The impact of the controlled emptying of in-sewer storage on wastewater treatment plant performance

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Abstract The use of in-sewer storage is generally considered to be an effective means of minimising the effects of intermittent discharges into receiving watercourses during combined flows. Despite this, very little information is available about the consequential effects these flows may have on recipient wastewater treatment plant performance. Typical problems may include biomass washout (hydraulic), and reduced biological reactor performance due to dilute loading (biological). A study is described where detailed analysis was carried out to ascertain the consequential effects of prolonged dilute loading on an activated sludge wastewater treatment plant in Perth, Scotland. Consideration was given to likely storage volumes which may have been utilised in the catchment to resolve local problems. A comprehensive analysis of resulting treatment plant performance was carried out for variations in flow and various wet weather loadings. It is concluded that storage may cause little or no benefit with respect to ammonia total emissions due to reduced treatment of dry weather flows subsequent to the prolonged combined loading period. This was exacerbated by the long regeneration times of nitrifying bacteria. However, an overall benefit with respect to BOD total emissions would always be expected, as appropriately sized storage would retain the first foul flush at the CSOs, thereby compensating the increased emissions from the downstream wastewater treatment plant.

Keywords Activated sludge treatment plant; CSO storage; fixed emissions; modelling; total emissions

Introduction

The importance of considering the discharges of both the sewerage system and wastewater treatment plant simultaneously to assess the impact on receiving waters is now well known (e.g. Durschlag et al., 1991; Harremoes and Rauch, 1996 and Guderian et al., 1998). However, the integration of planning and management for the various components has traditionally been poor (Lijklema, 1992). Significant progress was made in the UK with the introduction of the Urban Pollution Management (UPM 1st Edition) procedure (Foundation for Water Research, 1994) although the manual intimated the need for further studies on the impact of sewer storage on recipient treatment plant performance. Classical work (Durschlag et al., 1991) on the effect of in-sewer storage on the overall performance of combined sewers and WwTWs showed that increasing volumes of storage eventually produce little benefit in terms of the organic total emissions loads (CSO + WwTW) and may even be detrimental. Principally, due to the prolonging of high hydraulic loads and diluted inflows to the WwTW (Jack et al., 1999). The original conclusions were derived from the conceptual KOSIM model which was designed for long term simulations in response to the German annual loading standards (ATV, 1992). Later work by Guderian et al. (1998) focussed on real time control measures to limit total emissions by controlling the dry weather multiple being passed forward to treatment. Schutze (1998) considered the linking of all models within the rainfall – runoff – discharge chain, recommending that the parallel modelling approach is a prerequisite for investigating integrated control strategies which rely on information from numerous parts of the urban drainage system. The best
multiple of dry weather flow to be treated varies depending on the pollutant under consideration, so that the critical pollutant for a given receiving watercourse needs to be first determined. Control approaches based on available river capacity to accept discharges from treatment plants and sewers have been a further advance (Raso and Malgrat, 2000), however, such approaches may in some cases be opposed by political objections (not technical) to in-river standards rather than more traditional asset performance consenting. The principal objection being primarily due to the lack of control over ambient river concentrations prior to the rainfall event(s). Consequently, upgrading of sewerage systems with potential new in-sewer storage is now seen as a possible threat to the performance of the system as a whole. The principal concerns relate to the treatment plant itself where the typical problems have been highlighted by various authors (e.g. Henze, 1987; Durschlag et al., 1992; Harremoes et al., 1993; Ashley et al., 2001) as:

- aeration capacity exceeded as a result of a sudden impact of loading with oxygen depleting matter, and consequently, a reduction in nitrification capacity
- temperature drop in the reactor affecting treatability
- transport of activated sludge into the secondary clarifier reducing purification capacity
- increase in the solid content of effluent leaving the settling tanks as a result of hydraulic overloading.

Recent studies place an awareness on potential odour and subsequent treatability issues arising from septicity of stored waste-waters (Hvitved-Jacobsen and Vollersten, 2000; Ashley et al., 2001). Consequently new approaches were developed for the assessment of the Perth wastewater system in Scotland for total emission control (Jack, 1999).

**Sewerage system and treatment plant analysis**

The Perth (Scotland) drainage system serves a population of approximately 42,000 and drains around 15 km². The sewerage system is mainly combined with peripheral areas consisting of separate, partially separate and combined systems. The city centre is flat whereas the surrounding subcatchments are steep. This configuration leads to sedimentation problems in some trunk sewers. The WwTW consists of storm tanks, primary settlement, activate sludge aeration and final settlement tanks. Whereas it was recognised that there were no obvious operating problems with the WwTW, the spill performance of the sewerage system was unsatisfactory. A project was therefore undertaken between the Urban Water Technology Centre (University of Abertay Dundee) and the North of Scotland Water Authority, NoSWA to investigate the implications of in-sewer storage on the downstream wastewater treatment plants. The objectives of the project were the following.

- To develop a method to guide engineers through the process of defining the best storage volume (with respect to acute pollution) for any particular catchment.
- To achieve this: develop criteria for the selection of an appropriate computational simulation period required to investigate total emissions whilst minimising computing time; and develop a method to define appropriate rainfall periods for the analysis.

Comprehensive analysis of the sewerage system and wastewater treatment plant should be carried out using long term (10–20+years) continuous simulation, allowing the impact of the CSOs and the WwTW to be assessed for receiving water impact and acceptability. Unfortunately, this was impossible due to limitations of the available software with respect to long term hydraulic and qualitative simulations. Consequently, a major objective of the project was to develop a semi-continuous simulation technique which would allow accurate analysis of the system. The method developed to accommodate this was referred to as the Total Emission Analysis Period (TEAP) (Jack, 1999). The TEAP method was developed around the following constraints.

1. That the analysis period was required to be of a single “reference” duration from which
the emissions from all storage volumes being analysed could be compared.

2. As gradual draining of storage tanks may cause disruption to the WwTW after dry weather flows are re-established, the “reference” analysis period was required to be long enough to prevent different storage volumes appearing to produce similar results.

3. The “reference” analysis period required to be sufficiently long to ensure the effects of additional rain upon a “recovering” treatment plant were taken into consideration.

Based on the above, it was apparent that the Reference Analysis Period (RAP) should be calculated based on the recovery/disruption period which the largest feasible storage volume (which would be used in the catchment) would cause at the WwTW. This “largest feasible” volume was considered site specific and dependent upon a number of factors such as local rainfall characteristics, CSO spill frequency and the dilution capacity of the recipient watercourse. Once the RAP was defined via the largest feasible storage volume, the suitable storage volume to meet the required in-river standards could subsequently be identified. The method developed to identify the suitable storage volume is shown in Figure 1.

**Rainfall**

In order to reduce the simulation times it was proposed that only the worst case conditions in a typical year were analysed. This followed UPM acute pollution standards which provided allowable return periods for low dissolved oxygen and high ammonia concentrations. Analysis by Crabtree *et al.* (1993) showed that the one year return periods are most likely to be critical. Consequently, only the worst case rainfall events within the year required to be analysed, as the one year standards needed to be breached only twice in a typical year for the standards to be failed. A “rain-day” method (Jack, 1999) was developed to identify these rainfall periods.

![Flowchart of the method to identify required storage volume considering total emissions](https://iwaponline.com/wst/article-pdf/45/3/247/425144/247.pdf)

*Figure 1* Method to identify required storage volume considering total emissions
Perth total emission analysis

Using the TEAP or RAP and the rain-day methods outlined above, a total emission evaluation was carried out for the City of Perth. The maximum potential storage volume (used in the calculation to determine the RAP) was derived from a combination of the Method One spill frequency analysis technique (Henderson and Dempsey, 1990) and a storage assessment based on population (Scottish Development Department, 1997). A maximum storage volume of 10,000 m³ was identified which allowed for flood control and ensured that only a few rainfall events would cause CSO spills over a long term period. The WRc STORMPAC software was used to generate the synthetic long term historic rainfall for a ten year period. From the rainfall series the wettest winter and summer months were identified. In order to ascertain the RAP resulting from the maximum storage volume and the wettest periods, sensitivity testing of the WwTW was carried out to ascertain the period of disruption caused by various loading conditions. For example, it was identified that for the January 1970 rainfall data (Table 1) the wettest period within this month (6th–9th) subjected the treatment plant to full hydraulic loading for a period of 4 days. Using the results from the WwTW sensitivity analysis it was identified that 4 days of full hydraulic loading would cause no additional disruption for BOD, whereas an additional 3 days of simulation would be required for ammonia simulations to allow for disruptions to the nitrification process. The rainfall data were then checked to ascertain whether additional events would occur within the three day recovery period. For the January 1970 example, no significant rainfall (defined via sensitivity testing) occurred, therefore the RAP for this month was 4 days for the BOD total emission analysis and 7 days for the ammonia total emission analysis.

Table 1  Rain-day table January 1970

<table>
<thead>
<tr>
<th>Date</th>
<th>Duration (hrs)</th>
<th>Depth (mm)</th>
<th>Mean Int. (mm/hr)</th>
<th>Max. Int. (mm/hr)</th>
<th>Start Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>3</td>
<td>0.2</td>
<td>0.4</td>
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<tr>
<td>7</td>
<td>14</td>
<td>14.8</td>
<td>1.1</td>
<td>1.8</td>
<td>14:00</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>11.5</td>
<td>2.3</td>
<td>2.4</td>
<td>12:00</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>2.3</td>
<td>0.6</td>
<td>0.9</td>
<td>19:00</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>9.8</td>
<td>1</td>
<td>2.9</td>
<td>04:00</td>
</tr>
<tr>
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<td>4</td>
<td>1.5</td>
<td>0.4</td>
<td>0.6</td>
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<tr>
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<td>0.6</td>
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<tr>
<td>15</td>
<td>8</td>
<td>7.2</td>
<td>0.9</td>
<td>2.6</td>
<td>18:00</td>
</tr>
<tr>
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<td>3</td>
<td>1.3</td>
<td>0.4</td>
<td>0.7</td>
<td>07:00</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>04:00</td>
</tr>
</tbody>
</table>

Table 2  Perth total emission analysis – BOD (6th–10th January)

<table>
<thead>
<tr>
<th>BOD</th>
<th>0 m³ storage</th>
<th>10,000 m³ storage</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge – CSOs (kg)</td>
<td>3,834</td>
<td>1,899</td>
<td>-1935</td>
</tr>
<tr>
<td>Discharge – WTP (kg)</td>
<td>4288</td>
<td>4,846</td>
<td>+558</td>
</tr>
<tr>
<td>Total Emissions (kg) (CSO + WTP)</td>
<td>8122</td>
<td>6,745</td>
<td>-1377</td>
</tr>
</tbody>
</table>
Tables 2 and 3 show the resulting total emissions for Ammonia and BOD, respectively. With reference to Table 2, it can be seen that the 10,000 m$^3$ of storage has reduced the BOD load from the CSOs by 1,935 kg over the four day analysis period, whereas the emissions from the WwTW have been increased by 558 kg. Overall, the introduction of storage has decreased the BOD load by 1,377 kg. This was principally due to the CSO storage retaining the heavily polluted first flush, thereby compensating the increased emissions from the WwTW. Table 3 shows that the storage has caused an increase of 88 kg in ammonia mass over the seven day analysis period. The increase was attributed to the different loading conditions which the storage exerted on the WwTW and the affect these different conditions had upon the active autotrophic biomass concentrations within the reactor. This is demonstrated in Figures 2 to 4:

Figure 2 shows 24 hours of dry weather flow (hrs 0–24) prior to the 96 hours of full hydraulic loading (hrs 24–120). It can be seen that the graph has been extended by an extra 90 hours to demonstrate the plants’ return to normal operating conditions (hrs 120–210). Figure 3 shows that prior to the storm event the steady state effluent dry weather ammonia concentration peaks at 2 mg/l (hrs 0–24). The impact of the wet weather event is clearly demonstrated as the effluent ammonia concentrations quickly increase (circa 4 mg/l) due to the increased load and the reduced biomass concentration in the reactor (Figure 4). Figure 4 also demonstrates a continual decline in nitrifying biomass concentrations with time due to the dilute influent feeding the reactor. This is exacerbated by the storage scenario which causes a longer period of dilute loading and thus lower biomass concentrations when dry

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Perth total emission analysis – ammonia (6th–13th Jan)</th>
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<tbody>
<tr>
<td></td>
<td>Ammonia</td>
</tr>
<tr>
<td></td>
<td>0 m$^3$ storage</td>
</tr>
<tr>
<td>Discharge – CSOs (kg)</td>
<td>396</td>
</tr>
<tr>
<td>Discharge – WTP (kg)</td>
<td>865</td>
</tr>
<tr>
<td>Total Emissions (kg)</td>
<td>1,261</td>
</tr>
</tbody>
</table>

Figure 2 WwTW final effluent – flow (0 m$^3$ and 10,000 m$^3$ storage)

Figure 3 WwTW final effluent – ammonia (0 m$^3$ and 10,000 m$^3$ storage)
weather flows re-establish. The net effect is marginally poorer final effluent ammonia concentrations for the scenario where storage has been used. However, the increase in load as a consequence of storage would probably be unlikely to exacerbate any potential acute pollution problems within the receiving watercourse, as the principal increase occurs over the period of dry weather flows which follow the combined loading period (hours 120–210). It can be seen from Figure 5 that the load discharged during the earlier combined loading period (hours 24–116) is greater than the load discharged during the recovery period (hours 120–210). Consequently, it is evident that the combined loading period is more critical in terms of acute pollution i.e. if the acute pollution standards were breached it would most likely be as a consequence of the loads discharged over the wet weather period and not as a consequence of the loads discharged over the period of continued disruption.

However, this conclusion may not be generic as the increased load subsequent to the combined loading period may be problematic for very “flashy” river systems where the flow decreases very quickly thereby significantly reducing the assimilative capacity of the watercourse.

Conclusions

It was established that CSO upgrading, with any introduction of in-sewer storage should have no detrimental effects on the total emissions for the Perth wastewater system, and should overall be beneficial, although it would appear that storage is of limited use to control acute pollution from ammonia spills. Nevertheless, the temporal and spatial differences in ammonia discharges, as a consequence of storage, may still have localised benefits with respect to receiving water quality. However, the analysis also highlighted that ammonia concentrations in the final effluent of the WwTW deteriorate rapidly under storm conditions, indicating that 95%ile final effluent treatment plant standards can be put at risk as a consequence of simple combined loading. Large storage volumes (>10,000 m³) can serve to exacerbate this problem and with tighter ammoniacal nitrogen standards being placed on wastewater treatment plants this may be a significant finding. A United Kingdom
Water Industry Research project (Ashley et al., 2001) is currently being undertaken to investigate this potential problem further.

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References


