Managing sewer solids for the reduction of foul flush effects – Forfar WTP

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Abstract In times of high sewer flow, conditions can exist which enable previously deposited material to be re-entrained back into the body of the flow column. Pulses of this highly polluted flow have been recorded in many instances at the recently constructed wastewater treatment plant (WTP) in Forfar, Scotland. Investigations have been undertaken to characterise the incoming flows and to suggest remedial measures to manage the quality fluctuations. Initial visits to the works and incoming pipes indicated a high degree of sediment deposition in the two inlet pipes. Analyses were carried out and consequently, changes to the hydraulic regime were made. Measurements of sediment level, sediment quality, wall slime and bulk water quality were monitored in the period following the remedial works to observe any improvements. Dramatic alterations in each of the determinands measured were recorded. Analyses were then undertaken to determine long term sediment behaviour and to assess the future usefulness of existing upstream sediment traps. It was concluded that with proper maintenance of the traps, the new hydraulic regime is sufficient to prevent further significant build up of sediment deposits and reduce impacts on the WTP. Further investigations made by North of Scotland Water Authority highlighted trade inputs to the system which may also have contributed to the now managed foul flush problem.

Keywords Deposition; foul flushes; invert traps; sediment management strategies; sewer sediments

Introduction

Despite recent initiatives in the UK aimed at the harmonisation of a holistic approach to catchment management (Foundation for Water Research, 1998), operational practices are still often divided into their traditional groups of collection, treatment and receiving water. The development of an upgraded wastewater treatment plant at Forfar in the north-east of Scotland allowed the full application of a holistic approach to be made. A full drainage area study was carried out for the local water authority and models of each component of the system were constructed.

The town of Forfar covers a catchment area of approximately 210 hectares, containing a population of 15,000 people. The drainage system of the town is complex, with both fully combined and separate systems interacting within the system. The catchment is characterised by significant gradients draining towards a small loch to the west of the town, beside which the new treatment works is located. The loch is a well used local amenity, serving as a tourist attraction, water sports centre and fishing location. As a consequence of the local importance of the water body and its sensitivity, discharges to the loch must be strictly controlled. This has resulted in discharge consents of 2 mg/l for phosphates and 3 mg/l for ammonia. A stipulation has also been set by the environment agency (SEPA) that a significant spare capacity must be made available within the sewerage system to reduce the likelihood of flooding and discharge to the loch.

The WTP is a four basin Cyclic Activated Sludge System (CASS), which is a variation of a sequential batch process. This type of plant was not only chosen because of the restricted availability of land, but also because of its ability to handle fluctuations in loading.
The resulting compliance testing for the new £5.5M WTP revealed intermittent performance problems. This was shown to be linked to rainfall and manifested itself as large solids flushes and fluctuations of pH. Consequently a study was initiated at the University of Abertay Dundee, to determine the source of any possible disruptions to treatment plant processes and to assess potential wet weather impacts.

**Methods**

The first phase of the investigation took the form of a data collection exercise. Physical surveys, flow surveys and sediment surveys were carried out, concentrating on the lower reaches of the catchment. Wastewater samplers were installed at the inlet of the works and within the main legs of the system.

These exercises were complimented by a desk investigation and the use of both hydraulic and sediment transport modelling tools. A verified HydroWorks model was used to represent the flows in the system and sediment deposition and erosion rates were calculated using a sediment deposition model currently being developed at the University of Abertay Dundee (Fraser and Ashley, 1999). The sediment deposition model was developed and tested using the Dundee catchment so the Forfar study also served as a further test of the analytical methods used.

**Results**

The initial results of the field investigations yielded conflicting results. Although the physical surveys indicated sufficient pipe gradients in all parts of the catchment, measurements of flow velocity in the lower reaches of the catchment were so low as to render them only measurable during times of peak dry weather flow. In these areas significant bed deposits had developed in the two main parallel trunk sewers (Figure 1). These trunk sewers are of 900 mm and 600 mm diameter and connect the Town Centre to the WTP, with very few additional connections along their length. The configuration of these pipes means that the 600 mm pipe only operates in times of high flow. However, at the initial stages of the study, velocities in both sections of pipe were less than 0.01 m/s (the lower capacity of the flow meter used). For the purposes of this study only the 900 mm pipe will be considered further.

These very low velocities gave rise to significant rates of sediment deposition in the two trunk sewers, resulting in an average bed depth of 250 mm over a length of 775 m. This gives a total volume of sediment deposits in the 900 mm pipe alone of 117 m³. This material was found to be of high polluting potential, with an average BOD of 6575 mg/l. Although the pH of the samples taken was slightly acidic, no evidence was found to suggest that the sediments were responsible for the intermittent pH fluctuations experienced at the WTP. Table 1 indicates the key characteristics of the material.

Samples were also taken of bulk water and biofilms to ascertain the biochemical condition and processes of the effluent. The microbiological analysis was conducted based on the
Viable Count Method using different agar as media for the growth of the bacterial colonies under different incubation temperatures. This analysis showed that the nitrifying bacterial colonies were lower in Forfar \((4.17 \times 10^6 \text{ CFU})\) than has been found in comparable systems. During nitrification, ammonia is converted to nitrite and eventually to nitrate. Hence if the nitrifying bacterial colonies are reduced, transformation is inhibited. This goes some way to explaining the high concentration of ammonia within the samples taken. The optimum pH for nitrification is 8–9. As the recorded pH is much lower than this, it clearly indicates a breakdown of the nitrification process. At low pH, nitrification is limited or stops completely. Another observation during the field work at Forfar was the formation of a “white mat” like growth on the walls of the sewer which indicates the presence of fungal micellium. The Viable Count Method indicated higher fungal colony counts \((2.39 \times 10^7 \text{ CFU})\) than experienced in similar systems. Low pH favours the proliferation of fungal colonies as experienced by Forfar (Henze et al., 1995). The predominance of fungal colonies also leads to a low biofilm density (Characklis and Marshall, 1990) which interferes with the chemical breakdown processes. The high concentration of BOD\(_5\) and COD can be associated with the high organic solids concentration experienced before the change in the hydraulic regime.

The peak daily velocity condition of 0.030 m/s was used to generate the dry weather flow deposition rates for the 900 mm pipe. As storm flows are ignored at this stage, this result offers a worst case scenario and is used merely to indicate whether the current dry weather hydraulic regime is sustainable. The analysis is a development of the USEPA method (Pisano et al., 1979). As can be seen from Figure 2, the predicted levels of deposition do not reach a steady state condition as had been experienced in other investigations (Fraser et al., 1998; Laplace and Bachoc, 1990). Instead, sedimentation continues until the point of surcharging. Consequently, improvements to the dry weather flow regime were sought as a first point of action.

The consideration and measurements of the impacts of wet weather were far more complex. In general, it was observed that storm flows led to a temporary reduction of sediment levels. Consequently, it was hypothesised that the role of this particular sediment bed to the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Initial deposit characteristics</th>
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<tbody>
<tr>
<td>Mean diameter (mm)</td>
<td>0.15</td>
</tr>
<tr>
<td>Mean settling velocity (m/s)</td>
<td>0.003</td>
</tr>
<tr>
<td>% organic</td>
<td>97</td>
</tr>
<tr>
<td>BOD (mg/l)</td>
<td>6,575</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>18,000</td>
</tr>
<tr>
<td>NH(_4) – interstitial (mg/l)</td>
<td>18</td>
</tr>
<tr>
<td>pH</td>
<td>5</td>
</tr>
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Figure 2  Predicted levels of DWF deposition
intermittent loadings problem at the WTP must be significant. Due to sampling difficulties, only 2 full sets of storm data were collected at the time when the sediment bed was fully developed.

Figures 3 and 4 (above) indicate the levels of various determinands arriving at the WTP during a rainfall event occurring on 5/11/99. A substantial rise in TSS concentrations can be observed at the beginning of the event to levels of up to 10 times those experienced during DWF. Similar characteristics can be seen when considering COD concentrations. However, although a small peak of NH₄⁺ concentration can be observed on the rise of the hydrograph, this is not as pronounced as the other determinands, with the rise amounting to only a 15% increase from normal DWF levels, however, as demonstrated by Krebs et al. (1999), the total load of ammonia increased considerably due to the high flows. Following this initial increase in load, a dilution occurs before the DWF ammonia levels are re-established.

Although analysis of composite inlet samples extracted by North of Scotland Water Authority indicated that ammonia levels were in the normal range during storms, short term fluctuations (of the type shown above) would not be detected by the methods of sampling used. However, whether the type of slight “ammonia flush” shown above would seriously affect treatment performance remains in doubt. A more likely reason behind the initial unexplained loss of nitrification experienced at the WTP, involves the high BOD loadings. It is currently believed that the preferential breakdown of carbonaceous matter and the subsequent effect on dissolved oxygen available for nitrification is inhibiting the nitrification process.

An erosion prediction model was applied to this rainfall event to try to predict the flush of sediment released from the bed. The procedure is an empirically based relationship
which relates the sediment bed yield stress to applied bed shear stresses via bulk density and moisture content characteristics (Wotherspoon, 1994).

As the model is not time step dependent, the results are in the form of total load for the event. Difficulties were encountered as the erosion model predicted far greater removal of the bed than was observed in the field. This was believed to be as a result of the unusual characteristics of the extremely cohesive bed material. This has the effect of strengthening the bed for a particular bulk density. Consequently, the coefficient used to represent the cohesive characteristics of this almost exclusively organic material was replaced with a value more usually associated with clay (\(z = 0.725\); Mehta and Partheniades, 1975). Following this alteration, more realistic erosion depths were predicted. However, without detailed rheological analysis of the sediment yield strength characteristics, exact comparisons cannot be made.

Table 2 (above) shows a comparison between observed and predicted quantities of erosion for the rainfall event on 5/11/99. It can be seen that the erosion model predicts a far greater mass than was observed. The principal source of errors in this approach are as follows:

- the procedure requires detailed information of sediment rheology (unlikely to be known in advance);
- assumption that all material eroded will be subsequently transported to the treatment plant is restrictive;
- small-bore sampler tubes could only be located downstream of pumps, thereby allowing some settlement in the pump sumps.

North of Scotland Water Authority investigations into the source of the depositional problem revealed downstream controls by tree root penetration into the sewer. Remedial measures were take to rectify this and following consultation, a pumping regime to improve the mobility of sediments was implemented. The effect of these simple changes on both the hydraulic and qualitative conditions experienced at the inlet of the WTP were much more dramatic than had been anticipated.

The levels of sedimentation in the upstream sewer were observed to drop considerably over the following few weeks. Surveys of the deposit level and characteristics were carried out over this period.

As can be seen from Table 3 the total volume of sediment retained within the system over approximately 10 weeks reduces by nearly 200 m3. This represents 240 tonnes of material, which had to be collected from sedimentation tanks and sediment traps even during dry weather flow (as the material was extremely mobile). During this period the impact

Table 2  Calculated total load erosion

<table>
<thead>
<tr>
<th>Total measured event load (kg)</th>
<th>Total calculated event load (kg)</th>
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<tr>
<td>1,853</td>
<td>2,865</td>
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Table 3  Erosion of sediment volumes

<table>
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<tr>
<th>Survey date</th>
<th>Total volume of deposits (m³)</th>
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<tbody>
<tr>
<td>2/11/99</td>
<td>242</td>
</tr>
<tr>
<td>16/11/99</td>
<td>159</td>
</tr>
<tr>
<td>7/12/99</td>
<td>122</td>
</tr>
<tr>
<td>14/12/99</td>
<td>81</td>
</tr>
<tr>
<td>21/12/99</td>
<td>56</td>
</tr>
<tr>
<td>12/01/00</td>
<td>49</td>
</tr>
</tbody>
</table>
of rainfall could be seen. However, as the sewer diameter was not sufficient for man entry, only manhole surveys could be carried out, making detailed event by event analysis impossible.

The characteristics of the material which replaced the original deposits also changed dramatically. Table 4 shows the same determinands measured previously for the original sediments. As can be seen, the material is now composed of much more granular, larger particles, more typical of UK sewer sediments. The polluting potential of this material is now also diminished as can be seen from the reduced BOD, and COD concentrations.

Visual inspection of the site also indicated that the “white mat” like growth had ceased to exist, indicating that fungal colonies have now diminished and the nitrification process should no longer be inhibited. This is clearly demonstrated by the reduction in the ammonia concentration in the deposits as compared with the previous value (Table 1).

In order to ascertain the propensity of the new hydraulic regime for deposition, the same analysis carried out previously was applied to the new dry weather flows. Figure 5 shows the pattern of predicted dry weather deposition over a period of 1000 days. As can be seen the rate of build up is now much reduced when compared with Figure 2. Also, the new curve tends towards an equilibrium bed depth as the bed develops. The dry weather flow pumping regime was therefore confirmed as being acceptable. This, coupled with the periodic erosion of the new sediments during storm flows should ensure that excessive deposition does not occur in the future.

**Discussion and conclusions**

The original hydraulic regime created an upstream sediment bed, which acted as a substantial source of pollutants for the WTP. Sediment traps that were installed in an attempt to manage the problem were made useless in a matter of days as a result of the high filling rates experienced. Further data collection revealed the problem to be hydraulic, and due to its localised nature, manageable. The SCADA (Source Control and Data Acquisition) system recorded a combination of high and low pH, and initial investigations highlighted

<table>
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<th>Table 4</th>
<th>In-sewer deposit characteristics following change in hydraulic conditions downstream</th>
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<tbody>
<tr>
<td>Mean diameter (mm)</td>
<td>0.55</td>
</tr>
<tr>
<td>Mean settling velocity (m/s)</td>
<td>0.015</td>
</tr>
<tr>
<td>% organic</td>
<td>20</td>
</tr>
<tr>
<td>BOD (mg/l)</td>
<td>450</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>2,110</td>
</tr>
<tr>
<td>NH₄– interstitial (mg/l)</td>
<td>12</td>
</tr>
<tr>
<td>pH</td>
<td>6.5</td>
</tr>
</tbody>
</table>

**Figure 5** Predicted dry weather deposition rates
an industrial factory as the source of the problem. However, the fluctuations of pH still persisted, which inevitably had a knock on effect of the ammonia in the final effluent. Although the source of the pH fluctuations was not explicitly identified in this study, the improvements made to the system have given rise to a number of advantages:

• the WTP flush problem is now greatly reduced;
• the likelihood of intermittent discharges from the system to the receiving water are now also reduced as a result of the increased cross-sectional capacity of the trunk sewers;
• cost savings are likely as the sediment traps are now functioning correctly by further localising and storing the deposits (Fraser et al., 1998; Dartus et al., 1990).

Although full modelling of the sewer systems, treatment plant and receiving waters was used in the design and operation of the system, certain eventualities will always be unforeseeable. In addition, software limitations at present restrict the type of sediment deposition problem that can be examined (Ashley et al., 2001), but more importantly, the level of data collection will always limit the accuracy of the models (Harremoes, 1998; Jack et al., 1996).

However, the application of the modelling techniques detailed in this paper demonstrate that with the correct tools and targeted data collection, even very specific catchment problems can be analysed and managed.

The target of improving system operation is continuing at Forfar. The next stage of the project will involve the improvement of the design of the sediment traps protecting the WTP, in an attempt to optimise their trapping characteristics.

Use of the UPM Procedure has been shown to result in substantial overall cost savings both for individual schemes and for extensive planning programmes (Crabtree et al., 1995), but in order to achieve the full effect of the UPM philosophy, model capabilities and data collection need to be extended to continuing operational practices. For this to take effect within the UK, the various strategic divisions that form a catchment management team will need to work together more closely.

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References


