Bure Loop Dredging Scenario Technical Note

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Contents

1. Introduction 4
1.1 Report Outline and Background 4
1.2 Scope and Objective of the Report 5
1.3 Limitations of this study 6
2. Data and Quality Review 8
2.1 Introduction 8
2.2 Bathymetry Data 8
2.3 History of Dredging 9
2.4 Gauge Data 13
3. Broadlands Model Set Up 16
3.1 Introduction 16
3.2 Software and Model Parameters 16
3.3 Model Boundaries 16
4. Broadlands Dredging Methodology 17
4.1 Derivation of Dredged Cross Sections 17
4.2 Additional Dredging Cost Calculation 20
5. Model Results 23
5.1 Introduction 23
5.2 Design Event Profiles 25
5.3 October 2023, Storm Babet Event 30
6. Conclusions 35

1. Introduction

1.1 Report Outline and Background

This report describes results from a sensitivity test looking at the effect of dredging on water levels and flood risk along an 8km section of the River Bure known as the 'Bure Loop'. The sensitivity test was requested by the Environment Agency and Broads Authority upon consultation with local stakeholders. This follows the autumn and winter of 2023/24 when the Upper Thurne embankments were overtopped and extensive and long-lasting flooding occurred. Local stakeholders have suggested the bed levels along the Bure Loop do not allow the upper reaches of the Broads system to drain sufficiently.

The study is made possible by the Broadland Futures Initiative (BFI) which is a partnership for future flood risk management in the Broadland area. The main goal of the partnership is to agree a framework for future flood risk management that better copes with our changing climate and rising sea level. BFI is being delivered in a phased approach with the current 'Phase B' looking at producing a hydrological and hydraulic model of Broadland to help flood risk management policy and implementation measures, with consideration for the next 100 years. It is the new Broadlands model that has been used for this study.

The 'Bure Loop' is not strictly defined but refers to a segment of the Bure between Three Mile House (TG 50440 09516) and the confluence with the River Yare (TG 51927 07959) which bends from an east-west orientation to a north-south orientation. Indicative extent of the Bure Loop is included in Figure 1.

In addition to the mapping produced by the Broads Authority of water depth and sediment accumulation, a group of local stakeholders facilitated by the Water Level Management Alliance also identified areas where conveyance could be improved by dredging, shown in Figure 2. This figure also shows water depth for navigation, below mean low water level, from 2021 bathymetry survey undertaken by the Broads Authority. Note the Broads Authority dredge the channels on a regular basis (as per the sediment management prioritisation process outlined in the Waterways Management Strategy, section 4.1 https://www.broads-authority.gov.uk/__data/assets/pdf_file/0028/438607/Waterways-Management-Strategy-Action-Plan-2022-27.pdf). The target water depth or Waterways Specification set by the Broads Authority for the River Bure is 2.0 m below mean low water. Note that Waterways Specifications are set for navigation purposes only.

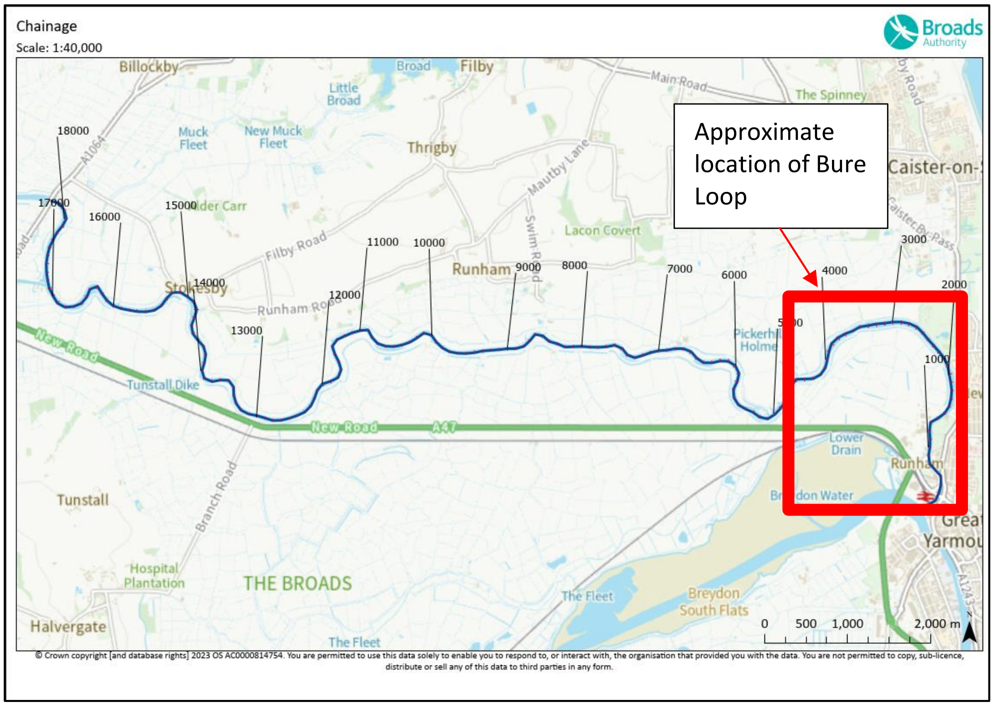

Figure 1: Lower Bure Chainage distances as provided by the Broads Authority. The Bure Loop is considered to be between chainage 0m (Confluence of River Bure and River Yare at Great Yarmouth) and chainage 4500m.

1.2 Scope and Objective of the Report

This report has been produced in response to the Environment Agency and Broads Authority request to use the new BFI Broadlands hydraulic model to investigate the possible benefit of additional dredging in the lower section of the Bure for flood risk management purposes.

This report illustrates the data used as part of this study, the methodology undertaken and the results of capital dredging below the normal standard of maintenance for navigational access in the lower Bure. The scope of works is:

- Estimate impact on river levels and flood risk of additional dredging activities along the Bure Loop through modification of the Broadlands model for three scenarios
    - Scenario 1: Baseline
    - Scenario 2: Bed levels set to -2.5mAOD.
    - Scenario 3: Bed levels set to -3.0mAOD.

Note both Scenario 2 and Scenario 3 use a bed slope of 2:1 from the current rond level[1] to the base of the channel. Existing bed levels below -2.5/ -3mAOD (depending on scenario considered) remained unchanged.

[1] Ronds are the areas of low lying land which lies between the river and the floodbank.

Scenario 2 and Scenario 3 were tested for a range of design events listed below:

- Fluvial (present day) – 50%, 20%, 5%, 1% Annual Exceedance Probability (AEPs) (downstream boundary MHWS)
- Tidal (present day) – MHWS, 5%, 1% AEPs (baseflow fluvial boundary)
- Fluvial (2040)- 50%, 1% AEP
- Tidal (2040)- 1% AEP

Additionally, the Environment Agency requested a test to understand how capital dredging would have impacted flooding for the October 2023 Storm Babet event without fully recalibrating the model. Upon consultation with the Environment Agency, the October 2023 event was represented using observed data at Great Yarmouth for the downstream boundary and 2% AEP fluvial inflows (further details on rationale provided in Section 1.4).

1.3 Limitations of this study

The Broadlands hydraulic model is still under review prior to final acceptance at the time of writing this report. The model has been successfully calibrated against eight events, both fluvial and tidal. The River Bure showed the weakest calibration of all reaches but met the +/-0.15m tolerance levels and the model results show good replication of level gauges.

A full calibration exercise for the October 2023 storm event was not deemed proportional for the purpose of this dredging study due to analysis of rainfall and level data across the whole Broadlands model- a verification exercise using the 2% AEP event with observed tidal conditions was undertaken instead. Further details included in Section 2.4.

This study does not investigate the impact of additional dredging on water levels during low fluvial flows or drought conditions.

The modelling does not investigate the impact of additional dredging on salinity levels and the salinity regime within the Broads' river system.

The model assumes all pumping stations are under normal operation during all events, unchanged from the Broadlands baseline model. The Broadlands model assumes a 2025 baseline, which accounts for an uplift of 50% for pumping stations in the Upper Thurne in line with the Upper Thurne pumping station programme.

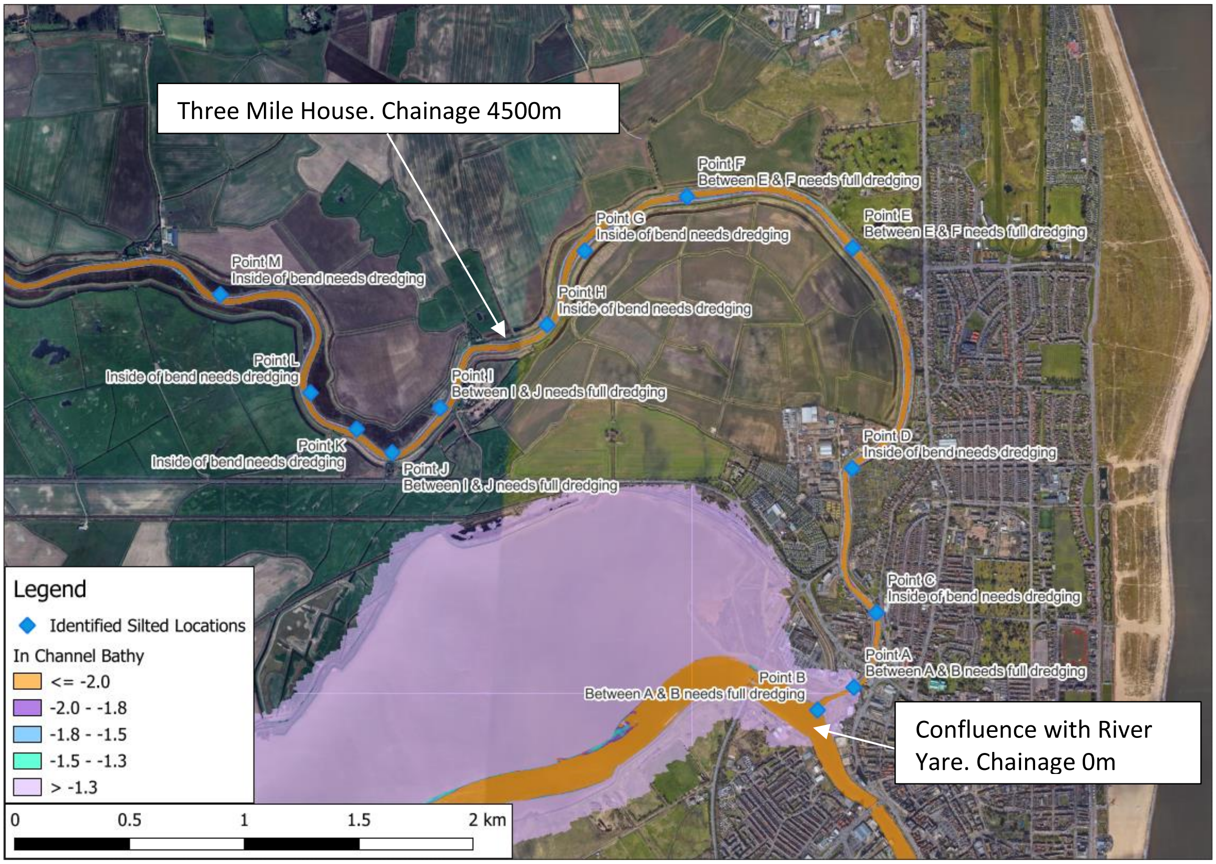

Figure 2: Locations identified by local stakeholders where conveyance could be improved along the Bure Loop. Note 'full dredging' indicates suggestion of dredging for whole channel width. Base mapping shows the water depths in metres below mean low water level, as used by the Broads Authority to drive their prioritization of maintenance dredging for navigation.

2. Data and Quality Review

2.1 Introduction

Beyond the data used as part of the Broadlands hydraulic model to date, the following datasets have been used in this study:

- Broads Authority Bathymetry Data (2021); Peel Ports Great Yarmouth Bathymetry Data (2022)
- Broads Authority History of Dredging (from 2005 to 2022)
- River Level Data for Great Yarmouth, Haven Bridge, Three Mile House, Breydon Bridge relevant to Storm Babet (October 2023)
- Cost estimates of dredging provided by the Environment Agency and Broads Authority

2.2 Bathymetry Data

The Broads Authority carries out a complete hydrographic survey of the navigable broads and rivers every five years. This is broken down into a rolling programme, with one fifth of the area surveyed every year. The most recent survey along the Lower Bure was supplied to JACOBS by the Broads Authority in 2021 and comprises of 1m gridded data, the survey was undertaken in 2019. As part of the Broadlands hydraulic model development methodology, the 2019 bathymetry was compared with existing model river channel cross-sections to confirm their continued use (please refer to ENV0001344C-JAC-ZZ-1PB-RP-HY-0010 for further details). Figure 3 shows bed levels in the hydraulic model (baseline, Scenario 2, Scenario 3) and bathymetry levels. The Broadlands model provides a static model in a system that is dynamic. The bed levels match the Broads Authority bathymetry data and the Broads Authority dredging level.

Whilst not directly impacting the Bure Loop dredging runs, it is worth noting the geometry of the River Yare in Great Yarmouth was based on the most recent bathymetry data from Peel Ports. The survey was undertaken in March 2022, and covers the River Bure between Vauxhall Bridge and the River Yare. The Third Crossing bridge and abutments are also included in the Broadlands model.

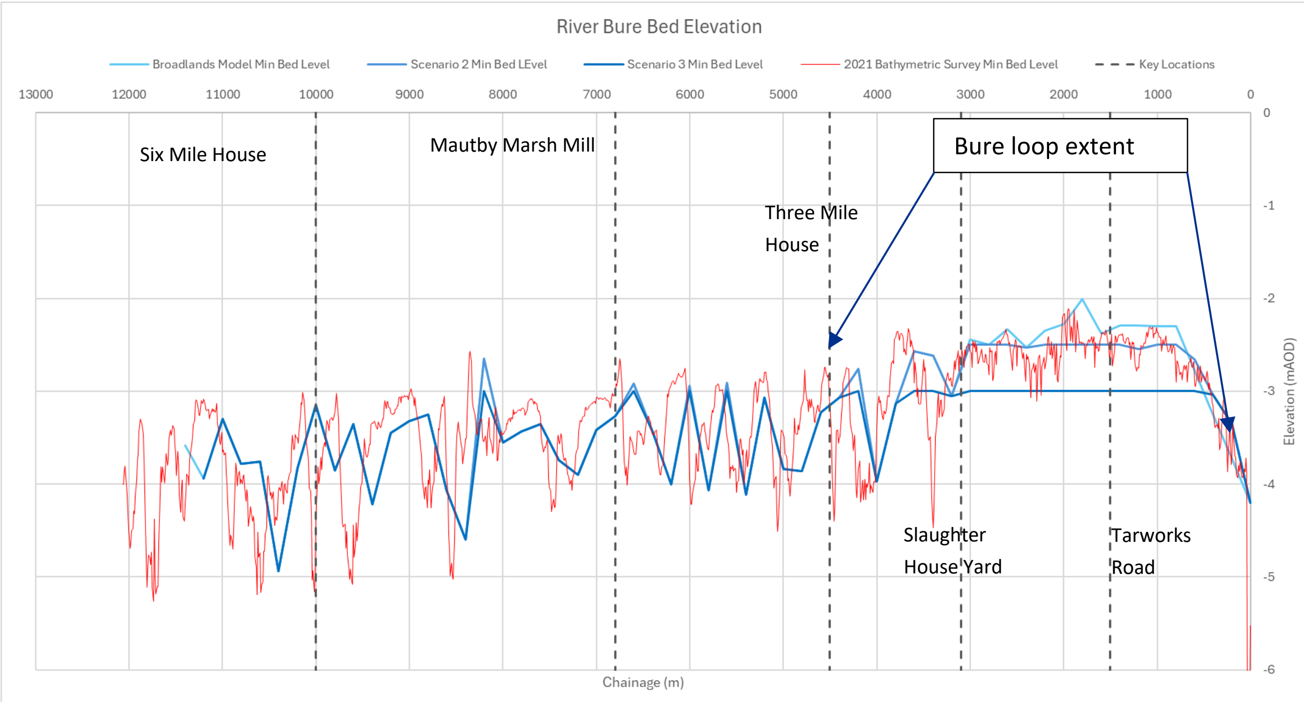

Figure 3: River Bure Bed Levels. 2019 bathymetry minimum levels highlighted in red.

2.3 History of Dredging

The River Bure is dredged by the Broads Authority in a priority based programme established through repeat hydrographic surveys and compliance with the Waterways Specifications, The Broads Authority's Waterways Specification along the Bure is 2.0 m below mean low water level (Figure 5) and is maintained for navigation purposes. It is understood each year around 40,000m^3 of material is removed annually across the Broads as part of the dredging projects.

A record from the Broads Authority of dredging activities is included in Table 1. The record confirms most stretches were dredged within the last 7 years with the exception of Acle- Six Mile House and Slaughter House Yard- Mautby Marsh Mill (with the latter lying within the Bure Loop extent). These locations meet the minimum draft levels of 2.0 m below mean low water level with most parts of the central channel and outside of bends being lower than that. Dredging locations are highlighted in Figure 4.

Table 1: List of Broads Authority dredging through the River Bure. Stretches relevant to the Bure Loop are highlighted in grey.

Dredging Reach	Last Dredge	Reach Extent
Juby's Farm - Hoventon Viaduct	2022/ 2023	Caen Meadow - Hoveton
Horning WW - Ranworth Dam	2016/ 2017	Blackhorse Broad - Ranworth Marshes
		Horning - Ranworth Dam
Acle Bridge - Stokesby	2015/ 2016	Acle Dyke - Mouth (Acle Straight)

Dredging Reach	Last Dredge	Reach Extent
Acle - Six Mile House	2013/ 2014	
Stokesby - Three Mile House	2017/ 2018, 2018/ 2019	
Slaughter House Yard - Mautby Marsh Mill	2011/ 2012, 2012/ 2013	
Tarworks Road - Mouth	2019/ 2020	
Mid Bure	2018/ 2019	
DS Acle Bends	2019/ 2020	Acle Boat Yard - Marsh Farm
Fleet Dyke	2007/ 2008, 2008/ 2009, 2019/ 2020	Fleet Dyke, Pilsons Green

Compliance with the targets for dredging was last reported to the Navigation Committee in October 2022 Waterways Specification Compliance report (Broads Authority). For simplicity the river stretches are broken down into management units for reporting. The two management units relevant to the Bure Loop are *Mautby Marsh Mill to Marina Quays* and *Marina Quays to Bure Mouth*.

The volume of dredging to achieve Waterways Specification of 2.0 m in these units is largely comprised of sediment accumulated on shoals on the insides of bends (see Figure 3), and a few areas on the very highest parts of the Bure Loop, where the bed level is within 2.0 m of the mean low water level, for example at the upstream end of Bure Park and along Tar Works Road.

Table 2 gives the dredge volumes to achieve Waterways Specification derived from the two main river surveys in 2019 and 2023, as well as an interim survey in 2022. It shows a steady accumulation of sediment since the last major dredge campaign in this area finished in 2018.

Table 2: Dredge volume (m^3) to achieve Waterways Specification

	2019 main river survey	2022 interim survey	2023 main river survey
Mautby Marsh Mill to Marina Quays	**16,420**	**17,330**	**23,670**
Marina Quays to Bure Mouth	**6,890**	**7,290**	**9,130**

From the 2023 hydrographic data (as per the map in Figure 3) the percentage non-compliance by area, of the two management units, was roughly 25% in each. Again, these areas of non-compliance are predominantly in the margins.

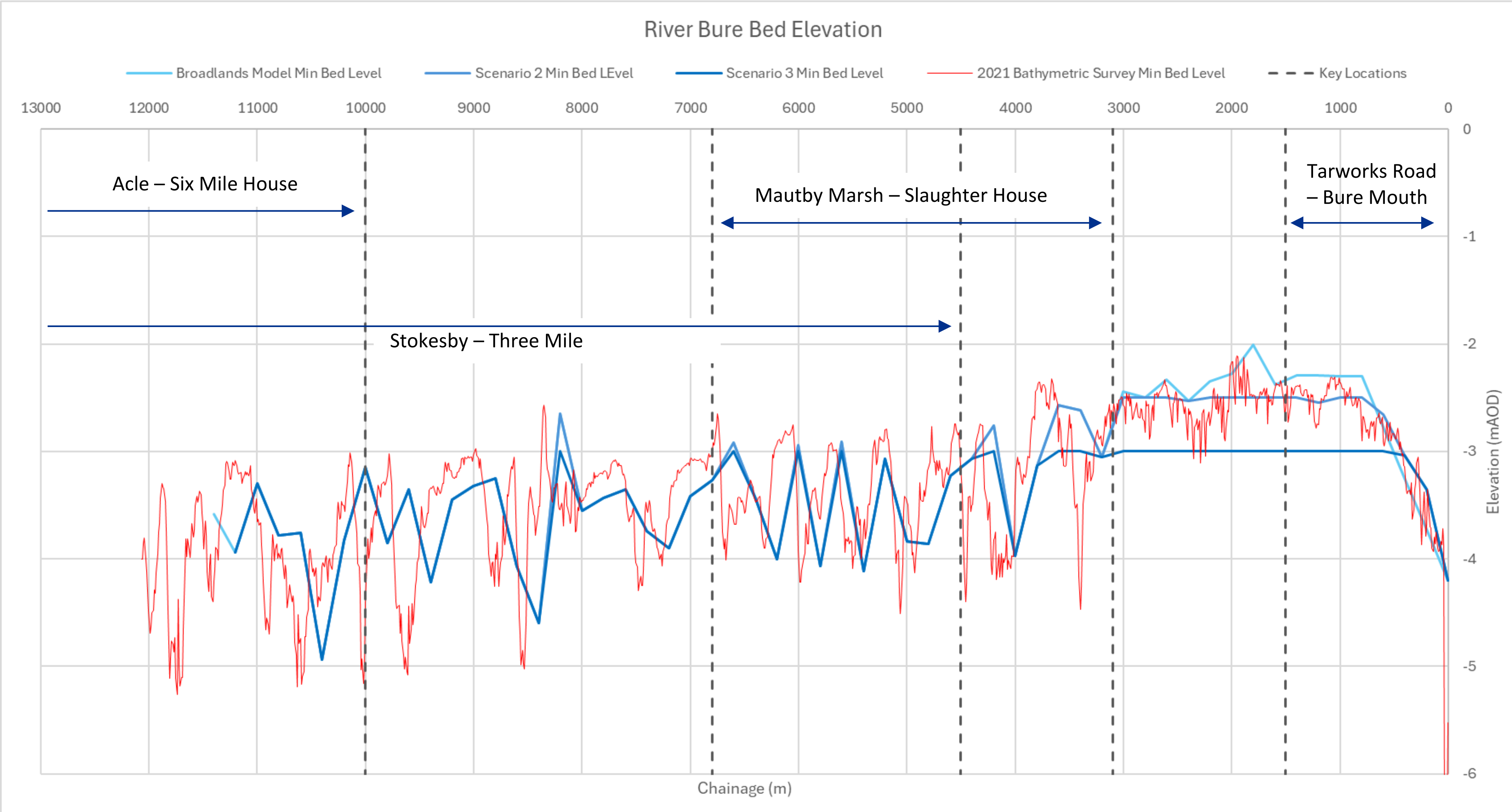

Figure 4: Broads Authority Dredge locations highlighted in Table 1.

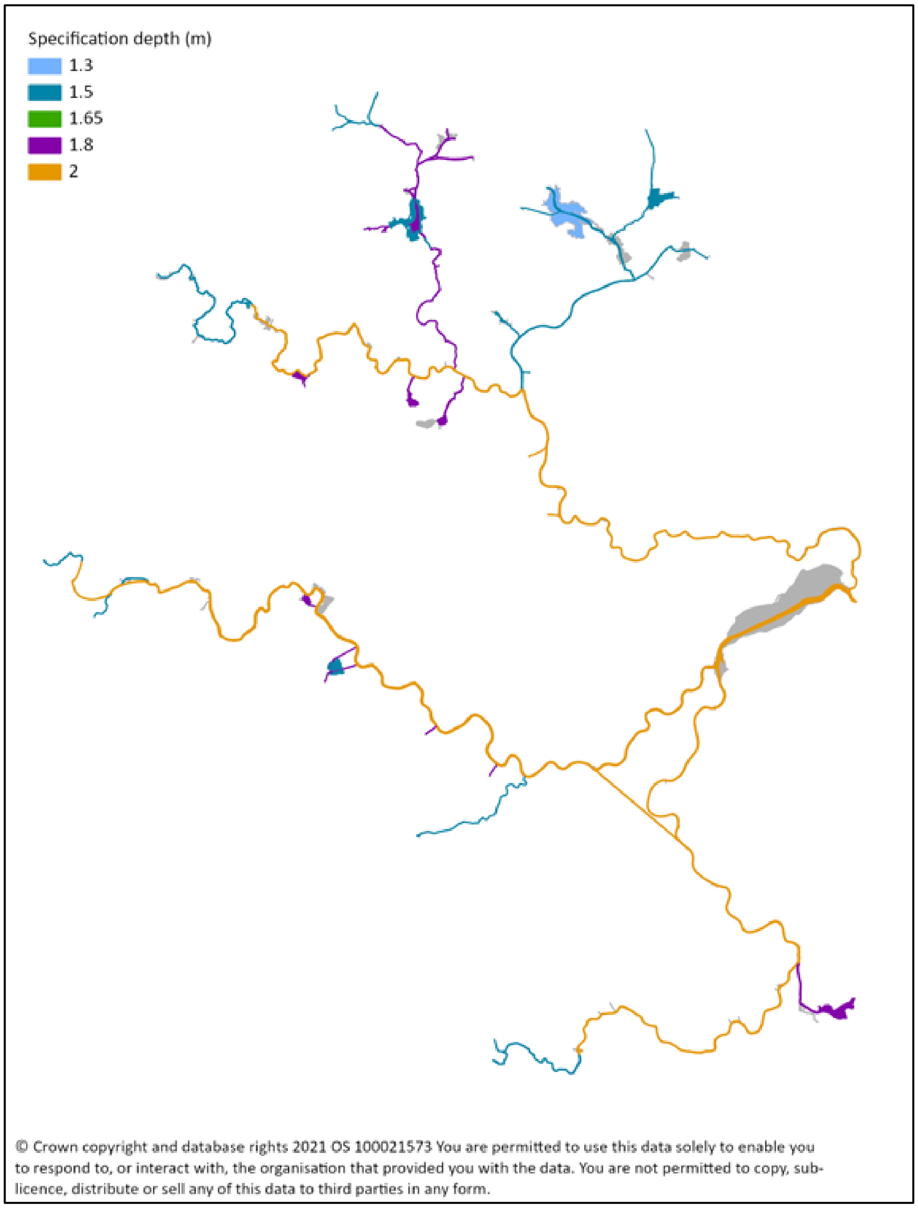

Figure 5: Broads Authority waterways specification depths for rivers and broads. https://www.broads-authority.gov.uk/__data/assets/pdf_file/0028/438607/Waterways-Management-Strategy-Action-Plan-2022-27.pdf.

2.4 Gauge Data

As part of this study, a verification exercise was undertaken using observed data for the October 2023 Storm Babet event at selected level gauges (Figure 6). A high-level review of the gauge data is included in Table 3- the review confirmed good quality of observed data at all stations for the October 2023 event.

Great Yarmouth is the closest station to the Broadlands hydraulic model downstream boundary and was therefore used to derive the downstream boundary conditions for the October 2023 verification. Level for other stations were used for comparison between observed and modelled data.

Upon consultation with the Environment Agency, it is understood rainfall depths for the October 2023 event at Acle closely align with rainfall depths for the 2% AEP design event for a range of storm durations (reported in Table 4). It is worth noting the critical storm duration for the model at this location is 65 hours.

To derive this the Environment Agency used extracts observed rainfall from the event at Acle and analyses the rarity of the event. The observed rainfall during the October 2023 event was the most significant rainfall event, further rainfall events over winter 2023-24 being smaller than this.

Table 3: Level stations considered as part of the October 2023 verification exercise

Gauge	Coordinates	% of 'GOOD' quality data
Great Yarmouth	TG 5057009524	100
Haven Bridge	TG 5349403822	100
Three Mile House	TG 5161208028	100
Breydon Bridge	TG5219807513	100

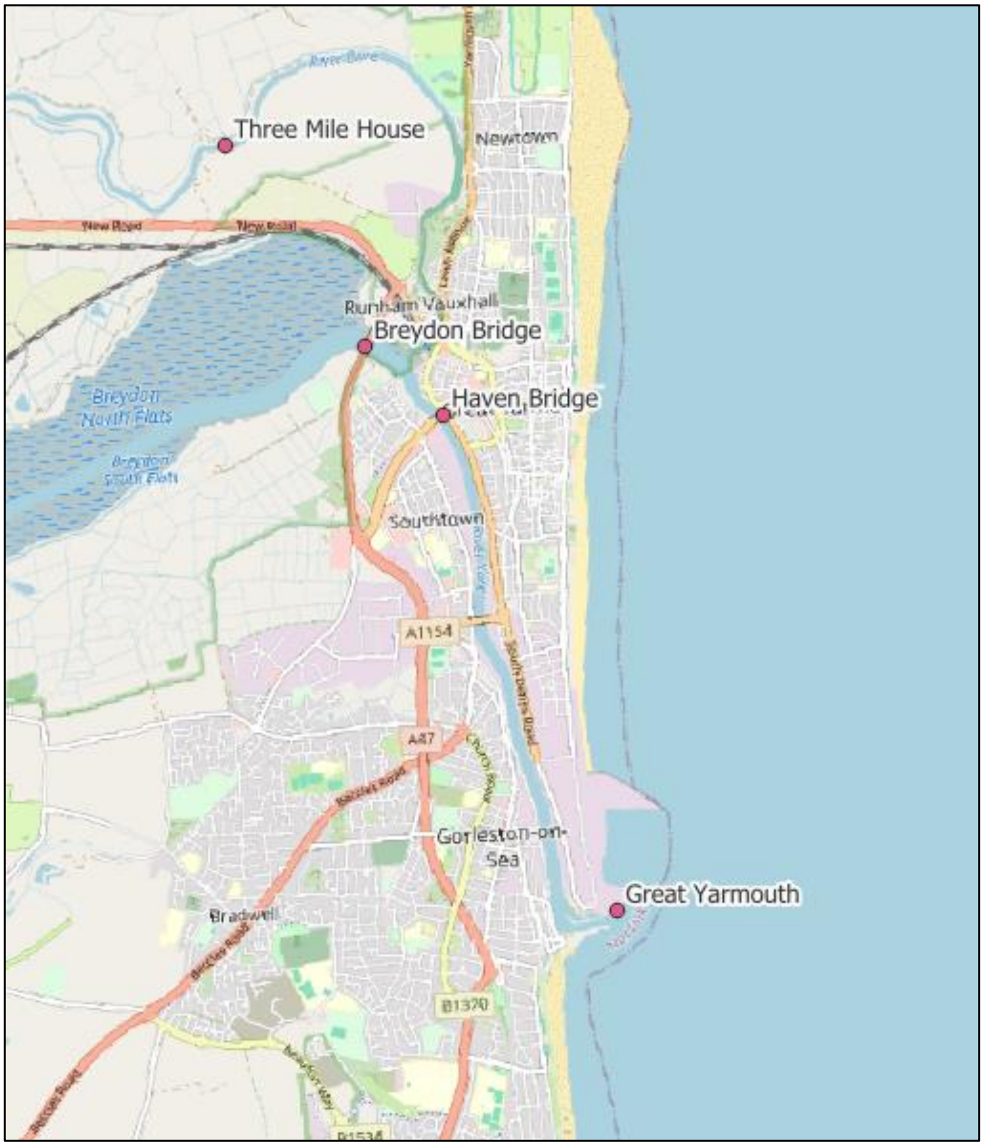

Figure 6: Location of level gauges considered for October 2023 verification exercise

Table 4: Rainfall depths during the Storm Babet event and the event rarity (Annual Exceedance Probability).

Storm Duration	AEP (%)	Rainfall Depth (mm)
6	4	51.14
12	2	70.27
18	2	78.27
24	2	84.4
36	2	93.31
64	2	104.83

3. Broadlands Model Set Up

3.1 Introduction

The Broadlands hydraulic model has been used to run the dredging scenario simulations. The model build methodology is set out in ENV0001344C-JAC-ZZ-1PB-RP-HY-0004; updates to the model include updates to embankment levels, additions of floodplain structures and floodplain schematisation.

The Broadlands model has been successfully calibrated using eight events between 2007 and 2022.

At the time of writing this report, the model and associated deliverables are currently under review by the Environment Agency and independent consultants ahead of final acceptance therefore further alterations to the model may occur.

3.2 Software and Model Parameters

Flood Modeller 6.1 has been used for this study. The model runs use double precision.

The model was run in an unsteady scenario. All parameters used for the simulations are consistent with the Broadlands model design runs as listed in ENV0001344C-JAC-ZZ-1PB-RP-HY-0004.

3.3 Model Boundaries

Model inflow boundaries comprise of design fluvial inflows generated as part of the BFI Phase B modelling. The downstream boundaries consist of a tidal boundary at Great Yarmouth and is based on observed data.

Climate change uplifts for 2040 events were set up as follows:

- **Fluvial flows:** 14% higher central uplift in line with the EA Guidance "Peak river flow climate change allowances by management catchment"[2].

- **Tidal levels:** 0.3m upper end uplift in line with the EA Sea Level allowances[3].

The Storm Babet, October 2023, simulations have been set up using the observed Great Yarmouth gauge levels and a 2% AEP fluvial inflow on the basis that Storm Babet was recorded as being a 2% AEP rainfall event at Acle.

[2] Peak river flow climate change allowances by management catchment. https://www.gov.uk/government/publications/peak-river-flow-climate-change-allowances-by-management-catchment
[3] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

4. Broadlands Dredging Methodology

4.1 Derivation of Dredged Cross Sections

For each scenario the cross sections and bed levels along the Bure Loop (as identified in Figure 1) were lowered to -2.5mAOD and -3.0mAOD for Scenario 2 and Scenario 3 respectively. The channel is defined using the points between the rond level rather than the embankments.

To preserve a stable bank a 2:1 slope was maintained for each cross section. Due to uncertainty over the stability of the sheet piles through Great Yarmouth it has been assumed that the current silt level at the sheet piles is maintained and the 2:1 slope starts at that level.

Examples of the changes to the cross sections are shown in Figure 7 - Figure 12 below together with change in cross sectional area caused by the additional dredging. Appendix D includes a comparison between locations of potential silt accumulation identified by local stakeholders. It is noted that model cross sections largely match the Broads Authority’s Waterways Specification depths, with a gradual bank slope to the rond/banktop level.

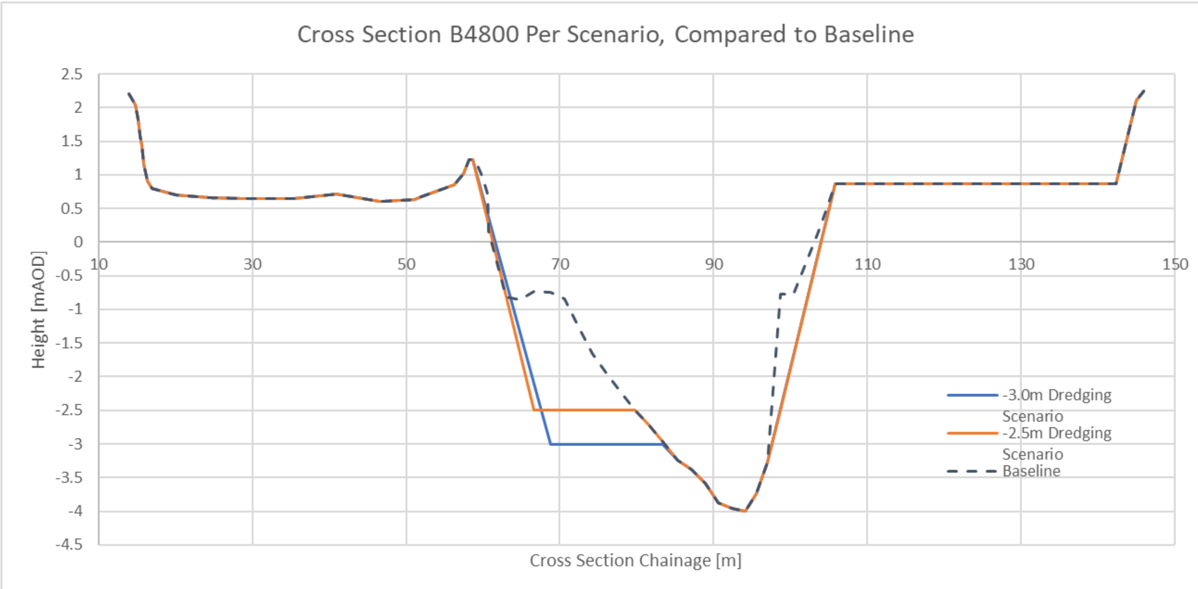

Figure 7: Plot of B4800 bed profile.

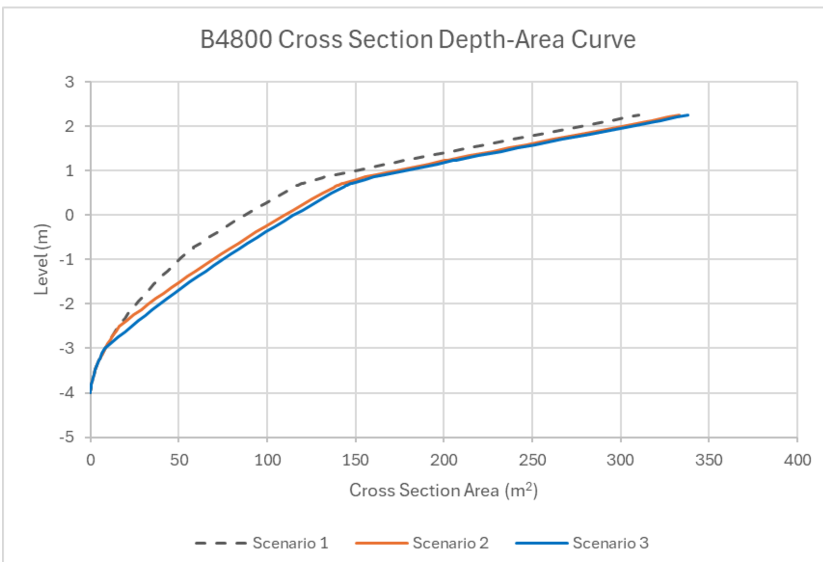

Figure 8: Cross Sectional Area for B4800. The scenarios provide an additional 20m^2 at 0mAOD.

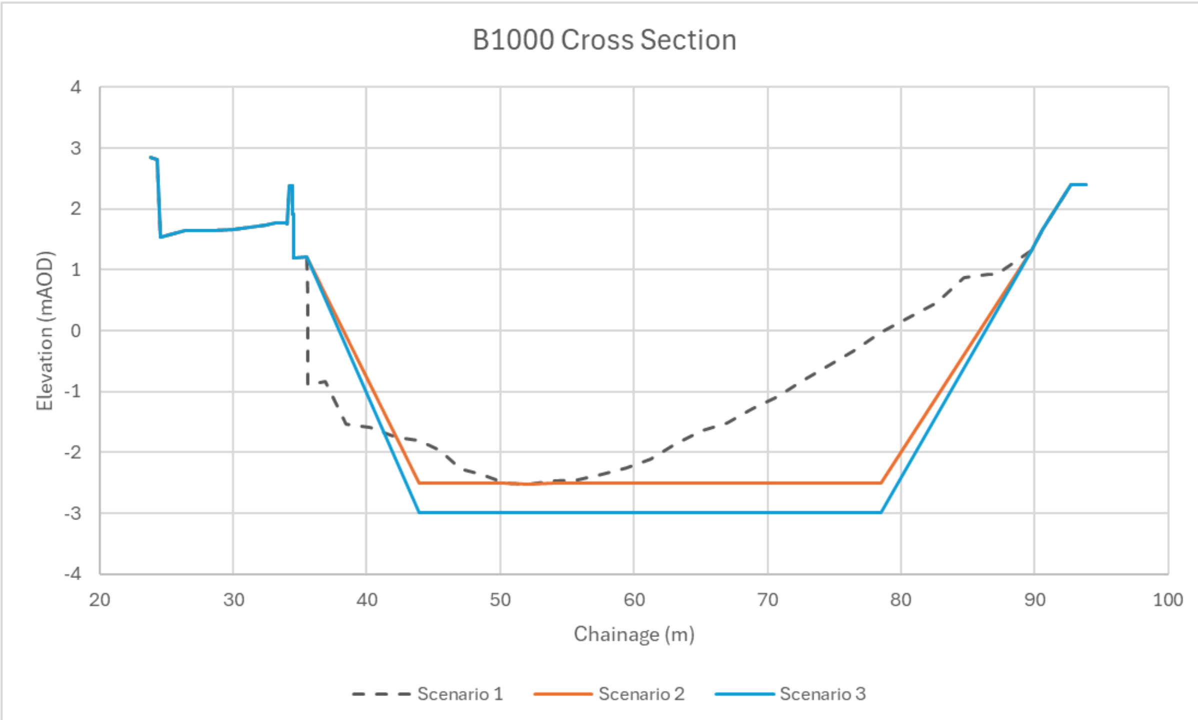

Figure 9: Cross Section of B1000, located at Bure Park.

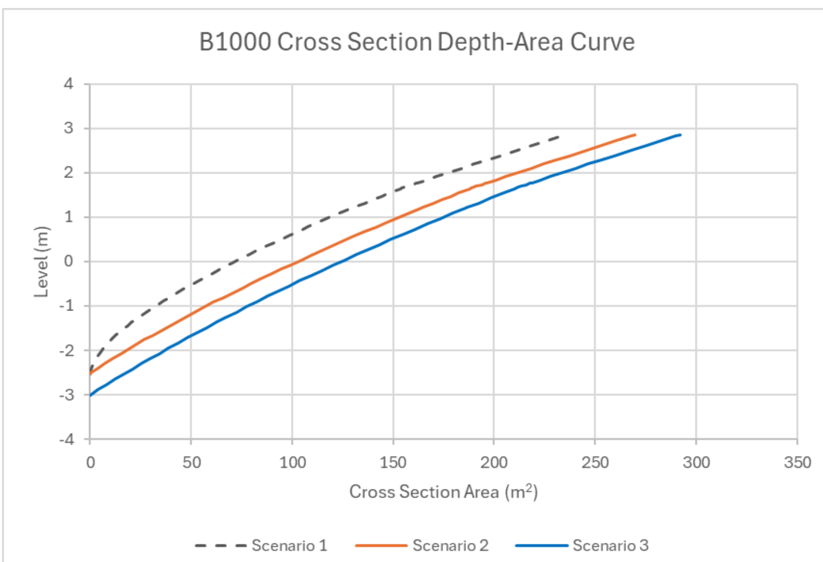

Figure 10: Cross Sectional Area for B1000. Scenario 2 cross section contains an additional 35m^2 and scenario 3 cross section contains an additional 56m^2.

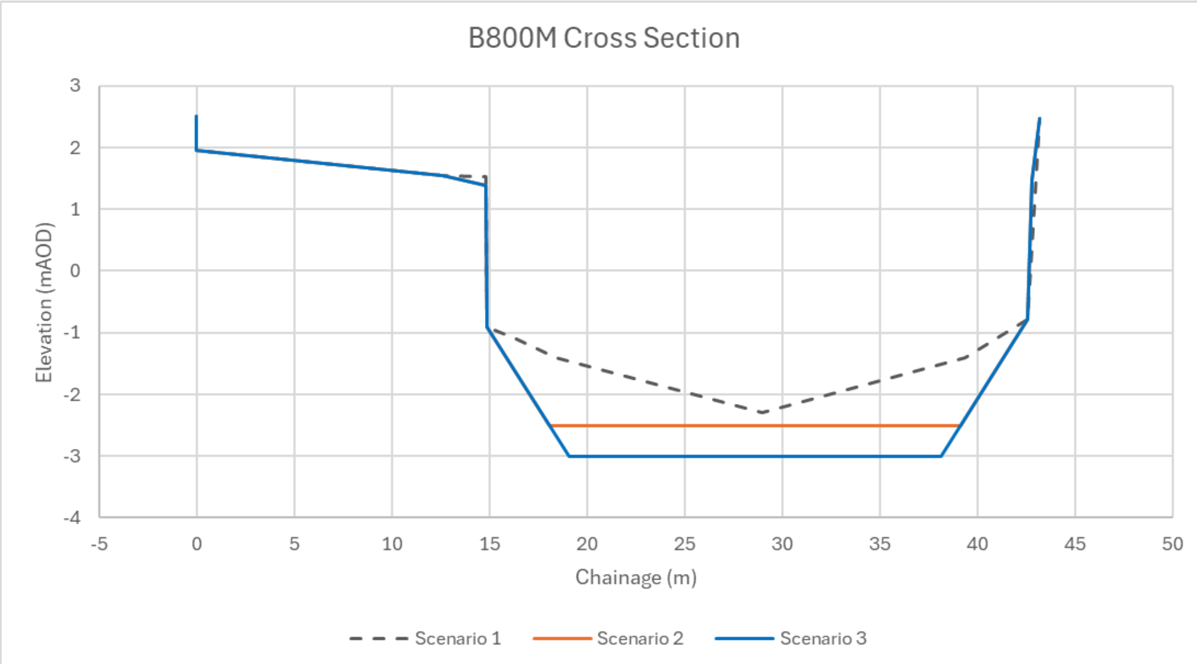

Figure 11: Cross Section of B800M, located in Great Yarmouth with sheet pile banks.

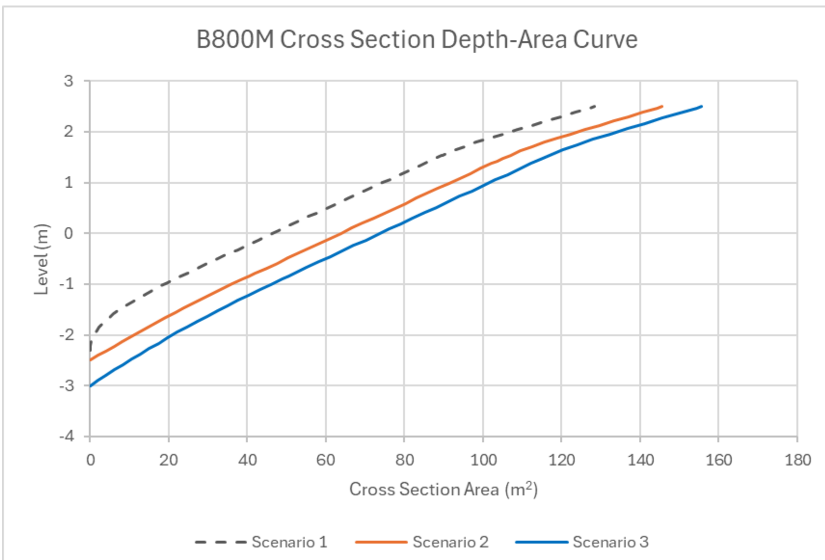

Figure 12: Cross Sectional Area for B800M. Scenario 2 cross section contains an additional 17m^2 and scenario 3 cross section contains an additional 27m^2.

4.2 Additional Dredging Cost Calculation

Following the updates to the cross section profiles, the total dredged volume has been calculated as follows:

- Calculate the area of each cross section using numerical integration (per scenario, including baseline)
- Subtract area of the corresponding baseline cross section from each of the scenario cross sections; to get an area difference per cross section.
- Utilise numerical integration between area difference of two adjacent cross sections and distance to next; to obtain volume difference between each cross section and the downstream section.

The method used to derive the dredged cross section profiles produced a small positive volume difference for some cross sections. This occurred when the slope of 2:1 adds material to the cross section. To obtain a total volume removed, these positive values were discarded. Appendix A contains the calculations used to obtain the total volume removed, with the results detailed in Table 5.

The cost of dredging can be very variable depending on scheme specific factors such as the sediment removal method, whether working from the bank or using floating plant, and how the dredged material is disposed of. In order to try and provide a degree of certainty around the high levels costs, the Environment Agency approached it's own construction cost managers for an idea of costings and the Broads Authority based on the prices of its current dredging regime for navigational purposes.

Using information provided by the Environment Agency's construction cost managers and the Broads Authority an average unit rate of £23.46 per m^3 is used to calculate the cost of each dredging scenario in Table 5. The Environment Agency source is a 2015 study reviewing cost estimates for channel management. It suggests using £13.80 per m^3 for dredging that was based on information originating from the Broads Authority and verified by British Waterways data. The figure, which is a 2007 value has been brought up to a present day value of £19.50 per m^3 following which a multiplier of 20% has been added for contingency to give £23.40 per m^3.

The Broads Authority currently undertake dredging on the Broads for navigation purposes. Previous work on the lower Bure in 2018 cost £15.95 per m^3. This figure been brought up to today's value of £19.60 per m^3 and a 20% contingency added resulting in a cost of £23.52 per m^3 which is very close to the previous source. Obtaining similar prices from the two organisations provides a reasonable level of certainty in the values provided in this document however, the figures should still be used with caution because a detailed design process (including how the additional dredgings could be disposed of and the necessary environmental approvals) has not been followed.

Table 5: Table of removed volume and estimated cost from each dredging scenario using the average of the two cost information sources

Scenario	Required removed Volume (m^3)	Estimated Cost (£, @ £19.55/m^3)	Estimated Cost +20% (£, @ £23.46/m^3)
Scenario 2	114,123	£2,231,000	£2,677,000
Scenario 3	198,048	£3,872,000	£4,646,000

Assuming a repeat dredging cycle of 10 years including 2025[4], two dredges will be required up to 2040 (in line with the end of the first epoch in the BFI plan). Therefore, based on the costs in Table 5, additional cost of maintaining the dredged levels are:

- £5.4m for Scenario 2 (assuming no further inflation)
- £9.3m for Scenario 3 (assuming no further inflation)

The removed volume for both scenarios significantly exceeds the BA's average yearly dredged material from the whole Broadland network of 40,000m^3. It is unlikely that all the additional material could be placed on the embankments and if the material had to be transported and disposed of at landfill then evidence taken from the Somerset Levels indicates the price could more than double.

[4] ENV0001344C-JAC-ZZ-1PB-RP-HY-0010 Broadlands Hydraulics Methodology - Appendix C

5. Model Results

5.1 Introduction

The model has been run for the scenarios listed in Table 6. Each event has been run for 360hrs.

Table 6: Events simulated as part of this study

Tidal AEP (%)	Fluvial AEP (%)	Epoch	Scenario 1 (Baseline)	Scenario 2	Scenario 3	Run name (SC2 for Scenario 2, SC3 for Scenario 3)
MHWS	50 (Bure, Ant and Thurne) Baseflow (Yare, Waveney)	Present day	✓	✓	✓	Broads_Dredge_50_FBAT_65hrs_2025_CC3 Broads_Dredge_SC2_50_FBAT_65hrs_2025_CC3 Broads_Dredge_SC3_50_FBAT_65hrs_2025_CC3
MHWS	50 (Bure, Ant and Thurne) Baseflow (Yare, Waveney)	2040	✓	✓	✓	Broads_Dredge_50_FBAT_65hrs_2040_CCHC14 Broads_Dredge_SC2_50_FBAT_65hrs_2040_CCHC14 Broads_Dredge_SC3_50_FBAT_65hrs_2040_CCHC14
MHWS	20 (Bure, Ant and Thurne) Baseflow (Yare, Waveney)	Present day	✓	✓	✓	Broads_Dredge_20_FBAT_65hrs_2025_CC3 Broads_Dredge_SC2_20_FBAT_65hrs_2025_CC3 Broads_Dredge_SC3_20_FBAT_65hrs_2025_CC3
MHWS	5 (Bure, Ant and Thurne) Baseflow (Yare, Waveney)	Present day	✓	✓	✓	Broads_Dredge_5_FBAT_65hrs_2025_CC3 Broads_Dredge_SC2_5_FBAT_65hrs_2025_CC3 Broads_Dredge_SC3_5_FBAT_65hrs_2025_CC3
MHWS	1 (Bure, Ant and Thurne) Baseflow (Yare, Waveney)	Present day	✓	✓	✓	Broads_Dredge_1_FBAT_65hrs_2025_CC3 Broads_Dredge_SC2_1_FBAT_65hrs_2025_CC3 Broads_Dredge_SC3_1_FBAT_65hrs_2025_CC3
MHWS	1 (Bure, Ant and Thurne) Baseflow (Yare, Waveney)	2040	✓	✓	✓	Broads_Dredge_1_FBAT_65hrs_2040_CCHC14 Broads_Dredge_SC2_1_FBAT_65hrs_2040_CCHC14 Broads_Dredge_SC3_1_FBAT_65hrs_2040_CCHC14
MHWS	Baseflow	Present day	✓	✓	✓	Broads_Dredge_MHWS_T_2025_CCUE Broads_Dredge_SC2_MHWS_T_2025_CCUE Broads_Dredge_SC3_MHWS_T_2025_CCUE
5	Baseflow	Present day	✓	✓	✓	Broads_Dredge_5_T_2025_CCUE

Tidal AEP (%)	Fluvial AEP (%)	Epoch	Scenario 1 (Baseline)	Scenario 2	Scenario 3	Run name (SC2 for Scenario 2, SC3 for Scenario 3)
						Broads_Dredge_SC2_5_T_2025_CCUE Broads_Dredge_SC3_5_T_2025_CCUE
1	Baseflow	Present day	✓	✓	✓	Broads_Dredge_1_T_2025_CCUE Broads_Dredge_SC2_1_T_2025_CCUE Broads_Dredge_SC3_1_T_2025_CCUE
1	Baseflow	2040	✓	✓	✓	Broads_Dredge_1_T_2040_CCUE Broads_Dredge_SC2_1_T_2040_CCUE Broads_Dredge_SC3_1_T_2040_CCUE
October 2023	2	Present day	✓	✓	✓	Broads_Dredge_Oct_23 Broads_Dredge_SC2_Oct_23 Broads_Dredge_SC3_Oct_23
October 2023	2	2040	✓	✓	✓	Broads_Dredge_Oct_23_2040CC Broads_Dredge_SC2_Oct_23_2040CC Broads_Dredge_SC3_Oct_23_2040CC

5.2 Design Event Profiles

Difference in max peak river levels (i.e. the highest water level that occurs during an event) between Scenario 1 (baseline) and Scenario 2/ Scenario 3 are included in Table 7 and Table 8 respectively. The tables cover locations between Great Yarmouth and the upper reaches of the Rivers Bure, Ant and Thurne. The following sites: Haven Bridge, Breydon Bridge, Three Mile, Acle and Potter Heigham are located along watercourses with flood risk management assets, typically embankments present. The results show the following:

- Scenario 2 and Scenario 3 show that dredging results in a larger tidal range upstream of the Bure Loop, the tidal peaks experienced are higher and the minimum tidal levels are lower (Figure 13).
- Scenario 2 and Scenario 3 show that dredging results in increased peak water levels for the tidal events. For example, the increase in peak levels at Acle in the 5% AEP tidal event are 0.07m and 0.11m in scenarios 2 and 3 respectively. The higher water levels at Acle during this event remained contained within the flood embankments.
- Scenario 2 and Scenario 3 show either no change or a nominal decrease (up to 0.02m) in peak water levels for all fluvial events in the upper reaches of the Bure, Ant and Thurne.
- With climate change the impact of dredging on future peak water levels (both tidal and fluvial) remains very limited across the Bure catchment. The greatest differences in peak water levels are for tidal events in which increased dredging causes a water level increase of between 0.05m and 0.09m at Three Mile House.

The tables and hydrographs below are included in the spreadsheet in Appendix B.

Additional analysis was undertaken on the receding limb of the events to better understand if dredging would have a positive impact on drainage of the upper reaches. Results are included in Table 9 and Table 10 below for the end of the simulation while Figure 14 and Figure 16 show the difference in levels over time. Key points as follows:

- Conveyance for the Bure Loop in Scenario 2 and Scenario 3 is increased, meaning water levels at the end of the event are lower than in Scenario 1. This difference occurring after the event peak is most pronounced at low tide. It is not a large level reduction in the upstream locations, for example up to 0.05m at Wayford Bridge in the 1% AEP fluvial event (Figure 16) but is much more so at low tide in the lower river reaches (Figure 14) where the increased tidal range noted above is a further factor.
- Due to the flat nature of the Broadlands, the system remains slow in draining after additional dredging works (Figure 15).

Table 7: Peak level difference between Scenario 1 (baseline) and Scenario 2 (-2.5mAOD). Positive values indicate a higher level in Scenario 2. Sections in grey are located in Great Yarmouth.

Scenario 2 v Scenario1	Scenario 1 MHWS Peak Level (mAOD)	Present Day level difference (m)								2040 level difference (m)			
		MHWS	50% F	20% F	5% F	1% F	5% T	1% T	Oct-23	2040 50% F	2040 1% F	2040 1% T	2040 Oct-23
Haven Bridge	1.04	-0.01	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.01

Scenario 2 v Scenario1	Scenario 1 MHWS Peak Level (mAOD)	Present Day level difference (m)								2040 level difference (m)			
		MHW S	50% F	20% F	5% F	1% F	5% T	1% T	Oct-23	2040 50% F	2040 1% F	2040 1% T	2040 Oct-23
Breydon Bridge	1.06	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.01
Three Mile	0.86	0.04	0.02	0.02	0.01	0.01	0.07	0.06	0.05	0.02	0.01	0.05	0.05
Acle	0.58	0.01	0.00	0.00	0.00	0.00	0.07	0.05	0.02	0.00	0.00	0.04	0.02
Potter Heigham	0.48	0.00	-0.01	-0.01	-0.01	0.00	0.01	0.01	0.00	-0.01	0.00	0.01	0.00
Barton Broad	0.47	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Wayford Bridge	0.47	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Horning	0.51	0.00	-0.01	-0.01	-0.01	-0.01	0.01	0.01	0.00	-0.01	-0.01	0.01	0.00

Table 8: Peak level difference between Scenario 1 (baseline) and Scenario 3 (-3.0mAOD). Positive values indicate a higher level in Scenario 3. Sections in grey are located in Great Yarmouth.

Scenario 3 v Scenario1	Scenario 1 MHWS Peak Level (mAOD)	Present Day level difference (m)								2040 level difference (m)			
		MHW S	50% F	20% F	5% F	1% F	5% T	1% T	Oct-23	2040 50% F	2040 1% F	2040 1% T	2040 Oct-23
Haven Bridge	1.04	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.01
Breydon Bridge	1.06	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.01
Three Mile	0.86	0.06	0.04	0.03	0.03	0.02	0.12	0.11	0.09	0.04	0.02	0.09	0.09
Acle	0.58	0.02	0.00	0.00	0.00	0.00	0.11	0.07	0.03	0.01	0.00	0.06	0.03
Potter Heigham	0.48	0.00	-0.02	-0.01	-0.01	-0.01	0.02	0.02	0.00	-0.01	0.00	0.02	0.00
Barton Broad	0.47	-0.01	-0.01	-0.01	-0.02	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Wayford Bridge	0.47	-0.01	-0.01	-0.01	-0.02	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Horning	0.51	0.00	-0.01	-0.01	-0.01	-0.01	0.01	0.01	0.00	-0.01	-0.01	0.01	0.00

Table 9: End of Simulation (360hr) level difference between Scenario 1 (baseline) and Scenario 2 (-2.5mAOD). Positive values indicate a higher level in Scenario 2. Sections in grey are located in Great Yarmouth.

Scenario 2 v Scenario1	Scenario 1 MHWS End Level (mAOD)	Present Day level difference (m)								2040 level difference (m)			
		MHW S	50% F	20% F	5% F	1% F	5% T	1% T	Oct-23	2040 50% F	2040 1% F	2040 1% T	2040 Oct-23
Haven Bridge	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Breydon Bridge	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Three Mile	0.27	-0.03	-0.04	-0.05	-0.06	-0.07	-0.04	-0.04	-0.10	-0.04	-0.07	-0.04	-0.09

Scenario 2 v Scenario1	Scenario 1 MHWS End Level (mAOD)	Present Day level difference (m)								2040 level difference (m)			
		MHWS	50% F	20% F	5% F	1% F	5% T	1% T	Oct-23	2040 50% F	2040 1% F	2040 1% T	2040 Oct-23
Acle	0.36	-0.01	-0.02	-0.02	-0.04	-0.04	-0.01	-0.02	-0.02	-0.02	-0.03	-0.01	-0.02
Potter Heigham	0.38	-0.01	-0.02	-0.03	-0.04	-0.03	-0.01	-0.02	-0.01	-0.02	-0.03	-0.02	-0.01
Barton Broad	0.37	-0.01	-0.02	-0.03	-0.05	-0.03	-0.02	-0.02	-0.02	-0.03	-0.03	-0.02	-0.01
Wayford Bridge	0.37	-0.01	-0.02	-0.03	-0.05	-0.03	-0.02	-0.02	-0.02	-0.03	-0.03	-0.02	-0.01
Horning	0.41	0.00	-0.01	-0.02	-0.03	-0.03	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01

Table 10: End of Simulation (360hr) level difference between Scenario 1 (baseline) and Scenario 3 (-3.0mAOD). Positive values indicate a higher level in Scenario 3. Sections in grey are located in Great Yarmouth.

Scenario 3 v Scenario1	Scenario 1 MHWS End Level (mAOD)	Present Day level difference (m)								2040 level difference (m)			
		MHWS	50% F	20% F	5% F	1% F	5% T	1% T	Oct-23	2040 50% F	2040 1% F	2040 1% T	2040 Oct-23
Haven Bridge	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01
Breydon Bridge	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.02
Three Mile	0.27	-0.05	-0.06	-0.07	-0.09	-0.11	-0.06	-0.06	-0.16	-0.06	-0.11	-0.06	-0.14
Acle	0.36	-0.01	-0.02	-0.03	-0.05	-0.05	-0.02	-0.02	-0.03	-0.03	-0.05	-0.02	-0.02
Potter Heigham	0.38	-0.01	-0.02	-0.03	-0.05	-0.04	-0.02	-0.02	-0.02	-0.03	-0.04	-0.02	-0.01
Barton Broad	0.37	-0.01	-0.03	-0.03	-0.06	-0.05	-0.02	-0.02	-0.02	-0.04	-0.04	-0.02	-0.02
Wayford Bridge	0.37	-0.01	-0.03	-0.03	-0.06	-0.05	-0.02	-0.02	-0.02	-0.04	-0.04	-0.02	-0.02
Horning	0.41	0.00	-0.01	-0.02	-0.04	-0.04	-0.01	-0.01	-0.02	-0.02	-0.03	-0.01	-0.01

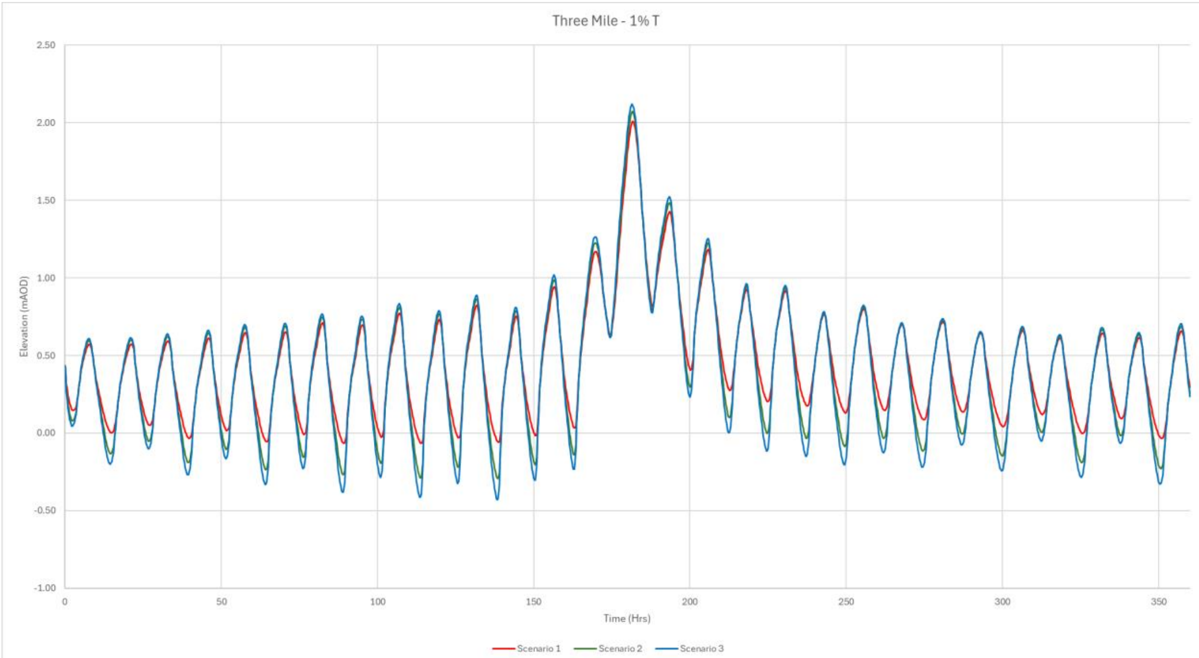

Figure 13: Water Levels for Three Mile House Tidal 1% AEP.

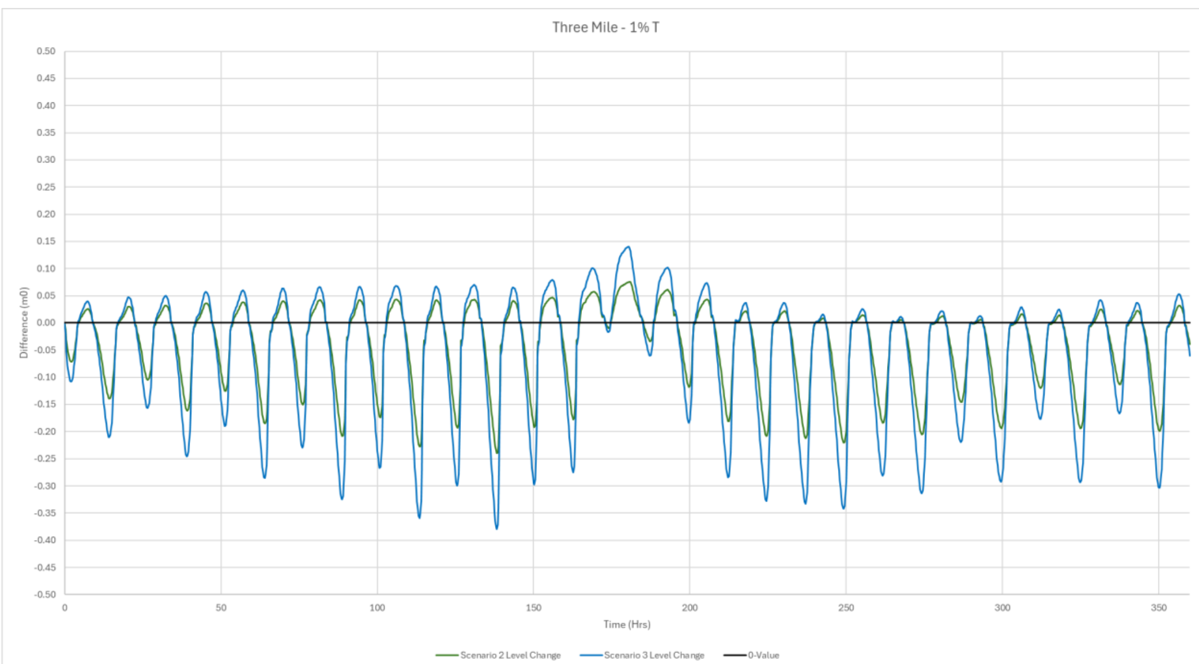

Figure 14: Difference in water levels for Three Mile House Tidal 1% AEP. A positive value indicates increased water levels in the scenarios.

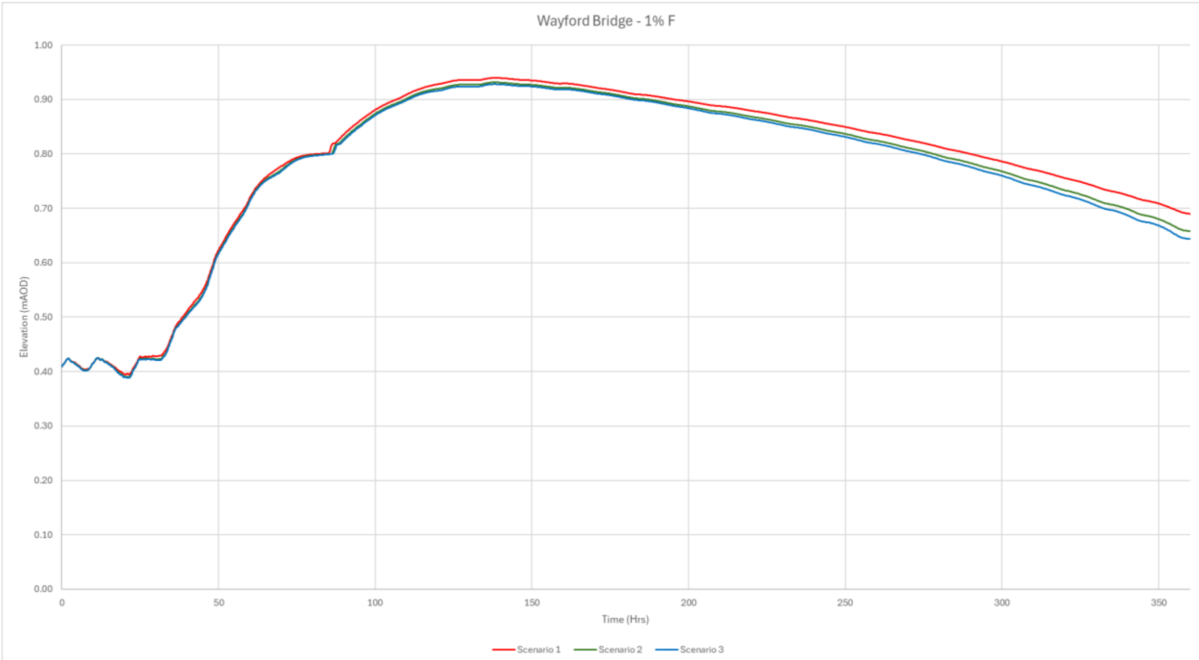

Figure 15: Water Levels for Wayford Bridge Fluvial 1% AEP.

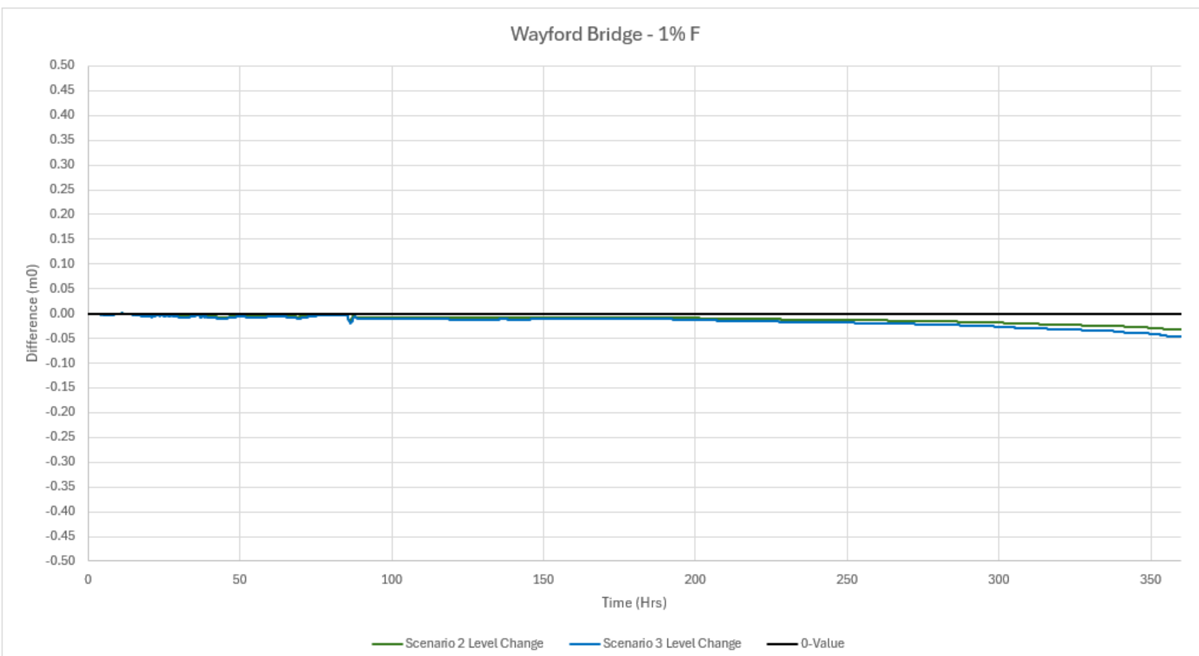

Figure 16: Difference in water levels for Wayford Bridge Fluvial 1% AEP. A positive value indicates increased water levels in the scenarios.

5.3 October 2023, Storm Babet Event

The results of the October 2023 simulation (Table 7 - Table 10) show no benefit of additional dredging on water levels along the Bure Loop with Scenario 1 (baseline) showing the lowest peak levels. Peak water levels at Three Mile and Acle are increased by 0.09m and 0.03m respectively (Table 7, with no differences elsewhere in the system. The results indicate a peak water level of 0.9mAOD at Potter Heigham (Figure 19), an area of particular interest. This level is at flood embankment top within the model and indicates a limited amount of overtopping of the banks and flooding of the adjacent marshes. In reality flooding within the Thurne catchment occurred shortly after Storm Babet following Storm Cieran. This point illustrates that for the purpose of this study the model was set up based on some relatively broad assumptions and while the results are sufficiently accurate in order to draw lessons, they may not exactly mirror what happened.

The maps in Appendix C show the maximum extent of modelled flooding for Scenarios 2 and 3 compared with Scenario 1, together with any difference in maximum flood depth. The majority of the reach is unaffected (level differences between 0.01m and -0.01m) by dredging. For both scenarios there is a reduction in flood depth in some places, mainly within the range 0.01-0.10m, largely in the Upper Thurne and more than 0.15m for a small area at the mouth of the Ant for Scenario 3. There is no significant reduction in flooding extent for either Scenarios 2 or 3.

The end of simulation results show a reduced water level (figures below), indicating the additional dredging scenarios allow a greater transfer of water through the Bure Loop. The differences in level are less than 0.05m for all locations and events aside from Three Mile House.

Comparison of Scenario 1 against the gauge data at Three Mile House (Figure 17) shows a good match of the peak level at 46hr. Results between 50hrs and 200hrs show gauge data below model data, this can be attributed to the use of design inflows. The last 100hrs of simulation match well against gauge data.

Using climate change uplifts on the October 2023 event indicate that for a similar event in 2040 will produce limited dredging benefits, with increased water levels around Three Mile House and Acle.

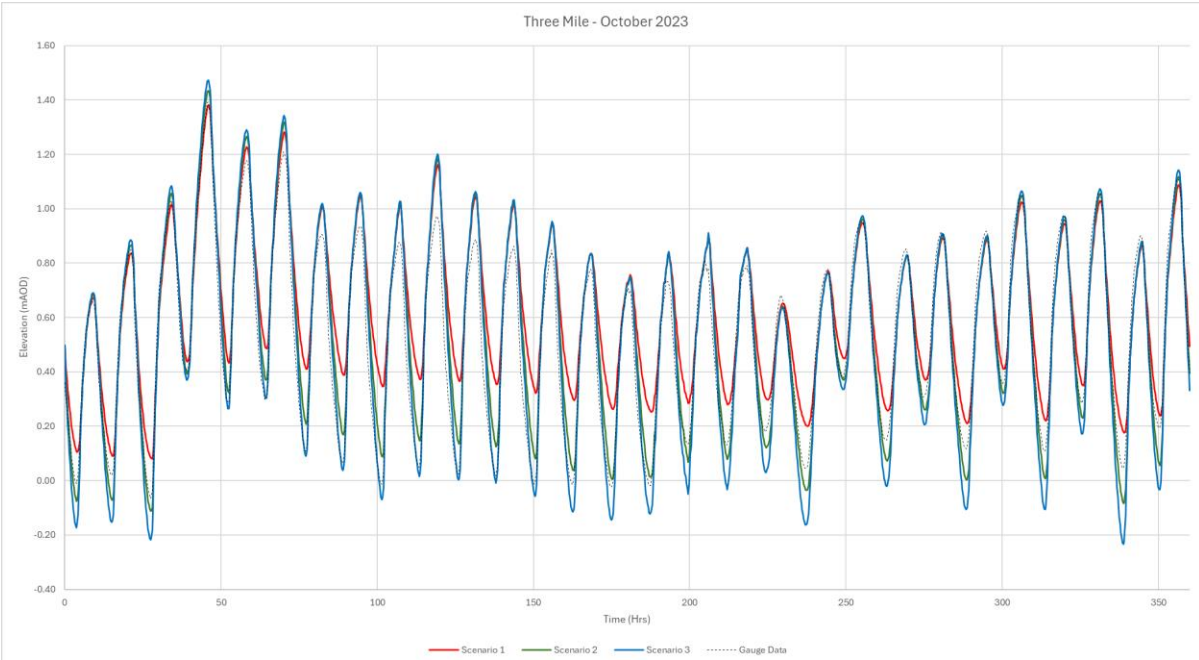

Figure 17: Water levels for the simulated October 2023 event at Three Mile House including Gauge Data.

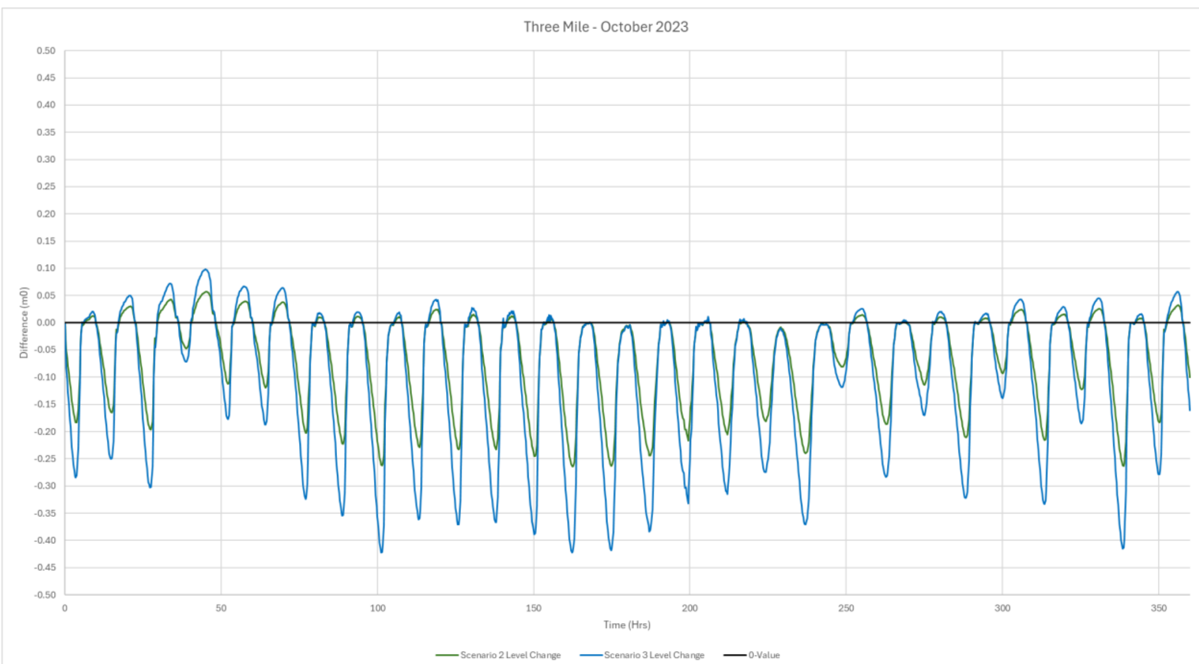

Figure 18: Difference in Water levels for the simulated October 2023 event at Three Mile House. A positive value indicates increased water levels in the scenarios.

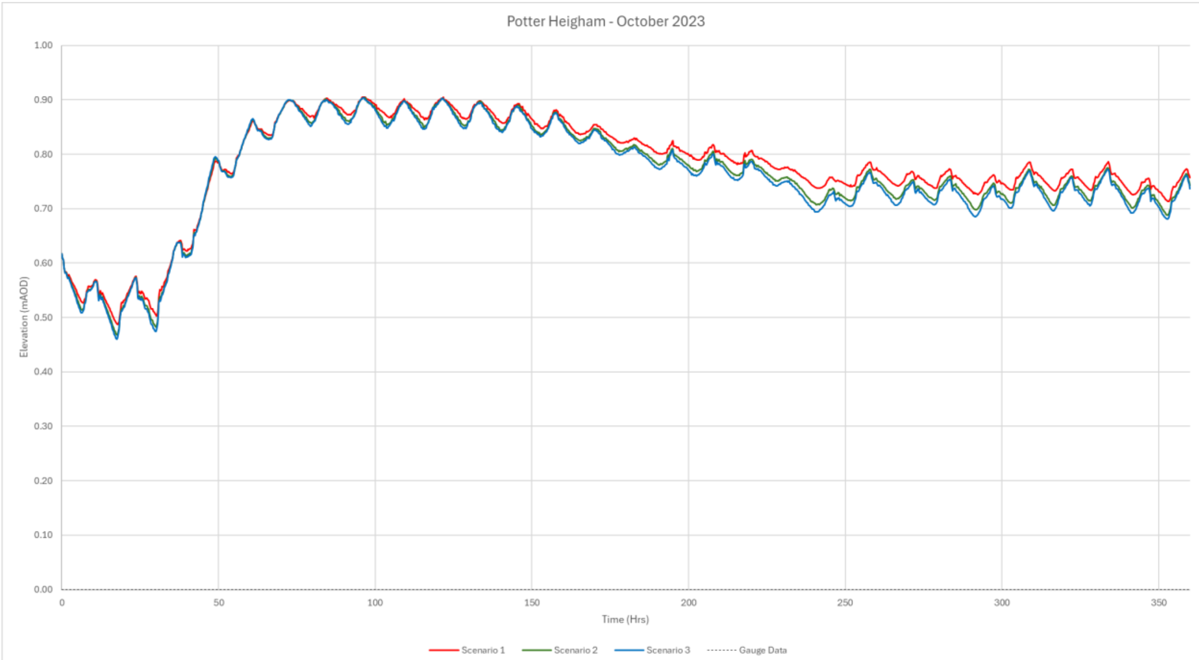

Figure 19: Water levels for the simulated October 2023 event at Potter Heigham.

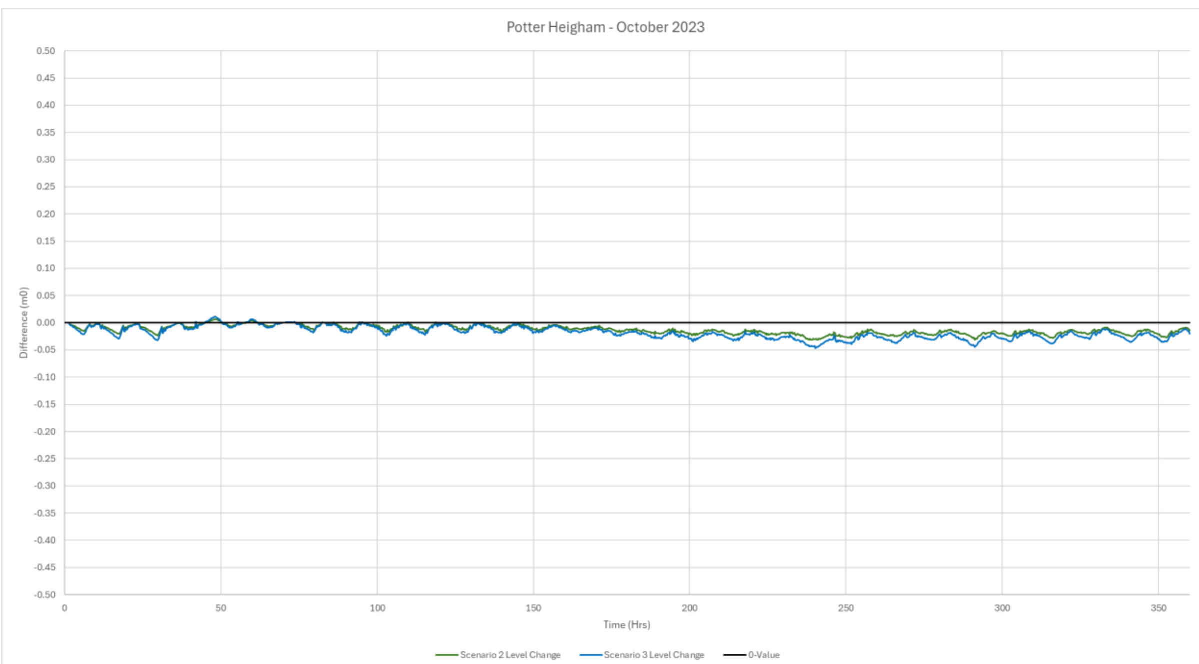

Figure 20: Difference in Water levels for the simulated October 2023 event at Potter Heigham. A positive value indicates increased water levels in the scenarios.

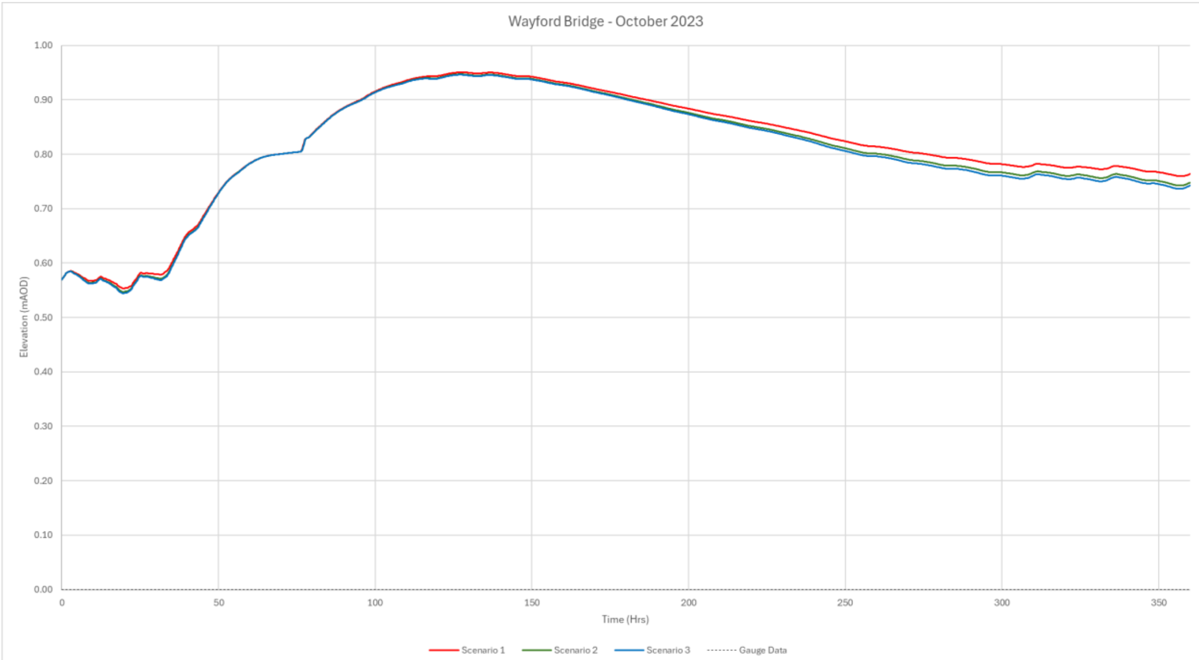

Figure 21: Water levels for the simulated October 2023 event at Wayford Bridge.

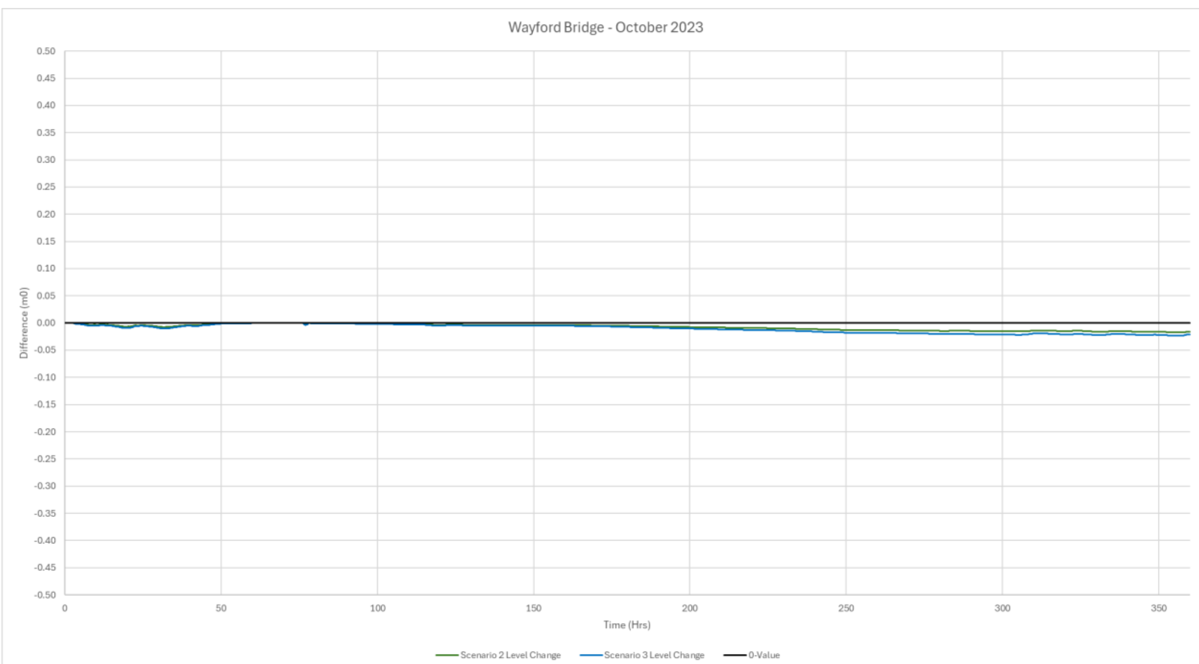

Figure 22: Difference in Water levels for the simulated October 2023 event at Wayford Bridge. A positive value indicates increased water levels in the scenarios.

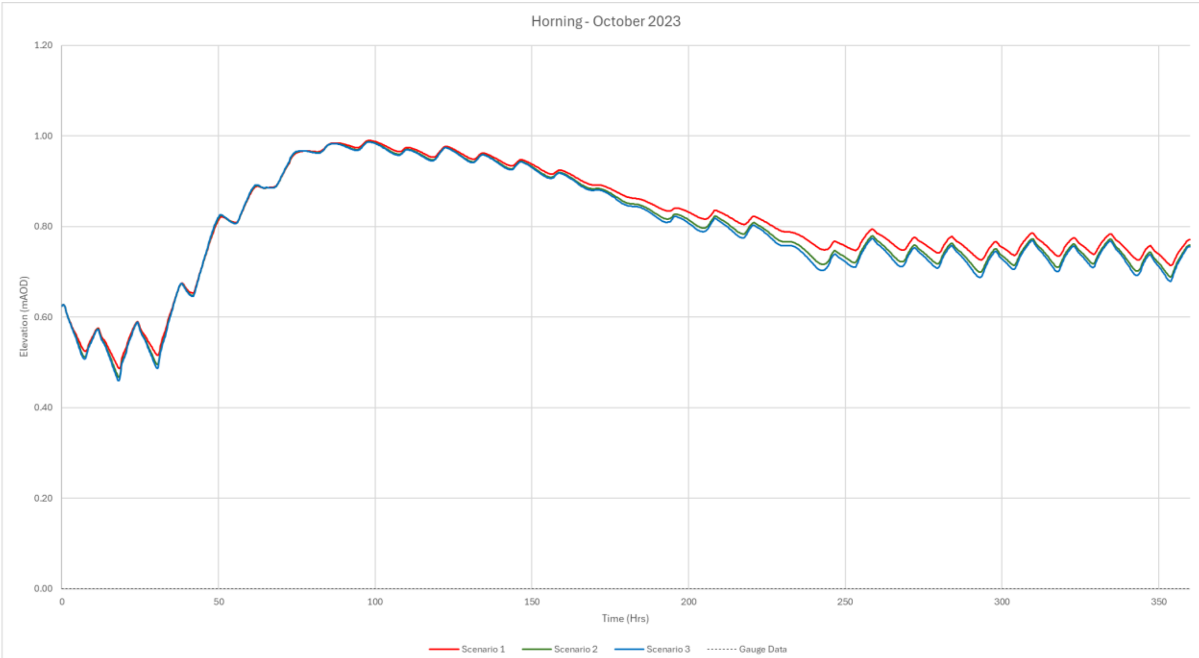

Figure 23: Water levels for the simulated October 2023 event at Horning.

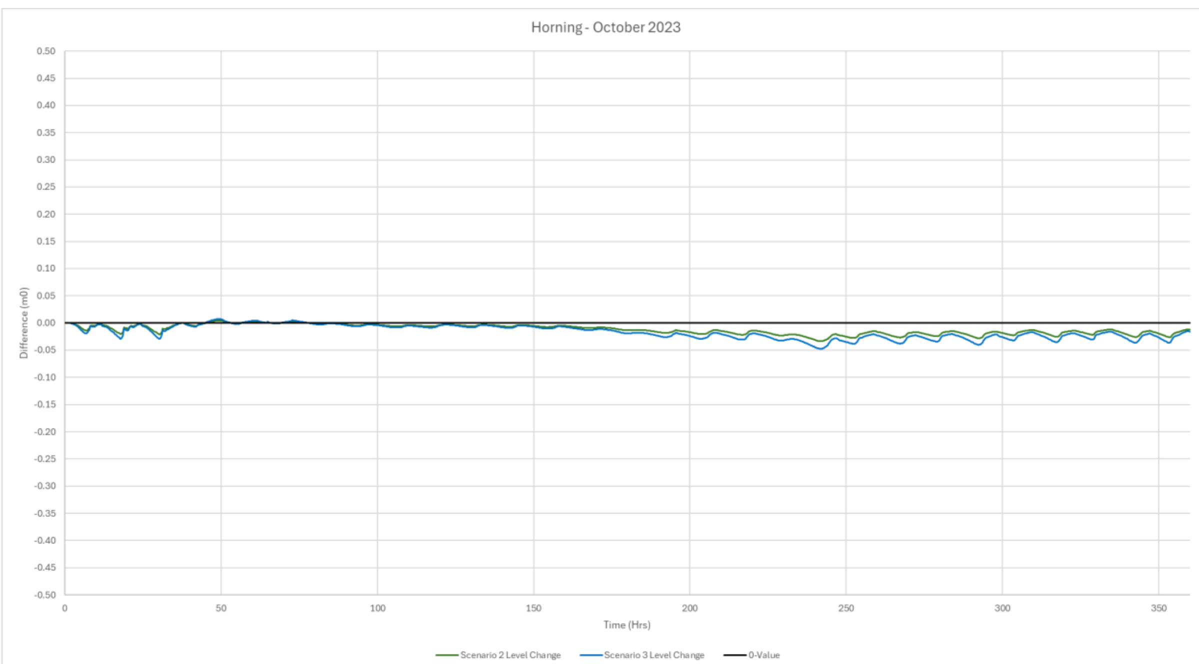

Figure 24: Difference in Water levels for the simulated October 2023 event at Honing. A positive value indicates increased water levels in the scenarios.

6. Conclusions

The Broadlands hydraulic model shows a good match with the latest available survey of the River Bure bed levels. The latest survey showed bed levels to be largely compliant with the 2.0 m below mean low water level specification along the Bure. Records from the Broads Authority confirm the area is generally dredged as per their plans. Mautby Marsh Mill to Slaughter House Yard, where sediment accumulation has been tracked, is a priority area for navigation dredging in the next three years, as identified by the Broads Authority process.

Capital dredging to -2.5mAOD (Scenario 2) and -3mAOD (Scenario 3) will increase cross sectional area by a maximum of 23% and 35% respectively through the Bure Loop (average of 6% and 11% for all sections). The additional dredging is likely to result in an additional 200,000m^3 (Scenario 3, 115,000m^3 for Scenario 2) of material to be disposed of; five times larger than the annual dredging regime for the whole Broadland river network. Based upon unit cost estimates the additional dredging is estimated to cost £4.6m (£2.7m for Scenario 2) per dredging cycle. The estimate does not include consideration to additional staff/ plant required or the additional licensing requirements. This report also does not investigate the environmental considerations of increasing the dredge volumes or the impact the additional conveyance will have in drought scenarios or on the salinity regime.

Model simulations were undertaken for a series of fluvial and tidal events including a simulation of the October 2023 flood event to understand impact of dredging on water levels within the river channel. The results show that additional dredging of the Bure Loop will increase the volume of water that can transfer in and out of the Broads river system, but for upstream locations such as Potter Heigham peak water levels during fluvial and tidal event are largely unchanged in both scenarios.

Following the event peak the differences in-channel water levels at Potter Heigham are less than 0.05m for all events tested in Scenario 2, and less than 0.06m for all events tested in Scenario 3. For the Storm Babet, October 2023 event the maximum decrease in water levels for Scenario 2 is 0.03m, and the maximum decrease in water levels for Scenario 3 is 0.05m. In terms of flood levels on land, the maps in Appendix C show that the majority of the modelled area is unaffected (level differences between 0.01m and -0.01m) by dredging. There is a reduction in flood depth with dredging mainly within the range 0.01-0.10m in some places largely in the Upper Thurne, and more than 0.15m for a small area at the mouth of the Ant, but there is no significant reduction in flooding extent.

For downstream locations such as Three Mile House and Acle dredging results in higher tidal event water levels and an increase generally in the tidal range. For Scenario 2 the peak water level increased by 0.07m at both Three Mile and Acle (5% Tidal Event - Table 7). For Scenario 3 the peak water level increased by 0.12m at Three Mile House and 0.11m at Acle (5% Tidal Event - Table 8). At these two locations the water levels were contained within the flood embankments for all the tidal events tested; together with experiencing significantly lower low tide levels.

Appendix A. Removed Volume Calculation

Table 11: Calculation used to determine the volume of material to be removed in the additional dredging scenario 2.

Node Label	Distance To Next	Scenario 2 Area (m^2)	Baseline Area (m^2)	Area Diff. (m^2)	Volume Diff. (m^3)	Cross Sectional Area Increase (%)
B9800D	200	283.5	283.5	0.0	0.0	0
B9600	200	229.6	229.6	0.0	0.0	0
B9400	200	249.4	249.4	0.0	0.0	0
B9200	200	212.3	212.3	0.0	0.0	0
B9000	200	267.6	267.6	0.0	0.0	0
B8800	200	295.3	295.3	0.0	0.0	0
B8600	200	303.6	303.6	0.0	0.0	0
B8400	200	290.4	290.4	0.0	0.0	0
B8200	200	240.4	240.4	0.0	0.0	0
B8000	200	219.5	219.5	0.0	0.0	0
B7800	200	248.0	248.0	0.0	0.0	0
B7600	200	245.1	245.1	0.0	0.0	0
B7400	200	254.6	254.6	0.0	0.0	0
B7200	200	369.0	369.0	0.0	-654.5	0
B7000	200	589.1	582.5	-6.5	-1807.2	1
B6800	200	240.2	228.7	-11.5	-1017.8	5
B6600U	0	191.1	192.4	1.3		-1
B6600D	200	191.1	192.4	1.3	614.9	-1
B6400	200	178.1	182.9	4.8	563.4	-3
B6200	200	206.7	207.5	0.8	-189.9	0
B6000	200	219.1	216.4	-2.7	292.6	1

B5800	200	261.7	267.4	5.7	366.9	-2
B5600	200	255.3	253.3	-2.0	-653.1	1
B5400U	0	256.7	252.2	-4.5		2
B5400D	200	256.7	252.2	-4.5	-2607.6	2
B5200	200	288.2	266.7	-21.5	-4607.5	8
B5000	200	299.2	274.6	-24.5	-4765.5	9
B4800	200	334.0	310.9	-23.1	-3565.0	7
B4600	200	315.4	302.9	-12.5	-3171.6	4
B4400	200	252.7	233.5	-19.2	-1631.5	8
B4200	200	293.1	295.9	2.9	-298.0	-1
B4000	200	276.5	270.7	-5.8	-2533.7	2
B3800	200	257.5	238.0	-19.5	-2603.0	8
B3600	200	340.5	333.9	-6.5	-3357.4	2
B3400	200	312.6	285.6	-27.0	-4498.9	9
B3200U	0	252.2	234.3	-18.0		8
B3200D	200	252.2	234.3	-18.0	-3166.8	8
B3000	200	222.8	209.1	-13.7	-1020.7	7
B2800U	0	163.7	167.2	3.5		-2
B2800D	200	163.7	167.2	3.5	144.3	-2
B2600	200	167.4	165.3	-2.1	-1498.4	1
B2400	200	228.3	215.4	-12.9	-3309.3	6
B2200	200	254.3	234.1	-20.2	-2751.2	9
B2000	200	198.8	191.5	-7.3	-2116.2	4
B1800	200	218.5	204.7	-13.8	-5265.9	7
B1600	200	307.3	268.4	-38.8	-5991.6	14
B1400	200	247.2	226.1	-21.1	-4629.4	9

B1200	200	222.0	196.8	-25.2	-5947.6	13
B1000	200	227.6	193.3	-34.3	-6017.0	18
B800	200	213.6	187.7	-25.9	-6630.3	14
B600	200	217.5	177.1	-40.4	-7335.1	23
B400	200	221.1	188.1	-33.0	-5261.5	18
B200	200	191.1	171.5	-19.7	-5349.5	11
B0U	0	189.8	156.0	-33.8		22
B0D	200	189.8	156.0	-33.8	-4478.2	22
B1200M	200	192.9	182.0	-10.9	2415.1	6
B1000M	200	157.8	192.9	35.1	1788.1	-18
B800M	200	144.3	127.1	-17.2	-2303.0	14
B600M	200	134.5	128.7	-5.8	-1018.4	5
B400M	200	140.0	135.6	-4.4	-803.2	3
B200M	200	137.8	134.1	-3.7	-1268.2	3
B0M	0	185.9	176.9	-9.0		5

Table 12: Calculation used to determine the volume of material to be removed in the additional dredging scenario 3.

Node Label	Distance To Next	Area (m^2)	Baseline Area (m^2)	Area Diff. (m^2)	Volume Diff. (m^3)	Cross Sectional Area Increase (%)
B9800D	200	283.5	283.5	0.0	0.0	0
B9600	200	229.6	229.6	0.0	0.0	0
B9400	200	249.4	249.4	0.0	0.0	0
B9200	200	212.3	212.3	0.0	0.0	0
B9000	200	267.6	267.6	0.0	0.0	0
B8800	200	295.3	295.3	0.0	0.0	0

B8600	200	303.6	303.6	0.0	0.0	0
B8400	200	290.4	290.4	0.0	0.0	0
B8200	200	240.4	240.4	0.0	-1155.1	0
B8000	200	231.1	219.5	-11.6	-2331.1	5
B7800	200	259.8	248.0	-11.8	-1516.3	5
B7600	200	248.5	245.1	-3.4	-708.4	1
B7400	200	258.2	254.6	-3.7	-3606.1	1
B7200	200	401.4	369.0	-32.4	-3973.5	9
B7000	200	589.9	582.5	-7.4	-2221.9	1
B6800	200	243.5	228.7	-14.9	-1826.4	6
B6600U	0	195.8	192.4	-3.4		2
B6600D	200	195.8	192.4	-3.4	334.8	2
B6400	200	176.2	182.9	6.7	873.4	-4
B6200	200	205.5	207.5	2.0	-166.6	-1
B6000	200	220.0	216.4	-3.7	73.0	2
B5800	200	263.0	267.4	4.4	-14.4	-2
B5600	200	257.8	253.3	-4.5	-1542.1	2
B5400U	0	263.1	252.2	-10.9		4
B5400D	200	263.1	252.2	-10.9	-4204.1	4
B5200	200	297.8	266.7	-31.1	-5587.8	12
B5000	200	299.4	274.6	-24.7	-5282.2	9
B4800	200	339.0	310.9	-28.1	-5212.4	9
B4600	200	326.9	302.9	-24.0	-5100.5	8
B4400	200	260.5	233.5	-27.0	-3153.9	12
B4200	200	300.5	295.9	-4.6	-1270.6	2
B4000	200	278.8	270.7	-8.1	-1864.6	3

B3800	200	248.5	238.0	-10.5	-2261.0	4
B3600	200	346.0	333.9	-12.1	-5189.3	4
B3400	200	325.4	285.6	-39.8	-5568.9	14
B3200U	0	250.2	234.3	-15.9		7
B3200D	200	250.2	234.3	-15.9	-3563.8	7
B3000	200	228.8	209.1	-19.7	-2480.0	9
B2800U	0	172.3	167.2	-5.1		3
B2800D	200	172.3	167.2	-5.1	-1086.6	3
B2600	200	171.1	165.3	-5.8	-2879.6	4
B2400	200	238.4	215.4	-23.0	-6106.1	11
B2200	200	272.2	234.1	-38.1	-5933.2	16
B2000	200	212.7	191.5	-21.3	-4089.0	11
B1800	200	224.3	204.7	-19.6	-8207.7	10
B1600	200	330.9	268.4	-62.4	-10622.4	23
B1400	200	269.9	226.1	-43.8	-8942.1	19
B1200	200	242.5	196.8	-45.6	-10203.9	23
B1000	200	249.7	193.3	-56.4	-9527.0	29
B800	200	226.5	187.7	-38.9	-10175.0	21
B600	200	240.0	177.1	-62.9	-11373.6	35
B400	200	239.0	188.1	-50.9	-9693.1	27
B200	200	217.5	171.5	-46.1	-9686.6	27
B0U	0	206.8	156.0	-50.8		33
B0D	200	206.8	156.0	-50.8	-7482.5	33
B1200M	200	206.0	182.0	-24.0	-90.3	13
B1000M	200	169.8	192.9	23.1	-411.9	-12
B800M	200	154.3	127.1	-27.2	-4284.5	21

B600M	200	144.3	128.7	-15.6	-2513.6	12
B400M	200	145.2	135.6	-9.5	-1823.9	7
B200M	200	142.8	134.1	-8.7	-3114.2	6
B0M	0	199.4	176.9	-22.4		13

Appendix B. Dredging Scenario Tabulated Results

This appendix is provided separately as ENV0001344C-JAC-ZZ-1PB-CA-HY-0004.

The spreadsheet provides hydrographs of the results from the modelling, with comparisons of scenario's 1, 2 and 3. The hydrographs can be altered by selecting the location in cell 'R1' and the event in cell 'R2'. To access the two cells the password "Dredging123" is required.

A secondary graph also shows the change in level between scenario 1 and scenario's 2 and 3.

Appendix C. Scenario Difference Maps

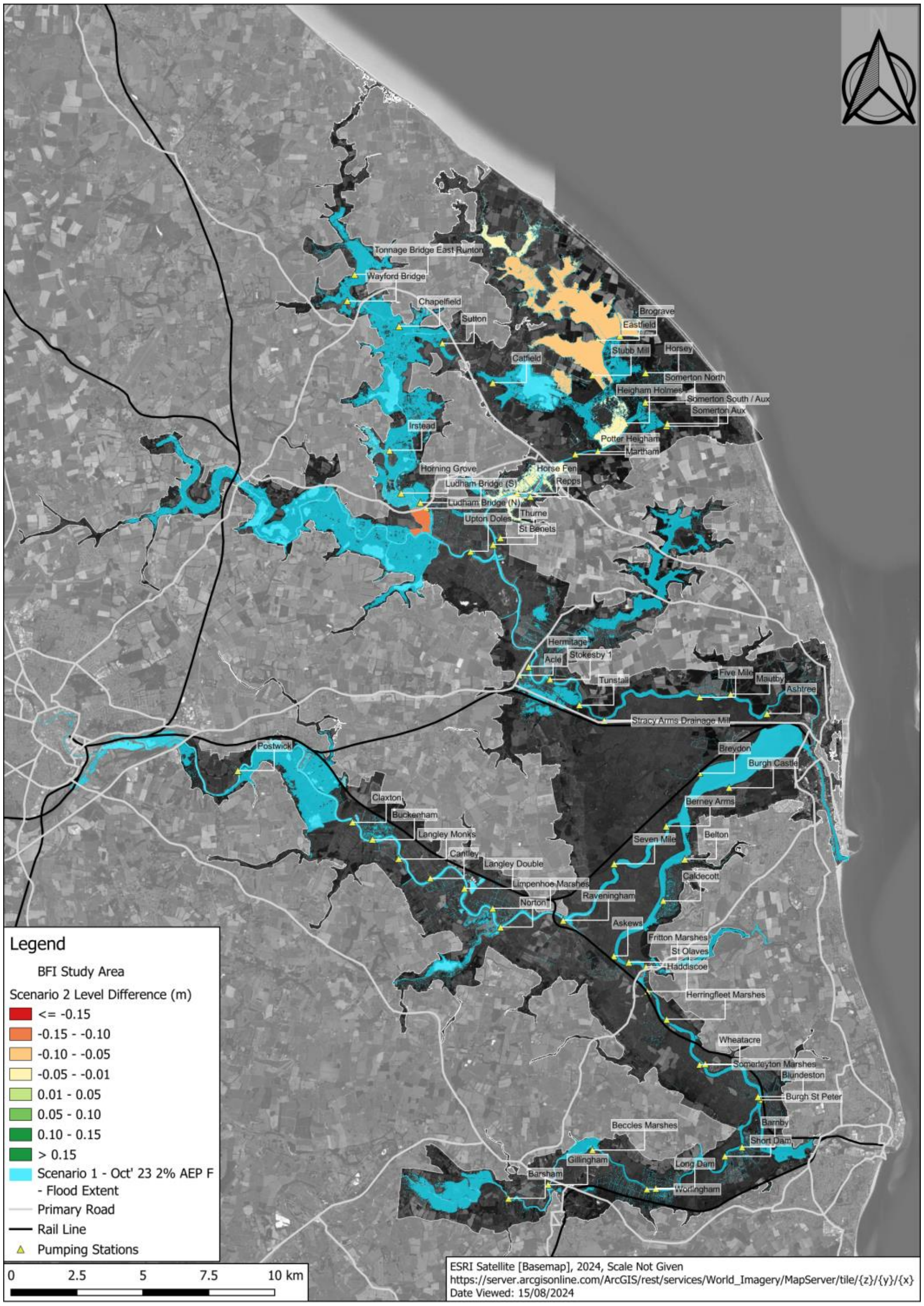

Figure 25: Scenario 2 difference map. Blue areas show no change in flooding between scenario 1 and scenario 2.

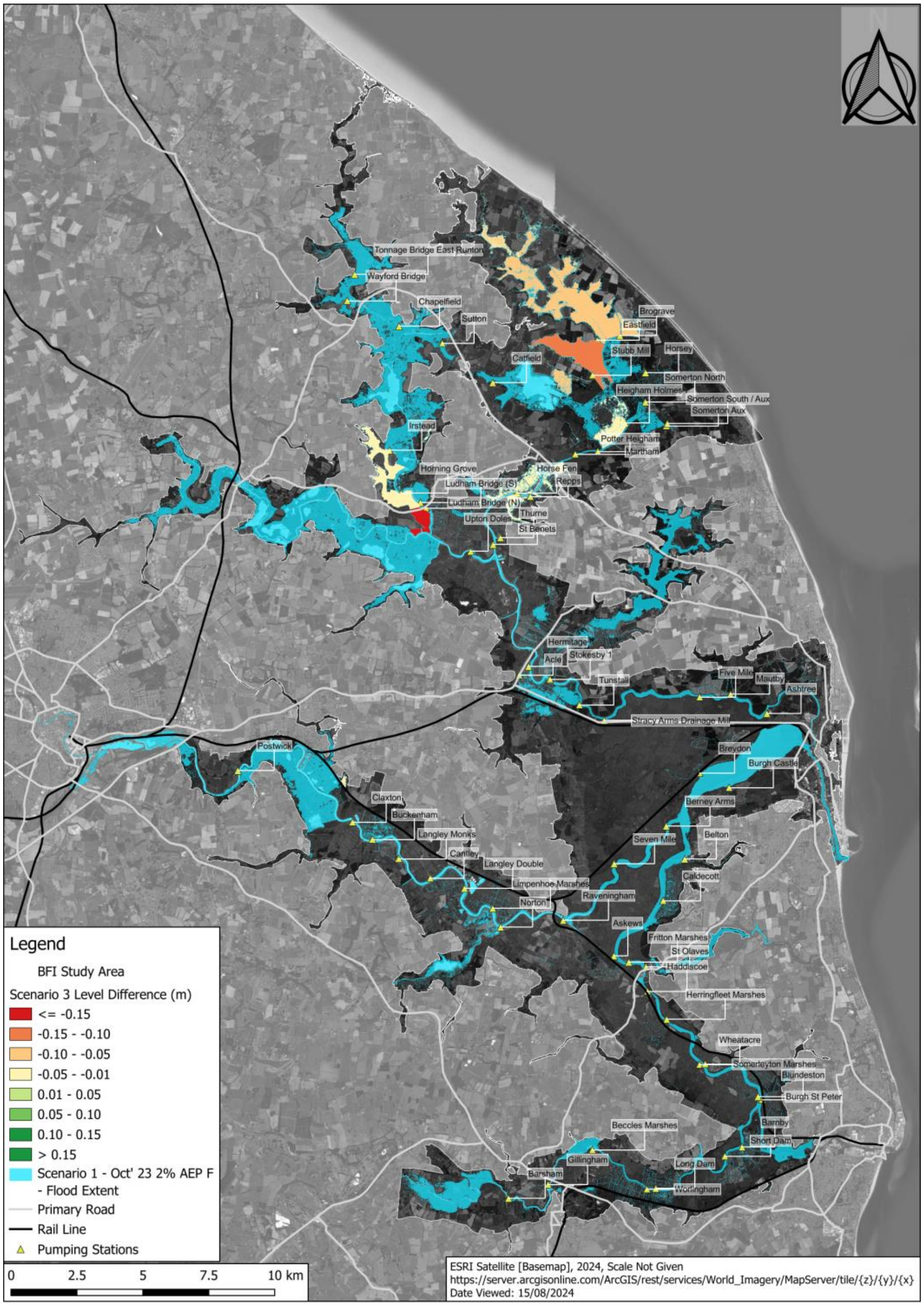

Figure 26: Scenario 3 difference map. Blue areas show no change in flooding between scenario 1 and scenario 3.

Appendix D. Potential silt accumulation at locations identified by local stakeholder

The Broadlands model cross-section profiles and the scenario cross sections for the points identified by a group of local stakeholders facilitated by the Water Management Alliance for areas where conveyance could be improved by dredging are shown below. The cross-section profiles for the scenarios have been built 2:1 slopes, however it is likely that following dredging the slopes will settle to a shallower profile. The location of these points are shown in Figure 27.

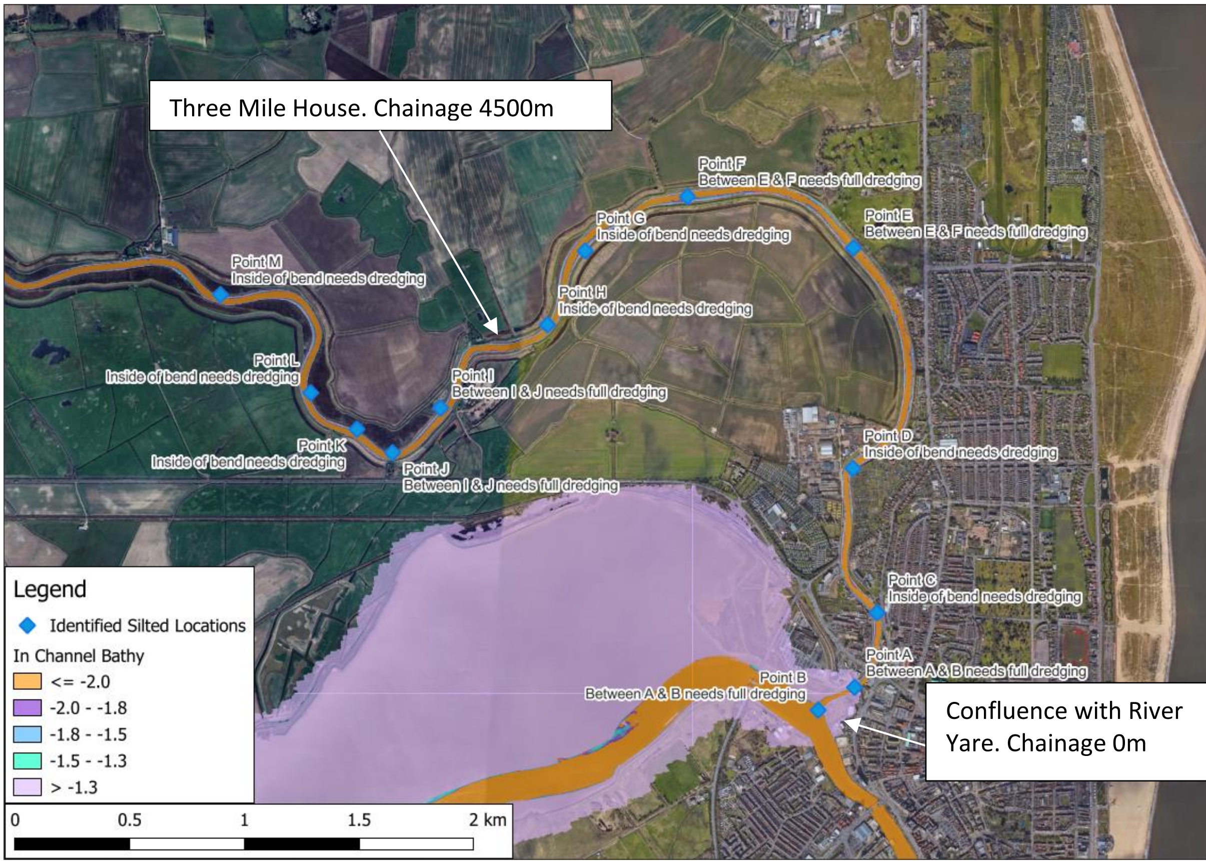

Figure 27: Locations identified by local stakeholders where conveyance could be improved along the Bure Loop. Note 'full dredging' indicates suggestion of dredging for whole channel width. Basemapping shows the water depths in metres below mean low water level, as used by the Broads Authority to drive their prioritization of maintenance dredging for navigation. Note to the colour key: The target water depth or Waterways Specification set by the Broads Authority for the River Bure is 2.0 m below mean low water.

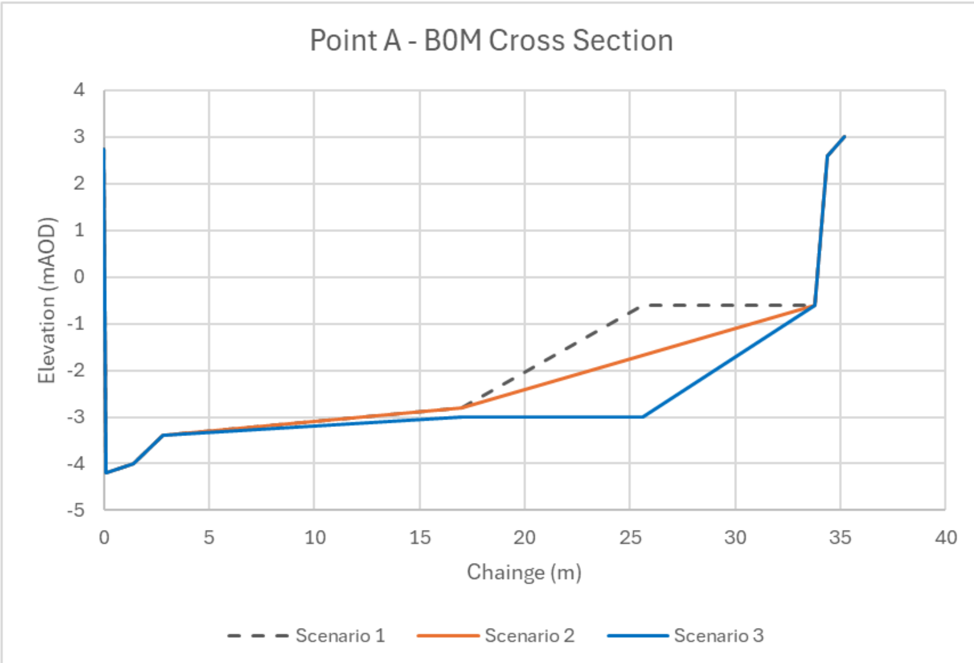

Figure 28: Point A – noted as requiring full dredging is predominantly below -2.5mAOD in the un-dredged scenario.

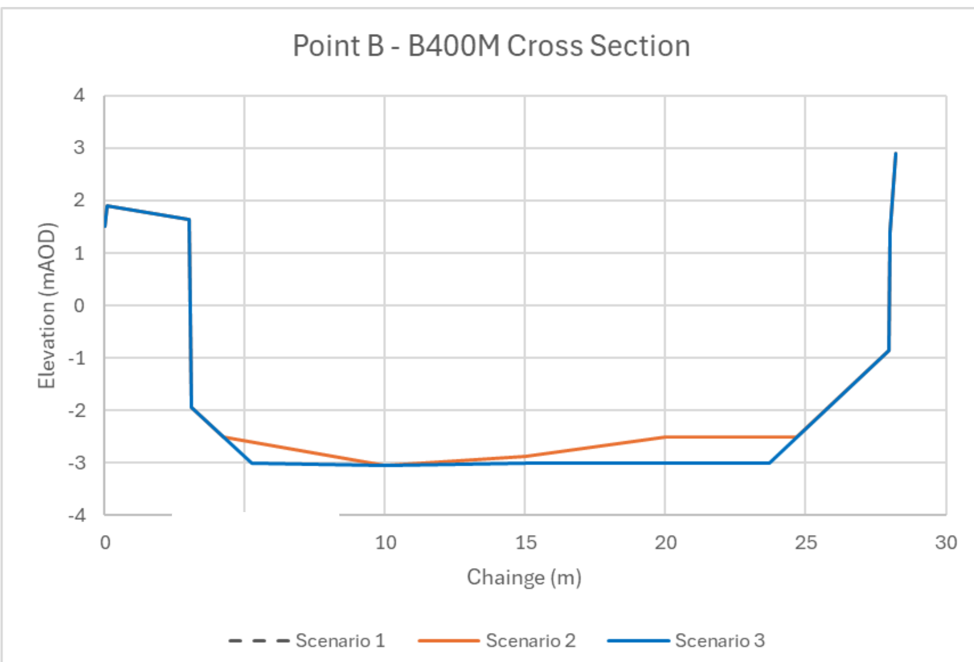

Figure 29: Point B– noted as requiring full dredging is represented by an interpolate in the baseline modelling, therefore scenario 1 is not represented.

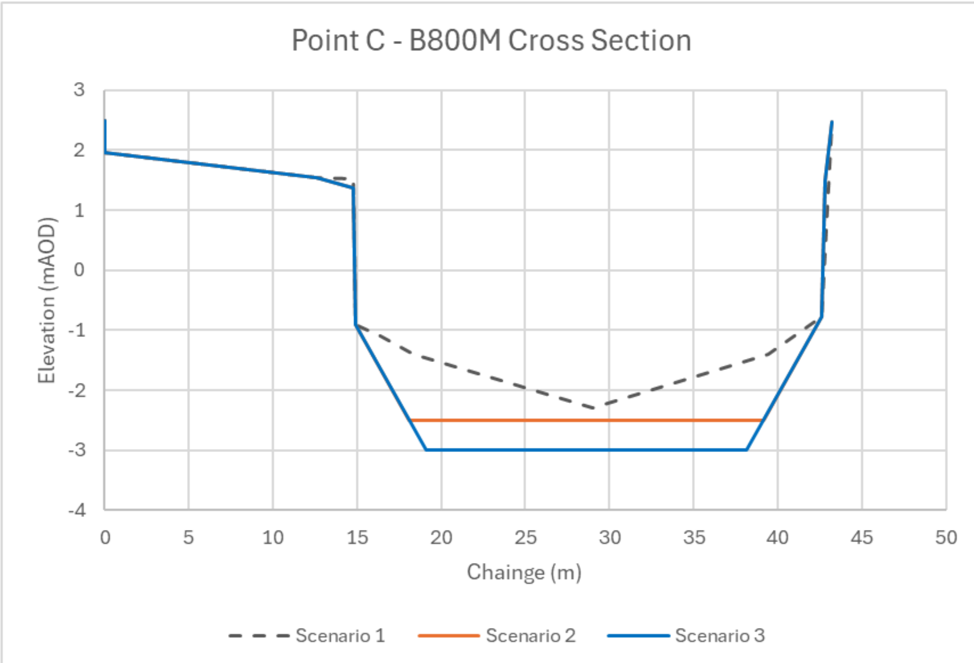

Figure 30: Point C - noted as requiring dredging on the inside bend (right bank). Material backs up against the sheet piles

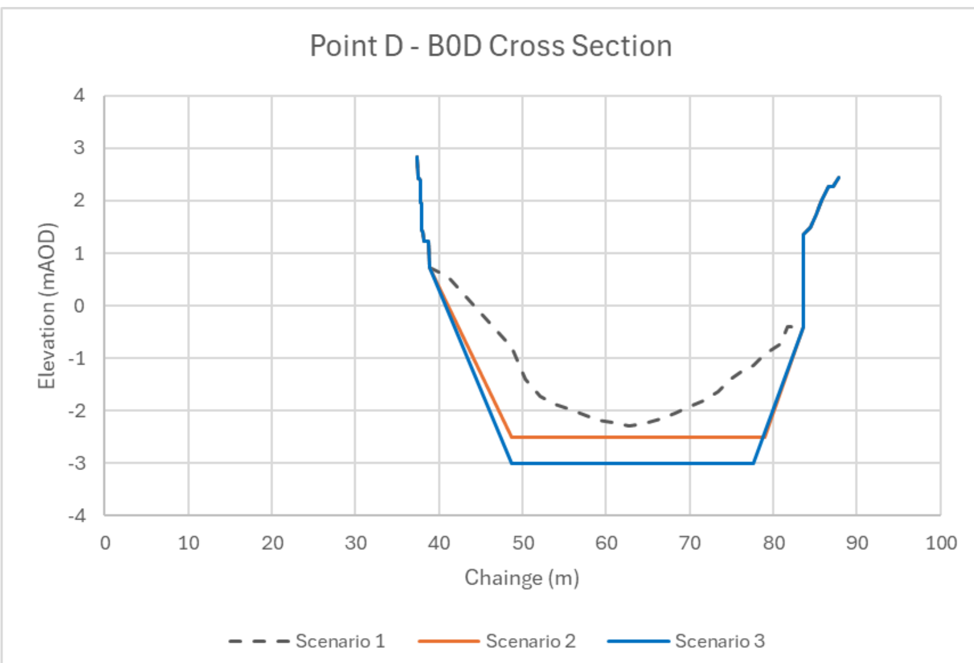

Figure 31: Point D - noted as requiring dredging on the inside bend (left bank). Minimum levels are below -2mAOD, however noted there is additional material on the left bank.

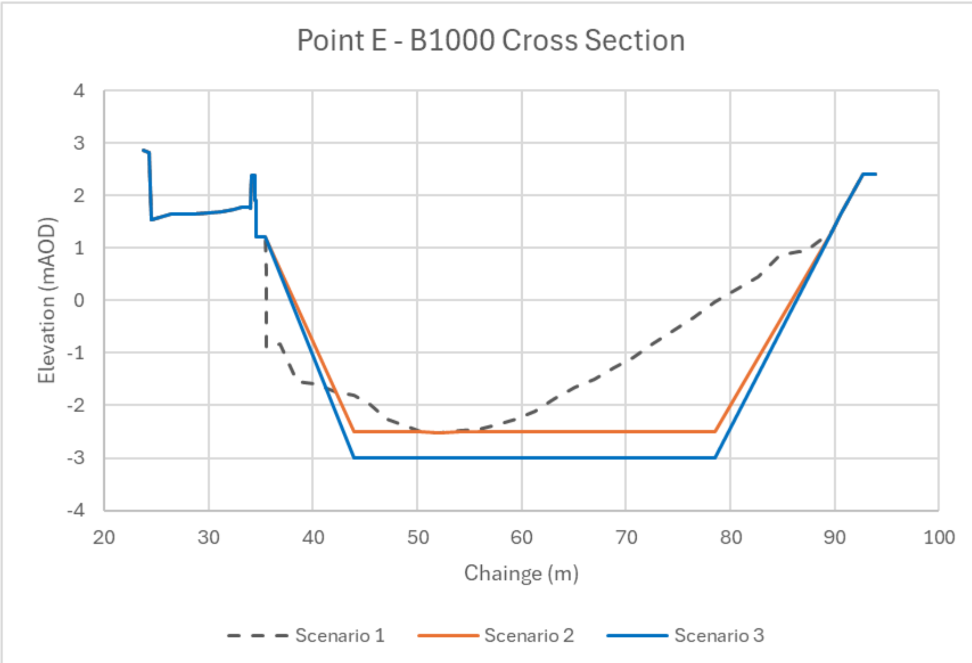

Figure 32: Point E – noted as requiring full dredging. Dredging would only be required on the right bank. A 2:1 slope would add material to the left bank.

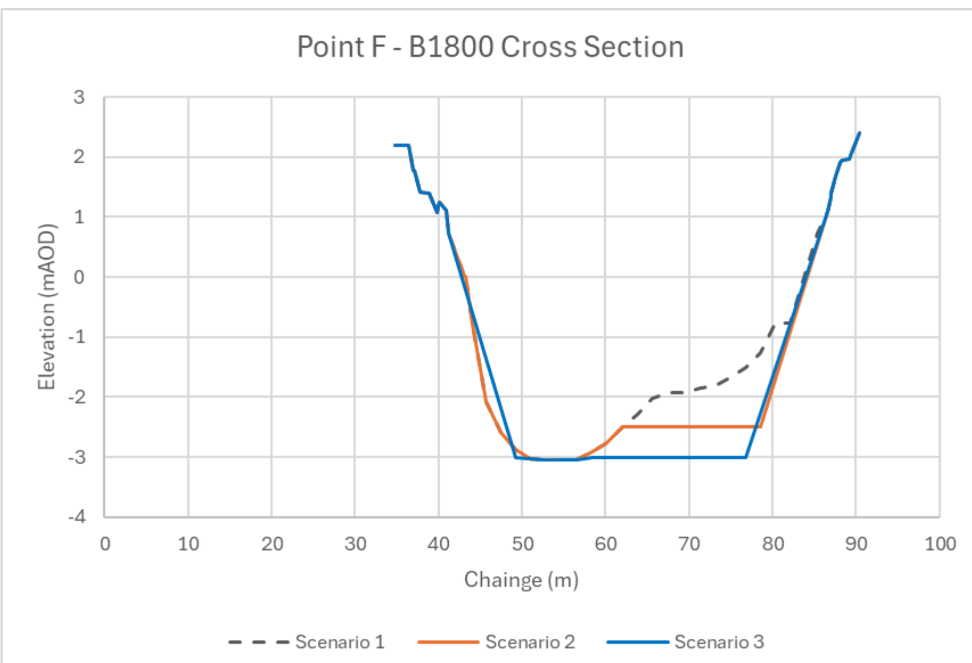

Figure 33: Point F - noted as requiring full dredging. The right bank has additional siltation, however minimum levels are around -3mAOD.

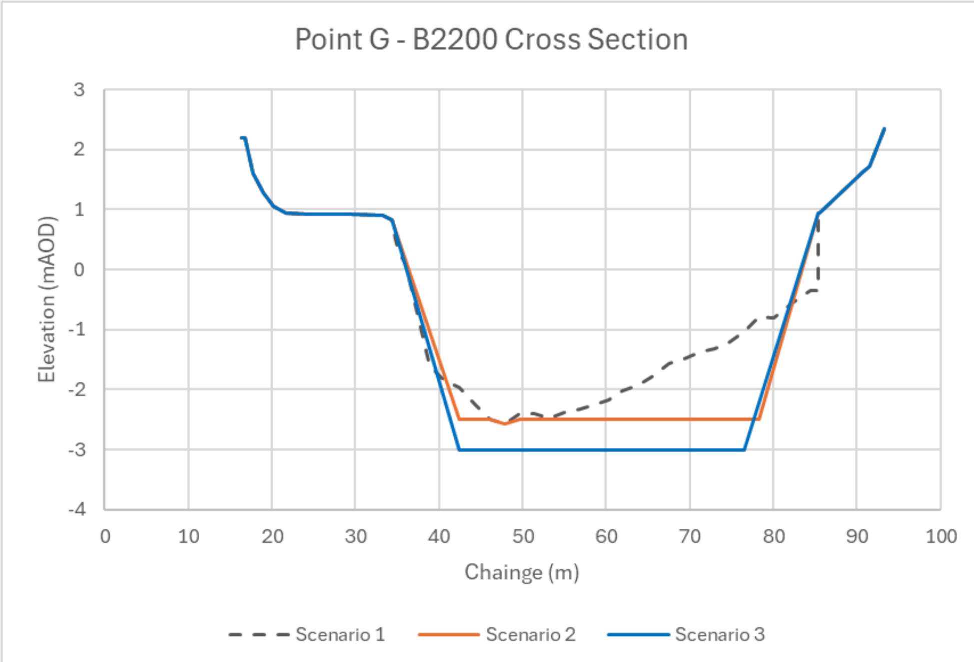

Figure 34: Point G - noted as requiring dredging of the inside bend (right bank). Minimum levels are below -2.5mAOD.

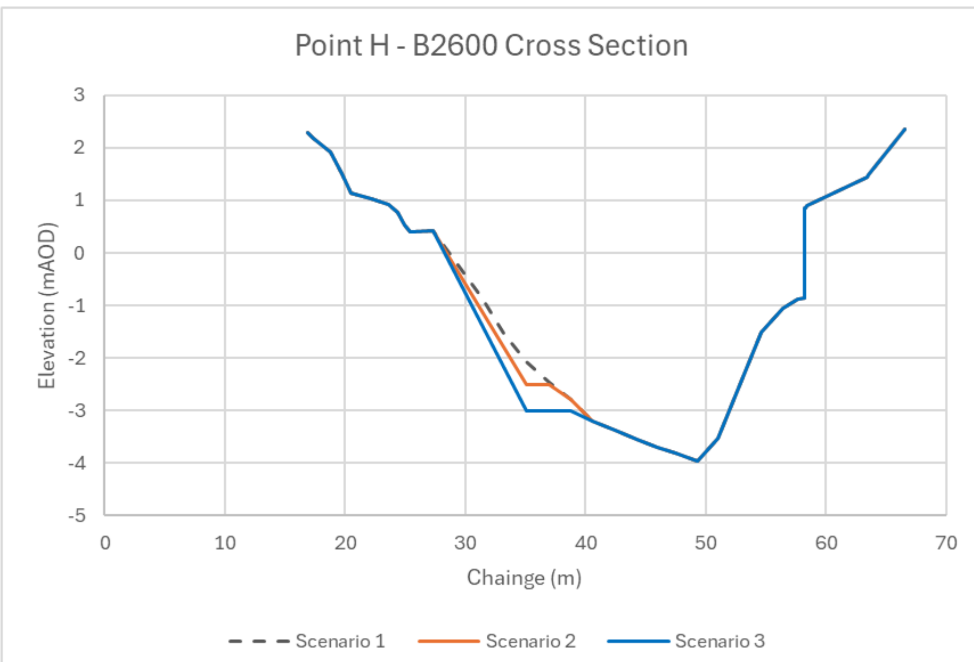

Figure 35: Point H - noted as requiring dredging of the inside bend (left bank). Slope and minimum levels are similar in all scenarios.

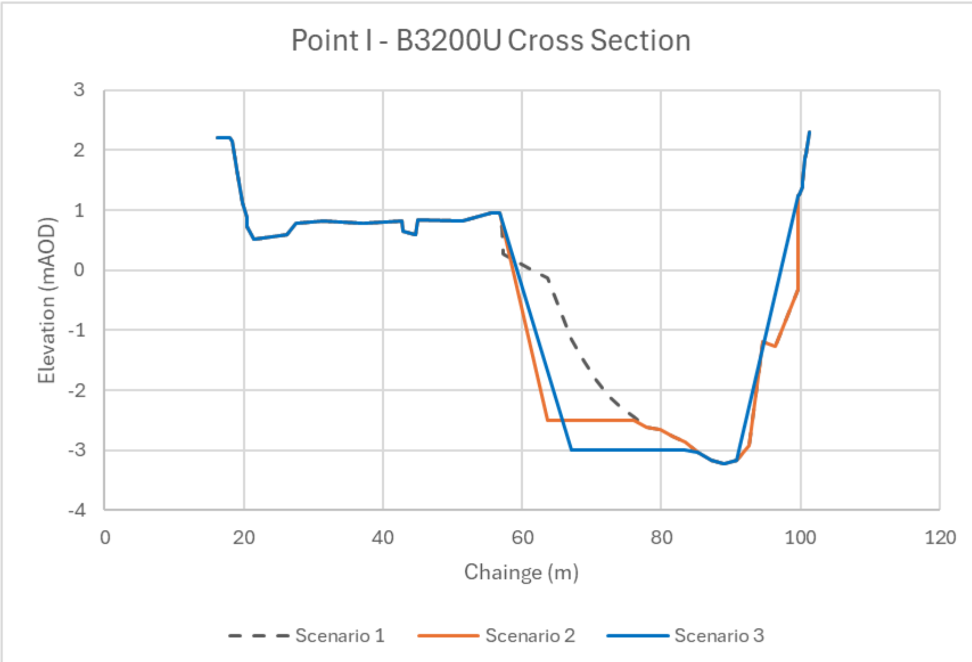

Figure 36: Point I - noted as full dredging is required. The channel is below -3.0mAOD, with a shallower slope on the left bank.

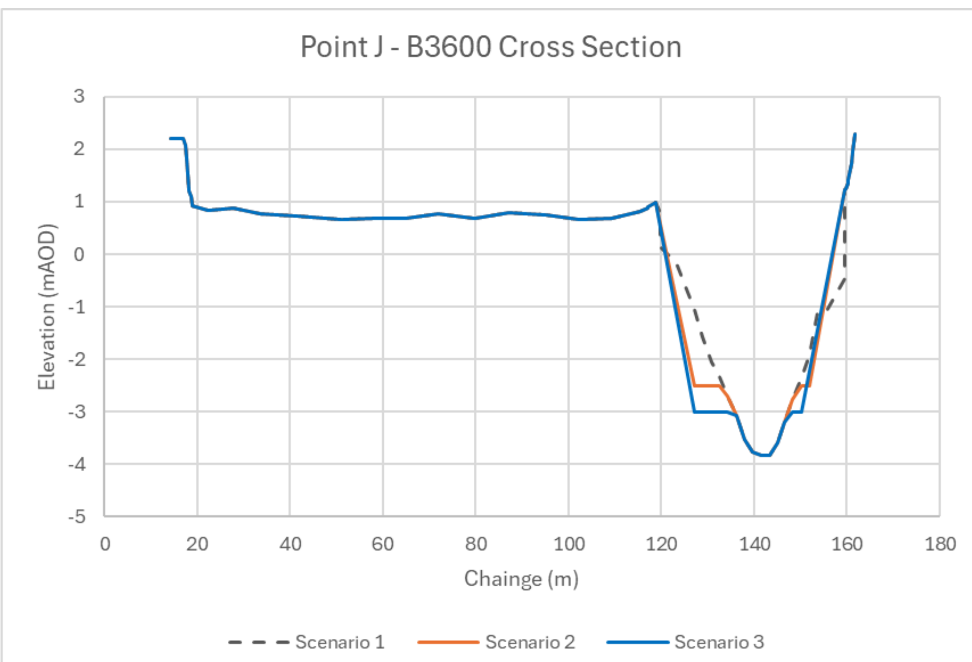

Figure 37: Point J - noted as requiring full dredging. The minimum level is below -3.0mAOD with a slope slightly shallower than 2:1.

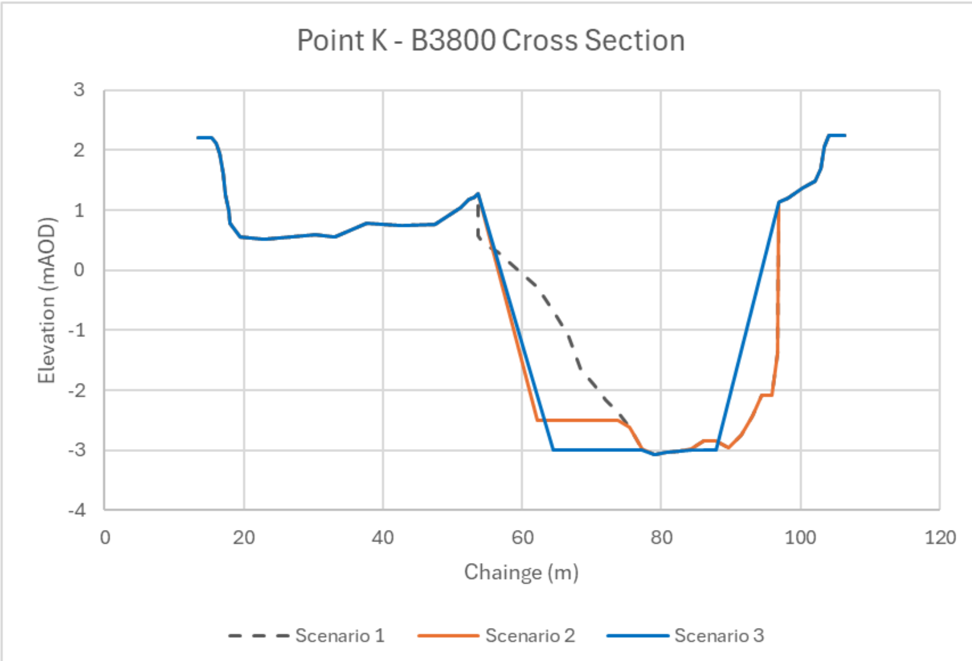

Figure 38: Point K - noted as requiring inside bend (left bank) dredging. Inside slope is shallow, however channel depth is reasonable.

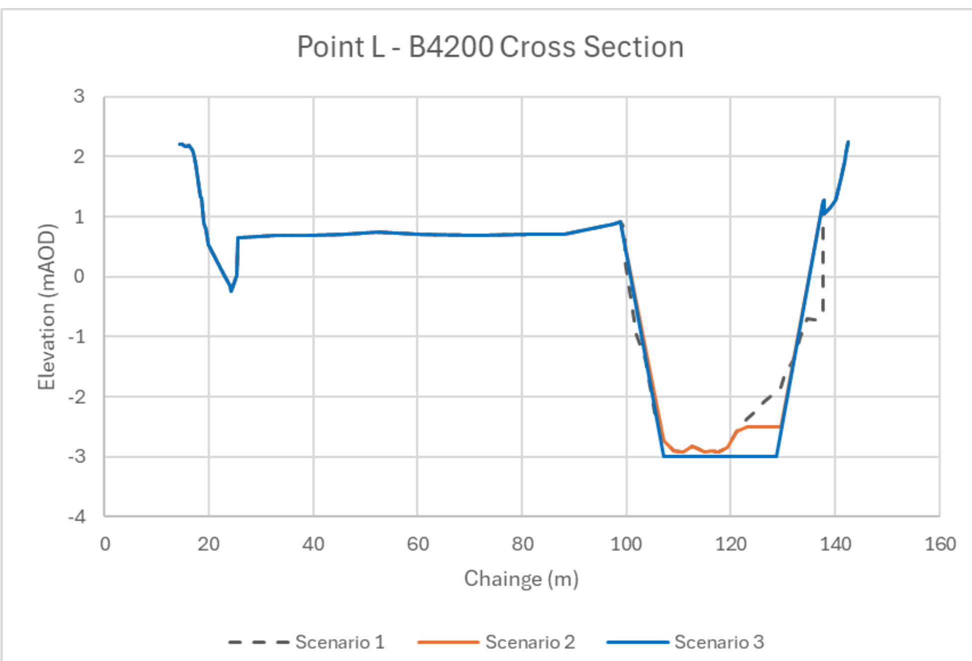

Figure 39: Point L – noted as in need of dredging on the inside bend (left bank), channel slope is already at around 2:1.

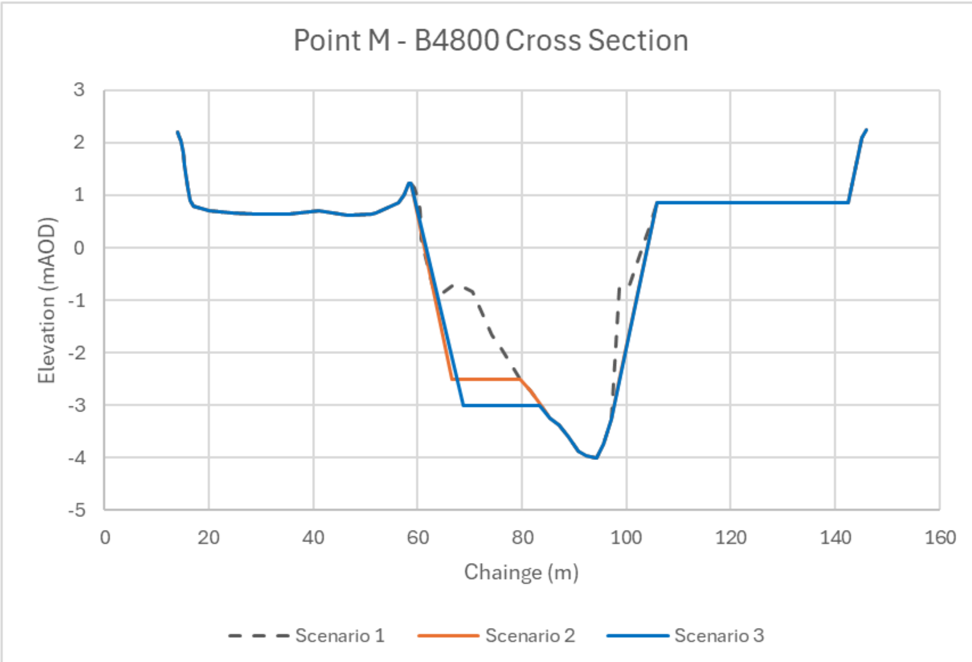

Figure 40: Point M - noted as requiring dredging on the inside bend (left bank). Minimum levels are below -3.0mAOD, some additional material on the inside of the bend.