Kingfisher Pond - Northstowe Hydrogeological Assessment

Baseline Conceptual Report

FWM8714-RT001-R01-00

February 2021

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Executive Summary

In 2015 residents in Longstanton reported that water levels in the local Kingfisher Pond had declined. There have been ongoing concerns since then. The year 2015 coincided with development at adjacent Northstowe.

HR Wallingford has been commissioned by South Cambridgeshire District Council (SCDC) on behalf of Longstanton Parish council (the client) to complete an independent review on the hydrogeology of Northstowe, Cambridgeshire. HR Wallingford proposed a three stage approach which was:

I. Review the hydrology and hydrogeology of the Kingfisher Pond and surrounding area prior to concerns being raised about its condition (2015) and develop a conceptual model of the area.
II. Review the more recent hydrology and hydrogeology and determine if the Kingfisher Pond has changed since 2015 and, if there is a change.
III. Determine the cause of the changes in the hydrology and hydrogeology of the Kingfisher Pond.

Due to discussions between the Longstanton Parish Council and SCDC the first phase of the project has been delayed.

This report completes **the first phase** and presents the conceptual model which outlines the hydrological and hydrogeological processes of the Kingfisher Pond and how it operated up until 2015 in terms of the groundwater – surface water interactions. The focus of this report is the Kingfisher Pond, additional water features in the local area have been reviewed to provide context for local hydrology. **This report does not conclude if the condition of the pond has changed since 2015 or suggest any reasons - this will come in Phase II.**

This conceptual model is to be reviewed by all relevant stakeholders before HR Wallingford continue with Phase II of reporting to determine if the groundwater level at Longstanton and the Kingfisher Pond has changed.

The conclusions within this report are based upon a literature review, analytical assessment of available data, and resident survey results. Due to covid-19 travel restrictions in place which began in Autumn 2020, a site visit to Longstanton has not been possible, but will be undertaken if easing of restrictions allows. A high-level summary of key findings is provided in Box 1.

Box 1: Summary of key findings of the local hydrogeology of the Kingfisher Pond

Our Key findings are:

There is no evidence in the data of a long-term trend of reducing rainfall in the area (1961-2015).

The pond is sited in drift deposits of sands and gravels which overlay low permeability clay.

There is limited measured data on water levels in the Kingfisher Pond prior to 2015.

There are several useful boreholes in the area, which show:

- That there is no long term evidence of groundwater levels declining before 2015
- The water level in the pond is at approximately the same level as groundwater level in the drift deposits.

There is a pipe which controls the level in the pond when water levels are high.

Water in the Kingfisher Pond and drift deposits are in hydraulic continuity, meaning that the water levels in the pond will reflect water levels in the drift deposits.

What happens next?

We propose a three week review period for stakeholders to consider the contents of this phase I report. Any comments should be sent to a.wilcox@HRWallingford.com before 26th February 2021. If these comments change our understanding of the Kingfisher Pond we will address them, if not we will begin Phase II of the project which is to understand the current condition of the pond (since 2015).

Contents

Tables

Photographs

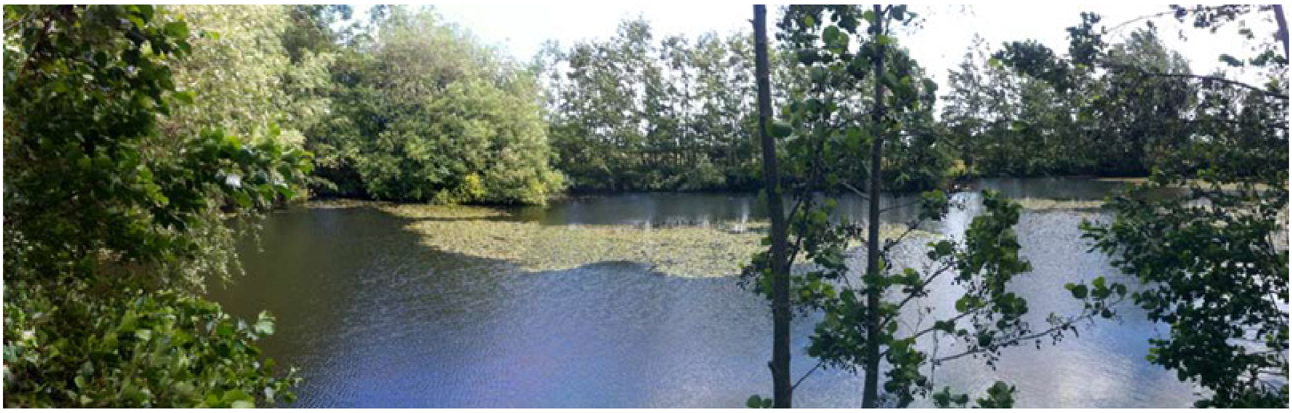
1. Introduction

1.1. Background

Longstanton is a village and civil parish located 10 km north east of Cambridge, Cambridgeshire. Throughout the village there are several surface water features, including the Kingfisher Pond (Photograph 1.1). The Kingfisher Pond is a large pond with a surface area of 3000 m^2 and (when full) a depth between 1.5 m and 2.0 m. The pond is a popular site for residents and can support an abundance of wildlife including the pond's namesake Kingfishers which nest in the banks of the pond.

Cambridgeshire's new town of Northstowe is a large development including up to 10,000 homes, a primary school and community leisure facilities (SCDC, 2020). Northstowe Phase I is a 97 ha site situated next to Longstanton. Hatton's road attenuation ponds form an additional 24 ha of Northstowe Phase I and are situated to the south west of Longstanton (Gallagher, 2012). The Kingfisher Pond is located on the main site of Northstowe Phase I (52°17'6.53"N, 0° 3'0.60"E) (Figure 1.1). The development of Northstowe Phase 1A included dewatering activities which occurred between May and September 2015 (Wardell Armstrong, 2017).

According to survey responses from residents, concerns that the surface water level of the Kingfisher Pond had declined were raised in December 2015. This resulted in fish kills and a near complete drying of the lake. Further concerns were raised for other surface water features in Longstanton, including the Hatton Farm ponds, private ponds and abstraction wells. Though seasonal fluctuations in water level are to be expected, residents have reported that the water levels in the pond have not recovered to its former state since the first decline in late 2015.



Photograph 1.1: The Kingfisher Pond, January 2012

Source: Courtesy of Clive Hayden (2020)

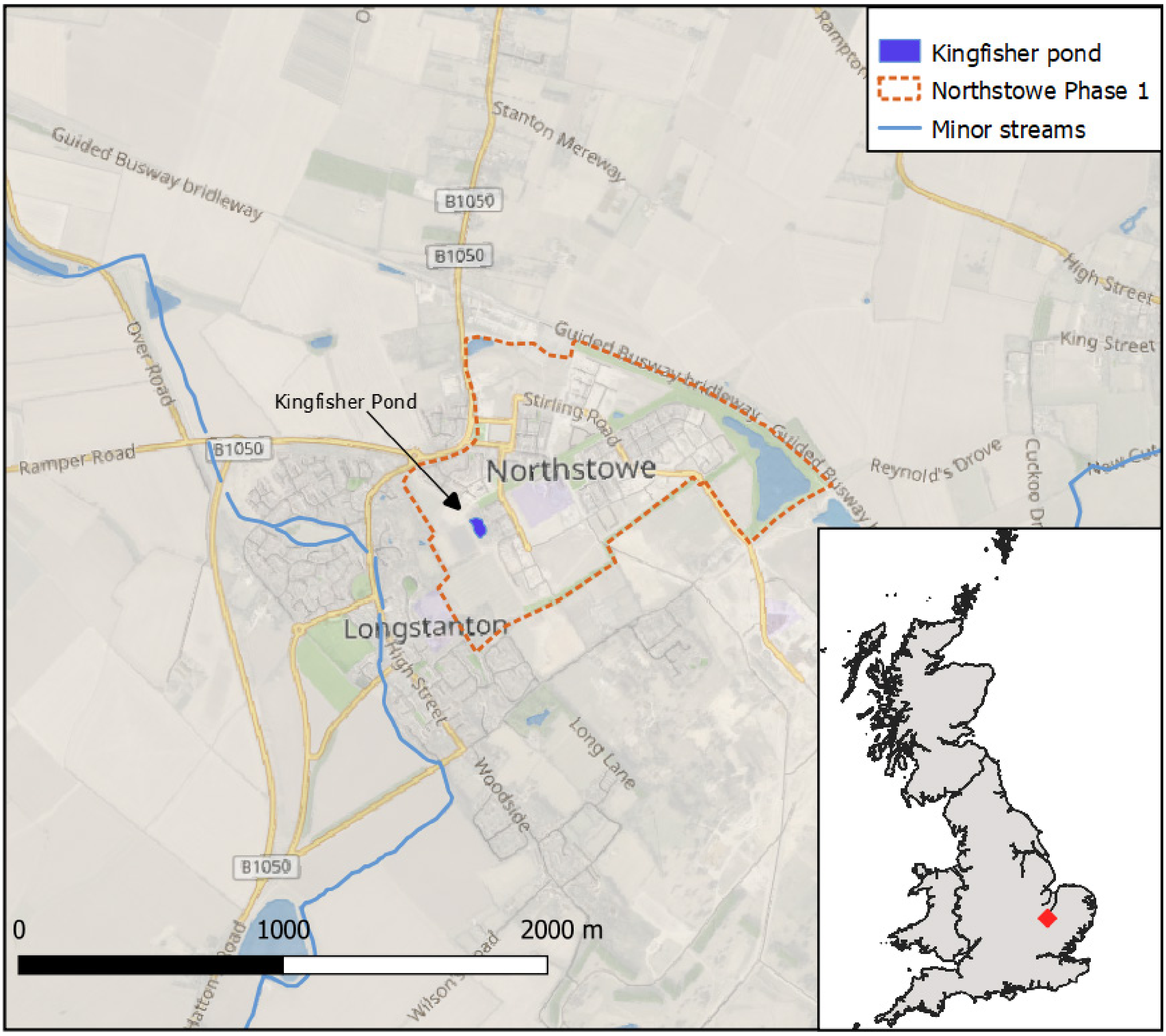


Figure 1.1: Map of Longstanton and Northstowe, highlighting the location of the Kingfisher Pond in relation to Northstowe Phase 1

Source: *OpenStreetMap reproduced in QGIS. Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org.*

1.2. Report scope

HR Wallingford have been commissioned to report on the Kingfisher Pond and the hydrogeology of Northstowe to determine if water levels have dropped, and if so, determine the reasons. As part of the investigation, HR Wallingford agreed to produce an initial report of the baseline state of the local hydrogeology and the Kingfisher Pond, prior to concerns being raised about the condition of the pond. Residents initially reported a fall in surface water level at the Kingfisher Pond in December 2015. Therefore, available data up to 2015 is reviewed within this report to produce the conceptual model.

The conclusions within this report are based upon a literature review, analytical assessment of available data and resident survey results. A complete summary of all data obtained is provided in Appendix A.

The report intends to present and analyse available data of the following:

- Local hydrogeology (Section 2).
- Local climate (Section 3).
- Local groundwater level (Section 4).

A conceptual understanding of the Kingfisher Pond based upon data presented in sections 2,3 and 4 is summarised in Section 5.

The aim of this report is to:

- Analyse and present available hydrogeological data.
- Review available literature of planning reports.
- Provide a conceptual understanding of the Kingfisher Pond.
- Outline next steps, including consulting on this document to ensure that all relevant parties have accessed it and agree with it, before Phase II commences.

2. Local geology and hydrogeology

2.1. Overview

The data reviewed in this section are:

- British Geological Survey solid and drift maps.
- British Geological Survey borehole logs.
- Northstowe Phase I planning reports.

The key findings in this section are:

- The bedrock of Longstanton is impermeable clay.
- The bedrock geology is overlain by drift gravel drift deposits with high permeability and porosity.
- The gravel is a secondary aquifer and is of significant to local water supply.

2.2. Bedrock geology

The bedrock geology of Longstanton is the Ampthill Clay Formation (AmC) and the West Walton Formation (undifferentiated), with the Kimmeridge Clay Formation (KC) present to the south (Figure 2.1) Borehole logs at Longstanton describe the lithology of the AmC as “clay, silty, blue-grey, fossiliferous, containing siltstone nodules". The AmC is classified as an aquitard of unproductive strata with no contribution to water supply or river baseflow (Environment Agency, 2020). The depth of the AmC at the site is undocumented but expected to be approximately 10m bgl (WSP, 2014). The AmC outcrops to the west and east of the superficial deposits in the vicinity of Longstanton indicating that the superficial deposits are confined.

2.3. Superficial geology

Overlaying the bedrock are superficial deposits (Figure 2.1) The dominant superficial deposits is the class 2 River Terrace Deposits (RTD) which runs south to north through the centre of Longstanton. The RTD extends across the broader region, as far south as the city of Cambridge and continuing northward to the town of Chatteris.

The RTD were deposited by rivers that flowed across the region from south to north. The rivers are assumed to be forerunners of the present-day River Cam. Borehole records describe the lithology as 'clayey' sandy gravel. The gravel has subangular and subrounded flint with sandstone and chalk, the sand is course and medium with fine, quartz with flint and chalk (BGS, 2020d). The RTD has high permeability and porosity, it is classified as a secondary aquifer by the Environment Agency indicating that the aquifer has significance to local water supplies.

A multitude of ponds and small lakes, including the Kingfisher Pond, are identifiable along the RTD. These water bodies are in hydraulic continuity with the groundwater and therefore the surface water levels reflect the groundwater levels of the RTD.

Wardell Armstrong (2017) concluded that the ground conditions met during site investigations at Northstowe Phase 1 were consistent with the published geological mapping.

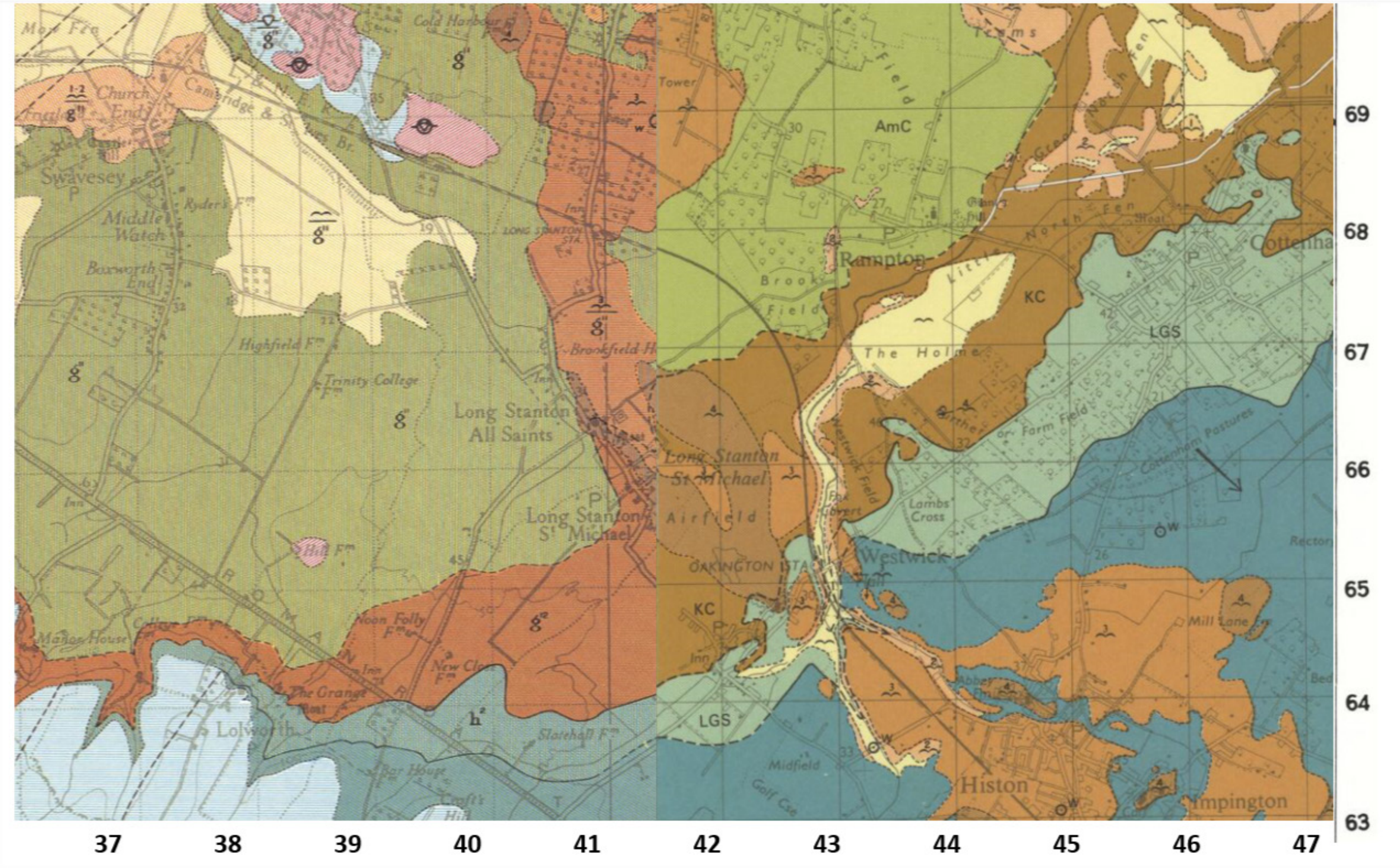


Figure 2.1: Solid and drift geological map of Huntington (187) and Cambridge (188)

Source: Geological Survey of England and Wales 1:63,360/1:50,000 geological map series [Old Series]

3. Local climate

3.1. Overview

The data reviewed in this section are:

- HadUK-Gridded (1km) precipitation for a 3km buffer around the Kingfisher Pond, 1961-2014 (Met Office, 2019).
- Meteorological Office for Cambridge National Institute of Agricultural Botany (NIAB), 1995-2014 (Met Office, 2020).
- Open water evaporation for the Kingfisher Pond, derived from the UK Centre for Ecology and Hydrology Potential Evapotranspiration dataset for Great Britain (Robinson *et al.,* 2020).

The key findings in this section are:

- Average monthly rainfall is fairly even throughout the year, with a maximum in August and minimum in February.
- There is no long-term trend to suggest declining or increasing rainfall between 1961-2014.
- There is no long-term trend to suggest a declining or increasing open water evaporation rate between 1961-2014.

3.2. Rainfall analysis

Surface water features, such as ponds, gain water through a combination of direct rainfall, surface run-off and recharge from an aquifer in hydraulic continuity, which is in turn influenced by local climate and anthropogenic influence. Surface water features can lose water via open water evaporation and leakage to the underlying aquifer. This behaviour is fixed neither spatially nor temporally. For example, a pond which gains under normal conditions, can lose during flood conditions as surface water levels rise above groundwater levels. To understand the behaviour of Kingfisher Pond in this context, Section 3 provides a summary of long-term climate for the region to determine how seasonal climate may affect the natural hydrogeological regime of the Kingfisher Pond. This is further discussed in the context of the groundwater – surface water interaction in Section 5.

Open water evaporation and evapotranspiration from the banks of the Kingfisher Pond is of minimal significance in comparison to the impact of regional rainfall and subsequent infiltration to groundwater. Open water evaporation over the Kingfisher Pond has been analysed for the period 1961-2014. This has been derived using the UK Centre for Ecology and Hydrology potential evapotranspiration dataset (Robinson *et al.,* 2020) and converted to open water evaporation using a set of monthly empirical factors developed by the Environment Agency (2001). The data shows that there is no long term trend in evaporation rate for the period 1961-2014. Full results and further details of the method used are provided in Appendix B.2.

In this section, rainfall data has been analysed from the Cambridge National Institute of Agricultural Botany (NIAB) dataset (Met Office 2020) and the Had-UK Gridded data set (Met Office, 2019). The Cambridge NIAB weather gauging station is located 7.5km south-east of Longstanton and is the closest available meteorological station to Longstanton. The HadUK-Gridded data is a 1km gridded dataset specific to a 3km buffer around the Kingfisher Pond, derived from the network of UK land surface observations. The data have been interpolated from meteorological station data onto a uniform grid.

Analysis for coincident dates showed that the HadUK-Gridded data and Cambridge NIAB gauged datasets are broadly consistent. For clarity, the Cambridge NIAB data is presented in this section, full analysis can be found in Appendix B.1.

Results show that for the period 1961 - 2014, rainfall on average falls evenly throughout the year. On average the wettest month is August and the driest is February (Figure 3.1). Annual average rainfall is 534mm. Figure 3.1 shows that though inter-annual fluctuation does occur, there is no long-term trend to suggest declining or increasing rainfall between 1961-2014.

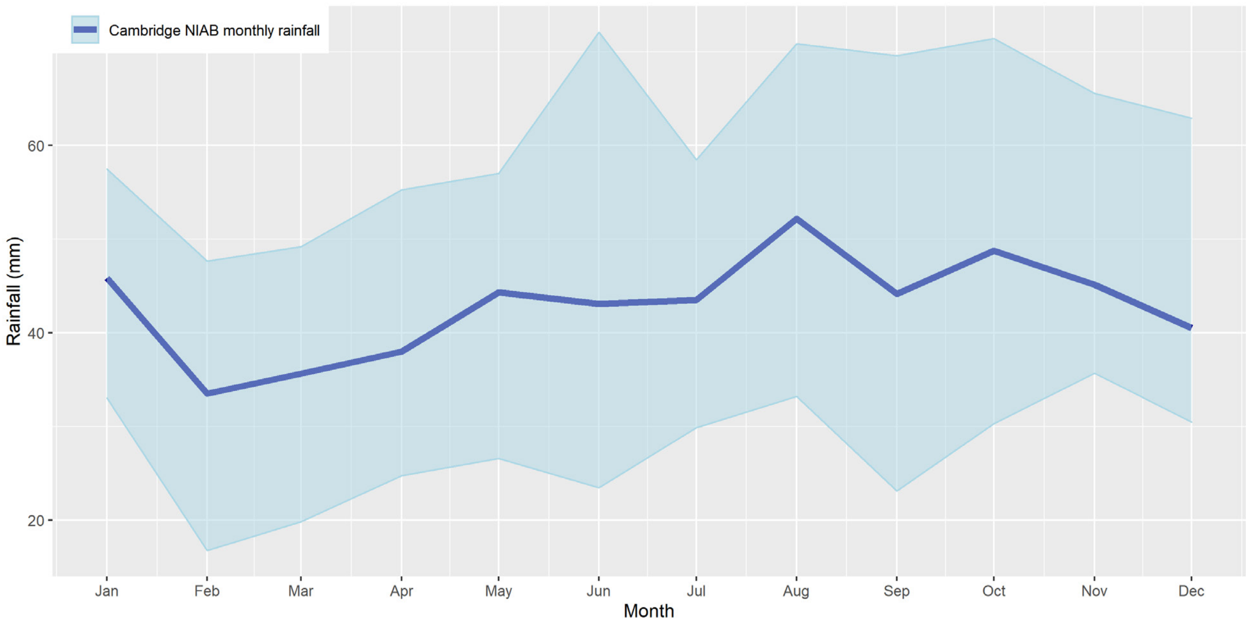


Figure 3.1: Monthly rainfall recorded at Cambridge NIAB meteorological station. Data from 01/01/1961 to 31/12/2014

Source: Cambridge NIAB meteorological station (Met Office, 2020)

Notes: Dark blue line is the median Q50 monthly rainfall
Light blue ribbon is the range of Q25 to Q75 rainfall range

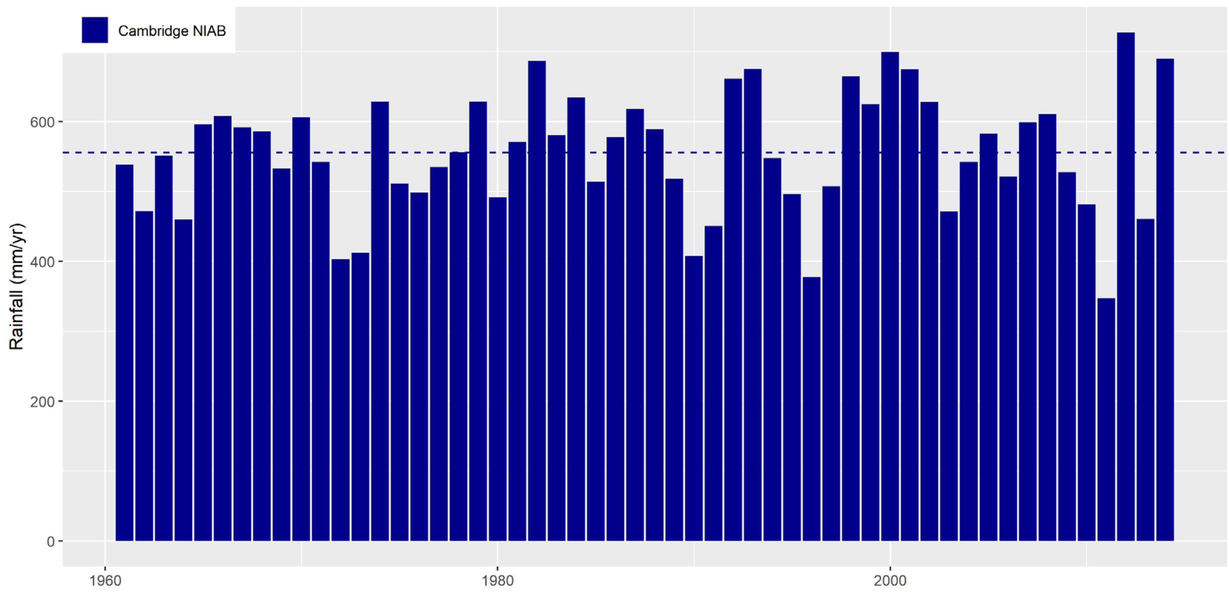


Figure 3.2: Annual total rainfall recorded at Cambridge NIAB meteorological station. Data from 01/01/1961 to 31/12/2014

Source: Cambridge NIAB meteorological station (Met Office, 2020)

4. Groundwater level

4.1. Overview

The data reviewed in this section are:

- Environment Agency groundwater monitoring boreholes within 10km of Longstanton.
- Northstowe Phase 1I planning reports.

The key findings in this section are:

- Regional long term groundwater levels remained stable between 1971 and 2015.

4.2. Local groundwater levels

Groundwater level data from the Environment Agency (2020) was provided for two boreholes within 10km of Longstanton (Figure 4.1). Both boreholes are located on the same RTD which underlies the Kingfisher Pond. Therefore, it is reasonable to assume that fluctuations in groundwater level in these two boreholes should be representative of seasonal and long-term trends in the groundwater level at the Kingfisher Pond. No borehole groundwater level in closer proximity to the Kingfisher Pond with timeseries data was available from the Environment Agency. The data provided covers the period between 1977 to 2019, however in this report only data prior to 2015 is presented to summarise changes in groundwater level prior to the observed decrease in surface water at the Kingfisher Pond.

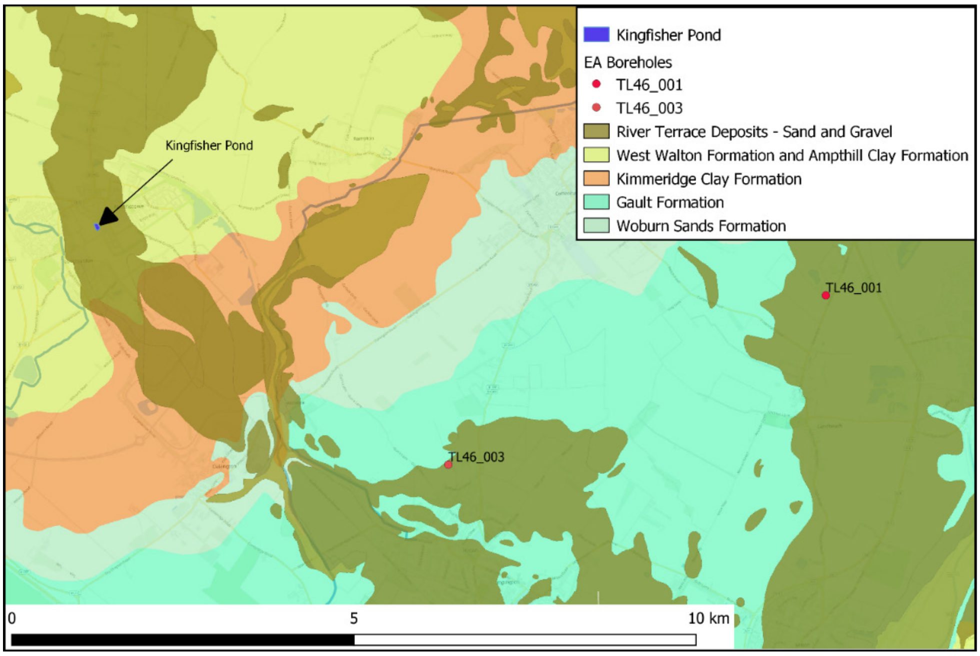


Figure 4.1: Map of boreholes TL46_001 (New Farm, Landbeach) and TL46_003 (Unwins Farm, Cottenham) in relation to the River Terrace Deposits and the Kingfisher Pond

Source: British Geological Survey 1:50 000 drift and bedrock geology, reproduced in QGIS. All rights reserved.

The data is provided in a timeseries which has not been collected at regular intervals. All data provided is marked on the graphs, with groundwater levels interpolated between data points. It is therefore important to consider that daily fluctuations of groundwater level cannot be represented in these graphs. The data is intended to demonstrate any occurrence of long-term changes to groundwater.

Figure 4.2 shows that the long-term fluctuations the groundwater level across the three boreholes has remained stable. Seasonal fluctuations are about 1 m. TL46_003 (Unwins Farm, Cottenham) has a groundwater level range between 6 mAOD and 7 mAOD, while TL46_001 (New Farm, Landbeach) has a groundwater level range between 2.5 mAOD and 3.5 mAOD.

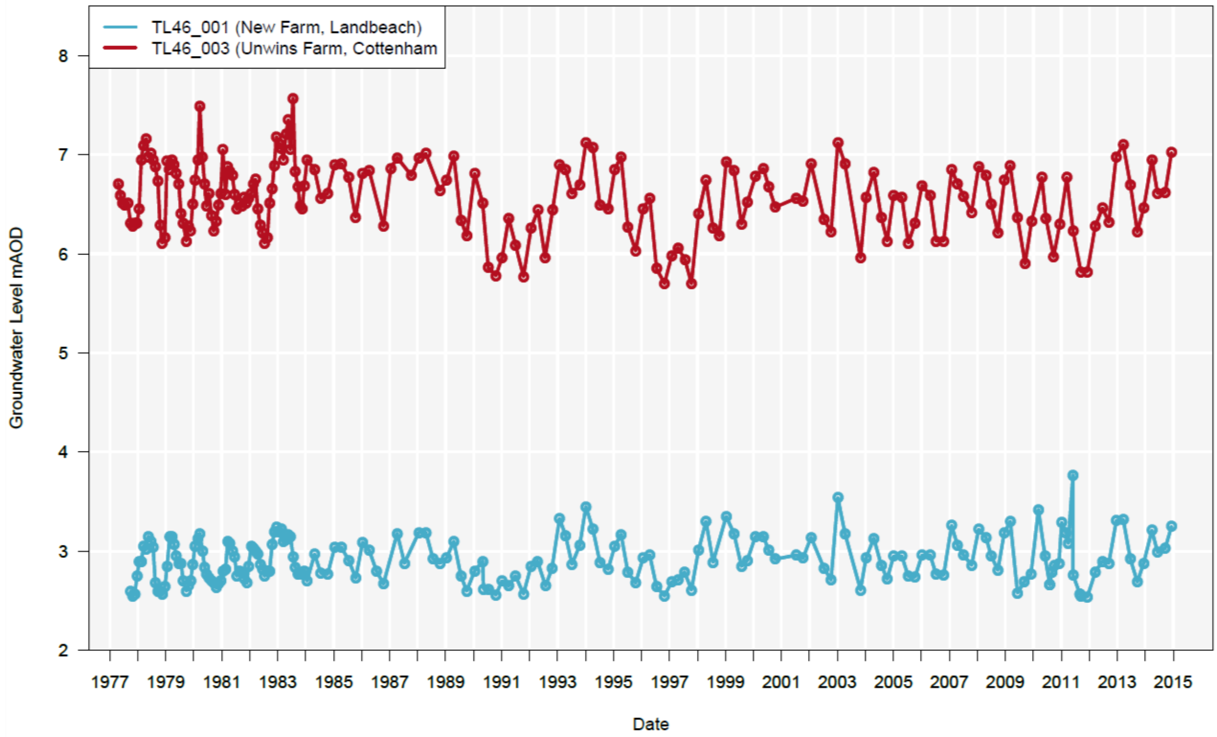


Figure 4.2: Groundwater levels at boreholes within 10km of Longstanton

Source: Environment Agency, 2020

4.3. Northstowe Phase I planning reports

As part of the planning works undertaken at Northstowe Phase I, the groundwater levels have been monitored at intervals between November 2005 and January 2016.

For this report HR Wallingford have reviewed the borehole monitoring records up to and including October 2014 to consider the range in recorded groundwater levels prior to the Northstowe development and the reported drop in the Kingfisher Pond surface water levels.

Of the monitored boreholes, BH125 is of particular interest given its proximity to the western bank of the Kingfisher Pond. The range of groundwater levels monitored between April and July 2014 is 7.2-7.4 mAOD. BH125 does not have any further published data prior to 2014. Other boreholes on the site of Northstowe Phase I indicate that the groundwater level at River Terrace Deposit is 6.8 mAOD and 8 mAOD between April and July 2014, with a general groundwater flow in north western direction inferred from groundwater level contours.

Table 4.1 gives a summary of the groundwater levels recorded at boreholes of interest. Figure 4.3 shows the locations of these boreholes and proximity to the Kingfisher Pond.

Table 4.1: Summary of borehole groundwater levels at Northstowe Phase I

Borehole	Geology of response zone	Range of monitored groundwater levels (mAOD))
BH111	River Terrace Deposits	7.14 - 7.33
BH124	River Terrace Deposits	7.11 - 7.34
BH125	River Terrace Deposits	7.20 - 7.40
BH126	River Terrace Deposits	7.34 - 7.53

Source: Data from Wardell Armstrong (2017)

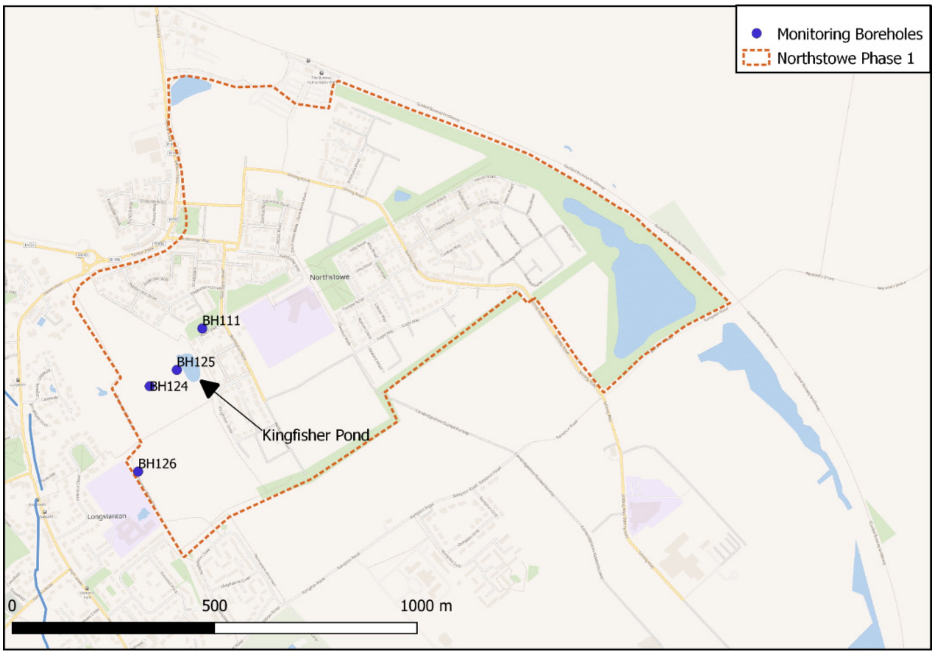


Figure 4.3: Map highlighting locations of boreholes of interest at Northstowe Phase 1

Source: Locations from Wardell Armstrong (2017) reproduced in QGIS

5. The Kingfisher Pond

5.1. Overview

The conceptual model of the Kingfisher Pond is based on the data presented in sections 2,3 and 4. In addition, the following data has been reviewed:

- Local resident surveys conducted by HR Wallingford in Autumn 2020.
- Photographs provided by residents.

The key points of the Kingfisher Pond conceptual model are:

- The Kingfisher Pond is in hydraulic continuity with the RTD aquifer.

- Groundwater levels in the pond therefore reflect the groundwater in the RTD.
- There are no indications that the groundwater levels in the RTD changed in the period up to 2015 therefore the there is no indication that the surface water level in the pond dropped in years up to 2015.

5.2. Details of the Kingfisher Pond

5.2.1. History

The Kingfisher Pond has been a continual feature in Longstanton for many decades since it was dug out in the late 1960/early1970's. The site was part of a golf course since the early 1990's and was agricultural land prior to that. The pond has previously been used to irrigate farmland and the golf course under a licenced abstraction during low rainfall years.

5.2.2. Topography

Kingfisher Pond has a surface area of 2950 m^2, it is in a subtle topographical depression allowing surface run-off to naturally recharge the pond. The average elevation of the surrounding land is 8-10 mAOD, with the elevation rising to >10 mAOD to the east of Longstanton.

5.2.3. Hydrogeology

The pond is situated in the centre of the RTD and confined below by the AmC (Figure 5.1:, Figure 5.2). The Groundwater levels next to the Kingfisher Pond have been recorded to be between 7.2 mAOD and 7.4 mAOD during monitoring between April and July 2014.

The depth of the pond (when full) is less than 2 m. Because it is a shallow pond, small drop in groundwater levels can significantly affect the pond.

Figure 5.1: Map showing location of the Kingfisher Pond on the RTD

Source: British Geological Survey 1:50 000 drift and bedrock geology, reproduced in QGIS. All rights reserved OpenStreetMap reproduced in QGIS. Map data copyrighted OpenStreetMap

5.2.4. Water levels in Kingfisher Pond

Surveyed surface water levels have been recorded in July 2011 a 6.92 mAOD and at 6.38 mAOD in January 2015 (Wardell Armstrong, 2017), whilst the groundwater levels in the preceding section were not measured at the same time as the levels in the pond, they are broadly consistent.

The surface water levels are estimated to be typically between 6-7.5 mAOD. No other data for the surface water level has been obtained prior to 2015 however residents have observed the pond to be at a “healthy” level with quick recovery prior to 2015.

After periods of abstraction for irrigation the water levels of the pond would decline but quickly recover within several days. Residents of Longstanton record the pond as quick to fill after abstraction for irrigation purposes, indicating that it refilled from the aquifer below as oppose to from rainfall. During historic significant droughts including 1976, there is no observational evidence to suggest that the Kingfisher Ponds levels significantly dropped, nor did water levels within local ponds and wells along the RTD. Photographic and anecdotal evidence from residents of Longstanton suggest that the pond within a level capable of supporting aquatic life until December 2015.

An overflow pipe was implemented in the pond to prevent the water overtopping the banks of the pond during periods of high winter rainfall. The overflow pipe allowed water to drain using a small weir leading to an overflow pipe and into a nearby ditch, the water then flows into a stream flowing through the village. The drain that it flows into some 200 m from the outlet pipe is maintained by the council as part of flood reduction measures. This drain runs alongside Hatton Park Primary school.

The main purpose of the overflow pipe is to allow the water to remain at a level where the kingfishers can nest in the banks of the pond. The pipe has since been damaged in 2014, a temporary fix to the pipe was later implemented and later fully renewed in September 2019. The presence of the overflow pipe indicates that water levels regularly reached high levels during winter.

5.3. Our conceptual Model

The diagram below summarises the key points relating to the pond. The key features are that:

- Rainfall falls directly on the pond and onto the RTD, topping up the pond and increasing groundwater levels.
- There will be evaporation from the pond particularly during summer.
- The pond and RTD are in hydraulic continuity, so there is exchange of water between the pond and the RTD, which means that the water level in the pond will change as groundwater levels in the RTD change.
- The RTD is essentially isolated from other aquifers given its linear nature and the underlying AmC.
- The pipe controls levels in the pond.

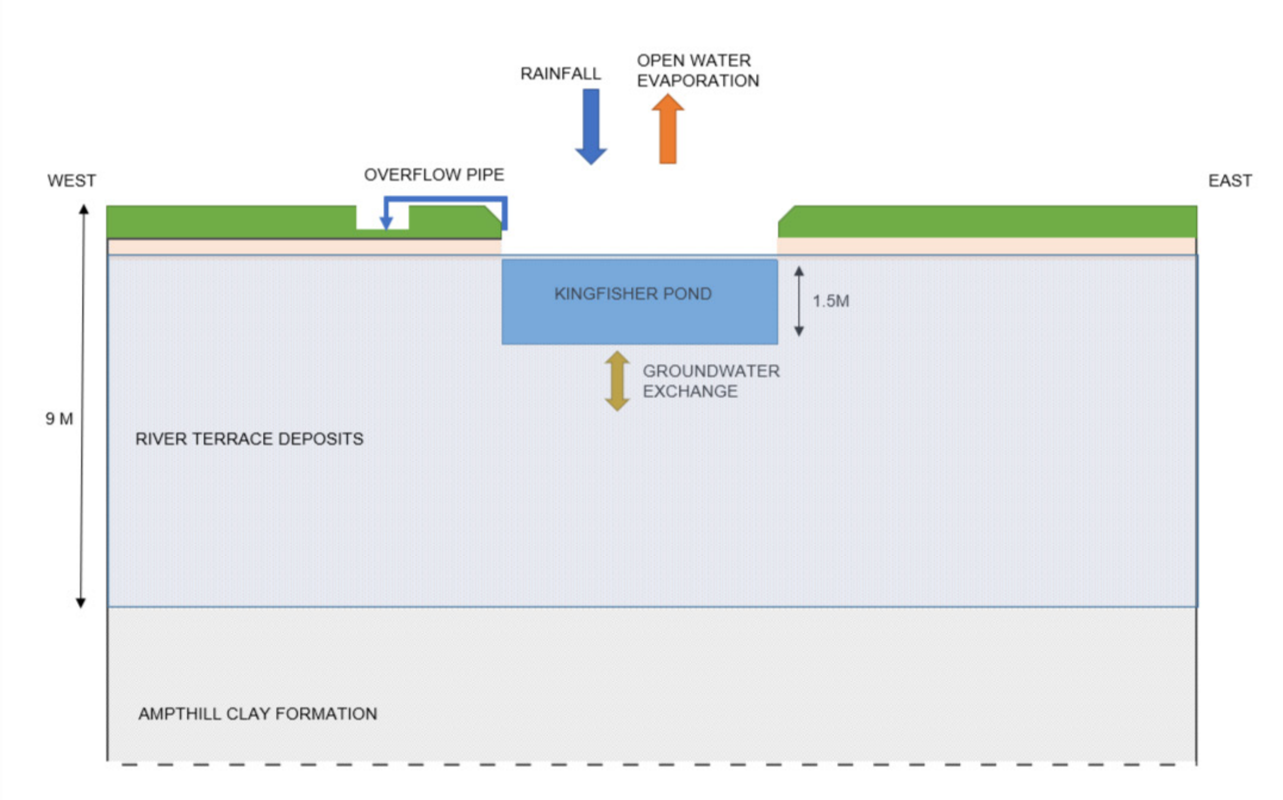


Figure 5.2: Schematic diagram describing the hydrogeological interaction of the Kingfisher Pond with the RTD aquifer

Notes: All measurements are approximate

6. Conclusion and further work

6.1. Conclusions

Regional rainfall data does not show any long-term trend between January 1961 and December 2014.

Additionally, the acquired Environment Agency boreholes from the same RTD aquifer do not show any long-term increase or decrease in groundwater levels in the data provided between 1977 and 2015. Groundwater levels reflect seasonal climate variability with a minimum occurring in September and maximum in March.

Data from boreholes adjacent to the Kingfisher Pond and records of levels in the pond indicate that the Kingfisher Pond is in hydraulic continuity with the RTD aquifer. The Kingfisher Pond is recharged by the RTD aquifer during normal conditions, changes in the local groundwater level will therefore be reflected in the surface water level of the pond.

A conceptual model of the Kingfisher Pond has been provided.

6.2. Next steps

It is important that key stakeholders agree this report before we move to Phase II which is to understand the condition of the pond now, and to ascertain if the condition has changed since 2015, and if so why.

We propose that stakeholders review this report, and provide any comments to HR Wallingford directly via

a.wilcox@hrwallingford.com.

We propose a three week period for receipt of those comments. In particular we need to understand if there is disagreement on the conceptual model.

We propose to ask two specific questions:

1. Do you agree with the conceptual model presented in this report?
2. If you have comments on the conceptual model what are they?

Once we have received these comments we will consider if our conceptual model needs to change. If not then we will progress to phase II which involves a more detailed review of information since 2015. We will then publish our Phase II report.

7. References

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WSP (2012b) Northstowe Phase 1 Planning Application Environmental Statement Technical Appendix H: Flood Risk Assessment.

WSP (2014) Northstowe Phase 1A Geo-Environmental Assessment.

Appendices

A. Data Summary

Table A.1: Summary of data sources

Data	Summary	Reference
Geological Data	British Geological Survey Solid and drift sheet map of Huntington- 187 (1:50,000)	BGS (1981)
	British Geological Survey solid and drift sheet map of Cambridge - 188 (1:50,000)	BGS (1975)
	British Geological Survey Drift Map WMS 1:50 000	BGS (2020c)
	British Geological Survey Bedrock Geology Map WMS 1:50 000	BGS (2020d)
	British Geological Survey Bedrock Geology Map 1:625 000	BGS (2020e)
	British Geological Survey borehole logs at locations in Longstanton and Northstowe	BGS (2020f)
Groundwater Levels	Environment Agency (East Anglia) groundwater levels	Environment Agency (2020)
	WSP Northstowe Phase 1 groundwater levels	WSP (2014a)
Reports	Wardell Armstrong Interim Report	Wardell Armstrong (2017)
	Northstowe Phase 1A Geo-Environmental Assessment	WSP (2014)
	Northstowe Planning Application: Planning Supporting Statement	Gallagher (2012)
Resident surveys conducted by HR Wallingford (2020)	Observational Evidence	NA
	Photographs	NA
Climatological Data	HadUK-Grid Gridded Climate Observations on a 1km grid over the UK, v1.0.0.0 (analysed for a 3km buffer around the Kingfisher Pond)	Met Office (2019)
	Gauged rainfall at Cambridge National I Agricultural (NIAB) Meteorological station (1961-2020)	Met Office (2020)
	Climate hydrology and ecology research support system potential evapotranspiration dataset for Great Britain (1961-2017) [CHESS-PE]	Robinson et al (2020)

B. Climate Data

B.1. Rainfall data comparison

The following graphs in Section B.1. show the comparison of the HadUK-Gridded dataset derived for a 3km buffer around the Kingfisher Pond with the Cambridge NIAB meteorological station. Coincident data is for the period January 1961 to December 2014.

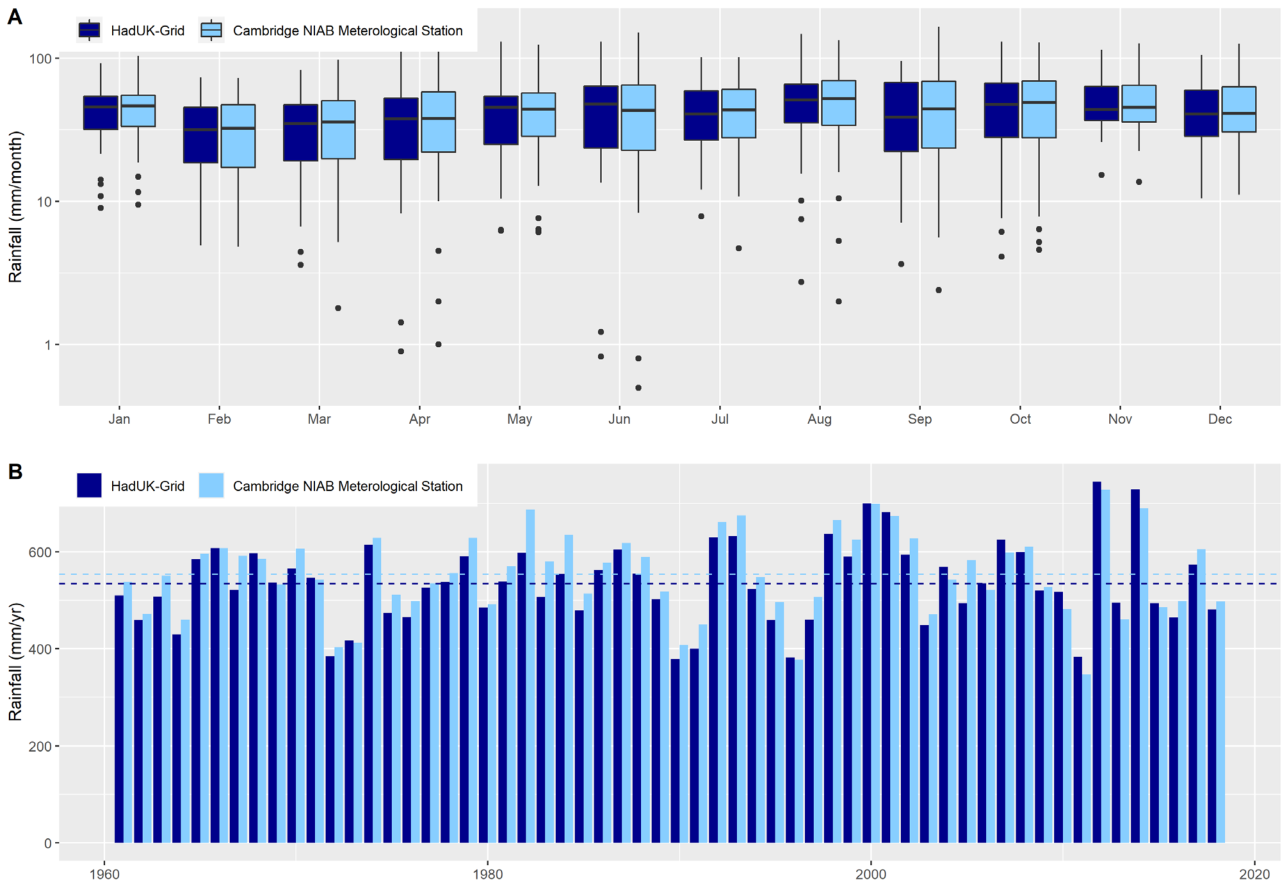

Figure B.1: Comparison of available rainfall data for the local area between January 1961 – December 2014

Source: HadUK-Gridded rainfall (Met Office, 2019)
Cambridge NIAB Meteorological Station gauged rainfall, (Met Office, 2020)

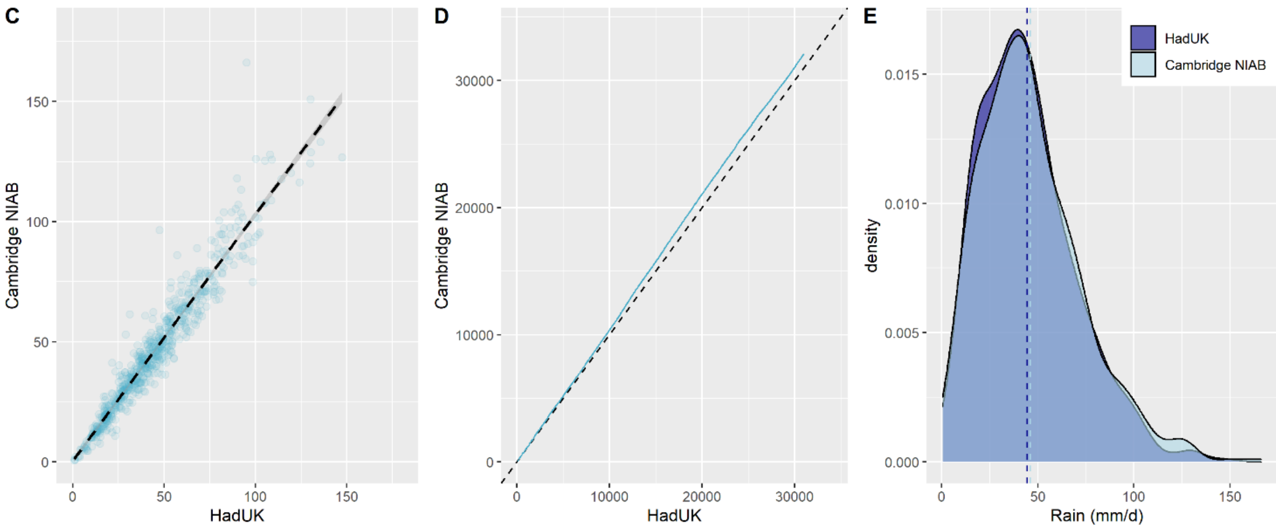

Figure B.2: Comparison of available rainfall data for the local area between January 1961 – December 2014

Source: HadUK-Gridded rainfall (Met Office, 2019)
Cambridge NIAB Meteorological Station gauged rainfall (Met Office ,2020)

B.2. Open water evaporation

To calculate the open water evaporation rate for the Kingfisher Pond, evapotranspiration data from the CEH potential evapotranspiration (PET) dataset (CHESS-PE) (Robinson et al., 2020) has been converted to open water evaporation using empirical factors from the Environment Agency (2001). The PET was subset for a large 25 km buffer area around Longstanton since PET has minimal spatial variation.

A number of assumptions are made when using the empirical factors method to calculate open water evaporation. All the assumptions made by the open water evaporation estimate empirical factors method are summarised in Estimation of Open Water Evaporation - Guidance for Environment Agency Practitioners R&D Handbook W6-043/HB (Environment Agency, 2001).

Those assumptions considered relevant to this study are outlined below:

- The assumption is made that the characteristics of the climate at Longstanton, from the perspective of evaporation, do not differ significantly from that found in the area of Kempton Park (southwest of London) where the empirical factors are derived.
- No major variation in monthly evaporation rates year to year.
- The water body is infinite in its lateral extent and of constant depth.
- Water is considered as low salinity.
- Changes in the heat content of the water body due to inflows, including rainfall, and outflow are negligible.
- Vegetation floating on the surface of the water is negligible.
- Meteorological conditions above the water body do not differ from those over the land from which the PET is derived.
- Net heat flow between the water body and underlying substrate is minimal.

Table B.1: Open water evaporation empirical factors

Month	Open Water Factor
Jan	1.43
Feb	1.14
Mar	0.92
Apr	0.95
May	0.91
Jun	1.02
Jul	1.24
Aug	1.37
Sep	1.47
Oct	1.99
Nov	2.29
Dec	1.95

Source: Estimation of Open Water Evaporation. Guidance for Environment Agency Practitioners R&D Handbook W6-043/HB. Environment Agency (2001)

Figure B.3 shows the average monthly profile for open water evaporation rate. As expected, peak evaporation occurs in summer when the temperature is highest. Figure B.4 shows the annual average open water evaporation. There is no long term trend indicating that open water evaporation is increasing for the period 1961-2014 The average open water evaporation rate is 1.87 mm/d.

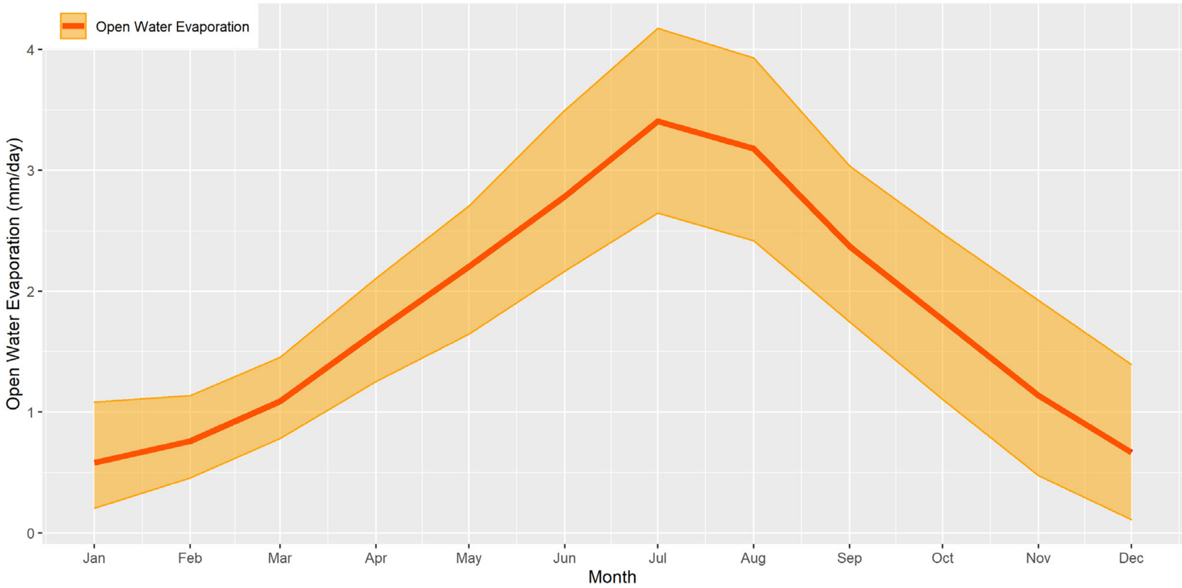

Figure B.3: Monthly profile for the daily average open water evaporation rate derived from potential evapotranspiration at Longstanton . Data from 01/01/1961 to 31/12/2014

Source: *CEH potential evapotranspiration Robinson et al., (2020) converted to open water evaporation using monthly factors developed by the Environment Agency (2001). Dark orange line is the median Q50 monthly evaporation. Light orange ribbon is the range of Q25 to Q75 evaporation range*

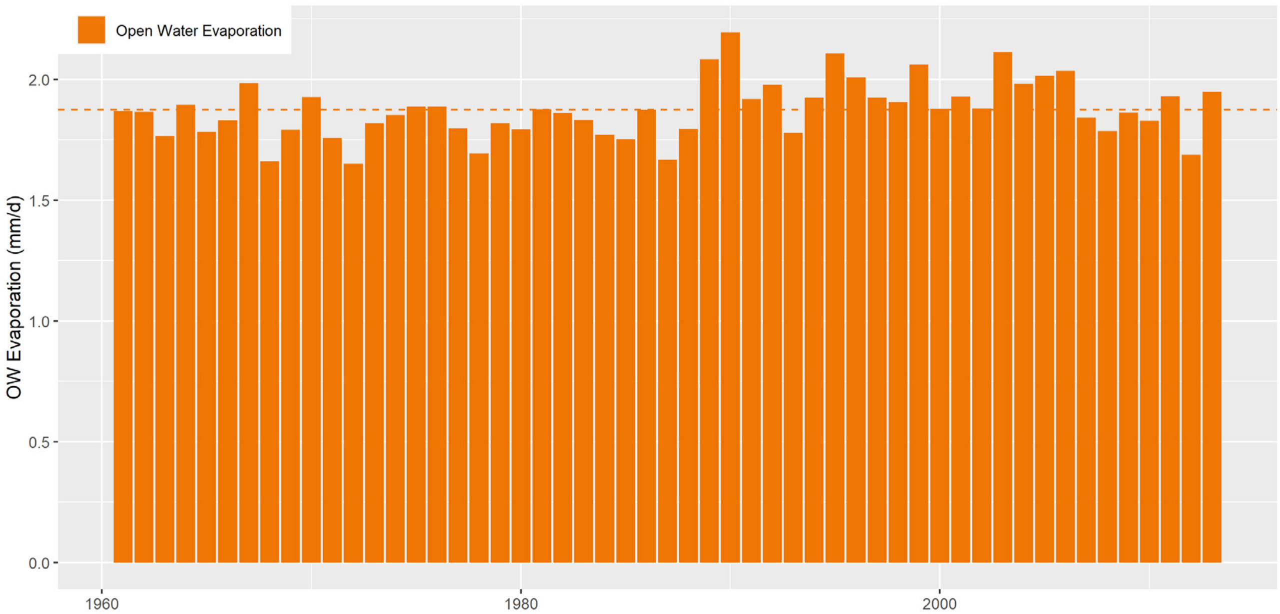

Figure B.4: Annual trend of daily average open water evaporation rate derived from potential evapotranspiration at Longstanton . Data from 01/01/1961 to 31/12/2014

Source: *CEH potential evapotranspiration Robinson et al., (2020) converted to open water evaporation using monthly factors developed by the Environment Agency (2001)*

C. Borehole Logs

TL 36 NE 9 | 9

TL 36 NE 9 **3981 6702** **Brookfield House, Long Stanton** **Block H**

Surface level +7.6 m
Water struck at +5.4 m
Dando Shell, 152 mm diameter
June 1976

Overburden 1.2 m
Mineral 1.1 m
Waste 2.1 m
Mineral 2.7 m
Bedrock 2.5 m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Terrace Deposits	Silt, very sandy, brown mottled grey, some flint and chalk pebbles	1.0	1.2
	'Clayey' sandy gravel, with grey pebbly silt waste between 2.3 and 4.4 m Gravel: fine with coarse, angular flint with some limestone and fine chalk Sand: medium and coarse, quartz with coarse flint and chalk Fines: upper bed very silty, yellow	5.9	7.1
Ampthill Clay	Clay, silty, grey-blue, fossiliferous, some siltstone nodules	2.5+	9.6

GRADING

	Mean for deposit *percentages*			Depth below surface (m)	*percentages*						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	$+1-4$	$+4-16$	$+16-64$	$+64$
a	28	58	14	1.2–2.3	28	16	36	6	12	1	0
b	7	46	47	4.4–5.4	9	6	18	14	31	22	0
				5.4–6.4	6	5	23	24	32	11	0
				6.4–7.1	7	6	21	21	34	11	0
Total	13	50	37	Mean for **b**	7	6	20	20	32	15	0
				Mean for total	13	9	25	16	26	11	0

Figure C.1: Borehole log TL36NE9 at Brookfield House, Longstanton (1976)

Source: British Geological Survey (2020f) Geoindex Onshore

TL46NW/33

TL46/112

...ing Equipment & Method: Dando 175 Cable Percussive	Borehole No 1
Boring: 200mm diameter to 20.00 metres	Date Commenced: 29.07.97
	Date Completed: 31.07.097
Casing: 200mm diameter to 13.00 metres	Ground Level: Not Available
	NGR: TL 4015 6646

GWL

Description	OD Level	Legend	Sample	Depth (m)	Date	Field Observation
Grey brown silty sandy Clay with roots			B	1.20		
Light brown Sand and Gravel			B	2.20	29.07.97	Water struck at 1.80m bgl am water stood at 1.80m bgl
			B			
			B			
Light grey silty slightly sandy Clay			B	5.60		Water struck at 5.60m Sealed off at 7.40m
			W			
Dark grey silty sand with black angular gravel			B	6.50		
Dark grey siltstone with fossils				7.40		
			B			
			B			
			B			
			B			
			B			
			W	13.50	30.07.97	Water struck at 13.00m Sealed off by casing at 13.50m am water stood at 7.40m
			B			
			B			
			B			
Dark fissured grey silty Clay with fossils. Siltstone 11.30 to 11.70, and 15.80 to 16.10m			B			
			B	20.00	31.07.97	Borehole Complete

Remarks: Borehole Record based on Drillers description. Borehole advanced by chiselling from 6.5 to 7.4m 2h; 11.3 to 11.7m 1h and from 15.8 to 16.6m 1h. On completion of drilling a 100mm diam liner/ screen was inserted to the bottom of the borehole with a 250 micron filter wrap over a screen section from 8.00m to 5.00 m depth below ground level. The annulus from the base of the borehole to 1.00m below ground level was filled with pea shingle and then the annulus sealed to ground level with bentonite. Water level after installation 6.81m bgl.

Originator MRG	**BOREHOLE RECORD** Not to scale	**GEORGE W LACK & SONS LTD**
Date 10.11.97	**CAMBRIDGE FISH PRESERVATION AND ANGLING SOCIETY**	Figure 1 Sheet 1 of 1

Figure C.2: Borehole log TL46NW33 at Nethergrove Lake, Longstanton (1997)

Source: British Geological Survey (2020f) Geoindex Onshore

TL 46 NW 4 4012 6769 Near Allotment Gardens, Longstanton Block D

Surface level +2.7 m
Water struck at +0.7 m
152 mm percussion
September 1977

Overburden 0.6 m
Mineral 0.8 m
Waste 0.5 m
Mineral 0.8 m
Bedrock 1.0 m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, dark greyish brown sandy clay loam becoming light olive-brown stony sandy clay at 0.3 m	0.6	0.6
River Terrace Deposits (Third Terrace)	a Sandy gravel Gravel: mainly fine, angular to subangular, brown and grey flint and well-rounded chalk with some ironstone, sandstone and quartz Sand: medium with fine, subangular to rounded, quartz with chalk and ironstone and coarse, rounded chalk and angular flint with ironstone and quartz; brownish yellow	0.8	1.4
	Clay, with chalk pebbles; light yellowish brown	0.5	1.9
	b 'Very clayey' sandy gravel Gravel: mainly fine, angular to subangular, brown and grey flint and well-rounded chalk with some ironstone, sandstone and quartz Sand: medium with fine, subangular to rounded, quartz with chalk and ironstone and coarse, rounded chalk and angular flint with ironstone and quartz; light grey	0.8	2.7
Ampthill Clay	Clay, stiff, with shelly horizons, dark grey	1.0+	3.7

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages					
	Fines	Sand	Gravel		Fines	Sand			Gravel	
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	$+1-4$	$+4-16$	$+16-64$
a	8	66	26	0.6–1.4	8	14	35	17	23	3
b	22	51	27	1.9–2.7	22	7	28	16	23	4
a+b	15	59	26	Mean	15	11	32	16	23	3

Figure C.3: Borehole log TL46NW4 at "Near Allotment Gardens), Longstanton (1977)

Source: British Geological Survey (2020f) Geoindex Onshore

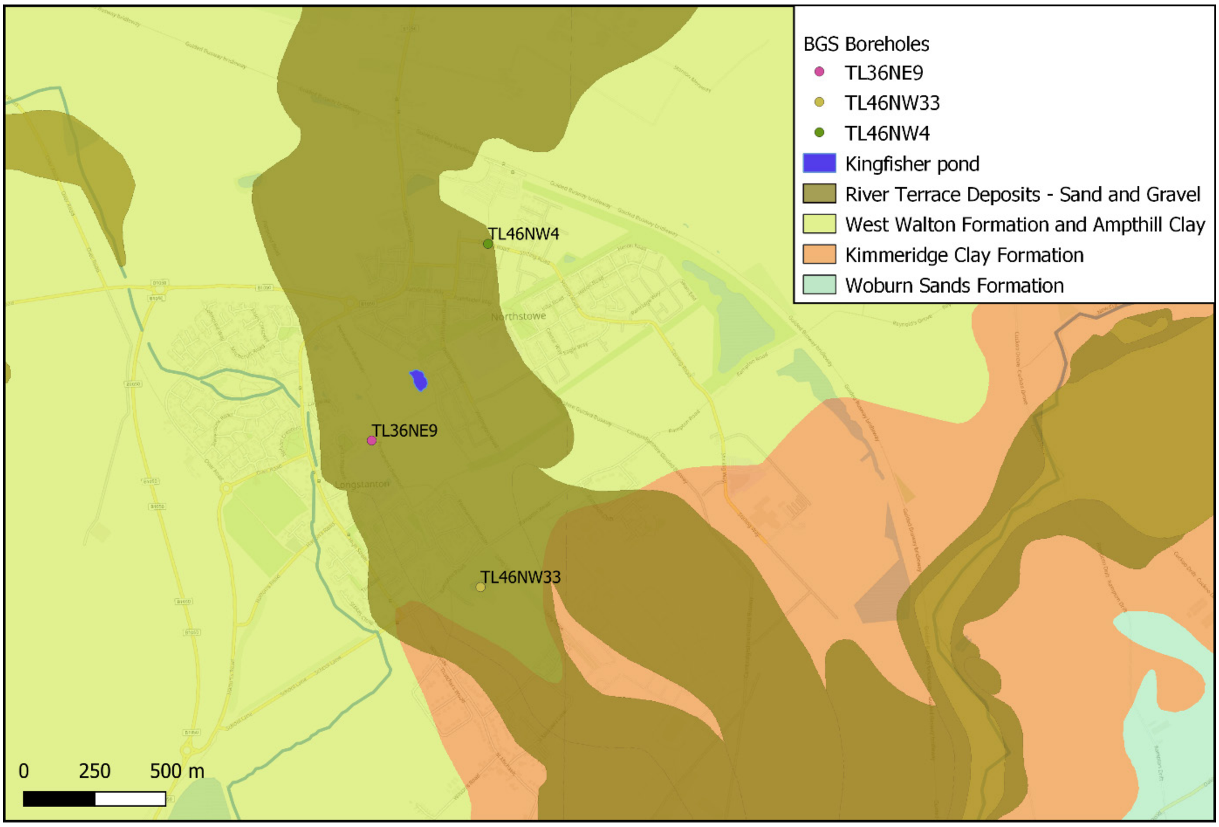

Figure C.4: Map highlighting locations of BGS borehole logs of interest at Longstanton

Source: Borehole locations from BGS Geoindex Onshore (2020f)
British Geological Survey 1:50 000 drift and bedrock geology, reproduced in QGIS. All rights reserved (British Geological Survey 2020c)

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