Great Yarmouth Third River Crossing

Application for Development Consent Order

Document 6.2: Environmental Statement Volume II: Technical Appendix 11F: Groundwater Modelling Study of the Bascule Pit Groundwater Control System

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (as amended) ("APFP")

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1 Introduction

1.1.1 Temporary works dewatering is required to lower groundwater pressures within and below cofferdams for the construction of the proposed bascules. The potential impact of the dewatering on the water environment needed to be assessed as part of the Great Yarmouth Third River Crossing Application for the Development Consent Order.

1.1.2 Environment Agency Report, SC040020/SR1 (Ref 11F.1), provides guidance on how to appraise the hydrogeological impacts of dewatering. The approach is risk based, matching the level of effort to the level of risk to the Environment. Three tiers, (levels of assessment), are identified, with the level of complexity and effort increasing from Tier 1 to Tier 3 in line with the level of risk. The guidance includes a scoring mechanism to identify the level of assessment required (the Tier of the assessment).

1.1.3 The scoring system is described below along with a summary of its application to the proposed dewatering and the resulting score, indicated in bold:

1. The aquifer characteristics: Principal Aquifer (Crag Group) will be impacted. **Weighted score = 6**
2. The presence of water dependent conservation sites: There are no groundwater dependent ecosystems near the Principal Application Site, but the River Yare is a SSSI. **Weighted score = 4 to 12**
3. The water resources availability status: There is no water availability map for groundwater, as a precaution, we have assumed that groundwater is not available. **Weighted score = 2**
4. The dewatering quantity: Maximum predicted by contractors was 15.3 L/s (1,300 m^3/d), which puts the quantity into the medium category (in the worst-case scenario). **Weighted score = 6**

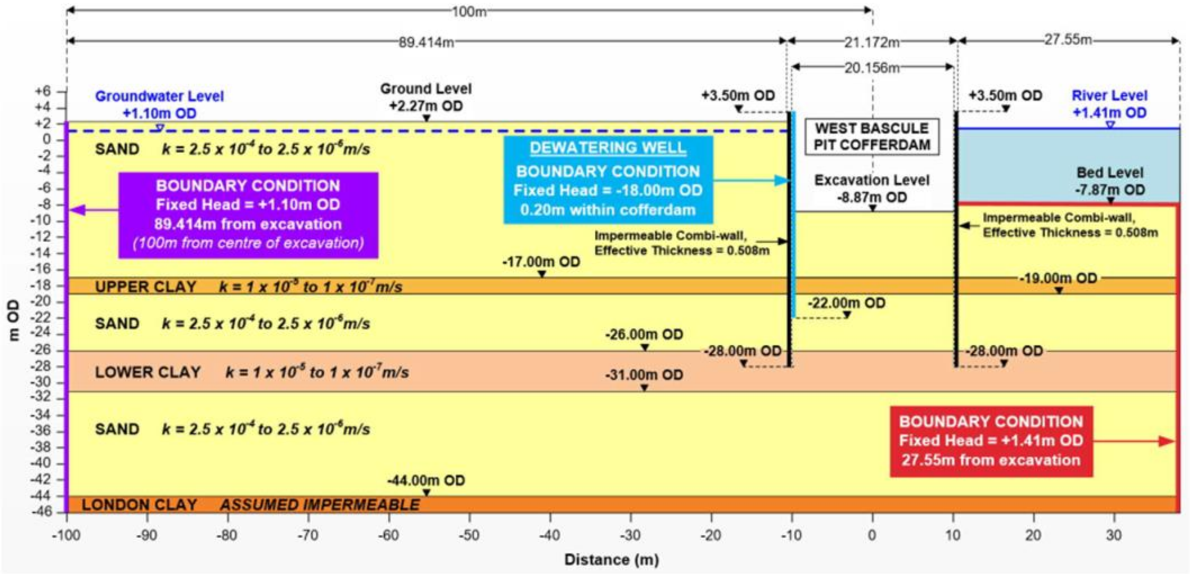
1.1.4 Total score is, therefore, between 18 and 26, which would indicate that a Tier 2 tool is appropriate. Tier 2 tools include analytical solutions, spreadsheets and basic numerical models.

1.1.5 The requirement to simulate the River Yare, the adjacent layered geological system and the cofferdam including piles meant that the adopted approach needed to be capable of representing different boundary conditions as well as spatially variable parameters.

1.1.6 A steady state MODFLOW model was considered the most appropriate for the assessment. The model was based on the Designer’s conceptual model of the site presented below for reference (Plate 1.1).

1.1.7 Symmetry of the ground conditions is assumed either side of the River Yare. Therefore, the model results are considered applicable to the assessment of potential impacts on both the west and east banks of the River Yare.

Plate 1.1: Copy of the Designer's Conceptual Model



2 Groundwater Flow Model Set Up

2.1 Modelling Approach and Modelling Code

2.1.1 A 3D distributed numerical modelling approach was selected as the most appropriate way to investigate the groundwater system close to the western bascule pit cofferdam. A model was constructed to represent groundwater flow through simplified geological layers of sand and clay, as described by the Design team. The modelling code selected was MODFLOW-2015, an industry standard code, with Groundwater Vistas V7 selected as the graphical user interface for building and viewing the model and results.

2.1.2 Construction dewatering is estimated to be required over a 21-month period, a potentially long enough time period for a new ‘equilibrium’ also known as ‘steady state’ to establish. Steady state computations were considered appropriate to the conditions and allowed for the investigation of the maximum extent of the cone of depression formed by dewatering.

2.2 Model Domain/Extents

2.2.1 The groundwater flow model covers an area of 1 km^2. The eastern boundary of the model is a simplified representation of the River Yare running directly north-south for the purposes of the modelling. The western bascule pit cofferdam is therefore located close to the eastern boundary of the model. The western model boundary was assigned a constant head value and set at 1km from the cofferdam to ensure dewatering estimations are not significantly influenced by the boundary condition. The north and south model boundaries were located to form a uniform square area of 1km^2 and set as no flow boundaries. The boundaries are thought to be significantly far enough away not to influence model results.

2.2.2 The top of the model was set at 2.27m OD to be consistent with the ground level presented as per information provided by the Design team. For the purposes of this modelling, the top of the model is assumed to be flat. The bottom of the model is at an elevation of -44.0m OD, which is understood to be the top of the impermeable London Clay Formation, as per information provided by the Design team.

2.3 Model Vertical and Horizontal Discretisation

2.3.1 The model grid was set up with a minimum grid refinement of 0.5 x 0.5 m along the impermeable combi-wall of the west bascule pit cofferdam, increasing to 1 x 1 m within the cofferdam. Model cell size increases gradually with distance from the cofferdam to a maximum cell size of 50 x 50 m at the model extents.

2.3.2 The model layers were set up to correspond to the conceptual hydrogeological units as per information provided by the Design team. The model consists of six layers, detailed in Table 2.1 below. Model layers were assumed to be flat and homogenous for the purposes of this study.

Table 2.1: Groundwater Flow Model Layers

Model Layer Number	Design Team Assigned Hydrogeological Unit (and Interpreted Geology)	Top Elevation (m OD)	Bottom Elevation (m OD)	Additional Information
1	Sand (North Denes Formation, Breydon Formation and the Happisburgh Glaciogenic Formation undifferentiated)	2.27	-17.0	
2	Upper Clay (Crag Group Aquifer)	-17.0	-19.0	
3	Sand (Crag Group Aquifer)	-19.0	-26.0	
4	Lower Clay (Crag Group Aquifer) – penetrated by the sheet pile wall	-26.0	-28.0	Impermeable wall penetrates the lower clay to -28.0m OD. In order to include this in the model the lower clay layer was divided
5	Lower Clay (Crag Group Aquifer) –	-28.0	-31.0	Thickness of lower clay which

Model Layer Number	Design Team Assigned Hydrogeological Unit (and Interpreted Geology)	Top Elevation (m OD)	Bottom Elevation (m OD)	Additional Information
	below the sheet pile wall			is below the bottom of the impermeable wall
6	Sand (Crag Group Aquifer)	-31.0	-44.0	The base of the model was set at -44.0m OD, corresponding to the top of the London Clay

2.4 Model Boundary Conditions and Initial Conditions

2.4.1 River boundary conditions are used on the eastern boundary of the model to represent the River Yare. The river bed level was set at -7.87m OD and the river level was defined as 1.41m OD (as per information provided by the Design team). Representation is simplified for the purposes of this model and the river is assumed to run north south along the eastern edge of the model.

2.4.2 The western model boundary was set as a constant head boundary condition, with a head of 1.1m OD assigned. This is based on the conceptual pre dewatering groundwater level as provided by the Design team. The development of a recharge function was considered beyond the level of complexity required and recharge was not applied to the model. Instead a constant head boundary was used as a surrogate for recharge to maintained groundwater levels. The significance of the constant head boundary is discussed in the results section.

2.4.3 In the information provided by the Design team, six deep groundwater control dewatering wells were proposed with a target dewatering level of -22.0m OD, to be located within the sheet pile wall of the west bascule pit cofferdam. Ten passive dewatering wells were distributed around the remaining walls of the cofferdam. For this model, drain boundary conditions were chosen to represent the dewatering wells so that groundwater heads could be lowered to the level as specified by the Design team; the deep wells were assigned a drain elevation equal to the target dewatering level (-22.0m OD) and the passive dewatering wells were assigned an elevation of -8.87m OD to represent the excavation level within the cofferdam. The resulting drain flow rates were then verified against proposed pumping rates and the flow rates simulated by the Design team's groundwater model.

2.5 Model Hydraulic Properties

2.5.1 A sensitivity analysis was conducted to consider a range of hydraulic properties for the sand and clay units. The ranges of hydraulic conductivity modelled were consistent with the conceptual model outlined by the information provided by the Design team. Table 2.2 presents the ranges of hydraulic conductivity (K) values modelled. A minimum, maximum and average value was chosen for each unit and the upper and lower clay units were assigned the same permeability.

2.5.2 Horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) were assumed to be equal for the purposes of this study as there was no data to suggest otherwise. This assumption means water will flow as easily in the vertical direction as it will in the horizontal within a given model layer and builds in a conservative (worst case) prediction of the effects of dewatering for each scenario.

2.5.3 The proposed impermeable pile wall was represented in the model by assigning a very low hydraulic conductivity to a 0.5 m wide area where the wall is to be located.

Table 2.2: Simulated Hydraulic Conductivity Values

Unit	Hydraulic Conductivity (m/s)
Sand	2.5×10^{-4} to 2.5×10^{-6}
Upper and Lower Clay	1.0×10^{-5} to 1.0×10^{-7}
Impermeable combi-wall	1×10^{-15}

2.6 Model Sensitivity Analysis

2.6.1 Sensitivity analysis was completed to understand the significance to the model predictions of the uncertainties in the hydraulic parameters assigned. Nine model sensitivity analysis scenarios were run with different combinations of hydraulic conductivity (K). The model properties for each model run are summarised in Table 2.3.

Table 2.3: Hydraulic Conductivity Sensitivity Analysis Model Runs

Scenario	Sand K (m/s)	Clay K (m/s)
1	2.5×10^{-5}	1.0×10^{-6}
2	2.5×10^{-5}	1.0×10^{-5}
3	2.5×10^{-5}	1.0×10^{-7}
4	2.5×10^{-4}	1.0×10^{-6}
5	2.5×10^{-4}	1.0×10^{-5}
6	2.5×10^{-4}	1.0×10^{-7}
7	2.5×10^{-6}	1.0×10^{-6}
8	2.5×10^{-6}	1.0×10^{-5}
9	2.5×10^{-6}	1.0×10^{-7}

3 Groundwater Flow Model Results

3.1 Simulated Flow to Groundwater Control Wells

3.1.1 The model results agree extremely well with the dewatering flows predicted in the Design team's groundwater model. Theoretical flow rates to all the groundwater control dewatering wells are within the range 0.16 L/s to 15.53 L/s. Table 3.1 summarises the dewatering flows predicted in all modelled scenarios. For reference the flow rates determine by the Design team are also provided.

Table 3.1: Simulated Total Flow Rate from Dewatering Wells for each Modelled Scenario

Scenario	Sand K (m/s)	Clay K (m/s)	Predicted Total Flow Rate to Wells (L/s)	Design Team Modelling Study Predicted Total Flow Rates (L/s)
1	2.5×10^{-5}	1.0×10^{-6}	1.59	1.53
2	2.5×10^{-5}	1.0×10^{-5}	6.07	5.45
3	2.5×10^{-5}	1.0×10^{-7}	0.21	0.21
4	2.5×10^{-4}	1.0×10^{-6}	2.06	2.10
5	2.5×10^{-4}	1.0×10^{-5}	15.53	15.28
6	2.5×10^{-4}	1.0×10^{-7}	0.21	0.22
7	2.5×10^{-6}	1.0×10^{-6}	0.62	0.55
8	2.5×10^{-6}	1.0×10^{-5}	1.24	1.12
9	2.5×10^{-6}	1.0×10^{-7}	0.16	0.15
Median			1.24	1.12
Mean			3.08	2.96

These results are presented graphically in Plate 3.1.

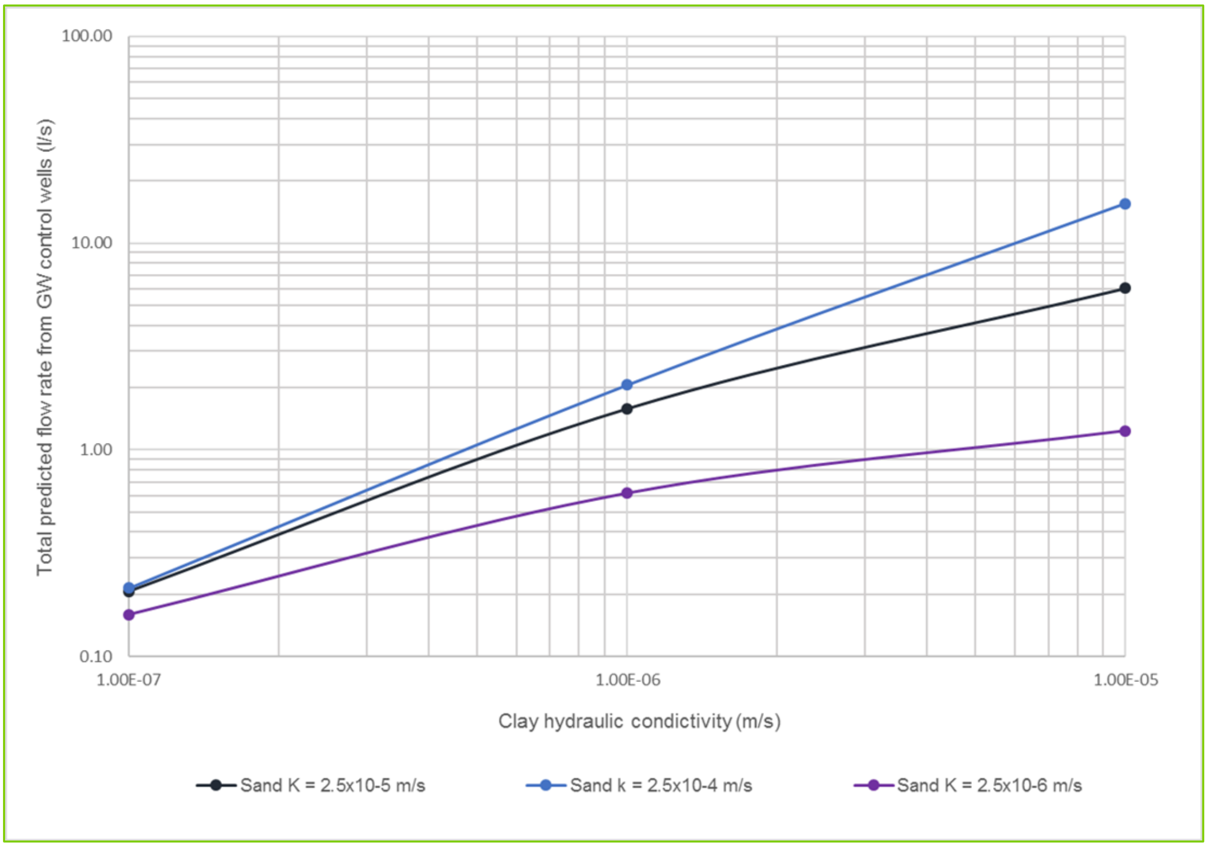


Plate 3.1: Sensitivity Analysis of Clay and Sand Hydraulic Conductivity

3.2 Impact of Dewatering on Local Groundwater Levels

3.2.1 The lateral impact of dewatering at the cofferdam varies depending on the hydraulic properties used in the model. Plate 3.2 shows drawdown from east to west in model layer 6, the thickest layer within the Crag Group Aquifer, for each scenario modelled.

3.2.2 Drawdown is greatest in Scenario 8 (worst case), which represents the impact in a low sand hydraulic conductivity and a high clay hydraulic conductivity setting. In this scenario the ‘clays’ are more permeable than the ‘sands’ and the effect of drawdown in the sands will propagate relatively easily across the clay layers.

3.2.3 The low sand hydraulic conductivity means a steeper cone of depression is formed and there is a greater impact on water levels near the cofferdam.

3.2.4 Plate 3.3 shows the drawdown predicted in model Scenario 8 (worst case) for all model layers. Immediately adjacent to the cofferdam the predicted drawdown is approximately 5.0m in the lower clay layer (model layer 5) and about 1.5m in the shallowest sand layer (model layer 1) reflecting the vertical attenuation of drawdown caused by the geological layering.

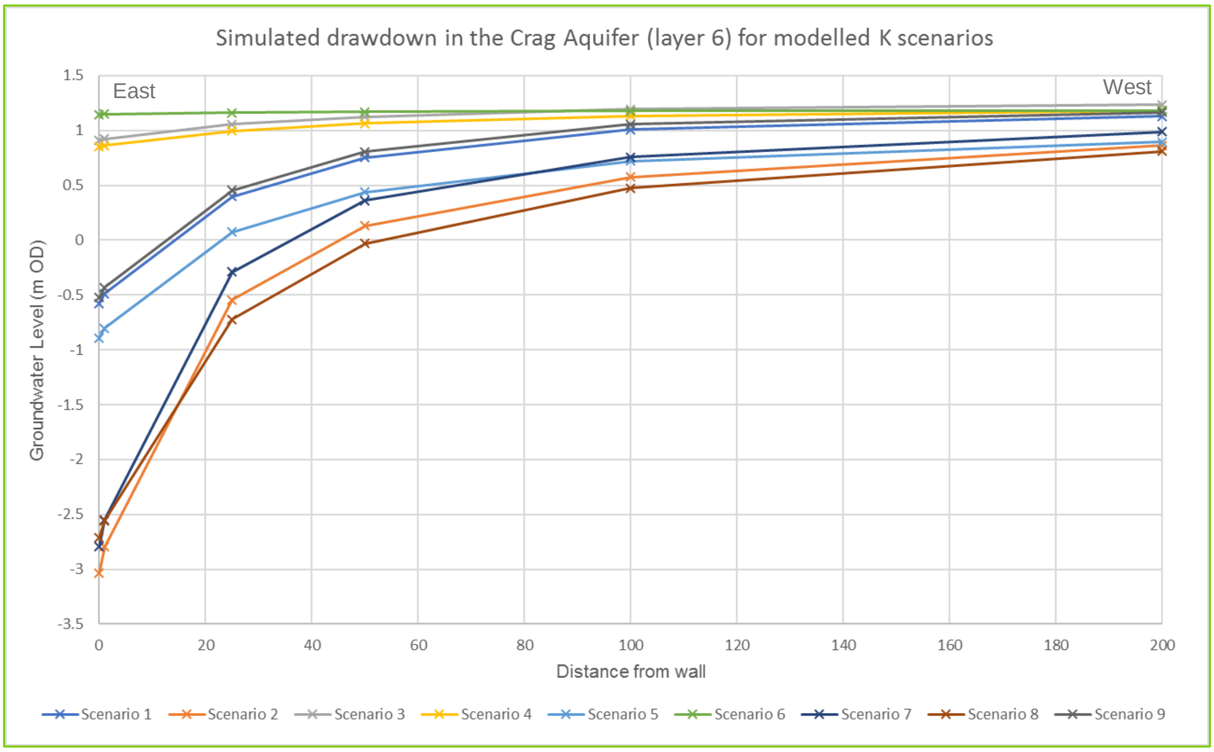


Plate 3.2: Simulated Drawdown in the Crag Group Aquifer (Layer 6) for all Scenarios Modelled

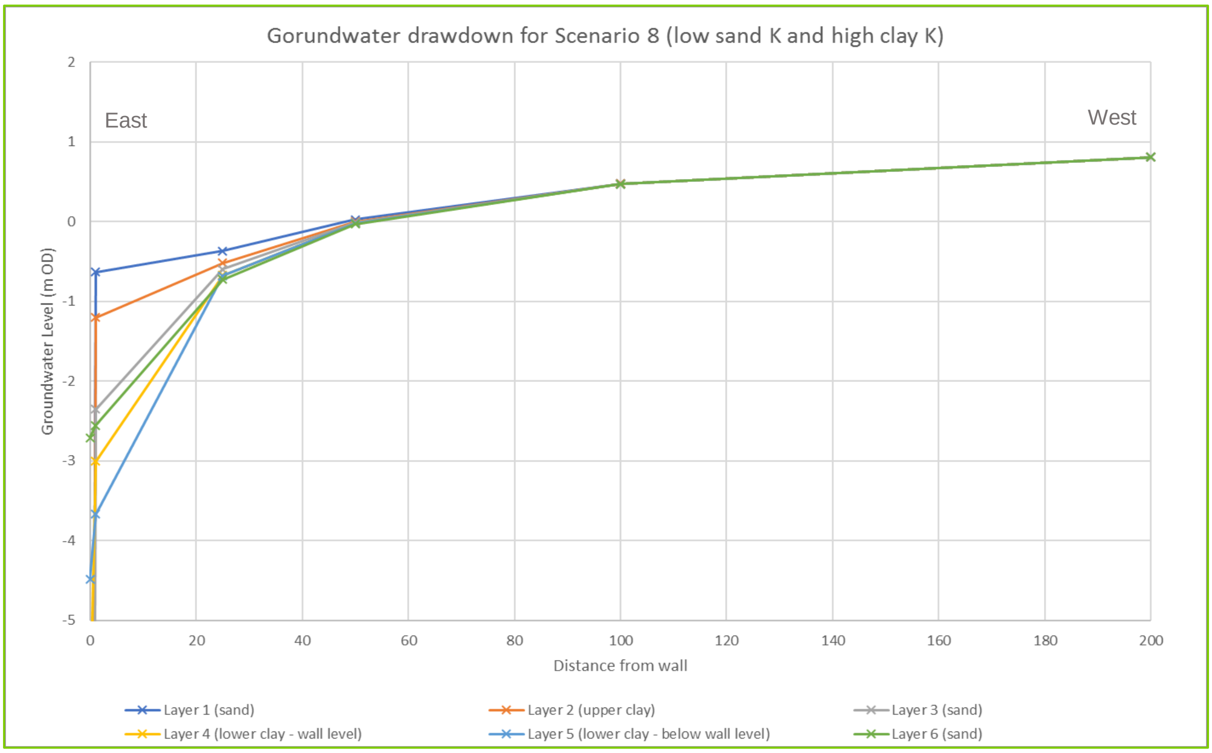


Plate 3.3: Worst Case Groundwater Drawdown (Scenario 8) with Distance from Cofferdam for each Model Layer

3.2.5 Drawdown will decrease exponentially with distance away from the cofferdam. The model simulates a drawdown of up to 5.0m close to the cofferdam, 1.8m at 25.0m distance, 0.6m at 100.0m distance, 0.3m at 200.0m distance, and 0.1m at 400.0m distance from the cofferdam (compared to the starting groundwater level of 1.1m OD).

3.2.6 The absence of a rainfall recharge model boundary condition means that the model recharge is sourced via the western constant head boundary, and to a lesser extent the river boundary condition to the east, providing a constant replenishment of groundwater to be dewatered at the cofferdam location. A hydraulic gradient will extend from the cofferdam simulated in the east to the constant head boundary in the west, albeit the gradient is extremely shallow and the drawdown insignificant at the constant head boundary. A consequence of the model set up is that there is no point in the model where zero drawdown occurs.

3.2.7 The model simplification and the propagation of drawdown that results are not significant by comparison with uncertainties within the conceptual model (Plate 1.1) e.g. geological layering and hydraulic properties. The results should be viewed as an umbrella that contains a realistic scenario within it. Scenario 8 (worst case) is very unlikely given the potentially unrealistic combination of hydraulic properties assigned to the clay and sand layers. Professional judgement suggests a maximum accuracy of 0.1m, and that 400.0m represents an effective limit of future drawdown.

3.2.8 Attachment A (Figure 11.2A and 11.2B from the Environmental Statement report) is a plan view illustrating model Scenario 8 (worst case) extent of drawdown – the 0.1m contour for Layer 1 (the North Denes, Breydon and Happisburgh Glaciogenic Formations) and Layer 6 (the lower Crag Group Aquifer) to the western side of the river. As described in Section 1, the model results are considered applicable to the assessment of potential impacts on both the west and east banks of the River Yare. An alternative and probably more realistic scenario where the clays and the sands have lower and higher hydraulic conductivities, respectively, would result in significantly less drawdown.

3.3 Potential Impact of Dewatering

3.3.1 Four potential receptors and three potential impacts are recognised. The receptors are the Crag Group Principal Aquifer, the North Denes Formation Secondary A Aquifer, (which is grouped in the model with the Breydon Formation and the Happisburgh Glaciogenic Formation in accordance with information provided by the Design team, nearby groundwater abstractions the closest of which is approximately 0.7km from the proposed cofferdam, and the River Yare. The potential impacts relate to changes in groundwater storage which include to the lowering of the water table and reducing the amount of water in the aquifer(s), changes in groundwater flow, and changes in groundwater quality.

3.3.2 Groundwater quality was not simulated within the groundwater flow model, however, groundwater flow directions may be interpreted in the context of groundwater mixing and potential changes in salinity.

Crag Group Aquifer

3.3.3 The Crag Group Aquifer, which is recognised as a Principal Aquifer, comprises sands, gravels, silts and clays. The aquifer properties of the Crag Group vary greatly depending upon the grain size of the sediments, degree of sedimentation and presence of semi-confining glacial sediments (i.e. the Happisburgh Glaciogenic Formation), although it is largely unconfined (Jones et al., 2000).

Groundwater Storage

- Maximum change to the groundwater level (drawdown) is predicted in the Crag Group Aquifer. The effect decreases rapidly with increasing distance, from a maximum of approximately 5.0m drawdown just 1.0m from the dewatering wells to less than 0.1m at 400.0m distance, under the worst case scenario simulated (Scenario 8).
- The modelled dewatering does not differentiate between water removed from the Crag Group Aquifer and that removed from overlying aquifers (North Denes, Breydon and Happisburgh Glaciogenic Formations). An estimate of the loss of storage may be based on the thickness of the respective aquifers (Table 2.1). The Crag Group Aquifer will contribute approximately 50% of water abstracted. The average (mean) dewatering rates simulated was 3.0 L/s, therefore half of this (1.5 L/s) is assumed to be from the Crag Group Aquifer, which is equivalent to 0.13 M L/day.
- There are no public water supply abstractions from the Crag Group Aquifer in the Principal Application Site and actual abstraction information (opposed to licensed limits) for the Crag Group Aquifer is difficult to find.
- A joint report produced by the British Geological Survey and the Environment Agency, (Ref 11F.2), refers to National Rivers Authority abstraction data from 1994 for the Lowestoft and Saxmundham area. It is unclear whether the data includes Great Yarmouth, but it nonetheless indicates the potential level of abstraction from the Crag Group Aquifer, which is reported as 4.5M m^3/year or 12.3M L/day. Based on this comparison, the average simulated dewatering rate is equivalent to approximately 2% of the total Aquifer abstraction (when dewatering simultaneously at both the western and eastern cofferdams is considered).

Groundwater Flow

3.3.4 Groundwater flow in the Crag Group Aquifer would naturally be towards the River Yare (locally) and more regionally towards the coast. The modelling study indicates a capture zone for the cofferdam of up to 400.0m, although the exact capture zone depends on recharge, which was not simulated in the groundwater flow model. All groundwater within the capture zone will migrate towards the cofferdam at the expense of discharge to the River Yare or overlying aquifers (and eventually to the coast).

Groundwater Quality

3.3.5 The groundwater flow model did not simulate groundwater quality. However, model results indicate that vertical flow will be induced from shallow layers (the North Denes, Breydon and Happisburgh Glaciogenic Formations) into the Crag Group Aquifer as it flows eventually to the cofferdam (Plate 3.4). This will occur to varying degrees depending on the scenario modelled.

3.3.6 Drawdown in the upper layers and groundwater flow vectors indicates that there is significant potential for mixing of groundwater within the cone of depression for the range of conceptual models simulated within the groundwater flow model. The amount of mixing depends on the contrasts between the hydraulic conductivities and the extent of layering. Continuous layers were simulated at a range of hydraulic conductivities, as per the Design team’s conceptual model. The more homogenous the ground the more mixing that will occur. In reality ground conditions are more variable than those simulated and the amount of mixing will be more influenced by the vertical and lateral changes in the geology.

3.3.7 The impact is dependent on the baseline groundwater quality, which is described in Chapter 11: Road Drainage and the Water Environment of the Environmental Statement Section 11.4.

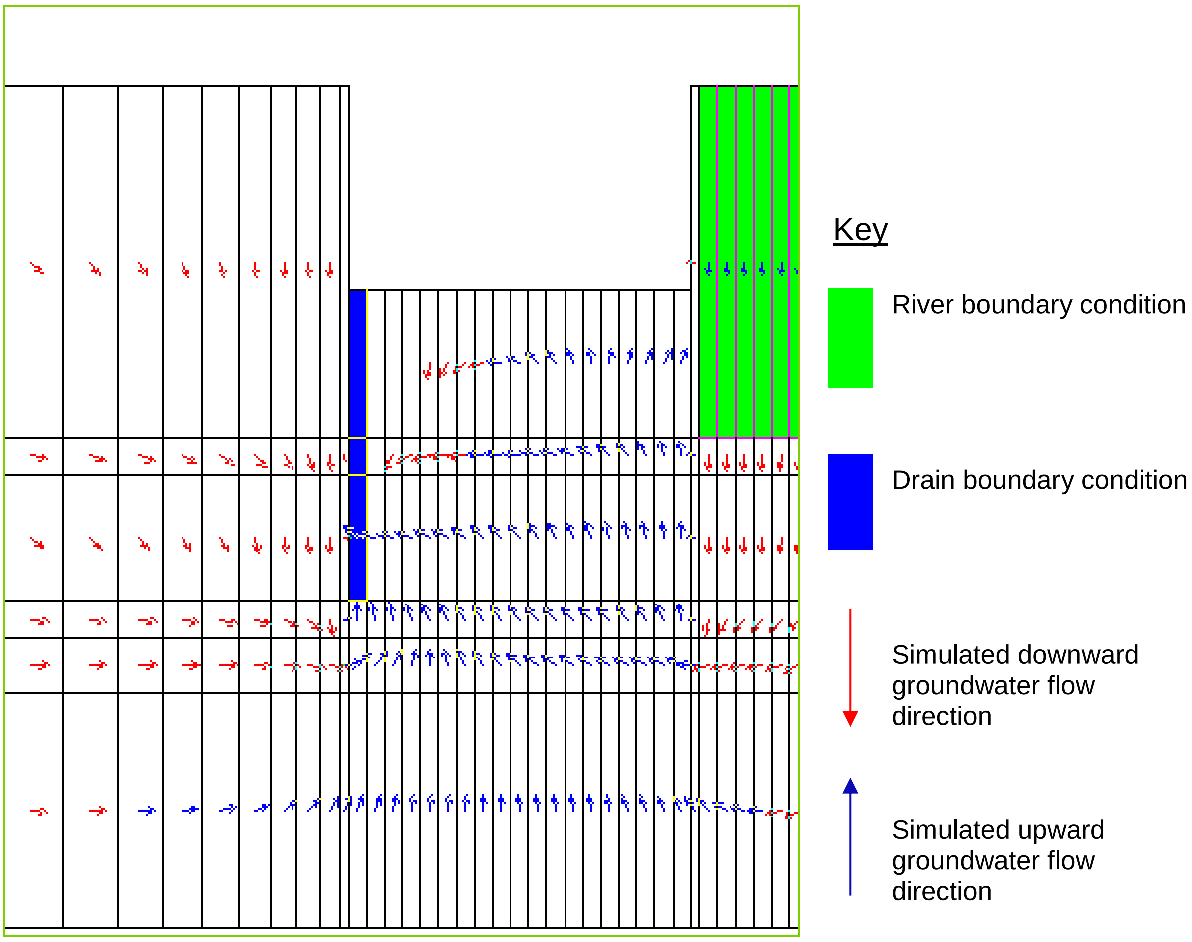


Plate 3.4: Groundwater Flow Vectors for Model Scenario 8. Groundwater moves through the Aquifer Layers and up inside the Cofferdam towards the Dewatering Wells

North Denes, Breydon and Happisburgh Glaciogenic Formations

3.3.8 The three superficial geological units may broadly be summarised as an upper sand (North Denes Formation) and lower gravel unit (Happisburgh Glaciogenic Formation) separated by clays of the Breydon Formation. More geological information may be found on the online British Geological Survey (BGS) Lexicon (Ref 11F.3). Of the three formations, the North Denes Formation is recognised as a Secondary A Aquifer. However, lateral and vertical variations in composition, i.e. the distribution and respective ratio of sand to clay, will result in a degree of connectivity across all three formations.

Groundwater Storage

- Groundwater drawdown reduces towards ground surface due to the layering within the geological sequence. In the worst-case scenario

(Scenario 8), drawdown 1m from the cofferdam is predicted to be approximately 1.8m and at 400.0m the drawdown will be approximately zero.

- The joint report produced by the British Geological Survey and the Environment Agency (Ref 11F.2) also includes data for the superficial deposits. Total abstractions were 5.4M m^3/year. Based on this information, dewatering from the three formations would represent less than 1% of abstraction. The abstractions and dewatering rates quoted are indicative and the presented in support of what is a qualitative assessment.

Groundwater Flow

3.3.9 The groundwater flow assessment described above for the Crag Group Aquifer applies equally to these three formations.

Groundwater Quality

3.3.10 The groundwater flow model did not simulate groundwater quality. However, construction dewatering is going to lower water levels in these three formations. The resulting drawdown is going to induce flow from the River Yare into the formations. The impact is dependent on the baseline groundwater quality, which is described in Chapter 11: Road Drainage and the Water Environment.

3.3.11 With reference to the geological description on the BGS Lexicon, the North Denes Formation is described as consisting of an elongate, wedge-shaped body of sand with subordinate gravel and thin layers of silty clay. The Breydon Formation is dominated by unconsolidated silt and clay with a shelly marine fauna. Sand is generally a minor component. The Happisburgh Glaciogenic Formation consists of a range of diamictons, sands and gravels, sands and laminated silts and clays. The superficial geology formations contain variable amounts of clays, however, the formations are anticipated to be hydraulically connected on a regional, and potentially local scale depending on heterogeneity (that was not simulated in the model), meaning groundwater quality should be consistent across all three formations unless stratification has occurred.

Groundwater Users

Groundwater Availability

3.3.12 The nearest licensed groundwater user is Camplings Ltd located approximately 0.7km from the west cofferdam. Modelling indicates that drawdown is unlikely to extend as far as this abstraction borehole. The drawdown simulated in the worst case scenario (Scenario 8), which is considered to be unlikely, indicates 0.1m drawdown at 400m, tending towards zero drawdown at 1km. As discussed above, the point of zero drawdown is influenced in the model by the constant head boundary and the 0.1m drawdown contour represents an effective limit to drawdown. The results indicate that that there could be minimal interference between the Camplings Ltd abstraction and the cone of dewatering required for temporary works under unlikely hydrogeological conditions. The magnitude of drawdown that occurs at the Camping Ltd well, if indeed there is any, is very likely to be within the seasonal range of groundwater levels and therefore natural changes in groundwater level. There is unlikely to be any significant impact at the further two abstractions sites identified.

Groundwater Quality

3.3.13 The Camplings Ltd source is further inland than the cofferdam and groundwater mixing local to the cofferdam caused by local changes in flow path is very unlikely to lead to any impact on water quality at the abstraction for the duration of the temporary works (construction stage). The temporary works dewatering is likely to capture groundwater from the River Yare and inland, this will therefore not propagate any pre-existing saline intrusions towards the groundwater abstraction. If dewatering wells are screened across multiple geological layers then groundwater quality mixing could occur.

3.3.14 Dewatering at the cofferdam is likely to induce groundwater exchange between layers, potentially affecting water quality locally. After the cessation of dewatering (in the operational stage of the scheme) the groundwater that has mixed in the area of the cofferdam may migrate towards Camplings Ltd source, depending on its area of influence. Consequently, there is a slight risk of longer term deterioration of water quality at the abstraction until the groundwater system returns to its pre-construction state. It is worth noting that the impact of this medium to long-term change in water quality is related to the baseline water quality, which is described in Chapter 11: Road Drainage and the Water Environment Section 11.4. Please note that the abstraction well capture zones have not been modelled as this was beyond the scope of this study, therefore the impacts described are inferred rather than explicitly modelled.

River Yare

3.3.15 The model was not designed to investigate groundwater surface water interactions and any changes in the hydraulic relationship in response to dewatering. However, results indicate a number of potential impacts are possible on the River Yare:

- Changes in baseflow. The conceptual model developed by Design team indicates that the hydraulic gradient is from the river to the adjacent aquifers. However, this is likely to vary seasonally and with tidal changes. Although not investigated by the model the dewatering activities are likely to reduce groundwater baseflow to the River Yare by the amount of water predicated to flow into the cofferdam when the river is gaining from groundwater. The groundwater flow model is assumed to apply to the temporary works on both the western and eastern banks. Flow to the river is, therefore, anticipated to be reduced by 6 L/s to 31 L/s for the ‘average’ and worst-case scenarios, which would represent an insignificant change in such a large river.

- River losses. The dewatering associated with the proposed cofferdam will induce flow from the River Yare. Although the pile walls will prevent flow directly into the cofferdam, small amounts of water will migrate into the shallow geological formations. Modelling indicates a maximum flow from the River Yare of 0.1M L/day.

3.3.16 Both potential impacts on the river may be mitigated by recirculating the water removed during dewatering into the River Yare, subject to the necessary Environmental Permit.

4 Summary and Conclusions

4.1.1 This report presents a dewatering impact assessment for the temporary works dewatering that would be associated with the proposed cofferdam and bascule construction. The level of risk was reviewed prior to modelling, in accordance with Environment Agency Report, SC040020/SR1 (Ref 11F.1), to determine the level of detail required in the modelling study. A simple 3D groundwater flow model was constructed in MODFLOW 2015 based on the conceptual model provided by the Design team. The model assumes homogenous flat layering, a simplified geology and no vertical anisotropy. The model was run in steady state with no recharge. The model was used to investigate the sensitivity of drawdown impacts to hydraulic conductivity.

4.1.2 The simulated dewatering rates at the proposed groundwater control wells agree well with those predicted during a previous modelling study (as completed by the Design team), giving a range of total flow rates between 0.16 l/s to 15.53 l/s. Nine scenarios were modelled to perform a sensitivity analysis on the range of hydraulic conductivity values provided for sand and clay. Of these model runs, results from Scenario 8 (low sand hydraulic conductivity and high clay hydraulic conductivity) were presented as these were considered the worst-case results in terms of dewatering impacts.

4.1.3 The impacts of the proposed dewatering on the water environment are summarised as follows:

- Negligible drawdown beyond 400.0m during the worst-case scenario modelled.
- Minor but insignificant loss of aquifer resource in both the Crag Group Principal Aquifer and North Denes Formation Secondary A Aquifer.
- Groundwater mixing will occur as water moves towards the cofferdam. The degree of mixing is dependent on the hydraulic properties of the geological formations. Mixing is likely under natural conditions and the resulting impact is therefore likely to be negligible.
- Potential interference between the cone of depression that will develop around the proposed cofferdam and the nearest licensed abstraction, Camplings Ltd, approximately 0.7km away, which could result in a minor but insignificant impact on borehole yield.

- Upon the cessation of dewatering there is potential for changes in groundwater quality to eventually impact on the Camplings Ltd borehole. The potential impact of the change cannot be assessed without information on the quality of water currently abstracted by Camplings Ltd, but given the location of the abstraction close to the coast (in and area of high salinity groundwater), it is considered that the impact will be minor and insignificant at worst and potentially negligible.
- The development of a steeper hydraulic gradient between the River Yare and the dewatered aquifer material will lead to an increase in the ingress of river water. Two potential impacts follow: the loss of river water at minor, but insignificant rate, and the change in groundwater quality, the impact of which depends on the baseline groundwater conditions.
- The proposed dewatering could result in a reduction of baseflow, (groundwater discharge), to the River Yare by a minor but insignificant amount. The impact of the change in baseflow regime could potentially be offset by discharging water from the dewatering activities into the River Yare, subject to conditions set out in an environmental permit.

5 References

Ref 11F.1: Boak R, Bellis L, Low R, Mitchell R, Hayes P, McKelvey P, Neale S. (2007). Hydrogeological impact appraisal for dewatering abstractions. Environment Agency Science Report SC040020/SR1.

Ref 11F.2: Ander, E. L., Shand, P. and Wood, S. (2006). Baseline Report Series: 21. The Chalk and Crag of north Norfolk and the Waveney Catchment Groundwater Systems and Water Quality. Commissioned Report CR/06/043N

Ref 11F.3: British Geological Survey Lexicon, 2019.