FACTORS INFLUENCING TEMPORAL EXFILTRATION RATES IN SEWER SYSTEMS

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The majority of sewer test rig studies have demonstrated a rapid exponential decline in exfiltration rates from open joints (Ellis *et al*., 2003; Blackwood et al., 2005; Vollertsen and Hvitved-Jacobsen, 2003) and this pattern of decline has been confirmed from various field studies (Klinger et al., 2005). Ultimate steady-state exfiltration rates are quoted to approach 10^{-3} to 10^{-6} l s^{-1} with minimum average daily rates per standardised leak area varying between 0.02 – 9.0 l d^{-1} cm^2. These steady-state conditions are typically reached within a period of hours to days.

A number of workers also report ultimate exfiltration rates of zero for various test runs although the sampling and reporting times are frequently less than 30 to 60 minutes. Such short term measurement periods can hardly be expected to yield detectable exfiltration flows. The detection limits from reported studies lie between 5 ml per day (0.005 l d^{-1}) for laboratory tests to 15 – 20 ml per day (0.015 – 0.02 l d^{-1}) for field testing. The detection limit on sewer pressure testing is much higher with one Californian study quoting a limit of 1.97 l d^{-1}. At these low detection limits, exfiltration loss over a period of 10 years could still amount to between 18 – 7190 litres per single joint and would be an order of magnitude higher for a conservative estimate of 10 leaking joints per kilometre sewer run. However, published European exfiltration estimates based on direct (laboratory/field) studies vary between 0.011 – 2.0 l s^{-1} km^{-1} in comparison with indirect measurements based primarily on water balance and groundwater monitoring studies which indicate losses between 1.4 x 10^{-5} – 0.179 l s^{-1} km^{-1}. The former direct investigations tend to yield over-estimates as a result of extrapolation up to full scale field coverage. On the other hand, the lowest indirect exfiltration estimates represent virtually watertight systems. Thus a range of 0.01 – 0.2 l s^{-1} km^{-1} is probably a more realistic range for mature, European sewer networks.

The assumption that equilibrium steady-state conditions will be maintained over extended periods of time is also questionable. This paper will demonstrate field and laboratory evidence for persistent variability and breakthrough of exfiltration under steady-state conditions. Such leakage following the establishment of steady-state exfiltration conditions has been reported from many studies and appears to be a characteristic feature of the sewer leakage mechanism. Leakage losses of up to 2 orders of magnitude above the equilibrium level can occur even under normal dry weather flow (DWF) operational conditions. It is argued that such breakthrough leakage is in part the result of instability in the growth conditions and ageing process of the colmation and bridging layers. However, a major influence on such long term leakage losses is the effect of small scale, diurnal kinematic wave pulses which generate temporary local increases in bed shear stress which in turn cause scour and mobilisation of the clogging layers. Such pulses are exacerbated in small diameter sewers due to the shunting or “sliding dam” nature of the sediment material moving along the sewer bed (Littlewood and Butler, 2003). Flow restriction following in-sewer accumulation locally increases velocity, turbulence and bed shear and the increasing hydrostatic head following back-up and partial blockage, will increase flow rates as defined by Darcy's law, through the accumulated layer. The shear rate through interstices in the retaining sediment subsequently increases, dislodging material and allowing more flow to pass. Thus the commonly held view that it is only sudden precipitous sewer backups which severely disrupt the hydraulic regime, and consequently initiate exfiltration breakthrough, is not a fully justifiable assertion.

The influence of variability and instability in flow velocities and related bed turbulence will be examined as an alternative to the assumed requirement of full pressurised conditions for the "rupture" of sealed joints. Little if any supporting evidence exists to underpin the legitimacy of the assertion that pressurised hydrostatic conditions are a pre-requisite for substantive sewer losses and "rupture" of the colmation and bridging layers. The paper will demonstrate that flow depths at $Q_{70/75}$ in a 150 mm pipe were sufficient to generate velocities of 7 – 8 $l\ s^{-1}$ and generate bed shear stress in excess of 2.5 $N\ m^{-2}$; the frequently quoted critical yield strength for cohesive sewer bed sediment. Some workers have suggested that even lower bed shear stresses in the order of 1.1 – 1.4 $N\ m^{-2}$ are sufficient to prevent biofilm growth as well as to scour the colmation layer.

The existing confusion concerning the correct separate definitions of the colmation, biofilm and bridging layers will also be addressed. The former is incorrectly assumed by some workers to be confined to the joint opening and any corroded (or scoured) mortar fill area lying within the joint. Mortar degradation caused by weak acetic acid can be significant with differing mortars having various mix granularities and differing susceptibilities to deterioration. The contained sulphides in organic bridging layers can cause severe leaching of the infill mortar and open up the joint to promote exfiltration loss. However, the immediate underlying (transition) area of the unsaturated bedding zone should also be included within the definition of the colmation layer. The significance of the variations in the colmation layer definition for quantification of the pressure head and for exfiltration loss will be explored together with the influence of growth rate, composition and ageing of the overlying biofilm layer on the overall leakage process. It will be shown that biofilm growth is uninhibited by anaerobic conditions that might become established at the sewer invert due to sediment and other accumulating organic materials.

References

Blackwood, D J, Ellis, J B, Revitt, D M., Gilmour. D J and Stainer, A. 2005. Exfiltration from sewers: Is it a serious problem? In: *Proceedings IWA 10th International Conference on Urban Drainage*, Copenhagen, Denmark.

Ellis, J B, Revitt, D M, Lister, P, Willgress, C and Buckley, A. 2003. Experimental studies of sewer exfiltration. *Water Science & Technology*, 47(4), 61-67.

Klinger, J, Wolf, L, Hotzl, H. 2005. Leaky sewers; Measurements under operating conditions. In: *Proceedings 4th WorldWide Workshop for Young Environmental Scientists*. (WWW-YES), 10-13 May 2005. Domaine de Cherioux, Vitry sur Seine, France

Littlewood, K and Butler, D. 2003. Movement mechanisms of gross solids in intermittent flow. *Water Science & Technology*, 47(4), 45 – 50.

Vollertsen, J and Hvitved-Jacobsen, T. 2003. Exfiltration from gravity sewer; A pilot scale study. *Water Science & Technology*. 47(4), 69-76.