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Deliverable 5.4.1

A knowledge base of existing techniques and technologies for sanitation system adaptation

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SEVENTH FRAMEWORK PROGRAMME

COLOPHON

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A knowledge base of existing techniques and technologies for sanitation system adaptation

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Author(s)
Paola Latona, Richard Ashley, Maria Adriana Cardoso, Luis Mesquita David, Pascale Rouault, Therese Schwarzböck

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This report is:
PU = Public

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1 Climate change impact on sanitation system

In the following picture a schematic representation of climate change effect on water system in general, and on sanitation system in particular has been provided.

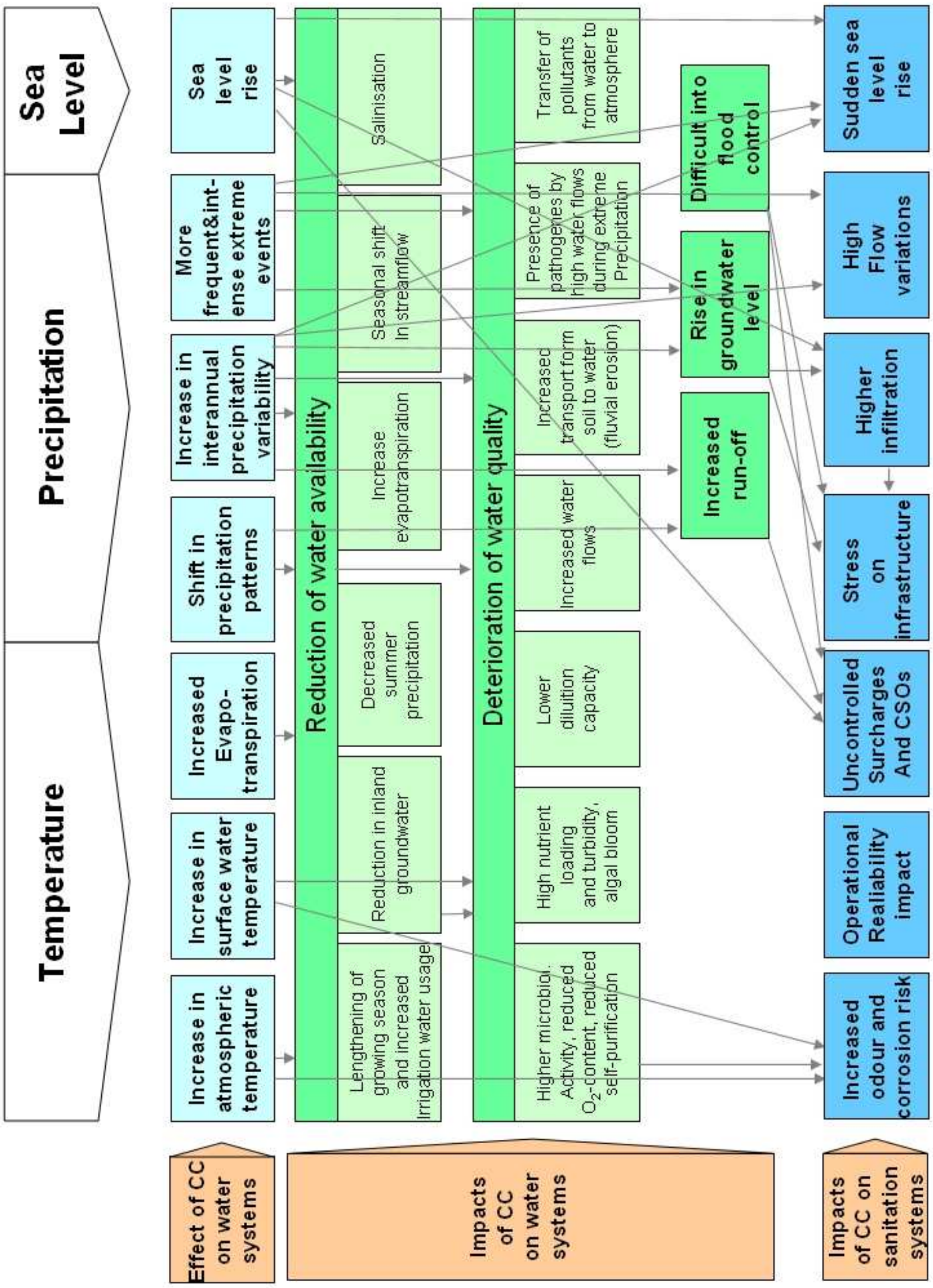


Figure 1-1: Climate change effects and impacts on water system and sanitation system.(based on Bates et al, 2008; DWA, 2010).

On the basis of the identified impacts on sanitation system, this report will provide a knowledge base of existing techniques about

- Odour and corrosion abatement;
- Increase in storage volumes/handling of volumes, in particular retrofitting of CSO stormwater removal systems, CSO control…;
- Improvement of sewer system: CSO treatment, infiltration detection techniques;
- Methodology to identify infiltrations in sewer system;
- Separate sewer: the first flush management;
- Decentralised solution: controlled infiltration, retention of rainwater (filter ponds, basins, …);
- Adaptation measures for joint effect of rainfall and tide.

Techniques and methodologies described in the following chapters, will not be exhaustive, but this paper will provide a good starting point for facing problems related to sanitation systems and adaptation on climate change impacts.

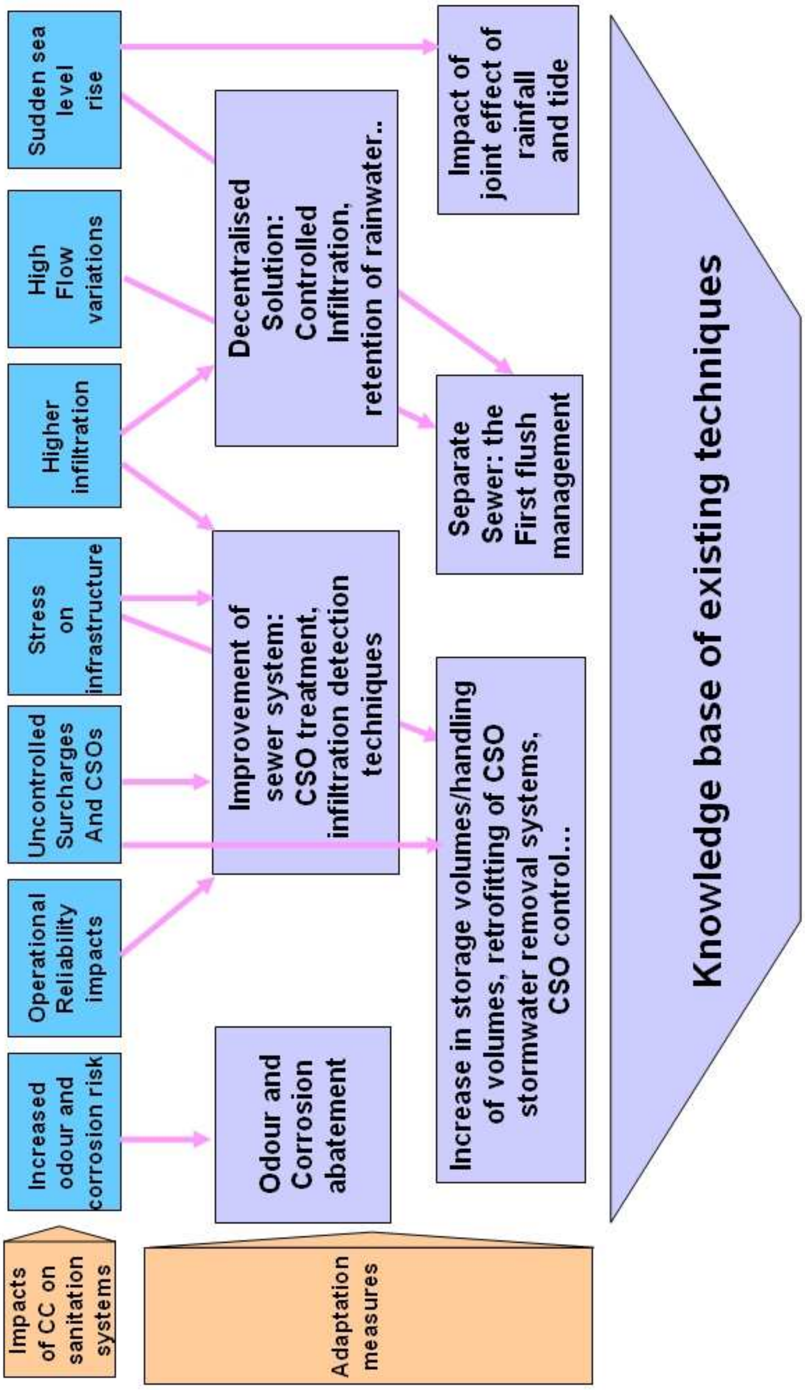


Figure 1-2: Climate change impacts and adaptation measure on sanitation system.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., (2008): Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat. Geneva. 210 pp.

DWA (2010): Klimawandel – Herausforderungen und Lösungsansätze für die deutsche Wasserwirtschaft. DWA-Themen. Hennef, Germany. Mai 2010. 33 pp

2 Odour and Corrosion abatement

2.1 Odour and Corrosion: description of the problem

Different effects of climate change, like a shift in precipitation pattern, sea level rise, and especially the increase in temperature have impacts on in-sewer processes. Lower solubility of oxygen in the water due to higher water temperatures leads to (faster) formation of anaerobic conditions which fosters the production of odorous and corrosive substances in sewer networks. The introduction of sulphate-rich waters (e.g. sea water) and/or a decrease in sewage flow – connected with a higher degree of pollutant deposition - additionally enhance the emergence of emissions. Especially developments during the last 10 years, such as demographic changes, decrease in specific and industrial water consumption, novel sanitary systems, or the renovation of leaky drainage channels to avoid infiltration are connected with the trend of decline in dry weather flow. Together with growing public concern over odours from wastewater treatment facilities, these phenomena have led to increasing numbers of odour complaints in urban catchments but also imply possible health risks and severe concrete corrosion by biogenic sulphuric acid. Costs for rehabilitation of corrosion-affected constructions and operation costs for permanent countermeasures cause elevated financial burden for utilities. (Stuetz & Frechen, 2001; ATV-DVWK-M 154, 2003; Barjenbruch, 2003; Lohse, 2010).

Details to the process of odour and corrosion formation in sewers can be found in diverse literature, e.g. in DWA-M 168 (2010); Stuetz & Frechen (2001).

2.2 Existing techniques/technology

There are a variety of methods to avoid, reduce or control odour and/or corrosion problems in sewer systems. The goal of this chapter is to compile and summarize information regarding abatement measures. Existing solutions and new approaches in odour and corrosion management, such as constructional measures in the planning and designing phase, measures to inhibit the development of anaerobic conditions, oxidation, bonding and adsorption of odorous and corrosive substances or the treatment of emerging gases are summarized, giving the key features of each measure. The most important advantages and disadvantages among the respective groups are pointed out. However generalized comparisons, especially across groups of measures (like liquid phase and gas-phase measures) are very difficult to conduct as the general objectives and logistics differ considerably. There are for example different effects for each measure; hence an effect analysis beforehand is necessary to conduct. A technology as the most applicable for all situations is impossible to identify as there is a virtually limitless number of unique odour control problems and challenges.

2.3 State analysis

Methods that are selected for abatement need to be chosen thoroughly and adapted to the specific local frame conditions. Precondition for a successful application of measures or combinations thereof, is the detailed knowledge about the existing drainage system. A state analysis can give insights into existing problems, and can help identify causes of the problems. table 2-1 gives examples of tools which can help characterize the existing drainage system in order to set up abatement strategies for odour and corrosion problems. Technical, ecological and economic arguments and requirements need to be considered and weighted for the specific application area.

table 2-1: Examples of tools for analysing existing drainage systems

State analysis: Characterization/identification/analysis of existing problems and causes	
Examples of tools	- Cadaster of indirect dischargers - Complaint database - Grid search - Analytical and sensory quantification of odour emission - Analytical measurement of wastewater parameters - Models for sulphide production - Geographical information systems (GIS) - Integration of information from daily activities of operation personnel - TV-inspections - Geometric surveying - Visual inspections - Sewer and corrosion surveys - Control of infiltration of groundwater - Data bases
Objectives of state analysis	- Fast detection of problems - Detect potential sources - Setting up a plan of priorities - Comprehensive, actual overview over the drainage system - Establish complaint management - Identification of critical conditions
Requirements	- Cooperation of operating company, planning department, supervisory authority, external experts (laboratory, engineering company, university, others) - Participation of the public - Availability of data - Considerations regarding variation of conditions with day of the week, daytime, rainfall, pipe section etc.
Further comments	- Regulations for self-monitoring usually envisage evaluations of the drainage systems in periods of 10 or 15 years. These are relatively long periods as there can be numerous sulphide and odour problems within this time span
References	Barjenbruch (2003); Weismann & Lohse (2007); Thistlethwayte (1972a); DWA-A 149 (2007); Lange & Reinhardt (2002)

Locations where emissions may occur include gravity sewers (long detention time, low slope, etc.), ramp manhole (possible stripping out of previously formed osmogenes), turn-off shafts, pumping stations (long contact times) transferring shafts of rising mains (stripping out of osmogenes which may be formed in the rising main), site of industrial discharge (Barjenbruch, 2003). Hence special attention should be paid to these points with potential odour and corrosion hazards.

2.4 Legislation

Drainage systems need to be planned, constructed and operated in compliance with regulative requirements. There is no international regulation defining standards for the emission of odours from sewer systems. However, the European Communities (Waste Water Treatment) (Prevention of Odours and Noise) Regulations 2005 (S.I. No. 787 of 2005) contain general binding rules requiring sanitary authorities to ensure that waste water treatment plants do not cause a nuisance through odours or noise emissions. These regulations stipulate that operators (i) maintain records of mandatory environmental standards, including those relating odours, (ii) provide details of all necessary steps taken to comply with regulations and (iii) annually report any incident arising from odours or noise in respect of any waste water treatment plant and any environmental complaints in relation to the operation of such plants.

The Council Directive 91/156/EEC amending Directive 75/442/EEC on waste stipulates that "Member States shall take the necessary measures to ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, and in particular: …without causing a nuisance through noise or odours".

The European directive on landfill and waste (1999/31/EC) stipulates that measures need to be taken to "minimise nuisances and hazards … through emissions of odours and dust" (EC, 2005).

The implementation of odour policies generally varies from country to another and from one activity to another. In recent years many states and nations have implemented or proposed policies regulating the impact of odours, mainly from agriculture and industrial activities. These regulations are based on qualitative approaches (e.g. occurrence of complaints), quantitative approaches (e.g. odour concentration, specific odour compounds) or on operational requirements such as setback distances. Only a few states specifically define a limit value for exposure to odour (Odournet, NA).

Considering the continuing implementation of odour policies, constructional or operational measures, which might become necessary, require consideration already in the planning stage to stipulate enough space and avoid high financial and constructional effort for post-installations.

2.5 Classification of measures

The extent to which a gaseous substance causes a problem is dependent on the original components (hence, the composition of the discharges into the sewer), the ways in which the wastewater and its products are treated and handled along the path and the extent to which they are transferred to the atmosphere where they can cause corrosion and pose a potential cause for odour complaints. The treatment or reduction of the emissions arising from the sewer is the last point of intervention in this sequence of problem development (Stuetz & Frechen, 2001; Weismann & Lohse, 2007). This progression of emission formation and connected points of intervention is illustrated in Figure 2-1.

To structure the catalogue, the considered measures were classified in terms of “where” in this sequence the measures are applied.

The measures have been classified as follows:

- Prevention (tackling the root causes)
  - Group A: Constructional measures
  - Group B: Operational measures
  - Group C: Regulation of discharges from industries (and pre-treatment)
- Prevention of emission (measures in the liquid phase)
  - Group D: Water treatment (Additives)
  - Group E: Water Treatment (other than additives)
- Prevention of immission (measures in the gas phase)
  - Group F: Air treatment
  - Group G: Compensation/Neutralisation/Masking
  - Group H: Air conduction

Figure 2-2 gives a general overview of available methods and illustrates the chosen classification of measures within this report.

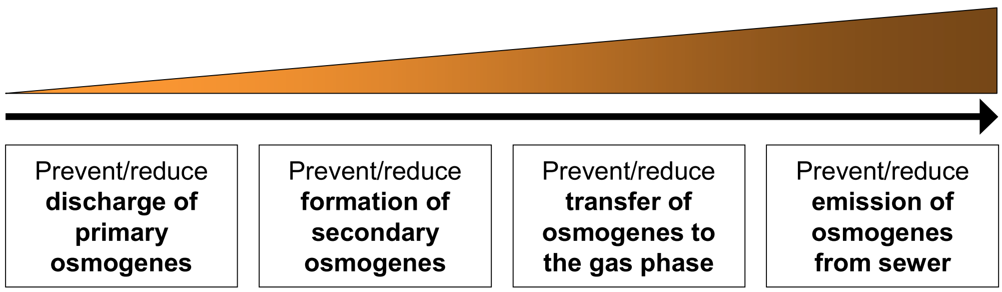


Figure 2-1: Progression of emission formation in the sewer and basic points of intervention (after Weismann & Lohse, 2007)

Against the background of emission formation sequence the control of odours need to move from an afterthought to a primary design consideration. Especially constructional and operational measures need consideration already in the planning stage. For example installations of ventilation systems, pneumatic pumping stations or high pressure cleaning devices require the stipulation of space for the equipment (Barjenbruch, 2003; Weismann & Lohse, 2007). Ex-post installations or measures to abate emissions after their emergence are often connected with high constructional and financial efforts. Hence, in order to tackle the problem the intervention should be “as soon as possible”.

What is tackled?

This elaboration includes no assessment of measures and generally all of them have to be tested for their feasibility for the respective application and project. Special attention should be paid to the effects of the different measures. It needs to be defined which general problem should be tackled: the problem of corrosion solely, of sulphide formation and H_2S (and connected problems of corrosion), the problem of emissions of any kind, or the problem of odour nuisance solely. The overview in Figure 2-2 gives a first statement regarding this approach by highlighting the measures in different colours depending on their effective restrictions:

O&C measure	Grey: General measures to reduce odour and corrosion in sewers. Have effect on odour and sulphide formation.
Only corrosion effective	Red: Measures that only tackle the problem of corrosion. Have no effect on the odour problem.
Only sulphide/ H_2S-effective	Yellow: Measures that only have an effect on sulphide. Other odorants than hydrogen sulphide are limited effected.
Limited corrosion effective	Green: Measures that are not or limited effective for the problem of corrosion. The intervention is only after the emissions occur. Hence the infrastructure can already be attacked by the released emissions. The effect on corrosion depends on the location of the measure.

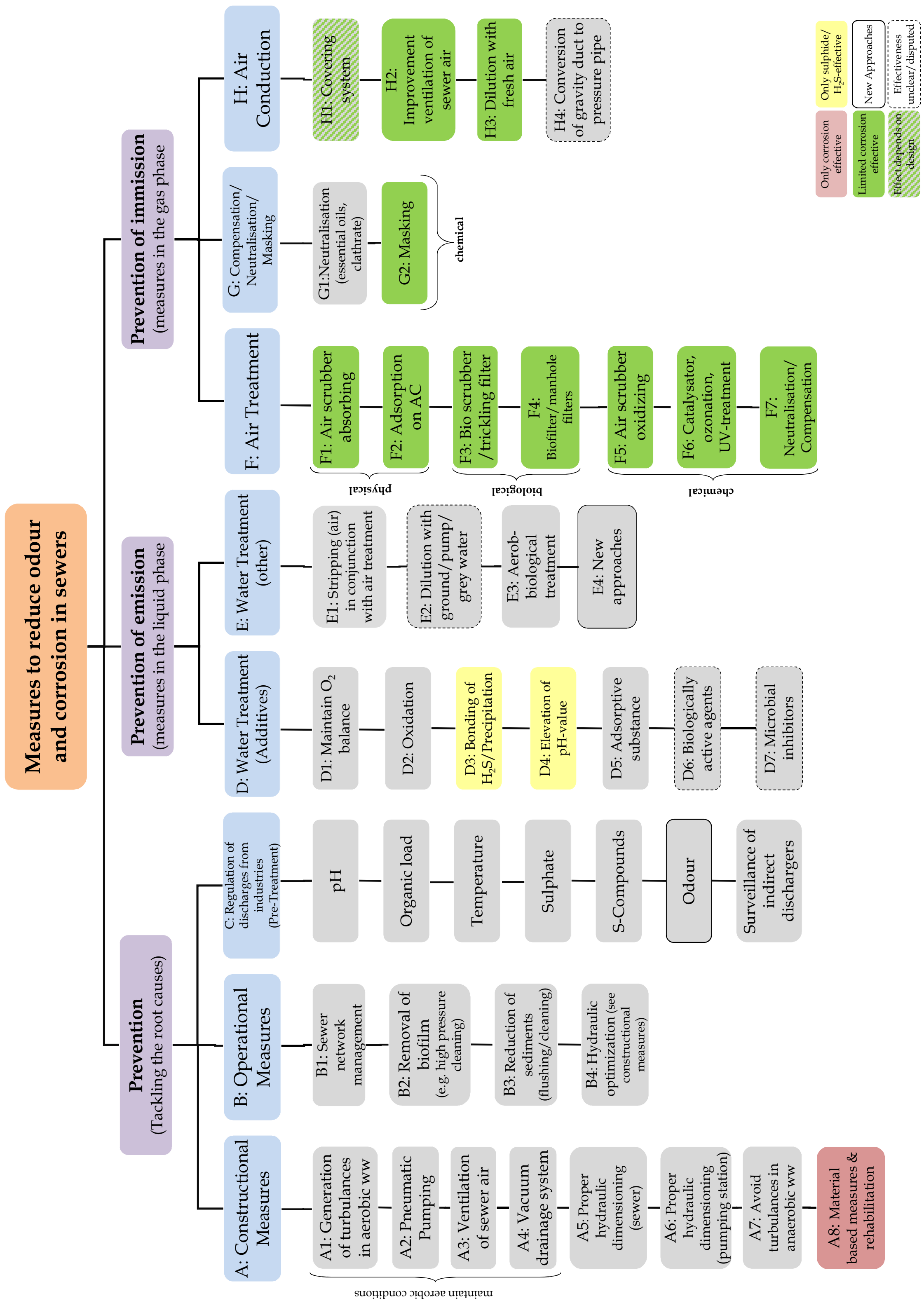


Figure 2-2: Overview and classification of considered measures to reduce odour and corrosion in sewer systems (no exhaustive list)* (based on ATV-DVWK-M 154; Barjenbruch, 2004; Weismann & Lohse, 2007; Barjenbruch *et al.*, 2008; Zhang *et al.*, 2008; Hillenbrand *et al.* 2010; Frey 2010b)

* The measures were classified after literature review, consultation with experts and practitioners and modified according to the author's understanding. The classification of measures is not a fact but an attempt to arrange and structure the various measures in a conclusive way.

2.6 Preventive measures – tackling the root causes

This category generally involves measure to **prevent the formation of secondary osmogenes** by allowing high flow velocities and therefore preventing the formation of anaerobic conditions, maintaining aerobic conditions by constructions or certain pumping strategies, allowing turbulences for oxygen introduction, preventing/removing depositions or sediments, ensuring a proper transport of odour-laden water (in a closed system), or preventing wastewater in non-operating channels.
Measures that only aim at minimizing the corrosion hazards are the application of corrosive-resistant materials or coatings of constructional parts.
The **prevention of the discharge of primary osmogenes** and relevant substances is the primary point of intervention and can be realized by regulative measures and surveillance of indirect dischargers.

2.6.1 Constructional measures (Group A)

Constructional measures should be generally considered already in the planning stage of a sewer network in order to avoid high constructional and financial efforts. Post installations are often only feasible when sufficient space was stipulated during planning.

A1-A5: Maintain aerobic conditions/avoid anaerobic conditions

General objectives are the prevention of anaerobic conditions and the prevention of the formation of (H_2S) emissions.
One should aim at an oxygen content in the wastewater above 0,1 mg/L.

(A1) Generation of turbulences in aerobic wastewater (hydraulic)

Description: Create falls, unevenness within the system to foster the entry of oxygen into the water
Realization examples: Falls, Baffles, Cascades (e.g. see Figure 2-3)
Advantages:
- Low effort for maintenance required

Limitations:
- Not practicable in anaerobic wastewater
- Need to consider possible changes of conditions (reduced water consumption in future)
- Falls and cascades require a large slope

References: Barjenbruch *et al.* (2008); Weismann & Lohse, 2007; ATV-DVWK-M 154 (2003), ATV-DVWK-A 157 (2000); DWA-M 158 (2006)

(A2) Pneumatic pumping

Description: Transport of wastewater and flushing by means of pressurized air to foster the entry of oxygen into the water
Realization examples: Compressed air replaces the wastewater in a pressure vessel. Oxygen is introduced into the water. Mixing of wastewater and air in a subsequent pressure main (e.g. see Figure 2-4).
Advantages:

- Flushing of force main possible
- Reduction of biofilm possible
- Transfer from pressure pipe with high turbulances

Limitations:

- High technical effort
- Air cushions at high points can cause resistances
- Increased energy requirement – 20-50 % higher than for hydraulic pumps (Fette & Heine, 2002)
- High construction costs (1-3 times higher than for hydraulic pumping stations) (Fette & Heine, 2002)

References: Fette & Heine (2002); Barjenbruch (2004); Weismann & Lohse, (2007); Hillenbrand *et al.* (2010

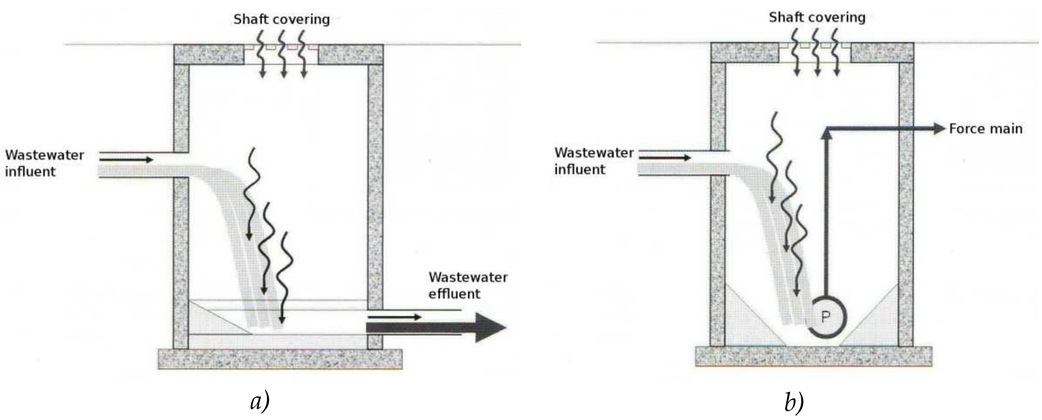


Figure 2-3: Scheme of shaft aeration by means of a fall a) in a gravity pipe shaft b) shaft before force main (Weismann & Lohse, 2007)

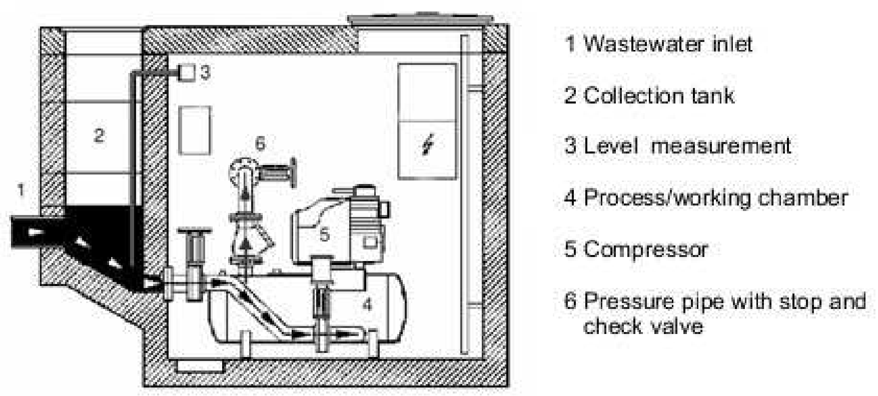


Figure 2-4: Scheme of pneumatic pumping station (Niemann, 1998)

(A3) Ventilation of sewer air

Description: Design of drainage system to allow for aeration and ventilation of sewer air.

Natural ventilation: Usage of "drag" exerted by the flow of wastewater

Forced ventilation: air is forced through the sewers using mechanical equipment

Realization examples:

- Multiple educt and induct vents with adequate diameter and height differences
- Chimneys
- Venting through each house connection
- Breaking up the system in zones
- Educts with flexible bulkheads
- Roof ventilation (for urban constructions) (see Figure 2-5)
- Fans (Forced ventilation) (see Figure 2-6)

Advantages:

- Simple methods
- No energy requirements for operation (natural ventilation)

Limitations:

- Does not necessarily prevent corrosion when applied as single measure
- Possible odour problem at the point of discharge
- Treatment of air might be necessary
- Natural ventilation: Effect varies dependent on daytime, flow rate, temperature (season), barometric pressure
- Less effective in summer
- Sometimes contrary direction of air stream can occur

References: ATV-DVWK-M 154 (2003); Thistlethwayte (1972a); Barjenbruch (2004)

Comment: Measures for air conduction see also section H

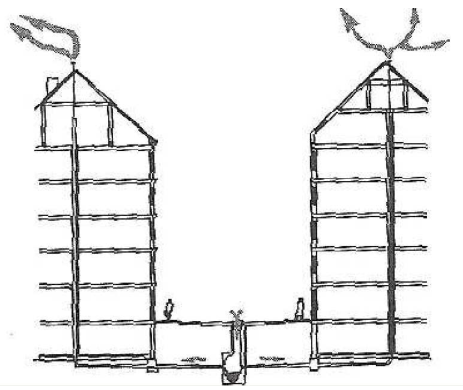


Figure 2-5: Roof ventilation in urban buildings (Nowak & Schattkovits, 2003)

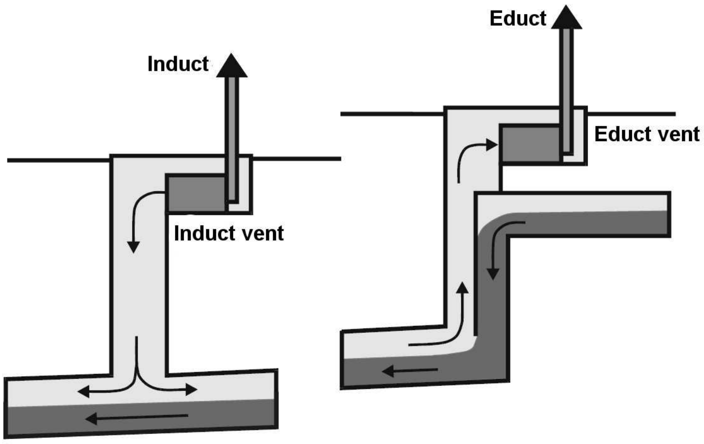


Figure 2-6: Forced ventilation of a gravity sewer with drop manhole (ATV-DVWK-M 154, 2003)

(A4) Vacuum drainage system

Description: Constant aerobic transport of the wastewater

Limitations:

- Limited length of the systems
- Problems with leak detection
- High precision in constructional laying of the pipes necessary

References: Fette & Heine (2002)

A5-A7: Proper hydraulic dimensioning

General objectives are to design the drainage system and the pumping stations in a way to avoid sediments, reduce retention times and maintain the oxygen balance in the wastewater.

(A5) Proper hydraulic dimensioning (sewer)

Description: Design of drainage system to improve flow velocities, avoid sediments and enable shear stresses

Realization examples:

Gravity sewer: adaptation of

- Profile of pipe (e.g. egg-shaped)
- Nominal diameter of pipe (partially-filling 20-90%) – e.g. Using relining or coating methods (see A8)
- Slope (increase)

Force main: adaptation of

- Nominal diameter (recommended values of flow velocities in Weismann & Lohse, 2007)
- Slope (to allow for a drainage at pump downtimes)
- Short lines with steady incline
- 2 pressure pipes with small diameter instead of one force main with big diameter
- Maintain minimum flow velocity (shear stresses ≥ 4N/m²)
- Stipulate only 1 transfer point with controlled air treatment

Advantages:

- Long-term measure
- No maintenance required

Limitations:
- In existing systems limited realizable
- High constructional effort
- High shear stresses can lead to erosion
- Biofilm formation can get very stable at high flow velocities
- Egg-shaped pipes: cleaning problems

References: Weismann & Lohse (2007); ATV-DVWK-M 154 (2003); Hillenbrand *et al.* (2010)

(A6) Proper hydraulic dimensioning (pumping station)

Description: Optimal design and dimension of chamber and pump performance to maintain O_2-balance, reduce odour formation and allow for a proper ventilation

Realization examples:
- Provide large water surface area for entry of oxygen in collection tank (e.g. see Figure 2-7)
- Enable turbulences
- Adjustment of cut-in and cut-out level (e.g. see Figure 2-8)
- Avoid backwater in the sewer
- Investigation of sulphide formation and oxygen consumption to adapt pumping cycle
- Aeration and ventilation of gas phase in the collection chamber
- Location of transfer shaft not in immediate vicinity of residential zones
- Reduce number of small pumping stations
- Stipulate additional collection tanks to compensate flow variations

Advantages:
- Long-term measure

Limitations:
- Only feasible in post installations when sufficient space was stipulated during planning
- Dependent on local conditions and possibilities
- In existing systems limited realizable

References: ATV-DVWK-M 154 (2003); Barjenbruch (2004)

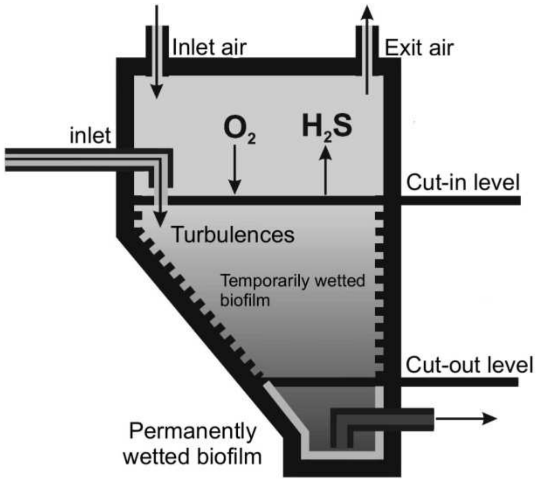


Figure 2-7: Typical wet well arrangement for sewage pumping (collection tank) (ATV-DVWK-M 154, 2003)

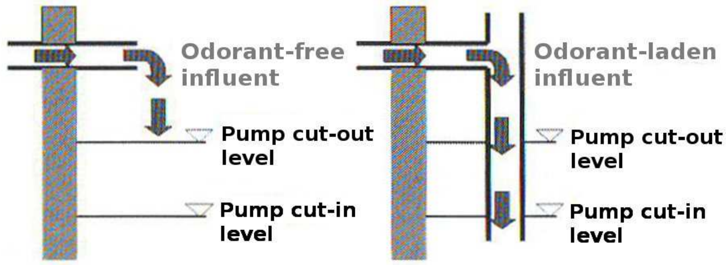


Figure 2-8: Wastewater influents, dependent on the water conditions (Weismann & Lohse, 2007)

(A7) Avoid turbulences in anaerobic wastewater

Description: Avoid transfer of present osmogenes into the gas phase (avoid stripping)

Realization examples:

Gravity sewer:

- Streamlined channels in shafts, esp. for falling wastewater; e.g. immersion tube, entry below water level
- Avoid ledges and falls, sharp changes of direction or major cross section changes

Force main:

- Entry of anaerobic wastewater in transfer shaft below the pump start-up level (Figure 2-8**Error! Reference source not found.**)

Transfer shafts: (see Figure 2-9 and Figure 2-10)

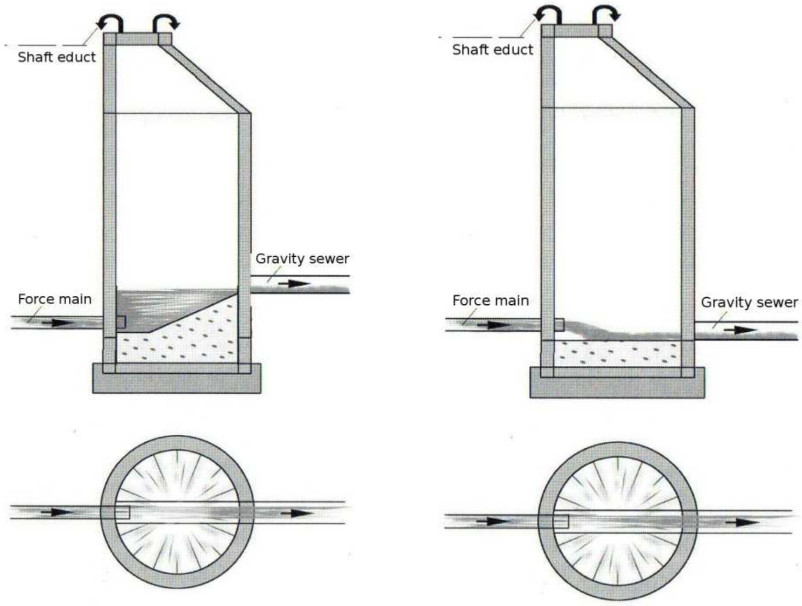
Advantages:

- Usually low maintenance required
- Relatively simple when already considered in planning stage

Limitations:

- In existing systems limited realizable
- Only in anaerobic wastewater

References: ATV-DVWK-M 154 (2003); Weismann & Lohse (2007)



a) *b)*

Figure 2-9: Transfer shaft with hydraulic supply a) for odour-laden wastewater b) for odour-free wastewater (Weismann & Lohse, 2007)

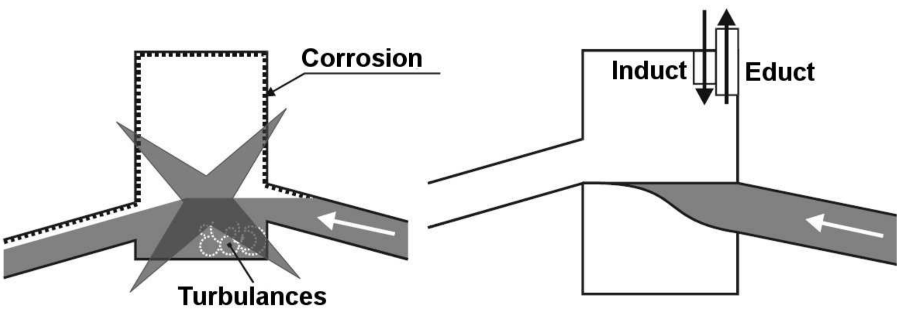


Figure 2-10: Transfer shaft from force main to gravity line (ATV-DVWK-M 154)

(A8) Material based measures and rehabilitation

Description: Reduce the threat of corrosion by choice of building materials or protection layers. Aims also on maximising the service life of constructions, increase the stability and provide sealings

Realization examples:

<u>Rehabilitation</u> of pipes, shafts, collection tanks, pumping stations:

- Renewal: exchange
- Renovation: lining, coating
- Repair: sealing, correction, injection

<u>Common methods of pipe rehabilitation:</u> e.g. Piper relining (see Figure 2-11), Burst lining-process, Groutings and coatings, etc. (Weismann & Lohse, 2007)

<u>Corrosion resistant materials</u>: concrete, vitrified clay, plastic material

<u>Sacrificial concrete layer</u>

<u>Protection layer</u> e.g. : fluosilicate solution

Advantages:

- High level of experiences with rehabilitation methods available (well-proven techniques)
- Technical regulations and guidelines are available (see References for examples)

Limitations:

- Requires high personnel effort and equipment
- If source of sulphide problem is not tackled: linings can be attacked again (esp. cement mortar facing)
- Some methods only applicable in accessible channels
- Usage of high grade concrete mixtures do not ensure a complete protection from corrosion.
- Does not tackle the problems of odour nuisance or health risks

References: ATV-DVWK-M 143 (2004); IKT-Handbuch (2007); DWA-M 159 (2005); DWA-M 168 (2010), DIN EN 752 (2008); Nielsen *et al.* (2008)

Figure 2-11: Pipe relining (IKT – Institute for Underground Infrastructure)

2.6.2 *Operational measures (Groub B)*

Primary objectives of operational measures are to ensure certain discharges, prevent the generation of sulphide sources (biofilm, sludge, sediments etc.), ensure optimal process adaptation and to prevent transfer of H_2S-rich wastewater.

(B1) Sewer network management

Description: Operational protection measures. Comprise preventive as well as curative measures for optimizing the operation of the drainage system

Examples/Tools:

- Adaption of operation of pumping stations, like:
  - Maintain a minimum flow velocity: 1,5 m/s (Weismann & Lohse, 2007)
  - Limit non-operation periods
  - Wastewater ventilation
  - Flushing of force mains

- Proper drawdown and retaining capabilities of collection tanks
- Drainage of short or small pressure pipes during non-operation periods
- Increase pumping frequency by reducing the feeding volume (lowering the cut-in level)
- Adjustment of cut-in and cut-out levels

- Maintenance in sewer, force mains, constructions, pumping stations
- Cleaning strategies (preventive cleaning, cleaning as required, tailor-made cleaning (see Weismann & Lohse, 2007) (see also B2 and B3)

Limitations:

- Removal of corrosion products reduces the rate of H_2S-oxidation in concrete pipes, but no effect on plastic (PVC, HDPE) pipes (Nielsen *et al.*, 2008)
- Comprehensive background information necessary about the drainage system, possible sources of problems, demographic developments etc.

References: Weismann & Lohse, 2007; DWA-M 168 (2010); ATV-DVWK-154 (2003); Thistlethwayte (1972a)

B2-B4: Sewer cleaning and maintenance

The main objective of sewer cleaning methods is the removal of depositions and biofilm in the channel in order to reduce the (anaerobic) biological activities in the biofilm and enable proper discharges.

(B2) Removal of biofilm
(B3) Removal of sediments

Realization examples:

Flushing methods:

- Surge flushing (sudden opening of a flap, gate, etc.)
- Rainwater flushing (if reservoirs are in the vicinity)
- Reservoir flushing (using block elements moving forward) (Figure 2-12, b))
- High pressure cleaning (100 – 180 bar): flushing water is injected in a hose at high pressure. Flush head contains jet. High velocities allow for cleaning and move the hose along the sewer. Recovery of flushing water possible (Figure 2-13).

Mechanical methods:

- Scraper (foamed plastic, expanded clay), shields, ploughs, balls
- Light expanded clay aggregate (Leca)

Further:

- "Resonant Pulsation"-method: high-frequency magnetic impulses (e.g. Fluid-liner) – only for force mains (Figure 2-14)
- Ultrasonic cleaning
- Vibration jets

Preventive measures:

- Cascade weir (Figure 2-15)

- Automated reservoir flushings
- Balls (e.g. regular/automated insertion) (Figure 2-12, a))
- Regular control of street drainage pits and dirt traps
- Cleaning of culverts, storage channels, section with low slope etc.
- Flaps, gates

Advantages:

- Foamed plastics are available in different diameters
- Maintains sewer conditions

Limitations:

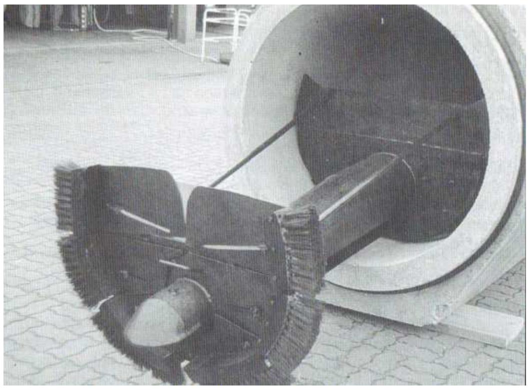
- Knowledge about the drainage system is necessary
- Requires high personnel effort and equipment
- Limited effect (need repetitions or implementation of automated system)
- Surge flushing: cleaning capacity of a few 100 m; not for persistent sediments
- Reservoir flushing: not for small pipe diameter (> DN 1.200); not for persistent sediments; new sediments if cleaning passes are too slow
- Scraper: risk that the scraper becomes stuck; in existing pressure mains usually no access for scrapers available
- Access for cleaning equipment – need to be considered already in planning stage

Comments: It is recommended to

- Combine methods with addition of inhibitors (e.g. as immediate measure)
- Document the inspection, cleaning campaigns and time intervals

References: ATV-DVWK-M 154 (2003); Barjenbruch (2004); DIN EN 14654-1 (2005); DWA-A 147 (2005); Barjenbruch (2007); Weismann & Lohse (2007); Barjenbruch *et al.* (2008); DWA-M 168 (2010); BMVBS (2010); Hillenbrand *et al.* (2010)

a)



b)

Figure 2-12: Sewer cleaning devices; a) balls for continuous cleaning b) "Polecat" serving as gate for reservoir flushing (Weismann & Lohse, 2007)

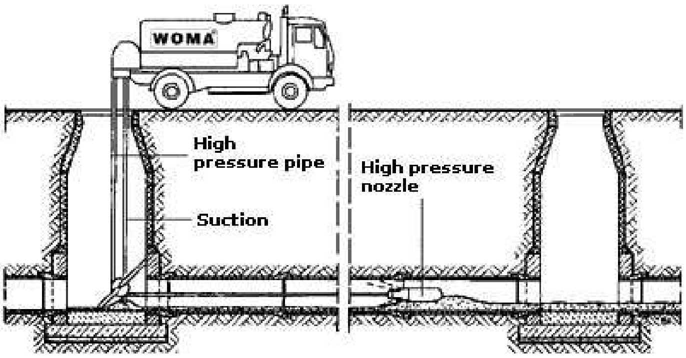


Figure 2-13: Principle of high pressure cleaning (WOMA GMBH)

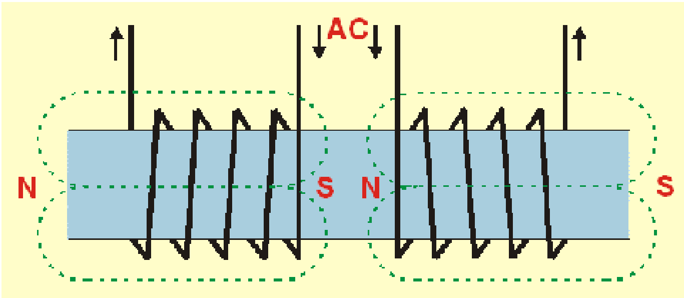


Figure 2-14: Principle of resonant pulsation method (Fluid-liner) (Caltech, ECS GmbH)

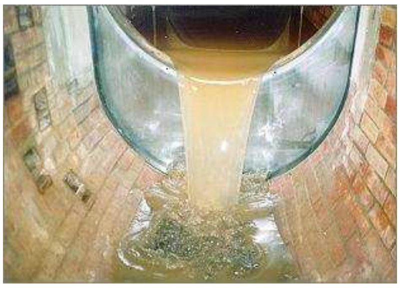


Figure 2-15: Cascade weir (ASA-Technik GmbH)

(B4) Hydraulic optimization

See constructional measures in chapter 2.6.1 , A1-A7

2.6.3 *Regulation of discharges from industries (Group C)*

(C) Regulation of discharges from industries (pre-treatment)

Different wastewater parameters are relevant for the presence or the formation of odorous emissions and corrosive substances. Table 2-2 provides a description of the effects of the most important parameters. Pre-treatment methods are exemplarily stated which could be applied to avoid the introduction of unfavourable constituents into the sewer in the first place.

Utilities are responsible for the surveillance of the compliance with the discharge regulations. Therefore representative tests of sewer air and wastewater are necessary (ATV-DVWK-M 154, 2003).
Compensation tanks for neutralising or controlling the discharge are mentioned by Weismann & Lohse, 2007 and ATV-DVWK-M 154 as general preventive measures.

Table 2-2: Preventive measures: Regulation of discharges (sources: ATV-DVWK-M 15, 2003; Weismann & Lohse, 2007; Frey, 2008; Frey, 2010b)

Parameter to be regulated	Influences/results in	Pre-treament (examples, depends on waste water composition)
pH	Gas emissions from the liquid phase depend on the dissociation equilibrium in the water (H_2S, NH_3) → potential for stripping into the sewer atmosphere	Measures like category D, e.g.: - Acidification (e.g. sodium hydroxide) OR - Alkalisation (e.g. organic acids, HCl)
Organic load	Especially easily degradable organic compounds lead to an increase in microbial processes → elevated oxygen consumption and anaerobic conditions	- Aerobic or anaerobic biological treatment like activated sludge process - Fixed bed reactor
Temperature	Biological activity increases with increasing temperature. High temperature foster the oxygen depletion in water, biofilm and sediments. Temperature dependent dispersion of dissolved H_2S and hydrogensulfid in the water. Sulphide problems when water > 20 °C (Weismann & Lohse; DWA-M-115, 2004)	- Heat exchanger
Sulphate	Serves as H+ acceptor for sulphate-reducing bacteria → increases tendency for sulphide production Industries with sulphate-loaded wastewaters are indicated in ATV-A 115, 1994 and DWA-M-115, 2004)	- Chemical precipitation (e.g. calcium hydroxide) - Biological sulphate reduction - Membrane filtration
S-compounds	Limit for Sulphide: 2mgS^{2-}/L (DWA-M-115-2, 2005) Potential sulphide-rich process water from industries like metal, chemical, petroleum processing, timber, paper and pulp, food, cleaning, rendering, textile. Industries with sulphide- and sulphite-loaded wastewaters are indicated in ATV-A 115, 1994; DWA-M-115, 2004)	Measures like D2 and D3, e.g. - Precipitation - Oxidation See chapter **Error! Reference source not found.**, D2 – D3
Odour	Introduction of primary osmogenes increase the overall odour potential of the wastewater. Limitation of odour concentration (ou/m³) or Odour Emission Capacity (OEC) as described by Frechen *et al.* (2009)	e.g. Measures like D and E (water treatment)

2.7 Prevention of emission – measures in the water phase

This group of measures includes measures which tackle the problem in the liquid phase. They aim at maintaining or creating aerobic conditions (e.g. oxygen injection) or creating an anoxic milieu (e.g. addition of nitrate) in order to prevent osmogenes to be formed, oxidizing (e.g. addition of potassium permanganate) or precipitating (e.g. addition of iron salts) of already formed sulphides and other odorants. Additionally some additives have inhibitive effects on sulphate-reducing bacteria (e.g. hydrogen peroxide), or should prevent present sulphides from transferring into the gas phase (e.g. alkalisation). Biological active agents (which should stimulate the degradation of odorants) and microbial inhibitors are considered as disputed measures regarding their effectiveness and their possible hazardous effects on the environment and humans. Figure 2-16 gives an overview of collected additives.

Other water treatment methods besides the dosing of substances, comprise the dilution of the wastewater with available water resources (disputed method and effect) or the treatment of the wastewater with aerob-biological techniques. Further the odorants can purposefully be transferred to the gas phase and treated accordingly.

Relatively unexplored technique for this application are the conversion of sulphide to elemental sulphur by electrochemical oxidation or microbial fuel cells, the usage of magnesium or calcium peroxide as slow releasing oxygen agents or the dosage of waste activated sludge (WAS). Further investigations for large scale implementations need to be conducted.

Hence, this category of prevention of emissions comprises measures which intervene in the process at the stages of **prevention of the formation of secondary osmogenes** or the reversion thereof, and the **prevention of the transfer of osmogenes** to the gas phase.

2.7.1 Water treatment (additives) (Group D)

The addition of chemicals is usually carried out by a dosing pump feeding the solution from a storage tank into the gravity sewer, the force main or into the collection tank of a pumping station. A dosing strategy needs to be elaborated, adapted to the specific effect of the additive and local situation (DWA-M 168, 2010).

Figure 2-16 gives a general overview on available and commonly used additives for reducing odour and corrosion in sewer systems. The usage of combinations of different agents (e.g. coupling iron salts with alkalisation) aims at broaden the spectrum of effects (e.g. precipitation of H_2S and preventing sulphide to strip out). However, these combined products are not field tested yet to the whole extent (Hillenbrand *et al.*, 2010).

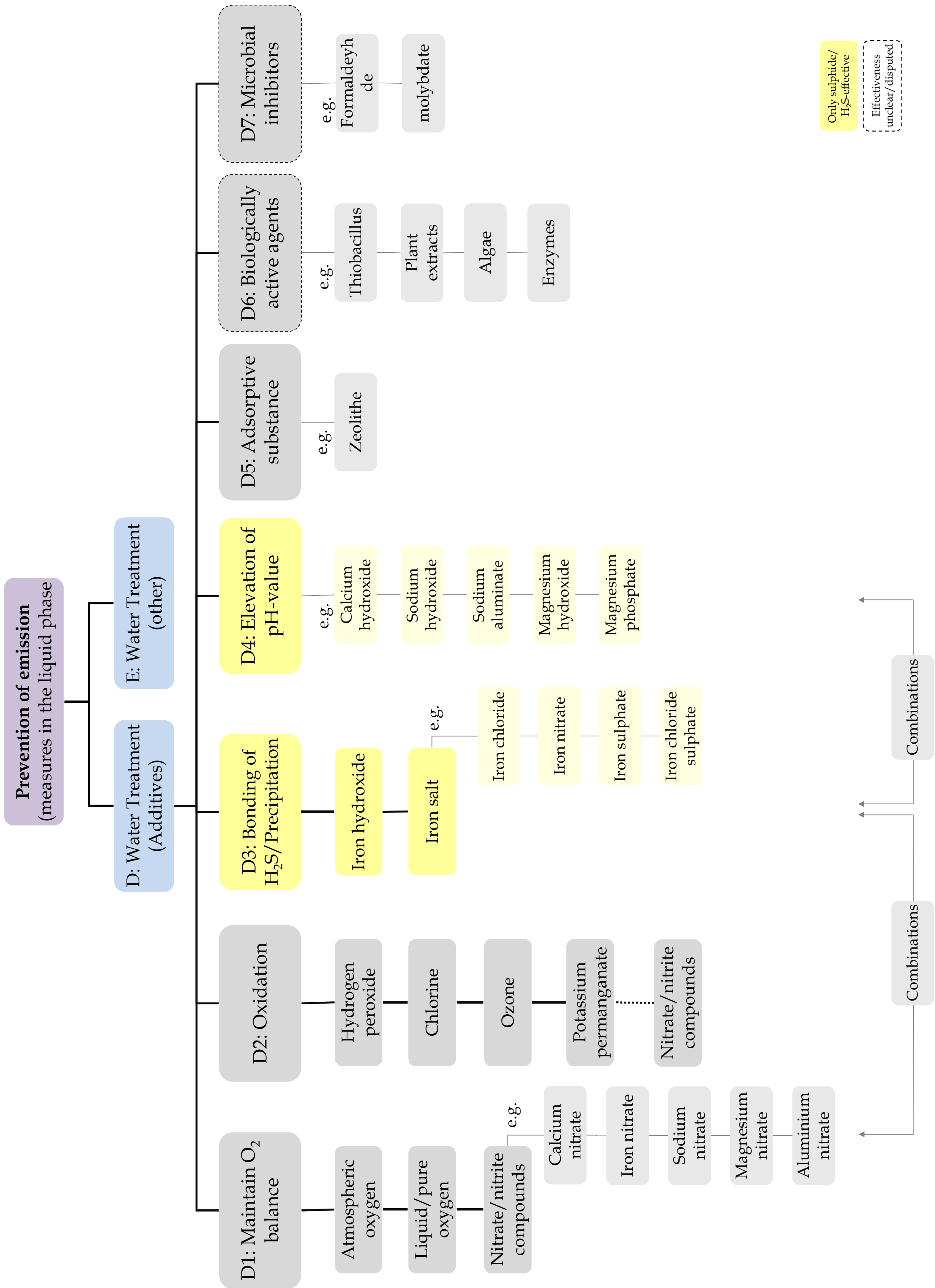


Figure 2-16: Overview of additives to the water phase to reduce odour and corrosion in sewer systems

D1: Maintain O_2-balance of the wastewater

Description: Addition of oxygen or chemical agents in order to maintain aerobic or anoxic milieu (to avoid anaerobic metabolic processes)

Atmospheric Oxygen

Examples:

- Pipes: Gas injection with perforated hose or by intermediate "air-flushings"
- Collection pit: drum diffuser, Ceramic diffuser, tube lance, etc.
- Pneumatic aeration system (esp. for short pressure pipes with small diameter)
- Hydraulic oxygen enrichment (turbulences)
- Flush pipe of pump (Figure 2-17)
- Products: e.g.: Drausy-hose, GRAFE-powerair, Flygt aerator and flush system; Hailo aeration system

Advantages:

- Oxygen is harmless for the environment
- Support/lengthening of natural aerobic conditions
- Air is available everywhere (→ no costs)
- Increase of cleaning effect

Limitations:

- High efforts for insertion of perforated hose (e.g. Drausy-hose)
- Limited by oxygen capacity of the water (45–50 mgO_2/L)
- Might only effect the bulk phase: Sulphide production continues in deeper layers of the biofilm (Gutierrez *et al.*, 2008)
- Investment costs
- In force mains: possible hydraulic resistances due to air cushions →reduces hydraulic capacity; energy consumption increases
- Only practicable for small diameter and for low declines
- Reduction of organic carbon (which might be necessary at the WWTP downstream)
- Possible stripping effects need to be considered
- No depot-dosing possible
- Increased energy requirement (compressor)
- Only 21 % of introduced air is available for O_2-balance
- Perforated hose: might causes clogging
- Hydraulic influences on pumping station/force mains need to be assessed

Comments: Treatment costs: 1-50 ct/m^3 (Urban, 2010)

References: ATV-DVWK-M 154 (2003); Barjenbruch (2003); Barjenbruch (2004); Weismann & Lohse (2007); Gutierrez *et al.* (2008)

Liquid/pure oxygen

Examples: Products e.g.:

- THIOX-method
- THIOCAT-method
- OXIDUCT
- SOLVOX

Advantages:

- Support/lengthening of natural aerobic conditions
- Oxidation of sulphide to elemental sulphur (incomplete)
- Higher oxygen concentration than atm. oxygen → higher DO levels can be achieved

Limitations:

- Limited by oxygen capacity of the water (45–50 mgO_2/L)
- Might only effect the bulk phase: Sulphide production continues in deeper layers of the biofilm (Gutierrez *et al.*, 2008)
- Investment costs
- In force mains: possible hydraulic resistances due to air cushions →reduces hydraulic capacity; energy consumption increases
- Only practicable for small diameter and for low declines
- Reduction of organic carbon (which might be necessary at WWTP downstream)
- Possible over-saturation leads to needlessly high substance consumption
- In oxygen saturated zones higher fire hazard

References: Fette & Heine (2002); Barjenbruch (2004); Weismann & Lohse (2007); Zhang *et al.* (2008)

Figure 2-17: Submerged pump with flush pipe (Jung Pumpen GmbH)

Nitrate/nitrite compounds

Examples:

- Calcium nitrate $Ca(NO_3)_2$: (e.g. Nutriox)
- Iron nitrate $Fe(NO_3)_3$: (e.g. Anaerite, Ecorsorb)
- Sodium nitrate $NaNO_3$
- Magnesium nitrate $Mg(NO_3)_2$
- Aluminium nitrate $Al(NO_3)_3$ (e.g. NICASAL)
- Combined products (e.g. VTA-Dolomin)

Advantages:

- Nitrate products are biologically degradable
- Application also for septic wastewater
- Reduction of organic odorants
- Effective, when residual nitrate content ≥ 0.5mgNO_3^--N/L (Barjenbruch, 2003)
- Support of natural aerobic conditions
- Dosing product is frost-resistant (liquid)
- Calcium nitrate: Ca^{2+}-cations have positive effect on microorganisms in WWTP
- No formation of organic acids

Limitations:

- Long reaction time (up to 40 minutes); in gravity sewers first reaction up to 3 days after first dosing
- Already built sulphides are hardy oxidized
- Organic carbon sources are consumed which are needed at the WWTP for denitrification
- No influence on short-term changes (impact loads)
- Nitrate-oxygen limits the effectiveness
- Possible deposits of iron-sulphide sludge in the drainage system
- Formation of nitrogen can cause gas cushions in non-ventilated force mains
- Possible formation of floating sludge or gas bubbles
- Overdosing leads to high nitrate levels in WWTP – need to be removed there
- Nutriox: Not usable for non-ventilated force main (Barjenbruch, 2004)

References: Hobson & Yang (2000) ; Fette & Heine (2002); ATV-DVWK-M 154 (2003); Barjenbruch (2003); Weismann & Lohse (2007); DWA-M 168 (2010); Gutierrez *et al.* (2010)

D2: Oxidation

Description: Oxidizing of already formed sulphide and other odorants. Provision of an oxygen source. Inhibition of desulfuricating bacteria.

Hydrogen Peroxide

Advantages:

- Long-lasting effects due to high oxidation power
- Support/lengthening of natural aerobic conditions
- Oxidation of also other osmogenes than sulphide
- Causes no hydraulic problems
- Reaction within few minutes (2–20 min retention time recommended)

Limitations:

- Oxidation power of oxygen limits the effectiveness for aerobic conditions
- Negative effects on microorganisms in the WWTP (bactericide)
- Corrosive effects
- Storage requirements (due to explosion hazard)
- Short lifetime → several dosing points necessary
- Oxygen-oversaturation is possible
- pH-dependent oxidation reactions
- Limited product stability (product decomposes)
- Explosion hazard (formation of peroxide)

References: Fette & Heine (2002); ATV-DVWK-M 154 (2003); Barjenbruch (2004); Weismann & Lohse (2007); DWA-M 168 (2010)

Chlorine

Examples:

- Aqueous solution: e.g. sodium hypochlorite NaCLO; calcium hypochlorite $Ca(ClO)_2$
- Gas

Limitations:

- Raise of AOX-concentrations in the wastewater
- May cause metallic corrosion
- Risk for personnel safety
- Expensive chemical

References: Thistlethwayte (1972a); US EPA (1991), Hillenbrand *et al.* (2010)

Potassium permanganate

Examples: Products e.g.: Red-O-pH2

- Oxidation of also other osmogenes than sulphide
- Support/lengthening/creation of natural aerobic conditions
- Conversion of anaerobic to aerobic conditions
- Application also for septic wastewater
- Dosing product is frost-independent

Limitations:

- Harmful and caustic substance
- Bactericide effects on microorganisms
- Only applicable for municipal wastewater (due to high oxidation power)
- Expensive chemical

References: Weismann & Lohse (2007); Zhang *et al.* (2008); Hillenbrand *et al.* (2010)

D3: Bonding of H_2S/precipitation

Description: Transformation of sulphide into non-soluble compounds (no prevention of formation of osmogenes)

Iron salt

Examples:

- Iron chloride: bivalent - $FeCl_2$, trivalent - $FeCl_3$ (e.g. Ferrogard, Ferissol, Bellair, Kronofloc)

- Iron sulphate: bivalent $FeSO_4$ (e.g. Quickfloc)
- Iron chloride sulphate: trivalent - $FeClSO_4^-$ (1.17gFe^{3+}/gS_2) (e.g Ferrifloc)
- Iron nitrate: trivalent – $Fe(NO_3)_3$ (e.g. Ecorsorb, Anaerite)

Advantages:

- Contribution of simultaneous phosphate-precipitation in WWTP (FeS shows bad sedimentation behaviour)
- Application also for septic wastewater
- Relatively short reaction times

Limitations:

- Organic sulphur components and other odorants are not or limited affected
- Not effective for pH< 6 (iron sulphide is soluble at lower pH)
- Increase of sludge production → must be separated at the WWTP
- Remaining odorants might need additional treatment
- Influence on nitrification of WWTP due to reduction of buffer capacity
- Precipitation products (sludge) possibly deposited in the channel
- Decrease of buffer capacity or pH-value → Formation of sulphuric acid (with iron sulphate), hydrochloric acid (with iron chloride)
- pH-value of solutions appr. 1 → caustic

References: Hobson & Yang (2000); Fette & Heine (2002); ATV-DVWK-M 154 (2003); Barjenbruch (2003); Weismann & Lohse (2007); DWA-M 168 (2010)

Iron hydroxide suspension

Examples:

- Iron hydroxide sludge from water works
- Iron hydroxide suspension: $Fe(OH)_3$ (e.g. GOSIL)

Advantages:

- Contribution of simultaneous phosphate-precipitation in WWTP (FeS shows bad sedimentation behaviour)
- Application also for septic wastewater
- Relatively short reaction times
- Usage of "waste" products (can be obtained from water works, e.g. by backflushing of filters)

Limitations:

- Organic sulphur components and other odorants are not or limited affected
- Not effective for pH< 6 (iron sulphide is soluble at lower pH)
- Increase of sludge production → must be separated at the WWTP
- Remaining odorants might need additional treatment
- Influence on nitrification of WWTP due to reduction of buffer capacity
- Precipitation products (sludge) possibly deposited in the channel
- Reaction times (up to 3 hrs) (Koch *et al.*, 2010).
- Water works sludge: transport and intermediate storage necessary
- to be considered: solid composition, particles size distribution, iron content (Koch *et al.*, 2010)

References: Barjenbruch (2004); Weismann & Lohse (2007); Koch *et al.* (2010)

The application of zinc and copper salts also leads to precipitation effects of sulphides, they however need special consideration regarding their bactericide (inhibitive) effects on microorganisms (Weismann & Lohse, 2007).

D4: Elevation of pH-value (alkalisation)

Description: Change dissociation forms of sulphide in the wastewater so that no volatile hydrogen sulphide is present, but non-volatile HS^- or S^{2-}. Thus, preventing the transfer of H_2S from liquid to gas phase.

Examples:

- Calcium hydroxide: $Ca(OH)_2$
- Sodium hydroxide: NaOH

Current research: generation of NaOH on-site by electrochemical oxidation in a non-sewer cell. Can provide caustic shock dose (May, 2010)

- Sodium aluminate $NaAl(OH)_4$: e.g. ABS-Kanalprogramm
- Magnesium hydroxide $Mg(OH)_2$: e.g. Sulfalock
- Magnesium phosphate: e.g. Pollfloc

Advantages:

- Usable in combination with precipitation agents (e.g. $FeCl_3$)
- Short reaction times
- Independent from sulphide concentration

Limitations:

- Effect starts at pH = 9
- As soon as the pH-value drops, volatile H_2S is present
- Dosing agents are highly caustic
- Corrosive effect when applied in combination with $FeCl_3$
- Organic sulphur components and other odorants are not affected
- Already formed sulphide is not degraded
- Possible sludge production and deposits
- Scaling of force mains possible
- Disruption of biological process in the WWTP possible due to elevated pH-value
- Emissions of ammonia NH_3 or other odorants possible (due to shift of dissociation equilibrium); risk for personnel
- pH is lowered due to dilution or formation of organic acids → then only a shift of the point of emission is achieved
- Not effective if downstream confluences

References: US EPA (1991); ATV-DVWK-M 154 (2003); Barjenbruch (2004); Weismann & Lohse (2007); DWA-M 168 (2010)

D5: Adsorptive substances

Description: Adhesion of odorants onto a bulk surface

Examples: Zeolithe

Limitations: Adsorption capacity limited by other wastewater components

References: Technical University Vienna (2005)

D6: Biological agents

Description: Addition of biological agents and bacteria to stimulate biochemical degradation of sulphides (and other odorants) and to reduce organic load to reduce sulphide genesis

Examples:

- Carrier with mixed biocenosis and enzymes (e.g. Microbe-Poro-Zeo-Lift)
- Thiobacillus (practicability in sewers unclear)
- Activated sludge (only 1 pilot operation)
- Tensides
- Plant extracts and herbs (e.g. POCO)
- Minerals, vitamins, trace elements (e.g. phosphor, nitrogen for high organic carbon-load)
- Algae (e.g. Alginat, Polyuronid from brown algae)

Advantages:

- Not hazardous to water or dangerous good

Limitations:

- Disputed method regarding economic efficiency, efficiency, practicability
- Practical applications yield very different results regarding effectiveness
- Low level of experiences

References: Barjenbruch (2004); Weismann & Lohse (2007)

D7: Microbial inhibitors

Description: Addition of inhibitive substances to inactivate bacterial products, inhibition of sulphate reducing bacteria and reduce sulphide formation

Examples: Formaldehyde, molybdate, nitrite

Advantages:

- Cost efficient (to be demonstrated)

Limitations:

- Low level of experiences
- Formaldehyde is genotoxic and carcinogenic to humans
- Risk to urban environment and health of sewer worker still needs to be investigated
- Several bacteria can easily adapt to formaldehyde

References: Zhang *et al.* (2009a)

2.7.2 *Other water treatment measures (Group E)*

E1: Stripping (air)

Description: Controlled transfer of odorants from liquid in gas phase through sufficient, purposeful turbulence. Additional mechanical effects and entry of oxygen is purposeful to reduce odour generation in subsequent parts.

Examples:

- Constriction (Venturi effect)
- Injector and baffle wall (Figure 2-18)
- Using electrical energy (Forced ventilation, turbulence generator)

Advantages:

- No need for addition of external substances or electric energy if realized as constriction
- No rotating mounting part
- Double effect (stripping of H_2S, entry of oxygen)

Limitations:

- Subsequent treatment of stripped air necessary
- Shaft needs to be made out of, or coated with corrosion resistant material
- Complete stripping effect possibly not achievable
- Investment and operation costs

References: Barjenbruch (2003); Barjenbruch (2004); Weismann & Lohse (2007)

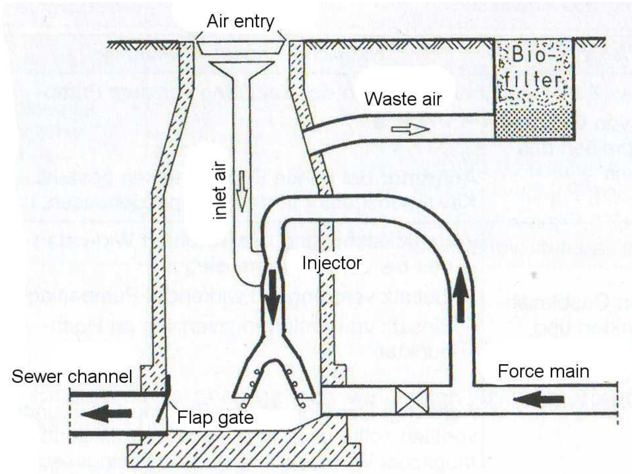


Figure 2-18: Principle of stripping unit (Injector) at a transfer shaft of a force main (Weismann & Lohse, 2007)

E2: Dilution with water

Description: Addition of water for dilution or flushing in order to shorten the retention time, reduce concentrations and reduce sediments. Additional effects like entry of oxygen and stimulation of microbial oxidation are purposeful

Examples: Groundwater, pump water, grey water, lake/river water

Advantages:

- No addition of chemicals
- Cleaning effect for pipes
- Usually inexpensive acquisition (compared to chemicals)

Limitations:

- Disputed measure as wastewater production is specifically increased
- Increased energy demand (pumps)
- Limited effect due to strong variations (Barjenbruch, 2003)
- Effects lasts only as long as treatment is carried out
- Investment costs for feeding
- Unfavourable influence on efficiency of biological phosphorous and nitrogen removal of the WWTP
- Adaptation to rainfall events necessary
- Legitimacy needs to be verified and regulations considered (esp. strict separation of drinking water and wastewater network)
- Higher flow rates should be considered during designing
- Silt must not be introduced

References: Thistlethwayte (1972a); ATV-DVWK-M 154 (2003); Barjenbruch (2003); Barjenbruch (2004); Weismann & Lohse (2007)

E3: Aerob-biological treatment

Description: Short term treatment of wastewater with Aerob-biological processes to degrade substrate for the sulphide reducing bacteria. Especially easily degradable substances

Examples:

- Rotating disc contactor (Figure 2-19)
- Other biofilm processes (with blockage free carrier material)

Advantages:

- No need for chemicals or agents

Limitations:

- Increased effort for start-up phase after downtimes
- Low COD-removal (< 5%)
- Influence of organic load on the sulphide production rate is disputed in literature
- High operational effort
- Degradation of easily degradable carbon compounds can have negative effects on the denitrification process in the WWTP and on the quality of the primary sludge for digestion
- Low level of experience

References: Freudenthal *et al.* (2003); Hillenbrand *et al.* (2010)

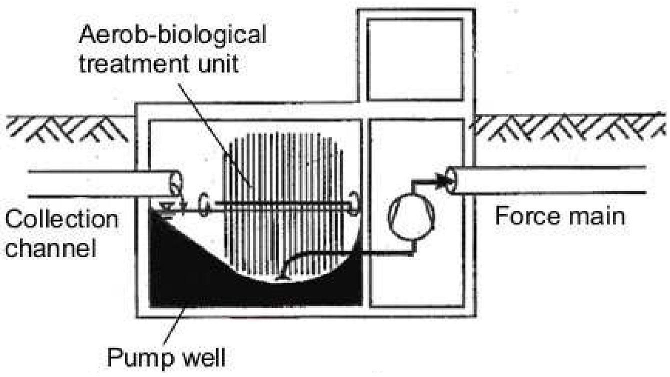


Figure 2-19: Rotating disc contactor installed at a pumping station (Freudenthal *et a.l*, 2003)

E4: New approaches

- **Microbial fuel cells – MFCs:** oxidation of sulphide to elemental sulphur
- **Electrochemical oxidation:** Oxidation sulphide by an electrode (anode) to elemental sulphur, which will precipitate in small granules. Sulphide should be converted into elemental sulphur. Investigations within an Australian Odour and Corrosion project revealed scale-up problems. Would require a very large surface area for the electrodes which need to be in contact with the wastewater flow
- **Slow release solid-phase oxygen (MgO_2/CaO_2)**
- **Phages**
- **Dosage of waste activated sludge (WAS)** from WWTPs: containing iron for sulphide precipitation, bacteria for using humic acid as electron acceptor, NO_3-N (→biological oxidation of sulphide by SOB)

Limitations: Further research necessary

References: Rabaey & Rozendal (2008); Zhang *et al.* (2008); Zhang *et al.* (2009b)

2.8 Prevention of emission – measures in the gas phase

This category basically includes measures which aim at **preventing or reducing the emissions of osmogenes to emerge from the sewer** and hence causing nuisance or health risks. They do only tackle the problem after sulphides and odorants have already been formed and have been transferred to the gas phase (**tackling the symptom**). Therefore their effect for corrosion reduction is limited as the oxidation of H_2S to H_2SO_4 can still occur provided that there is a contact surface where bacteria can dwell.

There are different techniques of air treatment which can be based on physical, biological or chemical processes. However, these processes are often combined and not so strictly discriminable.

Physical treatment methods rely on the influence on the gas concentration or gas properties by absorbing odorants or adsorbing them onto a material (like activated carbon). Air scrubbers usually also have a chemical effect when caustic scrubbing solutions are used. In newly developed systems adsorption methods are often combined with biological air treatment (e.g. using biofilter pellets) (Weismann & Lohse, 2007).

Biological treatment methods comprise the application of bio scrubbers, biotrickling filters and biofilters for odour reduction, which make use of microorganisms growing on a carrier and feeding from the odorants. Only biologically degradable and water soluble odorants are effected. One of the most applied methods for (local) odour nuisance is the manhole biofilter. It is easily applied as an immediate measure, however holds certain disadvantages. Manhole filters could pose a hindrance for the air flow and hence, prevent aeration. This then would lead to a conduction of the odorous air and shift to another emission point. This was also part of the results of a product test which was conducted by IKT (2010).

Chemical air treatment is based on the change of properties of air compounds by chemical reactions. Compared to the biological methods, generally all odorants are chemically treatable. However, different mechanisms of actions are realized in the different processes; e.g. treatment with oxidizing agents (air scrubber), photo oxidative treatment (UV-irradiation) or chemically disable odorants by applying a counter substance (neutralisation). Highly oxidative substances like ozone additionally have the effect of disinfection.

Neutralisation and masking of odorous air are often applied as immediate measures. These processes are however hardly controllable in terms of changing odour concentration, air flow and persistence of odorants. Their application is usually based on experiences.

Other possibilities to prevent problems locally are covering systems where the odorous air is conducted to another point of emission (where it does not cause nuisance or health risks or where it can be treated), or the dilution of the air with fresh air to make it "inodorous".

2.8.1 Air treatment (Group F)

Gas emissions from the sewer atmosphere are to be specifically treated. This can be done directly in the sewer or in installations aboveground (Weismann & Lohse, 2007).

The general objective of air treatments is the prevention of emission of odorous air to the environment in order to prevent all connected problems like odour nuisance, threat to humans and biogenic corrosion outside of the wastewater atmosphere.

F1-F2: Physical air treatment

Influence on the gas concentration and the properties of compounds.

F1: Air scrubber - absorbing

Description: Intimate contact of the scrubbing solution with the odorous gas stream in single- or multiple- stage processes.
Usually scrubbing solution is sprayed with nozzles or trickled on a fixed-bed (Figure 2-20).
Effects are the elimination of H_2S from air, reduction of other odorants (e.g. reduction of acids by neutralisation) or possibly additional chemical effects (chemisorption)

Examples of scrubbing solutions:

Scrubbing solution e.g.:

- Sodium hydroxide (NaOH)
- Hypochlorite (consumption: 25kg/kg of sulphur-containing compounds (Laplanche *et al.*, 1994)
- Hydrogen peroxide H_2O_2 (Karageorgos *et al.*, 2010)

Advantages:

- Elimination of H_2S and other odorants
- Reliability and flexibility
- Capability of treating large volumes of waste gas

Limitations:

- Dosing agents can be highly caustic (> pH 10)
- Complex controls (requires skilled operators)
- The odour-loaded solution requires disposal
- Carbon dioxide gets absorbed which leads to a higher product consumption
- For eliminating methyl mercaptan a pH of >11 is necessary (Dammann, 2005)
- Efficiency strongly depends on the composition of the air
- Efficiency needs to be tested for the specific application
- Required detention time of air in the scrubber increases with decreasing concentration of the substances

References: ATV-DVWK-M 154 (2003); Dammann (2005); Hillenbrand *et al.* (2010); Azzuro Inc.

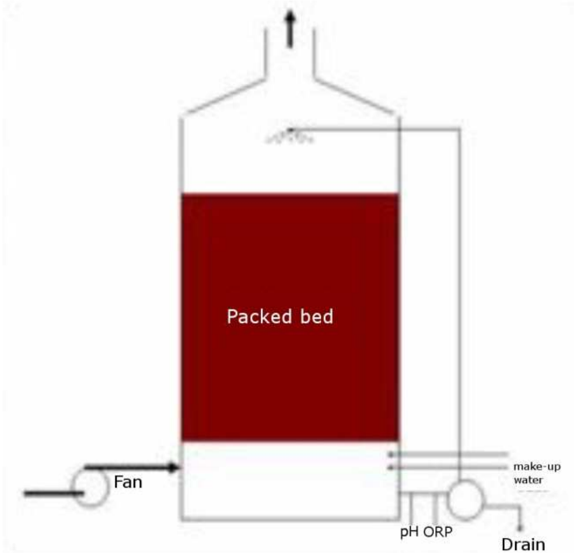


Figure 2-20: Scheme of a chemical scrubber (Azzuro Inc.)

F2: Adsorption on activated carbon

Description: Adsorption of the odorants (adsorbate) on a highly porous solid with high specific surface (adsorbent). Usually activated carbon (AC) is used as adsorbent (see Figure 2-22) Effect of catalytic oxidation of H_2S (when using doped AC)

Examples:

- Activated carbon (Figure 2-21)
- Doped activated carbon (e.g. with iodine, NaOH, KOH)
- Also: Zeolithe, clay, silica gel (Dammann, 2005, p23)
- Chemisorption filter (e.g. Odorcarb; Odormix SP)
- Types e.g.: manhole filter, tube filter, pumping shaft filter module, manhole cover with AC-filter

Advantages:

- Highly selective for H_2S when using doped AC
- Many construction types and easily integrable in systems

Limitations:

- Specially doped AC might requires disposal as special waste
- Used AC needs disposal or regeneration
- Regeneration can usually not be done on-site
- Not practicable for high concentrations (short lifetime of filters)
- High operation costs
- Costs for replacement of filters
- Competing adsorption of water vapour possible
- Caustic-impregnated AC is expensive to be regenerated
- Efficiency needs to be tested for the specific application

References: ATV-DVWK-M 154 (2003); Dammann (2005); Weismann & Lohse (2007); Karageorgos *et al.* (2010)

Figure 2-21: Activated carbon manhole filter (Romold GmbH)

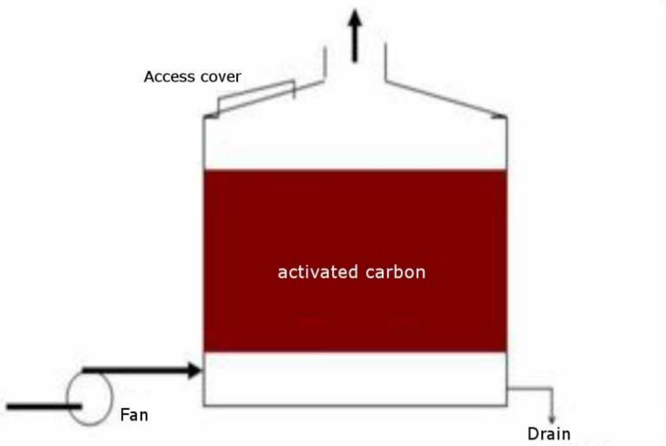


Figure 2-22: Scheme of an activated carbon filter for emission control at wastewater treatment plants (Azzuro Inc.)

F3-F5: Biological air treatment (degradation of odorants)

Odorants are degraded by microorganisms (after transfer into the liquid phase). Only biological degradable and water soluble odorants are treated

F3: Bioscrubber and biotrickling filter

Description: Transfer of odorants from gas to liquid phase by a scrubbing solution. Subsequent biological decomposition by microorganisms (in the water or by a biofilm on a carrier material) (see Figure 2-23 and Figure 2-24).
Effect of reducing H_2S-concentration and odorants (which are water soluble and biological degradable)

Examples:

- Carrier material e.g.: synthetic media, expanded clay, slag, grape seeds, chopped wood, compost,
- Scrubbing solution: usually water, if necessary addition of chemicals for pH-regulation

Advantages:

- Easy handling due to natural scrubbing solution (water)
- Different construction types possible
- Less prone to acidification than biofilter

Limitations:

- Effect starts after biological activity is cultivated

- Adjustment of pH-value might be necessary
- Additional equipment like dosing unit for nutrients or for pH-regulation
- Increase in salinity of scrubbing solution requires addition of fresh water
- Only water soluble odorants are reduced
- Production of excess sludge
- Formation of aerosols possible
- Efficiency needs to be tested for the specific application
- Possible clogging of fixed bed
- Possible calcification when low flow rates
- Higher operation costs than biofilter (due to higher water demand)

References: Stuetz & Frechen (2001); ATV-DVWK-M 154 (2003), Barjenbruch (2004); Weismann & Lohse (2007)

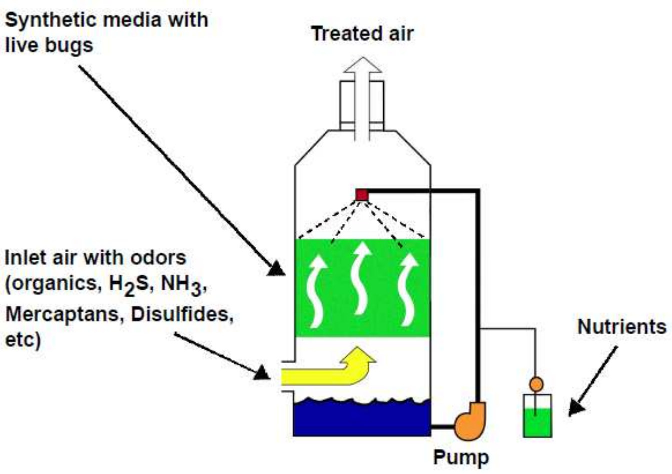


Figure 2-23: Scheme of a biotrickling filter for odour and VOC control (PRD Tech Inc.)

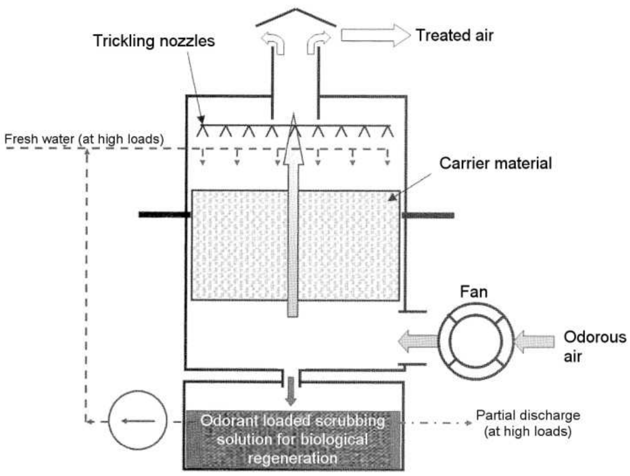


Figure 2-24: Scheme of a bioscrubber in counter flow principle (Weismann & Lohse, 2007)

F4: Biofilter

Description: Immobilized microorganisms in a bioreactor use air compounds for metabolic processes. Combination of physical (sorptive) and biological mechanism at the same place.
Effect of reducing H_2S-concentration and odorants (which are water soluble and biological degradable).

Examples:

Biofilter types e.g.:

- With/without forced ventilation (e.g. see Figure 2-26)
- Open/closed (e.g. container constructions)
- Manhole filter/container filter/pumping station filter
- Upstream/downstream
- Static/rotating

Carrier materials e.g.:

- Bark mulch, root wood, wood chips, peat, lava, expanded clay, heather, coconut fiber, mixed fillings, layered fillings, additives (e.g. Styrofoam), IHCS -Inert hydrophilic compound structure (e.g. clay, AC, cement, wood fibre, dung)
- Enrichment of materials with activated carbon or iron suspensions

Products e.g.: UGN-BEGA hybridfilter; biosesodor; COALSI; ROMOLD AC-filter; belfor, EKO biofilter (see Figure 2-25)

Application primarily as immediate measure (manhole filter)

Advantages:

- Natural filter materials
- Simple, flexible installation (manhole filter)
- Good biological degradation performance

Limitations:

- Effect starts after biological activity is cultivated (2 – 8 weeks after startup)
- Efficiency not constant during operating time
- Can handle H_2S-concentrations of 20ppm in average (Franke *et al.*, 2007)
- Optimal humidity, pH-value, oxygen, temperature and nutrient conditions necessary for degradation
- Complicated control of humidity
- Filter wetting results in a decrease in efficiency and pressure losses
- Generated acids need to be discharged or neutralized.
- Efficiency needs to be tested for the specific application
- Possible clogging
- Possible conduction of odorous air and shift to another emission point (manhole filter)

References: ATV-DVWK-M 154 (2003); Barjenbruch (2003); Barjenbruch (2004); VDI-guideline 3477 (2004); Franke *et al.* (2007); Weismann & Lohse (2007); IKT (2010)

Figure 2-25: Example of a manhole filter (EKO-Biofilter from Warwas)

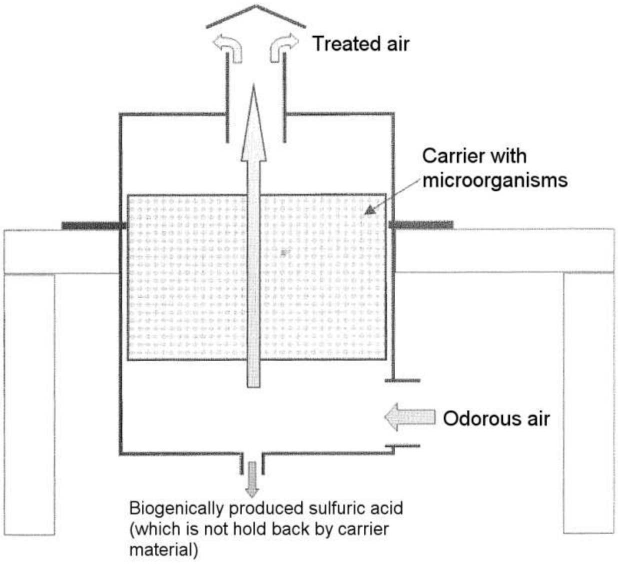


Figure 2-26: Scheme of a biofilter with natural ventilation (Weismann & Lohse, 2007)

F6-F8: Chemical air treatment

Change of properties of air compounds by chemical reactions. Generally all odorants are chemically treatable.

F5: Air scrubber - oxidizing

Description: Intimate contact of the scrubbing solution with the odorous gas stream in single- or multiple- stage processes. Usually oxidizing agent is sprayed with nozzles or trickled on a fixed-bed.

Effects: All oxidizable components of the gas stream get oxidized; Inactivation of bacteria and viruses; Absorption equilibrium between air and solution

Examples of oxidation agents:

- Hydrogen peroxide
- Ozone

- Chlorine
- (NaClO: not common any more due to formation of organochlorine substances)

Advantages:

- Also practicable for other odorants than H_2S (Weismann & Lohse, 2007)
- No by-products of ozone or hydrogen peroxide (decomposition)

Limitations:

- Scrubbing solution can be discharged as aerosol
- Possibly high chemical consumption
- Production of pollutant-loaded wastewater
- Energy requirement (for ventilation, ozonation)
- Hazardous substances for water
- Ozone : is unstable, needs to be generated on-site, is extremely toxic (MAK-value 0,1 ppm), and is ecologically critical

References: VDI-guideline 2443 (1995); ATV-DVWK-M 154 (2003); Weismann & Lohse (2007)

F6: Catalysator/Ozonation/UV-treatment

Description: Production of ozone by electrical discharges which is brought in contact with the air stream.
UV-irradiation of the air stream in the presence of oxygen. Objective to eliminate odorants by photooxidative reactions and chemically transform H_2S to sulphur and water.

Examples:

- Ozonation
- Ozone-contact reactor (McIlvaine, 1990)
- UV-irradiation

Advantages:

- Also practicable for other odorants than H_2S (Weismann & Lohse, 2007)

Limitations:

- Hazardous substances for water
- Ozone : is unstable, needs to be generated on-site, is extremely toxic (MAK-value 0,1 ppm), and is ecologically critical
- Energy requirement for ozonation
- Ozone residuals need to be destroyed (e.g. with activated carbon or catalysator)
- Pilot tests recommended
- UV-processes: not applied yet for sewer air treatment

References: ATV-DVWK-M 154 (2003); Weismann & Lohse (2007)

F7: Neutralisation/Compensation

See chapter 2.8.2 (Group G)

2.8.2 *Compensation/Neutralisation/Masking (Group G)*

Change of properties of air compounds by chemical reactions in order to reduce odour nuisances. Generally all odorants are chemically treatable.

G1: Neutralisation

Description: A specific unpleasant odorant is designated to a specific counter substance, which chemically transforms the odorant so that it is not perceived as a nuisance any more (catalytic process)

Examples:
- Essential oils (catalyst: Terpenes):
- Gel-plates (e.g. Gelactiv, C&D Brick) (Figure 2-27)
- Clatherate (cage molecules in which odorants are bound and then biologically degraded): e.g.: SinoAir; Sinodeen

Advantages:
- Relatively easy to handle
- Relatively easy an inexpensive measure
- Essential oils are predominantly natural substances
- Application as immediate measure

Limitations:
- Not controllable process (only based on experiences)
- In some cases the specific smell of the neutralising agents are perceived as unpleasant
- Possibility that odorants persist
- Gel-plates need sufficient air stream
- No lasting effect after end of contact
- Generally connected with an increase in odour concentration

References: ATV-DVWK-M 154 (2003); Barjenbruch (2004); Dammann (2005); Weismann & Lohse (2007)

G2: Masking

Description: A specific unpleasant odorant is designated to a specific pleasant counter substance, which masks the unpleasant smell. No chemical transformations occur (enclosing of the odorants).

Examples:
- Essential oils: e.g. Gelactiv, C&D Brick
- Other fragrances

Advantages:
- Relatively easy an inexpensive measure
- Essential oils are predominantly natural substances
- Application as immediate measure

Limitations:
- Not controllable process (only based on experiences)
- In some cases the specific smell of the neutralising agents are perceived as unpleasant
- Possibility that odorants persist
- Gel-plates need sufficient air stream

References: ATV-DVWK-M 154 (2003), Dammann (2005); Weismann & Lohse (2007)

Figure 2-27: Gel-plates before installation in Hannover (Rosenwinkel *et al.*, 2007)

2.8.3 *Air conduction (Group H)*

Air conduction measures comprise relatively simple methods, like covering manholes or transferring the air into a high stack. They are however limited and one needs to thoroughly consider possible shifts of the problem or even enhancements, regulations for air pollution and changing weather conditions.

H1: Covering systems

Description: Cover shafts or ventilation openings. Immediate measure to prevent problems locally. Primary objectives are the prevention of H_2S emergence from the shaft/pumping station and reduction of odour nuisances.

Examples:

- Manhole covers (**Error! Reference source not found.** and Figure 2-29)
- Rubber plug
- Amorphous covering system (Figure 2-31)
- Odour blocking valves (allow air and surface water to enter the sewer system) (Figure 2-30)

Advantages:

- Low maintenance requirements
- Practicable as local solution
- Amorphous covering: can include degradation of grease (by microorganisms on carrier material)

Limitations:

- Intake needs to be adapted (avoidance of strong turbulences)
- Sand trap necessary
- Often only as temporary measure feasible
- Problem is often shifted or enhanced
- Does not solve problems with work safety and corrosion
- Possibly problem with peaks
- Amorphous covering: pump is below filling material; problems with flow peaks

References: ATV-DVWK-M 154 (2003); Barjenbruch (2004); Barjenbruch & Rettig (2010)

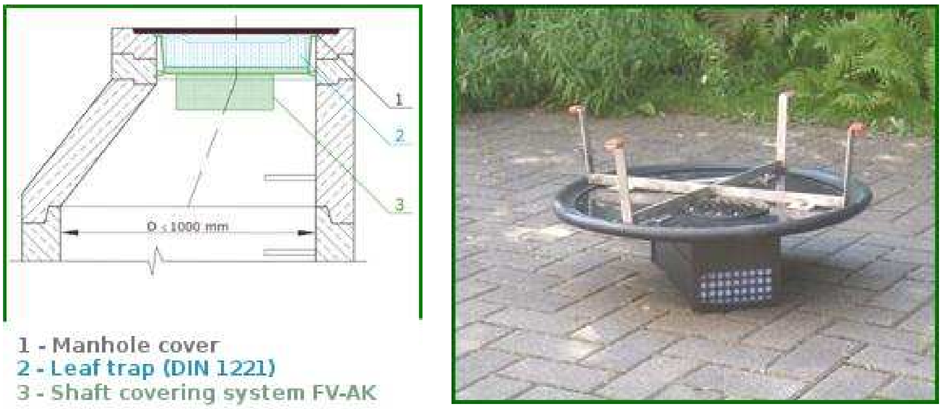


Figure 2-28: Shaft covering system (Unitechnics KG)

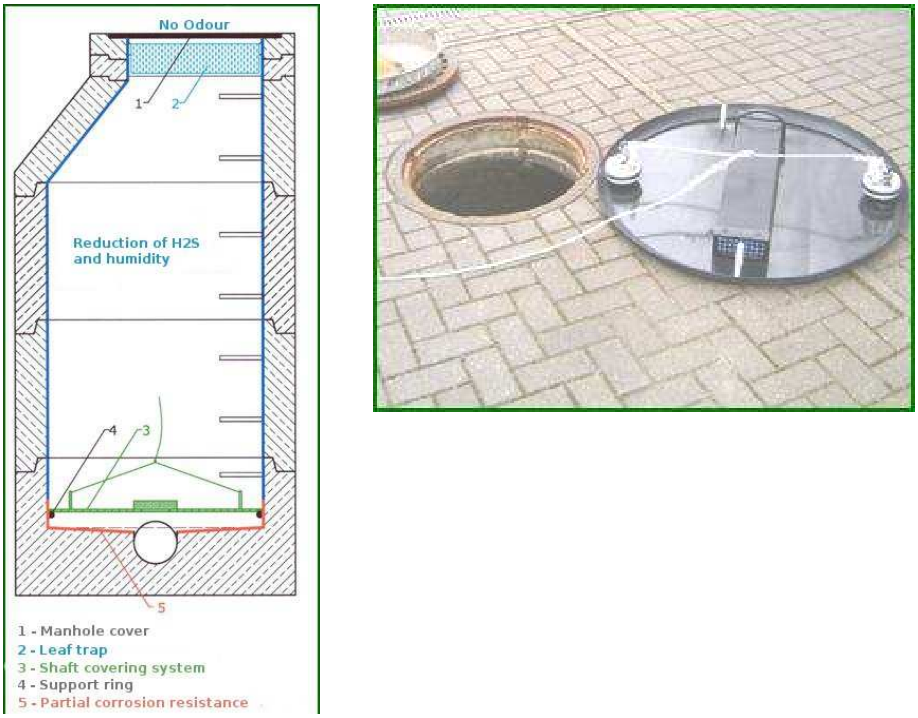


Figure 2-29: Shaft covering system at the shaft bottom (Unitechnics KG)

Figure 2-30: Covering system with odour blocking valves (Rosenwinkel *et al.*, 2007)

Figure 2-31: Example of amorphous covering system (Unitechnics KG)

H2: Improve ventilation of sewer air

Design of drainage system to allow for aeration and ventilation of sewer air.
Example: enlarged ventilation openings
See chapter 2.6.1 , A3

H3: Dilution with fresh air

Description: Dilute discharged air to render it inodorous. Reduction or avoidance of odour nuisance and/or health risks is in the fore

Examples:

- High vent stacks
- High velocity jets (increase of effective height and dilution effect
- Direct dilution at vent discharge (pre-discharge intake of dilution air)

Advantages:

- Simple measure

Limitations:

- Ventilation might be necessary
- Thermal inversion and down-draughts need to be considered
- Effect dependent on wind speed, location
- Problem is often shifted locally
- Limited effect or worsening of problem possible
- Odour is still perceived in the atmosphere

References: Thistlethwayte (1972a); ATV-DVWK-M 154 (2003)

H4: Conversion of gravity duct to pressure pipe

Description: Continuous or intermittent operation of a sewer as pressure main. Shift of problem to another point. Objective of shift emission to a point with no nuisance risk or a point which is effected anyway.

Examples:

- Conversion to pressure pipe
- Extension of pressure pipe

Limitations:

- Sewer must be filled completely while operation

- Possible intensification of problem
- Usually not successful when pipes already attacked by corrosion
- In conjunction with air treatment or controlled air conduction downstream

References: Thistlethwayte (1972a); Lange & Reinhardt (2002)

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2.10 Sitography

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www.asatechnik.de/produkte/produkte/kaskadenwehr.html
ECS GmbH (Caltech): http://www.calc-tech.de/fluid.htm
IKT – Institute for Underground Infrastructure:
www.ikt.de/printversionalle.php?NLID=70)#
Jung Pumpen GmbH: www.ikz.de/1996-2005/2004/17/0417069.php
Romold GmbH: http://www.romold.de/index.php?id=40&L=0
Unitechnics KG: http://www.unitechnics.de/index_de.htm
WOMA GmbH: http://www.woma-applications.com/deutsch.htm?/cont/de/reports/r_kanaltechnik_d.htm
PRD Tech Inc: http://www.prdtechinc.com/home.html
Azzuro Inc.: http://www.azzuro.com/default.asp
Warwas: http://www.bio-kanalfilter.de/

2.11 List of Abbreviations

ww	Wastewater
AC	Activated carbon
AOX	Adsorbable organic halogen compounds
appr.	Approximately
esp.	Especially
NR-SOB	Nitrate-reducing, sulphide oxidising bacteria
Redox	Reduction-Oxidation
SOB	Sulphide oxidizing bacteria
SRB	Sulphide reducing bacteria

UV	Ultraviolet
SAC	UV-adsorption coefficient

3 WWTP Wastewater treatment plant Increase storage volumes/handling of volumes: retrofitting of CSO stormwater removal systems, CSO control, RTC strategies

3.1 Description of the problem

Flows into sewerage systems originate from all urban surfaces and also from domestic, commercial and industrial inputs. In many places there is also significant inflow from groundwater through leaky sewers and many small surface water courses are connected into sewers (Ashley et al, 2004). Under climate changing conditions, these inflows may alter, depending on the precise and local nature of the changes. Even sea level rises, together with increased water levels in estuaries and tidal rivers, will impact on sewer systems where these discharge into these water bodies.

There are many other implications of climate change for the performance of combined sewerage systems and the continuing future use of combined sewerage systems has both advocates and opponents as there are advantages and disadvantages to their continued usage (e.g. Butler & Davies, 2010). In a recent review of the types of sewerage systems in use in member States in the EU (Thames Water, 2010), between 20% and 70% of all urban areas were found to be served by combined systems, with a significant proportion of these being built after the mid 20th Century.

table 3-1 shows the potential effects of climate change on the future performance of combined sewerage systems, adapted from Ashley et al (2008).

table 3-1: Implications and needs for elements of process.

Element of process/system	Implications for flows	Implications for quality of flows	Need for more information to reduce uncertainties	Potential ranges of relevance to urban drainage system	Model/analysis – what needs to be looked at.
Rainfall	More extremes; Local time and space resolution at scale needed for urban drainage is far inadequate; Essential to consider long series events with known statistics.	Depends on rainfall but also wind patterns and temperature/ effects on finest particles. Anthropogenic effects will also affect this.	Rainfall volumes and peaks will change. How significant are the quality aspects of rainfall?	Intensities increased by typically 20% and winter volumes may increase overall. Spatial changes – more clustered.	Range of examination to look at effects: +20% in intensity.
Runoff	Local changes in surface cover/soil moisture affecting the runoff processes. Potentially increasing contributing area (permeable). More potential evapotranspiration. Expect more direct rainwater use in water stressed areas, reducing runoff volumes.	More/less soil erosion desiccation of soils – higher/lower water table interaction. Warmer water passing into the sewer network.	Runoff changes important in both quantity and quality. Need better estimates of runoff rates and interactions. Investigate use of rainwater.	Temperature increases of up to 3^oC on current maxima.	Hydrological model performance in relation to soil moisture. Temp. increase on pollutants and generation, surface build up in inter-storm dry periods.
Sanitary and other inflows	Decrease DWF where there is water stress – but infiltration may increase where soil moisture is high. Industrial flows to reduce with more reuse.	More concentrated pollutants as pollutant load may remain same, but water use may fall. More rainwater use at source changing the inflow quality as well as quantity.	Investigate implications of large increases in concentrations in inflows.	Up to 100% increase in the concentration (but not loads) of DWF pollutants, such as BOD, COD and AmmN.	Double concentrations of these inputs and check consequences.
In-Sewer Hydraulics Sediment/ Dissolved	More inflows - higher flood risk as runoff overwhelms capacity. Interactive effects with sediment deposits will change conveyance (more and less).	More and different sediment inputs in high runoff peaks. Less transport of sediment in lower flow periods. Higher temperatures will lead to more biofilms – reducing dissolved organics but enhancing generation of gases and bioprocesses. More likely to get a rapid onset of anaerobic conditions.	Balance between the variations in inputs and consequences to be investigated.	Bioprocesses influenced by both temperature and pollutants. Temp ranges increase by 3^oC, pollutants likely to increase concentrations. More sediment related phenomena.	Temperature up by 3^o, increase pollutant concentrations by 100%. Check effect of 30% flow reductions; in northern hemispheres look at sediment data for warmer climates.
Receiving water	Both higher and lower flows at different times. Also higher temperatures.	Periods with low oxygen concentration likely to be more	Implications of interactive effects with discharges.	Potential for lower DO background levels.	Test effect of halving the minimum background DO.

		prolonged and frequent. Different flora and fauna populations changing the ecological status. Bacterial die-off rates both enhanced and reduced.	Revised standards to comply with e.g. Water Framework Directive (EU) and Clean Water Act (in USA).	Lower flows may coincide with CSO spills depending on relative times of concentration.	Lower flows in rivers – by at least 20%.
CSOs and associated storage	Longer and shorter storage times may occur in sewer and storage systems depending upon inflows.	Potential for onset of septicity and other problems specified in total emission studies (e.g. Durschlag et al, 1991).	Requires climate change scenario definition as many studies already done.	Rainfall, temperature and input changes all as outlined in the table above.	Vary parameters by ranges defined above.
WWTP	More peaky flow events. Flows – more in-system storage (at CSOs) transmits more flows to treatment.	Wider changes in rate and quality of flow arriving at the works. Temperature and load changes influence performance. Treatment processes may be more efficient at higher temperatures.	Many studies done on WWTP performance under wide range of conditions. Information should be available.	As above (e.g. Bixio et al, 2001).	All as above

The very valuable asset legacy of combined sewers, which have a long history of normative use in the EU, means there is considerable inertia against their abandonment in the foreseeable future and hence these need to be adapted to future conditions. In the EU, the Urban Wastewater Treatment Directive is severely constraining the way in which CSOs, the relief 'valves' from combined sewer systems, can be used and especially in relation to the acceptable frequency, nature and volumes of discharges, or spills into receiving waters. These divert excess flows above a 'setting' out of the sewer network into receiving waters. This may happen by design or when a pump station fails or there is a sewer blockage downstream.

Each Member State of the community is responsible for interpreting the Directive and the subsequent Water Framework Directive (WFD) in relation to CSO controls in their own way; with the latter now encompassing the former. Most States have chosen to take both a preventative stance by limiting CSO discharges to very few and/or of limited volume and flow rate as well as to integrate the assimilation of any discharges into the catchment as part of a River Basin Management Planning process. But there is no evidence of a single solution being seen as appropriate to all circumstances (e.g. Thames Water, 2010). Application so far has mainly entailed retrofitting measures to existing combined sewer networks to improve this source of pollution, but this solution is often confounded by pollution from sources other than wastewater causing greater water quality problems in the receiving water bodies (e.g. Beenen et al, 2010).

There are thus major challenges regarding the best way of managing CSO discharges. In London, for example, the existing more than 60 CSOs that spill regularly into the River Thames are to be collected by a new storage tunnel sewer laid under the river bed; but at a cost of some €6bn over the next 20 years: "*some variant of a storage and transfer tunnel was clearly identified as the only practicable and/or cost effective solution that can be implemented in a reasonable timescale*" (Thames Water, 2010a). The interception arrangements are shown in Figure 3-1. The proposed tunnel has been designed in response to the European Commission infraction proceedings against the UK Government alleging breach of the Directive due to the frequent and excessive quantity of storm sewage discharged from the CSOs.

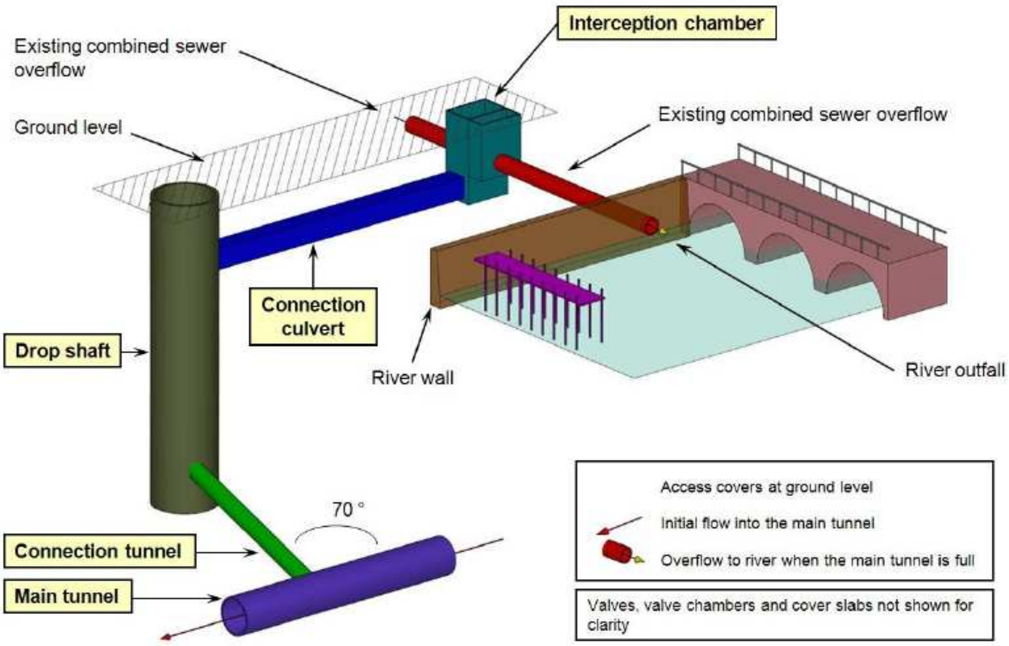

Figure 3-1: Interception arrangements for connecting existing CSOs to the Thames Tideway Tunnel (Thames Water, 2010)

This approach is claimed to be similar to many other instances of CSO control elsewhere in Europe (Thames Water, 2010), table 3-2. Although removal of stormwater at source before getting into the combined sewerage system has been adopted as preferable to what is planned in London in a number of large cities, particularly in the USA (e.g. Natural Resources Defense Council, 2006); but this option, together with combined sewer separation was rejected for London as too costly and unable to deliver within the EU's regulatory timescale (Thames Water, 2010b).

As well as the WFD, Flood Risk Management Plans (FRMP) are required by 2015, coordinated at river basin district level and focused on the reduction of potential adverse consequences of flooding and/or to reduce its likelihood. These must be coordinated with River Basin Management Plans; they must also involve public participation, and all assessments maps and plans must be made available to the public, also taking into account costs and benefits, flood extent, conveyance routes and areas of water retention (i.e. natural floodplains). They will address prevention, protection, preparedness and include promotion of sustainable land use practices, improved water retention and controlled flooding. Thus the challenge is how to simultaneously reconcile the requirements of flood risk management together with enhancements to receiving water quality at a cost that is not disproportionate. In terms of water management as a whole, these sewerage related challenges are also to be managed in relation to the water resource and drinking water requirements embodied in habitat and drinking water related Directives. Consideration also needs to be given to the wider sustainability aspects of any new or retrofit measures and energy, carbon and social considerations are also required (e.g. Thevenot, 2008).

table 3-2: Summary of CSO abatement approaches in large cities of the EU (alphabetically by country) (Thames Water, 2010).

Country	City	Driver	Approach/es	Cost	Status
Austria	Vienna	National guidelines	RTC, additional detention tunnel/basins. Tunnel 3km long, 30m deep, 7.0m dia.; 7 shafts	€123 M (RTC only)	Mostly operational
Croatia	Zagreb	Water quality Environment	RTC, expand collectors	-	Data collection/modelling
Czech Rep.	Prague	Flooding Water quality	Pre-treatment, expand interceptor, add retention tanks, expand WWTP	-	Part implemented, part planned
Denmark	Copenhagen	Bathing water quality	RTC, retention basins, WWTP expansion, sewer separation	-	Operational
Finland	Helsinki	Bathing water quality Environment	RTC, WWTP, sewer tunnels, separate sewers	-	Operational
France	Lyon	WFD Flooding	RTC, data collection, modelling	-	Operational
	Marseille	Bathing water quality	RTC, trunk sewers	-	Operational
	Paris	WFD	RTC, new/expanded WWTP, storage (reservoirs/tunnels)	€4000 M	Mostly operational
Germany	Berlin	National guidelines (via UWWTD)	RTC (local), SUDS, heightening CSO crests, storm tanks	-	Operational
	Hamburg	National guidelines (+ flooding)	Sewer separation, retention basins, interceptors, WWTP expansion	€767 M €7.7/m³	Operational
	North Rhine-Westphalia	Environment	Trunk sewer, disconnection of impervious areas, infiltration	€4.5 B	Part operational, part ongoing construction
Greece	Athens	Flood and pollution control	Interceptor sewer diversion/expansion	-	Planned
	Thessaloniki	Flood and pollution control	Additional interceptor	-	Under construction
Italy	Naples	UWWTD	Tunnel 12 km length up to 80m deep, vortex drop shafts; new WWTP; RTC; odour control	-	Operational
Netherlands	Rotterdam	Flood and pollution control	RTC, detention tanks and small scale SUDS	€11 M (tanks & RTC)	Operational
Portugal	Lisbon	Water quality (pollution)	RTC, on/off-line storage, interceptor sewer, WWTP upgrade	€160 M (to 2012)	Part operational, part ongoing construction
Spain	Barcelona	Flood and pollution control	RTC, detention tanks	-	Operational
Sweden	Stockholm	Various	Tunnels, WWTP	-	Operational

Legend: RTC = Real-Time Control; WWTP = Wastewater Treatment Plant; WFD = Water Framework Directive; UWWTD = Urban Wastewater Treatment Directive; SUDS = Sustainable Drainage Systems; CSO = combined sewer overflow

Climate change poses a particular challenge to the delivery of the WFD within the timescale of its implementation (Wilby et al, 2006). For example obtaining good ecological status of all specified surface waters in the EU by 2027 is thought to be over-ambitious and the uncertainties due e.g. to climate change are considered too great (Hering et al, 2010). This constrains potential approaches to adapting sewerage systems to climate change as the high costs of adapting need to be considered in terms of the WFD definition of 'disproportionate costs'; so far largely undefined in member States.

It is not only the WFD, as over the past decades, successive Directives across the water sector have led to large increases in energy usage, with attendant carbon and green house gas emissions, and continuing approaches to managing water for better compliance will continue this trend, as illustrated in Figure 3-2. So despite efforts being made to generate on-site electricity from renewable sources, increasing standards for wastewater systems are forcing yet more energy to be used in compliance.

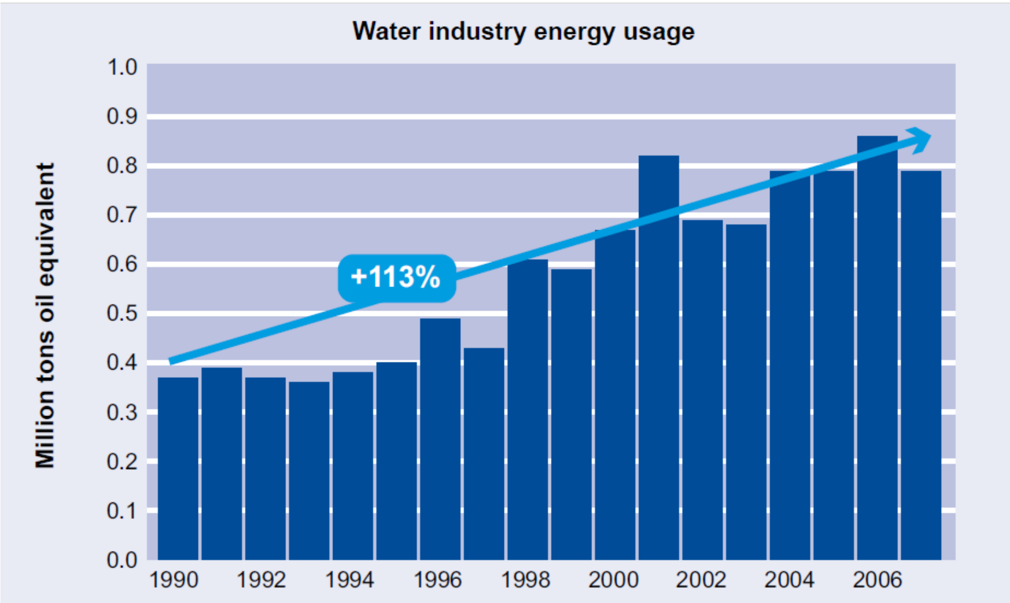

Figure 3-2: Energy use by the water industry in England and Wales (Severn Trent, 2010)

A UK Water Industry Research (UKWIR, 2003) project examined the impact of climate change on existing sewer systems in the UK and the physical improvements that might be required to return the networks to their current defined performance levels, especially as regards discharges to receiving waters. A relationship was found between the proportion of CSO storage volume required and the proportion of present day rain to reduce flooding risk to current standards.

Rainfall increases had a regional component thus the need for additional storage also varied with location – from a minimal amount to some 230% of current values. The annual CSO spill frequency and volume were found likely to increase by varying amounts across the UK, with smaller increases in spill frequency than spill volumes.

The models suggested that storage volumes required to maintain performance at current levels of spill volume were 10 times greater than that required to maintain current levels of spill frequency. Although there was an increase in CSO spill frequency in summer and winter, water quality analysis suggested little change in overall receiving water impact. This was due to the reducing duration of rainfall events under climate change; however, no account was taken of the expected reduction in river flow volumes, especially in summer. Therefore the assertion that receiving water quality will not change significantly is open to debate. Parallel work by Arnell, (2003) had predicted reductions in typical summer river flows of over 30% by 2020 and that winter flows would be slightly higher. The greater impact could come during the summer when the lower river flow rates would not provide for such high dilution from CSO discharges. This impact may be to some extent ameliorated by the reduced number of CSO spills observed in the summer due to the reduction in intense rainfall events.

The way in which CSOs are designed and modelled also influences what there likely predicted performance under changing climate will be. It is clear that CSO storage, in common with any storage options needs to be modelled using continuous time series rainfall estimates (e.g. Furlow et al, 2008).

From the above discussion it is apparent that there is no single and globally applicable type of solution to managing how best to adapt sewer systems and CSO spills in the light of climate change. Some of the approaches in use to adapt CSOs are considered below.
There are a number of approaches to managing CSO spills as listed below:

1. **Reduce CSO spill volumes**
   a. By removing flows at source before they enter the sewer network, either from the stormwater or sanitary inflow routes
   b. By increasing in-sewer volumes to reduce the volume that may spill by keeping more flow in the sewer network – either in the downstream sewer length and passed to the treatment plant – or by constructing purpose built local online or offline storage tanks or sewers at or upstream of the CSO; also passing more flow downstream to the treatment plant as illustrated in Figure 3-1.
2. **Combined sewer separation**
   Separation of combined sewers by taking either the storm flow or sanitary flow inputs out into a separate sewer network.
3. **Provide treatment before discharge**
   Remove solids and pollutants or otherwise treat the flow, via e.g. disinfection, so that it causes less impact on the receiving water course – this option does not reduce flow peaks.

Note that (3) above does not address the potential problems caused by high flow volumes or rates that may potentially impact physically on the receiving water causing e.g. erosion.

table 3-3: Advantages and disadvantages of removing inflows or increasing storage/treatment at CSOs

Measure	Technique	Advantages	Limitations
Inflow removal	Remove surface water inputs	Taking surface water out helps throughout the wastewater system. Redirects surface water for other potential uses. Can provide multi-functional benefits in urban areas.	May increase flood risk in areas where surface water removed. Depending on responsibilities, may transfer these from expert sewerage manager to local community who do not have the skills.
	Remove sanitary inflows	Where e.g. urine is separated can be used at source. Blackwater may be used but only after treatment. Removes most of the organic and chemical pollutants from the combined sewage.	Will remove only a small volume (typically 3%) of combined flow. Special arrangements are required for urine use (lengthy storage). Requires at-source wastewater system.
Combined sewer separation	Take storm flows out of combined system	Storm water has been considered to be cleaner than combined sewage and has less organic pollutants or pathogens and can be dealt with easier than combined sewage. Less shock loads to WWTW downstream as flow peaks reduced	Will result in two sewer systems unless alternative e.g. SUDS measures are used for the stormwater. There are significant risks from wrong connections of storm into sanitary sewer or vice versa. Sewer separation experience has shown that storm water needs to be treated before discharge into watercourses if in a separate piped system. Major retrofit separation programmes in Netherlands and Germany have been halted as a consequence (NORIS, 2007). Taking storm water out of a large sewer will reduce the hydraulic conveyance and lead to sediment deposition in the original sewer.

	Take sanitary, commercial or industrial flows out of combined system	If done this would convert the combined sewer to a separate storm sewer.	This option may only be if use for very limited disconnections. As above, there are significant risks from wrong connections. The combined sewer would convey only storm flows to the WWTW and this would necessitate changes to its processes.
Provide increased storage	In the sewerage system RTC Heightening CSO crests	Retains more of the combined sewage in the system. Also reduces volumes and flow rates discharged, reducing physical impacts.	Transfers more combined sewage to the treatment plant downstream.During low flow periods, enlarged sewer may experience sediment deposition.
	Using tanks RTC	As above, but temporarily holds back the flow to the treatment plant, releasing it more slowly and causing less impact to treatment plant. Usually provides greater volume than above and construction is less disruptive as more localised; i.e. not along sewer lengths.	Usually requires automation and control systems. Increased sedimentation in tanks requiring flushing.
Treatment of flow before spill	Remove solids or pollutants from flow	Screens can collect the larger floating or buoyant solids. Vortex separators can remove grit and larger suspended solids. Tank storage will provide settlement opportunities for solids.	Screenings need to be collected and disposed of. Grit and other solids also need to be removed and disposed as hazardous waste. Deposits in tanks need to be flushed out.
	Treat flow before discharge	Can remove pathogens, chemicals and solids.	Expensive, e.g. UV or chemical treatment. Can lead to residuals, e.g. contaminated particles to be disposed.

The effectiveness and robustness of technological responses to the future drivers impacting on sewerage systems in the current century were determined in a UK study (Ashley et al, 2006) as given in table 3-4.

table 3-4: Effectiveness and robustness of technological responses

Response (driver group)	Effectiveness	robust
Disconnection of Impervious Areas (Climate Change/ Land Use)	High	Yes
Water Re-use (Climate Change/ Land Use)	Low	Limited
Sewer conveyance improvement – using advanced surfaces or cleaning (Climate Change)	High - Locally effective	Limited
Real Time Control (Environmental Concerns/Climate Change)	High	Limited
Smarter Management – Energy Use (Energy and Resources)	High	Yes
Smarter Management - Nutrient Recovery (Environmental Concerns/Climate Change)	Low unless nutrient values increase highly	Limited
Smarter Management – Design, Sensors and Automation (Science and Technology)	High	Limited
New and Emerging Technologies to Mitigate Impact (Environmental Concerns)	High	Limited

table 3-4 was developed from workshops with the major sewer operators in the UK and shows that disconnection of stormwater inputs to sewer systems is the most effective and robust response to future threats. The 'robust' column in the Table relates to the 4 socio-economic scenarios examined for the future[1]. A response is believed to be robust if it is effective in future under all 4 scenarios. For example, RTC is not robust under certain low technology future scenarios (Local Stewardship) as such technologies would not be utilised in such socio-economic conditions. In the Table, the 'driver group' are the major future threats or challenges considered in the UKWIR study (Ashley et al, 2006).

In more recent work, a project known as 'Future Cities' has been looking at managing water systems with energy and 'green' structures as part of the required transformation of urban areas to face climate change (Frehmann & Athoff, 2010) and has concluded that 'soft' as well as hard structural measures are required that produce multi-value benefits. The target is to attain climate-proof urban areas in a cost-effective way.

3.1.1 *Removal of inflows*

The removal of stormwater from combined sewerage systems appears to be one of the most effective ways of helping combined sewerage systems cope with changing climate, as well as providing support for other urban system changes. However, the stormwater still has to be handled by other means

[1] These scenarios are described in Evans et al (2004) and Ashley et al (2006).
In PREPARED WA6 has specified an approach to scenario planning (see wiki).

unless it is used for supply purposes by harvesting and even then, it is unlikely that all of the stormwater will be removed in the harvesting process (Kim & Han, 2006).

Managing the water cycle

The importance of integrating the way in which stormwater is managed intrinsically with other elements of the water cycle and formal urban planning and layouts has been recognised recently in many countries. In Australia, this has become known formally as 'Water Sensitive Urban Design' (WSUD): "*…the integrated design of the urban water cycle, incorporating water supply, wastewater, stormwater and groundwater management, urban design and environmental protection* (Joint Steering Committee for Water Sensitive Cities, 2009).

WSUD encompasses the integration of (Wong, 2007):

- management of the three urban water streams of water supply, wastewater collection and rainfall runoff;
- the scale of urban water management from individual to regional levels;
- sustainable urban water management into the built form, incorporating building architecture, landscape architecture and public art;
- structural and non-structural sustainable urban water management initiatives

WSUD is seen by its' proponents as providing multiple benefits and value as illustrated in Figure 3-3, combining water quantity and quality benefits as well as social, amenity, biodiversity and other environmental values.

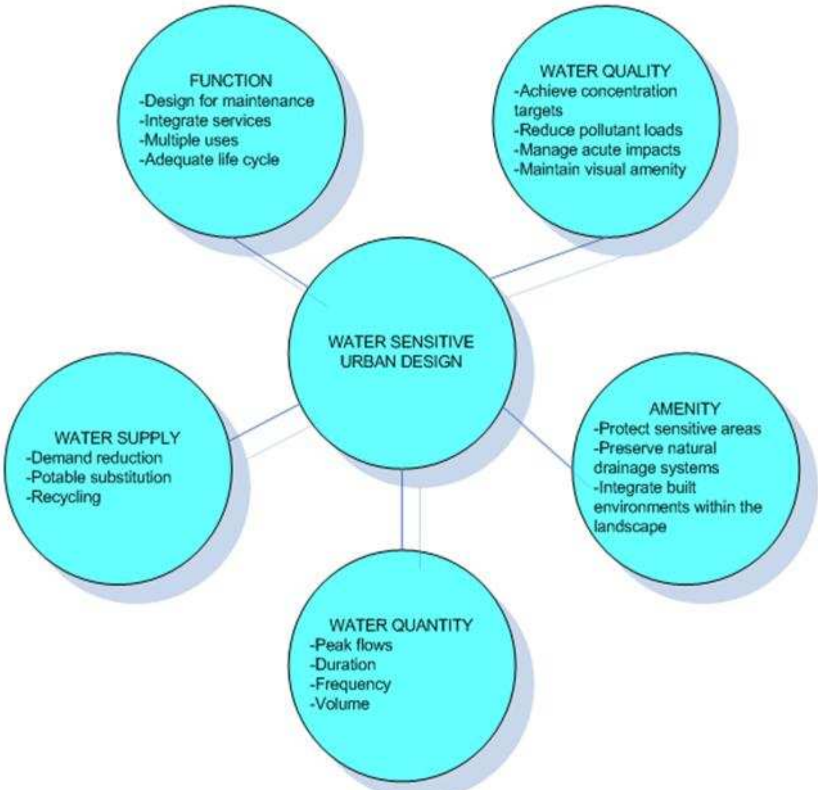

Figure 3-3: Water Sensitive Urban Design objectives (adapted from Joint Steering Committee for Water Sensitive Cities, 2009)

Elements of WSUD in relation to the urban water cycle are illustrated in Figure 3-4. Action in one sphere can have dual benefits, e.g. demand management can reduce water consumption as well as wastewater generation and in the context of this report, CSO spills[2].

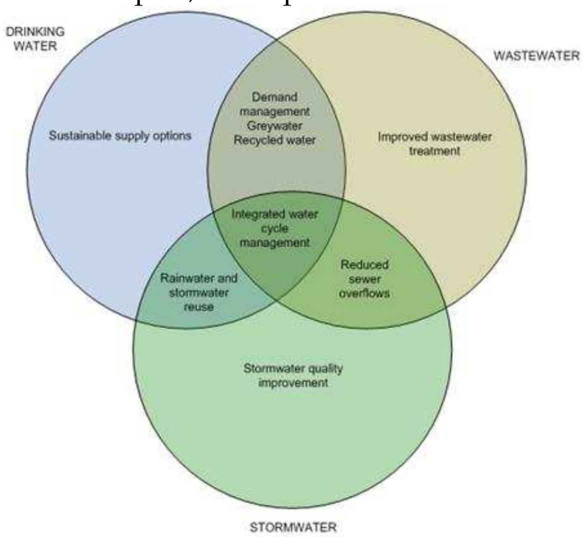

Figure 3-4: Integrated management of the urban water cycle and WSUD (Hoban and Wong, 2006)

[2] http://www.wsud.org/ accessed 14/12/10

This type of integrated approach is known as 'Low Impact Development' (LID)[3] in the USA (Figure 3-5); and 'Low Impact Urban Design and Development' (LIUDD) in New Zealand. In the USA, 'Best Management Practices' (BMPs)[4] are used to refer collectively to the components used to manage urban stormwater, comprising e.g. infiltration via pervious surfaces, bioretention areas, rain gardens and other measures. In the UK, these components are referred to as 'Sustainable Drainage Systems' (SUDS)[5] (Ashley et al, 2007). Most recently, the LID practices in the USA are increasingly being seen as equivalent to 'Green Infrastructure' (GI) (Benedict & McMahon, 2006)[6] as these measures are being seen as a means to provide attractive enhancements to the quality of life in urban areas whilst simultaneously dealing with stormwater runoff (e.g. USEPA, 2010) and have been taken up in the EU (Sylwester, 2009). However, using GI for the better management of surface water is often problematic for engineers as it is more subtle and more sophisticated than traditional 'hard' engineering (Wolff & Gleick, 2002) and therefore requires a broader spread of disciplines, co-operation, and co-funding across different organisations.

In New Zealand, LIUDD is described as a solution that combines the use of physical resources (built infrastructure assets) and natural resources (soils, plants, underground waters, streams and other fresh and saline surface waters) (Feeney et al., 2009).

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[3] http://www.epa.gov/owow/NPS/lid/ accessed 10th January 2011

[4] A BMP is a technique, process, activity, or structure used to reduce the pollutant content of a storm water discharge.

[5] This acronym has had different meanings since emerging in the UK in the 1990s; this is the current term and is defined as: *approaches that minimise the impacts from the development on the quantity and quality of runoff and maximise the amenity and biodiversity opportunities* (CIRIA, 2007)

[6] "*Green infrastructure is the interconnected network of open spaces and natural areas, such as greenways, wetlands, parks, forest preserves and native plant vegetation, that naturally manages stormwater, reduces flooding risk and improves water quality. Green infrastructure usually costs less to install and maintain when compared to traditional forms of infrastructure*. Green infrastructure projects also "*foster community cohesiveness by engaging all residents in the planning, planting and maintenance of the sites*."

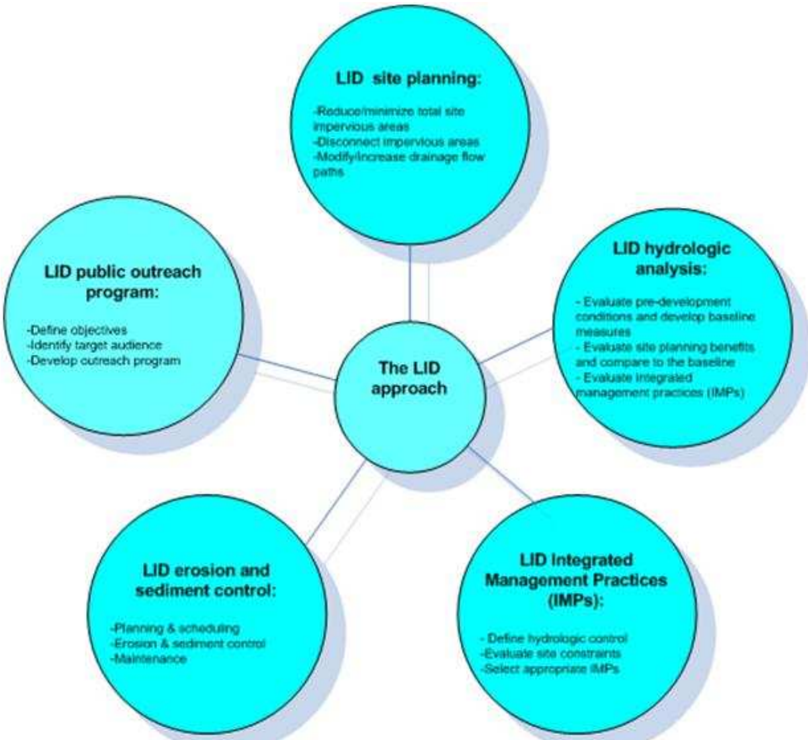

Figure 3-5: Major component of the LID approach

Effectiveness of removal of stormwater for CSO control

In a number of studies the potential effect of reducing the volumes of flows entering sewer systems has been examined. Parkinson et al., (2005) used an Infoworks model to look at low flush WC/ greywater re-use which resulted in lower sewer flow velocities during dry weather flow with higher sediment deposition. Performance of the downstream treatment plants was generally unaffected with minor reductions in sludge production. However, more acute pollution problems occurred as increased sedimentation and increased pollutant concentrations in the DWF (Dry Weather Flow) caused higher discharge loads from CSOs. Only the use of local storage and re-use of rainwater indicated a reduction in the volume of CSO discharges.

Modelling using commercial software to look at the performance of sewers under climate change has been undertaken as part of the UK Foresight Future flooding study (Evans et al, 2004) and in a study into sewerage systems for the 21st century (Ashley et al, 2006).

The SUDS manual (CIRIA, 2007) defines SUDS as: 'surface water drainage systems developed in line with the ideals of sustainable development' and it lists their attributes as:

- Reducing runoff rates, thus reducing the risk of downstream flooding;
- Reducing the additional runoff volumes and runoff frequencies that tend to be increased as a result of urbanisation, and which can exacerbate flood risk and damage receiving water quality;

- Encouraging natural groundwater recharge (where appropriate) to minimise the impacts on aquifers and river baseflows in the receiving catchment;
- Reducing pollutant concentrations in stormwater, thus protecting the quality of the receiving water body;
- Acting as a buffer for accidental spills by preventing direct discharge of high concentrations of contaminants to the receiving water body;
- Reducing the volume of surface water runoff discharging to combined sewer systems, thus reducing discharges of polluted water to watercourses via CSO spills;
- Contributing to the enhanced amenity and aesthetic value of developed areas; and
- Providing habitats for wildlife in urban areas and opportunities for biodiversity enhancement.

The manual states that through effective runoff control at source, the need for large flow attenuation and control structures is minimised, and that the variety of SUDS available allows the consideration of current and future land use and the needs of local people in design of the schemes. Examples of SUDS types available for surface water attenuation are given in table 3-5.

table 3-5: Examples of types of SUDS available for surface water attenuation

SUDS	Description
Filter strips*	Wide, gently sloping areas of grass or other dense vegetation that treat runoff from adjacent impermeable areas.
Swales*	Broad, shallow channels covered by grass or other suitable vegetation that convey and/or store runoff, and can infiltrate the water into the ground (if ground conditions allow).
Infiltration basins*	Depressions in the surface designed to store runoff and infiltrate water to the ground; may also be landscaped to provide aesthetic and amenity value
Wet ponds*	Basins that have a permanent pool of water for water quality treatment. They provide temporary storage for additional storm runoff above the permanent water level; may also provide amenity and wildlife benefits.
Extended detention basins*	Usually dry central basins with small permanent pools at the inlet and outlet. Designed to detain a certain volume of runoff as well as providing water quality treatment
Constructed wetlands*	Shallow water with wetland plants that improve pollutant removal and provide wildlife habitat
Filter drains and perforated pipes*	Trenches filled with permeable material; surface water from the edge of paved areas flows into the trenches, is filtered and conveyed to other parts of the site. A slotted or perforated pipe built into the base of the trench can collect and convey the water.
Infiltration devices*	Temporarily store water and allow it to percolate into the ground (where ground conditions allow)
Pervious surfaces*	Rainwater infiltrates through the surface into an underlying storage layer, where water is stored before infiltration to the ground for reuse or release to surface water (can be driveways, pavements, roads, car parks etc.)
Green roofs*	Systems which cover a building roof with vegetation. They are laid

	over a drainage layer, with other layers providing protection, waterproofing and insulation.
Soakaways	Small areas of (permeable) land dedicated to the percolation of rainwater
Rain gardens	Planted areas often acting as traffic calming islands to the sides of wide roads that collect road runoff, water the plants and provide infiltration
Sea streets	(Street Edge Alternatives) roads with adjacent green space that can be used for detention/retention/swales; can be used in conjunction with permeable paving
Street trees	Trees planted in the pavement that are watered by pavement runoff
Pocket SUDS	Small scale SUDS implemented opportunistically
Disconnection	Direction of roof runoff to local green space for infiltration to the ground rather than piped/sewered collection
Rainwater harvesting	Typically the use of water butts to collect rainwater for garden watering, but can also be done on a much larger scale and rainwater can be used within a building for non-potable use (e.g. toilet flushing)
Blue roofs	Collection of rainwater in dedicated (flat) roof reservoirs, providing insulation, cooling and habitat
General 'greening'	Restoring green space where ever possible in the local area to provide opportunity for surface water infiltration
Daylighting of culverted watercourses	Locating natural watercourses that have been culverted and opening them up with the potential to provide increased headroom as well as aesthetic and environmental benefits
Domestic / industrial demand management	The use of various financial or legislative means to reduce potable water use for non-potable purposes and encourage rainwater harvesting
Legislation	Such as the recently introduced planning legislation requiring planning permission to pave over a front garden greater than 5m² with a non-pervious material (www.planningportal.gov.uk)

* As described in the SUDS manual (CIRIA, 2007)

The precise forms of SUDS, the terminology and the way they are defined varies internationally and table 3-5 is not inclusive of all the types of systems classified as 'SUDS', 'BMPs' or 'LIDs' (Low Impact Development). The SUDS manual (CIRIA, 2007) also gives an indication of likely performance of the different types of SUDS with respect to quality of treatment potential and hydraulic control, table 3-6.

table 3-6: Quantity/quality performance of selected SUDS (source: SUDS manual, CIRIA, 2007, Table 5.7)

SUDS group	Technique	Total suspended solids removal	Heavy metals removal	Nutrient (phosphorus, nitrogen removal)	Bacteria removal*	Capacity to treat fine suspended solids and dissolved pollutants	Runoff volume reduction	Hydraulic control: Suitability for flow rate control (probability)		
								0.5 (1/2 yr)	0.1-0.3 (10/30 yr)	0.01 (100 yr)
Retention	Retention	H	M	M	M	H	L	H	H	H

	pond									
	Subsurface storage	L	L	L	L	L	L	H	H	H
Wetland	Shallow wetland	H	M	H	M	H	L	H	M	L
	Extended detention wetland	H	M	H	M	H	L	H	M	L
	Pond / wetland	H	M	H	M	H	L	H	M	L
	Pocket wetland	H	M	H	M	H	L	H	M	L
	Submerged gravel wetland	H	M	H	M	H	L	H	M	L
	Wetland channel	H	M	H	M	H	L	H	M	L
Infiltration	Infiltration trench		H	H	M	H	H	H	H	L
	Infiltration basin	H	H	H	M	H	H	H	H	H
	Soakaway	H	H	H	M	H	H	H	H	L
Filtration	Surface sand filter	H	H	H	M	H	L	H	M	L
	Sub-surface sand filter	H	H	H	M	H	L	H	M	L
	Perimeter sand filter	H	H	H	M	H	L	H	M	L
	Bioretention / filter strips	H	H	H	M	H	L	H	M	L
	Filter trench	H	H	H	M	H	L	H	H	L
Detention	Detention basin	M	M	L	L	L	L	H	H	H
Open channels	Conveyance swale	H	M	M	M	H	M	H	H	H
	Enhanced dry swale	H	H	H	M	H	M	H	H	H
	Enhanced wet swale	H	H	M	H	H	L	H	H	H
Source control	Green roof	N/A	N/A	N/A	N/A	H	H	H	H	L
	Rainwater harvesting	M	L	L	L	N/A	M	M	H	L
	Permeable pavement	H	H	H	H	H	H	H	H	L

Key: H-High impact; M-Medium impact; L-Low impact

In the USA, retrospective stormwater disconnection is often utilised to improve downstream water quality with less interest in water quantity control. For example, the WERF project reported by Weinstein et al (2006;

2009) is interested in using retrofits to reduce CSO spills. table 3-7 shows a qualitative assessment from this report of the effectiveness of certain BMP measures on volumes and peak flows.

table 3-7: Effectiveness of source controls on water quantity downstream (adapted from Weinstein et al, 2006)

Source control	Effect on volumes	Effect on peak discharges	Responsibility	Maintenance effort
Downspout disconnection	M	M	owner	Minimal
Infiltration practices	M	L	owner	Medium to high
Pocket wetlands	H	H	owner	Moderate to high – removal of debris, vegetation watering, sediment removal
Porous pavement	H	H	owner	As infiltration - may need vacuuming
Rain barrels/cisterns	M	L	owner	Minimal
Rain gardens	H	H	owner	Minimal Vegetation management
Rooftop storage*	H	H	owner	Minimal
Soil amendments	M	M	N/R	Included in other applications
Vegetated roofs	M	H	owner	Moderate Vegetation management
Vegetated swales	M	M	owner	As above

Key: H-High impact; M-Medium impact; L-Low impact
* This option was missing in the original Table ES-1 in Weinstein et al (2006).

The options in table 3-6 are mainly source controls and the performance applies in conditions found in the USA and therefore need to be considered carefully when applied elsewhere. There are issues for example with the 'ownership' of the stormwater which may be private, collective or municipal and could change in the case where retrofitting is implemented.

In a recent study for retrofitting surface water removal systems in London (Thames Water, 2010b), several options were considered for SUDS systems as illustrated in Table 3-8. These were considered in terms of the dense urban areas and less dense suburban areas in 3 study catchments. Their relative potential value for removing stormwater from the combined sewer network was assessed generically and ranked in terms of what was considered to be the most effective and also potentially usable as in table 3-8. Four different hydraulic mechanisms were considered, and these were initially ranked in preference order as follows:

a) Complete removal of flow from sewer network – 1st
b) Transfer to pervious areas adjacent – 2nd equal
c) Increasing initial losses (x mm) – 2nd
d) holding flows in storage/attenuation – 3rd

table 3-8: Potential SUDS, preference and indicative hydraulic performance in London (illustrations of some of these options are shown in Figure 3-6)

Surface type	Primary options	Expected Hydraulic performance	Preference rank
Roads	Pocket street infiltration	c) removes first 12 mm of storm runoff with subsequent drain down into network	3
	To adjacent pervious/SEA Streets[7]	b)	2
	Permeable road surface	c) removes first 25 mm of storm runoff & d)	1
	Off-site – local detention and swale conveyance	d)	4
Non-road hard standing (inc. car parks) Contiguous areas of man-made surfaces >200m²	Permeable surface storage	c) & d)	1
	Adjacent pervious	b)	2
	Off-site e.g. local detention	d)	3
Man-made surfaces other than above	Adjacent pervious	b)	1
Roofs	Green/blue	c) blue roofs can remove first 25 mm of storm runoff b)green can act as pervious storage for smaller storm events	4
	Soakaways	a)	1
	Disconnect to lawn (Classified as mixed permeability)	b)	2
	Water butts/RWH Where there is adjacent green space or hard standing to site them	c) can remove first 25 mm of storm runoff if oversized cistern used	3

[7] Street Edge Alternatives (Seattle Government, 2009).

The initial evaluation considered source control options only, in keeping with the preference hierarchy promoted by the Center for Watershed Protection (2007) and Weinstein et al (2006). This was because 'regional controls' (CIRIA, 2007), such as storage ponds, detention basins an inter-linking swales were considered as 'end-of-system' options, collecting runoff from a succession or number of contributing areas. Given the available guidance, the study concentrated initially on source controls as the best options as part of potential downstream 'treatment trains'.

 Pocket street infiltration in New Zealand	 Permeable pavement in the UK (Interpave: http://www.paving.org.uk)/
 Off-site local detention (Orleans, France)	 Transfer of roof drainage to pervious areas (Seattle, USA)
 Green roof Rotherham, UK	 Rainwater harvesting Melbourne, Australia

SEA street Seattle, USA

Pond and swales in Hannover, Germany

Figure 3-6: Examples of SUDS options for disconnecting stormwater from combined sewer networks

This assumption was found subsequently to be too limiting in the subcatchments investigated as these had considerable areas of green space that was found to be suitable for regional, or near end of system, SUDS such as storage ponds. This led to a re-evaluation of the potential stormwater disconnections from the initial appraisal and the final analysis and a refinement of the preference order.

Computer modelling of the performance of the potential options retrofit at a catchment scale in the London study (Thames Water, 2010b) suggested that the practicalities of removing stormwater in this way were inhibited by land availability, conflict with other utilities (buried cables etc.) and the scale of what was achievable. Costs also appeared to be high, but only a very limited range of benefits was considered (only the reduction in CSO spill frequency and volumes). Therefore such an option would also require additional measures, such as selective increased in-sewer storage, in keeping with what has been found in studies elsewhere, e.g. in San Francisco, Figure 3-7

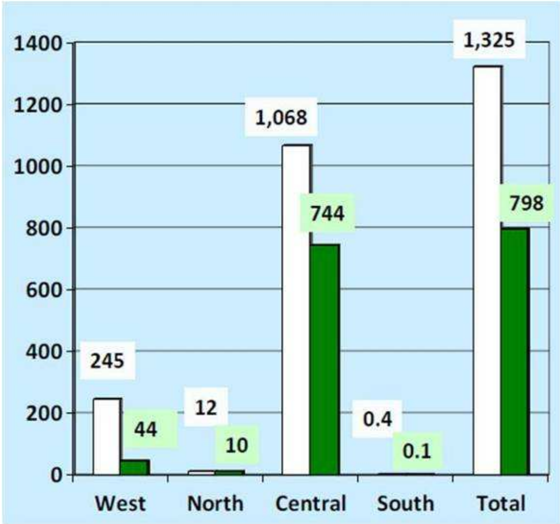

Figure 3-7: Modelled results for millions of gallons discharged from CSOs without (white) LID disconnection and with (green) LID disconnections for the city of San Francisco[8]

Perhaps the most persuasive argument for using SUDS, LIDs, BMPs or WSUD for surface water removal from combined sewer systems linked with GI provision (USEPA, 2010a) is the potential multi-value that accrues by doing this. There are a number of cost-benefit valuation tools being developed for drivers other than stormwater management in urban areas. The most relevant of these relate to green infrastructure (GI) and how the added values from this might be monetised. In the USA, the multi-functional cost value of GI has been linked to the use of non-piped low impact development (LID) drainage systems by the Center for Neighborhood Technology (CNT) and tools for valuation are available on-line (Wise et al, 2010) and the approach is heavily promoted by the USEPA for water quality enhancements (USEPA, 2009).

There are difficulties in assessing the intangible or non-monetisable 'costs' including changes to health and safety risks, noise impacts on individuals and disruption during construction. These may be assessed using a scoring or utility value system and applied using a scaled representation or spider diagram. Guidance on these costs is given in the UK SUDS manual (CIRIA, 2007).

When retrofitting for CSO control, different stakeholders will accrue different portions of the costs, whether monetary or not (e.g. UKWIR, 2009). Alternative options will also put different cost burdens on to different stakeholders. Ideally the most effective and efficient option(s) rather than the cheapest should be considered when comparing the costs and benefits, irrespective as to which stakeholders bear the cost burdens and which receive the benefits. Ideally any options selected should be the most sustainable or at least the most resilient to future changes.

[8] SFPUC http://sfwater.org/detail.cfm/MC_ID/13/MSC_ID/166/MTO_ID/581/C_ID/4611 accessed 20th January 2011

Inclusion of additional criteria to the list of benefits, such as water quality enhancements or protection from future risk, makes benefit assessment even more complex. The use of tools such as the USEPA (2009) water quality scorecard provides the means to make a comparative evaluation between options. Different SWM options will potentially benefit from a range of different stakeholders especially where a range of measures is expected and the benefits do not necessarily fall to the stakeholder responsible for funding the measures.

The GI valuation tools by Center for Neighbourhood Technology[9] can help provide monetised values for the benefits. This toolbox includes water and drainage systems as just one component of multi-functional urban GI. The CNT approach puts surface water at the heart of the valuation process. Figure 3-8 illustrates the added value of including GI and other multiple benefits in using GI for CSO control in Philadelphia using the CNT valuation tool. This shows a very substantial added value of using non-piped systems compared with a new storage tunnel for CSO pollution control.

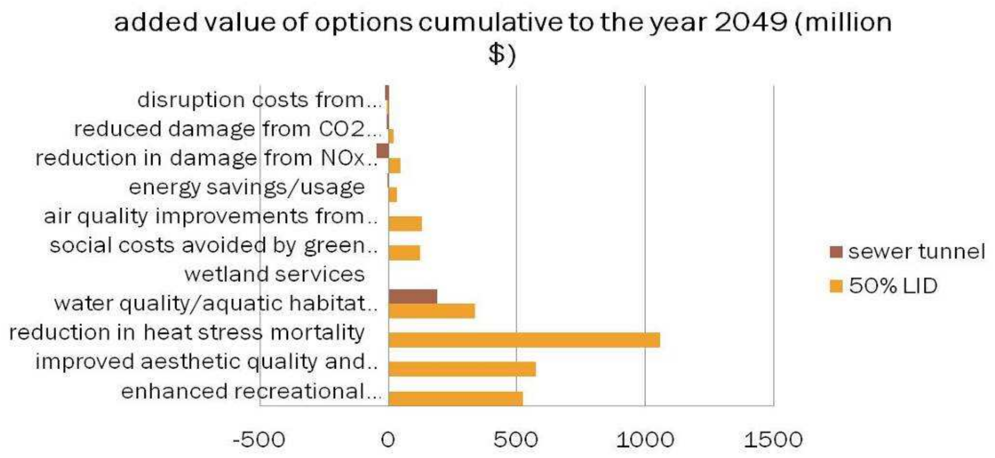

Figure 3-8: illustration of the added value of using GI for stormwater management in Philadelphia compared with a sewer tunnel (Wise et al, 2010)

The GI Option provides total added benefits to the city of $2.8bn
Compared with a sewer tunnel, with added benefits of $130M

As a minimum the core benefits that need to be included when considering the options for removing stormwater from sewers are:

- Flood risk, with the impact locally and also at the wider catchment scale
- Water quality improvement and risk reduction, or buffering to future impacts (ecosystem protection)

and ideally:

- Contribution to urban place making and aesthetics
- Carbon impacts (embodied and operational)

[9] http://logan.cnt.org/calculator/calculator.php accessed 20th January 2011

In addition, the following criteria should also be considered but are often neglected in the valuation (GINW, 2011):

1. Climate change mitigation and adaptation
2. Water and flood management
3. Quality of place
4. Health and well-being
5. Land and property values
6. Investment
7. Labour productivity
8. Tourism impacts
9. Recreation and leisure
10. Biodiversity
11. Land management and products from the land
12. Other – e.g. transport and education

In a US study Gunderson et al (2011) have shown that in each case reviewed, for Portland, Kansas, Chicago and New York, the costs of reducing CSO spills using a combination of green infrastructure with grey (some additional sewer storage) was significantly cheaper, even without taking into account the added-value benefits listed above.

Relating the above discussion to adapting to climate change, there is a widespread view that GI related stormwater systems are likely to be more resilient and adaptive than traditional piped systems (e.g. Faram et al, 2010; Frehmann & Althoff, 2010).
table 3-9 shows a proposed approach to adaptation of stormwater systems that is staged. In each stage there may be good reasons for utilising a portfolio approach that includes the use of conventional style systems where these are the most resilient. The proposed approach involves evolution from reliance on 'centralised, capital intensive' infrastructure towards a mix of centralised and decentralised approaches and finally to a scenario where decentralised systems are dominant. The greatest challenge in realising such a vision relates to the inherently fragmented nature of a decentralised system; requiring a need for wider stakeholder engagement, ultimately to the level of the private householder. The challenge becomes as much sociological as technological, demanding a more diverse supporting skills base, an open minded attitude towards new ideas, and above all else, an appropriately flexible, aligned and envisioned political and professional regime.

table 3-9: Short, medium and long term approaches to drainage adaptation in the context of the existing built environment (Faram et al, 2010)

Short term - Seek opportunities to reduce the volume of stormwater entering the existing sewer system and accommodate surplus flows elsewhere.

- **Rainwater harvesting, downspout disconnection & diversion to adjacent green areas:** Rainwater can be used to replace valuable mains water both inside the property or outside. The presence of green space immediately adjacent to buildings (e.g. grassed areas including front gardens) even if small, can provide some stormwater management opportunities. Simple adaptations can be made to divert downspout flows to these areas, allowing stormwater to be collected and infiltrated into the ground. Full-cost charging for stormwater drainage, as recently endorsed by Ofwat in England and Wales (Ofwat, 2009) should encourage uptake of this.
- **In-pipe storage and surface ponding:** In many instances there may be opportunities to take advantage of 'spare capacity' in existing drainage infrastructure, for example, at stormwater entry points or in pipework, through strategic implementation of flow controls. In some cases, it may be both possible and acceptable to accommodate surplus flows in a controlled way on urban surfaces such as car parks and roads during extreme events as has been done in Skokie, USA (Carr and Walesh, 2008), where it has been shown that such approaches are both effective and cost-beneficial. Further examples are presented by Barber *et al*. (1994) and Hides (1994) the latter including a case in London.
- **Engagement:** Each of these will need to be supported by community engagement programmes, ideally delivered by independent stakeholders as opposed to the incumbent regime players. This will be necessary to demonstrate the need and promote the message requiring behavioural change. This engagement process will also be required to address cautious attitudes towards 'new' approaches that may be held by professionals and policy makers.

Medium term – It is unlikely that the incremental approaches presented above will be adequate alone and they will need to be supplemented over time. Additional provisions are also likely to be needed in response to changing climate conditions. The implementation of strategic SUDS components with a greater capacity may be necessary.

- **Semi-centralised 'soft' SUDS implementation:** Where there is space availability, it may be possible to implement 'soft' SUDS options into the existing built environment, to intercept road drainage or downspout flows. There are some examples of this type of implementation, such as the SEA streets in Seattle (Hinman, 2005), typically applied in urban scenarios where land is available within or close to the drainage area (DTI, 2006).
- **Integrated hard/soft SUDS approaches:** Where space is not available, or where such an approach may otherwise present opportunities, it may be more appropriate to implement 'hard' SUDS options or a combination of 'hard' and 'soft' options. This may involve for example the use of permeable paving, sub-surface storage, infiltration facilities or engineered treatment facilities. In the retrofit context, such an approach has been applied in the Chicago green alleys programme (CDOT, nd).

Long term – it is possible to imagine scenarios in which buildings have green roofs, the use of rainwater to replace mains water is maximised and stormwater management features on the surface using vegetated structures such as swales, ponds and wetlands are a common feature of the built environment e.g. as is now developing in Philadelphia (Smullen *et al*., 2008).

- **Green buildings & 'working around water' through urban replenishment:** Current/existing urban development is designed around the use of 'conventional' urban drainage. As a result, space for 'soft' SUDS is at a premium and options will be limited. For example, alternative roofs systems such as green roofs can only be retrofitted on roofs with the right pitch and load bearing capacity (although lightweight green roofs require much less alteration to roof structures). High levels of capital investment may be required to make this level of step change. But a commitment to change will, over time and through the process of urban replenishment, provide opportunities to ensure design takes account of water management, evolving to a position where this sits at the heart of urban design, equivalent to the 'water sensitive urban design' (WSUD) in Australia, e.g. Landcom (nd). This type of approach needs a strategic vision.
- **Sociological engagement and internalisation:** SUDS and associated 'source control'

techniques are fundamentally decentralised, and therefore fragmented, not just physically, but also in terms of the level of stakeholder engagement required and also levels of stakeholder responsibility. A sustainable future for surface water management will require organisations and individuals to take responsibility, but will also create new opportunities for service providers. Fundamental to this will be the need to change attitudes, which takes time.

Overall it is apparent that a multi-beneficial approach, especially relying on non-piped systems as more robust to climate change is believed to be the best way forward. Coupling surface water storage for example, with using the stored water for ground source heat pumps is feasible and being implemented (e.g. Coupe et al, 2010) as illustrated in Figure 3-9. This was a retrofit installation to address surface water flooding and which has provided 1kW of energy via ground heat pumps for every 15km^2 of new paving.

Figure 3-9: Permeable paving at Ground Work Trust - Derbyshire Head Quarters UK that collects the water for heating buildings

3.1.2 *Combined sewer separation*

Sewer separation here means the creation of an additional sewer network, specifically for stormwater. It may even need the creation of two new sewer networks as the original combined system may not be suitable to convey either the separated storm or sanitary sewage. Inevitably, separation will also mean that one or other of the new separated sewer systems will require pumping and there will be a considerable carbon footprint from this and also the operation process and construction of the new systems (e.g. Thames Water, 2010c).

For many years it was presumed that surface or stormwater runoff was 'clean' and that simply channelling it to a watercourse or similar receptor would be adequate. For this reason many separate sewer systems were constructed with outfalls to a river and separate outfalls conveying sanitary, industrial and commercial flows to treatment. It was around the 1950s that studies showed that pollution from storm sewer discharges were often as bad, if not worse than combined sewer overflows, depending on the nature of the land area drained (e.g. table 3-10).

table 3-10: Examples of pollutants in sanitary and stormwater flows (Engelhard & Rauch, 2008)

Flow condition	BOD_5 (mg/l)	COD (mg/l)	P_{total} (mg P/l)	N_{total} (mg N/l)	Cadmium (µg/l)	Copper (µg/l)	Zn (µg/l)
Dry weather flow							
Minimum	17	45	0.12	13.9	0.8	18	45
Median	178	403	4.5	34.2	2.0	58	232
maximum	503	1070	27.0	93.8	10.0	181	600
Stormwater flows							
Minimum	2	6	0.03	0.7	0.3	3	1
Median	13	81	0.42	2.4	2.3	48	275
maximum	162	551	11.58	8.8	37.0	1800	3563

Stormwater pollution was considered in depth in the EU 5th framework Daywater project (e.g. Thevenot, 2008) which reviewed the pollutants contained in stormwater runoff and related these to possible hazards in receiving waters and this may be used as a starting point for devising appropriate approaches to control these. This is especially important now in the EU due to the need to control priority pollutants[10]. The follow-on ScorePP[11] project has further developed the ideas: including looking at control at source of stormwater and the behaviour of priority substances at wastewater treatment plants. In this project the effectiveness of SUDS at dealing with priority pollutants was shown to be important, with different options removing different amounts of e.g. heavy metals as shown in Figure 3-10.

[10] The so-called priority hazardous susbtances and groundwater directives are daughter directives of the WFD (DIRECTIVE 2008/105/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council)

[11] http://www.scorepp.eu/index.php accessed 20/01/11

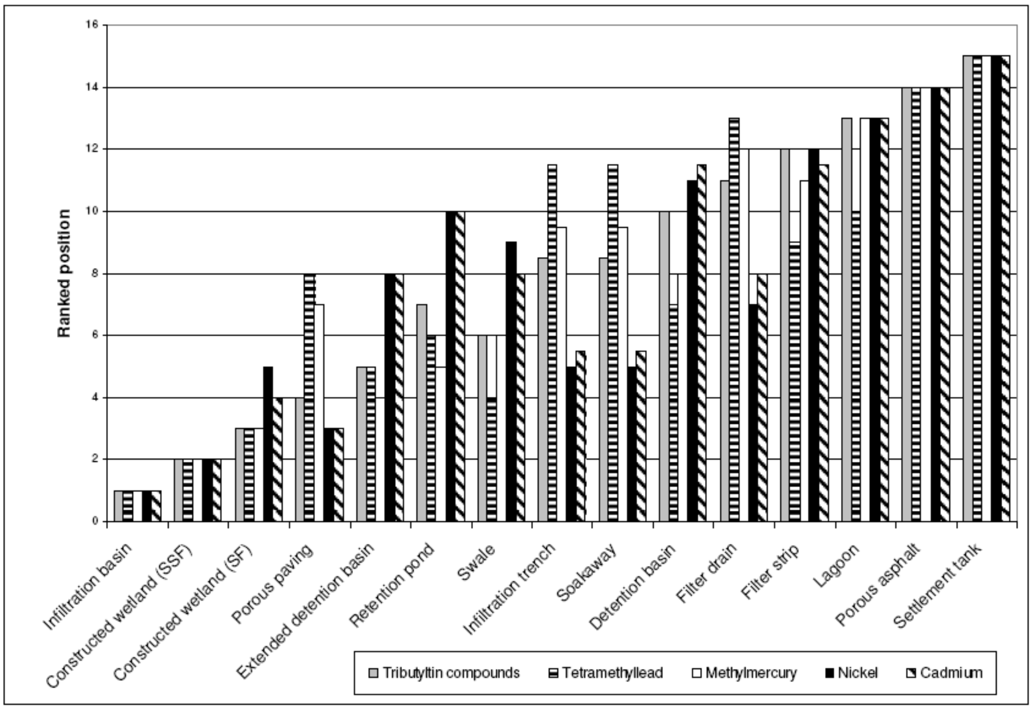

Figure 3-10: Relative effectiveness of certain SUDS in removing heavy metals (Scholes et al, 2008)

Nevertheless a UK study (Ross et al, 2004) suggests that it would be 'inappropriate to introduce additional control measures (e.g. stormwater treatment) based on the removal of priority hazardous substances alone'.

The Daywater project used the SEWSYS model (Ahlman, 2006) to identify the sources and flux of pollutants in surface water drainage systems then this was used to evaluate the relative benefits of separation of non-foul flows in combined sewers. In the NORIS project (Hurley et al, 2007) this model was also used to investigate the separation of combined sewerage systems and to consider the utilisation of proprietary inlet quality control systems at gully inlets to improve the inflow quality; Figure 3-11.

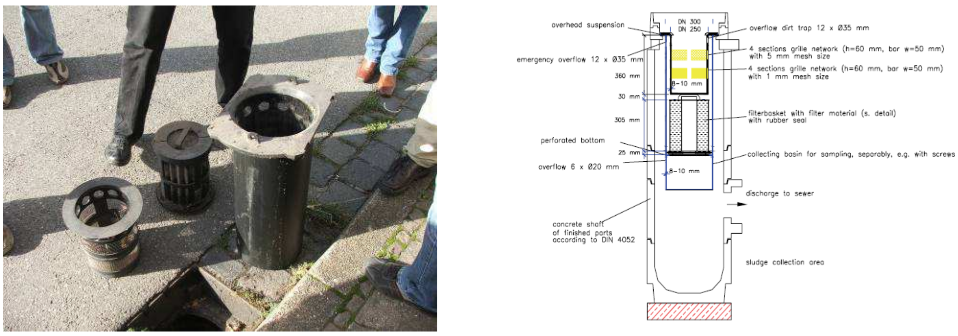

Figure 3-11: the Inolet gully insert filter system to improve runoff quality prior to entry into stormwater sewers (Sommer et al, 2007)

In the NORIS (No Rainwater in sewers) EU INTERREG IIIb programme project[12], a case study was conducted in the district of Linden in the city of

[12] http://www.noris-interreg.eu/ accessed 20/01/11

Hannover, Germany. SEWSYS source and flux simulations of the combined system that was currently being separated showed clearly that changing from a combined sewer system to a partly separated system reduced the pollution load of phosphorus (P) entering the receiving water.

Most P originated from sanitary wastewater. In the original combined system the CSOs were responsible for more than 10% of total discharge of P to the receiving water. In the partly separated system the discharges from CSOs were considerably reduced with only one or two overflow events per year and the stormwater from separated areas contributed less than 2% of the total P load. A reduced number of overflow events in the new partly separated system meant that more P could be treated in the WWTP at high treatment efficiency (about 90% in the SEWSYS model). Hence, the total load of P to the receiving water was reduced by some 9%.

The removal of nitrogen (N) in the WWTP was only about 50% of what comes in and therefore the reduction of total load to the receiving water in the new system was not as great as for P. The SEWSYS simulations showed that changing from a combined sewer system to a partly separated system actually *increased* the overall pollution load of stormwater related substances such as copper, zinc, lead, cadmium and PAH (polyaromatic hydrocarbons) going to the receiving watercourse. The heavy metals load increase ranged from 17 to 44% and for PAH the increase was 22%. It was shown therefore that there is a need to implement additional measures to reduce stormwater pollution in the Linden area and not simply allow direct discharges from the separate stormwater system. The SEWSYS approach of source based pollution analysis offered an opportunity to implement such measures where they are the most beneficial. The road surface contributed the greatest amount of copper, zinc and PAH in the Linden catchment. Therefore it made sense to implement pollution reduction measures for the road surfaces in the separated area using e.g. the Inolet filters.

In a parallel study in NORIS in Wieringerwerf (Holthaus et al, 2005), a small village in the Northern part of the Netherlands with 6000 inhabitants, achieved a 38% disconnection of stormwater from the combined sewer system. Extensive monitoring of the impacted receiving waters was undertaken as part of the NORIS project, following the actual disconnection, based on standards laid down in the WFD.

The Netherlands Ministry of Housing, Spatial planning and the Environment presented the “policy document rainwater and sewage” in June 2004. This document had four aims: preventing the pollution of rainwater, retaining and storing of rainwater, separating rainwater from sanitary flows during transport and integral consideration at a local level. The Dutch water policy for the 21st century aims at the retention, storage and transport of rainwater, which means that relatively clean rainwater will not be transported over large distances and will not subsequently be purified. The separation of rainwater from combined sewer systems is an important theme. Aims for the separation of rainwater were included in the Dutch Fourth Policy Plan of Water

Management (NW4). For the planned period (to 2006), with separation of 60% of the rainwater for new housing estates and 20% stormwater separation in existing urban areas (*ibid*). The Dutch government established a Maximum Permissible Concentration (MPC) for pollutants in surface waters.

The monitoring in Wieringerwerf after unstallation of separated drainage system revealed hardly any long term effects of stormwater runoff on diatom and macrofauna species communities as this depended largely on intrinsic ecosystem features (salinity, sediment structure, nutrient status). However, Wieringerwerf's diatom and macrofauna community was structured by specific intrinsic ecosystem drivers (N:P ratio) and the contribution of stormwater discharges was therefore difficult to detect. Short term effects were mainly attributed to increased dynamics in salinity and increase of metals (total and dissolved zinc and thus bio availability). The concentration of zinc in ponds after runoff exceeded the Maximum acceptable Concentration, indicating temporal acute potential risk for the aquatic species communities present. Quality was determined by chemical parameters and toxicity endpoints (e.g. mortality of crustaceans). The quality of the stormwater varied in time and space. Biological tests (bio assays) with stormwater, combined with sophisticated chemical assays (Toxicity Identification and Evaluation (TIE)) revealed an unexpected group of metals causing mortality for crustaceans: Metals specifically present in stuccoworks (e.g. cobalt, vanadium) were responsible for the observed mortality of the animals. The metals were eventually attributed to a local plasterer who rinsed and emptied his buckets in the stormwater inlets. This example shows the importance of clear communication with inhabitants regarding the quality of storm water run-off, and its environmental consequences when separation has been effected.

The use of SEWSYS in these studies helped reveal potential problems of the pollutant ranges modelled.

Another German study considered the possibility of developing general rules for the separation of combined sewers using a model similar to SEWSYS called KOSMO. From this three classes of substances were defined in terms of the relative change in pollution between combined and separated systems:

- Surface runoff substances with a high elimination rate in WWTPs, such as heavy metals and PAHs – separate sewerage leads to higher emissions as these substances are found in both surface water and flows to treatment
- Dry weather flow derived substances that have a low elimination rate in the WWTP – as these go only to the WWTP these substances are not relevant to stormwater management, although reduction of stormwater to treatment may enhance their removal rates
- Dry weather flow derived substances that have a high elimination rate in the WWTP – these substances are emitted more from combined systems than separate.

Elsewhere, technologies are being developed for the treatment of surface water, e.g. in Australia so that it can be used as a resource, Figure 3-12.

Figure 3-12: Modular filter units for treating storm drainage in Melbourne (can also be associated with street tree pits)

Due to water stress, recovery and use of rainwater as supplies is under detailed investigation in Melbourne and a range of techniques are being studied (e.g. Centre for Water Sensitive Cities, 2011[13]). These techniques can be used retrofitted in any catchment where there are CSO problems.

In conclusion, when considering separation of the storm and sanitary inputs to combined sewers, each individual situation (catchment) needs to be looked at specifically and locally in context and there are no general rules.

3.1.3 Providing increased storage by adding storage tanks

Storage may be provided in either the sewers or at or near the CSO in a tank. This is simply an increase in the internal volume available for the flow to build up. There are extensive sources of guidance for CSO improvements and adding storage e.g. US EPA14. A major selection of a storage related option – a new 7.7m diameter overflow sewer is illustrated in Figure 3-1, underway in London. This collects excess flows offline as shown and stores these temporarily in the tunnel from which it then pumps the water to treatment once the flow peak has subsided. Additional storage may also be provided at inlet works to treatment plants in the form of storm tanks. In some cases storage at CSOs can be increased simply by raising the overflow weir height, however, this may cause backing up in the sewer network and also increased sedimentation in the tank or CSO forebay area.

The UWWTD and other earlier standards related to aquatic habitats and bathing waters prompted a surge to retrofit storage in the 1000s of CSOs in Europe from the 1980s onwards (e.g. Defra, 2002). Much of this work was designed to reduce the spill frequency to only a few times in a year (e.g. 3 times in a bathing season) and to spill a reduced volume. The UWWTD also prompted the abandonment of many marine outfalls (both long and short) in a 'one-option-fits-all' approach that led to much more flow being treated than

[13] http://www.watersensitivecities.org.au/ accessed 20/01/11
[14] http://cfpub.epa.gov/npdes/cso/guidedocs.cfm?program_id=5 accessed 20-01-11

before. With attendant chemical dosing, this caused massive increases in energy use and hence environmental impacts on land (sludge) and to the air (greenhouse gases).

Three common philosophies for tank design have emerged:
- tanks that are designed to be self cleansing
- tanks that are designed specifically to retain sediments as a settlement tank
- tanks for the specific retention of the first flush

The type of tank in use is described in UK's Urban Pollution Management Manual (FWR, 1998): On-line tanks form an integral hydraulic component of the system. The tank consists of an enlarged section which fills when the inflow exceeds the maximum allowable through flow. Discharge from the tank is controlled by a throttle at the downstream end. A high level overflow should be provided to allow discharge of extreme flows.

Off-line tanks are physically separated from the main system. Flow only enters the tank under storm conditions when excess flow is diverted into the tank from the CSO diversion chamber. The stored flows may be returned to the system by gravity where the site allows, or by pumping.
Storage systems may be online, within the sewer, but acting as an enlargement (Figure 3-13, right) or offline (as shown in Figure 3-1) and may be at the CSO or remote (usually upstream). Figure 3-13 (right) shows an online retrofitted CSO chamber in the UK, illustrating the massive scale of some of these.

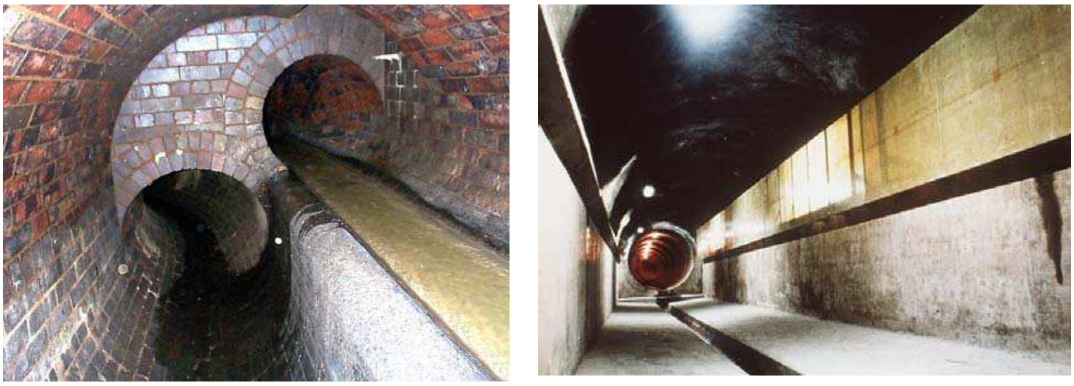

Figure 3-13: CSO chambers in the UK – on the left is a CSO without storage and one with storage is on the right

On-line and off-line tanks have different volume and flow control requirements. All other factors being equal, an off-line tank will need to have less volume to achieve comparable performance to an on-line tank. However, on-line tanks are less complex, with a single flow regulator being used to control both through flow and tank filling and emptying. Where a throttle is used it should be designed so as not to pass more than the maximum permissible continuation flow under any operating conditions.

Off-line tanks are more complex in operation, requiring separate flow regulators for regulating the continuation flow and the flow to the tank. Off-line tanks are also more susceptible to sedimentation problems than on-line tanks which convey continuous dry weather flow.

There are three basic types of tank: tank chambers; tank sewers and tank shafts:

- Tank chambers can be of variable form and are usually constructed from reinforced concrete. As a rule, the general arrangement of a tank chamber should be as simple as possible. However, layouts which use multiple chambers, especially when they are in series and involve complex systems of weirs and flap valves, may be used where spills are to particularly sensitive waters. The principal advantage of tank chambers over tank sewers is that large volumes may be contained in a relatively small area. Chambers can be used in both on-line and off-line configurations.
- Tank sewers are essentially oversized sewers designed to retain excess flows. They may be on-line or off-line. They can be circular, oval or rectangular in cross section.
- Tank shafts may be employed where the available area for construction is small, the ground conditions are unstable or a large differential head is available. Tank shafts are often relatively cheap to construct.

All detention tanks should be covered, except in special circumstances (e.g. within STW compounds), otherwise they present a health and safety hazard and release odours. They must be vented to allow air to be expelled during filling and, hence, prevent covers from being blown off.

Stored sewage is often held in a quiescent state in detention tanks and grit particles in the sewage will tend to settle out causing a build up of sediment. This can lead to a need for frequent automatic or manual cleaning after storms. Larger tanks may incorporate some form of agitator; for example, in the form of a series of propellers, to maintain solids in suspension during storage.

Detention tanks should be designed to be, as far as possible, self cleansing whilst in operation. The deposition of sediment can be minimised by appropriate design and the use of flushing devices to aid cleaning during, or following, drain down."

In the UK, various design guides (e.g. FWR, 1994) gave recommendations for the hydraulic design of four types of CSO chamber: the high side weir; stilling pond; vortex with peripheral spill and hydrodynamic separator. Equivalent guides were developed for other countries, including USA and Germany (DWA - A166 - Entwurf), although the UK was virtually unique in defining the need for screens on the CSO outlets to catch large organic, mainly floating, solids.

In addition, the many and diverse solids conveyed in combined sewers (Ashley et al, 2004) mean that any slowing of the flow in a storage area will inevitably result in solids deposition in the tank. Much work in the 1990s and since has been devoted to managing these solids. There are various flush devices and the Thames Tideway Tunnel plans to use gated systems to hold back water and then flush solids from the tunnels once the overflowed sewage has been pumped out.

Whilst providing increased CSO storage is attractive for reducing spill frequency and amounts, there is a limit to the value of increasing the storage volume. This is because the overall discharge of pollutants from the CSO overflow and the downstream WWTW may actually increase, although the flow peak and volumes may be reduced. There are also other problems due to odour and septicity of the stored sewage and other impacts in relation to the interaction with theWWTW downstream as illustrated in table 3-11. The table shows that adding excessive in-sewer storage can already cause problems and that climate change effects, assuming increased runoff flows and increases in temperature, may both exacerbate these problems and or mitigate them. Increased inflows diluting the combined sewage will tend to cause hydraulic overloading and possibly flushes of solids and pollutants. Whereas elevated temperatures will provide improved biomass performance and better removal of carbon, nitrogen and phosphorus.

table 3-11: Interactive effects of increased in-sewer storage volumes and downstream WWTW performance (adapted from Ashley et al, 2001)

Problem	Comments and effect of climate changes	Relationship to added in-sewer storage
Flushes of solids during DWF peaks.	Problem would only arise where WWTW is small and DWF peaking ratios are high. Could be a problem where additional catchments have been added after original construction of WWTW. Organic solids may be more fermented if temperatures increase	Not an in-sewer storage problem unless long retention times. In-sewer storage may attenuate this problem. Increased storage will allow more degradation of organic solids in elevated temperatures
Flushes of concentrated AmmN during DWF peaks	As above, but with climate change more nitrification would occur in sewer before getting to WWTW	As above
High hydraulic loading and or dilute inflows caused by infiltration during DWF	Infiltration endemic in most systems. Dilutes sewage and increases hydraulic load. No expected climate change effect other than possibly higher flows of stormwater and increased dilution.	Problem is mainly one of increasing hydraulic load at WWTW. Reactor may be adapted to weak sewage due to high infiltration. May be less resilient to higher concentrations during storms, with or without extended storage.
Wet weather Ammonia load flush	On rising stage of storms – dissolved pollutant peak precedes traditional foul flush. May be exacerbated by climate change or made less significant.	Displacement from primary settlement tank and possibly flows into storm tanks, followed by ammonia pulse into reactor. Provision of additional in-sewer storage likely to reduce this effect.

		Reactor very sensitive to elevation in temperatures during hotter periods.
Solids and related pollutant flushes and peak loadings	High hydraulic loading, potentially high pollutants may be made worse or better by elevated temperatures. In-sewer sediment erosion and re-erosion of deposits in tanks. But increased inter-storm dry periods may allow solids to consolidate. More solids and flows retained with modified CSOs. Ultimately solids discharged from WWTW will be less biodegradable than where they are discharged from the CSO.	Impact on inlet works and preliminary stages notable. High hydraulic loads to reactor and FST. Provision of additional in-sewer storage likely to reduce concentrations and loads early on in event (although these may be increased overall by greater retention). Increased amount of solids conveyed likely to increase sludge volumes although under climate change the reactor may be more efficient.
Prolonged peak hydraulic load overloading reactor and washing out biomass. Possible high/low strength.	High hydraulic load, but pollutants (and nutrients) possibly diluting. Although more intractable in-sewer sediments may still be eroding. Biodegradability poorer. Nitrogen removal affected by reduction in organic acids. Bio-P removal is affected by higher oxygen (anaerobic stage), redissolution of phosphates depends on the organic acids (lower in wet weather), and the process is affected by nitrates (higher in storms). Imbalance of P-release (recovers quickly with organic substrate) and P-uptake (slow to recover) can lead to increases in P in the final effluent at the end of a storm. Climate change may prolong the problem with higher flows.	Timing and nature of flow peak affected by in-sewer storage. Peak may be considerably prolonged (and have temporally variable biodegradable solids and nutrients). In-sewer storage will prolong period less degradable sewage enters WwTW and make this effect worse.
Draining down of storage with high/low strength.	Deposition of solids and associated pollutants in sewers and tanks. Initially strong, then weak sewage. May be problematic for nutrient removal.	As above, except hydraulic loading on WWTW reducing.
Re-establishment of DWF.	Establishment of 'normal' operation may take prolonged period and be even longer with climate change.	Extended in-sewer storage may prolong this period.
Low VFAs	High VFAs produced during septicity, otherwise bio-P removal requires chemical addition. Elevated temperatures may assist.	Increased retention times increase potential for VFA production and other readily biodegradable organics. Hence new storage may be beneficial if VFAs are generated.
H_2S & VFA production	Toxicity, odours, corrosion effects and potential sludge bulking/foaming problems which may be worse with elevated temperatures.	Extended in-sewer storage increases the risk that anaerobic conditions will occur. Requires moisture and contact with surfaces for corrosion and this will get worse with climate change.

The classic work by the Total Emissions study group (Durchschlag et al., 1991) was demonstrated in a number of German applications; e.g. Treatment of 2 x peak DWF, with sludge loading of 0.10kgBOD_5/kgTSS-day and a high in-sewer (CSO) storage volume (>20m^3/ha), the total load of COD discharged from the combined sewer system and WWTW outfall system as a whole was barely reduced based on results using the KOSIM model. For Nitrogen and Phosphorus excessive storage can lead to increases in emissions as illustrated in table 3-12.

table 3-12: total emissions from a wastewater system (adapted from Jack & Ashley, 2001)

BOD	0m^3 Storage	10,000m^3 Storage	Difference
Discharge – CSOs (kg)	3,834	1,899	-1935
Discharge - WWTP (kg)	4288	4,846	+558
Total Emissions (kg) (CSO + WWTP)	8122	6,745	-1377
Ammonia	0m^3 Storage	10,000m^3 Storage	Difference
Discharge – CSOs (kg)	396	308	-88
Discharge – WWTP (kg)	865	1,041	+176
Total Emissions (kg) (CSO + WTP)	1,261	1,349	+88

The second part of table 3-12 shows an increase in total discharges of ammonia when excessive storage is provided.

The problems of interactions can be summarised (Ashley et al, 2001):

- Conventional activated sludge systems may be prone to significant increases in both TSS and ammonia concentrations and loads due to the introduction of either medium or large storage. However, biological phosphorus removal (where applied) is likely to be improved for the scenarios with extended in-sewer storage. This improvement is a combination of dilution of phosphorus by the increased storage and the beneficial effects of VFAs when present in the sewage.
- The presence of VFAs may have a potential impact on effluent quality where there is large storage near the WWTW, and may also provide the potential for odours, H_2S and associated problems. However, VFAs are rapidly oxidised within aerobic lengths of the sewer, so that unless the storage is close to the WwTW the VFA production in the storage tanks has little effect on the VFAs in the crude sewage at the sewage works.
- The effect of low temperatures may exacerbate the usual loss of nitrification capacity following a storm, as the extended in-sewer storage drains down.
- Controls can be effective at alleviating the problems caused by extended in-sewer storage. Although Return Activated Sludge (RAS) rate control was found to be effective at reducing ammonia discharge, step-feed was found to be the most appropriate control option to alleviate the effects of extended in-sewer storage, despite potentially increasing suspended

solids ammonia in the final effluent. For most scenarios the increase in effluent solids, in the absence of step-feed, was a greater threat to meeting effluent consents than the rise in ammonia levels.

The above will be complicated by climate change effects especially as the bio-chemical processes are very dependent upon temperature.

In conclusion it is apparent that the introduction of additional in-sewer and CSO storage to alleviate CSO spill problems is not straightforward in terms of the relative impact on overall polluting discharges. Integrated modelling is required of the sewer network, CSO and WWTW using both single storm events (maxima) and also time-series rainfall. The sensitivity of the quality performance of the entire system to changes in parameters that will vary due to climate needs to be tested using models to determine the appropriate amount and location of any additional in-system storage. Although effective and accurate models for the quality performance of combined sewer systems do not yet exist (Schellart et al, 2010), there are still many studies reported that purport to provide useful information and on which designs of new storage systems are based.

3.1.4 *Treatment of flows before spill*

Screens are covered in 4.3 below but hydrodynamic separators are not included.

Hydrodynamic separators are used to remove solids from combined sewage in association with CSOs. These have been extensively studied for some two decades. For example, Brombach & Michelbach (1996) suggested that these may be effective at removing fine-medium solids and reduce the concentration of pollutants such as BOD, COD, etc between the inflow and the spilled flow components at CSOs. By inference the pollutant concentration of the continuation flow is increased, but a full understanding of the magnitude of this change and its subsequent impact on the system downstream are, as yet, not fully quantified for all geometries and sizes of the different designs of chamber.

Figure 3-14 illustrates a typical flow-through vortex separator (Andoh & Saul, 2003)

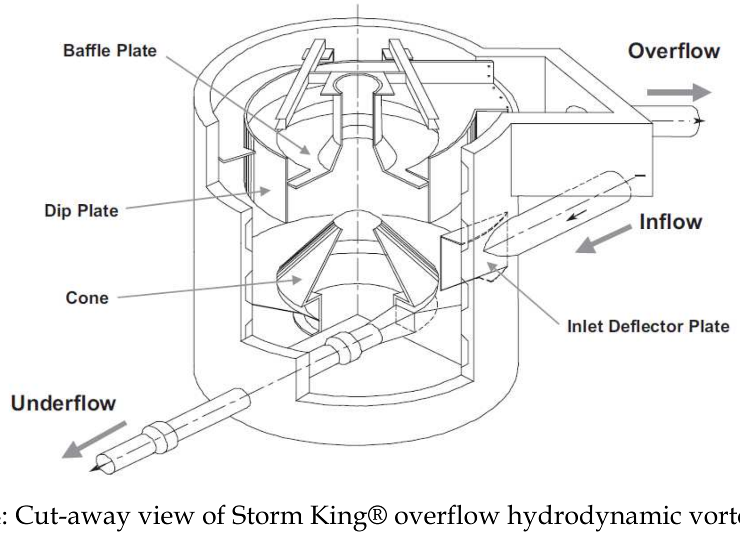

Figure 3-14: Cut-away view of Storm King® overflow hydrodynamic vortex separator HDVS (Hydro International)

The typical efficiency of suspended solids removal is shown in Figure 3-15. It illustrates that when the influent concentration is low, then the removal efficiency of these devices will also drop (day 56). Advances in CFD provide the means to enhance the effectiveness of these devices.

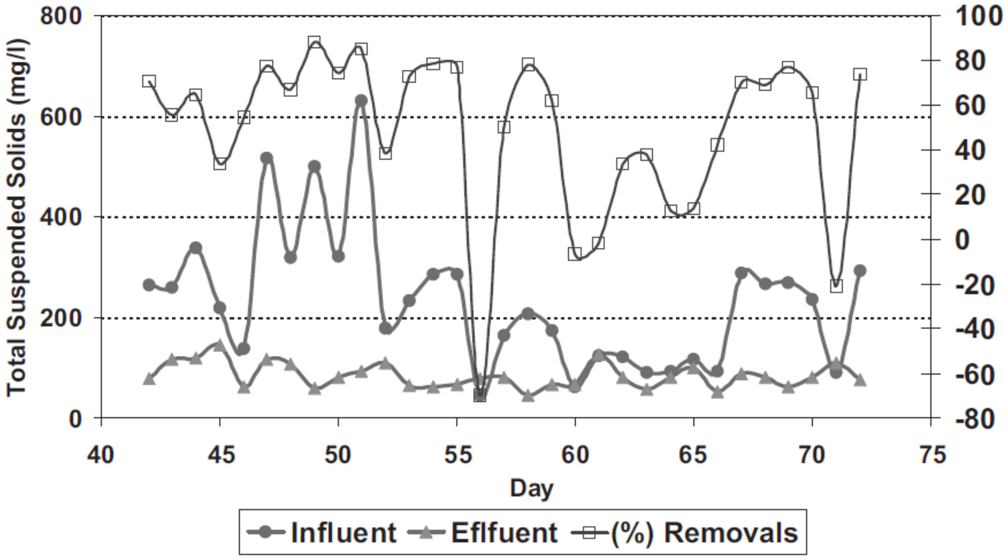

Figure 3-15: influent and effluent and % solids removal in an HDVS

3.1.5 Providing increased storage with RTC strategies

A more advanced approach, to handle volumes and control CSS and CSO, is the use of real time control systems.

When municipalities/utilities think to RTC, they should consider a range of possible solutions, starting from simple and potentially culminating in a "global predictive optimal" configuration. The real time control system is a method to collect data and to make operations depending on data acquisitions. It could be really simple, just showing the registered data and in this way leaving the operator deciding what to do, or more complex combining measurement and models and decision procedure.

A complex system would be the best choice, but the application of RTC can provide benefits just from the control of a single device (locally) or many elements throughout the system (globally). Full descriptions of the various levels of RTC are comprehensively described by Vallabhaneni et al. (WEF, Collection System 2010) and shown in the following picture (Figure 3-16).

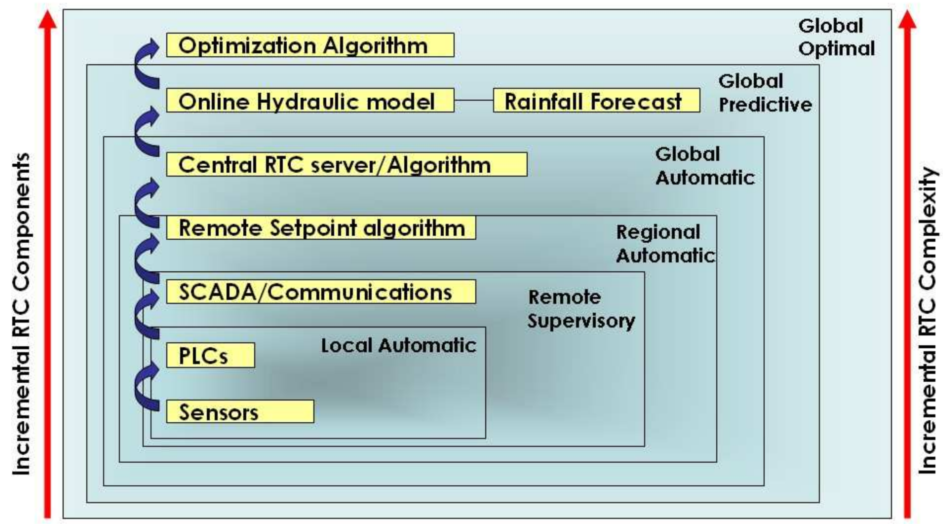

Figure 3-16: Levels of complexity and components in RTC application (Vallabhaneni et al., CDM 2010)

RTC system generally performs the following functions (USEPA, 2006):

- Collects information about the current state of the sewer network
- Compares the current state of the sewer network with the desired state of the sewer network
- Determines the settings for the control facilities that will bring the sewer network (closer) to the desired state
- Implements the settings into actions of the final control elements (e.g., gates, pumps, inflatable dams);

and can be used for different purposes, such as:

- Reducing or eliminating sewer backups and street flooding
- Reducing or eliminating sanitary sewer overflows (SSOs)
- Reducing or eliminating CSOs
- Managing/reducing energy consumption
- Avoiding excessive sediment deposition in the sewers
- Managing flows during a planned (anticipated) system disturbance (e.g., major construction)
- Managing flows during an un-planned (not anticipated) system disturbance, such as major equipment failure or security related incidents
- Managing the rate of flow arriving at the wastewater treatment plant.

For designing an RTC system, components, process equipment, instrumentation, SCADA, communications methodologies and local control devices have to be considered. Furthermore some suggestions on how to manage the project design is given in the following points (EPA/600/R-06/120, September, 2006).

Components

Either equipments (sensors, pumps, gates..) or/and software related to control actions and that may collect, process, or deliver data to other parts of the overall system are considered as RTC components.

All components are usually represented graphically as an architecture that links all parts of the system (see Figure 3-17).

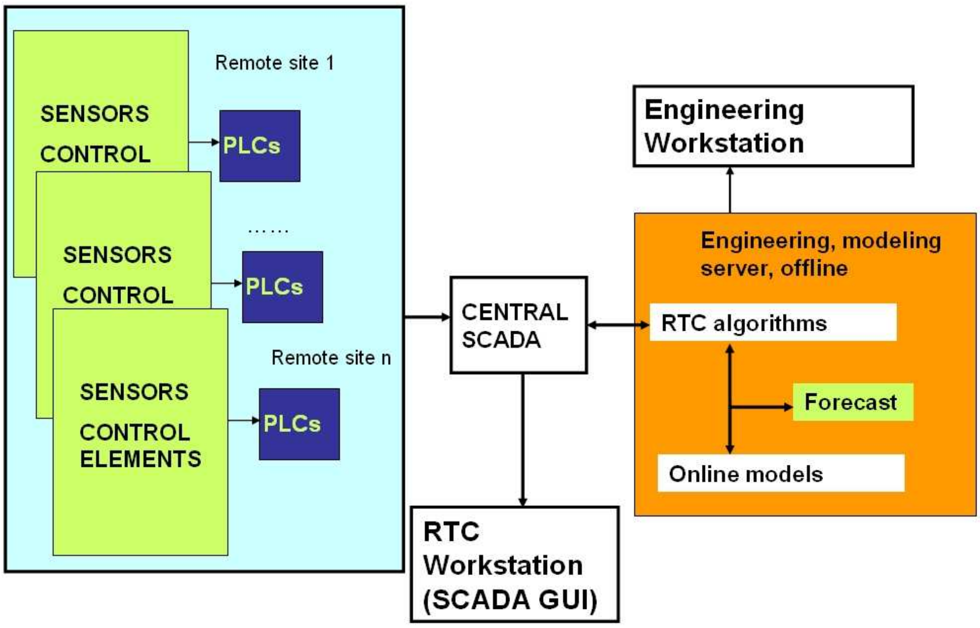

Figure 3-17: Example of RTC architecture and componentsfor a global rtc

In each remote site, a local processing unit (PLC) or a remote terminal unit (RTU) collects the signals (measurements) from the sensors and also provides outputs (control setpoints and signals) to the control elements (pumps, gates, etc.) PLCs are usually programmed to execute control of the facilities within their area. These PLC programs include setpoints that are defined locally (within each PLC) and are also capable of receiving a "remote" setpoint from the central server.

The information from the remote sites is collected through telemetry and delivered to a central location via SCADA system. Usually, the information that is collected from the field is displayed in "real-time" to the operator at the RTC workstation and stored in the central servers that may be located at the main control facility. The central SCADA system also provides "remote" setpoints to each remote site. The information stored in the main SCADA servers includes the current (real time) and past (archived) measurements from all the remote sites.

This information is normally used in the following ways:

- Operating staff make real time decisions based on the information that they receive online
- Engineers use the measured data to analyze system performance, develop computer models of the sewer system, and design new RTC algorithms
- The RTC algorithms are normally connected to the SCADA database; they retrieve the information about the status of the system, and provide the setpoints back to the SCADA system in real time.

Process equipment

Process equipment in a sewer system consists of gates, weirs, and pumps that serve as components in the broad category of diversion structures, commonly found in combined sewer systems where high flows may be experienced during storm events. These structures may contain movable elements and electrically operated equipment or sophisticated control systems associated with them.

While passive control structures, configured to split the flows in different ways, could not be considered as RTC, simulations and analyses of operational strategies often provide insight into how these passive structures could be adjusted for optimal effect. In an active diversion, flows can be affected by a control element such as sluice gates, movable weirs, pumping stations.

Instrumentation and monitoring of urban drainage networks

RTC systems typically require only a few types of basic measurements, such as *water levels* within pipes, manholes, and structures, as well as *flow rates* and *rainfall amounts*. Due to advers environment conditions of the urban drainage network (corrosive atmosphere, explosive atmosphere, high humidity, presence of oils and greases, organic waste, industrial wastes…), instrumentations have been designed to work in a corrosive and potentially explosive atmosphere with periodic submergence and in general, these sensors represent nowadays a mature technology with many thousands of installations providing reliable and accurate information.

Power is always required for instrumentation. For critical locations and measurements, a backup (or redundant) power source is desirable. If an instrument is to be used for RTC (not just for monitoring), requirements for reliability are higher and it is especially important to ensure uninterrupted operation.

Maintenance of instrumentation is key to its reliability. Experienced operators will monitor and periodically check the trends of signals coming from all of the key instruments.

When automation and RTC are introduced into the organization, organizational aspects of maintenance will come into play. It is important that the maintenance crews understand the RTC of the network, are familiar with maintenance issues specific to sewer networks (e.g., manhole access, traffic control) and also have proper experience with RTC equipment. For large systems, specialized maintenance crews can be a good approach.

Maintenance can also be improved by using Computerized Maintenance Management Systems (CMMS), software that helps operators manage the maintenance of the facilities and the equipment in the field

Hereby a list of more applied sensors is presented:

- *Level Sensor Technology* Various technologies have been successfully used for level measurement including mechanical, pressure transmitters, ultrasonic, and bubblers. The direct submerged pressure transmitters and two types of ultrasonic level technologies are the most often used.

- *Flow Sensor Technology* Continuous flow measurements are often critical to the control of an urban drainage network. Various technologies have been successfully used for flow measurement; however, flumes and area/velocity flow meters are most often used.
- *Rainfall Sensor Technology* Rainfall meters are used to measure precipitation. Historically, these measurements are used for calibration of hydrologic and hydraulic models. In RTC systems, these measurements can be used as part of a forecast of the affects of precipitation.
- *Rainfall Forecasting Technology* Precipitation forecasts are difficult to perform and avaluate. The factors that define a forecast include the forecast horizon and the intensity, duration, volume, spatial and temporal distribution within the storm, and possibility even the type of precipitation.

<u>Supervisory Control And Data Acquisition (SCADA)</u>

A SCADA system acquires process data from field instruments and final control elements and then presents that information to a centralized location where human operator can initiate supervisory control commands.

Over the years, microprocessor technology has evolved, becoming much more powerful and inexpensive such as the cost of digital memory.

Modern systems now employ RTUs or PLCs with more computing power and memory: in this way sophisticated RTC algorithms execute in the RTU itself. The central human operator is kept constantly apprised of the automatic controls being implemented by the remote units and can always assume remote, manual control. In certain instances, the system operator may be required to "approve" planned control actions prior to their being implemented remotely.

The fundamental purpose of a SCADA system is to communicate data and control commands from a centrally located operator to geographically dispersed remote locations. Electronic media are therefore required: telephone, fiber-optic cable, radio systems, cellular telephone, internet wireless system.

<u>Communications Methodologies</u>

The methodology employed by the SCADA system to exchange data between the master station and the RTUs can have a significant influence on the type of communications media to be used.

Common applied methodologies are:

- Master-slave
- Report-by-exception
- RTU cry-out
- Peer-to-peer communication

The most common methodology is referred to as "master-slave". In this scheme, the master station polls each RTU in a pre-determined, round robin fashion. In the simplest implementation, each RTU reports the current value of each input/output (I/O) point in its database and the master station transmits the required state of all control points.

In a more sophisticated scheme referred to as "report-by-exception," the RTU reports only those discrete points that have changed state and those analog points that have changed by more than an adjustable deadband. Likewise, the master transmits only those control points that have changed since the last RTU scan. Report-by-exception schemes reduce the amount of communications traffic, allowing the use of lower throughput communication media, but are more complex to program.
Another communications methodology which can be used to limit the amount of data transferred between the master station and RTU is referred to as "RTU cry-out". In this scheme, the RTU itself initiates communications to the master station when data changes beyond an adjustable deadband. This communications method requires sophisticated software to arbitrate when two or more RTUs cry-out at the same time; however, it can be very effective especially in mostly quiescent applications.
An additional system requirement that affects the choice of communications media is the need for peer-to-peer communications: for example, a remote pump station may be controlled by a tank level measured by another RTU. In these applications, both the communications media and methodology must be designed to allow communication between RTUs without the intervention of the master station.

Local Control Devices

There are two general categories of devices that can be used as local control devices: Programmable Logic Controllers (PLCs) and Remote Terminal Units (RTUs). The evolution of these two types of devices was distinctly different.
Recent advances in PLC design have eliminated their shortcomings in regard to continuous control applications. The International Electrotechnical Commission (IEC) has developed the IEC 1131-3 standard which defines five PLC programming language standards as follows:

- Ladder logic
- Sequential function chart
- Function block diagram
- Structured text
- Instruction list

Most modern PLCs support the full range of IEC 1131-3 languages allowing very sophisticated RTC applications to be developed. The choice between using PLCs or RTUs as local control devices is largely determined by preference. As recent advances in technology have blurred the line between an RTU and PLC, the term "RTU" will be used to indicate a generic field automation unit in the remainder of this section.

SCADA Design Considerations

The most varied and complex issues in designing a SCADA system are associated with the physical installation of the RTUs. By the very nature of wastewater collection and conveyance systems, the RTUs that are part of the SCADA system will most likely be installed in somewhat challenging environments. Design considerations for RTU installation include:

- equipment enclosures,

- environmental conditioning, and
- field interface wiring.

Equipment Enclosures
Remote site conditions associated with a wastewater SCADA system are typically not conducive to the electronic components that are part of the RTUs. In order to protect the RTU components and to extend their useful life, particular care must be given to the design of the RTU enclosures. Some institute (such as the National Electrical Manufacturers Association NEMA, in USA) have already defined a set of standards for equipment enclosures.
Environmental Conditioning
In addition to selecting the appropriate enclosure, it is important to ensure that the required environmental conditioning is provided for the RTU equipment. Temperature extremes, both heat and cold, have detrimental effects on the RTU's electronic equipment. The typical operating range for RTU components is 0 – 60°C. For installations in colder climates, subzero operating, thermostatically-controlled enclosure heaters are generally included as part of the RTU design requirements.
When RTU installations exhibit high ambient temperatures a simple sun shield is often sufficient to keep the cabinet temperatures within an acceptable range. For additional cooling, thermostatically-controlled cooling fans can be added to the RTU design. For the most extreme conditions, sealed-system air conditioning units can be utilized.
A document published by the National Fire Protection Association (NFPA) entitled NFPA-820 Standard for Fire Protection Measures in Wastewater Treatment and Collection Facilities, addresses the means of protection to be applied for electrical equipment installed in hazardous locations as defined by NFPA-70 National Electrical Code.
Field Interface Wiring
The field interface wiring associated with SCADA system RTUs represents a sizable portion of the overall system costs, either as initial costs and for maintaining the integrity of the wiring over the life of the SCADA system.
There are a number of design techniques which can be used to lower the life-cycle costs associated with field interface wiring:

- To employe comprehensive standard for wire labelling (ISA, ANSI…), it is critical that all interface wiring be clearly labeled with permanently affixed wire tags. It is a good practice to install wire tags on both ends of interface cables, especially long ones.
- To use separate, dedicated field termination panels. These panels can be installed in advance of the RTU enclosures. This practice allows the field interface wiring to be installed and tested while the SCADA system is still being developed in the factory and RTU enclosures can be installed once the system has passed factory testing.
- One technology that promises to simplify the issues associated with field interface wiring is "smart" process equipment and instruments. Instead of requiring individual interface cables for each signal, these devices utilize serial cables that can provide control and monitoring information about all signals associated with the device. Some protocols allow multiple devices to be multi-dropped on the same cable. There

are currently a number of smart instrument protocols, including HART, FieldBus, and ProfiBus. As this technology evolves and is applied on a more widespread basis, the costs and design considerations associated with field interface wiring will be simplified.

Other Design Considerations

Other non-technical considerations which can have a significant impact on the success of a SCADA system project include:

- system documentation requirements,
- training requirements, and
- system testing requirements.

System Documentation Requirements

System specifications typically define the appropriate levels of engineering, user, and technician documentation. The problem is that the delivery of system documentation usually occurs late in the project when everyone's attention is focused on getting the SCADA system installed and operational. One approach for addressing this issue is to require three distinct submittals for each required document:

- preliminary document, define the format of the manual and provide sufficient detail to review the basic outline and scope of the topics which will be addressed early in the project as soon as 90 days after notice to proceed
- draft document, generally complete (at least 90%) and should be clearly marked to indicate where all missing or incomplete information will be included required at 30 days prior to the start of factory testing
- final document, required before the start of field acceptance testing.

Training Requirements

Comprehensive training should be provided to system users on a number of different levels, including overview, user, engineer, system administrator, and maintenance. Overview training should be presented to all users to provide a basic introduction to the SCADA system but is especially important for utility management.

- User training should cover not only the basic operation of the SCADA system but should also address aspects of system operation specific to the particular application and a member of the client's staff will need to work with the system supplier in developing the training materials.
- Engineer training should cover the steps necessary to expand the SCADA system,
- System administrator training should address such tasks as tape backups and recovery, software upgrades, and maintenance of system files, such as operator log-in IDs and access rights.
- Maintenance training should focus on the steps necessary to troubleshoot system malfunctions. Typically, system hardware maintenance is limited to the PLC/RTU level. Most modern SCADA systems utilize standard, off-the-shelf computer components at the top-end level. Repair of this type of hardware is usually best left to the computer manufacturer. It is important for the owner's staff to be able to troubleshoot RTU and communication system problems and make repairs from system spare components.

System Testing Requirements
Four formal, witnessed tests should be conducted on the SCADA system:

- Factory Demonstration Test (FDT), should be a comprehensive demonstration of every functional aspect of the SCADA system. The contractor should develop a test procedure that clearly describes each individual test, including setup, simulation required, and expected results. The test procedure should be reviewed by the owner and engineer. The SCADA system should not be shipped to the project site for installation until there has been a successful completion of FDT. The FDT usually includes a list of functions that are checked off during the test.
- I/O Point Checkout should be witnessed by the owner and should be conducted on an RTU-by-RTU basis. After the contractor has completed installation of an RTU (including all associated instrument calibration), he should test every input and output point for proper operation. End-to-end testing should use the process graphic displays to verify proper operation of the I/O points all the way to the operator control console.
- Site Demonstration Test of the functions, software, and performance of the SCADA system should be conducted after all system elements have been installed and the I/O Point Checkout has been completed, to verify complete operation of the system.
- System Availability Demonstration, the owner should conduct a System Availability Demonstration test utilizing all equipment, software, and services of the SCADA system in normal day-to-day operations. During the test the system should be required to meet the availability criteria and performance requirements defined in the system specifications.

<u>Project Delivery Methods for SCADA</u>
The most common approach is referred to as design-bid-build. In this approach, the owner employs a design consultant to develop a set of bid documents that define the required functionality of the SCADA system. The owner then solicits proposals from qualified contractors. Some agencies use a selection process in which the contractor's proposal and approach are evaluated along with the proposed price. Once selected, the contractor has single source responsibility for the SCADA system implementation. Due to the specialized nature of SCADA projects, often a System Integrator (SI) will perform the work. A SI is a specialized contractor that implements SCADA systems. The SI can fulfill the role of General Contractor or Sub-Contractor depending on the scope of the project.
Modern SCADA systems utilize easy-to-use, intuitive tools for the development of the system database, graphical displays, control strategies, and reports. Many owners have begun to take advantage of this system flexibility by assigning the SCADA system configuration to a team of their internal resources and staff from the design consultant. This approach allows for much more flexibility during system implementation and provides significant hands-on training for the owner's staff, but can result in higher initial system costs.
An alternative project delivery approach is design-build. In this approach, the owner develops general functional requirements for the SCADA system; this

is often considered a 30% design. The project is then awarded to a team which has responsibility for system design and implementation. The design-build approach can sometimes result in a shorter overall project duration.

Data Validation, Filtration, Aggregation, and Storage
An RTC system usually gets most of its data from a SCADA system. However, there might be more than one SCADA system involved in an RTC system covering a sewer network and other sources of real-time data might be needed to run the RTC system properly. Further, if the RTC system is a part of a reporting and decision support system, then data from sources in addition to SCADA will be needed. Finally, SCADA systems are primarily designed to control production processes and are therefore often not flexible enough to cover the different tasks to be performed by an RTC system for sewer networks. An efficient and cost effective method to overcome these shortcomings is to use a data management and storage system as a part of the RTC system in order to carry out necessary tasks as:

- Data integration from different sources
- Data validation and filtration
- Data storage and aggregation
- Handling of identified events and scheduled tasks (automatic reporting)
- Hosting of the (model-based) RTC algorithm

The RTC system usually communicates with a SCADA on: measurements (levels, flows, gate positions….); status information (pumps and valves on/off….); counters (elapsed operation time for pumps….), etc.,
This information is read from the SCADA by the RTC system (typically once a minute). Data from other sources such as, radar weather systems, downstream wastewater treatment plants, remote monitoring stations, etc. can also be collected and included together with the SCADA data, and passed through the same information path.
The necessary data are transferred to the RTC algorithm after necessary signal conditioning (validation, filtration, aggregation, etc.). The RTC algorithm can be different for different scenarios, as different control strategies can be necessary to handle different situations. The chosen RTC algorithm provides the setpoints for the controllers that function within the individual control structures and facilities in the sewer system; setpoints are communicated through the SCADA system and control action is implemented at the final control element.

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4 Improvement of sewer system: CSO treatment

4.1 CSO treatment: description of problem

During periods of heavy rainfall the capacity of the Combined Sewer System may be exceeded, often causing untreated combined sewage and storm water to back up into basements and to overflow from manholes onto surface streets. To prevent the excessive combined flows from directly impacting public health via basement and street flooding, CSS outfalls were designed to discharge directly into receiving waters during heavy rainfall through Combined Sewer Overflows.

CSOs can contain untreated domestic, industrial, and commercial wastes, as well as storm water runoff and the population will be confronted with odour problems, visual pollution (toilet) paper, rubber, plastic foils, etc) and bacteria which can cause health risks and many receiving waters can exceed water quality standards.

The more intense and frequent rainfall events due to climate changes, have increased the potential pollutant impact of CSOs on the water environment.

4.2 Legislation

On 23 October 2000, the Directive 2000/60/EC of the European Parliament and of the Council (in short, the Water Framework Directive - WFD – was adopted. The aim of the WFD is to be the operational tool, setting the objectives for water protection for the future. The ecological quality status of water bodies is based on the status of biological, hydromorphological and physico-chemical quality elements (Borja, A. 2005). In 2008, the European commission presented a list of priority (hazardous) substances (Directive 2008/105/EC[15] of the European Parliament and of the Council), present in surface water (cadmium, mercury, lead, nickel, organochlorine compounds, pesticides, polycyclic aromatic hydrogencarbonic compounds, phosphor, nitrogen and endocrine disrupting substances). Among other substances, endocrine disrupting substances can cause a serious impact on natural waters and on human health. For this reason, in the next future, advanced treatment will be necessary to remove these substances from WWTP-effluents and CSO water (Scherremberg, S. M., 2006).

4.3 CSO Primary treatment techniques

During primary treatment a portion of suspended solids and organic matter are removed (Metcalf & Eddy, 2003). In this paragraph some of primary techniques are described.

4.3.1 Wetlands

Description Wetlands are generally vertical flow soil filters with a detention basin on top of the filter layer. A drainage system with pipes leads the filtrated CSO water to the outflow structure. A throttle in the outlet structure

[15] published in the OJ L348 on 24 December 2008, p. 84

controls the filtration rate and the detention time. Sand with a diameter 0-2 mm is recommended (Uhl, M., Dittmer, U., Fuchs, S., 2005), which should contain 10-15% of carbonate to enable long-term nitrification and retention of heavy metals. The vegetation on the filter is mostly reed (see Figure 4-1). This vegetation keeps the top layer of the filter bed permeable.
Realization examples see Figure 4-1.
Advantages The main processes in a wetland are reducing the peak flow, removal of suspended solids and removal of soluble and suspended pollutants. An advantage is that a wetland can fit perfectly into a rural area.
Limitations The filter bed can clog when the vegetation is not sufficiently enough developed. A disadvantage of wetlands is the large area that the filter requires.
References Uhl, M., Dittmer, U., Fuchs, S., 2005
Comments Additionally, a pre-treatment is necessary to minimize the chance that the filter bed clogs.

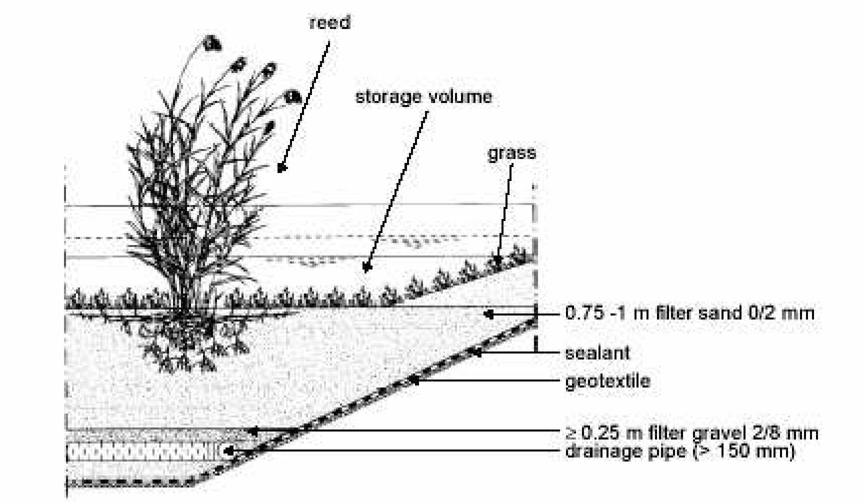

Figure 4-1 : Cross section of wetland

4.3.2 *Settling and storage tanks*

Storage tanks are built to provide extra storage in the sewer system (see also chapter 2).
Description It is a quantity control and can be used on-line or off-line. If a storage tank is filled and finally flows over, untreated water flows into the catchment area. Two different types of storage tanks are described (Krebs, P., Holzer, P., Huisman, J.L., Rauch, W. 1999): first flush occurring or not. If a first flush effect is expected, the tank needs to act as a storage tank. At the end of a storm event the tank is emptied by pumping the water back into the sewer system.
Advantages Advanced settling techniques can reduce the storage volume to one third of the original volume.
Limitations Building storage is expensive due to the large tanks which leads to high construction and material costs.
References Krebs, P., Holzer, P., Huisman, J.L., Rauch, W. 1999, David, L.M. and Matos, J.S., 2005

Comments If there is no first flush effect expected, the tank is used as a settling tank with a constant flow through the tank to the receiving water. In this way the suspended solids concentration in the overflow water will decrease by sedimentation. The flow velocities are low to provide optimal conditions for solids to settle. The hydraulic surface load must not exceed 10 $m^3/h/m^2$ and expected SS removals of 50-70% are highly uncertain (David, L.M. and Matos, J.S., 2005).

4.3.3 *Coarse screens*

Description Coarse screens (uniformly spaced bares) can be applied as primary treatment to prevent solids from entering the overflow pipe (Butler, D., Davies, J. W. 2000). Two types of coarse screens can be distinguished: horizontal reciprocal screens and tangential flow screens.

Realization example The horizontal reciprocal screen is made of narrow stainless bars. The screen is placed parallel to the flow direction.

Figure 4-2: Vertical mounted CSO screen type RSW, as retrofit in a existing stormwater treatment work, ROMAG AG - Combined Sewer Overflow Screens for Overflow Structures, Water-Technology.net

A horizontal screen can run continuously and cleaning takes place automatically during filtration or by hand after filtration.

A tangential flow screen contains a fine mesh cylindrical screen. Water comes in with a tangential direction, solids will swirl towards the centre where they are collected and water passes through the screen. In this way less particles will accumulate on the screen compared to the horizontal reciprocal screen (Metcalf & Eddy 2003).

Advantages Coarse screens prevent solids from entering the overflow pipe.

Limitations Disadvantages of coarse screens are the maintenance costs and the extra energy necessary for the automatic cleaning. In case electrical power is not available a disposable mesh sack can be used, but it requires to remove sack after every spill (Butler, D., Davies, J. W. 2000). Coarse screens have a mesh width of 25-50 mm (Metcalf & Eddy 2003) and can get clogged when the receiving water contains a large amount of floating material.

References Butler, D., Davies, J. W. 2000, Metcalf & Eddy 2003

4.3.4 *Sieving treatment*

Description the application of a sieve is useful to separate suspended solids from water and avoids solids from entering into the overflow pipe.

Realization examples The mesh width is smaller than 6 mm. A rotary drum sieve filter can be applied combined with a storage tank and an emergency overflow construction, as applied in Birkenfeld (Germany) (Bosman Water Management B.V. 2006). When the storage tank is filled the excess water will flow towards the sieve with a mesh width of 4 mm. When the headloss increases the sieve starts to rotate. A brush on top of the sieve is used to clean the sieve. Additionally, the sieve can also be cleaned with a backwash.
Figure 4-3 illustrates a rotary drum sieve. After a storm event the sieve chamber is emptied by gravity. The residual water will carry most of the accumulated material. In Denmark, research has been carried out by Andersen et al. (2005) with a rotary drum sieve followed by a disc sieve. The mesh width of the rotary drum sieve was 100 μm and 20μm for the disc sieve.
Advantages The removal efficiencies of SS were by the rotary drum sieve 50-80% and additionally 5-40% removal by the disc sieve.
Limitations automatic cleaning with brush and backwas is required to avoid clogging.
References Bosman Water Management B.V. 2006

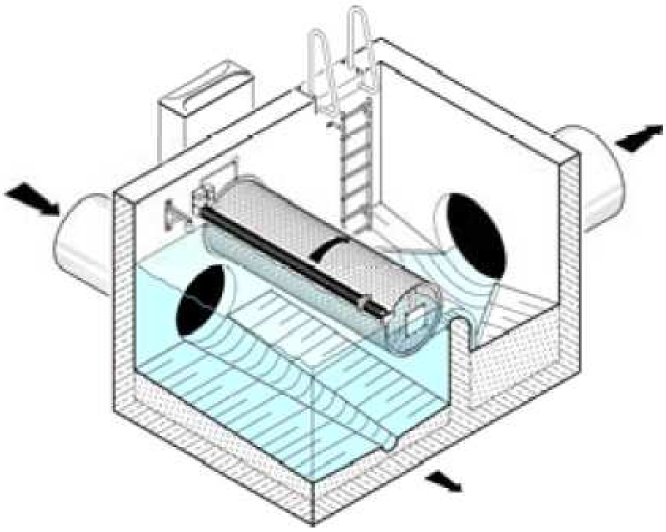

Figure 4-3: A rotary drum sieve
(Veolia)http://www.johnmeunier.com/lib/johnmeunier/9F8686vy0ZTfU5ngs521LED4.pdf

4.3.5 *Netting TrashTrap™ System*

Description The Netting TrashTrap™ System (EPA 832-F-99-037, September 1999) of Fresh Creek Technologies Inc. captures and removes trash and floatables from Stormwater and CSO discharges using the natural energy of the flow to trap trash, floatables and solids in disposable mesh nets.
Realization examples Four modular models have been developed to meet site-specific requirements:

- ✓ In-Line Netting TrashTrap®, a modular chamber containing the capture apparatus for holding the disposable nets, installed in-line with the outfall pipe, particularly well suited for densely populated locations.

- ✓ End-of-Pipe Netting TrashTrap®, installed at the end of the pipe. These units are often installed as a retrofit to an existing outfall structure.
- ✓ Floating Netting TrashTrap®, a pontoon structure floating at the end of the outfall.
- ✓ ChannelGuard™ System, a modular structure configured for one or more nets based on site parameters and installed within the outfall channel walls. The system is serviced with a crane truck reaching into the top of the system. No confined-space entry is required during routine servicing since the nets are lifted from the channel when performing the net change out.

The netting mesh size opening is available from 5mm up to 625mm. The standard nets (Fresh Creek Technologies Inc.), are designed to hold up 0.7 m^3 of floatables and a weight of 227 kg (EPA 832-F-99-037, September 1999). Flow velocities above 2m/s require special, more expensive, high velocity nets (EPA 832-F-99-037, September 1999).

Advantages The removal efficiencies for floatables measured at several sites in the USA are between 93-97% (EPA 832-F-99-037, September 1999). The netting TrashTrap™ system has no moving parts and no complicated cleaning procedure (Fisher, R., 2002). The life expectancy of the netting TrashTrap™ system is about 20 years.
Limitations The nets need to be replaced regularly to prevent odour annoyance to the surroundings and visual pollution.
References EPA 832-F-99-037, September 1999, EPA 832-F99-008 September 1999
Comments Typical construction and installation costs for range from € 20.000 to € 120.000. O&M costs are estimated at € 800 per year (EPA 832-F99-008 September 1999).

4.4 CSO Secondary treatment techniques

Secondary or advanced treatment is the enhanced removal of suspended solids and organic matter from wastewater. Techniques like activated carbon, membrane filtration and rapid sand filtration have proven to work for WWTP-effluent. For the treatment of CSO water these techniques are not yet feasible. Thus innovations and new solutions are needed.

4.4.1 Lamella plate clarification

Description Lamella plate clarification is a form of advanced settling combined with storage, widely applied in the wastewater industry. The process is mostly combined with dosage of coagulant or polymer to bind particles but it will also work without any chemicals. In a lamella clarifier solids settle at the lamella and will fall down into a sludge basin from where it can be pumped away.
Realization examples Research in Brunoy and Vigneux (France) (Daligault, A., Meaudre, D., Arnault, D., Duc, V., Bardin, N., Aires, N., Biau, D., Schmid,

J., Clement, P., Viau, J. –Y., 1999)0 has shown the mean removal efficiency for suspended solids of 54% and the removal range for Brunoy was 0-90% and for Vigneux 0%-60%. During the test period high removal rates were reached when the amount of suspended solids in the influent exceeded 300mg/l.

Advantages can work with or without chemicals retention time and footprint are 1/3-1/4 of settling tank; it can be placed in already existing storage tank; concentrated sludge 3%.

Limitations requires grit removal and fine screens; three stage of flocculation enhance floc formation; low overflow rates, longer retention time; peak efficiency reached after 120 min; plugging between lamella plates.

References Daligault, A., Meaudre, D., Arnault, D., Duc, V., Bardin, N., Aires, N., Biau, D., Schmid, J., Clement, P., Viau, J. –Y., 1999; Norwalk Water Pollution Control Authority http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf

4.4.2 *Chemically enhanced high rate sedimentation*

Chemically enhanced high-rate sedimentation is applied in two commercial technologies, the Actiflo® (Veolia Water) and the DensaDeg® (Ondeo Degremont). The main advantage of these techniques is the very high rate of treatment, which allows a relatively small footprint. The high coagulant and coagulant aid dosages make high pollutant removal rates possible.

Actiflo®

Description The Actiflo® method (Plum, V., Dahl, C.P., Bentsen, l., Petersen, C.R., Napstjert, L., Thomsen, N.B., 1998) (Marsalek, J., 2005) is a very compact and prefabricated physico-chemical treatment, the system footprint is between 5 and 20 times smaller than the footprint of conventional clarification systems of similar capacity (Krüger, 2005). Algaes, SS, BOD, COD and phosphorus will be removed.

Realization examples The process scheme of an Actiflo® is presented in Figure 4-4. First the wastewater is finely screened and degritted. Secondly metal salt is dosed into the water. After rapid mixing microflocs are formed. These flocs will bind ortho-phosphate (PO_4). In the injection mixing tank polymer is dosed, which will form larger flocs in the flocculation tank where also the microsand is added to the water. The microsand will incorporate into the flocs, which makes the flocs heavy and they can easily be removed by sedimentation. After this stage the water enters the settling zone with lamella. The sludge is treated with a hydrocyclone, the residual water together with the microsand is returned to the injection mixing tank. The Actiflo® is not sensitive for influent concentration fluctuations and shows limited sensitivity to hydraulic peak loads (Plum, V., Dahl, C.P., Bentsen, l., Petersen, C.R., Napstjert, L., Thomsen, N.B., 1998). The Actiflo® system can be expanded with a mixed media filtration. The mixed media filter uses a minimum of three granular materials of different sizes and specific gravity. The coarse material is at the top of the filter and becomes finer towards the bottom. After backwash stratification takes place. The water flows in downflow direction trough the filter bed. Because of the fine particles and pore sizes the filter bed is able to remove Cryptosporidium and Giardia lamblia (Krüger, 2005). Under the mixed filter bed is a direct media retaining underdrain placed. This drain is made of several prefabricated blocks of plastic with a stainless steel top. These blocks are necessary for the support of the gravel, for the distribution of the backwash water and to distribute the air evenly over the filter bed Krüger, (2005).

Advantages

The Actiflo® was compared with DensaDeg® and showed the following advantages(Norwalk Water Pollution Control Authority, http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf):

- pilot tests indicate a more stable operation than DensaDeg®. Other advantages are the application of microsand as ballast ,
- avoids concern w/ water chemistry
- shorter retention time than DensaDeg
- requires less coagulant and polymer to achieve the same removal rates than the DensaDeg units
- can handle a wider range of operating and influent conditions than the DensaDeg units.

Limitations the retention time in the installation is about 10 minutes (David, L.M. and Matos, J.S., 2005); Grit removal and fine screening (8mm) to avoid hydrocyclon clogging; Maintenance of hydrocyclone; Sludge concentration 0.3%; Difficult to dispose of thin sludge; Produces a higher volume of sludge; Tanks require water when not in service; Requires odor control; Dealing with sand can be difficult.

References Plum, V., Dahl, C.P., Bentsen, l., Petersen, C.R., Napstjert, L., Thomsen, N.B., 1998; Marsalek, J., 2005; Krüger, 2005; Plum, V., Dahl, C.P., Bentsen, l., Petersen, C.R., Napstjert, L., Thomsen, N.B., 1998; David, L.M. and Matos, J.S., 2005; Norwalk Water Pollution Control Authority http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf

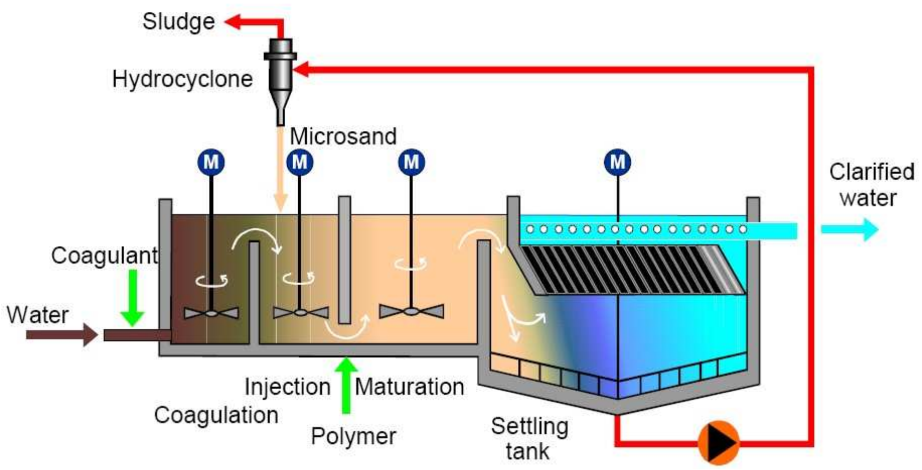

Figure 4-4: Actiflo® process (Krüger, 2005)

<u>DensaDeg®</u>

Description Two types of the DensaDeg® were designed, the DensaDeg® and the DensaDeg® 4D. The DensaDeg® 4D was especially designed for high rate clarification at CSOs and for sanitary sewer overflows (SSO). This system combines four functions in one process: grit removal, grease and oil removal, clarification and sludge thickening.

Advantages Advantages of the DensaDeg® 4D (Ondeo Degremont)
Small footprint; High removal efficiency (grit and grease removal); Automatic control of start up; Low effluent values for SS, COD and BOD5; solids removal efficiencies typically greater than 85%; sludge as ballast; concentrated sludge 3-8%; tanks do not require water when not in service.

Limitations Pre-screening required; Requires sludge blanket buildup, lag time; Dry start up results in poor performance; Highly polluted first flush

References Norwalk Water Pollution Control Authority
http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf

4.4.3 Dissolved air floatation (DAF) system

Description In DAF systems, air at a pressure of several atmospheres dissolves in the CSO water and is later released under atmospheric pressure. During the pressure phase, released air bubbles attach to suspended solids and take the solids to the water surface where they are removed. The advantage of the DAF system over a settling tank is that small particles, which slowly settle, can be removed more completely and in a shorter time0. The DAF system can also be applied in combination with chemical addition.

Realization examples The design criteria for a DAF system depend largely on the type of surface of the particulate matter. To ensure high yields, laboratory tests and pilot tests are necessary. The performance of the DAF system depends on the ratio of the volume of air to the mass of solids required to the degree of clarification. The hydraulic loading rate is between 3-10 m/h and the theoretical retention time is 20-40 minutes (Lenntech Water treatment & air purification Holding B.V.)

According to bench scale testing by 0a DAF system alone obtained removal efficiencies for suspended solids of 90% and combined with chemical addition a removal efficiency of 99%. A research 0application of coagulation/flocculation with an anionic polymer, a DAF system followed by sand filtration and UV disinfection Results showed that the influent concentrations of TSS (Total Suspended solids) do not affect the effluent. Removal efficiencies for TSS obtained by the DAF system can exceed 90%. The efficiency of the DAF system reached its maximum level in the first minutes of operation, which is very important because the installation has to be able to work intermittently. Together with the removal of TSS, also pollutants attached to the TSS are removed. This resulted in removal efficiencies of 80% - 90% for BOD5, phosphorus and metals. The combination of these processes led to very high overall removal efficiencies, to physico-chemical pollution removal and microbiological disinfection, regardless the ingoing concentrations.

Advantages System can adapt well to wet weather flow; Maximal efficiency reached after 1 min; Little sensitivity to influent pollutant loading; Filtration increase UV transmittance to 50 %.

Limitations High maintenance compared with lamella; Efficiency depends on type of particulate matter; Large footprint

References Lenntech Water treatment & air purification Holding B.V.
Norwalk Water Pollution Control Authority
http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf

4.4.4 High rate synthetic media filtration

Description Synthetic medium filtration can be used as a polishing step after physical separation technologies like a vortex separator or sedimentation. The influent of the filter has to be clear of heavy solids and coarse floatable materials. The configuration can be downflow or upflow.

Realization examples Fuzzy Filter® is a synthetic medium filtration. A Fuzzy Filter® removes particles with diameter of 5-80 micron and have some advantages compared to a sandfilter, namely (Schreiber LLC):

- ✓ high filtration rates with flow rates up to 90m/h, for rapid sand filtration flow rates are between 5-20m/h;
- ✓ low backwash waterflow;
- ✓ no loss of filter medium, the filter medium is obtained between two perforated plates;
- ✓ completely enclosed filter unit;
- ✓ low operation costs;
- ✓ Large storage capacity in the filter bed.

The water passes the filter medium for partical removal. This filter medium consists of polyvinyllidene balls which are highly porous (85%). The porosity of the medium can be modified by compressing the filter. This means that during a first flush the medium can be compressed a little to prevent clogging and when diluted water enters the filter the medium can be compressed more to remove smaller particles. When the filter is compressed, the top layer of the filter medium is more compressed than the lower part. As a result of this, the larger particles will be removed immediately at the bottom of the filter and the top layer will remove the smaller particles. The cleaning frequency depends on the feedwater quality. A cleaning procedure takes about 10 minutes.

The Columbus Water Works of Columbus, Georgia in the USA tested the Fuzzy Filter® for the control of CSOs. The Fuzzy Filter® treated effluent from vortex separators. The filter medium was slightly compressed and the configuration was downflow. The loading rates varied between 40-68m/h. Fine particulate matter with diameter of 10-20 micron was removed. The pollutant removal rates for total suspended solids were 70%, for oil and grease 80%, for phosphorous 60% and for heavy metals 50-70%. A correlation between total suspended solids removal per unit volume of the filter medium was found, as well as a relation between the headloss across the filter medium with the volume of the filter medium.

Advantages High filtration rates with flow rates up to 90m/h, for rapid sand filtration flow rates are between 5-20m/h; Low backwash waterflow; No loss of filter medium; Completely enclosed filter unit; Low operation costs; Large storage capacity in the filter bed.

Limitations Pre-treatment is needed (i.e. vortex separator)

References http://www.schreiberwater.com/CSO.shtml; Norwalk Water Pollution Control Authority http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf

4.4.5 *Membrane filtration*

Description During membrane filtration a semi permeable membrane divides two phases. The permeability of the membrane depends on the pore size and on the particle size. The inflow of the membrane is called feedwater, the water which passes the membrane is called permeate water and the part which is resisted is called the concentrate. The driving force for membrane filtration is the pressure difference between the feedwater and the permeate, called the Trans Membrane Pressure (TMP). The membranes need to be cleaned when the TMP is too high. This cleaning can be done by a back-flush or a forward-flush. After a certain period of time, which depends on the fouling capacity of the feedwater, the membranes need to be cleaned with chemicals.

Most of the membranes are made of polymers or macro molecules and are available in many different types. The most important parameters on which the membrane type depends, are the size and the origin of the particles. Using membrane filtration for the treatment of raw sewage water, typical limitations of biological processes0, like influence of temperature, feed stability, toxicity and start up period, are avoided. In the next paragraphs microfiltration and ultrafiltration will be described.

Realization examples

<u>Microfiltration (MF)</u>

The specific pore size for microfiltration (MF) is 0.08 to 10μm but the range 0.1-0.4μm is mostly used.The advantage of these large pore sizes is that the TMP can be relatively low, namely 0.3 to 3 bar. MF membranes are available as plate, capillary and tube. Lab scale experiments with microfiltration have been done to determine the membrane pore size capable of reducing bacteria to negligible levels.

Primary sewage effluent from Allegheny County Sanitary Authority, Pittsburgh in the USA was used to simulate CSO water. Primary sewage effluent contains less suspended solids but it contains bacteria levels, which can also be expected in CSO water. For the experiments Membralox Tl-70 Alpha membranes with pore sizes of 0.2μm, 0.8μm, 2.0μm and 5.0μm were used. These membranes are ceramic, tubular microfiltration membranes. Membranes with a pore size of 0.2μm produced a slightly greater permeate flux than the 0.8μm membranes. This behaviour is believed to occur due to severe internal fouling. The 0.2μm membrane appears to be a barrier to Faecal Coliforms, Escherichia Coli and Enterococci, while the 0.8μm membrane shows breakthrough of bacteria.

<u>Ultrafiltration(UF)</u>

The pore size of ultrafiltration (UF) membranes is in the range of 1,5 to 100 nm .The TMP is between 0.3 and 7 bar. Dissolved salts and smaller molecules can pass the membrane. Suspended solids, bacteria and viruses are retained. When dealing with raw wastewater the feed first passes a simple mechanical pretreatment and is then filtrated directly on a membrane. The UF membranes separate the undesired compounds of the water. BOD, P and N

are not removed, thus the permeate contains a large amount of nutrients which makes reuse for irrigation an option. The low turbidity (<1 NTU) and the absence of particles make it possible to produce high quality water of the permeate. Odours and organic compounds are not removed with UF. The concentrate contains a large amount of bacteria and micro organisms.
A disadvantage of this system is the fouling of membranes. The advantages of membrane filtration are that the process can work discontinuously and that a high automation and remote control can be implemented. These advantages and the quality of the permeate make direct UF useful for CSO treatment.

Advantages for MF Advanced removal of SS is possible
For UF more advanced removal of SS compared with MF.
Limitations Fine sieving necessary to prevent clogging, Netting Trash Trap™ as pretreatment; Chemicals are needed to clean regularly the membrane
References Scherremberg, S. M., (2006), Norwalk Water Pollution Control Authority http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf

4.5 CSO Adsorption techniques

Adsorption techniques are used to remove dissolved pollution, for example heavy metals. In this chapter activated carbon and zeolites will be described.

4.5.1 Activated Carbon Filtration

Description Activated carbon is used for the removal of organic compounds and some inorganic compounds like nitrogen, sulphides, heavy metals and endocrine disrupting substances. Most of the organic molecules are retained at the surface of the activated carbon.
Realization examples Activated carbon can be applied in a Granular Activated Carbon (GAC) filter, by inline addition of Powdered Activated Carbon (PAC) or in a continuous moving bed adsorption (MBA). When using activated carbon for the polishing of WWTP effluent, GAC is mostly used (Metcalf & Eddy, 2003). The GAC has a diameter of 0.25-3mm and is placed in a fixed bed.
After a certain period of time, which depends on the polarity of the removed compound, the filter will break through. At this moment the GAC needs to be regenerated and reactivated. This regeneration and reactivation is done at high temperatures in combination with oxidizing gases0
Advantages Remove organic micro pollutants, heavy metals, sulphides and nitrogen; small footprint; 2 min of start up.
Limitations The filter bed can get clogged when suspended solids enter the system; so good pretreatment, removing SS, is necessary. Larger organic compounds, like humic acids, can block pores of the activated carbon. As a result of this blockage the smaller organic micropollutants cannot adsorb on the activated carbon anymore. Regeneration of activated carbon requires high cost.
References Metcalf & Eddy, 2003, Scherremberg, S. M., 2006.

4.5.2 *Zeolite*

Description Zeolite is a natural occurring ion exchange material, which is used in CSO case for the removal of ammonium. For the removal of ammonium a naturally occurring cationic inorganic zeolite clinoptilolite or a synthetic zeolite can be applied.

Realization examples Natural and synthetic zeolites have the same features: that are a high level of ion exchange capacity, adsorption, porous structure, molecular sieve and a low density. Because of a longer lifetime, the synthetic zeolite is mostly applied. The efficiency of cationic ion exchange depends on the temperature, the pH, the contact time, the concentration of the cation in solution and the structural characteristics of zeolite0.

Clinoptilolite is the most abundant natural zeolite. It naturally contains the cations calcium (Ca), potassium (K) and sodium (Na) and removes besides ammonium, heavy metals and organic substances.

The ions removed by zeolites, are ammonium (NH_4^+) and nitrate (NO_3^-). The regeneration of the zeolite is done with lime. The ammonium ions, which are removed from the zeolite, are converted to ammonia, which is stripped in a later stage. In this system extra care should be taken to prevent calcium carbonate precipitation in the pipelines, the stripping tower or in the zeolite ion exchange bed. The treatment process can be operated in batch or in continuous mode. When using a batch process a mixed tank is applied. In the tank the zeolite is mixed with the water. When the reaction is complete, the zeolite is separated from the water, regenerated and reused.

Packed bed columns are used in continuous mode, usually with downflow system. The regeneration is done by backwashing with a regeneration solution. SS have a negative effect on the process. Often multimedia filtration (sand and anthracite) is applied as a pre-treatment step. When the concentration in organic substances is high, an extra pre-treatment is needed. For the design of a column one of the most important parameters is flow rate.

Advantages Remove ammonia and heavy metals; smaller footprint than AC.

Limitations The filter needs to be backwashed regularly. Synthetic zeolites have two problems0: 1. the resin has a higher affinity for sulphate than for nitrate and when sulphate is in water it limits the removal capacity of nitrate; 2. nitrate dumping can occur.

References Metcalf & Eddy, 2003, Scherremberg, S. M., 2006.

4.6 CSO Disinfection techniques

Description Sewage water contains a large amount of bacteria and pathogenic micro organisms, which can be dangerous for public health. To reduce the chances of diseases, the wastewater should be disinfected especially when the water is discharged near recreation places.

Realization examples Disinfection is the process of destructing or inactivating pathogens by oxidation or radiation. For oxidation of pathogens chlorine has been commonly applied in the past, but this technology may not be feasible at all CSOs for the following reasons:

- ✓ intermediate and highly variable flow rate;
- ✓ high SS concentration;
- ✓ variation in temperature;
- ✓ variation in bacteriological composition;

- ✓ chlorine can be prohibited in the receiving water;
- ✓ CSOs are often located in remote areas, this requires automated systems.

Because chlorine disinfection may not work in all situations new techniques were developed, such as ultraviolet (UV) radiation and ozonation.
To have a good disinfection with UV treatment, pre-treatment with a reduction of SS to 40-80 mg/l is needed. Ozone is very poisoning and can already be explosive in a mixture with air from 10% and higher. This is a major disadvantage because it brings an enormous risk for the surroundings when built in an urban area.
Chlorine is very frequently applied for disinfection of water. A disadvantage is that chlorine is not effective at low dosing rates and carcinogenic by-products can form. Chlorine has the advantages that it also decreases BOD and ammonia concentrations and that it is more cost effective compared to other disinfection methods.
Advantages UV start up occurs within a minute and non chemicals addition is required.
Chlorine is cost effective and provides a good BOD and ammonia reduction.
Limitations UV Not efficient for rapid changes in flow; Lamps foul rapidly.
Ozone Poisoning and explosion risk
Chlorine Not effective at low dosing rates; Its product can form carcinogenic by-products**.**
References Metcalf & Eddy, 2003, Scherremberg, S. M., 2006.

4.7 CSO treatment: advantages and limitations resume

Analysed CSO treatment techniques are resumed in the following table0 (Norwalk Water Pollution Control Authority http://www.wpcanorwalk.org/wp-content/uploads/2010/03/Appendix-G-Matrix.pdf)

table 4-1: summary of analysed CSO treatment techniques and evaluations.

Measure	Technique	Advantages	Limitations
Primary treatment techniques	Wetland	PERFECT FOR RURAL AREA	LARGE FOOTPRINT FLOW RATE < 0.15 M3/MS
	Settling and storage tanks	IF ALREADY BUILT, COULD BE USED FOR PRE-TREATMENT OR FOR LAMELLA PLACEMENT	WFD NOT FULFILLED LARGE FOOTPRINT EXPENSIVE TO BUILT
	Screening, sieving system	ROBUST SYSTEM REMOVING LARGE POLLUTANTS	REGULAR CHECKS TO PREVENT CLOGGING OR AUTOMATIC CLEANING SYSTEM
	Netting TrashTrapTM	NOT EXPENSIVE FOR REDUCING	NETS HAVE TO BE REPLACED AFTER

		FLOATABLE PLACED INSIDE SEWAGE PIPELINE NO CHEMICAL DOSAGE	1-2 CSOS (DEPENDING ON THE EVENT)
Secondary treatment techniques	Lamella Plate clarification	CAN WORK WITH OR WITHOUT CHEMICALS RETENTION TIME AND FOOTPRINT ARE 1/3-1/4 OF SETTLING TANK CAN BE PLACED IN ALREADY EXISTING STORAGE TANK CONCENTRATED SLUDGE 3%	REQUIRES GRIT REMOVAL AND FINE SCREENS THREE STAGE OF FLOCCULATION ENHANCE FLOC FORMATION LOW OVERFLOW RATES, LONGER RETENTION TIME PEAK EFFICIENCY REACHED AFTER 120 MIN PLUGGING BETWEEN LAMELLA PLATES
	Actiflo®	SMALL FOOTPRINT HIGH REMOVAL EFFICIENCY MICROSAND AS BALLAST COMPARED WITH DENSADEG: -SHORTER RETENTION TIME -REQUIRES LESS COAGULANT AND POLYMER -CAN HANDLE A WIDER RANGE OF OPERATING AND INFLUENT CONDITIONS	GRIT REMOVAL AND FINE SCEENING (8MM) TO AVOID HYDROCYCLON CLOGGING MAINTENANCE OF HYDROCYCLONE SLUDGE CONCENTRATION 0.3% DIFFICULT TO DISPOSE OF THIN SLUDGE PRODUCES A HIGHER VOLUME OF SLUDGE TANKS REQUIRE WATER WHEN NOT IN SERVICE REQUIRES ODOR CONTROL DEALING WITH SAND CAN BE DIFFICULT
	DensaDeg® 4D	SMALL FOOTPRINT HIGH REMOVAL	PRE-SCREENING REQUIRED

		EFFICIENCY (GRIT AND GREASE REMOVAL) AUTOMATIC CONTROL OF START UP LOW EFFLUENT VALUES FOR SS, COD AND BOD5; SOLIDS REMOVAL EFFICIENCIES TYPICALLY GREATER THAN 85% SLUDGE AS BALLAST CONCENTRATED SLUDGE 3-8% TANKS DO NOT REQUIRE WATER WHEN NOT IN SERVICE	REQUIRES SLUDGE BLANKET BUILDUP, LAG TIME DRY START UP RESULTS IN POOR PERFORMANCE HIGHLY POLLUTED FIRST FLUSH
	DAF (Dissolved Air Floatation)	SYSTEM CAN ADAPT WELL TO WET WEATHER FLOW MAXIMAL EFFICIENCY REACHED AFTER 1 MIN LITTLE SENSITIVITY TO INFLUENT POLLUTANT LOADING FILTRATION INCREASE UV TRANSMITTANCE TO 50 %	HIGH MAINTENANCE COMPARED WITH LAMELLA EFFICIENCY DEPENDS ON TYPE OF PARTICULATE MATTER LARGE FOOTPRINT
	Fuzzy filter®	HIGH FILTRATION RATES WITH FLOW RATES UP TO 90M/H, FOR RAPID SAND FILTRATION FLOW RATES ARE BETWEEN 5-20M/H; LOW BACKWASH	PRE-TREATMENT IS NEEDED (I.E. VORTEX SEPARATOR)

		WATERFLOW; NO LOSS OF FILTER MEDIUM; COMPLETELY ENCLOSED FILTER UNIT; LOW OPERATION COSTS; LARGE STORAGE CAPACITY IN THE FILTER BED.	
	Membrane Filtration MF	ADVANCED REMOVAL OF SS IS POSSIBLE	FINE SIEVING NECESSARY TO PREVENT CLOGGING, NETTING TRASH TRAPTM AS PRETREATMENT CHEMICALS ARE NEEDED TO CLEAN REGULARLY THE MEMBRANE
	Membrane Filtration UF	MORE ADVANCED REMOVAL OF SS COMPARED WITH MF	FINE SIEVING NECESSARY TO PREVENT CLOGGING, NETTING TRASH TRAPTM AS PRETREATMENT CHEMICALS ARE NEEDED TO CLEAN REGULARLY THE MEMBRANE
Adsorption techniques	Activated Carbon Filtration	REMOVE ORGANIC MICRO POLLUTANTS, HEAVY METALS, SULPHIDES AND NITROGEN SMALL FOOTPRINT 2 MIN OF START UP	ADVANCED REMOVAL OF SS IS NEEDED TO PREVENT CLOGGING HIGH COST FOR REGENERATION OF ACTIVATED CARBON
	Zeolite	REMOVE AMMONIA AND HEAVY METALS SMALLER FOOTPRINT THAN	PRE-TREATMENT IS NEEDED HIGHER AFFINITY WITH SULPHATE THAN NITRATE:

		AC	FIRST FLUSH CAN CAUSE FILTER SATURATION WITH SULPHATE AND NITRATE CANNOT BE ADSORBED
Disinfection techniques	UV	START UP WITHIN A MINUTE; NO CHEMICALS ADDITION.	NOT EFFICIENT FOR RAPID CHANGES IN FLOW LAMPS FOUL RAPIDLY
	Ozone	-	POISONING AND EXPLOSION RISK
	Chlorine	COST EFFECTIVE; BOD AND AMMONIA REDUCTION.	NOT EFFECTIVE AT LOW DOSING RATES; ITS PRODUCT CAN FORM CARCINOGENIC BY-PRODUCTS

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5 Reduce infiltration - A methodology for the identification of infiltration in sewer system

5.1 Infiltration in sewer system: description of problem

Sanitary sewer systems often show functional problems as a result of significant portion of the total flow originating from infiltration, storm water inflows and industrial effluents. Extraneous flows into the separate sanitary sewer systems can result in significant performance decrease, both in sewer systems and in treatment plants, consequently causing negative impacts on receiving water bodies.

Sources of extraneous flows into sanitary sewer systems include rain induced flows (illicit connection of drains from private properties; misconnection of drains from gullies; misconnection of storm sewers; entry of surface water through manhole covers), infiltration (groundwater entering through pipe and manhole walls; cross leakage from water supply mains and storm sewers) and unauthorised industrial connections. This problem has been reported in different countries as seriously reducing functional performance of the systems as well as significantly increasing operation costs (Ainger, C. M., Armstrong, R. J., Butler, D. 1998). Problems derived from these extraneous flows include:

- ✓ Reduction of the sewer system hydraulic capacity, eventually leading to overcharge, overflows and flooding.
- ✓ Hydraulic surcharge, overflow and efficiency reduction at treatment facilities.
- ✓ Increased pollution of receiving waters.
- ✓ Operational costs and structural condition deterioration.

As consequence, failure to meet established basic performance requirements often occurs, leading to unwanted impacts on the overall performance of water utilities.

These problems are emphasised by the increase in heavy rainfall events and possible higher ground water level, due to climate change effect.

5.2 Example of a methodology to detect infiltration in sewer system

Mechanisms aiming at detecting and reducing excessive flows are particularly important when compliance with discharge directives is to be achieved, and impacts on receiving water bodies and operation costs are significant. In this paper a methodology applied by Saster of Mediterranea delle Acque S.p.A. for addressing this problem is presented.

The methodology is based on the integrated analysis of networks that is provided by the following steps:

1. *network characterization;*
2. *computerization of data;*
3. *monitoring of rain and flowrate, model calibration and data analysis;*
4. *network rehabilitation plan and functional analysis.*

This modular approach allows to obtain immediate and useful results at the end of each step.

5.2.1 *Network characterization and field survey*

The characterization of network consists of paths localization and geometric features check with collection of all material and proper field measurement in site. The good knowledge of the sewer network is a basic step for a modern management of technology assets. The field survey is necessary also to identify possible pipe bursts, anomalies in gates or sewer overflow operation, excessive sediments storage along sewer that can compromise operation of main sewer.

A good knowledge of network is achieved by collection of:

- ✓ available information about the sewer system including GIS maps, topographic relief maps, maps of sewer network with, if available, info about channel and pipe dimension, slope, depth and material of bottom;
- ✓ projects on sewer network and state of projects;
- ✓ characteristics and project of tank, CSO, pumping stations, sensors and available instruments.

All the information are selected and cross-examined in order to identify any mismatches and to identify the more suitable manholes for future inspection. The manholes will be numbered and noted on the road. Each manhole characteristics and dimensions have to be noted down.

At the end of this phase all manholes and inspection chambers have been quoted and maps are updated.

Network characterization is completed by geometric survey of inspection chambers, especially, where there are junctions, changes in dimensions or quotes, and where there are hydraulic jumps, weirs, pumping stations, tanks.

When a standard inspection is not possible, operators can verify dimensions of a specific step of network by using a magnetic probe.

The topographic survey aims at georefering all collected data, giving to each focal point the geographic coordinates and quote. Plants and special structures are subjected to a detailed survey in order to achieve a geometric and functional scheme.

5.2.2 *Computerization of data*

All data are transferred to data management software environment. GIS maps show the topographic relief. The network is schematised as an arcs and nodes structures: if there is not an inspection chamber where expected (i.e. where there are junctions or intersections) a virtual chamber is created. All data are validated, and each significant point has its own document.

5.2.3 *Monitoring activity, model calibration and data analysis*

This phase aims at evaluating the conservation state of sewer network, through analysis of flows in the sewer and detection of infiltration or inflow.

The reference points of the sewer network to host flowrate sensor and raingages sensor, are chosen on the basis of geographic, topographic information and looking at the hydraulic features of the sites. Each site is

chosen on a map and then verified with field survey, to check if operational and maintenance work is allowed.
Raingauges are fixed as well as some (usually three) flowrate sensors. The other flowrate sensors are mobile because they have to be re-located in different sites, narrowing the distances between two sensors, phase after phase, following the bisection method, in order to identify as better as possible the source of infiltration.
Raingauges measures aim at identifying flows in the sewer network in wet and dry period.
Flow sensors aim at obtaining the basin water volume collected through a specific trunk sewer, or the water volume difference between two points to find possible infiltration of ground water or inflow into the sewer system. At the end of this phase, the network response to recorded rainfall events is known.
Collected data are checked and only good periods are selected for the next analysis. Flow measures in the sewer network could be affected by errors due to the instrument or the location. Even if instruments were calibrated in lab condition and hydraulic conditions are respected (far from curves, jumps…), the sewer environment could be really tough and cause errors in the measure, due to sediments on the probe, to incoherent bottom creating turbulence (false signals), or to very clean water (no particles on water surface).
In order to limit the choice of periods with possible errors, levels and flows are plotted as scattergraph: LogH/LogQ should follow a rectilinear pattern. Other patterns show anomalies from standard conditions (see Figure 5-1).

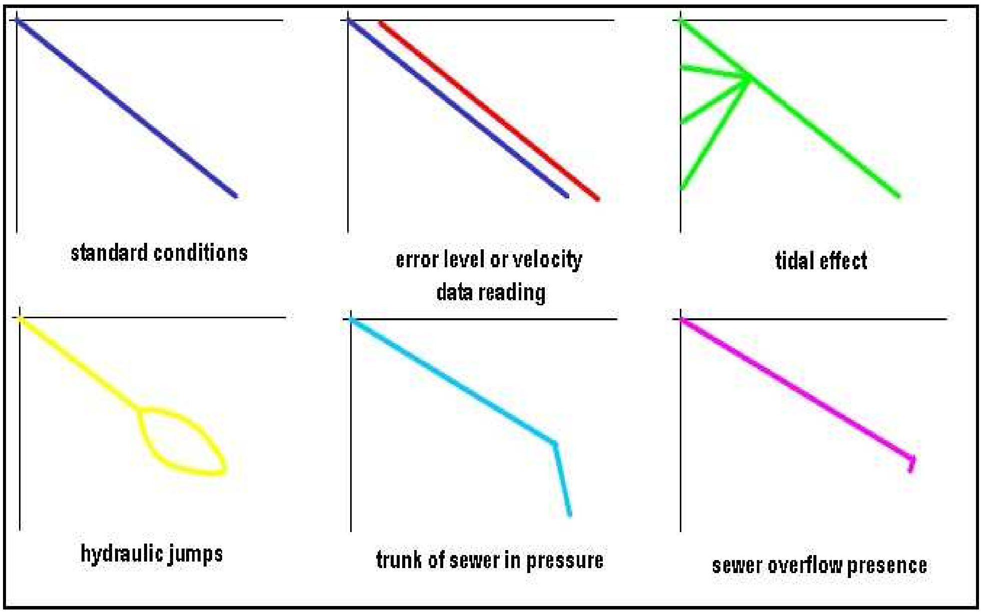

Figure 5-1: LogH/LogQ scatter plot.

<u>Dry period analysis</u>
It aims at identifying water infiltration from guilles, groundwater, irrigation channels, that in dry weather conditions can infiltrate in the sewer network system. Two surveys on validated data are accomplished:

- ✓ Flow/level instantaneous data analysis during night period;

- ✓ Comparison between mean daily measured flow and mean daily theoretic flow for each trunk and site.

The minimum night flow, if no infiltration occurs, should be a negligible flow, with respect to the mean value. With the analysis of the minimum night flow it is possible to understand if infiltration or inflow occurs.

This analysis is effective if sensors are installed in the upper trunk of network. If sensors are installed in the terminal trunk of basin, the registration of night flow could be affected by daily water consumption.

With the measure of flowrate for each trunk, it is possible to know the *measured mean daily characteristic water volume* (MCV). To calculate the *theoretic mean characteristic daily water volume*, the eq. inhabitants, the distribution and the waste water production per capita (or drinking water consumption) are taken into account (TCV).

The differences between MCV and TCV for each trunk, provide a list of critical areas that leads manager to establish where further surveys are required. Narrowing flow sensor following the bisection method, it is possible to reach those trunks with more severe conditions, assigning a priority to rehabilitation and maintenance works.

<u>Wet weather period</u>

The flow hydrographs of selected events are compared with rainfall histogram: if the hydrograph path shows an instantaneous and steep response to the rainfall, it means that storm water inflow comes from illicit junction of combined trunk of sewer network from new industrial or residential areas to the sanitary sewer system. If the hydrograph shows a smooth and lagged path with respect to the rainfall event, it means that water could come from groundwater, or from manholes infiltration.

<u>Application limit</u>

The methodology could be applied only in macro-areas. Narrowing the distances between two flow sensors in a critical trunk of sewer, operator has to take into account that the measurement error could reach values up to 5%.

The methodology allows to select trunks for a further and more detailed survey. Aiming at reducing or eliminating infiltrations with proper rehabilitation works, detailed surveys through inspection chambers or video-inspection on more critical trunks are required.

5.2.4 *Network rehabilitation plan*

In the previous phase, trunks of sewer with anomalies are classified according to their rank of severity. A rehabilitation plan for each point is drawn up and a mathematical model to simulate old and rehabilitated sewer network is defined.

Models are used to simulate existing conditions and to develop suggestions for optimization of the sewer system. Such an optimization could include introduction of real time control or rehabilitation works within the system.

One of the models that can be used for sewer network modelling is InfoWorks™ CS, for identifying and justifying cost effective infrastructure improvements. Other applications include urban flooding and pollution prediction and the modelling of water quality and sediment transport

throughout the network. As well as supporting fast and accurate network modelling, there are specific tools to support the modelling of sub-catchment take-off and infiltration. InfoWorks™ CS facilitates the swift modeling of total networks or any sub-network.
Another model for sewer network simulation is MOUSE, a professional engineering software package for simulation of surface runoff, flows, water quality and sediment transport in urban catchments and sewer systems. The program can be applied to any type of pipe network with alternating free surface and pressurised flows. MOUSE is a dynamic, user-friendly modelling tool for the analysis, design, management and operation of both simple and large pipe networks. It provides a complete and effective working environment for sophisticated urban drainage and sewer engineering. InfoWorks™ CS (MWH Soft) and MOUSE (DHI) are both commercial products.
For evaluating the impact of inflow and infiltration on sanitary sewer overflows, the free software of EPA, SWMM could also be applied. The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps. It is widely used throughout the world for planning, analysis and design related to stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well.

Once chosen the software, GIS data have to be transferred in the hydraulic software environment, together with data of permeability of catchment or sub-catchments.
The model is calibrated on significant events, registered by installed sensors (raingages and area-velocity flow meter).
To simulate the network, the calibrated model will run with synthetic rainfall of certain return period as input. The simulation output will find the most critical points: a rehabilitation plan will be applied for each point and the rehabilitated network will be simulated to confirm the efficiency of rehabilitation plan.

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6 First Flush Management for reducing pollution (separate sewer system)

Climate changes involve an increasing probability of extreme rainfall events also in extratropical regions. This leads to increased flows and the consequent need to collect and treat first flush runoff. In the separate sewer system the risk of pollution of receiving water bodies is given by contaminants usually collected in the first minutes of rain. This problem is more stressed for catchments with a high percentage of impervious areas. In this chapter the phenomena of first flush and some techniques to reduce pollutant load are briefly described.

6.1 Description of problem

Pollutants deposited on to exposed areas can be dislodged and entrained by the rainfall-runoff process. Usually the stormwater that initially runs off an area will be more polluted than the stormwater that runs off later, after the rainfall has cleansed the catchment. The stormwater containing this high initial pollutant load is called the first flush. First flush collection systems are employed to capture and isolate the most polluted runoff, with subsequent runoff being diverted directly to the stormwater system.

The stormwater pollution problem has two main components: the increased volume and velocity of surface runoff and the concentration of pollutants in the runoff. Both components are directly related to development in urban and urbanizing areas. The first aspect contributing to stormwater pollution is the increasing of impervious cover. It comes in rooftop imperviousness from buildings and other structures, transport imperviousness from roadways, parking lots, harbour loading docks, other transportation-related facilities and impaired pervious surfaces, also known as urban soils, which are natural surfaces that become compacted or otherwise altered and less pervious through human action.

The second aspect of urbanization that contributes to urban stormwater pollution is the increased discharge of pollutants. As human activity increases in a given area, the amount of waste material deposited on the land and in drainage systems increases.

First-flush characterization of pollutants has been monitored from highway and other road surface runoff by several investigators (Bertrand-Krajewski, Chebbo, and Saget 1998; Charbeneau and Barrett 1998; Deletic 1998; Geiger 1987; Gupta and Saul 1996; Larsen, Broch, and Andersen 1998; Legret and Pagotto 1999; Saget, Chebbo, and Bertrand-Krajewski 1995; Sansalone and Buchberger 1997; Thornton and Saul 1987). According to the Natural Resource Defence Council of USA, the principal contaminants of concern for stormwater fall into seven categories, listed in the following table.

table 6-1: Principal contaminants of first flush according to the Natural Resource Defence Council of USA

Categories	Examples
Metals	zinc, cadmium, copper, chromium, arsenic, lead
Organic chemicals	pesticides, oil, gasoline, grease
Pathogens	viruses, bacteria, protozoa
Nutrients	nitrogen, phosphorus
Biochemical oxygen demand (BOD)	grass clippings, fallen leaves, hydrocarbons, human, and animal waste
Sediment	sand, soil, and silt
Salts	sodium chloride, calcium chloride

To reduce pollution from stormwater in receiving water bodies, techniques have been developed in order to increase pervious draining areas, or to treat collected first rain water before it reaches seas, lakes or rivers.
The volume of water to be treated depends on country regulation. In the USA the water quality volume has been defined as the storage needed to capture and treat the runoff from 90% of the average annual rainfall.

6.2 Existing techniques/technology for first flush pollution abatement

In this paragraph, some technologies for abatement of pollutant load associated with first flush events or wash-off areas are presented. Solutions can be classified as concentrated or distributed: the former usually installed downstream with respect to the drainage network, and the latter usually installed upstream or at the same location of the inflow into the drainage network.
Treatment methods can also be classified in intensive (small footprint) treatment and extensive (large footprint, prevention) measures.

The first flush of streets or other impervious areas contains high quantity of sediments, such as sands, dusts, metals and others solids. In this context, it is useful to adopt sedimentation treatment techniques to remove most of pollutants. Filtration and floatation techniques are also applied, particularly as additional treatments.

6.2.1 Sedimentation treatment

Description

Sedimentation treatment, that is usually applied in underground settling tanks, is a basic treatment that exploits the gravity force to separate water from solid particles.

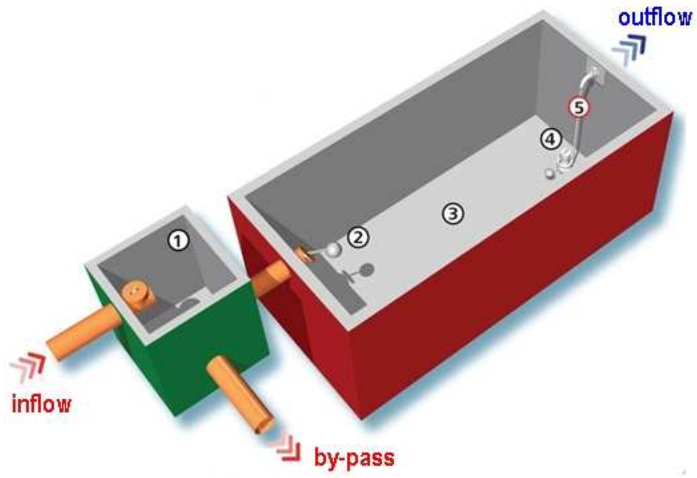

Figure 6-1: scheme of a sedimentation tank, for uptake and storage of stormwater. The capacity of tank is used for sedimentation and removal of solids before the discharge in the receiving water body. 1. automatic floodway tool, 2. float shutoff valve; 3. grit removal chamber, floatation/ sludge storage, first flush storage chamber, 4. lifting pump, 5. flowmeter.

A reduction of pollutant substances in large areas (such as cars parking areas) could be obtained by application of distributed sedimentation treatment: in particular, sediments can be reduced by the installation of little settling tanks along and under the storm drain system (under the inlet grates). The efficiency of this application depends on the frequency of cleaning operations. Underground storage is most often used in developments where land availability, shape and land costs predicate against the development of surface stormwater Best Management Practices (BMPs).

Examples

Settlement and storage tanks can be considered an intensive and concentrated measure. It can be applied under parking lots, roadways and paved areas associated with commercial, industrial and residential developments.

Advantages:

- Reduction of stormwater runoff flow.
- Extended storage and slow, measured release of collected stormwater runoff.
- Being a good option for high density or urban areas with limited available space or unusual shapes or where land is expensive.
- System instillation can be accomplished rapidly using prefabricated modular systems.
- Durability and long life (50 years plus for most systems).
- Increased level of public safety over open ponds and other surface stormwater BMPs.
- Insulation from freezing.
- Aesthetically pleasing to public in that such systems are out-of-sight and thus out-of-mind.

Limitations Underground stormwater storage provides minimal stormwater quality benefits, but can be a successful segment to a development's overall stormwater management plan, when coupled in-line with other stormwater BMPs.

References

Stormwater Management- Underground Storage http://www.lakesuperiorstreams.org/stormwater/toolkit/underground.html

6.2.2 *Filtration treatment*

Some filtration systems, evaluated as Best Management Practices, are listed below (http://www.stormwatercenter.net, "A review of stormwater treatment practices"):

1. Surface sand filter

Description

The filter bed and the sediment chamber are above ground. It is generally designed as an off-line practice, where only a given water volume is directed to the filter. It consists of a pretreatment basin, a water storage reservoir, flow spreader, sand and underdrain piping. Effective in removing many of the common pollutant runoff, sand filters have shown a moderate level of bacterial removal. They have not been effective in removing dissolved solids and nitrate-nitrogen. Pollution removal is 87% of TSS, 59% of TP (total phosphorus) and 32% of TN (total nitrates). For the design, pretreatment and sand filter are essential. Drainage areas directed to each sand filter should be less than 5 acres (almost 2 hectares) in size. Sand filters are very adaptable and have few site constraints. They can be used in high-density urban sites with small drainage areas that are completely impervious (such as parking lots). Intended primarily for quality control and not for quantity control: a diversion structure, such as a flow splitter or weir, is provided to route the first flush of runoff into sand filter, while the remainder continues on to a storm-quantity-control (if any) or in the urban drainage system. [http://www.metrocouncil.org/environment/Watershed/bmp/CH3_STFiltSurfSand.pdf].

Advantages:

- Applicable in small drainage areas (1-10 acres);
- Have few constraints, applicable to most development sites;
- Good retrofit capability;
- Take up little space and can be used on highly developed and steeply clopped sites;
- High removal efficiency for TSS.

Limitations:

- Pretreatment required to prevent filter clogging;
- Maintenance required every 6 months to 5 years depending on watershed;
- Relatively costly to build and install;
- An elevation difference (ca 4 feet or about 1.20 meters) between the inlet and outlet of the filter is usually needed;
- Not applicable in areas of high water table;
- Should not be used where heavy sediment loads are expected;
- Generally do not provide quantity control;

- Performance reduced if underdrains and filter media freeze.

References

http://www.metrocouncil.org/environment/Watershed/bmp/CH3_STFiltSurfSand.pdf

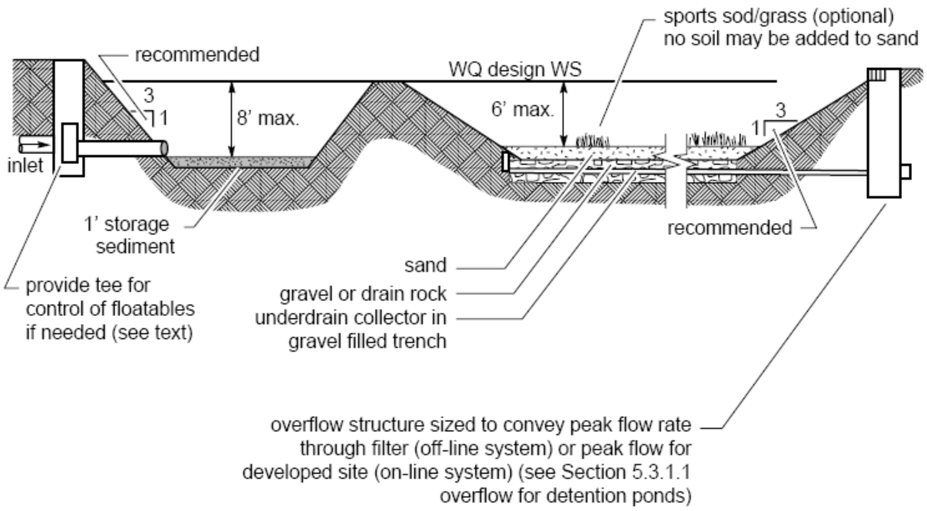

Figure 6-2: Surface sand filter, cross section view, recommendation for design. [Washington, 2000]

2. Underground filter

Description

It is similar to the surface filter except that the sand filter (or other media) and underdrains are installed below grade in a vault. They are intended to address the spatial constraints that can be found in intensely developed urban areas, where drainage areas are highly impervious. Underground filters are most effective when designed off-line; they are intended primarily for quality control. A diversion structure is provided to route first flush of runoff into the underground filter, while the reminder continues on to a stormwater quantity control practice (if any). Underground sand filter is typically a three-chamber system. The initial chamber takes care of pretreatment, utilizes a wet pool and temporarily stores runoff. The first chamber is connected to a second sand filter chamber by a submerged wall. Water flows to and is spread over the sand filter where pollutants are either trapped or strained out. These two chambers temporarily store water during storms. Perforated drains extend into a third chamber collecting filtered runoff. This solution has proven to be effective in removing many pollutant substances (TSS, Heavy Metals, Floatables as primary benefits, TP, TN, Oil and Grease, Feacal coliforms, BOD as secondary design benefit).

Advantages

- Applicable in small drainage areas (1-10 acres);
- Have few constraints, applicable to most development sites, they can be used where space limitations preclude above-ground facilities;
- Good retrofit capability;

- May require less space than other practices and can be used on highly developed with steep slopes;
- High removal efficiency for TSS.

Limitations

- Frequent maintenance required depending on watershed;
- Relatively costly to build and install;
- An elevation difference between the inlet and outlet of the filter is usually needed;
- Should not be used where heavy sediment loads are expected;
- Generally do not provide quantity control;
- Performance reduced if underdrains and filter media freeze.

Examples

Examples of underground filters are the District of Columbia Sand Filter (D.C. sand filter, 1980) and the Delaware Sand filter (see the perimeter sand filter) developed by Shaver and Baldwin (http://www.metrocouncil.org/environment/Water/BMP/CH3_STFiltUnderground.pdf).

Proprietary filters are the StormFilter™ (see in the following lines) and the HydroKleen™.

References

http://www.metrocouncil.org/environment/Water/BMP/CH3_STFiltUnderground.pdf

3. Perimeter sand filter

Description

It is also known as Delaware Sand Filter, it includes a sedimentation chamber and a filter bed. It is designed as an on-line practice, with all flows entering the system through grates, with larger events bypassing treatment by entering an overflow chamber. An advantage is that it requires little hydraulic head, a good option in areas of low relief. It is highly accepted by the community, but the cost and maintenance can be high. This solution can remove 79% of TSS, 41% of TP, and 47% of TN, although these numbers are based on limited data. It has small footprint and it is a good solution for parking lots.

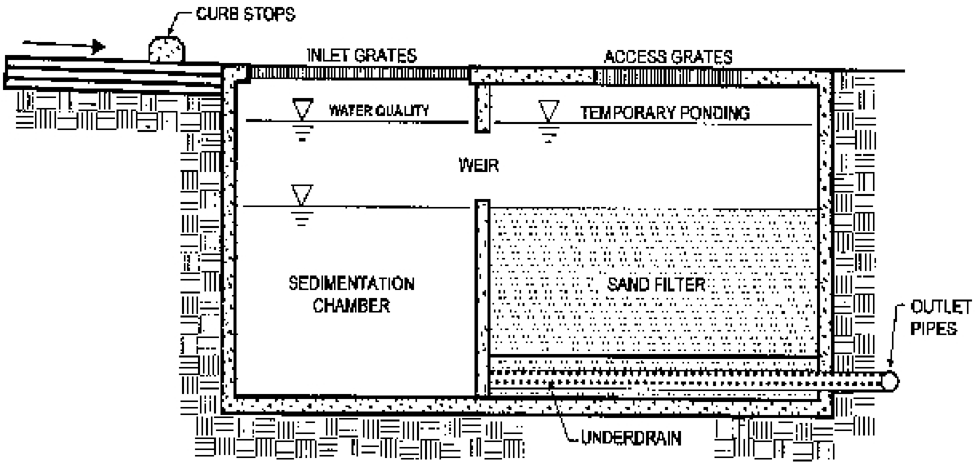

Figure 6-3: perimeter sand filter, profile view http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm).

Advantages

- Applicable in small drainage areas (1-10 acres);
- Have few constraints, applicable to most development sites, they can be used where space limitations preclude above-ground facilities;
- Applicable in very impervious areas such as parking lots;
- Little hydraulic head is required;
- May require less space than other practices and can be used on highly developed with steep slopes;
- High removal efficiency for TSS.

Limitations

- Permeability of sand may decrease with time; therefore, maintenance is required;
- Relatively costly to build and install;
- Excessive runoff during storm periods is temporarily ponded above normal pool and sand layers;
- Do not provide quantity control.

References

http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/water/quality/perimetersandfil.pdf; source: Design for Stormwater Filtering Systems, Center for Watershed Protection

There are also pocket sand filters and bioretention areas included in measures suggested by the Centre of Watershed Protection, but they are less applicable to highly urbanised areas.

In underground filters, sediment removal could be reached by the application of a vortex chamber or a conventional sedimentation tank.

If flux of water is pre-treated in a vortex chamber (see Figure 6-5), the efficiency of pollutant removal can reach the 84% for the TSS and 98% of hydrocarbons, against 70% and 80%, respectively, with sediment tank without vortex pre-chamber (see the conventional sedimentation+filtration in

Figure 6-4). Furthermore the system with vortex pre-chamber allows to obtain the removal of 69% of BOD_5, 59% of COD and 85% of lead.

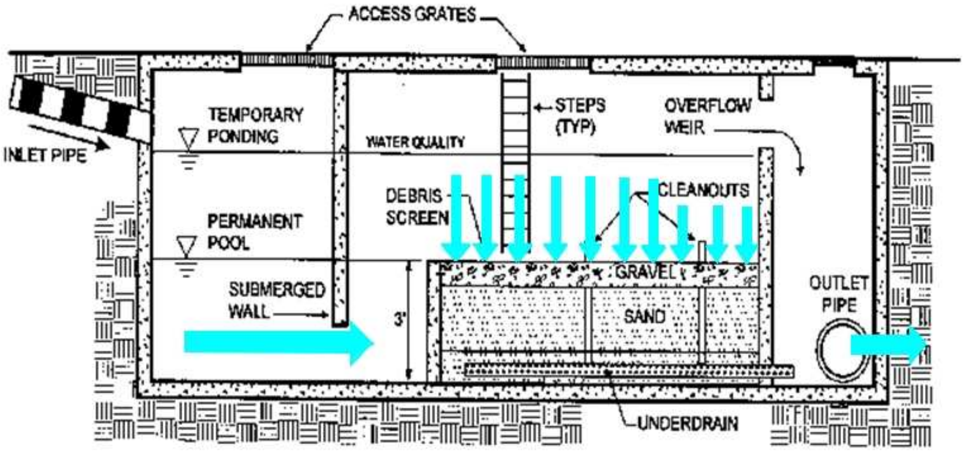

Figure 6-4: Underground filter with conventional sedimentation tank (profile view) [http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm]

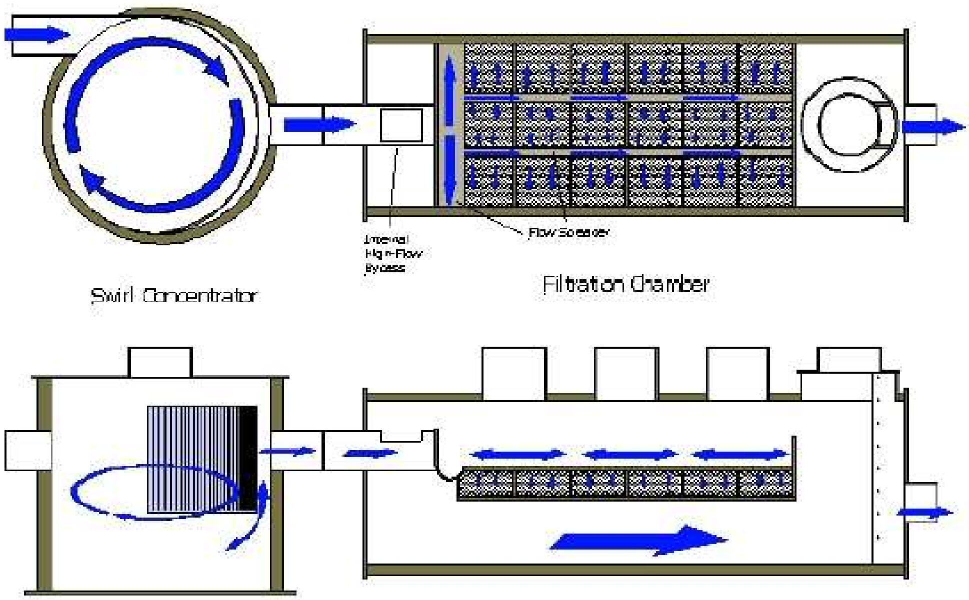

Figure 6-5: Plan view and profile view of a filtration treatment plant with a pre-chamber of Vortex sedimentation.

Characteristics of filtering systems

Description

Common characteristics of filtering systems are that filtering media can be sand, soil, gravel, peat or compost but they all filter pollutants entrained in stormwater runoff. Second, filtering systems are typically applied to small drainage areas (five acres or less). Third, filtering systems are designed solely for pollutant removal. Water volumes from extreme events are bypassed around the filter to a downstream stormwater management facility.

The filter media is incorporated into the filter bed. The three key properties of the bed are its surface area, depth, and profile. The required surface area for a filter is usually calculated based on the amount of impervious area treated and the media itself, and may vary due to regional rainfall patterns and local criteria (or regulations) for computing water volumes that have to be treated. A relatively shallow filter bed is generally preferred for hydraulic and cost reasons, and because most pollutants are trapped in the top few inches of the bed.

Many key pollutant removal mechanisms associated with filters are related to the filter media (Centre for Watersheed Protection CPW2000). For example, filtration, adsorption, and microbial action are all influenced by the media type.

The application of Compost has given results of 90% of TSS, 88-98% of heavy metals and 85% of fats and oils.

New concept filtration systems consider the application of:

- Different filler of loose material put in layers;
- One or more layers of zeolite or GAC (granular activated carbon), or fibers from thermoplastic synthetic;
- Tools in which the filter layer is placed into cartridges that allow backwash of filters.

Examples

The application of multi-layer filters is easy to be applied in prefabricated plastic boxes, with pre-sedimentation and grates too (see the Figure 6-6).

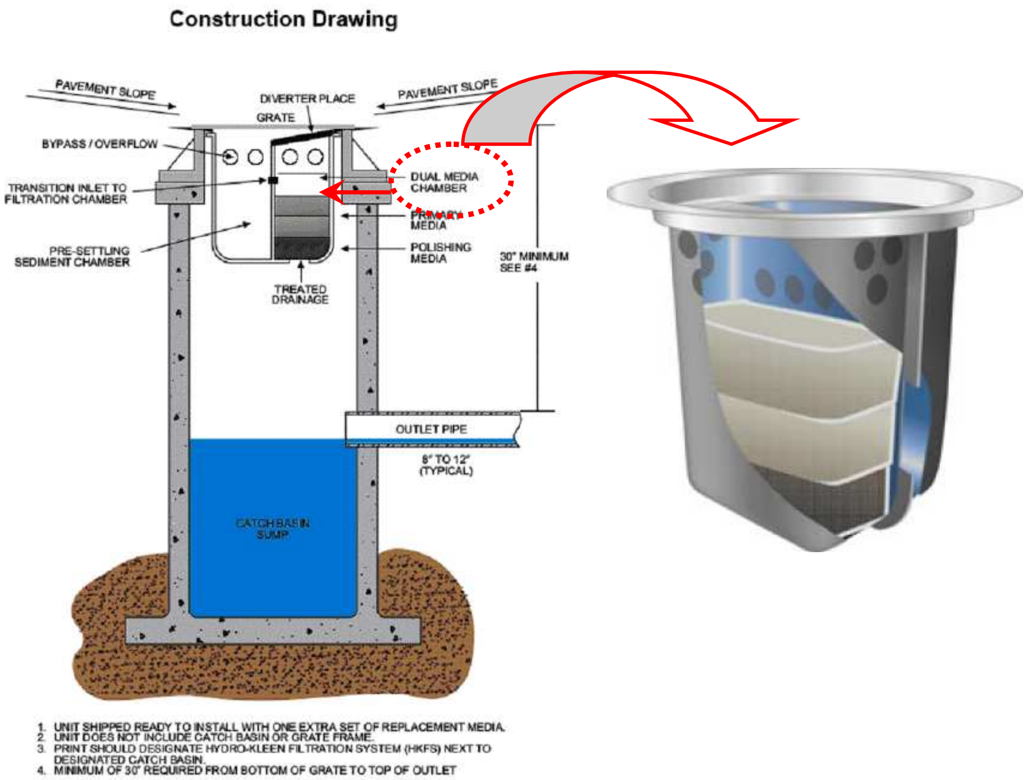

Figure 6-6: Profile of a filtration system with a prefabricated module (Hydro-Kleen™, Stormwater Filtration System.

http://www.acfenvironmental.com/PDFs/WaterQualInserts/Broc-Hydro-Kleen.pdf)

The application of a zeolite layer allows a good metals removal: one or more layers of zeolite can give different efficiency (see the table below).

table 6-1: removal efficiency (percentage) applying one, two or three layers of zeolite.

LAYER	**Zn** %	**Pb** %	**Cu** %	**Cd** %
1	39	72	44	30
2	53	83	58	51
3	69	98	76	75

The insertion of a GAC filter to a sand filter layer only allows to remove oils, fats and organic compounds, because of the adsorption properties of activated carbons.

Advantages

High removal efficiency can be obtained with the application of thermoplastic fibers, placed in plastic or stainless steel boxes, that allows further than the filtration action, also a coalescence effect of hydrocarbons, PBC (Polychlorinated biphenyls), Cu, Zn, Pb, Cr VI and other heavy metals. This system does not require the application of a sedimentation pretreatment that means minor volumes and costs.

Removal efficiency are 90% of TSS, 98% of Cu, 89% of Pb, and 99% of Zn and hydrocarbons.

Limitations

All filter need washing operational and maintenance. To avoid this problem, many backwash systems have been introduced at the end of filtration. These systems are made by one or more modules in cylindrical cartridges; each cartridge is made up by a cylinder of metal surface that contains the filter media, and by a layer of filter material (sand, perlite, GAC, compost or other adsorbing materials), at the end there is a internal valve that enable the connection with the water discharge allowing the backwash of cartridge.

References

Centre for Watersheed Protection CPW2000

Stormwater Filtration System. http://www.acfenvironmental.com/PDFs/WaterQualInserts/Broc-Hydro-Kleen.pdf

BMP example: StormFilter™

Description

A best management practice (BMP), designed to meet stringent regulatory requirements, is the Stormwater Management StormFilter™ . It removes the most challenging target pollutants – including fine solids, soluble heavy metals, oil, and total nutrients – using a variety of sustainable media. Its patented, surface-cleaning system prevents surface blinding, which extends the cartridge life cycle (http://www.contech-cpi.com/Products/StormwaterManagement/Filtration/StormwaterManagementStormFilter.aspx). A StormFilter™ consists of concrete vault that house siphon-driven cartridges containing alternative filtration media (fabric inserts, perlite, zeolite, patented CSF leaf media). A typical StormFilter™ contains an inlet bay which serves as a grit chamber and provides a flow transition into the cartridge bay. This transition is via a flow spreader that traps floatables, oils and surface scum prior to their entering the cartridge bay. After the surface scum is separated by the flow spreader, the water passes over an energy dissipater and begins filling the cartridge bay. Once the water reaches a designed level, water is pulled through the filtration media where pollutants are abated. The treated stormwater passes through a slotted center tube where it is then routed via pipe manifold, cast into the floor of the concrete vault. After leaving the pipe manifold, the treated water can be sent directly to a waterway.

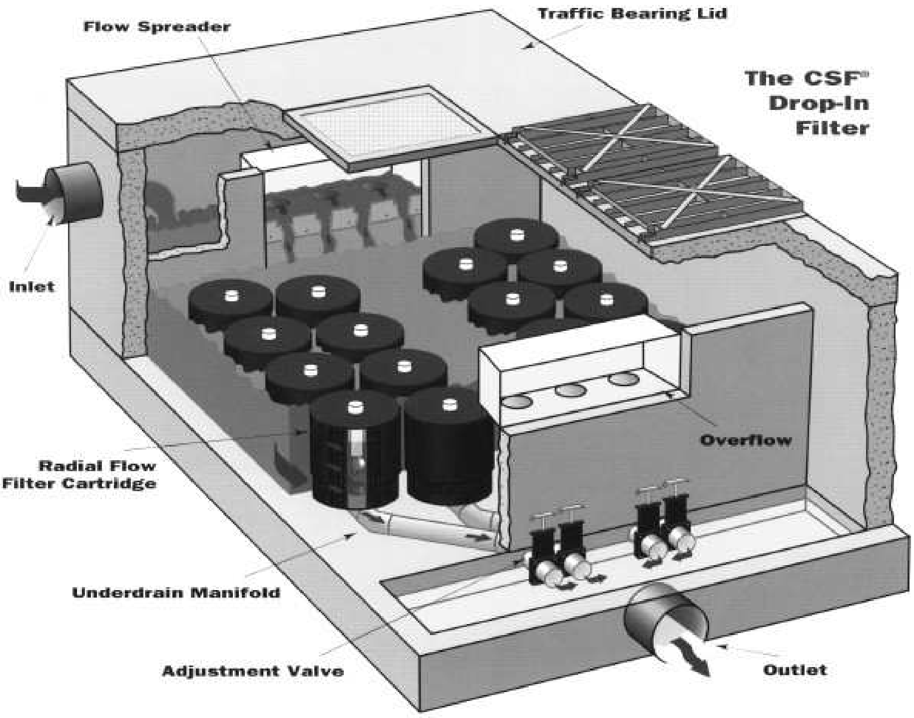

Figure 6-7: General scheme of StormFilter™ plant (source Stormwater Management Inc., Minnesota Urban Small Site BMP Manual http://www.metrocouncil.org/environment/Water/BMP/CH3_STFiltUnderground.pdf).

Advantages

The system (see Figure 6-7) could be applied in-line or off-line, in a concentrated (many cartridges concentrated in a unique chamber, along the drainage network) or distributed way (many single cartridges under grates along streets…).

This system allows to remove 94% of TSS, 78% of COD, 70% of TN, 58% of TP, 80% of TPH (total petroleum hydrocarbon), 81% of Cu and Pb, and 78% of Zn.

References

Contech Construction Product Inc. http://www.contech-cpi.com/Products/Stormwater-Management/Treatment/Stormwater-Management-StormFilter.aspx
Minnesota Urban Small Site BMP Manual http://www.metrocouncil.org/environment/Water/BMP/CH3_STFiltUnderground.pdf

6.2.3 Floatation systems

Treatments based on floatation are usually applied to remove pollutants from industrial plants drainage areas. Most of pollutants deposited on these impervious areas are oils, fats and hydrocarbons.
Oil separators aim at removing all pollutant with a specific weigh lower than water unit weight.
There are three types of oil separator units: gravity oil separator, coalescence oil separator, adsorbing pillow oil separator.

Gravity oil separator

Description

Gravity oil separator, as an API oil-water separator (see Figure 6-8), is a device designed to separate gross amounts of oil and suspended solids from the wastewater effluents of oil refineries, petrochemical plants, chemical plants, natural gas processing plants and other industrial sources. The name is derived from the fact that such separators are designed according to standards published by the American Petroleum Institute. The API separator is a gravity separation device designed by using Stokes Law to define the rise velocity of oil droplets based on their density and size. The design of the separator is based on the specific gravity difference between the oil and the wastewater because that difference is much smaller than the specific gravity difference between the suspended solids and water. Based on that design criterion, most of the suspended solids will settle to the bottom of the separator as a sediment layer, the oil will rise to top of the separator, and the wastewater will be the middle layer between the oil on top and the solids on the bottom. Typically, the oil layer is skimmed off and subsequently re-processed or disposed of, and the bottom sediment layer is removed by a chain and flight scraper (or similar device) and a sludge pump. The water layer is sent to further treatment (usually dissolved air flotation DAF for removal of residual oils and biological treatment for dissolved chemical compounds).

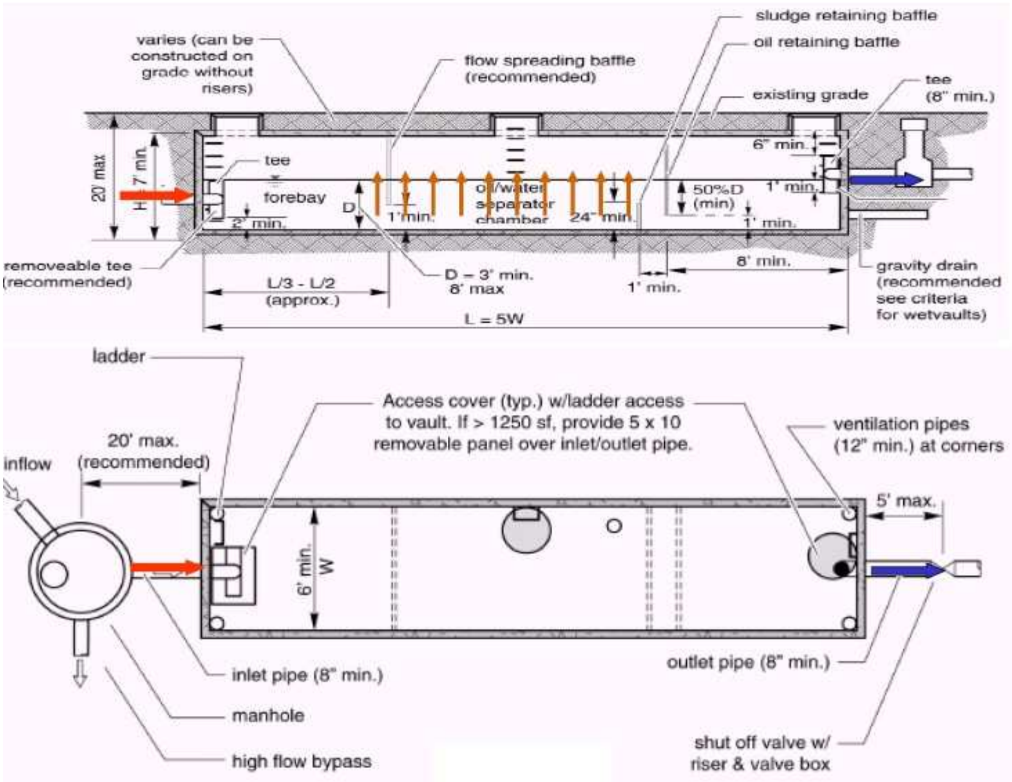

Figure 6-8: Gravity oil separator for first flush treatment in industrial areas, source API 421.

Examples

As an example, the BaySaver® Separator (see Figure 6-9) is a physical separator, relying on gravity settling, flotation, and other related mechanisms, to remove sediments, floating debris, and free oils from stormwater. The system comprises three main components: the BaySaver Separator Unit, the Primary Manhole (PM), and the Storage Manhole (SM). Both manholes are of standard concrete construction and function as sediment-accumulation sites.

Both manholes are of standard concrete construction and function as sediment-accumulation sites. During a storm event, the Separator Unit acts as a flow control to route the influent flow through the most effective flow path for treatment. For example, under low-flow conditions, the entire influent flow is treated in the PM and SM. Under moderate flows and up to the maximum treatment rate, water is treated through both the PM and SM, with a portion of these flows diverted through T-pipes.

The T-Pipes are structures that enhance the performance of the system during high-intensity storm events that are below the MTR of the separator. This flow path allows for full treatment of floatable pollutants, while still treating sediments under moderate flow conditions. During maximum flow conditions or maximum hydraulic rate, most of the influent flow passes over the bypass plate and will not be treated.

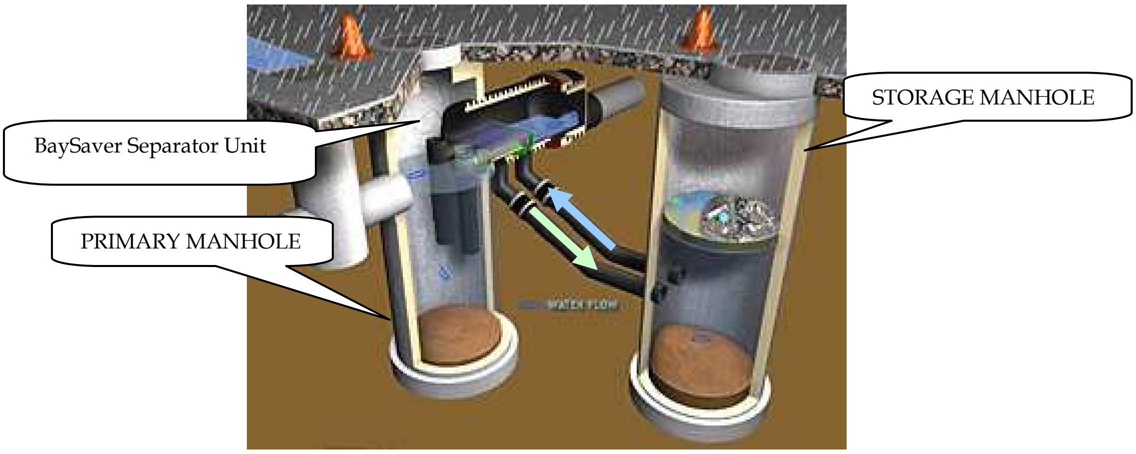

Figure 6-9: BaySaver® Separator (http://www.baysaver.com/flash/demo_separator.html)

This system requires inspection every trimester (4 times at year) and an annual maintenance operation, unless a large amount of collected sediments and oils is noted.

Advantages

Due to variability of rainfall characteristics, automatic devices are often applied.

Limitations

Gravity oil separators require large areas not always available, therefore prefabricated structures are preferred.

References

BaySaver, Technologies Inc., Engineering, stormwater solutions, http://www.baysaver.com/Working_With_Us/engineers/BaySeparator/index.html

"Teoria di disoleazione delle acque di prima pioggia" http://etd.adm.unipi.it/theses/available/etd-09072004-173516/unrestricted/capitolo2.PDF

Coalescence oil separator

Description

If the floatation treatment exploits a coalescence effect, it is possible to reduce the volume occupied by the chamber of about 40%: this effect is given by oleophilus mobile devices in plastic material inside the oil separation chamber. These elements are characterised by a wide specific surface (corrugated plates, etc.) and allow to obtain hydrocarbons concentrations lower than 5 mg/l.

Examples

An example of coalescence separator has been developed by Ecol (http://www.ecol-group.com/technology.php) as shown in the following picture.

Figure 6-10: coalescence oil separator produced by ECOL Sp. z o.o. (LLC).

Advantages

Coalescence oil separators are recommended for fuel basis, petrol stations, car parks, transport basis, industrial areas, storage areas.

References

Ecol Group site. http://www.ecol-group.com/index/Catalouge_of_Separators.pdf

Adsorbing pillow oil separator

Description

These pillows preferentially absorb oils and greases, helping to accelerate the breakdown of absorbed hydrocarbons by bacterial action. The pillows are designed for the continuous absorption of oily waste but may also be used to assist in spill clean up operations absorbing excess oils and grease from accidental spillages.

Advantages

Combining a blend of hydrocarbon degrading bacteria and oleophilic fibre, pillows application degrades the blooms of hydrocarbon-based materials commonly found in interceptors and similar oily water catchment systems (Accepta 7120, http://www.accepta.com/biological-treatment/oil-absorbent-pillows.asp).

References

Accepta 7120, http://www.accepta.com/biological-treatment/oil-absorbent-pillows.asp

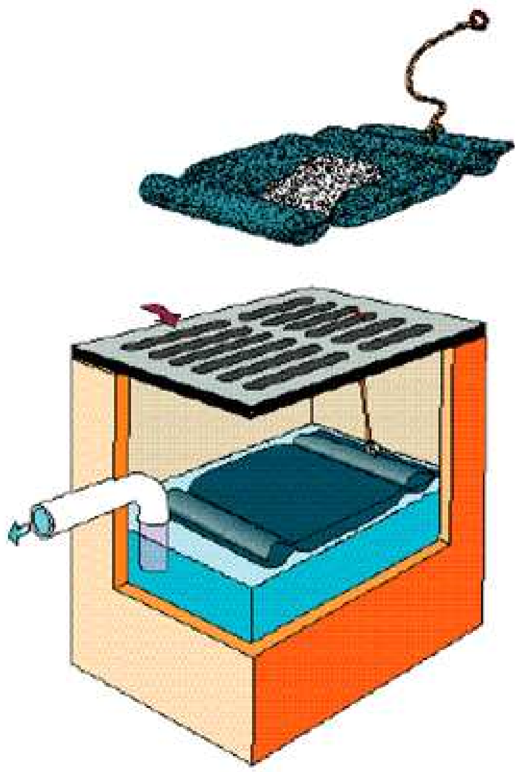

Figure 6-11: oil separation by adsorbing pillow.

6.3 Conclusions

In the paragraph 6.2, some of technologies applied for first flush pollutant abatement have been described. Prevention and extensive methods have not been analysed because less adaptable to already developed high urban environment. Intensive or concentrate solutions for first flush treatment have been described. Sedimentation, filtration and floatation mechanism solutions have been analysed, but it is not easy to make a comparison: the application of one or the other solution depends on pollution features of water and this is strongly dependent on land use.

Sedimentation is quite always required as treatment or pretreatment, associated with filtration, to prevent clogging of filter media. Filtration has shown to be the most applicable method, because many solutions are already tested and listed as BMPs (Stormwater Manager's Research Center).

About cost consideration, filters have such varied designs that it is difficult to assign a cost to filters in general (Brown and Schueler, 1997), but typical total cost of installation ranged between \$2.50 and \$7.50 per cubic foot (ca between 70 €/m^3 to 200 €/m^3). The cost per impervious surface unit treated varies considerably depending on the region and design used. It is important to note that, while underground and perimeter sand filters can be more expensive than surface sand filters, they consume no surface space, making them a relatively cost-effective practice in ultra-urban areas where land is at a premium (http://www.stormwatercenter.net/).

At the end of this collection study, it can be said that:

- Research and regulation started to be more aware about first flush effect in the last 20 years.
- Research concentrates on pollutant characteristics and methods for substances abatement and design criteria to treat the first runoff.
- Legislation changes its point of view, not only point sources pollution but even distributed sources and regulation on the water receiving body.
- Producers of systems for cleaning water, adapt their solution for first flush.
- Practices for preventing the phenomena started to be applied.

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6.5 Sitography

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- Baysaver Technologies Inc., http://www.baysaver.com/working_with_us/engineers/BaySeparator/specs.html
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- Minnesota Urban Small Sites BMP Manual http://www.metrocouncil.org/environment/Water/BMP/manual.htm
- High efficiency coalescence separator **ESK,** http://www.ecol-group.com/technology.php
- "Il controllo della qualità delle acque di pioggia defluenti sulle superfici stradali e sui piazzali", Presentation of Prof. Gaspare Viviani, "Giornata di studio, Le opere idrauliche nelle costruzioni stradali", 18th March 2010, http://www.idra.unipa.it/convegnoAII/180310/Viviani14.pdf
- StormFilter™ http://www.contech-cpi.com/Products/StormwaterManagement/Filtration/StormwaterManagementStormFilter.aspx

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7 Decentralised solutions: controlled infiltration, retention of rainwater

7.1 Introduction

The IPCC (Intergovernmental Panel on Climate Change), the most watched scientific body in the world for climate change research and analysis, cites a 90% chance of increased frequency of heavy rainfall events, heat waves, and hot extremes in the 21st century (IPCC 2007).
Increased spring and winter precipitation, decreased precipitation in fall and by 15% in summer, higher, warmer, flashier (shorter, more intense) summer runoff resulting in greater water level fluctuations, erosion and pollutant loading, a doubling of intense storms, are all predicted effects due to climate change expected in this century.
Shorter, warmer winters with reduced ice cover and 15% - 40% increased rain/sleet runoff, hotter, longer growing season with longer, more intense droughts and decreased annual groundwater recharge and decreased stream baseflow are some other expected impacts.

In order to adapt to climate change effect, decentralised practices could be a solutions, because adaptation measures to consider are:

- Use of low-impact building and site design to maximize water infiltration on-site.
- Restoration of natural drainage systems (wetlands, floodplains, forest cover).
- Increased water conservation measures.

In the nineties, a new approach toward urban stormwater management was discussed and found its support in new legislation in several European countries. Besides hydraulic requirements for retention and infiltration capacity, the pollutants contained in the runoff water are of primary importance in future stormwater drainage concepts. Source control of hazardous pollutants by choosing alternative materials for the construction of buildings, roads and vehicles is considered to be most sustainable but will only be effective on a long-term perspective (Boller, 2004).
In addition, new facilities for decentralized hydraulic retention combined with barrier systems for the most hazardous substances are proposed allowing for ecologically safe discharge of the stormwater into the local environment. Soil passage have been investigated and turned out to represent efficient retention systems which can well be integrated into infiltration and hydraulic retention facilities. The structures for stormwater handling should be integrated into local landscaping.

7.2 Existing techniques/technology

In this paragraph some of stormwater treatment practices are analysed (Stormwater Manager's Resource Center – SMRC, Ellicott City, Maryland):

1. Porous pavements;
2. Infiltration basin;

3. Infiltration trench;
4. Bioretention;
5. Grassed channel;
6. Wet pond.

Other practices have been described in paragraph 3.1.1.

7.2.1 Porous pavement

Description

Porous pavement is a permeable pavement surface with an underlying stone reservoir that temporarily stores surface runoff before infiltrating into the subsoil. Pavement options can be porous asphalt, pervious concrete, and grass pavers. Porous asphalt and pervious concrete appear the same as traditional pavement from the surface, but are manufactured without "fine" materials, and incorporate void spaces to allow infiltration. Grass pavers are concrete interlocking blocks or synthetic fibrous grid systems with open areas designed to allow grass to grow within the void areas.

Realization examples

The ideal application for porous pavement is to treat a low traffic or overflow parking area. Porous pavement may also have some application on highways, where it is currently used as a surface material to reduce hydroplaning.

In country areas, porous pavement can be applied, while it cannot be used where sand is applied to the pavement surface because clogging can occurs. Care also needs to be taken when applying salt to a porous pavement surface since chlorides from road salt may migrate into the groundwater.

It is possible to use this application in cold climate too: some experience suggests that snow melts faster on a porous surface because of rapid drainage below the snow surface (Cahill Associates, 1993).

In ultra urban areas in which little pervious surface exists, porous pavement is a good option because they consume no land area. They are not ideal for high traffic areas, however, because of the potential for failure due to clogging (Galli, 1992).

In stormwater hotspots (commercial nurseries, auto recycle facilities, commercial parking lots, fueling stations, feet storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/unloading facilities, public works storage areas, hazardous materials generators, vehicle service and maintenance areas, and vehicle and equipment washing/steam cleaning facilities), it should not be applied due to the potential for groundwater contamination. Since porous pavement can only be applied to relatively small sites, use porous pavement as a primary or widespread method for watershed retrofitting (stormwater management practice to improve water quality, protect downstream channels, reduce flooding,…) would be expensive.

Siting and Design Considerations

A potential porous pavement site needs to meet the following criteria:

- Soils need to have a permeability between 0.5 and 3.0 inches (ca 1.25 and 7.5 cm) per hour.
- The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface.

- Porous pavement should be located at least 2 to 5 feet (ca 0.3 m to 1.5 m) above the seasonally high groundwater table, and at least 100 feet (300 m) away from drinking water wells.
- Porous pavement should be located only on low traffic or overflow parking areas, which are expected to be not sanded during wintertime conditions.

Five basic features should be incorporated into all porous pavement practices: *pretreatment, treatment*, *conveyance*, *maintenance reduction*, and *landscaping*.

Pretreatment: in most porous pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Because the surface serves this purpose, frequent maintenance of the pavement surface is critical to prevent clogging.

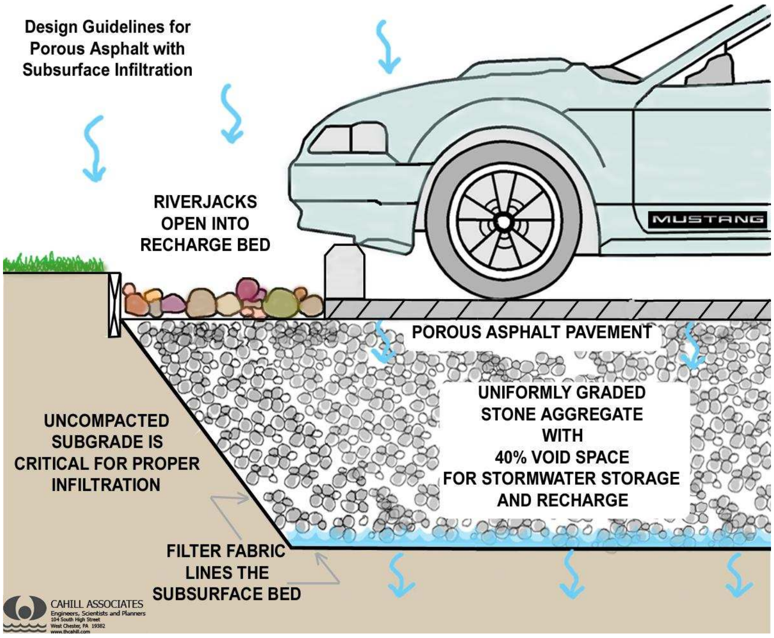

Figure 7-1: A schematic cross section of permeable paving. In some applications, the crushed stone reservoir below the paving is designed to store and infiltrate rooftop runoff as well. Image: Cahill Associates, Inc. 2004. (http://www.eot.state.ma.us/smartgrowth/07toolkit/lid/regional_planning/LID/permeable_paving.html)

Treatment: the stone reservoir below the pavement surface should be composed of layers of small stone directly below the pavement surface (see Figure 7-1), and the stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, porous pavement is sized to treat a small event, such as the *water quality storm* (i.e., the storm that will be treated for pollutant removal) which can range from 0.5″ to 1.5″ (half a inch is almost equal to 1.25 cm).

Conveyance: water is conveyed to the stone reservoir through the surface of the pavement, and infiltrates into the ground through the bottom of this stone reservoir. A geosynthetic liner and sand layer should be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs also need some method to convey larger storms to the storm drain system.

Maintenance Reduction: one non-structural component that can help ensure proper maintenance of porous pavement is the use of a carefully worded

maintenance agreement that provides specific guidance to the parking lot, including how to conduct routine maintenance, and how the surface should be repaved. Ideally, signs should be posted on the site identifying porous pavement areas.
Landscaping: the most important landscaping objective for porous pavements is to ensure that its drainage area is fully stabilized, thereby preventing sediment loads from clogging the pavement.

Limitations
In addition to the relatively strict site constraints for porous pavement, a major limitation to the practice is the poor failure rate it has experienced in the field. Several studies indicate that, with proper maintenance, porous pavement can retain its permeability (e.g., Goforth et al., 1983; Gburek and Urban, 1980; Hossain and Scofield, 1991). When porous pavement has been implemented in communities, however, the failure rate has been as high as 75% over two years (Galli, 1992).
Porous pavement requires extensive maintenance compared with other practices and lack of maintenance is the major reason of failure. Every month, the paving area need to be clean of debris and sediment, paving has to dewater between storms. Maintenance includes, when needed, mowing upland and adjacent areas, seeding bare areas, vacuum sweep to keep the surface free of sediment. Once a year, inspect the surface for deterioration.
Porous pavement is significantly more expensive than traditional asphalt, it could cost two or three times, on the other hand, porous pavement can create savings in terms of storm drain costs and land consumption.

Advantages
Porous pavement can be used to provide groundwater recharge and to reduce pollutants in stormwater runoff. Some data suggest that as much as 70% to 80% of annual rainfall will go toward groundwater recharge (Gburek and Urban, 1980). These data will vary depending on design characteristics and underlying soils. They both suggest high pollutant removal, although it is difficult to extract these results to all applications of the practice.

table 7-1: Pollutant removal of porous pavement (Winer, 2000) 1-Data based on fewer than five data points

Pollutant	**Pollutant Removal (%)[1]**
TSS	95
TP	65
TN	82
NOx	NA
Metals	98 - 99
Bacteria	NA

References
Stormwater Manager's Resource Center – SMRC, Ellicott City, Maryland

7.2.2 *Infiltration basin*

Description

An infiltration basin is a shallow impoundment that is designed to infiltrate stormwater into the soil. It has a high pollutant removal efficiency, and can also help recharge the groundwater, thus restoring low flows to stream systems. It can be problematic at many sites because of stringent soils requirements. In addition, some studies have relatively high failure rates compared with other stormwater treatment practices.

Realization examples

This practice needs to be applied very carefully, as their use is often sharply restricted by concerns over groundwater contamination, site feasibility, soils, and clogging. Applicable in most regions of the country, with some design modifications in cold and arid climates, it should not be applied in regions of karst topography, for sink hole formation and groundwater contamination.

In very urban areas, infiltration basins can rarely be applied due to space limitations. Even in stormwater hotspots, where activities generate highly contaminated runoff, infiltration basins should never be applied, due to potential groundwater contamination (see Risk of Groundwater Contamination from Infiltration of Stormwater, Article 104 in the Practice of Watershed Protection).

Infiltration basins have limited application as a stormwater retrofit.

<u>Siting and Design Considerations</u>

Designers need to ensure that the soils on the site are appropriate for infiltration, and that designs minimize the potential for groundwater contamination, and long term maintenance problems.

Infiltration basins have been used as regional facilities, providing both water quality and flood control. This practice may be feasible if the soils are particularly sandy. In general, the practice is best applied to relatively small drainage areas (i.e., less than ten acres, ca 40000 m^2), and exclusively for groundwater recharge and water quality treatment.

The bottom of infiltration basins needs to be completely flat to allow infiltration throughout the entire basin bottom. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging, but soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. The infiltration rate should range between 0.5 and 3 inches (ca 1.25 and 7.5 cm) per hour. Detailed soil tests are needed to determine if fragipans, hardpans or other confining layers are present. In addition, the soils should have no greater than 20% clay content, and less than 40% silt/clay content (CWP, 1998).

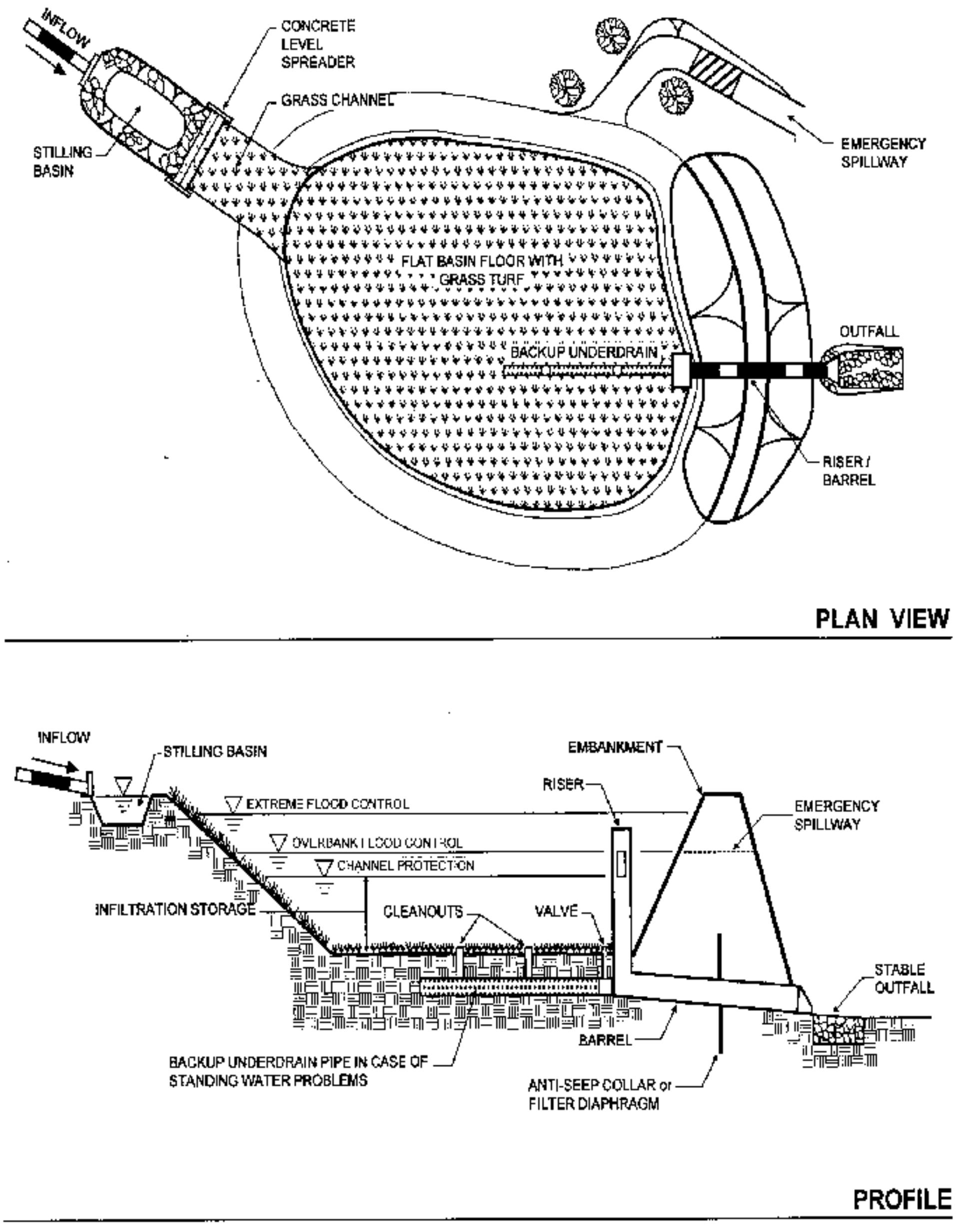

Figure 7-2: Plan view and profile of an infiltration basin.

Designers always need to provide significant separation distance (2' to 5' – 60 cm – 150 cm) from the bottom of the infiltration basin and the seasonally high ground water table, to reduce the risk of contamination. Infiltration practices should also be separated by at least 150 feet (45 m) from adjacent drinking water wells.

Designers should incorporate "multiple pretreatment", using practices such as grass swales, sediment basins, and vegetated filter strips in series, prior to the infiltration basin.

To enhance the pollutant removal of an infiltration basin, designers need to stabilize upland soils to ensure that the basin does not become clogged with sediment. The basin needs to be sized in order to assure that the volume of water to be treated infiltrates through the bottom in a given amount of time. Because of this, infiltration basins designed on less permeable soils will be significantly larger than those designed on more permeable soils.

Stormwater needs to be conveyed through stormwater treatment practices safely, and in a way that minimizes erosion. In general, infiltration basins is an "off-line" practice, designed to treat only small storms.

To reduce the maintenance burden, designers need to provide access to the basin and its forebay for regular maintenance activities and, where possible, provide a means to drain the basin, such as an underdrain, in case the bottom becomes clogged. This feature allows the basin to be drained and accessed for maintenance in the event that the water has ponded in the bottom of the basin, or the soil is saturated.

Landscaping can enhance the aesthetic value of stormwater practices, or improve their function. In infiltration basins, the most important purpose of vegetation is to reduce the tendency of the practice to clog. Upland drainage needs to be properly stabilized with a thick layer of vegetation, particularly immediately following construction. In addition, providing a thick turf at the basin bottom helps encourage infiltration and prevent the formation of rills in the basin bottom.

Limitations

Infiltration basins are not generally an attractive practice, particularly when they clog. If they clog, soils become saturated, and the basin can be a source of mosquitoes. In addition, they may not be feasible because of concerns over groundwater contamination and sufficient soil infiltration. Finally, maintenance of infiltration practices can be burdensome, as they have the highest rate of failure of any stormwater treatment practice.

Regular maintenance is critical to the successful operation of this practice, and cost could be high because, if improperly maintained, it may be necessary replace the basin after a relatively short period of time.

In arid regions, infiltration practices are often highly recommended because of the need to recharge the groundwater; in this case pretreatment should be even more strongly to ensure that the practice does not clog.

In extremely cold climates, infiltration basins may be an infeasible option.

Advantages

Infiltration basins recharge the groundwater because runoff is treated for water quality by filtering through the soil and discharging to groundwater.

Very little data are available regarding the pollutant removal associated with infiltration basins. It is generally assumed that they have very high pollutant removal, because none of the stormwater entering the practice remains on the surface. Schueler (1987) estimated pollutant removal for based on data from land disposal of wastewater. The average pollutant removal, assuming the infiltration basin is sized to treat the runoff from a one inch storm, is as follows:

table 7-2: Pollutant Removal Efficiency of Infiltration Basins (Schueler, 1987)

Pollutant	**Pollutant Removal (%)**
TSS	75
TP	60 – 70
TN	55 – 60
Metals	85 - 90
Bacteria	90

These removal efficiencies assume that the infiltration basin is well designed and maintained.

Infiltration basins are relatively cost-effective practices, because little infrastructure is needed when constructing them. They typically consume about 2% to 3% of the site draining to them, which is relatively small. Maintenance costs are estimated at approximately 5% to 10% of construction costs.

References

Stormwater Manager's Resource Center – SMRC, Ellicott City, Maryland

7.2.3 *Infiltration Trench*

Description

An infiltration trench is a rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale or sediment basin, before entering the trench. Runoff is then stored in the voids of the stones, slowly infiltrated through the bottom and into the soil matrix over a few days. The primary pollutant removal mechanism of this practice is filtering through the soil.

Realization examples

Infiltration trenches need to be applied very carefully. While trenches can be applied in most regions, their use is sharply restricted by concerns such as site feasibility, potential groundwater contamination, soils, and clogging.

It is not feasible in regions of karst topography, because of sink hole formation and groundwater contamination.

This solution can seldom be applied in the ultra urban environment. The two main reasons are the potential of infiltrated water to interfere with existing infrastructure, and the relatively poor infiltration capability of most urban soils.

Infiltration trenches should not receive runoff from stormwater hotspots, unless the stormwater has already been fully treated to avoid potential groundwater contamination. They may be used as a stormwater retrofit, but only for small sites (less than five acres), and it is often hard to find suitable areas for infiltration in already urban or suburban watersheds because of hotspots and poor soils.

<u>Siting and Design Considerations</u>

While trenches can be applied in a variety of situations, their use is frequently restricted by concerns over groundwater contamination, soils, and clogging (see Figure 7-3).

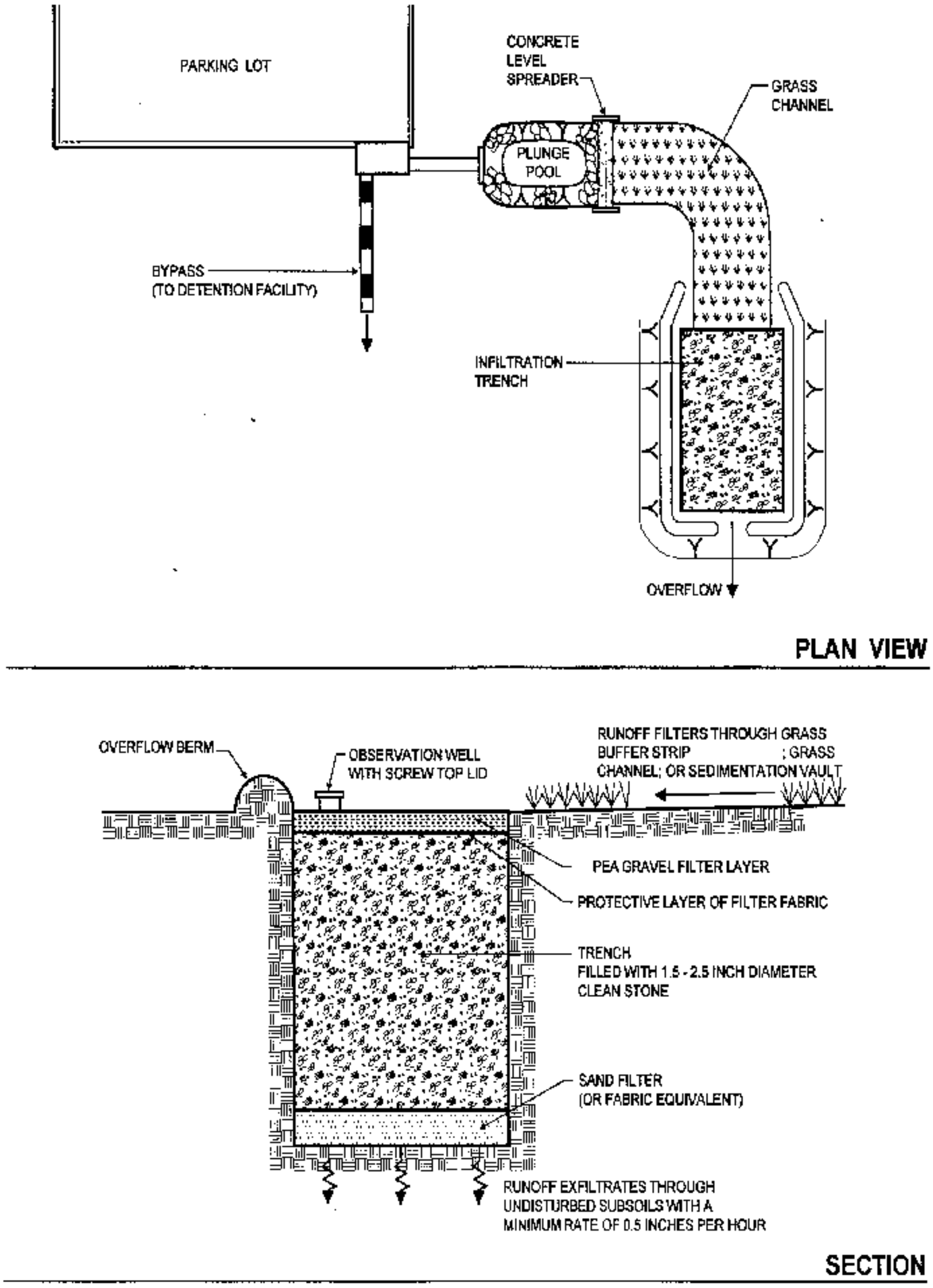

Figure 1. Infiltration Trench

Figure 7-3: Plan view and profile of an infiltration trench.

Generally they are applied to relatively small sites (less than five acres) that have relatively high impervious cover. Placed on flat ground, the slopes of the site draining to the practice can be as high as 15%.
Soils must be significantly permeable to ensure that trenches can infiltrate quickly enough to reduce the potential for clogging. In addition, soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. The infiltration rate should range

between 0.5 and 3 inches (ca 1.25 and 7.5 cm) per hour. In addition, the soils should have no greater than 20% clay content, and less than 40% silt/clay content (CWP, 1998).

Designers always need to provide significant separation from the bottom of the infiltration trench and the seasonally high ground water table, to reduce the risk of contamination and trench failure. In addition, infiltration practices should be separated at least 150 feet (45 m) from adjunct drinking water wells.

Infiltration trench designs vary considerably, depending on site constraints and the preferences of the designer and community. There are some features, however, that should be incorporated into every infiltration trench design. Pretreatment is essential for infiltration trenches, in order to make pretreatment effective, designers should incorporate "multiple pretreatment" into every trench.

Treatment design features enhance the pollutant removal capability of a trench. During the construction process, the upland soils of infiltration trenches need to be stabilized to ensure that the trench does not become clogged with sediment. Furthermore, the trenches should be filled with large clean stones that can retain the required volume water to be treated in their void space. Like infiltration basins, trenches should be sized so that the treatment volume can completely infiltrate through the trench bottom in twenty-four hours.

Stormwater needs to be conveyed through stormwater treatment practices safely, and in a method that minimizes soil erosion. Designed to treat only small storms, trenches should be "off-line". Finally, the sides of an infiltration trench should be lined with a geotextile fabric to prevent adjacent soils from clogging the practice.

Designers need to incorporate maintenance reduction features into the trenches to reduce future maintenance needs and make regular maintenance activities easier to perform. As with all practices, infiltration trenches should have a direct access path for maintenance activities. An observation well (i.e, a perforated PVC pipe that leads to the bottom of the trench) is needed to enable inspectors can monitor the drawdown rate. Where possible, trenches should have a means to drain the practice if it becomes clogged (such as an underdrain). An underdrain pipe with a shutoff valve can be used as an overflow in case the trench becomes clogged.

In infiltration trenches, there is no landscaping on the surface practice itself. In arid regions, infiltration practices are frequently recommended because of the need to recharge the groundwater. In extremely cold climates infiltration trenches are not feasible.

Limitations

Infiltration trenches do not detract visually from a site and they provide no visual enhancements. Their application is limited due to concerns over groundwater contamination (*Risk of Groundwater Contamination from Infiltration of Stormwater*, Article 104 in The Practice of Watershed Protection) and other soils requirements. Finally, maintenance can be burdensome, and infiltration practices have a relatively high rate of failure.

Infiltration practices require regular maintenance and inspections to perform properly. In general they have historically had a high rate of failure, compared with other stormwater treatment practices. One study conducted in Maryland (Galli, 1992), revealed that less than half of the infiltration trenches investigated (of about fifty) were still functioning properly, and less than one third still functioned properly after five years. Many of these practices, however, did not incorporate advanced pretreatment. Infiltration performance should improve by carefully selecting the location and with proper design features (Failure Rates of Infiltration Practices Assessed in Maryland, Article 101 in The Practice of Watershed Protection).

Infiltration trenches are slightly expensive, when compared to other stormwater practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about $5 per cubic foot of stormwater treated (SWRPC, 1991; Brown and Schueler, 1997).

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration trenches have a high failure rate (See Maintenance Considerations). In general, maintenance costs for infiltration trenches are estimated between 5% and 20%of the construction cost. In order to ensure long term functionality of the practice, realistic values are closer to the 20% range.

Advantages

Infiltration trenches can generally provide groundwater recharge, pollutant control, and can help channel protection.

Very little data are available regarding the pollutant removal associated with infiltration trenches. It is generally assumed that they have very high pollutant removal, because none of the stormwater entering the infiltration trench remains on the surface. The following table provides pollutant removal estimates derived from CWP's National Pollutant Removal Performance Database for Stormwater Treatment Practices.

table 7-3: Pollutant Removal Efficiency of Infiltration Trench (Winer, 2000) 1: Data based on fewer than five data points

Pollutant	Pollutant Removal (%)[1]
TSS	NA
TP	100
TN	42.3
NOx	82

Infiltration trenches typically consume a relatively small 2% to 3% of the drainage site. In addition, they can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

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Stormwater Manager's Resource Center – SMRC, Ellicott City, Maryland

7.2.4 *Bioretention*

Description

Bioretention areas are landscaping features adapted to treat stormwater runoff on the development site. They are commonly located in parking lot islands or within small pockets in residential land uses. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. During storms, runoff ponds above the mulch and soil in the system. Runoff from larger storms is generally diverted past the facility to the storm drain system. The remaining runoff filters through the mulch and prepared soil mix, is collected in a perforated underdrain, and is returned to the storm drain system.

Realization examples

Bioretention systems are generally applied to small sites, but can be applied to a wide range of development. It is feasible in many climate and geologic situations, with some minor design modifications.

Bioretention facilities are ideally suited to many ultra urban areas, such as parking lots. While they consume a fairly large amount of space (approximately 5% of the area that drains to them), they can fit into existing parking lot islands or other landscaped areas.

They can be used to treat stormwater hotspots as long as an impermeable liner is used at the bottom of the filter bed, and they are well suited for stormwater retrofit, by modifying existing landscaped areas, or if a parking lot is being resurfaced. In highly urban watersheds, they are one of the few retrofit options that can be employed. However, it is very expensive to retrofit an entire watershed using bioretention areas since they treat small sites.

<u>Siting and Design Considerations</u>

Bioretention can be applied on many sites, taking into account they have to be small. When used to treat larger areas, they tend to clog. In addition, it is difficult to convey flow from a large area to a bioretention area. Bioretention areas are best applied to relatively shallow slopes (usually about 5%) rather ensuring that the runoff enetring a bioretention area can be connected with the storm drain system. It is important to note, however, that these areas are most often applied to parking lots or residential landscaped areas, which generally have gentle slopes.

Bioretention should be separated from the watertable to ensure that the groundwater never intersects with the bottom of the bioretention area, preventing possible groundwater contamination and practice failure.

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community, but some features, should be incorporated into all bioretention areas (see Figure 7-4).

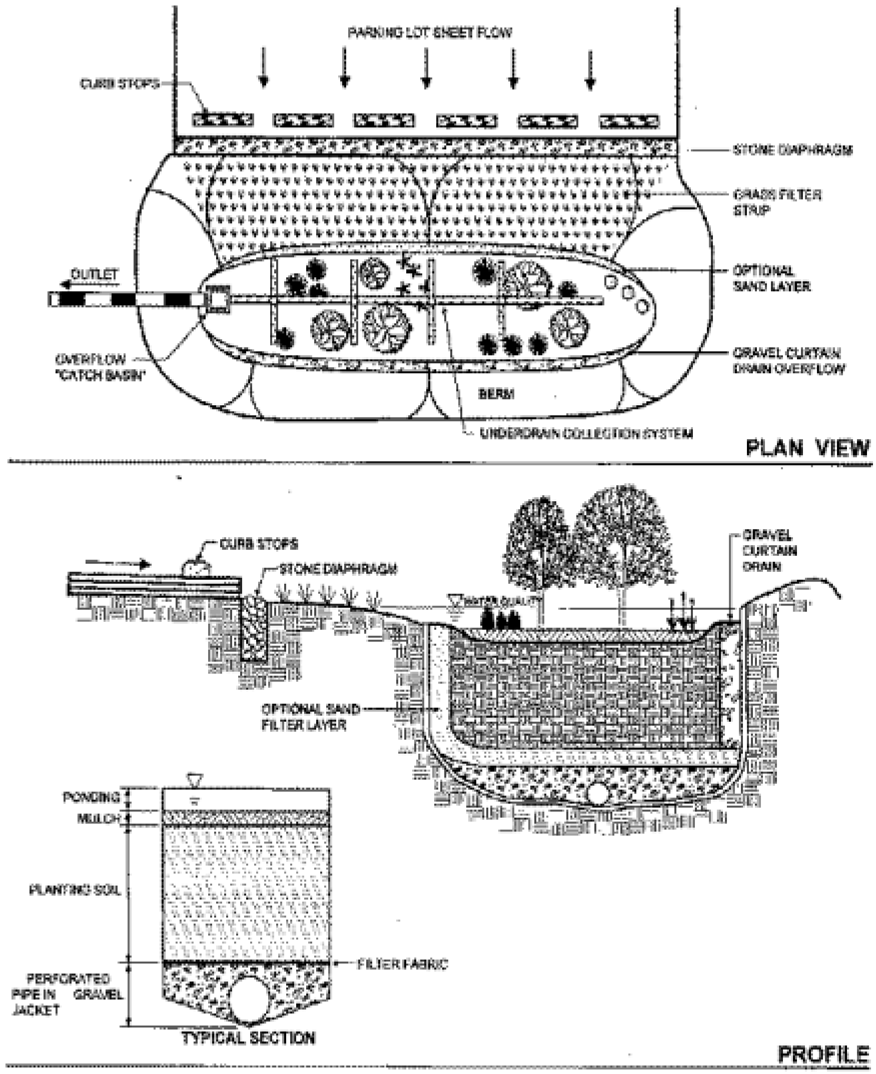

Figure 7-4: plan view and profile of a Bioretention practice.

Incorporating pretreatment helps to reduce the maintenance burden of bioretention, and reduces the likelihood that the soil bed will clog over time. Runoff can be directed to a grass channel or filter strip to settle out coarse sediments before the runoff flows into the filter bed of the bioretention area. Other features may include a pea gravel diaphragm, which acts to spread flow evenly and drop out larger particles.

The bioretention system should be sized be between 5% and 10% of the impervious area draining to it. The practice should be designed with a soil bed that is a sand/soil matrix with a mulch layer above the soil bed. The bioretention area should be designed to pond a small depth of water (6" to 9", 15 cm to 22.5 cm) above the filter bed.

Stormwater should be conveyed to and from the practice safely and minimize erosion potential. Bioretention areas are designed with an underdrain system to collect filtered runoff at the bottom of the filter bed and direct it to the storm drain system. Designers should also provide an overflow structure to

convey flow from large storms (that are not treated by the bioretention area) to the storm drain system.
Designers should ensure that the bioretention area is easily accessible for maintenance.
Landscaping is critical to the function and appearance of bioretention areas. It is preferred that native vegetation is used for landscaping, where possible. Plants should be selected that can withstand the hydrologic regime they will experience (i.e., plants that tolerate both wet and dry conditions). At the edges, which will remain primarily dry, upland species will be the most resilient. Finally, it is best to select a combination of trees, shrubs, and herbaceous materials.
In arid climates, bioretention areas should be landscaped with drought tolerant plant species.
In cold climates, this practice can be used as a snow storage area. When used for this purpose, or if used to treat parking lot runoff, the bioretention area should be planted with salt tolerant, and non-woody plant species.

Limitations
Bioretention areas cannot be used to treat large drainage areas, limiting their usefulness for some sites. Although bioretention areas do not consume a large amount of space, incorporating bioretention into a parking lot design may reduce the number of parking spaces available. Finally, the construction cost of bioretention areas is relatively high compared with other stormwater treatment practices.
Bioretention requires seasonal landscaping maintenance. In many cases, this practice require intense maintenance initially to establish the plants, but less maintenance is required in the long term. In many cases, maintenance tasks can be completed by a landscaping contractor, who may already be hired at the site. Bioretention areas do not usually recharge the groundwater, except in the case of the partial exfiltration design.
Cost is relatively high.

Advantages
Bioretention areas can provide pollutant removal. Little pollutant removal data has been collected on the pollutant removal effectiveness of bioretention areas. In fact only one study has been conducted (Davis et al., 1998). The data from this study is presented table 7-4.

table 7-4: Pollutant Removal Efficiency of Bioretention (Davis et al., 1998)

Pollutant	Pollutant Removal (%)
TSS	81
TP	29
TN	49
NOx	38
Metals	51 – 71
Bacteria	58

Assuming that bioretention systems perform similarly to swales, their removal rates are relatively high.
Cost is relatively high but, when evaluating the costs of bioretention is that it often replaces area that would likely be landscaped anyway. Thus, the true cost of the bioretention area may be less than the effective construction cost. Similarly, maintenance costs for bioretention areas are not very different from normal landscaping maintenance. Land consumed by bioretention areas is relatively high compared with other practices (about 5% of the drainage area). However, this land should not be considered lost, since it is often fits with existing setbacks and landscaping requirements.

7.2.5 Grass Channel

Description

The term "swale" (grassed channel, dry swale, wet swale, biofilter) refers to a series of vegetated, open channel practices that are designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. As stormwater runoff flows through the channels, it is treated through filtering by the vegetation in the channel, filtering through a subsoil matrix, and/or infiltration into the underlying soils. There are many design variations of the grassed swale, including the grassed channel, dry swale and wet swale. The specific design features and treatment methods differ in each design, but all are improvements on the traditional drainage ditch. Each incorporate modified geometry and other design features to use the swale to treat and convey stormwater runoff.

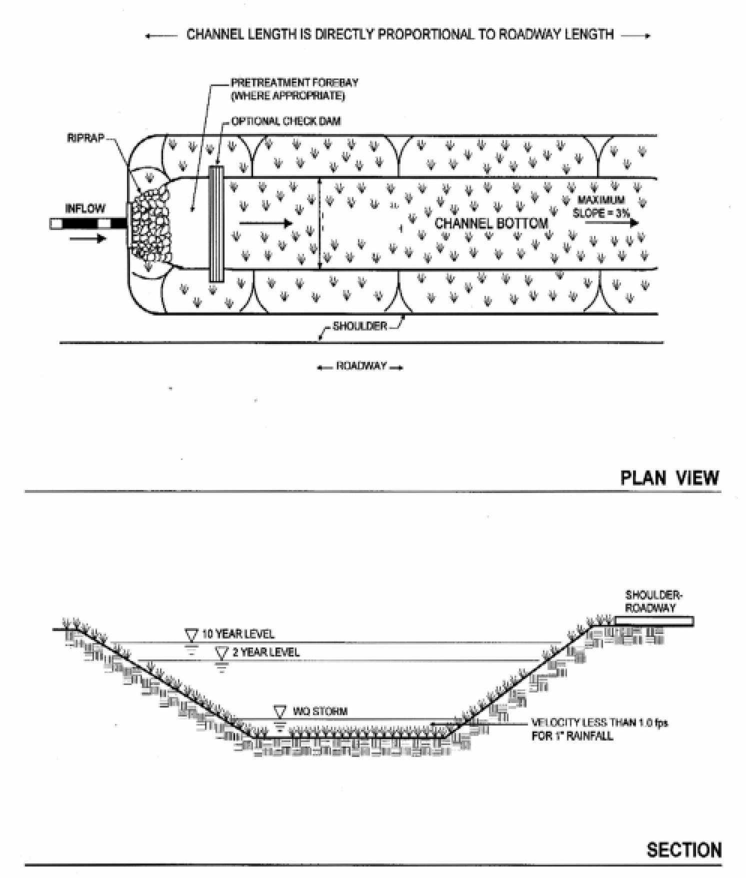

Figure 7-5: Plan view and section of a typical grassed channel (www.stormwatercenter.net/.../Grass%20Channel.GIF).

Realization examples

Grassed swales can be applied in most development situations with few restrictions. Swales are well-suited to treat highway or residential road runoff because their linear nature. In arid and semi-arid climates, the value of swales needs to be balanced against the water needed to irrigate them.

Grassed channels are generally not well suited to ultra urban areas because here most runoff is conveyed in underground storm drain pipes rather than open channels on the surface.

With the exception of the dry swale design, hotspot runoff should not be directed toward grassed channels. Swales infiltrate stormwater and can intersect the watertable, thereby increasing the risk of groundwater contamination. One common retrofit opportunity is to use grassed swales to replace existing drainage ditches.

Siting and Design Considerations

Individual grassed channels should generally treat small drainage areas (i.e., less than five acres). In larger areas, the stormwater flow velocity through the practice becomes too great to treat runoff or prevent erosion in the channel. For the same reasons, slopes should be less than 4%.

Grassed channels can be used on most soils with the exception of highly impermeable soils. Restrictions on the depth to groundwater depend on the type of channel used. In the dry swale and grassed channel options, the bottom of the swale should be at least two feet above the groundwater, to prevent a moist swale bottom, or groundwater contamination. In the wet swale option it is permissive to intersect the watertable since treatment is enhanced by a wet pool.

Open channels generally have a trapezoidal or parabolic cross section with relatively flat side slopes (generally flatter than 3:1), slowing runoff velocities, providing more contact with vegetation to encourage filtering and infiltration and getting runoff receive some pretreatment along the side slope. The flat channel should be between 2 and 8 feet (0.6 – 2.5 m) wide.

Pretreatment is needed in each option: a small forebay should be used upstream of the channel to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river run gravel) can also be used to pretreat runoff that enters the sides of the channel.

In addition to treating runoff for water quality, grassed swales need to convey larger storms safely. Typical designs allow the runoff from the 2-year storm to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

Limitations

Individual grass channels cannot treat a very large drainage area. Grass channels do not appear to be effective at reducing bacteria levels in stormwater runoff. Wet swales may become a nuisance due to mosquito breeding. They, however, generally do not contribute to groundwater recharge, as infiltration is impeded by the accumulation of organic debris on the bottom of the swale.

If designed improperly (e.g., proper slope is not achieved), grassed channels will have very little pollutant removal. A thick vegetative cover is needed for proper function.

Maintenance of grassed channels mostly involves maintenance of the grass or wetland plant cover.

Pollutant removal is not good for some bacteria, and modest removal capability occurs for phosphorous. While it is difficult to distinguish between different designs based on the small amount of available data, grassed channels generally have poorer removal rates than wet and dry swales, although wet swales appear to export soluble phosphorous (Harper, 1988; Koon, 1995).

Advantages

In general, grassed swales (except for wet swales) can be used to meet groundwater recharge and pollutant removal goals.

Grassed channels and dry swales provide some groundwater recharge if a high degree of infiltration is achieved by the practice. Few studies are available regarding the effectiveness of grassed channels. However, the data suggest relatively high removal rates for some pollutants.

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Stormwater Manager's Resource Center – SMRC, Ellicott City, Maryland

7.2.6 Wet Pond

Description

Wet ponds are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). Ponds treat incoming stormwater runoff by settling and algal uptake. The primary removal mechanism is settling while stormwater runoff resides in the pool.

Nutrient uptake also occurs through biological activity in the pond. Wet ponds are among the most cost-effective and widely used stormwater treatment practices. While there are several different versions of the wet pond design, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain stormwater runoff and provide greater settling.

Realization examples

Wet ponds are a widely applicable stormwater treatment practice. While they may not always be feasible in ultra-urban areas or arid climates, they otherwise have few restrictions.

Wet ponds can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site, or in stormwater hotspots, but it need significant separation from groundwater.

Wet ponds are widely used for stormwater retrofits, and have two primary applications as a retrofit design. In many communities, dry detention ponds have been designed for flood control in the past. It is possible to modify these facilities to develop a permanent wet pool to provide water quality treatment and modify the outlet structure to provide channel protection.

<u>Siting and Design Considerations</u>

Wet ponds need sufficient drainage area to maintain a permanent pool. In humid regions, a drainage area of about 25 acres (about 10 hectares) is typically needed, but greater drainage areas are needed in arid and semi-arid regions. Upstream slope can reach values up to about 15%. The local slope within the pond should be relatively shallow, however. There must be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system by gravity.

Unless wet ponds receive hotspot runoff, ponds can often intersect the groundwater table. However, some research suggests that pollutant removal is moderately reduced when groundwater contributes substantially to the pool volume (Schueler, 1997).

Pretreatment features are designed to settle out coarse sediment particles before they reach the main pool. A sediment forebay is a small pool (typically about 10% of the volume of the permanent pool) located near the pond inlet. Coarse sediments are trapped in the forebay, and these sediments are removed from the smaller pool on a five to seven year cycle.

In order to enhance the ability of wet ponds to remove pollutants from stormwater runoff, all designs should have features to increase the amount of time that stormwater remains in the pond, such as increasing the volume of the permanent pool.

Typically, ponds are sized on the volume of water treated for pollutant removal (water quality volume). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorous removal.

Wet ponds should always be designed with a length to width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer flow path through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a

"treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system.
The outfall of pond systems should be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. In order to prevent warming at the outlet channel, designers should provide shade around the channel at the pond outlet.
To reduce maintenance operations, ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no low flow orifice should be less than 3 inches in diameter (smaller orifices are more susceptible to clogging).
Direct access is needed to allow maintenance of both the forebay and the main pool of ponds. In addition, ponds should generally have a drain to draw down the pond or forebay to enable periodic sediment clean outs.

Limitations

When improperly located, wet pond construction may cause loss of natural wetlands or high quality forest. Although wet ponds consume a small amount of space relative to their drainage areas, they are often inappropriate in dense urban areas because each pond is generally quite large.
Use of ponds is restricted in arid and semi-arid regions due to the need to supplement the permanent pool. In cold water streams, this practice is not feasible due to the potential for stream warming. Wet ponds may cause some community concerns regarding safety.
In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed.
Wet ponds generally cannot provide groundwater recharge, as infiltration is impeded by the accumulation of organic debris on the bottom of the pond.

Advantages

Wet ponds can generally provide flood control channel protection, and pollutant removal functions. One result of urbanization is channel erosion caused by increased stormwater runoff. Traditionally wet ponds have been designed to provide control of the two-year storm . It appears that this design storm has not been effective in preventing channel erosion, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996). Choosing a smaller design storm (one-year) and providing longer detention time (12 to 24 hours) is now thought to be the best method to reduce channel erosion.
Wet ponds are among the most effective stormwater treatment practices at removing stormwater pollutants. A wide range of research is available to estimate the effectiveness of wet ponds. The following table provides pollutant removal estimates derived from CWP's National Pollutant Removal Performance Database for Stormwater Treatment Practices.

table 7-5: Removal efficiency for Wet Pond practice. 1- the '±'indicates one standard deviation.

Pollutant	**Removal Efficiency (%)[1]**
TSS	80 ± 27
TP	51 ± 21
TN	33 ± 20
NOx	43 ± 38
Metals	29 – 73
Bacteria	70 ± 32

There is considerable variability in the effectiveness of wet ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance.

Landscaping of wet ponds can make them an asset to a community, and can also enhance the pollutant removal. A vegetated buffer should be created around the pond to protect the banks from erosion, and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an aquatic bench (a shallow shelf with wetland plants) around the edge of the pond. This feature provides some pollutant uptake, and also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

Wet ponds are relatively inexpensive stormwater practices. Ponds do not consume a large area (typically 2-3% of the contributing drainage area). It is important to note, however, that these facilities are generally wide, because the contributing drainage area is large.

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5% of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into ponds systems may be spread over a relatively long time period.

In addition to water resource protection benefits of wet ponds, there is some evidence to suggest that they may provide an economic benefit by increasing property values. The results of one study suggest that "pond front" property can increase the selling price of new properties by about 10% (US EPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25% when located near a wet pond (Emmerling-Dinovo, 1995).

7.3 Conclusions

In this chapter some stormwater practices as decentralised solution have been analysed, other technologies have been presented in paragraph 3.1.1.

It is difficult to make a comparison among different practices, they all depend of site and stormwater features. Decentralised solutions could be applied for water quality treatment volume, groundwater recharge or flood control: the application of one measure or the other depends on the main aim to be reached.

Compared with intensive and built infrastructures, they have no environmental impact and these practices could often improve sites characteristics. No chemicals are used for treatment and maintenance operation could be reduced if proper devices are considered.

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8 Adaptation measures for joint effect of rainfall and sea level rise

8.1 Description of the problem

Climate changes will affect the frequency, magnitude, duration and local and temporal distributions of rainfall as well as of the sea level. In some regions it is expected the increase of hydrological extremes and sea level rise (see the deliverable D2.2.1 on the Prepared framework, Ugarelli *et al.*, 2011), which will have important implications on sewer systems performance as well as on the design of new systems. Management policies and practices may need to be adapted so that objectives for protection of safety and health, property and natural environment will continue to be met in a changed climate.

The joint effect of changes in rainfall patterns and sea level rise will especially affect sewer systems located in coastal zones or tidal estuaries, where there will be an increased risk of:

- damaging infrastructures and other assets;
- overpassing pumping capacity;
- flooding areas and properties;
- flooding of WWTP;
- saltwater intrusion into the sewers reducing WWTP treatment efficiency and accelerating asset deterioration;
- stormwater inflow and groundwater infiltration;
- treatment efficiency reduction;
- overflows from sewer systems;
- receiving water quality reduction.

As a consequence, greater demands are expected in the management and treatment of wastewater with the inherent increase in needs of protection, infrastructure requirements and energy and consumables consumption (CH2M Hill, 2009).

8.2 Legislation

According to the Strategic Environmental Assessment (SEA) Directive under the EU SEA Directive (European Directive 2001/42/EC) planners are legally obliged to consider climate change when developing spatial plans. Climate change must be considered at various stages of the SEA process. There are two climate change issues to address – the impact constraints set by climate change on the plan, and the plan's effects on future Greenhouse Gas (GHG) emissions. The Water Framework Directive (WFD) is an overarching programme to deliver long-term protection and improve the quality of groundwater, surface water and associated wetlands. Though the Directive does not currently require climate change to be taken into account, it will be implemented in planning cycles which allow consideration of long-term environmental trends, of which climate change is one.

8.3 Overview of existing techniques and technology

A description of measures to prevent or reduce problems in sewer systems due to changes in rainfall and sea level is presented in this section. Existing solutions and new approaches can be classified as hard structural, soft structural and non-structural measures.

Sewer systems subject to the joint effect of rainfall and tide have to respond simultaneously to upstream and downstream solicitations. Therefore, in these systems, adaptation must be analysed taking into account the integrated system as well as considering appropriate combinations of different technologies as solutions.

In this report, conventional hard structural measures include the increase of storage volumes, installation of non-return valves, relocation and redesign of CSO structures impacted by tide, protection, rehabilitation and upgrading of pumping stations and WWTP, disconnection of upstream catchments from downtown flooding areas, sewer separation, sewer system rehabilitation and stormwater and CSO treatment. Soft structural measures include a wide range of individual SUDS techniques, usually combined into a coherent system, to provide a decentralised stormwater management, such as green roofs, soakways, pervious pavements, infiltration trenches, swales, ponds and detention basins.

Non-structural adaptation measures for joint effect of rainfall and sea level rise include operational and maintenance measures, planning and design practices, regulatory and legal measures, public awareness and education actions, incentives and penalty initiatives.

8.4 Hard structural measures

8.4.1 Install non-return valves

Description of measure: Install non-return valves in sewer outfalls affected by tide or in sewer pipes located downstream basements or low-lying areas prone to flooding due to backflow.

Effect/objective: 1) Prevent sewers from filling with tide water thus mitigating floods, in-sewer settling and impacts in WWTP and pumping stations. 2) Mitigate floods in basements and low-lying areas due to backflow.

Application area: Outfalls affected by tide and sewer pipes subject to backflow.

Handling: Regular inspection is needed (US EPA, 1999) but no specific maintenance is required if the valves are not exposed to the accumulation of debris or present problems, such as warpage, leaks and cracks.

Requirements: Flap valves should be fixed so as to avoid the accumulation of debris around the invert.

It is convenient that valves are installed within an outfall bay or otherwise protected from direct wave action by baffles (Mission Rubber, 2010).

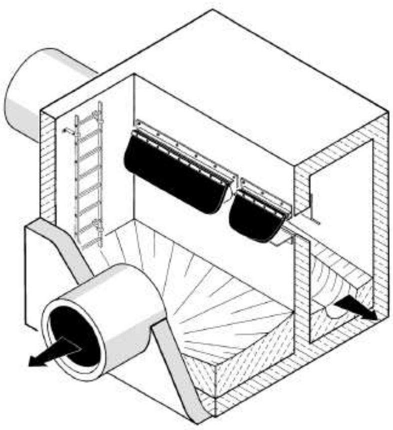
Advantages: Simple in construction and operation and inexpensive devices.

Limitations: Typical flap gates are subject to fouling, sticking, warpage and to become stuck. Stainless steel flap gates require appreciable hydraulic heads to operate against their own weight, which may aggravate flooding. Elastomeric (duckbill) check valves can overcome many of those problems and are designed to open with smaller head requirements and to close over larger debris (EPA, 1999). Some are manufactured with an outer layer specially formulated to repel growth of marine organisms (Power Plant Supply Co, 2010). Check valves manufactured with flexible rubber flaps may also reduce headloss and improve corrosion resistance (John Meunier Inc., 2008).

Further characteristics/Comments: In particular cases, such as for basement protection, it may be convenient to combine a flap valve (for automatic closure) with a ball or gate valve (that requires manual or hydraulically activated closure) to provide a more positive seal (Kansas Ready.gov Web site, 2010, http://www.ksready.gov/floods.shtml). Valve chambers shall be provided where necessary to allow maintenance (EN 752:2008).

Examples:

Figure 8-1: Elastomeric (duckbill) check valves. Image: Power Plant Supply Co. (http://www.powerplantsupplyco.com/products.php?prod_id=105)



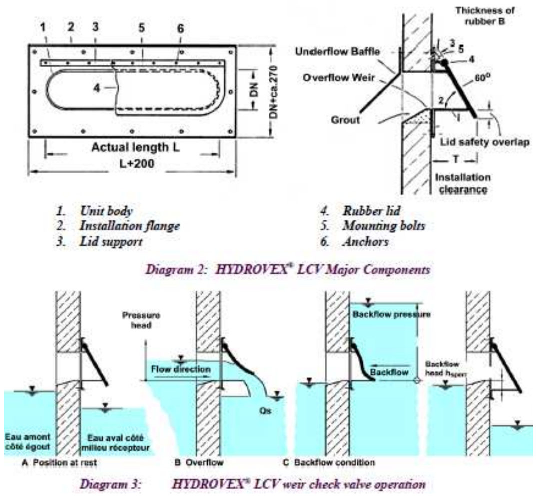


Figure 8-2: Non-return valves manufactured with flexible rubber flaps within a CSO structure. Image: John Meunier Inc. HYDROVEX® LCV Check Valve (http://www.veoliawaterst.com/processes/lib//pdfs/productbrochures/brochures_hydrovex/B546jz5WLh70IQ51jwhu3ZiQ.pdf)

References: Mission Rubber (2010), US EPA (1999), Power Plant Supply Co (2010), John Meunier Inc. (2008), Kansas Ready.gov Web site (2010).

8.4.2 Disconnect upstream catchments from downtown areas

Description of measure: Disconnect sewers draining upstream catchments to low-lying drainage system.

This may also be achieved by the use of non-return valves within the sewer network (see section 8.4.1 of this report).

Effect/objective: Mitigate floods in low-lying areas caused or aggravated by stormwater transfer from upstream catchments.

Prevent runoff contamination by foul water overflowed from the sewers.

Handling: The use of non-return valves requires regular inspection.

Application area: Low-lying sewer networks prone to flooding.

Requirements: The interceptor sewers draining the upstream catchments must be able to work with both gravity and pressurised flow along the low-lying area.

Limitations: Network disconnection usually requires the construction of additional outfall sewers or of a new shallow drainage in the low-lying area.

This measure may be difficult to apply if the upstream sewer network has several connections to the downtown network.

Further characteristics/comments: In the case of a combined sewer along the waterfront it should be evaluated the viability to construct separate storm sewers (NYCDEP, 2010, Chapter 13, p.18).

8.4.3 Resize or relocate to higher locations CSO structures impacted by tide

Description of measure: Resize or move to higher locations CSO structures influenced by tide.

Effect/objective: To rehabilitate the performance of the CSO structures impacted by climate changes, improving the interception of foul water to the WWTP and avoiding the intrusion of sea water to pumping stations and to WWTP (which increases costs and risks of failure and impacts the biological treatment).

Handling: Resize or relocate CSO structures will probably reduce maintenance needs.

Application area: CSO structures.

Requirements: Relocation of CSO structures may require the construction of new interceptor sewers.

Resize and relocation of CSO structures may significantly depend on local conditions and topography.

Advantages: Eliminate or reduce the impact of sea water level in the CSO performance, improving the confidence and resilience of the system.

Limitations: The area located downstream CSO structures enlarge due to its relocation, increasing the foul flow which may need to be pumped to the WWTP.

Further characteristics/comments: It should be evaluated the viability to separate the sewer system located downstream of the CSO structures (see section 8.4.4 of this report).

The downstream sewer outfalls must be equipped with tide valves (see section 8.4.1 of this report).

References: Matias et al. (2010), Semadeni-Davies *et al.* (2008).

8.4.4 Separate combined sewers

Description of measure: Convert combined sewer systems in separate systems.

Effect/objective: Improve foul water and stormwater separation.

Reduce stormwater inflow to pumping stations and WWTP and improve the quality of wet-weather discharges to the receiving bodies.

Application area: Applicable to the whole catchment, but may be particularly relevant in areas influenced by tide (NYCDEP, 2010, p.18).

Requirements: Requires sewer system rehabilitation and typically the construction of new sewers for the foul water or the construction of a separate surface water drainage system.

Most building drainage systems may also need to be separated.

The existing sewer network has to be carefully repaired so that the holes left by the disconnected sewer entrances do not become a location for groundwater to enter.

(Pitt, 2001, p. 147; Thames Water, 2010a, p. 64)

Advantages: - Reduce inflow to the WWTP; - Improve the level of treatment at the WWTP; - Improve the quality of the wet weather discharges and, consequently, the quality of the receiving water and; - replace aging infrastructure (Municipality of Leamington, 2006, p.2).

Limitations: Separation of combined sewers may be conditioned by soil occupation, i.e. by other existing infrastructures.

Separation of sewer systems draining large areas is expensive and may require a long period of time to implement (Pitt, 2001; Thames Water, 2010a, p. 64).

The implementation of a new foul or new surface water network may have high negative social impacts during construction, due to transport disruption, access restrictions for residents, restaurants, businesses and tourist attractions, noise and odour pollution and the presence of heavy vehicles and machinery (Thames Water, 2010b, p. 53-55).

Further characteristics/comments: Where a new system is being proposed, surface water should be kept separate from other wastewater (EN 752:2008).

References: NYCDEP, 2010, p.18; Pitt, 2001, p. 147; Thames Water, 2010a; Thames Water, 2010b, p. 53-55; Municipality of Leamington, 2006, p.2).

8.4.5 Stormwater and overland flow control

Description of measure: Restrict stormwater entering the sewer system, through implementation of inlet controls and disconnection of roof and other impervious areas, create surface flow path diversions and enhance the inlets capacity in critical flooding areas.

Effect/objective: Enhance inlet and overland flow preventing flooding in low spots and low-lying areas.

Requirements: Requires a comprehensive assessment of the catchment, so as not to transfer major problems from one area to another, but to share the risks in a most cost-effective solution.

Advantages: Can be implemented in phases and separate actions.

Limitations: Water can build up on private property creating liability issues for the water utility.

Further characteristics/comments: Runoff diverted from impervious areas and overland flow may be retained and infiltrated by decentralised solutions such as described in sections 3.1.1 and chapter 7.

References: City of Toronto (2008), Waters *et al.* (2003), WMO (2008).

8.4.6 Sewer system rehabilitation

Description of measure: Rehabilitate the sewer system by means of repair, renovation or replacement of sewers and manholes.

Effect/objective: Reduce sea water and ground water intrusion through damaged sewer networks.

Integrated improvement of hydraulic, structural, environmental and operational performance of the sewer network.

Application area: Applicable to the whole catchment, but may be particularly relevant in the area influenced by tide.

Requirements: Open-cut and trench-less techniques exist for sewer system repair, renovation or replacement.

Selection of the most appropriate rehabilitation technique depends on factors, as follows: nature and extension of existing deficiencies; structural, hydraulic, environmental and operational performance requirements for the system; costs and phasing; and local conditions, such as catchment activities, traffic, soil and subsoil occupation and relationship to other infrastructure works.

Further characteristics/comments: Sewer system rehabilitation will also contribute to reduce sewer exfiltration.

References: CEN (2008), prEN 15885:2008, Stein (2001), Waters *et al.* (2003).

8.4.7 Built in-sewer storage tanks or tunnels

Description of measure: Built in-sewer storage tanks or tunnels.

Effect/objective: Attenuate peak flows and/or reduce CSO discharge impacts (in the last case, decreasing CSO discharge frequency, volumes and associated pollutant loads).

Handling: Needs regular maintenance, which may require significant manpower if sedimentation occurs. Tide may aggravate sedimentation conditions.

Application area: Sewer systems, but particularly in those located in densely urbanised areas.

Requirements: Sizing and design must be based on studies at the basin scale, using mathematical models and, where appropriate, integrating impacts at the WWTP and receiving water bodies (Ashley et al., 2002; IETC, 2002, Section 3, Chapter 6.11.1).

Advantages: Underground construction, requiring less space availability at the surface than other solutions.

Well-known solution.

The storage potential of detention facilities usually can be increased through the use of real-time control (see section 3.1.5).

Limitations: Usually requires some maintenance.

Stormwater is not managed as a resource or as an amenity source.

Energy consumption and consequent increase of costs and carbon footprint if pumping is required (Stovin et al., 2007, p.5 and p.22-23).

Further characteristics/comments: Detention structures may also serve to equalise dry-weather flows or to provide treatment by settling to wet-weather discharges.

Storage allows increasing the volume of combined flow sent to the WWTP, but may also affect the WWTP performance (Ashley et al., 2002).

This measure was further developed in section 3.1.3 of this report.

Examples: Thames Tideway Strategic Study (TTSS); IETC (2002, Section 3, Chapter 6.11.1).

References: Burroughs (1999), Stovin et al. (2007, p.5 and p.22-23); IETC (2002, Section 3, Chapter 6.11.1); Ashley *et al*. (2002).

8.4.8 Provide in-receiving water storage facilities

Description of measure: Install floating pontoons and flexible curtains in the receiving water, near the CSO outlets, to create an in-receiving water storage facility.

Effect/objective: Reduce the frequency and volume of CSO discharges.

Handling:

Application area: Receiving water body.

Requirements: Stored CSO flows have to be pumped to the WWTP after the storm.

Advantages: Does not require land or underground space availability.

Limitations: The feasibility of this technology depends in part on whether the floating pontoons are a hindrance to navigation. The structure needs to be protected from damage caused by high winds or wave action. The availability of volume depends on tidal variations (Philadelphia Water Department, 2009, Section 8, p9).

Pumping to the WWTP requires energy consumption and, therefore, increases the costs and carbon footprint of the solution.

Further characteristics/comments: Emptying the stored water following the storm may affect the WWTP (Ashley et al., 2002).

According to Philadelphia Water Department (2009, Section 8, p9), this technology has been used for CSO control in Brooklyn, New York, but no example was found in the literature or internet.

Field et al (1995) describe a research installation built in the USA that uses an operating principle based on density difference for displacement. The sea water is displaced vertically by lower density CSO influent which forms a layer above the denser sea water. According to these authors, in the late 1970's there was an application for stormwater control in three freshwater lakes near Stockholm, Sweden, using sequentially adjacent bays with openings between them to allow the movement of the stormwater and lake water, based on a plug flow principle..

References: Field et al (1995); Philadelphia Water Department (2009, Section 8, p9); Ashley et al. (2002).

8.4.9 Protect pumping stations, WWTP and other facilities

Description of measure:

- Protect housing, mechanical and electrical equipment and real-time control devices from flooding caused by the joint effect of high intensity rainfall and tide level. This measure can be achieved by increasing elevation of equipment within buildings, making building openings watertight, constructing barriers or levees or raising or relocating the facility.

- Improve access to assets during floods.

- Protect infrastructures and equipment from increased corrosion conditions due to saline water intrusion and, in the case of higher temperatures, increased levels of septicity. This measure can be achieved by using corrosion-resistant materials, protective coatings and ventilation systems.

- Review the needs for back up power supply and warning and telemetry systems since the risk for power failure and other problems is higher during extreme weather situations.

- Ensure safe, reliable and control odour operations to manage higher risks of flooding and septicity.

- Prevent sea water intrusion into the sewer network through outfalls, CSO structures and degraded sewers and manholes. This measure can be achieved by adopting the measures presented in sections 7.2.1, 7.2.3 and 7.2.5.

Effect/objective: Protect pumping stations, WWTP and other facilities from higher risks of flooding and from damage and failure of equipment.

Application area: Pumping stations, WWTP and other facilities.

Advantages: Improve overall performance and reliability of the system, reducing operational costs and risks of flooding and of direct discharges to receiving water bodies.

Further characteristics/comments: The system-wide interactions between the different facilities, interceptors and forcemains must be considered to identify where and how specific improvement projects should be combined (Paschke and Simon, 2007). Protective measures should be coordinated with rehabilitation options and designed based on a risk analysis and a cost-benefit assessment. Measures should be prioritised based on a strategic source of information and following an updated ongoing framework for regular planning (King County, 2008).

References: King County (2008); Paschke and Simon (2007), WMO (2008).

8.4.10 Upgrade pumping stations

Description of measure: Resize, upgrade or even relocate pumping stations.

Effect/objective: Adapt pumping stations to receive higher inflows (from rainfall and from sea water and groundwater intrusion) and to respond to increased pumping requirements, in terms of volume, duration and elevation height, due to the rising downstream water level.

Application area: Pumping stations.

Advantages: This will improve the reliability of the system, reducing operational costs and risks of flooding and of direct discharges to receiving water bodies.

Limitations: Increasing pumped volumes will increase energy consumption and asset deterioration.

Further characteristics/comments: Rising sea water level may also require the installation of pumping stations at stormwater systems currently draining by gravity.

References: King County (2008); Paschke and Simon (2007).

8.4.11 Upgrade WWTP

Description of measure:

- Upgrade processes for increased treatment requirements, in terms of treatment volumes and efficiencies.

- Built detention tanks upstream the WWTP and/or upgrade treatment processes to receive higher inflows and probably more diluted water during wet weather periods.

- Provide salt removal treatment for effluents reused or disposed in sensitive environments (e.g. reverse osmosis).

Effect/objective: Adapt WWTP to receive higher wet and dry weather inflows (from rainfall and from sea water and groundwater intrusion) and to respond to increased treatment requirements, for wet and dry weather conditions.

Application area: WWTP.

Advantages: Improve the quality of the discharges to the receiving water bodies.

Limitations: Treatment upgrade involves capital costs and probably also increases operational costs associated to the use of chemicals, energy consumption and manpower.

Further characteristics/comments: This measure must consider the existing techniques presented in section 4.

References: King County (2008); Howe et al. (2005); Prepared Report D2.4.1.

8.4.12 *CSO and stormwater treatment*

Description of measure: Improve solids separation in CSO structures and built stormwater and CSO treatment facilities as described in sections 4 and 5 of this report.

Treatment may be limited to the removal of solids and floatables from CSO discharges or may include high-rate clarification and disinfection

Effect/objective: Increase level of treatment and treated volume of CSO and stormwater discharges to mitigate pollution in receiving bodies.

Application area: End-of-pipe solution, particularly applicable to systems with significantly polluted discharges or discharging to sensitive bodies.

Advantages: Improve the quality of CSO or stormwater discharges to the receiving bodies.

Further characteristics/comments: This measure must consider the existing techniques presented in sections 4 and 5 of this report.

Examples: Technologies used for removing solids and floatables from CSOs include: baffles, booms, netting systems, swirl concentrators, vortex separators, screens and trash racks.

Recent upgrades in WWTP and CSO sedimentation tanks are using lamella plate clarification and chemically enhanced clarification for wet weather pollution abatement. Two of the most used technologies are the DensaDeg® and Actiflo® which utilize ballasted flocculation. The BioActiflo® is a biologically and chemically enhanced clarification.

Some of the more common technologies for disinfection include chlorine gas, sodium hypochlorite, chlorine dioxide, ultraviolet radiation, and ozone. Sodium hypochlorite is the most common technology for disinfection of CSO discharges, which have the disadvantage of causing toxic effects on the receiving waters. Two of the more common means for inactivating chlorine in treated effluent are application of gaseous sulfur dioxide or liquid sodium bisulfite solution.

References: Burroughs (1999), David L.M. and Matos J.S. (2005), Philadelphia Water Department (2009), NWPCA (2007).

8.5 Soft structural measures: decentralised solutions

Description of measure: Soft structural measures usually intend a decentralised stormwater management reducing the hydraulic input to the sewer system by means of source control; attenuating peak flow by mobilisation of surface storage or provision of additional storage; reducing pollutant inputs using vegetation to filtrate or adsorb pollutants from runoff before entering the system; decreasing planned pollutant discharges to receiving waters by treating surface water discharges. These adaption techniques are described in detail in sections 3.1.1 and 7.

Effect/objective: their use should be considered as an adaptation measure to cope with changes in rainfall characteristics by:

- reducing runoff rate and peak, thus the risk of downstream flooding;
- reducing runoff volume, thus the risk of downstream flooding and system overflow;
- reducing pollutant concentrations in stormwater, thus protecting receiving waters.

Application area: these solutions can be applied to the whole catchment, according to their type (see sections 3.1.1 and 7). However, their application in downstream areas can be limited by tide impact that could affect their performance.

Handling: these solutions must be well maintained to assure good performances (see sections 3.1.1 and 7).

Requirements: As previously mentioned, these measures must be appropriately combined with measures adopted to minimize tide effects. The requirements for each measure are presented in sections 3.1.1 and 7.

Comments: these measures can be applied to systems already consolidated; neverthless their potential must be considered in the development of new systems or new expansion areas.

Examples: pervious pavements, infiltration trenches, soakways, green roofs, swales, ponds, detention basins.

References: NSUDSWG (2004), Woods-Ballard et al. (2007), EN 752:2008, AGO (2007), Penney and Wieditz (2007), TRCA (2009).

8.6 Non structural measures

8.6.1 Operational solutions

An effective operation of sewer systems is a means to improve its performance and allows for a better management of the whole system. This is especially relevant when sewer systems have to respond to considerably different solicitations. Operational solutions can be implemented by using regulation, developing operation plans, monitoring the system, using real-time control (RTC) or by reducing and controlling extraneous inflows to the system, namely stormwater inflows and infiltration.

Description of measure: Flow regulation through the use of valves, gates, weirs, pumps.
Effect/objective: maximization of the use of existing flow capacity and storage
Application area: sewers, storage tanks, WWTP, pumping stations, upstream and downstream parts of the catchment.
Handling: these solutions must be well maintained to avoid failures and to enssure good performances.
Requirements: these measures must be appropriately combined with measures to increase storage volumes as those presented in section 3.1.3.
Comments: these technologies can be applied to systems already consolidated installing new or enhancing existing regulators.
References: CEN (2008), Laaser et al. (2009).

Description of measure: Operations plan.
Effect/objective: to ensure preventively that sewer systems perform in accordance with the functional requirements.
Application area: sewers, manholes, outfalls, pumping installations, overflows, detention tanks, inverted siphons, separators, grit chambers, gullies.
Handling: definition of inspection routines and of operation of pumping stations, special components and detention tanks; setting dam boards, valves and weirs; assignment of responsibilities for carrying out procedures; definition of contingency plans.
Requirements: knowledge of the system and expected changes in rainfall and tide scenarios.
Comments: this measure must consider the existing techniques of operation of pumping stations and WWTPs presented in section 3.1.3
References: CEN (2008), AGO (2007), Penney and Wieditz (2007).

Description of measure: Monitoring the system.
Effect/objective: to record relevant variables in the sewer system such as dry weather flow and inputs to the system; effluent quality, quantity and frequency at point of discharge to receiving waters; toxic and/or explosive gas mixtures and discharge from system to treatment works.
Application area: sewers, manholes, outfalls, pumping installations, WWTP, overflows, detention tanks.
Handling: definition of monitoring routines, maintenance of the equipment and sensors, samples conservation and handling, data collection, data analysis and processing.
Requirements: suitable instrumentation including: monitoring equipment (e.g. level, flow, pressure, speed, voltage, current, power factor, gas content, hours run etc.); indication of operation of duty/standby pumps; telemetry systems or data transmission systems. Knowledge about instrumentation, safety procedures and data analysis.
References: CEN (2008), IWA (2010).

Description of measure: Real-time control.
Effect/objective: improve use of wastewater infrastructure reducing overflow volumes and loads as well as capital and operational expenditure.
Application area: sewers, storage tanks, pumping installations.

Handling: maintenance of the equipment and sensors, samples conservation and handling, data transmission. The control can be manual, automatic as well as local, global or integrated (sewer system and WWTP). See section 3.1.5.
Requirements: sensors (raingauges, water level sensors, flowmeters, quality sensors); controllers (pumps, gates, weirs, valves); supervisory control and data acquisition, data transmission systems, operator interfaces. See section 3.1.5.
References: Schütze et al., 1999, Schütze et al. (2004a), Schütze et al. (2004b)

Description of measure: Reduction and control of inflow and infiltration (I/I).
Effect/objective: improve use of wastewater infrastructure reducing inflow and infiltration volumes as well as decreasing capital and operational expenditure.
Application area: sewers, sewer cross connections, manholes, service connections.
Handling: maintenance of the equipment and sensors.
Requirements: monitoring of the system, disconnection of wrong and illegal connections, rehabilitation or renovation techniques; trained personnel and equipment.
Comments: different methods and techniques can be selected, depending on the objectives and conditions of application (see section 4).
References: Woods-Ballard et al. (1997)

8.6.2 Maintenance solutions

The strategies for maintaining drain and sewer systems are planned or reactive, or a combination of both. An effective maintenance of sewer systems, through the development of maintenance plans, allows for a better functional performance of the system.

Description of measure: Removal of flow constrictions and cleansing.

Effect/objective: restore the use of existing flow capacity.

Application area: sewers, manholes, inlets, service connections, inverted siphons, storage structures.

Handling: periodic cleaning; waste disposal is subject to legal requirements

Requirements: requires trained personnel and equipment.

Limitations: may need regular interventions.

Comments: different cleaning techniques can be selected, depending on the objectives and conditions of application (e.g. *manual or mechanical escavation, flushing, jetting, high pressure water jetting with high volume suction, winching, rodding, flails, cleaning balls or scour plates)*

Examples: roots removal, grease removal, sediment cleaning

References: CEN (2008), EN 14654-1:2005

Description of measure: Equipment maintenance.

Effect/objective: reduction the risk of failures.

Application area: pumping stations, wastewater treatment plants, valves and regulators, gates.

Handling: periodic cleaning, pumps overhaul.

Requirements: requires trained personnel.

Limitations: may need regular interventions.

Examples: clear debris or sediment that may block the flapper in the valve; mechanical or electrical equipmente repair.

References: CEN (2008)

Description of measure: Local repair or local replacement of damaged pipes or other structures.

Effect/objective: to maintain the function of pipes and other structures and equipment.

Application area: sewers, manholes, inlets, service connections, inverted siphons, storage structures.

Requirements: requires trained personnel.

Comments: Reactive (or crisis) maintenance involves responding to failures and problems as they are identified. It is appropriate for those parts of the system that can function with little or no maintenance. Different repairing techniques can be selected, depending on the objectives and conditions of application.

References: CEN (2008)

Description of measure: Maintenance plan.

Effect/objective: to ensure that the sewer system performs in accordance with the functional requirements.

Application area: sewers, manholes, outfalls, pumping installations and equipment, WWTP installations and equipment, overflows, detention tanks, inverted siphons, separators, grit chambers, gullies.

Handling: The strategies for maintaining drain and sewer systems are planned or reactive, or a combination of both.

Requirements: requires trained personnel.

Comments: definition of the type of maintenance strategy to be used in each component of the system and the monitoring requirements and frequencies. Local repair or local replacement of damaged pipes or other structures in order to maintain their function; cleaning and removal of sediments, obstructions to restore hydraulic capacity; maintenance of mechanical plant. Planned maintenance includes a programme of work to remedy the defects and problems identified during inspection. It is particularly required to reduce the incidence of failure where the consequences are severe.

References: CEN (2008), AOG (2007)

8.6.3 Planning and design criteria

Description of measure: Planning and design methods and criteria.

Effect/objective: ensure that systems can continue to function as designed under future climate scenarios.

Application area: in new developments and systems or existing developments and systems.
Requirements: alternative planning and design methods and criteria.
Comments: to include future climate change conditions in planning and design of new systems and rehabilitation solutions, restrict the site selection of new facilities.
Examples: design based on risk criteria; consider climate change conditions in the design of systems, SUDS and storage facilities.
References: NSUDSWG (2004), Shaw et al. (2007), AGO (2007), Penney and Wieditz (2007), TRCA (2009), IWA (2010).

8.6.4 Regulation, incentives and public awareness measures

Description of measure: New regulation and legislation.
Effect/objective: to enforce and define application conditions and impact control of different measures or solutions (e.g. SUDS, disconnections).
Application area: in new developments or existing developments.
Requirements: legal expertise, existence of a regulatory body.
Comments: definition of land use regulations, runoff control regulations, design criteria, control obligations.
References: EPA (1993).

Description of measure: Incentives and penalties.
Effect/objective: to ensure good sewer system performance by promoting the use of adequate solutions, e.g. use of SUDS, elimination of wrong cross-connections.
Application area: new developments, existing developments.
Requirements: definition of incentives or penalties
Comments: Financial incentives could be used to encourage developers, sewerage undertakers and customers, to promote the use of best practices for volume reduction, peak attenuation, and pollution reduction.
References: DEFRA (2007).

Description of measure: Public awareness and education.
Effect/objective: to build community and public awareness, information, education and support.
Application area: development areas, schools.
Handling: dealing with public and large audiences.
Requirements: public relations and communication techniques.
Comments: development of information programmes, public partnerships.
References: EPA (1993), AGO (2007).

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