Intermittent Discharges - Environmental Review, Treatment and Solutions

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Acknowledgement and Disclaimer

WRc would like to acknowledge United Kingdom Water Industry Research Limited (UKWIR) for supporting the project on intermittent discharges and their kind permission to present a summary of the project to WaPUG at the Spring Meeting. This paper is based on information previously reported to UKWIR members through the final project report [1].

1 Introduction

A collaborative project has recently been completed to investigate unconventional treatment options for CSO discharges as alternatives to sewer storage. The project has been commissioned by UKWIR.

The project has been initiated against the considerable investment by Water and Sewerage Companies (WSCs) in the remediation and upgrading of CSOs that is due to continue and intensify over the AMP3 period (2000-2005). There is a concern in the Water Industry that future discharge standards from CSOs might be tightened substantially, with requirements to meet stringent quality criteria, for example in terms of BOD or bacteriological standards. When considered within the context of OFWAT's final determination figures, it is important that WSPs investigate alternative, sometimes novel, cost-effective solutions to problems of CSOs to ensure regulatory compliance at reasonable cost.

As part of the project the following tasks have been undertaken:

- Assess the environmental impact of intermittent discharges on both inland and coastal receiving waters;
- Review processes which may be suitable for treating intermittent discharges;
- Evaluate suitability of short-listed processes or options;
- Assess the feasibility of developing accurate mathematical simulations of selected processes or options.

The research contractor for the project is WRcPLC.

2 Survey of CSO Discharges and Environmental Impact

A UCSO questionnaire was sent to members of the Steering Group. The nine utilities, which responded, have between them approximately 7,000 UCSOs, of which half are scheduled to be upgraded in AMP3. The survey results indicate the following:

- Majority of UCSOs fail due to aesthetic quality of the discharged stormwater;
- Significant number are failing to meet microbiological standards;
- A number of UCSOs fail to comply with quality requirements (e.g. BOD, AmN).

UCSOs display a broad range of spill rates with an even distribution across the range. The range of UCSO spill flows is vast, from 1 l/s up to 56,000 l/s.

UCSO locations are distributed fairly evenly between rural, urban and suburban areas. A majority discharge to small streams, but there were also significant numbers that discharged to sea or large watercourses.

The major disadvantages in respect of fitting a treatment plant at a CSO are:

- Site remoteness in rural areas - limiting manual supervision and intervention and making it difficult to ensure that the process functions adequately and that failures are dealt with in a timely fashion;
- Poor road access - necessary for installation and maintenance of either storage or treatment facilities;
- Lack of local power supplies - required by most upgraded installations;
- Restricted space for construction - limiting selection of suitable treatment options;
- Proximity of housing (in urban areas) – raising concerns about the impact of noise and odour from treatment.

A significant number of UCSOs will require storage solutions. In the event that storage cannot be adopted as the means of coping with the excess volume of storm water, then treatment processes would need to be applied.

3 Identification of Suitable Treatment Processes

A survey of plant supplier information within the UK and overseas was undertaken to identify process options at CSOs suitable for removal of BOD, ammonia, SS, bacteria and viruses. Scientific literature was also reviewed to identify options. Anaerobic treatment processes were excluded from the survey because they are more suited to tropical countries and do not operate as effectively at the low wastewater temperatures found in the UK during the winter.

The survey and review identified about 49 different treatment processes. These could be classified into seven categories of treatment comprising: Settlement, Flotation, Filtration, Centrifugation, Biological treatment, Disinfection, and Physical/chemical removal of ammonia.

The following criteria were used to select a shortlist of processes:

CAPEX - Substantial expenditure is required to upgrade CSOs. Hence methods that minimise capital cost are of paramount importance.

Maintainability - The plant must be mechanically reliable in operation.

Operability – The plant should be simple to operate.

Small Footprint - Space at CSOs is limited for the installation of treatment plant. Hence plant should have a minimum footprint.

Low Power - Treatment plant installed at a CSO should either require no power or have a low power requirement.

No Chemicals - It is an advantage to install plant, which does not require chemicals because this avoids their transport to site, which could cause a disturbance to the local population.

Minimum Nuisance - CSOs can be located in built up areas close to housing. Hence treatment plants installed at CSOs should be quiet and should not be prone to the generation of odours or cause a fly nuisance.

Sensitivity to flow changes – It is beneficial to install plants that can treat peak flows and loads with minimal impact on effluent quality.

The short-listed processes and the main reasons for their selection are discussed below:

- **Ballasted sedimentation** [2] provides for a compact treatment process which occupies less area than chemically-assisted sedimentation;

- **Chemically-assisted lamella sedimentation** is widely used in the wastewater industry compared to the limited use of ballasted sedimentation;
- **Lamella DAF** has a small footprint compared to other types of DAF [3];
- **Pulsed-bed sand filters** [4] have the lowest head requirement of all the different types of sand filter that are available and have been designed for filtration of settled wastewater. The other types of filter have been rejected;
- **Vortex separators** [5] with chemical enhancement for sedimentation, may also be competitive. They are claimed to have a smaller footprint than lamella settlers;
- **High-rate biological filters** are suitable for removal of soluble BOD as well as particulate BOD and SS. The levels of soluble BOD present in storm water are low and may not be sufficient to make this type of process cost-effective.
- **Rotating Biological Contactors** are suitable for removal of soluble BOD and also nitrification.
- **Submerged Aerated Filters and Biological Aerated Filters** [6] are suitable for removal of soluble BOD and also nitrification.
- **Membrane activated sludge treatment** are compact and produce a high-quality effluent. Again there may be issues of ensuring that the membrane can discharge adequate flow for all expected inflow intensities, but this process may be worth further investigation. There are also requirements associated with ensuring adequate screening of the storm water to ensure that the membranes do not rapidly foul which would make the process uneconomic.
- **Reed beds** [7] have been used for treatment of stormwater at wastewater treatment works. The land area required by a reed bed is likely to make the process only feasible for CSOs with small spill volumes.
- **Chemical Disinfection (e.g. chlorination)** [8,9] using sodium hypochlorite is a low-cost method for treating spills from CSOs. Per acetic acid and chlorine dioxide may also be suitable. By-products from chemical treatment may have a harmful effect on the environment and this approach is not accepted by the Environmental Regulator for continuous discharge.
- **UV disinfection** [5] is the method recommended by the Environmental Regulator to disinfect secondary effluent from wastewater treatment works. Primary effluents contain higher levels of suspended solids, which shield micro-organisms from UV radiation. Hence pre-treatment of CSO spills would be required. Use of iron-based coagulants can decrease UV transmission because iron absorbs UV. In addition iron and aluminium salts have been implicated in fouling of UV systems.

Although ballasted sedimentation has been used to treat storm water spills, other short-listed processes have not been used in such applications. Consequently, several uncertainties exist regarding the viability of these processes in dealing with intermittent discharges.

For example there is a lack of information on the ability of biological treatment systems to survive and recover from periods of starvation, and about their ability to be maintained in a healthy state through bleeding in small quantities of substrate during periods of dry weather.

In the case of physical chemical treatment systems it is not clear how quickly they would be able to start up and respond to the first spill. It may require flow sensors located upstream in the sewerage system to warn of the onset of a storm so that the treatment plant has sufficient time to start up in advance of the spill.

Piloting work would be essential to demonstrate the suitability of these processes for application at CSOs.

4 Technical Issues to Consider in determining Treatment Solutions

4.1 Effect of Effluent Quality on Plant Selection

The effluent quality requirements will vary significantly between CSOs. Some sites may only require a reduction in aesthetic pollution, for which screens would be appropriate. Other sites will require treatment of pollutants (e.g. BOD, AmN). Owing to the variation in effluent quality requirements between sites, only broad categories of required effluent quality can be defined at this preliminary stage. Potential treatment plant options for each of these categories are given below:

- BOD, SS – physical/chemical treatment (e.g. lamella separator, ballasted sedimentation, dissolved air flotation, vortex separator) and biological treatment (e.g. high-rate biological filter, rotating biological contactor, horizontal-flow reed bed treatment),
- AmmN – biological treatment (e.g. membrane activated sludge plant, biological aerated filter, vertical-flow reed bed),
- Microbiological pollutants (bacteria and viruses) – chemical disinfection (e.g. chlorination), UV disinfection, membrane treatment.

The Environmental Regulator is considering applying consents for aluminium and iron. This may restrict the applicability of physical/chemical treatment systems and increase the opportunity for installation of biological treatment plants at sites where storage is not practicable.

Before chemical disinfection can be considered, the Environmental Regulator would require environmental impact studies to be undertaken requiring complex chemical and ecotoxicological analyses. The risk of producing residuals and by-products, which have a harmful effect on the environment, would be assessed. These studies are extremely expensive and are not practical to carry out at every site. This would make the economics of chemical disinfection unsound in comparison to UV disinfection.

4.2 Storm Water Flows and Loads

The constituents of storm water are similar to that of a dilute sewage. It contains particulate and dissolved biodegradable matter (BOD), organic matter which is not easily biodegradable (COD), volatile suspended solids (e.g. fats, grease), inert solids (e.g. grit, plastics), nitrogen (e.g. ammonia), phosphates, and pathogens (e.g. bacteria, viruses). The design of each process needs to take account of the effect of the lower concentration of pollutant matter on plant performance.

The flow rate of storm water varies widely between CSO sites depending on the characteristics of the sewerage system and the severity of the wet weather. The key design parameter is the maximum flow rate of storm water that will need to be treated.

A prime consideration in the design and operation of sewerage systems is the CSO spill frequency. It depends on the relationship between sewer hydraulic capacity, sewage flow rate and storm water run off. It varies widely between CSOs. At some sites the annual spill frequency may be as low a five times per year. At other sites the spill frequency is significantly higher, e.g. fifty times per year.

The spill frequency is an important factor to consider when assessing the feasibility of installing treatment plant at a CSO. For example the feasibility of installing a treatment plant at a CSO might be expected to be more likely if a spill occurs once per week than if it occurs once per month.

During freezing temperatures in the winter, salt (deicer) applied to roads can increase the levels of chloride present in run-off from levels of less than 100 mg/l Cl to levels of between 2000 to 3000 mg/l Cl. In principle these concentrations are sufficient to impact on the nitrification performance of biological treatment processes increasing effluent ammonia levels. However nitrification rate falls with temperature and at low temperatures (e.g. 5 to 8ºC) it stops. The Urban Waste Water Treatment Directive (UWWTD) permits operators of biological treatment plant to seek dispensation during exceptionally cold temperatures when deicing salt would be applied.

4.3 Plan Area Requirements

There is a lack of space at CSO sites. Hence a major consideration is the compactness of the treatment plant. Will it fit in the space available at such sites? Often the site of a CSO is close to housing. Consideration needs to be given to environmental aspects such as odour generation, noise from blowers and pumps, and visual obtrusiveness.

Table 1 below presents typical superficial velocities for some of the options. Dividing the spill rate by the superficial velocity enables the plan area requirement for the treatment plant to be estimated.

The land area requirement for a treatment plant should include not only the area of the main plant and equipment but also a buffer zone round the plant to allow for roads and landscaping. This land area requirement should be compared with that available. If the required area is exceeded, a more compact treatment plant should be considered.

Plant type	**Superficial velocity (m/h)**
Ballasted lamella plate sedimentation	100 to 150
Vortex separator	50
Lamella Dissolved air flotation,	30
Chemically-aided lamella plate separation	15 to 20
High-rate biological filter	20
Pulsed-bed mineral medium filter	10
UV disinfection	20
Chlorination	5
Biological aerated filter	2 to 3
Membrane activated sludge plant	2 to 3
Rotating biological contactor	0.2
Reed bed	0.05 to 0.1

Table 1 - Plant indicative superficial velocities

Table 1 above indicates that reed beds operate at the lowest superficial velocity (about 0.1 m/h) and hence have the largest plan area requirement, e.g. a spill rate of about 100 m^3/h would require a plan area of about 1000 m^2. Thus reed bed treatment systems would require a substantial area to treat large spills and hence are not practicable for such applications.

For large spill rates (25,000 m^3/h), physical/chemical treatment processes which operate at high superficial velocities (e.g. ballasted sedimentation – 100 m/h) have comparatively small footprints (e.g. 250 m^2).

4.4 Pre-treatment Requirements

It is expected that each of the short-listed processes would need to be preceded by suitable screening plant to remove gross solids and prevent blockages in downstream plant and equipment. For physical/chemical treatment plant and activated sludge treatment systems screening would be sufficient pre-treatment. In the case of membrane activated sludge plant, fine screens (e.g. 2 mm) would be required to avoid fouling of the membrane surface by fibres in the storm water.

At wastewater treatment works, high-rate biological filters and biological aerated filters are often located downstream of primary sedimentation tanks. There are a few examples of biological filter plants treating screened sewage e.g. WRc LoSluj process. At CSO installations the use of fine screening upstream of biological filters should be adequate dispensing with the need for sedimentation tanks.

For UV disinfection to be effective, physical/chemical pre-treatment plant would be required to reduce storm water SS down to levels below about 20 to 30 mg/l. Such pre-treatment may need to use cationic polyelectrolytes to avoid potential scaling of UV tubes arising from the use of iron or aluminium salts.

4.5 Treatment Plant Requirements

Biological Treatment

A preliminary assessment of the feasibility of biological treatment has been undertaken using dynamic modelling package to simulate the performance of an activated sludge plant reactor treating CSO spills. Two examples were tried. One used artificial spills and the other spills as measured in a catchment over a 1-year period. For both spill scenarios, no maintenance flow was attempted to the bioreactor - during periods of no-spill the reactor survived solely through endogenous respiration.

The results of this assessment indicate that there is negligible treatment of the influent ammonia, given the slow growth rates of nitrifiers. Large quantities of nitrifiers would die off during the periods when there was negligible ammonia in the tank, and then fail to grow back rapidly enough during the CSO spill event.

The results also indicate that initially effluent from the bioreactor contains a high COD. Heterotrophs grow rapidly and bring the COD down. Because of the high growth rate the response of the bioreactor to the incoming COD is rapid.

In principle a small sewer bleed to the aeration tanks would be required to maintain the concentration of heterotrophs because of their high growth rate and ability to respond to increases in load. Because of the expected intermittent nature of CSO spills and low growth rate of nitrifying bacteria it may be difficult to maintain an active nitrifier population. For maintenance of biological nitrification, a flow of sewage would be required during dry weather to provide an ammonia load that matched the maximum ammonia load that would be discharged during the maximum storm spill. This would enable a sufficient population of nitrifying bacteria to be maintained during dry weather conditions to treat the storm flows.

During dry weather the treated effluent would be returned to sewer to avoid a discharge of effluent to the receiving waters. Alternatively since a biological treatment plant at a CSO would produce an effluent comparable to that of a traditional activated sludge plant, treated effluent may be discharged directly to the receiving waters during dry weather if consented by the Environmental Regulator.

Physical/chemical Treatment

This type of plant is more amenable to rapid start up and shut down in response to a storm than biological treatment. It would not need a sewer bleed during dry weather.

Start up would need to be triggered by the rise in the level of wastewater within the sewerage system. An appropriate time (e.g. 5 to 15 minutes) would need to be built into the control system between detecting the rise in wastewater level and the occurrence of the first spill so that the plant has sufficient time to start up.

For chemical dosing system a suitable control system would be required to adjust chemical dose rate to SS load of the storm water. A suitable detection system would comprise a flow meter and a turbidity meter to measure storm water flow and quality.

Reed Beds

Constructed wetlands need to be wetted to prevent them drying out in a few weeks of drought and might need to be periodically wetted to prevent this. Sewage cannot be used because it would quickly cause the channels of the bed to clog and fail. An alternative source such as receiving waters, borehole water or stored treated effluent may be required to keep the bed water levels topped up during dry weather.

There is a wide range of different types of constructed wetlands that are available. These include surface and sub-surface flow systems constructed from either soil or gravel are available [10].

4.6 Estimating Process Performance

At present, long-term performance data for treatment plants at CSOs are limited to a number of sites overseas, where ballasted sedimentation has been installed. Reed bed treatment systems have been used at UK sites to treat storm flows at wastewater treatment works but not at CSOs. In view of the lack of performance data available for plant under UK operating conditions, long-term pilot plant testing would be required to demonstrate the reliability of any future process.

The accuracy of mathematical modelling of CSO treatment processes is limited by the following uncertainties:

- Unknown magnitudes and duration of the CSO spill, in both flow and quality;
- Limited data of CSO treatment options with which to derive mathematical models;
- Difficulties assessing correct values for calibration parameters without committing to building a pilot unit.

Despite these limitations, modelling is still a useful tool in providing additional information for making judgements on selection and likely effectiveness of processes.

4.7 Sludge Disposal – Impact on Sewerage System

A benefit of treatment at a remote CSO compared to a sewage treatment works is that screenings, grit and sludge do not need to be handled or disposed of from site. These waste products can be returned to the sewer for transport to the treatment works.

In the event that the downstream sewer or treatment works cannot cope with extra sludge arising during a storm, storage of sludge would also be required. This would require the installation of costly sludge storage facilities, which are unlikely to be cost-effective at a CSO.

5 Economic Assessment of Potential Treatment Solutions

The cost-effectiveness of the short-listed treatment options have been compared on the basis of capital and operating costs estimated for the retrofit of treatment plant options at CSOs. It should be stressed that the costs used for this exercise are indicative only and are required for the purpose of comparing costs of different processes.

The approach adopted for costing has been to treat the plant as a 'black-box', which includes all the equipment associated with the plant but excludes equipment to connect the plant to the CSO and to the receiving waters. Plant sizes have been estimated from the typical maximum hydraulic loading rates that can be applied to each type. Physical/chemical treatment plant is assumed to operate during wet weather when there is a spill. Biological treatment plant is assumed to operate continuously with a sewage bleed during dry weather to maintain biomass levels.

This analysis indicates the following:

- Reed beds appear to be the cheapest option for each of the spill rates;
- Of the other biological treatment processes, membrane activated sludge treatment is the most expensive option and biological aerated filters are the least expensive;

- Of the physical/chemical treatment processes, lamella CAS, Ballasted CAS, DAF lamella and Vortex separator have similar unit costs;
- Of the disinfection process, physical/chemical treatment followed by UV disinfection is the most cost-effective for spills between 100 and 1000 m3/h. At higher spill rates chemical disinfection becomes more cost-effective.

Table 2 presents the most cost-effective options identified for three different spill rates and the three required types of treatment.

Type of treatment	**Size 1 100 m^3/h**	**Size 2 1000 m^3/h**	**Size 3 25,000 m^3/h**
BOD, SS removal	Reed bed (horizontal-flow), high-rate filter, rotating biological contactor, biological aerated filter	Ballasted lamella sedimentation, biological aerated filter	Ballasted lamella sedimentation,
Ammonia oxidation	Reed bed (vertical-flow), Biological aerated filter, Rotating biological contactor, Membrane ASP	Biological aerated filter, Membrane ASP	-
Disinfection	Chemical treatment + UV or chemical disinfection, membrane treatment	Chemical treatment + UV or chemical, disinfection, membrane treatment.	-

Table 2 - Comparison of Potential Treatment Options

6 Conclusions

1. There is no simple, cheap practicable generic solution to improve the quality of CSO discharges. Solutions are likely to be highly site specific.
2. The provision of treatment at CSOs would need to take account of the facts that many rural sites are remote, have poor road access and lack local power supplies. Conversely others have restricted space for construction and would need to avoid creating nuisance from noise and smells.
3. For removal of SS and BOD at small rural catchments, reed bed treatment systems may be most appropriate. Test work is required to demonstrate the optimum method to prevent reed beds from drying out during dry weather.
4. For large urban CSOs the ballasted lamella plate sedimentation process appears to be most suitable for BOD and SS removal. Pilot trials would be required to verify this.
5. For oxidation of ammonia the most suitable process options comprise small footprint plants such as biological aerated filters and membrane activated sludge plants.
6. The accuracy of mathematical modelling of CSO treatment processes is limited by uncertainties over the magnitude and duration of the CSO spill, limited performance data for CSO treatment options with which to derive mathematical models and difficulties assessing correct values for calibration parameters without committing to building a pilot unit. Despite these limitations, modelling is still a useful tool in providing additional information for making judgements on selection and likely effectiveness of processes.

7 References

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