3 EXFILTRATION

3.1 Introduction

As stated in the Introduction, exfiltration causes reduced flows in the sewerage system, due to leaks and outflows from faults in the fabric of the system.

Exfiltration in sewer systems can cause many problems, including:

- Contamination of surrounding soils
- Pollution of groundwater, aquifers and receiving waters
- Failure of pipelines and structures due to erosion of supports
- Ground subsidence due to erosion of underground soils.

Ground failure and subsidence is often the result of infiltration/exfiltration cycles, whereby flows leak in and out of the system, eroding the finer material in the surrounding soils, progressively reducing support, and eventually causing failure. The *Sewerage Rehabilitation Manual (4th Edition, WRc, 2001)* describes this failure mechanism in detail.

Sewer systems are required to be designed, to be constructed, and to use materials that will ensure that leakage of sewage from the system is minimised. Excessive leakage or exfiltration, sufficient to cause structural and/or environmental damage, can constitute a failure to meet these requirements.

Worldwide, reduction of exfiltration is most commonly undertaken to correct pollution of subsoils and their groundwater, in particular aquifers used for water abstraction. Pollution of water supply systems is less likely since the water pressure inside the pipes normally prevents entry of groundwater.

3.2 Definitions of Exfiltration

The term “exfiltration” is used for water exiting the sewer system into the ground. Exfiltration leaves the sewer system through openings such as: displaced or open pipe joints, cracks, fractures and breaks in the fabric of the main sewer and its lateral connections, and in manholes and chambers. Exfiltration also occurs through openings, allowing sewage to discharge to ground or watercourses. Sewage flows from overflows, drain valves and the like, are not classed as exfiltration, since such outflows are intended as part of system operation.

3.3 Irish Experience of Exfiltration

There is very limited literature available relating to exfiltration studies or removal programmes in Ireland. Drainage area studies have identified Inflow and Infiltration as a problem, but not Exfiltration except where there are obvious major leakage points revealed by CCTV work. The difficulty in identifying exfiltration is that any such leakages from damaged systems tend to be masked by the much larger infiltration flows.

The GDSDS experienced this situation whereby infiltration flows were sufficiently large to be quantified, whereas exfiltration flows could not be identified due to flow monitor tolerances and the wide spread of monitoring locations.

The report, *Reliability of sewers in environmentally vulnerable areas (CIRIA, 1996)* describes how in 1992, a public water supply serving approximately 1500 households in Naas, County Kildare, became grossly contaminated by sewage. This left 26 people hospitalised and approximately 4000 people ill, suffering varying degrees of gastro-intestinal disorders. The incident was due to contamination of a borehole, supplying the town with groundwater for drinking. The contamination was traced to a blockage in a sewer next to the borehole with consequent seepage of sewage into the borehole. The supply was apparently chlorinated, but this appears to have failed to deal with the pollution. Super-chlorination of the source and supply network only completely remediated the situation some two weeks after the original pollution incident.

There is no systematic requirement in Ireland to record the location of boreholes, wells and springs, which are used for water supply. There are therefore no databases, for convenient reference of groundwater extraction sites.

One output of the Drinking Water New Sources Development Study, completed for Dublin City Council in 2003, was a database of locations where groundwater is used for non-domestic purposes. This is mainly a record of deep boreholes taking water from hard rock aquifers in the Greater Dublin area. However it is not a comprehensive database of all groundwater use, and the probability is that there are many small domestic and agricultural users that go unrecorded. For rural communities this deficiency is being addressed by the new Water Bill, which requires the Water Service Authorities to be responsible for privately run group water schemes, through a licensing system.

The general hydrogeological situation in Greater Dublin is that there are two aquifers, of (a) shallow gravels and (b) deeper fractured limestones. They are frequently separated by clay layers and hydraulically isolated from each other.

The aquifer most at risk from leaking sewers is the shallow gravels. It is not extensively used for water supply, and certainly not for drinking water, because it shows signs of contamination from urban activities. Guinness uses it for heat exchangers and Trinity College use it for a heating scheme, and there are other reports of it being used for industrial purposes. Whilst there may be a resource available from the gravels, public perception of the aquifer being contaminated may render it inappropriate for use in public water supply.

Where the gravel and limestone layers are separated by clay, the low permeability clay layer prevents downward seepage of contaminated water. Where the drift cover is thin or absent, there is a risk that downward contamination of the limestone aquifer can occur.

Corroded linings may allow seepage of contaminated water directly into older boreholes. Being fissured, the limestone cannot provide natural filtration. Groundwater will only provide dilution if the contamination is chemical rather than biological.

3.4 International Experience of Exfiltration

The relevance of international experience of exfiltration is similar to that for Inflow and Infiltration.

A recent technical review of exfiltration in UK and Germany (*A Review of the Effects of Sewer Leakage on Groundwater Quality, CIWEM Journal, March 2003*) concluded that infiltration/exfiltration will be found in all sewerage systems, with the direction of flow being determined by the level of groundwater relative to the sewer. Sewage exfiltration in Germany was estimated at about 5% of base flow, and in Nottingham as 1.5% to 2% of base flow. Overall, 23% of the sewers of England and Wales have faults that could allow leakage. The review also found that sewage exfiltration pollutes both shallow and deep aquifers.

This finding contradicts earlier studies (*Exfiltration from Gravity Sewers – A Pilot Study, Vollertsen and Hvitved-Jacobsen, Aalborg University, Denmark, 2002 and Groundwater Pollution from Subsurface Excavations, US EPA, 1975*) that exfiltration rates and microbiological contaminants are attenuated by a clogging zone of organic matter around the leak.

Experiments in exfiltration (*The effects of Sediments on Sewer Exfiltration, Ellis, Revitt, Lister and Willgress, Urban Pollution Research Center, Middlesex University, 2002*) also found the low likelihood of exfiltration in sewers subject to sedimentation, as well as suggesting that sewer leakage may be random in nature and dependant on local pipe, hydraulic and groundwater circumstances. The study estimated exfiltration to be no more than 5% to 10% of average daily dry weather flow.

CIRIA research *(Reliability of sewers in environmentally vulnerable areas, CIRIA Project Report 44, 1996)* found no conclusive evidence that leaking sewers are a common cause of groundwater pollution, or that properly constructed sewers using best modern practice will contribute to such contamination. However CIRIA did find that several factors, such as age, condition, ground movement and aquifer vulnerability, might increase the risks of contamination.

UK sewerage policy since the 1980's has been to maintain only critical sewers, corresponding to 23% of the total length, with the remainder being repaired only in emergency. This policy has resulted in a repair or replacement frequency (based on length) of once every 1300 years. The age of sewerage assets is increasing due to the relatively few new sewers being constructed.

Table 3.1, taken from the CIWEM Journal of March 2003, shows the history of UK sewerage assets. Although older sewers have a greater frequency of faults, more modern sewers rely on a granular surround, which aids the creation of leakage paths.

These statistics could usefully be compared with those of the Dublin Region, when such information becomes available.

Construction Period	Approx. Length (km)	Large Sewers	Small Sewers	Support System	Leakage Reasons
To circa 1900	60000	Brick/lime mortar	Brick/lime mortar Open jointed or socketed pipelines, clay sealed	Laid in trench bottom/ as dug surround	High frequency of pipeline faults/open joints. Leakage depends on porosity of bedding/surround.
1900 to 1930s rigid pipelines	136000	Brick/cement mortar, or in-situ concrete	Glazed clayware, socketed joints with tar/bitumen inserts. Concrete ogee in wall or socketed joints. Both made rigid with concrete	Laid on trench bottoms/ as dug surround. Some concrete bedding	Large sewers improved. Smaller sewers have high frequency of fractures in pipes/joints. Leakage dependant on porosity of bedding/surround.
1930 to 1960s rigid pipelines	60000	Some brick, precast concrete with rigid joints becoming more popular	As above, with water testing of new pipelines and national construction guidelines	As above	Slight improvement in construction. Leakage dependant upon porosity of bedding/surround.
1960 to Present flexible pipelines	46000	Mostly concrete/sliding-ring socketed joints	Mostly vitrified clay and concrete/sliding-ring socketed joints. Sleeve joints in small-size clay. Limited use of other materials, such as uPVC and asbestos cement	Granular bedding and/or surround	Improved construction with fewer faults. Granular surround allows leakage to quickly dissipate.

Table 3.1 History of UK Sewerage Construction *(Review of Effects of Sewer Leakage on Groundwater Quality, CIWEM Journal, March 2003)*

Although studies and research may appear to be inconclusive, we can conclude that:

- exfiltration occurs from all sewerage systems;
- exfiltration can be minimised by good quality sewerage construction materials and practices;
- sewerage in the vicinity of vulnerable aquifers is likely to cause ground water pollution.

The policy for exfiltration should therefore address these aspects with the view of minimising their occurrence and impact.

3.5 Causes of Exfiltration

There are many sources of exfiltration from sewers. Apart from obviously incorrect openings, all are caused by structural defects, including cracks, fractures, joint displacement, deformation, collapse, reverse gradients and unsealed connections. These defects result from one or more of the following causes:

Unsatisfactory Construction

The most common cause of exfiltration is poor technique in laying pipes. Considering the lack of knowledge in ground engineering and the increasing traffic loads being applied, Victorian brickwork construction demonstrates that good craftsmanship has resulted in very durable sewers. However such sewers are very dependant on support from the surrounding ground. Failure of the backfilling can lead to leakage, progressive weakening and eventually structural failure, often with ground subsidence. Lime mortar is susceptible to hydraulic abrasion and chemical attack, with resulting direct leakage and settlement cracking.

Early clay pipes were of inferior quality, initially with open joints and later with spigot and socket joints. However jointing using puddle clay squeezed out and caused settlement and tarred hemp joints were attacked by sewer gas.

Later sewers, particularly those laid in the 1920's to 1960's often suffer from material problems, poor workmanship and the engineering design may also be suspect. The use of rigid joints, which were subject to fracture on settlement continued to the 1960's.

Although modern sewers are generally well engineered, they are sometimes poorly constructed. The most common faults include failure to remove temporary supports (usually bricks) and poorly made connections. Plastics and GRP pipes will absorb deformations but will eventually fail, if backfill is inadequately laid and compacted.

Manholes and chambers can also suffer from poor construction, as well as failures at the transition from pipeline to structure. In-situ concrete structures can leak due to honeycombing from inadequate compaction.

Third Party Damage

Being generally lower in the ground than other services, sewers probably suffer fewer instances of damage than other services. However unlike others, sewers do not cause immediate disruption when damaged. The result is more long lasting damage, because damage is often covered over with inadequate repair, or no repair at all.

Service Damage

Deterioration of the sewerage fabric will occur in use. Brick sewers are susceptible to wear, spalling and mortar loss due to high velocity flows, scouring and sewer gases. Pitch fibre pipes progressively lose structural strength. Concrete pipes and manholes are very vulnerable to hydrogen sulphide damage. Clay and plastic pipes are generally not susceptible to service wear if correctly engineered and laid.

Operational Damage

Roots can cause blockage, structural damage and opening of joints. Siltation leads to blockage and excessive pressure, hence producing leakage. Sustained surcharge of sewers will have the same effect. Damage can be caused by maintenance of sewers, particularly from the use of inappropriately high water pressure during jetting. Plastics pipes are especially vulnerable to such damage.

3.6 Estimation of Exfiltration

Since exfiltration is the negative aspect of infiltration, its estimation uses the consideration of dry weather flow (DWF).

The formula is similar to Method 2 – DWF calculation in Section 2.6, except that exfiltration (Ex) is negative.

DWF = PG - Ex + E, where

DWF = Average dry weather flow (measured)

P = Catchment population

G = Wastewater generation per capita

Ex = Exfiltration

E = Industrial effluent

The comments in Section 2.6 regarding values and accuracy of parameters also apply.

The other methods of estimating infiltration, as detailed in Section 2.6, will be relevant to the estimation of exfiltration.

3.7 Costs of Exfiltration

Since exfiltration results in reduction of flows in the sewerage system, it could be argued that such leakage actually saves costs of pumping and treatment. However any such "savings" must be offset by reduction in the working life of the pipeline and environmental damage caused by pollution of groundwater.

Where exfiltration is near a groundwater abstraction source, the risk of contamination can be quantified, and costed (*Reliability of sewers in environmentally vulnerable areas, CIRIA Project Report 44, 1996)*. At most locations, contamination of the soils is difficult to measure, let alone undertake a cost-benefit analysis. Other effects of exfiltration, such as damage to pipe bedding and loss of support following infiltration/exfiltration cycles are equally hard to quantify.

Nevertheless the adverse effects of contamination and short-lived assets on public relations, damage to buildings, traffic disruption, etc, could be more significant than any cost-benefit analysis.

3.8 Survey Techniques for Exfiltration

The techniques for identifying infiltration identified in Section 2.7 apply to the identification of exfiltration. Survey work should be carried out in dry conditions where the groundwater table is at its lowest, thus encouraging leakage to occur.

However it must be recognised that where exfiltration occurs, the same faults will also result in infiltration, with the likelihood that infiltration flows will mask any exfiltration leakage.

Dye Testing

Dye testing involves flushing non-toxic dyes down suspect foul sewers and observing nearby surface water drains, water courses and ground surfaces for traces of the dye emerging.

Dye testing is a labour intensive process, and may involve digging of observation pits to try and pinpoint the leakage area.

Visual Inspection

Although very useful for infiltration, CCTV is less successful for locating exfiltration as it relies totally on the visual record. Unless there is a major leak or damage, minor exfiltration such as through defective joints is very difficult to see, especially if located below water level.

Sonar supplies a fairly accurate image of the profile of the pipe wall, both above and below water. Again small defects are difficult to identify.

Manual surveys involve opening manholes in a progressive manner at periods of low flows, and noting any inexplicable flow patterns. Success is limited to identification of very large leaks, with the likelihood of leakage being masked by infiltration.

Isolation Testing

This technique involves isolating a section of sewer and observing flows and/or carrying out air and water pressure tests. Being most suitable for testing of new sewers, testing specifications are contained in the New Development Policy.

3.9 Lateral Drains

Lateral drains on private lands present exfiltration risks, and therefore reinforce the need for strategies for survey as a condition of sale of the building, and for proper sealing upon change of use or demolition of the connected premises.

3.10 Exfiltration Removal

The techniques and selection method for removing exfiltration are generally similar to those for infiltration detailed in Section 2.9, in Appendix C and in the Sewerage Rehabilitation Manual.