YORKSHIRE WATER SERVICES

AMP7 WFD Water Quality Investigations

Costa Beck Miscellaneous Investigation

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Yorkshire Water Services

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SUMMARY

1. In an AMP6 water quality modelling investigation, Yorkshire Water found that a downstream portion of the Costa Beck did not comply with salmonid dissolved oxygen fundamental intermittent standards (DO FIS) due to an unknown water quality mechanism not represented in the model used. Potential sources of this unknown mechanism were proposed by the Environment Agency to potentially be:

   a. decomposing sediment with a high oxygen demand being discharged from the Pickering Wastewater Treatment Works (WwTW) during high flows and

   b. a slug of low dissolved oxygen (DO) water being discharged by the Black Sike.

   Yorkshire Water and the Environment Agency agreed that further investigation was required in AMP7 in order to understand what mechanisms were controlling DO in the watercourse.

2. In order to recalibrate and verify the AMP6 model for the AMP7 study, a data survey was conducted at several locations along the Costa Beck from late 2019 to early 2021. This timeframe allowed for a wide variety of sampled conditions to provide a robust dataset for characterising sources. The measured determinands used to recalibrate and verify the AMP6 model in this investigation were DO, sediment oxygen demand (SOD) and temperature. In addition, the outfall pipeline from the works to discharge point in the Costa Beck was surveyed for evidence of septicity or solids accumulation.

3. Simultaneously, the Environment Agency had placed sondes on the Black Sike (a drain discharging to the Costa Beck downstream of the WwTW discharge), and therefore data was available for this source which had not been available in the AMP6 study.

4. As an additional component, a brief consideration of the history and various key aspects of Costa Beck have been reviewed, in order to place the study in context. This raises a number of considerations, including sediment infiltration of the spring-head, the potential for water quality to be affected by commercial practices being undertaken on the river, and river management practices.

5. Following a review of the AMP7 data survey, the AMP6 model was re-calibrated to include the AMP7 Black Sike DO data. Additionally, a time-varying SOD component (applied to the AMP6 model as a means of matching the model to the field data) was removed as it was found to be inconsistent with SOD measured across the channel and had no significant impact on modelled DO in the Costa Beck.

6. The re-calibrated model yielded identical results to the AMP6 model downstream of the Pickering WwTW but produced DO sags downstream of the Black Sike. Given the AMP6 model was accepted for the purposes of the AMP6 UPM study, with some qualification regarding its ability to represent DO sags, it is concluded that the re-calibrated model provides a better representation of the system.

7. To identify and assess the primary mechanisms controlling the DO sags in the Costa Beck, several sensitivity tests were conducted relating to the Pickering WwTW and the Black Sike.

8. For the Pickering WwTW three scenarios were tested: 1) removing the Pickering WwTW; 2) increasing SOD; 3) decreasing reaeration. DO was not decreased by scenario 1) and only slightly by scenario 2) and 3).

9. For the Black Sike two scenarios were tested: 1) decreasing Black Sike DO inputs to zero; 2) increasing Black Sike flow inputs. Scenario 1) produced additional DO sags throughout the simulation period but did not alter the DO sags already present in the re-calibrated model due to these periods already being near-zero. Scenario 2) amplified the DO sags already present in the re-calibrated model but had no significant impact on other periods.

10. Overall, this investigation concludes that the Black Sike is the primary control on DO sags in the Costa Beck and that the Pickering WwTW has an insignificant impact. Furthermore, DO sags can be amplified by a combination of high flow and low DO inputs from the Black Sike by flushing a slug of low DO water into the

Costa Beck. It is conjectured that in some circumstances organic pollution may accumulate in the Black Sike, and then a large flow event (for example a significant rainfall event) would flush such a slug of pollutant into the Costa Beck. Evidence recently provided by the Environment Agency regarding a dairy producing ice cream has provided some evidence for a potential source of elevated levels of organic material on the Black Sike. Model runs set up to represent such an event, demonstrate that DO sags similar to those observed will occur, driven by low water quality in the Black Sike.

CONTENTS

LIST OF TABLES AND FIGURES

Tables

Figures

GLOSSARY

AMP6
Asset Management Plan 6

AMP7
Asset Management Plan 7

BOD
Yorkshire Water Services

DO
Dissolved Oxygen

DO FIS
Dissolved Oxygen Fundamental Intermittent Standards

EA
Environment Agency

NH_4
Ammonia

SOD
Sediment Oxygen Demand

STW
Sewage Treatment Works

UPM
Urban Pollution Management

WwTW
Wastewater Treatment Works

YWS
Yorkshire Water Services

1. INTRODUCTION

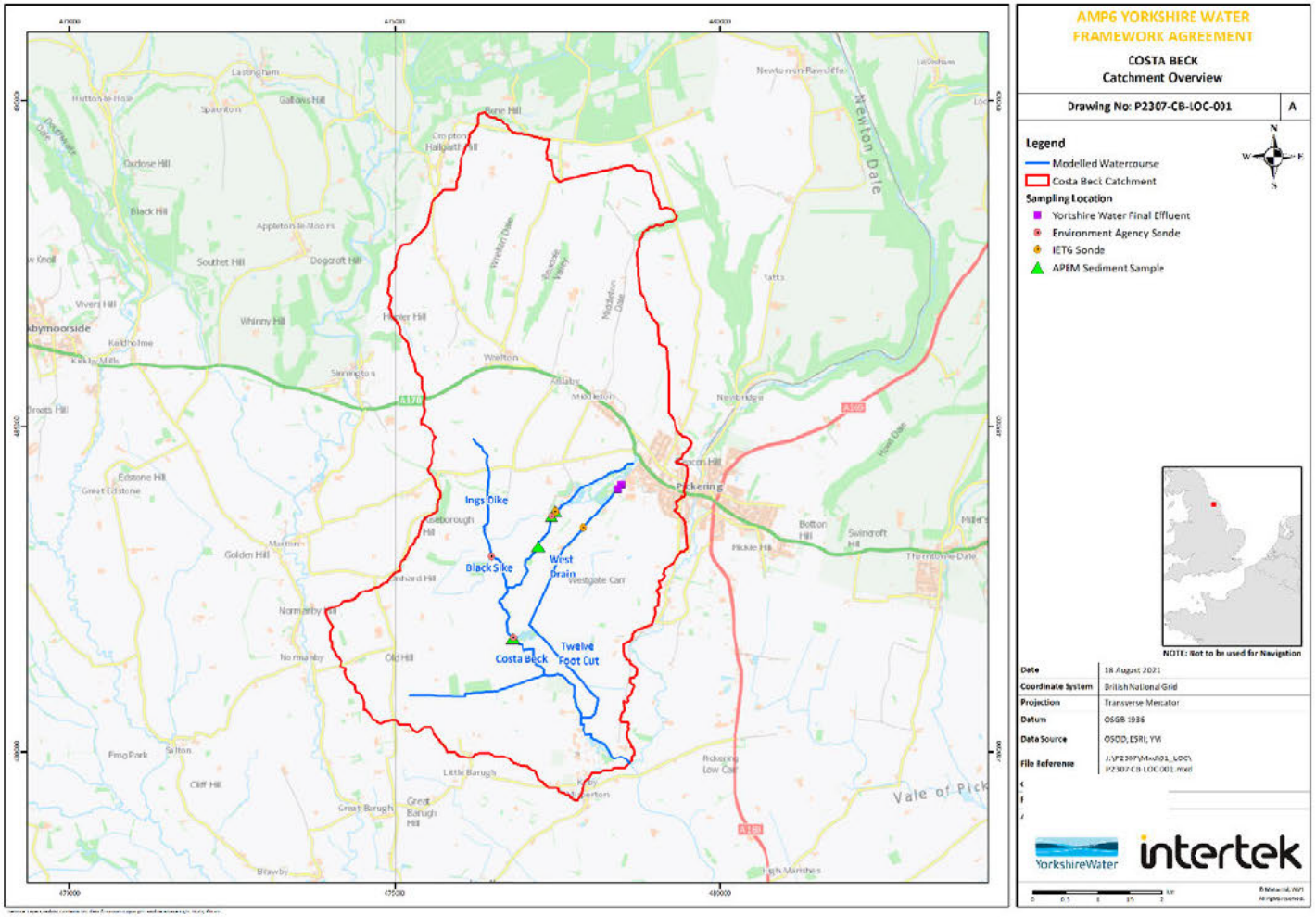
1.1 Purpose

This document has been prepared under the specialist framework agreement between Yorkshire Water Services (YWS) and Intertek Energy and Water Consultancy Services (Intertek).

The purpose of the document is to report the findings of the Costa Beck Investigation assessment undertaken as part of the Asset Management Period 7 (AMP7) investigations programme. The assessment has been undertaken by Intertek on behalf of YWS.

The report details an investigation seeking to improve water quality model performance and understanding of water quality issues previously reported under the Asset Management Period 6 (AMP6) Urban Pollution Management (UPM) study for Costa Beck. The AMP6 study did not adequately represent water quality and sediment effects in the Costa Beck, with specific Environment Agency concerns regarding low dissolved oxygen (DO) values in parts of the Costa Beck, and the failure of the AMP6 model to replicate them.

Figure 1-1 Catchment overview of the study area



1.2 Background

The investigation area is Costa Beck in North Yorkshire (waterbody ID GB104027068480), a spring-fed watercourse that arises to the south-west of Pickering (SE7871984488) and proceeds through a rural catchment in a broadly southerly direction prior to its confluence with Pickering Beck (SE7908081178). Pickering Wastewater Treatment Works (WwTW) discharges to Costa Beck via a 1.3km long outfall; there are also two fisheries (Willowdene Watercress and Trout Farm, and Costa Fisheries) and watercress growing facility on the Beck, upstream of the WwTW.

In AMP6 YWS undertook an UPM study of the impact of its discharges to Costa Beck from source to Pickering Beck. The UPM study concluded that water quality in Costa Beck is not significantly impacted by YWS assets, but that part of the water body downstream of the Pickering WwTW outfall did not comply with the salmonid dissolved oxygen (DO) fundamental intermittent standards (FIS) during the sonde survey period as a result of additional unknown water quality mechanisms that were not represented in the AMP6 water quality model.

This non-compliance, due to additional unknown water quality mechanisms not represented in the water quality model, led to extra work by YWS including quality monitoring by sonde of the Pickering WwTW final effluent at the sewage works, and re-running of the water quality model setting the (DO) level in the Pickering WwTW final effluent to zero. This did not replicate the monitored DO depression, suggesting that the works in normal operation is not significant to the sag, but that the source remained unidentified.

Subsequent research by YWS and the Environment Agency (EA) have revealed the following information pertinent to YWS assets:

- Raw and decomposed sewage litter and a 10-metre-long thick black line of silt in the channel has been observed from the Pickering WwTW outfall
- Two grayling have been observed to turn over and die in Costa Beck downstream of the Pickering WWTW outfall
- Some sections of the 1.3km long Pickering WwTW outfall pipe have dropped leading to sediment build up

This information lead YWS and the EA to the hypothesis that sediment building up in the Pickering WwTW outfall pipe during normal flows may be decomposing in anoxic conditions, turning black and producing toxic chemicals such as unionised ammonia, hydrogen sulphide and phosphine. Toxic decomposition products could be being released from the sediment in the Pickering WwTW outfall pipe during normal flows. During high flows the decomposing sediment could be flushed from the Pickering WwTW outfall pipe. This would cause an oxygen demand from the water in Costa Beck at a much faster rate than the biochemical oxygen demand (BOD) included in the AMP6 Costa Beck UPM study's water quality model. Therefore, the unexplained oxygen sags in that study leading to the observed non-compliance with the salmonid DO FIS could be caused by chemical oxidation not included in the AMP6 Costa Beck UPM study's water quality model.

In addition, since the AMP6 UPM study, the EA have deployed sondes on the Black Sike, a tributary, which have demonstrated low DO flows into the Costa Beck, which could also be the cause, either completely or in combined effect, of the recorded DO sag in the Costa beck. Thus, the reasons for the DO sag may not be 'unknown water quality mechanisms' as set out in the MSF, but in fact the exclusion of a significant source of pollutants in the form of the Black Sike in the AMP6 study.

1.3 History and Context

Costa Beck has a complex history and there are a number of influences which lead to a combination of impacts. The following section considers a number of these factors to highlight the potential complexity of factors affecting water quality in the Beck, and highlights several factors which may (or have) play a part in water quality performance of the Costa Beck.

The Keld Head Spring is the source of Oxfolds Beck and Costa Beck that comprise waterbody GB104027068480 Costa Beck from source to Pickering Beck. Since before 1854, according to Ordnance Survey mapping, a man-made mill race has existed between Keld Head Spring and High Costa Mill SE7773583924 and Low Costa Mill SE7753783761. A sluice from the mill race at SE7865184423 provides water to a drain known as West Drain on the 1854 Ordnance Survey map. Oxfolds Beck is formed from several tributaries arising between the mill race and Street Lane to its north, including Middleton Drain which takes the surface water flow from Middleton via a surface water drain, YW asset reference 36376000044. The beck crosses beneath the mill race and is joined by West Drain at SE7800983865. Oxfolds beck flows to Low Costa Mill where it is joined by the mill race to form Costa Beck.

The following sections contain hyperlinks to reference material that supports the text. These are highlighted in blue.

1.3.1 Sediment load from Newbridge Quarry

According to an EA employee on 21st March 2019, "Keld Head Springs is 16 feet (5 metres) deep and has become full of silt over the last few years. On the same date, 'sand volcanoes', were present within Keld Head Spring and the depth of water above sediment was approximately 20cm". A Costa Fisheries employee also stated in 2019 that Keld Head Springs used to be much deeper in past decades.

Sharon Thomas's Master's Degree Thesis, 'Conceptual model of the Corallian limestone and origin of sediment at Keld Head Springs, Pickering (Newcastle University, 2010) concludes, 'Connectivity was proven by MS2 between the quarry and Costa Beck Springs… it is concluded that the Corallian Limestone may be saturated with sediment, and rainfall events allow the forcing of sediment particles through the fractures and fissures of the aquifer to accumulate in Costa Beck.'

1.3.2 Relocation of Pickering WwTW's discharges

In March 1931 the Pickering Wastewater Treatment Works (WwTW) final effluent and storm discharges were to West Drain at SE7825583913, according to a drawing entitled, 'Effluent sewer', on the Yorkshire Water Engineering Document Management System (YW EDMS). By May 1993 this had been replaced by a 1.3km long outfall pipe to the current outfall to Costa Beck at SE7745283668 according to a drawing entitled, 'Sampling and measurement chamber for works final effluent' on the YW EDMS.

1.3.3 Trout and watercress farms upstream of the Pickering WwTW discharge

Willowdene Watercress & Trout Farm have produced trout and watercress in pools inline and offline of West Drain for decades. There is a split in West Drain at SE7863084383. The eastern branch runs parallel to Westgate Carr Road before feeding four offline fish pools. The western branch has about a dozen inline fish pools within it. A March 2009 image on Google StreetView shows sacks of Skrettings fish feed stacked beside the offline fish pools at Willowdene. In the same images these pools closest to Westgate Carr Road have paddlewheel aerators running in them, enabling higher loads of fish.

The fish hatchery at High Costa Mill was taken over by Northern Trout from the National Rivers Authority in 1995. The site, previously known as Costa Spring Hatchery Ltd., was originally established in 1932 to provide brown trout for rivers in the North of England. A Costa Fisheries employee on 13th

May 2019 and an EA employee on 21st March 2019 both stated that the reduction in fish escapes from Costa Fisheries since 1995 was a cause for the perception of current low fish numbers. Pickering Fishery Association on 23rd September 2018 stated, 'The Costa maintained its formidable reputation until relatively recently. Unfortunately, it has declined severely in recent years and is currently the subject of an Angling Trust led investigation into the cause of its predicament.' The Costa Fisheries site appears to have approximately 40 fish pools.

Watercress beds are in use at Willowdene watercress and trout farm. Natural England concluded from an intensive study of watercress farms on the River Itchen SAC that, 'These are a significant source of pollution in the headwaters. Monitoring has also shown some high levels of suspended solids in the receiving river linked to bed-cleaning operations on some watercress farms. Ammonia levels above the river quality objective have been recorded in a few places recently'. This conclusion is specific to the River Itchen, but it may be that watercress beds on the West Drain, Oxfolds Beck and Costa Beck may pose similar risks to ecology.'

1.3.4 Fine sediment on the bed of Costa and Oxfolds Becks

Yorkshire Water site visits on 21st March and 13th May 2019 found significant fine sediment coating the bed of the mill race, Oxfolds Beck and Costa Beck from Keld Head Springs to Low Costa Mill. On 13th May 2019 water was clear with evidence of fine sediment on the bed of Oxfolds Beck upstream of the bridge at Low Costa Mill. Gravel on the bed of Costa Beck downstream of the bridge at Low Costa Mill and upstream of Pickering WwTW outfall appeared however to be clear of fine sediment. Trout were in evidence upstream of Pickering WwTW outfall. At the mouth of Pickering WwTW outfall some sewage fungus was in evidence, probably *Sphaerotilus natans* or *Leptomitus lacteus*. Costa Beck was evidently more turbid downstream of Pickering WwTW outfall, but the bed gravel was apparently clear of fine sediment. Trout were seen at similar densities downstream of Pickering WwTW outfall as upstream.

Below Gatehouses flow monitoring station patches of fine sediment and sewage fungus, probably *Sphaerotilus natans* or *Leptomitus lacteus*, were seen. The next open field drain downstream of Pickering STW outfall on the east bank showed sewage fungus, probably *Sphaerotilus natans* or *Leptomitus lacteus*. Significant stands of water crowfoot, *Ranunculus aquatilis, were* seen in Costa Beck, some with brown sediment/algae on leaf surfaces above water. Some evidence also of *Azolla filiculoides*. Significant growth of sewage fungus, probably *Sphaerotilus natans* or *Leptomitus lacteus*, among some watercress on the edge of Costa Beck. No fish seen downstream of the open field drain downstream of Pickering WwTW.

1.3.5 Conflicting reports of fish populations

A Fish Legal update in 2009 states, 'Fish Legal has pushed the EA for action on behalf of the Pickering Fishery Association to investigate the crash in fish numbers on the spring-fed Costa Beck. The fishery is threatened from all sides from over-abstraction and flow diversion, diffuse pollution, intermittent sewage discharges and discharges from an in-river fish farm and a watercress growing operation. Following a meeting with the Agency in March 2008 a £20,000 monitoring scheme has begun and teams from across a number of disciplines are now working together to identify and move towards a restoration programme for this once renowned brown trout fishery.'

However, in May 2017 the, 'hopelessly optimistic angler', website reported fishing Costa Back and summarised their day, 'Five browns, two rainbows, smashed twice. In terms of size of fish I don't think I've had a better day on the becks. It was good to say hello to an old friend and we'll be keeping in touch.'

1.3.6 Watercourse morphology cited as the main reason for the failing watercourse

According to an article on the East Yorkshire Rivers Trust website, 'the morphology of Costa Beck has a significant impact on its ecology. On Friday, 9th November 2012, nine members of the EA reported for work and gave up their 'free' time to assist with Costa Beck Channel Restoration. The team tackled an area which is situated within the scheme and has been recognised as being over wide and too deep for the water's available flow. Coir rolls, brush wood bundles, a tree 'kicker'* and green engineering techniques were all used to address the problem by speeding up the flow leading to producing the natural processes needed for keeping gravels clean and enable natural recruitment of native species like brown trout and grayling, this being the main reason for the water body being categorised as 'failing'.'

1.3.7 Environment Agency dredging damaged Costa Beck

According to the Wild Trout Trust, 'downstream of the Gatehouses gauging station the Costa Beck was the subject of a legal case around 2001/02 when the Anglers' Conservation Association won damages on behalf of PFA against the EA. Weed cutting was necessary on this stretch to prevent the gauging weir from drowning out, but difficulties in operating the weed cutting boat were being caused by previously installed habitat improvements. This resulted in the EA dredging this part of the river.'

1.4 Aims and Objectives

The Investigation Objectives are defined in the MSF as:

'*The primary aims of the investigation are to establish whether the AMP6 UPM study did not adequately represent water quality and sediment effects arising from the Pickering WwTW outfall, and to determine if the Black Sike has a similar impact on water quality. In short, to assess and update the model such that the model represents DO sags detected in monitoring data*.

These aims will be achieved by completing the following objectives:

1. Develop the AMP6 MIKE11 model based on new and existing data and use it to assess compliance of river water quality with relevant intermittent standards. This includes consideration of sediment and chemical oxidation effects
2. Compare the observed water quality of the river with the relevant intermittent standards during the investigation and undertake a modelling assessment broadly following the UPM approach to establish significance of YWS assets. Produce a Cause and Effect report by the regulatory date. This and any associated reports should provide sufficient information to allow the EA to review the investigation and assess whether it has met all the above objectives.

To complete these objectives, the following hypotheses will be investigated and/or tested:

1. Inputs from agricultural drains (Black Sike Drain) are significantly impacting the DO levels and ecological health of Costa Beck.
2. Sediment building up in the Pickering WwTW outfall pipe is breaking down anaerobically, releasing toxins into the water column and causing rapid oxygen demand from the water column when washed from the outfall at high flows.
3. The Pickering WwTW inlet works is currently not operating optimally for minimising spill volumes and spill frequency.

1.5 Structure of the Report

The report is set out to explain the study in a sequential manner:

- **Section 2** – Methodology (the steps taken to conduct the investigation).
- **Section 3** – Data Collection (the collection of field data in order to understand quality and provide data suitable for the build, calibration and validation the AMP6 model).
- **Section 4** – Re-calibration and Verification (adjustments made to the AMP6 model and confirmation of its suitability for representing the Costa Beck water quality).
- **Sections 5** – Model Runs (adjustments made to the updated AMP7 model to test the scenarios in which the DO sags detected in monitoring data are represented).
- **Section 6** – Results and Discussion (comparison of model outputs with WFD standards, and how sensitivity affects predictions, and overall appraisal of what the model scenarios are able to tell us regards to the AMP6 model, water quality performance and the key sources of low DO).
- **Section 7** – Conclusions and Recommendations (conclusions arising from the study, in regard to the AMP6 model's representation of water quality in the Costa Beck, and what actions (if anything) YWS are able to do to undertake).

2. METHODOLOGY

2.1 Model Setup

The AMP6 model built by YWS has been used for this study (MWH, 2017). The model has been assessed for its overall performance, and to investigate the inclusion of the Black Sike. The model calibration has been re-assessed against data available after the AMP7 survey phase.

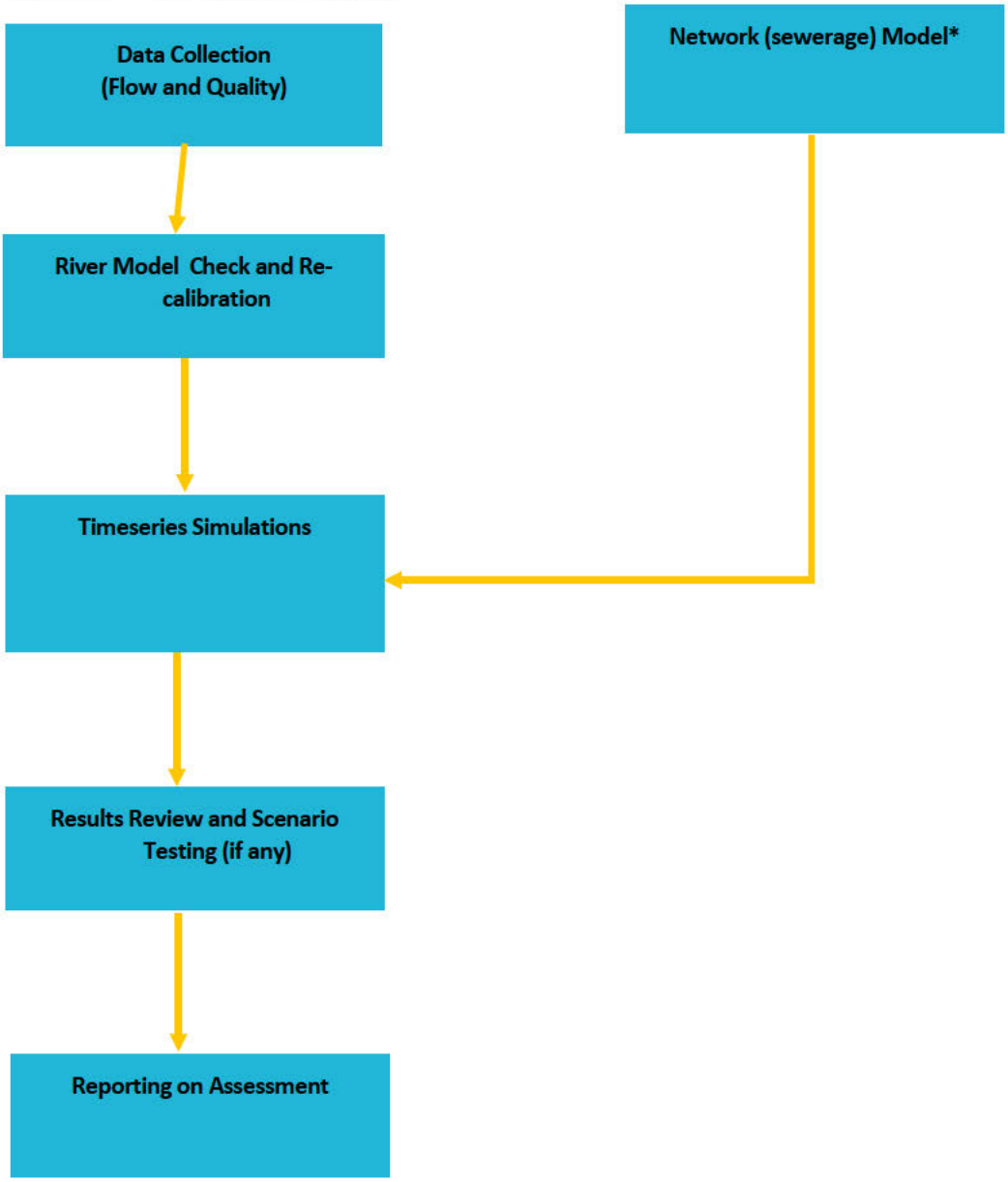
The AMP6 model is a MIKE11 model which was calibrated and validated and accepted for the purposes of the AMP6 UPM study (although with some qualification regarding its ability to represent DO sags).

A one-dimensional model is appropriate for use in this type of investigation as they provide an array of computational methods for steady and unsteady flow in branched and looped channel networks, and floodplains. Furthermore, they are applicable to flow conditions ranging from steep river flows to tidally influenced narrow estuaries and describe subcritical and supercritical flow locally. These models include advanced formulations for simulating flow through a variety of standard structures as well as complex structures.

MIKE11 has an in-built water quality module, ECOLAB. ECOLAB is a flexible numerical laboratory for ecological modelling. The process functions can consist of mathematical functions, built-in functions, forcings, constants, and state variables. The mathematical and built-in functions are functions that are already defined in ECOLAB and can be used directly by referring to them. An example of a built-in function computes the oxygen saturation concentration using arguments such as salinity and temperature.

The schematic approach to the model development is shown below in Figure 2-1. The schematic represents the split in delivering a flow model prior to the development of a water quality model, but otherwise sets out a standard MIKE11 modelling approach that has been implemented in many studies across the UK, including the application of the network (sewerage) model to provide intermittent spill data.

Figure 2-1 Model Development



* the network model will be required as a flow input, and also to provide a ten year spill series for the storm overflows

2.2 Model Boundaries

The upstream boundary of the model is situated at the Beck – Keld head (the spring source of the Costa Beck).

The downstream boundary is placed at the confluence with Pickering Beck.

Watercourse beds are also a boundary to the model. The bed boundary is a factor in oxygen consumption for the watercourse (SOD). It is a reservoir of settled organic material, hence the incorporation of SOD in the model. For the AMP6 model, SOD has been used a as calibration factor. Therefore, SOD data has been collected for this study to re-calibrate/verify calibration of the model.

Several tributaries along the Costa Beck have been represented as inputs to the AMP6 MIKE11 model (i.e., as a boundary). These inputs are dynamic, i.e., they reflect temporally changing flow and quality and are not inputted as constants. One of these inputs represents the Black Sike and, as part of the AMP7 data survey, DO has been measured on the Black Sike for the current investigation. Thus, with the Black Sike proposed to be a potential mechanism of low DO in the Costa Beck, particular focus was on the assessment between the AMP6 model inputs for the Black Sike and the AMP7 survey data.

It should be noted that the Black Sike was not represented as a further tributary in the model, but remains as a boundary (albeit with much improved input data).

2.3 Running the River Model

The characterisation of sources is a key issue in the overall assessment; how sources have been represented, and a thorough understanding of the potential inaccuracies or assumptions involved, is vital to the interpretation of results.

Sensitivity testing is a fundamental component of the overall process and is particularly important in testing results where assumptions have been made, and to demonstrate the level of confidence in the model, and how robust results might be. Sensitivity testing should demonstrate:

- Key sources, and how they react under different load or discharge conditions
- How sensitive compliance is to modification of run parameters.
- The robustness of any assumptions or estimated values
- The potential for unidentified sources to be affecting results

The precise nature of sensitivity runs can only be determined when the validated model is complete, and model uncertainties are understood.

Here, after the AMP6 model was recalibrated, several sensitivity tests were conducted to investigate the potential mechanisms responsible for the DO sags in the Costa Beck. The tests related to:

- The influence of inputs from the Pickering WwTWs
- The influence of SOD in the Costa Beck
- The influence of reaeration in the Costa Beck
- The influence of inputs from the Black Sike

3. DATA COLLECTION

In order to recalibrate and verify the AMP6 model, field data was collected at several locations along the Costa Beck from late 2019 to early 2021. This timeframe allows for a wide variety of sampled conditions to provide a robust dataset for characterising sources. The measured determinands used to recalibrate and verify the AMP6 model in this investigation are discharge, DO, SOD and temperature.

3.1 Pickering WwTW

It has been proposed that the Pickering WwTW may be responsible for the DO sags by not operating to an acceptable standard. Subsequently, YWS provided data relating to their assets that are pertinent to the study. This data includes spot samples of several determinands in the Pickering WwTW final effluent sampling point (NGR SE78428403) between 02/07/2019 and 11/12/2020 and hydrogen sulphide within the 1.3km outfall pipe (approximately 500m upstream of its discharge into Costa Beck) from 09/07/2020 to 20/01/2021 (Appendix A1). Additionally, a sonde (S0001) was deployed 500m in the Pickering WwTW outflow pipe (NGR SE7789383444; Figure 3-1) to measure NH_4, DO, pH and temperature every 5 minutes from 09/07/2020 to 06/01/2021. The determinands recorded in the Pickering WwTW final effluent measured by the sonde showed stable and consistent levels throughout the collection period. Specifically, hydrogen sulphide levels show insignificant amounts of anaerobic digestion products were being generated in the outfall pipe. This indicates that the Pickering WwTW is operating at an acceptable standard with no evidence of septicity or any other issues with the WwTW operations.

3.2 Costa Beck

To assess whether re-calibration was required for the Costa Beck itself, data was collected at several points along the channel. Firstly, YWS provided flow and quality data from 09/07/2020 to 06/01/2021 at Low Costa Mill (NGR SE7747383695). Flow was recorded every 15 minutes (Figure 3-2) while quality was recorded every 5 minutes (Figure 3-3). For quality, ammonia (NH_4), DO, pH and temperature were the determinands measured.

DO, pH, temperature, and NH_4 were also measured by EA at two other locations on the Costa Beck every 30 minutes from 15/05/2020 to 16/10/2020. One location was situated at Costa Beck Gatehouses Environment Agency gauging station (NGR SE7740883620; Figure 3-4) and the other at Costa Lodge (NGR SE7681881754; Figure 3-5).

SOD was measured by APEM in late summer/autumn 2020 at four locations along the Costa Beck (Figure 3-6) – three locations upstream of the Black Sike (NGR SE7747283695/Site 1; NGR SE7740683618/Site 2; NGR SE7720483154/Site 3) and one downstream (NGR SE7681281741/Site 4). SOD measurements were taken over a 60-minute period on four separate days for each location using an isolating technique and then measuring the oxygen demand associated with the isolated sample. A chamber is used to isolate a known area of sediment, and then measuring change in dissolved oxygen over time.

3.3 Black Sike

To aid investigations of the Black Sike, the EA recorded DO and unionised ammonia from 02/07/2019 to 10/08/2020 every 30 minutes on the Black Sike (NGR SE7648482997; Figure 3-7). Initially, data was recorded at NGR SE7668082703 but the site became ponded and increasingly full of weeds. Thus, the sonde was relocated upstream to NGR SE7648482997 on 12/11/2019 and data prior to this time was flagged as suspect. Despite this complication however, over 12 months of data at the site was still available to re-calibrate the AMP6 model.

Figure 3-1 Sonde water quality measured by YWS in Pickering WwTW outfall pipe, 800m downstream of Pickering WwTW and 500m upstream of discharge to Costa Beck (NGR SE7789383444; S0001)

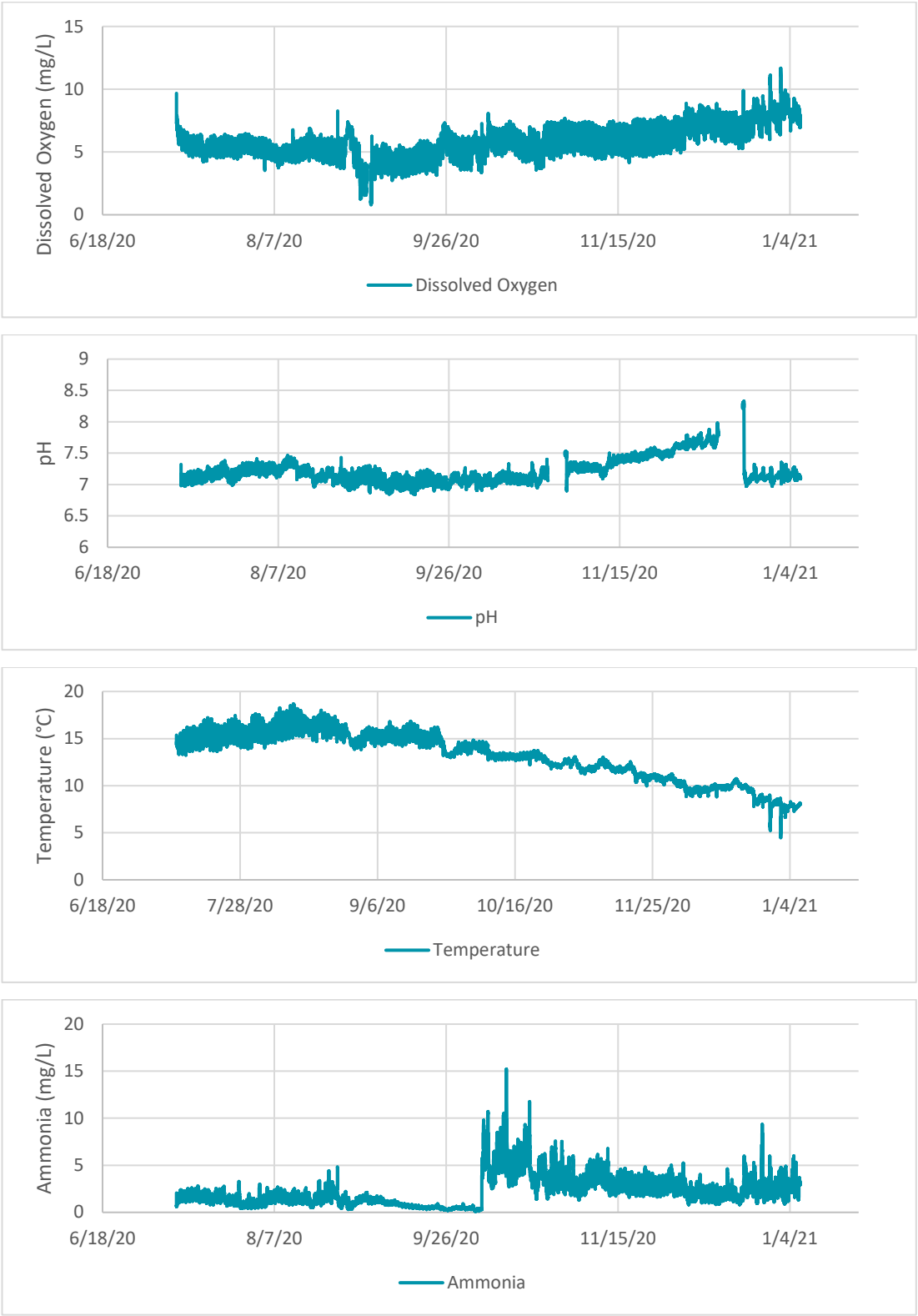


Figure 3-2 River flow measured by YWS at Low Costa Mill (NGR SE7747383695)

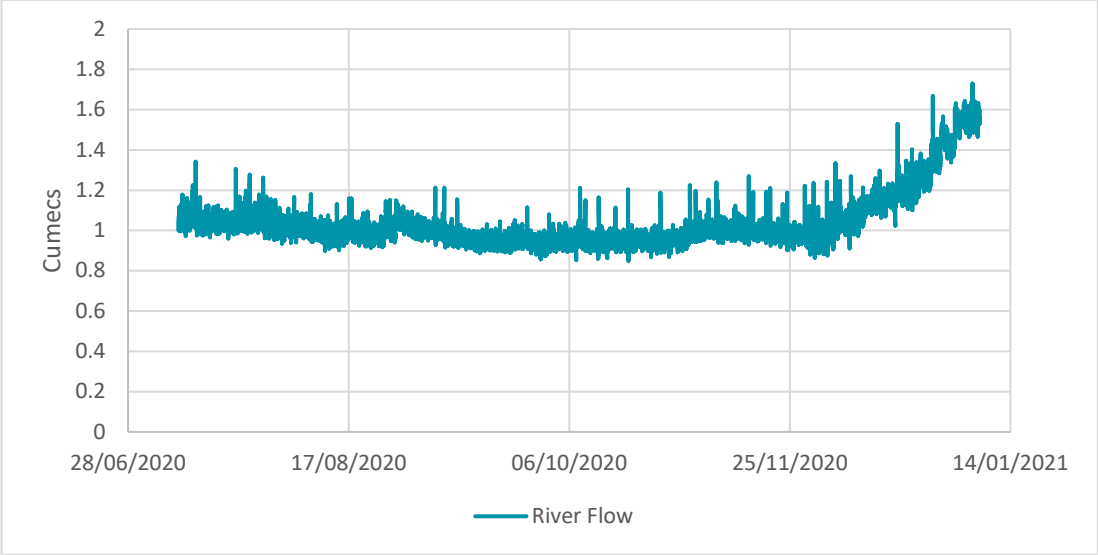
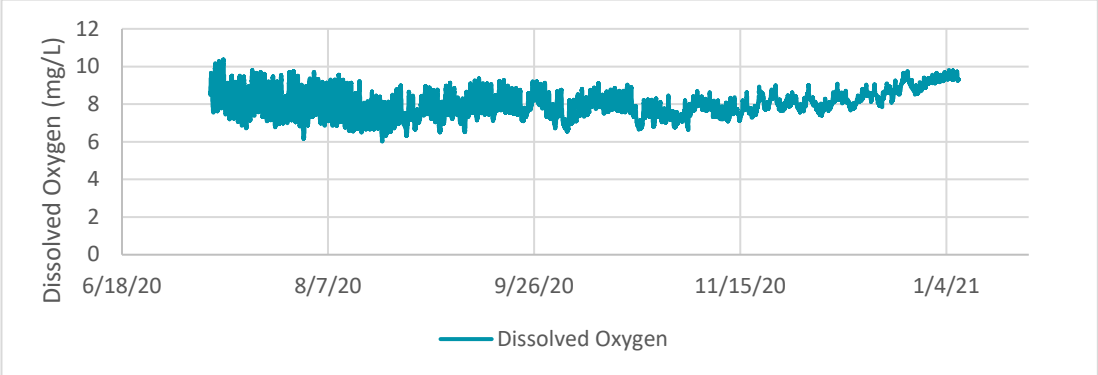
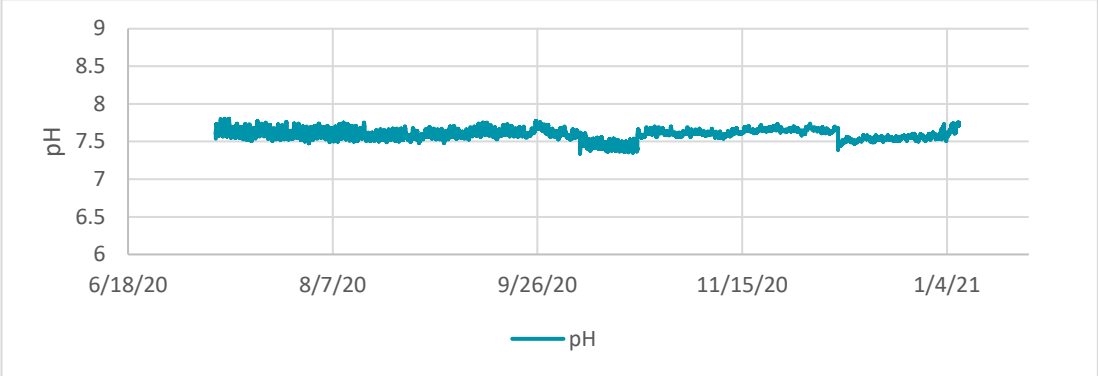
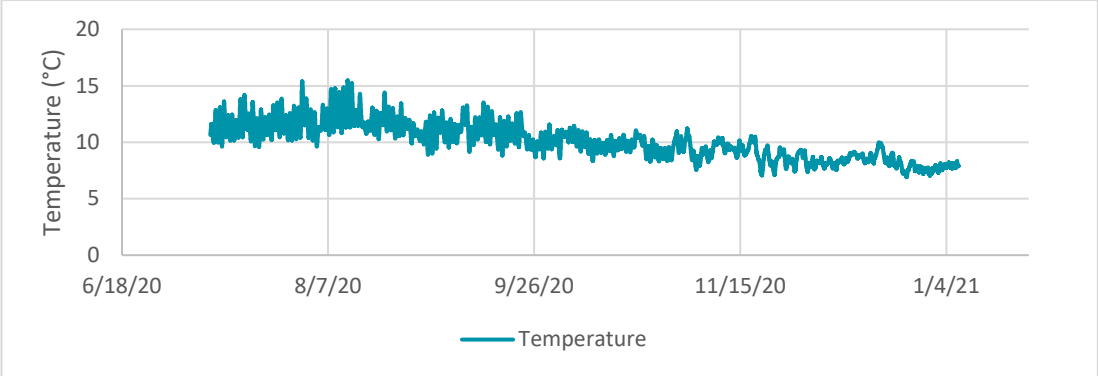


Figure 3-3 Sonde water quality measured by YWS at Low Costa Mill (NGR SE7747383695; S0002)







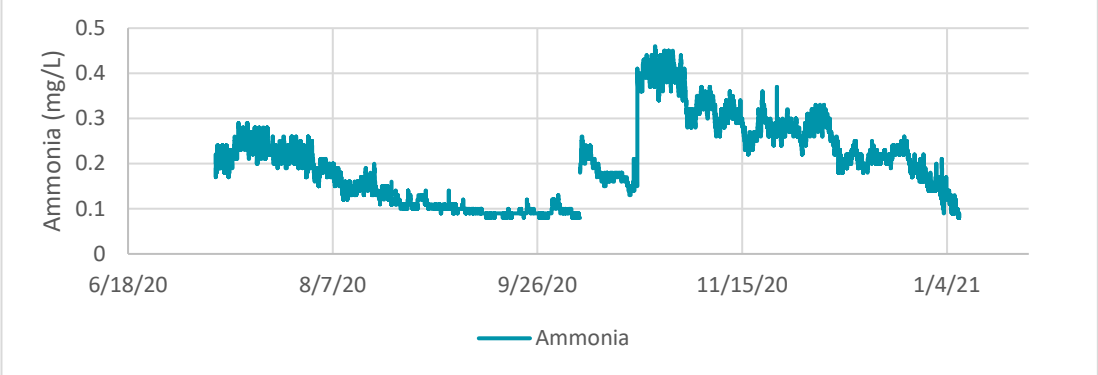


Figure 3-4 Determinands measured by EA at Costa Beck Gatehouses Environment Agency gauging station (NGR SE7740883620)

Figure 3-5 Determinands measured by EA at Costa Beck Costa Lodge (NGR SE7681881754)

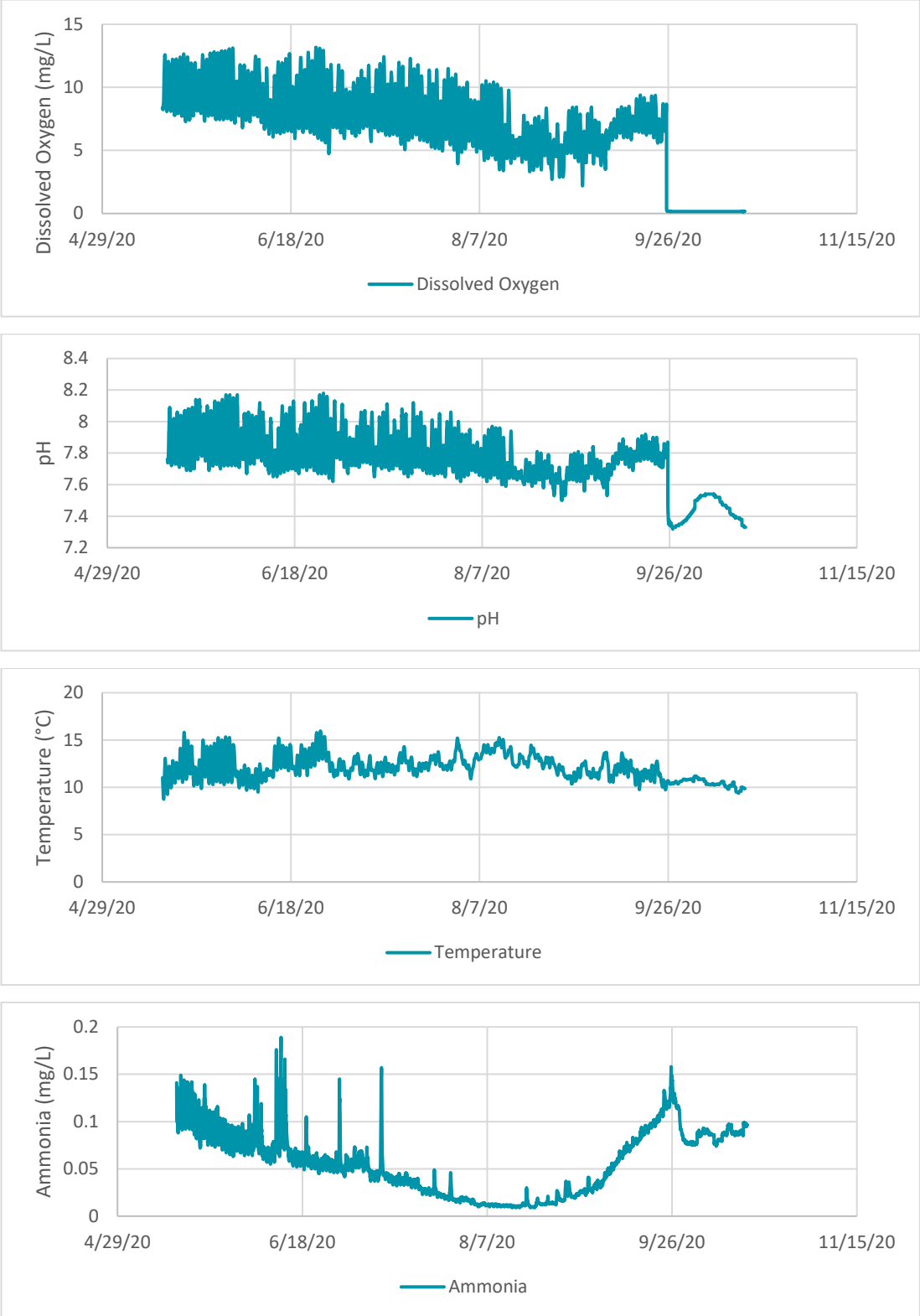
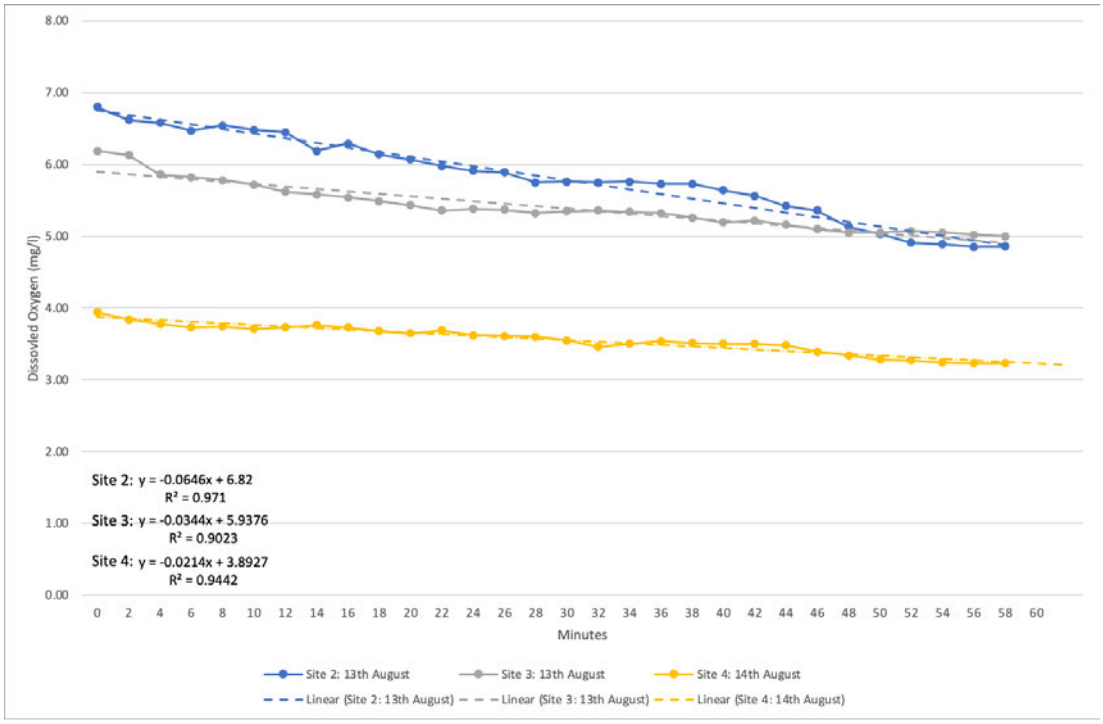
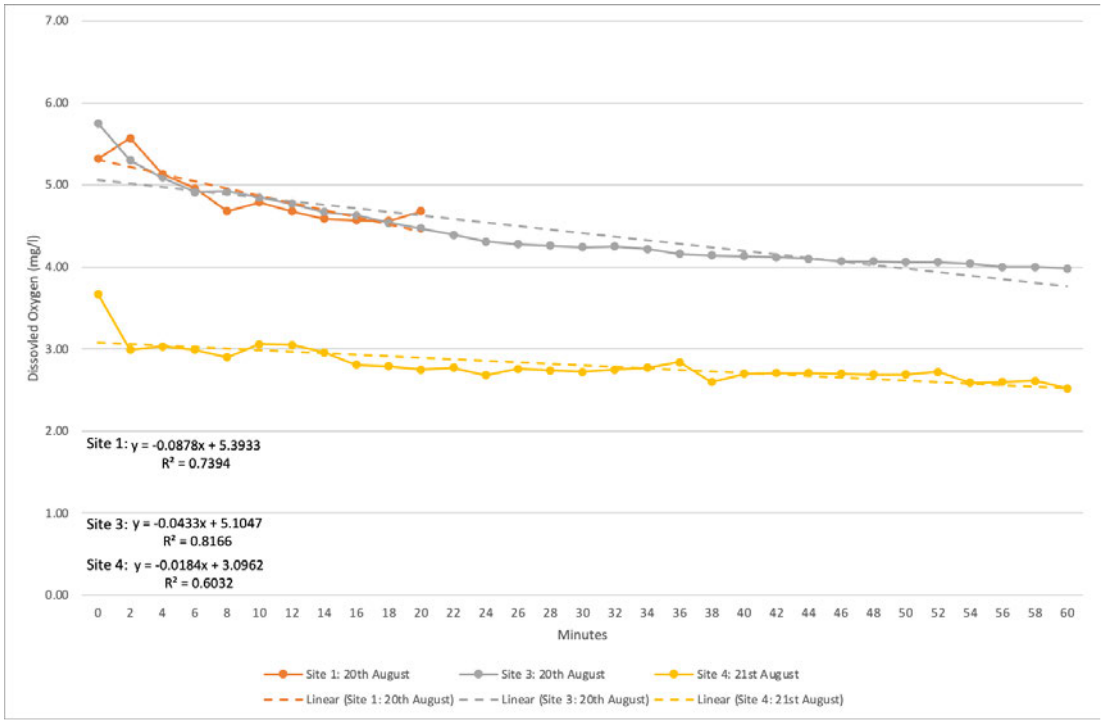
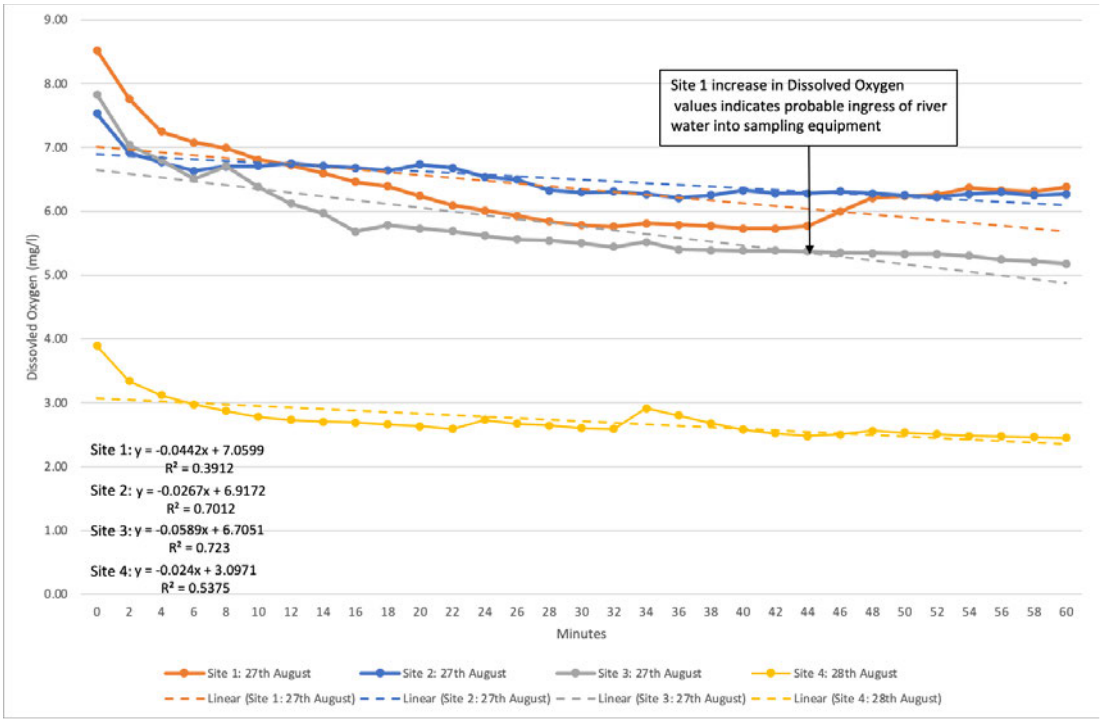


Figure 3-6 SOD measured along the Costa Beck at SE7747283695 (Site 1), NGR SE7740683618 (Site 2), NGR SE7720483154 (Site 3), NGR SE7681281741 (Site 4)






Site 1 increase in Dissolved Oxygen values indicates probable ingress of river water into sampling equipment
Dissolved Oxygen (mg/l)
Minutes
Site 1: y = -0.0442x + 7.0599
R² = 0.3912
Site 2: y = -0.0267x + 6.9172
R² = 0.7012
Site 3: y = -0.0589x + 6.7051
R² = 0.723
Site 4: y = -0.024x + 3.0971
R² = 0.5375
Site 1: 27th August
Site 2: 27th August
Site 3: 27th August
Site 4: 28th August
Linear (Site 1: 27th August)
Linear (Site 2: 27th August)
Linear (Site 3: 27th August)
Linear (Site 4: 28th August)

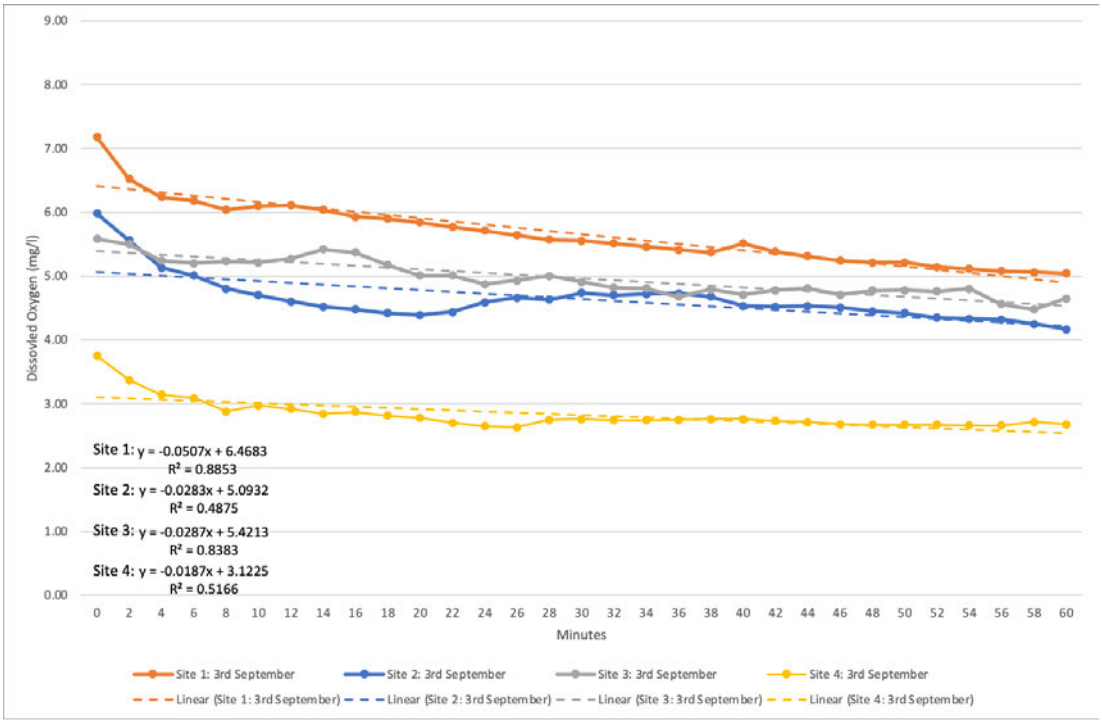
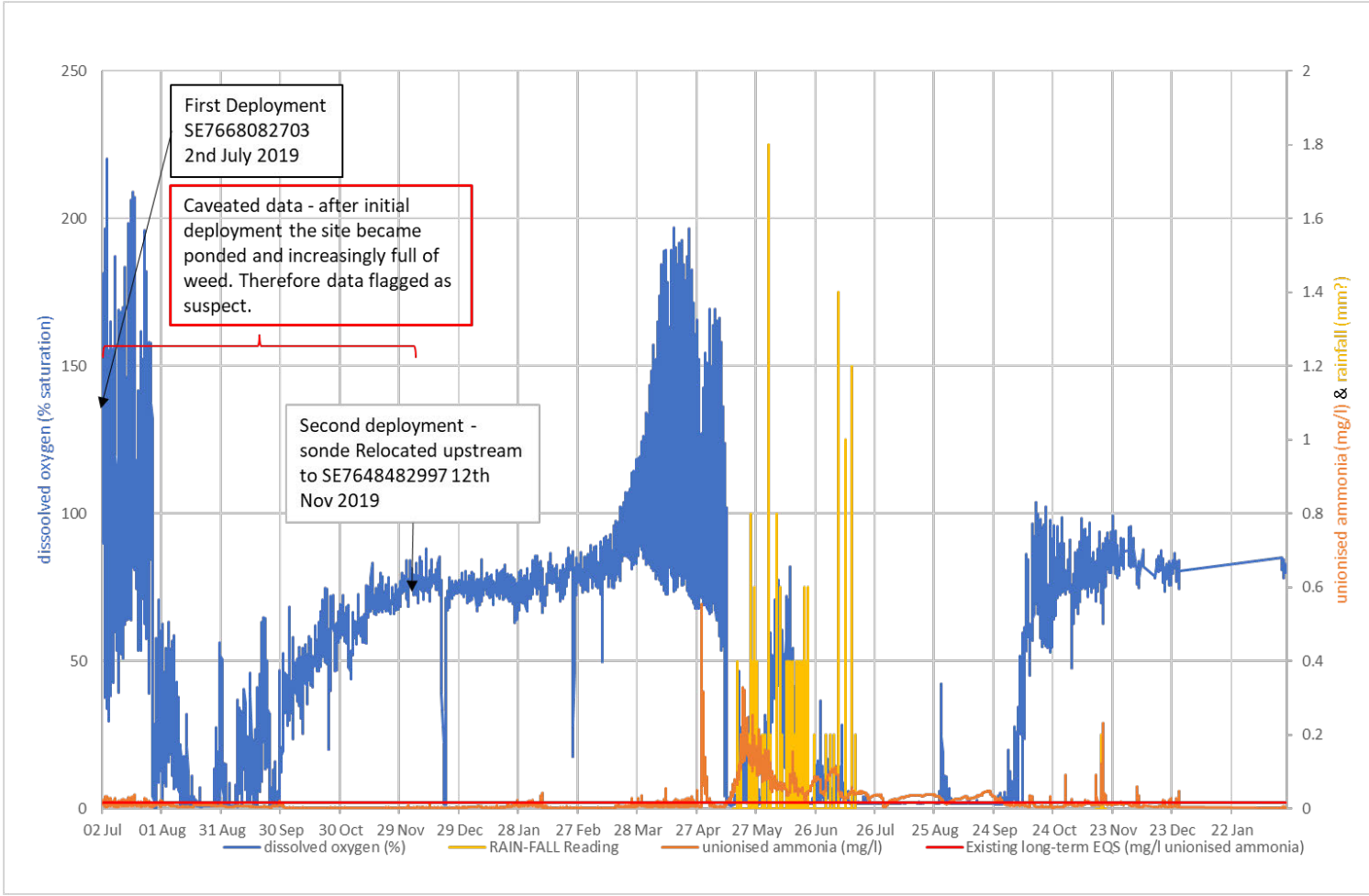

Dissolved Oxygen (mg/l)
Minutes
Site 1: y = -0.0507x + 6.4683
R² = 0.8853
Site 2: y = -0.0283x + 5.0932
R² = 0.4875
Site 3: y = -0.0287x + 5.4213
R² = 0.8383
Site 4: y = -0.0187x + 3.1225
R² = 0.5166
Site 1: 3rd September
Site 2: 3rd September
Site 3: 3rd September
Site 4: 3rd September
Linear (Site 1: 3rd September)
Linear (Site 2: 3rd September)
Linear (Site 3: 3rd September)
Linear (Site 4: 3rd September)

Figure 3-7 Dissolved oxygen and unionised ammonia on the Black Sike tributary at first (NGR SE7668082703) and second deployment (NGR SE7648482997)



4. RE-CALIBRATION AND VALIDATION

There is an existing calibrated model, which was accepted for the purposes of the AMP6 study. However, while to model generally performed well, it did not represent observed DO sags at Costa Lodge (NGR SE7681281741). Subsequently, the AMP6 model was re-run with parameters changed to reflect the AMP7 survey data, but rainfall data from the AMP6 model run period was used. This enables direct comparison and assessment of the accuracy of the newly parameterised model to better represent the observed DO sags.

Many of the AMP7 survey data sites are at the same location as point sources included in the AMP6 model. Consequently, the data used in the AMP6 model and the AMP7 survey data were compared for each corresponding location to identify any discrepancies between the two. In particular, there was a focus on pollutant load arising from the Black Sike (termed 'Ings Dike' in the AMP6 model) as the original study did not adequately represent observed DO sags in the Costa Beck downstream of the Black Sike. Additionally, the influence of SOD as a calibration parameter in the model was investigated to better understand the influence of potential anaerobic break down of built-up sediment in the water column during high flows and to deliver a model that better fits the collected field data.

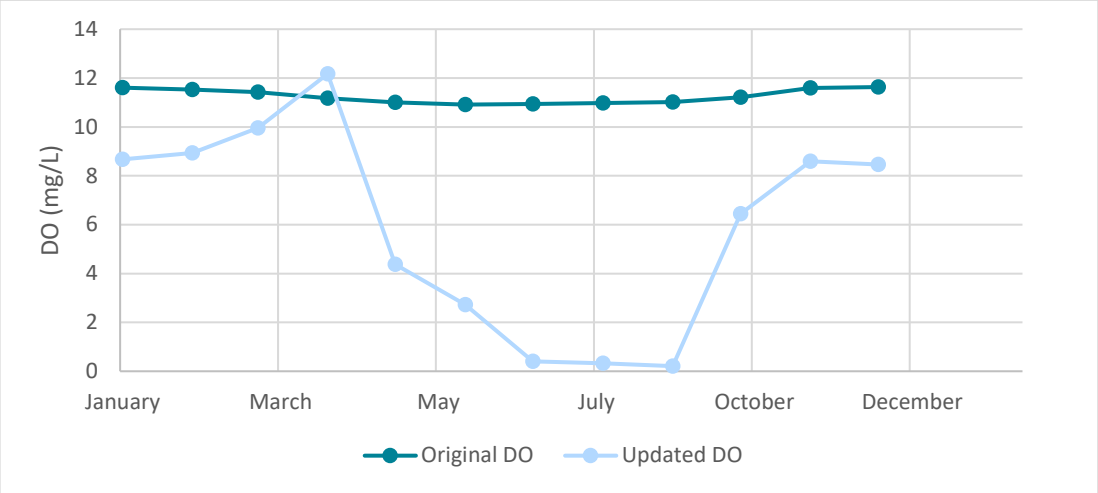
4.1 Time-Varying SOD

In order to represent lows in DO downstream of the Costa Beck, the AMP6 model applied a time-varying SOD on the lower reach (downstream of the Black Sike-Costa Beck confluence). The values used were 27.5g/m^2/day for summer/autumn and 7.55g/m^2/day for spring/winter values - compared to global values of 55g/m^2/day upstream of this point. This is an extremely high value for this parameter and does not fit with SOD data recorded across the Costa Beck for the current investigation as Figure 3-3 shows higher rates of SOD upstream of the Black Sike-Costa Beck confluence compared to downstream. Furthermore, removing and adjusting the time-varying SOD had little impact on the DO in the Costa Beck, due to the low contact time of the sediment. Thus, time-varying SOD was removed from the model and a global value of 5g/m^2/day was also applied to the downstream reach of the channel. This was based on field data collected for the purposes of this investigation, and SOD values generally used in water quality models.

4.2 Black Sike DO

Significant differences were found between the DO data collected for the current investigation and the DO data included in the AMP6 model for the Black Sike (Figure 4-1). While consistent monthly DO values were previously used, the data collected for the current investigation indicated a significant drop in DO during the summer/autumn to almost 0 mg/l in June-August. This was viewed as additional evidence for the removal of the time-varying SOD as it provided a potentially alternative explanation to DO sags in the Costa Beck over this period. Therefore, the Black Sike values in the AMP6 model were replaced with the values recorded for the current investigation.

Figure 4-1 Monthly DO used for the Black Sike in AMP6 model and recalibrated model



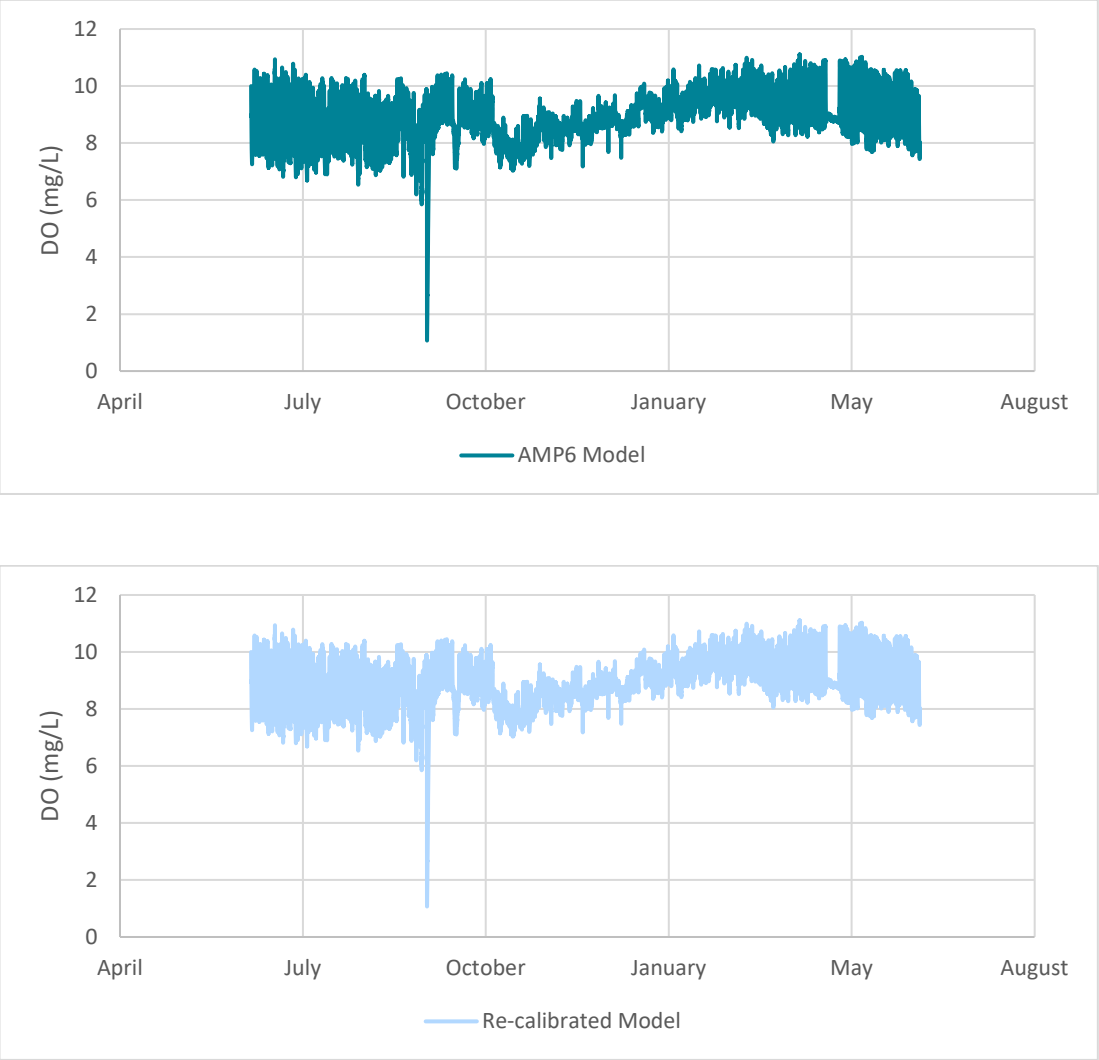
4.3 Point Sources

Following the discrepancies found between the DO values for the Black Sike, the temperature and DO inputs for other point sources in the model that were included in the AMP7 data survey were evaluated. This included the upstream boundary of the model (NGR SE7747383695; S0002) and 500m within the WwTW outflow pipe NGR (SE7789383444; S0001). The AMP7 data for the upstream boundary showed no significant differences from the AMP6 data. The AMP7 data for Pickering WwTW outflow pipe showed minor differences. However, given the data was only recorded over a relatively short timeframe, the differences are likely to be annual variations. Therefore, it was concluded that the AMP7 data supported the set-up of the AMP6 model in terms of point sources, and so no values were changed for any point source in the original model (other than the Black Sike).

4.4 AMP6 vs AMP7 Model

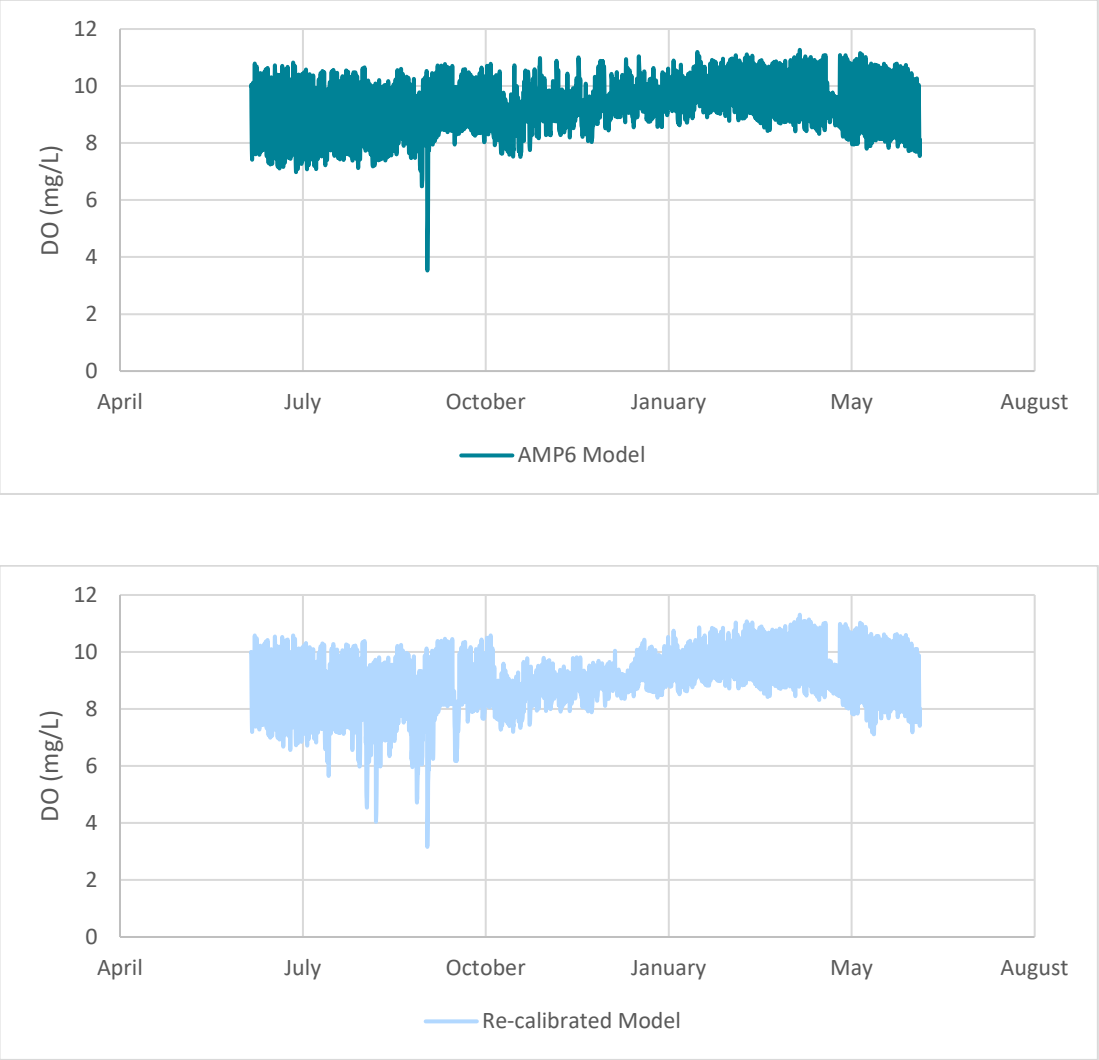
The AMP6 model was re-run with parameters changed to reflect the AMP7 survey data, but rainfall data from the AMP6 model run period was used. This enables direct comparison and assessment of the accuracy of the newly parameterised model to better represent the observed DO sags. No significant differences in DO were produced from the AMP6 and re-calibrated model downstream of the WwTW (Figure 4-2). DO is generally between 7-11mg/L throughout the year in both models. There are a couple of minor sags dropping to 6mg/L and a major sag in September dropping to around 1mg/L.

Figure 4-2 AMP6 model and the re-calibrated model downstream of the WwTW



The DO produced by the AMP6 model downstream of the Black Sike was similar to that downstream of the WwTW. DO again remains consistently between 7-11mg/L, with the only difference being a less dramatic sag in September as the signal weakens. Results for the re-calibrated model show the production of several DO sags between July and October ranging from 6-4mg/L (Figure 4-3). This correlates well with the low DO values included in the updated model for the Black Sike and thus may indicate this is a mechanism for the low DO in the Costa Beck which was being explained or accounted for previously by high SOD concentrations in the AMP6 model. This data and initial consideration does demonstrate that the Black Sike is likely to be a factor in low DO situations in the Costa Beck, and it is proposed that the model set-up identified here (removal of excessive SOD values, and incorporation of more accurate Black Sike data) is the basis for the AMP7 study and analysis.

Figure 4-3 AMP6 model and the re-calibrated model downstream of the Black Sike



4.5 Conclusions regarding the Costa Beck MIKE11 model

The AMP6 model was broadly, a good representation of the watercourse, and this is reflected in the general agreement with the AMP6 monitoring data. A consideration of the AMP6 model with the AMP7 field data and the EA data from the Black Sike has allowed a revised calibration to deliver a more accurate model. The specific alterations to achieve this are outlined in Table 4.1. In summary

- The point sources (apart from the Black Sike) are as the AMP6 model
- Flows have not been altered
- The time varying SOD values of the AMP6 model have been removed and replaced with a constant
- The Black Sike has been represented using the EA data, with corresponding variation in DO previously not represented in the AMP6 model
- These changes have produced a more accurate model, able to better replicate DO sags in the Costa Beck.

These changes (the 'AMP7 model') are regarded as providing a more accurate model of the Costa Beck, and as such this model is recommended for use in this investigation and for any subsequent assessment of Costa Beck.

Table 4-1 Adjustments made to AMP6 Model

Model Feature	Adjustment
Flow	AMP7 survey data supported the AMP6 model so no flow values were adjusted.
Point Sources	The DO from the Black Sike point source was updated to that collected during the AMP7 survey. No other point sources were adjusted as they were supported by the AMP7 survey data.
Time-varying SOD	A time-varying SOD component was removed as it was found to have a negligible impact on DO in the Costa Beck.

5. AMP7 MODEL RUNS

As a deterministic assessment, the AMP7 model was run with a time series of input data, the length of which was chosen in order to meet both the technical requirements of the study and following the EA's guidance on the length of the data period to be used. As with previous studies, the model was run in line with the sampling data timescale.

Following a review of the AMP7 survey data, re-calibration of the AMP6 model comprised of removing the time-varying SOD component, as it was found to have a negligible impact on DO in the Costa Beck, and the inclusion of AMP7 Black Sike DO data. While having no impact on DO in the Costa Beck upstream of the Black Sike, the adjustments created multiple DO sags downstream of the Black Sike between July and October. However, the DO sags only ranged from 6-4mg/L and subsequently may not be low enough to explain the non-compliance with the salmonid DO FIS. Furthermore, there is no evidence of significantly low DO values or detrimental impacts relating to low DO in the Costa Beck during the survey period.

Therefore, given that there is no indication of a low DO event during this time period, the following sensitivity tests were conducted to investigate potential mechanisms absent from the AMP7 survey data that could produce such an event. These related to:

- The influence of discharges from the Pickering WwTW
- The influence of SOD in the Costa Beck
- The influence of reaeration in the Costa Beck
- The influence of flow in the Black Sike
- The influence of DO in the Black Sike

Since the results from the Pickering WwTW survey showed no evidence of septicity (see Section 3.1) no test was performed to represent this mechanism.

Table 5-1 outlines the specific alterations made for each scenario.

Table 5-1 Scenario tests to investigate DO sags in the Costa Beck

Scenario	Alteration Made
No Pickering WwTW	Final effluent and CSO inputs removed
Increased SOD	Global SOD increased from 5 to 10
Decreased Reaeration	Reaeration decreased by 50%
Increased Black Sike Flow	Black Sike flow input increased by 100%
Decreased Black Sike DO	Black Sike DO input decreased to 0

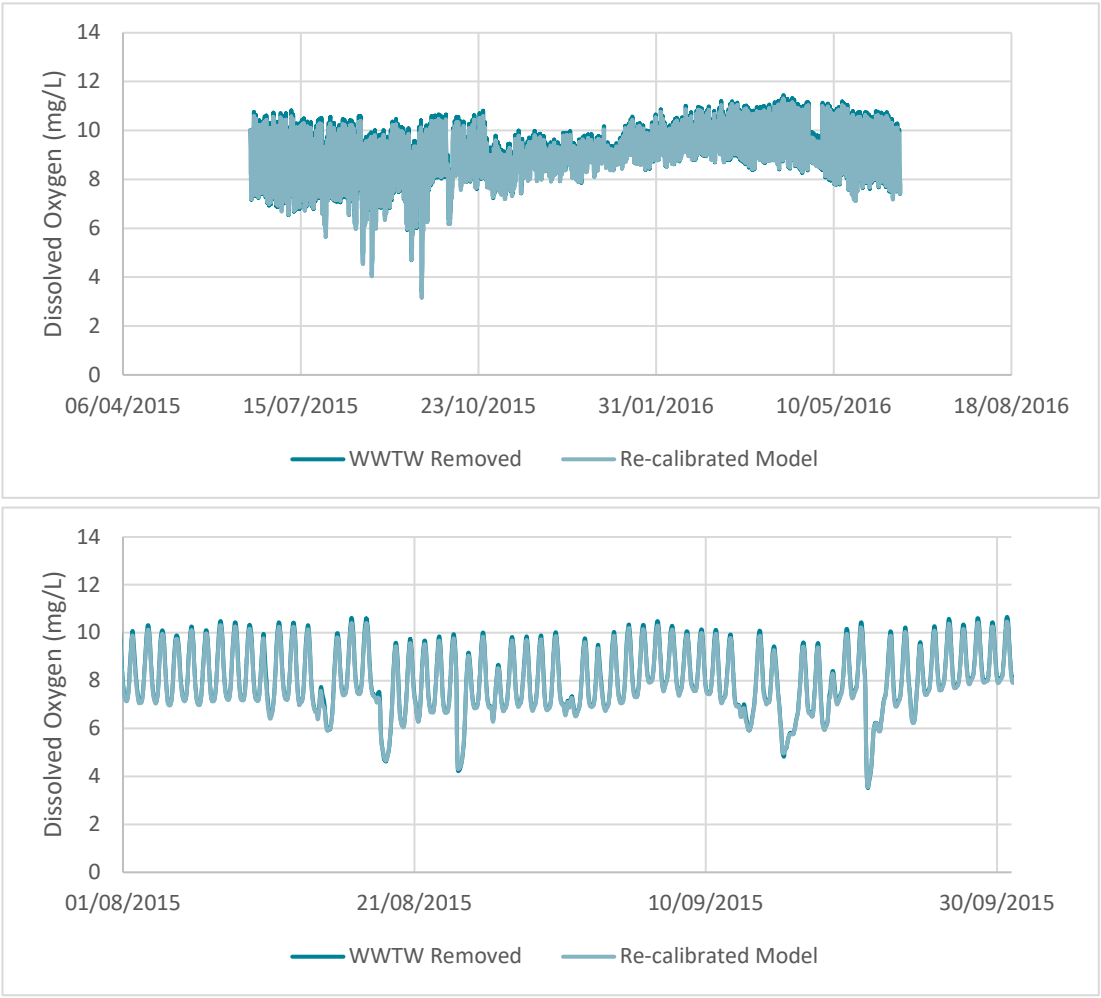
.

5.2 Pickering WwTW

One hypothesis offered to explain the Costa Beck's non-compliance with the salmonid DO FIS was that the Pickering WwTW was not operating at an acceptable standard. This could lead to discharges low in DO and high in oxygen demand being flushed into the Costa Beck to create DO sags. Therefore, sensitivity tests were conducted to determine the influence of the Pickering WwTW on DO in the Costa Beck by assessing the impacts when:

1. Pickering WwTW is removed from the model
2. In-stream SOD is increased
3. Reaeration is decreased

Figure 5-2 Impact of removing the Pickering WwTW

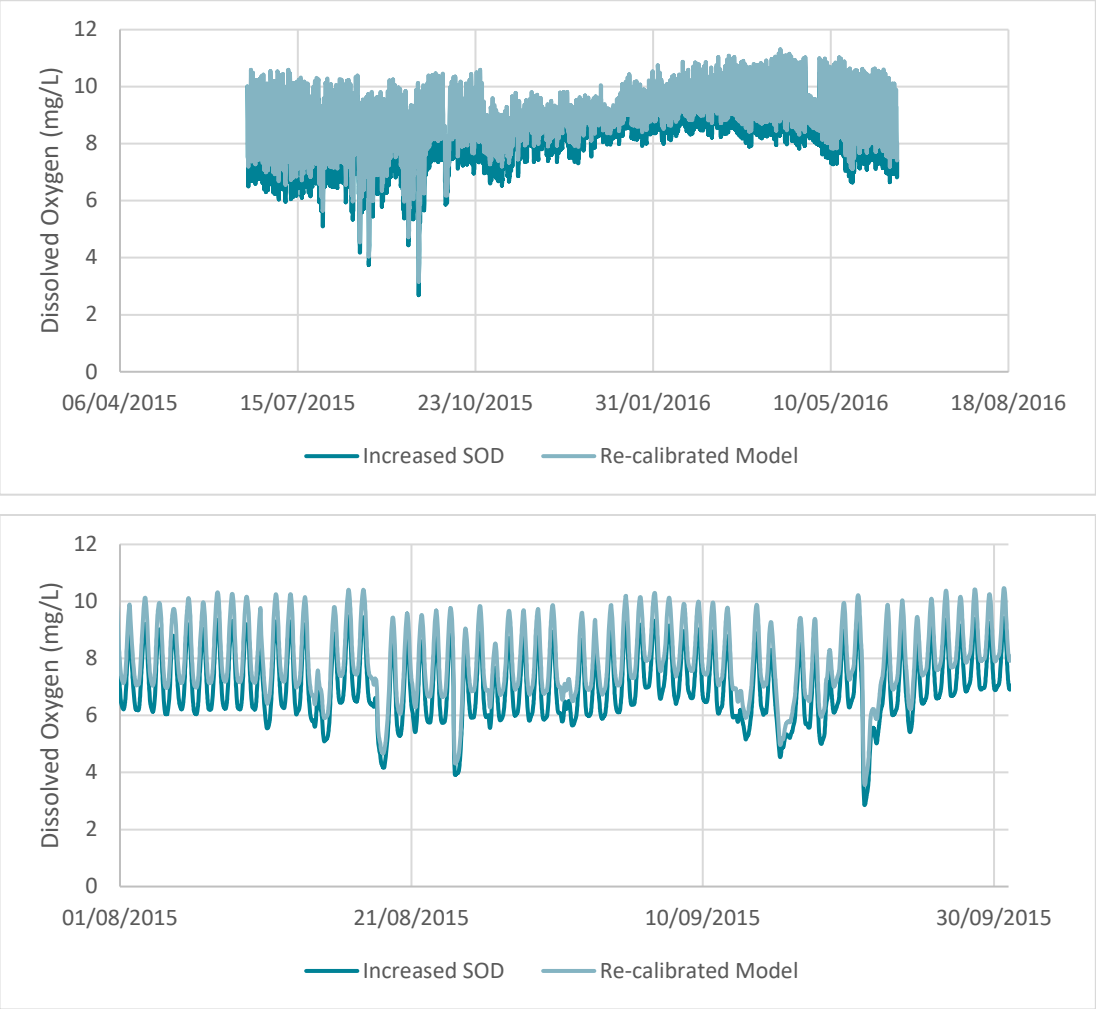


5.2.2 Removal of Pickering WwTW

It has been proposed that the Pickering WwTW may be responsible for DO sags in the Costa Beck due to decomposing sediment being flushed from the outflow pipes during high flows and creating an increased oxygen demand in the channel. Therefore, a scenario was conducted to investigate the impact on DO in the Black Sike when inputs from the final effluent and CSOs were removed (Figure 6-1).

However, contrary to this hypothesis, the results showed that removing inputs from Pickering WwTW had no significant impact on DO in the Costa Beck – with lows in DO identical. Subsequently, the results of this sensitivity test suggest that the Pickering WwTW is not a control on DO sags in the Costa Beck.

Figure 5-3 Impact of increasing global SOD from 5 to 10



5.2.3 Costa Beck SOD

Alternatively, the lack of impact from the Pickering WwTW may be a result of the global SOD value used in the model. Since the suggested mechanism relates to discharges with high oxygen demand from sediment, rather than simply low DO water, the global SOD in the model may be too low to represent the demand. Therefore, another scenario was tested in which global SOD in the Costa Beck was increased from 5g/m^2/day to 10g/m^2/day (Figure 6-2).

Unlike the previous scenario, the results from this model run did have an impact on DO within the Costa Beck by decreasing it across the entire simulation. However, the impact was only minor and thus excessive rates of SOD would be required in order to produce significant DO sags. Subsequently, given SOD was measured across the Costa Beck and showed no indication of reaching these extreme levels, it is not deemed to be a feasible primarily mechanism.

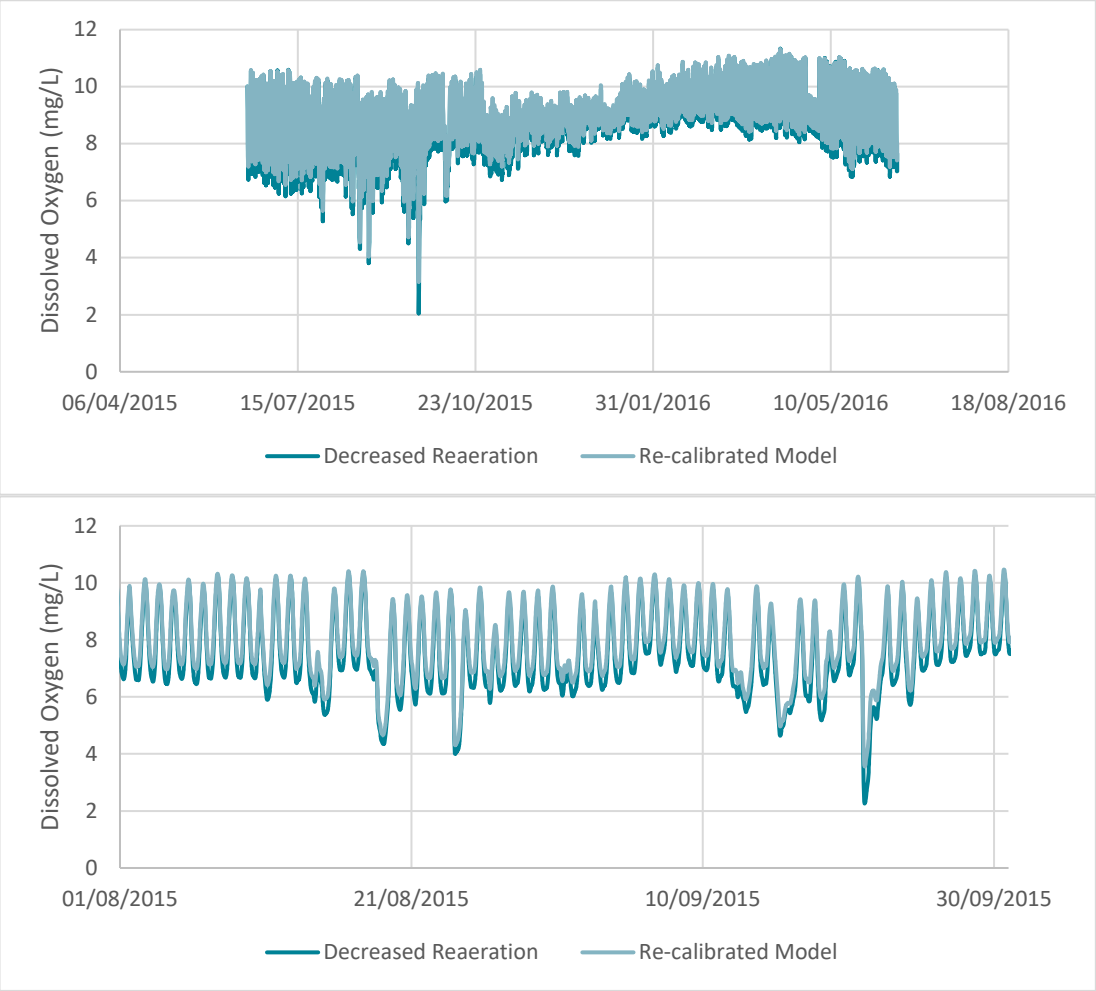
5.2.4 Reaeration

Reaeration is a process used to prevent anaerobic conditions in wastewater by adding a supply of oxygen to the system. Hence, if an insufficient amount of oxygen is added to the Pickering WwTW

wastewater, it may dilute the DO concentration in the Costa Beck and led to DO sags. Therefore, a scenario was tested in which reaeration was reduced by 50% in the Costa Beck (Figure 6-3).

The results showed a decrease in DO across the entire simulation. However, like the SOD scenario, the decrease was very minor and not significant enough to be a primarily mechanism influencing DO in the Costa Beck.

Figure 5-4 Impact of decreasing reaeration by 50%



5.3 Black Sike

The re-calibration of the AMP6 model indicated that the Black Sike is a source of DO sags in the Costa Beck. Therefore, sensitivity tests were conducted to investigate the conditions under which the Black Sike could further amplify DO sags in the Costa Beck.

5.3.1 Black Sike DO

The first scenario tested to investigate the influence of inputs from the Black Sike was to decrease DO inputs from the Black Sike to 0 (Figure 6-4). This was conducted to give an indication of the magnitude and duration of low DO inputs from the Black Sike required in order to produce significantly lower DO values in the Costa Beck.

The model run resulted in significant DO sags across the entire simulation with a low of 3.2mg/L. However, while many mor DO sags were produced, all but one of the sags already produced by the re-calibrated model remained unchanged. Furthermore, the newly produced sags only reached levels

similar to those already present. This is because the DO inputs during the periods the sags occurred in the re-calibrated model were already near-zero. Thus, to amplify the DO sags produced from the re-calibrated model, a further decrease in DO inputs from the Black Sike alone is not sufficient and another mechanism must be applied in combination.

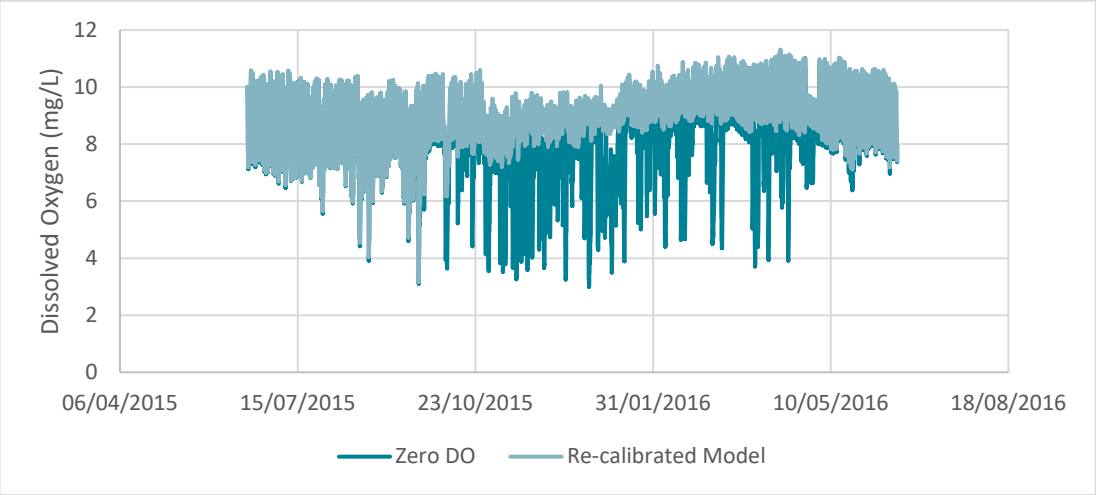
5.3.2 Black Sike Flow

The second scenario tested to investigate the influence of inputs from the Black Sike was to increase flow inputs from the Black Sike by 100% (Figure 6-5). This allowed for an investigation into a potential 'slug' mechanism in which low DO water builds up in the Black Sike and is then flushed into the Costa Beck during high flows. Given DO inputs for the Black Sike for July-October are near-zero, an increase in flow should see further decreases in the DO sags during this period if the hypothesis holds true.

The results did in fact show a decrease DO in the Costa Beck during this period, with a minimum of 2.6mg/L compared to 3mg/L for the re-calibrated model. Also, no significant differences occurred for the other periods. Subsequently, this supports the hypothesis outlined above as an increase in flow inputs from the Black Sike led to decreased DO in the Costa Beck when DO inputs from the Black Sike were near-zero – by flushing low DO water into the Costa Beck. Conversely, no significant impact was made to DO in the Costa Beck when DO inputs from the Black Sike were not low and the water flushed into the Costa Beck did not have substantial differences in DO concentration.

Thus, these results indicate DO sags in the Costa Beck could be amplified by a combination of near-zero DO inputs from the Black Sike and high flow inputs absent from the AMP7 data survey led by flushing significant amounts of low DO water as a slug into the Costa Beck.

Figure 5-5 Impact of decreasing DO inputs from the Black Sike to zero



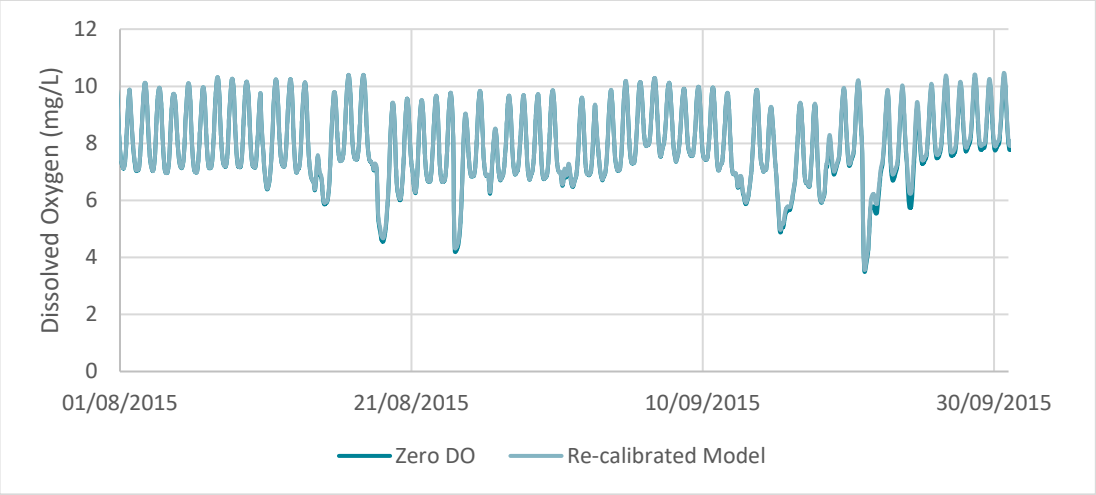
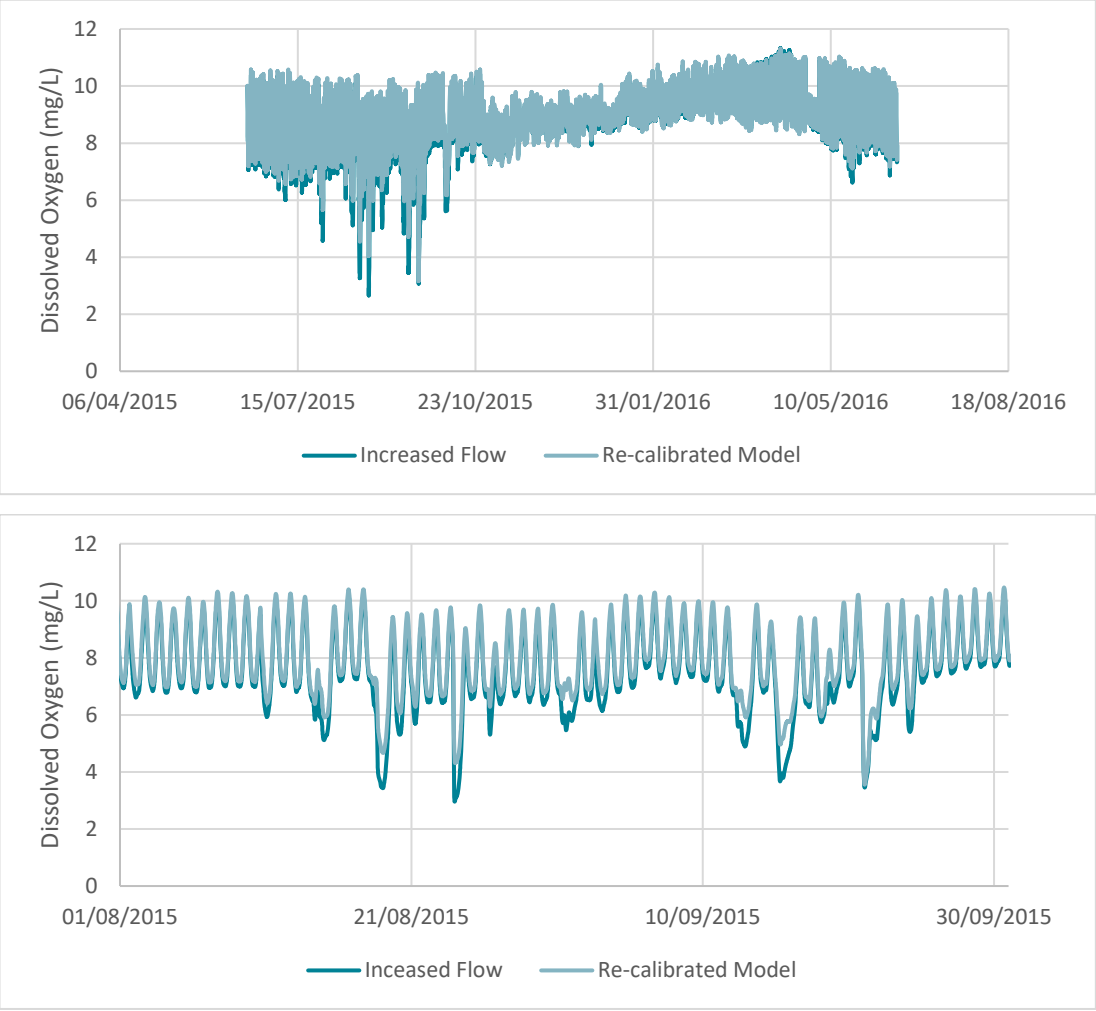


Figure 5-6 Impact of increasing flow inputs from the Black Sike by 100%



6. CONCLUSIONS

The assessment reached the following conclusions:

1. Following a review of the AMP7 data survey, the AMP6 model was re-calibrated to include the AMP7 Black Sike DO data. Additionally, a time-varying SOD component was removed as it was found to be inconsistent with SOD measured across the channel and had no significant impact on modelled DO in the Costa Beck.
2. The re-calibrated model yielded identical results to the AMP6 model downstream of the Pickering WwTW but produced DO sags downstream of the Black Sike. Given the AMP6 model was accepted for the purposes of the AMP6 UPM study, with some qualification regarding its ability to represent DO sags, it is concluded that the re-calibrated model provides a better representation of the system.
3. To identify and assess the primary mechanisms controlling the DO sags in the Costa Beck, several sensitivity tests were conducted relating to the Pickering WwTW and the Black Sike.
4. For the Pickering WwTW three scenarios were tested: 1) removing the Pickering WwTW; 2) increasing SOD; 3) decreasing reaeration. DO was not decreased by scenario 1) and only slightly by scenario 2) and 3).
5. For the Black Sike two scenarios were tested: 1) decreasing Black Sike DO inputs to zero; 2) increasing Black Sike flow inputs. Scenario 1) produced additional DO sags throughout the simulation period but did not alter the DO sags already present in the re-calibrated model due to these periods already being near-zero. Scenario 2) amplified the DO sags already present in the re-calibrated model but had no significant impact on other periods.
6. Overall, this investigation concludes that the Black Sike is the primary control on DO sags in the Costa Beck and that the Pickering WwTW has an insignificant impact. Furthermore, for DO sags can be amplified by a combination of high flow and low DO inputs from the Black Sike by flushing a slug of low DO water into the Costa Beck.

Providing improvements to Costa Beck water quality, and managing the risk of future DO sags, would appear to be a matter of improving quality in the Black Sike. We are aware of EA information regarding a dairy farm that had been producing ice cream, and possibly discharging to the Black Sike. Such a discharge, if uncontrolled, could provide a significant source of organic pollution, which could be a mechanism for the DO sags in the Black Sike (and subsequently the Costa Beck).

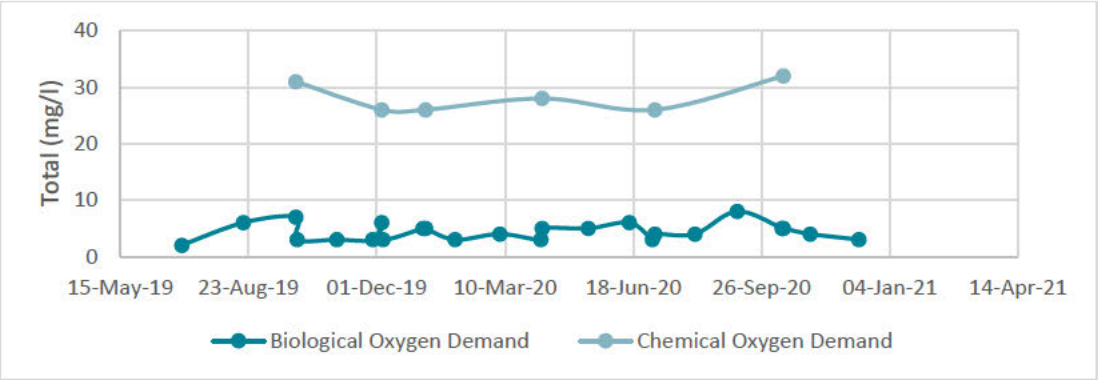
REFERENCES

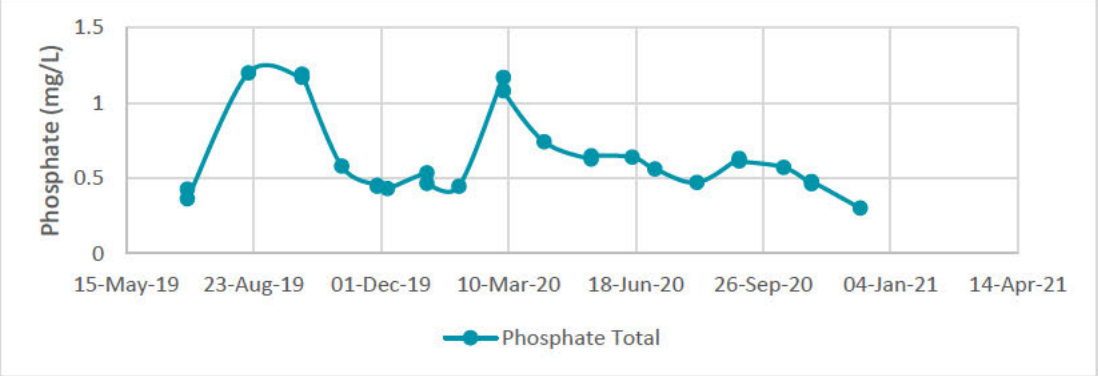
1 MHW. (2017). Cause and Effect Report. S3399 UPM Modelling Studies - Costa Beck. RT-WKF-1052-01

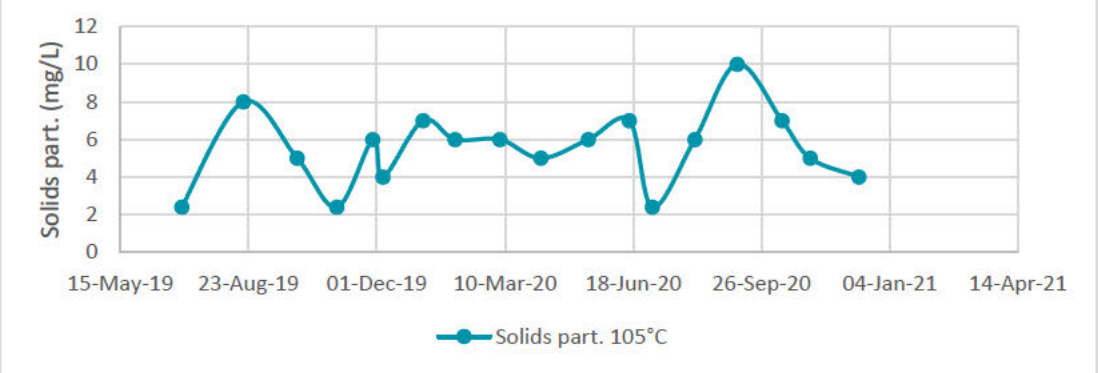
APPENDIX A

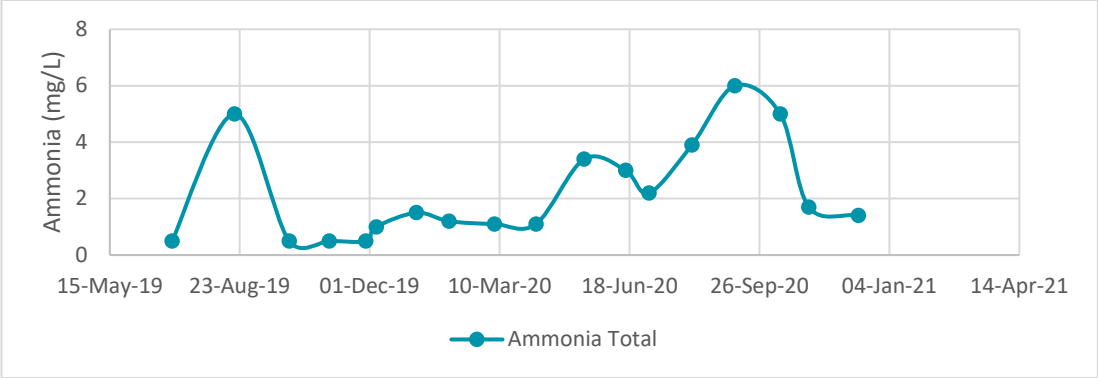
YWS Data Measured in Pickering WwTW

A.1 SEVERAL DETERMINANDS MEASURED AT PICKERING WWTW FINAL EFFLUENT (NGR SE78428403)









A.2 HYDROGEN SULPHIDE MEASURED BY IETG 500M IN THE WWTW OUTFALL PIPE (NGR SE7789383444; H0001)