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A low cost method to detect polluted surface water outfalls and misconnected drainage.

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Abstract: Sewer misconnections lead to discharge of wastewater direct to rivers and streams. They are difficult to detect due to their intermittent discharges and the wide range of compounds which can be discharged. Optical brighteners are strong indicators of the presence of sewer misconnection discharge in surface water sewers, representative of many components of misconnections, and easily identified. The authors have developed and tested a promising method to identify optical brighteners in sewer systems using inexpensive passive samplers and a simple analysis method. The method is used to identify large areas of four sewer systems which are polluted with misconnection discharge. Limited validation shows that the method successfully indicated diffuse pollution in the surface water sewer system.

1 Introduction

Polluted surface water outfalls (PSWOs) can be major sources of faecal indicator organisms (O'Keefe et al., 2005), nutrients, and toxic compounds (Environment Agency, 2007; UKWIR, 2012), which can significantly impact receiving waters. Sewer misconnections are the connection of grey or foul water drains to surface water sewers, leading to direct discharge of untreated wastewater to rivers and streams. They are a key contributor of pollution to PSWOs, and can discharge a wide range of pollutants (UKWIR, 2012; Ellis, 2013). Misconnections discharge intermittently and therefore pose problems for monitoring, as impacts may only be observed during discharge.

Monitoring PSWO effluents generally takes the form of either spot sampling, taking an instant sample at a point which can be stored for later analysis, or continuous monitoring, placing a sampler or sensor in situ which will collect samples over time. Passive sampling allows integrated sampling for indicators over time without producing individual data points. Due to the intermittent nature of misconnection discharges, continuous monitoring or passive sampling are the most promising methods to identify these discharges, as spot sampling will only identify effluent if it is present at the time of sampling.

Commonly monitored components include nutrients, sewer solids, bacterial growth, biochemical oxygen demand (BOD), ammonia, phosphorus and pH, among others (Environment Agency and Water UK, 2014). These components are present in a wide range of discharges, and so the value of them for specifically identifying and tracing misconnection discharges is limited. Though misconnections discharge a wide variety of pollutants which could be used as indicators, such as triclosan or tryptophan, these are not expected to be present in many discharges, and can be expensive to monitor, therefore limiting their functionality as indicators.

Optical brighteners (OBs) are a promising indicator of misconnection effluent in surface water sewers, as they are found in many components of effluents, including discharge from washing machines, sinks, and toilets. This paper presents the first UK trial of an inexpensive, simple, passive sampler for OBs in surface water sewers.

2 Current and developing practice

Aesthetic indicators such as turbidity, sewage fungus, and solids are common results of polluted discharge, which are easily identified and develop quickly following exposure to polluted discharge (Hickey, 1988; Pitt et al., 2004). These are either observed on natural substrates, or can be sampled in sewers using caging to trap solids (Environment Agency and Water UK, 2014). However visual indicators are not always present in misconnection discharge, and are not uniquely a result of misconnection discharges, they can be present as a result of other inputs to sewer systems, and therefore do not definitively indicate the presence of misconnections on a sewer system.

Distributed temperature sensing uses fibre optic cables, temporarily inserted into sewer systems, to detect changes in temperature of water entering sewer systems (de Haan et al., 2011). This can be very time-efficient, but is also expensive at around €10-12 (Approximately £8-9) per meter of sewer tested including analysis costs (Schilperoort et al., 2013). This also requires considerable technical knowledge to operate the temperature sensor (Hoes et al., 2009). While this method is rarely used at present, if costs can be reduced it may become more widely accessible.

Passive water chemistry samplers can be used in rivers to observe changes in concentrations of chemicals over time periods from days to months (Namiesnik et al., 2005; Vrana et al., 2005; Zhang and Davison, 2000). These are inexpensive, do not require external power, and do not require regular maintenance (Zabiegala et al., 2010), however they have not been tested for monitoring misconnection effluents, and may only be sufficiently sensitive to identify large, or constant, discharges.

Dye testing involves pouring fluorescent dye into appliances in households, which can then be detected in the surface water sewer system if the appliance is misconnected (Hoes et al., 2009; Environment Agency and Water UK, 2014). Dye testing is only used once a region of the sewer system suffering from misconnections is identified using other methods, as it is a relatively slow process, visiting individual properties to perform testing. However, this is the only method at present which unambiguously identifies specific appliances which are discharging to the surface water system, and therefore is needed in the final stage of misconnection correction actions.

Further information on these and other less commonly used methods for tracing and correcting sewer misconnections in the UK and USA can be found in Environment Agency and Water UK (2014) and Center for Watershed Protection and Pitt (2004) respectively.

3 Passive sampling for optical brighteners

3.1 Method

Optical brighteners (OBs) are chemicals which fluoresce under ultraviolet (UV) light and do not occur naturally in the environment. They have a high affinity for fabrics such as cotton, and are commonly used in laundry detergents, toilet paper, and cleaning products (Burres, 2011). These are components which are expected to be present in the majority of misconnection effluents (UKWIR, 2012). OBs have been used to identify illicit discharge to surface water sewers (Braun, 2011), usually using a fluorometer to measure the fluorescence of discharged water. Fluorometers are relatively inexpensive, though they require flow in the sewer, so will not detect a response if there is no flow or no optical brighteners discharged at the time of sampling. Therefore the ability to identify intermittently discharged misconnection effluents is limited. To overcome this limitation, an in situ passive method has been tested and developed to identify misconnection effluents in the field using OB free tampons as a sorbent to collect OBs.

Laboratory testing was performed to determine concentrations of detergent at which fluorescence would be observed. Twenty five microliters of detergent, the smallest volume which could accurately be measured, were added to 25 litres of tap water. A tampon was submerged in the container for 5 seconds. OBs adsorbed to the tampon immediately, and were still identifiable up to 30 days after initial exposure (figure 1). Modern washing machines discharge between 29 and 144 litres of water per use, with an average of 77 litres (Australian government WELS 2014). This equates to roughly 0.65ml of detergent per litre of discharged water if manufacturers recommendations for the volume of detergent used in an average laundry load are used. This therefore means that even with a 300 times dilution in the sewer pipe, which is far beyond anything which could be expected from normal sources, polluted discharge would still be observable.

For sampling OBs in situ, tampons were fixed in surface water sewers, either by tying to a suitable point in the sewer, or tied to lengths of bamboo cane which could then be wedged in the sewer so that they lay in the invert of the sewer out of direct sunlight to avoid photo decay of optical brighteners. If there was flow in the sewer at the time of sampling, the tampon was briefly exposed to the flow and tested for fluorescence on site using an inexpensive UV light, if suitable darkness could be achieved to accurately identify fluorescence. However sufficient darkness could not be achieved in the field during this trial, so samples were transferred to the lab for testing. If a positive response was not observed instantly, tampons were left in situ for a three day period, to ensure polluted discharge was not missed. Three days was empirically found to be the optimum time to leave a sample in place to avoid fouling, but ensure a good exposure time, with five and seven days exposure leading to considerable fouling of the samples. When samplers were removed from the sewers, they were placed in individual zip-lock bags and stored in darkness to avoid contamination between samples and photodecay of OBs until samples could be exposed to a UV light to test for fluorescence. The cost of initial purchase of raw materials (UV light, cotton, apparatus to attach them in place) in this investigation was approximately 20 pence per sampler.

3.2 Field trial

Sampling was performed in 16 surface water sewer outfalls across three catchments in the Sheffield area in March 2013. Nine of the 16 outfalls were indicated as discharging OBs. Four sewer systems were further investigated using the method in accessible manholes to trace OB containing effluent to its source. Samplers were returned to the laboratory and tested for OBs using an inexpensive 365nm UV light. Where OBs were found below a section of sewer, but not above it, a misconnection was indicated between the two points, and therefore an area of the system to be dye tested could be identified (figures 2 and 3).

The method successfully identified areas of the sewer systems in which further investigation using dye and visual misconnection inspection could be performed. This significantly reduced the area in which detailed investigation was required, and thus reduced cost of follow up investigations. Samples corroborated well, with indicated misconnected points joining up, and correctly connected points joining up. The method showed only one conflict over four catchments where a sewer was indicated as correctly connected at one point, but misconnected further up the catchment (figure 3).

Visual inspection of properties was performed in part of sewer system 3 (figure 3). A sink and a soil stack were found misconnected in this area. These misconnections were corrected, though additional sampling could not be performed, to determine whether other misconnection problems existed in the system after correction, due to budgetary constraints.

3.3 Practical issues

When large quantities of suspended solids are present in sewer systems, tampon samplers can become fouled, and fluorescence masked to the extent that if OBs are present, fluorescence is not observable. Once significantly fouled, washing the sampler did not remove enough of these solids to allow analysis to be performed on the sampler. A shortened period of exposure reduced the risk of this problem, however to ensure the same exposure period as samplers on other outfalls, samplers were replaced more frequently, which increased the cost for those points.

At some sewer outfalls, samplers were vandalised by members of the public. This only occurred when sampling outfalls, and only at sites which were close to footpaths, even though they were generally not visible from the footpath. This may be avoided by inserting the samplers further into the outfall, though in the present study this was not possible without contravening health and safety requirements.

There is a risk of misinterpretation of fluorescence due to the presence of oil (Lambert et al., 2003) or surface discharges of OB containing compounds, such as from car washing with soaps, though these still indicate an abuse of the system and so are important to identify as they cause polluted discharge to the receiving water. Oil, which also should not be present in the surface water sewer system, will leave a coating on the sampler, and therefore should be easily identified. Surface discharge of OB containing compounds are not expected to be a frequent occurrence, but may cause confusion where they do occur.

The major limitation of the method is that some misconnections may not discharge compounds containing OBs, and therefore will not be detected using the method. Combining the optical brightener method with other established methods, such as visual inspection methods, allows an integrated sampling strategy so that a weight of evidence approach can be taken to identify systems which require further investigation.

3.4 Further development

This study demonstrated that the method successfully identified misconnection discharge in surface water sewer systems, however budget limitations prevented full validation of the sewer systems from being performed. The next development of the method should be to perform a full validation of the method, including full tampon sampling throughout several sewer systems, and thorough dye testing to ensure that where misconnections are indicated, they are found, and where they are not indicated, they are not found. This would give a better indication of the accuracy of the method and may discover methodological improvements which may in turn change costs.

Following thorough method validation, the main improvement which could be made to the method is to develop a way to protect the sampler from sewer solids. Fouling is a major problem for the method at present, limiting the time that samplers can be left in situ, yet it is one of the easiest limitations to overcome. Solving this may require development of a protective barrier to block solids, or a cleaning process to clean off solids, and leave OBs in place on the sampler. This would reduce the number of visits required, and therefore reduce costs of sampling, though it would increase the cost of individual samplers.

4 Conclusion

This paper presents the first UK investigation of an inexpensive and simple passive method to identify sewer misconnection effluents using cotton samplers onto which optical brighteners bind. The method successfully identified optical brighteners in surface water sewer systems, and limited validation showed misconnections were present where they were indicated. Further development may improve the method and either increase or decrease the current low costs. This proved a very promising method for identifying sewer misconnections and other diffuse pollution discharge to surface water sewer systems. Pending further validation, this is recommended for investigation of sewer misconnections in surface water sewer systems.

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FIGURES

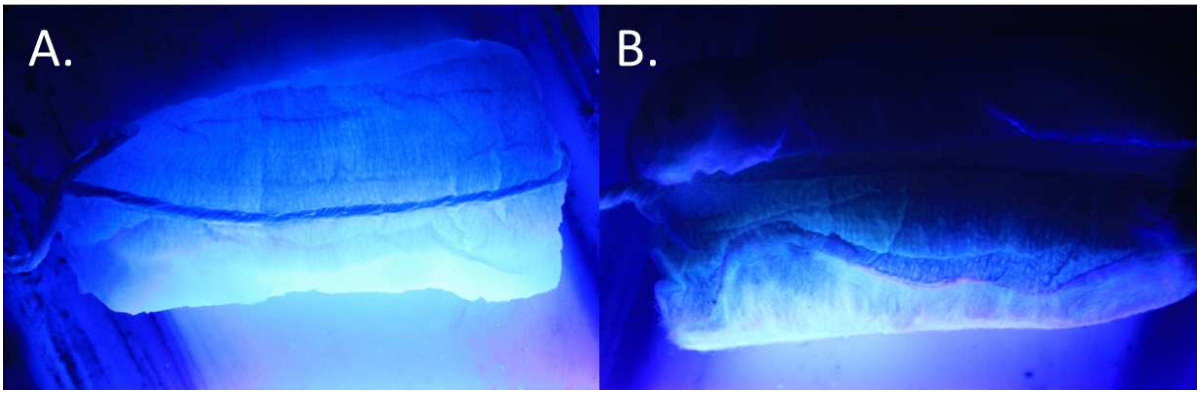

Figure 1. Samplers exposed to UV light to detect fluorescence. A. Fluorescing tampon sampler. B. Non-fluorescing tampon sampler.

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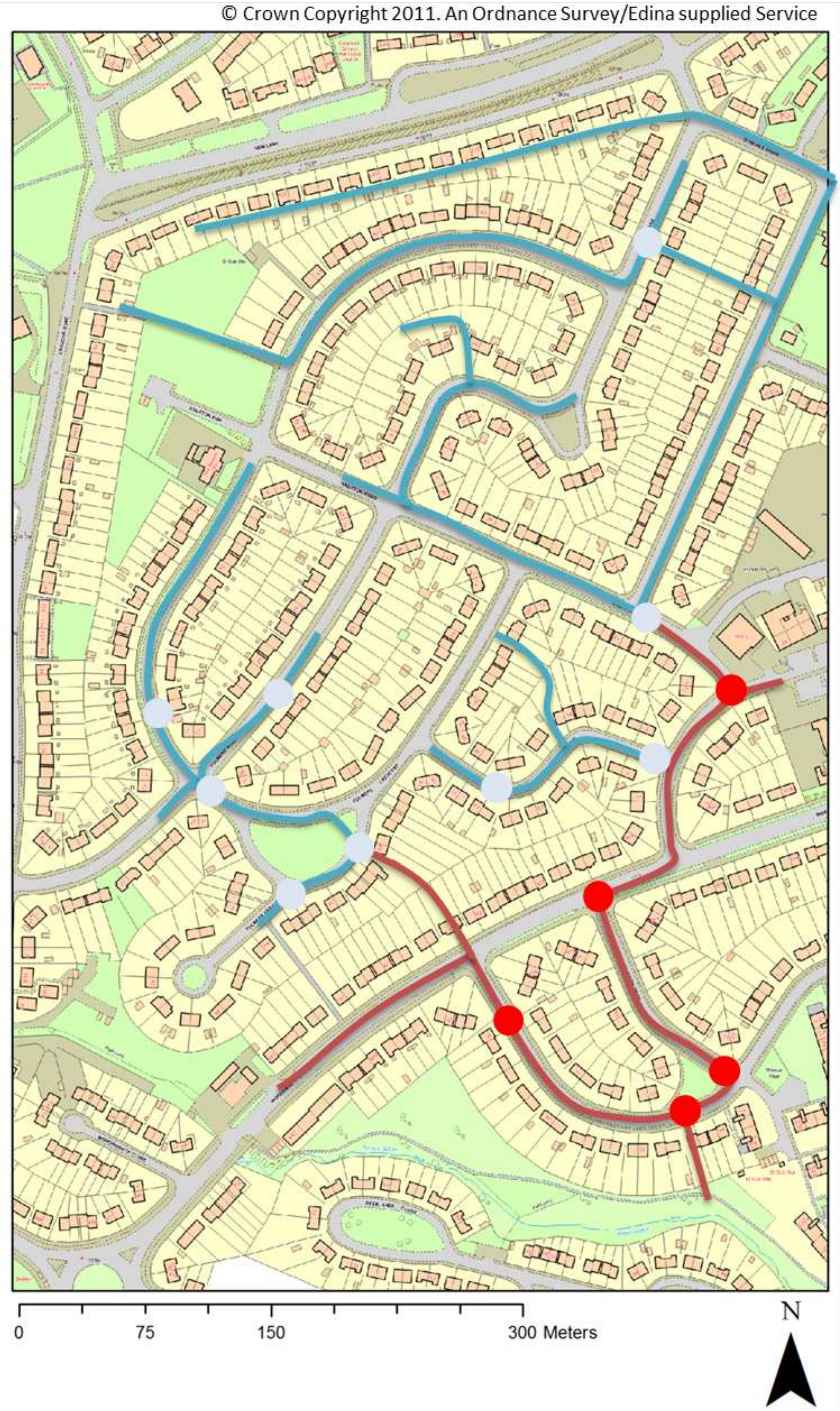

Figure 2: Sewer system 1, Sheffield. Red dots indicate manholes where optical brighteners were detected with tampons and pale blue dots where none were detected.

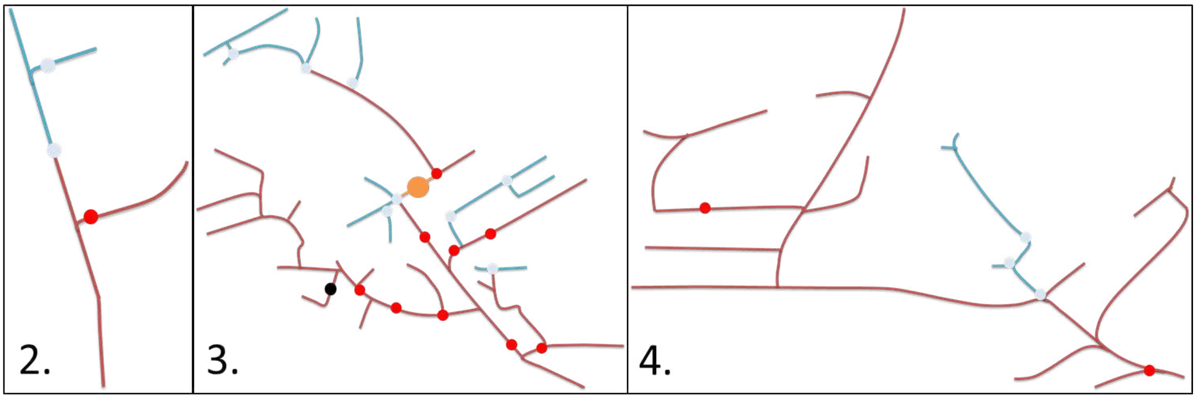

Figure 3: Sewer systems 2, 3 and 4, Sheffield. Colour coding as Figure 2. The black circle in sewer system 3 indicates where validation has been performed and misconnections observed. The orange circle in sewer system 3 indicates where a conflict was observed between upstream and downstream samples.