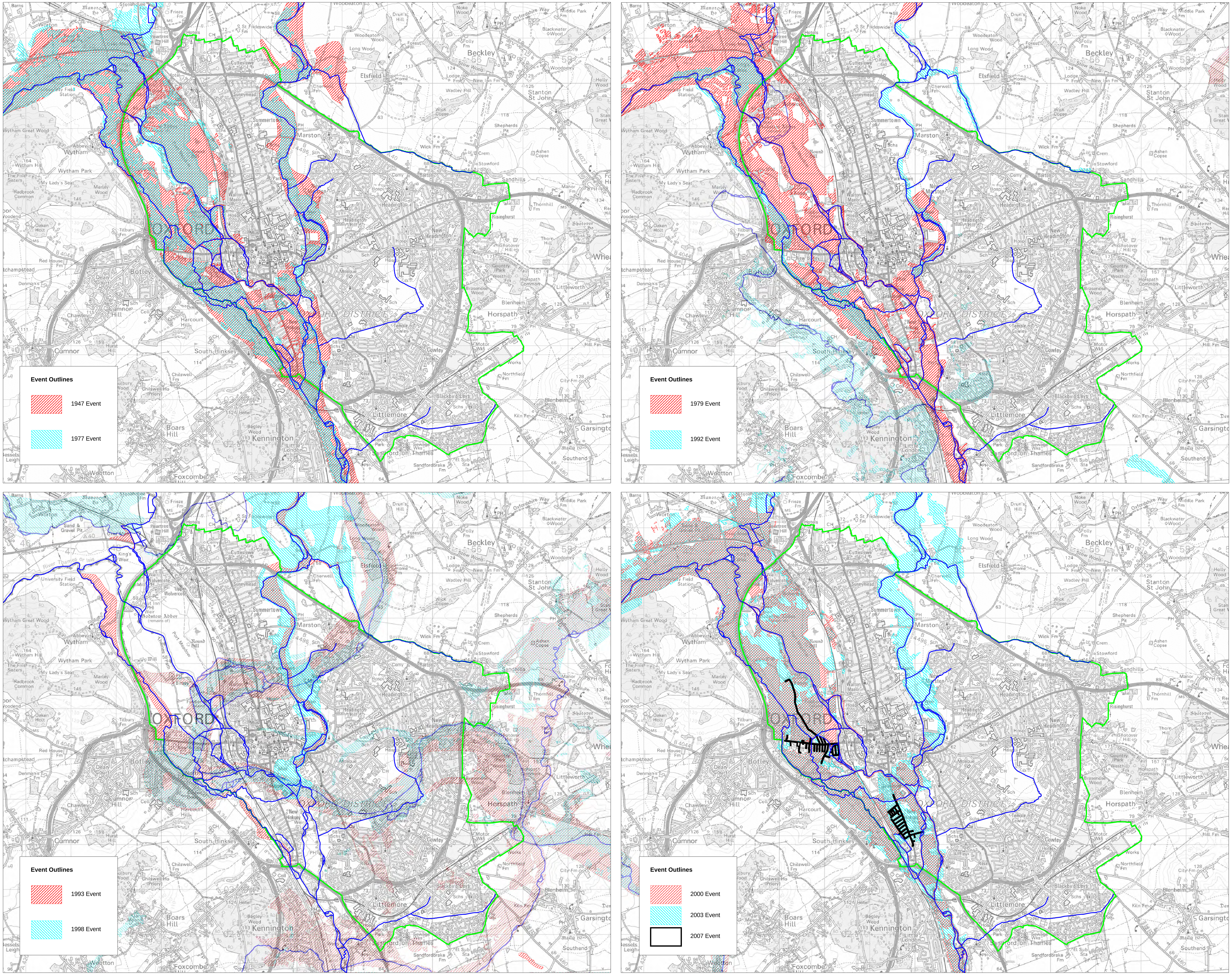
APPENDICES

APPENDIX A – Historical Flood Event Mapping



Legend

River Centreline

Study Boundary

N

SCALE: NTS

Project Title:

Oxford City SFRA - March 2011

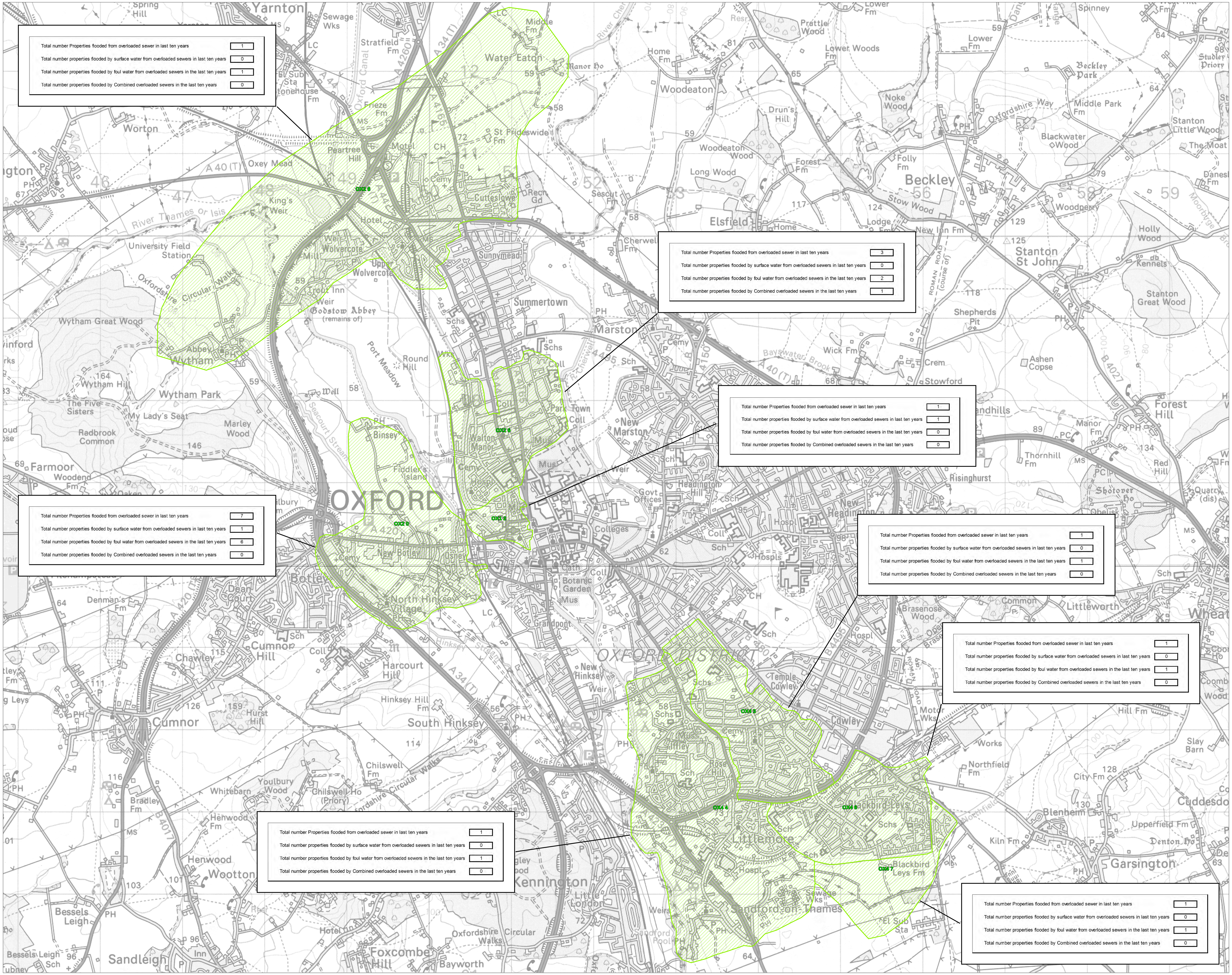
Figure Title:

Historical Flood Outlines

Document Reference: **5093353/62/DWG/003**

Figure Number: **Appendix C**

ATKINS



Legend

Postcode Areas

SCALE: NTS

N

Project Title:

Oxford City SFRA - March 2011

Figure Title:

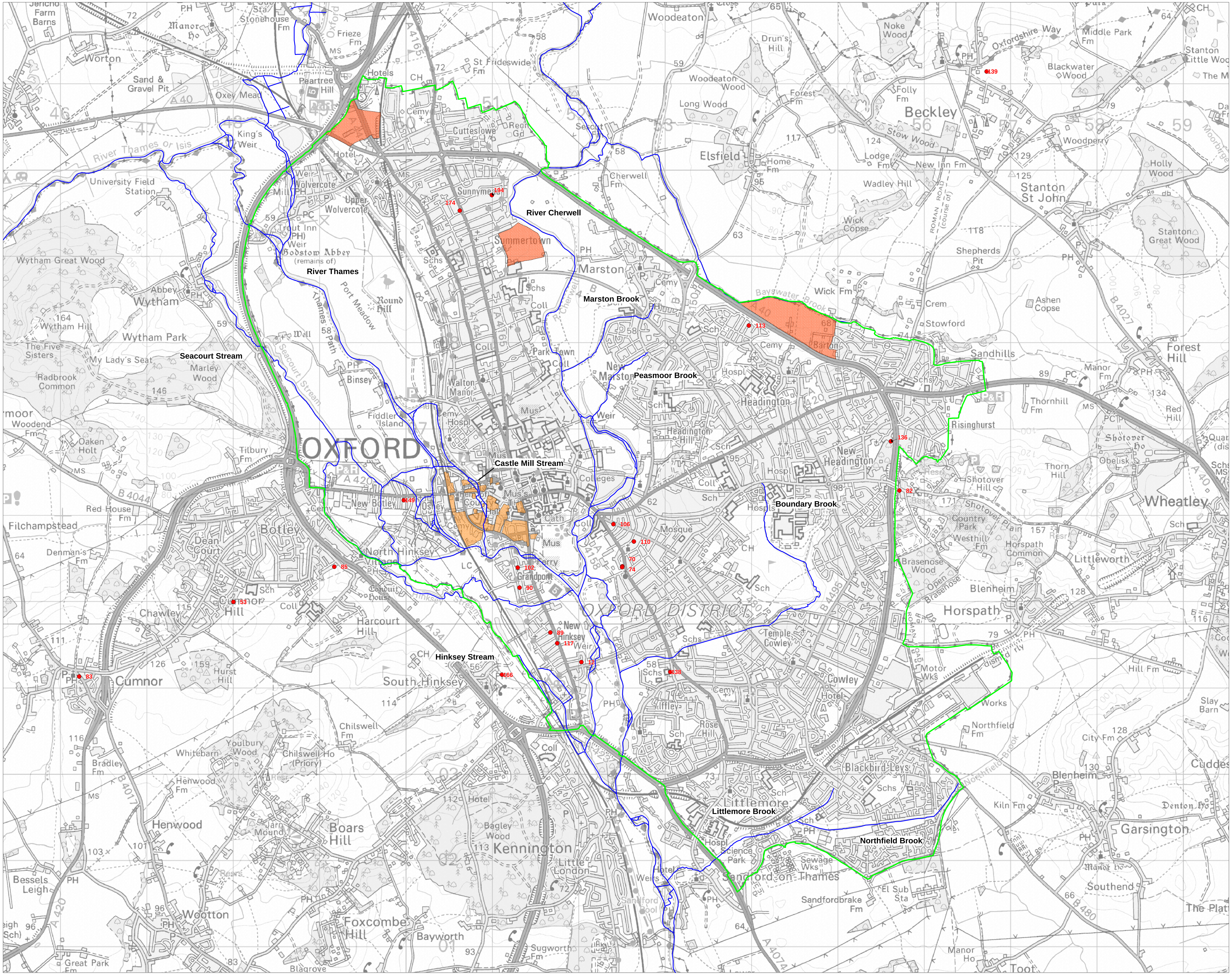
Thames Water Sewer Flooding Incidents by Postcode Area

Document Reference: **5093353/62/DWG/001**

Figure Number: **Appendix A**

OXFORD CITY COUNCIL

ATKINS



Legend

- River Centreline
- Study Boundary
- Strategic Development Sites
- Indicative Sites within the West End
- Ground Water Flooding Incidents (Labelled with call reference number)

SCALE: NTS

N

Project Title:
Oxford City SFRA - March 2011

Figure Title:
Registered Groundwater Flooding Incidents

Document Reference: **5093353/62/DWG/002**

Figure Number: **Appendix B**

APPENDIX B – Card Geotechnics Hydrology Report

Exeter College

Ruskin College, Oxford

Basement hydrological assessment report

October, 2012

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Card Geotechnics Limited ("CGL") has prepared this report in accordance with the instructions of Stockley on behalf of Exeter College ("the Client") under the terms of its appointment for consulting engineering services by the Client dated 30th August 2012. The report is for the sole and specific use of the Client, and CGL shall not be responsible for any use of the report or its contents for any purpose other than that for which it was prepared and provided. Should the Client require to pass copies of the report to other parties for information, the whole of the report should be so copied, but no professional liability or warranty shall be extended to other parties by CGL in this connection without the explicit written agreement thereto by CGL.

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Reference CG/8069	Revision 0.0	Issue Date October 2012	

Contents

FIGURES

APPENDICES

1. INTRODUCTION

Exeter College, Oxford, is proposing to redevelop part of Ruskin College, including the demolition of existing buildings and construction of 4 to 6 storey buildings with a single storey basement level. The façades of the original college along Walton Street and Worcester Place are to be retained.

Card Geotechnics Limited (CGL) has been commissioned to undertake a review of the groundwater information available for the site and environs to provide an appropriate groundwater level for the proposed basement design, in accordance with the design philosophy set out in BS 8102:2009 – *Code of practice for protection of structures against water from the ground*, and to assess the potential impact of the basement on local groundwater levels.

This report presents the findings of a desk based study of the available ground and groundwater conditions in the surrounding area taking into account published and unpublished geological records from the British Geological Survey and council records. Site investigation data for the site has also been reviewed, along with information available from CGLs recent work at Oxford University Press (OUP) and publicly available information for the recent Radcliffe Observatory Quarter (ROQ) development in central Oxford.

The report assesses the impact of the proposed basement on the local and regional groundwater regimes and the risk associated with the potential for increased groundwater levels as a result of the proposed basement. This report also includes a 2 dimensional groundwater flow analysis using FLAC finite difference software to assess the change in flow regime and upstream porewater pressures generated by construction of the new basement.

2. SITE CONTEXT

2.1 Site location

The site is located at Ruskin College, at the junction between Walton Street and Worcester Place, Oxford, OX1 2HE. The OS Grid Reference of the site is approximately 450919, 206638 and the site location is shown in Figure 1. Figure 1 also shows the nearby OUP and ROQ basement sites, from which information has been derived to support groundwater modelling.

2.2 Site Layout

The site is approximately rectangular in shape, with dimensions of 75m by 25m.

The site is currently occupied by the buildings of Ruskin College, providing student accommodation and teaching facilities. The buildings range from two to five storeys in height, with variable levels of part to full single storey basements. There is also a relatively small open space/courtyard in the central and southern portion of the site. The site is bounded by Walton Street and Worcester Lane to the north and east of the site, respectively. To the south and west are the grounds and buildings of Worcester College.

Plans and sections showing the existing site layout are provided in Appendix A.

2.3 Proposed development

It is proposed to demolish the existing buildings on site whilst retaining the façades of the original Ruskin College buildings along the north eastern and eastern boundaries. A single storey basement is to be constructed across the majority of the site footprint, excavated within a secant piled wall to a floor level of 56.4mOD. Existing basements will need to be deepened by between 1.5m and 3.0m whilst in other areas new basement excavations will extend to a maximum depth of 4.0m below ground level (bgl). The secant wall does not extend fully to the eastern edge of the site, where the existing basement and floor levels of the Ruskin buildings are being largely retained. An open courtyard area steps up to ground level from the basement along the southern boundary.

Plans of the proposed site layout are provided in Appendix B and proposed excavation levels and depths are shown in Figure 4.

3. GROUND AND GROUNDWATER CONDITIONS

3.1 Introduction

This section of the report collates desk based information, historical boreholes and on-site and off-site intrusive investigation data. Public and private sources have been consulted to supplement the site specific data and establish the hydrogeological regime of the site and surrounding area.

Borehole locations and derived groundwater levels and contours are summarised in Figure 2.

3.2 Published geology

According to British Geological Map Sheet 236[1] the site is underlain by the Northmoor Sand and Gravel Formation (terrace gravels of the River Thames) and the Oxford Clay at depth. More recent alluvial deposits outcrop approximately 100m to the south west of the site.

3.3 Historical boreholes

There are limited BGS borehole records in the near vicinity of the site. The nearest of these include several boreholes at the former Radcliffe Infirmary approximately 350m north of the site, a single borehole on Cardigan Street 350m north west of the site, and a series of boreholes along Rewley Abbey Court 250m south west of the site and Worcester College Pond.

The BGS borehole records largely coincide with the geological map of the area and show that, under a thin veneer of Made Ground (typically <1.0m), siliceous sands and gravels are encountered representative of the Northmoor Sand and Gravel Formation and Summerton-Radley Sand and Gravel Formation. These soils are, however, characterised by intermittent soft to firm clay horizons perhaps representative of historical flood plains. The river terrace gravels are overlain by soft alluvium in those boreholes closer to the River Thames.

[1] Witney, England and Wales Sheet 236. 1:50,000 Series. Solid and Drift Geology. British Geological Survey, 1982.

The Oxford Clay was encountered in the majority of the boreholes where depths of investigation were sufficient, and comprised firm becoming stiff to hard blue/grey clay.

3.4 On-site Intrusive Investigations

3.4.1 Ground conditions

A previous ground investigation has been undertaken at the site by Geotechnical and Environmental Associates Limited (GEA) in May 2012[2], and comprised the following works:

1. A desk study;

2. An intrusive investigation comprising a single cable percussion borehole to 20m depth, including in-situ standard penetration testing and disturbed/undisturbed sampling. The borehole was excavated outside the site perimeter on Worcester Place. 20 hand dug trial pits were also excavated to expose existing foundations;

3. Geotechnical and geoenvironmental laboratory testing;

4. Interpretative reporting for both geotechnical and geoenvironmental requirements.

A second phase of investigation was being undertaken at the time of writing, including the excavation of 3 additional boreholes with monitoring installations. Preliminary logs have been provided along with the results groundwater monitoring. The locations of the boreholes are illustrated in Figure 2.

Based on the four boreholes completed, the ground conditions on site are summarised below in Table 1:

[2] GEA (23 May 2012) *Ruskin College Oxford – Desk Study and Ground Investigation Report*

Table 1: Summary of ground conditions

Stratum	Depth to top (mbgl) Level [mOD]	Thickness (m)
MADE GROUND comprising dark brown to orangebrown sandy gravelly clay/clayey gravelly sand with fragments of brick, concrete, ash and coal.	0 [59.83 – 57.90]	0.50 – 1.70
Soft orange light brown silty sandy gravelly CLAY / loose to medium dense brown clayey silty SAND with occasional gravel / loose orange brown clayey silty sandy GRAVEL. [NORTHMOOR SAND AND GRAVEL]	0.50 – 1.70 [56.20 - 59.33]	1.90 – 5.80
Initially soft becoming very stiff dark blue grey fissured silty CLAY with occasional sandy partings. [OXFORD CLAY]	2.40 - 6.80 [52.2 – 57.43]	Proven to 20mbgl

The Northmoor Sand and Gravel at the site is characterised by both cohesive and granular units, possibly representing cyclical depositions of terrace deposits during flood events. In the trial pits the Northmoor Sand and Gravel was typically encountered as a clayey silty sand and gravel. Similarly variable superficial ground conditions were encountered at the OUP and ROQ sites (see below).

It is noted that gravel was encountered to a depth of 6.8mbgl in borehole BH1, and to a depth of 6.5mbgl in borehole BH4. Gravel was not encountered in boreholes BH2 and BH3, with the alluvial deposits in this area comprising silts and clays. It is possible that the presence of the gravels represents a former river channel across the western half of the site.

3.4.2 Groundwater

A groundwater strike was recorded during the first phase of investigation in borehole BH1 in the granular Northmoor Sand and Gravel at a depth of 6.2m (52.80mOD), which rose to 3.1mbgl (55.90mOD) after a period of 20 minutes. Groundwater strikes were recorded within trial pits TP1 – TP7 at levels of between 57.2mOD and 57.4mOD generally in the north and eastern areas of the site. Trial pits TP9 – TP25 did not encounter groundwater, no log was provided for trial pit TP8.

During the second phase of investigation, groundwater strikes were recorded as fast inflows in boreholes BH2 and BH4 at depths of 2.3m and 6.3m, respectively. A seepage was recorded in borehole BH3 at 3.0m during the site works.

Subsequent monitoring of boreholes BH2, BH3, and BH4 on four occasions recorded water levels between 57.9mOD and 55.1mOD across the site, typically lower in borehole BH4. Groundwater monitoring records are summarised Table 2 below (provided by GEA).

Table 2: Groundwater monitoring results

Date	Borehole BH2 Depth to water (m) (level m OD)	Borehole BH3 Depth to water (m) (level m OD)	Borehole BH4 Depth to water (m) (level m OD)
11/9/2012	2.15 (57.68)	1.52 (57.38)	2.67 (55.23)
20/9/2012	2.20 (57.63)	1.58 (57.32)	2.84 (55.06)
27/9/2012	1.96 (57.87)	1.35 (57.55)	2.39 (55.51)
8/10/2012	1.90 (57.93)	1.28 (57.62)	2.26 (55.64)

The results indicate a fall in groundwater levels to the south and west, consistent with the broad regional trend. It is noted that there is an approximate 2.5m drop in water level across the site in boreholes BH1 and BH4. It is considered that this is due to the presence of a substantial thickness of gravels across the western half of the site acting as a preferential flow path for groundwater in this area. This corresponds to groundwater observations within the trial pits, with water present in the north and east at shallow depth only.

3.5 Off-site intrusive investigations

A site investigation was completed at the OUP site approximately 200m north of the site, comprising 2 boreholes to 20.45m and 16.45m bgl. Here both cohesive and granular units of the Northmoor Sand and Gravel were encountered, again indicative of the variability of this formation over relatively small spatial scales. The Northmoor Sand and Gravel was underlain by stiff to very stiff sandy clays of the Oxford Clay Formation at levels varying between 57mOD and 54mOD.

A large scale investigation was completed at the Radcliffe Observatory Quarter (ROQ, formerly the Radcliffe Infirmary) some 350m north of the site, with information from this investigation partly available through the Oxford City Council planning website (ref. 09/02535/FUL). The site investigation comprised excavation of 9 cable percussive boreholes. Again the ground conditions comprise Made Ground over variable River Terrace Deposits with thicknesses recorded between 4.1m and 5.2m. The River Terrace Deposits generally comprise medium dense to very dense orange silty sandy gravel varying to silty gravelly sand with occasional pockets or layers of sandy gravelly clay.

The Oxford Clay was encountered in all of the boreholes, generally described as stiff becoming very stiff blue grey and green grey calcareous clay, thinly laminated and very closely to closely fissured in parts, with occasional fossils.

3.6 Local topography

The local topography is characterised by the higher level river terraces sitting above the adjacent floodplains of the River Thames and River Cherwell. Oxford City centre is thus situated on relatively high ground between the major rivers to the west and east of the city. The site is located on the western slope of this river terrace plateau.

The natural slope of the site drops from east to west towards the Oxford Canal and the River Thames located 300m and 500m west of the site, respectively. The ground level drops from 60.5mOD on Walton Street to 58mOD at the site's western boundary, representing a local gradient of 1:30 or 2°.

3.7 Hydrogeology

3.7.1 EA aquifer designations

The Environment Agency[3] has produced an aquifer designation system consistent with the requirements of the Water Framework Directive. The designations have been set for superficial and bedrock geology and are based on the importance of aquifers for potable water supply and their role in supporting surface water bodies and wetland ecosystems.

The Northmoor Sand and Gravel underneath the site is classified as Secondary A aquifer. Secondary A aquifers are permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. The alluvium is also classified as a Secondary A aquifer.

[3] www.environment-agency.gov.uk (September 2012)

The Oxford Clay encountered at depth is classified as an Unproductive Strata. Unproductive Strata are rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.

3.7.2 Hydrogeological flow

Both BGS and publicly available data have been consulted to establish the local hydrogeological regime and groundwater flow direction. A recent report commissioned by the Environment Agency on groundwater flooding in Oxford[4] has also been consulted.

The hydrogeological regime in Oxford and the surrounding area is characterised by shallow groundwater levels, across the floodplain areas to the west of the site, groundwater is typically less than 1mbgl in winter and 2mbgl in summer. The older river terrace deposits form a relatively higher ridge between the River Cherwell and the Oxford Canal and as such, groundwater levels, which are considered to be in continuity with both, are slightly deeper across the urbanised Oxford area.

The site itself is approximately 4m to 5m above the water level in Castle Mill Stream and the River Thames. The recent alluvial deposits of the Thames and Cherwell floodplains typically comprise 1m of silty clay underlain by 5m of sands and gravels[4] across the western area of the site, with up to 5.3m of mixed silty clay and sand in the east. As such, the older river terraces are likely to be in hydraulic continuity with the alluvium and the rivers.

The Oxford Clay represents a regional aquiclude, inhibiting the vertical movement of groundwater from the overlying superficial deposits. Therefore, groundwater is likely to flow laterally through the superficial deposits and radially outwards from the river terrace plateau towards the floodplains of the River Thames to the west and River Cherwell to the east, and also towards the confluence of the two rivers approximately 1.8km south east of the site. It is likely that confined water bearing units are present within the Northmoor Sand and Gravel..

Monitoring data has been combined with groundwater data from BGS and publicly available information, including data from the OUP and ROQ sites, to derive local groundwater flow directions as shown n Figure 2. The results broadly conform to the hydrogeological interpretation of the study, which is summarised conceptually in Figure 3.

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[4] Macdonald DMJ. Et al (2007) Groundwater and flooding in Oxford. Defra 42nd Flood and Coastal Management Conference, York, 2007. Available online : http://www.groundwateruk.org/downloads/Oxford_Defra_Paper_2007.pdf

The groundwater information available for the site suggests that groundwater is discontinuous, broadly flowing towards the south and west, with flow likely to be occurring within sand channels and lenses between more silty/clayey horizons. There is a considerable increase in thickness of the gravels in the south of the site, which appears to be acting as a local drain, causing groundwater levels to drop considerably in this area. It is concluded that groundwater flow across the site will be generally slow through the eastern areas, with velocity controlled by low permeability silts and clays, with lenses and sand channels where present. The slow flow creates a limited supply to the gravels, which are capable of draining much faster, causing the drop in groundwater level evident from monitoring.

A conceptual model of the deduced flow regime is summarised in Figure 3b.

3.8 Hydrology

The floodplain of the River Thames is located to the west of the site and the course of the river is some 500m west of the site at its nearest point. Castle Mill stream branches off from the Thames and flows parallel to Oxford Canal, 300m south west of the site at its nearest point (see Figure 2).

Worcester College Lake is located some 80m south west of the site. The lake is understood to be connected by a sluice to the canal and is at the same level as the canal. It is considered likely that the lake is in hydraulic continuity with local groundwater.

Records from the EA[3] indicate that a Zone 3 floodplain is located immediately adjacent to the site's south western boundary. Zone 3 floodplains are areas that could be affected by flooding of rivers if there were no flood defences. This area could be flooded from a river by a rainfall event that has a 1 per cent (1 in 100) or greater chance of happening each year.

A Zone 2 floodplain extends partly onto the western half of the site. Zone 2 floodplains represent the additional extent of an extreme flood from rivers. These areas are likely to be affected by a major rainfall event, with up to a 0.1 per cent (1 in 1000) chance of occurring each year.

The extent of historical extreme floods may account for the presence of soft cohesive horizons within the Northmoor Sand and Gravel close to the superficial boundary with the alluvium.

4. RECOMMENDATIONS FOR GROUNDWATER

4.1 Impact of proposed basement construction on groundwater

Borehole records indicate that the basement formation at 56mOD (to include excavation for 350mm slab) will be within the Northmoor Sand and Gravel, some 4m above the Oxford Clay. Monitoring indicates that groundwater levels fall from some 57.9mOD to 55.6mOD across the site and as such the basement formation will be at or below groundwater level.

The excavations required across the site are summarised diagrammatically in Figure 4, showing the existing basement levels and additional excavations required to achieve the new formation level.

A secant pile wall is proposed around the basement perimeter to form the basement walls. Toe levels for the piles are expected to penetrate into the Oxford Clay, which will intercept the groundwater table and effectively create a fully impermeable basement box.

4.2 Recommended design groundwater level

BS 8102:2009 – *Code of practice for protection of structures against water from the ground* recommends a risk assessment to be undertaken to establish design groundwater levels where monitoring data is available. Monitoring results indicate groundwater levels from some 57.9mOD to 55.6mOD across the site, with higher values in the north. Flood levels inferred from the EA maps represent transient groundwater levels at or close to ground level at the site and as such a groundwater level of 58mOD is recommended for persistent conditions, with a design water level at ground surface for 'extreme' flood events as a transient, emergency loading condition.

Enquiries to Thames Water assets indicate that there is a 3" distribution main situated along the eastern boundary of the site beneath Walton Street and a 5'' distribution main along the northern boundary along Worcester Place. A 10'' trunk main also runs in a north south alignment on the eastern side of Walton Street. Foul and surface water drains also run along both these highways. Rupture of any of this infrastructure would be unlikely to generate a transient groundwater level greater than ground surface as stipulated for extreme flood events and, as such, no additional measures are recommended in this regard. Details of Thames Water infrastructure are included in Appendix C.

5. GROUNDWATER MODELLING

5.1 Previous hydrogeological modelling

A number of sites in close proximity to Ruskin College have been subject to groundwater modelling to assess the impact of basement construction on the local hydrogeological regime. These are summarised in the following sections.

5.1.1 Radcliffe Observatory Quarter – 2009

The ROQ project is located some 350m to the north of Ruskin College and includes the excavation of a 4.3ha two storey basement. Given the size of the basement, Pell Frischmann Ltd. undertook groundwater modelling to assess the impact of the basement on the local hydrogeology and hydrology as part of the Environmental Impact Assessment for that site in 2009. Their report is available on the Oxford City Council planning website (ref. 09/02535/FUL) and relevant findings/conclusions are summarised below:

a. Groundwater levels were found to decrease from the east of the site (59.2mOD) to the west (58.7mOD (SW) to 58.2mOD (NW)); with an average gradient of 1:600 falling to the west.

b. In-situ testing recorded the permeability of the local gravels to be of the order of 1.07×10^{-4} m/s and a conservative mean value of 3×10^{-3}m/s was used in the analysis with reference to the Environment Agency's R&D publication 120[5].

c. The groundwater regime was found to be relatively stable on site over a 12 month monitoring period.

d. The Pell Frischmann analysis considered regional hydrogeology/hydrology in terms of the very large Observatory Quarter basement's potential impact on the River Cherwell and the Oxford Canal. It concluded that the basement would not have an impact on the regional hydrogeology or hydrology.

e. Local variations in groundwater level were not considered.

[5] LandSim. Landfill performance assessment: Simulation by Monte Carlo method R&D Publication 120. Environment Agency (1996).

5.1.2 Oxford University Press – 2012

A groundwater modelling exercise using FLAC software was completed by CGL at a site 200m north of Ruskin College (planning ref 12/00371/FUL). A single storey basement is proposed across the entire site footprint.

The results suggest a negligible groundwater rise and is based on typical hydraulic gradients assumed for the area for a local hydrological and hydrogeological study undertaken for the ROQ site to the north and east of the site.

5.1.3 Summary

Both of the modelling exercises competed by CGL and Pell Frischmann suggest that basement construction in similar ground conditions and in close proximity to the site do not have a significant impact on the local hydrogeology. It is therefore considered likely that the proposed Ruskin College development will have a similarly low impact on local groundwater levels and flow rates – however analysis will be undertaken to assess this effect.

In terms of infiltration/water supply, it is noted that the proposed development footprint is currently occupied by impermeable hard-standing or buildings and, as such, the new construction will not materially affect the infiltration characteristics of the site.

5.2 Analysis

The construction of the new basement will create an impermeable barrier to groundwater flow and calculations have been undertaken to assess the impact of the basement on local groundwater levels. The analysis has been undertaken using two-dimensional finite difference software, (FLAC), to compute groundwater flow rates and pore pressures based on Darcy's Law.

Historical borehole data and site monitoring records have been combined to establish the regional groundwater gradient in the vicinity of the site as illustrated in Figure 2. The flow gradient is input into the FLAC model and steady state conditions established. FLAC's calculated pore pressure gradient is illustrated in Figure 3 and is consistent with contouring based on available data.

A permeability of 1 x 10^{-3}m/s was used for the entire site as a highly conservative value in order to establish worst case responses to changes in flow conditions should a gravel channel become obstructed by the construction of the basement. The basement area was 'excavated' within the model by applying a permeability of 0m/s in the basement area, and setting initial pore pressures to 0kPa, allowing for the basement to be dewatered and to create a long-term watertight box.

Flow vectors before and after basement construction are illustrated in Figures 6 and 7, showing the obstruction caused by the new basement.

Pore pressure changes have been assessed along lines broadly orthogonal to the regional flow direction (typically SW) with lines intersecting the site boundary, 10m to the northeast, and 20m to the northeast. The results are summarised in Figure 8 and indicate a maximum increase in groundwater pressure of some 0.55kPa at the basement perimeter, corresponding to an increase in groundwater levels of some 5.5cm above existing levels at the site perimeter, reducing to 3.8cm at 10m distance, and 2.9cm at 20m distance.

The FLAC analysis indicates that groundwater rises around the basement perimeter are minimal, with the maximum occurring toward the upstream side of the basement. The effects reduce rapidly with distance away from the basement. These values are considered to be worst-credible estimates as they assume a uniform high permeability within the gravels and unobstructed existing flow. In reality there will be clay lenses/layers within the gravels that significantly reduce the vertical permeability of the soils, forcing groundwater to dissipate laterally around the perimeter of the basement, rather than rising vertically.

On the basis of the analysis, the impact of the basement on local groundwater levels is considered to be minor and is very unlikely to affect local properties, even those with basements.

6. SUMMARY AND CONLUSIONS

1. It is proposed to construct a new basement at Ruskin College, Oxford with a secant piled wall around its perimeter that will obstruct local groundwater flow.

2. Studies undertaken for major new basements in the area indicate that groundwater flows generally toward the south and west in the vicinity of the site (towards the River Thames). This observation is supported by historical borehole data.

3. Groundwater levels drop by some 2m to 2.5m across the site and it is considered that this is due to a significant increase in the gravel thickness in the west of the site. It is considered that groundwater flow rates are likely to be controlled by the mixed/low permeability silt, clay and sand deposits in the east, with the deep gravels providing under-drainage in the west and reducing groundwater levels accordingly.

4. A design ground water level of 58mOD is recommended for persistent conditions based on available monitoring data. Groundwater should be taken at ground level for transient, extreme conditions given the site's location in the floodplain of the River Thames.

5. A finite difference model has been constructed to assess the impact of the basement on local groundwater levels. The model takes worst case permeability assumptions, effectively assuming that a sand channel becomes blocked, to determine the maximum likely groundwater rise caused by the basement. The result is a maximum increase of 5.5cm at the up-gradient (north east) site boundary, reducing to 3.8cm at 20m distance. The impact of such a rise is considered to be negligible, given that the nearest upstream structures are some 10m to 15m away, and given the conservative assumptions made in the modelling. It is also recognised that existing foundations and basements to the northeast of the site will reduce existing flow rates, and correspondingly reduce the impact of the current basement on groundwater levels.