Stodmarsh Water Quality Modelling

Dover District County Council

P0006031

September 2022

Daniel Minski (Intertek), Tania Iglesias (APEM), Georgina Selwyn (Intertek), Paul Taylor (Intertek), Michael Dobson (APEM) and Rob Moore (APEM)

Client:	**Dover District County Council**
Address:	**White Cliffs Business Park,** **Whitfield,** **Dover** **CT16 3PJ**
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Project Director: **Michael Dobson (APEM)**

Project Manager: **Rob Moore (APEM)**

Other: **Daniel Minski (Intertek), Georgina Selwyn (Intertek), Paul Taylor (Intertek) and Tania Iglesias (APEM)**

APEM Ltd
Riverview
A17 Embankment Business Park
Heaton Mersey
Stockport
SK4 3GN

Tel: 0161 442 8938
Fax: 0161 432 6083

Registered in England No. 02530851

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Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
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1	23/07/21	All	All	APEM draft report	Michael Dobson
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3	23/09/21	All	All	Draft Intertek report submission	Richard Dannatt
4	24/09/21	All	All	Final draft report	Heather Webb
5	18/11/21	All	All	Final Intertek report submission	Gina Selwyn
6	23/11/21	All	All	Final modelling report	Tania Iglesias
7	07/08/22	Appendix 2	21 to 23	Final modelling report	R Moore
8	12/09/22	All	All	Final report following client comments	R Moore

Summary

Dambridge wastewater treatment works (WwTW), in Wingham, Kent, lies within the area administered by Dover District Council (DC). In common with other WwTWs it discharges nutrients into the environment in its treated final effluent, these eventually enter the Little Stour and then the Great Stour rivers. There is concern that these nutrients may be contributing to the elevated nutrient levels in water bodies in Stodmarsh Lakes system, which lies along the Great Stour downstream of Canterbury. Stodmarsh is upstream of the point where nutrient inputs from Dambridge WwTW enter the Great Stour, but as the river is tidal there is potential for upstream movement during incoming tides.

DC commissioned APEM to undertake an investigation into potential connectivity between Dambridge WwTW and the water bodies at Stodmarsh. To support its scoping study, APEM commissioned Intertek, to model the potential connectivity between Dambridge WwTW and Stodmarsh Lakes system

The process included the construction of an appropriate model of the tidal Stour system that is capable of modelling both flows and nutrient transport in the area of interest, and undertaking model runs to determine whether there is connectivity between Dambridge WwTW and the entry point to Stodmarsh Lakes system, and if so, under what conditions.

The River Stour model, which covers the tidal reaches of the Great Stour and Little Stour, enabled the potential for connection to be assessed under two scenarios: 1) a worst-case, when Great Stour discharge was very low (Q95) continuously for four years; 2) a realistic flow pattern, based on actual recorded flows for the period 2016-19. The model was conservative, in that it assumed: a) Dambridge WwTW effluent was entering the Little Stour at its tidal limit, several km downstream of its actual point of entry; and b) that contaminants did not decay or otherwise be removed, but were simply diluted by the volume of water present. It was based on adding a tracer to the effluent inputs and determining the level of dilution this underwent before reaching Stodmarsh.

The River Stour model was calibrated and validated against field measurements of water level, flow and salinity. The calibration and validation data include historical flow data from the Environment Agency gauge at Plucks Gutter, located below the confluence of the Great Stour and Little Stour, salinity field data, and water level from the Shoothill GaugeMap. The calibration is considered the best achievable based on the available data and is sufficient for the purposes of the study.

Using realistic scenario dispersion rates and river flows, the average number of dilutions that the tracer underwent was 2,400,000,000 at the entry point to Stodmarsh NNR Lake. The minimum dilution seen under the realistic flow scenario, is over 990,000, and it demonstrates the low concentration of tracer in the system at Stodmarsh NNR Lake. Based on the average WwTW final effluent concentration of 1.513 mg/l for total phosphorus, the minimum dilution would give a worst-case concentration at Stodmarsh NNR Lake of 0.0015 µg/l.

Even allowing for the assumed lack of decay of the tracer in the model, the concentrations anticipated at Stodmarsh NNR Lake are below the limits of detection of the methods used for water quality sample analysis.

Additionally, physical constraints on connectivity (connectivity is only possible when river levels are greater than 2.44 m at the sluice separating the Great Stour and Stodmarsh) were explored. The model results indicated that hydrological connectivity was only detected once. However, no tracer was detected at the sluice on that occasion. This is because the water level will only exceed the 2.44 m threshold under very high flow conditions. Under these high flows, pollutants will be forced downstream in the river and out towards the coast, so it is improbable that there will be connectivity under these conditions in future.

In conclusion, the model demonstrated that, although there is a potential hydrological connection between Dambridge WwTW and Stodmarsh, there won’t be any measurable contribution of the effluent discharge to nutrient loading in the lake.

Following a meeting with Natural England additional modelling and analysis of the total nitrogen (TN) and total phosphorous (TP) load arriving at Stodmarsh National Nature Reserve (NNR) lake and at Hersden tidal lake was carried out.

Two additional scenarios were modelled for each location: the 2022 and 2040 population for TP and TN at permit levels. The water quality model was amended to include the new nutrient levels The model outputs were a time series in 15-minute intervals of concentration of nutrients to reach the receptors and through calculations these were converted into an annual mass per year (kg per year).

The results indicated that the total load that reaches the sluice gate at the entrance to Stodmarsh NNR Lake is extremely low. To demonstrate this, the total population for both scenarios and the annual wastewater nutrient load for both scenarios were used to calculate a nutrient load per person. When compared to the modelled outputs the predicted impact from Dambridge WwTW is approximately equivalent to less than 0.001 persons contribution per year. When it is considered that this overall load would have to be diluted through the total water volume available in the lake in order to compare it to the compliance standard, it is clear that there is no impact.

The results of the modelling for Hersden Tidal Lake show that there is no connectivity from Dambridge WwTW.

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Glossary

1D…..One-Dimensional

CTD…..Conductivity, Temperature, Depth

D…..Dispersion coefficient

DC…..District Council

EA…..Environment Agency

NRFA…..National River Flow Archive

UKHO…..United Kingdom Hydrographic Office

WwTW…..Wastewater Treatment Works

1. Introduction

1.1. The nature of the problem

The Stodmarsh wetland complex, comprising a series of open water lakes, reedbeds and marsh, is situated adjacent to the upper tidal reach of the Great Stour River east of Canterbury. It has historically suffered from eutrophication as a result of excessive nutrients entering from the catchment. The wetland area is an important habitat that holds various statutory designations: Site of Special Scientific Interest (SSSI), Ramsar site, Special Protection Area (SPA) and Special Area of Conservation (SAC). The north eastern half of the area is a National Nature Reserve (NNR). As a freshwater site, several of the open water bodies (henceforth referred to as the Stodmarsh lakes) are failing both nitrogen and phosphorus standards for favourable condition of Natura 2000 sites, with potential impacts on important wildlife for which the area is designated (Natural England: *Stodmarsh and Nutrients – Non-Technical Summary*, November 2020).

Controlling the negative impact of excessive nutrient input into Stodmarsh requires several measures, including ensuring no further increase in nutrient loading from new developments. Following the issue of Natural England guidance on achieving nutrient neutrality for Natura 2000 sites, all local authorities in the catchment affecting Stodmarsh Lakes system are required to apply the guidance package and follow Habitats Regulations Assessment to stage 2 Appropriate Assessment, before any planning applications for development in the catchment can be granted. Development of new housing, including that within the new local plan, must demonstrate nutrient neutrality.

In the case of Dover District Council (Dover DC), only a small proportion of the River Stour catchment is within the local authority boundary, and this is within the lower reaches of the Little Stour sub-catchment. The Little Stour joins the Great Stour approximately 7 km downstream of Stodmarsh Lakes system, being pumped up to the level of the tidal reach by Stourmouth Pumping Station. Therefore, any nutrient inputs from Dover DC activities would need to be transported upstream by this distance to enter the Stodmarsh Lakes system. Despite the small proportion of the catchment area within its jurisdiction and low probability of impact, it is important that Dover DC has a full understanding of its role in affecting nutrient loads in Stodmarsh Lakes system, in order to enable further development to proceed without having any further impact on the site.

The specific contributor within the Dover DC area is Dambridge wastewater treatment works (WwTW). In common with other WwTWs, it discharges treated final effluent to the environment. This final effluent contains nutrients (nitrogen and phosphorus) which are the determinands of interest to this report.

The final effluent from Dambridge WwTW drains via the Wingham River to the Little Stour and then (at its confluence with the Great Stour) to the River Stour, finally reaching the North Sea/English Channel in Pegwell Bay south of Ramsgate. The land is very flat and the River Stour/Great Stour/Little Stour are tidal for up to 30 km inland – the Great Stour as far as Fordwich upstream of Stodmarsh Lakes system, and the Little Stour as far as West Stourmouth, downstream of the Wingham River confluence.

The aim of this study is to determine whether there is the potential for a hydraulic connection enabling water discharged from Dambridge WwTW to reach Stodmarsh and enter the lakes. Only if this occurs would the consented effluent discharge from Dambridge WwTW have the potential to affect nutrient loading into Stodmarsh Lakes system.

1.2. The method used

In order to determine the probability of a connection between Dambridge WwTW, a modelling approach was developed in association with Intertek Energy & Water (Intertek), a specialist water modelling consultancy. The bulk of the content of this report derives from the model that Intertek developed to better understand upstream movement of water along the Great Stour.

The model was created specifically for the Great Stour catchment, and compared with existing data on water levels, river flow and salinity. It was then run under a range of scenarios, to gain and understanding of water movement upstream from the Little Stour confluence. The model is based on the assumption that water discharged from Dambridge WwTW includes a tracer and considers the proportion of the tracer released that reaches Stodmarsh Lakes system. This approach can be followed in a real-world experiment, by for example adding a fluorescent dye to a discharge and monitoring its concentration at different points in the river. The advantage of a modelling approach, however, is that it can be tested under different flow conditions without requiring these to actually occur.

Further technical details on model development and testing are provided in Appendix 1.

1.3. The study area

The study area covered by the model includes the mouth of the River Stour, and the upstream limits of the model include the Great Stour and the Little Stour, as far as Fordwich at the upstream end of Stodmarsh Lakes system. The full extent of the study area is shown in Figure 1. The Stodmarsh lakes system dominate the river characteristics in the upper section of the model. Below this point, the river channel is largely dominated by tidal processes. It has a shallow gradient throughout. Reserve Lake in Stodmarsh Lakes system is connected to the Great Stour via a sluice.

The entry point of the Stodmarsh lakes system to the river is taken as to the east, as indicated in Figure 1, which is upstream of the Grove Ferry gauging station.

The model added the tracer into the Little Stour at the upstream limit of the model at Stourmouth Pumping Station (see Figure 1). Although this is approximately 6.5 km downstream of Dambridge WwTW and so is conservative, the flow at this location is controlled by a pumping station hence the discharge from the WwTW will only be discharged to the lower (tidal) Little Stour when the pumps are in operation.

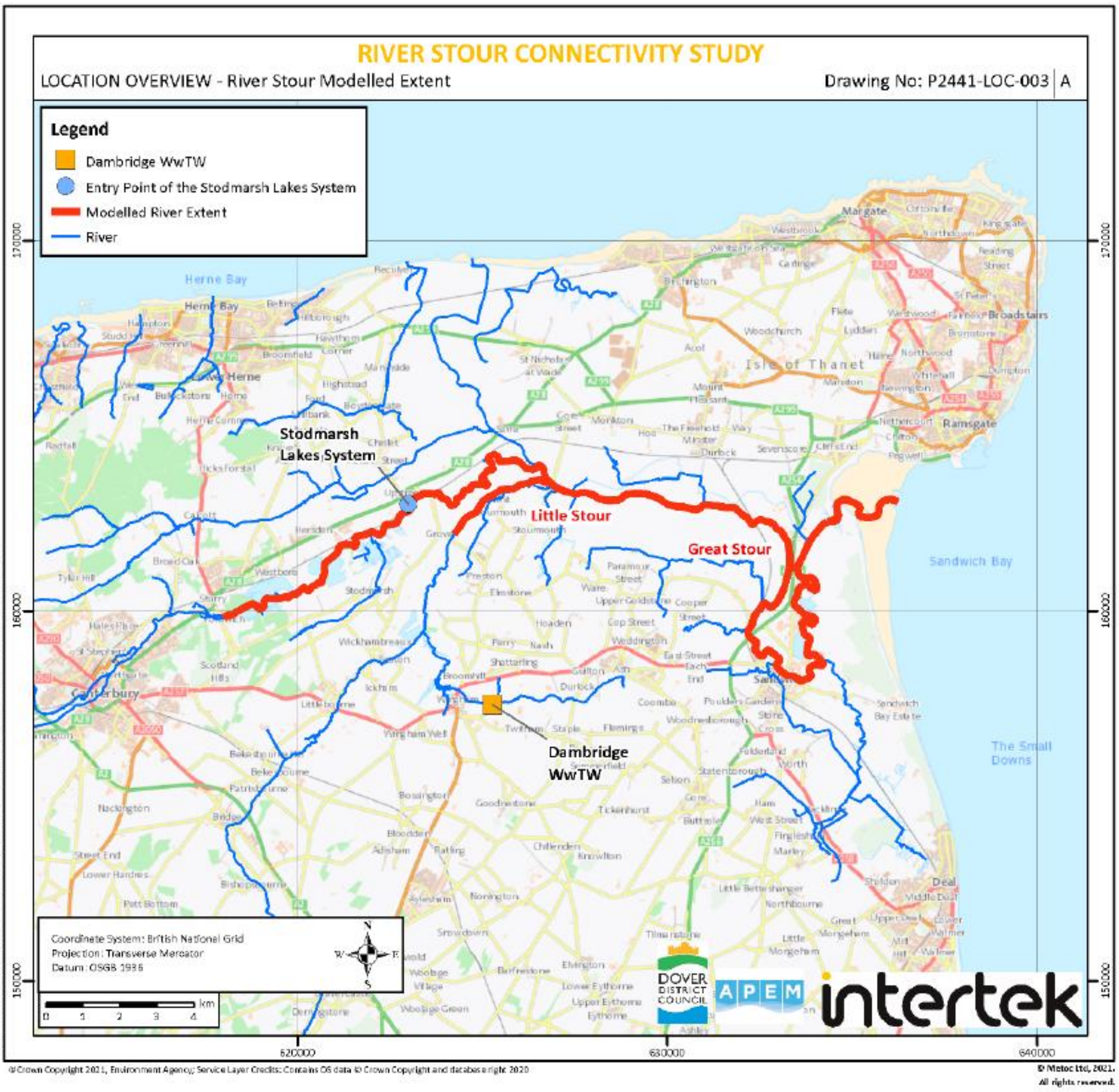

Figure 1. River Stour model extent

2. Method

The River Stour model was calibrated and validated against field measurements of water level, flow and salinity. The calibration and validation data include historical flow data from the Environment Agency (EA) gauge at Plucks Gutter; located below the confluence of the Great Stour and Little Stour, and salinity and water level data from the Shoothill GaugeMap. The calibration is considered the best achievable based on the available data and is sufficient for the purposes of the study. Further details of the calibration and validation are provided in Appendix 1.

The model assumed that the tracer used did not decay, and so that the entire concentration added to the Little Stour would remain in the water. This is in contrast to nutrients, which will be removed from the water via a series of natural processes including uptake by plants. A nominal concentration of 1 Kg/L was used to ensure that there was sufficient mass of tracer to allow detection at Stodmarsh Lakes. It should be noted that this is not representative of the discharge concentration of any particular nutrient or determinand, but simply represents an arbitrary discharge 'load' for the purposes of the connectivity assessment. The concentration used is extremely high; as a comparison the actual average (mean) concentration of phosphorus discharged from Dambridge WwTW is 1.513 mg/L, over 660,000 times less than the modelled tracer.

The model was run from February 2016 to September 2019 (1,308 days or 31,392 hours).to cover a variety of tidal conditions. Two river flow scenarios were modelled:

- Constant low (Q95) flow. This gives the worst-case condition; by modelling a consistently low river flow in conjunction with a varying tide over the long duration of the model run. The results of this scenario are not realistic but predict the connectivity under the extreme worst-case conditions.
- Time varying flow. This scenario was modelled incorporating the actual river flows recorded during the five year period and aimed to provide a more realistic view of the connectivity by modelling a combination of river flows and tidal conditions over a long time period. The results of this scenario give a realistic view of the connectivity between the WwTW and Lakes system.

For each of the river flow scenarios, three dispersion coefficients (rates at which the tracer mixes in the river water) have been modelled: low dispersion (D=1 m^2/s), realistic dispersion (D=5 m^2/s) and high dispersion (D=25 m^2/s) to determine the sensitivity of the connectivity between Dambridge WwTW and Stodmarsh to dispersion. The model calibration determined that a dispersion coefficient of D=5 m^2/s was the most appropriate; however, testing the higher and lower dispersion values gives an envelope of results which the connectivity will fall within under any extreme conditions.

If connectivity is noticed, a further study on the physical connection between the Great Stour and Stodmarsh will be carried out. Information was obtained from NE to determine how the sluice between them works:

"With regard to connectivity to the NNR lake, Natural England has a hydrological report that is in draft, under review and not completed, but indicates that the connectivity will only be when the new sluice is opened or in flows above approximately 2.44m to let water in. The sluice which has only been in place since early 2018 has not yet been opened for abstraction purposes as one of its functions is to improve control of water from the Stour to the lakes.

Historically greater connectivity occurred via the old sluice and in future the sluice will need to be opened when water levels in the lake drop to ensure there is sufficient water for the sites conservation management.”

This is interpreted as connectivity between the river and Stodmarsh is only physically possible under two conditions:

1. When the sluice is manually opened.

2. When the river level at the sluice is greater than 2.44 m.

It was not possible to model the first condition as the parameters that trigger the sluice to be opened were not provided.

Appendix 2 sets out the detail of additional modelling and analysis of the total nitrogen (TN) and total phosphorous (TP) load arriving at the NNR lake and Hersden tidal lake.

3. Results

3.1. Tracer connectivity

The results presented for each scenario include:

- Time series of tracer concentration at the eastern point of Stodmarsh. This is the closest point of the water bodies to the WwTW discharge and so represents the worst-case in terms of connectivity.
- Number of dilutions of the tracer at Grove Ferry. The number of dilutions provides an indication of the amount of tracer remaining in the system. High dilution indicates that much of the tracer has been lost, mainly through transport downriver and into the sea.

3.1.1. Worst-case scenario

Figure 2 shows the tracer concentration under the low river flow scenario and with the three different dispersion coefficients. Table 1 presents the minimum and average dilutions of the tracer at the same location and for the same scenarios.

The time series results in Figure 2 indicate that under continuous low flow conditions there would be connectivity between the WwTW discharge and Stodmarsh Lakes system throughout the modelled period and under all dispersion coefficients.

Under the more realistic dispersion coefficient (D=5), the worst-case is that pollutants are diluted more than 1.5 million times. The model predicts that there will be apparent connectivity at Stodmarsh Lakes system for a total of 15,573 hours (648 days) out of the total 31,392 hours (1308 days), equivalent to 49.6%. Under the same dispersion coefficient, the average number of dilutions is 52,000,000, putting contaminants below the detectable limit. For example, assuming the mean total phosphorus concentration from Dambridge WwTW of 1.513 mg/L, would give a worst-case (maximum) concentration of 0.18 µg/L at Stodmarsh, and an average concentration of 0.00003 µg/L.

Table 1. Tracer Dilution at the Grove Ferry gauging station: worst-case flow scenario

Dilution	Low dispersion	Realistic dispersion	High dispersion
Minimum dilution	16,000,000	1,600,000	6,400
Average (mean) dilution	830,000,000	52,000,000	58,000
% of time in which tracer is modelled to show apparent connectivity	21.8	49.6	99.8
Number of hours in which tracer is modelled to show apparent connectivity	6,843	15,573	31,329
% of time in which tracer is modelled to be above LOD	0	0	0

3.1.2. Realistic flow Scenario

Figure 3 shows the tracer concentration under the time-varying river flow scenario and with the three different dispersion coefficients. The results clearly show that while there is some connectivity it is dependent on the dispersion coefficient used and only occurs during limited periods – typically when spring tides occur when river flows are low. At the most likely dispersion coefficient of 5 m^2/s, connectivity is very limited, with low concentrations of tracer detected.

At the calibrated dispersion coefficient of 5 m^2/s, apparent connectivity is very limited, with low concentrations of tracer detected at the eastern point of Stodmarsh Lakes system for 3,912 hours (163 days) out of the total 31,392 hours (1308 days) which is just under 12.5 % of the total run time of the model. However, the model shows that concentrations of total phosphorus and total nitrogen are below the LOD and can be considered effectively zero.

Table 2 presents the minimum and average dilution of tracer predicted at Stodmarsh Lakes system for each dispersion coefficient. Similar to the low river flow scenario, the greatest number of dilutions are seen under the highest dispersion scenario (D=25).

Overall, while there is some potential connectivity under certain tide and flow conditions, for a significant proportion of the modelled run there is no connectivity. During the times when connectivity is seen, the dilution is very high – over 990,000 times for the most likely scenario. Any nutrients released from Dambridge WwTW would therefore be much more highly diluted by the time they reached the lake system than in the worst-case scenario described above, the average final effluent total phosphorus concentration of 1.513 mg/L being diluted to 0.0015 µg/L.

Table 2. Tracer Dilution at the Grove Ferry gauging station: realistic flow scenario

Dilution	Low dispersion	Realistic dispersion	High dispersion
Minimum dilution	8,700,000	990,000	5,300
Average (mean) dilution	2,600,000,000	2,400,000,000	340,000
% of time in which tracer is modelled to show apparent connectivity	5.2	12.5	67.5
Number of hours in which tracer is modelled to show apparent connectivity	1,632	3,912	21,189
% of time in which tracer is modelled to be above LOD	0	0	0

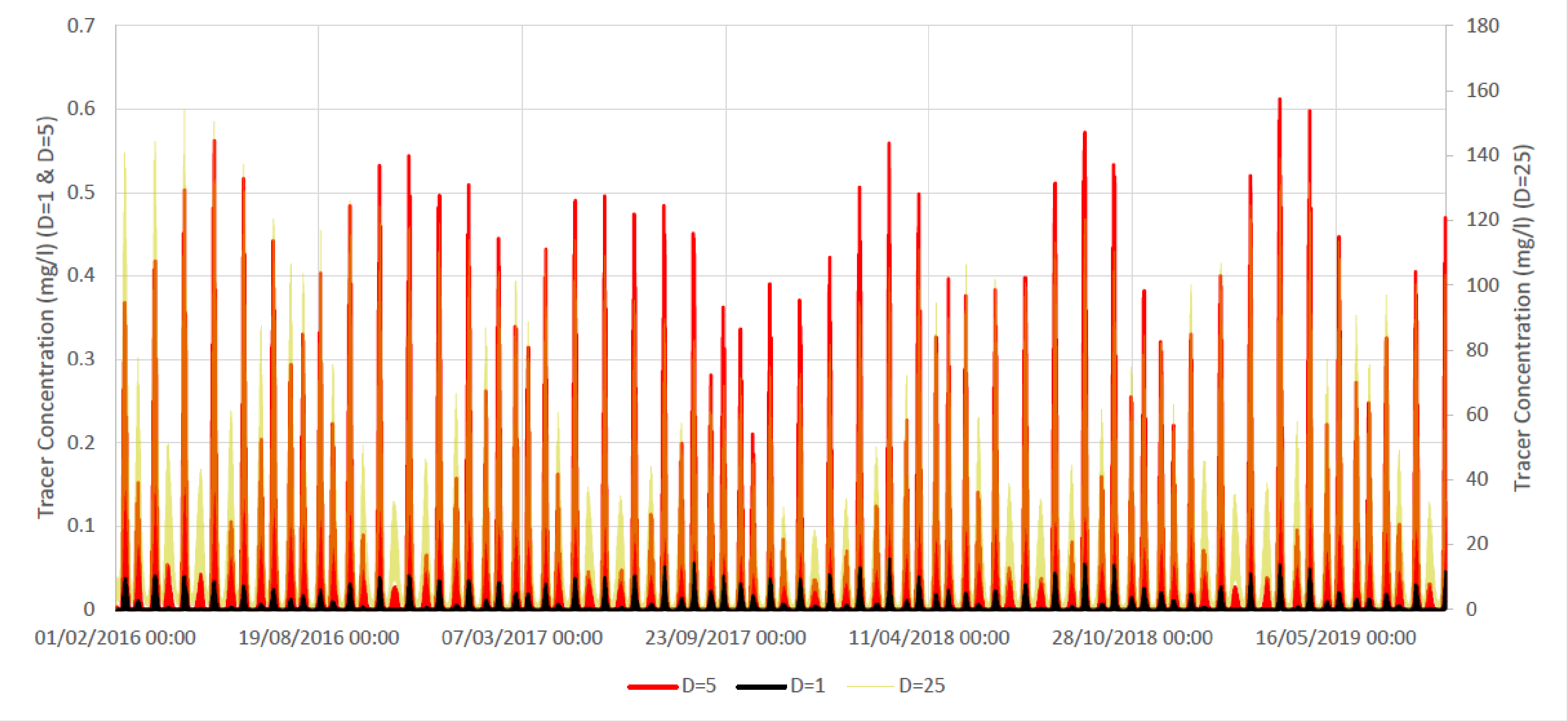

Figure 2. Tracer concentration at the Grove Ferry gauging station: worst-case flow scenario

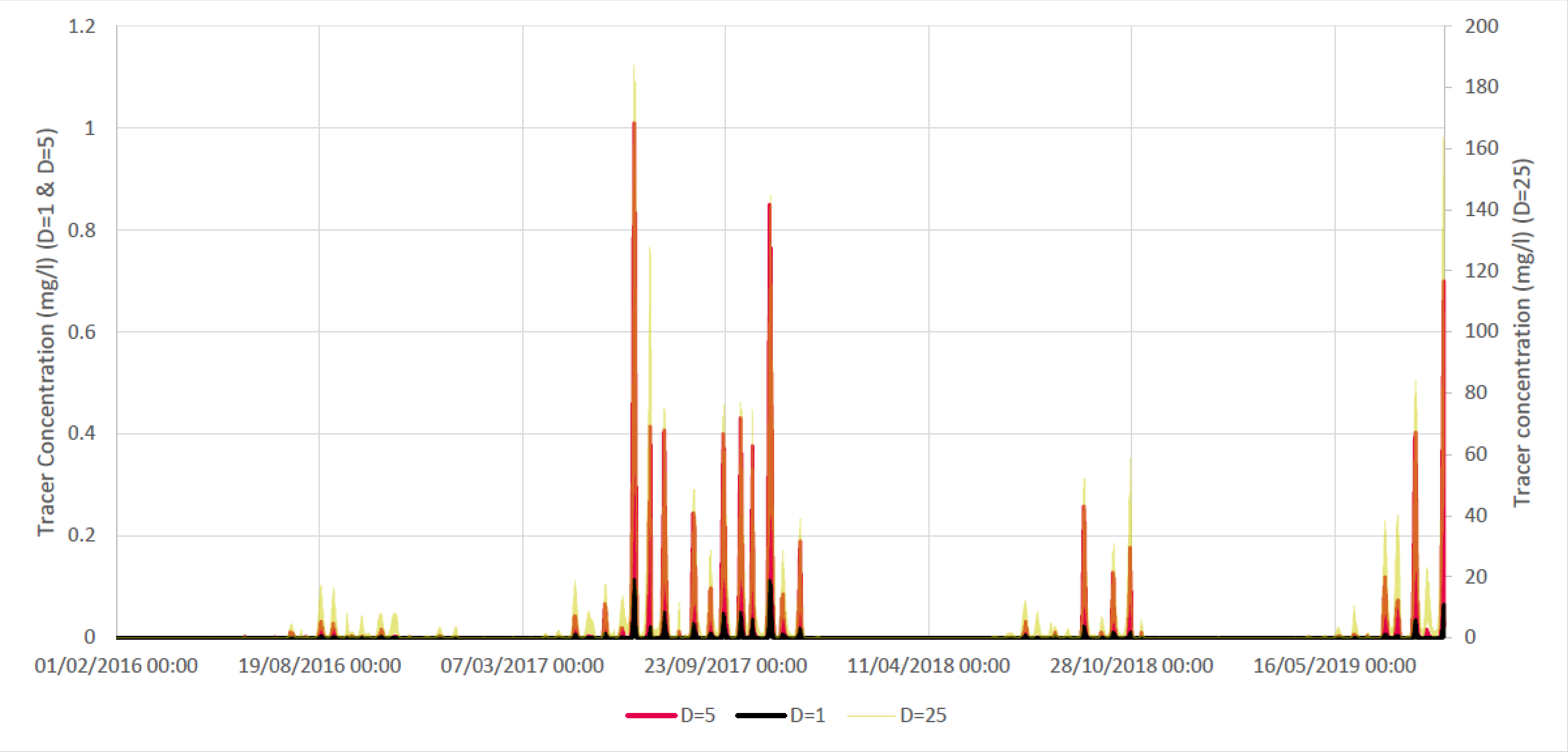

Figure 3. Tracer concentration at the Grove Ferry gauging station: realistic flow scenario

3.2. Physical Connectivity Analysis

In order to determine whether any tracer from Dambridge WwTW would enter Stodmarsh when the river level was above 2.44 m, the water levels at the sluice location were extracted from the model, then during any periods where the level exceeded the 2.44 m threshold, the tracer concentration was calculated. The model was run with time-varying flows only (section 3.1.2) in order to calculate the most realistic water levels and the most likely periods when the 2.44m threshold is exceeded.

The results are shown in Figure 4 and Figure 5.

Figure 4 shows that the modelled water level at the sluice only exceeded the 2.44 m threshold once during the four year modelled time period (2016 – 2019).

Figure 5 shows that during the time that the water level exceeds 2.44 m, the tracer representing the discharge from Dambridge WwTW has zero concentration at the sluice under all three dispersion coefficient scenarios.

The results suggest that, during the modelled time period, no discharge from Dambridge WwTW would have been able to enter Stodmarsh as the only time that the water level exceeded the threshold, there was zero tracer concentration.

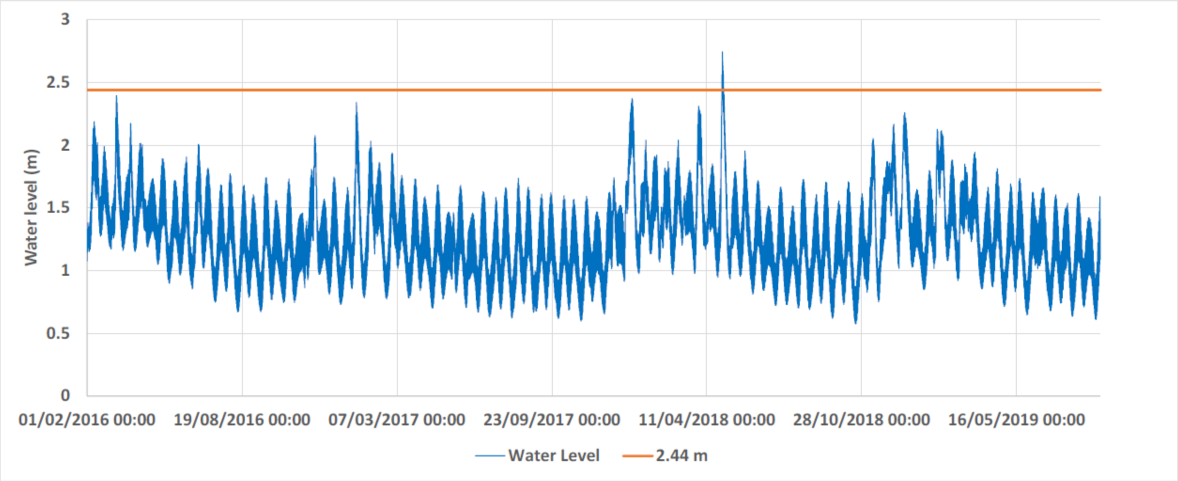

Figure 4. Modelled water level at sluice

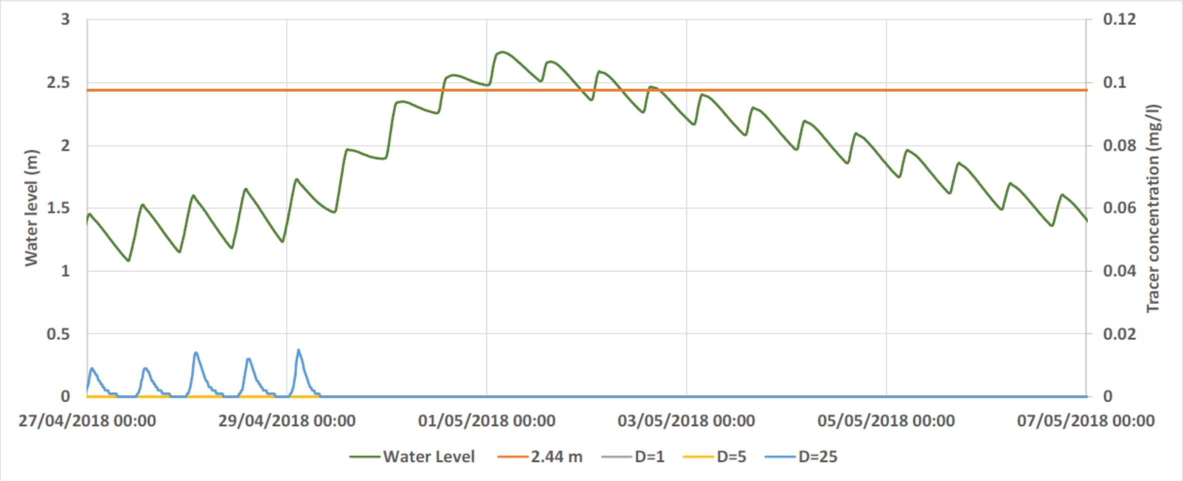

Figure 5. Tracer concentration when modelled water level >2.44 m

4. Discussion and Conclusion

The hydrodynamic model created for the Great Stour tidal reaches shoes that under extreme conditions there is potential for a connection between Dambridge WwTW and Stodmarsh Lakes system, meaning that some water discharged in the effluent from the WwTW could be carried upstream to Stodmarsh Lakes system. However, dilution would be so great, even under extreme worst-case scenarios (continuous very low river flow and high tides) that any contaminants transported from the WwTW will be at concentrations well below the best available laboratory limits of detection.

The tracer study results indicate a generally intermittent connectivity between Dambridge WwTW and Stodmarsh Lakes system. Connectivity is seasonal and restricted to periods of high tidal range (spring tides) and low river flow when the propagation of the tide upstream is greatest. Under realistic flow scenarios, the connection would be for short periods, when low flows coincide with high tides. During years with low flow, such as 2017, there would have been several such potential occurrence in summer and autumn, but in 2016 there would have been hardly any such connections under realistic flow scenarios (as shown by the number of peaks in Figure 3).

The approach taken was conservative, to allow for worst-case options. The assumed contaminant from Dambridge WwTW was added at the Little Stour tidal limit, which is approximately 6.5 km downstream of the actual outfall. The Stodmarsh system was assumed to be a single point towards the lower reaches of the site, rather than further upstream at the sluice connecting Reserve Lake with the Great Stour. The contaminants were assumed not to decay or otherwise be removed, and so were only subject to dispersion and dilution. Even under these scenarios, concentrations reaching Stodmarsh were extremely low.

When assuming there is no restriction on the physical connection between the Great Stour and Stodmarsh, the tracer study results (Section 3.1) indicate a generally intermittent apparent connectivity between the Dambridge WwTW and Stodmarsh. Apparent connectivity is restricted to periods of high tidal range (spring tides) and low river flow when the propagation of the tide upstream is greatest. When connectivity does occur, there is significant dilution between the Dambridge WwTWs and the water bodies within Stodmarsh, such that nutrients released from the WwTW would be undetectable.

However, when the physical constraints on connectivity are accounted for, i.e. that connectivity is only possible when river levels are greater than 2.44 m at the sluice separating the Great Stour and Stodmarsh, the model results in Section 3.2 indicate there was no connectivity throughout the modelled time period as during the one period where the river level was greater than 2.44 m, no tracer was detected at the sluice. This is because the water level will only exceed the 2.44 m threshold under very high flow conditions. Under these high flows, pollutants will be forced further downstream in the river and out towards the coast, so it is improbable that there will be connectivity under these conditions in future.

The model can only predict the potential connectivity due to the water level overtopping the threshold of 2.44 m, and it cannot predict whether there would be any connectivity from the manual operation of the sluice.

In addition, Appendix 2 sets out the detail of modelling and analysis of the total nitrogen (TN) and total phosphorous (TP) load arriving at the NNR lake and Hersden tidal lake

In conclusion, therefore, the model demonstrates that there will be no measurable contribution of Dambridge WwTW effluent discharge to nutrient loading in Stodmarsh.

Appendix 1 Model build and calibration

This appendix describes in detail the construction, calibration and validation of the River Stour model, in particular advection and dispersion processes. The model has been constructed, calibrated and validated to a level dictated by the available data. The key characteristics of the river are represented well, and the tidal component has been validated against water level data. The calibration of the model has been done through altering hydrodynamic characteristics and the advection processes have been calibrated by adjusting the dispersion coefficient.

Model Construction

Model Boundaries

A hydrodynamic model is driven by a specified set of open boundary conditions (which take the form of time series of water elevation or flux at the model boundaries). Boundaries are located sufficiently far from the area of interest to eliminate potentially erroneous boundary effects common to all numerical models.

The River Stour has three open boundaries: 1) freshwater inputs on the Great Stour; 2) freshwater inputs on the Little Stour; 3) the downstream tidal boundary. The upstream boundaries are driven by flow measured at the two upstream gauges: Horton on the Great Stour and Littlebourne on the Little Stour. Table 3 shows the mean flows of these two rivers.

Table 3. Summary of rivers and mean river flows

River	Mean flow (m^3/s)
River Stour	2.5
Little Stour	0.26

The downstream boundary, where the river meets the open sea, is driven by tidal water level predictions derived from the UK Hydrographic Office (UKHO) TotalTide software.

Model Parameters

Model Time step

A maximum time step of five seconds is used in the model and an initial warm up period is given for all runs to allow water levels and flow to stabilise.

Bed roughness

Bed friction (resistance) is one of the major factors that influence the hydrodynamics of a water body, particularly the propagation of the tide up the river channel. This bed resistance is represented in the hydrodynamic model by the Manning number, n ($m^{1/3}/s$).

Dispersion Coefficient

Mixing processes in the riverine, estuarine and coastal waters are dominated by mechanical (turbulent) dispersion caused by variations in flow velocities. This is significantly larger than molecular diffusion or Fickian diffusion along concentration gradients. Mixing is therefore represented in the model using the dispersion coefficient, D (m^2/s), which may be entered as a single value over the entire model domain, or as a dispersion coefficient map.

Model Calibration and Validation

Model Selection

MIKE 11 is an industry standard and widely used one-dimensional (1D) hydrodynamic and dispersion model. MIKE 11 can simulate time varying flow and dispersion in non-uniform open channels and includes definitions for structures.

Calibration and Validation Guidelines

Calibration is achieved by fitting the model output to observed data by varying the calibration coefficients. The degree of fit between model and observation determines the level of model calibration; poor fit suggests poor calibration, good fit suggests good calibration. The degree of fit will vary from location to location, depending on local conditions and how well these can be represented in the model. The quality of the observed data is also a significant factor in determining calibration, and is a function of instrument type, accuracy, resolution, deployment location and environmental conditions.

Model fit to field data can be assessed in two ways:

- visual comparison of the model output against observed data: the shape, trend, range, and limits of model output and observed data;
- statistical comparison of the difference between observations and the model outputs to determine the frequency with which the model fits the measured data within defined limits, e.g., 80% of the model predictions are within 0.1 units or 10% of the observed value.

In practice both methods should be used if possible, as no single method provides a full assessment of model performance.

For this study, a visual method of comparison, between model output and field data, has been utilised as the primary method of calibration due to the relatively low resolution of the available data.

Model calibration and Validation Data

Measured data are required to provide a reference against which the performance of the model can be evaluated. Ideally, calibration and validation data should be distributed throughout the model domain. It is also preferable to have data from a variety of sources so that the model calibration or validation is not reliant on a single dataset that may have inherent limitations. In this case, the model was calibrated and validated against a combination of datasets from various data sources and at a variety of locations (Figure 6 and Table 4).

These include:

- Plotted water level data from Shoothill GaugeMap (www.gaugemap.co.uk) during the modelled time period (2016 to 2021);
- Daily river flow data from the EA river gauge at Plucks Gutter from 2007 to 2021;
- Measured water level data at Grove Ferry, downloaded from the River Levels website: (https://riverlevels.uk/great-stour-chislet-groveferry-tidal#.YTJCq_IKjIW). This includes the daily maximum, minimum and average water level from 2012 to 2021
- Environment Agency (EA) routine monitoring (WIMS) data taken at a number of locations along the river: Grove Ferry, Plucks Gutter and Sandwich Toll Bridge from 2016 to 2019 were used to provide salinity data for calibration.

- Conductivity Temperature Depth (CTD) profiles undertaken by APEM in March 2021, at three locations along the river: Grove Ferry, Plucks Gutter and Sandwich Toll Bridge.

Table 4. Calibration Locations

Site Name	Easting	Northing	Data type
Plucks Gutter	626898	163430	Daily river flow (EA) Salinity (EA WIMS) CTD (APEM)
Grove Ferry	623563	163183	Water level (River Levels, Shoothill GaugeMap) Salinity (EA WIMS) CTD (APEM)
Sandwich Toll Bridge	633201	158291	Salinity (EA WIMS) CTD (APEM)

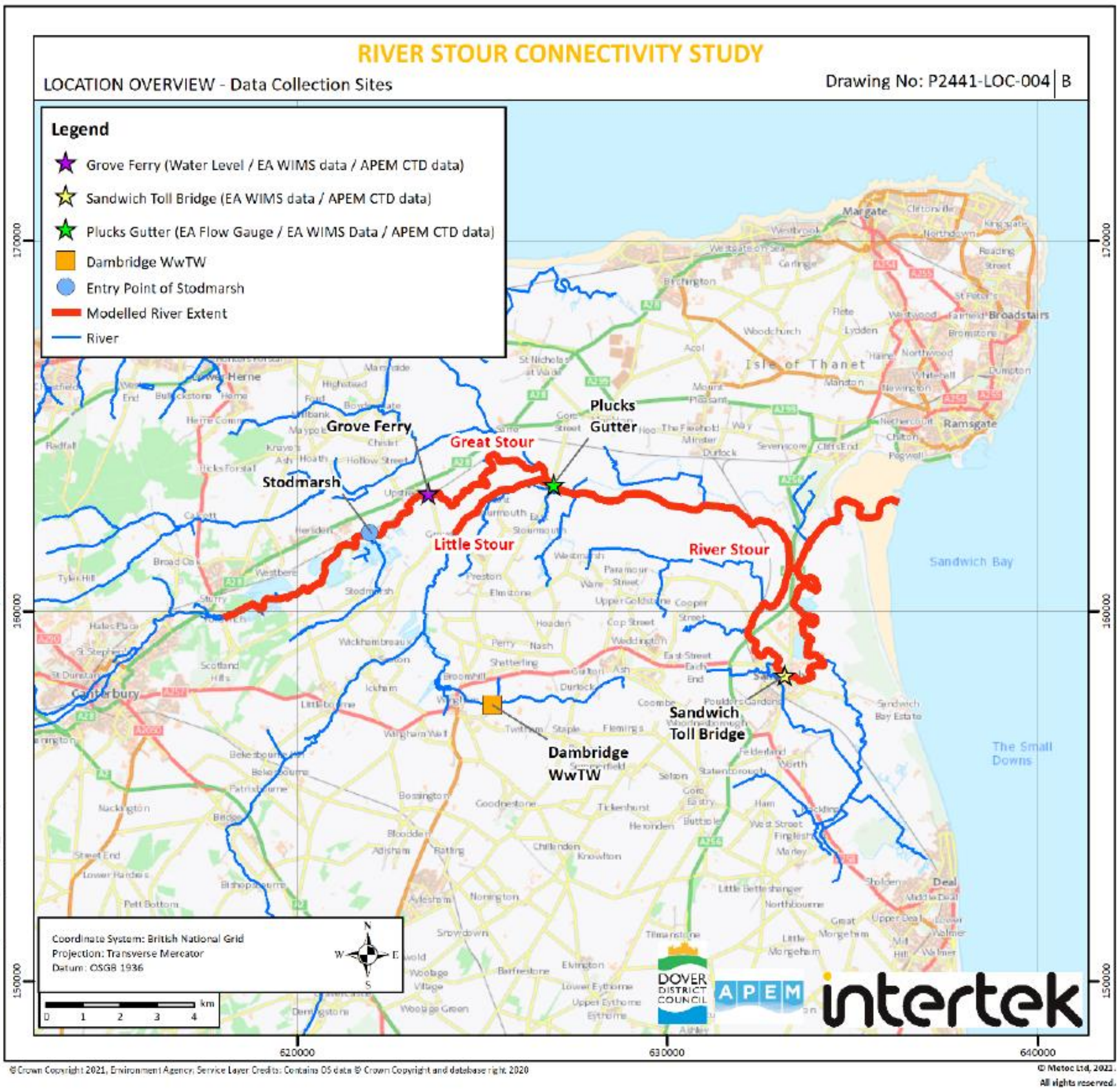

Figure 6. Calibration Locations

Water Level

Measured water level data at Grove Ferry have been downloaded from the River Levels website: https://riverlevels.uk/great-stour-chislet-groveferry-tidal#.YTJCq_lKjIW.

These are daily measurements of the minimum, average and maximum water level at that site. The maximum daily water level from the data has been plotted and compared to the maximum daily value predicted by the model and is shown in Figure 8.

Water level data, from the Shoothill GaugeMap website, were visually compared with the model output. This is an open data source that holds data collected by the EA, Office of Public Works and Farson Digital Ltd. The data are recorded in 15-minute intervals and presented in graphical form by Shoothill GaugeMap.

Visual comparison between the two datasets was undertaken for the Grove Ferry gauging station at intervals over the five-year model run. Statistical analysis was not possible with the GaugeMap data, as the data itself cannot be downloaded or extracted from the website, so it was only possible to do spot checks on the modelled data against the website data. Having water level data directly from the gauges would have allowed for statistical analysis but these data were not available. However, the visual comparison method was adequate to check that the model was performing.

River Flow

Daily river flow data were requested from the EA and used to complete the hydrodynamic calibration of the model. The Plucks Gutter gauge had data from 2007 to 2021 with some gaps. From 2016 to 2021 there was a complete dataset that could be used for model calibration. In order to avoid any potential issues caused by missing data between 2007 and 2016, the 2016 – 2021 period was chosen to be used to calibrate the model against.

Salinity

Salinity data were acquired from two sources. The EA routine monitoring (WIMS) data provided spot samples that covered 2016 to 2019 in low resolution. This allowed visual calibration over a longer time period by comparing the modelled output with the spot sampled data. APEM provided CTD data which had salinity data at three locations over a 12-hour tide at 30-minute intervals in March 2021. This was used for a high-resolution calibration process of the modelled data.

Calibrated Model Parameters

Model calibration has been undertaken by fine tuning model parameters, to produce the optimum model performance when compared against field data. The primary means of calibration was by adjusting the bed friction (Manning coefficient) and dispersion coefficient. Results of successive iterations of the model were visually compared with the calibration data to find the optimum bed roughness and dispersion coefficient within the model.

The Manning coefficient applied in the model is fundamentally a calibration parameter and is the primary mechanism for calibrating the hydrodynamic model. Manning coefficients are typically within the range of 0.02 to 0.06 for rivers. A Manning coefficient of 0.04 achieved a good fit and was used for the entire model.

The longitudinal dispersion coefficient is a crucial calibration parameter for 1D water quality modelling. The same methodology was implemented to determine the optimum dispersion coefficient in which several iterations of the model were run. After results were compared to the field data, to see which presented the best visual fit, a dispersion coefficient of 5 m^2 /s was chosen as achieving best fit.

Model Calibration Results

Hydrodynamic Calibration

The hydrodynamic component of the River Stour model was calibrated through visual comparison with field data collected at the EA Plucks Gutter gauge. Figure 7 shows the results with a Mannings Coefficient of 0.04. The results show that the model is underpredicting flows compared to the observed data but is considered to provide an acceptable level of fit. As the method of gauging at this site is not known it is not possible to determine its accuracy and whether any difference between model and observation is due to the model or the method of flow measurement. The model clearly reproduces the shape of the flow hydrograph and trend in the flow over time. The timing of the change in flow direction as the tide turns, which will be important to connectivity, is also well reproduced and the magnitude of the flow is predicted reasonably well.

The river flow at this location is both negative and positive as the gauge is within the tidal section of the river. The gauge at this location will measure the direction of flow which will change depending on the direction of the tide.

Water levels in the River Stour model were validated by the Shoothill GaugeMap source of data, by visually comparing the water levels in the two datasets. The results of this comparison showed the model to be much more closely matched with the water levels than the flows. Throughout the five year period of the model run the modelled water level is consistently within 5 cm of the observed level. The modelled range in water levels (0.339 m) was also compared to the GaugeMap range (0.418 m) which gave good agreement, with only a small difference of 0.019 m (1.9 cm).

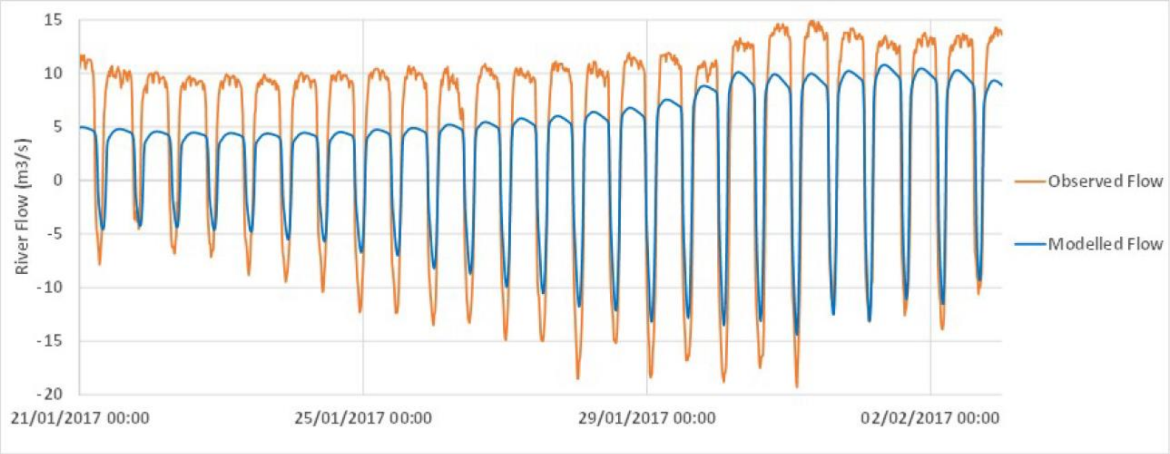

Figure 7. Model Results compared to Plucks Gutter Gauge

Note: due to tidal influence at the gauge, negative flows are recorded indicating the river is flowing in the opposite direction.

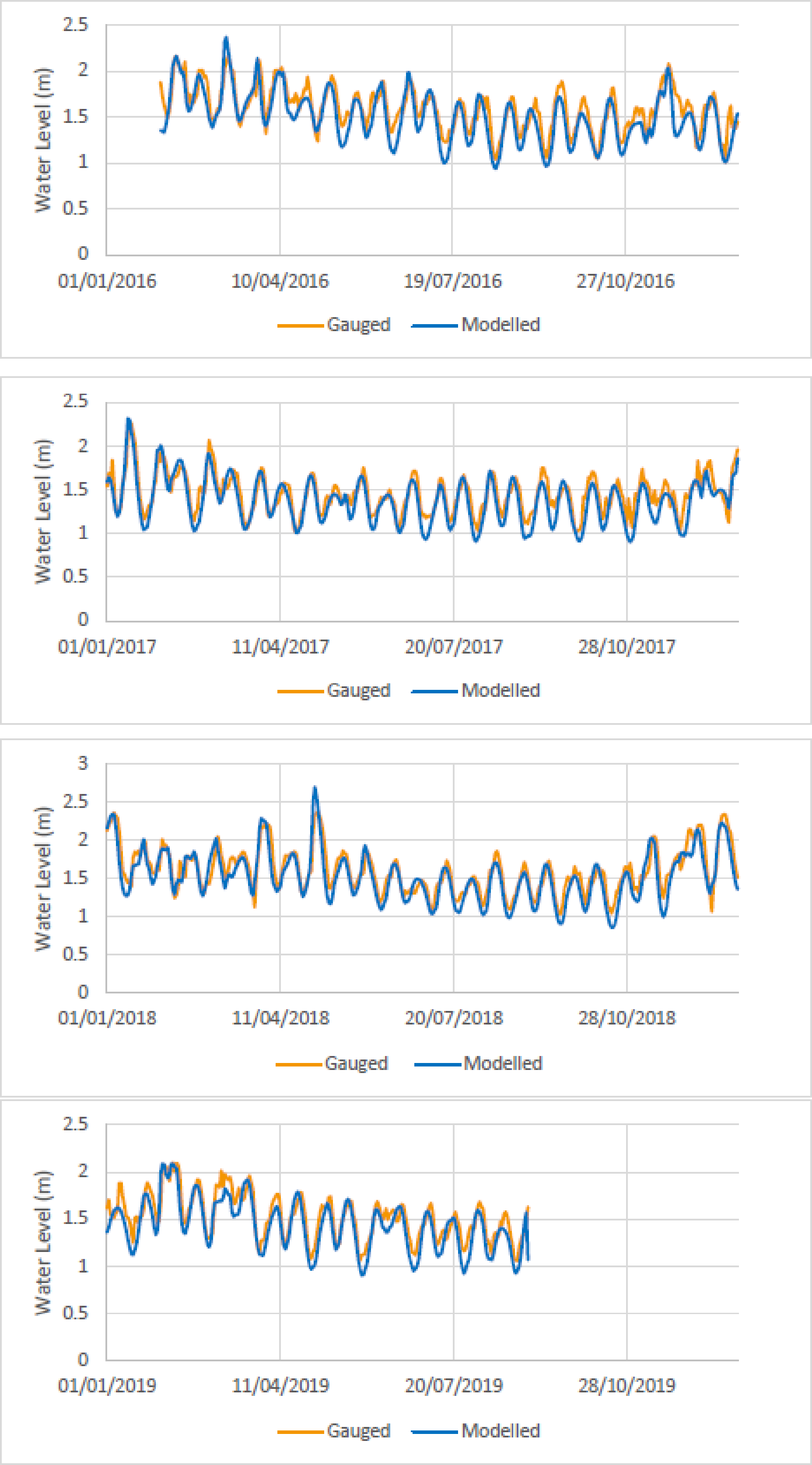

Figure 8. Model water levels compared to Grove Ferry

Advection-dispersion Calibration

The advection-dispersion component of the River Stour model was calibrated through visual comparison with the field data collected by WIMS. The WIMS data is a long-term dataset of spot samples. However, sample frequency is relatively low and not sufficient to allow statistical comparison. Figure 9 and Figure 10 show two spot sample salinities from the WIMS dataset compared to the modelled salinity. These, and the other spot sample data, indicate that the model predicts the range of salinities observed in the river over a tidal cycle and the transport of salt into the estuary and river due to tidal forcing.

The model was validated against a series of CTD profiles undertaken by APEM, in March 2021. Figure 11 shows the model is predicting the observed low salinity over the survey period. There is an offset between model and observed data of 0.5 ppm, this is well within acceptable tolerance and may be due to an instrument offset or the effects of dissolved chemicals other than salt that can affect conductivity measurement.

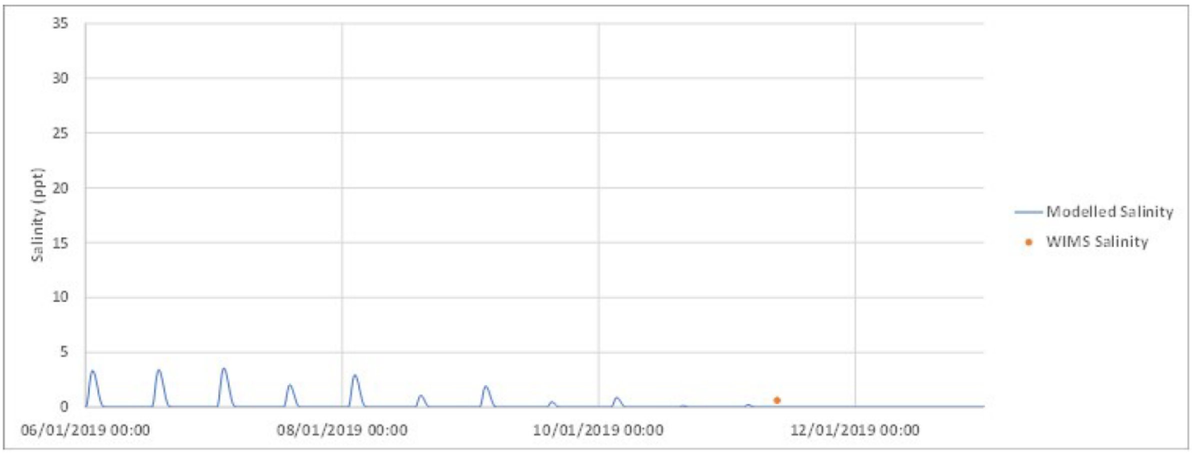

Figure 9. WIMS Salinity data compared to Stour River Model During Low Tide at Sandwich Toll Bridge

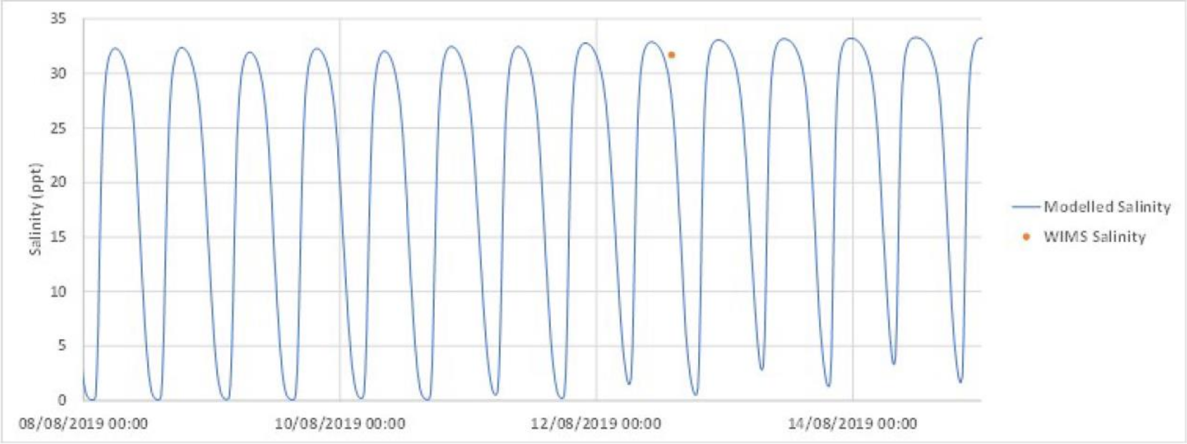

Figure 10. WIMS Salinity Data Compared to Stour River Model During High Tide at Sandwich Toll Bridge

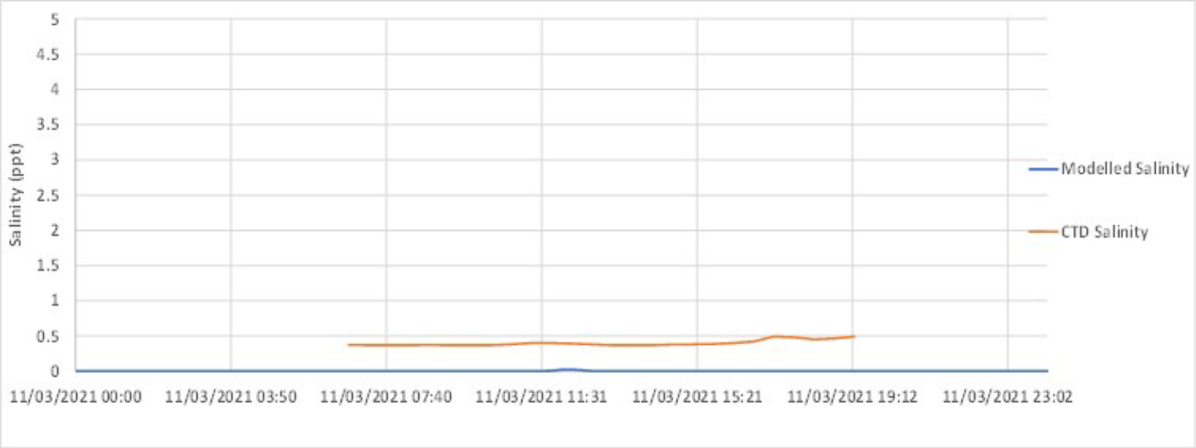

Figure 11. APEM Salinity Data Compared to River Stour Model at Sandwich Toll Bridge

Appendix 2 Stodmarsh additional hydraulic modelling

Modelling approach

Following a meeting with Natural England additional modelling and analysis of the total nitrogen (TN) and total phosphorous (TP) load arriving at the NNR lake and Hersden tidal lake was carried out. This assessment builds on the work previously undertaken to assess impacts from Dambridge WTW at the NNR lake.

For the modelling assessment we used the same MIKE11 model as used previously. This is a fully dynamic model developed specifically for the purpose of modelling the discharge from the Dambridge WTW, which was calibrated and validated against measured data. The model was agreed with Natural England as being appropriate for the previous study and for the additional assessment.

The model represented the time-varying flow in the river (including the river flow and tidal influence) and modelled the advection, dispersion and dilution of any source / discharge into the river, including specifically the discharge of TN and TP from Dambridge WTW. The discharge from Dambridge WTW was modelled with a uniform daily average flow and constant concentration of TN and TP, based on the permit information. The inputs from the WTW were agreed with Dover District Council (DDC).

It should be noted that the outfall from Dambridge WTW is approximately 7km upstream of the model’s upstream boundary on the Little Stour. However, this was modelled as if it discharges at the model boundary, which is a conservative, yet reasonable approach, since there will be very little loss of TN or TP in reality between the actual outfall location and the modelled location.

The model outputs have been interrogated to determine the TN and TP load arriving at the selected points within the model reach. The load was calculated as a timeseries by multiplying the volume of water in the river by the concentration of TN and TP on each timestep. As TN and TP is assumed to be fully mixed through the model ‘cell’, this will provide a valid prediction of the load at each timestep.

The model was run for three years, and the annual average TN and TP loads arriving at the two assessment points were calculated from the modelled timeseries. The model was run in a conservative mode, i.e. no decay or loss terms (e.g. representing uptake by plants) was included. The TN and TP load discharged from Dambridge WTW therefore remained in the river system, unless lost at the downstream tidal boundary to the sea.

Modelling results

The results of the additional modelling are presented below. Note: the following results are based on a report issued by Intertek.

Additional modelling has investigated the connectivity between Dambridge waste water treatment works (WwTW) and two new locations which are shown in Figure 12: the sluice gate which connects the main channel of the Great Stour to the NNR Lake and then the entrance to the Hersden Tidal Lake further upstream. This further modelling is to establish the total nutrient load that will reach the receptors annually.

Figure 12. River Stour model and new extraction locations

Two scenarios were modelled for each location: the 2022 and 2040 population for total phosphorous (TP) and total nitrogen (TN) at permit levels. The details for the model input values for Dambridge WwTW that were provided by Dover District Council and Southern Water and are shown in Table 5.

Table 5. Local Plan Nutrient Budget Figures (SWS)

Scenario	Population	Wastewater (l/day)	Permit conditions (mg/l)	
			Nitrogen	Phosphorus
2022	14,318	1,718,160	27	2
2040	20,523	2,462,808	27	0.25

The Stour Model was amended to include the new nutrient levels by inputting the WwTW as an upstream boundary. Four runs have then been completed. One run for the two nutrients over the two scenarios. The model outputs were a time series in 15-minute intervals of concentration of nutrients to reach the receptors and through calculations these were converted into an annual mass per year (kg per year).

The results indicate the total load that reaches the sluice gate at the entrance to the NNR Lake is extremely low (Table 6). To demonstrate this, the total population for both scenarios and the annual wastewater nutrient load (calculated using NE Stodmarsh calculator) for both scenarios have been used to calculate a nutrient load per person. When compared to the modelled outputs the predicted impact from Dambridge WwTW is approximately equivalent to less than 0.001 persons contribution per year. This arises from a modelled PE of over 20 000 in the 2040 scenario.

When it is considered that this overall load would have to be diluted through the total water volume available in the lake in order to compare it to the compliance standard, it is clear that there is no impact.

Table 6. Model results for the sluice gate at the entrance to the NNR Lake

Scenario	TP (kg per year)	TN (kg per year)
2022	0.00004	0.00054
2040	0.00001	0.00080

The results of the modelling for Hersden Tidal Lake show that there is no connectivity from Dambridge WwTW (Table 7).

Table 7. Model results at the entrance to Hersden Tidal Lake

Scenario	TP (kg per year)	TN (kg per year)
2022	0	0
2040	0	0