DEVELOPING QUARRIES ON FLOODPLAINS – A CASE HISTORY

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Abstract

There is a geomorphological link between the deposition of sand and gravel deposits and the presence of major rivers and floodplains. The Oxfordshire Minerals and Waste Plan (Oxfordshire County Council, 1996) shows that the main deposits of sharp sand and gravel are found in the Thames and the Windrush valleys and that commonly the water table in these river valleys is usually near the surface.

Given the link between mineral deposits and floodplains, the development of quarries within floodplains cannot be avoided. Complexities relating to the development of such quarries relate to the impact of dewatering on sensitive receptors, water injection schemes to mitigate dewatering impacts, flood risk during operation and associated evacuation procedure, the interpretation of the impacts of the restoration materials on the groundwater flow regime and the potential for the restoration scheme to impact on flood risk as a consequence of changes in catchment storage.

Depending on the hydrogeological conceptual model and the presence of sensitive receptors, the scope of the interpretation of these risks may range between qualitative screening, scoping calculations or detailed numerical modelling.

This case study is of the hydrological and hydrogeological approaches taken in support of a planning application for the development of Tarmac's Caversham Area C extension area. The area is located in the catchment of the River Thames and predominantly within Flood Zone 3. The case study presents the complexity of assessing the development of the quarry and associated restoration with inert materials within a Flood Zone. Given the setting of the site, the sensitivity to the variation of groundwater level and the interpretation of the potential change in the impact of flooding were key factors that were quantified as part of the project.

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Introduction

Within Oxfordshire the most important minerals are aggregates (Oxfordshire County Council, 1996). The main deposits of sharp sand and gravel are found in the Thames and the Windrush valleys with less extensive deposits in the valleys of the Cherwell, Evenlode, Ock and Thame. Many deposits are in proximity to rivers and their floodplains and utilisation of this mineral requires development on those floodplains. Developable sites are typically agricultural with proximity to established residential settlements. Given these factors it is essential that flood risk of the operation and surroundings as a consequence of the development are managed.

Typically the water table is shallow and dewatering is required in order to work the mineral, therefore the impacts of dewatering on abstractions must be managed, and baseflow to dependant surface waters and archaeological features must be protected. It is also necessary to consider long term impacts from the restoration of workings: the potential for changes in groundwater elevation or direction from the baseline, and the potential for a change in the overall flood risk.

Site background

LafargeTarmac Ltd (subsequently Tarmac Ltd) commissioned Golder Associates (UK) Ltd to undertake an assessment of the potential hydrogeological and hydrological impact, including a flood risk assessment in support of a planning application for sand and gravel extraction in extension Area C of Caversham Quarry, near Reading in South Oxfordshire (shown on Figure 1) (Golder Associates, 2011). The proposed area of extraction comprises 33.5 hectares of agricultural land. It is bounded to the west by Spring Lane, to the south by agricultural land (beyond which lies village of Sonning Eye), and to the north by Berry Brook. The River Thames flows in a northeasterly direction to the east of the eastern boundary of the site.

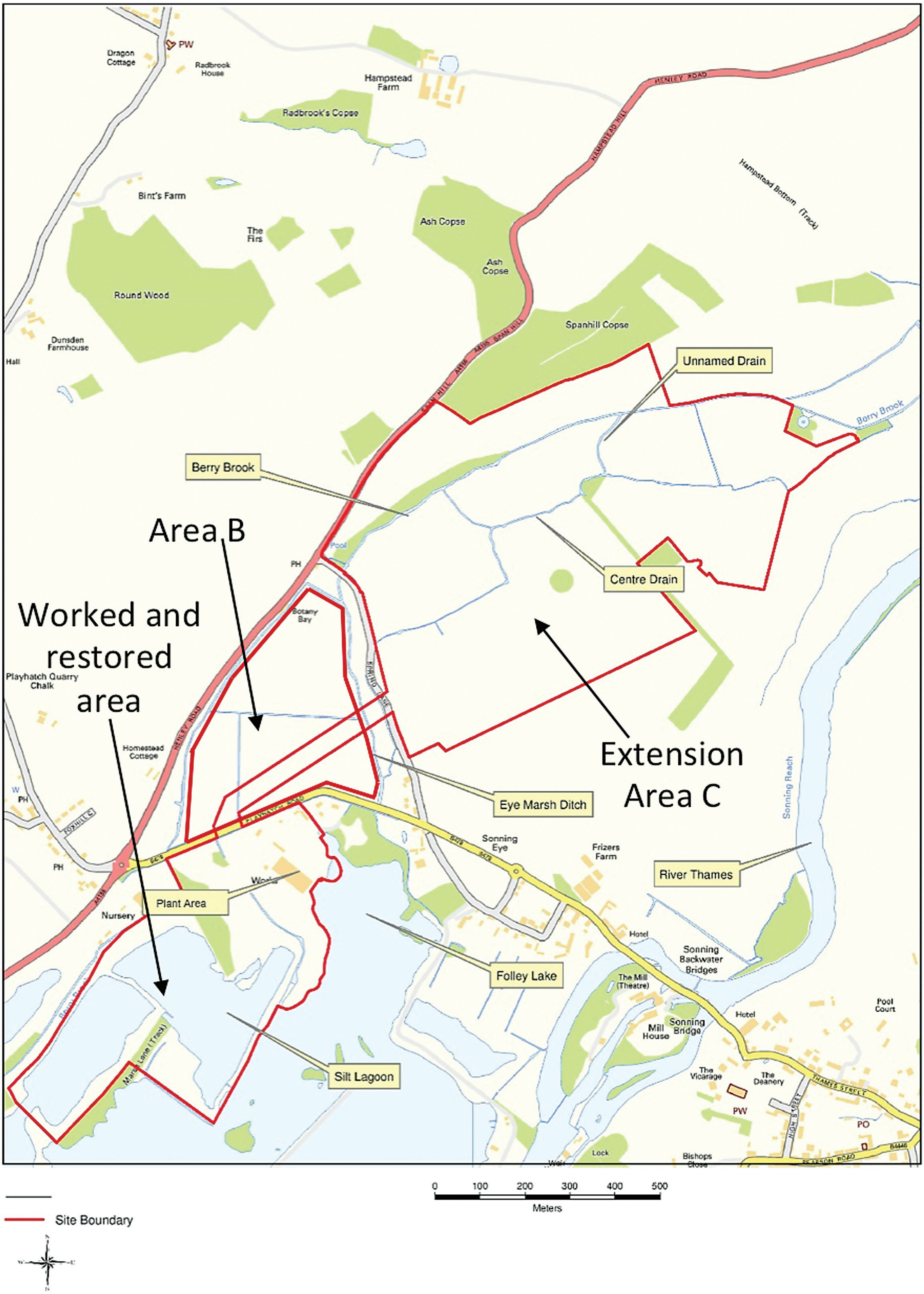

Figure 1. *Caversham Quarry and nearby surface waters.*

Tarmac Ltd proposes to extract 1.86 million tonnes of sand and gravel from extension Area C. The sand and gravel deposits will generally be worked dry. Following mineral extraction and during restoration the void will be dewatered to facilitate the placement of inert restoration materials. Working of Area C will progress in a phased approach, comprising 12 phases. During the operational period, it is anticipated that at each stage of the development, up to two phases will be actively extracted at any given time with one phase in the process of restoration, and a fourth phase under preparation (e.g. stripping overburden). Dewatering may therefore be undertaken from up to two active phases at any point during the works.

Restoration is proposed to be achieved through filling of parts of all phases with inert materials, and restoration of the northern part of the site to open water and wetland habitat.

Geology

The site is underlain by Quaternary drift deposits (loam and alluvium), beneath which lies the Cretaceous Upper Chalk. To the northwest and southeast of the site, the Chalk is overlain by Tertiary deposits; the Lambeth Group (Reading Beds) and London Clay. These units also outcrop on higher ground to the northeast. Drift deposits, predominantly comprising sand and gravel (Plateau Gravels), overlie bedrock in higher areas of ground across the wider area.

The drift, Quaternary Alluvium and the Langley Silt will be worked. The drift deposits comprise clayey and sandy silt, peat, silty sandy clay and sand and gravel. The mineral at the site ranges in thickness between c.1 to 6m with an average thickness in Area C of 3.8m.

Hydrogeology

The Chalk underlying the site is designated by the Environment Agency, as a Principal (Major) Aquifer, capable of supporting large abstractions for public supply or other purposes.

The majority of Area C is not located in a groundwater Source Protection Zone (SPZ), with the exception of the northeastern extent which lies in SPZ III (Total Catchment) of a public water supply abstraction located *c*.3km to the northeast. There are 23 licensed and 13 unlicensed groundwater abstractions within 2km of the site from the drift deposits and the Chalk.

The drift deposits and the Chalk at the site are water bearing and it is considered likely that groundwater in the drift deposits and the Chalk are in hydraulic continuity. Groundwater levels in the drift deposits have been monitored in six monitoring wells within Area C, approximately every month since 2004 (BH5-BH10) and since May 2012 in a further four monitoring wells (BH11-BH14), shown on Figure 2.

Based on the monitoring data groundwater levels in the drift deposits are typically 1.5m below ground level

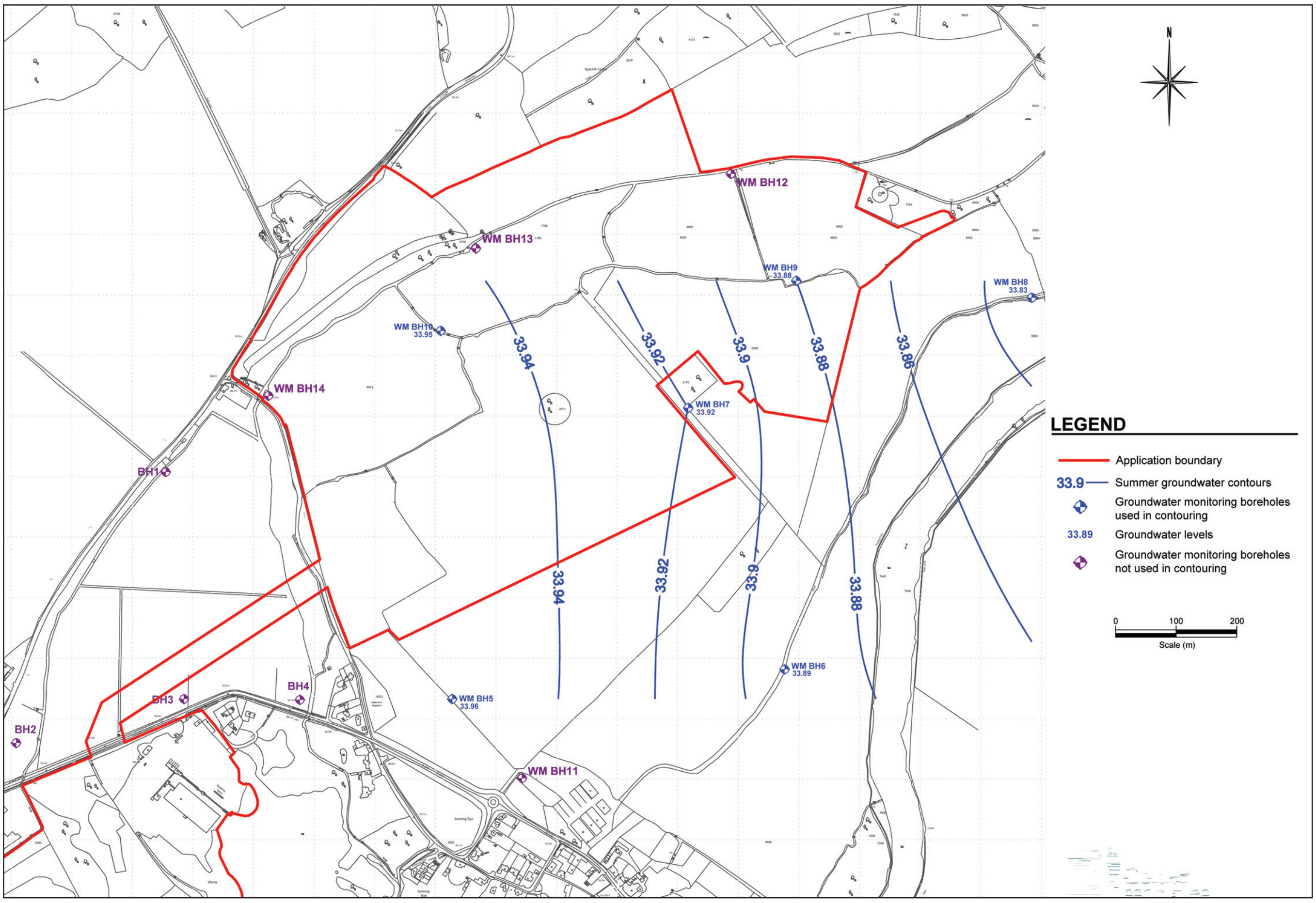

Figure 2. *Borehole and groundwater monitoring well locations, and summer groundwater level contours within extension Area C, indicating a flow direction to the east.*

(mbgl), in the range of approximately 33m Above Ordnance Datum (mAOD) to approximately 35mAOD with a seasonal fluctuation of between c.1-1.5m. Groundwater levels increase to close to ground level during periods of winter flood. The direction of groundwater flow is towards the River Thames in the east (Figure 2).

Hydrology

The site is located in the catchment of the River Thames which, in the vicinity of the site, flows towards the northeast and is c.200m southeast of the extraction area at its closest point (Figure 1). The Berry Brook which is a tributary of the River Thames flows to the northeast adjacent to part of the northern boundary of the site and enters the River Thames c.1km northeast of the site. The Eye Marsh Ditch, which is a tributary of the Berry Brook, flows to the north and is located c.50m west of the western edge of the site and joins the Berry Brook close to the northwestern boundary of the site. Folley Lake, which was formed by the flooding of former sand and gravel workings, is situated c.200m southwest of the site.

A relatively large proportion of the site is susceptible to flooding in a 20% (1 in 5) design event due to flooding from the River Thames, and for this reason the site is categorised as Zone 3b Functional Floodplain in the National Planning Policy Framework (NPPF) planning terms, (Department for Communities and Local Government, 2012).

Hydrological And Hydrogeological Impact Assessment

To maintain dry workings, dewatering in the active phase(s) will take place to an elevation equivalent to the base of the drift deposits but will not extend in to the Chalk. Mitigation of drawdown outside of the development is proposed through the discharge of pumped groundwater to the Berry Brook and the Eye Marsh Ditch.

The purpose of the assessment was to determine potential impacts of dewatering Caversham Quarry Area C upon groundwater levels in the drift in the vicinity of the site, and upon nearby groundwater and surface water receptors. The assessment was also to consider potential effects on groundwater flow following restoration of the quarry void with imported inert fill materials. In order to ascertain the conceptual model understanding of groundwater level and flow direction, the background groundwater elevations were measured and analysed.

Dewatering effect from other extraction areas

Dewatering of Area B, adjacent and to the west of Area C (Figure 1) was undertaken between 2010 and 2012 to facilitate the working of material. The water was pumped to Berry Brook and Eye Marsh Drain. Monitoring data prior to the dewatering of Area B and remote from that influence of dewatering were used to ascertain the natural range of seasonal variation in groundwater levels. Boreholes BH1 to BH4 located within Area B (all 325m or less from the point of pumping) were influenced by dewatering, with a drawdown of up to 2m in BH2, 1.5m in boreholes BH1 and BH3 and c.1m in BH4. The variation in drawdown is interpreted to relate to the proximity to the points of discharge to pumped groundwater and the availability of recharge.

Beyond Area B a limited response to dewatering was observed with no response observed beyond 623m from the dewatering sump. Beyond this radius the hydrograph responses were similar to the background response and hence could be assessed to be effectively at or beyond the range of influence of de-watering.

Calculation of Theoretical Radius of Influence and Estimated Flow Volumes

A first order assessment of the radius of influence and flow volume associated with dewatering Area C was calculated using the Marinelli and Niccoli (2000) methodology, as presented in the Environment Agency (EA) published Tier 1 Groundwater Analytical Equation Tool (EA, 2007). The assessment considered the influence of dewatering associated with simultaneous operation of two phases located in the western site area with a combined area of 61,030m^2. The phases are considered the most sensitive part of the working area due to their proximity to Berry Brook passing along the northern site boundary, the Eye Marsh Ditch passing along the western boundary and the proximity to residences close to the western boundary. Dewatering would occur to the base of the drift deposits but would not extend into the underlying Chalk.

The assessment indicated a radius of influence from dewatering, under steady state conditions of c.485m from the quarry void, with an estimated inflow of approximately 92,940m^3/d. This estimate is considered likely to overestimate the radius of influence of the abstraction because the calculation does not consider the effect of short-circuiting recharge via the Berry Brook and the on-site groundwater recharge lagoon, which is likely to act to mitigate the impact of dewatering at greater distance north of the site.

Mitigating measures with regard to sensitive receptors such as archaeological remains were put in place with the setting of trigger levels for groundwater elevation in monitoring boreholes based on the long term background monitoring record. An action plan was put in to place with the specification design for recharge trenches in the event of a discernible reduction in groundwater elevation at these sensitive receptors.

Assessment of the effect on groundwater flow of inert restoration materials

Restoration of the site will be achieved by the importation of inert materials. An assessment of the effect of restoration with inert fill materials upon the groundwater flow regime and groundwater levels in the site vicinity was undertaken using a MODFLOW groundwater model.

A comparison of calculated groundwater levels for the pre-development and post-restoration scenarios is presented In Figure 3.

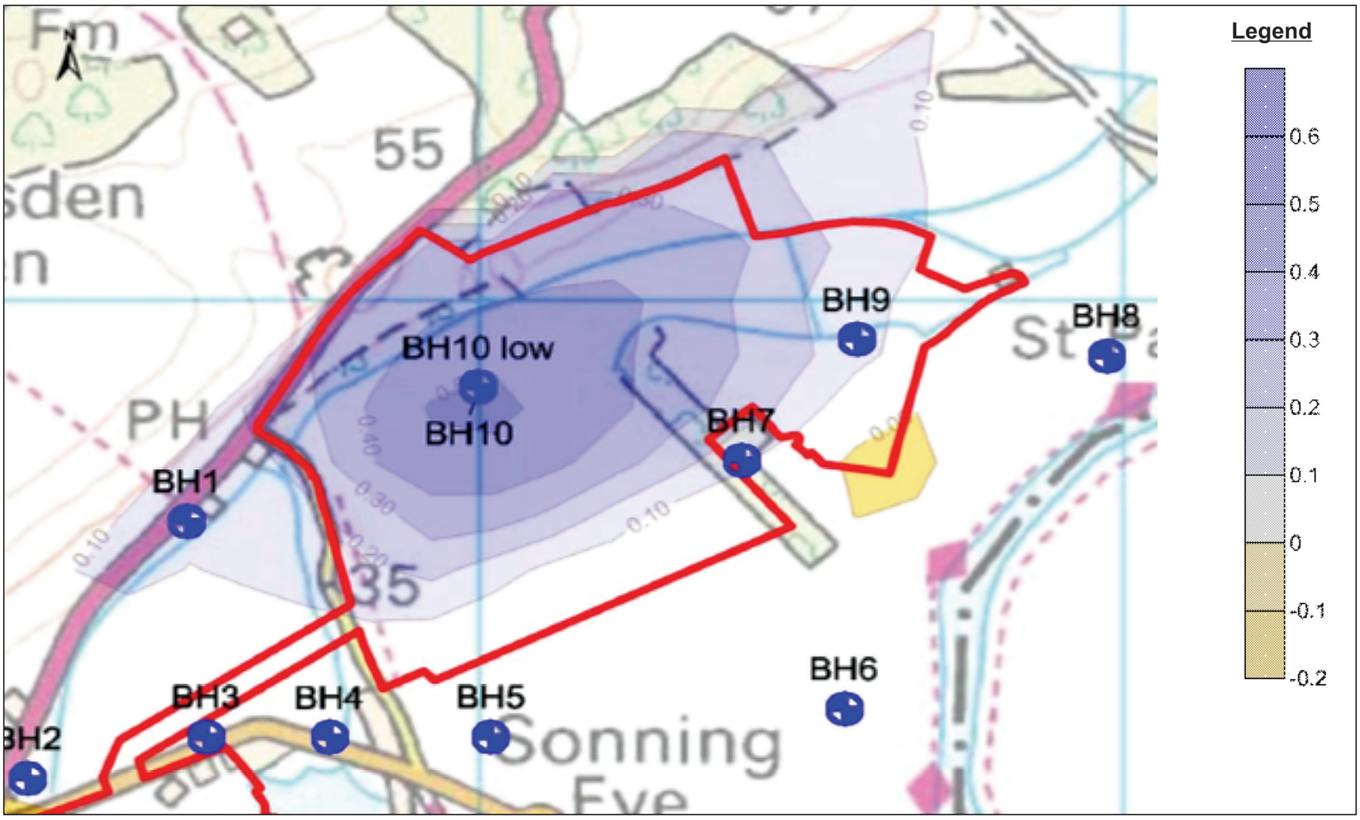

Figure 3. *Outcome of MODFLOW interpretation showing the elevation of groundwater levels post-restoration above the pre-development, calculated groundwater levels in the sand and gravel in extension Area C (relative change in metres).*

It was calculated that restoration of the site may result in an increase in water table elevation to a peak level of approximately 0.5m above pre-development levels localised within the inert material in the site centre. There will be no significant changes in groundwater levels external to the site.

No buildings are located within the area with a greater than 0.1m change in water table elevation. A slight increase in groundwater level beneath the Berry Brook is indicated, potentially resulting in a slightly increased groundwater discharge to the brook.

A comparison of flow paths for pre-development and post-restoration scenarios are presented on Figure 4 to 7.

Particle flow pathlines simulated in the MODFLOW model and groundwater level contours suggest that in the sand and gravel horizon, the effect of restoration at the site is to divert flow on the southwestern boundary, south toward Folly Lake, and from there to the River Thames (Figure 5). This point of discharge to surface water is upstream of the current discharge point (Figure 4). The change in flow is not considered likely to have any detrimental impact on surface water receptors.

Flow pathlines simulated in the Chalk indicate that in the pre-development scenario (Figure 6), lateral flow occurs to the margin of Berry Brook, where discharge into the brook at shallow depth results in upward flow within the Chalk. From this point, groundwater either discharges to the Berry Brook (in 40% of the particles simulated) or flow continues laterally in the sand and gravel horizon to the River Thames (in 60% of the particles simulated).

In the post-development scenario (Figure 7), the presence of lower permeability material results in increased upward flow into Berry Brook and an increase in groundwater discharge from the Chalk into the Brook (c.80% of flow pathlines based on those simulated). Although less groundwater flows beneath the site into the River Thames in a c.300m zone immediately east of the site, the flow will continue and reach the Thames c.1km downstream via Berry Brook. There will be no overall change in the rate of groundwater discharge to the Thames.

Based on the calculated groundwater heads and flow pathlines, restoration of part of Area C with inert fill material is not considered likely to have an adverse effect on receptors potentially sensitive to groundwater level or flow changes (surface water or properties) in the vicinity of the site.

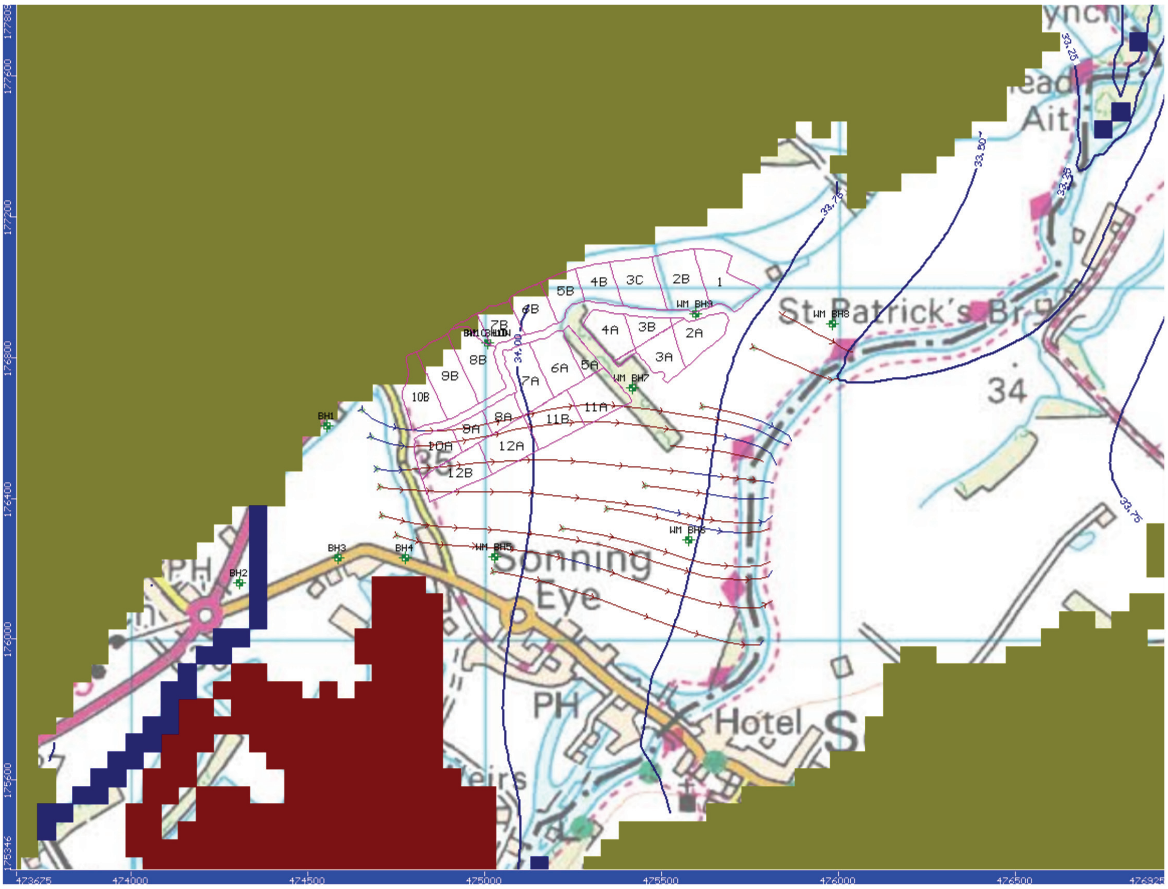

Figure 4. *Pre-development scenario: groundwater flow paths in the sand and gravel, shown in relation to the extraction phases (green cells = dry condition; red cells = constant head boundary, Folley Lake; blue lines = groundwater level contours; red lines with arrows = particle flow pathlines; pink cell boundary lines = extraction phases within Area C).*

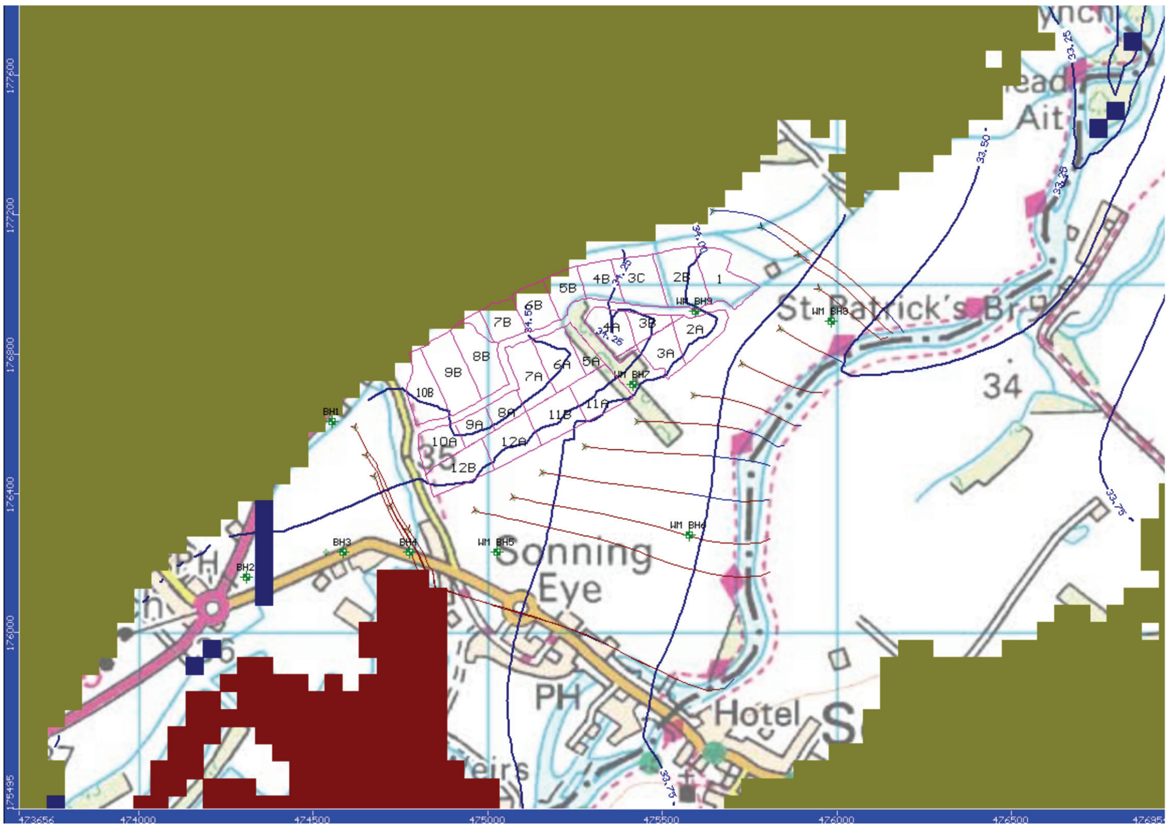

Figure 5. *Post-development scenario groundwater flow paths in the inert fill shown in relation to the extraction phases. (green cells = dry; red cells = constant head boundary, Folley Lake; blue lines = groundwater level contours; red lines with arrows = particle flow pathlines; pink cell boundary lines = extraction phases within Area C).*

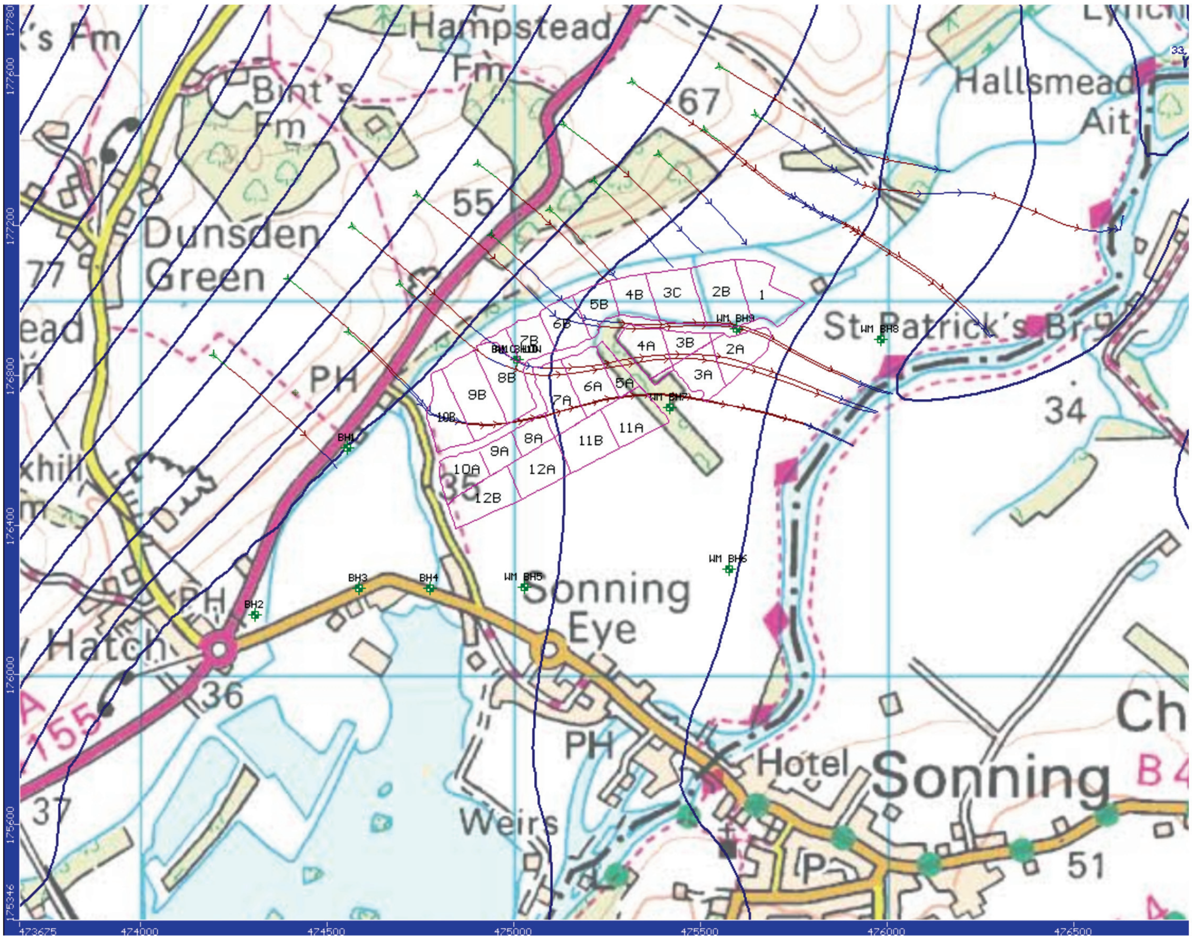

Figure 6. *Pre-development scenario groundwater flow paths in the chalk shown in relation to the extraction phases. (blue lines = groundwater level contours; red lines with arrows = particle flow pathlines; pink cell boundary lines = extraction phases within Area C).*

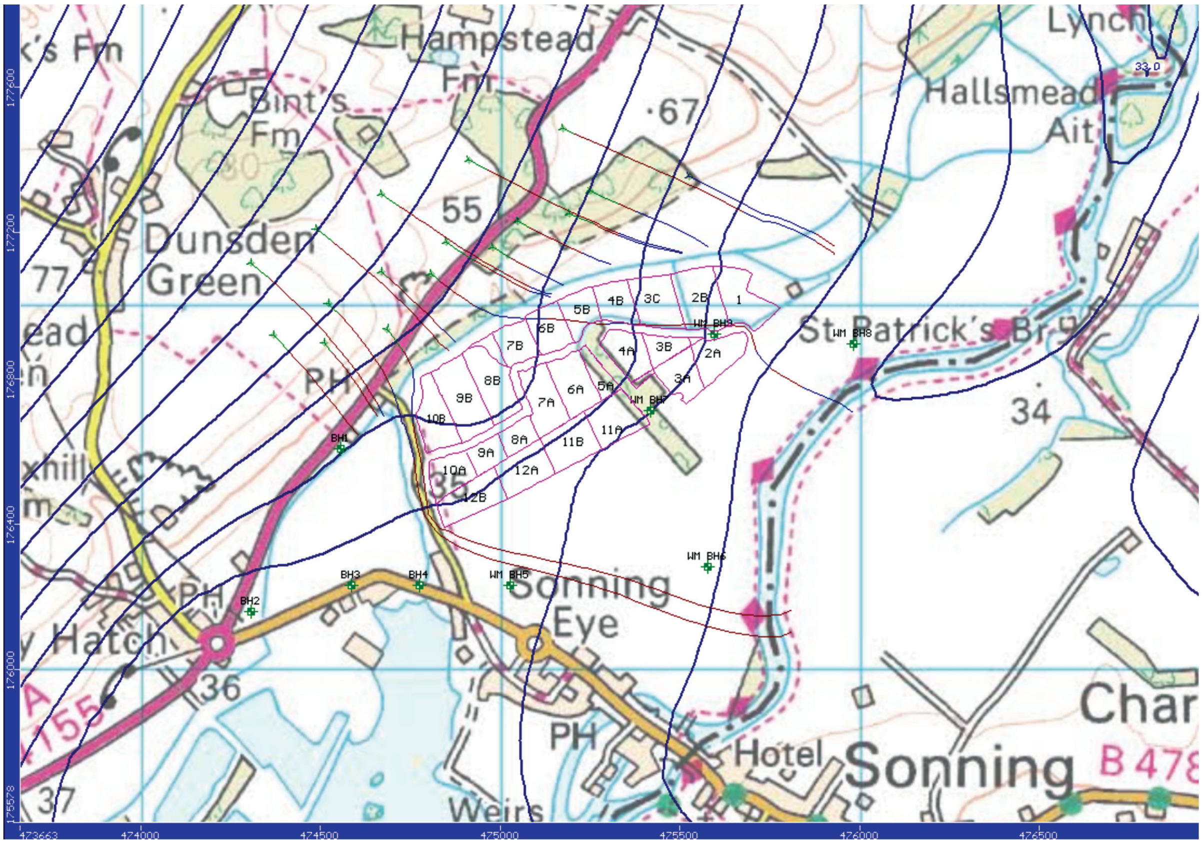

Figure 7. *Post-development scenario groundwater flow paths in the chalk shown in relation to the extraction phases. (blue lines = groundwater level contours; red lines with arrows = particle flow pathlines; pink cell boundary lines = extraction phases within Area C).*

Flood Risk Assessment

A detailed Flood Risk Assessment (FRA) was carried out in accordance with the NPPF which categorises the proposed development as 'water compatible development', and is therefore appropriate in areas that are susceptible to relatively frequent flooding. It is essential however to ensure that the risk of flooding, both to the operation itself, and to the surrounding area as a result of the proposed development, is managed effectively and sustainably.

The EA has carried out detailed modelling of the Zone 3b Functional Floodplain in proximity to the River Thames and Berry Brook

Historical flood maps indicate that the site (and much of the surrounding area) was entirely flooded during flood events in 1947 and 2003, and that the northern portion of the area within the application boundary was also flooded during flood events in 1974, 1977, 2000 and 2007. Anecdotal information from site personnel working at the adjacent operational quarry area (Caversham Quarry Area B) indicates that the area is prone to relatively frequent flooding (every few years).

The FRA considered the influence of the development on floodplain storage at each stage of the development (Table 1). The result of the assessment was that flood plain storage at each stage and elevation is unchanged or increased.

The FRA also considered the influence of the related plant area (Figure 1) on floodplain storage. An assessment of the proposed scheme is summarised in Table 2. A minor reduction of flood plain storage was identified within the plant area. This has been mitigated by the development of a compensatory (low level) storage area, also in the plant area (Figure 8).

Operational management impact on flood risk

It has been demonstrated that the development will provide a net increase in flood storage, however, there is a risk that soil storage bunds could impede flood flows. It is not possible to position these bunds outside of the areas that are at risk of flooding, and hence the orientation of the bunds has been arranged parallel to the flow to minimise any potential disruption to overland flow paths.

The proposed conveyor will transport material from the extraction area in the northeast to the processing plant in the southwest, mirroring the general direction of flood flows across the site. To minimise the potential risk of any obstruction to flow, the conveyor will be situated on a raised steel truss.

The site is currently an agricultural area and there are no known issues of flooding associated with surface water runoff within the site (and/or the surrounding

Elevation (mAOD)	Additional Storage (m^3), above existing — Development phase				
	At end of Phase 1	At end of Phase 3	At end of Phase 6	At end of Phase 12	Post restoration
34.7	116,468	177,855	210,180	162,235	49,990
34.9	115,184	173,047	130,389	255,496	75,163
35.1	113,119	168,433	187,481	262,267	77,828
35.3	112,088	168,414	188,881	270,270	79,734
35.45	110,722	169,885	192,284	278,169	80,906
35.6	109,906	171,786	197,018	282,584	81,551
35.8	107,154	173,047	218,058	285,379	82,535

Table 1. *Assessment of flood plain storage at Caversham Area C.*

Elevation (mAOD)	Volume of storage lost (m^3)	Cumulative volume lost (m^3)	Mitigation - volume of storage (m^3)	Mitigation - cumulative volume (m^3)
35.5 - 35.6	4	4	4	4
35.6 - 35.7	6	10	6	10
35.7 - 35.8	8	18	8	18
35.8 - 35.9	12	30	12	30
35.9 - 36.0	20	50	20	50
36.0 - 36.1	26	76	26	76
36.1 - 36.2	40	116	40	116
36.2 - 36.3	50	166	50	166
36.3 - 36.35	40	206	40	206

Table 2. *Assessment of flood plain storage for the plant area.*

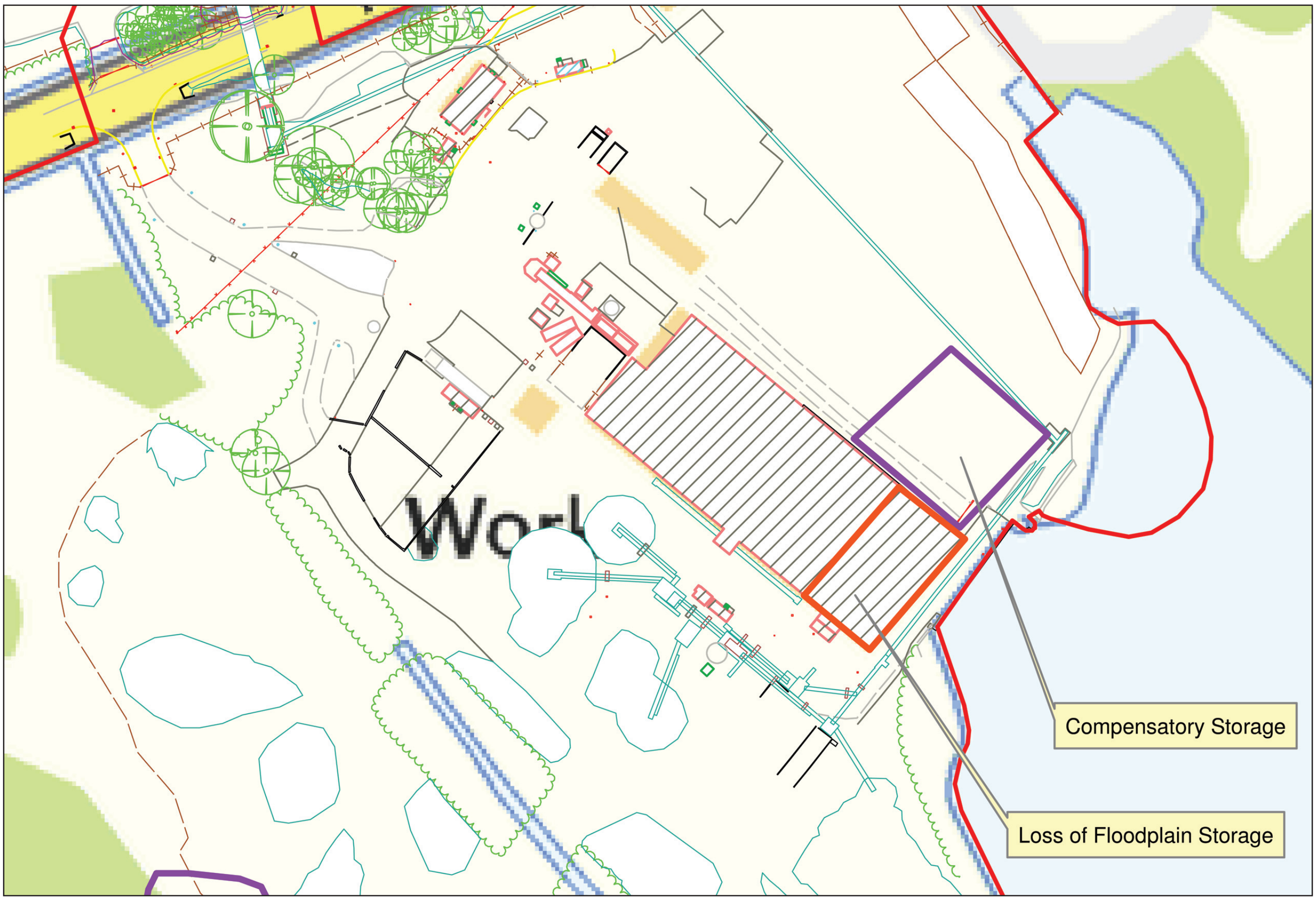

Figure 8. *Plant area; compensatory flood storage (the location of the plant area is shown on Figure 1).*

area). Nevertheless, the proposed access road will increase the extent of hardstanding and will therefore lead to an increase in surface water runoff. The increase in the area of hardstanding within the site will be c.8,680m^2, resulting in an increase in the volume of runoff during a 1% Annual Exceedance Probability (AEP) plus climate change (20%) rainfall event of c.1,069m^3. The release of runoff from the site must be restricted to the Greenfield runoff rate, estimated to be 0.4l/s/ha. Appropriate water management infrastructure has been specified in order to manage the release of runoff from the site.

Summary

An assessment of the hydrogeological and hydrological impact of a proposed quarry development at Caversham Area C has been undertaken.

An assessment of the potential radius of influence and pumping volume associated with dewatering of the working area of the quarry indicates the radius of influence to be approximately 485m from the quarry void, with an estimated inflow of approximately 92,940m^3/d. However, the methodology used to undertake this calculation is likely to overestimate the radius of influence of the abstraction because it does not consider the effect of short-circuiting recharge via the Berry Brook and the on-site groundwater recharge lagoon, which is likely to act to mitigate the impact of dewatering at greater distance north of the site.

The inert restoration has the potential to affect groundwater levels. A groundwater flow model indicated that changes in water table elevation will be localised to the site and will not extend significantly into the wider Thames flood plain. A slight increase in groundwater levels in the sand and gravel and Chalk aquifers beneath Berry Brook may increase flow in the Brook, however it is considered that this will not lead to any detrimental impact on either the Berry Brook or River Thames. The assessment considered the potential impact of the development upon flows in surface water courses in the vicinity of the site. During operational phases, abstracted groundwater will be directed to surface water courses as required to augment flows, following settlement in appropriately located lagoons. As groundwater will be re-circulated in this manner, it is considered that quarrying activities are not likely to adversely impact flows in surface water courses in close proximity to the site. Review of historic water level data for the Berry Brook and the Eye Marsh Drain indicates that this is already happening in relation to dewatering of previous phases of sand and gravel extraction.

The proposed water compatible sand and gravel workings, located in Flood Zone 3, are considered appropriate in accordance with the NPPF. A number of mitigation measures have been carefully established and incorporated into the phased development of the site to ensure that the potential impact upon the existing fluvial and surface water flooding regime is in no way worsened. These will also ensure that the risks of flooding to the proposed operations (and operators) will be managed safely throughout the lifetime of the development. There will be no impact on flood risk due to the use of inert restoration materials as flood dissipation is principally by overland flow rather than infiltration.

The proposed restoration of the site will deliver a net increase in the available floodplain storage volume for the region.

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