

# Sustainable drainage systems

## Hydraulic, structural and water quality advice

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## 9.13

## ON-/OFF-LINE STORAGE

### Box 9.13.1

*Key considerations for on-/off-line storage*

<p><b>Description</b></p> <p>Storage of runoff in underground tanks or other structures such as oversized pipes.</p> <p><b>Design criteria</b></p> <ul style="list-style-type: none"> <li>• Standard surface water drainage design using limiting outflow rates to determine storage volumes</li> <li>• <i>Sewers for adoption</i>, 5th edition (WRc, 2001a)</li> <li>• structural design to relevant standards.</li> </ul> <p><b>Pollutant removal</b></p> <p>Very poor.</p>	<p><b>Applications</b></p> <p>Suitable where there is limited space and treatment is not a priority.</p> <p><b>Limiting factors</b></p> <ul style="list-style-type: none"> <li>• Does not provide any treatment and so needs to be used in conjunction with other treatment techniques</li> <li>• may require deep excavations for large storage volumes.</li> </ul> <p><b>Maintenance</b></p> <ul style="list-style-type: none"> <li>• Inspection for silting and blockages every six months</li> <li>• removal of silt and blockages as required.</li> </ul>
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### 9.13.1

### Description

This section refers to on-line or off-line storage in tanks or other underground structures. On- and off-line storage is also provided by other SUDS techniques (for example, ponds and wetlands), but these provide some degree of treatment to the runoff. Tanked storage does not provide any significant treatment of pollution in runoff.

Tanked storage is provided to detain runoff on site and release it at the required rate into the receiving watercourse or sewer, thus reducing peak storm flows from a site. The tanks can take the form of oversized pipes, concrete tanks, corrugated steel pipes and plastic cellular tank systems, among others.

The design of on or off-line storage is well understood and only those aspects not covered in existing design standards and guidance are discussed here.

### 9.13.2

### Suitable applications

Underground on- or off-line storage may be provided where there is little room for other above-ground techniques such as ponds, which require large areas to implement. On- or off-line storage does not provide any significant treatment to runoff and should be used in conjunction with other techniques.

### 9.13.3

### Advantages and disadvantages

The advantages and disadvantages of on- or off-line storage in underground tanks are summarised in Table 9.13.1.

**Table 9.13.1** *Advantages and disadvantages of on- or off-line storage systems*

Advantages	Disadvantages
Well understood both in design and construction terms	Does not provide any treatment of runoff
Does not take up large amounts of site area and can be located under most areas of a site	Can require deep excavations if a large storage volume is necessary

## 9.13.4

### Performance

#### Pollutant removal

On- or off-line storage is used only to attenuate peak flows from a site. It does not provide any reduction in volume or significant pollutant removal and must be combined with another SUDS technique to achieve the water quality criteria (Section 4.3).

#### Hydraulic performance

On- or off-line storage is a conventional drainage technique whose performance is well understood.

## 9.13.5

### Design criteria

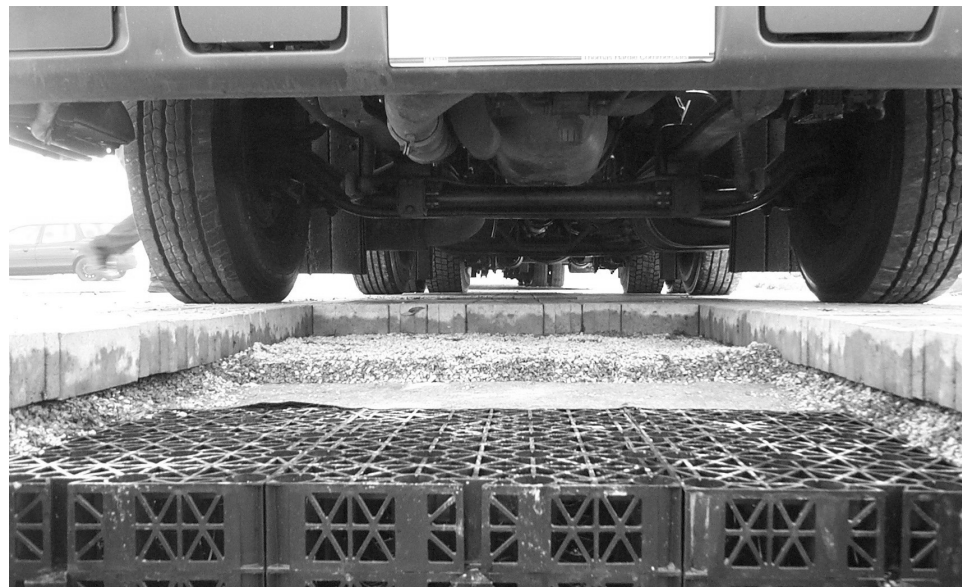
#### Pipes or tanks

The hydraulic and structural design of on- or off-line storage using pipes or tanks should be in accordance with *Sewers for adoption*, 5th edition (WRc, 2001a). The structural design of pipes should also be in accordance with BS EN 1295:1998 *Structural design of buried pipelines under various conditions of loading*.

## 9.13.6

### Structural design of geocellular plastic structures

Modular plastic geocellular units are increasingly being used as a cost-effective method of providing stormwater infiltration and attenuation tanks below new developments (Figure 9.13.1). It is emphasised that these tanks are structures and should be designed as such using structural theory, in a similar way to tanks constructed in other materials such as concrete. They are often used below areas that are trafficked by heavy goods vehicles that can impose significant loads on them.



**Figure 9.13.1** Plastic modular storage tank below a trial car park at Coventry University. View taken during deconstruction at the end of a one-year trial (SEL Environmental Limited)

In particular the effects of creep and deflections on overlying paved surfaces should be carefully considered. On occasions the individual units are also subject to bending, which will require analysis. Limit state design methods can be used to design these tanks (Box 9.13.2).

The philosophy of limit state design can be used so that the structures remain safe and suitable for use throughout their design life. A limit state is defined as “a limiting condition beyond which the structure stops fulfilling its intended function” (Day, 1997). The concept of limit state design is to consider the probability distributions of all parameters (applied loads and material strength and stiffness) to provide better level of control over risk and improved consistency than can traditional designs based on permissible stress or lumped factors of safety.

The load and material factors used for the structural design of concrete or steel are derived to achieve a target probability of failure and are specific to particular load and material types. With careful consideration, however, the guidance on appropriate load and material factors used for other structures can be applied to the design of plastic tanks.

The two most common limit states to be considered are:

- **ultimate limit state** – the structure should not collapse under foreseeable overload. The main consideration is strength
- **serviceability limit state of deflection** – in this case, deflections should be at acceptable levels (to prevent cracking in the overlying surfacing, for example).

**Loads**

Characteristic loads are a best estimate of the load likely to be placed on a structure during its design life. The characteristic load is multiplied by a partial factor of safety to produce a design load. This allows for:

- statistical variations in load
- increased loads due to tolerances in construction
- unforeseen load conditions.

The partial factors depend on the consequences of the limit state and the probability of particular combinations of load occurring at the same time. The loads that are applied to plastic tank structures are the same as those applied to other structures (such as traffic loads applied to bridges) and the probability of occurrence will be the same. Therefore, the guidance from structural design codes for other materials (eg BS 8110:1997) can be used to determine the partial load factors for plastic tank design (Table 9.13.2). The most common combination of loads will be dead plus live load.

**Table 9.13.2** Partial load factors from BS 8110, Part 1:1997 (dead and live load combination)

Load type	Ultimate limit state	Serviceability limit state
Dead load	1.4	1.0
Live load	1.6	1.0

The consequences of collapse are more serious than for cracks occurring in the surface. A higher factor is used for the ultimate limit state, therefore, so that the risk of the limit state being achieved is lower. Lorries can also impose very high dynamic loads on the boxes, depending on their speed, and factors should be applied to allow for this in design.

**Surfacing and allowable deflections**

The type of surface overlying the storage tanks determines the levels of deflection acceptable under loading. A reinforced aggregate surfacing, for example, is able to tolerate greater deflections than an asphalt surfacing. The nature of the deflections also needs to be considered, as they are elastic and will be repeated during the lifetime of the structure. Block paving is a relatively flexible material that can tolerate elastic deflections up to about 1.5 mm without adverse effects.

To account for factors such as variations during manufacture, variability and uncertainties in material strength (for example, due to extrapolation of data), damage during installation, and environmental effects, the design strength must be obtained by applying a material partial factor of safety  $\gamma_m$ , appropriate to the material and limit state. This also allows for the effects of fatigue (reduced strength as a result of repeated application of load).

The only readily available guidance on choice of material factors for thermoplastic materials in load-bearing applications is for geogrids used in earth reinforcement applications (BS 8006:1995 and Ingold, 1994).

The partial factor for materials,  $\gamma_m$ , is made up of the components listed below.

- $\gamma_{m11}$  – applied to reduce the characteristic strength to give a minimum likely value. It covers possible reductions from the control test specimens and allows for inaccuracies in the assessment of the resistance of a structural element resulting from modelling errors. For tightly controlled geogrid production,  $\gamma_{m11}$  is normally between 1.05 and 1.1. Depending on the level of testing undertaken on stormwater storage units and the extent of quality control testing, a conservative value is usually adopted. Also the systems are often complex three-dimensional structures, which should be taken into account.
- $\gamma_{m12}$  – applied to take account of the extrapolation of creep test data. It is also used to allow for the absence of fatigue testing. A suggested value of  $\gamma_{m12}$  is (Ingold, 1994):

$\gamma_{m12} = \text{Log} (t_d/t_c)$ <p>where:  <math>t_d</math> = design life  <math>t_c</math> = duration of creep test</p>	(9.13.1)
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- $\gamma_{m21}$  – applied to take damage during construction into account.
- $\gamma_{m22}$  – applied to take environmental conditions into account. Polyolefins used in the manufacture of most stormwater units are resistant to most contaminants they are likely to come into contact with (although a site-specific assessment should be undertaken). A minimum value of 1.1 should be adopted, which is the minimum value recommended for reinforced earth applications (Ingold, 1994).

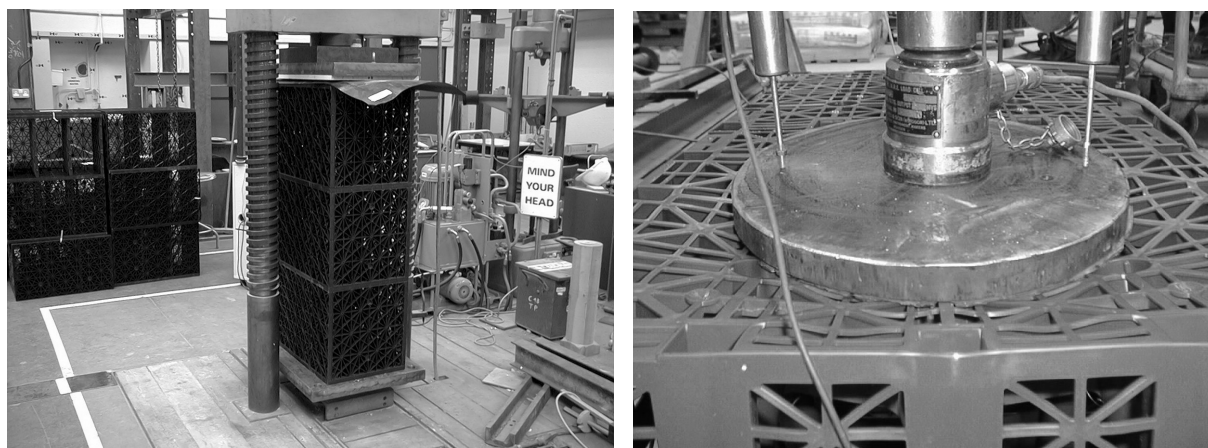
The factors should also allow for synergistic effects, that is, the combined effects of construction damage, environmental conditions and lower-than-expected strength may combine to give a greater effect than the three acting individually. Lower material factors may be used depending on the consequences of failure (for example, lower values may be used where a thin 150 mm plastic tank is placed below a paved area, since collapse is unlikely to cause overturning of vehicles). Again greater factors are applied to the ultimate limit state analysis so that the risk of collapse is at an acceptable level.

### Materials and laboratory testing

Most cellular stormwater tanks are manufactured using plastic (usually polypropylene or polyethylene) and are complex structures in their own right. Many manufacturers quote a single value of compressive strength for the units or simply express strength as a load the units can carry. Product literature often does not make clear how the strength or load has been derived.

On cellular structures where the load capacity is provided by a series of vertical columns or plates, compression testing should be undertaken at different points to find the worst-case load capacity. Bending tests may be required to allow the design of some configurations. Care should be taken to ensure that the strength derived from testing is representative of the system's performance in service, and more than one test configuration may be required (Figure 9.13.2). Where columns are an important load-bearing component, the structure may need to be tested with more than one size of platen to determine how load is distributed through the structure.

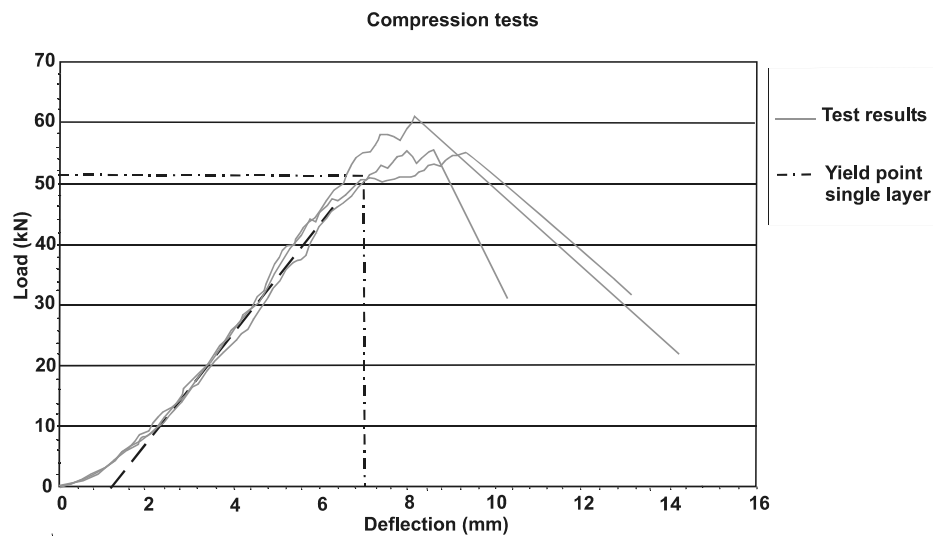
A complete set of independent test results for any proposed units should be requested from the manufacturer including, as a minimum, stress and strain curves for vertical and lateral compression and creep tests under sustained long-term loads. This allows the ultimate compressive strength and deflection performance of the units to be determined. In the absence of a specific test method for these types of materials, the method described in BS EN 124:1994 for determining the strength of manhole covers can be used, as it applies the load via a 300 mm plate, which is similar in dimensions to a vehicle tyre footprint. Testing with the load applied in several positions may be required to determine the worst credible parameters for a unit.



**Figure 9.13.2** *Compression test configurations on plastic cellular structures*

In the tests shown in Figure 9.13.2, the units were placed on a concrete floor and the load applied using a plate that covered the whole unit (a) and also a 300 mm-diameter circular plate (b). Several sets of tests should be undertaken on the top and sides of the units, with the load applied at different locations to determine the worst-case strength and stiffness parameters.

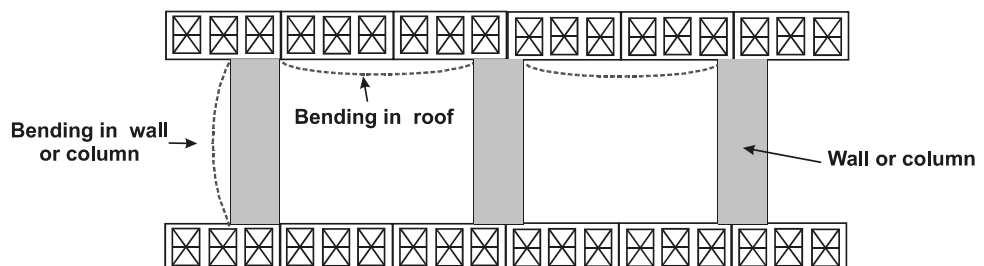
Typical results from laboratory tests to determine short-term compressive strength and deflection rates for a plastic cellular unit are shown on Figure 9.13.3. The design lines can be determined following the advice provided by the American Society for Testing and Materials in ASTM D-1621-00 (ASTM, 2000). The initial load-deflection relationship shows a lag similar to the effects of seating error in soils. As specified in ASTM D-1621-00, this part of the graph is ignored and the straight part is extended backwards to establish the correction for the zero offset. The ultimate compressive strength is determined at the yield point.



**Figure 9.13.3** Example stress-strain curve for compression tests (illustration only)

### Bending

Some systems use the individual units or columns to form tanks with an open internal void. This means the units are subject to bending stresses, and analysis using simple compression tests can underestimate the ultimate strength and possible deflections (Figure 9.13.4).



**Figure 9.13.4** Bending in box structure with an internal void

Bending tests are required to allow a more rigorous structural analysis of these structures.

## Creep

Creep and fatigue can significantly affect the long-term performance of plastic structures and need careful consideration in design. Creep occurs because the long polymer chains which form the polyolefin tend to slide over each other so that there is a time-dependency to the stress-strain diagram. A load placed on a polymer material will result in an initial deformation, but with the load remaining over time, further deformation will occur.

The rate of creep becomes greater as the applied load increases. Plastics also behave in a viscoelastic manner, so that if loads are removed some of the creep is recovered. Fatigue is loss of strength that occurs due to repeated application of traffic or other loads, which may reduce the strength of the units in the long term. The results from an example creep test are shown in Figure 9.13.5.

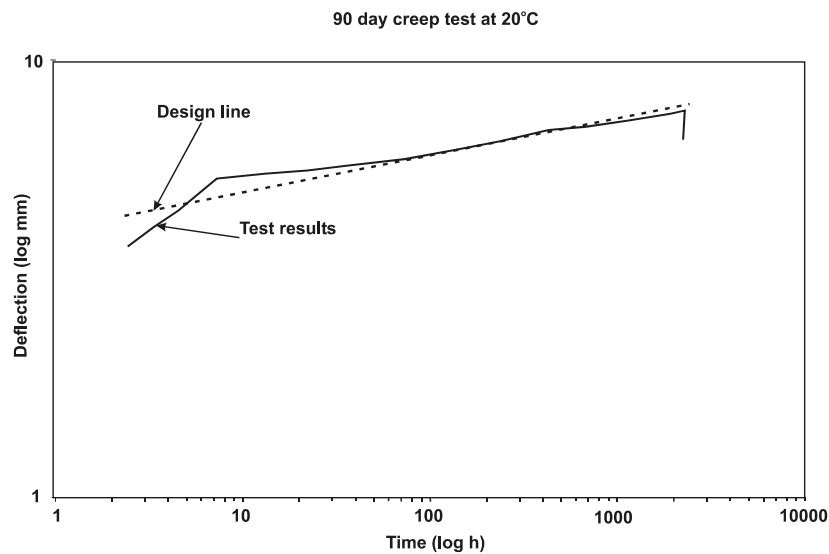


Figure 9.13.5 Example creep test results

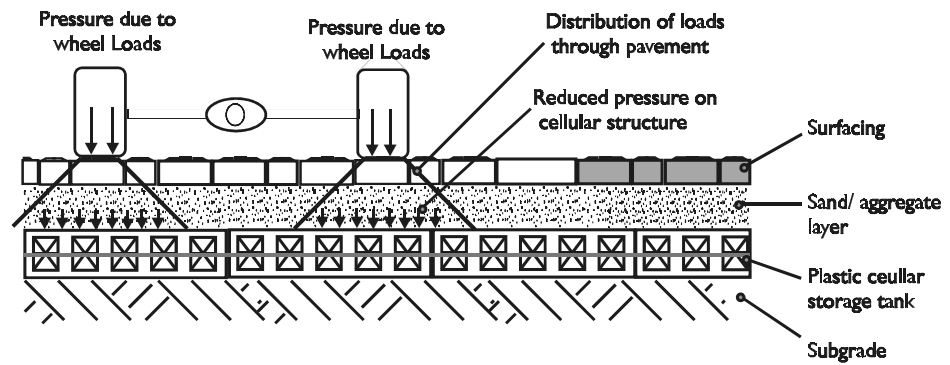
The results of creep tests are normally plotted as deflection versus time on a log-log graph so that the relationship between deflection and time can be more clearly identified. The intercept on the y axis is the extent of the seating error and initial elastic deflection that occurs on loading. Thus a long-term rate of deflection can be determined. The only advice available on creep test data in a similar situation relates to geogrids used in reinforced earth structures (Jewell, 1996). This suggests that creep test data should not be extrapolated in time to more than two orders of magnitude. For example, using the results of a 90-day test means that a design life of up to 20 years can be allowed for.

### 9.13.6

## Structural design considerations

Designers of plastic cellular water storage systems should consider the following:

- service dead and live loads should be identified
- dead loads will include fill material placed over the units and any other permanent or long-term loads such as storage tanks, for example
- live loads include distributed loads and point loads from wheels. Wheel loads from vehicles can impose very high concentrated loads on the units. Analysis is needed to determine the thickness of overlying material required to distribute the loads evenly and prevent overloading or excessive deflection of the units (Figure 9.13.6).



**Figure 9.13.6** Spread of load below a wheel

- construction plant such as excavators, cranes and compaction plant can impose significant loads on the systems before they are provided with final cover. The deformations that occur during construction should also be considered
- earth and water pressures impose lateral loads. These should be assessed and allowed for by designers
- flotation can occur if tanked systems are located below the water table
- the bearing capacity and settlement characteristics of the underlying soil
- risk of chemical or biological attack
- the effects of temperature variations on the plastic materials (especially with respect to creep).

### Full-scale testing

Where very shallow cover depths or unusual configurations are proposed, or where heavy loads are to be applied, the design may be confirmed by testing of full-scale sections of pavement (Figure 9.13.7). This gives increased confidence in the predicted performance of a system.



**Figure 9.13.7** Testing of a full-scale pavement incorporating a plastic cellular sub-base replacement system

Monitoring of installed systems under actual full-scale loading can also be undertaken to validate design theories, as shown in Figure 9.13.1.

## Operation and maintenance

Conventional storage is often perceived to be maintenance-free. This is incorrect, although the methods are different and the frequency of maintenance may be less than that required for other SUDS techniques.

The recommended maintenance schedule for storage tanks is provided in Table 9.13.3.

**Table 9.13.3** Maintenance requirements for storage tanks

Operation	Frequency
Inspection for silting and blockage of outlets	Six-monthly
Removal of silt and blockages	As necessary

## OIL SEPARATORS

Oil separators may be included in SUDS schemes to provide pre-treatment to runoff where necessary, (for example, surface water runoff from stormwater hotspots where the potential for spillages of hydrocarbons is high).

In comparison with other SUDS systems, oil separators are heavily reliant on frequent routine maintenance to prevent pollution. As they are hidden, any pollution that is trapped in the system is not obvious; if not removed, such pollution can easily become re-suspended in heavy rainfall events. This may be mitigated to some extent by incorporating automatic monitors, as required by British Standard BS EN 858-1:2002. The advantage of oil separators is that they do not take up surface space and can be used in urban situations.

Oil separators should be designed in accordance with BS EN 858-1:2002, *Separator systems for light liquids (eg oil and petrol). Part 1: Principles of product design, performance and testing, marking and quality control*. Guidance is also provided in Pollution Prevention Guideline no 3 (PPG 3), *Use and design of oil separators in surface water drainage systems*, published by the Environment Agency/Scottish Environmental Protection Agency.

## INNOVATIVE TECHNIQUES

There is continuous innovation in the area of SUDS techniques and particularly in the development of modular systems that can be used in dense urban areas, where the scope for using other techniques may be limited. The suitability of these techniques for use on any site should be assessed on their own merits.

In the USA, a system has been developed that incorporates filtration, sedimentation and a submerged gravel wetland system into a tank just 3 m in diameter. The use of internal baffles and compartments creates a tortuous route for the runoff's flowpath through the system (Winkler, 1997). The system can be used in urban situations and is capable of removing up to 98 per cent TSS.

The use of pervious surfaces is limited in stormwater hotspot locations, for example where there is a high risk of spillages of hydrocarbons. One method of overcoming this is to incorporate an oil interceptor into a pervious pavement (Wilson *et al.*, 2003). The system is constructed using a plastic sub-base replacement to provide the storage. Its pollutant retention capabilities for a range of scenarios have been assessed including a

catastrophic oil leak from a car engine, followed by car washing and then a fuel spillage. The results indicated that the performance of the system was much better than required for a conventional oil interceptor (BS EN 858-1:2002) by a factor of between 10 and 50.

There are various hydrodynamic devices (known as swirl separators in the USA) that have become more widely used in recent years. The concept is that sediment is removed as the runoff flows in a swirling path (USEPA, 2002). There are several types available, each of which incorporates a different detail, such as additional oil and silt traps. They do require continuous maintenance to ensure continuing operation, however. Another drawback is the lack of independent data on the systems' effectiveness in removing pollutants (USEPA, 2002).