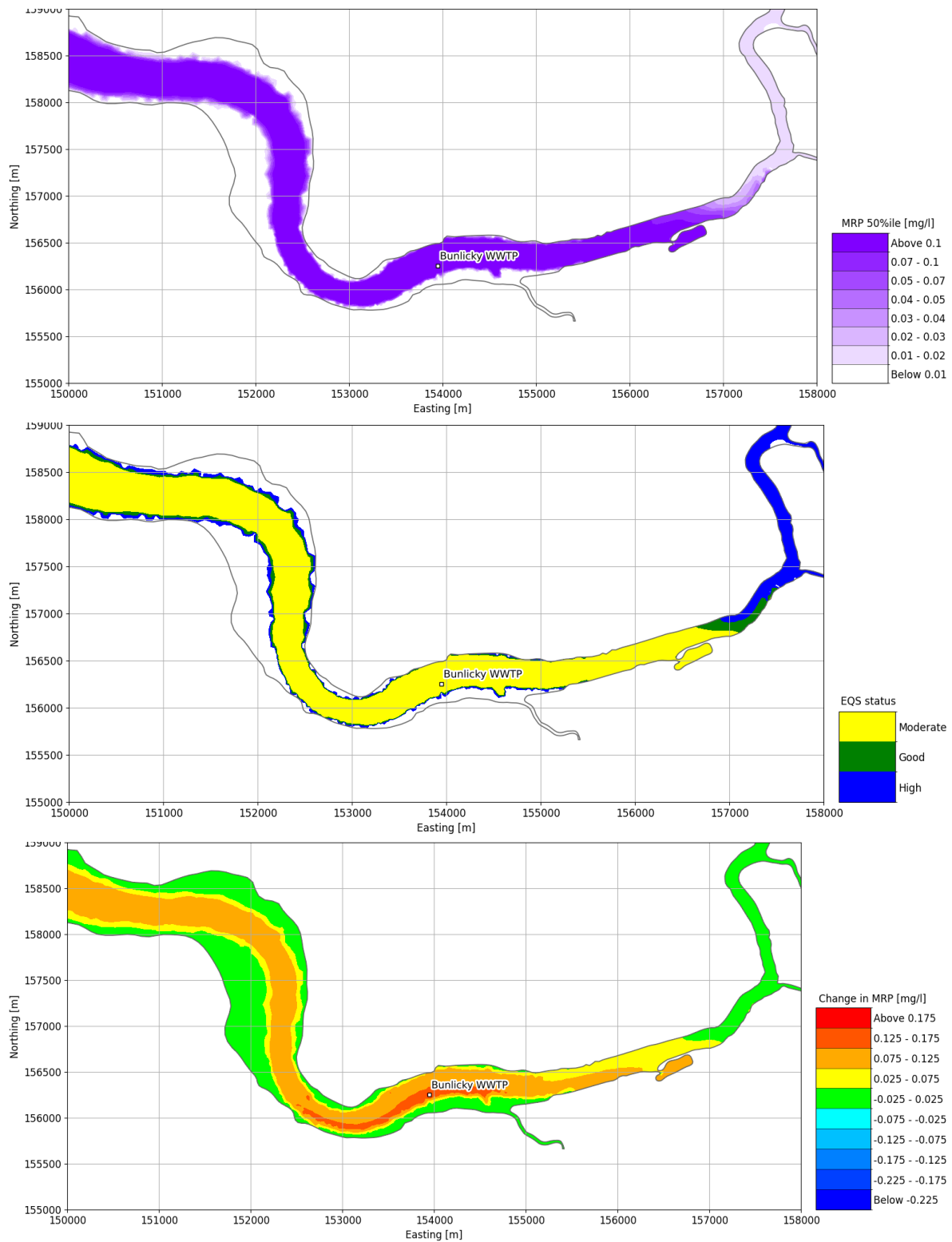


Figure 4-35: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C04 (summer).

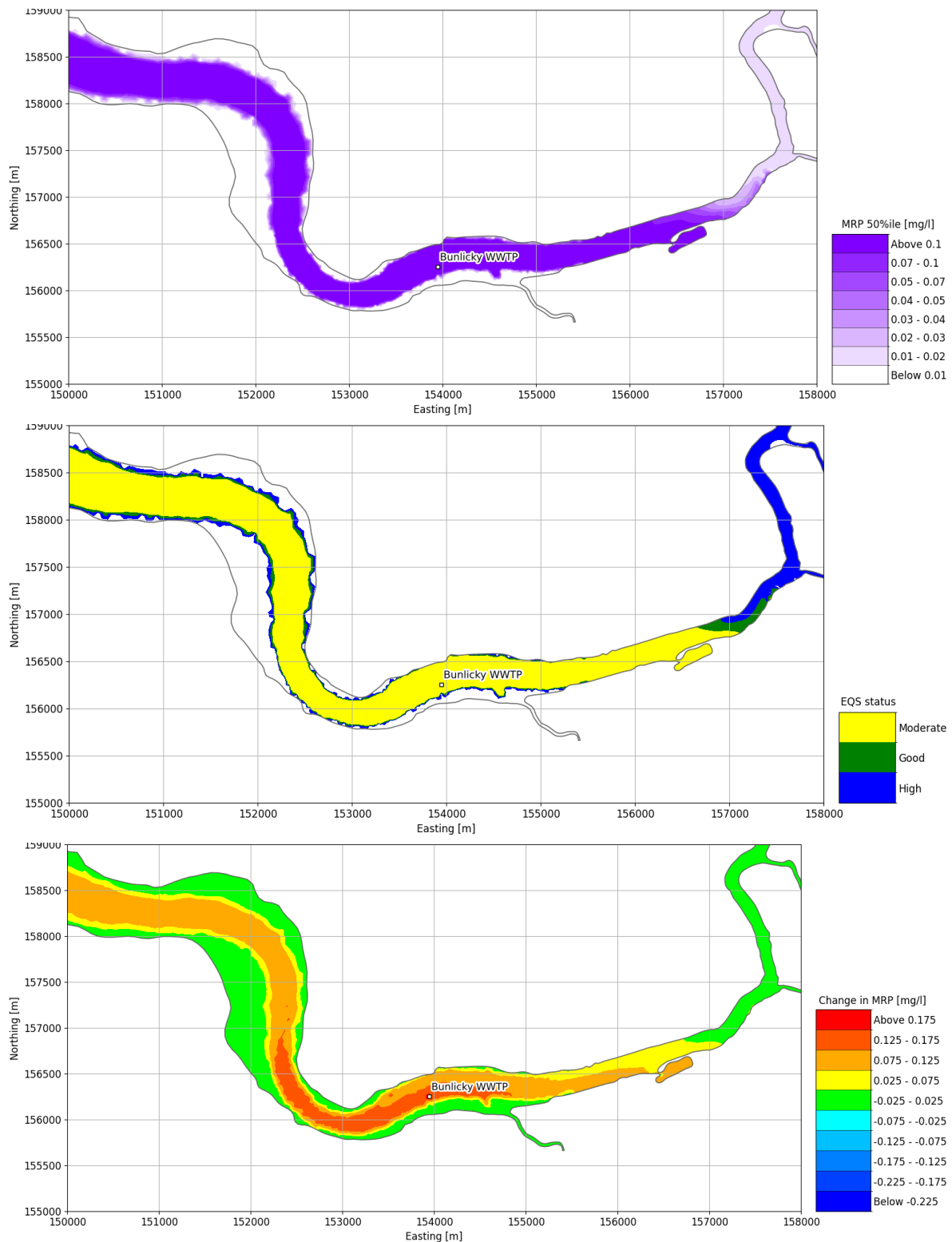


Figure 4-36: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C05 (summer).

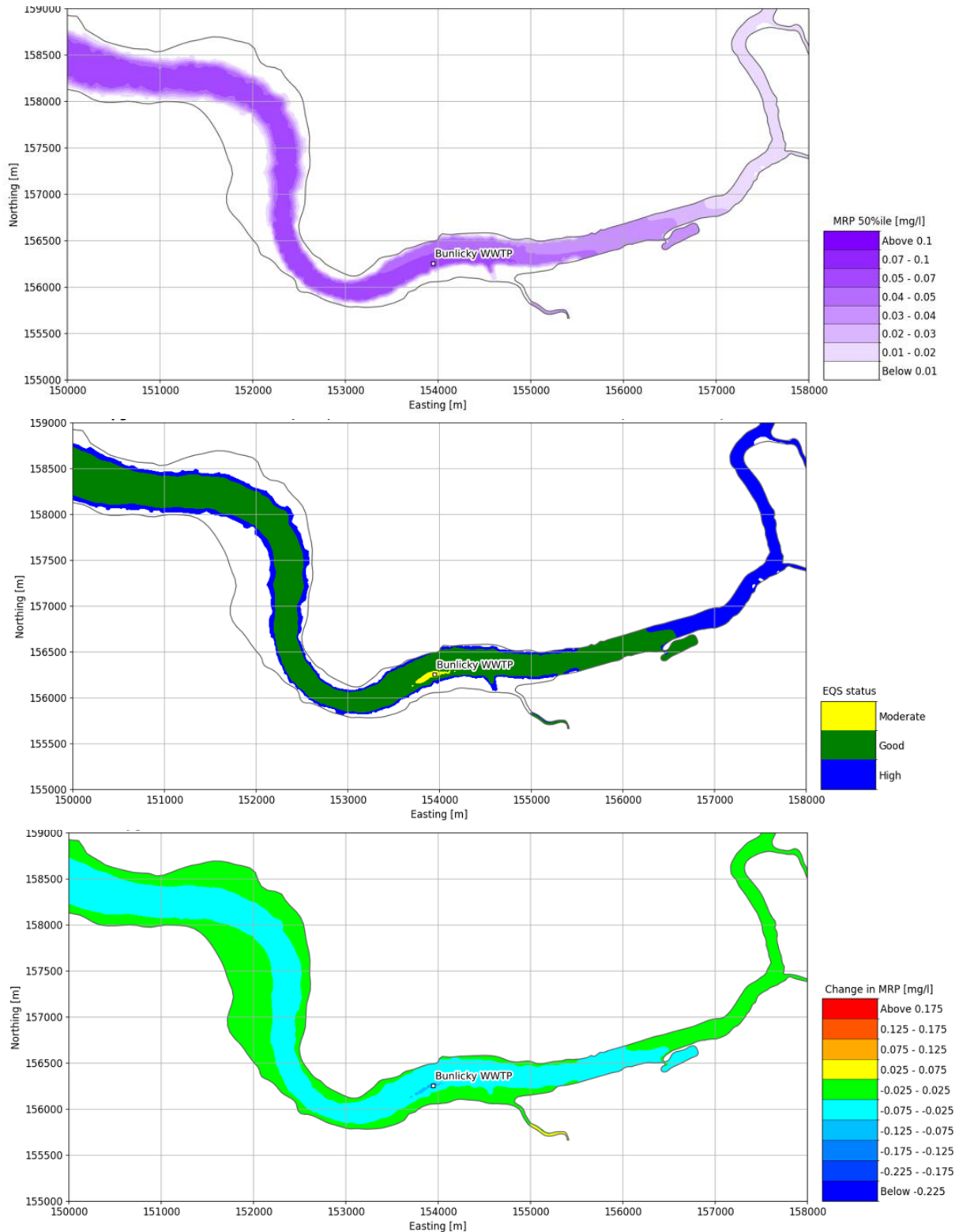


Figure 4-37: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C06 (summer).

4.2.3.2 Winter conditions

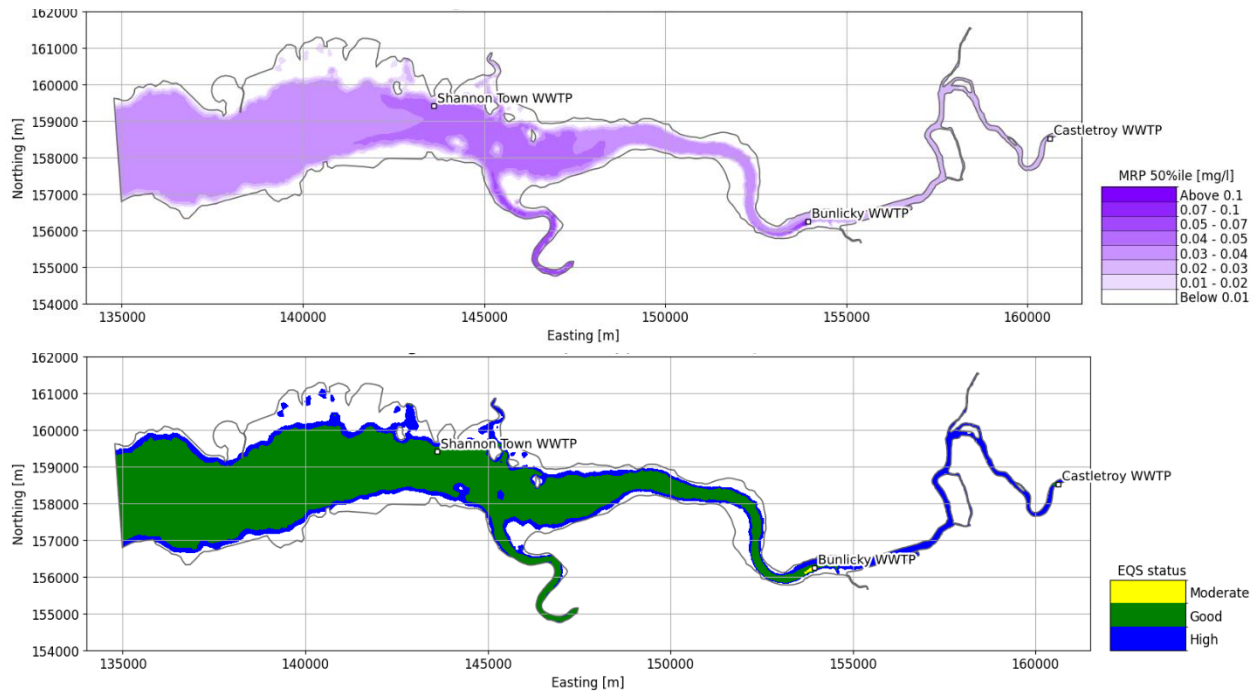


Figure 4-38: Depth-average concentration of MRP 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (winter), full estuary overview.

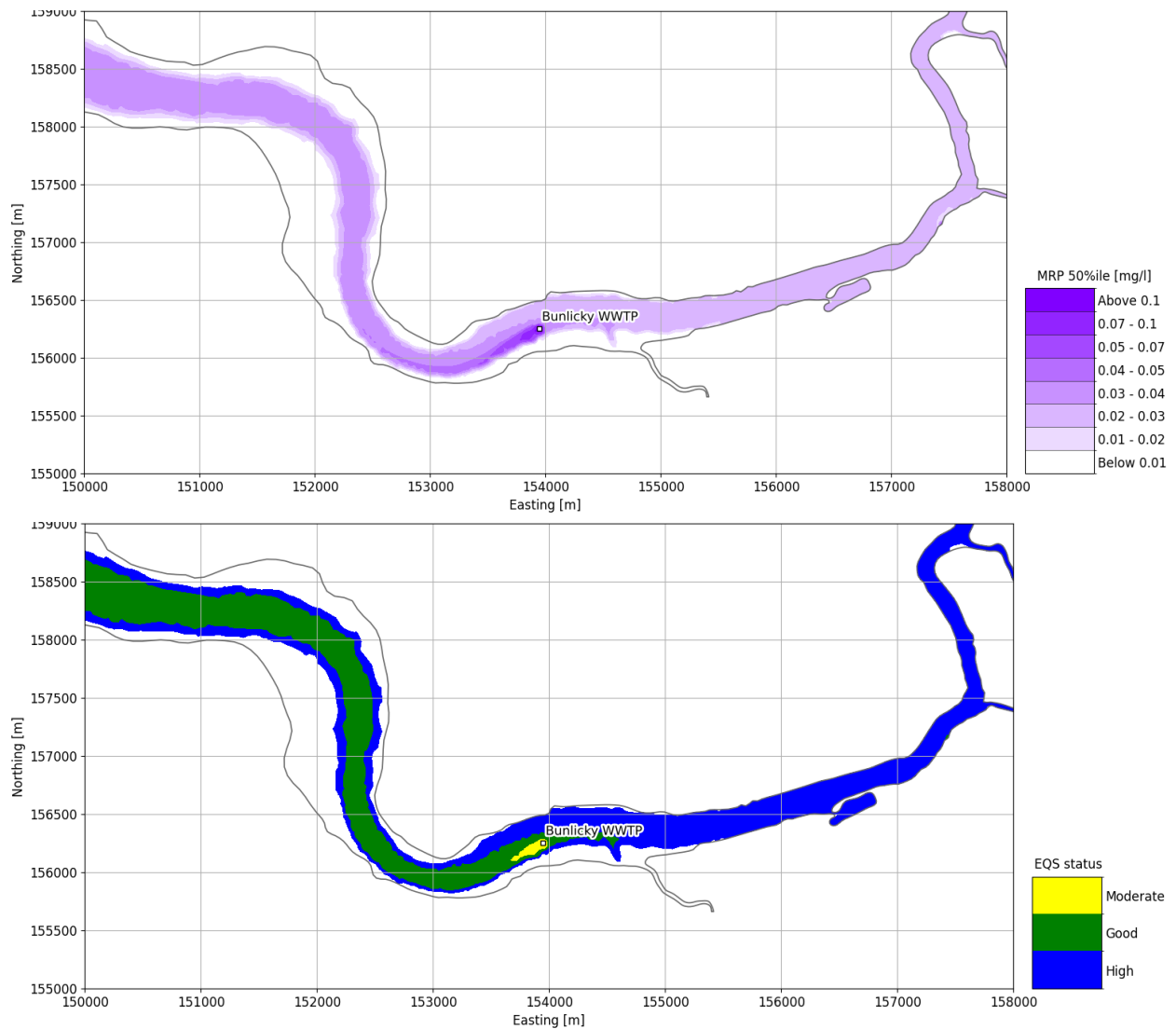


Figure 4-39: Depth-average concentration of MRP 50%ile (upper panel) and Indicative Quality Plot (lower panel) for existing situation A01 (winter).

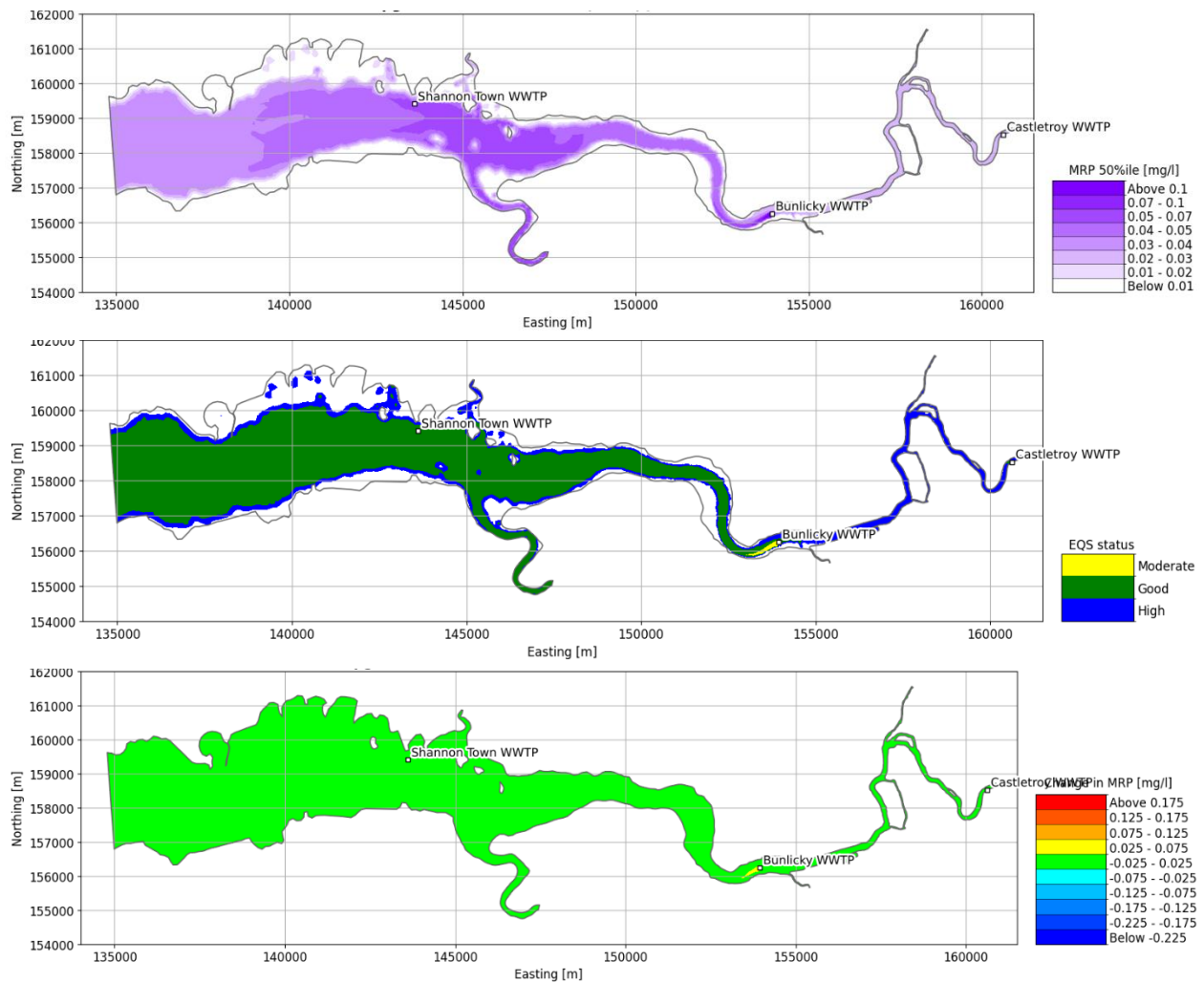


Figure 4-40: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (winter), full estuary overview.

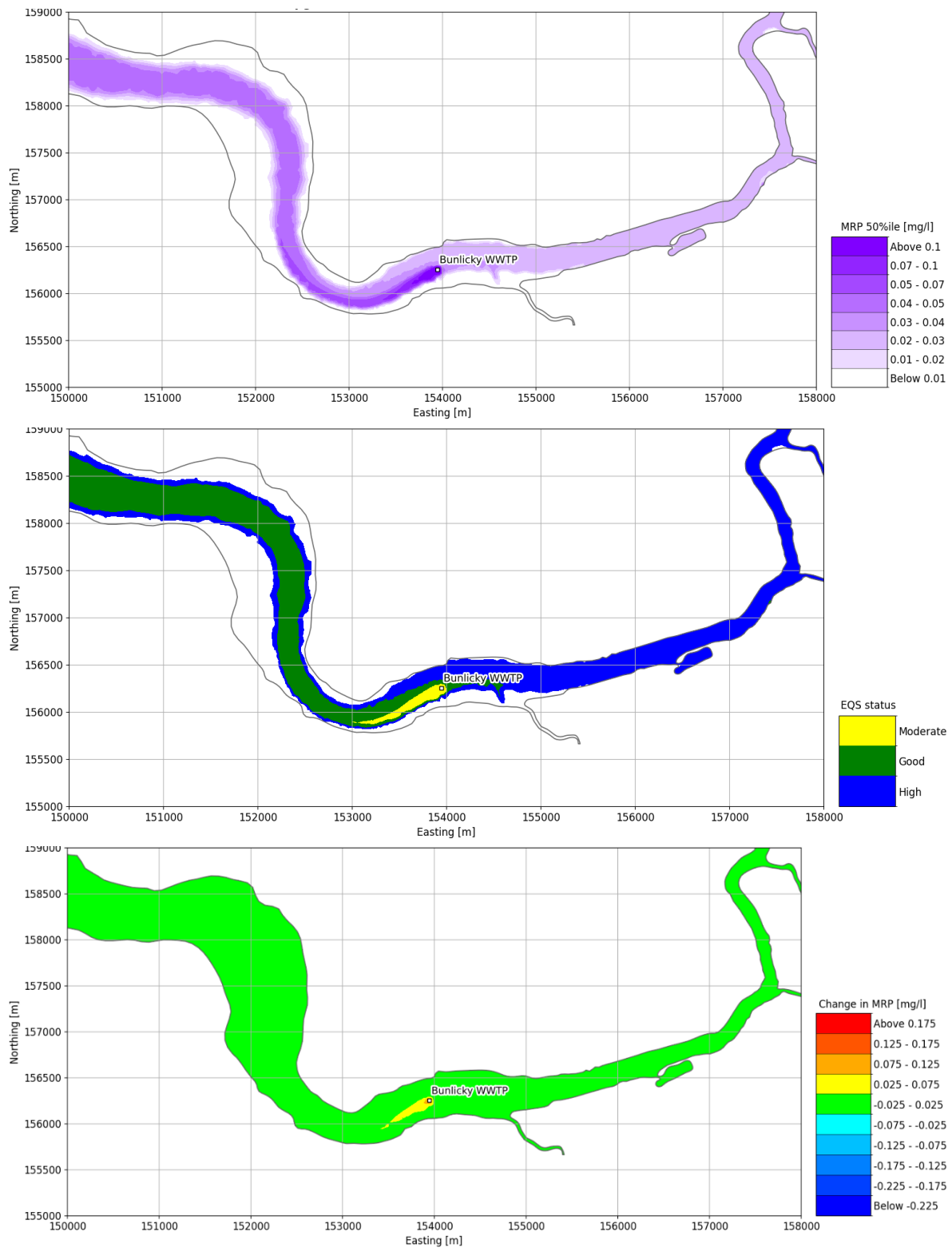


Figure 4-41: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C02 (winter).

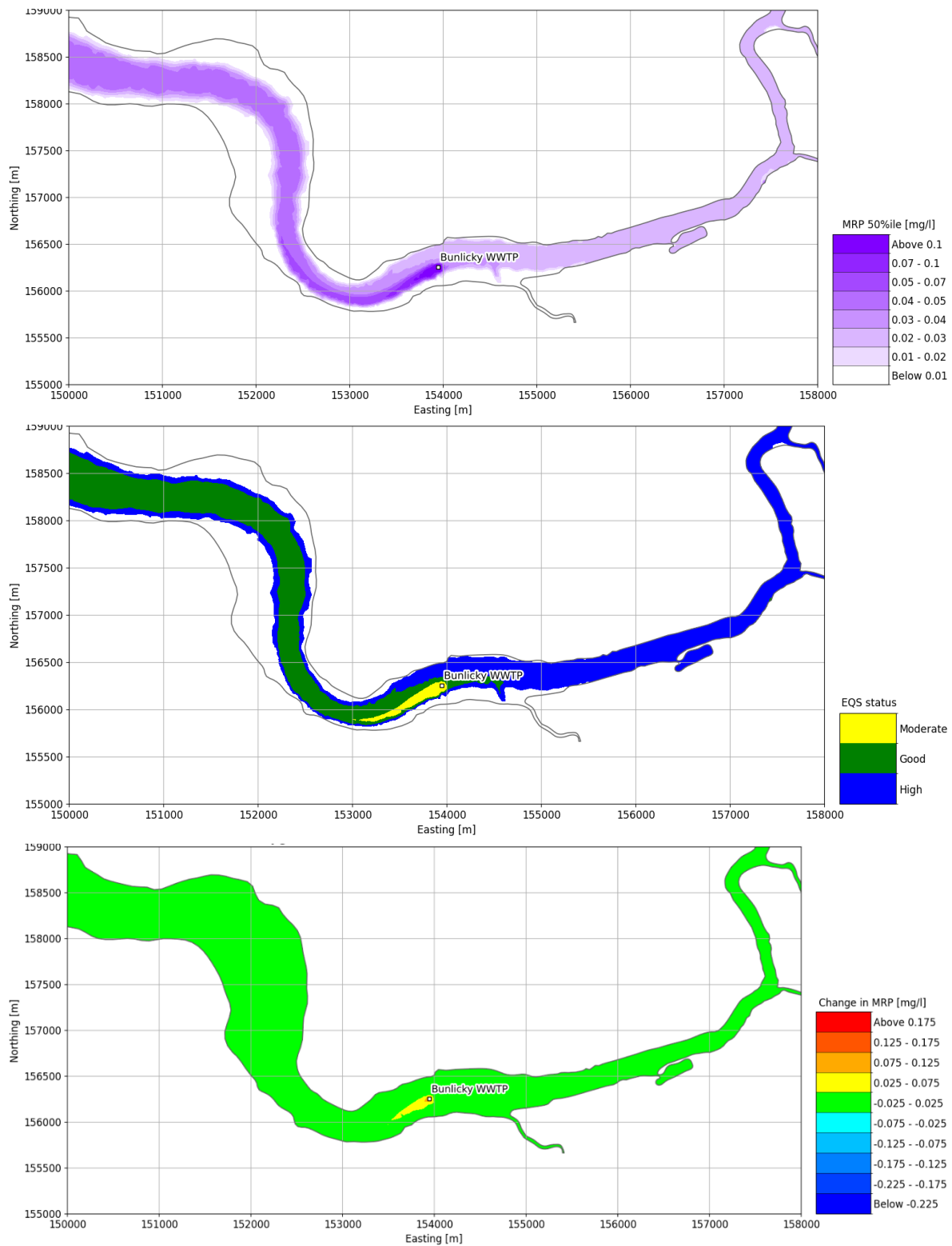


Figure 4-42: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C03 (winter).

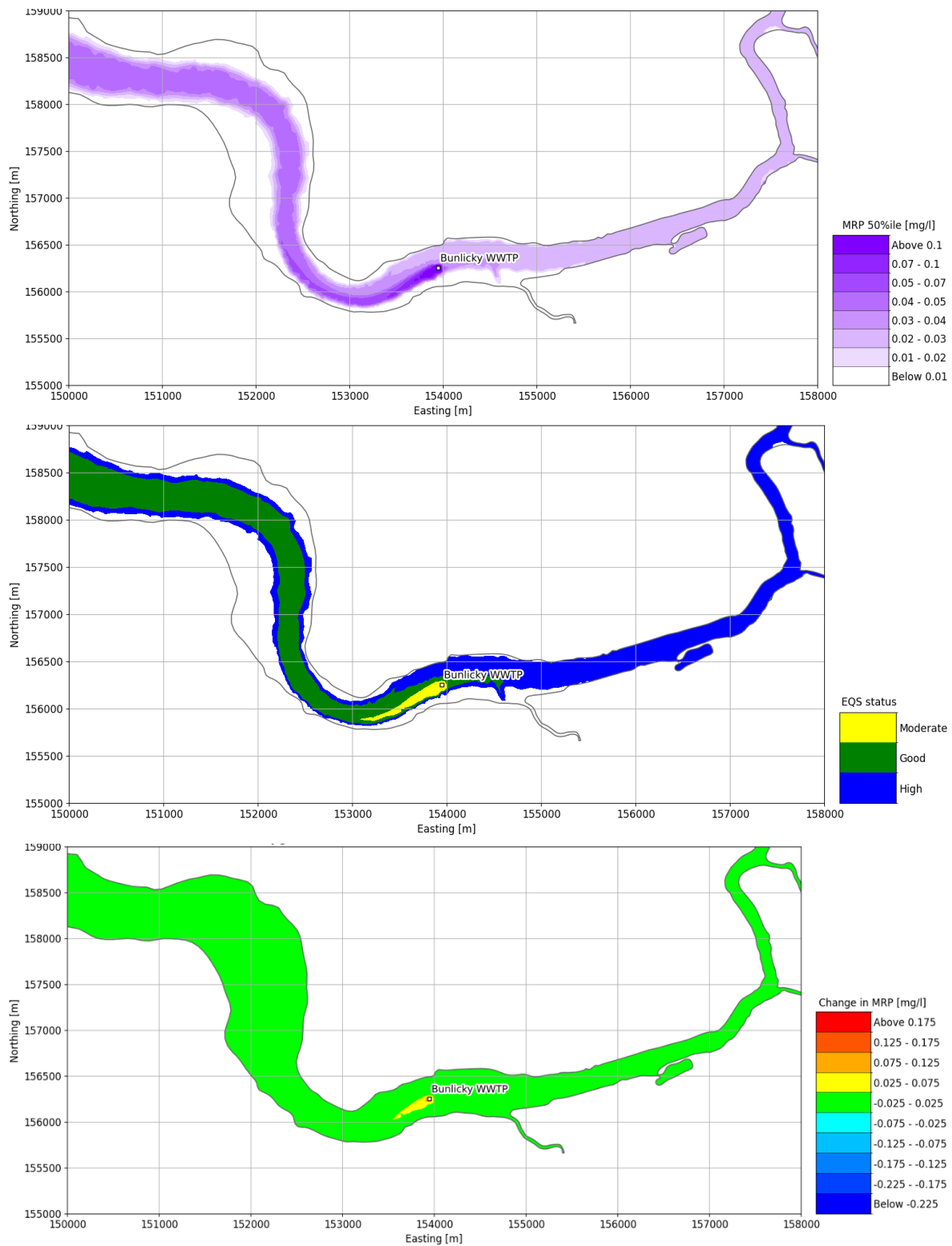


Figure 4-43: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C04 (winter).

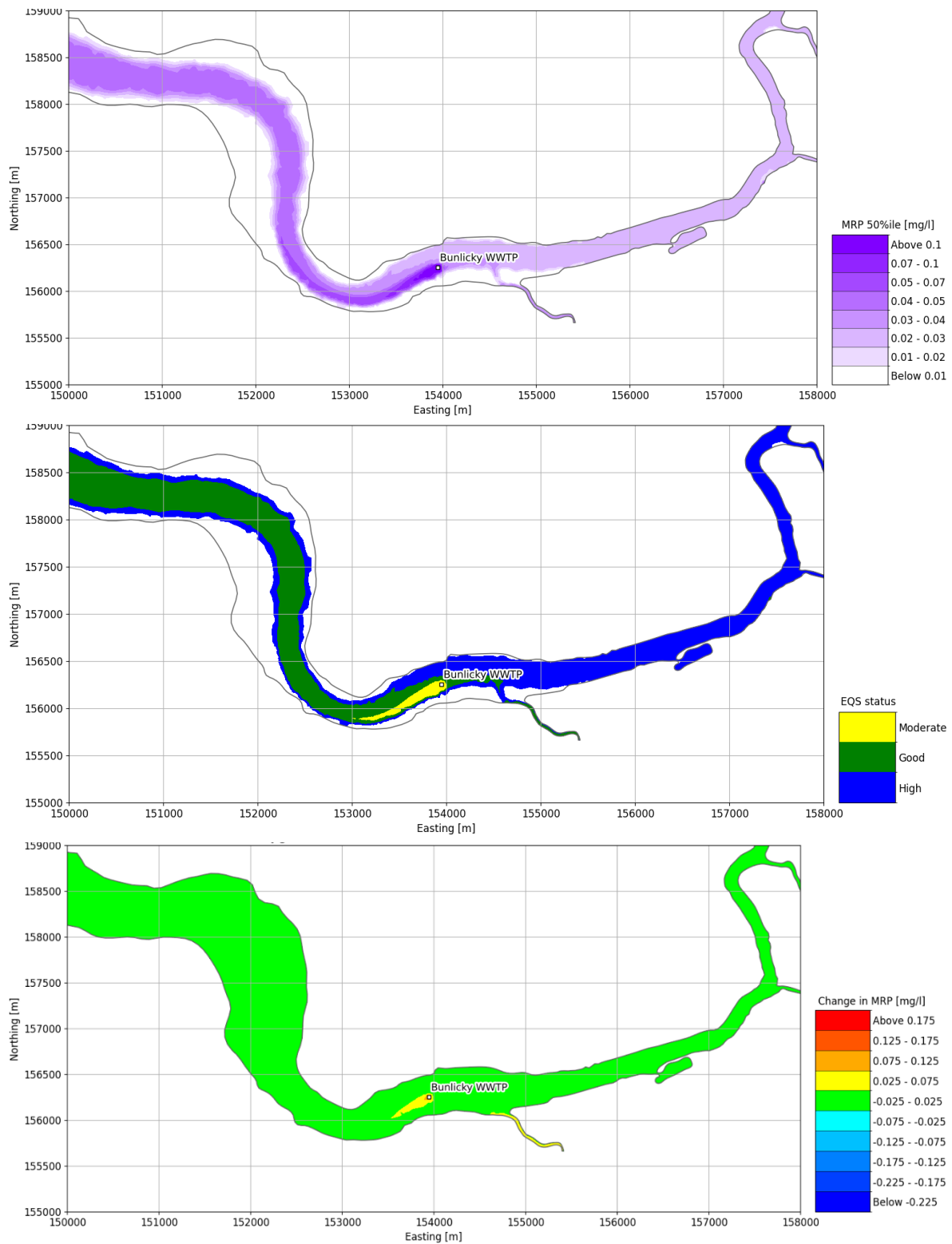


Figure 4-44: Depth-average concentration of MRP 50%ile (upper panel), Indicative Quality Plot (middle panel) and Delta Plot (lower panel) for upgrade scenario C05 (winter).

5 Conclusions

This report presents the results and assesses the potential impact of the existing and proposed discharges on the receiving water and whether this may lead to the exceedance of the EQS status, categorized as high, good, or moderate, for the upgrade of Bunlicky WWTP and a combined upgrade of Bunlicky WWTP, Castletroy WWTP, and Shannon Town WWTP.

The extent of the mixing zones for different water quality parameters was determined based on statistical analysis of model results across the spring-neap tidal cycle for the baseline situation and different WWTP upgrade scenarios. The following conclusions can be drawn from the analysis:

- **BOD:** The study area is characterized by a high status based on indicative WQ for BOD. In the baseline situation, the extent of the BOD mixing zone with good and moderate EQS status is limited to the area in close proximity to the outfall. However, all WWTP upgrade scenarios result in a significant expansion of these mixing zones. In the summer period, the length of the mixing zone with good EQS status increases from 110 to 270-290 meters (0.1 to 0.3% of the estuary), while the length of the mixing zone with moderate EQS status increases from 70 to 110 meters (0.07 to 0.1%). In the winter period, the extent of the mixing zones with good and moderate EQS status is similar to the summer period, at 290 (0.3%) and 130 (0.1%) meters, respectively.
- **DIN:** For DIN, a large part of the study area is characterized by a good EQS status in both summer and winter conditions under the baseline scenario. As no DIN EQS is defined for WFD Transitional Waters, this status is based on indicative water quality thresholds for DIN in WFD Coastal Waters. With the WWTP upgrade, the length of the good EQS status zone expands slightly in summer conditions, while a moderate EQS status zone emerges near the outfall. However, the length of this moderate EQS status zone is minimal, reaching a maximum of 80 meters (0.08% of the estuary). In winter conditions, there are no notable changes in indicative WQ status following the WWTP upgrade.
- **MRP:** For MRP, a large part of the study area shows MRP background concentrations are already elevated, resulting in 'Moderate' indicative WQ status for MRP in summer conditions. In winter conditions, the area generally shows a 'Good' indicative WQ status with only moderate indicative WQ status within 350 m near the outfall under the baseline scenario. In the WWTP upgrade scenarios, only summer scenarios show a notable increase (> 0.060 mg/l corresponding to a 'Moderate' WQ status in the absence of background MRP), with impacts extending from approximately 2.5 km upstream to 8 km downstream (11% of the estuary). This leads to an expansion of the 'Moderate' WQ status, from 16 to 18.5 km (16 to 18% of the estuary) in the summer conditions and from 350 to 1,100 m (0.3 to 1%) in the winter conditions. Reduction of the MRP concentration at the outfall following an EPA license review resulting in improved treatment of the EQS status of the study area in the summer conditions from predominantly moderate to good status, with moderate status observed only directly near the outfall.

Overall, the Bunlicky WWTP upgrade is expected to increase concentrations of all analysed water quality parameters, with the highest increases occurring near the outfall. However, the overall impact on water quality within the study area remains limited: DIN largely complies with EQS for a transitional water, with only minor and localised 'Moderate' EQS status near the outfall (up to 130 m), while BOD shows localised 'Moderate' status up to 80 m, resulting in limited non-compliance. In contrast, MRP is already predominantly non-compliant under baseline conditions (up to 16 km). The cumulative impact with the upgrade further deteriorates under all upgrade scenarios (up to 18.5 km). This reflects a cumulative deterioration rather than the introduction of new impact areas. Without elevated background concentrations, the additional load would result in 'Moderate' water quality conditions extending from around 2.5 km upstream to 8 km downstream (11% of the estuary).

The upgrade of Bunlicky WWTP is designed to sustain development and protect water quality, therefore it will be able to meet better treatment standards for MRP and BOD than the current licence. In this upgrade scenario with improved treatment standards, the length of the BOD mixing zone is significantly reduced, and the MRP mixing zone shows a marked improvement in status from moderate to good status compared to the current situation.

6 References

- (n.d.). *European Union Environmental Objectives (Surface Waters) (AMENDMENT) regulations 2019, Statutory Instruments No. 77 of 2019.*
- HaskoningDHV. (2021). *Model Scoping Report for Bunlicky WWTP Upgrade, Ref. BH6548-RHD-ZZ-XX-RP-Z-0007.*
- HaskoningDHV. (2022). *Survey Interpretive Report for Bunlicky WWTP Upgrade.*
- HaskoningDHV. (2023). *Model Calibration and Validation Report for Bunlicky WWTP Upgrade.*
- Uisce Éireann. (2022). *Technical Standards - Marine Modelling IW-TEC-100-015, Revision 3.00.*

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