Science of the Total Environment 551–552 (2016) 163–174

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Urban surface water pollution problems arising from misconnections

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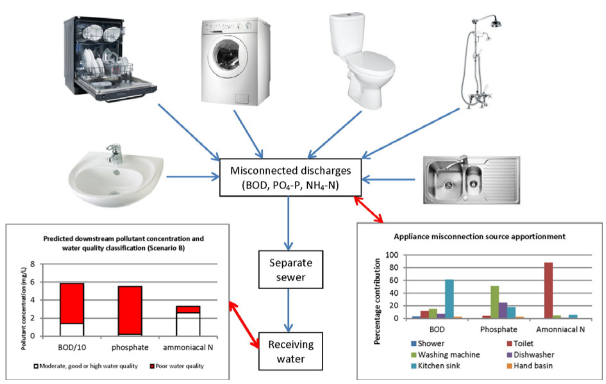
HIGHLIGHTS

- A methodology for assessing pollution impacts due to misconnections is described.
- Downstream receiving water concentrations are predicted for BOD, PO_4-P and NH_4-N.
- Elevated dilution ratios fail to address poor water quality associated with PO_4-P.
- Toilets, kitchen sinks and washing machines pose the main misconnection problems.
- BOD and NH_4-N pollution problems are solved by reducing appliance contributions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 December 2015
Received in revised form 28 January 2016
Accepted 29 January 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Misconnections
Stormwater sewers
Urban surface waters
Pollutant (BOD, PO_4-P, NH_4-N) loadings
Remediation schemes

ABSTRACT

The impacts of misconnections on the organic and nutrient loadings to surface waters are assessed using specific household appliance data for two urban sub-catchments located in the London metropolitan region and the city of Swansea. Potential loadings of biochemical oxygen demand (BOD), soluble reactive phosphorus (PO_4-P) and ammoniacal nitrogen (NH_4-N) due to misconnections are calculated for three different scenarios based on the measured daily flows from specific appliances and either measured daily pollutant concentrations or average pollutant concentrations for relevant greywater and black water sources obtained from an extensive review of the literature. Downstream receiving water concentrations, together with the associated uncertainties, are predicted from derived misconnection discharge concentrations and compared to existing freshwater standards for comparable river types. Consideration of dilution ratios indicates that these would need to be of the order of 50–100:1 to maintain high water quality with respect to BOD and NH_4-N following typical misconnection discharges but only poor quality for PO_4-P is likely to be achievable. The main pollutant loading contributions to misconnections arise from toilets (NH_4-N and BOD), kitchen sinks (BOD and PO_4-P) washing machines (PO_4-P and BOD) and, to a lesser extent, dishwashers (PO_4-P). By completely eliminating toilet misconnections and ensuring misconnections from all other appliances do not exceed 2%, the potential pollution problems due to BOD and NH_4-N discharges would be alleviated but this would not be the case for PO_4-P. In the event of a treatment option being preferred to solve the misconnection problem, it is shown that for an area the size of metropolitan Greater London, a sewage treatment plant with a Population Equivalent value approaching 900,000 would be required to efficiently remove BOD and NH_4-N to safely dischargeable levels but such a plant is unlikely to have the capacity to deal satisfactorily with incoming PO_4-P loads from misconnections.

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http://dx.doi.org/10.1016/j.scitotenv.2016.01.198
0048-9697/

1. Introduction

Surface water misconnections occur when sewage or wastewater, arising from household appliances such as toilets and washing machines, are incorrectly connected. Such misconnections have become a significant water management issue in the UK (Environment Agency, 2013a), with the national environmental regulatory agency estimating that as many as one in five properties may have misconnections discharging wastewater effluent directly to receiving waters via separate sewer systems (Environment Agency, 2007). National estimates of the total numbers of properties in the UK possessing offending misconnections vary between 130,000 and 1.25 M (Royal Haskoning, 2010; Dolata et al., 2013; Ellis and Butler, 2015) and the illicit wastewater discharges from misconnected properties can directly impact on receiving water quality potentially prejudicing the achievement of relevant environmental quality standards (EQSs). Total numbers of officially recorded pollution incidents attributed to misconnections only amount to about 250 per year (Environment Agency, 2012), but pressure analysis of water bodies in England and Wales failing Water Framework Directive (WFD) "good status" during 2012 showed that the urban and associated transport sectors were directly responsible for a total of nearly 1500 failures. Excess concentrations of phosphate, ammonia and BOD were identified as the source of 29%, 9% and 4% respectively of these urban diffuse pollution failures (Environment Agency, 2013a). It is therefore highly likely that misconnections can exert a detrimental impact on urban receiving water quality although the scale and severity of such impacts remains to be adequately quantified (Ellis and Butler, 2015). The development of effective river basin management plans (RBMPs) under the statutory requirement of the EU WFD (CEC, 2002) depends on adequate quantification of such illicit urban diffuse pollution inputs and their potential impacts on receiving water quality (Ellis and Mitchell, 2006).

There is only limited field evidence to clearly link the long term chronic attribution and impacts of household wastewater misconnections on receiving water pollutant loadings and environmental quality standards. Modelling therefore becomes an essential approach in both quantifying the specific sources affecting daily discharges from domestic premises (particularly the potential contribution of individual domestic appliances), and in exploring their potential receiving water impacts (Environment Agency, 2013b). Generic source apportionment modelling of urban wet weather discharges on a catchment scale have been developed (Crabtree et al., 2009; Crabtree et al., 2010) based on Monte Carlo simulations to predict receiving water responses to such effluent inputs. However, there has been very little quantified consideration of attributions for specific wastewater sources associated with separate surface water (stormwater) systems. Wastewater flows have been traditionally measured in terms of per capita consumption and concentrations, but such average-based determinations can be misleading given the diversity and complexity of domestic water usage as reflected in differing technological and socio-demographic household water practices (Pullinger et al., 2013). Despite continued national regulatory insistence that UK water companies develop their forward water management planning based on per capita water use, there have been increasing arguments for a more detailed analysis of usage micro-components to explore and explain the inherent variability contained within the "average" data (Makki et al., 2011; Parker and Wilby, 2012).

This paper attempts to identify the potential effect of misconnections on the organic and nutrient loadings to urban surface waters through the disaggregated quantification of BOD, ammonia (NH_4-N) and phosphate (PO_4-P) loads discharged from various domestic sources and appliances. Specific household micro-component data drawn from surveyed urban catchments in London and Swansea (South Wales) are used to provide detailed calculations of misconnection loadings and dilution ratios and as a basis for extrapolation to wider catchment situations. The adopted approach is based on simple, well recognised generic volume-concentration and mass balance determinations rather than on any more complex, blackbox process-based procedures. Despite the simplicity of the applied methodological approach, it is acknowledged that the basis for the derivation is data-rich and the robustness of the procedure is an essential consequence of the density of information acquired by the micro-component analysis. The described approach has not been previously attempted and in this respect it represents an innovative procedure which would support planning-level strategies for better management of urban drainage discharges and future improvement of in-stream urban water quality. The novelty of the proposed method is in its simplicity and capability for ready field verification through a rapid low-cost, screening-level application which permits the work-up of draft risk assessment and catchment management plans for heavily modified waterbodies (HMWBs) in urbanised areas and as a basis for further priority study.

2. Methodology and study sites

The application of a simple volume-concentration approach for determining pollutant loads from urban discharges has been widely used (Marsalek, 1991; Ellis and Viavattene, 2014). Such procedures have been tested by various workers against annual load estimates derived from deterministic multi-parameter hydrologic methods and have been found to either match or even outperform the more complex modelling algorithms (Van Buren et al., 1997). The functionality of complex operational modelling can be confounded by definitions of boundary conditions as well as process dynamics and kinetics which often make them difficult to calibrate and unwieldy to implement and collect reliable real-time data. Such complex research-type models are better suited to process-knowledge improvement rather than simplified management tools (Wainwright and Mulligan, 2003).

The available volume and concentration data for domestic appliance discharges is not usually expressed as event mean concentrations (EMCs) but either as specific unique (one-off) values or sample averages. Whilst individual appliance volumes and pollutant concentrations should not be inherently random in nature, catchment greywater outputs can be expected to be influenced by culture, life style, dietary and other personal factors. Thus the extension of international appliance volume-concentration data to geographically differing urban locations needs to be applied with caution.

2.1. Appliance pollutant loading to surface waters

Abel (2008) proposed a formula to calculate the misconnection daily domestic appliance BOD loading (kg day^{-1}) to receiving waters and a similar relationship also applies to other pollutants such as phosphate and ammonia. The formula considers the pollutant loading as a function of the total population served in the catchment (P_{tot}), the number of occupants per property or dwelling (N_p), the total number of properties investigated (N_{prop}), the number of each type of individual appliances misconnected (N_{apmis}) and the appliance loadings (kg capita day^{-1}; A_l). In the case of BOD the equation is:

$$BOD = [P_{tot}/N_p] \times [N_{apmis}/N_{prop}] \times A_l \times N_p \quad (1)$$

But P_{tot}/N_p = the number of properties (N_{prop}) and so this equation simplifies to:

$$BOD = N_{apmis} \times A_l \times N_p \quad (2)$$

2.2. Pollutant concentration downstream of a misconnection discharge

Assuming efficient mixing, a basic mass balance approach can be applied to determine the pollutant concentration downstream of a dry