West Sussex Lead Local Flood Authority
Over The Wall Drainage Study

FEASIBILITY STUDY

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CONTENTS

1. INTRODUCTION

Five hundred and eighty-nine of the world's cities are ports. In the developed world, many of these benefit from defended coastlines protecting them against steadily rising sea levels. Presently, 40% of the world's population live within coastal regions and this percentage is anticipated to continue to increase.

In the UK there are 17 sea port towns and cities. In these locations, sites historically occupied by trade and industry associated with the port are increasingly being re-developed for residential, office and leisure uses. Over 5.3 million UK citizens live in coastal towns and, like many other parts of the UK, the population of these coastal towns is continuing to rise.

Shoreham-by-Sea has a population of 20,547 as indicated by the 2011 census, The ONS 2021 census data shows that the Adur district population, in which Shoreham-by-Sea is located, has increased by 5.4%.

The global mean sea level has increased by 200 mm since the beginning of the mid 19th century[1] and measurements acquired by both ground and satellite instruments indicate that the rate of sea level rise has been increasing over the last 20 years. The primary components of sea level rise are:

- **Ocean expansion.** As global temperatures increase, the sea warms and the water expands (thermal expansion). Thermal expansion of the oceans results in sea level rise of 1.6 +/- 0.5 mm per year.
- **Mountain glaciers.** As global temperatures increase, the mountain glaciers shrink as they melt faster than the mass they gain through snowfall. Mountain glacial melt could raise global sea levels by 50 mm.
- **Ice sheets.** As global temperatures increase, the ice sheets shrink as they melt faster than the mass they gain through snowfall. Ice sheet melt could raise global sea levels by a significant amount. The ice sheet of Greenland could increase sea level by 7 m.

During the last ice age, the north of the UK had an extensive ice sheet above it, while the south of England did not. The pressure from the force of the ice sheet pushed the UK crust down in the north, which caused the southern crust to rise. The re-adjustment of the Earth's crust, due to the Ice-sheet no longer being present, results in the north of the UK rising on average by 1 mm a year, while the south on average sinks at a rate of 1 mm per year.

1 IPCC, 2022: Climate Change 2022: *Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

1.1 Tackling an increasing threat

Our harbourside and seaside areas are increasingly under threat from rising sea levels and climate change factors that impact high tide levels. Not only are we dealing with protecting these areas from flooding from the sea, but also from surface water flooding (also known as pluvial flooding). Traditional surface water gravity drainage systems are coming under increasing pressure due to increased rainfall intensities, higher groundwater levels and higher sea level/tidal levels, which results in longer periods during which the systems cannot drain into the tidal waters alongside. This tidal locking is resulting in significant flooding behind tidal defences.

This report explores some of the issues of draining the Shoreham Harbour Regeneration development area into tidal waterbodies, with a particular focus on reducing the surface water storage requirements and the associated flood risk of proposed developments and adjacent local properties and public areas. Designing for free discharge at outfalls as an assumption is general best practice, whether it is a gully into a receiving pipe, highway drain, or sewer draining into a watercourse. In tidal areas where sea levels affect an outfall, the joint probability of high tide coinciding with a rainfall event needs to be evaluated in terms of the downstream hydraulic influence. One driver for this study has been the observation that insufficient attention is currently placed on assessing the impacts of sea level rise upon tidal locking and consequential surface water flood risk inside of defended coastlines / estuaries. There are numerous instances of outfalls from drainage systems being constrained by water levels in downstream receiving systems or rivers. The concept of designing drainage using joint probability has been around for a few years, but there is a need to develop best practice in this area with the support of appropriate awareness raising, design guidance, and tools[2].

Most research and guidance in the surface water management area is focused on development areas that drain to sewers or non-tidal watercourses. However, coastal development can be at risk from, and contribute to, surface water flooding, as well as being at risk from tidal and groundwater flooding.

The recommendations made in this report are aimed at minimising the discharge to tidally locked outfalls, reducing the volume of surface water beneath these average tidal levels, thereby reducing the extent of surface water flooding behind tidal defences and flooding issues associated with combined sewer overflows. The means to achieve it is what we have referred to as 'Over-the-Wall' drainage.

> The Over-the-Wall (OTW) drainage principle involves draining, managing and discharging as large a proportion as feasible of the developmental runoff above the 'design' maximum predicted high tide level.

2 Defra (2015) Evidence review of factors contributing to surface water flooding from Section 19 LLFA reports. Final Report FD2692 dated 21 Oct 2015.

1.2 UKWIR Big Question 6: Project 03

In 2019 UK Water Industry Research launched their Big Question Programme – twelve questions challenging the water industry to be more sustainable and equitable in terms of water supply and wastewater management. The questions ranged from “how will we achieve zero leakage in a sustainable way by 2050” to “how do we remove more carbon than we emit by 2050”. Question 6 of these big questions would be the most pertinent to this review.

Question 6 (BQ6) is: ‘How do we achieve zero uncontrolled discharges from sewers by 2050?’ UKWIR have instigated a series of research projects aimed at answering each ‘big question’. BQ6 has been broken down into eight tasks, which when combined should answer the original question. Task 3 will categorise the area characteristics of the development and how these influence the actual design practice and what alternative approaches can reasonably be used to meet current SuDS best practice. Task 4 is an exploration of the possible changes that might be made to current standards and criteria with particular attention on achieving greater benefits for the performance of receiving sewers.

At the time of publication, the UKWIR Big Questions was still in progress, however the interim answers are as follows:

- Create an advocacy to force the inclusion of SuDS in town and country planning (High Priority)
- Create best practice standards and benefits for surface water drainage (High Priority)
- Use Natural Flood Management in urban areas for surface water drainage (Medium Priority)
- Restore lost/covered watercourses and natural runoff pathways (Medium Priority)
- Rainwater capture and greywater recycling and make it more widespread (not prioritised)
- ‘Sponge’ Cities opportunities and case for more widespread use of permeable surfacing (Medium Priority).

All of the interim answers overlap with the mitigations and guidance highlighted within this document. For the Shoreham-by-Sea area, this report aims to be a best practice standard, which highlights the benefits of the Over-the-Wall and SuDS approach to the area.

Following the methodology highlighted in chapters 5 and 6 will not only allow the development to comply with the guidance highlighted in the SuDS Manual but will provide answers to the UKWIR Big Question 6.

2. THE OVER-THE-WALL PRINCIPLES

2.1 The problem

Development adjacent to tidal waterbodies is often at an elevation that results in drainage outfalls that are below the Mean High Water Springs (MHWS) tide level. In some cases, new development is on land that is protected from tidal flooding by coastal defences, with portions of the development's external environment being below the Highest Astronomical Tide level.

This is being exacerbated by steadily rising sea levels. The Environment Agency state that between the years 2000 (its baseline) and 2125 sea level will rise by 1.2 m with a potential to reach 1.6 at the upper end of their modelling.

The sea is not at the same level throughout the UK due to the gravitational differences in different parts of the UK, and atmospheric and ocean circulations. The Mean Sea Level (MSL) at Shoreham is 1.95 m AOD. Based on the UKCP 2018 RCP8.5 scenario, the mean sea level rise is expected to be 1.5 m. Therefore, the mean water level at high spring tide is projected to be 3.03 m AOD.

To comply with flood risk requirements, the sea defence level needs to be able to manage the 0.5% Annual Exceedance Probability (AEP) flood level in 2115. This level is circa 5.4 m AOD, which is above most of the existing sea defences in this region. Existing sea defences would need to be raised by 1 m, and in some areas 2 m, to meet this requirement.

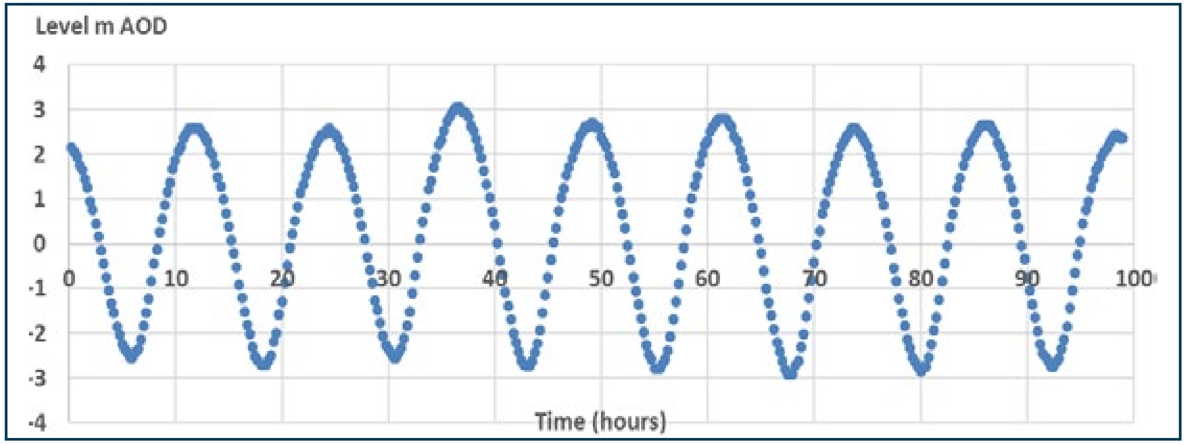
2.1.1 The effect of tidal submergence of outfalls and the need to attenuate

Tidal outfalls typically require a form of non-return valve, such as a traditional flap valve, to prevent seawater from entering the pipe network and flooding development at high tides when the sea level may be higher than areas protected by sea defences.

Submergence of outfalls during tidal fluctuations can mean that surface water cannot drain away from development effectively, or at all, if it is raining during the submerged period. This is due to the higher tidal water body exerting pressure upon the submerged valved outfalls. The action of tidal water pressure on an outfall and the period of time that the outfall is unable to drain, due to the tide, is called tidal locking.

Without the temporary storage of development runoff during these events, flooding is likely to occur behind the coastal defences. This can be within the development itself, or elsewhere within a surface water sewer catchment if the development is on a shared network, depending upon the design of that system.

By storing runoff within the development during the phase of tidal locking, flooding can be averted, with the stored runoff discharging once the tide drops below the outfall. A system that has water above the tide line, but an outlet below, will have an associated pressure gradient and this hydraulic pressure could be sufficient to open the flap depending on the weight of the flap and all the elements of the flap valve being in good working order. However, a flap value would still form a restriction to the free discharge of water or, at worst, lack of maintenance could result in the flap valve seizing in an open position allowing the tide to enter the surface water system. The risk of the flap not being in good working order increases the longer the flap is submerged.



MWHS tide in year 2121 in Shoreham (average estimate)

2.1.2 Existing development

As sea levels rise, the existing outlets will become below the MHWS tidal levels, which will tidally lock the existing development, causing the surface water sewer systems to be under pressure and result in an increased threat of surface water flooding. Many past developments were designed to the lower criteria required at the time, which means there would not be sufficient storage provided nor adequate protection. Retrofit measures on these existing developments to reduce runoff altogether, to provide greater amounts of attenuation, or reduce the amount that drains to tidally locked outfalls would be beneficial.

Tidal Locking: During high tides the water pressure from sea / tidal river will prevent water from rivers, sewer connections and direct discharges from flowing in.

2.1.3 The impact of outfall invert levels on runoff storage volume requirement

The lower the invert of an outfall into tidal waterbodies, the longer that inlet will be submerged during high tides. As runoff may be continually being generated during the tidal locked phase, the longer that the outfall is submerged, the greater the volume of temporary storage required to prevent flooding from stormwater runoff. This tidal locking will be exacerbated with sea level rise.

The chosen attenuation technique can influence the outfall invert level and therefore the tidal lock period, which has positive feedback on the required attenuation volume. Deeper attenuation features themselves generate larger attenuation volume requirements. There is a correlation between outfall invert level and the cost to attenuate runoff. Essentially, the higher the elevation of the outfall, the less storage is required to reduce flooding, resulting in less associated cost. Table 1 shows how different systems with different depths perform with differing ground level.

Commonly used techniques for storing runoff include underground geocellular structures, tanks or oversized pipes. The excavation, supply and installation costs of such features can be significant.

Table 1 – Percentage reductions in volume (against tanked storage option) for 2 ha site with four outfalls

Highest platform ground level (m AOD)	Drainage system adopted	Climate change 30 year rainfall MHWS tide Scenario 1	Climate change 100 year rainfall MHWS tide Scenario 2	Climate change 2 year rainfall 200 year tide Scenario 3
3.5	Shallow tank + principles outlined in this document	0%	0%	45%
4.0	Tank	0%	0%	0%
4.0	Shallow tank	0%	0%	-6%
4.0	Shallow tank + principles outlined in this document	0%	0%	47%
4.5	Tank	0%	0%	0%
4.5	Shallow tank	0%	0%	-12%
4.5	Shallow tank + principles outlined in this document	0%	0%	44%
5.0	Tank	0%	0%	0%
5.0	Shallow tank	0%	0%	-19%
5.0	Shallow tank + principles outlined in this document	0%	0%	43%

2.1.4 Risks associated with tidal outfalls

Flap valve outfalls can be blocked closed due to the build-up of sand, mud, rocks or debris on the outside of the outfall, or through damage or wear. This can mean that the discharge rate is limited or blocked completely, resulting in upstream flooding when it rains sufficiently to exceed the blocked valve's limited discharge capacity.

They can also be kept open by similar debris being caught in the mechanism or opening, or again through damage or wear. This can then allow tidal seawater to flow back into the pipe network and flood upstream areas that are at a lower level than the sea level.

If this happens in a system with tank storage, silt or sand can enter the pipes and storage tanks, blocking them or limiting their future capacity and potentially requiring expensive remediation.

Typically, the risk of blockage is reduced the higher the invert and the potential duration of back-flow (if blocked open) is reduced to the point where outfalls above the maximum projected sea level have a minimal risk of blockage and back-flow.

For flashy river catchments such as the River Ouse in East Sussex, intense rainfall can be accompanied by prolonged periods of swollen rivers where water levels are very high which was evidenced by the October 2000 flooding in Lewes. Tidal locking on surface water systems, for communities in this context, can significantly increase the severity and duration of flooding

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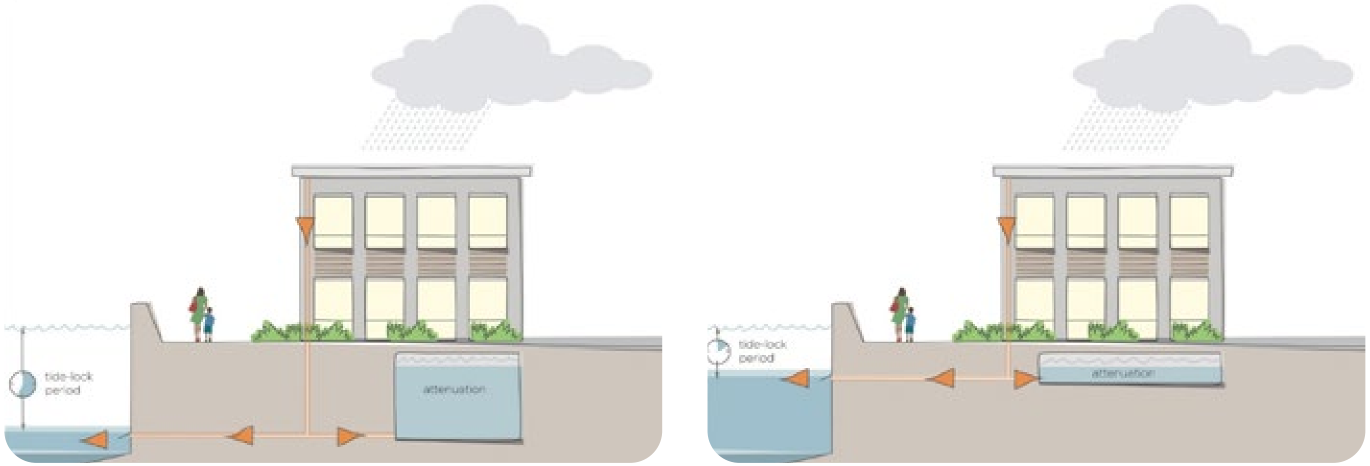
Example of flap valve partially open.



Graphic showing the impact of outfall invert level on storage requirements. Two versions of development – one with low outfall and larger attenuation box and one with higher outfall and smaller, shallower attenuation box.

2.2 Over-the-Wall: discharging above sea level or above sea defences

Ultimately, if the outfall level is high enough not to become tidally locked, there is no requirement for tidal locking storage and the risk of surface water flooding is dramatically reduced.

The potential benefits of discharging above maximum sea level are:

- Reduced requirement for runoff storage, reducing build complexity, costs, and ongoing maintenance liabilities.
- Increased opportunity for integrating SuDS techniques to clean runoff, prior to discharge into the marine environment.
- Increased resilience to flooding.
- More visible flow and management of runoff in the landscape, leading to visually interesting developments and wildlife habitat opportunities.
- Ease of maintenance.
- More acceptable to the Lead Local Flood Authority.
- Where surface water flooding does occur behind tidal defences, if the outfall is at, or as close to, the elevation of the design tide as possible, it can mean that the recession of the surface water flooding can occur more rapidly than an outfall well below the flood level of a swollen river/coast.
- The potential scope for re-use in irrigation or rainwater harvesting; a particularly significant consideration for West Sussex that is currently a water stressed region.
- Shallower systems have less CDM risk associated.
- The combination of features and purposes of materials, such as sub-base and attenuation in pervious paving, will reduce materials.
- One lorry of Permavoid is equivalent to 27 lorry loads of aggregate, thus reducing truck cycles and the carbon footprint of the development.

2.3 Retrofit application

There may be opportunities to improve the drainage performance of existing developments adjacent to tidal waterbodies, or relieve capacity issues in surface water sewer networks, by redirecting all, or a proportion, of their runoff to Over-the-Wall solutions.

Many of the Over-the-Wall options explored in this report are appropriate for retrofit applications and could be designed to bring added character to a development. The principles outlined later in this report have been used extensively within retrofit applications and, crucially, many of the principles of the Over-the-Wall approach involve keeping the surface water attenuation as shallow, or elevation as high as possible.

When designing sustainable drainage in retrofit applications, one of the keys to a simpler design and construction is keeping the features as shallow as feasible. By doing this, the risk of hitting services, contamination and groundwater etc. is minimised.

CASE STUDY – Queen Caroline Estate, London

Retrofit SuDS as part of amenity improvements to c.2500 sq.m. of public open space. The main SuDS components were:

- Green roofs
- Rain gardens
- Swales
- Basins
- Permeable paving

For a more comprehensive overview of the Queen Caroline Estate, London project please visit Susdrain.org

3. CONTEXT

This report focuses on the potential application of the Over-the-Wall drainage approaches within the Shoreham Harbour Regeneration Area, however the principles are applicable in any area draining into tidal waters.

The interpretation of government and best practice guidance for determining surface water storage requirements for new waterfront developments is considered to vary widely. As a consequence, there is a lack of consistency in design that, arguably, will leave a legacy of issues in the future for schemes that are not sufficiently conservative. The proposals made within this chapter provide the best practice guidance for not only the West Sussex region, but also the south coast and beyond.

3.1 Shoreham Harbour hydrogeological context

Shoreham-by-Sea is located on the estuary of the River Adur which flows southward from the chalk hills of the South Downs situated to the north. Characteristics of this context include:

- The whole of the Shoreham Harbour area and surrounding Adur region is underlain by a Cretaceous chalk horizon, the main aquifer for the region. Chalk is porous and allows for both horizontal and vertical movement of groundwater. Its hydraulic gradient is from the higher South Downs where the aquifer is recharged moving down toward the River Adur and the sea which both act as the main groundwater discharge elements.
- The raised beach deposits and the tidally influenced saline intrusions act as a significant barrier to groundwater movement. At times of high groundwater recharge pressure from the excess water higher up the hydraulic gradient can result in pressure within the Shoreham area causing vertical movement of groundwater resulting in potential springs and the emergence of groundwater.
- The sub-surface saline intrusion is linked to sea levels. The tide will affect the saline intrusion and this moving barrier can cause a pressure response in the groundwater in the chalk. This means that groundwater will rise and fall with the tides, and the higher the tides the higher the groundwater.
- The current Mean Sea Level is 1.95 m AOD. The anticipated Mean High Water Springs (MHWS) tide level in 2115 is 3.03 m AOD. The anticipated 1 in 200 year tidal flood level is 5.4 m AOD.
- Large sections of the existing sea defences in this area are below the 1 in 200 year tidal flood level and will need to be raised by 1 m in most parts and 2 m in some areas.
- Changing pluvial runoff rates, due to climate change, and the impact on existing drainage networks.
- As with many parts of the UK, much of the existing sewer capacity is older and there is currently not enough capacity within them due to the historic culverting of watercourses to the sea or River Adur, the increase in population of the area and the increased intensities of rainfall associated with climate change.
- Shoreham Harbour has significant flood defences thoughout, with some areas in good condition and some areas in poor condition. Proposed improvements to the sea wall have been identified as part of the Joint Area Action Plan. These areas include The Western Harbour Arm, Southwick Waterfront and Aldrington Basin.
- Shoreham Harbour has a mixture of low to medium rise houses with newer sea fronting developments. There are areas along the front available for house boats.

The A259, which is a critical south coast link road running east from Emsworth, Hampshire, and terminating at Folkestone, runs through Shoreham-by-Sea. As the road passes through the Shoreham Harbour area, it falls below the 2115 1 in 200 year flood level, and at one point adjacent to Tarmac Wharf & Freewharf, below the existing flood defences. All road drainage on the A259 relies upon gravity to discharge to the sea, leaving the infrastructure and adjacent areas vulnerable to the effects of climate change.

3.2 Shoreham Harbour Joint Area Action Plan

The Shoreham Harbour Joint Area Action Plan (JAAP) is a strategy, prepared by the Shoreham Harbour Regeneration Partnership, for the regeneration of Shoreham Harbour and the surrounding areas. The Shoreham Harbour Regeneration Partnership is made up of Adur District Council, Brighton & Hove City Council, West Sussex County Council, and Shoreham Port Authority. The Partnership also works closely with a number of other organisations including the Environment Agency, Homes England, Highways England, Natural England, and Historic England.

The plan was prepared in conformity with the National Planning Policy Framework (NPPF) and Planning Practice Guidance (PPG), and includes proposals and policies for new housing and employment generating floor space; and for upgraded flood defences, recreational and community facilities, sustainable travel, environmental and green infrastructure improvements. The JAAP sets a planning policy framework to guide development and investment decisions within the Shoreham Harbour Regeneration Area up to the year 2032.

The plan was adopted by Adur District Council, Brighton & Hove City Council, and West Sussex County Council in October 2019 and contains the following:

- A long-term vision, objectives and strategy for the Shoreham Harbour Regeneration Area.
- Themed area-wide policies on climate change, energy, sustainable building, flood risk, sustainable drainage, economy, employment and biodiversity, to name a few.
- Proposals for seven character areas, including four allocations for new development.
- An outline of how the Shoreham Harbour Regeneration project will be delivered, monitored and implemented.

The regeneration of Shoreham Harbour and surrounding areas is a longstanding aspiration of all the project partners. The partnership produced this plan to identify realistic, deliverable and sustainable proposals for the regeneration area. The JAAP will help to generate investment and access funding for improved infrastructure, including sustainable transport, flood defences and sustainable drainage. It supports the safeguarding of the important function of Shoreham Port, including the importing and handling of aggregates and minerals.

Further information, along with the JAAP, can be found on the West Sussex County Council's website: www.adur-worthing.gov.uk/media/Media,155803,smxx.pdf

3.3 Flood risk

Flooding can come in six forms, and all should be considered when looking at a site. The six forms are fluvial (from rivers), pluvial (from the land), tidal, groundwater, sewers and other artificial sources.

For river and tidal flooding, the NPPF uses four Flood Zones to characterise flood risk. These Flood Zones refer to the probability of river and sea flooding, ignoring the presence of defences, and are detailed in Table 2.

Table 2 – NPPF Flood Zones

Flood Zone	Definition
1	**Low probability** (less than 1 in 1,000 annual probability of river or sea flooding in any year (<0.1%)).
2	**Medium probability** (between 1 in 100 and 1 in 1,000 annual probability of river flooding (1%–0.1%) or between 1 in 200 and 1 in 1,000 annual probability of sea flooding (0.5%–0.1%) in any year).
3a	**High probability** (1 in 100 or greater annual probability of river flooding (>1%) in any year or 1 in 200 or greater annual probability of sea flooding (>0.5%) in any given year).
3b	**Functional floodplain.** This zone comprises land where water has to flow or be stored in times of flood. Land which would flood with an annual probability of 1 in 20 (5%), or is designed to flood in an extreme flood (0.1%) should provide a starting point for discussions to identify functional floodplain.

The NPPF classifies the vulnerability of developments to flooding into five categories. These categories are detailed in Table 3. Based on the vulnerability of the development, the NPPF states within what Flood Zone(s) a development is appropriate. The flood risk vulnerability and Flood Zone 'compatibility' of developments are summarised in Table 4.

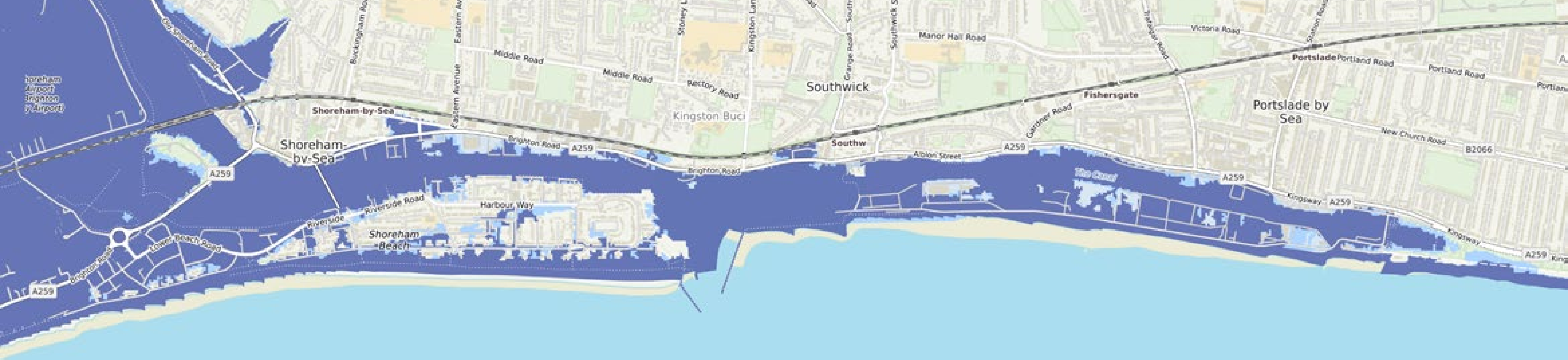
Table 3 – Vulnerability Classification

Flood risk vulnerability classification	Examples of development types
Essential infrastructure	Transport infrastructure Utility infrastructure (e.g. water treatment works and wind turbines)
Water compatible	Flood control infrastructure Water and sewerage infrastructure Navigation facilities Water based recreation
Highly vulnerable	Emergency services Basement dwellings Mobile home parks
More vulnerable	Hospitals and other health services Residential establishments Educational establishments
Less vulnerable	Commercial establishments (e.g. shops, restaurants and offices)

Table 4 – Development Compatibility

Flood risk vulnerability classification	Essential	Water compatible	Highly vulnerable	More vulnerable	Less vulnerable
Flood Zone 1	✓	✓	✓	✓	✓
Flood Zone 2	✓	✓	Exception test required	✓	✓
Flood Zone 3a	Exception test required	✓	✕	Exception test required	✓
Flood Zone 3b	Exception test required	✓	✕	✕	✕

✓ Development is appropriate ✕ Developments should not be permitted



Flood zones at Shoreham-by-Sea

The majority of Shoreham-by-Sea is in Flood Zone 1. However, large areas along the bank of the River Adur and around the harbour are in Flood Zone 2 and Flood Zone 3 meaning they are at medium to high probability of flooding, respectively.

Shoreham-by-Sea is susceptible to pluvial flooding due to the larger proportion of impermeable areas and built-up nature. Much of this flooding will concentrate in low-lying areas where water cannot easily drain away. Basements and cellars are at an increased risk as they are situated below ground level and potentially below sea level. All modern basement design should allow for a head of water to bare against the full height of the basement. However, water that rises above the thresholds by-pass the basement waterproofing and protection.

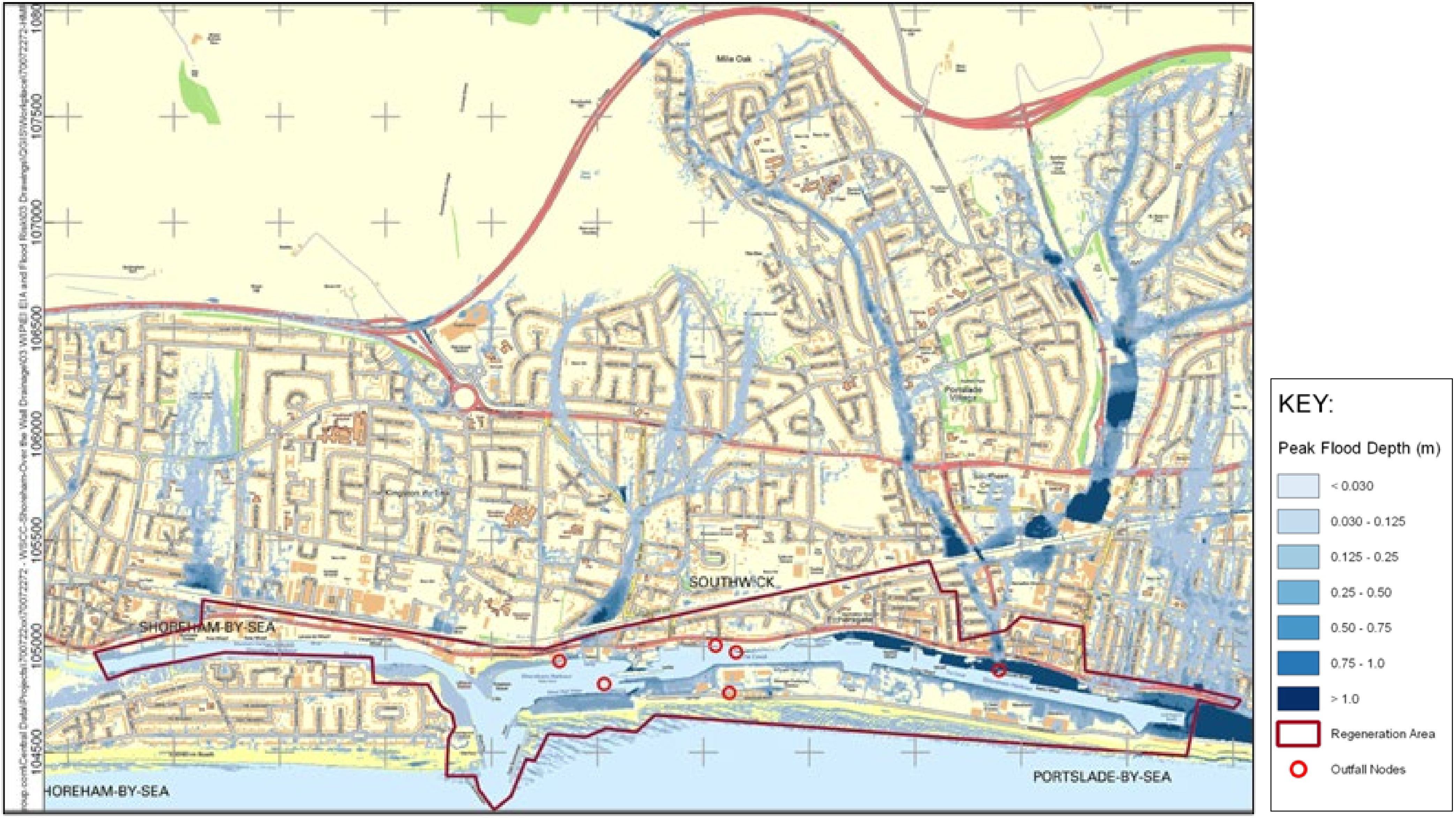
WSP prepared a report titled “Strategic Modelling in the Shoreham Regeneration Area”. They modelled flooding within the area by assessing the peak flood depths and flow routes for the 1 in 100 year rainfall event combined with an MHWS tide, taking into account climate change (year 2121) at pre-development and post-development stages.

They used the Southern Water 1d Infoworks model (representing the pipe network) and converted it to 1d-2d using the latest version of the ICM Infoworks tool, creating hydraulic connectivity between the pipe network system and the ground terrain at modelled nodes (manholes). This way it was possible for them to model overland runoff entering the network at the model nodes as well as the overflowing of model nodes when the pipe network system is fully surcharged.

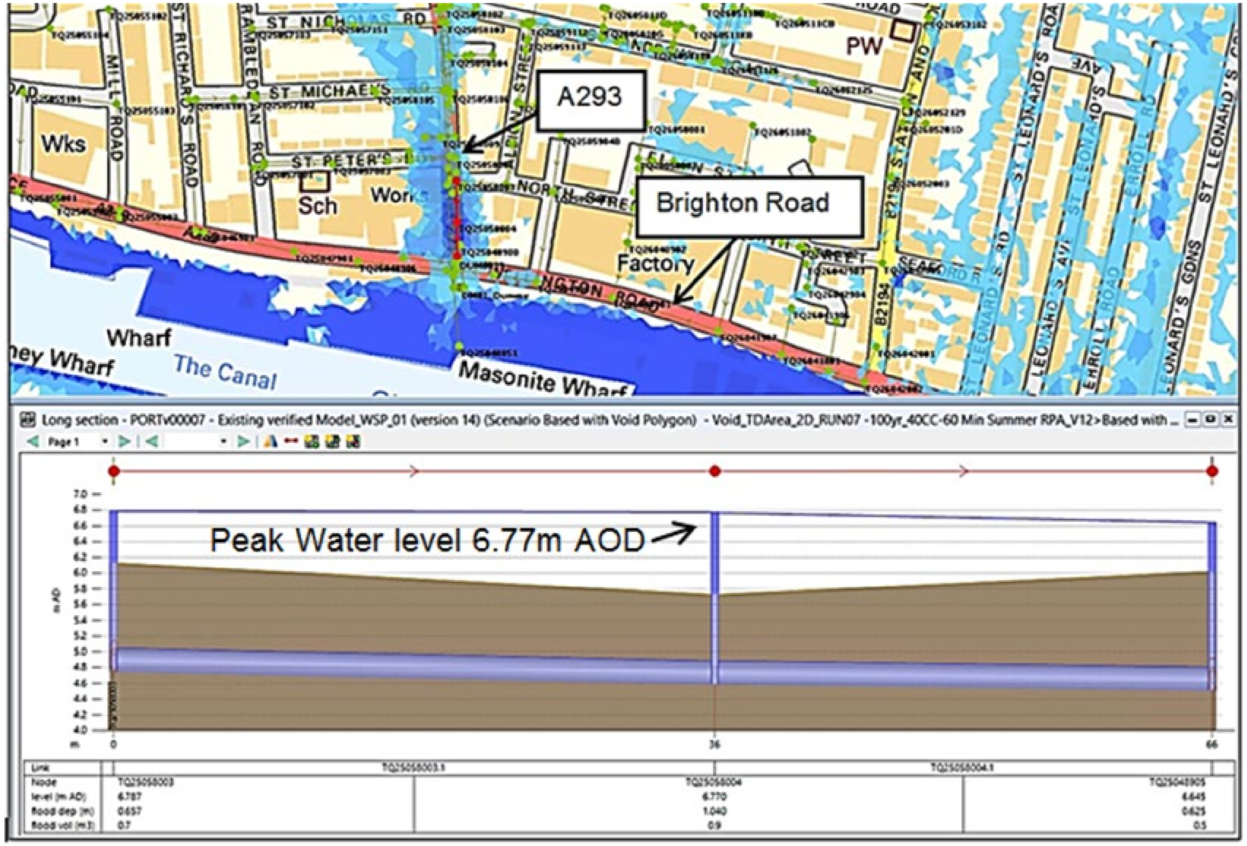
Their pre-development model indicates that the majority of the surface water and combined drainage systems running north to south towards the Shoreham Harbour Regeneration Area will be overflowing in particular in the vicinity of the existing outfalls to the harbour. WSP identified two hotspots on the east side of the area that need to be carefully considered to ensure that new development is safe and does not increase flood risk to the area, or elsewhere. One of the hotspots they highlighted in their report was an area around the junction of Brighton Road with the A293.

Their post-development model assessed the effect of removing roof runoff from any proposed development within the Shoreham Regeneration Area. This could be achieved by a combination of Over-the-Wall drainage, rainfall harvesting, or directing to water-compatible uses. Their model indicates that the extent of flooding is similar to pre-development conditions, but with significant reductions in flood depths, as a result of the Over-the-Wall approach. Peak floods depths were modelled to be reduced in large areas by up to 0.15 m and in some areas by up to 0.25 m.

The modelling demonstrates that Over-the-Wall drainage can be used to minimise the effects of surface water accumulation inside engineered sea defences, thereby reducing surface water flood risk. Used in conjunction with other flood risk measures, it forms an important component of resilience against long-term flood risk in waterfront development areas.



Pre-development climate change flood risk - peak flood depths at Shoreham



Pre-development climate change flood risk - plan and long section of the A293

Flood impact map between the Over-the-Wall and pre-development condition, WSP Technical Note, Strategic Modelling in the Shoreham Regeneration Area, April 2021

3.4 Drainage and maintenance in the coastal environment

Coastal environments bring unique conditions that can impact the wear, maintenance and vulnerability of drainage systems.

Salt-laden rain and spray can corrode metals and moving parts, outfalls can become blocked by tidal debris or shifting silts and sands, wind-blown sand can build up within development and get washed into drainage systems and sea birds have a tendency to deposit shells and other material on roofs where they can block outfalls or pipework.

3.5 Geology

The Shoreham area is underlain by the White Chalk Subgroup, comprised of three formations, the Culver Chalk Formation, the Newhaven Chalk Formation, and the Seaford Chalk Formation. The lithology of these formations is described [respectfully] as chalk with flints; discrete marl seams, nodular chalk, sponge rich, and flint seams throughout.

The thickness of the subgroup is variable, but is thought to be between 350 m and 515 m thick.

The superficial deposits underlying the area consist of alluvium, beach, river terrace, and tidal flat material, consisting of a mix of clay, silt, sand, and gravel.

The South Downs rise to a ridge of around 240-300 m in elevation above sea level. During a period of high rainfall and when groundwater levels are high, this can generate rapid runoff onto the coastal flood plain. At the base of the slope of the South Downs, a spring line runs along the change in geology from chalk to clay causing an emergence of groundwater into nearby streams and ditches. Above the clay sits a band of sand alluvium in which there can be a high prevalence of perched groundwater that can create saturated ground conditions over the winter months. Where the clay layers are interrupted for example by beach deposits, particularly prevalent in the Shoreham area, the pressure on the groundwater drives it upwards increasing the potential of groundwater flooding and adding to the likelihood of saturated conditions. Saline intrusion can create additional problems for both foul and surface water drainage networks and it is very reasonable to assume that as sea levels rise over the next few decades, the prevalence of saline intrusion will also increase.

Infiltration

Chalk is a type of limestone and tends to have a high porosity. Where chalk forms an aquifer, most of the transmissivity results from the enlargement, by solution, of fractures within the chalk which leads to areas of high permeability. Chalk is the area’s regional aquifer and allows tidally induced intrusion from the sea. This will result in high groundwater levels influenced by the tide. Chalk can also dissolve and leave voids in the rock as surface water moves through. These voids are known as solution features and, if they form close to foundations, could result in the undermining of the structure.

While infiltration could be the primary means of discharge for any development, because of the risk of high water and solutional features it is critical that a full site investigation (SI) including full BRE365 testing should be undertaken prior to design to advise if infiltration is appropriate.

3.6 Existing drainage

As with many areas of the UK, there are several different drainage systems including:

- Land drains for agricultural purposes
- Highway drainage that take surface water from roads and highways
- Surface water drainage that take surface water from roofs and paved areas
- Foul drainage that take wastewater from homes and businesses
- Combined drainage that take both wastewater and surface water

The waste and combined water in Shoreham-by-Sea area is served by two Southern Water drainage sub-catchments: East Worthing with a sewer catchment reference of WOEA and Shoreham with a sewer catchment reference of PORT, both of which are in the Adur main catchment. As well as Shoreham the WOEA catchment also serves Lancing, Sompting, Worthing, Ferring, Findon, Goring on Sea and Tarring. WOEA has in excess of 1,167 km of sewers conveying wastewater to the treatment works via 26 wastewater pumping stations. The treated water from the WOEA treatment works is permitted to discharge to the English Channel. The PORT Catchment serves Shoreham, Brighton, Portslade, Southwick, Hove, Lancing and Fishergate. PORT has in excess of 400 km of sewers conveying the wastewater to the PORT treatment works via 16 wastewater pumping stations, three of which are located within Ropetackle Street, Beech Green and Harbour Way.
During heavy rainfall the capacity of the combined sewers can be exceeded; additionally the sewers can become blocked by a foreign object – both scenarios can result in localised flooding. To mitigate against this flooding, combine sewer overflows or CSOs can be installed, which release water into rivers to prevent the flooding of homes or business. There are 156 CSOs in the Adur catchment.

3.7 Traditional approach

A traditional approach would be to utilise underground clay or plastic pipes at a typical starting cover depth of 1.2 m (to reduce damage by loading). Drainage pipes would be sized to accommodate the area and flow velocity required for self-cleansing at full bore. There would be no source control attenuation or restriction of runoff rates on a site-level basis. Each catchment area served by a small pipe (150 mmØ-300 mmØ typically depending on area) would gradually feed into a larger network of mid-oversized pipes (450Ø-1500Ø typically) until they reach an end-of-line attenuation feature such as oversized pipe storage (>1500Ø) or a geocellular storage tank, prior to outfall.

The traditional approach relies on self-cleansing velocities to move sediment downstream through the network. The upstream (entry-point) sediment removal processes are minimal, in the form of catchpit gullies, catchpit manholes, and silt traps which require ongoing maintenance for them to be effective. The majority of pollutants adsorb to sediment particles providing, what has been thought to be, an effective way of removing pollutants from the system, so long as proper maintenance is carried out. This method provides a removal process but does not provide treatment; in the case of a storm event, catchpits can get 'flushed' by runoff velocities higher than expected, dislodging and transporting any built-up sediment and associated pollutants downstream, causing a point-load cocktail of pollutants to discharge at outfall, if end-of-line treatment is not provided.

Falls to achieve self-cleansing velocities increase the downstream depth of the network significantly. For example, every 100 m of 150Ø pipework at a self-cleansing velocity of 1:100 increases the downstream depth by 1 m. Larger pipes require less fall, for example, 100 m of 300Ø at a self-cleansing velocity of 1:245 is only 0.408 m, however this benefit is outweighed by the requirement for soffit-soffit connections. Each 150Ø-300Ø connection, for example, increases the downstream depth by an additional 150 mm.

In terms of overall sustainability, the transport and installation of pipework and manhole chambers requires significant transport, excavation, and backfill with suitable granular materials and concrete surround.

End of line tank

The conveyance of surface water through a traditional pipe network without source control restriction will result in an oversized end-of-line tank prior to outfall. The depth of the tank will likely be beneath the tidal level due to the self-cleansing velocity, soffit-soffit pipe connection requirements and minimum cover level requirements.

Relying on an end-of-line tank, particularly in a coastal environment, will require significant volumes of concrete slab and surround to counteract the buoyancy of the tank in a high groundwater area.

Pumping

For surface water drainage, West Sussex LLFA will not accept a pumped conveyance in anything other than extreme circumstances.

Compensatory storage

As outlined within this document, where the outfall is at risk of being below the tidal level either now or in the future, tidal locking will need to be taken into account. Additional compensatory storage will need to be provided to mitigate against flooding caused by surface water runoff being unable to discharge from the development.

Within a traditional approach, due to factors outlined here, such as self-cleansing velocities and minimum cover levels, the outlet from a development following the traditional approach has a greater chance of having an outlet situated below the tide line.

Treatment (interceptors)

Without the benefit of source control or site control, sustainable surface water runoff treatment methods such as filtration, bioremediation, aerobic digestion, etc, surface water storage volumes prior to outfall will likely be infused with a high load of multiple pollutants.

Traditional drainage infrastructure for surface water 'treatment' involves by-pass and full-retention interceptors. These are large, below-ground, concrete chambers that comprise a sump, weir and baffle system that separates both sediment and floating hydrocarbon pollution (oils, etc) and retains them both until they can be removed manually and taken to landfill for remediation.

The disadvantage of such a 'treatment' solution is that no treatment is offered until the pollutants are removed by the maintenance provider. The sludge removed from the interceptor will be considered contaminated and the disposal of this sludge will have a very high cost. Also, the influx of detergents (from car washing or similar activities) may reduce the separation capacity of the chambers, by emulsifying with the oil layer and allowing hydrocarbon pollutants to pass through, unencumbered.

The excavation depths and significant expected concrete requirements to offset buoyancy are further disadvantages of this treatment type.

4. DESIGN CRITERIA

The Over-the-Wall (OTW) Approach should be fully integrated into the development and area masterplan and should be considered an essential and fundamental part of the land use. Through integration with the masterplan process, the OTW approach can work in conjunction with other aspects of the project's design.

To enable this integrated approach to be fully developed, the OTW approach should be considered as early as feasible, allowing its adoption into the master planning stage and enabling the site-specific benefits to be developed as the project progresses.

To minimise potential flood risk on the proposed development and any other areas adjacent to the development, the OTW approach proposes the following key design criteria principles for the surface water drainage strategy:

- People and property must be protected from all flooding sources, including the development's drainage system and relevant overland flow paths.
- The development must not exacerbate flood risk for neighbouring developments.
- Potential pollution risks should be mitigated by the use of source control and the SuDS management train.
- Enhancement of the urban and landscaping design of the development.
- CDM2015 principles should be followed throughout and opportunities identified to mitigate against the primary health and safety concerns associated with drainage design. Producing a good OTW design only becomes possible when the design and management of the project is integrated as part of the whole design rationale. This is achieved by a multidisciplinary team involved from the outset of the project, from optioneering through to detailed design.

An ideal design team will vary from project to project and can include:

- Urban designers
- Landscape architects
- Engineers
- Architects
- Planners
- Ecologists
- Developers

It is critical the design team engages with the key regulatory authorities from the outset, including the Environment Agency, the Local Planning Authority and the Lead Local Flood Authority, as well as other key stakeholders such as the sewerage undertaker and, where appropriate, the port authority.

4.1 Hydraulic design

To mitigate against flooding on the development and to ensure that the proposed drainage system is robust enough to be secure against the most extreme events, it is proposed that the drainage systems that encompass the OTW approach are all designed to manage the following parameters:

1. The 3.33% annual exceedance probability (AEP) storm event combined with a MHWS tide;
2. The 1% AEP storm event combined with a MHWS tide;
3. The 50% AEP storm event combined with a 0.5% AEP tide

The annual exceedance probability (AEP) is the probability of an event occurring in any given year. Historically, this was conveyed by the return period classification, but the return period classification often gives a misconception that the storm will not happen for the design life.

The 3.33% AEP Storm event is the standard in which there is no surface flooding and all tanks, storage devices and pipes should be considered working in 'free flow' conditions.

During the 1% AEP Storm event, some managed surface ponding can be permitted, provided it does not affect vulnerable receptors, there are suitable access and egress pathways, and the ponding sits below the 150 mm threshold levels.

While scenarios 1 and 2 are recognised within the DEFRA non-statutory technical standards, the third scenario is not. This scenario is an important test of how the development will cope with an extreme tidal event in combination with a rainfall event. For this scenario managed flooding will be accepted in localised areas, with no increase to risk of internal flooding or off-site flood risk.

A range of storm events should be used from the 10 minute duration through to the 48 hour duration all coinciding with the peak of the tidal level occurring simultaneously with the peak flow at the outfall.

Conventional calculation and modelling programs will assist and, where feasible, should be used to determine the volumes and flow rates. Appropriate calculation and modelling packages can include but are not limited to MicroDrainage, InfoDrainage, Tuflow, Hydromodeller, and MIKEFLOOD. When using these packages, it is important that correct and not default values are used throughout.

National standards, local planning standards and documents from West Sussex Council, or other relevant guidance from approving or adopting agencies, may take precedence over information highlighted within this chapter.

To account for the more volatile weather patterns resulting from Climate Change, it is proposed that all designs include an additional 45% added to their peak storm intensity values.

4.1.1 Discharge criteria

The OTW approach will discharge direct to the River Adur or the English Channel and as outlined in the DEFRA non-statutory technical standards S1. Where the drainage systems discharge to a surface water body that can accommodate uncontrolled surface water discharge without any impact on flood risk from that surface water body (e.g. the River Adur or the sea), the peak flow control standard and volume control standard need not apply.

The OTW approach is to get runoff discharge directly into the water body above the high tide line. Therefore, large diameter pipes would negate this principle as they would, in practice, result in being situated beneath the high tide line. As such, unless proved otherwise, the maximum diameter discharge into the receiving water body should be 300 mm in non-pressure piped systems.

4.1.2 Direct roof discharge

In principle, roofs will be above the sea walls and it is encouraged, where feasible, for the roof drainage to discharge directly over the sea wall, or above the high water line. Where geoenvironmental conditions permit, no conditions will be made to roof water that discharges directly Over-the-Wall. Considerations will need to be made in areas with low tides, mudflats and geology that could be subject to scour.

4.1.3 Outlets

The invert of any outlets should be set as high as feasible. The outlet should be set at equal to or ideally above the Mean High Water Springs (MHWS) tide level. Climate change impacts should be incorporated into this level. In Shoreham, the MHWS in 2121 is expected to be 3.03 m AOD. This is the lowest level at which any outlet should be set. However, MHWS varies around the country at different locations, therefore the lowest outlet level will vary across the UK. MHWS will need to be checked and confirmed prior to any design being undertaken. A non-return valve is proposed for any outlet for the instance where the water level could rise above the outlet level.

There should be no restriction to the number of outlets used if increasing the outlet number results in the diameter of the outlet being reduced.

4.1.4 The first 5 mm principle

From hard standing areas, the first 5 mm of any storm event is often considered to be the most polluted, as it is the rainfall that generates the most movement of oils and silts through runoff. The first 5 mm of any storm event coming from potentially contaminated areas (hard standing) should be prevented from discharging.

4.2 Treatment design

Historically, there was little consideration of diffuse urban pollution entering the marine environment via drainage, however there is growing awareness of the compound impact of the many drainage connections that outfall directly into the sea. Potential sources of pollution are deposited on roads, footpaths and roofs. These are deposited by animals, vehicles, humans and natural deterioration of materials. The main contaminants deposited are:

- Total Suspended Solids (TSS), these are sediments entrained in the surface runoff and can be small fragments of branches, leaf litter, bird waste and tyre residue.
- Heavy metals: such as breakdown of debris, hydrocarbons and exhaust gases.
- Hydrocarbons: oils and petrol from vehicles.
- Nutrients (phosphorus and nitrogen).
- Microplastics.

The expected pollutant mixture and concentration are heavily influenced by land use. There are a range of methods, that varies in complexity and data requirements, used to determine site-specific conditions, such as:

- Simple index approach – using indices of likely pollution levels and SuDS performance capacities.
- Risk screening – a more detailed approach, taking into account traffic density and site-specific infiltration potential.
- Detailed risk assessment – site-specific information defining the likely pollutant mixture and its significance, combined with more detailed analysis of SuDS treatment potential.
- Process-based treatment modelling – a time series rainfall analysis to determine likely statistical distribution and concentration of generic pollution in runoff; detailed treatment models.

The risk to the surface water needs to be managed effectively. The approach used to determine site-specific surface water treatment requirements has to be agreed upon with the drainage approving body and environmental regulator.

Each year, billions of tonnes of debris and other pollutants enter the oceanic environment. Pollution from surface water runoff impacts the health of fluvial and marine aquatic ecosystems.

Tidal aquatic environments are subjected to urban litter wash-off during high tide events. The nonpoint pollution sources, due to their dispersed nature, are more difficult to control when compared to the point pollution sources.

Eutrophication is a process in which a water body, either a lake, river or coastal area, becomes enriched with nutrients. It is primarily just nitrogen, or both nitrogen and phosphorus, that increases phytoplankton productivity. This enhanced productivity can lead to ‘algal blooms’ and the increased productivity results in increased Biochemical Oxygen Demand (BOD) within the water body. This increased BOD can result in bottom water hypoxia/anoxia causing fish to suffocate due to depleted oxygen and habitat degradation.

The main source of nutrients getting into water bodies comes from agricultural runoff, however nutrients from urban surfaces originating from animal waste, leaf litter, fertilisers etc. are also entrained during storm events and discharge ultimately to open water bodies, such as the River Adur. Surface water runoff mobilises nutrients that move both horizontally and vertically at surface and subsurface level. It can take a significant amount of time for the accumulated nutrients to reach the receiving water body. As a result of nutrient enrichment, an increase in dense algal growth has been observed in many harbours along the south coast in recent years.

Local Authorities are required to ensure that the new developments have a robust mitigation plan in place to avoid any negative impact on the local environment and wider internationally important nature conservation sites. The mitigation measures are required to be secured in perpetuity, because the proposed mitigation plan needs to be agreed upon and approved by the managing body of the receiving water.

Nutrient Neutrality, in principle, aims to reduce the net nutrient concentrations entering the aquatic environment by offsetting the discharge within the catchment. New development needs to apply mitigation measures and/or offset the surplus of the nutrients within its catchment to ensure that there is no increase in nutrient outputs, post-development.

The Over-the-Wall solutions, outlined later, can be tailored to suit site-specific treatment requirements. There is a wide variety of treatment processes that can be embodied into sustainable drainage features, such as sedimentation management, (bio-)filtration, separation, adsorption, biodegradation, volatilization, precipitation, hydrolysis, oxidation, reduction and substitution, plant uptake and photolysis.

Within the Shoreham area, there are two principal point sources of pollution which are the surcharging of the surface water and combined sewers during times of heavy rainfall which either cause surface flooding upstream or activation of Combined Sewer Overflows (CSOs) that discharge to the sea and the relationship between foul discharge tidal locking, surface water flooding and infiltration into the foul system.

During times of heavy rain, the existing infrastructure will struggle to manage the volumes and flows of water entering into it. This will cause the sewerage system to become surcharged and will result in flooding from the sewer at constrained/bottlenecks in the network and flooding in low spots. CSOs were designed to act as relief valves to prevent sewer flooding and therefore in heavy rain when CSOs are activated, some sewage will bypass the sewage treatment process and be released into the environment with at best minimal treatment. While the CSOs were originally designed to mitigate against surface water flooding and combined sewer surcharge, climate change, urban creep and new development connected to combined sewer systems, means that CSOs no longer prevent it. Water from combined sewers contain human faecal matter, industrial chemicals, household cleaning products, personal care products, pharmaceuticals and pesticides.

In 2000, the River Ouse flooded substantial parts of Lewes in East Sussex, due to prolonged high rainfall. The flooding was exacerbated by the sewers becoming surcharged and flooding above the ground. The EA Autumn 2000 Floods Review & Lessons Learned documents identified; in total 613 residential and 207 business properties were flooded along with 16 public buildings[3]. One thousand people were displaced as a result and the total damage cost of the flooding was estimated at £88 million. Following the floods, a survey was conducted into the health impacts of the flood affected population. The results found that there was a significant impact on psychological health, coupled with an increase in illness such as earache, skin rashes and gastrointestinal issues.

While the 2000 flooding primarily affected Lewes, had the River Ouse caused the flooding downstream in Newhaven, the pollution that affected the Lewes public would have affected the sea. This type of pollution could have a significant impact on the health of any users of the sea (bathers, fishermen), while also killing wildlife and ruining habitats.

3 The Environment Agency Southern Region 2001 *Autumn 2000 Floods Reveiw* ISBN 1857055705.
The Environment Agency 2001 *Lessons Learned Autumn 2000 Floods* ISBN 1857055063.

5. OVER-THE-WALL TECHNIQUES AND NEW TECHNOLOGY

The principles showcased within this chapter could enable the proposed development to discharge most, if not all, of its water above the tidal line. These proposals will offer a significant reduction in flood risk on and off the development site and, if implemented correctly, should offer no additional cost to the development.

5.1 Aerial approach

Historically, there are numerous examples of water being transferred at a higher level, the most well-known being the aqueducts of the Roman era. Gargoyles and open downpipes are other commonly used historical approaches; however, this method isn't as common as it once was.

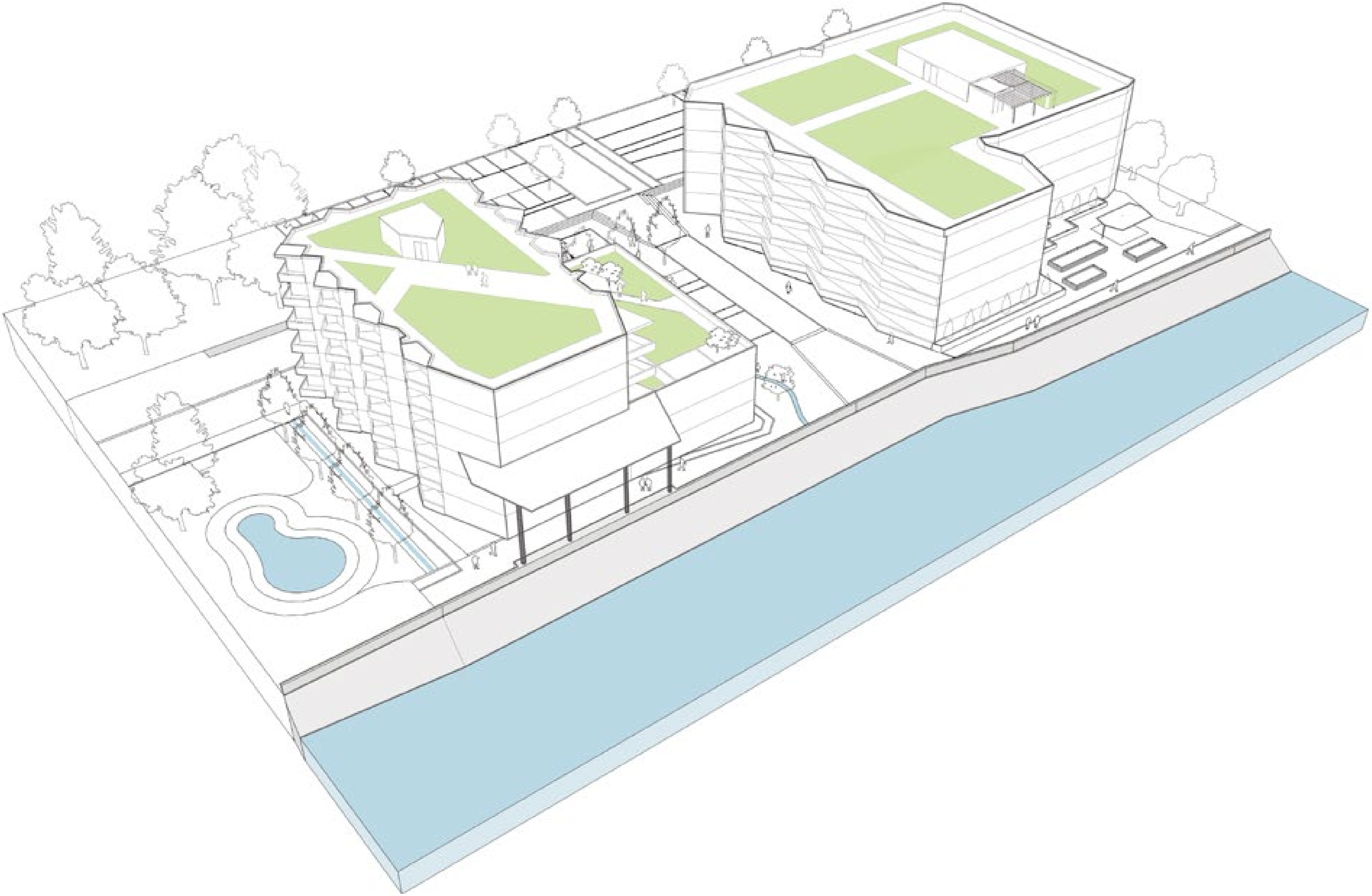
Projected roofs

Building roofs may be projected by cantilever or support columns over the sea defence wall, allowing them to drain directly into the tidal water body, via a hanging pipe or rain chain type arrangement.

One benefit of this approach is the shelter provided beneath the projected roof, which is particularly appropriate for pedestrian walkways and developments with active commercial pedestrian frontages, such as shops and cafés.

This option has the potential for creative design to make a feature of the rainwater falling from the roof above.

PROS	CONS
Simple gravity fed system without valves	Consideration of scour required at fall point
Can be designed to be a positive architectural feature in the development	Additional support structures, such as columns or cantilevers required
Allows access between buildings and waterfront	Unable to drain ground level surfaces (although reduced ground level to drain as the walkway is sheltered)
Provides sheltered waterfront walkway suitable for commercial active frontages	Maintenance access and potential impact to be considered
Simple downpipe or drop system is robust and easily maintained from roof level	Possible planning considerations
Brings public closer to water	Requires full building intergration



Projected buildings

Similar to the projected roof, upper storeys of waterfront buildings may be projected by cantilever or support column, over the defence wall, allowing rainwater to be discharged over the wall.

Again, shelter is offered beneath the building overhang and the discharging rainwater can be designed as a dynamic feature, or as a simple rainwater pipe attached to or within a support column.

PROS	CONS
Simple gravity fed system without valves	**Consideration of scour required at fall point**
Can be designed to be a positive architectural feature in the development	**Additional support structures, such as columns or cantilevers required**
Allows access between buildings and waterfront	**Unable to drain ground level surfaces (although reduced ground level to drain as the walkway is sheltered)**
Provides sheltered waterfront walkway suitable for commercial active frontages	**Maintenance access and potential impact to be considered**
Simple downpipe or drop system is robust and easily maintained from roof level	**Possible planning considerations**
Brings public closer to water	**Requires full building integration**

CASE STUDY – No.1 London Bridge

The roof from No. 1 London Bridge projects over the side of the Thames River Wall and has been designed so that any water that falls on the roof, sheets down over the glass and is deposited directly into the river.

As this water discharges directly into the river without restriction, there is no requirement for an attenuation tank, which would have been installed below the tidal line, the outfall of which would have been tidally constrained and which probably would have required a pumped system at extensive cost given subterranean installation beneath the development in a cramped and likely saturated zone. The exemplary design also creates a sheltered public realm beneath the roof and when it rains the rain creates a spectacle that can be safely viewed by the public from beneath the roof.

The neighbouring buildings could also have benefited from the OTW approach, with either the roofs discharging onto the sloped roofs, or by mimicking the same principles and discharging directly over the river wall.

No.1 London Bridge. Image source: paving.org.uk

Raised channels

An aerial or raised channel can be at any height above the defence wall level and can convey runoff from elevated surfaces such as roofs, multi-storey carparks and podium decks.

The supported channel may be open, or in the form of a closed pipe and may discharge freely once past the defence wall or alternatively, could fall in a controlled way via rain chains or a vertical continuation of the pipe, terminating higher than maximum tide level.

Aerial channels can be designed to allow pedestrian or vehicular movement beneath, however heights may need to be agreed with height warnings put in place to avoid strikes.

Aerial channels can be designed to complement the building and provide an attractive feature supporting climbing plants, lighting, seasonal banners or creating in interesting feature.

Aerial channels can intercept down pipes as they progress down the building and convey the runoff over the wall to the receiving water body.

PROS	CONS
Simple gravity fed system without valves	**Consideration of scour required at fall point**
Can be designed to be a positive architectural feature in the development	**Additional structures required**
Water flow is visible and can be a spectacle when it rains	**Unable to drain ground level surfaces**
Can be used to define boundaries such as garden spaces	**Blocks continual access between buildings and waterfront**
East to maintain from ground level	**Possible planning considerations**
Rainwater is accessible for irrigation	**Requires full building integration**
Simple to build without need for support structures such as columns or contilevers	**Potential greater requirement of concrete**
Less vertical drop over wall so less scour potential	**Full structural waterproofing will be required**
Can be used in combination with defence wall level access routes or boardwalks	

CASE STUDY – Bewdley School

This new science block at Bewdley School features three aerial channels where building-mounted rainwater pipes are intercepted at first floor level and taken over a paved outdoor teaching space to a rill or rain garden. In each case, the aerial channel terminates in a scientific kinetic feature demonstrating the force or flow of water. The design comprises a tipping bucket that allows students to calculate the rate of flow from that section of roof, a waterwheel demonstrating the power of dropping water, and a 'Torricelli Tube' a vertical tube with small holes regularly spaced up the side that demonstrates the Torricelli principle of the effect of water head on the rate and pressure of flow of water from the holes.

Bewdley School. Image source: paving.org.uk

5.2 Localised raised site levels (podiums)

Within the Shoreham region, many of the new developments have been installed on elevated levels. There are several reasons for this and these include providing features beneath the finished ground level, such as car parking and maintenance rooms, and elevating the site so that views are improved. If site levels are raised to the same level or above as the defence wall, then water may be conveyed at the surface in sett or grated channels or rills, over the wall.

The wholesale raising of land can result in altering existing flow route and could potentially increase the flood risk for neighbouring and upstream areas. As such the wholesale raising of land is specifically not permitted within the West Sussex Manual for the Management of Local Flood Risk (formerly the Policy for the Management of Surface Water). However, through the use of podiums, site levels can be raised while existing flow routes remain as existing. This approach also allows the drainage of other hard surfaces to be discharged over the wall, though runoff from vehicular surfaces should be passed through SuDS features to remove sufficient pollutants, before discharge into the sea.

Surface conveyance techniques have the benefits of being visible and legible, providing visual interest and are easily maintained.

Any surface water management techniques used on areas of raised site levels should follow the principles highlighted in the SuDS & Shallow Drainage section, as traditional methods could still result in the discharge being below the sea level, due to falls and minimum covers.

PROS	CONS
Simple gravity fed system without valves	**Consideration of scour required at fall point**
Reduces the visual and spatial impact of the defence wall	**Imported material may be required to raise site levels sufficiently**
Water flow is visible on the landscape surface and can be designed as interesting landscape features	**Falls required through the landscape from the back of site to the waterfront making levels progressively higher away from the waterfront**
Allows access between buildings and waterfront	**Can create additional drainage issues for 'inboard' sites / features immediately adjacent because of the raised ground levels**
No support structures required	**Possible Planning considerations**
Conventional downpipes	**Requires full building intergration**
Drains ground level surfaces	**Potential greater requirement of concrete**
Easy to maintain from ground	
Rainwater is accessible for irrigation	
Simple to build without need for support structures such as columns or contilevers	
Less vertical drop over wall so less scour potential	
Raised levels can be formed using waste or demolition aggregate or be in the form of a podium landscape over parking	
Water flow can be through the landscape in vegetated features such as swales and rain gardens creating a drought resilient verdant development	
Discharge is able to be more diffuse, in some cases as a sheet flow over the wall edge and at multiple points along the waterside edge of the development. This reduces the contribution to scouring	
Area can double up as an amenity space	

5.3 Revised sea wall/incised channel

The sea defence line does not need to follow the waterfront site boundary. It can be projected into the site, creating a lower area that could be a plaza that relates positively to the water. Whilst this may be above normal high tide levels, in extreme tides, it can be designed to safely flood.

The potential benefit of such features is that the 'wall', that we are trying to drain over, has been brought further into the development allowing more surfaces such as second-layer buildings and ground surfaces to drain into it.

This sunken area could contain surface conveyance features such as rills, channels or swales carrying runoff to the tidal waterbody in engaging ways.

PROS	CONS
Simple gravity fed system without valves	Some consideration of scour required at discharge point
Reduces the visual and spatial impact of the defence wall	Imported material may be required to raise site levels
Water flow is visible on the landscape surface and can be designed as interesting landscape features	Public space can flood occasionally so safe egress should be considered in the design
Creates more diversity and connection to the sea / river along the waterfront edge	After flood event, space may require cleaning to remove silt, sand and debris
Enables buildings and surfaces behind the waterfront to drain at the surface	There is a loss of land associated with this principle, as a portion of it is given back to the sea/river. This means communal areas will be smaller
Allows access between buildings and waterfront	Possible Planning considerations
No support structures	Requires full building integration
Conventional downpipes	Potential greater requirement of concrete
Able to drain ground level	Full structural waterproofing will be required
Easy to maintain from ground	
Rainwater is accessible for irrigation	
Simple to build without need for support structures	
Reduces scour potential	
Reduces the extent of raised level within the development by moving the defence line inboard	
Water flow can be through the landscape in features such as swales & rain gardens creating a drought resilient development	
Can reduce the amount of fill required to the back of the site	
Can serve as a slipway and be combined with mooring pontoon access or water taxi station	

5.4 Pressurised drainage

Pressurised drainage systems differ from conventional roof drainage in that the drainage system is designed to run at positive and negative pressures and the pipe systems are designed to accommodate these pressures in the system.

Tidally locked sites can use the positive pressure induced through a high hydraulic head to force open submerged valved outfalls. The principle is that a valved outfall pushed closed by the pressure of a rising tide will result in a build up of water in the drainage system behind the valve, if it is raining. If that system is only connected to features at an elevation higher than the defence wall, such as development roofs, and has no means of escape at a lower level than the high tide, water will back up vertically in the system until such a level that the hydraulic head of water in the system is greater than the forces acting against the outfall valve, forcing the valve open and draining the system until the pressures balance and the valve closes again.

Technical considerations of this approach are that the pipe system will be subject to higher pressures than under conventional applications, with pressure increasing proportionate to the invert of the outfall relative to maximum sea level. The possibility of leaking at joints, rupture of pipes or damage to external rainwater pipes should be considered and mitigated in the design.

A siphonic system is a pressurised drainage system that uses negative pressure to 'suck' the water from the roof. The siphonic system works through baffles above the outlets prevent the ingress of air into the roof inlets and pipe network. This results in pipes that are full of water and that generate a siphonic 'sucking' effect that can convey flow in pipes with negligible falls at self-cleansing velocities. Siphonic roof inlets differ from conventional ones in that they have a solid lid over the pipe opening, with a shallow perimeter opening between this and the roof surface, taking water laterally into the outfall through this gap. Their pipework also differs in that it is able to continually stay close to ceiling level, is narrower in gauge and has sealed joints to allow it to withstand the additional pressure exerted by the siphonic effect.

However, gravity systems can also be used with pressurised below-ground pipework systems, which utilise the drop form gutter height to discharge height to drive flows at a greater rate rather than the simple hydraulic gradient of which the pipework would allow.

A paper presented at the first National Conference on Sustainable Drainage at Coventry University in 2001 set out a methodology by which gravity or siphonic drainage systems, if connected to sealed underground pipe systems with suitable rodding facilities, could allow the surplus hydraulic head to be used to drive flow back above the lower drainage level, using a similar principle to that of an inverted siphon in a sewer system (Wearing M.J., Shuttleworth A. and Cooper P. (2001) An innovative method for moving, storing and re-using roof drainage water, Proceedings of the First National Conference on Sustainable Drainage, 18-19 June 2001, Coventry University, ISBN: 1 903818 06 0).

At least one system of this type has been designed in the UK and has been in use for in excess of 15 years without any issues or additional maintenance. Subject to suitable detailing and design, there is no reason why a system of this type could not be fully functional and allow water to be discharged over the sea wall and away from the site. This approach could have been used to address 'troublesome' outlets historically, however it has not been picked up by the wider drainage community. Siphonic drainage is usually considered on large in-land industrial and 'mega-store' type buildings. This disconnect between the traditional type of use and the use on smaller residential blocks associated with the OTW principle could mean that the engineers with the most understanding of siphonic systems and how to get them to work in an Over-the-Wall project are not approached to work on this type of project.

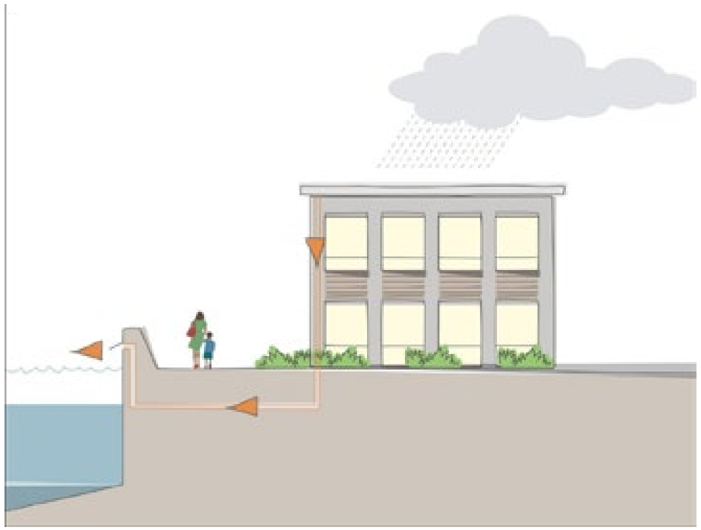
Any pipework which is installed for pressure systems (positive or negative pressure) will need to be designed by an experienced M&E or Public Health Engineer to the following standards:

- ASME B31.
- BS 4504 Circular flanges for pipes, valves and fittings.
- BS 2971 Specification for Class II welding of carbon steel pipework for carrying fluids.
- BS EN 752 Drain and Sewer systems outside buildings.
- BS 8490 Guide to Siphonic roof drainage systems.
- BS 6464 Specifications for reinforced plastic pipe, fittings and joints for process plant.

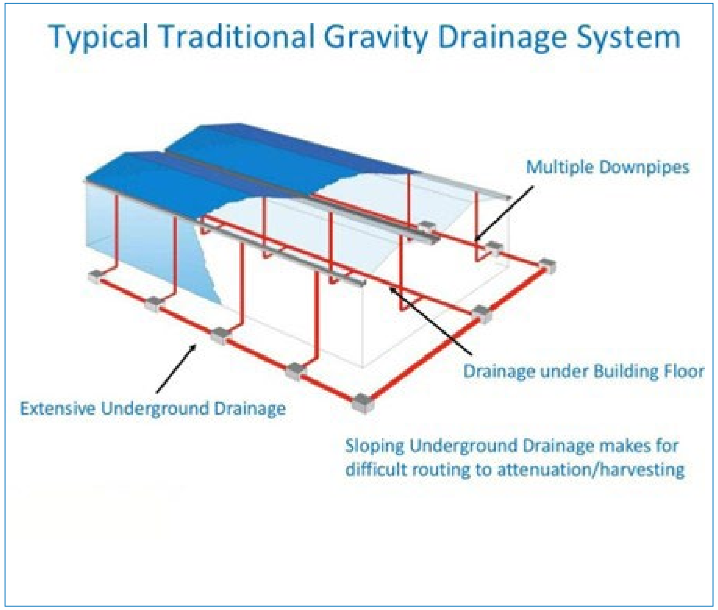
The pipework once installed will need to be tested 1.5x maximum design pressure as outlined in BS EN 806.

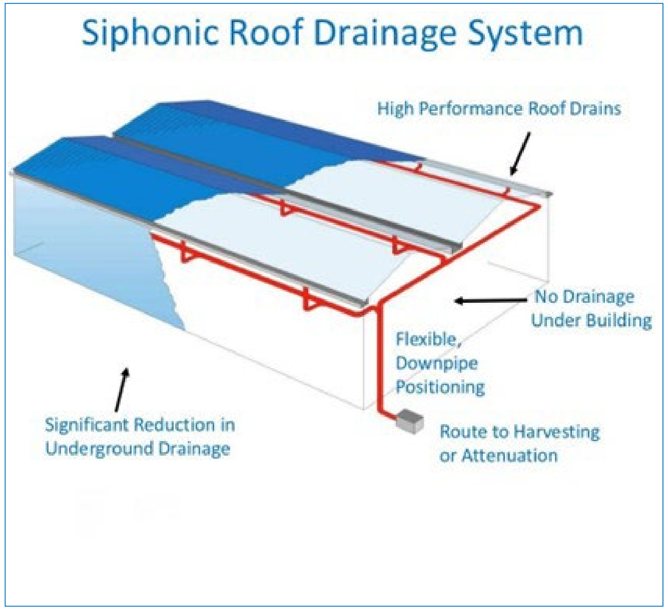
However, at the Over-the-Wall Drainage Project Workshop held in March 2020, Brian Rousell, the Shoreham Port Director of Engineering, expressed his concerns regarding siphonic drainage with regard to maintenance and risk, with particular regard to the tendency of seagulls to drop shells and other debris on roofs, resulting in blocked roof inlets and pipework.

PROS	CONS
Fewer downpipes are needed	**All pipework will need to be designed and built to accomondate the pressure**
Allows acces between buildings and waterfront	**Novel technique**
Flexible positioning of downpipes	**Scour will need to be mitigated**
Reduction in undergroun drainage	**Unable to drain areas close to sea level**
Flexibility in seawall outlet level	**Valves may be required**
Smaller diameter pipework	**Special roof outlets required**
	Experienced siphonic designers will need to be consulted



Schematic of potential pressurised arrangement in tidal context



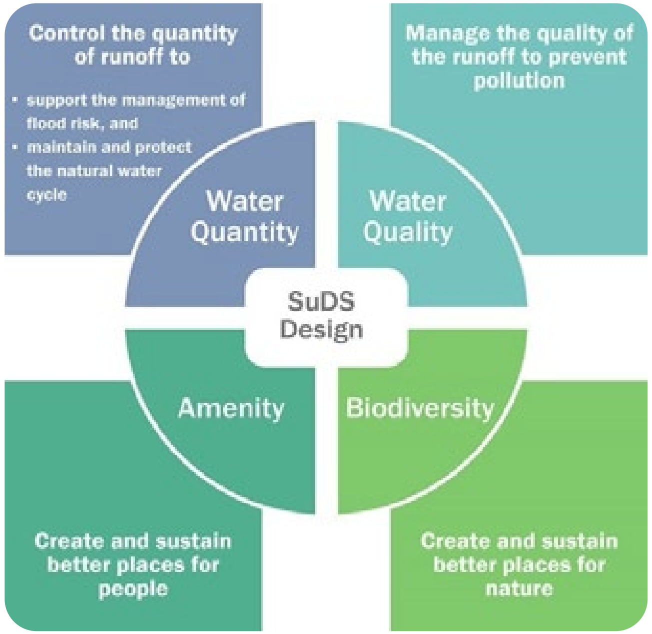


Siphonic drainage arrangements compared to conventional graivity drainage systems.

5.5 SuDS and shallow drainage features

The higher the drainage feature sits, the less compensatory storage is required and if the base of the feature sits above the high tide level, there will be no requirement for compensatory storage. Sustainable drainage systems (SuDS) are designed to maximise the benefits available through surface water storage. The use of SuDS should enhance the places where people live work or play and provide significant benefits to the community. The four 'Pillars' of good SuDS design are:

- Water Quantity
- Water Quality
- Amenity
- Biodiversity



SuDS can take many forms; they can be either at the surface or below surface and can be Green (with vegetation) or Grey (hardstanding only). Whether they are green or grey they mimic nature by managing the runoff close to where it has fallen (Source Control) and conveying the runoff along the system at rates similar to natural flow rates. Where combined with the green element, SuDS can encourage evapotranspiration of the rainfall reducing the amount of water discharged while encouraging biodiversity benefits. The management train methodology encourages a shallow design approach which is ideal for an Over-the-Wall application.

SuDS are more sustainable as an Over-the-Wall approach because they:

- Manage runoff volumes and flow rates from hard surfaces, reducing the impact of urbanisation on flooding;
- Provide opportunities for using runoff where it falls;
- Protect and/or enhance water quality (reducing pollution from runoff);
- Protect natural flow regimes in watercourses;
- Are sympathetic to the environment and the needs of the local community;
- Provide an attractive habitat for wildlife in urban watercourses;
- Provide opportunities for evapotranspiration from vegetation and surface water;
- Can be very shallow and can, when working as part of an integrated system, discharge above the tidal level even though the water may have travelled a relatively long way;
- Create better places to live, work and play (amenity benefits);
- Have significant health and safety benefits in comparison to traditional methods;
- Offer a significant carbon benefit to the development. Green SuDS offer carbon capture and most SuDS have lower operational and embedded carbon compared to conventional drainage systems.

Pervious paving (PP)

Pervious paving is a pavement suitable for vehicle and pedestrian trafficking, which allows runoff to percolate through the surface and into the underlying sub-base layers for storage.

Pervious pavements can be incorporated into a development in the following ways:

- Access roads and driveways;
- Service yards;
- Pathways;
- Outdoor terrace areas.

Pervious pavements should intercept rainfall falling directly onto the PPP and runoff from adjacent areas during the peak storm with a minimum infiltration value from pavement layer to storage layer of 2500 mm/hour (for new pavements). The associated sub-base material can either be geocellular, aggregate, or a combination.

Permeable Block Paving:

Permeable block paving, like traditional paving, is made up of impervious concrete blocks, however, permeable blocks have special small cut-outs or extensions that ensure that the blocks are laid at a set distance allowing the water to percolate through to the porous sub-base below.

Concrete:

Porous concrete is concrete with a low fines count and a high void content. This high void content allows water to permeate through itself and into the porous sub-base below. Due to the strength of the concrete, porous concrete is often found within service yards.

Resin bound aggregate surfacing:

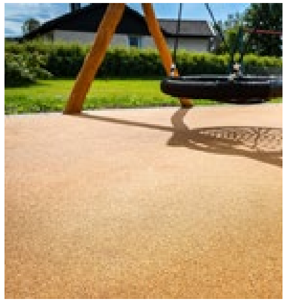
Like porous concrete, the resin-bound aggregate surfacing has a low fine, high void content and therefore allows water to percolate through. Unlike porous concrete, it comes in various shapes and sizes and has an attractive architectural feel.

Grass/gravel retention/reinforcement structures:

Using plastic or concrete structures with large openings for grass or gravel can be installed in areas that normally wouldn't be suitable for grass or gravel, where it is because of loading, ground conditions, or gradient falls.

Sustainable porous surfacing:

In recent years the porous surface using a more sustainable surfacing has become more widespread. Most of these follow the same low fine, high void concept as porous concrete. One such product is Corkeen. Corkeen is a surfacing product that is made out of sustainably sourced cork. Corkeen has a high hydraulic conductivity allowing water to fall through itself very quickly, but it is also soft, protecting people against falls. The Corkeen system is often found in play parks where it offers fall protection whilst also managing rainfall. Incorporating this into a SuDS design will allow a park to transform into a SuDS park. In addition to the hydraulic and fall benefits of the Corkeen product, cork, its parent constituent, has a net negative carbon balance.



Design of the sub-base layer (and capping layer if required) should be undertaken by a competent pavement/highway engineer. The determining factor associated with the thickness of the sub-base is its structural element.

Pervious paving has a proven track record of providing silt and hydrocarbon treatment, and several scientific papers highlight that it outperforms an oil/silt separator[4]. Typical treatment processes occurring in pervious paving are:

- The trapping of silt and attached contaminants;
- Biodegradation of hydrocarbons within the pavement construction;
- Settlement and retention of solids;
- Adsorption of contaminants by the aggregates.

Pervious pavement is a relatively shallow system with a surface build-up varying between 100-130 mm and a sub-base between 250-350 mm. This means that the maximum depth of the base of the drainage structure can be as shallow as 350 mm.

PROS	CONS
Drainage and road sub-base combined	**Ongoing maintenance requirement**
Cooler surfaces (reduction in Urban Heat Island effect)	**Adoption issues**
Provides surface water treatment	**More expensive than traditional pavement**
Can be made from recycled products	**certain products may not be suitable for HGV use**
Can take extra surface water catchments into itself	**Needs protection during the site consturction stage**
Lower risk of ice formation at the surface	

4 2017. CIRIA - *The SuDS Manual C753*. 1st ed. [ebook] London: Ciria. Available at: <http://www.ciria.org/Resources/Free_publications/SuDS_manual_C753.aspx>

CASE STUDY – Bridget Joyce Square

The project, occupying part of Australia Road, is located between a school and two playgrounds in the heart of White City. The previous road and parking formed a hazard for children crossing the road and made school drop-off and pick-up difficult.London Borough of Hammersmith & Fulham, saw the opportunity to provide a better space for the community at the same time as creating a landscape that manages rainwater through Sustainable Drainage (SuDS). The new construction consisted of SuDS drainage under 2000m^2 of new Tegula Paving with the water run off diverted into four No Rain gardens and several planting areas. Plus, a 250lm wiggly wall feature was retained in the paving and in the walking wall across the rain gardens. These curved shaped wall features, traditional for this area, were retained by introducing curved kerbs.

Overhead channels carry the water flow away from the building toward a 'rainchain' formed of a helix of steel ropes secured to the base of the raingarden. When it rains, water flows over the steel ropes and is spread between the splaying ropes as dancing sheets held by surface tension. Randomly each sheet's tension breaks and quickly disappears to be reformed moments later.

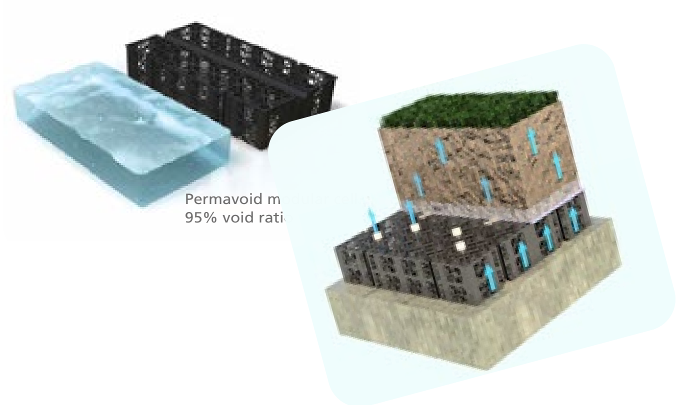
Most new SuDS developments restrict water flowing into the sewage systems to five litres per second (l/s). The reason for this is concerns that slower flows can cause pipe blockages. This project designed the drainage outlets to reduce the risk of blockage even with flows of 1 l/s. Over a single year, the scheme will halve the volume of water entering the sewer.

Raised channels – Bridget Joyce Square

Sub-base replacement – Permavoid

Permavoid is a multifunctional modular, interlocking, plastic, geocellular unit designed for use as a combined drainage component and sub-base replacement system. It has an exceptionally high compressive strength and bending resistance within joints, creating a horizontal structural 'raft' that is ideal for shallow attenuation systems This high compressive strength and ability to form a structural raft allows the Permavoid to be situated in a pavement at a much shallower depth. For example, Permavoid can be situated as shallow as 130 mm underneath a car park. By situating itself much higher in the horizon, it keeps the drainage system much shallower, reducing the depth of the outlet making it ideal for use in a waterfront, tidally constrained environment.

The modules have a very high void ratio of 95% to achieve a highly efficient water storage capacity. The Permavoid is made up of 85 mm and 150 mm thick interlocking geocellular units that can be combined to produce deeper attenuation systems (85 mm, 150 mm, 235 mm, 300 mm, 450 mm, etc.). The units are made from 100% recycled plastics and are 100% recyclable at the end of their usable life.



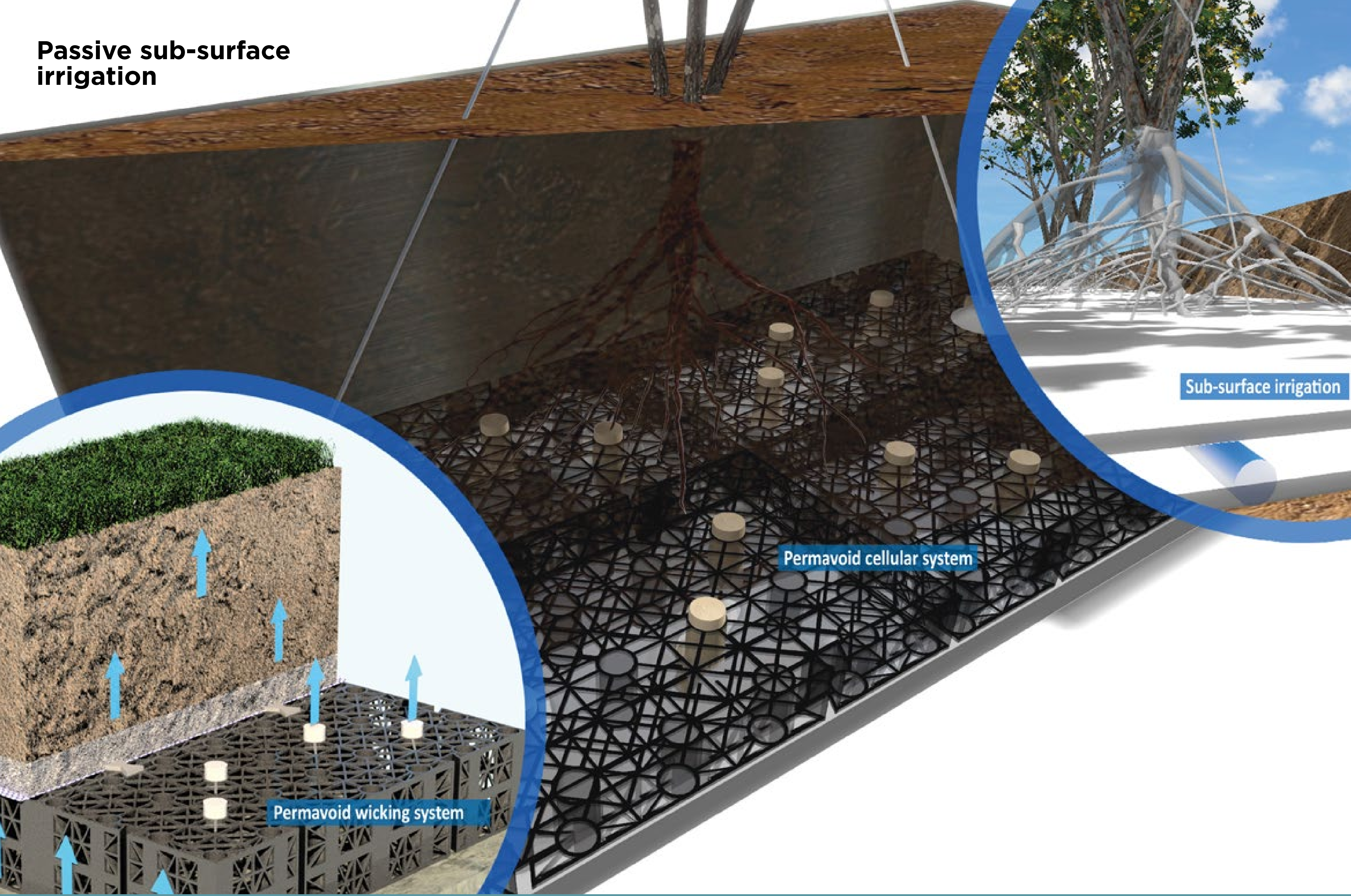
The Permavoid attenuation has been designed with dedicated components, e.g., rainwater diffuser chambers and Permaties, that have all been created to work together as a structural attenuation system.

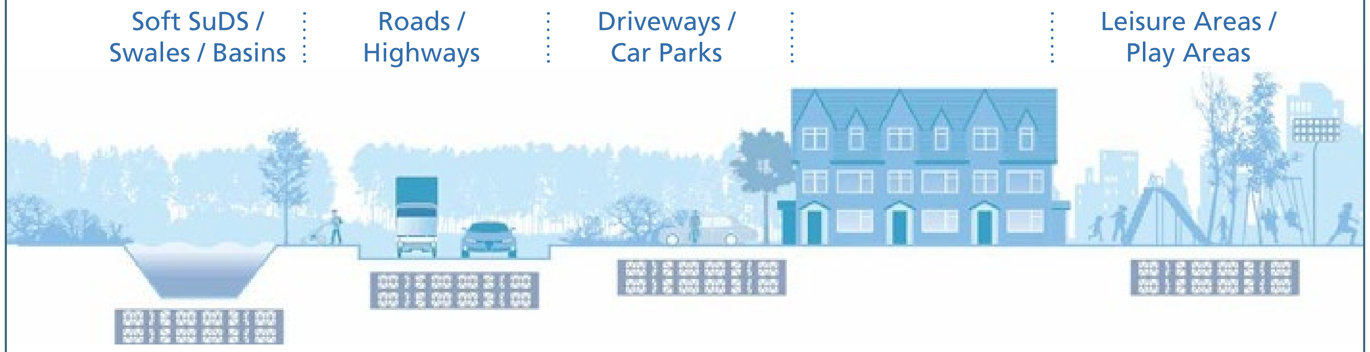
Permavoid can work with any type of surfacing proposed, whether permeable or impermeable and because it can be installed at a shallow level, it has a much greater chance of sitting above the MHWS level.

Permavoid can incorporate a passive irrigation system which uses water held within the Permavoid to provide irrigation via the use of capillary materials installed within and around the units. Passive irrigation maintains the soil moisture content at between 15% and 45% by volume, ensuring plants have the correct amount of soil moisture to promote growth and prevent wilting. Passive irrigation enables plants with medium water demands to be installed with shallow growing media depths and also reduces evaporation and over-spraying losses associated with overground irrigation systems. Plants irrigated using the passive technique rather than above ground tend to have a healthier root system.

www.polypipe.com/civils/permavoid-85150

Passive sub-surface irrigation





Please note: Illustrations are for guidance only. Not to scale.

PROS	CONS
Exceptionally high compressive strength and bending resistance	High unit cost
Shallow attenuation system reducing excavation costs	Must be installed by suitably qualified installers
High void ratio to achieve highly efficient water storage capacity	Units have fixed dimensions and can’t be cut down to shape
Made from 100% recycled plastics and 100% recyclable at the end of its life	
Can be used in combination with a green roof to passively irrigate planting	
Can be used in areas susceptible to high groundwater	
Can be used to passively irrigate plants from below	

CASE STUDY – Walthamstow Stadium Redevelopment

The Permavoid system was called upon to provide surface water management for the redevelopment of Walthamstow Stadium, North London.

The Permavoid system was specified due to its ability to work as a suitable sub-base replacement, meaning deep excavation was avoided at a site which contained contaminated ground and was susceptible to a high water table.

Located adjacent to the River Ching and on a former greyhound track, the Walthamstow Stadium development included 294 new homes on a site full of sustainable drainage features, such as green roofs and permeable paving.

Utilising the high strength of the Permavoid system, the system was installed beneath 4,500 m^2 of permeable paving to provide 1,500 m^3 of surface water storage to meet the requirements of the Environment Agency.

The design features 150 mm deep Permavoid attenuation cells with a filtration geotextile laid on top, between the cells and the permeable paving. The filtration geotextile acts as a barrier to treat surface water, stopping silts and hydrocarbons from entering the tank, therefore, treating the runoff at source. The sides and base of the Permavoid tank were wrapped in a geomembrane to allow for attenuation before discharging into the river, using flow controls, at a rate previously set by the Environment Agency.

Green roofs

The roof space on buildings can be designed to grow vegetation and store water. These are known as green roofs. Green roofs also provide additional green infrastructure benefits to their host building and local area, including reducing energy demand of the building, increasing PV output, improving the aesthetics of the building, and providing additional green space.

However, adjacent to a salty climate, such as next to the sea, the design and specification of a green roof are key to ensuring its long-term. Green roofs generally have relatively shallow (50-300 mm depth) substrate layers and use drought and stress-tolerant planting schemes. Green roofs are also designed to be low maintenance. Generally, irrigation schemes are not needed. The following are the component layers required for a green roof:

- Drainage layer - The drainage layer is designed to allow excess water to drain away from the base of the green roof, preventing water logging. Key performance criteria include water storage capacity, flow rate, weight, and compressive strength. This layer can also be used to retain water for irrigation use.
- Moisture retention layer - A geotextile blanket that is placed in addition to the filter and root barrier layer. This allows the retention of water at the base of the substrate. Additional, thicker water-retentive layers can also be laid, for example, stone wool insulation material.
- Filter layer - A woven or non-woven filter membrane designed to prevent movement of the substrate (chiefly clay and silt particles) into drainage and water harvesting layers. Key performance criteria include weight, density, flow rate, tensile strength and effective pore size.
- Root barrier - A barrier to prevent root ingress into the drainage/water harvesting layer. This should be tested to EN 13948. Key performance criteria include weight, density, tensile strength and elongation break.
- Substrate - An engineered soil/growing media. Usually designed to be lightweight with low nutrient content in order to reduce excessive plant growth. Other characteristics include the ability to quickly drain water and the long-term support of specified vegetation. Substrate should be tested by laboratory accredited to carry out testing to BS8616. Substrate depth will determine plant choice.
- Vegetation - A green roof should have vegetation that can cope with relatively shallow substrate depths, and soil moisture fluctuations and does not require large amounts of vegetation. The vegetation chosen should be appropriate to the region. Vegetation can be used to attract rare or endangered species of insects and/or pollinators.

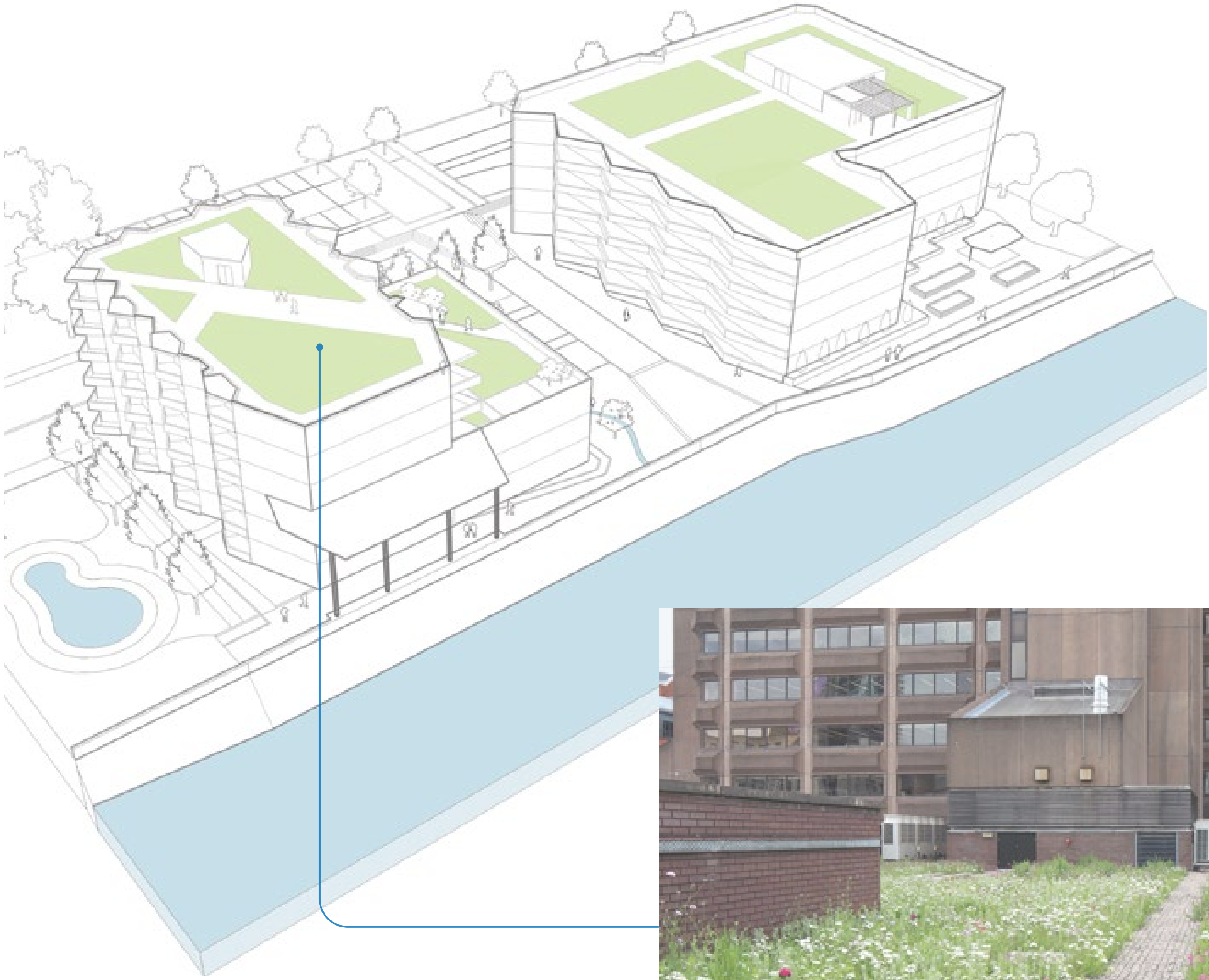
Green roofs offer a significant delay to the time frame between rain and discharge from the roof. The delay could offset the time at which the roof discharges into the water body to avoid the peak of the high tide.

A green roof can be also used in conjunction with projected buildings or projected roof principles outlined earlier. Other items to consider when designing a green roof include;

- The total weight loading of the green roof system at field capacity should be accounted for in structural calculations.
- Allowance should be made for maintenance at least twice a year. This should include, inspection and clearance of all drainage outlets, as well as plant maintenance and replacement.
- Green roofs should ideally have secure access from within the building. Appropriate fall arrest or barriers should be used around the roof perimeter.

Green roofs are suitable for all sizes and scales of buildings or structures. Green roofs can be incorporated on traditionally sized buildings and can be included in any structure as small as a bus shelter.

PROS	CONS
Increases life span of roof	**Greater expense than traditional roof**
Boost thermal perfromance	**Greater maintenace requirement**
Acts as a sponge and collects surface water	**Requires similar number of outlets as traditional roof**
Enhances biodiversity of the development	**Suitable waterproofing to be used**
Could enhance amentiy of development	**Heavier than traditional roof**
Can enhance air quality	
Cooler surfaces (reduction in Urban Heat Island effect)	
BREEAM points	
Noise reduction	



Bruntwood Green Blue Roof, Manchester. Image source: STRI Group Ltd

Blue roofs

Blue roofs are designed to store water on a roof, either for re-use and irrigation, or to reduce the discharge from the roof during storm events. Capturing and attenuating rainfall at source reduces the impact on the development and surrounding infrastructure, slowing, storing, and restricting the flow.

Blue roofs, in general, are installed on flat roofs, but can be installed on roofs with a shallow fall (not exceeding 1:80).

Blue roofs can host vegetation, can be fully paved/hard-surfaced, or can be a combination of both. By using a combination of hard and soft landscaping, a blue roof can become a multi-functional area acting as a roof/garden/terrace/water storage area.

Unlike green roofs and traditional roofing methods, blue roofs significantly reduce the number of outlets on the roof. The number of outlets could be reduced down to one outlet with an overflow. A blue roof can be also used in conjunction with projected buildings or projected roof principles outlined earlier. Blue roofs can discharge from the roof vertically through the building, but when using the OTW approach, they should discharge via a side parapet, which ideally would discharge directly over the wall.

When using appropriate software to design blue roofs, they can be designed to cascade from one to another. The cascading approach is advantageous as it keeps the water moving toward the harbour at high level (on the roofs) rather than it being brought to the basements and then moved toward the harbour via gravity. A further benefit is that the time of concentration between each roof may not overlap, this could result in lower flows of water discharging from the development.

The benefits of blue roofs especially when combined with passive irrigation are:

- Greater levels of evapotranspiration from green infrastructure, resulting in greater building and local environment cooling.
- Blue-green roofs, where incorporated with elements of the passive irrigation system, require less formal irrigation water compared to conventional green roofs.
- A reduction in the number of roof outlets offers less risk of leaks. This reduction also means there will be a reduction in the number and size of any internal pipework, if the roof is drained vertically, potentially freeing up internal space.
- Able to discharge directly over the sea wall, if adjacent.
- Vegetated roofs with access to water (via passive irrigation) are cooler at the surface than corresponding brown roof or impermeable roof. This is due to enhanced evapotranspiration of the water. If photo-voltaic panels are installed, the cooler the air is around them, the more efficient they are.
- Blue roofs can be designed into a building to provide a feature with multiple uses.

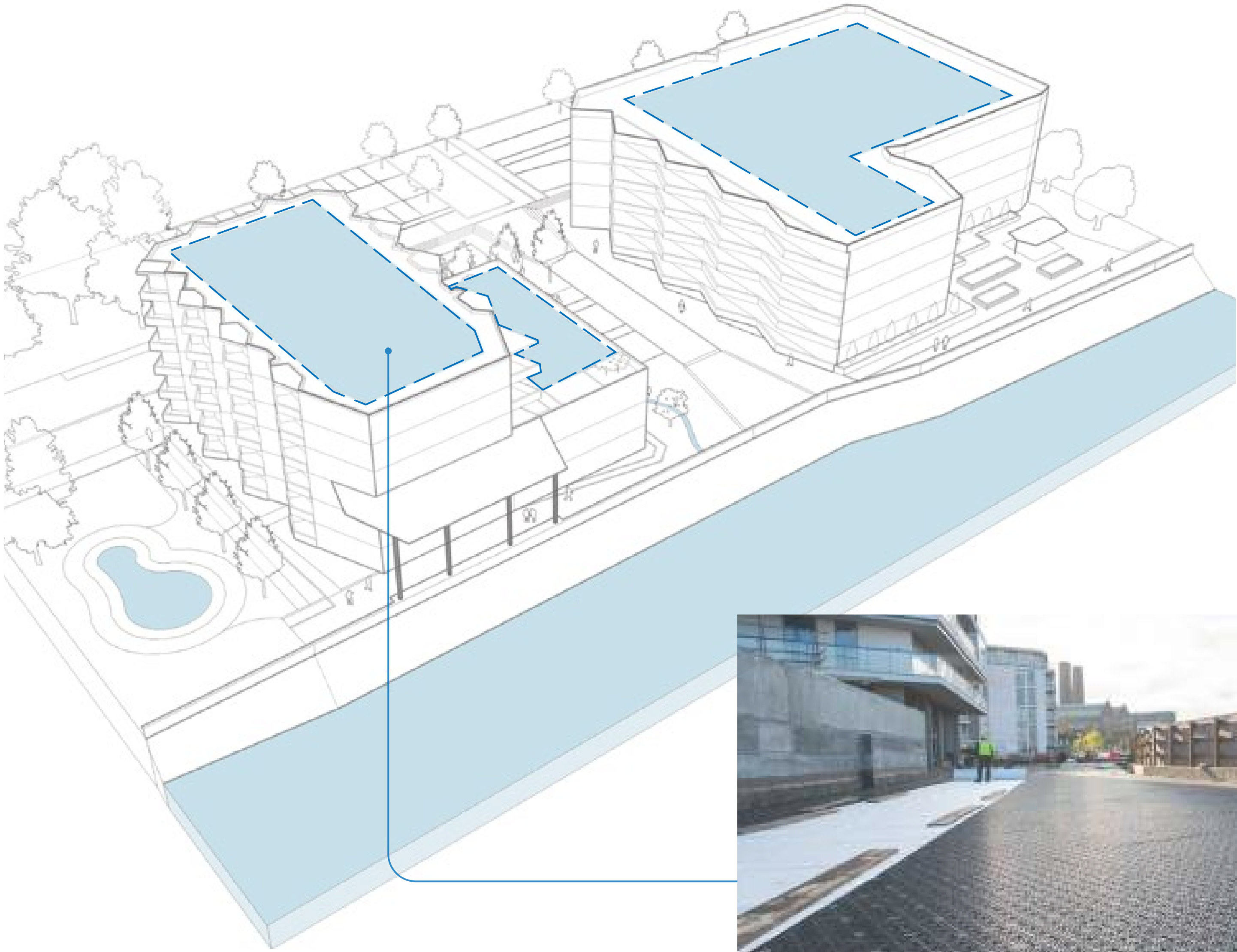
Other items to consider when designing a blue roof include:

- Total maximum weight loading of the system, when full, should be accounted for in structural calculations.
- Each roof requires at least one main outlet (which can be flow controlled) and one unrestricted overflow.
- The inlets, outlets and chambers will need twice yearly access for maintenance and clearance. If the maintenance regime is followed allowance should be made for maintenance at least twice a year. This should include inspection and clearance of all diffuser and outlet chambers, and drainage structures.
- The roof should have easy access for maintenance.

No managed ponding is acceptable on blue roofs.

COMPONENTS REQUIRED FOR A BLUE ROOF:

- Drainage and water storage/irrigation layer - The layer should be thick enough to manage the required amount of water. Water stored in this layer can be used to passively irrigate vegetation located above the system. Key performance criteria include water storage capacity, hydraulic conductivity, weight, compressive strength and perforated area.
- Moisture retention layer – A geotextile blanket allows the retention of water at the base of the substrate and wicks water from damp areas to dryer areas.
- Sub-base layer – A layer between the surfacing layer and the blue roof layer. This can be formed of standard type 1 sub-base, modified low fines sub-base, or flat-based pedestals.
- Geotextile Layer – A barrier to prevent silt and debris ingress into the drainage/water/sub-base layer. Key performance criteria include weight, density, tensile strength and elongation break.
- Diffuser/catchpit layer/outlet chambers – At any point where water enters the blue roof layer from other sources, a diffuser chamber is needed to allow water to diffuse into the blue roof layer. The diffuser chamber also doubles as a catchpit intercepting any silt and debris. An outlet chamber is required at every outlet point to give access when construction is finished.



PROS	CONS
Increases life span of roof	Greater expense than traditional roof
Boost thermal perfromance	Greater maintenace requirement
Acts as building attenuation	Requires similar number of outlets as traditional roof
Could enhances biodiversity of the development	Suitable waterproofing to be used
Could enhance amentiy of development	Suitable overflows required
Can enhance air quality	Heavier than traditonal and green roof
Cooler surfaces (reduction in Urban Heat Island effect)	Leaks are more difficult to identify
Noise reduction	Repairs are more difficult to make
Can be roof top gardens or amenity spaces	
Can enhance energy production when coupled with photo-volatic cells	
Fewer outlets required	
Smaller internal pipework requirement	

CASE STUDY – One Tower Bridge

The roadways between the buildings at the One Tower Bridge Development, including Duchess Walk and Still Walk, are built on a podium deck above a basement carpark. A Blue roof layer has been installed on top of the podium deck. The available depth for the installation of a blue roof layer was less than 500 mm. As the roadways are trafficked, the Permavoid system was used due to its strength. As the maximum depth from ground level was less than 500 mm, the blue roof system discharges into the River Thames, above the tidal levels and, as such, compensatory storage is not required. In addition to this having the storage layer sat on the podium deck, the attenuation was taken out of the car parking areas, freeing up an area that can be rented out as resident car parking spaces, which offered a significant return.

Shallow green SuDS

Swales

A swale is a small landform that collects water and conveys it along itself, toward a discharge point. Swales can be relatively shallow, circa 300-500 mm deep, with shallow graded sides (not exceeding 1 in 3) A swale can collect runoff directly from a pavement or roadway, or runoff can feed into them via proprietary inlets.

Swales are often vegetated and can be underdrained with a pipe or with Permavoid. Swales are excellent water conduits and can convey water at gradients of 1:500.

Rain gardens

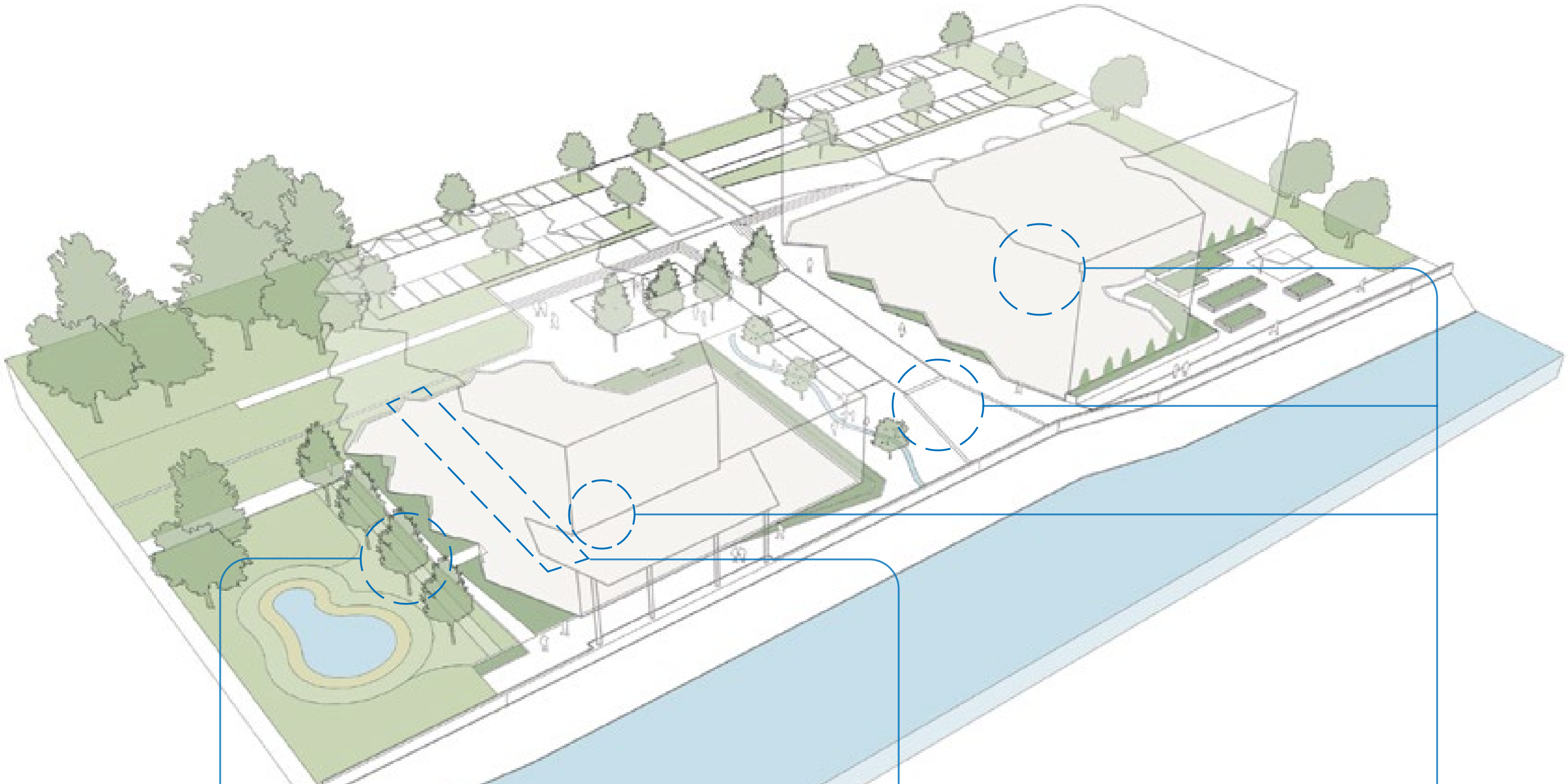
A rain garden is a planted area that incorporates vegetation to enrich natural habitats in an area. The principle behind a rain garden is similar to that of a bioretention system and similar benefits can also be delivered, with the rain garden being smaller. Rain gardens provide an attractive, low-maintenance, and wildlife-friendly space that can be enjoyed by the local community.

Bioretention areas

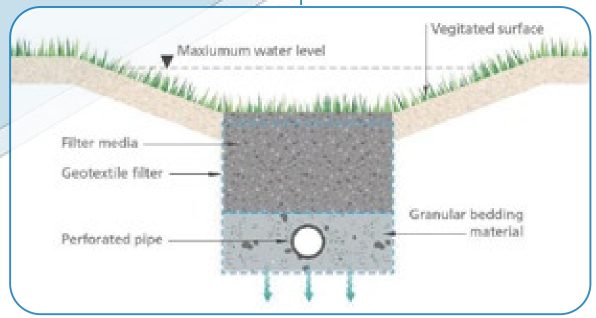
The Bioretention system can bring great added value to dense urban environments. It is an engineered component comprising a shallow drained depression, with enhanced vegetation and engineered subsoils, with the potential to incorporate additional subsurface storage. It is able to reduce flow rates and volumes of runoff entering the system.

Various landscaping techniques can be used across the system to maximise the benefits of a bioretention system. The benefits include:

- Creating water storage capacity;
- Reducing flow rates from the system;
- Delivering source-control treatment of the runoff;
- Creating attractive green spaces;
- Creating aesthetically pleasing environments, which positively impact the mental wellbeing of the community and increase the monetary value of nearby land;
- Reducing local temperatures through heat absorption and retention;
- Returning moisture to the atmosphere through evapotranspiration from the vegetation (also delivering evaporative cooling);
- Potential for enhanced amenity through integration with the local development plan;
- Creating high-quality habitats for native plants and wildlife;
- Noise reduction via vegetative buffering;
- Air quality improvements.



Bioretention area



Swales

Rain gardens

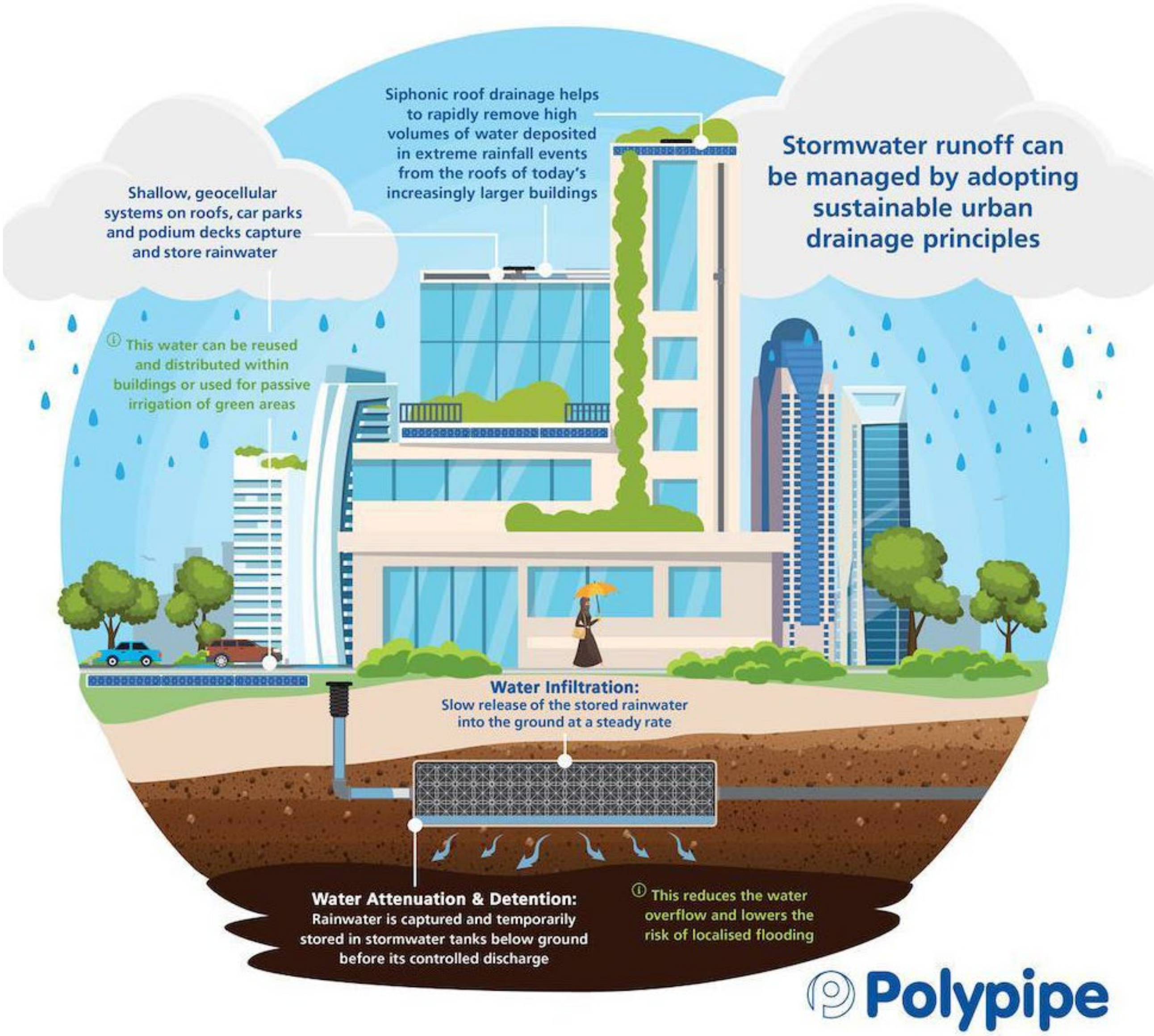
5.6 Re-use

Rainwater re-use helps to reduce the volume of water discharged, while mitigating against water scarcity. Ideally, developments within the Shoreham region should employ rainwater re-use, such as rainwater harvesting, where possible. Rainwater re-use helps reduce potable water demand and the discharge of water. Rainwater can be utilised for a variety of applications, e.g. cleaning, irrigation and flushing toilets.

South East England is a water-stressed region. Many SuDS features can be used locally to capture, treat and manage water for re-supply of cleansed water to buildings and/or landscapes. Rainwater harvesting can be installed at a range of scales, from individual property scale to site-wide schemes.

Reuse could be provided by a formal, dedicated rainwater harvesting system, or it could be integrated into the Permavoid as passive irrigation within green SuDS features or green-blue roofs or through a combination of the two.

Calculations highlighting the amount of water able to be collected and the amount of water required (supply and demand) should be undertaken prior to construction. Whilst water butts fall within the definition of rainwater harvesting, the use of water butts must not be included in any storage calculations, as they rely on their owners emptying them before storm events.



5.7 Smart/Active

One issue with rainwater harvesting systems is that there is a chance that the system could be full when the peak storm event occurs and as such, any attenuation potential provided by the systems is lost. This issue can be mitigated via the enhancement of the rainwater harvesting systems into active and/or smart rainwater harvesting systems. The enhancement for both of these systems is through the inclusion of data and data integration.

The outline principle for smart tanks is for the rainwater harvesting/attenuation system to hold water and only discharge when key criteria have been met. In the vast majority of systems, this is an incoming storm and current water level. In principle, the system is connected to a weather forecasting service and it discharges ahead of the rainfall event to ensure that it is empty enough, to receive the incoming rainfall.

There is a scale to 'smart' features ranging from simple smart water butts, right through to systems that incorporate artificial intelligence (AI) to make decisions.

Active

An active rainwater harvesting (RWH) tank differs from a traditional (passive) RWH tank, as it integrates weather forecasting. The RWH tank will have a link to a weather forecasting service, which will 'watch' the weather forecast for the area. The RWH tank will 'hold' the water until it sees a rainfall event and at this point, it will actively manage the volume of water stored in the system by actuating the drainage outlet.

There are various levels of active systems from cheaper, less sophisticated, systems to more expensive, more sophisticated systems. The less sophisticated systems will inform the owner of the RWH tank that a weather event is incoming and for them to 'open the tap' or drain the system in preparation. This system does not accommodate for the level of rainfall received and it relies heavily on human input, without which it will fail.

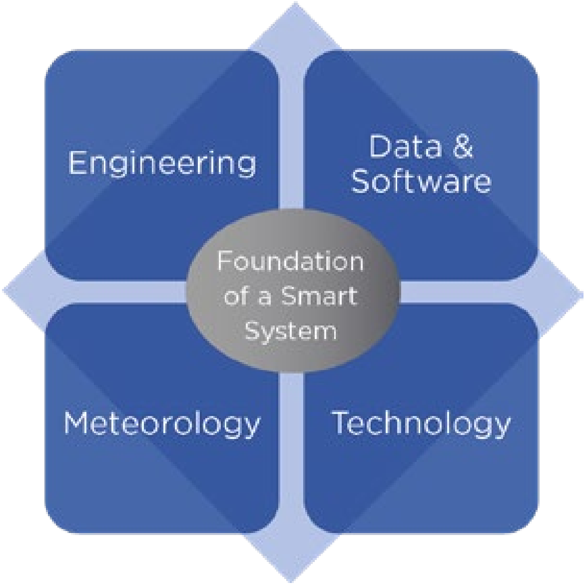
Whereas a more sophisticated system will automate the opening and closing of the valve and will also identify an amount to discharge, which correlates to the current spare capacity and the anticipated volume of water it will receive.

Smart

A smart rainwater harvesting tank is an active system, but with an integrated artificial intelligence feature. A smart tank will review its performance and measure if the prediction it originally made was accurate and if it wasn't, what would need to be done to make it more accurate. The more times a smart system receives rainfall events and/or discharges, the more accurate the system becomes. smart systems also have the potential to 'communicate' with the existing infrastructure, such as water authority sewers or EA-owned assets.

Smart systems can integrate more sensors into themselves and as such, integrate more rules. These rules or application programming interface (API) can be changed, or can use other criteria. For a waterfront development area such as the Shoreham region, the API could include the tidal information. In this way, if the storm event and the high tide were to coincide, then the system could empty the rainwater tanks/attenuation tanks so that there is enough storage to manage this overlap. However, unlike the traditional method, where this water would just discharge to the sea once the tide has subsided, in a smart system, the water would be held for re-use.

A smart system should follow the four pillars of smart principal.



Polysync

The Polysync system is a smart system that has been developed based on the four pillars of Smart. It uses an optimisation engine provided by a large data processing company called Kisters and its weather forecasting integration is the gold standard, 15 min updated forecast, to a postcode level. The Polysync system has been installed on an existing roof at the Bloc Building in Manchester, that historically would have been dismissed as being too lightweight to hold a green roof. The principle of the smart tank is to combine the rainwater harvesting tank into the attenuation tank. The smart tank keeps as much water as possible for rainwater harvesting (more than a traditional harvesting system) and makes decisions on when to discharge, based on the incoming weather. By holding water for passive irrigation, the depth of the substrate can be thinned to levels that are usually considered too shallow for effective vegetation growth. The roof discharges to the United Utilities sewer, but importantly when it does discharge, it discharges ahead of the storm, when the sewer can accommodate the flow. It holds water and doesn't discharge during the storm event, when the sewer is at capacity.

The communication system in Polysync is based on the Water Information System by KIsters (WISKI) system. WISKI is a comprehensive software that efficiently streamlines all tasks of the process chain: from data acquisition and storage, to data validation and analyses, to reporting and collaboration. WISKI standardises and automates its routines which allows Polysync to be able to 'talk' with 99% of sensors available on the market.

The data from the Polysync system on the Bloc roof is showing that the smart system is intercepting the water and holding it for passive irrigation and significantly reducing the amount of water getting to the sewer system. The Polysync system and the blue roof at the Bloc Roof in Manchester won the 2022 SuSDrain award for regeneration and retrofit – small scale.

5.8 Managing scour

Scour is created when the water discharging onto a surface has enough energy/velocity to erode it. The critical methods of managing scour is either to reduce the energy or discharge it onto/into something that doesn't erode.

Water discharging from a site over a large area, for example using the projected roofs or projected walkways method, similar to Fulham Football Club, then entering the harbour is diffuse, i.e, spread over a larger area. Diffuse discharges have significantly lower energy than point discharges and as such the risk of scour is reduced. Where the development discharges via a limited number of outlets, this discharge will be concentrated and the risk of scour is high. Using energy diffusion methods like discharging the runoff via stone filled gabions or perforated vertical outfalls that would discharge through the full tidal range will reduce the risk of scour. Discharging to areas where scour would not be an issue, i.e. onto a material hard enough to cope with the energy involved or direct into the sea, will solve this problem but are location specific and a new development may not have the geology or sea levels to suit.

The issue of scour was discussed in relation to the proposed Kingston Wharf development and it was considered that the placement of stone-filled gabions beneath the boardwalk structure could dissipate the erosive energy of water discharged via an Over-the-Wall technique and thus minimise scour.

6. CASE STUDIES

The following case studies are developments that have been designed using the Over-the-Wall principles.

6.1 Ropetackle

The proposed development at Ropetackle North sits alongside the River Adur in Shoreham, southeast England. The complex site is bordered by a raised railway embankment to the south, the A283 (Old Shoreham Road) to the east, and the River Adur to the west. The site was previously a disused land with derelict buildings and was identified by the Environmental Agency as a flood plain.

The development had plans to be a mixed-use residential and commercial scheme, comprising approximately 15,050 m^2 of impermeable area consisting of car parks, access roads, mixed-use areas, footpaths and buildings.

The surface water from the development was proposed to discharge to the adjacent River Adur, as is currently the case. Tidal locking in the river meant that, at certain times, water was unable to leave the site causing flooding. It was established that the development would require 6 hours of storage capacity to manage the 1 in 100 year storm event + 30% for climate change. This equated to 1,073 m3 of surface water storage.

The SuDS was designed so that the surface water runoff from trafficked areas would be collected and treated by the sub-base below the permeable paving. The sub-base consists of 300 mm porous sub-base layer overlying a 150 mm Permavoid conduit, wrapped in Permafilter SuDS geotextile

Roof areas were designed to discharge directly to the Permavoid layer within the trafficked areas, or in some cases to Polystorm attenuation crates (PSM1) within the garden areas. All rainwater pipes (RWPs) discharge via catchpit inspection chambers or to back inlet gullies with filter screens, to prevent silt from entering the tank systems.

By providing the required storage primarily within pervious sub-base and Permavoid, the discharge was much shallower reducing the tidal lock time and mitigating against surface flooding on the development.

6.2 Fulham

Situated on the Banks of the River Thames, Fulham FC has expanded its riverside stand, which will increase the stadium's total capacity from 24,300 up to 30,000 people. The proposal for the extension is to provide a community hub and 'place to go' on non-match days, by creating a riverside walk next to the stand extension and enabling the route to become part of the Thames Pathway.

The proposed stand and the riverside walk is to extend over the River Thames, with the club purchasing a section of the River Thames to enable this build-over.

The shape of the stand is designed to be aesthetically pleasing for a riverside development, while allowing windblown rain, falling on the face of the stand, to fall via sheet flow over the riverside walk and directly into the river.

The riverside walk has been designed to have a 'floating' timber decking footway, made using steel trusses connected to the riverside stand. Rain falling onto the riverside walk will fall between the timber decking and directly into the river.

As a result of the Over-the-Wall principles which have been used on this development, attenuation and/or compensatory storage has not been required for the riverside stand and walkway.

Supporter congregation areas between the riverside stand and the north and south stands are refurbished existing areas and not built above the ground level. In these areas, pervious surfacing, coupled with Permavoid, is used to collect and manage the surface water falling onto it. Through the use of the Permavoid sub-base replacement system, the connection from this area into the river is above the tidal range of the River Thames.

7. STAKEHOLDER ENGAGEMENT

A stakeholder engagement workshop was held at Shoreham Port Authority offices on 6th March 2020, attended by representatives of the following organisations:

- West Sussex County Council
- Robert Bray Associates
- Shoreham Port Authority
- Southern Water
- Adur and Worthing Councils
- University of Portsmouth
- Environment Agency
- HOP Engineers
- Natural England

7.1 The purpose of the engagement workshop

The purpose of the event was to discuss the drawbacks of conventional tidal locked drainage systems with surface water storage tanks, introduce the principle of Over-the-Wall drainage, brainstorm and explore ideas of how it could be implemented on projects and highlight any technical, cost or maintenance concerns of the various Over-the-Wall drainage options.

7.2 Engagement workshop agenda

A copy of the agenda can be found at Appendix xxx. As well as setting out the purpose of the workshop, key content included:

Context for meeting

a. Highlighting the issues associated with defended coastlines and gravity sewer systems;
b. Alignment of project with UKWIR project BQ6 project 03: Surface water drainage from new developments;
c. Recent experience / innovation in relation to waterfront drainage led by Robert Bray Associates.

Shoreham Harbour Regeneration & Over-the-Wall drainage

Exploring the site specific considerations in relation to:

a. Masterplan;
b. Opportunities;
c. Constraints – Developer priorities / timeline; boardwalk; mudflat scour; structural & visual resilience; health and safety considerations / crime and vandalism considerations; other Port Authority considerations?

Conceptual ideas of how drainage may be approached

This was led by Robert Bray Associates exploring different approaches to building and site layouts and how water could be conveyed through a site.

Breakout sessions

These were held during the afternoon, comprising groups of three or four delegates; each group was tasked with exploring how the Over-the-Wall design concept could be applied to one of the development sites within Shoreham Harbour Western Arm. This afforded the opportunity to consider waterfront development for three separate sites with differing contexts and challenges.

Feedback from the breakout sessions and the workshop as a whole

This helped shape the project going forwards from the outset.

7.3 Workshop outputs

The physical outputs included:

- The summary notes and marked-up drawings from the breakout sessions (see examples in Appendix xxx), and
- The workshop presentations by Ray Drabble and Robert Bray Associates.

In addition to this there was valuable collaboration between Southern Water and the projects consultant modelling team to allow use of the Southern Water network model to assess the long-term implications of sea-level rise on their network.

7.4 Summary of findings of the workshop

Arguably, the most significant finding was that there were not considered to be any fundamental show-stoppers to achieving Over-the-Wall drainage. Shoreham Port Engineers had first-hand experience with siphonic roof drainage and had experienced maintenance issues with their system as a consequence of seagulls, and this highlighted the need for further investigation by the project team. For some developments, e.g. Kingston Wharf, it is the frontage of the development itself that forms the tidal defence and the riverwalk lies outside of the defence and floods at certain high tides. It was recognised that this made the concept of Over-the-Wall drainage simpler as conveyance across the site from the main structure to a physically removed tidal defence was not a requirement. Where issues had been identified, there were innovative suggestions as to how these might be addressed. For example, scour of mudflats was considered and routing over the wall drainage through a gabion wall section to diffuse flow was suggested. A key consideration going forwards was further examination of the easement requirements for maintenance of sea defences stipulated by the EA and this fully emphasised the value of incorporating Over-the-Wall drainage considerations at master planning where site / building layouts are being considered.

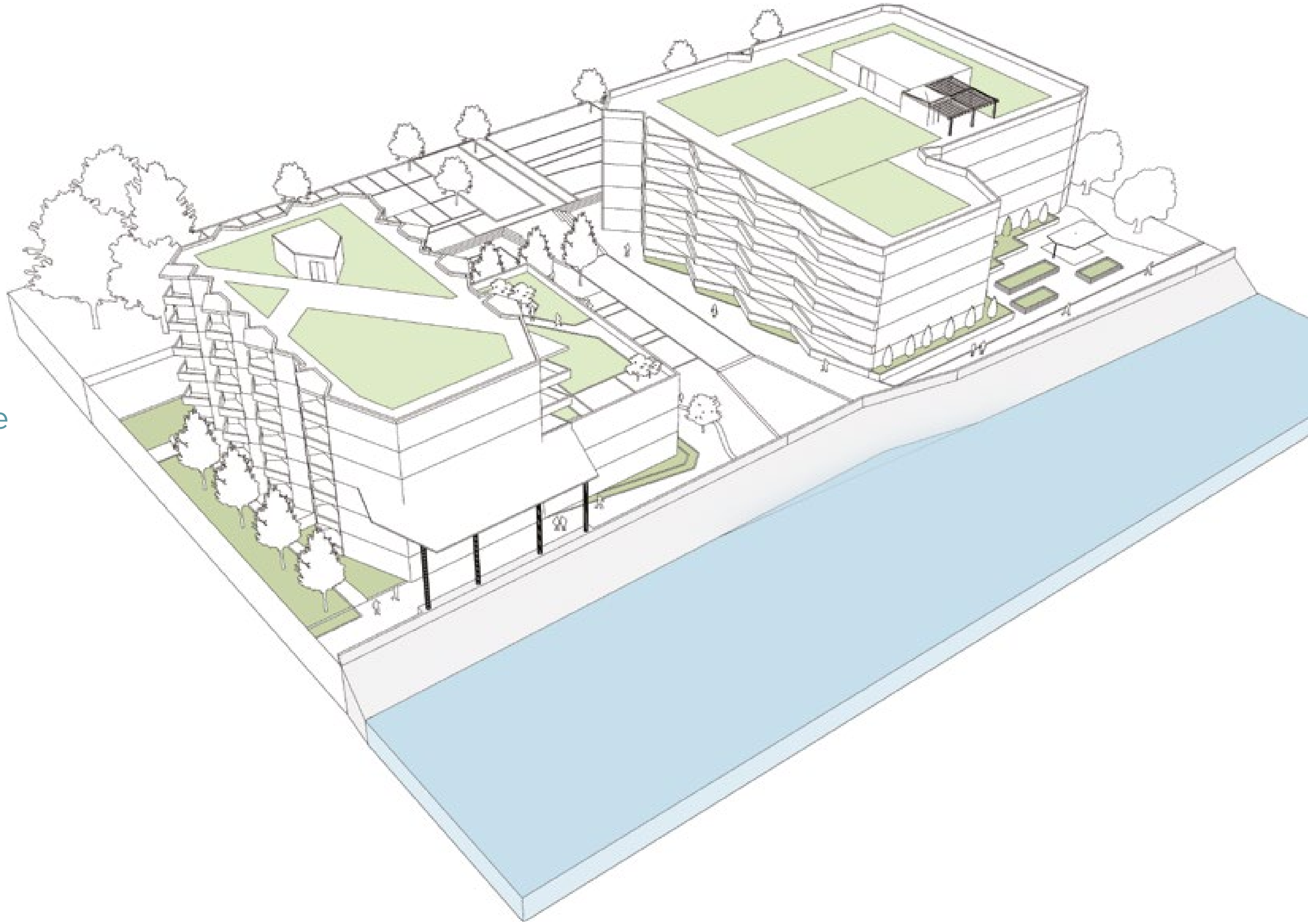
8. COST COMPARISON

An important part of decision making is to understand the costs and benefits involved. One aim of this project is to explore the feasibility of Over-the-Wall drainage techniques compared to traditional methods.

8.1 Over-the-Wall candidate site

To do this, we produced a mock up development.

The proposed development consists of two multistorey buildings. Associated with the buildings there are 38 external car parking spaces, a small playground, communal green areas and a central courtyard between the buildings. One of the buildings, the eastern building, will have a split roof at different levels. The upper roof is proposed to be used for plant and will be an extensive green roof.



SITE CONSTRAINTS

- Manage 1 in 100 year rainfall event with a 40% climate change uplift
- Site 8,500 sq.m in size
- Tidal lock of traditional tank results in a 240 cu.m additional volume
- Storage estimate based on above criteria = 275 cu.m
- Max tidal level 0.6 m bgl
- Groundwater hydraulically linked and at 0.6 m bgl
- Maximum discharge pipe size = 300 mm Ø

The pipe size will result in a restriction to the discharge preventing free discharge of the storm event. As such an attenuation will be required to manage the runoff from the design storm at the point where free discharge no longer happens and the pipe restriction begins.

8.2 Costings

A full detailed breakdown of the costings can be found in Appendix xxx. Pervious surfacing, blue and siphonic roof drainage was included within the mitigation measures/costings within Over-the-Wall solutions, and therefore, items that usually wouldn't be included with external drainage such as traditional paving or internal pipework have also been included within the costings.

For cellular structures, such as the attenuation tanks, Permavoid, and all associated fixtures, fittings and pipework, Polypipe have kindly provided actual costings for all these elements.

Traditional solution

The proposed cost for the traditional solution is £407,928.40 + VAT.

Over-the-Wall solution

The proposed cost for the traditional solution is £401,419.90 + VAT.

Summary of costings

There is £6,508.5 or 1.62% percent difference between both costs. As such it would be reasonable to state that the Over-the Wall principle is at worse cost neutral. As stated above it is important that like-for-like costs are pursued, such as counting the relevant macadam area when comparing against pervious pavements.

Not all attenuation tanks are created equal

Within the attenuation tank market there is a huge variation in types of attenuation tank from concrete to plastic. There are pros and cons for each of the differing materials, such as cost, carbon footprint, and suitability. Within the plastic cellular structures there is again a huge variation of types from traditional "milk crate" types to honeycomb voided structures, through to plate structures.

Differing plastic attenuation structures will have differing loading capabilities with those that are "stronger" being able to be installed at a shallower depth. Permavoid, for example, is a sub-base replacement system and can be installed into a trafficked pavement with a cover as slender as 130 mm. However, this cost comes with price difference and when comparing Permavoid to a standard medium or light duty cell, the price difference will be marked. Where there is a reason to manage the water at a shallow/high level, such as high tide level (Over-the-Wall) high groundwater or contaminated ground, Permavoid becomes more cost effective.

When using plastic attenuation tanks structural calculations undertaken by a competent engineer and in line with CIRIA Guidance C680, C737 and the British Plastic Federation report on designing geocellular drainage systems. These reports should also be used when determining the relevant characteristics/figures for the attenuation tank.

Outside of costings

The costings given within Appendix xxx are for materials only and do not include cost of labour and equipment and nor do they include the cost of landscaping.

The Over-the-Wall scenario is a much shallower design. Shallower designs often are quicker and easier to construct and can potentially reduce the amount of spoil generated and removed to landfill. A quicker construction will save money in labour and plant hire costs. By constructing above the groundwater, the requirement to dewater the attenuation trenches and holes is not required or kept to a minimum. It would be estimated that the cost of a small scale dewatering system (pump hire and out of hours labour) would begin at around £3500 + VAT per week. As depth or flow rate increases the size of the pumpset would need to increase as well, increasing the weekly cost.

An Over-the-Wall solution can involve the use of green infrastructure. Green infrastructure has both a capital and ongoing (maintenance) cost; neither of these have been included within cost comparison as the planting regime will be particular to site, its locations and its landscape design.

Benefits

Many of the Over-the-Wall mitigation techniques are SuDS or Blue/Green infrastructure solutions. The use of Blue/Green infrastructure has additional benefits on top of those focused on in this report. These benefits can include improvements in air quality, reduction in crime, increase in health and wellbeing, and increase in property values. The CIRIA B£ST tool is a structured method to estimate the value of the multiple benefits that blue/green solutions provide.

9. SUMMARY

Shoreham-by-Sea is situated along the southern coast of the United Kingdom, which places existing and proposed developments in this area at risk of global sea level rise. Shoreham population has increased by 5.4% since 2011 placing further pressure on the existing infrastructure and requiring new housing developments to be built. It is likely that these developments will discharge to tidally influenced watercourses or sewers.

The current Mean Sea Level is 1.95 m AOD. The anticipated Mean High Water Springs (MHWS) tide level in 2115 is 3.03 m AOD. The anticipated 1 in 200 year flood level (0.5AEP) is 5.4 m AOD. Large sections of the Shoreham region are below 1 in 200 year flood level. Where sites are or their drainage is below the tide level, the drainage becomes tidally locked and is unable to discharge while the outfall is submerged. As such this means that additional volume of attenuation is required to mitigate against this tidal locking. With climate change impacting the United Kingdom the intensity of storms will increase, as will sea levels meaning that greater volumes of tidal locking mitigation will be required.

All future developments should manage the following scenarios:

- The 3.33% Annual Exceedance Probability (AEP) storm event combined with a MHWS tide;
- The 1% AEP storm event combined with a MHWS tide;
- The 50% AEP storm event combined with a 0.5% AEP tide.

WSP undertook the hydraulic modelling of the three scenarios for a site in the Shoreham Regeneration Area with WinDes software (Appendix xxx). The model shows that for all three scenarios (Chapter 4.1) an Over-the-Wall approach using Permavoid requires less storage.

WSP also highlights the importance of modelling the combination of the 50% AEP storm event combined with a 0.5% AEP tide, as this parameter is not often considered but can result in significant flooding throughout the life of the development.

Discharges from the development are to be above the MHWS 2115 year level (3.03 mAOD) and can be unrestricted. However, the maximum outfall diameter should be no greater than 300 mm.

The Over-the-Wall approaches are a combination of direct discharge from above (projected building and roofs/siphonic systems/green roofs) and shallow solutions (Permavoid/pervious surfacing, and Blue/Green infrastructure). Using the Over-the-Wall approach will feature a robust sustainable SuDS solution and conversely using a SuDS solution for a waterfront development will also increase the likelihood for a discharge above the MHWS.

Existing waterfront developments will have been constructed to an older standard but will be subject to the same rise in sea levels, therefore increasing their flood risk. Many of the Over-the-Wall approaches can be retrofitted into a development. The use of retrofit Over-the-Wall solutions will enhance the resilience of the development and, given many of the solutions are shallow or above ground, these are much simpler to retrofit than traditional drainage solutions.

An Over-the-Wall solution will offer significantly cleaner runoff to the receiving water body and could reduce the risk of eutrophication.

When considered as a whole and comparably, an Over-the-Wall solution should not be any more expensive than a traditional solution and when labour and hire costs are included it should be noticeably cheaper. However, where green infrastructure is used there will be a higher ongoing maintenance cost.

Rainwater is an essential resource and should be re-used wherever possible. New technology such as ‘smart’ tanks can be incorporated into new developments to maximise the potential re-use. These will be able to predict and mitigate against the combination of high tide and peak storm occurring simultaneously. Smart systems should be able to bring in additional sensors and be able to ‘communicate’ with other infrastructure such as sewers.

This report focuses on the potential application of the Over-the-Wall drainage approaches within the Shoreham Harbour Redevelopment Regeneration Area, however the principles are applicable in any area draining into tidal waters.

appendix 1

title

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