Appendix A: Hydroecology Modelling Technical Report: Greater Cambridge Area

1 Introduction

1.1 Aim

The aim of this investigation is to evidence any possible current or future ecological impacts of abstractions to waterbodies influenced by Cambridge Water Company's (CWC) abstractions, through application of hydro-ecological modelling. To do so, two main aims were established:

1. Following Environment Agency (EA) guidance[1], develop a hydro-ecological model, using data from waterbodies within CWC's water resource zone, and the wider East Anglia area.
2. Apply the hydro-ecology model to undertake scenario-analysis. Scenario-analysis will be used to evidence the current impacts of abstraction, alongside the possible impacts if abstractions were to be increased.

This work will aid assessment of whether abstraction growth to Fully Licensed rates is likely to cause ecological impact or WFD deterioration of the waterbodies under investigation within the Greater Cambridge area.

1.2 This Report

This report presents the results of hydro-ecological modelling using macroinvertebrate data that was undertaken to assess the current and possible future abstraction impact on rivers within the Greater Cambridge area.

The main body of this report: details the study area in Greater Cambridge and East Anglia (Section 2.1); describes the macroinvertebrate, flow, and associated modelling datasets (Section 2.2); explains the approach used to develop hydro-ecological models, and how these were applied for scenario analysis (Section 2.3); describes the model results, for both the LIFE model (Section 3.1) and WHPT-ASPT model (Section 3.2); describes the results of scenario analysis, for each of the waterbodies under investigation (Section 3.3); and finally, summarises the current and future risk of ecological impact from abstraction (Section 4.1) .

2 Methods

2.1 Study Area

The list of waterbodies potentially influenced by CWC's abstractions are outlined in Table 1 in Appendix 1 - Baseline data of risk of deterioration to water bodies from water abstraction). A subset of these waterbodies (n = 10) were taken forward for scenario analysis assessment (coloured mustard in Figure 2-1). Although these waterbodies are of primary interest in assessing current and possible future abstraction impacts on macroinvertebrate communities, additional sites from other waterbodies in East Anglia area were considered to improve model calibration and performance by providing a greater gradient of pressures including flow alteration (coloured green in Figure 2-1).

[1] Environment Agency, (2018). Position Statement: Environmental Flow Indicator; Annex: Required levels of evidence to support development of a local flow constraint.

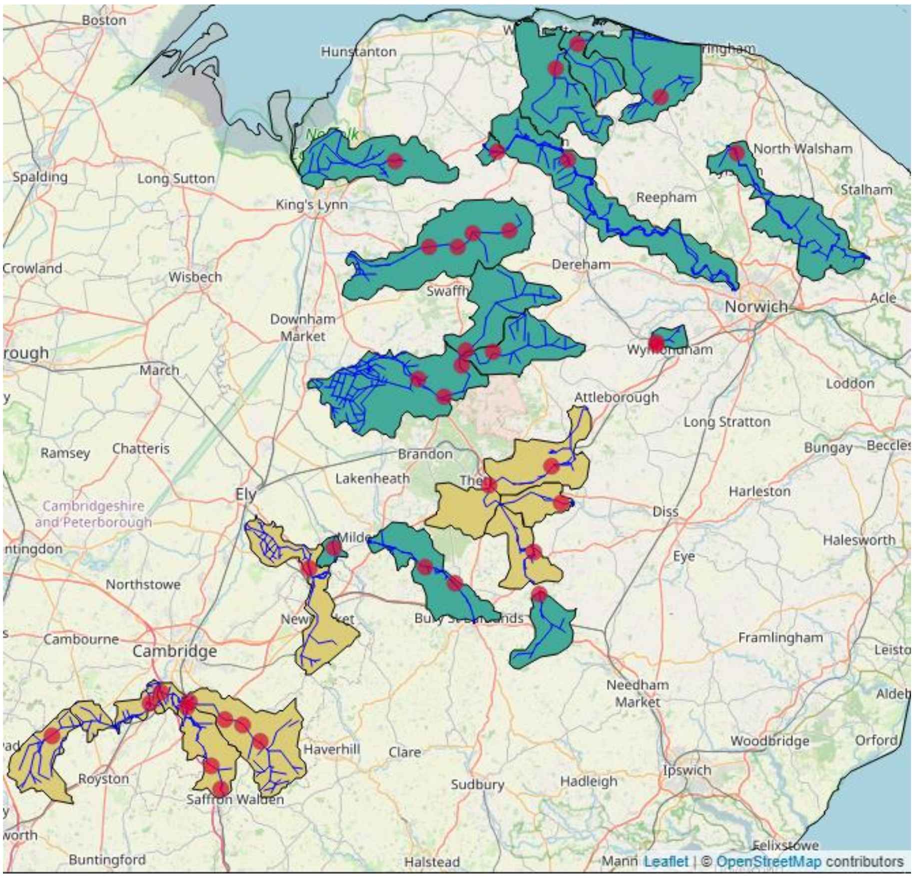

Figure 2-1 Location of waterbodies used in the models and their macroinvertebrate sampling points (mustard-coloured waterbodies are those under investigation and influenced by CWC abstractions; green coloured waterbodies are those in the wider East Anglia area)[2]

2.2 Data sets used

2.2.1 Macroinvertebrate data

Macroinvertebrate sampling sites were screened for their suitability to be included in the model calibration dataset. Sites were excluded for having one or more of the following:

- Less than 5 spring and autumn macro-invertebrate samples since 1995.
- Incomplete environmental base data to generate expected scores from the River Invertebrate Classification Tool (RICT).
- No corresponding stream cell in the groundwater model (either Cam & Bedford Ouse (CBO) or Northern East Anglian Chalk (NEAC))
- Inadequate groundwater model calibration.
- Major water quality issues or other over-riding pressures.
- Not having an adequately paired River Habitat Survey (RHS).
- Having environmental variables distinctly dissimilar from other sites (determined via PCA-analysis)

Macroinvertebrate biotic scores for the sites of interest were obtained via the EA's Ecology and Fish Data Explorer[3]. All samples were collected following the standard 3-min protocol with 1-min hand search as outlined in EA Operational Instruction 018_08 (Environment Agency, 2017). Only spring (March-May) and autumn (September-November) data were used in the analysis due to an insufficient number of summer (June-August) samples being available for analysis. Data prior to 1995 were excluded from the model calibration dataset as quality assurance procedures were less rigorous during this time. Not

[2] Map data from Open Street Map and is available under the Open Database License (OpenStreetMap).
[3] https://environment.data.gov.uk/ecology/explorer/

all recent macroinvertebrate data could be used (e.g., post March 2020) due to the restricted availability of more recent groundwater modelled flow timeseries data.

Macroinvertebrate data were summarised using the family-level LIFE metric (Extence *et al*, 1999) and the WHPT-ASPT metric; both metrics were used as measures of macroinvertebrate community response in the modelling. The LIFE index is widely used to assess the impact of flow and flow pressure on macroinvertebrate communities, and WHPT-ASPT provides a measure of ecological health and is one of two metrics used to classify the macroinvertebrate status of WFD waterbodies.

LIFE (F) and WHPT-ASPT scores were standardised against reference conditions using observed/expected (O/E) ratio scores. Expected scores were derived using the River Invertebrate Classification Tool (RICT), which utilises site-specific environmental base data to generate them. The use of standardised as opposed to observed scores allows comparison of scores between rivers and sites that have different environmental characteristics and hence macroinvertebrate community composition. Biotic scores for samples were averaged when multiple samples were collected in the same season.

A total of 1122 samples from 37 sites were used for model calibration and analysis. Of these, 15 sites were in the 10 waterbodies potentially affected by CWC abstraction. A full list of macroinvertebrate sample sites used in the model can be found in Appendix I.

2.2.2 Signal crayfish pressure

The presence of signal crayfish (*Pacifastacus leniusculus*) can modify macroinvertebrate communities, which can subsequently lead to the impact on biotic scores such as artificially inflating LIFE and WHPT-ASPT (Mathers *et al*, 2016a, 2016b). This is a result of having negative impacts on slow-moving taxa (e.g., snails and leeches) that tend to have the lowest index scores. To account for signal crayfish pressure within the model, each macroinvertebrate site was screened for signal crayfish presence by assessing available records from Environment Agency data[4]). All samples in the dataset were then assessed for signal crayfish impact and assigned a score between 0-2. A score of 0 indicated no / negligible impact, 1 indicated a minor impact and 2 indicated a major impact.

2.2.3 Flow Data

Modelled flow timeseries data was derived from CBO and NEAC groundwater models; for both models, timeseries data were available to April 2020. Monthly flow timeseries data (Ml/d) were extracted for three scenarios:

- Historical – this scenario represents the historical flow timeseries incorporating groundwater and surface water abstractions and discharges as they have changed over time.
- Naturalised – this scenario represents the historical flow timeseries with the removal of artificial influences, such as abstractions and discharges.
- Fully Licensed – this scenario represents the historical flow timeseries if all abstraction licences were operating at their fully licensed limit, but discharges held at Recent Actual rates. It is used to provide a projection of flows and deterioration risks represented by potential increases in pumping up to permitted limits.

Macroinvertebrate sites were paired to the nearest corresponding flow timeseries location within the groundwater models. To quantify the degree of abstraction pressure at each macroinvertebrate site, the long-term historical Q75 flow was calculated and expressed as a ratio of the long-term naturalised Q75 flow to yield a long-term Q75 Residual Flow Ratio (RFR) variable (termed LTQ75RFR). A ratio of 1 indicates that were flows are not influenced (i.e., at natural); ratios <1 indicate a progressively greater degree of abstraction pressure (i.e., flow reduction), and ratios >1 indicates that flows are higher than natural (i.e., the watercourse is discharge-rich). Previous studies (Bradley *et al,* 2013) of

[4] https://nbnatlas.org/

macroinvertebrate response to flow alteration have found that measures of long-term abstraction pressure at Q75 demonstrate a significant relationship with LIFE and WHPT-ASPT response metrics

Additionally, to quantify natural hydrological variability over time, the historical Q75 flow was calculated using a 12-month moving window and expressed as a ratio of the long-term historical Q75 at that site. Ratios > 1 therefore indicate a time period when flows were higher-than-normal for that site, and ratios < 1 indicate a time period when flows were lower-than-normal for that site. Because this flow history metric (termed (Q75_anomaly) represents deviations from the long-term historical flow at each site, it is unaffected by the degree of flow alteration, and uncorrelated with the LTQ75RFR flow alteration metric described above.

2.2.4 River morphology condition

River morphological alteration metrics were included as previous research has demonstrated that the degree of channel modification can influence the macroinvertebrate communities and their sensitivity to flow, with communities of more modified rivers showing greater sensitivity (Dunbar *et al*, 2009, 2010). This information was derived from available EA RHS survey data and used the Habitat Modification sub-Score (HMS) for re-sectioned bed and banks to assess the degree of channel modification. This score varies from 0 (no re-sectioning) to 2800 (heavily re-sectioned).

2.3 Hydro-ecological Modelling

2.3.1 Modelling Approach

Hierarchical Generalised Additive Models (HGAMs), implemented using R’s (v4.1.2; R Core Team 2021) mgcv library (Wood, 2022), were used to model spatial and temporal variation in the LIFE and WHPT-ASPT macro-invertebrate metrics. HGAMs allow relationships between the explanatory variables and the response to be described by smooth curves (Wood, 2017), whilst also incorporating terms to represent unexplained site-to-site variation (Pedersen et al., 2019).

For each macro-invertebrate metric, the O/E ratio on each sampling occasion was modelled as a function of the predictor variables listed in Table 2-1. Candidate variables were screened to identify and eliminate any that were strongly correlated and therefore not suitable for inclusion in the model. A mixture of continuous and categorical predictors were included within the model (Table 2-1) as fixed effects, and a ‘factor-smooth’ term (Pedersen et al. 2019) was used to model random site-specific intercepts and time trends; the inclusion of a ‘factor smooth’ term allowed the temporal trend to vary from site to site.

Initial exploratory modelling fitted separate hydro-ecological relationships for Spring and Autumn data, for both LIFE (F) and WHPT-ASPT models. This found that response metrics (both LIFE (F) and WHPT-ASPT) demonstrated a similar shape and scale of response to flow history and flow alteration when using both Spring and Autumn data; as such, the decision was taken to include both spring and autumn data in a single model, for each of LIFE (F) and WHPT-ASPT.

Interacting pressures can have a compounding effect on ecological receptors. For example, Dunbar et al. (2009, 2010) found that macroinvertebrate communities of more highly modified rivers demonstrate a greater sensitivity to flow history. In addition, small, shallow streams may be more sensitive to abstraction pressure than larger, deeper, slower-flowing rivers. As there were insufficient data to suitably account for all possible interactions in the models, possible interactions were tested during the exploratory stage. Flow history x season, abstraction pressure x re-sectioning, and abstraction pressure x river size did not yield strong or interpretable effects on response metrics, and so were not included within the final model.

The final model was fitted using restricted maximum likelihood (REML) to optimise the degree of smoothing. A ‘double penalty’ approach was also applied to the model; this acts to eliminate terms that had no significant effect on the response metric from the model, and provides an efficient, one-step method for model selection (Whittingham et al 2006; Visser et al. 2018).

Table 2-1 Predictor variables used to model spatial and temporal variation in LIFE (F) and WHPT-ASPT O/E

Variable name	Description
Season	Two-level factor indicating Spring (March to May) or Autumn (September to November) macroinvertebrate sample.
LTQ75RFR	The long-term historical Q75 flow expressed as a ratio of the long-term naturalised Q75 flow, to yield a long-term Q75 Residual Flow Ratio (RFR) variable (LTQ75RFR). A ratio of 1 indicates that were flows are not influenced (i.e., at natural); ratios <1 indicate a progressively greater degree of abstraction pressure (i.e., flow reduction), and ratios >1 indicates that flows are higher than natural (i.e., the watercourse is discharge-rich).
Q75_anomaly	The historical Q75 flow over the 12 months prior to sample collection, expressed as a proportional change from the mean of these values at each site. Provides a measure of flow history, with values > 1 indicating a time period when flows were higher-than-normal and values < 1 indicating a time period when flows were lower-than-normal relative to other macroinvertebrate samples at that site.
Q75_anomaly_lag1	Calculated as per Q75_anomaly, but for the 13-24 months preceding sample collection.
Year.2005	Calendar year of sample collection (centred to 2005 = 0 to improve model stability, 2005 being the rough mid-point of the macro-invertebrate sample dataset). Describes long-term trends in the macro-invertebrate metrics due to factors other than changes in flow.
river_size	Long-term annual mean naturalised flow (Ml/d) estimated by groundwater modelling, log10 transformed to reduce skew, was used as an indicator of river size (i.e., discharge) and channel size/volume at each site. Preferred to mean channel width, mean channel depth, slope and distance from source as it has been shown to provide a more robust indicator of watercourse size.
SILT_CLAY	Substratum composition at the sampling location, estimated as the percentage of silt and clay.
rhs_rsctned_bnk_bed	River Habitat Survey (RHS) habitat modification sub-score, ranging from 0 to 2800, representing the degree and extent of bed and bank re-sectioning at each site.
SITE_ID	A factor representing random variation in macro-invertebrate community composition from site to site.

2.3.2 Scenario Analysis

Using the flow alteration (LTQ75RFR) and flow history (Q75_anomaly and Q75_anomaly_lag1) metrics as inputs, the hydro-ecological models were then used to predict LIFE (F) O/E and WHPT-ASPT O/E at a selection of monitoring sites within the waterbodies of interest, under each of the Historical, Naturalised, and Fully Licensed scenarios (as detailed in Section 2.2.3).

Predictions of LIFE (F) O/E were compared to a guideline value of 1.00 and predictions of WHPT-ASPT O/E were compared to WFD standards.

The comparison of predicted macroinvertebrate LIFE (F) O/E and WHPT-ASPT O/E scores between modelled Historical and Naturalised scenarios allowed an assessment to be made of how O/E scores would alter without artificial conditions (i.e., abstractions and discharges). Similarly, running the model under a Fully Licensed scenario indicated how LIFE (F) O/E and WHPT-ASPT O/E scores would alter from increased abstraction from Historic and Naturalised scenarios and the degree of any impact.

3 Results

3.1 LIFE

3.1.1 Model Results

Figure 3-1 shows partial effects plots for the LIFE model, which illustrate the effect of each predictor variable on LIFE (F) O/E whilst holding the other variables constant. Model diagnostics are provided in Appendix II.

- **Long term flow alteration (LTQ75RFR)** had a strong association with mean LIFE (F) O/E. Overall, LIFE (F) O/E was found to be reduced at monitoring locations subject to the highest degree of abstraction pressure (i.e., as LTQ75RFR tends towards 0) (Figure 3-1; plot second from the right, top row); however, it should be noted that the number of monitoring locations with an abstraction reduction of >30% (i.e., where LTQ75RFR < 0.7) was limited. Similarly, LIFE (F) O/E was found to be reduced at monitoring locations with augmented flow (i.e., where LTQ75RFR > 1).
- LIFE (F) O/E was highest at sites where flows were reduced due to abstraction by 10% (i.e., where LTQ75RFR = 0.9) (Figure 3-1), indicating that LIFE (F) O/E is increased at monitoring locations with long-term abstraction pressure of up to 10% flow reduction, when compared to monitoring locations with unaltered flow.
- **Flow history (Q75_anomaly)** had a strong positive association with LIFE (F) O/E, with higher LIFE (F) O/E ratios following periods of higher flow, as Q75_anomaly increased from 0 to 1.5 (Figure 3-1; right-hand plot, top row).
- As Q75_anomaly increases from 1.5 to 3.5, the flow history-LIFE (F) O/E relationship levels-out, and the strength of effect reduces, and when Q75_anomaly > 3.5 (i.e., when flows were increased by >250%, relative to the long-term historical flow), there is a negative association between flow history and LIFE (F) O/E; however, when Q75_anomaly > 1.5 (i.e., when flows were increased by >50%, relative to the long-term historical flow), there is high uncertainty in the flow history-LIFE (F) O/E relationship.

- Overall, **lagged flow history (Q75_anomaly_lag1)** had a strong positive association with LIFE (F) O/E, with higher LIFE (F) O/E ratios following periods of higher flow in 13-24 months preceding sample collection (Figure 3-1; left-hand plot, middle row). The relationship between lagged flow history and LIFE (F) O/E was steepest when Q75_anomaly_lag1 ranged from 0 to 1.5 (i.e., when flows were reduced, or increased up to 50%, relative to the long-term historical flow); above Q75_anomaly_lag1, the strength of association was weaker, and the level of uncertainty in the association increased substantially.
- **Bed and bank re-sectioning** did not demonstrate a statistically significant association with LIFE (F) O/E and the model selection process eliminated the term from the model (i.e., the final relationship was flat) (Figure 3-1; plot second from the left, middle row).
- The **percentage of silt and clay substrate** did not demonstrate a statistically significant association with LIFE (F) O/E and the model selection process eliminated the term from the model (i.e. the final relationship was flat) (Figure 3-1; right-hand plot, middle row). This result indicates that RICT, which uses the substrate composition as one of its predictor variables, is able to successfully control for any effect of natural spatial variation in substrate composition.
- **River size** did not demonstrate a statistically significant association with LIFE (F) O/E and the model selection process eliminated the term from the model (i.e., the final relationship was flat) (Figure 3-1; plot second from the right, middle row). This result indicates that RICT, which uses several measures of river size as predictor variables (width, depth, discharge category, distance from source), is able to successfully control for any effect of natural spatial variation in river or channel size.
- Across all sites, mean LIFE (F) O/E demonstrated a strong **temporal trend**, with both spring and autumn data increasing by an average of 0.04 between 1995 and 2020 (Figure 3-1; plots far-left and second from the left, top row); such improvement is in line with previous studies. Site-specific trends are described further below.

- Mean LIFE (F) O/E was, on average, 0.01 higher in autumn than in spring (Figure 3-1; middle plot, bottom row), a small **seasonal difference** that is consistent with previous, similar studies.
- Mean LIFE (F) O/E was, on average, 0.05 higher at sites with a major crayfish impact, compared to un-impacted sites (Figure 3-1; right-hand plot, bottom row). LIFE (F) O/E was negligibly increased at sites with a minor crayfish impact, compared to un-impacted sites.
- The inclusion of a 'factor-smooth' term allowed the model to account for unexplained **site-to-site variability** in mean LIFE (F) O/E, as well as **site-specific trends** over time; this is visualised in Figure 3-1 (left-hand plot, bottom row).

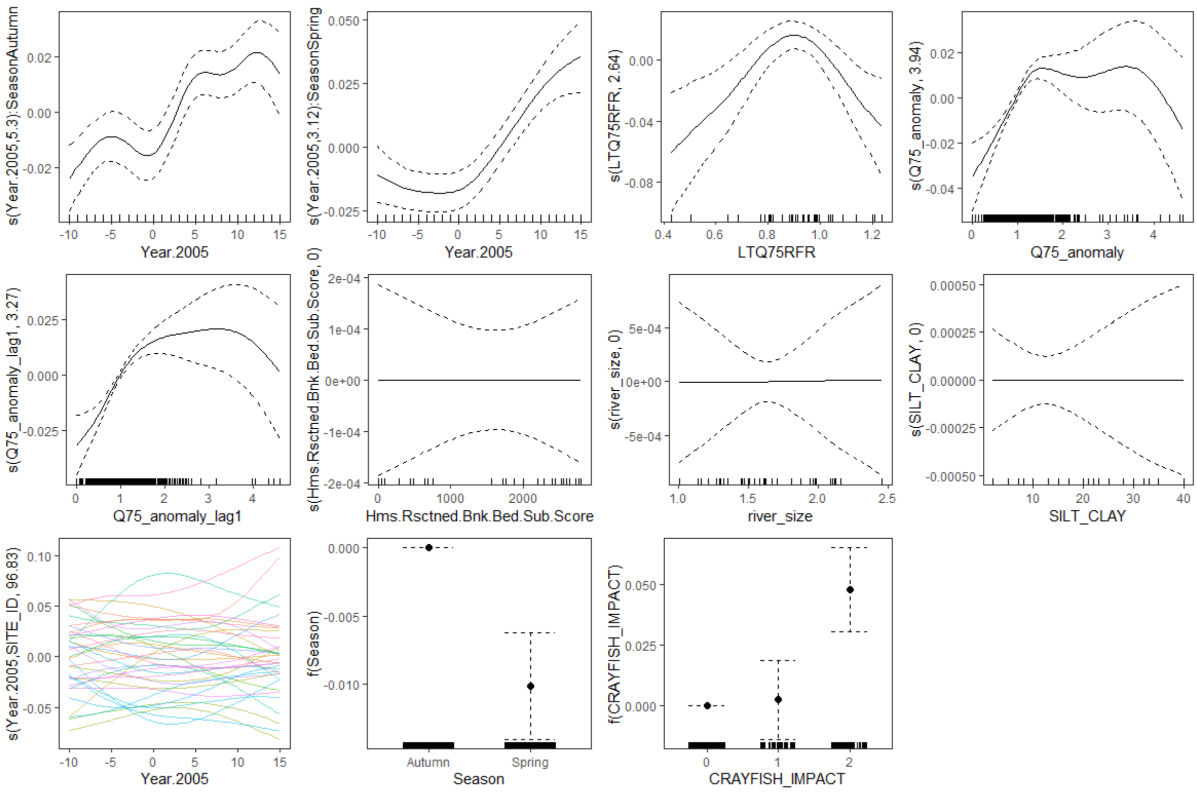

Figure 3-1 Effect of flow alteration (LTQ75RFR), flow history (Q75_anomaly, Q75_anomaly_lag1), bank and bed re-sectioning, substrate composition (SILT_CLAY), time (Year.2005), monitoring location (SITE_ID), season, crayfish impact, and river size on mean LIFE (F) O/E (vertical axis). Dashed lines show 95% confidence intervals.

3.1.2 Predictive Performance

The model explained 73.8% of the total variation in the calibration dataset (Figure 3-2), of which the fixed effects explained 66.3% and the unexplained site-specific effects (Year x Site 'factor-smooth') explained ~7.5%. The model explained the historical trends in LIFE (F) O/E well at most sites (Figure 3-3 and Figure 3-4) but had a slight tendency to under-predict very high (> 1.15) LIFE O/E ratios.

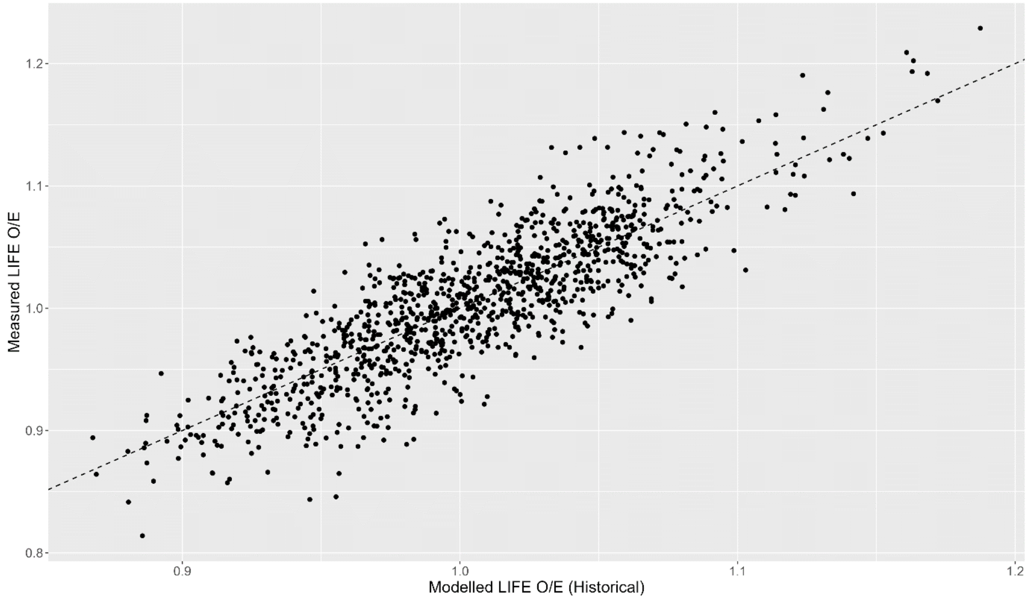

Figure 3-2 Relationship between measured and modelled LIFE (F) O/E under the historical scenario

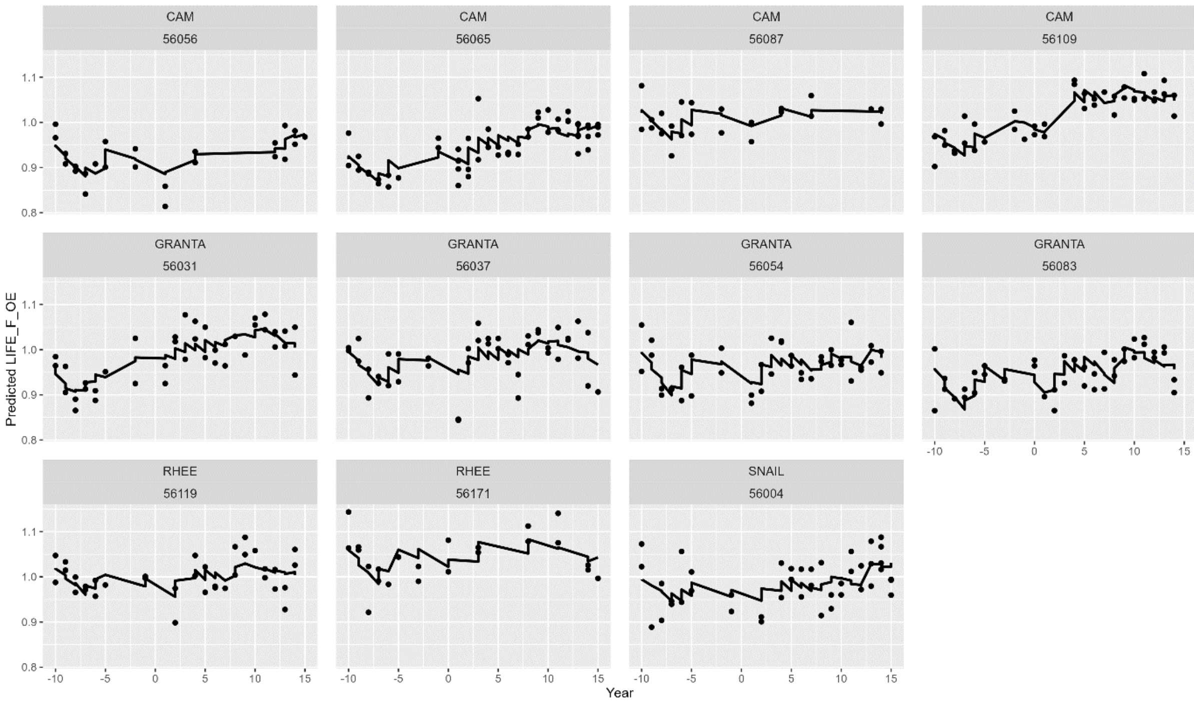

Figure 3-3 Measured (points) and modelled (lines) predictions of LIFE (F) O/E under the historical scenario for CBO Model sites

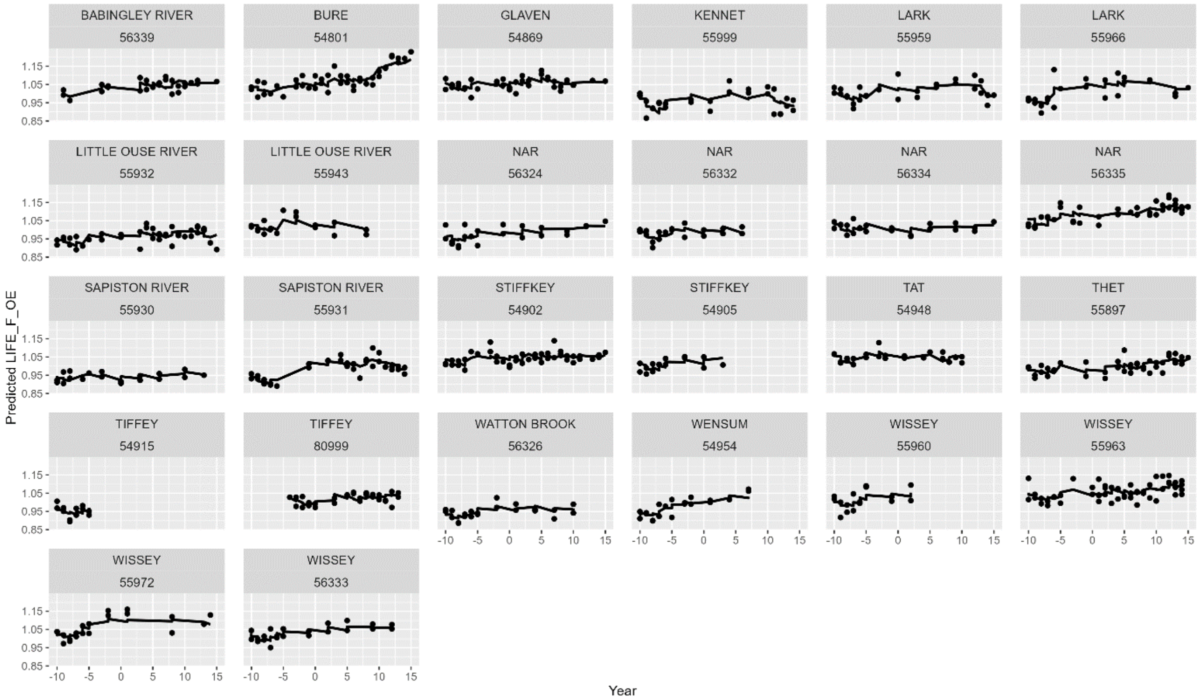

Figure 3-4 Measured (points) and modelled (lines) predictions of LIFE (F) O/E under the historical scenario for NEAC Model sites

3.2 WHPT-ASPT

3.2.1 Model Results

Figure 3-5 shows partial effects plots for the WHPT-ASPT model, which illustrate the effect of each predictor variable on WHPT-ASPT O/E whilst holding the other variables constant. Model diagnostics are provided in Appendix III.

- **Long term flow alteration (LTQ75RFR)** had a reasonably strong association with mean WHPT-ASPT O/E. Overall, LIFE O/E was found to be reduced at monitoring locations subject to the highest degree of abstraction pressure (i.e., as LTQ75RFR tends towards 0) (Figure 3-5; plot second from the right, top row); however, it should be noted that the number of monitoring locations with an abstraction reduction of >30% (i.e., where LTQ75RFR < 0.7) was limited. Similarly, WHPT-ASPT O/E was found to be reduced at monitoring locations with augmented flow (i.e., where LTQ75RFR > 1).
- WHPT-ASPT O/E was highest at sites where flows were reduced due to abstraction by ~10% (i.e., where LTQ75RFR = ~0.9), indicating that WHPT-ASPT O/E is increased at monitoring locations with long-term abstraction pressure of up to 10% flow reduction, when compared to monitoring locations with unaltered flow.
- **Flow history (Q75_anomaly)** had a strong positive association with WHPT-ASPT O/E, with higher WHPT-ASPT O/E ratios following periods of higher flow, as Q75_anomaly increased from 0 to 1.5 (Figure 3-5; right-hand plot, top row).
- As Q75_anomaly increases above 1.5 (i.e., when flows were increased by >50%, relative to the long-term historical flow), the flow history-WHPT-ASPT O/E relationship plateaus, and then demonstrates a negative association as Q75_anomaly increases above 3 (i.e., when flows were increased by >200%, relative to the long-term historical flow); when Q75_anomaly > 1.5, there is high uncertainty in the flow history-WHPT-ASPT O/E relationship.

- Overall, **lagged flow history (Q75_anomaly_lag1)** had a strong positive association with WHPT-ASPT O/E, with higher LIFE O/E ratios following periods of higher flow in 13-24 months preceding sample collection (Figure 3-5; left-hand plot, middle row). The relationship between lagged flow history and WHPT-ASPT O/E was steepest when Q75_anomaly_lag1 ranged from 0 to 1.5 (i.e., when flows were reduced, or increased up to 50%, relative to the long-term historical flow); above Q75_anomaly_lag1, the strength of association was weaker, and the level of uncertainty in the association increased substantially.

- **Bed and bank re-sectioning** had a significant relationship with WHPT-ASPT O/E; however, this was associated with a relatively high level of uncertainty. Overall, WHPT-ASPT O/E was lower at highly re-sectioned sites (rhs_rsctned_bnk_bed > 2000) compared to un-modified sites (rhs_rsctned_bnk_bed = 0) (Figure 3-5; plot second from the left, middle row). However, the model predicted WHPT-ASPT O/E to be highest at sites with a moderate level of re-sectioning (rhs_rsctned_bnk_bed = 1000 to 1500), but this was associated with a high level of uncertainty, given the limited number of sites with re-sectioning scores within this range.
- The **percentage of silt and clay substrate** did not demonstrate a statistically significant association with WHPT-ASPT O/E and the model selection process eliminated the term from the model (i.e. the final relationship was flat) (Figure 3-5; right-hand plot, middle row). This result indicates that RICT, which uses the substrate composition as one of its predictor variables, was able to successfully control for any effect of natural spatial variation in substrate composition.
- **River size** had a statistically significant, but reasonably weak, positive association with WHPT-ASPT O/E, with WHPT-ASPT O/E scores increasing with increased river size (Figure 3-5; plot second from the right, middle row); this relationship is associated with a high level of uncertainty for both the smallest and largest sites within the dataset.
- Across all sites, mean WHPT-ASPT O/E demonstrated a strong **temporal trend**, with both spring and autumn data increasing by an average of 0.1 or 0.11, respectively, between 1995 and 2020 (Figure 3-5; plots far-left and second from the left, top row); such improvement is in line with previous studies. Site-specific trends are described further below.
- Mean WHPT-ASPT O/E was, on average, 0.035 higher in autumn than in spring (Figure 3-5; middle plot, bottom row), a small **seasonal difference** that is consistent with previous, similar studies.
- Mean WHPT-ASPT O/E was, on average, 0.03 higher at sites with a major crayfish impact, compared to un-impacted sites (Figure 3-5; right-hand plot, bottom row). In contrast, WHPT-ASPT O/E was, on average, slightly decreased (~0.02 lower) at sites with a minor crayfish impact, compared to un-impacted sites.
- The inclusion of a ‘factor-smooth’ term allowed the model to account for unexplained **site-to-site variability** in mean WHPT-ASPT O/E, as well as **site-specific trends** over time; this is visualised in Figure 3-5 (left-hand plot, bottom row).

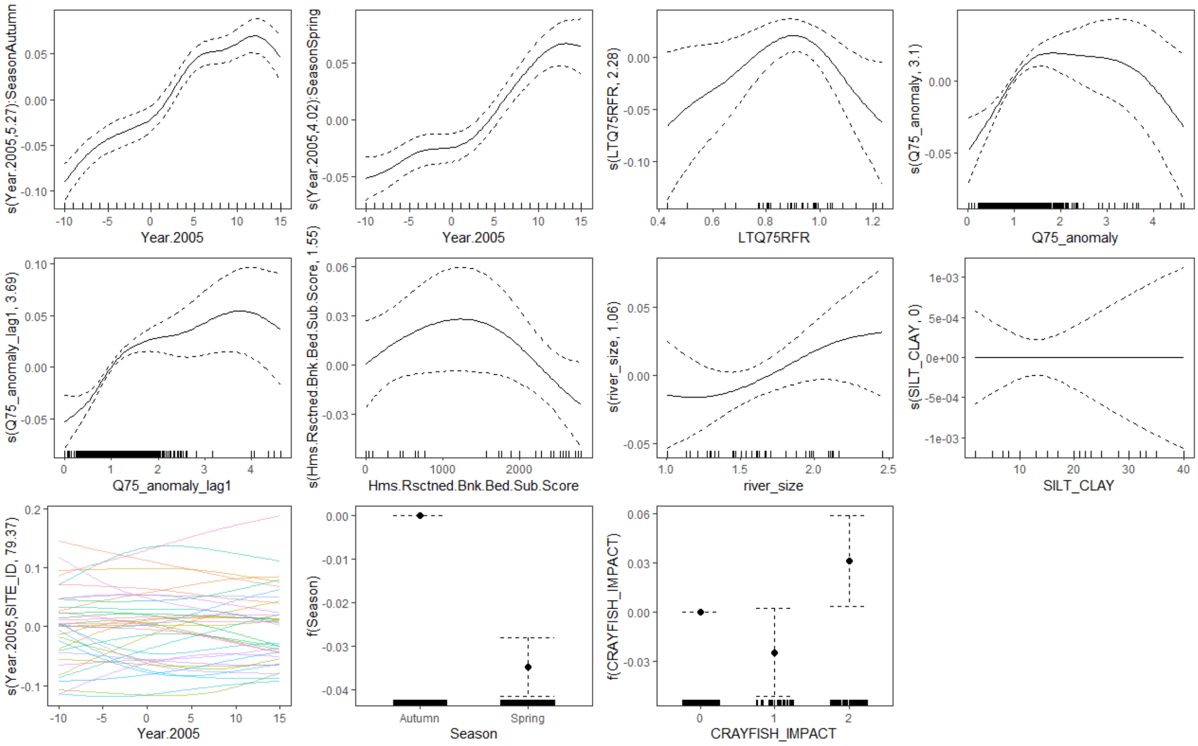

Figure 3-5 Effect of flow alteration (LTQ75RFR), flow history (Q75_anomaly, Q75_anomaly_lag1), bank and bed re-sectioning, substrate composition (SILT_CLAY), time (Year.2005), monitoring location (SITE_ID), season, crayfish impact, and river size on mean WHPT-ASPT O/E (vertical axis). Dashed lines show with 95% confidence intervals.

3.2.2 Predictive Performance

The model explained 77.1% of the total variation in the calibration dataset (Figure 3-6), of which the fixed effects explained 72.4% and the unexplained site-specific effects (Year x Site 'factor-smooth') explained ~4.7%. The model explained the historical trends in WHPT-ASPT O/E well at most sites (Figure 3-7 and Figure 3-8) and demonstrated reasonably good predictive performance, but overall had a slight tendency to over-predict WHPT-ASPT O/E, particularly at the lower range of observed WHPT-ASPT O/E ratios (WHPT-ASPT O/E < 0.9).

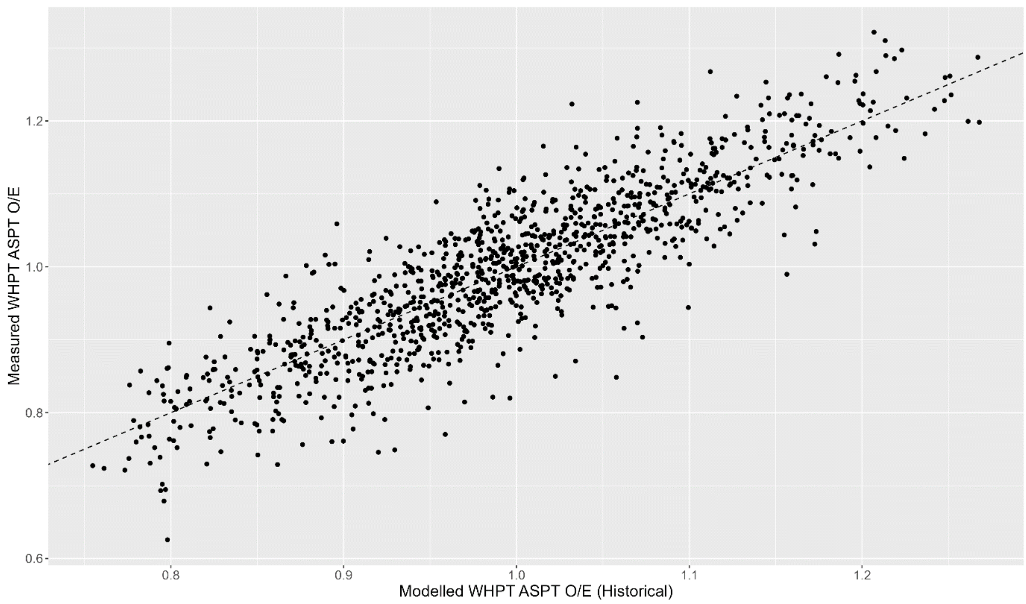

Figure 3-6 Relationship between measured and modelled WHPT-ASPT O/E under the historical scenario

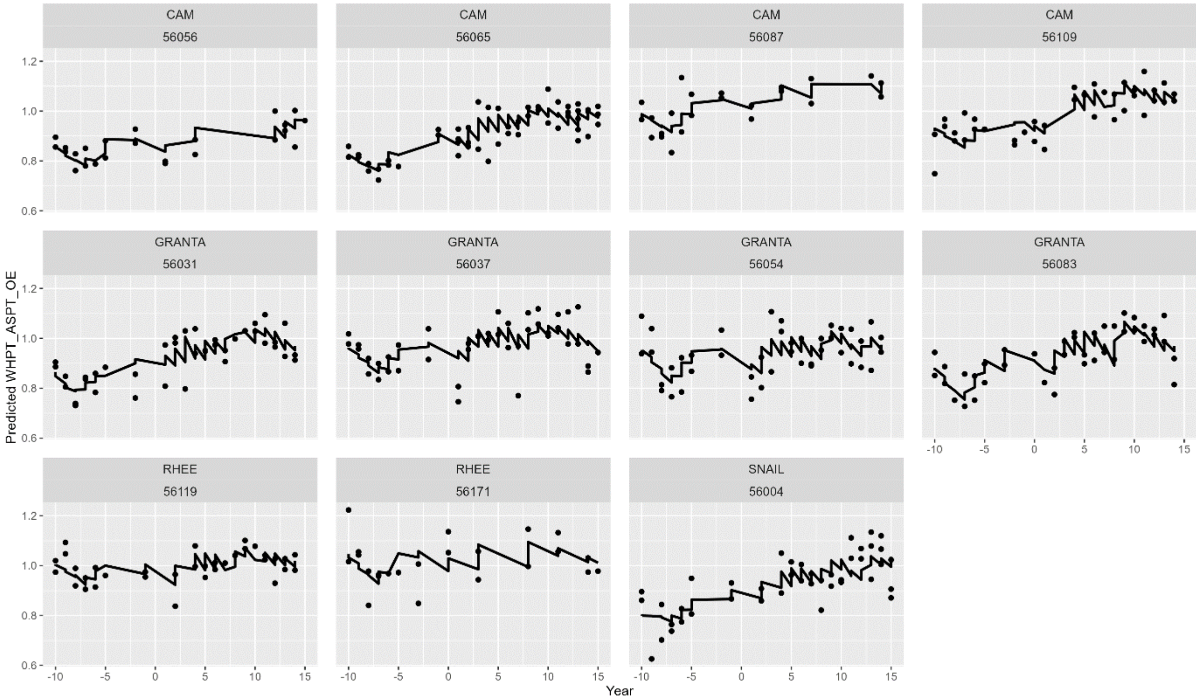

Figure 3-7 Measured (points) and modelled (lines) predictions of WHPT-ASPT O/E under the historical scenario for CBO Model sites

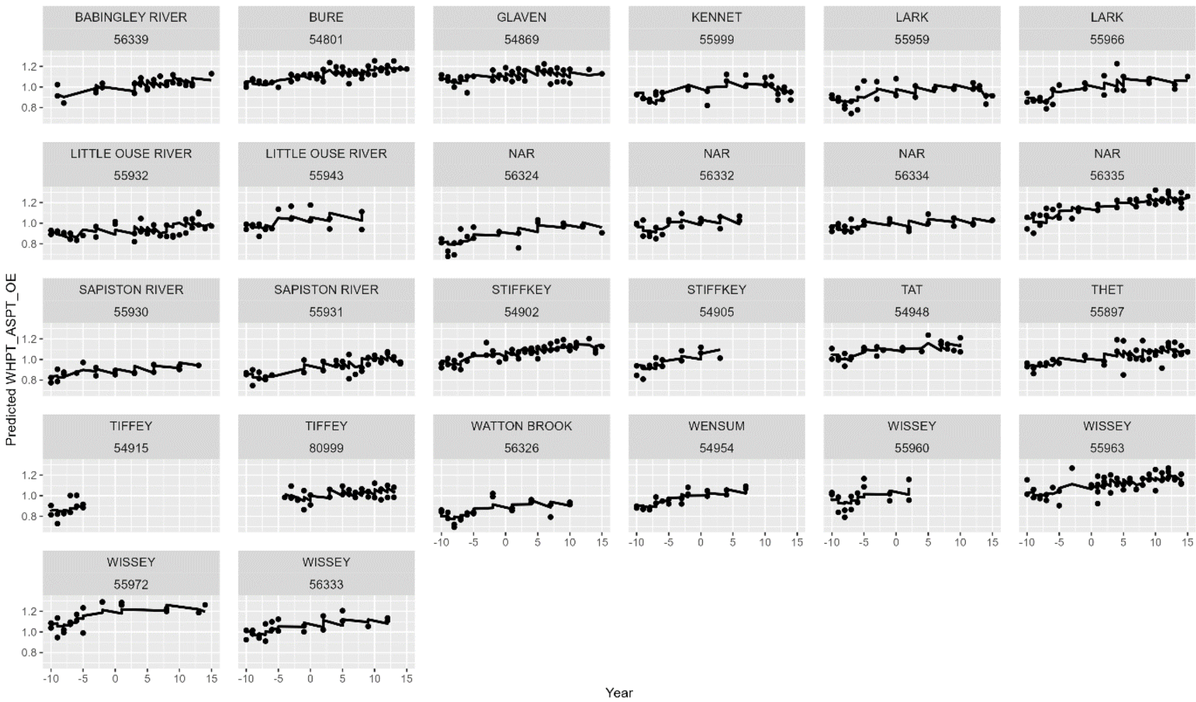

Figure 3-8 Measured (points) and modelled (lines) predictions of WHPT-ASPT O/E under the historical scenario for NEAC Model sites

3.3 Waterbody scenario analysis

This section presents model predictions for each waterbody and site of interest, under each of the three modelled scenarios (Historical, Naturalised, and Fully Licenced; see Section 2.2.3). The results have been subdivided into waterbodies, and LIFE (F) O/E and WHPT-ASPT O/E ratios are presented for each site of interest. The figures pertaining to LIFE (F) and WHPT-ASPT show predicted O/E scores for historical, naturalised and fully licensed scenarios as orange, blue and black points respectively. For LIFE (F) figures, predicted O/E scores are plotted against a red dashed threshold boundary of 1.0 with scores <1.0 indicating a progressively greater degree of flow pressure. For WHPT-ASPT figures, predicted O/E scores are presented against a background of horizontal colour bands that depict indicative macroinvertebrate WFD classes: High (blue), Good (green), Moderate (yellow), Poor (orange) and Bad (red).

3.3.1 GB105033037590 Cam (Audley End to Stapleford)

Model outputs for WB GB105033037590 are shown in Figure 3-9 and Figure 3-10 for LIFE (F) O/E and WHPT-ASPT O/E respectively. The outputs are presented for three sites moving from upstream to downstream:

- 56056 Littlebury
- 56065 Great Chesterford Road Bridge
- 56087 Dernford Lock Gauging Station

3.3.1.1 Historical abstraction impact

The model outputs show a general improvement in LIFE (F) O/E and WHPT-ASPT O/E over time and an improving trend when moving downstream in the waterbody. Comparison of LIFE (F) and WHPT-ASPT O/E scores predicted under the naturalised and historical scenarios indicates that the macroinvertebrate community of GB105033037590 Cam (Audley End to Stapleford) has been subject to impact from abstraction pressure, with the most notable impacts being observed at Littlebury (56056) and Great Chesterford Road Bridge (56065); see Figure 3-9 and Figure 3-10.

-Figure 3-9 shows that predicted historical LIFE (F) O/E scores are consistently and markedly lower than the naturalised scenario throughout the entire timeseries at the two sites. The impact of abstraction is indicated further with recent (2015-2020) predicted historical LIFE O/E scores falling below 1.0, in contrast to the predicted naturalised scenario, which showed scores above 1.0. Predictions for recent (2015-2020) historical LIFE (F) O/E scores are 4-7% and 3-5% lower than naturalised scenario scores.

Similar results were observed for WHPT-ASPT (Figure 3-10). The naturalised scenarios for Littlebury (56056) and Great Chesterford (56065) show predicted O/E scores to be consistently higher in the absence of abstraction over the entire length of the timeseries. There are periods when abstraction pressure is predicted to lower the indicative WFD class (based on WHPT-ASPT O/E) either from High to Good or from Good to Moderate status; recent (2015-2020) WHPT-ASPT O/E predictions for Littlebury (56056) demonstrate a decrease in indicative macroinvertebrate WFD class from High to Good status. A similar impact is also indicated for Great Chesterford Road Bridge (56065); however, predictions made under the Historical scenario are close to the High-Good boundary.

Dernford Lock Gauging Station (56087) further downstream shows less impact from abstraction pressure on the macroinvertebrate community with historical predicted LIFE (F) O/E and WHPT-ASPT O/E scores showing a smaller deviation from the naturalised scenario. Recent (2015-2020) historical WHPT-ASPT O/E scores are typically 2% lower than naturalised scores with both scenarios showing an indicative High macroinvertebrate WFD class.

The model results support the reported Band 1 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody (as outlined in Table 1 in Appendix 1 - Baseline data of risk of deterioration to water bodies from water abstraction).

3.3.1.2 Fully licensed abstraction impact

The model output for the Fully Licensed scenario shows a significant adverse impact from increased abstraction pressure across all sites. Predictions for recent years (2015-2020) show a decrease in LIFE (F) O/E scores to values between 0.87-0.9 indicating a significant negative impact on the macroinvertebrate community with predicted scores falling by up to 16%. A similar adverse impact is also indicated by WHPT-ASPT O/E scores where the indicative WFD classification status for each site is predicted to deteriorate against the historical scenario. For example, Littlebury (56056) shows a deterioration from Good to Moderate status, Great Chesterford Road Bridge (56065) shows instances of a two-class deterioration from High to Moderate, and of a one class deterioration from either Good to Moderate or High to Good status. Similarly, Dernford Lock Gauging Station (56087) shows instances of deterioration from High to Good status.

The model results support the reported Band 2 2019 hydrological regime compliance band for levels of abstraction based on Fully Licensed quantities.

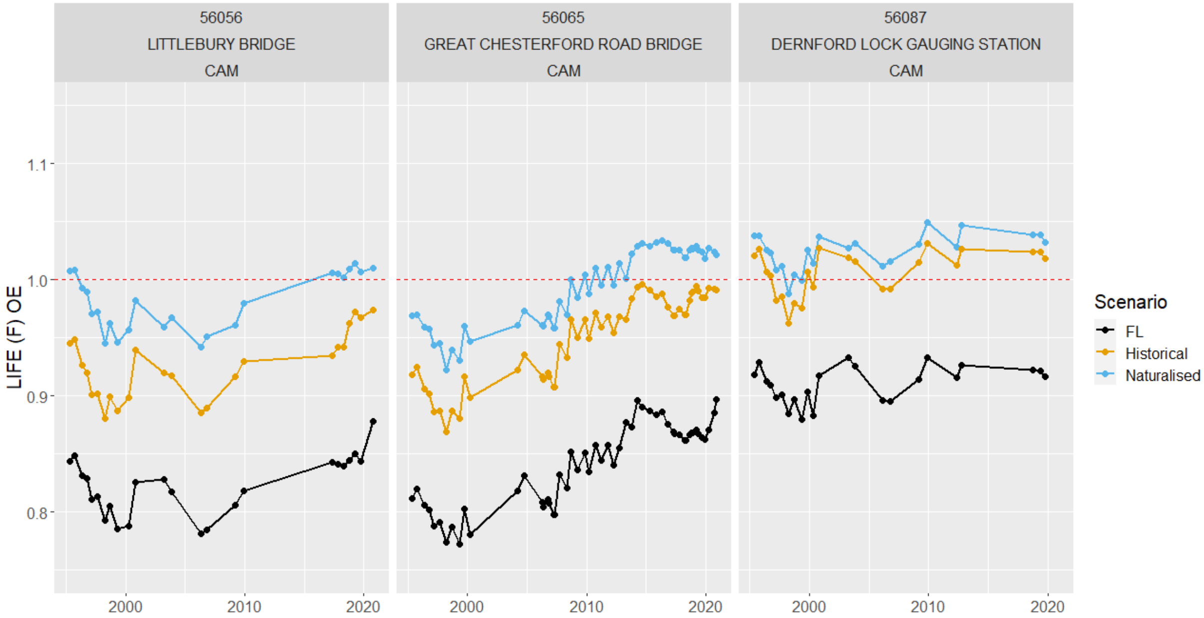

Figure 3-9 Predicted LIFE (F) O/E scores for historical, naturalised, and fully licensed scenarios for sites in GB105033037590 Cam (Audley End to Stapleford)

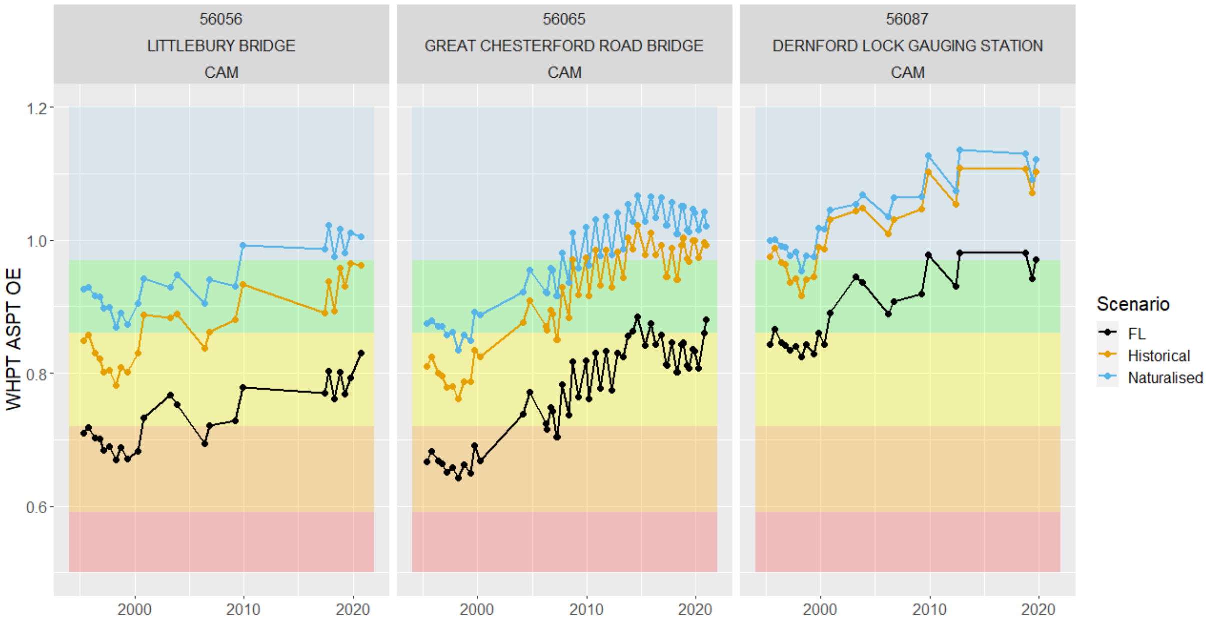

Figure 3-10 Predicted WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for three sites in GB105033037590 Cam (Audley End to Stapleford)

3.3.2 GB105033037600 Cam (Stapleford to Hauxton Jct.)

Model outputs for WB GB105033037600 are shown in Figure 3-11(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site within the waterbody was used, and is located downstream of Dernford Lock Gauging Station (56087) in the upstream waterbody:

- 56109 Hauxton Mill

3.3.2.1 Historical abstraction impact

The model outputs show improvements in LIFE (F) O/E and WHPT-ASPT O/E scores over time; However, it is important to recognise that the presence of the invasive non-native signal crayfish (*P. leniusculus*) has, in part, influenced the elevation of both metrics seen from around 2003 onwards. Predicted historical LIFE (F) O/E scores are lower than predicted naturalised LIFE (F) O/E scores, indicating an impact of abstraction pressure on the macroinvertebrate community throughout the timeseries, which continues into recent years (2015-2020).

Predicted historical WHPT-ASPT O/E scores also show deviation from naturalised, indicating an impact of abstraction pressure. It is, however, more difficult to assess the impact of abstraction on WFD classification status due to the influence of signal crayfish on macroinvertebrate community composition. In the absence of signal crayfish WHPT-ASPT O/E scores are likely to be slightly lower (see Figure 3-5) bringing recent (2015-2020) historical (and naturalised) scores closer to the High-Good boundary.

The model results support the reported Band 1 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody.

3.3.2.2 Fully licensed abstraction impact

A significant adverse impact to macroinvertebrate communities due to increased abstraction pressure is predicted under a Fully Licensed scenario. Recent (2015-2020) LIFE (F) O/E scores are predicted to decline to between 0.96-0.98 compared to 1.05-1.07 and 1.07-1.09 for the historical and naturalised scenarios, respectively. Similarly, the indicative macroinvertebrate WFD class status is predicted to decline from High to Good status, even despite the influence of signal crayfish on the macroinvertebrate community of the site.

The model results support the reported Band 2 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities.

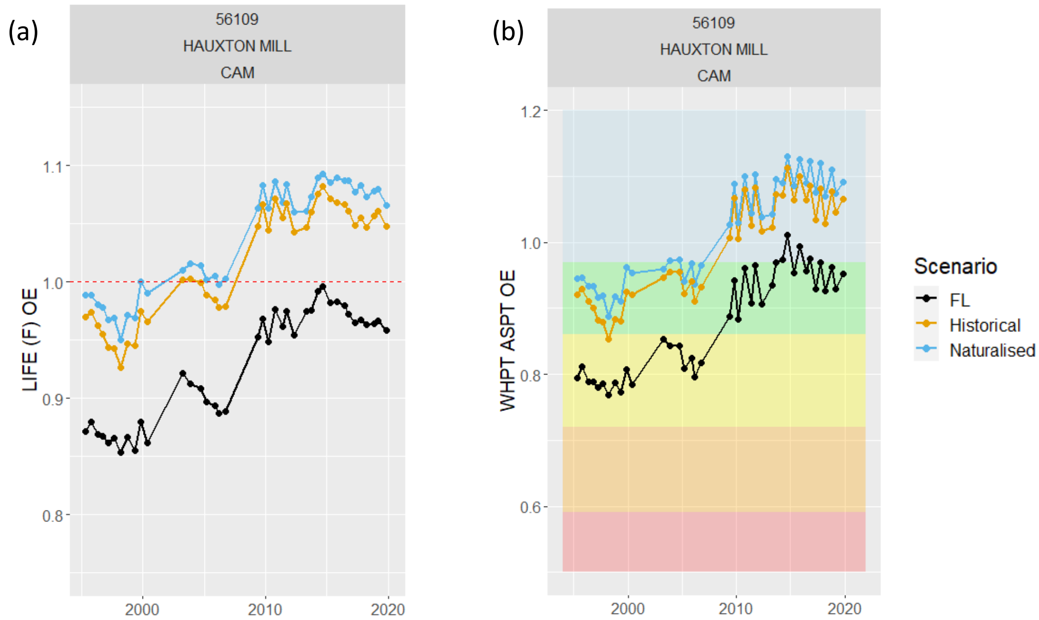

Figure 3-11 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Hauxton Mill, River Cam in GB105033037600 Cam (Stapleford to Hauxton Jct.)

3.3.3 GB105033037610 Rhee (DS Wendy)

Model outputs for WB GB105033037610 are shown in Figure 3-12(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E, respectively. One site within the waterbody was used, and is located downstream of Tadlow Bridge Farm (56171) in the upstream waterbody GB105033038100:

- 56119 Haslingfield Road Bridge

3.3.3.1 Historical abstraction impact

The model outputs indicate a very slight / negligible impact of abstraction pressure on the macroinvertebrate community at Haslingfield Road Bridge (56119) for both LIFE (F) O/E and WHPT-ASPT O/E scores across the timeseries. This is depicted by only a slight difference in metric scores between historical and naturalised scenario scores.

The model results support the reported Compliant 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody.

3.3.3.2 Fully licensed abstraction impact

Under the fully licensed scenario, an adverse impact of abstraction pressure on the macroinvertebrate community is predicted. Recent (2015-2020) LIFE (F) O/E scores are predicted to decline typically by 3%, relative to historical and naturalised scenarios, falling below the threshold of 1.0, and the indicative macroinvertebrate WFD status suggests a risk of deterioration if abstraction were to increase to fully licensed, deteriorating from High to Good status.

The model results in this instance do not support the reported Compliant 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities.

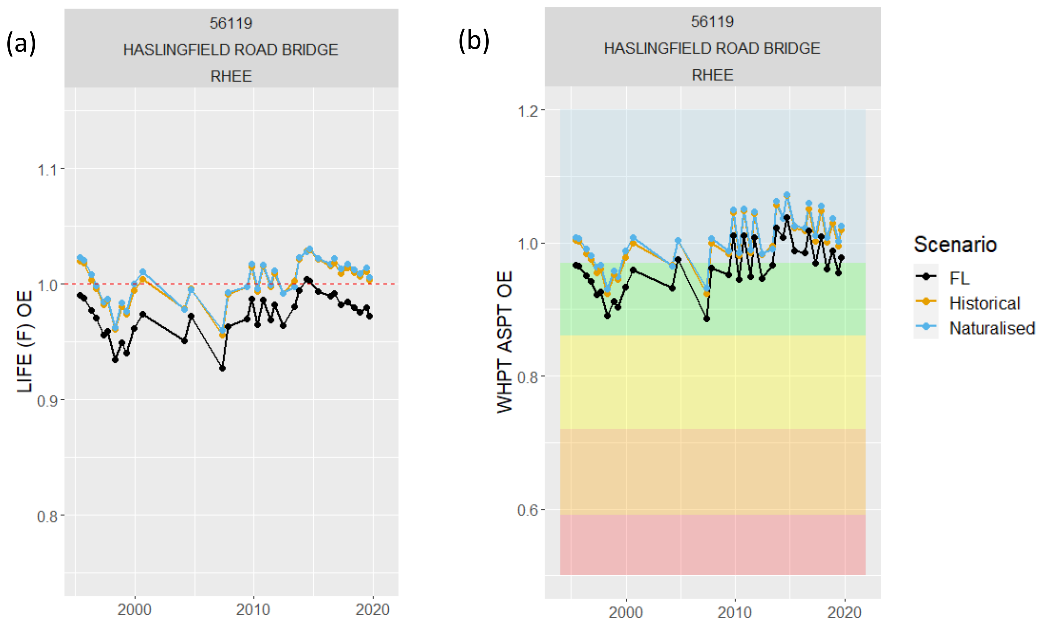

Figure 3-12 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Haslingfield Road Bridge, River Rhee in GB105033037610 Rhee (DS Wendy)

3.3.4 GB105033037810 Granta

Model outputs for WB GB105033037810 are shown in Figure 3-13 and Figure 3-14 for LIFE (F) O/E and WHPT-ASPT O/E, respectively. The outputs are presented for four sites, moving from upstream to downstream:

- 56031 A604 Linton Bypass
- 56037 Hildersham Ford
- 56054 Bourn Bridge
- 56083 Stapleford Road Bridge

3.3.4.1 Historical abstraction impact

The model outputs show a general increase in LIFE (F) O/E and WHPT-ASPT O/E over time at each site and a descending trend in scores when moving downstream in the waterbody. It is important to recognise that signal crayfish are present within the waterbody and may have influenced the elevation of both biotic scores at two of the sites; Hildersham Ford has shown a minor signal crayfish impact from 2012 and Bourn Bridge has shown a minor impact between 2016-2017 and a major impact from 2018 onwards.

The model did not indicate an abstraction pressure impact on the macroinvertebrate community at the two most upstream sites, A604 Linton Bypass (56031) and Hildersham Ford (56037), with historical and naturalised scores for both O/E metrics displaying similar values. In contrast, an increasing abstraction impact is observed moving downstream to sites Bourn Bridge (56054) and Stapleford Road Bridge (56083).

Bourn Bridge (56054) shows an impact of abstraction pressure in the most recent years (2015-2020) with historical LIFE (F) O/E scores being lower than naturalised; this is mirrored in WHPT-ASPT O/E scores where abstraction pressure is predicted to lower the indicative WFD class from High to Good on occasions.

Stapleford Road Bridge (56083) shows a significant adverse impact of abstraction pressure on the macroinvertebrate community with a large deviation in both biotic scores between historic and naturalised scenarios. Predicted historical LIFE (F) O/E scores in recent years (2015-2020) are up to 12% lower than naturalised scores with historical scores falling below a LIFE (F) O/E score of 1.0. Historical WHPT-ASPT O/E scores in recent years (2015-2020) also show the same scale of deviation with predicted scores being up to 15% lower than predicted naturalised scores; this indicates that abstraction pressure has impacted macroinvertebrate communities and lowered the indicative macroinvertebrate WFD class status from High to Good status.

The model results support the reported Band 1 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody.

3.3.4.2 Fully licensed abstraction impact

All four sites show some adverse impact of abstraction under the Fully Licensed scenario; however, three of the sites show notable impacts – Hildersham Ford (56037), Bourn Bridge (56054) and Stapleford Road Bridge (56083). Recent (2015-2020) predicted fully licensed LIFE (F) O/E scores across these three sites are typically 9-12% lower than historical scores, and at Stapleford Road Bridge scores are up to 20% lower compared to the naturalised scores. Recent (2015-2020) fully licensed WHPT-ASPT O/E scores also show significant decreases relative to historical predictions, resulting in deteriorations in indicative macroinvertebrate WFD class statuses under the fully licensed scenario. For example, Hildersham Ford (56037) shows instances of a decline in macroinvertebrate WFD class from Good to Moderate, Bourn Bridge (56054) also shows a deterioration from Good to Moderate status, and Stapleford Road Bridge (56083) shows instances of a two-class deterioration from High to Moderate and single class deteriorations of High to Good and Good to Moderate status.

Predictions for A604 Linton Bypass (56031) indicate a less severe impact of abstraction on the macroinvertebrate community. Recent (2015-2020) LIFE (F) O/E scores show a typical 2% decline from 1.00-1.04 to 0.97-1.03. Despite this reduced impact compared to the three downstream sites, WHPT-

ASPT O/E scores do show instances of indicative macroinvertebrate WFD class deterioration from High-Good status.

The model results in this instance support the reported Band 3 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities.

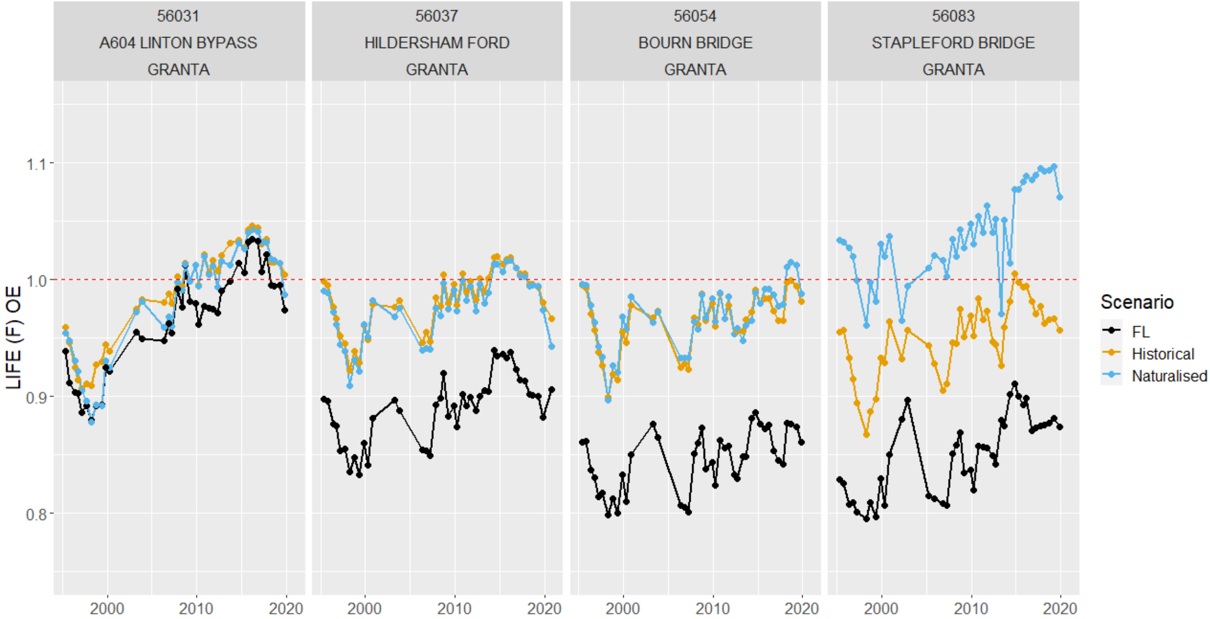

Figure 3-13 Predicted LIFE (F) O/E scores for historical, naturalised, and fully licensed scenarios for four sites in GB105033037810 Granta

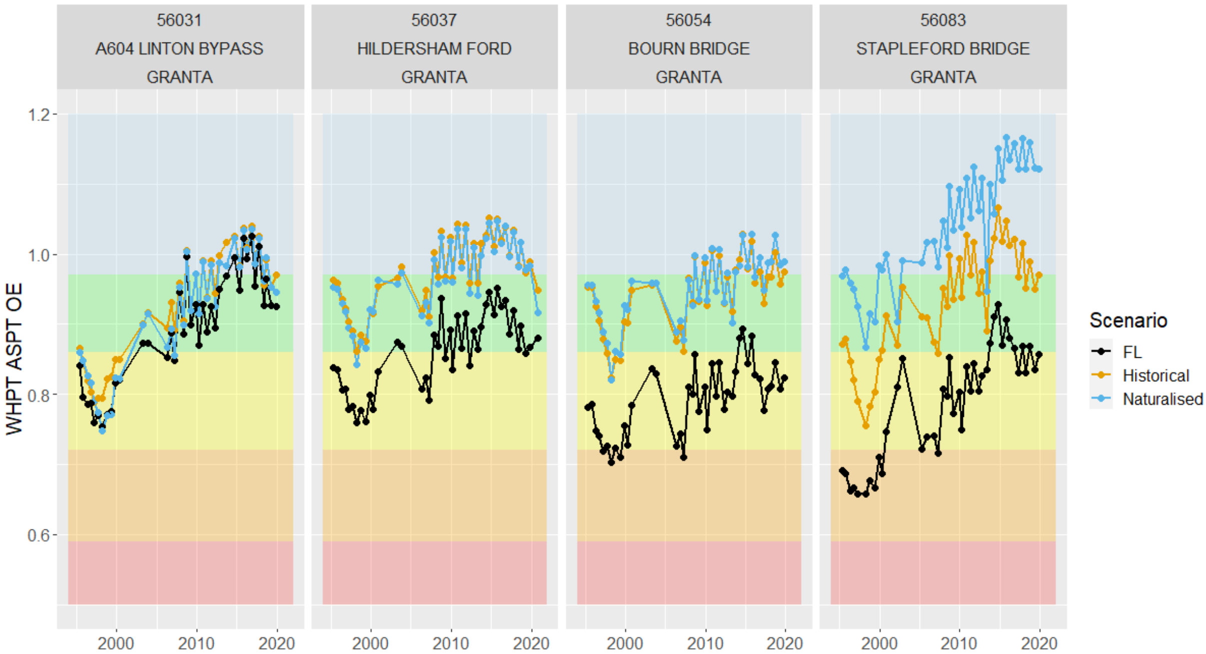

Figure 3-14 Predicted WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for four sites in GB105033037810 Granta

3.3.5 GB105033038100 Rhee (US Wendy)

Model outputs for WB GB105033038100 are shown in Figure 3-15(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site within the waterbody was used, and is located upstream of Haslingfield Road Bridge (56119), which is in waterbody GB105033037610:

- 56171 Tadlow Bridge Farm

3.3.5.1 Historical abstraction impact

The model predictions were not indicative of an impact of abstraction pressure at Tadlow Bridge Farm (56171), with LIFE (F) O/E and WHPT-ASPT O/E scores showing similar predictions across the timeseries and between historical and naturalised scenarios. A negligible impact is depicted in some years prior to 2000, indicated by only a slight difference between historical and naturalised scenario scores. Post-2000 no discernible abstraction impact can be observed.

Given that no waterbody assessment was undertaken for the 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) no comparison against the model results can be made.

3.3.5.2 Fully licensed abstraction impact

The model output indicates no discernible abstraction impact at the site under the fully licensed scenario with similar results displayed for the historical and fully licensed scenarios.

Given that no waterbody assessment was undertaken for the 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities no comparison against the model results can be made.

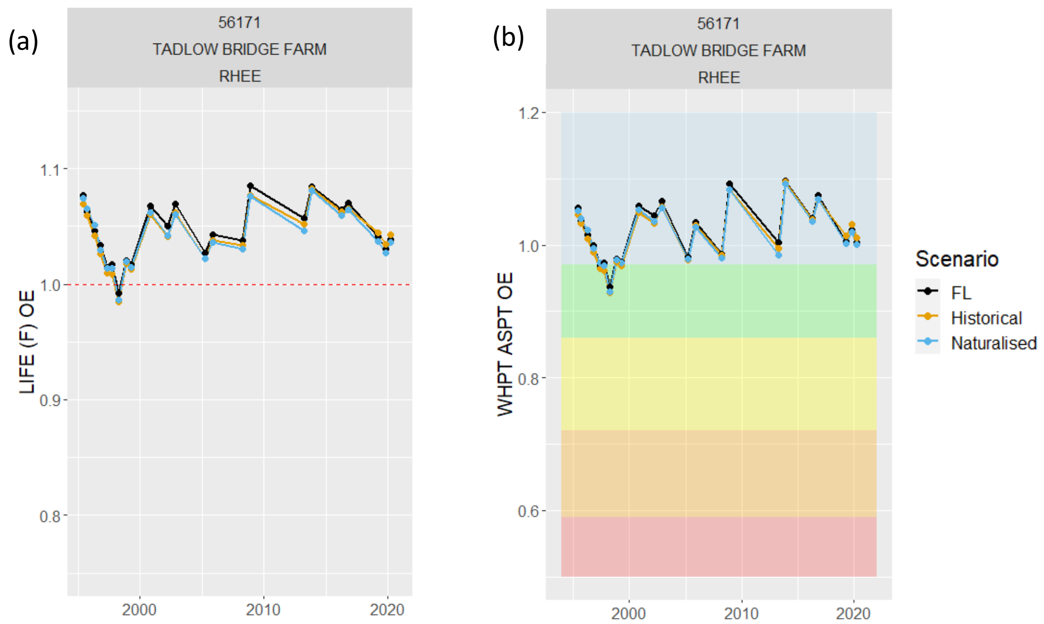

Figure 3-15 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Tadlow Bridge Farm, River Rhee GB105033038100 Rhee (US Wendy)

3.3.6 GB105033042860 Soham Lode

Model outputs for WB GB105033042860 are shown in Figure 3-16(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site was used within the waterbody:

- 56004 River Lane Fordham

3.3.6.1 Historical abstraction impact

The model output shows an improvement in both LIFE (F) and WHPT-ASPT O/E metrics over time, with WHPT-ASPT O/E in particular showing consistent improvements in scores from 2010. Signal crayfish are present at the site and are thought to have impacted the macroinvertebrate community from 2016. This influence has led to the elevation of both biotic scores, which is most apparent with a distinct uptick in LIFE (F) O/E scores from 2018 onwards.

The model predictions show that historical LIFE (F) O/E and WHPT-ASPT O/E scores as being lower than the naturalised scenario over the full extent of the timeseries. In recent years (2015-2020) predicted historical LIFE (F) O/E scores are typically 3% lower than naturalised, and prior to signal crayfish impact were also under the threshold of 1.0. In recent years (2015-2020) predicted historical WHPT-ASPT O/E scores are typically 4-5% lower than naturalised scores, with predictions being indicative of High status under the naturalised scenario, and more borderline Good/High status under the historical scenario. However, unlike other waterbodies and sites reported in Section 3.3, the historical LTQ75RFR for this site was >1 (~1.14) indicating that flows are discharge-rich (against naturalised) as opposed to indicating an abstraction pressure. The model outputs show a non-linear relationship where O/E metrics reduce where flows are augmented above naturalised (see Figures 3.1 and 3.5). Hence the model predicts an impact from augmented flows.

The model results do support the reported Compliant 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody.

3.3.6.2 Fully licensed abstraction impact

The model output indicates a negligible / no discernible abstraction impact at the site with similar predicted O/E metric scores displayed between the fully licensed and naturalised scenarios in recent years (2015-2020). The impact of the fully licensed scenario is also predicted to be smaller than that of the historical scenario with both O/E biotic scores being lower for the latter. Under the fully licensed scenario, the LTQ75RFR for the site was ~0.82. At this value the adverse impact of abstraction is less than the adverse impact of flow augmentation observed under the historical scenario. Therefore, metric scores predicted under fully licensed show some reduction relative to naturalised but are higher than historical.

The model results in this instance do not support the reported Band 2 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities.

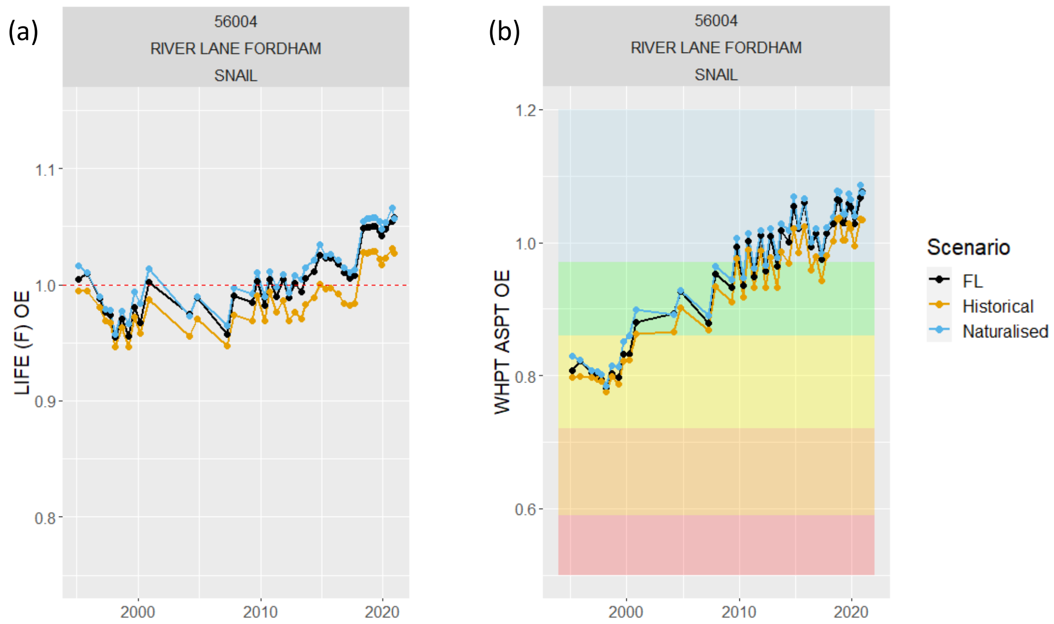

Figure 3-16 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for River Lane Fordham, River Snail GB105033042860 Soham Lode

3.3.7 GB105033043070 Sapiston River

Model outputs for WB GB105033043070 are shown in Figure 3-17(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site was used within the waterbody:

- 55931 Bardwell Bridge

3.3.7.1 Historical abstraction impact

The model outputs show a very small to negligible difference between LIFE (F) O/E and WHPT-ASPT predictions made under the historical and naturalised scenarios and were not indicative of an impact of abstraction pressure at the site. However, it is important to recognise that the presence of signal crayfish, which may have, in part, contributed to the elevation of both O/E metric scores post-2000 onwards.

The model results do not support the reported Band 1 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody.

3.3.7.2 Fully licensed abstraction impact

The model predictions show a notable impact of increased abstraction pressure on the macroinvertebrate community under the fully licensed scenario throughout the timeseries, as indicated by both LIFE (F) O/E and WHPT-ASPT O/E predicted scores. Recent (2015-2020) fully licensed LIFE (F) O/E scores range from 0.92-0.95 compared to 0.98-1.02 of historical and naturalised scenarios, showing a typical decline of 7%. Similarly recent (2015-2020) fully licensed WHPT-ASPT O/E scores show a decline of 7-9%, resulting in instances of a decline in indicative macroinvertebrate WFD class status from High to Good.

The model results in this instance support the reported Band 3 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities.

Figure 3-17 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Bardwell Bridge, Sapiston River GB105033043070 Sapiston River

3.3.8 GB105033043090 Little Ouse (DS Sapiston Confl)

Model outputs for WB GB105033043090 are shown in Figure 3-18(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site was used within the waterbody:

- 55943 Nun's Bridge Thetford

3.3.8.1 Historical abstraction impact

The macroinvertebrate sample data for Nun's Bridge Thetford extends from 1995 to 2013. The model output across the timeseries shows that predicted historical LIFE (F) O/E and WHPT-ASPT O/E scores are typically similar or slightly increased relative to naturalised scenario scores. There are however two main instances, Spring 1999 and Autumn 2013 where both historical biotic O/E scores are slightly lower than naturalised scores. The model results hence indicate a negligible to no discernible abstraction impact on the macroinvertebrate community.

The model results do not support the reported Band 1 2019 hydrological regime compliance band for recent actual levels of abstraction (2010-2015) for the waterbody.

3.3.8.2 Fully licensed abstraction impact

The model output for the fully licensed scenario shows both LIFE (F) O/E and WHPT-ASPT O/E scores to be significantly lower than historical and naturalised scenarios, indicating a significant adverse impact of increased abstraction pressure on the macroinvertebrate community. Predicted fully licensed LIFE (F) O/E scores are typically 5-6% lower than historical and naturalised scenarios. The model indicates that naturalised Spring and Autumn 2013 LIFE (F) O/E scores would decline from 1.00 to 0.95 and 1.02 to 0.96 respectively under the fully licensed scenario. The WHPT-ASPT O/E fully licensed scores show several instances of a decline in indicative macroinvertebrate WFD class from High to Good status. This includes Spring 2013 where the WHPT-ASPT O/E score is 6-7% lower than historical and naturalised scenarios. Although no recent (2015-2020) data was available for model calibration when making subsequent predictions, the expectation is that relative differences in O/E scores between the fully licensed and the historical and naturalised scenarios would continue. Hence an abstraction impact on the macroinvertebrate community is expected to persist.

The model results in this instance support the reported Band 3 2019 hydrological regime compliance band for levels of abstraction based on fully licensed quantities.

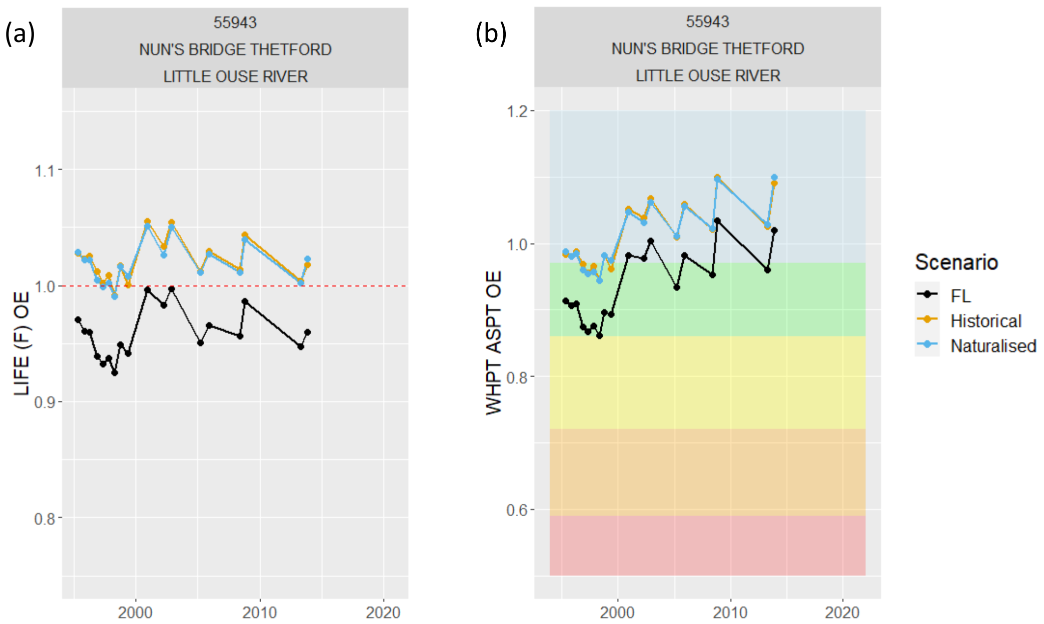

Figure 3-18 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Nun's Bridge Thetford, Little Ouse River GB105033043090 Little Ouse (DS Sapiston Confl)

3.3.9 GB105033043100 Little Ouse (DS Hopton Common)

Model outputs for WB GB105033043100 are shown in Figure 3-19(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site was used within the waterbody:

- 55932 Road Bridge Knettishall

3.3.9.1 Historical abstraction impact

The model predictions show a negligible to no discernible abstraction impact on the macroinvertebrate community at the site, with historical LIFE (F) O/E and WHPT-ASPT O/E scores either being similar or slightly higher than naturalised scores throughout the time series.

3.3.9.2 Fully licensed abstraction impact

Under the fully licensed scenario there is a predicted adverse abstraction impact on the macroinvertebrate community. Recent (2015-2020) LIFE (F) O/E scores are predicted to decline by 2% relative to historical and naturalised scenarios. The recent (2015-2020) indicative macroinvertebrate WFD status shows a risk of deterioration, with WHPT-ASPT O/E scores declining from High to Good status for most of this period. Predicted fully licensed WHPT-ASPT O/E scores are typically 3% lower than historical and naturalised scenario scores.

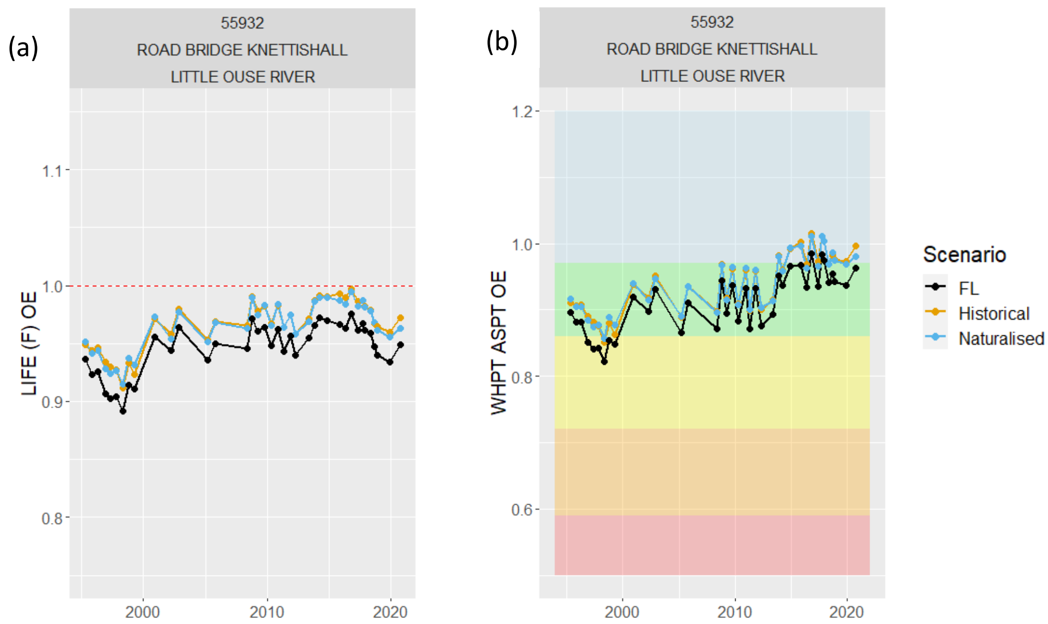

Figure 3-19 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Road Bridge Knettishall, Little Ouse River GB105033043100 Little Ouse (DS Hopton Common)

3.3.10 GB105033043190 Thet (DS Swangey Fen)

Model outputs for WB GB105033043190 are shown in Figure 3-20(a) and (b) for LIFE (F) O/E and WHPT-ASPT O/E respectively. One site was used within the waterbody:

- 55897 Bridgham Track Bridge

3.3.10.1 Historical abstraction impact

The model predictions show negligible differences between historical and naturalised LIFE (F) O/E and WHPT-ASPT O/E scores indicating no discernible abstraction impact on the macroinvertebrate community at the site.

3.3.10.2 Fully licensed abstraction impact

The fully licensed scenario also predicts marginal / negligible differences from historical and naturalised LIFE (F) O/E and WHPT-ASPT O/E scores indicating a negligible to no discernible impact of increased abstraction pressure on the macroinvertebrate community at the site.

The model results are likely to reflect the less flow sensitive nature of the site with it being relatively wider and deeper compared to other sites.

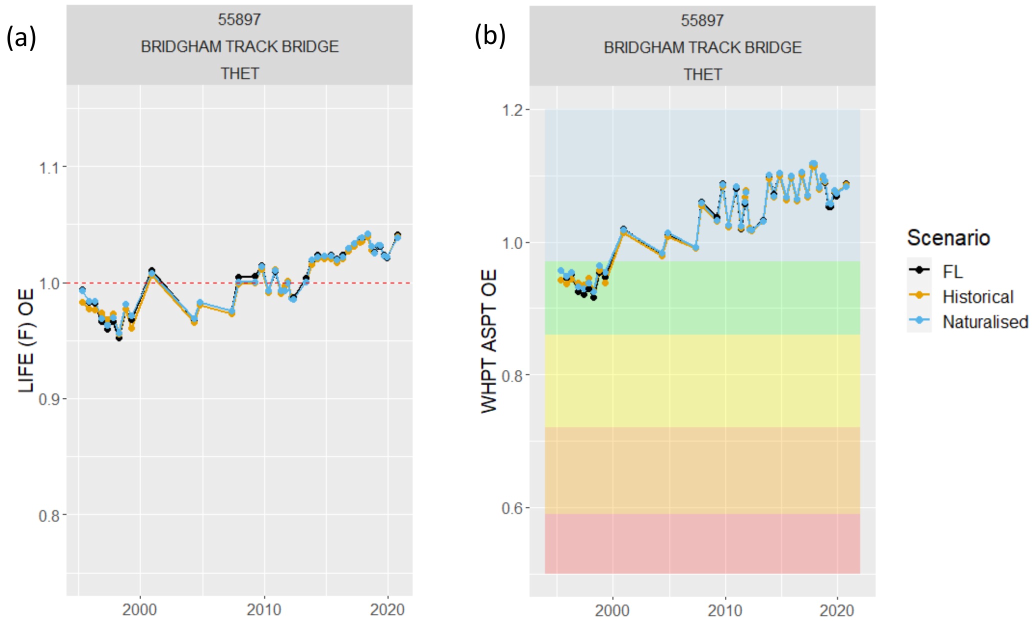

Figure 3-20 Predicted LIFE (F) O/E and WHPT-ASPT O/E scores for historical, naturalised, and fully licensed scenarios for Bridgham Track Bridge, River Thet GB105033043190 Thet (DS Swangey Fen)

4 Summary

4.1 Current and future risk of ecological impact from abstraction

The aim of this report was to investigate the ecological impact caused by abstraction and the effects of future growth in abstraction to waterbodies influenced by Cambridge Water Company's (CWC) abstractions. A hydroecological model using macroinvertebrate and groundwater modelled flow data was developed and used to predict abstraction impacts on 10 WFD surface waterbodies of interest (see Table 4-1 below):

Table 4-1 Predicted model results of recent and future abstraction impacts on macroinvertebrate communities

WFD waterbody	Sites assessed	Recent abstraction pressure impact	Future abstraction pressure impact (fully licensed scenario)
GB105033037590 Cam (Audley End to Stapleford)	56056, 56065, 56087	Adverse impact	Adverse impact
GB105033037600 Cam (Stapleford to Hauxton Jct.)	56109	Adverse impact	Adverse impact
GB105033037610 Rhee (DS Wendy)	56119	No / negligible	Adverse impact
GB105033037810 Granta	56031, 56037, 56054, 56083	Adverse impact	Adverse impact
GB105033038100 Rhee (US Wendy)	56171	No / negligible	No / negligible
GB105033042860 Soham Lode	56004	No / negligible	No / negligible
GB105033043070 Sapiston River	55931	No / negligible	Adverse impact
GB105033043090 Little Ouse (DS Sapiston Confl)	55943	No / negligible	Adverse impact
GB105033043100 Little Ouse (DS Hopton Common)	55932	No / negligible	Adverse impact
GB105033043190 Thet (DS Swangey Fen)	55897	No / negligible	No / negligible

Table 4-1 shows that the model indicated that macroinvertebrate communities at three of the ten waterbodies had recently been adversely impacted by abstraction:

- River Cam (GB105033037590) Audley End to Stapleford
- River Cam (GB105033037600) Stapleford to Hauxton Junction
- River Granta (GB105033037810)

The River Cam (GB105033037590) and River Granta (GB105033037810) waterbodies showed the largest abstraction impacts; here, the differences between predictions of LIFE (F) and WHPT-ASPT O/E scores made under the naturalised and historical scenarios were greatest. When making predictions for recent years (2015-2020), both waterbodies had sites that were indicative of High status under the naturalised scenario but were indicative of Good status under the historical scenario. Both waterbodies also had sites where predicted LIFE (F) O/E for recent years (2015-2020) was above the threshold of 1.0 for the naturalised scenario and below 1.0 for the historical scenario. Most notably predicted historical LIFE (F) O/E scores at Stapleford Road Bridge were 10-11% lower than naturalised.

Under the fully licensed scenario the model showed the greatest deleterious impact on macroinvertebrate communities with seven of the ten waterbodies being adversely impacted (see Table 4-1).

- River Cam (GB105033037590) Audley End to Stapleford
- River Cam (GB105033037600) Stapleford to Hauxton Junction
- River Rhee (GB105033037610) Downstream of Wendy
- River Granta (GB105033037810)
- Sapiston (GB105033043070)
- Little Ouse (GB105033043090) Downstream of Sapiston confluence
- Little Ouse (GB105033043100) Downstream of Swangey Fen

With exception of GB105033042860 Soham Lode[5], the fully licensed scenario saw increased instances and severity of indicative macroinvertebrate WFD class deterioration and / or a greater suppression of LIFE (F) O/E scores. In particular, the River Cam (GB105033037590) and Granta (GB105033037810) showed instances of a two-class indicative WFD deterioration and LIFE (F) O/E score declines of up to 16%. The additional five impacted waterbodies either showed instances of an indicative macroinvertebrate WFD class deterioration from High to Good status and / or showed a significant suppression of LIFE (F) O/E scores indicating an adverse impact on the macroinvertebrate community caused by increased levels of abstraction.

4.2 Considerations and recommendations

It is appropriate to acknowledge that modelling is an iterative process and that the predicted model values presented should not be seen as absolute. Model predictions may under- or over-estimate absolute values of the LIFE (F) O/E and WHPT-ASPT O/E metrics under specific environmental or temporal conditions; however, the models are suitable in providing an indication of the relative change in ecological community response between different flow or abstraction scenarios. Resultingly they can be applied for assessment of the relative scale of ecological impact and status deterioration that could result from change in abstraction pressure. The results and predictions arising from the application of the models presented should be considered as part of a weight of evidence approach to defining sustainable levels of abstraction. Moreover, future refinements and enhancements, such as inclusion of water quality data and using daily flow time-series data for calculating flow alteration and flow history statistics, could be made to improve model performance and further account for remaining unexplained variance. The model outputs and results are, however, relatively consistent with previous studies (Bradley et al, 2017).

The predicted abstraction impacts pertain to the sites used in the model. There is potential that other sites on a watercourse or within a water body could be more sensitive to abstraction pressure but were unable to be included (e.g., insufficient / lack of data). It is also important to note that abstraction pressure was based on Q75 statistics, which was a result of using modelled monthly flow data as it provides a more reliable estimate than Q95. Q75 represents moderate to low flow conditions, and the results may present more conservative assessments of ecological impact than Q95 (low flows), particularly at sites that are prone to drying during drought.

[5] Refer to Section 3.3.6.1

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6 Appendices

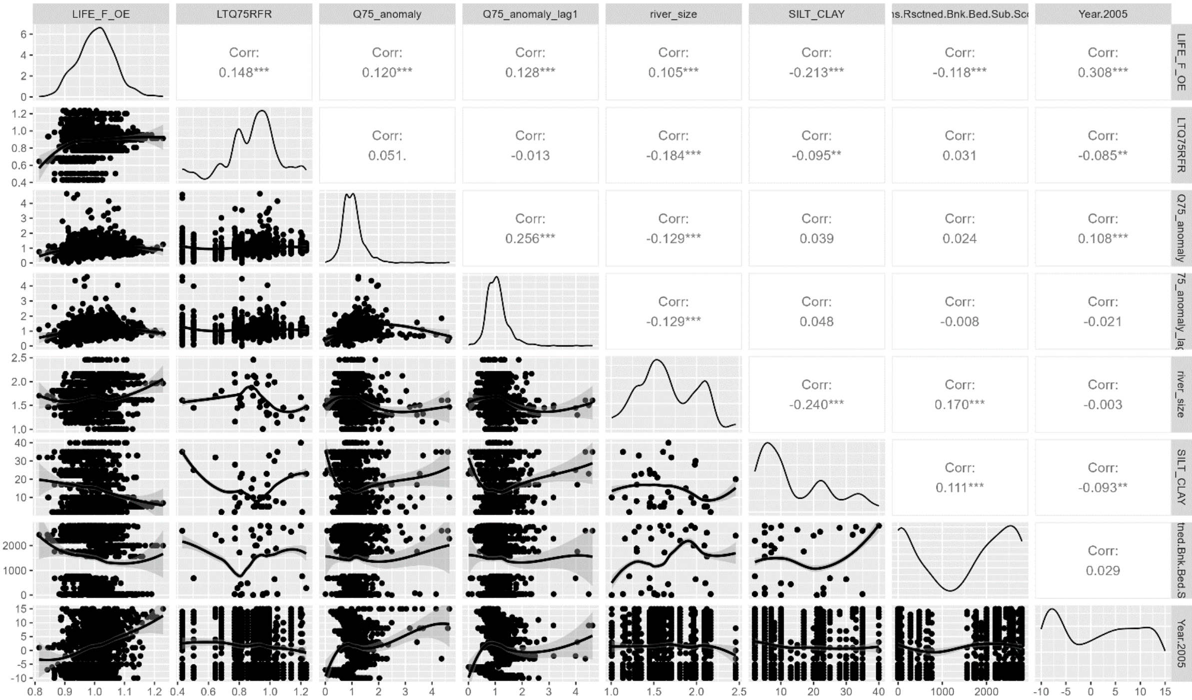
6.1 Appendix I List of macroinvertebrate sampling points

Watercourse	Site ID	Site Name	Waterbody ID	Groundwater Model
CAM	56056	LITTLEBURY BRIDGE	GB105033037590	CBO
CAM	56065	GREAT CHESTERFORD ROAD BRIDGE	GB105033037590	CBO
CAM	56087	DERNFORD LOCK GAUGING STATION	GB105033037590	CBO
CAM	56109	HAUXTON MILL	GB105033037600	CBO
RHEE	56119	HASLINGFIELD ROAD BRIDGE	GB105033037610	CBO
GRANTA	56031	A604 LINTON BYPASS	GB105033037810	CBO
GRANTA	56037	HILDERSHAM FORD	GB105033037810	CBO
GRANTA	56054	BOURN BRIDGE	GB105033037810	CBO
GRANTA	56083	STAPLEFORD BRIDGE	GB105033037810	CBO
RHEE	56171	TADLOW BRIDGE FARM	GB105033038100	CBO
SNAIL	56004	RIVER LANE FORDHAM	GB105033042860	CBO
KENNETT	55999	BECK BRIDGE	GB105033043020	NEAC
LARK	55959	HENGRAVE BRIDGE	GB105033043051	NEAC
LARK	55966	LACKFORD BRIDGE	GB105033043051	NEAC
SAPISTON	55931	BARDWELL BRIDGE	GB105033043070	NEAC
LITTLE OUSE	55943	NUN'S BRIDGE THETFORD	GB105033043090	NEAC
LITTLE OUSE	55932	ROAD BRIDGE KNETTISHALL	GB105033043100	NEAC
THET	55897	BRIDGHAM TRACK BRIDGE	GB105033043190	NEAC
SAPISTON	55930	BULL BRIDGE PAKENHAM	GB105033043280	NEAC
BABINGLEY	56339	B1153 RB HILLINGTON	GB105033047620	NEAC
WISSEY	55960	BODNEY BRIDGE	GB105033047630	NEAC
WISSEY	55963	ICKBURGH BRIDGE	GB105033047630	NEAC
WISSEY	55972	DIDLINGTON LODGE BRIDGE NORTHWOLD	GB105033047630	NEAC
NAR	56324	LITCHAM ROAD BRIDGE	GB105033047791	NEAC
NAR	56332	WEST LEXHAM ROAD BRIDGE	GB105033047791	NEAC
NAR	56334	CASTLE ACRE ROAD BRIDGE	GB105033047791	NEAC
NAR	56335	WEST ACRE ROAD BRIDGE	GB105033047791	NEAC
WATTON	56326	LITTLE CRESSINGHAM ROAD BRIDGE	GB105033047870	NEAC
WISSEY	56333	LINGHILLS FARM BRIDGE AND FORD	GB105033047890	NEAC
BURE	54801	INGWORTH BRIDGE	GB105034050930	NEAC
TAT	54948	TATTERFORD COMMON	GB105034051140	NEAC
TIFFEY	54915	RAIL BRIDGE D/S STW	GB105034051220	NEAC
TIFFEY	80999	CHAPEL LANE BRIDGE	GB105034051220	NEAC
GLAVEN	54869	EDGEFIELD BRIDGE	GB105034055780	NEAC
STIFFKEY	54905	STIFFKEY VILLAGE ROAD BRIDGE	GB105034055830	NEAC
STIFFKEY	54902	D/S WIGHTON BRIDGE	GB105034055840	NEAC
WENSUM	54954	GREAT RYBURGH BRIDGE	GB105034055881	NEAC

6.2 Appendix II LIFE O/E Model

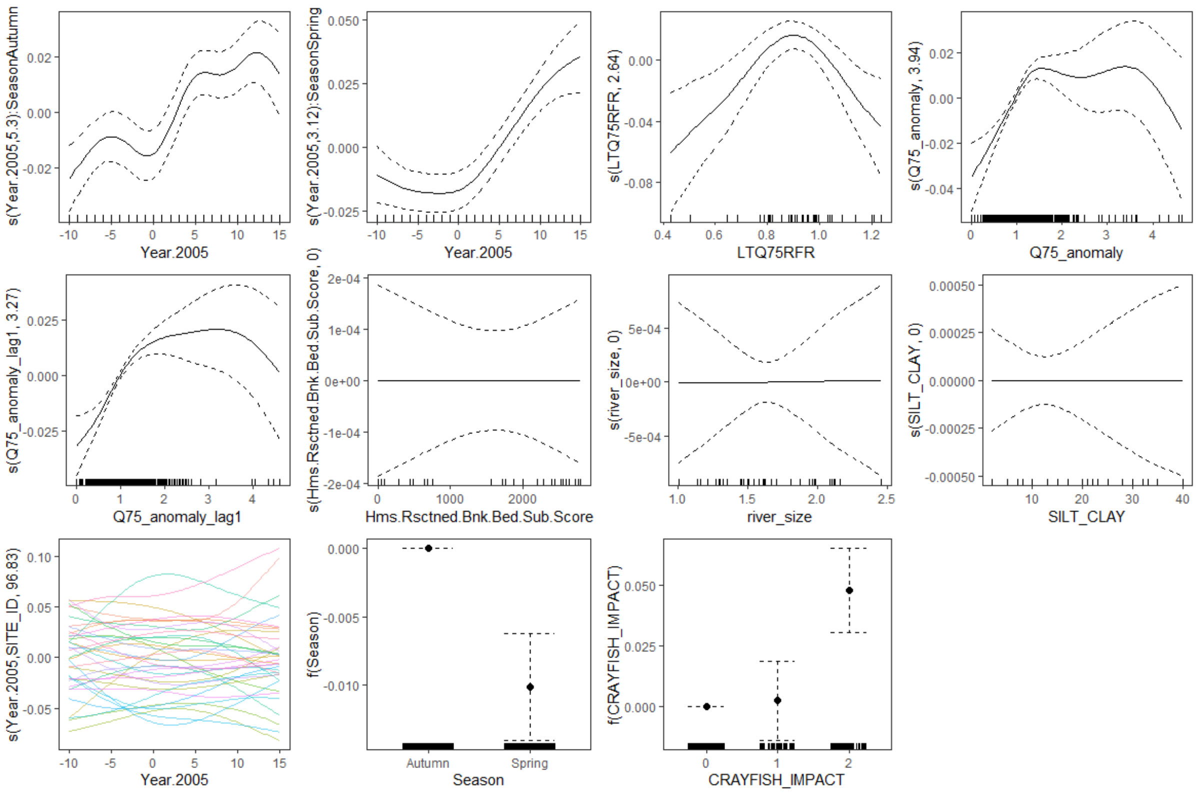
6.2.1 A.1 Pairwise correlations between variables

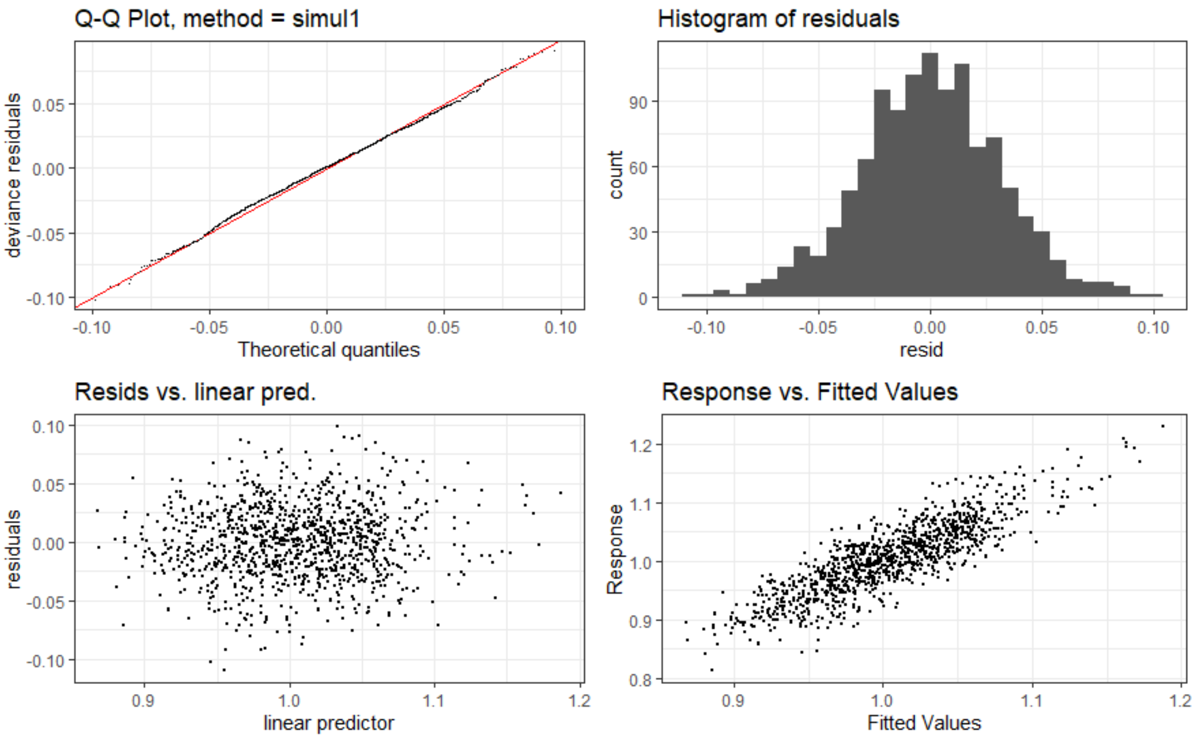
Pairwise correlations among potential response and explanatory variables were explored, to aid in deciding which metrics to include within the model.



6.2.2 A.2 LIFE O/E Model

```
Family: gaussian
Link function: identity

Formula:
my.variable ~ Season + CRAYFISH_IMPACT + s(Year.2005, by = Season) +
    s(LTQ75RFR) + s(Q75_anomaly) + s(Q75_anomaly_lag1) +
s(Hms.Rsctned.Bnk.Bed.Sub.Score) +
    s(river_size) + s(SILT_CLAY) + s(Year.2005, SITE_ID, bs = "fs")

Parametric coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)       1.005478   0.005568 180.597  < 2e-16 ***
SeasonSpring     -0.010124   0.002002  -5.058 5.05e-07 ***
CRAYFISH_IMPACT1  0.002625   0.008354   0.314    0.753
CRAYFISH_IMPACT2  0.048009   0.008818   5.444 6.54e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                                      edf Ref.df     F  p-value
s(Year.2005):SeasonAutumn       5.301e+00      9 3.824  < 2e-16 ***
s(Year.2005):SeasonSpring       3.119e+00      9 4.193  < 2e-16 ***
s(LTQ75RFR)                     2.636e+00      9 2.035  < 2e-16 ***
s(Q75_anomaly)                  3.937e+00      9 6.712  < 2e-16 ***
s(Q75_anomaly_lag1)             3.267e+00      9 7.064  < 2e-16 ***
s(Hms.Rsctned.Bnk.Bed.Sub.Score) 2.126e-04     9 0.000 0.003825 **
s(river_size)                   1.569e-03      9 0.000 0.000644 ***
s(SILT_CLAY)                    5.313e-04      9 0.000 0.032664 *
s(Year.2005,SITE_ID)            9.683e+01    359 3.662  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.707   Deviance explained = 73.8%
-REML = -2060.8  Scale est. = 0.0010979  n = 1122
```



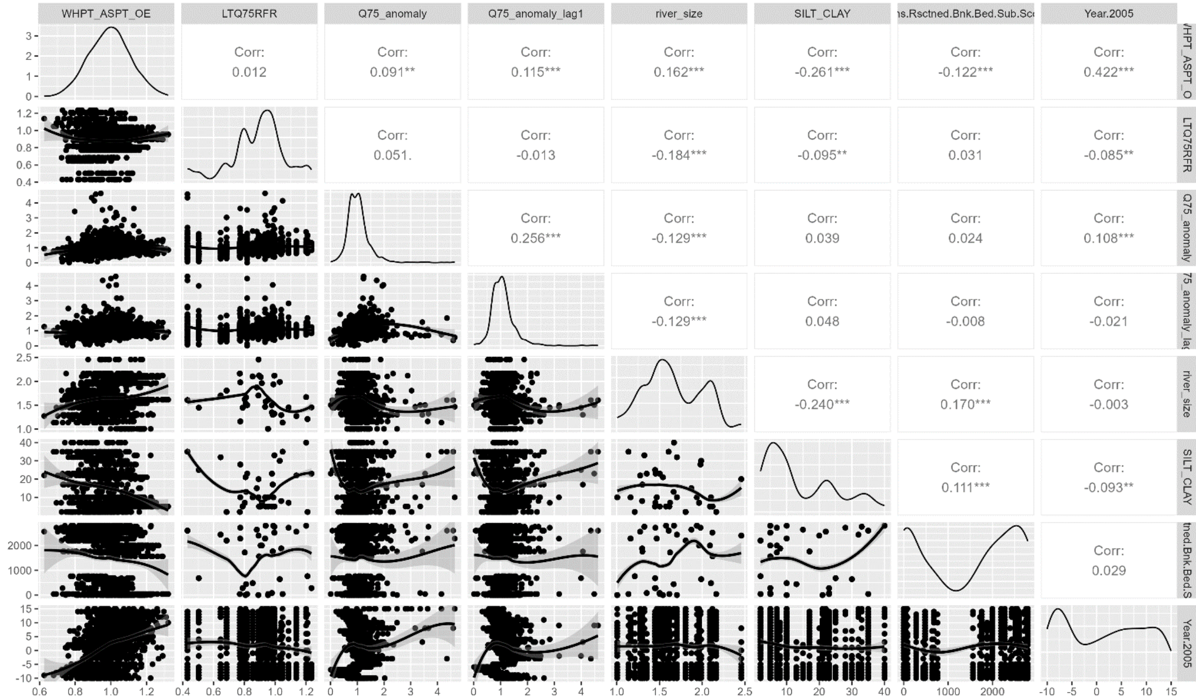


Q-Q Plot, method = simul1
Histogram of residuals
Resids vs. linear pred.
Response vs. Fitted Values
deviance residuals
Theoretical quantiles
count
resid
residuals
linear predictor
Response
Fitted Values

6.3 Appendix III WHPT-ASPT O/E Model

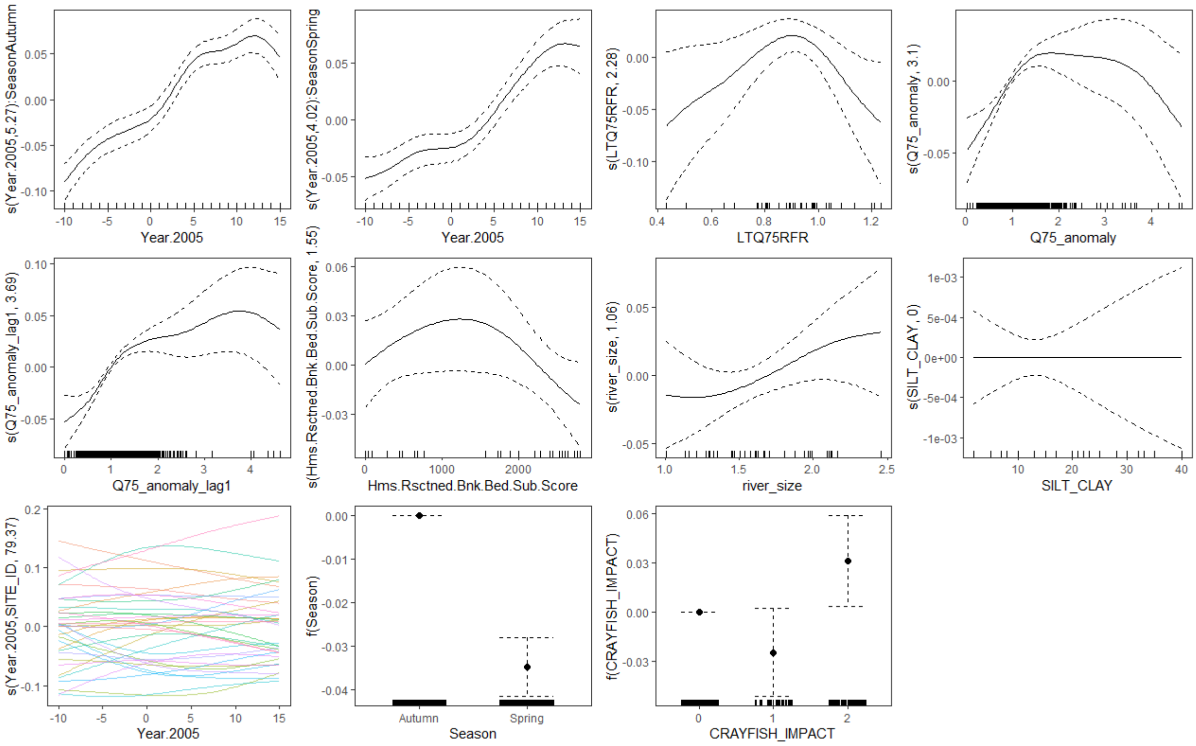
6.3.1 B.1 Pairwise correlations between variables

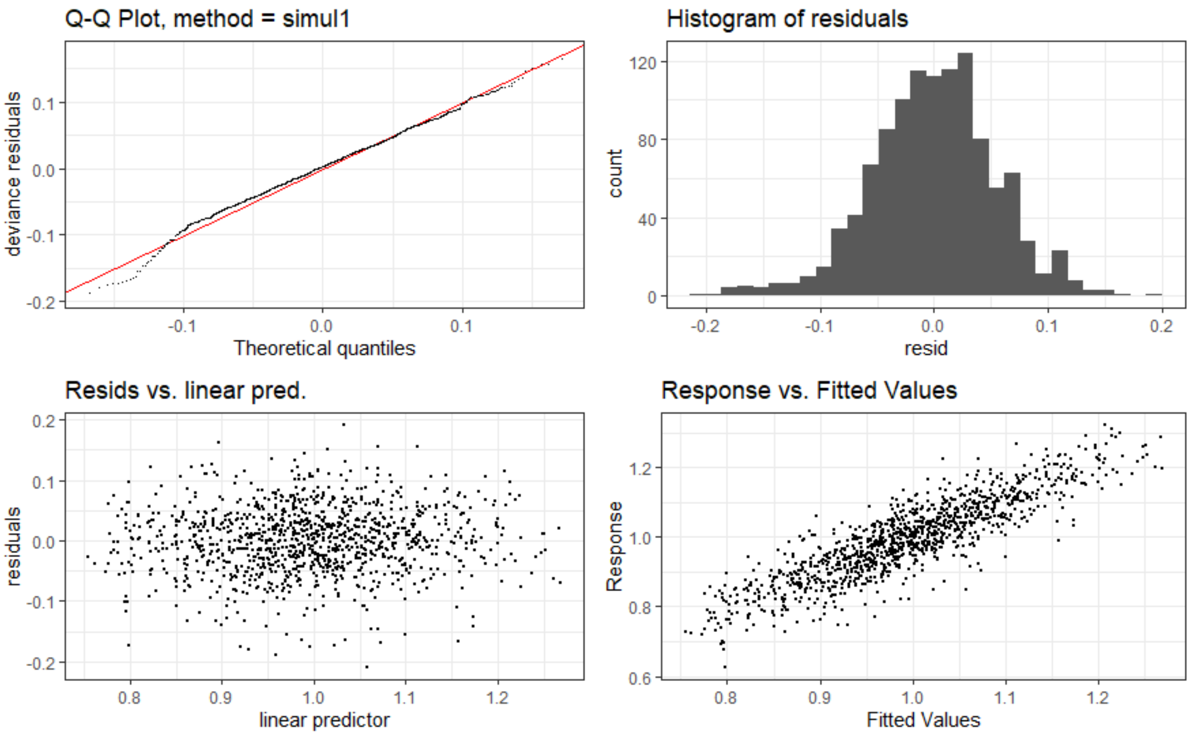
Pairwise correlations among potential response and explanatory variables were explored, to aid in deciding which metrics to include within the model.



6.3.2 B.2 WHPT-ASPT O/E Model

```
Family: gaussian
Link function: identity

Formula:
WHPT_ASPT_OE ~ Season + CRAYFISH_IMPACT + s(Year.2005, by = Season) +
    s(LTQ75RFR) + s(Q75_anomaly) + s(Q75_anomaly_lag1) +
s(Hms.Rsctned.Bnk.Bed.Sub.Score) +
    s(river_size) + s(SILT_CLAY) + s(Year.2005, SITE_ID, bs = "fs")

Parametric coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)       1.010377   0.010399  97.163   <2e-16 ***
SeasonSpring     -0.034787   0.003484  -9.984   <2e-16 ***
CRAYFISH_IMPACT1 -0.024481   0.013780  -1.777   0.0759 .
CRAYFISH_IMPACT2  0.031274   0.014157   2.209   0.0274 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                                      edf Ref.df      F p-value
s(Year.2005):SeasonAutumn       5.266e+00      9 11.651  <2e-16 ***
s(Year.2005):SeasonSpring       4.016e+00      9  6.673  <2e-16 ***
s(LTQ75RFR)                     2.277e+00      9  0.950  <2e-16 ***
s(Q75_anomaly)                  3.098e+00      9  4.201  <2e-16 ***
s(Q75_anomaly_lag1)             3.691e+00      9  7.603  <2e-16 ***
s(Hms.Rsctned.Bnk.Bed.Sub.Score) 1.547e+00     9  0.442  <2e-16 ***
s(river_size)                   1.061e+00      9  0.334  <2e-16 ***
s(SILT_CLAY)                    6.557e-04      9  0.000   0.263
s(Year.2005,SITE_ID)            7.937e+01    359  3.429  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.748   Deviance explained = 77.1%
-REML = -1450.5  Scale est. = 0.0033319  n = 1122
```




Q-Q Plot, method = simul1
deviance residuals
Theoretical quantiles
Histogram of residuals
count
resid
Resids vs. linear pred.
residuals
linear predictor
Response vs. Fitted Values
Response
Fitted Values