Properties have historically suffered flooding from the Silk Stream and its tributaries with major flooding occurring in 1947, 1963, 1977, 1982, 1988, 1992, 1999, 2007 and 2008.

Details and photographs from the 1982 flood are provided in Appendix A. This flood event (peak daily-averaged flow of 5.52 m^3/s) caused the death of three children. Most of the historical flood events occurred during summer, as the characteristics of the Colindale area (urbanisation and low soil permeability) make it susceptible to short intense rainfall events, which typically occur during the summer period.

The "flashy" hydrographs resulting from summer thunderstorms (see Figure 5 above) are presented in Figure 8 and are discussed below.

3.2.2 Flood hydrographs

The summer 2007 flood event indeed highlighted the quick response to rainfall in the Silk Stream catchment, as flows increased from 0.5 m^3/s (base flow) to 16.9 m^3/s (peak discharge) in just 2 hours and 15 minutes. In order to characterise this feature, the Time of Concentration (Tc) and the Time to Peak (Tp) for the Silk Stream have been calculated.

Tc was calculated using the Bransby-Williams and the Kinematic wave equations. Both methods yielded similar results (219.9 and 199.1 minutes, respectively).

Tp was calculated using the following formula:

$Tp\ (hr) = 4.27\ .\ DPSBAR^{-0.35}.\ PROPWET^{0.80}.\ DPLBAR^{0.54}.\ (1+URBEXT)^{-0.77}$, where

- DPSBAR: Mean drainage path slope;
- DPLBAR: Mean drainage path length;
- PROPWET: Index of proportion of time that soils are saturated, based on estimates of soil moisture deficit;
- URBEXT: FEH index of fractional urban extent, judged from digital maps of land cover at 50m intervals.

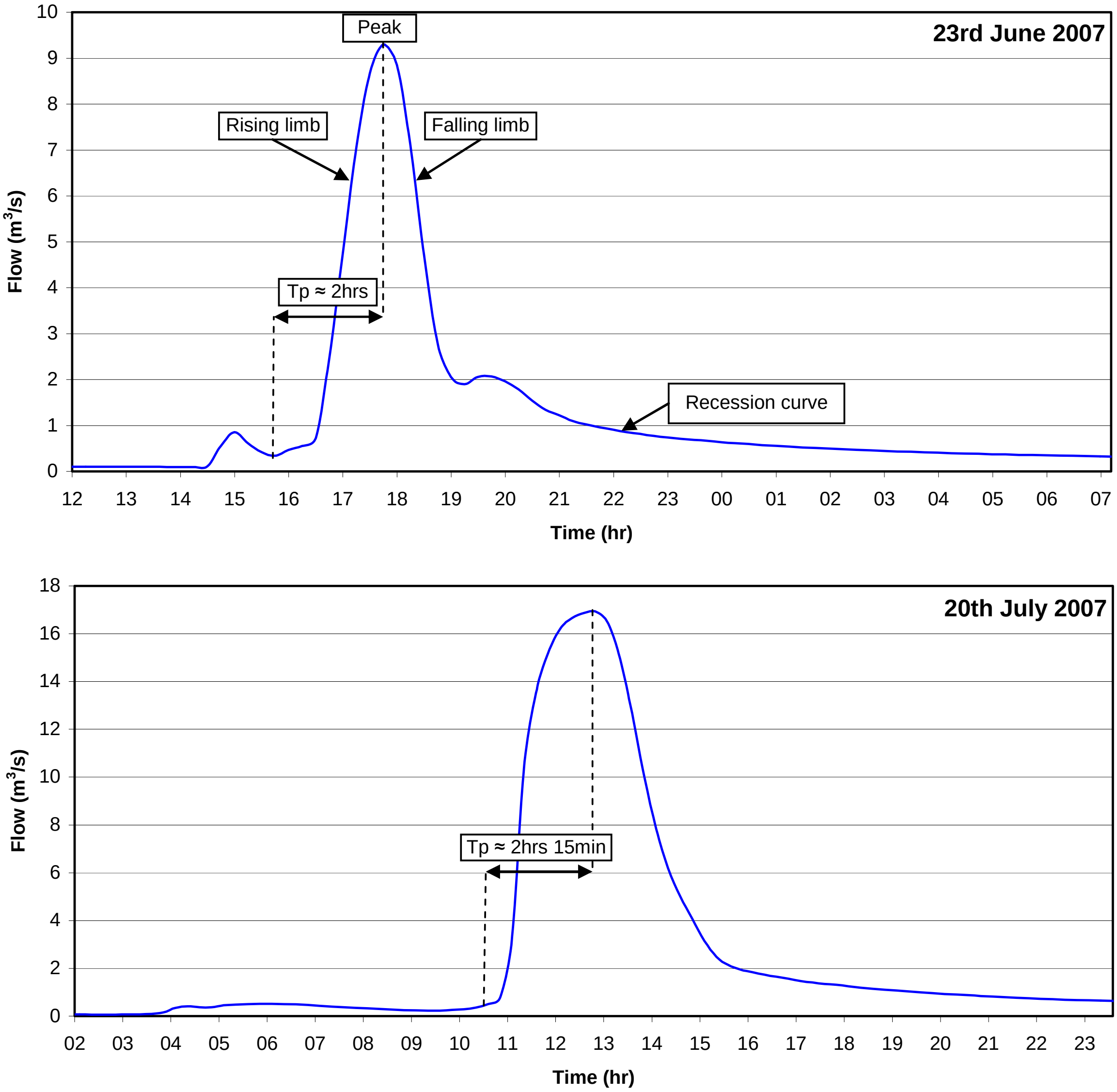
From this equation, a value of 54.3 minutes was found for Tp, which is significantly less than the observed values on the hydrographs for two of the main three flood events that occurred in the last two years (see Figure 8). The reason for this underestimation of Tp may be:

- the amount of storage within the Silk Stream catchment associated with the recently completed flood alleviation scheme;
- the sewerage system may be laid out so that the length of the flow path is increased and more than offsets the increased flow velocity, resulting in a longer hydraulic lag time. However, no sewer data was provided for this study and this parameter could not be assessed.

Should more detailed flood modelling be undertaken in the future, we recommend that the model calibration process use historical information on flood levels, as well as recent observed flood levels. Figure 7 below gives examples, the left-hand side picture shows deposition of vegetation following a high flow period; the right-hand side picture shows historical water levels during the 1982 flood event, as reported by residents.

Figure 7 - Historical flood levels

Figure 8 - Hydrographs of the 2 major summer 2007 flood events in the Silk Stream



3.2.3 Historic flood defence improvement schemes on the Silk Stream

Following a flood event in September 1992, six sites were chosen to provide a catchment wide flood alleviation scheme benefiting 613 properties along the Silk Stream, Edgware Brook and Deans Brook. Bury Farm and Edgwarebury Park are the preferred final two sites for the scheme and have a storage capacity of 34,000 and 14,000 m^3 respectively, providing flood alleviation to an additional 133 properties along the Edgware Brook. However, pre- and post-scheme flood zone mapping demonstrated that the scheme has a minimal impact on the flood zone extent within the Colindale AAP area.

3.2.4 Summary of culverted watercourses in Colindale

Culverted watercourses are often considered to present an increased flood risk due to the risk of blockages within their sections. There is only one known operating culvert within the Colindale AAP (The Aerodrome Ditch, see Figure 9 below), its total length is unknown. However, based upon site visit and data collection, we recommend that an asset inspection survey is carried out to assess the capacity, asset life and risk of failure.

Figure 9 - The Aerodrome Ditch, culverted section under railway

3.3 Sewer flooding

Sources of flooding

During heavy rainfall, flooding from artificial drainage systems may occur if:

- the rainfall event exceeds the capacity of the drainage system;
- the system becomes blocked by debris or sediment;
- the system surcharges due to a high water levels in rivers.

Sewer flooding was identified in the Strategic Flood Risk Assessment using historical records and data from Thames Water DG5 database (between August 1997 and August 2007) detailing the total number of flood incidents that have affected both internal and external property. The DG5 dataset was only provided on a five-digit postcode area, which made it difficult to determine more precisely where sewer flooding problems may have occurred in the Colindale APP area.

Method of assessment

Although the sewer flooding data provided did not include any recorded flooding incidents to properties within Colindale, there is some evidence of historical sewer flooding on roads as shown on Figure 10 below, based on information provided by Barnet Council's Highways Department. Hence, although not required at the outline SWMP stagey, a need to assess the capacity of the Thames Water sewer network for a future detailed SWMP has been identified. As an interim measure, we have liaised with Thames Water and requested a copy of their sewer network.

Figure 10 - Photographic evidence of sewer flooding on roads, Colindale, 2004 ***(courtesy of LB of Barnet Highways Department)***

3.4 Groundwater flooding

3.4.1 Geology

Sheet 256 of the British Geological Survey (BGS) 1:50,000 Scale Geological Series provides information on the geology of the Colindale area, and this is reproduced within Figure 11. At this locality London Clay outcrops, and is expected to be around 20 m thick. This is underlain by the Lambeth Group, comprising approximately 15 m of mottled clay with sand and pebble beds, which in turn is underlain by roughly 130 m of undifferentiated White Chalk.

Colindale is within an upper catchment setting, and therefore Drift deposits associated with surface watercourses are limited. Nonetheless, there is a thin ribbon of Alluvium (mainly sand, silt and clay) associated with the Silk Stream and its tributaries. The thickness of these deposits is uncertain.

3.4.2 Hydrogeology

The London Clay is an aquiclude and does not permit groundwater flow. The underlying Lambeth Group probably behaves as a minor aquifer, and the deeper White Chalk is classed as a major aquifer (aquifers allow groundwater flow).

As part of the Strategic Flood Risk Assessment[3], the Environment Agency provided depth to Chalk groundwater contours for the Colindale APP study area, based on records since January 2004. There is one Chalk borehole within the Colindale area, TQ28/001 (Figure 11), and this indicates a depth to Chalk groundwater of 40 m.

[3] Scott Wilson, Strategic Flood Risk Assessment for the Colindale Area Action Plan, September 2008.

The Alluvial Drift deposits may behave as a minor aquifer (allowing minor groundwater flow) or an aquitard (restricting groundwater flow), depending on the proportion of sand at different localities.

3.4.3 Groundwater and surface water interactions

The surface London Clay aquiclude is thought to be around 20 m thick. Therefore, even if Chalk and Lambeth Group groundwater levels rise, there is no potential for groundwater interaction with ground level or surface waters.

Where they contain a greater proportion of sand, the Alluvium deposits are likely to be in hydraulic continuity with the Silk Stream, allowing groundwater / surface water interaction.

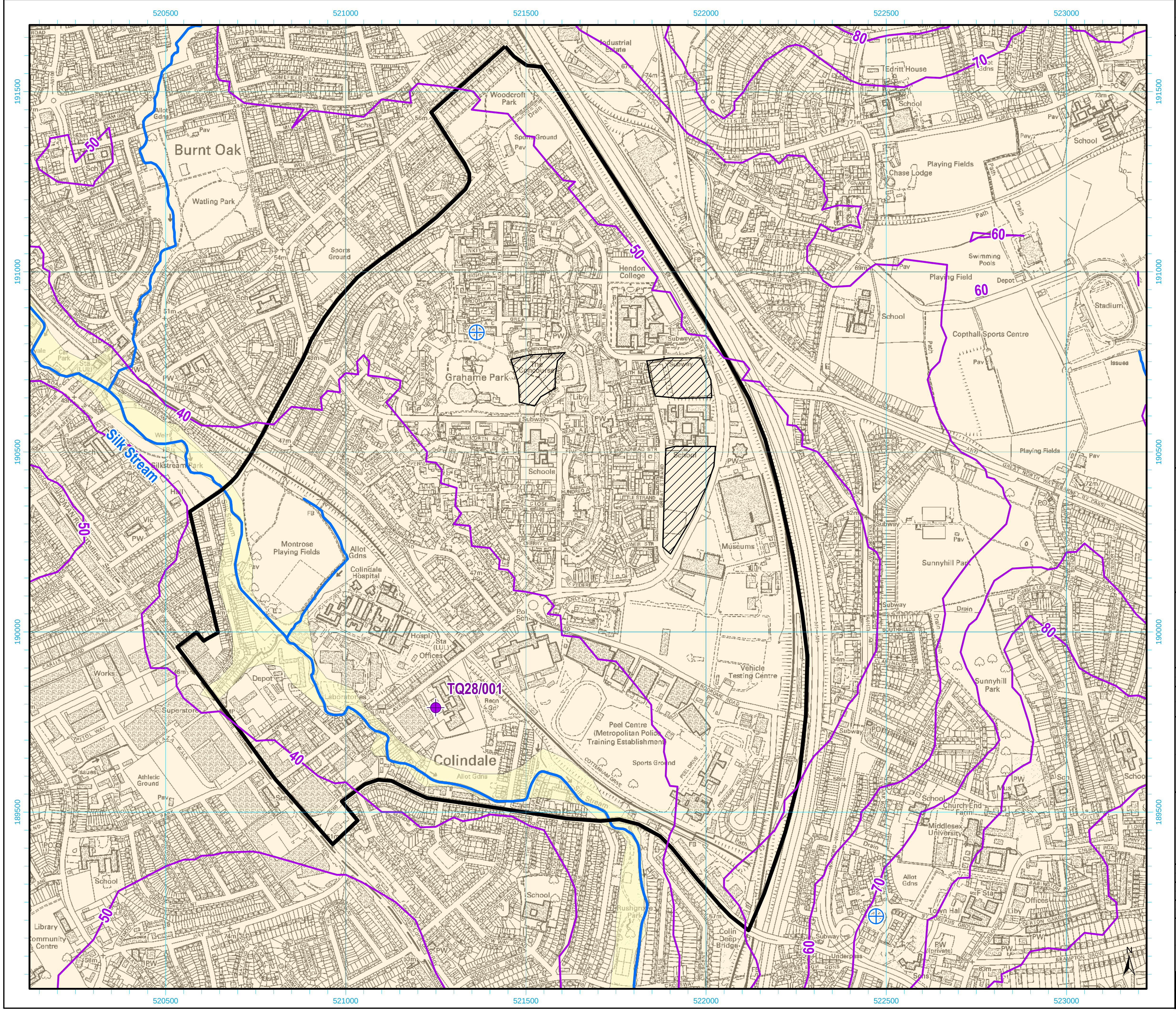
3.4.4 Potential for Groundwater Flooding

Groundwater flooding is often associated with Chalk catchments, which allow groundwater to rise to the surface through permeable subsoil following long periods of wet weather. However, Colindale is underlain by the impermeable London Clay aquiclude, which prevents Chalk groundwater from rising and causing groundwater flooding at basement level or ground level. Therefore the risk of groundwater flooding from this particular mechanism in the APP study area is considered to be very low.

Groundwater flooding can also be associated with substantial Alluvium and River Terrace Drift deposits. Stream levels may rise following high rainfall events but still remain "in-bank", and this can trigger a rise in groundwater levels in the associated Alluvium deposits. The properties at risk from this type of groundwater flooding are probably limited to those with basements, which have been constructed within Alluvium deposits. For this type of flooding to occur, the Alluvium must also behave as an aquifer i.e. contain a high proportion of sand.

A third mechanism for groundwater flooding could occur where the ground has been artificially modified to a significant degree. If this ‘made ground’ is of substantial thickness and permeability, then a shallow perched water table may exist. This could potentially result in groundwater flooding at properties with basements. Areas mapped by the BGS as containing made ground are shown in Figure 11.

It should be noted that there is one reported groundwater flooding incident in the Colindale area. This is located north of Grahame Park (Figure 11). It is possible that this incident has been mis-reported as a groundwater flood event, as there is a lack of evidence to support any of the three groundwater flooding mechanisms described.



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Legend

- Colindale AAP Study Area
- Main watercourses
- Reported Groundwater Flooding
- Chalk Groundwater Contour (mbGL)

Geology

- Made Ground
- Alluvium
- London Clay

NOTES

Revision Details	By / Check	Date	Suffix

Drawing Status: FINAL

Job Title: COLINDALE AAP

SURFACE WATER MANAGEMENT STRATEGY

Drawing Title: COLINDALE HYDROGEOLOGICAL MAP

Scale at A3: 1:10,000

Drawn	SC	Approved	MG
Stage 1 check	Stage 2 check	Originated	Date

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Drawing Number: FIGURE 11 | Rev

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3.5 Urban pluvial flooding (surface water flooding)

3.5.1 Source of flooding

Overland flow occurs when runoff from heavy rainfall flows over land. It often occurs when the soil is saturated and natural drainage channels or artificial drainage systems do not have the capacity to absorb the additional flow. The Environment Agency has produced maps showing areas susceptible to surface water flooding to assist Local Authorities with for emergency planning (note: these maps were due to be released at the end of May 2009. However we understand that there has been a delay and the Environment Agency has not released the Susceptibility Maps at this time).

The main focus of this outline SWMP is to provide an indicative assessment of surface water flood risk in Colindale and evaluate opportunities for the strategic location of SUDS, thus providing spatial planners and developers with bespoke SUDS guidance.

3.5.2 Method of assessment

Our approach to identification of areas susceptible to surface water flood risk was twofold:

- collection of historical surface water flooding data from relevant sources (see Section 3.5.3 below);
- modelling of urban pluvial flooding (see Section 3.5.4 below).

We believe this combined approach provides a sound assessment of surface water flooding across the Colindale AAP, as historical flooding incidents gives a first-hand picture of critical areas and allows checking the outputs of computer-based techniques, which in turn enable to identify other areas at risk of surface water flooding.

3.5.3 Historical flooding information

3.5.3.1 Environment Agency

During the 1992 flood event, Mr Paul Corley (Environment Agency) reported that residential properties located along The Greenway were affected by surface water flooding even though the Silk Stream was observed to be within its banks. Our preliminary analysis based upon field observations supports this observation, particularly given that finished floor elevations for the residential properties located along the Greenway are lower than the roadway.

Rushgrove Avenue (at the junction with Colindeep Lane), located in the south-eastern corner of the study area, was also reported to have experienced surface water flooding. Field observations confirmed that this low-lying area could receive significant inflows in times of heavy rains from surrounding streets located on higher grounds.

3.5.3.2 Barnet Council Highway Department

Given that urban pluvial flooding involves interactions between the river system, surface water runoff and the roadway drainage network, we requested and received data from Barnet Council Highways Department on historical flooding incidents. This information has been completed during site surveys (see Appendix B).

Table 6 - Reported locations of LB of Barnet Highways flooding incidents

No	Road	Description of flooding incident / issue
1	Colindale Avenue @ junction with Edgware Road	Blocked and defective road gully at this location.
2	The Greenway adjacent to No. 118	Highway flooding – fluvial resultant from submerged surface water sewer outfall into Silk Stream Main River.
3	Cecil Road, adjacent to No. 1	Blocked gully.
4	Montrose Avenue, near No. 66	Resultant from submerged surface water sewer outfall into Silk Stream Main River.

3.5.4 Approach to modelling surface water

A variety of different software modelling approaches is available to assess surface water flood risk in urban areas. Given that SWMPs are a new and evolving tool, we have decided to undertake the hydraulic modelling required for the outline stage using two software packages; MIKE 21 two-dimensional hydraulic modelling software and the Automatic Overland Flow Delineation Model developed by Imperial College. Each approach is described in detail below.

Central to a risk-based surface water management approach is the prediction of where and how frequently flooding occurs; now and in the future.

Whilst being a powerful tool for assessing surface water flood risk, modelling is still an evolving technique for which a site tailored cost/benefit compromise needs to be established. There exist relatively low-cost but broad and approximate approaches (topographic index analysis / 2D overland routing of a spatially uniform rainfall event), and more time-consuming / expensive, but also more complex and accurate techniques (decoupled/coupled sewer model with 1D/2D overland routing). Due to the high-level nature of the present study and the unavailability of sewer data, and since the modelling tools and methodologies to assess urban flood risk are still evolving, we elected to utilise two different modelling approaches belonging to the first group mentioned above, in order to confirm and validate the results.

3.5.4.1 Description of MIKE 21 modelling methodology

A two-dimensional (2D) hydraulic model utilising MIKE 21 was constructed for the entire Colindale Area Action Plan area. The MIKE 21 system is a two-dimensional software package that was developed by the Danish Hydraulic Institute Water & Environment. The MIKE 21 system is comprised of four main groups of numerical models. They are hydrodynamic, sediment process, wave, and environmental hydrodynamic models.

We obtained the LiDAR (light detection and ranging) topography data in two formats – Digital Surface Model (DSM) format, which includes all buildings and solid objects in the area, and Digital Terrain Model (DTM) format, where the buildings and solid objects are filtered out of the data leaving only the ground surface (bare earth).

In order to simulate runoff and flow paths the DSM data was used during the mesh generation stage of the model (pre-processing). This allowed identification of the locations of significant buildings in the area and trace around them in order to better simulate flow paths.

The LiDAR data is received as raw ascii xyz data (easting, northing and elevation), at a resolution of 1 metre by 1 metre. This data is then imported into a GIS package (MapInfo Professional v8.5.32) using the software's Vertical Mapper extension. This process converts the raw information into a continuous 2-dimensional grid that can be manipulated and queried later in the process.

In addition to the topography data above, Master Map mapping information and aerial photography were also used to guide the model derivation.

MIKE 21 Model Development & Generation

In order to create the 2-dimensional topographical mesh on which to simulate the rainfall-runoff scenarios, the buildings and general topographical features of the area had to be digitised by hand. This was done using the DSM topographical data, Master Map mapping and aerial photography.

The shapes of the significant buildings, roads and topographic contours were defined within a MapInfo Professional GIS environment then imported into the modelling software (DHI MIKE21 Mesh Generator application). This process defines the basic shape and important features of the resulting mesh.

Once the shape and details of the mesh are finalised, the DTM format LiDAR data (bare earth) is imported into the mesh to provide the final 2-dimensional 'playing field' for the model runs.

A separate elevation value is imported for each triangle that makes up the mesh. This highlights the importance of correctly defining a mesh to include all the required features, as the model's resolution is limited compared to the raw LiDAR data.

For this study, we utilised two simplified Manning's roughness coefficients over broad areas, including 0.04 to represent the urban land use and 0.07 to represent the Greenfield areas of Colindale. Should a more detailed study be undertaken in the future, more specific Manning's roughness can be ascribed to smaller areas.

3.5.4.2 Description of the Automatic Overland Flow Delineation modelling tool

The Automatic *Overland* Flow Delineation Tool (AFDT) was used along with the MIKE21 model to produce a robust assessment of probabilistic pluvial flooding. To validate and confirm the results of the MIKE 21 urban pluvial modelling, we utilised a tool known as the *"Automatic Overland Flow Delineation Tool"* which is a hybrid between the "rolling ball" method (Lea, 1992) and the "direct rainfall" (Dow et al., 2008) method giving us a secondary assessment of urban pluvial flood risk in Colindale.

The AFDT was developed by Imperial College in conjunction with UKWIR[4] and generates overland flow networks based on Digital Elevation Models (DEM). This tool enables the creation of overland flow networks automatically. It uses a Digital Elevation Model to identify the key features of a one-dimensional overland flow network, terrain depressions and flow paths and their cross-sectional area.

This tool can be summarised in four steps:

1. Identification of flood prone areas based on the DEM, in which every terrain depression is characterised by depth, area and area-volume curve;
2. Delineation of flow paths using a DEM-based flow routing algorithm;
3. Delineation of cross-sections for each delineated flow path based on DEM;
4. Generation of the input files for urban drainage hydraulic models.

At the end of the overland flow network delineation process, the files generated by the tool are ready to be imported into an urban drainage hydraulic simulation model (e.g. InfoWorks). Alternatively, the results produced by the tool can also be used independently, i.e. without being coupled with sewer network & rainfall-runoff models, as a means of analysis of overland surface flow.

For the purpose of this project, the LiDAR data was modified to allow flowpaths to cross the railway and the M1 road through known culverts, roads or footpaths. This provided more accurate results in terms of flow path delineation and ponding areas. Finally, results needed to be filtered to remove small ponds that are only due to local minimums within the LiDAR data. As a result, only ponding areas with a depth greater than 1 metre were kept.

[4] Maksimović et al., *Overland flow and pathway analysis for modelling of urban pluvial flooding*, Journal of Hydraulic Research, 2009.

We believe that the results from the Automatic Flow Delineation Tool offer an improvement over those from the "rolling ball" technique in the context of Colindale; and that the tool follows a significantly different approach of the "direct rainfall" approach commonly used in 2D modelling.

N.B.: this approach to identify flood prone areas does not require a defined rainfall. It is a physically-based modelling approach using, as a first step, DEM information only. It thus should be seen as a DEM enhancement that can *then* be coupled with a rainfall-runoff model and a sewer network model to obtain a fully integrated 1D-1D model that accounts for the dynamic interactions between surface features (pathways & ponds) and the sewer network (manholes and pipes).

Table 7 below summarizes the differences between the two modelling approaches, highlighting their respective advantages and drawbacks.

Table 7 – Summary of the characteristics of the two modelling approaches used

Software	MIKE 21	Automatic Overland Flow Delineation Tool
Developer	Danish Hydraulic Institute	Imperial College
Hydrology	4 different scenarios tested: - Storm duration: 1 or 2 hours - Return period: 1 in 100 year - With and without allowance for Climate Change (+30% increase in rainfall intensity at a 100 year horizon)	Defined rainfall not required. The tool is based on the Digital Elevation Model only.
Topographic data	LiDAR "Bare-Earth" Main Buildings and streets accounted for	LiDAR "Bare-Earth" The LiDAR data has been modified to account for known culverts and footpaths across the railway and the M1 road that provide an overland flow paths (see Figure 12)
Manning's Roughness (N)	N = 0.07 over rural areas (main green spaces) N = 0.04 over urban areas (concrete areas: streets, car parks, roofs, etc.)	n/a
Modelled area	Due to heavy calculation requirements, limited to Colindale AAP and surrounding area	Entire extent of available LiDAR data (4 squares of 2km by 2km, i.e. 16 km^2)
Outputs	Ponding areas (Maximum Flood Depth only)	Ponding areas and preferential (overland) flowpaths
Results filtering	None applied (all computed ponding areas are displayed)	Filter applied: only ponding areas with a depth greater than 1 metre are displayed.

3.5.5 Outputs from urban pluvial modelling

The outputs from both MIKE 21 and the Automatic Overland Flow Delineation Tool strongly correlate to historical surface water flooding incidents, reported by the Council Highways Department and the Environment Agency.

3.5.5.1 Results from the Automatic Overland Flow Delineation Tool (AFDT)

The main results from the AFDT are described in the following table and are shown in detail on Figure 12 below.

Table 8 - Summary of automatic overland flow delineation tool outputs

Flood classification	Source	Pathway	Receptor
Overland flow	On Clay catchments, there is a significant amount of runoff due to the low permeability of clay soils. Since clay soils do not absorb rainwater, a very high percentage runs off flowing down preferential pathways (natural valleys).	There are four principal overland flow pathways roughly running from the northern part of the sub-catchment to the southern part of the sub-catchment toward the main valley of the Silk Stream in the south of the study area. Runoff flows down natural depressions and valleys.	Across and down road infrastructure and down natural valleys. Connecting to the Silk Stream through man-modified drainage ditches.
Ponding of surface water (in low spots and depressions)	Small valley depressions and topographic low spots. Sometimes a result of infrastructure modifications (e.g., road raising, railway embankment).	There are two significant ponding areas. One which extends westwards from the existing amenity pond at Grahame Park and one to the southwest of Montrose Park where flooding of residential properties along Montrose Avenue and The Greenway was previously reported. The problems along the Greenway are strongly linked with the local topography and the lack of a well defined flood plain in the immediate vicinity.	Residential infrastructure near Grahame Park and southwest of Montrose Park.

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Legend

- Colindale AAP - Study Area
- Development Sites
- LiDAR modifications
- Flow Paths
- Ponds Depth > 1m

NOTES

Revision Details	By	Check	Date	Suffix

Drawing Status: FINAL

Job Title: COLINDALE AAP

SURFACE WATER MANAGEMENT STRATEGY

Drawing Title: AFDT MODELLING OUTPUTS

Scale at A3: 1:7,500

Drawn	TB	Approved	MG
Stage 1 check	Stage 2 check	Originated	Date

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Drawing Number: FIGURE 12

Rev

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3.5.5.2 Discussion / Comparison of results

Figure 13 below shows the outputs from the two modelling approaches used. Both methods show that rainwater drains towards the Silk Stream, resulting in ponding that roughly follows the extent of Flood Zone 2. This basic observation gives confidence in the accuracy of both models when assessing other critical areas elsewhere in the Colindale AAP.

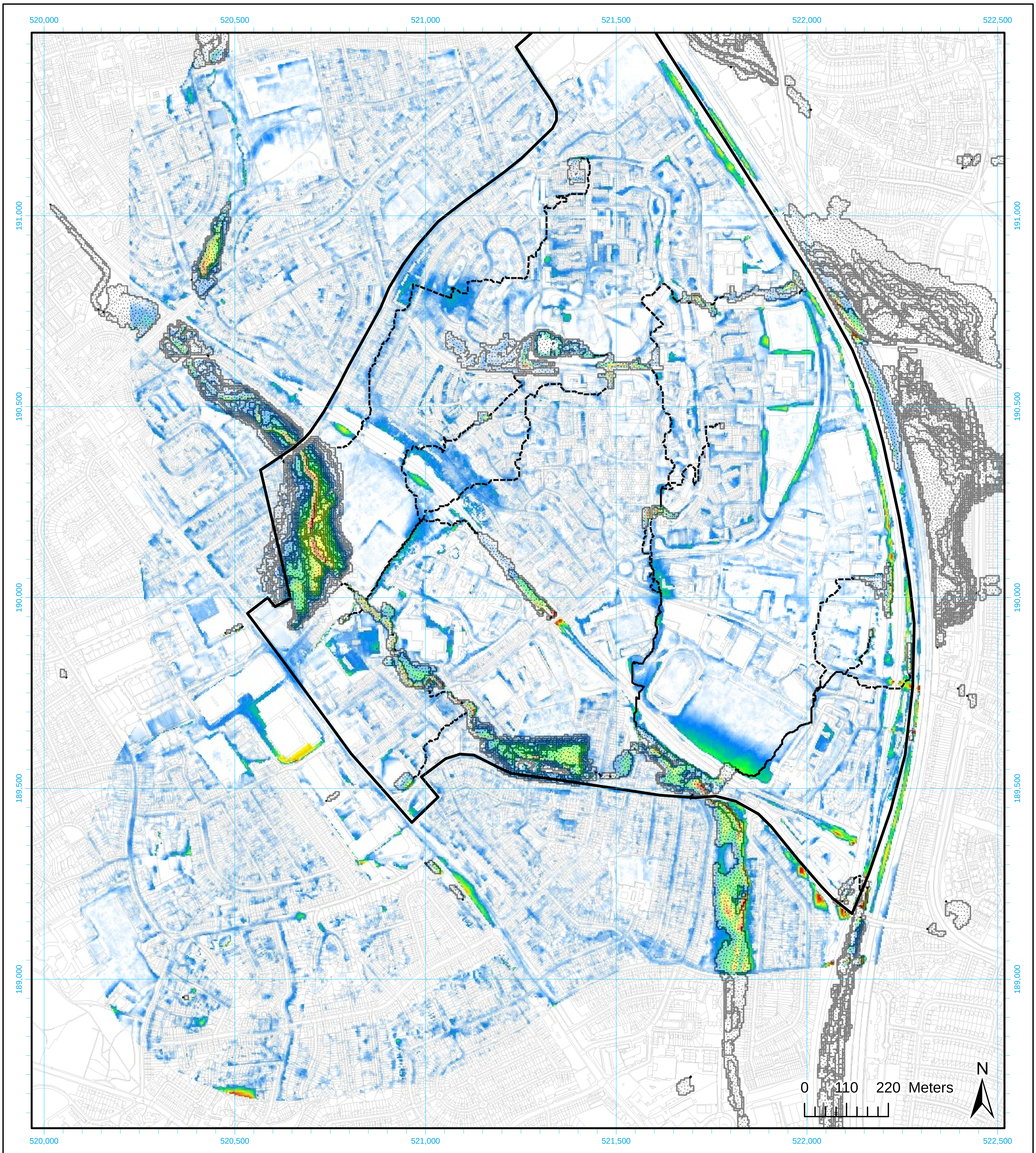
An important result from this study is that both pluvial modelling tools have demonstrated that Development Sites 23 and 24 on Edgware Road, previously flagged up in the Colindale AAP SFRA as being potentially at risk of surface water flooding, actually have no significant overland flow coming from the steep topography to the south. However, this will have to be confirmed at FRA stage through more detailed modelling techniques taking into account all surrounding buildings as well as the sewer network.

The identification of preferential flow paths and ponding areas through modelling provides the required evidence base to undertake a high level drainage strategy for the Colindale AAP, in terms of localisation of conveyance and attenuation SUDS (please refer to the discussion on the Surface Water Management Train in Section 5.4 below).

Important modelling notes

The AFDT approach indicates significant ponding on the eastern side of the M1, **outside of the study area**. However, this is owing to drainage from the steep topography to the East accumulating along the motorway, as no modification of topographic data could be carried out in this area (to account for culverts and/or underground footpaths acting as preferential flow paths), as no data was available for this zone which is located outside of the study area. These ponds should therefore not be considered as relevant.

For the same reason, the modelled ponding areas in MIKE 21 along the north-eastern side of the railway (Booth Road and Cottenham Drive) should also not be considered to be relevant for the purposes of this study. This is confirmed by the outputs from the AFDT approach which accounted for such culverts and footpaths under the railway and demonstrated no significant ponding in the corresponding locations.



Legend

- Colindale AAP - Study Area
- AFDT output: Ponds Depth > 1m (see Figure 12)
- AFDT output: Flow Paths (see Figure 12)

MIKE 21 output
Maximum Flood Depth (m)
1 in 100 yr event + Climate Change (2 hrs storm duration)

0
1
2
3
4
5

Scale at A3
1:10,000

Project Title
COLINDALE AAP
SURFACE WATER MANAGEMENT STRATEGY

Drawing Title
MIKE 21 Pluvial Modelling Outputs
(1 in 100 year event + Climate Change, 2 hours storm duration)
and comparison with AFDT Modelling Outputs

FIGURE 13

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Drw: TB	App: MG	Rev: ??
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4 Identification of Critical Drainage Areas (CDAs)

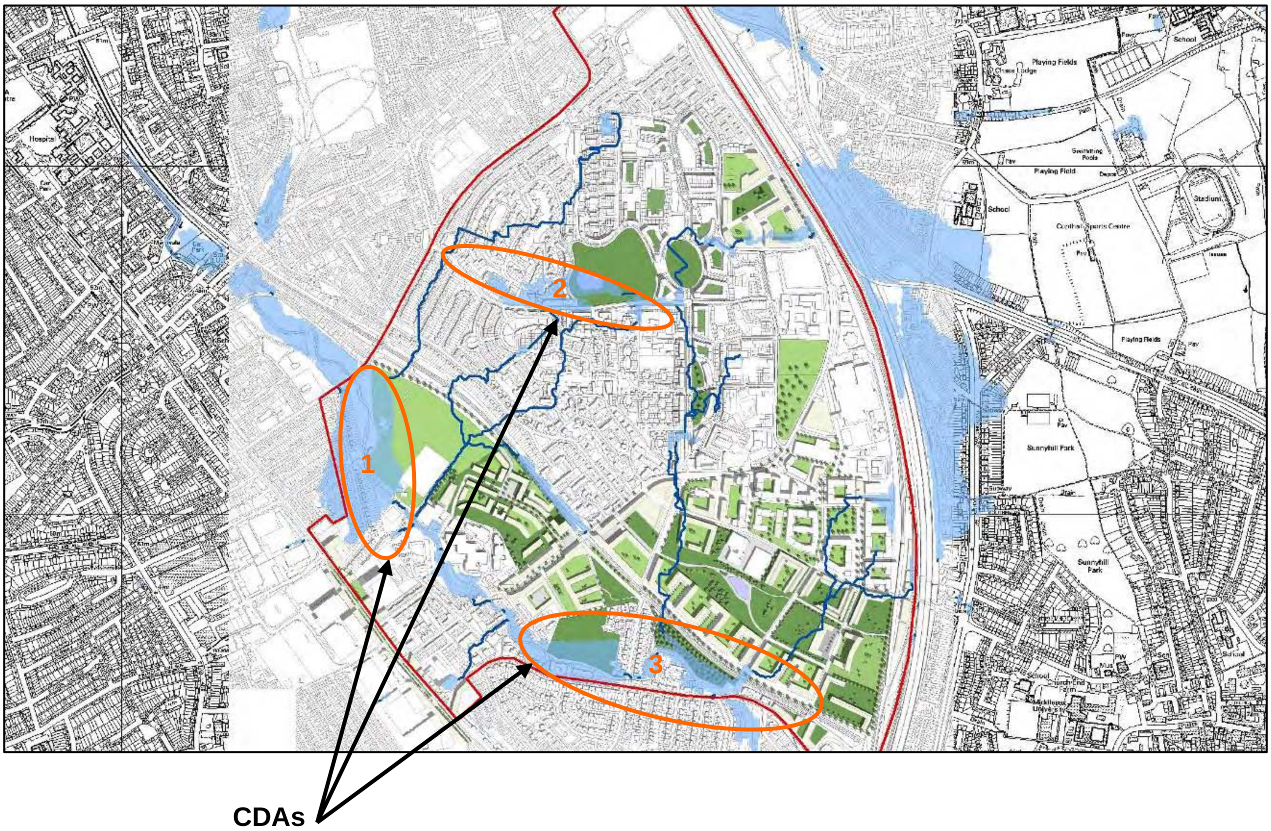
4.1 Location of Critical Drainage Areas

A component of this study is to identify Critical Drainage Areas (CDAs), and surface water flooding “hot spots”. CDAs have been identified by considering both the area-wide pluvial flood risk assessment with a fluvial flooding assessment. The underlying hypothesis is that CDAs are characterised by the amount of surface water runoff that drains into the CDA, its topography and hydraulic conditions of the river system, as well as receptors (properties, infrastructure and people) that can be affected by flooding. The method applied includes:

- The locations and mechanisms of surface water flooding hot spots were determined, through an iterative approach of undertaking a review of the Level 1 SFRA and further consultation with the Environment Agency and Thames Water;
- Historical flooding data was obtained which described all sources of flood risk and identified historical “hot spots”, known blockage areas and areas;
- Number of properties/population at risk and vulnerable critical assets;
- Future development potential and planned land uses;
- Topography (low-lying);
- Contributions from sub-catchments.

Based upon a combination of field visits, hydraulic modelling and historical flood risk information, we have identified, three distinct CDAs within Colindale. These CDAs are in areas where there are either multiple sources of flooding or the sources involve interactions between river flooding, surface water flooding and sewer flooding. These CDAs are highlighted in the circled areas on the map below.

Figure 14 - Identification of Critical Drainage Areas



CDA 1 - The Greenway: a low-lying area adjacent to the Silk Stream that receives inflows from higher ground on both sides of Edgware Road. The area is at risk from both surface water and river flooding.

CDA 2 - Lanacre Avenue between Montrose Avenue and Grahame Park: a low-lying area draining the entire northern part of the Colindale AAP, that is at risk from surface water flooding only. Pedestrian subways in Grahame Park comprise several gullies, which are entirely blocked with sediment.

CDA 3 - Colindeep Lane, between Hanover Court and Rushgrove Avenue: the conditions here are similar to those experienced at The Greenway - an area with a history of surface water and river flooding.

4.2 Identification of high-level options linked to the CDAs

One of the key aims of this study is to support new investment in the Colindale Area and flag up opportunities to shape the indicative masterplan. We have therefore sought an approach that provides maximum flexibility.

4.2.1 CDA 1

One of the challenges associated with the flooding shown in the Montrose Park area is the convergence of overland flow paths from Edgware Road, from Grahame Park and from the local road topography. Flooding may also be exacerbated by the lack of a well defined flood plain in this immediate vicinity. It is recommended that options are explored to secure a Section 106 Agreement regarding the flood risk locally, as part of the regeneration of Colindale Avenue and Edgware Road (Corridors of Change 1 & 3) to offset the cost of future improvements to the layout, configuration and topography of Montrose Park. The utilisation of the southern part of Montrose Park as a flood detention storage area would help reduce flooding along adjacent residential areas (The Greenway and Montrose Avenue) and reduce peak discharges downstream, thereby minimising community disruption from surface water flooding.

4.2.2 CDA 2

With regard to Grahame Park, there may be an option of re-designing the storage pond within the park to accommodate the surface water flow to the east. Based upon site visits and results from the modelling, the storage pond at Grahame Park, in its current state, is an under-utilised asset. It is recommended that the storage pond at Grahame Park is designed to capture and attenuate surface water flow, thus reducing the downstream flood risk around Montrose Park (CDA 1) and the Silk Stream. If this recommendation is considered favourable by the Council, additional modelling could provide indicative data that will assist with future pond configuration and sizing.

4.2.3 CDA 3

With regard to the proposed flood storage pond at the Peel Centre Park, there are two options.

Option 1 – includes the provision of swales to route surface water from the overland flow paths (originating from Grahame Park in the north and Beaufort Park in the east) to a single large flood detention storage area as shown in the current indicative masterplan configuration.

Option 2 – includes the provision of two smaller flood storage areas within the proposed Peel Centre Park. One of the flood detention storage ponds could be sited on the western margin of the park and could pick up surface water from the overland flow path that originates from Grahame Park and the other storage pond could be sited along the eastern margin of the Peel Centre Park to collect the preferential flow path originating from the Beaufort Park area. Directing the flow from the overland flow paths into the flood detention storage ponds via open grass-lined swales with 2:1 side slopes is recommended. This option may provide cost savings as the storage ponds are located closer to the overland flow paths, thus reducing the length of any flow conveyance structures (swales and culverts).

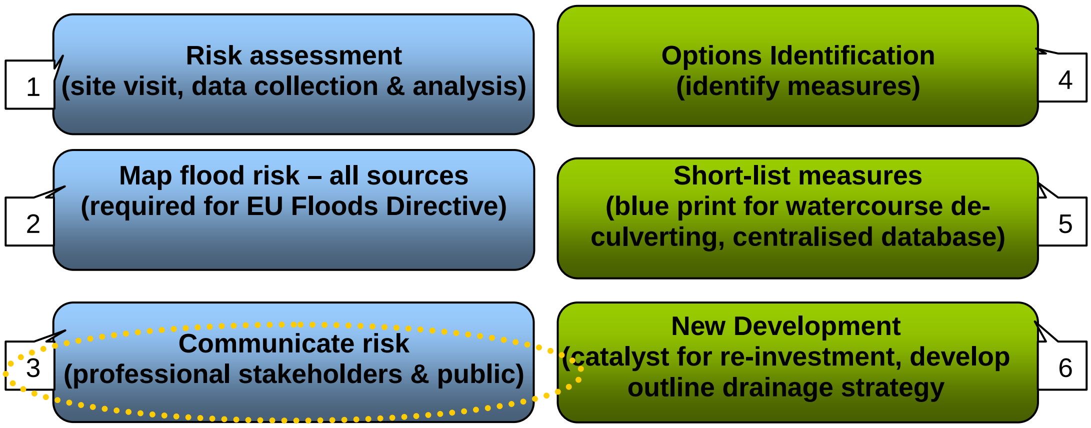
4.3 Key Benefits

The benefits of the flood risk management proposals within the CDAs identified are:

- The creation of storage ponds and swales at the Peel Centre to reduce downstream peak flows and serve as an exemplar new public park for the local area, encouraging a diversity of uses into an area of dense urban development. The storage ponds could be planted with reed beds which are amongst the most important habitats for birds in the UK, supporting distinctive breeding bird assemblages. Reed beds also act as a filter system, helping to improve water quality.
- The storage ponds could encourage the interaction between people and nature, helping to educate people of the area's natural resource, and the importance of protecting it.
- These storage ponds could be a catalyst for other regeneration projects in the area, such as restoration of the Silk Stream river corridor.
- The creation of a new larger flood storage pond at Grahame Park (CDA 2) could be used to attenuate overland flows and improve the flooding situation downstream at Montrose Park (CDA 1). The design of a larger storage pond at Grahame Park could facilitate the creation of a more natural looking pond, allowing a diverse range of habitats to be created and provision of new footpaths and viewing platforms.
- The design of the southern portion of Montrose Park as an on-line flood storage area (option to be explored in conjunction with a Section 106 agreement) would provide accompanying new foot, bicycle paths and amenity areas.

Following the identification of the Critical Drainage Area(s), the next step in our SWMP methodology is to assess the available options to mitigate flood risk through a short listing of measures (see process diagram below). This is discussed in detail in the following section. Also, it may be worthwhile for the Council and its partners to consider how information on flood risk is communicated to the public and to stakeholders.

Figure 15 - Excerpt of Surface Water Management Plan methodology



5 Outline Drainage Strategy for Colindale

5.1 Drainage Impact Assessment (DIA)

This outline SWMP can be used as a tool to implement well designed SUDS through a Drainage Impact Assessment (DIA) as each development site is progressed. This DIA should include a Surface Water Management Train[5], for which guidance tailored to the situation in Colindale is provided under Section 5.4.

It is recognised that urban development impacts upon both the rate and the volume of runoff. In addition, there are often water quality impacts (e.g. sediments, nutrients, pH, temperature) on receiving watercourses. The Colindale AAP offers a valuable opportunity to improve surface water management in the Silk Stream catchment by (i) controlling the peak rate of stormwater runoff, (ii) reducing the volume of runoff within the Corridors of Change and (iii) minimise the pollution load from stormwater runoff to the Silk Stream.

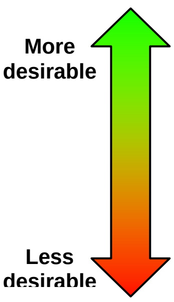
The basic elements of a DIA include:

- An examination of drainage patterns including overland flood pathways during extreme events
- Brief summary of how the drainage design provides SUDS techniques (in accordance with CIRIA guidance[6])
- Summary of SUDS to be considered
- Soil classification for the site
- Consideration of ground and groundwater conditions
- Calculation of runoff flow for the range of critical rainfall events
- Attenuation designed for a relevant return period for the rainfall events
- Confirmation of maintenance responsibility

5.2 New Development

Toward this end, and as part of the outline SWMP for Colindale, a preliminary assessment of the following was undertaken:

1. The peak runoff rates from the proposed development sites, under different development options;
2. The London Plan Section 4A.14 (pg 213) on Sustainable Drainage sets out a drainage hierarchy for new development, in order to manage surface water as close to the sources as possible, as follows:



- Store rainwater for later use
- Use infiltration techniques
- Attenuate rainwater in ponds
- Attenuate rainwater in tanks for gradual release to a watercourse
- Discharge rainwater direct to a watercourse
- Discharge rainwater to a surface water drain

[5] CIRIA Website, http://ciria.org/suds/suds_management_train.htm, July 2005.
[6] CIRIA C697, The SUDS Manual, 2007.

- Discharge rainwater to the combined sewer

3. The peak forward discharge rates to be achieved, in line with the targets in:
   - The London Plan[7] (Supplementary Planning Guidance 2006): achieve 50% attenuation of the undeveloped site surface water runoff - Brownfield runoff rate - at peak times;
   - The Mayor's Preferred Standard[8] – achieve 100% attenuation of the undeveloped site surface water runoff - Brownfield runoff rate - at peak times;
   - The Environment Agency[9]: the post-development rate of runoff should be no greater than the Greenfield rate of runoff for a range of annual probabilities (100%, 33% and 1%).

   whichever is the most restrictive. However, these criteria can be relaxed by regulators where appropriate, or where it is impractical to meet these requirements;
4. For each development option, the required attenuation / long-term / treatment storage for each development site, grouped into "Corridors of Change". Site-specific indicative storage volumes are presented below in Table 11 and Appendix C.

5.3 Identification of AAP development options

A spatial planning approach to the Local Development Framework (and Area Action Plans) is recommended to ensure the most efficient use of land by balancing competing demands within the context of sustainable development. One of these competing demands will be the space required to effectively manage flood risk.

A preliminary assessment has been carried out following the guidance provided by Defra[10], the Environment Agency and CIRIA[11][12].

5.3.1 Calculation of peak runoff rates from proposed AAP development sites

To estimate the potential flood risk from the proposed development sites the amount of rainfall that does not infiltrate through the ground, but contributes to runoff from the site, was calculated.

The Rational Method was used to estimate the runoff that will occur from each development site. Runoff has been calculated for the existing site (assumed to have 100% impermeable coverage, made of paved areas and London Clay) and for two development options where the proportion of impermeable areas reduces to 75% and 50% respectively, thus accounting for a wider use of SUDS.

The Rational Method uses the following general formula:

$Q_{100} = C\textit{i}A$, where

- Q100 is the estimate of the peak rate of runoff for the 1 in 100 storm event.
- C (unitless) is the runoff coefficient; fraction of runoff, expressed as a dimensionless decimal fraction, that appears as surface runoff from the contributing drainage area.
- i is the average rainfall intensity for the 1 in 100 storm event during that period of time equal to the Time of Concentration Tc.

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[7] The London Plan, Supplementary Planning Guidance - Sustainable Design and Construction, Section 2.4.4 p.47-52. May 2006.
[8] The London Plan, Supplementary Planning Guidance - Sustainable Design and Construction, Section 2.4.4 p.47-52. May 2006.
[9] Defra / Environment Agency, *Preliminary rainfall runoff management for developments – R&D Techincal Report W5-074/A/TR/1 Revision C*, Flood and Coastal Erosion Risk Management R&D Programme, June 2007.
[10] Defra / Environment Agency, *Preliminary rainfall runoff management for developments – R&D Techincal Report W5-074/A/TR/1 Revision C*, Flood and Coastal Erosion Risk Management R&D Programme, June 2007.
[11] CIRIA X108, Drainage of Development Sites – Aguide, Kellagher R., HR Wallingford 2004.
[12] CIRIA C697, The SUDS Manual, 2007.

- A is the contributing tributary drainage area to the point of design which produces the maximum peak rate of runoff.

For each development site, the Time of Concentration (Tc) depends on the characteristics of the sub-catchment (as defined in the Flood Estimation Handbook CD-ROM) where the development site is located. Tc was calculated using both the Bransby-Williams and the Kinematic Wave equations. Results generally proved to be similar, and the method giving the shortest Tc (thus the highest rainfall intensity) was selected. From this, the amount of rainfall in this time was calculated using the Depth Duration Frequency module in the FEH CD-ROM[13].

The runoff coefficient (C) is dependent on the characteristics of the ground surface. This varies from 0.05 for flat sandy areas to 0.95 for impervious urban surfaces (tarmac/concrete). The values that were used for the different Development Options were:

- Permeable covering – 0.3
- Impermeable covering – 0.9

Table 8 below shows that runoff rates increase with an increase in the percentage of impermeable surfaces. The higher the percentage of impermeable surfaces, the larger the quantity of attenuation will be required on site to provide an improvement to the current situation and to prevent any increase in the runoff from the site post development.

[13] Centre for Ecology and Hydrology, Flood Estimation Handbook (FEH) CD-ROM 2, 2007.

Table 8 - Peak rate of runoff for the 1 in 100 year storm event, using the Rational Method

							Runoff Q (l/s)		
							Existing	Option B	Option C
							% of impermeable area		
No.	Site Name	Area (Ha)	Tc (min)	I (mm/hr)	0.3	0.9	100%	75%	50%
					Runoff Coefficient for permeable covering, C1	Runoff Coefficient for impermeable covering, C2			
1	Grahame Park (Lanacre Avenue)	35	61.5	50.07			4,385	3,654	2,923
2	Beaufort Park (Aerodrome Avenue)	10	50.0	59.48			1,488	1,240	992
3	Zenith House (Edgware Road)	1	31.9	83.02			208	173	138
4	Former National Grid/Kidstop Premises (Edgware Road)	0.6	31.9	83.02			125	104	83
5	Barnet College (Grahame Park Way)	5.1	61.5	50.07			639	532	426
6	Peel Centre East (Colindale Ave/Aerodrome Road)	3.8	61.5	50.07			476	397	317
7	Peel Centre West (Aerodrome Road)	14.7	50.0	59.48			2,188	1,823	1,458
8	Farrow House (Colindeep Lane)	0.9	50.0	59.48			134	112	89
9	British Library (Colindale Avenue)	2.3	61.5	50.07			288	240	192
10	Colindale Hospital (including frontage & Phase 2)	6.6	61.5	50.07			827	689	551
11	Middlesex University Halls (Grahame Park Way)	2.2	85.9	39.05			215	179	143
12	National Blood Service expansion site	0.6	81.7	39.79			60	50	40
13	Brent Works (Colindale Avenue)	0.7	61.5	50.07			88	73	58
14	Land between railway line (Aerodrome Road)	0.7	50.0	59.48			104	87	69
15	Site along Watford Way	1	50.0	59.48			149	124	99
16	McDonalds Site (Edgware Road)	0.5	31.9	83.02			104	87	69
17	Burger King & Eyeland Site (Edgware Road)	0.4	31.9	83.02			83	69	55
18	Merit House (Edgware Road)	1	31.9	83.02			208	173	138
19	Green Point (Edgware Road/The Greenway)	0.5	31.9	83.02			104	87	69
Optional	Former electricity board land site	0.3	31.9	83.02			62	52	42
Optional	Land inbetween Library and Brent Works	0.25	61.5	50.07			31	26	21
Sites in Brent									
20	Oriental City (Edgware Road)	3	31.9	83.02			623	519	415
21	Capitol Way (Edgware Road)	3.15	31.9	83.02			654	545	436
22	Asda Site (Edgware Road)	2.5	31.9	83.02			519	433	346
23	Sarema House (Edgware Road)	1.7	31.9	83.02			353	294	235
24	Retail Park (Edgware Road)	4	31.9	83.02			831	692	554
	Total for Corridor of Change 1 - Colindale Avenue (m^3/s)						**1.77**	**1.47**	**1.18**
	Total for Corridor of Change 2 - Aerodrome Road (m^3/s)						**4.13**	**3.44**	**2.75**
	Total for Corridor of Change 3 - Egdware Road (m^3/s)						**4.02**	**3.35**	**2.68**
	Total for Corridor of Change 4 - Grahame Park Way (m^3/s)						**5.02**	**4.19**	**3.35**
	Total for Colindale AAP (m^3/s)						**14.94**	**12.45**	**9.96**

Attenuation is required to prevent the development increasing the flood risk to neighbouring properties during the 1 in 100 year storm event. The sustainable management of rainfall from a development is an essential element in reducing the risk of flooding to and from a development site in the future. Annex F of PPS25[14] promotes the use of Sustainable Drainage Systems (SUDS) in new developments. SUDS aims to mimic natural systems whereby water is held close to the source, then released slowly over time. This acts to both reduce peak discharge and to promote the settlement of sediment thereby improving the water quality of any resulting discharge. Many of these systems will also contribute to the Sustainability Rating of any proposed development under the Code for Sustainable Homes.

5.3.2 Calculation of indicative storage volume requirements for AAP development sites

In order to assist the Council and the Developers, three Development Options were developed that represent three conceptual scenarios with increasing permeable coverage and use of SUDS. The underlying objective was to provide flexibility with regards to growth. The following three parameters were considered:

Table 9 - Parameters describing three conceptual development scenarios

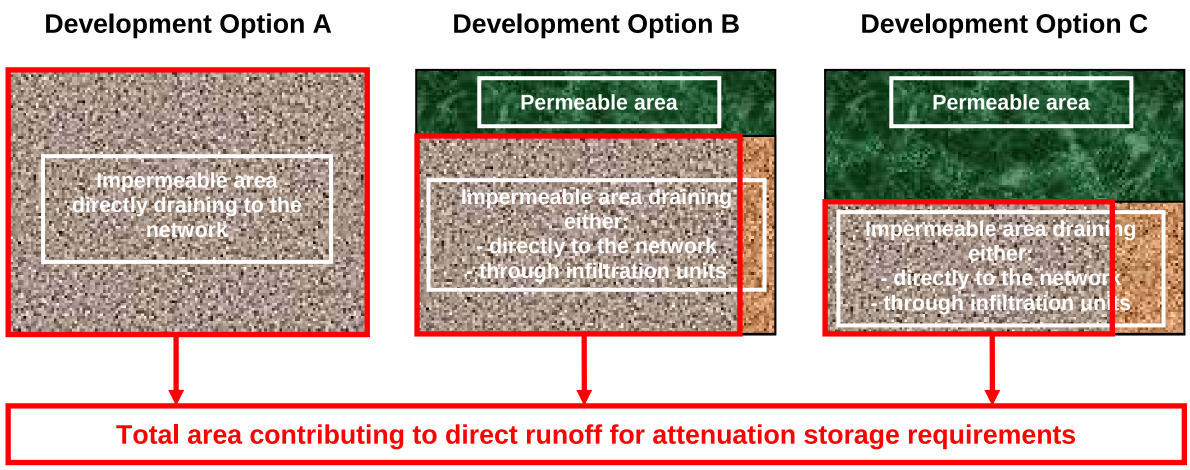
Conceptual Development Options	A	B	C
Proportion of impermeable coverage (PIMP)	100%	75%	50%
Proportion of paved area draining to the network or directly to the river (α)	100%	90%	80%
Proportion of pervious area draining to the network or directly to the river (β)	100%	90%	80%

The PIMP parameter reflects overall development option choices regarding the relative balance between green and paved areas and is thus used in calculating both attenuation and treatment storage requirements.

The α[15] and β[16] parameters more particularly reflect choices made regarding the scale of SUDS implementation, and are used in calculating attenuation and treatment storage requirements, respectively:

Figure 16 below summarizes the assumptions made in the three Conceptual Development Options.

Figure 16 - Schematic diagram of contributing areas for each Conceptual Development Option



[14] Communities and Local Government, *Planning Policy Statement 25: Development and Flood Risk*, December 2006.
[15] The α parameter decreases when more hard surfaces are drained to infiltration units and can be assumed to be not contributing to runoff. Due to the ground conditions in the study area, it has been estimated that no more than 20% of the hard surfaces could be draining to infiltration units in the best-case scenario (Option C).
[16] The β parameter decreases when more hard surfaces are drained to infiltration units and pervious pavements and can be deemed not to require treatment in terms of 'VTreatment'[16] for a pond. Due to the ground conditions in the study area, it has been estimated that not less than 80% of impermeable areas with direct runoff could require treatment in the best-case scenario (Option C).

The first step when undertaking preliminary storage volume calculations is to calculate the Greenfield runoff rate for a range of annual probabilities (100%, 33% and 1%). The preferred methodology for small catchments (<25 km^2) is described in the Institute of Hydrology Report $N^0$124. The IH mean annual flood flow rate equation is as follows:

$$QBAR_{Rural} = 0.00108\ AREA^{0.89}.SAAR^{1.17}.SOIL^{2.17}\text{, where}$$

- QBARRural = Catchment mean annual peak flow (approximately 43% annual probability or 2.3 year return period) (m3/s)
- AREA = Catchment area (km2)
- SAAR = Standard average annual rainfall for the period 1941 to 1970 (mm)
- SOIL = Soil index (from Flood Studies or Wallingford Procedure WRAP maps). It is a weighted sum of individual soil class fractions, where:

$$SOIL = 0.1\ SOIL_1 + 0.3\ SOIL_2 + 0.37\ SOIL_3 + 0.47\ SOIL_4 + 0.53\ SOIL_5$$

Table 10 - Greenfield runoff rate calculations for the 100%, 33% and 1% annual probability

Corridors of Change	1 - Colindale Avenue	2 - Aerodrome Road	3 - Egdware Road	4 - Grahame Park Way	TOTAL COLINDALE AAP
Site Numbers	**6,9,10,12,13 (1)**	**2,7,8,11,14**	**3,4,15-24 (2)**	**1,5**	
Total Area (ha)	14.25	28.5	19.65	40.1	102.5
Greenfield Runoff Rates					
Q_{1yr} (l/s)	58.38	104.74	80.50	147.12	390.74
Q_{30yr} (l/s)	159.34	285.88	219.72	401.56	1,066.50
Q_{100yr} (l/s)	219.10	393.08	302.12	552.14	1,466.44

(1): includes land in between Library and Brent Works (optional development site).

(2): includes former electricity board land site (optional development site).

N.B.: an industry standard software package (MicroDrainage) was used to validate the results.

Attenuation storage aims to limit the peak rate of runoff from the development to the receiving watercourse to the corresponding Greenfield runoff rate for a range of annual flow rate probabilities. The outlet structure dictates the rate at which the attenuation volume will drain.

Table 11 below presents the calculated gross storage volumes aggregated by Corridors of Change. These are approximate volumes only at this outline stage, estimated for information and as a general guide for masterplanning only. Further detailed analysis is required to develop final estimates. A site-specific table of results is available in Appendix C.

Table 11 - Gross storage volumes for SUDS sizing

Corridors of Change	1 - Colindale Avenue	2 - Aerodrome Road	3 - Egdware Road	4 - Grahame Park Way	TOTAL COLINDALE AAP
Site Numbers	6,9,10,12,13 (1)	2,7,8,11,14	3,4,15-24 (2)	1,5	
Total Area (ha)	14.25	28.5	19.65	40.1	102.5
Development Option 1: *100% impermeable area*					
$V_{Attenuation\text{-}100yr}$ (m^3)	9,235	16,569	12,735	23,273	61,811
Development Option 2: *75% impermeable area*					
$V_{Attenuation\text{-}100yr}$ (m^3)	5,871	10,532	8,095	14,794	39,292
Development Option 3: *50% impermeable area*					
$V_{Attenuation\text{-}100yr}$ (m^3)	3,110	5,581	4,289	7,839	20,819

A model of the proposed drainage system should be assembled and run at the detailed design stage, with the depth-storage area relationship and other details represented accurately to ensure that adequate storage has been provided and the discharge criteria have been met. The calculations presented above should not be used for design purposes.

5.3.3 Climate change

The Environment Agency recommends that a factor of 20% is applied to rainfall intensity for modelling of flooding and attenuation for residential developments. The MIKE 21 software was used to simulate the 1 in 100 year event + 20% to accommodate for climate change. In addition, the storage calculations presented take climate change into account by applying a factor of 1.1 to rainfall depths[17]. This is necessary as Climate Change will increase probability of flooding from all sources.

5.3.4 Risk based approach

Under PPS25 steps are required, where feasible, to improve downstream flood risk by reducing discharge. Reducing the discharge rate to the "Greenfield" run-off is realistically the maximum achievable improvement where infiltration is not an option (due to the underlying clay soils).

5.3.5 Discharge rates within new development

With the exception of the Peel Centre storage pond(s), the proposed re-designed storage pond at Grahame Park, and the proposed on-line flood detention storage reservoir at Montrose Park, other regional strategic storage areas are not recommended due to topographic and infrastructure constraints. The total discharge for all of the proposed development sites will be limited to the Greenfield runoff rate for the 1 in 100 year flood event, i.e. 1,466 l/s. The location and detailed design of each of the flood detention storage areas must be confirmed through the production of site-specific Flood Risk Assessments at the planning application stage.

5.3.6 Designing for exceedance

It is feasible that discharge in excess of Greenfield runoff can be routed to the Thames Water network (if it can be demonstrated that the network does not surcharge during a 1 in 2 year storm event as recommended in the Sewers for Adoption 6th Edition).

To management the risk of residual flooding, we suggest an Operation and Maintenance (O&M) strategy is developed to minimise the failure of drainage assets, such as gullies, drains and storage areas. Again, these details should be fully addressed in site-specific Flood Risk Assessments.

[17] Defra / Environment Agency, *Preliminary rainfall runoff management for developments – R&D Techincal Report W5-074/A/TR/1 Revision C*, Flood and Coastal Erosion Risk Management R&D Programme, June 2007.