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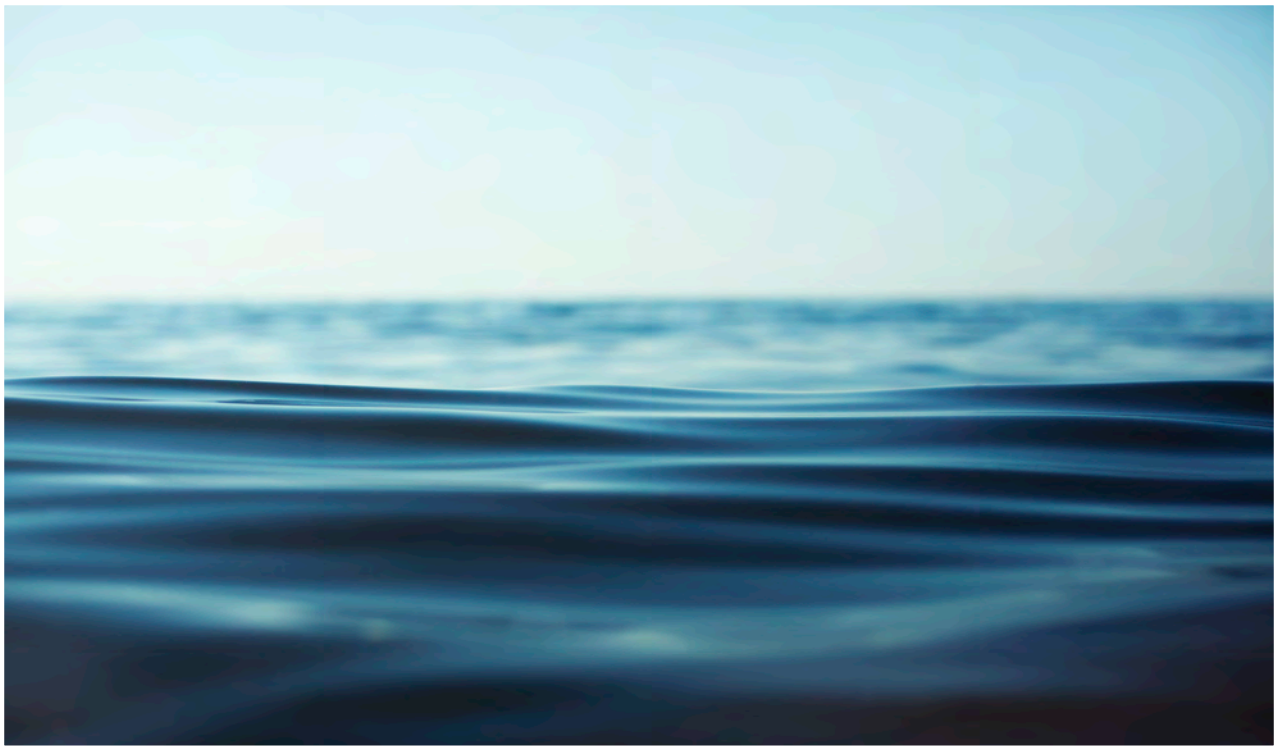
Kingfisher Pond - Northstowe Hydrogeological Assessment

Phase III Report



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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 initial development at adjacent Northstowe Phase 1.

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-phase 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 then;

III. Determine the cause of the changes in the hydrology and hydrogeology of the Kingfisher Pond.

The Phase I report was completed and distributed to Longstanton Parish Council and South Cambridgeshire District Council in February 2021. That report detailed how the pond and local hydrogeology operates under natural conditions. SCDC and Longstanton Parish Council (LPC) were in agreement of the conclusions presented in the Phase I report. The report was distributed to residents and other stakeholders who agreed with the understanding of the Kingfisher Pond's hydrogeology. However, there were some comments on the report. To ensure transparency all the comments received regarding the Phase I report have been added to an appendix in a revised Phase I report.

The Phase II report was completed and distributed in April 2021. That report detailed the available data between 2015 and 2021 for hydrogeology, climate, and land use change. It was concluded that groundwater levels fell below normal conditions between autumn 2015 and winter 2020/21. By March 2021 groundwater levels had risen, but the water level in the Kingfisher Pond was below those experienced prior to 2015. It is unclear if this represents a temporary or sustained recovery. SCDC and LPC reviewed the data and conclusions presented in the Phase II report. As with the Phase I report, all comments have been added to an appendix in a revised Phase II report.

This report completes the **third phase** and presents HR Wallingford's understanding of the reasons for recent hydrogeological changes to the Kingfisher Pond and the shallow aquifer which underlies the area. The key findings are presented in Box 1:

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

Our key findings are:

The Kingfisher Pond is situated in, and in hydraulic continuity with, the underlying River Terrace Deposit (RTD) aquifer. The water table is shallow and therefore changes to the RTD will have a large impact on the Kingfisher Pond's water levels.

The groundwater levels in the RTD fell below the normal historic range between autumn 2015 and autumn 2020.

Regional and local climate data indicates that there were several dry periods between 2015 and 2020. The RTD is responsive to weather and therefore groundwater elevation will be expected to fall following prolonged dry weather. Recent heavy rainfall in winter 2020/21 coincided with a recorded rise in groundwater level. It is not clear if this increase in groundwater elevation will be sustained.

Local land use change as a result of the development of Northstowe is concluded as the most significant impact on the RTD groundwater elevation. The key impacts are as follows:

- Initial construction dewatering in 2015 and 2016 lowered groundwater levels to 5 m below ground level and the rate of abstraction was reported as being approximately 6 Ml/d. This caused an initial drying out of the Kingfisher Pond and other ponds and groundwater-fed features.
- The construction of Northstowe has changed the recharge of the RTD and ponds and other groundwater-fed features, in particular the Kingfisher Pond.
- It is unclear if the design principles of the greenways have been met, or if they will continue to reduce groundwater levels in the RTD and Kingfisher Pond below historic levels.

Water levels in the Kingfisher Pond were observed to have risen in early 2021. The rise in water level coincided with above average rainfall between December 2020 and February 2021. However, despite the above average rainfall, the water levels remained approximately 0.3 m below pre-2015 pond water levels. Whilst water levels in the Kingfisher Pond have risen recently, it is currently unclear if water levels in the Kingfisher Pond will be sustained, or if, as a result of the land use change and greenways, the pond will generally have lower water levels than in the past, or will be more susceptible to dry weather. Given the location of the pond, it is considered to be more susceptible to these land use and drainage changes than other ponds.

Whist we conclude that the Northstowe development is the primary cause of the changes to the Kingfisher Pond and other ponds in the area, we are unable to comment if cracks observed in Longstanton Village Institute or All Saints Church are a result of the development. We suggest a specialist be asked to comment on this. We can provide names of suitably qualified experts.

We recommend that monitoring is installed and maintained to determine the impacts of the Northstowe Development on the Kingfisher and other groundwater-fed features.

What happens next?

We propose a two-week review period for stakeholders to consider the contents of this Phase III report. Any comments should be sent to a.wilcox@HRWallingford.com before 4th June 2021. If these comments change our conclusions of the Phase III report, we will address them. This Phase III report is the final report from HR Wallingford for this contract. Whilst we would be happy to undertake further work, this would be as a new contract.

Contents

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 water features, including the Kingfisher Pond. The Kingfisher Pond is a large pond with a surface area of 3000 m^2 (when full) and a depth up to 2 m. The Kingfisher Pond is located on the main site of Northstowe Phase 1 (52°17'6.53"N, 0° 3'0.60"E) and is underlain by a shallow aquifer called the River Terrace Deposits (RTD).

The water levels in the Kingfisher Pond were reported to decline in autumn 2015, coinciding with a reported decline in water level at several other lakes, ponds, and wells in Longstanton. HR Wallingford are reviewing these reported changes in the Kingfisher Pond since 2015. Other hydrogeological features which are located in the RTD are also being reviewed to understand the extent of changes to the local hydrogeology.

HR Wallingford completed and distributed the Phase I report to SCDC and LPC in February 2021. The report was to 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 the local hydrogeology. The emphasis of the Phase I report was on the importance of the RTD which underlay Longstanton and are the principal water supply to surface water features including the Kingfisher Pond. The RTD are classified as a Secondary A aquifer with significance to local groundwater (WSP, 2014a; Environment Agency, 2017a).

The key findings of the Phase I report were:

- The pond is sited in RTD which consists of sands and gravels which overlay low permeability clay.
- Water in the Kingfisher Pond and RTD are in hydraulic continuity, meaning that the water levels in the pond will reflect water levels in the RTD. This means that if water levels in the RTD rise then the water levels in the Kingfisher Pond will also rise, up to the level of an overflow pipe. Likewise, if groundwater levels in the RTD fall, then water levels in the Kingfisher Pond will fall.
- There are several other ponds and lakes also situated on the drift deposits. These will be affected by a change in groundwater level under the assumption they are also in hydraulic continuity with the drift deposits.
- There is limited measured data on water levels in the Kingfisher Pond prior to 2015.
- There is no evidence in the data of a long-term trend of reducing rainfall in the area (1961-2015).
- 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 the same level as groundwater level in the drift deposits.

Following the Phase I report, HR Wallingford completed the Phase II report in April 2021 which described the change in RTD groundwater level and other relevant hydrogeological data since 2015. The Phase II report presented analytical data and observational evidence compiled in the local area from 2015 onwards, the approximate time at which there were reports that the water levels in the Kingfisher Pond had declined. The key findings of the Phase II report were:

- The groundwater elevation in the RTD underlaying Longstanton and the Kingfisher Pond have dropped to below normal conditions in the period between autumn 2015 to autumn 2020.

- The water level in the Kingfisher Pond and other water features on the RTD rose to near pre-2015 levels in winter 2020/21, however water levels in the Kingfisher Pond were about 0.3 m below pre-2015 levels. The winter 2020/21 increase in groundwater elevation coincided with above average rainfall across large parts of the UK, with extensive flooding in some parts of East Anglia.

The conclusions drawn in the Phase II report were supported by the following evidence:

- Observational evidence and photographs confirm that the water levels in the Kingfisher Pond and other local ponds initially declined in autumn 2015. The minimum level observed at the Kingfisher Pond occurred in 2017 when the Kingfisher Pond completely dried out. The pond's water levels have remained below normal between autumn 2015 and 2020.
- Groundwater levels on the site of Northstowe initially declined in autumn 2015. This followed below average spring rainfall and the dewatering of Northstowe Phase 1A.
- Boreholes monitored on the site of Northstowe show that groundwater levels were below typical levels throughout March 2017 to December 2020. This did not coincide with prolonged dry weather.

Local land use change includes both the construction of the A14 and the construction of Northstowe. Analysis of planning reports show that:

- Construction dewatering of the RTD aquifer to a depth of 5 m below ground level occurred in two phases: Phase 1A in May to September 2015 and Phase 1B in May to November 2016.
- The Northstowe surface drainage strategy comprises of swales and two greenways feeding the clay lined attenuation ponds.
- The urbanisation of the site has changed the surface area of permeable land available for direct infiltration and recharge of the RTD.

1.2. Report Scope

This report is intended to conclude on the reasons for the recent hydrological changes and decline in groundwater elevation. The focus of this report is the Kingfisher Pond, however other local ponds within the same RTD hydrogeological system are considered where appropriate.

The conclusions within this report are based upon analytical assessment of available data, resident survey results and a site visit.

The report includes the following sections:

- Summary of available data and limitations (Section 2);
- Summary of conceptual hydrogeology model (Section 3);
- Discussion of recent changes in local hydrogeology (Section 4);
- Conclude the reasons for the decline in groundwater levels (Section 5);
- Recommendations for further work (Section 6).

The aim of this report is to:

- Summarise the Phase I and Phase II report;
- Conclude the reasons for the change in local groundwater levels since 2015;
- Highlight limitations of the report;
- Provide recommendations for the Kingfisher Pond;

- Outline next steps, including consulting on this document to ensure that all relevant parties have accessed it and agree with it.

2. Summary of available data

2.1. Overview

Data from a range of sources was considered to ensure that the review provided a comprehensive summary of all changes occurring in the local area. This section intends to summarise the limitations and uncertainties in the data and how they may impact the conclusions presented in this report.

The key points of this section are:

- There is comprehensive data and literature on the bedrock and superficial geology;
- There is comprehensive rainfall data available which is considered suitable for the purpose of the report;
- There is available groundwater elevation data for the RTD from several sources, however there are limitations of the temporal and spatial coverage of the data;
- There are limited surface water level data at the Kingfisher Pond. Therefore, conclusions of changes to the Kingfisher Pond's surface water elevation are primarily based upon observational evidence, including photographs.

2.2. Data limitations and uncertainty

Within the Phase I and Phase II report, limitations to the available data have been highlighted alongside the data presented where appropriate.

In this section, the data has been highlighted as Low, Medium, or High confidence depending on the comprehensiveness, quality, and resolution of the data. Classifications are given as a confidence index in Table 2.1. The classifications are assigned to the data and are summarised in full in Table 2.2.

Table 2.1: Confidence index

Score	Data
High	Comprehensive data availability.
Medium	Data available but resolution is either temporally or spatially relatively coarse for purpose.
Low	Limited data availability or the data cannot be verified

Notes: Note that this provides indicative guidance only.

Table 2.2: Summary of data and limitations

Data type	Data subcategory	Source	Confidence classification and justification *
Geological	Bedrock geology	BGS (1975; 1981; 1976; 2020a; 2020d; 2020e) Wardell Armstrong (2017) WSP (2014a)	Bedrock geology confirmed as the Ampthill Clay (AmC) from multiple sources including BGS maps and Northstowe on-site ground investigation. There is high confidence in the bedrock geology classification.
	Superficial geology	BGS (1975; 1981; 1976; 2020b; 2020c; 2020f) Wardell Armstrong (2017) WSP (2014a)	Superficial geology confirmed as the RTD by multiple sources including BGS maps and Northstowe on-site ground investigation. There is high confidence in the superficial geology classification.
Climate	Rainfall	Cambridge National Institute of Agricultural Botany (NIAB) (Met Office, 2021) Had-UK 1 km gridded daily rainfall (Met Office, 2019)	The Cambridge NIAB rain gauge is located 5 km away from the Kingfisher Pond. While local variations in regional rainfall do occur, the use of the Cambridge NIAB rainfall station is not a significant limitation in this assessment. The Phase I report confirmed that this data was consistent with Met Office Had-UK 1km gridded data.
	PET	Robinsons et al. (2020)	The rate of open water evaporation was estimated using CHESS-PE (Robinsons et al., 2018) data converted to open water evaporation with the use of empirical factors (Environment Agency, 2001). This method is documented in detail in the Phase I report appendix. The open water evaporation is an

Data type	Data subcategory	Source	Confidence classification and justification *
			approximation and not derived from local physical data, however the limitations of this method are considered minimal within the context of the conclusions drawn from the data.
Groundwater level	Environment Agency (East Anglia) groundwater levels at Redlands Hall and Therfield Rectory	Environment Agency (2018; 2021)	The groundwater elevation is recorded at regular intervals using industry standard techniques. These boreholes are not significantly affected by abstractions, making them suitable for analysis of climatic variation. There is high confidence in the quality of the data available. Within this project, the data is used as a reference for regional changes and is not used directly to infer conclusions on the Kingfisher Pond or RTD.
	Northstowe Phase 1 groundwater levels	WSP (2014a) Wardell Armstrong (2017)	There is limited data available during the period of dewatering throughout 2015 and 2016. The extent to which groundwater drawdown occurred during the initial dewatering is therefore uncertain. The process of groundwater level recovery following initial dewatering is unclear due to lack of regular data recordings.
	Groundwater levels recorded by borehole loggers at BH144 Northstowe Phase 1	L&Q (2021)	Regular data available throughout period 2017 to 2020 have been supplied by L&Q. There is high confidence of this data due to the frequency of data and the consistency with observational evidence.

Data type	Data subcategory	Source	Confidence classification and justification *
	RTD Environment Agency monitoring boreholes at Unwin's Farm and New Farm	Environment Agency (2020)	There are limited measurements available, and data has not been collected at regular intervals. The data is therefore only used as an indicator of long-term trends but interpolation of groundwater elevation between data points is unreliable.
	Groundwater level obtained by HR Wallingford in March 2021	HR Wallingford (2021b)	HR Wallingford took a measurement at Unwin's Farm borehole during the site visit. This measurement was added to the Environment Agency data.
Kingfisher Pond water level	Recordings of surface water level of the Kingfisher Pond	Wardell Armstrong (2017)	There are minimal recordings taken during the Northstowe Phase 1 development. Therefore, conclusions of changes to the Kingfisher Pond's surface water elevation are primarily based upon observational evidence and absolute water depth is an approximation.
Surface water flow	Longstanton river and stream flow data	A data request was submitted to the Environment Agency however no information was held for the Cottenham Lode, Longstanton Brook and Reynolds Drain or for relevant gauging or flow records in the area	No data avallabile.
Site Observations	Photographs	HR Wallingford, 2021b	Dated photographs of the local area provide a useful understanding of the conditions at the specific location and point in time. The data is used as supporting evidence and conclusions are not drawn solely from photographs. The

Data type	Data subcategory	Source	Confidence classification and justification *
			confidence associated with this data has therefore been classified as high.
Resident Surveys	Photographs	NA	Resident surveys are intended to gain an understanding of local changes and the history of the local area. Dated photographs of the local area provide a useful understanding of the conditions at the specific location and point in time. The data is used as supporting evidence and conclusions are not drawn solely from photographs. The confidence associated with this data has therefore been classified as high.
	Anecdotal Evidence	NA	Anecdotal evidence has been used as supporting evidence but not relied on as stand-alone data. Survey data may include personal bias in recollection where not supported by physical data. There are therefore limitations associated with this data and it has been classified as medium confidence.

*Notes: * Uncertainty classifications provided in Table 2.1.*

3. Conceptual model

3.1. Overview

The Phase I report (HR Wallingford, 2021a) presented a conceptual understanding of the hydrogeology of the Kingfisher Pond. This detailed the bedrock geology, superficial geology and how the pond recharges under natural conditions.

The key points of the conceptual model are:

- 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 pond is situated in the centre of the RTD and confined below by the Ampthill Clay (AmC) (BGS 2020a, BGS 2020b) (Figure 3.1; Figure 3.2);
- The depth of the pond (when full) is less than 2 m. Because it is a shallow pond, a small drop in groundwater levels can significantly affect the pond;
- 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 isolated from other aquifers given its linear nature and the underlying AmC (BGS 2020a, BGS 2020b);
- 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 pipe therefore partially controls levels in the pond in the event groundwater levels are high.

3.2. Model diagram

Figure 3.1 presents a conceptual diagram of the pond and the underlying geology. This diagram displays a conceptualisation of the exchange between groundwater and surface water. Figure 3.2 present the BGS 1:50 000 drift deposit map (BGS, 2020c) highlighting the location of the Kingfisher Pond within the RTD.

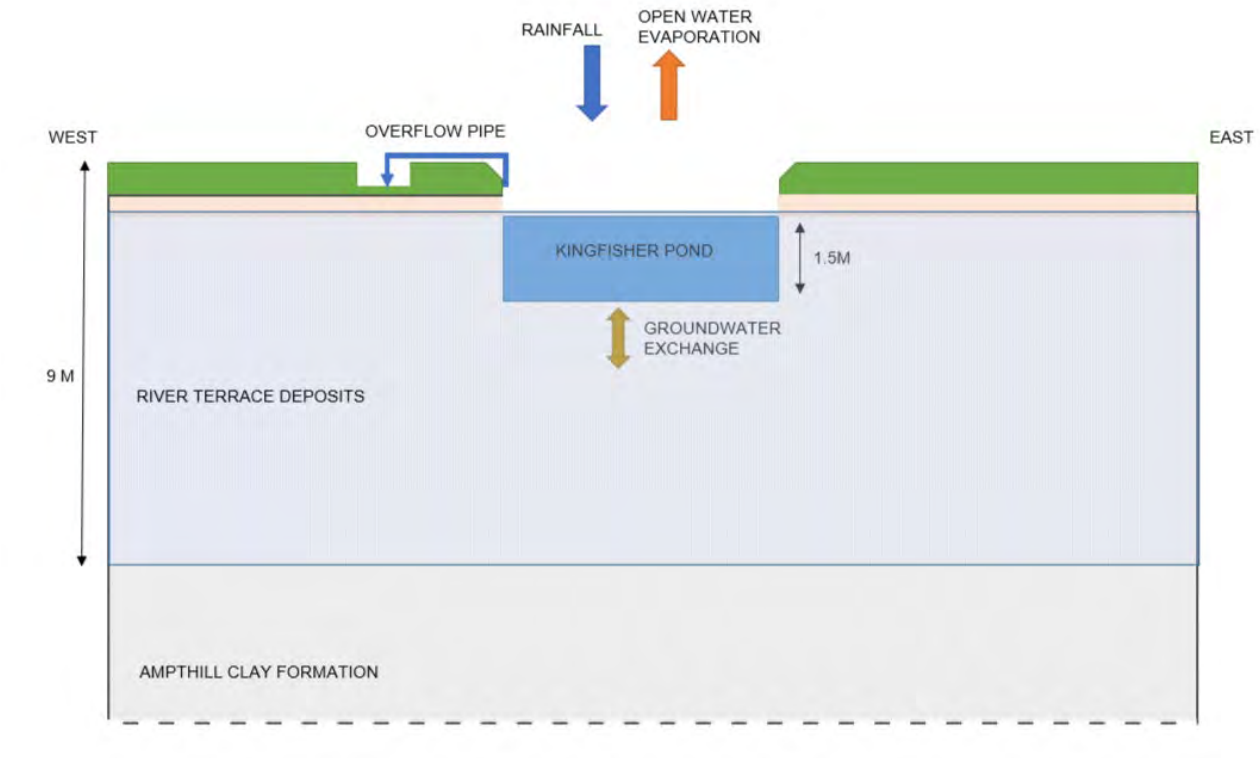

Figure 3.1: Schematic diagram describing the hydrogeological interaction of the Kingfisher Pond with the RTD aquifer

Source: HR Wallingford (2021a)
Notes: All measurements are approximate.

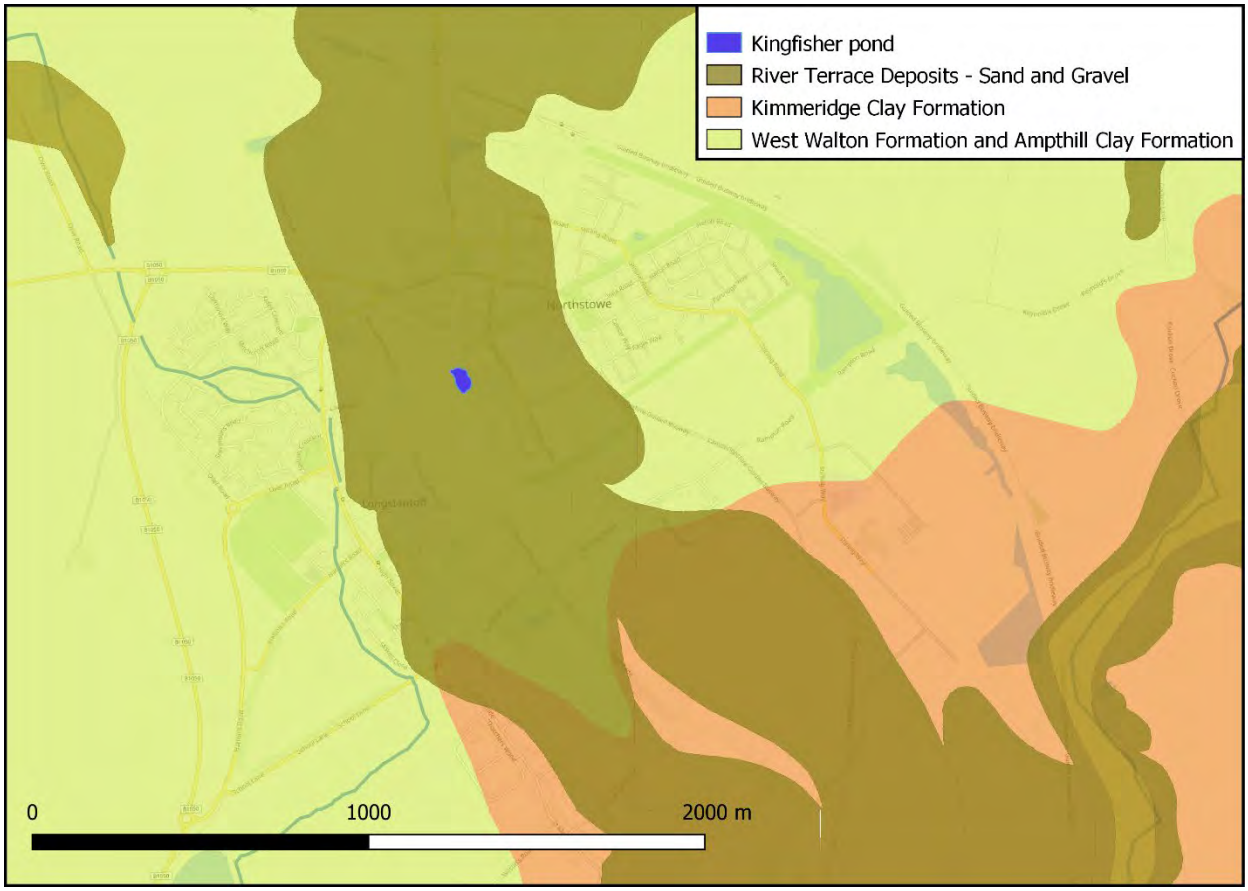

Figure 3.2: Geological map showing location of the Kingfisher Pond on the RTD

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

4. Discussion of recent changes

4.1. Changes to local climate

The Phase I (HR Wallingford, 2021a) and Phase II (HR Wallingford, 2021b) report presented local climate data from Cambridge NIAB meteorological station (Met Office, 2021).

The results indicate that there were no long-term trends in rainfall and open water evaporation between 1961 and 2015. The results also show that while the cumulative rainfall between 2015 and February 2021 has been similar to the long-term average (LTA) (1961 – 2020), there have been several periods when recorded rainfall was below the LTA.

It is documented that the RTD is highly responsive to local rainfall (WSP, 2014a). Therefore, the dry periods will have had an impact on groundwater levels. Conversely, heavy rainfall would be expected to be followed by a quick increase in RTD groundwater. The response occurs in two way: firstly, direct rainfall onto the surface area of the pond and second by infiltration through permeable topsoil to recharge the RTD.

The main periods of below average rainfall between 2015 and 2021 occurred in spring 2015, summer 2016, summer 2018, winter to spring 2019 and spring 2020. During these periods, it is likely that below average rainfall contributed to the drop in RTD groundwater elevation.

However, anecdotal evidence from residents highlights that previous dry summers prior to 2015 have not resulted in the Kingfisher Pond, Nethergrove Lake and Larkfield Well drying out. This included notable dry years including 1976, 2003 and 2011. Additionally, periods of heavy rain in 2016 and 2017 did not restore groundwater levels, as evidenced by the photographic evidence and the that the overflow pipe has not been needed to be used.

It is therefore concluded that the while dry periods between 2015 and 2021 may have exacerbated the drop in groundwater levels, they were not the principal cause for the decline.

4.2. Changes to groundwater level

The Phase I (HR Wallingford, 2021a) and Phase II (HR Wallingford, 2021b) report presented groundwater level for both local (RTD) and regional (chalk) aquifers.

4.2.1. Regional boreholes

The regional chalk monitoring boreholes showed that there were several periods where groundwater levels were classified as below normal for prolonged periods in 2017 and 2018. The Environment Agency monthly water reports attribute the flux in groundwater level to climatic conditions.

Notably, these chalk groundwater levels remained within the normal range during 2015. Therefore, this does not imply that the initial drop in Northstowe groundwater levels was reflective of a regional dry climate. Nevertheless, the dry climate in 2017 to 2019 implies that that there was regionally low rainfall. This would have impacted the low Northstowe groundwater elevation and impeded recovery.

4.2.2. Local boreholes

Data was presented for the Environment Agency monitoring boreholes situated along the RTD within 10 km of Longstanton. The RTD Environment Agency boreholes do not exhibit a long-term trend throughout the period of data available between 1977 and 2021.

Data was also presented for the site of Northstowe. There is limited data available on the boreholes between 2015 and 2017 when initial observations of a decline in water level at the Kingfisher Pond were reported.

The data points collated at monitoring boreholes on site show that following dewatering in 2015 there was a decline in groundwater elevation. The available data for Northstowe Phase 1 boreholes recorded in January 2015 and January 2016 shows that groundwater elevations recorded in January 2016 (post Phase 1A dewatering) were comparable to those recorded in January 2015 (pre-Phase 1A dewatering). However, groundwater levels in March 2017 were lower than the winter of 2016. This indicates that the groundwater levels did partially recover following the initial dewatering, however more recent data (observational and physical) shows that this was not sustained. There is a lack of regular data points recorded in this period and therefore conclusions drawn on the groundwater elevation during this time are limited.

More regular data from borehole loggers on the site of Northstowe show that groundwater elevation on the RTD was below typical levels (as defined by Wardell Armstrong) throughout March 2017 to December 2020.

Seasonal fluctuations are on the order of 1 m. Maximum winter groundwater elevation exceeded the boreholes' lowest pre works level, however groundwater elevation dropped up to 0.8 m below the lowest pre works elevation in summer. Groundwater elevation rose to above typical levels in December 2020 and remained at or above typical groundwater level between December 2020 and March 2021.

The groundwater level data shows that the drop in groundwater level was partially reflected in trends exhibited in the chalk aquifer. This highlights the importance of regional climate to local groundwater. However more detailed data shows depressed groundwater elevations occurring following initial dewatering and throughout 2017 to 2020. The groundwater elevation remained depressed despite several periods of above average rainfall. It is therefore concluded that the low rainfall periods between 2015 and 2021 exacerbated the drop in groundwater levels but were not the primary cause for the decline in 2015 or the reason that Northstowe groundwater levels were consistently below typical elevation for the proceeding years.

4.3. Changes to land use

Within the Phase II report (HR Wallingford, 2021b), significant changes to local land use were reviewed. These were the construction of the A14 and the development at Northstowe.

The A14 is not considered to be an important factor influencing the RTD. This is concluded because the construction began in autumn 2016, notably after the initial drop in groundwater elevation in autumn 2015. Significantly, the A14 does not intersect with the RTD near Longstanton and is therefore unlikely that the construction would impact recharge of the RTD.

The development of Northstowe is the **primary cause** for the drop in groundwater elevation observed from 2015 to 2020. The data evidenced in the Phase II report (HR Wallingford, 2021b) is used to conclude the following:

4.3.1. Dewatering

- The reason for dewatering was to remove groundwater from the site during the construction work. Although the amount of water abstracted during the dewatering was not measured, there is some information provided, including in the Wardell Armstrong Interim Report (Wardell Armstrong, 2017). This report describes 1.5 km of trenches and typical flow rates of 5 l/s per 100 m of trench. This equates to around 6.5 Ml/d. In the first period of dewatering (May and September 2015) the amount of dewatering is therefore calculated to be between 580 Ml and 970 Ml. In the second period (May and November 2016) the amount of dewatering is calculated to be between 970 Ml and 1360 Ml. By comparison the volume in the Kingfisher Pond (when full) is approximately 6 Ml. Initial construction dewatering in May to September 2015 lowered RTD groundwater level by 5 m (Wardell Armstrong, 2017). Following the cessation of initial Phase 1A dewatering, the groundwater levels partially recovered.
- Construction dewatering in May to November 2016 for Phase 1B caused a further drop in RTD groundwater elevation and the Kingfisher Pond, Lady Walk Pond and Hatton's Farm Ponds surface water elevation.
- During Phase 1B water was recycled back to the Kingfisher Pond, however it was unable to sustain a recovery of water levels as the water drained through the bottom of the pond to the underlying RTD.

Given the agreed conceptual model, it is infeasible that the dewatering that occurred adjacent to the Kingfisher Pond did not result in a reduction of levels in the Kingfisher Pond (and any other ponds or features affected by the lowering of groundwater levels in the RTD).

4.3.2. Change in recharge

Following the dewatering, urbanisation and the reduction of permeable land cover has changed the recharge to the RTD and the Kingfisher Pond. Immediately surrounding the pond are various houses, tennis courts and sports pitches. Each of these will have changed the recharge to the RTD immediately around the Kingfisher Pond. Further afield the construction of roads, other buildings and other changes in land use will also have affected recharge.

It is noted that Wardell Armstrong (Wardell Armstrong, 2017) state that "Land Drainage from the sports pitches in the east of the site is directed towards the Kingfisher Pond" however it is not clear if or how this has been implemented. WSP (2014b) state in the Surface Drainage Strategy that infiltration to the RTD would occur from the sports pitches, allotments and orchards. While recharge to the RTD would support the water levels in the Kingfisher Pond, it has not been shown to be effective in allowing the RTD to recharge to previous levels.

4.3.3. Changes to drainage

The design of Northstowe includes the installation of ditches (referred to as greenways) to prevent flooding. These greenways provide a preferential flow pathway allowing water to travel attenuation ponds. A key design principle was to maintain the greenways above the water table otherwise the greenways would convey groundwater from the aquifer towards the attenuation ponds (Wardell Armstrong, 2017). Given the shallow groundwater table, careful construction of the greenways would be required to prevent permanent lowering of the water levels in the RTD.

WSP (2014) state that the typical water level in the RTD is 0.5 to 2 m below ground level. Photograph 4.1 (HR Wallingford, 2021) shows a typical section of one of the greenways. In this photo it is apparent that there are long sections of the greenways which are greater than 0.5 m deep. It is unclear if the design principle of maintain the greenways above the water table has been met. There is a possibility that these greenways are located below the natural water table in the RTD in some sections.

Photograph 4.1: Greenways on the site of Northstowe

Source: HR Wallingford, March 2021

5. Conclusion

This report combines the evidence collected in the Phase I and II reports, a subsequent visit to the site and our expertise. This report concludes that there are several key factors which have resulted in the decline in groundwater levels and therefore impacts on the Kingfisher Pond and other ponds in the area:

5.1. De-watering

Dewatering during the early development at Northstowe initially reduced groundwater level to 5 m below surface level. Large quantities of water were abstracted during the two dewatering phases. This caused an almost immediate and significant drying out of the Kingfisher Pond and the RTD. There is very strong evidence to support this, including the fact that work during the Phase 1B dewatering to recycle water into Kingfisher Pond was not able to sustain water levels in the pond.

5.2. Post dewatering (2016 to 2020)

The groundwater levels have not recovered for a number of reasons, including:

- Recharge has been affected by urbanisation;
- The greenways on the site of Northstowe may provide a preferential flow pathway for water from the RTD to the greenways and to the attenuation ponds, and it is not clear if the design principle has been met. These greenways provide a mechanism for maintaining groundwater levels at below their pre-2015 levels.

5.3. Post 2020

As evidenced in the Phase II report (HR Wallingford, 2021b) the groundwater levels at Northstowe and the Kingfisher Pond had **mostly** recovered in winter 2020/21, although the water levels in the Kingfisher Pond were approximately 0.3 m below those shown in historic photographs. This period coincided with regional high groundwater levels and above average rainfall recorded between December 2020 and February 2021. Rainfall in March 2021 was similar to the long term average.

Of all the groundwater-fed features in the area, the Kingfisher Pond is the closest to the development at Northstowe. It is most likely to be affected by the changes in recharge and drainage.

At the time of writing (April 2021) it is unclear if the levels in the Kingfisher Pond will return to their pre-2015 levels. It is also unclear if the pond will be more susceptible to periods of low rainfall in the future.

5.4. Other factors

Regional rainfall has remained at or below average for most of the time since 2015, which has compounded the difficulty in understanding the various impacts on water levels in the RTD. The RTD is shallow, and responds quickly to rainfall, so during periods of dry weather water levels will decline. However, the evidence shows that in spite of these fluctuations in rainfall, the initial dewatering is the main cause of the drying out of Kingfisher Pond and the RTD.

We can find no evidence of other impacts (e.g. the construction of the A14). The A14 is not situated on the RTD and both the temporary construction and post operation of the road are unlikely to have had any significant impacts on the groundwater levels in the RTD or Kingfisher Pond.

5.5. Damage to buildings

During this study we received reports of cracks in various buildings, including All Saints Church and Longstanton Village Institute. The reasons for such cracks are a specialist subject, and HR Wallingford is not able to comment on the cause of such cracks. We suggest that further advice is obtained from a specialist.

6. Recommendations

Our recommendations depend on stakeholders' expectations for the Kingfisher Pond and how the pond and groundwater levels in the RTD respond in the long-term.

6.1. If the Kingfisher Pond recovers

It is possible that after further extensive rainfall groundwater levels in the RTD may fully recover to their pre-2015 levels. To understand this than HR Wallingford recommend the following:

- Regular monitoring of the Kingfisher Pond surface water levels and other ponds in the area (namely Nethergrove Lake and Lady Walk Pond);
- Regular monitoring of the groundwater elevation in the RTD underlying Northstowe and Longstanton;
- Regular monitoring of groundwater levels adjacent to and flows in the greenways to ensure that they have been constructed in accordance with the Design Principles and that they are not dewatering the RTD. The flooding impacts need to be considered.

6.2. If the Kingfisher Pond does not fully recover

It remains possible that the Kingfisher Pond and other features may be affected in the long-term by the changes in recharge and construction of the greenways. This may include being more susceptibility to dry periods or a more permanent lowering of groundwater levels. If this occurs then it may be necessary to make some engineering changes, which could include:

1. Supporting water levels in the Kingfisher Pond;
2. Deepening the pond;
3. Improving the greenways to ensure that they are in accordance with the design principles.

Given concerns about cracks in the brickwork of the Longstanton Village Institute and All Saints Church specialist advice should be sought.

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