Redington Frognal Neighbourhood Forum

Red Frog Sub-surface Water Features Mapping

Summary Report

Revision A | 1 April 2016

Job number 246648-00

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1 Introduction

The Redington and Frognal Neighbourhood Forum (Redfrog) have commissioned Arup to undertake a high level desk-based mapping assessment of subsurface water features (lost streams and springs) in the Neighbourhood Forum area, which is situated in the London Borough of Camden (Figure 1).

The purpose of the work is to provide an independent assessment of whether there were any water features that have been lost from the surface in the area of interest and provide an indication of where they may be.

There are a number of ways in which this information can be used in the long term, including: development of a community mapping exercise to raise awareness of the hidden water and environmental history of the area; identifying the potential for reopening (or "daylighting") culverted watercourses for environmental and social amenity benefits; investigating the potential to reduce clean water entering the sewer network (and thus reduce wastewater treatment or sewer flood risk).

1.1 Scope of Work

The scope of Arup services includes;

- The collation and analysis of freely available historical maps and records, including local community reports and records (provided by the Client)
- Geospatial analysis using freely available digital topographic data,
- A high level hydrogeological review
- Compilation of spatial data and results of the analysis into KML format for use in freely available Google Earth software

The scope at this stage does not include ground investigation, numerical hydrological water balance modelling, hydraulic groundwater or surface water flow modelling, or analysis of Thames Water's sewer network records to verify or quantify the flow or nature of any hidden water features.

The aim of this work is to provide a reasonable indication of whether there were historical water sources in the area of interest, and an indication of the location of these to a degree of confidence reflective of the available data.

1.2 Project Limitations

This report has been commissioned by and prepared on behalf of the Redington Frognal Neighbourhood Forum. Funding for this work was provided in the form of a grant to the Redington Frognal Neighbourhood Forum from the City of London.

The work was performed with the sole purpose of evaluating potential locations of historical water sources and compiling of a spatial database of potential water features in the area of study by use of an independent high-level mapping assessment. The work undertaken is limited to the scope of services described above.

The work performed by Arup should not be relied as conclusive evidence of locations (or lack of locations) of sub-surface water features described in this report both due to the inherent uncertainty of their locations and the limited nature of the scope of services performed. The sources reviewed in this report are not exhaustive. Additional maps and historical sources for the study area are likely to be available from other archives and at cost. A list of recommended sources is provided in Section 5.

2 Methodology

No single type of evidence is infallible or completely certain, thus there is a need to consider evidence from a range of sources. Mapping is a useful tool to plot evidence from a variety of sources, however expert judgement is still required to integrate the supporting and conflicting evidence based on the strength of specific information.

The high-level mapping assessment was based on multiple lines of evidence, which included:

1. Topographic flowpath modelling,
2. Review and interpretation of historical maps,
3. Search and review of historical records and literature,
4. Review and interpretation of place and street names,
5. Review of anecdotal local knowledge provided by the client,
6. Hydrogeological review to analyse the potential position of springlines.

The evidence has been collated and analysed within a Geographical Information System (GIS). This approach has been based on a published methodology developed by the author [1].

The final map has been produced as a KML file, compatible with Google Earth software, and suitable for the client to distribute and edit in future should more information come to light.

2.1 Topographic flowpath modelling

Over time, watercourses and their headwater streams erode the land and create valleys. As towns and cities expanded, these valleys were sometimes filled in by urban development such as roads and buildings, smoothing over the valley bottoms and frequently resulting in the ditches and watercourses being encased in drainage culverts below the surface. Despite this, it is often still possible to distinguish subtle features in the contours of the land (topography) which can indicate where valleys may once have been, thence where water may once have flowed (topographic flowpaths).

Topographic flowpath modelling was undertaken for the study area using the Ordnance Survey (OS) Terrain50 digital elevation model (DEM) and tools within ArcGIS software. This DEM provides ground elevations on a 50 m grid. The analysis calculates the direction of the slope in each grid cell, and generates a "flowpath" line based on the topography and the number of accumulating "upstream" cells in the grid that are draining to it. The most upstream point at which a flowpath is demarcated is approximately calibrated by adjusting the flow accumulation threshold to visually match up the modelled stream origins with the known positions of other nearby open, relatively natural watercourses on

Hampstead Heath that are shown on modern maps (OS Open Raster, Google Maps), as per the method outlined in [1].

The OS Terrain50 product has a coarse resolution compared with other DEM products, such as LiDAR. Free Open Government LiDAR was unavailable for this area, so the Terrain50 product was the best available digital data. Higher resolution topographic data would enable greater confidence in the delineation of topographic flowpaths but must be purchased at additional cost.

The confidence in the topographic flowpath modelling is limited by the resolution of the data, and also by the fact that it is based solely on the topography, and does not factor in hydrological or hydrogeological processes such as infiltration into the soil. The data also reflect the modern ground surface, and not the contours prior to development; as such, a degree of interpretation is required.

The results of this analysis indicate a topographic flowpath parallel with Heath Drive and Redington Gardens, and another to the east leading up the road named Frognal. Outside of the neighbourhood area are topographic flowpath lines draining from Child’s Hill (on the northern edge of the area) towards the northwest, from Fitzjohn’s Avenue (southeast of the area) draining to the south, and from Hampstead centre (east of the area) draining to the southeast. The results of the analysis are presented in Figure 2.

2.2 Historical maps

Readily available historical maps were obtained online and, where possible, downloaded and georeferenced in the GIS as overlays onto the modern maps and topographic flowpath modelling results. The maps were analysed to determine possible watercourses and water related features, which were then digitised as lines and points in the GIS.

Historical maps of different dates vary in their scale, coverage and therefore their resolution and depiction of water-related features. A degree of interpretation is required, such as deciding whether a line marked on an historical map is a field boundary or a watercourse - clues such as curved or meandering lines can indicate the latter.

Additional maps are likely to be available in archive collections. Various possible sources of these maps, which have not been consulted as part of this assessment are provided in Section 5.

Map name	Date	Source accessed
Ordnance Survey		
Ordnance Survey, 5' to the mile (1:1056)	1893-5	National Library of Scotland
Ordnance Survey 6" to the mile (1:10,560)	1873, 1894, 1920	National Library of Scotland
Ordnance Survey 1" to the mile (1:63,360)	1896	

Map name	Date	Source accessed
Ordnance Survey 25" to the mile (1:2500) (County Series mapping)	c.1850 (London First Editions, published 1870), 1896, 1915, 1938	
Other maps		
John Rocque's map of Hampstead	1762	www.theundergroundmap.com
The Environs of London, J.H. Colton.	1860	www.theundergroundmap.com
Stanfords Outer London (1:106,065)	1901	www.theundergroundmap.com

Table 1 Historical maps consulted for study

2.3 Historical records and literature

A variety of easily accessible non-map based data and information was also compiled from a search of historical records and literature which was cross-referenced and plotted in GIS. An exhaustive search of historical records may produce additional information, however this was outside of the scope of this work. The records that were used are summarised below with additional possible archive sources presented in Section 5.

Historical texts, records, books and images mentioning springs, wells, watercourses and water infrastructure (such as the development of the sewers), particularly prior to the nineteenth century, were reviewed.

Early development of water supply in this area was related to the availability of natural springs and the ponds on Hampstead Heath, and engineering works would have been closely related to the natural hydrology and hydrogeology. As development and water demand increased, there would have been a need to import water supplies from outside the local area. Later development of the area as driven by population expansion of London meant that early engineering works would have been closely tied to the hydrogeology of the area, but later on proceeded independently as more significant water supplies were required.

For instance, the results included information which indicated that the covered Kidderpore Reservoir was not designed to capture local springs, as with early reservoir ponds on Hampstead Heath. Instead the reservoir was constructed in 1867 to store treated water extracted from the Thames at Hampton, and pumped by steam engine to high ground on Hampstead Heath for gravity distribution to nearby homes [2] [3].

This therefore indicated that there was probably not an immediate and plentiful clean spring water supply in the vicinity captured in the reservoir. Baker et al [4] identifies the Blacket's Well forming an early border marker near Platt's Lane on Childs Hill. This does not feature on maps after approximately 1850, but is named on some of the older, coarser maps found.

Contemporary studies on the lost rivers of London have also been reviewed. These include some of the study area but generally not in great detail. For example, books by Barton [5], Talling [6], Bolton [7][7] and Myers [8] all indicate the source of the Westbourne as the green space below Whitestone Pond, close to Branch Hill, with marshy ground observed at some times of year where another pond used to be, before this dried up. This pond was the subject of several Constable paintings, and was likely to have been dug down through the shallow sandy clay layer to the clay layer below, forming a collection point for shallow groundwater and rainwater (Figure 3).

Other paintings can also be of use such as Figure 4 which indicates the source of the other Westbourne branch at Frognal Hall.

2.4 Place and street names

Street and place names, historical and current, referencing "spring", "well", "water", "brook" or "burn" often reflect proximity to historical water-related features.

Shepherd's Well is the source of the Tyburn, whose springs had long been tapped into water supply conduits and shallow wells.

In reference to other sources, the branch of the Westbourne sourcing near to Branch Hill was called the Cannon Stream. All that remains today is the street Cannon Hill, where maps show that the watercourse followed this street as it was upgraded during the Victorian period for housing. The Cannon Stream was culverted through here [9].

2.5 Local knowledge

"Citizen Science" (local knowledge collated by the client from members of the community) was also considered. Hand annotated maps and observations provided by the client were cross referenced and digitised in GIS.

Findings included an understanding that the spring line occurs at approximately the 90mOD elevation, that there was a watercourse from an historical well near Platt's Lane (which corroborates the references to Blacket's Well), other numerous wells, springs and buried streams known in basements and gardens of households, and present or past poplar and willow trees (often located in wet riparian soils).

The evidence was mapped and interpreted on a case by case basis. The reported springline at the 90mOD elevation is approximately correct, and is consistent with the analysis of the geology and hydrogeology. A reference to the (former) existence of a well can be an indication that the water table is not far below the surface at the location. However, this is only likely to be the case if the “well” was an engineered shaft or chamber constructed to collect water from a spring; not all reported “wells” are such features. Boggy ground, however, could be the surface seepage emergence of shallow groundwater, or alternatively a localised area of impermeable soils that result in collection of rainwater near the surface, and nothing to do with groundwater. Water could even be from leaking mains water pipes; none of the evidence provided suggests that this is likely to be the case, as they are long term observations – however, chemical analysis of the waters could help to confirm their origin [1].

There are a number of reported sightings of underground watercourses that do not appear to be well supported by other lines of evidence, and it is worth commenting on these. One is a reported underground watercourse flowing from the covered Kidderpore Reservoir along Croft Way to Finchley Road. This is plausible as it is in the vicinity of a water reservoir, however evidence suggests this reservoir was not designed to collect local spring water but as storage for treated water pumped from elsewhere. It is plausible that the reservoir has an overflow pipe but this is likely to discharge directly to sewer rather than an underground watercourse. Engagement with Thames Water could confirm if the observations relate to a known asset. Historical maps do not show a watercourse in this area, rather wells and pumps which would indicate the water table is below the ground surface. Furthermore, topographic contours do not support a valley shape draining towards the main Cannon Stream.

In another example, an underground watercourse is reported to flow in a northwesterly direction beneath basements in the area between Finchley Road, Frognal Lane and Bracknell Gardens, to meet the Cannon Stream as it crosses the Finchley Road. As with the example above there is little other evidence from historical maps, local topography or documentary information to support the inference of an underground watercourse in this area. Topographic information indicates that this area is on a ridge of higher land between two small valleys – the Cannon Stream approximately 200 metres to the west, and a Westbourne headwater tributary 200 metres to the east.

It is possible that some formalised drainage channels were constructed as part of land drainage efforts for building foundations and gardens in and around the spring-line. It is possible that some observations of underground watercourses are of these drainage channels.

Verification of inferred underground watercourses requires a site investigation to further evaluate the source, nature, elevation and destination of the water. It is also important to note that, given the shallow depth to groundwater in much of this area, basement excavations may frequently reach the water table. As such, not all observations of running water through basements necessarily reflect the presence of an original surface water feature at that location – the stream channel may have initiated further down the hill slope, and the basement intercepted the water table further up the hillside.

All local knowledge and observations of underground water have been included in the mapping exercise, however only where additional evidence supports the observations are lines also updated with mark the best estimate of the locations of lost watercourses.

2.6 Review of Local Geology and Hydrogeology

The hydrogeology of London is well documented. Arup have been involved in a number of other projects in the area relating to hydrogeological impact of basements and prepared the guidance document for subterranean basement developments in Camden [10]. Geological maps, memoirs and other relevant documents were reviewed in order to provide a brief summary of the known hydrogeological conditions in the area. This summary is presented in Section 3.

3 Hydrogeology

3.1 Geology

A detailed description of the London Basin geology can be found in the British Geological Survey, Geology of London text [11]. The geological strata relevant to this study are those which are found at or close to the ground surface and are described in Table 2.

Geological Period	Group	Formations	Typical Thickness
Palaeogene	Thames	Bagshot Formation: fine grained-sand with thin clay beds	10 – 25m
		Claygate Member: alternating beds of clayey silt, silty clay, sandy silty and fine grained sand London Clay: Predominantly clay with some silty clay and claystone beds	90 – 130m

Table 2 Geological strata of relevance in the study area

The strata described in Table 2 were deposited in the Eocene period from around 55 to 49 million years ago (Ma). The Bagshot Formation and Claygate Member were both deposited in tidally influenced shallow marine waters. Both units contain fine grained sands however the Claygate member contains a greater proportion of silt and clay beds. The London Clay underneath predominantly comprises of clay material that was deposited in deep sea conditions.

The Bagshot Formation outcrops at the surface in the Hampstead Heath area which represents the highest ground in the Borough. Outcrop of the Bagshot Formation extends into the most northern part of the study area around Reddington Road and Rosecroft Avenue and also to the south of Oak Hill Park.

The Claygate Member outcrops over much of the north and central parts of the study area. The remainder is sited on the London Clay. The study area is now largely developed and it is expected that some areas may have Made Ground overlying the natural outcrop. Made Ground is typically highly variable in composition.

Figure 5 shows the distribution of geological strata outcrop in the study area. It should be noted that there is always some uncertainty with geological boundaries and they should not be taken as exact.

3.2 Groundwater

3.2.1 Background

Groundwater is the water present beneath the Earth's surface in soil pore spaces and in the fractures of rock formations. An aquifer is an underground water bearing rock or soil through which groundwater can flow and/or be extracted. All other things being equal groundwater will move through gravels and sands much easier than silts and clays due to the relative sizes of the pore spaces between individual grains.

The distinction between buried rivers, as a manmade feature, and natural groundwater flow in geological materials is an important distinction. At no location in the study area does groundwater in natural materials flow in the form of an underground river; it is only groundwater that has reached the surface and since been culverted and buried by the development of London that flows in this manner.

3.2.2 Groundwater in the study area

London is underlain by two aquifer systems; the deep Chalk aquifer which is present across the entire London Basin and a shallow superficial aquifer comprising of unconsolidated deposits. The shallow system includes the Bagshot Formation and Claygate Member as well as the River Terrace Deposits, and is variably distributed across London.

The two aquifers are hydraulically separated by the London Clay and lower permeability parts of the Lambeth Group. The lower aquifer comprises of the Chalk Formation, overlying Thanet Sand Formation and permeable parts of the lower Lambeth Group. The lower aquifer is located at significant depth in the study area (approximately 130m based on BGS well data).

The Claygate Member and Bagshot Formation form part of the shallow aquifer system. Precipitation landing on the open heathland of Hampstead Heath soaks into the soils and accumulates in the Bagshot Formation and sandier units of the Claygate Member below. The groundwater then flows radially away from the high ground toward the lower ground, discharging at springs located around the heath.

Spring lines typically occur at the junction of the Bagshot Sands and underlying clay units. The Claygate Member beneath the Bagshot Formation, which also contains sandy units can act as an aquifer, allowing groundwater to be transmitted through them. This geological complexity means that springs may occur at the boundary between the Bagshot Formation and Claygate Member, but also at the boundary between the Claygate Member and London Clay, and potentially anywhere in between depending on the local hydrogeological conditions.

The residence time of water in the Bagshot Formation and Claygate beds is likely to be short. The springs on the Heath tend to discharge in greater quantity during the winter and early spring when precipitation is greatest. During drier months the groundwater levels in the Bagshot Formation reduce and the spring discharge correspondingly decreases.

The geological boundaries between the Bagshot Formation and Claygate Member and Claygate Member and London Clay have been traced to indicate a zone of most likely spring discharge which is presented in Figure 6.

3.3 Hydrogeology and rivers

The rivers in the vicinity of Hampstead Heath, whether currently visible at the surface or concealed below ground, relate to the hydrogeology of the area. The geology, as described in the sections above, gives rise to a spring source at the surface where the permeable geology meets impermeable clays below. This springline circulates the Heath at approximately the 130 m contour line, but variations in the composition of the soils will result in springs being located within a range of this elevation. Over many thousands of years, the discharge of springwater can erode a surface channel and contribute a seasonally varying baseflow.

Rainwater also drains into the channels, further developing the shapes of tributary watercourses. Further downhill, the volume of water flowing into the river increases as the contributing catchment area increases and as tributaries merge together. The flow in these groundwater-fed rivers fluctuates with rainfall, but has a relatively steady baseflow component from the springs, which can fluctuate seasonally in response to weather patterns, longer term climatic changes, or even influenced by humans through pumping and other activities. In London, the groundwater-fed rivers would have met the River Thames in areas such as modern day Westminster. Prior to human settlement these areas would have resembled an open expanse of wetland marsh due to the flat topography and seasonal and tidally-influenced flooding from the Thames and its tributary rivers [5].

4 Mapping Results

The final map is shown on Figure 7 and the Google Earth based KML has been supplied with the report

The following provides a description of the major findings of this study.

4.1 Sources of River Westbourne

The River Westbourne, one of London's most famous lost rivers (also known at points along its length as the Kilbourne) rose from numerous springs and headwater streams on the western edge of Hampstead Heath. This study finds evidence that there are two major tributary headwaters of the Westbourne, which are located in the Redington Frognal area.

The Cannon Stream was a name given to the branch beginning at the former Branch Hill pond, which flowed down the route of the current Redington Gardens and Heath Drive, and was joined by minor spring-fed tributaries from near Blacket's Well (behind Rosecroft Avenue) and from Greenaway Gardens. These minor tributaries are likely to have been seasonally flowing and, by the turn of the industrial revolution, already modified somewhat for use as small field ditches or to form boundary hedgerows, and numerous small ponds marked on historical maps indicate that these were spring-fed ponds. The Cannon Stream then flowed beside Cannon Hill Street, which was named after the watercourse, before feeding ponds on West End. En route to modern Kilburn, this watercourse became known as the Kilbourne Stream.

The second main tributary branch rose in the grounds of Frognal Hall, off Frognal Lane. Illustrations show spring-fed ponds in the grounds, and historical maps show small streams draining the hillside, flowing south to meet the Cannon Stream near Kilburn.

With the development in this area, by the turn of the twentieth century the open watercourses, springs and ponds had mostly disappeared from the surface and were either placed into culverts or infilled.

4.2 Sources of the Rivers Tyburn and Fleet

Slightly beyond the extent of the Redington Frognal area are the spring sources of two of London's other famous lost rivers. In Hampstead centre, numerous wells and springs were exploited for drinking water and spas during the nineteenth century. These are clustered at some of the main headwater streams of the River Fleet, which drains towards the southeast, joining branches from the dammed spring ponds (now swimming ponds) on Hampstead Heath. The Whitestone Pond, itself a dew pond (an artificial pond, often lined with clay, to collect rainwater) and unlikely to be spring-fed at that elevation, may be considered to lie on the watershed between the Cannon Stream (Westbourne) catchment to the immediate southwest, and the River Fleet catchment to the east.

At the southern edge of the Redington Frognal area, Fitzjohn's Avenue is the location of the source of the River Tyburn. The Shepherd's Well was likely engineered by leading or piping springwater in the vicinity to a collection point. There is substantially more recorded about this well and system than has been recorded about wells and springs feeding the source of the Westbourne. Sources indicate that the stream flowing from the Shepherd's Well was exploited by forming a conduit to deliver this higher quality water to London (Figure 8).

4.3 Where are the waters now?

The Redington Frognal area once contained numerous small watercourses, fed by groundwater springs from Hampstead Heath. The many surface features such as ponds, and subsurface features such as wells show that water was close to the surface in this area.

Urban development has since concealed many of the open water features below the ground surface into pipes or culverts. Reports remain of wells, and of watercourses flowing through basements. Urban development often increases the elevation of the ground over time, such that these "buried" waters could once have originally been open surface water features. Furthermore, urban development often includes land drainage to lower the groundwater levels around foundations and in gardens. It is possible that groundwater levels relative to the ground surface have therefore fallen over time. Sustainable drainage systems (SUDS) which have become more prevalent in recent years may have offset this overall trend.

Water from streams and spring may now be flowing in the sewer network, which is a combined sewer system in this area (meaning that the sewers convey both wastewater and rainwater to the sewage treatment works). It was common practice during the early development of sewers to simply cover the watercourses that had become polluted open ditches, and use these as sewers. In such a case, the spring-fed waters would be ultimately flowing to the sewage treatment works rather than the River Thames. Alternatively, it is possible that there is a sub-network of surface water culverts or pipes that keep the waters separate from the sewer network - however, almost all of London's original lost rivers, streams and springs have now been converted into sewers.

5 Recommendations for Further Work

This study has been undertaken with reference to a limited search of relevant and freely available information accessible from the internet. There are many other sources of information that could be accessed by visiting archives and/or at some cost. The following will potentially house much primary and secondary archive source types relevant to the study objectives and may be consulted by the client to gather additional information:

- British Library – general and specific maps of many types, ages, scales and topographic detailing.
- Camden Local History Library/Hampstead local history museum/Metropolitan Archives – maps, books, reports, studies, parish records, LCC records, newspaper cuttings, prints and photographs, files of Metropolitan Board of Works and various archives of the City of London/Corporation of London (owners of Hampstead Heath).
- National Archives/Out of London Archives – maps, historical governmental records and private archives.
- Local Borough Council – engineering and planning records and expert knowledge of technical staff.
- Thames Water- engineering and planning records and expert knowledge of technical staff.
- Institution of Civil Engineers – books, reports and manuscripts on sewers and London drainage.
- Geological Society of London/Geological Survey of England – maps, books, reports, manuscripts, studies, field mapping reports and manuscripts.
- Historic England, Swindon – national air photographic archives

It is recommended that the outputs from the study are used to engage with Camden Council and Thames Water. Access to digital map data of the sewer network and of any minor watercourse culverts that are known would serve to improve the existing dataset. Reviewing the locations of springs and streams from this search with the location of sewers and culverts could indicate whether the water has been “captured” into the sewer network.

An analysis of sewer flow monitoring data or water chemistry [1] may be used to indicate the presence of clean baseflow in the sewer network. Where this occurs, there is reduced capacity in the sewer network for wastewater and for coping with heavy rainfall. Removing clean baseflow by uncovering and separating lost springs, watercourses (and rainwater) into surface water features could offer benefits to the water company. It may also lead to an overall reduction in risk from sewer overflow flooding to residents in the area.

The analysis could help to indicate if there are discrete spring inflow points to the sewer network at which separation may be feasible. The viability of separation and uncovering of buried streams and springs would also depend on their water quality. Naturally, many of the springs in this area of Hampstead Heath were chalybeate (iron-rich) waters. Shallow groundwater is vulnerable to urban pollution due to its proximity to the surface and the quality may need to be assessed.

Numerous cities have uncovered (or daylighted) lost rivers and streams that had been buried in culverts [12] [13]. This can often bring numerous enhancements to the environment, local amenity, aesthetic, flood risk and land value. Many cities are also exploring the adaptation of urban space from "grey" to "green" infrastructure. Sustainable drainage systems (SuDS) and rainscaping can introduce more naturalistic ways of managing surface water sustainably, both helping to reduce flood risk, improve water quality, and bring numerous wider social and economic benefits.

In order to restore buried watercourses to the surface there will be a number of challenges to overcome, including:

- Many of the watercourses may now be integrated with the combined sewer system, and the wastewater and clean water would need separating. This has been done in Zurich, Switzerland, but can be expensive and would need discussion with the water company about the relative merits of such a proposal.
- Restoring flowing watercourses to the surface may be difficult where they now flow at a considerable depth below the ground level – Made Ground and basements of urban development have distorted the original ground levels in the area.
- There are major space constraints, both for allowing safe and sufficient space for watercourses at the surface, but also providing a route for water to drain to downstream (there is a considerable distance to the nearest open river).

Given these restoration difficulties, it could instead be possible to incorporate natural ponds into gardens within the catchments of the identified lost watercourses as part of a sustainable drainage system. These ponds could be of benefit by providing attenuation of rainfall runoff that would otherwise flow straight into the combined sewers during a storm which could help to alleviate local capacity or flooding issues. In reality, it would be difficult at this stage to confirm or quantify any benefits of this, as it is highly dependent on location and suitable design. However, there is evidence that numerous ponds across the landscape have been covered or infilled, and there may be intrinsic, aesthetic and natural value in restoring some of these.

Further refinement to the topographic modelling may be made by utilising LIDAR data. The LIDAR data would need to be purchased at cost and any additional modelling may be undertaken outside of the scope of this work. This work is likely to strengthen the current results, however at present we do not expect that the results will be significantly different to justify the additional cost.

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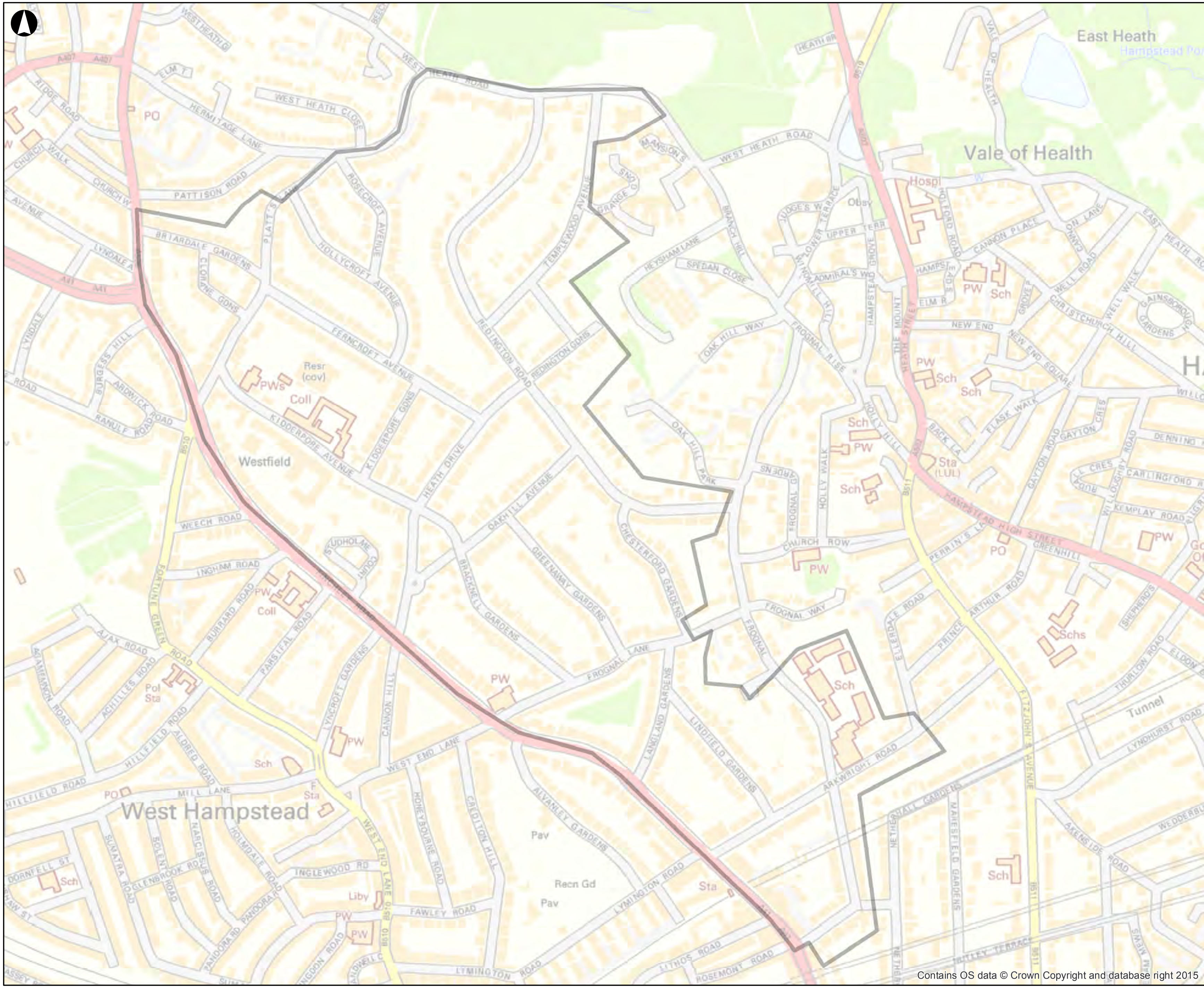
Figures

A3



Legend

Redfrog Plan Area

Issue	Date	By	Chkd	Appd
F1	2016-01-20	AB	JL	MC

Metres: 0 80 160 320

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Client
Redington Frognal Association

Job Title
RedFrog Hydrogeological Mapping

Redington Frognal Study Area

Scale at A3
1:6,000

Job No	Drawing Status
246648-00	For Issue

Drawing No	Issue
001	F1

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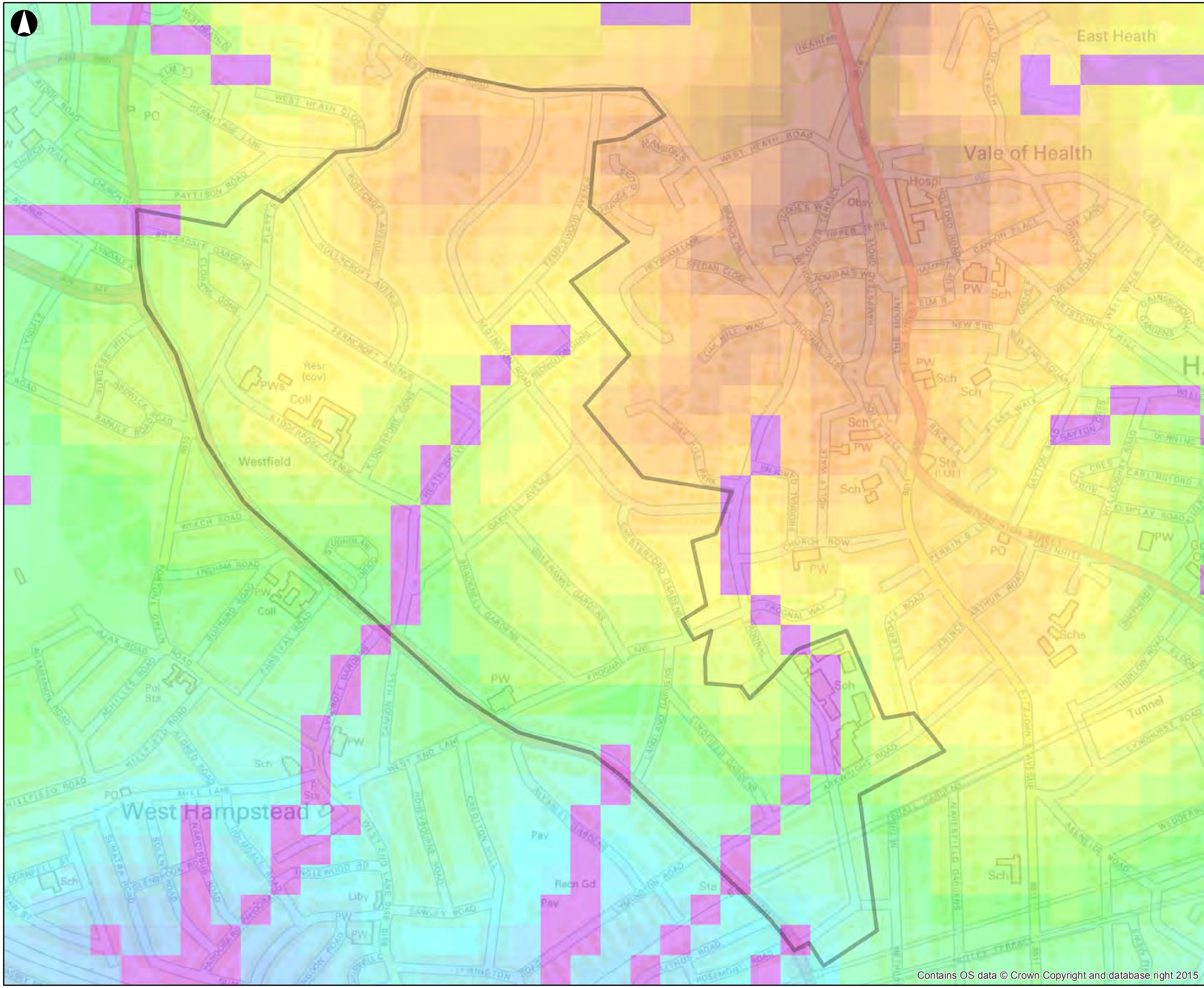
A3



Legend

- Redfrog Plan Area
- Modelled flowpath

OS Terrain50

Elevation (mAD)

High : 159.6

Low : -2.3

F1	2016-01-20	AB	JL	MC
Issue	Date	By	Chkd	Appd

Metres: 0 80 160 320

ARUP

Client
Redington Frognal Association

Job Title
RedFrog Hydrogeological Mapping

Flow path analysis results

Scale at A3 **1:6,000**

Job No	Drawing Status
246648-00	**For Issue**

Drawing No	Issue
002	**F1**

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http://media.vam.ac.uk/media/thira/collection_images/2006AR/2006AR0987.jpg

Red Frog Sub-surface Water Features Mapping
Constable painting of Whitestone Pond

ARUP

246648-00

FIGURE 3

http://www.theundergroundmap.com/image.html?id=2902

Red Frog Sub-surface Water Features Mapping
Illustration of Frognal Hall indicating a branch of the Westbourne

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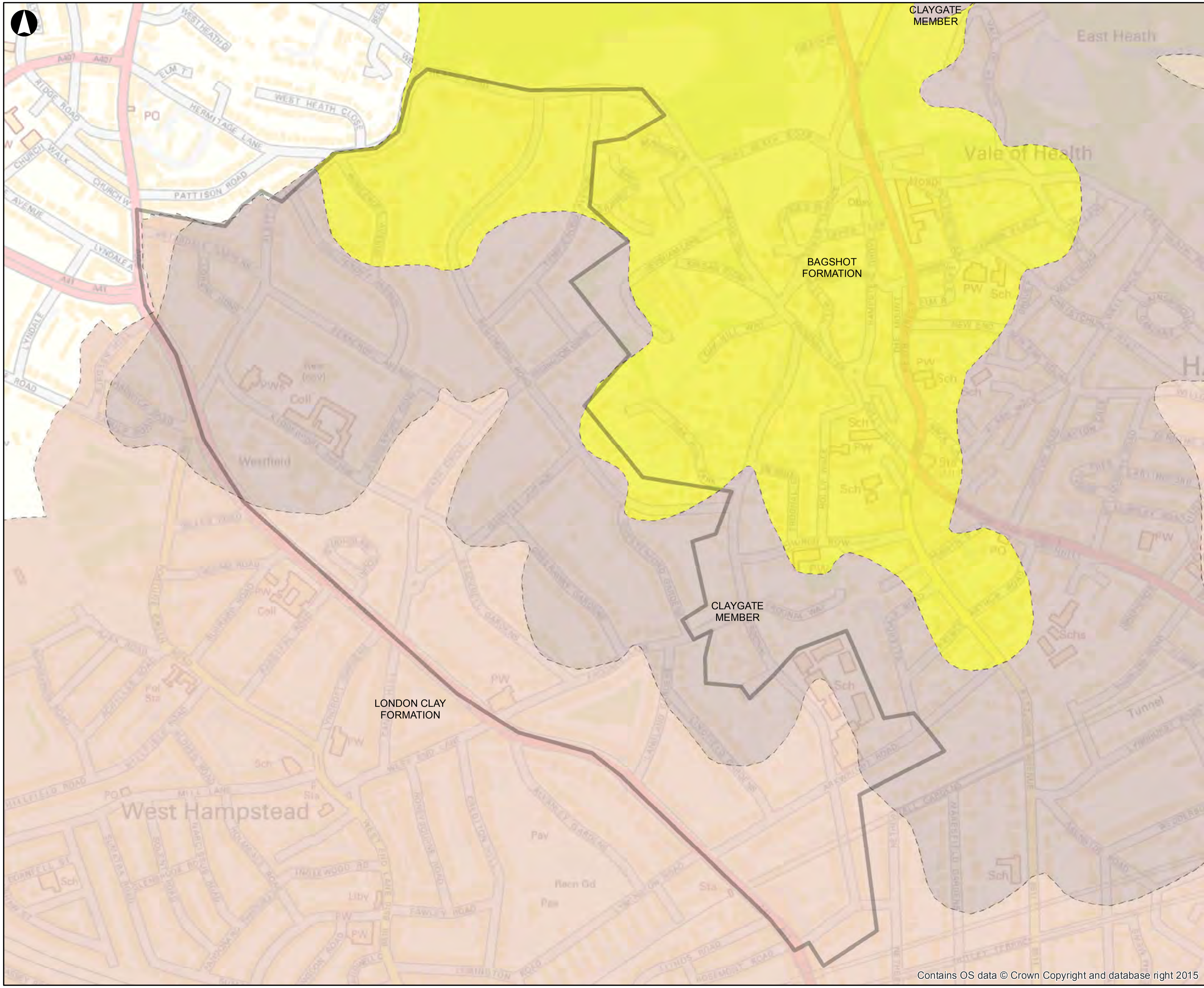
246648-00

FIGURE 4

A3



Legend

Redfrog Plan Area

BGS 1:10K Solid Geology

Geological Units

- BAGSHOT FORMATION
- CLAYGATE MEMBER
- LAMBETH GROUP
- LONDON CLAY FORMATION

Issue	Date	By	Chkd	Appd
F1	2016-01-20	JL	JL	MC

Metres: 0, 80, 160, 320

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Client
Redington Frognal Association

Job Title
RedFrog Hydrogeological Mapping

1:50,000 Scale Geological Map of the Study Area

Scale at A3
1:6,000

Job No **246648-00**
Drawing Status **For Issue**
Drawing No **005**
Issue **F1**

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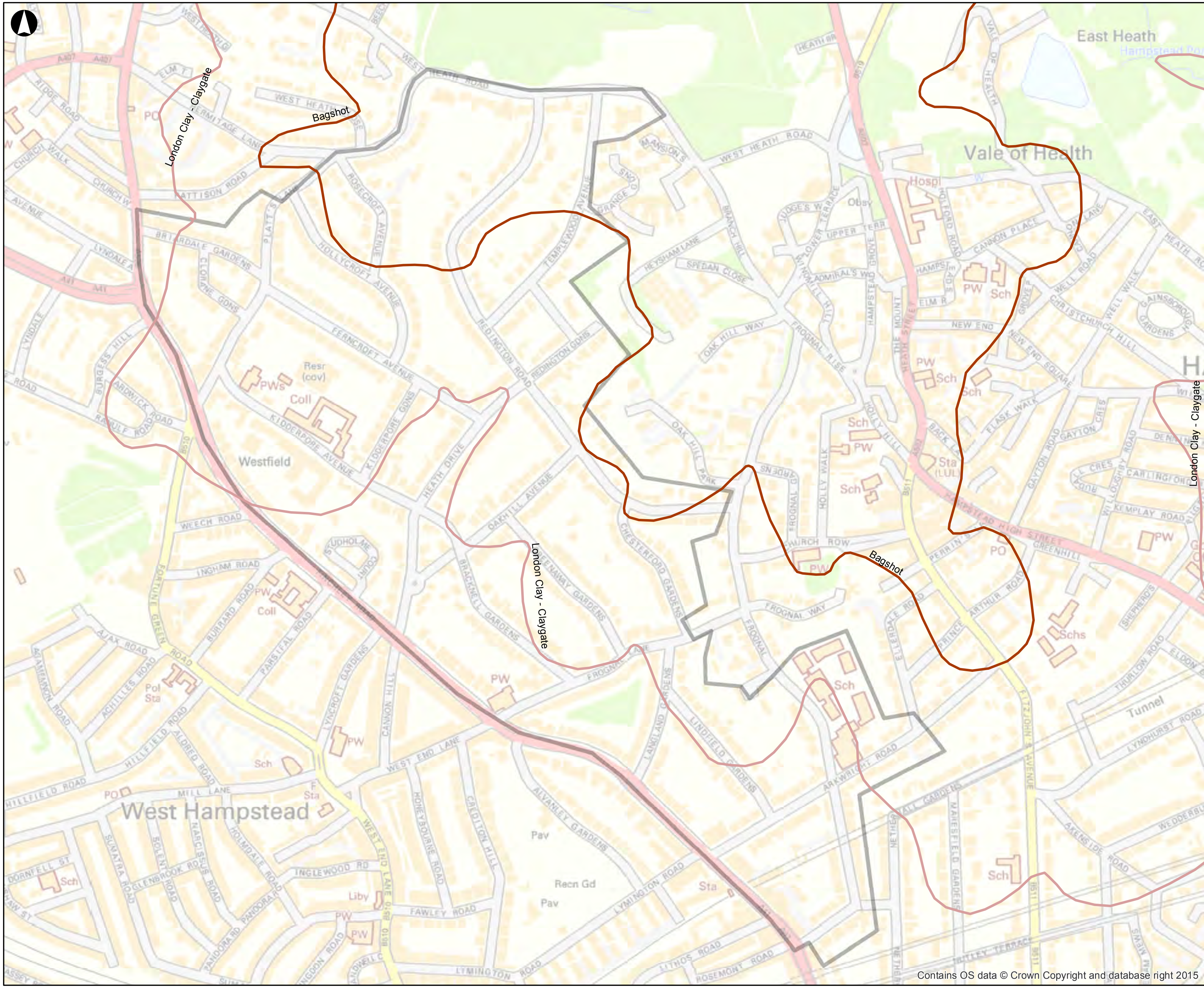
A3



Legend

Springlines

- Bagshot
- London Clay - Claygate
- Redfrog Plan Area

F1	2016-01-20	AB	JL	MC
Issue	Date	By	Chkd	Appd

Metres 0 80 160 320

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Client
Redington Frognal Association

Job Title
RedFrog Hydrogeological Mapping

Geological boundaries and indicative spring areas

Scale at A3
1:6,000

Job No **246648-00**
Drawing Status **For Issue**
Drawing No **006**
Issue **F1**

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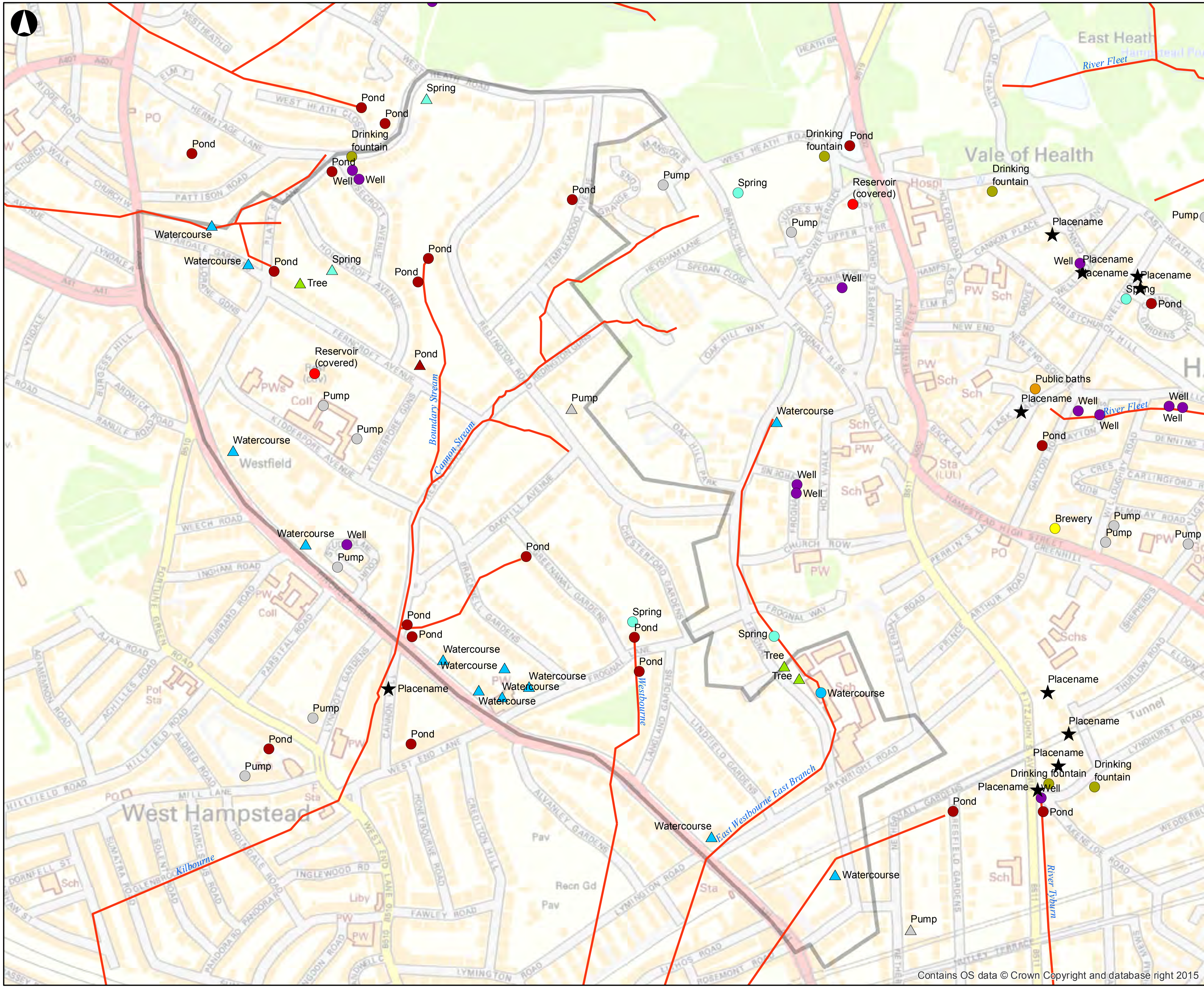
A3



Legend

Point water features

- Brewery
- Drinking fountain
- Placename (past or present)
- Pond
- Pond (Local Knowledge)
- Public baths
- Pump
- Pump (Local Knowledge)
- Reservoir (covered)
- Spring
- Spring (Local Knowledge)
- Tree (Local Knowledge)
- Watercourse
- Watercourse (Local Knowledge)
- Well

Line water features

- Watercourse network (best estimate)
- Redfrog Plan Area

Issue	Date	By	Chkd	Appd
F1	2016-01-20	AB	JL	MC

Metres: 0, 80, 160, 320

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Client
Redington Frognal Association

Job Title
RedFrog Hydrogeological Mapping

Results map

Scale at A3: **1:6,000**

Job No: **246648-00**
Drawing Status: **For Issue**
Drawing No: **007**
Issue: **F2**

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http://www.theundergroundmap.com/image.html?id=2961

Red Frog Sub-surface Water Features Mapping
Illustration showing Shepherd's Well

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FIGURE 8