Sixfields, Harvey Reeves Road and Ransome Road landfill sites redevelopment

STEVE BALL[1], EMMA HILL[2] & HELEN MORGAN[3]

[1] *English Partnerships. (e-mail: steveball@englishpartnerships.co.uk)*
[2] *Halcrow Group Ltd. (e-mail: hille@halcrow.com)*
[3] *Scott Wilson (formerly Halcrow Group Ltd.) (e-mail: helen.morgan@scottwilson.com)*

Abstract: Northampton is within one of four major growth areas identified in the Government's "Sustainable Communities Plan" of 2003. The two former landfill sites of Sixfields and Harvey Reeves Road were identified as key areas for development, being close to Northampton Rugby Football Club and Northampton Town Football Club. Ransome Road landfill was identified for redevelopment for mainly residential purposes. This paper will discuss the geological and environmental influences on the redevelopment from design to construction.

Prior to the Master Plan being determined the constraints were identified; a major consideration being the ground conditions and environmental security of the sites. Former partial development of the Sixfields site involved the removal of landfill material beneath the plot of a stadium and the provision of access roads, which have suffered from uneven settlements.

A new link road (the Southern Development Link Road) was constructed across two of the landfill sites. Follow-on development of the land adjacent to this new road included car parks for the rugby and football clubs, a new recycling centre, a new bus depot and employment land. These additional uses allowed the translocation of existing businesses from other sites in Northampton, thus enabling redevelopment of those sites.

Remediation of the sites was required to protect the local surface and groundwater from landfill leachate, and adjacent properties from landfill gas. The remediation took the form of permeable reactive barriers with passive barriers to channel the groundwater flow to the reactive sections of the wall. Gas vent trenches were installed and the existing capping was enhanced.

Load trials were undertaken on the landfill deposits and systems of ground improvement determined for the formation to roads and car parks.

The above designs were integrated with the differing requirements of interested third parties, including Government regulatory agencies, wildlife trusts, archaeologists, flood protection, etc.

Résumé: Northampton çe trouve dans les quattre régions de croissance identifiées dans le 'sustainable communities plan de 2003.' Les deux emplacements de déchets à Sixfields et Harvey Grieves Road ont éeé identifiées comme régions de cléfs pour le development parcequ'ils sont situées au proximité etroite du Northampton Clubs de Rugby et de football. L'emplacement de déchet a Ransome Road a été identifiée pour le redevelopement a but résidential. Cette papier va discuter les influences géologiques et de l'ambiant de la conception jusqu'a la construction.

Avant de determiner le 'Master Plan' on a examiné les contraintes: une considération principale etait l'état du sol et l'état de sécurité environmental des cites. Une dévelopment partiel precedente de Sixfields a impliqué le deplacement de materiaux dechets sous la cite d'une stade et la provision de routes d'access qui ont soufferts en raison de tassement inégal du sol.

Une nouvelle route de lien (Southern Development Link Road) a été construite sur deux emplacements de déchet. Dévelopment suivant du sol adjacent a la nouvelle route a inclus la formation du parking pour les clubs de rugby et de football, une centre nouvelle pour le récyclage, un dépôt d'autobuses et une emplacement pour le development commercial. Ces usages additionelles permettaient la translocation des entrepreises existantes , d'autres emplacements a Northampton et ainsi permettant le redevelopement de ces emplacements.

Rémédiation des emplacements etait nécessaire pour la protection de l'eau du sol contre lixiviate et pour la protection de bâtiments dans le vicinity contre flux de gaz. Rémédiation a pris la forme de barrières réactives perméables avec barrières passives pour diriger l'eau jusqu'aux sections réactives du mur. Des fossés de passage de gaz ont été installées et couvrtures existantes ont été augmentées.

Les épreuves ont été entreprises sur les dépôts de déchet et une système pour améliorer l'état du sol pour le formation de routes et de parking.

Les conceptions ce dessus ont été integrée avec des conditions différentes des tiers inclus les agences régulatrices de gouvernements, confiances de la vie sauvage, archéologistes, protection contre les inandacions.

Keywords: landfill, groundwater contamination, remediation, settlement, compaction, gases

INTRODUCTION

The Government's Sustainable Communities Plan identified Milton Keynes and South Midlands as a major growth area, which is likely to provide 370,000 more new homes by 2031. Northampton is included within this growth area and Northampton Borough Council was able to secure £17.1m of funding for enabling housing provision, facilitating infrastructure provision and land acquisition. However the grant required that all major infrastructure be developed by April 2006.

In September 2002 English Partnerships and Northampton Borough Council signed a joint agreement, the Northampton Brownfield Initiative, to develop brownfield sites in Northampton. Three sites (Sixfields, Harvey Reeves Road and Ransome Road) were identified for early action. The three sites are located in the valley of the River Nene and contain a total of about 97ha (240 acres) of derelict, vacant and underused land (Figure 1).

The aim of the Northampton Brownfield Initiative is to remediate and redevelop these three sites to create homes, jobs and leisure opportunities for the local area.

Halcrow Group Ltd was appointed in September 2002 to carry out a Stage 1 Feasibility Study and Framework Plan for the three sites. The Stage 1 report provided a strategy for the development of the sites and identified the need for ground investigation work to assess the extent of contamination and to enable groundwater modelling and quantitative risk assessments to be carried out. Consequently ground investigation work was undertaken at the three sites during 2003 and 2004. The results of this work enabled the design of ground remediation to address the potential contamination and geotechnical issues at the sites.

This paper summarises the findings of the ground investigations, the ground remediation and the geotechnical ground improvement methods which will allow the redevelopment of the sites. The paper first discusses the work undertaken at the Sixfields and Harvey Reeves Road sites and finishes with a discussion of the proposed and ongoing works for the Ransome Road site.

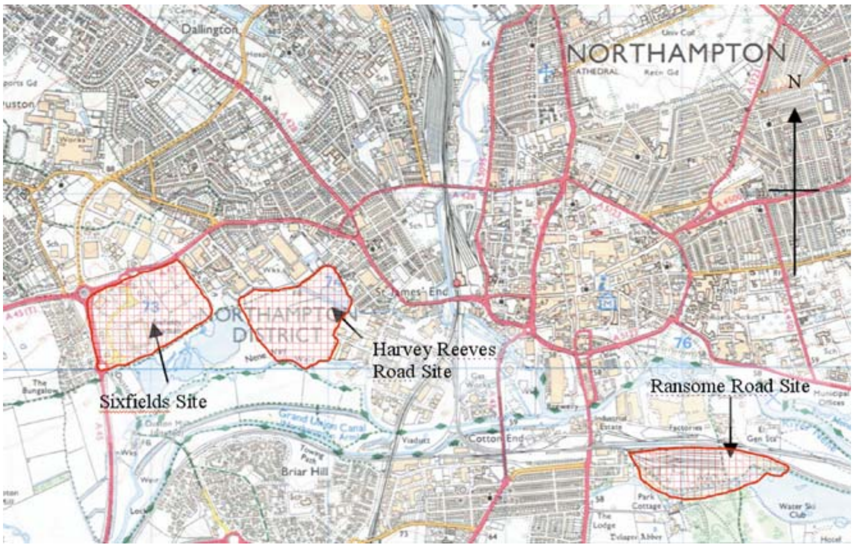

Figure 1. Site Location Plan

The Sites

The three sites are all close to major highway routes into Northampton and close to the town centre. The relationships between the sites were incorporated into the Development Framework Masterplan for the sites.

Sixfields

Sixfields is at the western edge of the existing town but almost 6,000 houses are proposed to the west of the site. The site contains the Sixfields Community Stadium and car parks (used by Northampton Town Football Club), other retail and leisure developments, a recycling centre and a large amount of unused land. It is proposed that the existing uses are extended and facilitated by the construction of a link road (named the Southern Development Link Road (SDLR)) between Harvey Reeves Road and Sixfields, and the relocation of the existing recycling area to a purpose built facility on the Harvey Reeves Road site.

Harvey Reeves Road

The Harvey Reeves Road site is bounded to the north by Northampton Rugby Football Club (NRFC) and its training pitches on the north of the site, whilst the remainder of the site is open ground. The construction of the link road between Sixfields and Harvey Reeves Road will allow the combined use of new car parks on the Harvey Reeves Road site by NRFC and Sixfields Stadium, including Northampton Town Football Club and there are also plans to develop the car parks into a ‘park-and-ride’ site for the town. In addition the recycling centre from Sixfields is to be relocated here as are some of the businesses from Ransome Road.

Ransome Road

The Ransome Road site is located on the south-eastern side of the town. The site is currently occupied by railway sidings, a small informal industrial estate and open ground. The land to the north of the railway line, outside the former landfill site, is proposed for residential development by commercial developers who are working in partnership with English Partnerships to produce an integrated development. The site itself is proposed for residential use with associated community developments.

SIXFIELDS AND HARVEY REEVES ROAD SITES

Site history

The Sixfields and Harvey Reeves Road landfill sites, and areas around them, were extensively quarried during the mid 20th century for sands and gravels and ironstone. After extraction, many of the quarries were allowed to flood, forming large water features, one of which is still evident today to the south east of the Sixfields landfill site (Storton's Pits, as shown in Figure 2).

During the 1960's, the sites became unlined dilute-and-disperse landfills constructed within the former quarries. The landfills accepted local household waste and inert wastes, as well as council tanker liquid wastes, which were disposed of in lagoons at the Harvey Reeves Road landfill site. In the later years (1980's) the sites only accepted inert trade and commercial wastes with large amounts of spoil and building rubble. The landfills were closed in the late 1980's and early 1990's.

Since closure, the Sixfields landfill site has been partially re-developed for commercial and leisure uses (including the construction of a stadium for Northampton Town Football Club); whereas the Harvey Reeves Road landfill has remained largely undeveloped with only some rugby training pitches in the north.

Ground conditions

Geology

Ground investigation work at the Sixfields and Harvey Reeves Road sites during 2003 and 2004 recorded the presence of the following deposits:

Table 1. Summary of ground conditions at the Sixfields and Harvey Reeves Road sites

Northern Sixfields Site	Southern Sixfields Site and Harvey Reeves Road Site
Landfill	Landfill
Northampton Sand Ironstone	Alluvium
Upper Lias Clay	River Terrace Deposits
	Glacial Lacustrine Deposits

A buried former glacial channel was encountered beneath the Harvey Reeves Road site and southern parts of the Sixfields site. The channel was found to be infilled with Glacial Lacustrine Deposits which are soft to stiff, grey sandy, slightly gravelly clays and silts with coarse sand lenses and in places sand and silt lamella, which become a stiff grey clay with fewer sand lenses, with depth.

The landfills were found to vary in depth from less than 2m to over 12m and the deposits encountered were generally cohesive in nature, containing cardboard, wood, metal, plastic, brick, concrete, tarmac, fibrous mattress stuffing, cloth, glass, rubber, polythene, ceramic, ash and clinker, amongst others.

At the Harvey Reeves Road Site and the southern parts of Sixfields sites, the landfill deposits were commonly recorded to be directly underlain by the sands and gravels of the River Terrace Deposits (up to 5m in thickness), which in turn were found to be underlain by Glacial Lacustrine Deposits of unproven thickness. The absence of a liner at the base of the landfills meant that the River Terrace Deposits were acting as a major pathway for the off-site migration of contaminants from the landfills.

Hydrogeology

Groundwater flows in a south, south-easterly direction across the sites (as shown in Figure 2). Groundwater levels were encountered within the lower levels of the landfills and the top of the underlying River Terrace Deposits.

Large surface water bodies exist to the south of the landfills. These include Storton's Pits, which is a wetland feature managed by Northampton Wildlife Trust, the River Nene (which flows from west to east and forms the southern boundary of Harvey Reeves Road site) and Duston Mill Reservoir (all of which are indicated in Figure 2). These water bodies are believed to be hydraulically connected to the landfills via the permeable River Terrace Deposits.

Groundwater flow at the Sixfields landfill site is affected by the presence of a leachate pumping system around the existing Sixfields Football Stadium, the effect of which can be seen in Figure 2. During the construction of the existing stadium, the landfill deposits were removed, leaving the stadium at a lower level than groundwater levels, and the leachate pumping system was installed to reduce groundwater levels in the landfill deposits directly to the north and east of the stadium.

Groundwater flow from the landfill sites is likely to flow through the remaining beds of sands and gravels (the River Terrace Deposits) and into Storton's Pits and Duston Mill Reservoir to the south of the site, although surface water sampling and testing has shown no direct evidence of this, possibly due to the dilution effect of the large water bodies. The River Nene is perched on Alluvium immediately south of the Harvey Reeves Road Site, but not to the east, and it is possible that groundwater from the site is entering the River Nene to the southeast of the site.

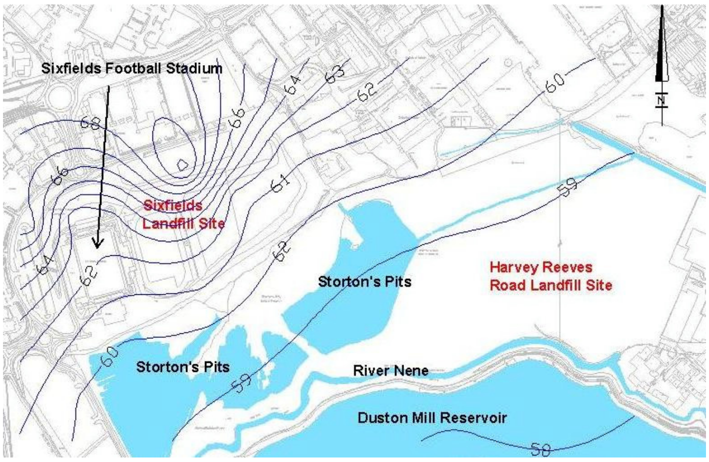

Figure 2. Groundwater contour plan (groundwater levels shown in mAOD)

Conceptual Model and Risk Assessment

The risk associated with potential contamination of the site may be assessed in terms of a source, pathway, receptor relationships. A pathway can be defined as the route by which the source of contamination comes into contact with the target. Targets may include fauna, flora, Controlled Waters, building fabric, the atmosphere and the wider environment. A risk does not exist unless there is a plausible source-pathway-receptor relationship.

As the landfill sites are directly underlain or abutted to permeable River Terrace Deposits, a direct pathway via groundwater flow through the River Terrace Deposits is present between substances recorded in the landfill and the adjacent surface water bodies.

For the landfill sites, the following sources, pathways and receptors have been identified:

Table 2. Summary of source, pathway, receptor linkages at the Sixfields and Harvey Reeves Road sites

Sources	Pathways	Receptors
Substances present within the landfill deposits, including: • heavy metals, • ammonia, • chloride, • phosphate, • manganese, • volatile and semi-volatile organic compounds • hydrocarbons • ground gases	• Dermal contact • Direct ingestion • Surface water flow • Groundwater flow	• Surface water bodies (Storton's Pits, River Nene and Duston Mill Reservoir) • Groundwater • Site end-users • Construction / maintenance workers • Infrastructure building fabric and foundations • Adjacent site users, the general public and the wider environment

Based on the results of the ground investigations, a conceptual model of each site was constructed to illustrate these linkages. A simplified version of the conceptual model for the Harvey Reeves Road site is illustrated in Figure 3 below.

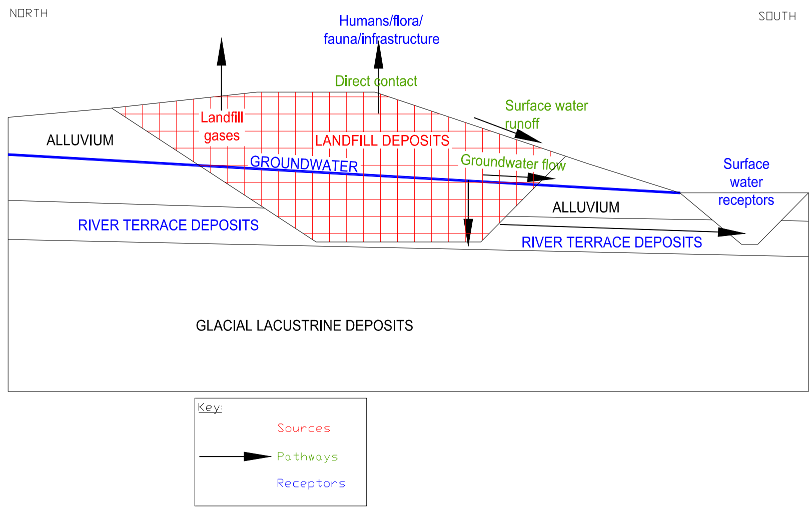

Figure 3. Simplified Conceptual Site Model of the Harvey Reeves Road site

The conceptual model illustrates the geology and hydrogeology of the Harvey Reeves Road site and identifies potential pollutant linkages.

Tier 2 quantitative risk analysis was undertaken for both sites, based on Environment Agency R&D Publication 20 (Marsland and Carey, 1999). This and the conceptual model enabled the design of remediation and mitigation measures to remove the potential pollutant linkages associated with the landfills.

Remediation scheme

Scope

In order to sever the pollutant linkages identified in the conceptual models, a remediation scheme was designed, in consultation with the Environment Agency, for the two landfill sites. Various options were appraised and discounted on grounds of sustainability, cost/benefit, long term management commitments, etc. The selected remediation scheme included mitigation of groundwater pathways and ground gas pathways, as well as protection measures for human health risks.

Groundwater remediation

Groundwater remediation was the largest challenge at the Sixfields and Harvey Reeves Road sites. Removal of the source of the contamination was a non-sustainable solution quickly dismissed. The size of the site precluded a complete circling of the site with an impermeable groundwater barrier as it would affect, unacceptably, the groundwater regime of a much larger area. A Soil Mix Reactive Barrier (SMRB) was selected because it would allow groundwater to flow into and out of the site, but the active sections of the barrier would absorb the harmful substances so ensuring that only water of an acceptable quality left the site. In addition, the in situ method of installation, unlike a slurry wall, does not require the excavation and disposal of materials and, as the barrier was to be constructed directly within the landfill deposits in some areas, the disposal costs of excavated arisings would have been substantial.

The design involved the use of a reactive barrier along the downstream side of the landfill sites with a passive barrier along the eastern and western sides of the sites to ensure that groundwater flow from the landfill is directed towards the active barrier (as shown in Figure 4). The western side of the Sixfields site was not included in this remediation scheme, as this area of the landfill was outside the Client's landownership. Similarly the centre of the landfill was not included, as landfill material was previously removed during the construction of the football stadium in conjunction with the installation of a pumping system to collect leachate from the existing developments. The barriers to each of the two sites were designed to function separately but were installed under a single contract.

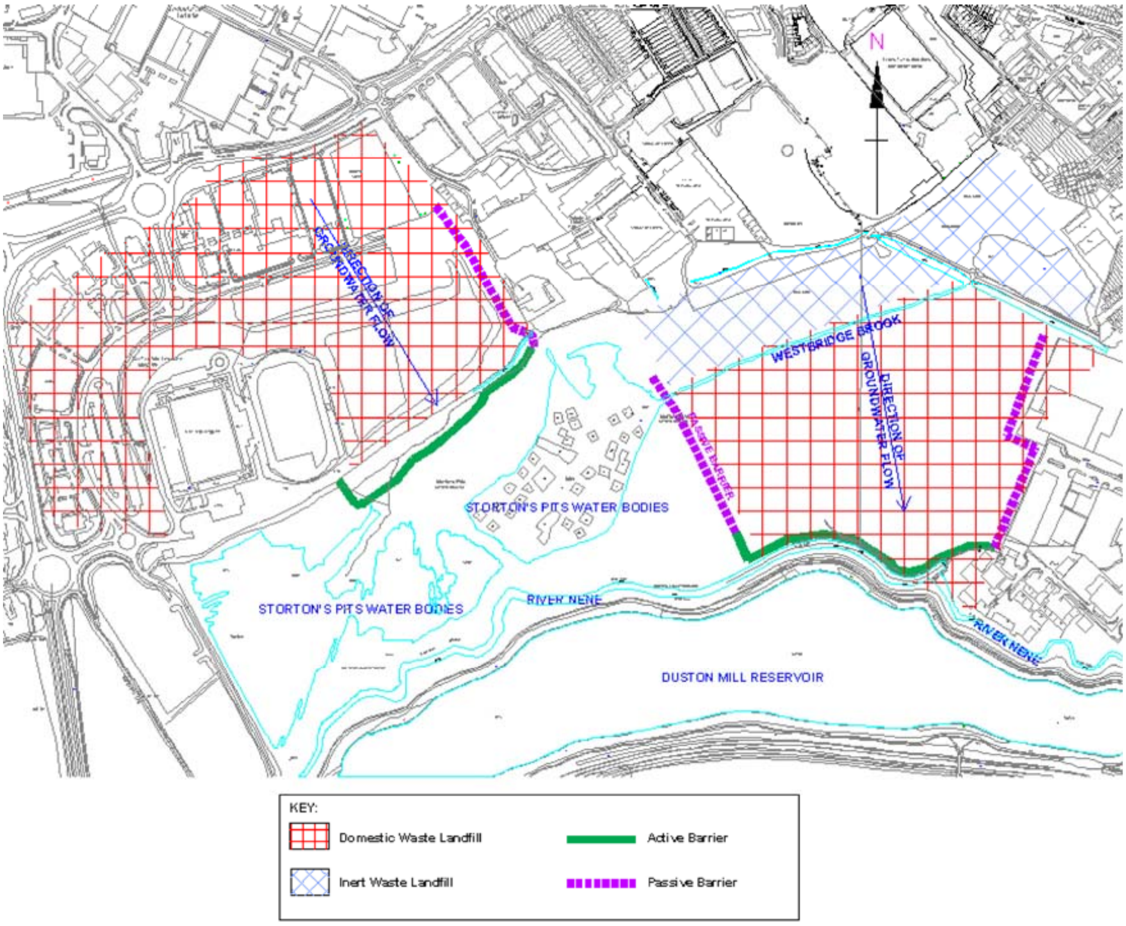

Figure 4. Sixfields and Harvey Reeves Road Plan

The active barrier was designed by Envirotreat, using its patented E-clay® technology, designed to reduce levels of the identified contaminants of concern to threshold levels agreed with the Environment Agency, and for a barrier life of fifty years. In order to design the E-clay mix, Envirotreat carried out site-specific laboratory treatability trials and flux calculations in accordance with the Environment Agency's permeable reactive barrier guidelines (Carey *et al.* 2002). Groundwater modelling using Environmental Simulation International's Groundwater Vistas Version 4 MODFLOW programme was undertaken in order to model the impact of the active barriers on groundwater levels at the site.

The active and passive sections of the barrier were installed using a system of contiguous 'piles' formed by soil mixing process using a flight auger rig (as illustrated in Figure 5). The passive barrier was formed by the installation of a single line of contiguous piles and the active by the installation of a double line of contiguous piles, necessary to achieve sufficient thickness of E-clay® material.

The installation of the passive and active barriers required a Mobile Plant License and associated Site Specific Working Plan to the requirements of the Environment Agency.

A total of 3300 columns were installed over a length of approximately 1500m, incorporating 34,500 linear metres of columns. Site works began in January 2005 and the last column complete in July 2005.

The depth of the barrier ranges from approximately 6m to 14m. The toe-in depth of the barrier had to be sufficient to ensure any leachate from the landfills did not flow under the barrier. In the north of Sixfields this required installing the barrier a minimum of 1m into the Upper Lias Clay deposits. In the rest of the site this involved the barrier being installed a minimum of 1m into the Glacial Lacustrine Deposits (GLD), although this was increased to 2m or 3m in vulnerable areas, such as the south east corner of the Harvey Reeves Road landfill. The designed toe-in depth was decided by Halcrow following a detailed investigation of the properties of the GLD including in-situ and laboratory permeability testing and detailed geotechnical examinations of the fabric of the material.

Figure 5. Photograph of in-situ soil mix barrier installation

The landfill extended close to the eastern edge of the existing Sixfields site and both the eastern and western edges of the existing Harvey Reeves Road and the passive barrier in these locations had to be installed through the landfill material. This left small areas of landfill outside the barrier, which was unavoidable due to existing structures, land ownership and water bodies. Obstructions and large concrete blocks encountered in the landfill proved problematical to the piling works. When encountered at relatively shallow depth, the obstructions were excavated, however when encountered at greater depths, the barrier had to be extended around the obstructions.

The location of the sites, adjacent to the Storton's Pits wildlife area, meant that site works in certain areas had to be undertaken with an ecologist present and in limited working areas (as illustrated in Figure 6), in order to minimise disruption to local wildlife.

Figure 6. Construction of piling platform for groundwater barrier within sensitive wildlife areas

Ground gas remediation - vent trenches

An assessment of ground gas risks based on recorded levels of landfill gases at the landfill sites was undertaken using the Card (1995), and Wilson & Card (1999) methods. This confirmed the risk of ground gas from the Harvey Reeves Road landfill migrating northwards towards existing properties; a gas vent trench already existed at the Sixfields landfill to protect adjacent properties. A ground gas vent trench was installed along the northern and eastern edge of the Harvey Reeves Road site as a precautionary measure to provide mitigation and protection for off-site receptors. The vent trench contained a slotted pipe surrounded by gravel, the trench extended to at least the depth of the groundwater or the base of the fill. Vent stacks to disperse any gases were constructed at intervals along the trench; these were extended to eaves-level where adjacent properties were present.

Human Heath protection

The landfill deposits were found to be overlain by a crude, non-engineered, capping layer. The layer was recorded to be between approximately 0.2m and 4.5m thick across the two landfills and generally consisted of firm to stiff sandy gravelly clays. The distinction between the capping material and landfill deposits was based on the nature of the fill content (mainly brick and concrete) and the increased clay content when compared to the domestic waste landfill deposits beneath. This crude capping layer was suitable for re-engineering to provide a low permeability cap to the landfills which would reduce the amount of infiltration into the landfill deposit, consequently reducing the production of landfill leachate, as well as severing the contaminant pathway between the landfill deposits and site-users. This re-engineering was incorporated into the ground improvement works and is described below.

SITE RE-DEVELOPMENT

Scope

Re-development of the two former landfill sites was constrained by the ground conditions encountered. The presence of landfill deposits, in excess of 10m in depth in places, would not provide suitable founding medium for large, settlement intolerant structures due to inherent highly variable stiffness, non-engineered placement and potential for significant long term settlement.

Domestic wastes commonly contain a large proportion of organic material which decomposes over time, producing landfill gases and causing a reduction in volume of the landfill (Charles & Watts, 2001). Domestic waste landfills are subject to three main types of settlement:

- immediate settlements (elastic responses due to loading)
- long-term creep settlement (due to the self weight of the fill)
- long-term biodegradation settlement (due to bio-chemical decomposition and/or physical-chemical changes such as oxidation).

Edil, Ranguetter & Wuellner (1990) stated that factors affecting the magnitude of settlement include:

- Initial refuse density or void ratio
- Content of the decomposable materials in the refuse
- Fill height
- Stress history
- Leachate level
- Environmental factors such as moisture content, temperature and gases present

Due to the age of the Harvey Reeves Road and Sixfields landfill sites, self weight creep settlement and bio-degradation will have been occurring over a period in excess of 15 years and a percentage of the long-term settlement will already have occurred.

CIRIA C557 (Barry *et al*, 2001), states that a large proportion of the long-term settlement of municipal waste occurs in the first five years following landfilling and that nearly all settlement occurs over thirty years. The Sixfields landfill is now over 20 years old (having been closed in 1985) and the Harvey Reeves Road landfill is now over 15 years old (having been closed in 1990). As the progress of long-term settlement of a landfill can be approximated to an exponential decay, it follows that over half of the long-term settlement has already occurred at the sites.

Due to the age of the fill deposits (with landfilling starting in the 1960's), the older deposits will already have been densified by the overburden loading from later fill deposits and the remaining settlement potential for these deeper deposits will be (in accordance with the CIRIA work) at a residual state. This densification of the older landfill deposits is confirmed to an extent by the low permeability (as little as 6 x 10^{-8}m/s) measured in the deeper deposits. Accordingly, it is the near-surface landfill deposits that would be the principal source of the remaining settlement.

Therefore, in order to construct upon the landfills, extensive ground improvement works were required to improve bearing capacities and reduce the risks of total and differential settlements. Any large structures would require piling into underlying deposits and at the Harvey Reeves Road site, although the underlying Glacial Lacustrine Deposits are soft in nature and therefore a poor host for piles. Consequently the scope of redevelopment of the Harvey Reeves Road site was constrained to light, settlement tolerant, low-level buildings with large areas of exterior hardstanding. At the Sixfields landfill, the presence of more competent Northampton Sand Ironstone and Upper Lias Clays beneath the landfill deposits in the north provides suitable strata for piles to a large structure. Accordingly, the Master Planning process was able to accommodate end uses that included larger retail and leisure structures in this part of the site.

The initial phase of development began in March 2005 and included the construction of a link road (the Southern Development Link Road) across both landfill sites and large areas of car parking across the Harvey Reeves Road landfill site.

Ground improvement to the road

In order to construct an adoptable road across the landfill sites, extensive ground improvement design was required. It was decided not to pile the foundations to the road due to the costs involved and the inflexibility of the final structure compared with the surrounding land. Therefore a combination of dynamic compaction and geo-gridded mattress was used for the sub formation design, as shown in Figure 7.

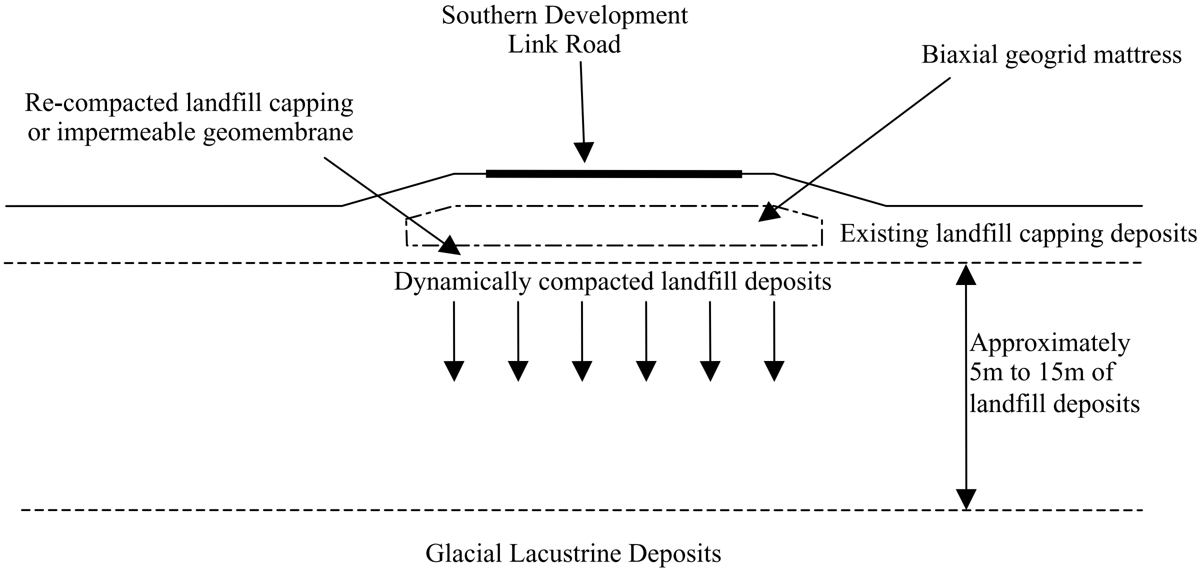

Figure 7. Standard construction detail for the SDLR

Dynamic Compaction

Prior to compaction works, the existing landfill capping deposits were stripped off to within 300mm to 500mm of the landfill waste. This deepened the effective treatment depth and allowed for the re-engineering of the existing capping deposits after compaction works in order to enhance the effectiveness of the existing landfill cap.

Dynamic compaction was undertaken along the full length of the SDLR, where landfill was present, and across the full width of the road carriageway. The objective of treatment was to improve the performance of the ground to an end-product safe bearing capacity of 100kPa. Due to the nature of the fill materials to be treated it was considered impractical to specify settlement performance. However, the contractor was required to show both by calculation and verification testing, that the treatment depth was equal to or greater than 5.0m from formation and that the average energy input across the ground improved area was equal to or in excess of 2800 kNm/m^2.

Details of the dynamic compaction specification proposed by the Contractor to achieve the specified energy input and treatment depth are given in Table 3 below.

Table 3. Summary of Contractor's dynamic compaction specification

Pass	Grid size (m)	Drop height (m)	Tamp weight (kN)	Number of drops	Energy (kN/m^2)
1	3.65 x 2	15	78.5	12	1935.12
2	3.65 x 2	13	78.5	6	838.55
3	1.8 x 1.8	7	78.5	1	169.56
				Total energy (kN/m^2)	**2943.23**

The works were undertaken using an NCK Crawler Crane, as shown in Figure 8 below.

The dynamic compaction weight generally produced imprints of between approximately 0.4m and 0.6m, although in some areas, imprints of over 1m were recorded. The imprints were infilled with granular fill from the piling platform.

Upon completion of the dynamic compaction works, the piling platform was covered by either a minimum of 500mm of re-worked landfill capping deposits, or an impermeable membrane (depending upon required final site levels).

Figure 8. Photograph of dynamic compaction rig

Geogrid mattress

Above the dynamically compacted landfill deposits and the low permeability re-worked capping or geomembrane, a geo-gridded mattress was constructed (as shown in Figure 7). The mattress consisted of two layers of biaxial geogrid with Type 1 granular fill in-between and was designed to mitigate the effects of differential settlements below the road.

Ground improvement to car parks

The Harvey Reeves Road site was proposed to be developed, in part, as large areas of car parking (approximately 58 hectares) partly for the use of adjacent land owners as discussed above. In order to provide ground improvement to the landfill deposits over such a large area, it was proposed to use a rapid high energy impact compaction technique rather than dynamic compaction.

The Landpac High Energy Impact Compaction (HEIC) technique in conjunction with Continuous Impact Response (CIR) mapping was used to improve the sub formation to the car parks. The technique is an in-situ ground improvement treatment technique which involves tracking a three or five sided high energy impact machine across the site (as shown in Figure 9). The rotating drum effectively drops a 10 to 22 tonne weight from heights ranging from 150mm to 230mm.

Figure 9. Photograph of Landpac HEIC plant

A trial using this system was undertaken in 2004 across a small area of the landfill, in conjunction with plate load testing on both treated and untreated areas. The load tests were applied over a rigid area of 2m by 2m, with the application of 50kN/m^2 of load, applied in stages over an hour. The load tests were undertaken 21 days after the HEIC had been undertaken (to allow for the dissipation of any increased porewater pressures) and were monitored for a total of 16 days. The load test within the HEIC trial area recorded settlements of 8mm over the 16 day period, while the load test outside the HEIC trial area recorded settlements of 14mm over the same time period.

The depth of influence of the HEIC is related to the type and weight of drum, as well as soil type, stratigraphic features and efficiency or energy loss of the HEIC process on soft surfaces. Improvement depths of 2m to 4m are commonly recorded with the process. While the depth of ground improvement would not be as great as dynamic compaction, the benefits of using HEIC for this work included the quick coverage of the site, lower peak vibrations and increased site coverage due to manoeuvrability.

In conjunction with the HEIC, the CIR mapping technique was used to record the degree of ground improvement achieved. This system measures ground response using an accelerometer mounted on the impact drum which records the deceleration of the drum at impact, the location of which is determined by GPS. The CIR mapping is useful in the identification of pockets of soft material or materials which are unsuitable for compaction. Once identified, these can then be locally excavated and replaced with better quality material.

As with the dynamic compaction, prior to the HEIC work the existing landfill capping deposits were stripped to within 300mm to 500mm of the landfill waste in order to increase the effective depth of treatment and to allow re-engineering of the capping. Each car park area was subject to more than forty passes with the HEIC plant.

The HEIC recorded induced settlements of up to approximately 200mm and 400mm across the sites.

FUTURE MONITORING

Validation testing of the remediation works will be undertaken by means of monitoring for a minimum of two years following completion of the remediation and construction works. Monitoring includes groundwater monitoring for the remediation works, ground gas monitoring and residual settlement monitoring for the SDLR.

Groundwater monitoring

Thirty-one monitoring boreholes were installed across the two landfill sites during the remediation works. The borehole installations were constructed with one response zone within the permeable River Terrace Deposits immediately below the landfill deposits (through which the majority of groundwater flow was expected to occur) and in the monitoring boreholes located downstream of the active barriers a second response zone was included within the Glacial Lacustrine Deposits in order to monitor the effectiveness of these deposits as a low permeability toe-in strata.

Six monitoring boreholes were constructed within the centre of the active barrier in order to monitor breakthrough of any contaminant of concern. Data loggers were installed in four of the monitoring boreholes in order to provide data on instantaneous groundwater levels every thirty minutes. An initial programme of groundwater monitoring for two years was agreed with the Environment Agency.

The groundwater modelling carried out as part of the design process had indicated some minor increases in groundwater level across the site. Whilst not critical, there was concern that these might impact existing high groundwater levels in some low-lying areas of the sites Accordingly, basic provision for an emergency groundwater pumping system was required by the Environment Agency as a contingency, should groundwater levels back-up unacceptably behind the active barriers. The emergency pumping system consists of eight wells (four at each landfill site) in order to allow swift installation of groundwater pumps should they be required. To date this system has not had to be used.

Settlement monitoring

Settlement pins are to be installed along the length and across the width of the SDLR, once construction is complete, in order to monitor the long-term settlement of the road. Monitoring will be undertaken for a minimum of two years following completion of the road. The results of the settlement monitoring will provide useful information on the long-term behaviour of the landfill deposits and aid in the design of ground improvement for other plots within the landfill sites.

Gas monitoring

Further ground gas monitoring boreholes are to be installed across the areas of car parking in order to enable determination of any change to the gas regime following compaction and re-capping of the landfill. These monitoring boreholes will also be monitored for a minimum of two years following completion of the car parks.

RANSOME ROAD SITE

The Ransome Road site is the third site planned to be developed by the Joint Initiative. Progress on this site can be made following relocation of existing site users to the Harvey Reeves Road Site, planned to be undertaken in late 2006.

Site history

The site was originally mostly open land of undefined use in the early 20th century. No development was undertaken on it until 1963 when extraction of gravel took place in the southern part of the site. This gravel pit was then infilled with wastes, the nature of which is unrecorded and, because of its age, non-regulated. After closure of the landfill in 1968, the landfill was redeveloped for light industrial and commercial uses such as haulage yards and a scrap yard.

The northern part of the site is currently used as a depot to store railway infrastructure repair materials, which are transported out by train. There are some derelict listed buildings in this area and the majority of the surface is covered by train tracks of which only two are active.

The eastern part of the site remains undeveloped open land.

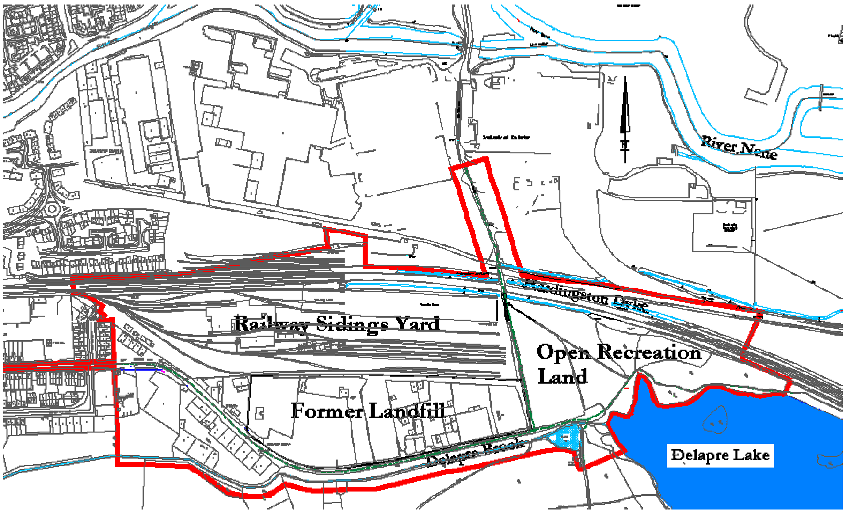

Figure 10. Ransome Road Site Plan

Ground conditions

Geology

The first phase of ground investigation was undertaken at the site in 2003. A second phase of ground investigation was then undertaken in 2005 to enable the detailed design of a remediation scheme for the site. The results of these ground investigations confirmed the ground conditions at the site to consist of made ground, landfill deposits (mainly domestic wastes generally found to consist of clayey sandy gravel with foam, brick, glass, leather, metal, plastic, rubber, polythene and occasional fibrous textile and ash), underlain by Alluvium, River Terrace Deposits and Upper Lias Clay. The landfill has been recorded to be between approximately 0.2m and 6m in depth and in some cases, directly underlain by the permeable River Terrace Deposits. Limestone bands have been encountered at depth below the site, and are part of the Upper Lias Clay strata.

In some areas of the site, the landfill deposits were found to be directly underlain by the permeable River Terrace Deposits. The absence of a liner at the base of the landfill means that the River Terrace Deposits are acting as a major pathway for the off-site migration of contaminants from the landfill.

Hydrogeology

Groundwater flow at the site is in a northeasterly direction towards the River Nene, which is located approximately 300m north of the site. Other surface water bodies include the Delapre Brook which borders the southern edge of the site and the Delapre Lake which is located to the east of the site (as shown in Figure 10). The Brook is classified as a Critical Ordinary Watercourse (meaning that it has the potential to put at risk from flooding large numbers of people and property). A number of other small water courses run along the northern edge of the site (including the Hardingston Dyke), adjacent to the railway line. Groundwater monitoring has shown the Delapre Brook and Delapre Lake to be in hydraulic continuity with groundwater at the site which flows mainly within the River Terrace Deposits and/or the lower parts of the landfill.

The River Terrace Deposits and Alluvium associated with the River Nene are classified as a Minor Aquifer by the Environment Agency. The Upper Lias Clay is classed as a non-aquifer.

Conceptual model and Risk Assessment

The landfill deposits were found to contain elevated levels of a number of potentially harmful substances (as listed in Table 4). These substances present a potential risk to site end users, flora/fauna and buildings on this area of the site, groundwater within the River Terrace Deposits and surface water bodies on or adjacent to the site (Delapre Lake, Hardingston Dyke and Delapre Brook). The River Nene is perched on alluvium within the Northampton area and is therefore unlikely to be a receptor to contamination at the Ransome Road site.

A Tier 2 quantitative groundwater risk assessment was undertaken based on Environment Agency R&D Publication 20, (Marsland and Carey 1999). The sources, pathways and receptors identified for the Ransome Road site are shown in Table 4:

Table 4. Summary of source, pathway and receptor linkages at the Ransome Road site

Sources	Pathways	Receptors
Substances present within the landfill deposits, including: • Heavy metals • Hydrocarbons • Ammonia • Manganese • Ground gases/vapours Localised sources were also identified in the Made Ground deposits within the site.	• Dermal contact • Direct ingestion • Surface water flow • Groundwater flow	• Surface water bodies (Delapre Brook, Delapre Lake, Hardingston Dyke) • Groundwater • Site end-users • Construction / maintenance workers • Infrastructure building fabric and foundations • Adjacent site users, the general public or the wider environment

Based on the results of the ground investigations, a conceptual model of the site was constructed to illustrate these linkages. This conceptual model was then used to aid in the development of the site masterplan.

Current Work

Following completion of a second, more detailed ground investigation, Halcrow has developed a groundwater model of the site (using Environmental Simulation International's Groundwater Vistas Version 4 MODFLOW programme). This modelling work will allow detailed design of the groundwater remediation scheme for the site. Currently it is proposed to use a similar groundwater barrier system as has been installed at the Sixfields and Harvey Reeves Road sites, in conjunction with ground gas protection and human health mitigation measures.

CONCLUSIONS

The three former landfill sites within Northampton had been identified as candidates for the Part IIa Register of Contaminated Land, based on their potential to degrade ground and surface water. This combined with the strategic locations of the landfills within an expanding town led to the development of the Northampton Brownfield Initiative, which planned to remediate and develop the sites to provide leveraged residential, leisure and job opportunities for the local area.

The final end use of the three sites was determined by the environmental, geological and engineering possibilities for the land combined with the overall needs of the town. This holistic view of re-use was only possible following multi-disciplinary feasibility studies and framework plans. In particular the end use of the Harvey Reeves Road site was restricted by the thickness of the landfill and the soft natural materials below this, which dictated the ground improvement and redevelopment possibilities.

The aim of the contamination remediation strategy was to sever identified pollutant linkage using sustainable and low-maintenance technologies. Implementation of this strategy required integrated design drawing on a broad range of disciplines in order to deal with the environmentally sensitive nature of the adjacent land as well as the design and co-ordination of site works with key land-owners and regulatory bodies, all of which had to be undertaken within very short time scales.

The remediation of two of the three sites comprised the installation of soil mix reactive barriers, a gas vent trench and enhancement of existing capping materials. Ground improvement techniques for the proposed enabling roads were selected on the basis of ground conditions and end-use, and involved dynamic compaction and geo-gridded mattresses beneath the adoptable roads and High Energy Impact Compaction beneath the car parks.

The aim of the ground improvement was to provide a flexible foundation which, while reducing long term creep settlements, would also reduce the potential effects of long term differential settlements induced by remnant biodegradation.

The schemes presented here will provide an improved environment for the inhabitants and wildlife of Northampton and will allow the construction of improved facilities for the existing and future residents.

Corresponding author: Mrs Emma Hill, Halcrow Group Ltd, Lyndon House, 62 Hagley Road, Birmingham, B16 8PE, United Kingdom. Tel: +44 121 456 2345. Email: hille@halcrow.com

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