Retrofitting SuDS in your catchment – a case study

Presenters: Laura Benton and Pablo Souto, Mott MacDonald

Laura.benton@mottmac.com; Pablo.souto@mottmac.com

A holistic solution to reduce flood risk

While the implementation of SuDS in new developments has become common industry practice, the retrofitting of SuDS is emerging as a technique on its own, with the added risks of having to adapt to established urban environments and communities. This paper presents a SuDS retrofit case study, covering site selection, stakeholder engagement, concept design through to construction, and associated challenges integrating into the existing local infrastructure. The SuDS measures discussed in this paper form part of Thames Water's Counters Creek Flood Alleviation Scheme (CCFAS) in north west London.

Counters Creek Flood Alleviation Scheme was developed following widespread basement flooding caused by intense rainfall and surcharging of the sewer system in the Royal Borough of Kensington and Chelsea (RBKC) and the London Borough of Hammersmith and Fulham (LBHF). The solution has evolved over time as understanding of flooding mechanisms and catchment knowledge improved. Thames Water is committed to reducing flood risk to their customers, implementing three robust measures across the target areas before March 2020 to achieve a catchment-wide benefit. The three measures include:

1) Property level isolation by installation of pumping devices called FLIPs.
2) Local schemes increasing sewer capacity and storage volume where there are clusters of reported flooding.
3) Implementation of sustainable drainage systems (SuDS) to reduce peak flows into the sewer network and mitigate possible detriment from FLIPs.

Where FLIPs are implemented, the storage that is used by the system is reduced as flood water can no longer enter properties, resulting in an increase in top water level (TWL) locally under surcharge conditions. An InfoWorks ICM catchment model was used as a tool to model the impact of FLIPs and identify local increases in TWL. The key challenge was to mitigate these increases in TWLs, by attenuating flows and minimising the impact on the local community. The principles of SuDS were embraced to design solutions that could address this while adapting to the existing infrastructure and streetscape.

Assessment of top water level changes

1,787 basements across the catchment had reported flooding historically. To understand the local changes in TWL, these basements were represented in the model. A simplified representation was deemed appropriate to review likely changes in TWL across the catchment: all 1,787 basements were modelled by adding a representative storage volume to the shaft of the nearest node to the property. The shaft depth was set at the average basement connection depth from 2,500 surveys. This meant that basement storage was only mobilised during periods of high surcharge. Where multiple basement properties were believed to be connected, a larger volume was applied to the shaft to represent the cumulative basement volume. A cross-check was carried out against the verification monitors to confirm that no significant changes were made to the original verification as a result of this addition.

The model created with all 1,787 basements was designated as the new '2011 baseline' model which represented the pre-scheme baseline.

900 FLIPs had already been installed during previous AMP schemes. It was important to capture changes to the catchment where measures were already implemented. An 'AMP6 baseline' model was developed to represent FLIPs that had already been installed in the catchment. This was achieved by removing the basement volumes applied in the 2011 baseline model at properties where FLIPs were known to be installed before AMP6. A further model was created to represent the final Counters Creek FAS scheme, including all proposed FLIPs and local schemes. Again, FLIPs were represented simply by removing the basement storage from the model where FLIPs were proposed. The 'proposed' model represents the as-designed Counters Creek FAS scheme.

Due to the large volume of storage removed from the system by disconnecting basement storage, there was potential that a localised water level rise could occur. It was not known if all basements were connected, existed or were likely to be affected by changes in TWL, but the risk needed to be understood so targeted investment decisions could be made. An existing dataset, generated in AMP5, was used to assess neighbouring property risk. The basement dataset consisted of approximately 44,000 basements of varying confidence. The 44,000 basements were not fully represented in the model and risk was assessed by the change in top water level in the nearest sewer. This dataset meant that a change in TWL for each basement property could be quantified and a comparison made between the baseline model, AMP6 model and proposed models.

It was agreed that basement flooding, if it were predicted to occur at lower return periods where no flooding had been reported previously, would be of greater impact to the customer than flooding predicted at higher return periods. At lower return periods, the larger strategic sewers in the catchment also have capacity so flows are transferred, reducing risk across the catchment. Therefore, properties showing increases in TWL at lower return periods are more likely to be affected locally. It should be noted that there are also properties that will increase in risk during the higher return periods when the strategic storm relief sewers are full.

Risk was assessed by comparing the AMP6 Baseline Model and the Proposed Model, as these best represented the current catchment and its future state. The risk criteria agreed is shown in Table 1. The likelihood of occurrence was determined by the return period at which the risks occurred. Several iterations were carried out before the agreed selection criteria of a high risk occurring in the 1:1 year, 1:5 year or 1:10 year return period events. These high risk and high likelihood areas were promoted for SuDS schemes. Areas of medium risk and high or medium likelihood (i.e. 1:20 year event) were promoted for long term monitoring.

		Proposed Model – property predicts flooding?	
AMP6 Baseline Model –property predicts flooding?		Yes	No
	Yes	High	Low
	No	High	Low

Predicted change in top water level	Risk Category
Greater than 100mm	High
Between 50mm and 100mm	Medium
Less than 50mm	Low

Table 1 - Criteria used for Risk-Likelihood Assessment of Trigger Properties

The risk-likelihood assessment identified five streets as being high risk. A cross check was also carried out against the customer reported flooding database to determine if there were any flooding records for the properties identified to confirm the presence of basements and support the model predictions. Streets designated as medium risk were considered for long term monitoring to validate the model outputs. This could then provide justification for further SuDS investment in future AMPs if risks materialised.

Testing a concept

The engineering assessment initiated the concept design process, by identifying plan area and depth of potential attenuated storage systems. By looking at street furniture and known services, the largest possible volume was calculated for the streets selected. The attenuated storage areas were simplified and added to the 'proposed model' as a scenario in InfoWorks ICM. The proposed model with storage could then be used to reassess the risk-likelihood assessment and determine if the attenuated storage had a beneficial effect on the trigger properties.

Whilst this was not a detailed representation of the SuDS systems, the initial modelling element was to prove the concept that by providing localised attenuated storage, TWLs could be reduced locally. The impact on TWLs was assessed using the same risk-likelihood assessment: where previously identified as a trigger property, the assessment would confirm if the risk reduced with both the FLIPs measures and the SuDS systems installed. Some streets were found to have a more marked effect than others. Findings indicated that the proximity of SuDS to the FLIPs had the most pronounced effect. Due to the complex interconnectivity of the network, some areas also showed less benefit.

Using a risk-based approach to determine the likely impact on neighbouring properties, it meant that a standard level of protection was not set as design criteria. The SuDS were being used to remove detriment from the FLIPs rather than providing flood protection for a specific design event. The design criteria agreed, therefore, was set out to reduce the number of trigger properties on the street. The scheme was progressed to the next design stage where this was achieved. However, where there was very little impact, further streets were considered to increase the available storage.

Delivering the four SuDS pillars with the local residents

For the five streets identified, potential mitigation measures were considered. These consisted of SuDS solutions which aimed to address the four pillars: water quantity, water quality, biodiversity and amenity. The success of each depended largely on the engineering and local constraints of the streets, along with the potential storage capacity of each of the solutions considered.

'Water quantity' is the key driver of this project. The first consideration was the maximisation of contributing catchment areas into the SuDS system, which was challenging due to the nature of the existing streets. Another key challenge to fully address the 'water quantity' was the limitation to reduce the runoff volume using infiltration due to the proximity to the property basements and the ground conditions. On top of this, there was insufficient space to provide 'green' SuDS (e.g. bio-retention areas) within the parking bays as this could exacerbate the current pressure on on-street parking provision.

Water butts were also considered during the feasibility review: low flows are designed to pass through the water butt and enter into the sewer, meaning that flows were only managed during surcharge of the sewer. For the purpose of mitigating detriment this would not achieve significant benefit as the sewer system would already be at capacity before the water butts started being utilised as storage. Furthermore, the storage volume in each water butt was limited, meaning that properties along one street would require multiple water butts installed. There were also concerns related to the uptake of water butts on a street: not all residents were guaranteed to consent and adopt the maintenance of the water butts. Therefore, this measure was discounted.

Block permeable pavement with geocellular sub-base storage was considered as this could be constructed in modules and retrofitted in the existing streets. This solution was finally selected as the preferred option for the SuDS measures. To maximise contributing area, consideration was given to connecting roof areas in addition to areas within the highways boundary. Roof areas were discounted at an early stage due to the likely disruption to customers by having to enter individual properties and carry out works to divert roof drainage to the new geocellular storage system. Furthermore, a shallow connection from properties into the geocellular units would prove challenging due to the existing services in the footway.

In addition to the permeable pavement, the team also proposed the integration of 'raingarden pockets' into the design, as shown in Figure 1. These 'pockets', generally 2m x 2m, could be located at dead spots or discreet locations in the longer streets without having significant impact on parking provision. These raingardens are part of the hydraulic system of the permeable pavement: geocellular units below the substrate are connected upstream and downstream to the sub-base storage of the permeable pavement. These units include a gravel sump and rockwool material to provide passive irrigation to the substrata by capillary action, thus removing some runoff volume from the sewer. The system also intercepts runoff directly from the highways via kerb openings; a measure that, together with a filter geotextile installed in the permeable paving, provides pollution control should the system be connected to a surface water sewer in the future. These systems, which address the four pillars of SuDS, were designed in collaboration with LBHF and with the technical input from manufacturers (Polypipe Ltd and SEL Environmental Ltd).

Figure 1 - Visualisation of raingarden areas used in consultation with stakeholders

Early consultation with stakeholders was critical to the success of the project. Initial discussions offered opportunities relating to the adoption of SuDS by LBHF and the communication strategy with local residents. This communication strategy, led jointly by LBHF and Thames Water, included drop-in consultation sessions on each of the streets, which allowed residents to understand better the design and be consulted on the proposals. The input from residents helped to refine the designs, especially in the provision of raingardens, which were relocated or ruled out in some streets.

Detailed Design – making the concept buildable

The main objective of the SuDS detailed design was to develop five safe and constructible solutions that could provide the required storage whilst maximising the benefits to the local communities. The five streets were discussed with LBHF to initiate stakeholder engagement and gain an understanding of potential issues related to design and construction of the SuDS systems. The assessment of risks and opportunities was an essential first stage of the design: the potential requirements of the different stakeholders were considered, and the lessons learnt from previous pilot schemes in the area were fed into the appraisal.

Detailed hydraulic modelling and analysis to assess the local performance of the SuDS system was done using MicroDrainage as this was deemed the most appropriate tool. The design considered a number of standards and guidance as listed under 'References'. To assess the performance in the catchment, the best tool for the job was InfoWorks ICM. To speed up the data transfer between the two models, inflow hydrographs were used to represent outflows from the SuDS systems into the network via the outflow control. Contributing areas draining to the SuDS systems were removed from the ICM model to represent diversion to the attenuated storage. The interface between the two models proved a challenge. It is understood that later versions of ICM have an add-on to improve the MicroDrainage and ICM linkage.

Retrofitting in a constrained site

The core solution of the SuDS schemes was the retrofit of block permeable pavement in the parking bays of these residential streets. The main storage element selected in the solution was a geocellular sub-base replacement as this could provide approximately 3 times more volume than permeable unbound sub-bases and therefore reduce the depth of excavation and risk of clashing with underground utilities. Other ancillary elements include inspection chambers to restrict the flows from the sub-base replacement and new manholes to provide a downstream connection into the combined sewer system. The flow control chambers were provided with orifice and weir plates to minimise discharge rates and maximise the storage capacity. Orifice sizes were set to a minimum of 50mm diameter to minimise discharge rates while reducing the risk of blockage. The downstream manholes included flap valves and foul air traps to prevent back flows, odours or gases entering the SuDS system. Figure 2 shows the construction of one of the five streets and the elements used to integrate into the existing infrastructure.

During the risk appraisal, initial estimates indicated that an approximate 1m of construction depth would be required in the parking bays. The presence of multiple underground features was expected at this depth, including live or abandoned utilities along the parking bays, lateral utility connections into the properties and tree roots protruding from the footway. These constraints could make the scheme unfeasible as the programme did not allow for service diversions.

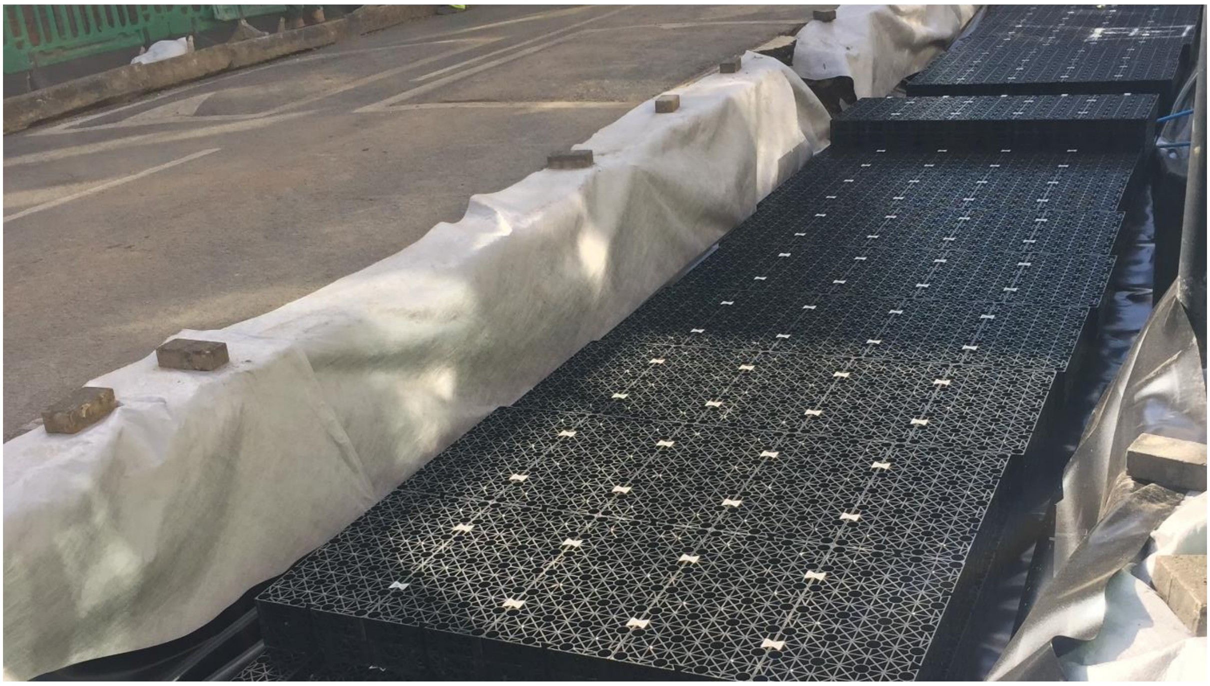

Figure 2 - Construction of one of the five streets

Several actions were taken by the team to respond to this challenge:

1) Undertake surveys, including Ground Penetrating Radar (GPR) and trial pits at specific locations to expose underground utilities. Whilst the GPR survey identified the key utilities, it was inconclusive in the determination of depths and the location of several services, especially those abandoned. The undertaking of further ground surveys and trial pits did not eliminate the risk of finding unexpected underground features during construction but increased the level of confidence in the design. In particular, a second phase of trial pits during the design phase was critical to mitigate the issues that would have arisen during construction.

2) Early consultation with the Stakeholder Undertakers / Utility Providers: The early consultation and coordination with Stakeholder Undertakers allowed the team to establish site-specific requirements at the start of the design phase. These requirements included exclusion zones near critical utility assets (e.g. high pressure gas mains), agreements and procedures for the removal of abandoned services, clearances and protections to live assets and requirements for working in the vicinity of certain services. Nearly all the streets had on average one redundant gas or water main to be removed, more than ten laterals connections crossing the parking bays at shallow depths and one live utility running within or in close proximity of the excavated area. The scheme was presented as a ‘reinstatement’ of the parking bays with a modular pavement construction that would be categorised as a street of Special Engineering Difficulty (SED) as per the New Roads and Street Works Act 1991. The design had to consider the potential need for emergency access to underground services and propose method statements for reinstatement.

3) Develop ‘modular’ solutions: the different constraints did not allow for the provision of the standard permeable pavement cross section throughout the length of the scheme. As a response to these constraints, the team developed ‘modular’ solutions that could adapt to different scenarios found on site. These solutions involved different configurations and combinations of geocellular units and 4/20 graded sub-base material.

4) Clash check in 3D model: Modelling the utilities and the geocellular sub-base in a 3D environment helped to bring more confidence on the setting out of the permeable paving, as shown in Figure 3. It also helped to quantify the resulting storage capacity of the system.

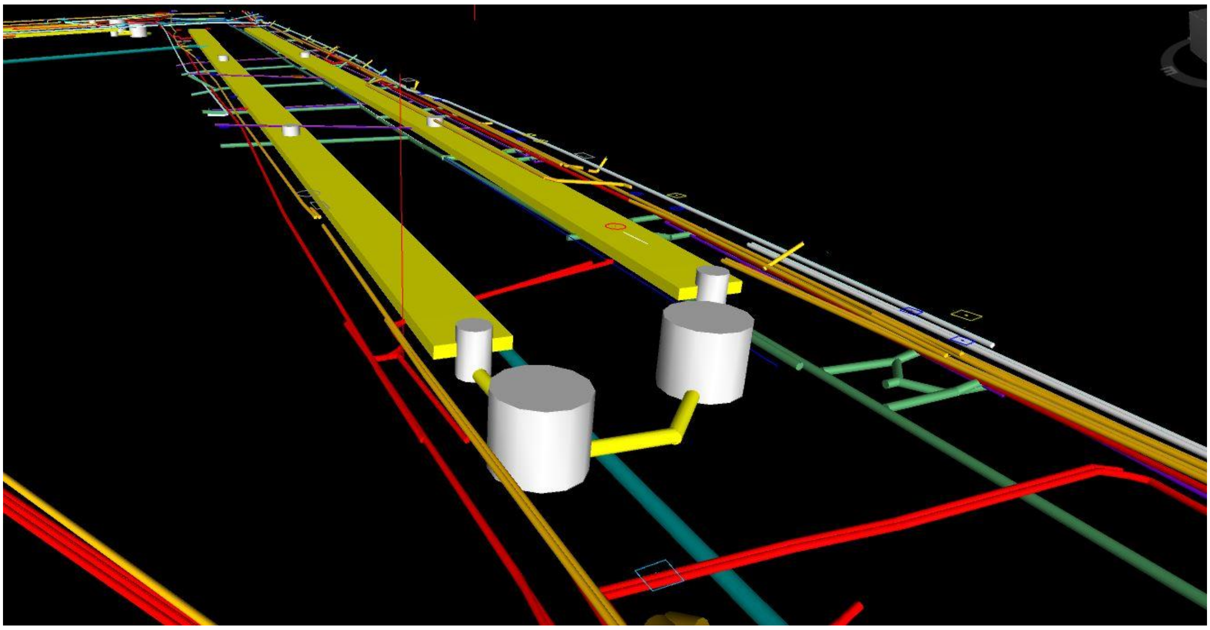

Figure 3 - Example of clash check with existing utilities and proposed geocellular sub-base

A robust solution that learned from previous experiences

Whilst guidance is available for the structural design of geocellular systems, testing material in systems with low cover is limited. This guidance and lessons learnt from other pilot schemes was used in the pavement design.

As the parking bays were within the highway, it was considered that they should be designed for commercial vehicle overrun. Published guidance for geocellular storage structural design warns that they may be vulnerable to traffic damage when installed below pavements at less than 1m cover. A proprietary permeable concrete base was provided below the block pavers to provide protection to the geocellular units. This was chosen because it has improved flexural strength, crack resistance and load-spreading ability under repetitive loading compared with permeable hydraulic bound material and traditional no-fines concrete. Moreover, its placement avoids the need for compaction plant to traffic over the geocellular units. To obtain a low cover pavement design, analysing the base thickness required customisation of the approach set out in CIRIA C737 which covers structural design using geocellular units.

Conclusions and opportunities

Construction of the five streets is approximately 50% complete at the writing of this paper. The key lessons learnt are:

- Rethinking the traditional 'level of protection' has allowed for opportunities to be realised within the catchment, offering smaller-scale solutions bringing quantifiable benefits for the customers.
- Detailed modelling is not always required to demonstrate the effects of a scheme. Where possible the extent of modelling should be proportional to the level of confidence of the model and the desired outcomes of the investigation.
- A collaborative approach with the Local Authority is key for the success in the implementation of SuDS retrofit schemes.
- Early coordination with Statutory Undertakers and surveys are essential to understand above and below ground constraints.
- Design needs flexibility and modular solutions that can adapt to specific constraints.
- Traffic loading assessment and pavement design needs to be specific to the site.
- Several issues were experienced during construction with the laying of permeable concrete. Incorrect methods of laying could lead to loss of permeability in the concrete base.
- There are opportunities to deliver the four pillars of SuDS – engagement with the supply chain is important to identify innovative products.

Figure 4 - Example of completed scheme showing permeable pavement and geocellular storage below parking bays

References

Sewers for Adoption 7th Edition
Highways England Design Manual for Roads and Bridges (DMRB)
Defra 'Non-statutory technical standards for sustainable drainage systems', 2015
CIRIA C753 'the SuDS Manual', 2015
CIRIA C737 'structural design of modular geocellular drainage systems', 2016
BS 7533-13:2009 'Pavements constructed with clay, natural stone or concrete pavers', 2009