Table of Contents

Appendices

EXECUTIVE SUMMARY

Background

The Greater Dublin Strategic Drainage Study (GDSDS) requires the recommendation of policies for the future provision and management of drainage services in the region. These drainage policies are to assist Local authorities in complying with their legal responsibilities, their planning and development objectives and are to, in so far as practicable, conform to good international practice. A particular requirement from the Study is that Policies adopted across the region should facilitate a uniform and consistent approach to urban drainage infrastructure planning, design, construction and operation.

The drainage policies will also result in improved customer service. In the case of Inflow, Infiltration and Exfiltration, the policy should concentrate on minimising such flows, thus facilitating future development and reducing costs for providing, operating and maintaining collection, pumping and treatment facilities

This volume of the drainage policies is entitled "Inflow, Infiltration and Exfiltration" and is concerned with identification of similar approaches for the Local authorities to adopt to reduce, and maintain control of these flows, which are adversely affecting the sewerage and drainage systems of the region.

Inflow and Infiltration both cause increases in the legitimate flows in the sewerage system. Inflow is where surface waters enter the foul sewerage system directly, and Infiltration is where the increased flows are due to groundwater entering the foul system through faults in the pipework, manholes and chambers. Inflow and Infiltration cause reduced capacity for legitimate sewage flows, increased pressure on treatment capacity and encourage structural deterioration and damage. The most significant effect for the Dublin Region is that the capacity of the foul system and treatment facilities is compromised, resulting in restrictions in their ability to service new developments.

Exfiltration causes reduced flows in the foul system, due to leaks and outflows from faults and openings in the pipework, manholes and chambers. Exfiltration of foul flows results in contamination of the surrounding soils and possible pollution of groundwater.

Since both Infiltration and Exfiltration involve flows passing through physical defects in the sewerage fabric, they often occur together in conjunction with fluctuating groundwater levels. This continuing flow mechanism can result in erosion of surrounds and foundations to pipes and manholes. In serious cases failure of the asset or ground subsidence has resulted.

Since most exfiltration involves relatively modest flows leaving the system, it is much more difficult to identify than infiltration. However since exfiltration relies on the same defects in the sewerage fabric, it frequently occurs along with infiltration.

Policy Objectives

The approach requires application of Best Management Practices (BMPs) from international experience, so that the following objectives are achieved:

- The presence and causes of inflow, infiltration and exfiltration (I/I/E) in the region's sewerage systems are recognised;
- I/I/E in the region's sewerage systems will be identified and flow quantities estimated;
- Survey and reduction works will be carried out with optimum cost-benefit;
- Specifications and practices for sewerage construction will be imposed to minimise I/I/E;
- Asset management systems will be targeted to minimise I/I/E and its adverse effects on the operation of the sewerage system and the overall environment.

Current Situation in the Dublin Region

The Drainage Departments in the Dublin Region have long suspected that there are substantial quantities of inflow and infiltration in the sewerage systems of the Region. These suspicions have been confirmed by verification of the hydraulic models under the GDSDS. Existing approximate infiltration flows for the Ringsend WwTW catchments are:

Catchment	Infiltration Flows in l/s
Grand Canal System	615
City Centre/ Docklands	558
Dun Laoghaire	338
Rathmines & Pembroke High Level	500
Total Infiltration Flow	2011 l/s

The flow to full treatment at Ringsend WwTW is 11m3/s; 2011l/s comprises 18% of this flow. At a daily sewage discharge per household of 650 litres, 2011l/s corresponds to 267,300 households.

Significant increases in flows have been measured in both the 9B and 9C trunk sewers following storms, as can be seen from the flow monitor results contained in Appendix A. Such increases indicate that surface water runoff (up to 5 times DWF) is entering the separate Blanchardstown foul system, and up to 8 times DWF for the Lucan Clondalkin 9B system. These are the main sewers discharging to the Grand Canal Tunnel Sewer and Ringsend WwTW. There is widespread pollution of aquifers from sewage exfiltration to the groundwater.

The infiltration situation for all the GDSDS foul/combined catchments is demonstrated in the tables contained in Appendix B. The worst affected catchments are City Centre/Docklands and Dun Laoghaire West Pier East with infiltration exceeding 50% of DWF. The least affected catchments are North Dublin, Shanganagh and Bray. Most catchments have infiltration in the order of 30% to 40% of DWF.

Exfiltration is difficult to identify except where major pipe defects or breaks occur, allowing significant escapes of flow. No such instances were detected during the GDSDS. However we can be confident that exfiltration is occurring in tandem with infiltration.

The causes for this situation are typical of those affecting sewerage systems worldwide, and can be summarised as:

- Faults in the sewerage fabric, due to age of the assets, ground movement, surface loadings, inadequate designs, deterioration of materials and defects in construction;
- Operational faults, such as missing or damaged manhole covers, faulty flap valves, openings allowing inflow at high river and tidal levels;
- Illegal stormwater connections due to poor supervision of construction and local modifications to accommodate drainage of extensions, patios and driveways

Control of Inflow, Infiltration and Exfiltration

Most I/I/E occurs in relatively small quantities throughout the extent of the sewerage system, and is hence difficult, time-consuming and expensive to identify. For that reason a control policy based on reiterative reduction, based on homing-in from the general area to particular significant sources, is the most cost-effective approach.

The most cost-effective policy is to minimise I/I/E in the first place. This can best be done by strictly controlling the quality of new and renovated sewerage installations, and by ensuring that best quality materials and construction techniques are used, to provide a long-lasting leak-free system. Connections must also be correctly made, and private drains and abandoned sewers managed to minimise the risk of leakage. Rigorous checking by Council Inspectors will ensure that sewerage construction will achieve its maximum life with minimum defects.

Policy for Inflow Infiltration and Exfiltration

The policy principles are to:

- Adopt an Infiltration Reduction Procedure to reduce inflow, infiltration and exfiltration flows in the existing sewerage systems in the most cost-effective manner; the Local Authorities should conduct a pilot study into I/I/E reduction to establish the cost-effectiveness of such reduction programmes in the Dublin area.

- Adopt sewerage construction specifications and procedures to ensure that new and renovated sewerage systems avoid the defects which result in inflow, infiltration and exfiltration

Policy Acceptance and Implementation

Acceptance of the Policy across the region will require implementation at various levels, as follows:

Council Drainage Departments: carry out pilot area for I/I/E reduction to establish the cost-effectiveness of reduction programmes in the Dublin area; agreement to adopt the Infiltration Reduction Procedure, based on the results of the pilot area investigation, showing assessment and renovation requirements, and associated costs; agreement to carry out future maintenance of sewer system models to support the Infiltration Reduction Procedure.

Council Legal Departments: agreement to requirement that private lateral drains be surveyed and renovated as a condition of sale of premises;

Council Drainage Inspectorate: agreement to extension of construction inspections to include private drains;

Council Drainage Department and Inspectorate: agreement on setting up of programme of public education and local investigations to identify mis-connections of stormwater flows to the foul system;

Council Drainage Operations Department: correction of faulty flap valves, manhole covers and other openings potentially allowing inflow into the sewerage system;

Water Services Authorities: agreement to setting up and maintenance of register of water source boreholes, and liaison with Drainage Departments on borehole location and usage of yield with respect to the presence of sewerage systems;

Other Regional Policies being adopted from the GDSDS will support this Policy, as follows:

Environmental Management Policy: adoption of SuDS to minimise the risk of stormwater runoff being mis-directed to the foul system;

New Development Policy: changes to construction specifications and inspection procedures to improve quality and durability;

Regional Drainage GIS: collection, maintenance and presentation of information to support risk management for I/I/E and the Infiltration Reduction Procedure.

1 INTRODUCTION

This document comprises Volume 4 of the Regional Policies being recommended as part of the Greater Dublin Strategic Drainage Study (GDSDS), and is entitled "Inflow, Infiltration and Exfiltration".

The objectives of the Inflow, Infiltration and Exfiltration (I/I/E) Policy are to define practical solutions to the problems, in terms of asset management, construction and inspection practices and specifications. Among the issues considered are:

Sources and causes of I/I/E in the Dublin Region and worldwide;

Extent of inflow and infiltration found in the Dublin Region;

Methods of quantifying, locating and reducing I/I/E;

Economics and cost-benefit of I/I/E reduction.

Many of the methods of reducing I/I/E involve improvements in specifications for construction and inspection of drainage and sewerage systems. These details are contained in the Regional Policy on New Development, and are cross-referenced from this Policy.

1.1 Background

The Policy document addresses the requirements of the Brief to produce a policy on Infiltration and Exfiltration. Both mechanisms adversely affect the legitimate flows in constructed foul sewerage systems.

Inflow and Infiltration both cause increases in the legitimate flows in the sewerage system. Inflow is due to surface waters entering a separate foul sewerage system through misconnected gullies or downpipes, and Infiltration is where the increased flows are due to groundwater entering the foul system through faults in the pipework, manholes and chambers. Inflow and Infiltration cause reduced capacity for legitimate sewage flows, increased pressure on treatment capacity and possible structural damage. The most significant effect for the Dublin Region is that the capacity of the foul system and treatment facilities is compromised, resulting in restrictions in their ability to service new developments

Exfiltration causes reduced flows in the foul system, due to leaks and outflows from faults and openings in the pipework, manholes and chambers. Exfiltration of foul flows results in contamination of the surrounding soils and possible pollution of groundwater. Continuing leakage can result in erosion of surrounds and foundations to pipes and manholes. In serious cases failure of the asset or ground subsidence has been caused.

Infiltration and Exfiltration thus comprise three mechanisms, and the policy has therefore been entitled "Inflow, Infiltration and Exfiltration".

1.2 Report Structure

Section 2 deals with Inflow and Infiltration, with Section 2.2 defining the components of flow in sewer systems. Sections 2.3 and 2.4 report on Irish and international experience respectively.

Section 2.5 covers the causes of Inflow and Infiltration and Section 2.6 describes current best practice methods for estimating its quantity.

Section 2.7 deals with the costs of Inflow and Infiltration, and in particular the need for comparing the cost of its acceptance with the cost of identifying and removing it.

The cost of identifying and removing I/I is dependent on survey and rehabilitation techniques and renovation techniques, which are covered in Sections 2.8 and 2.9.

Section 3 covers Exfiltration, which shares a lot of its content with the Infiltration elements contained in Section 2.

Section 4 contains the strategy for dealing with Inflow, Infiltration and Exfiltration using short, medium and long-term measures.

Section 5 summarises the Policies for Inflow, Infiltration and Exfiltration, and deals with their implementation.

Appendix A contains samples of flow measurement in the 9B and 9C catchments of the Grand Canal system, from the flow survey of December 2001 to February 2002, showing inflow and infiltration.

Appendix B lists the base infiltration levels at flow monitors and at catchment level, found during the dry weather verification of hydraulic models of the GDSDS foul catchments.

Appendix C contains information on sewer renovation techniques, extracted from CIRIA Report for RP501.

2 INFLOW AND INFILTRATION

2.1 Introduction

Inflow and infiltration (I/I) in sewer systems can cause many problems, including:

- increased operational and capital costs in the sewer network and at treatment plants;
- reduced sewer and treatment capacity leading to increased operation of combined sewer overflows, flooding and pollution;
- reduced sewer and treatment capacity restricting future development;
- lowering of groundwater levels leading to detrimental effects on local water resources;
- loss of soil into sewers causing operational problems and structural damage.

These problems all ultimately result in increased costs. As mentioned in the first bullet point above, there is the direct cost of conveying and treating illegal flows. Accepting illegal flows results in additional costs in extending existing assets or building new facilities, or in being restricted in servicing future development. Passage of flows through faults in the fabric will shorten the operating life of the facilities with corresponding additional costs.

Sewer systems are required to operate to basic performance requirements (*European Standard EN 752-2: 1996, Drain and sewer systems outside buildings, Part 2 Performance Requirements*). Excessive inflow and infiltration can constitute a failure to meet certain of these requirements.

Worldwide, reduction of I/I is most commonly undertaken in order to reduce capital expenditure required by legislation. For example, in a new sewage transfer and treatment works scheme, it may be more cost effective to locate and remove excessive infiltration than to size transfer mains and treatment units to deal with existing levels. Alternatively, high levels of I/I may be identified and addressed during a drainage area study carried out as part of a general sewerage rehabilitation programme.

It is not always cost effective to reduce or eliminate infiltration. There is often uncertainty over the practicalities and, furthermore, little understanding of the relative costs of continuing to accept I/I versus the costs of I/I reduction. However, various strategies and procedures for addressing I/I problems on a systematic basis have been developed and implemented.

2.2 Definitions of Inflow and Infiltration

A typical hydrograph showing the components of flow in a foul/combined sewer system is given in Figure 2.1. The figure shows a period of 7 days with a rainfall event occurring on the fourth day.

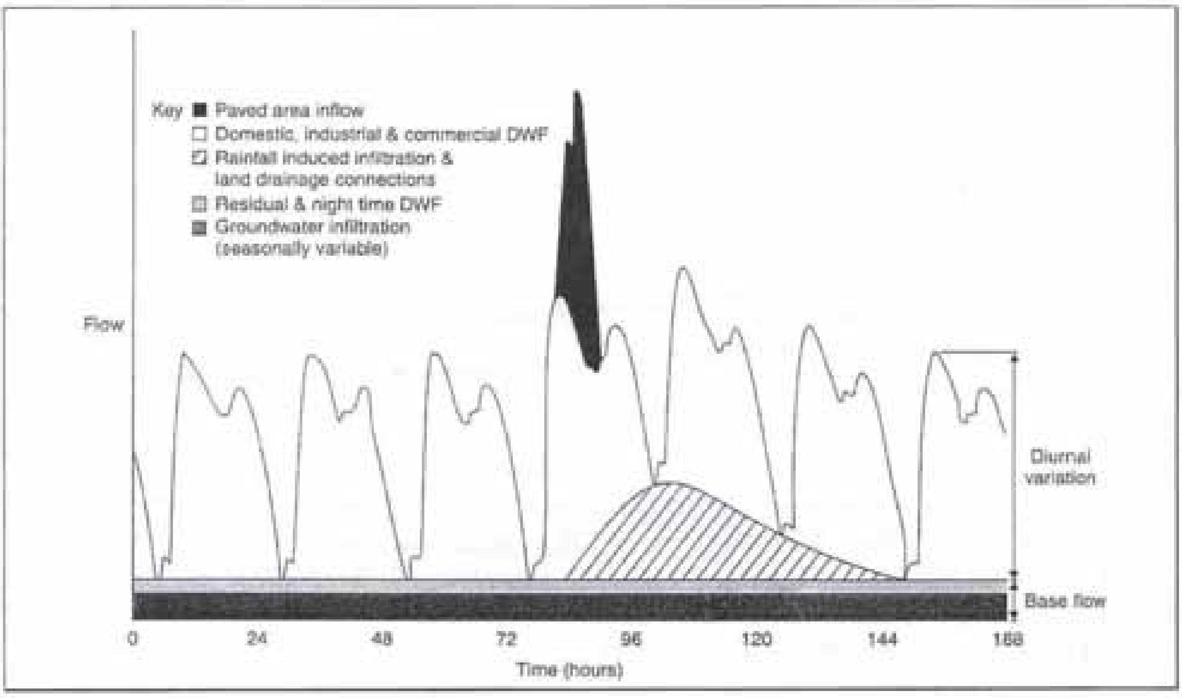

Figure 2.1 The Components of Flow in a Foul/Combined Sewer System

The term "infiltration" is used for water entering the sewer system from groundwater or from below ground level. The term "inflow" is used for water entering the sewer system directly. The expression "I/I" refers to the combined effects of inflow and infiltration.

Infiltration enters the sewer system through openings such as: displaced or open pipe joints; cracks, fractures and breaks in the fabric of the main sewer and lateral connections, and manhole chambers.

Inflow enters the sewer system via sources such as faulty manhole covers, cross-connections from surface water sewers/domestic drains and land drainage connections. In addition, in separate sewer systems, inflow includes the mis-connected direct runoff of surface water to the foul sewer system. In Ireland, the term "inflow" is not generally used for stormwater runoff entering sewers that were designed to operate as combined systems.

Table 2.1 shows the relationship between the various sources of inflow and infiltration that make up the total I/I influents in both dry and wet weather.

Source	Condition	Category
Groundwater infiltration *(may occur if the groundwater level is above the sewer invert level and may be seasonally influenced)*	**Background / base / dry weather infiltration**	**Infiltration** *(enters sewer system from the ground)*
Tidal infiltration *(infiltration of seawater from tidally saturated ground which the sewer crosses – will coincide with tidal cycles and will be most obvious during spring tides)*		
Leaking water mains		
Seepage of rainfall through subsoil of permeable areas *(may persist for days or weeks depending on the extent and permeability of the catchment subsoil)*	**Rainfall induced infiltration**	
Leaking storm sewers		
Domestic drain connections	**Dry weather inflow**	**Inflow** *(enters sewer system directly)*
Tidal inflow *(e.g. via combined sewer overflow outfall pipes)*		
Land drainage connections	**Rainfall induced inflow**	
Cross-connections from surface water sewers/domestic drains		
Mis-connected direct runoff of surface water to the foul sewer system *(in separate sewer systems)*		
River inflow via backflow in combined sewer overflows *(can exhibit similar properties to rainfall induced infiltration as the response time of the river is slower than that of the sewer)*		
Surface runoff and entry through manhole covers		

Table 2.1 Inflow and Infiltration Constituents

The maximum flow passed forward to a treatment works is often dominated by inflow, due to storm events. However, the background / base / dry weather infiltration is usually constant throughout the day and can therefore form a significant proportion of the total annual flow. Furthermore, reduction of dry weather infiltration will automatically reduce the overall quantity of wet weather infiltration.

2.3 Irish Experience of Inflow and Infiltration

There is limited literature available relating to infiltration studies or removal programmes in Ireland. Drainage area studies (undertaken as part of the design process for new sewage transfer/treatment schemes or to address deficiencies such as flooding) have often identified I/I as a problem and local authorities have followed up with works to locate sources and reduce flows.

The 2001 to 2004 Greater Dublin Strategic Drainage Study covered 18 foul/combined sewerage catchments with a combined population of 1.4 million (about 1/3 of the total state population). A major programme of flow measurement (480 flow monitors and 270 raingauges) and sewerage modelling in these catchments provided an opportunity for an initial assessment of infiltration, albeit on a ‘snapshot’ basis due to the short-term sewer flow surveys. Table 2.2 shows the existing approximate infiltration flows for the Ringsend WwTW catchments.

Catchment	Infiltration Flows in l/s
Grand Canal System	615
City Centre/ Docklands	558
Dun Laoghaire	338
Rathmines & Pembroke High Level	500
Total Infiltration Flow	2011 l/s

Table 2.2 Infiltration Flows into Ringsend WwTW

Appendix B provides a summary of the infiltration assessment for all catchments.

Data collection during the early stages of the GDSDS provided information on I/I from previous studies and investigations. The following examples give an impression of the situation in parts of the Greater Dublin Area.

- The presence and effects of infiltration have long been recognised in Dublin. The design report for the Grand Canal Drainage Scheme (1968) included assessments of the existing drainage networks draining to the Main Pumping Station.
    - In the 34,000 population Rathmines and Pembroke (low level) catchment “a considerable portion of the Pembroke area lies below the level of h.w.o.s.t. (high water of spring tide) and a large quantity of subsoil water finds its way into the sewers”. Pumping records at the terminal station suggested that average infiltration was in the order of 80 l/s or 25% of total dry weather flow.
    - In the 341,000 population Centre City Main Drainage network, infiltration was estimated at 156 l/s or 12% of total dry weather flow.
    - Daily flow records at the Main Pumping Station serving the Centre City catchment were analysed. The report makes several references to infiltration:

        “The daily flows at this station show a wide variation… and even flows during long periods of dry weather are influenced to some degree by antecedent rainfall”;

        “The development of the system during the past has been such that certain watercourses and streams which drained to the old city area were incorporated in the drainage system.”

"Infiltration from the tidewaters of the Liffey is also appreciable as the old city sewers which originally drained to the River are now equipped with tidal flap valves and operate as storm overflows."

- A sewer modelling study of Dublin Docklands in 2000 found that flows in the main city centre sewers showed a marked response to tide levels. Flows at the Main Lift Pumping Station were found to rise substantially with the tide. Tidal effects were also noted in other sewers further from the River Liffey.

- A short-term flow survey was undertaken in the Grand Canal Trunk Sewer (GCTS) catchment in the winter of 2001. On three selected 'dry' days, minimum nighttime flows at the downstream end of the GCTS ranged from 150 l/s to 500 l/s, with the corresponding range of infiltration estimated at 10% to 50% of total dry weather flow. This demonstrates the significant influence of preceding rainfall.

- Investigations for the Lower Liffey Valley Regional Sewerage Scheme found high rates of groundwater infiltration, particularly in the mid-autumn to mid-spring period. Increased pumping times were noted at pumping stations and infiltration was described as 'a serious problem'. It was also evident that some surface water pipes were connected to supposedly separate foul sewers. In Leixlip, Celbridge and Maynooth, infiltration typically ranged from 25% to 75% of total dry weather flow. In Kilcock, the minimum recorded infiltration was 45% of dry weather flow (flows from Kilcock are pumped twice before reaching the WwTW at Leixlip). The study proposed both sewer rehabilitation and some separation and diversion of surface water.

- A study to identify sewage disposal options for a major development in South Dublin (Adamstown Area Action Plan) reported infiltration of 70 l/s, or 30% of dry weather flow, in a catchment area of 2300ha. Inflow of surface water to the foul system was also found to be considerable with up to 20% contributing impermeable area in some subcatchments. Identification and removal of surface water connections was recommended prior to connection of foul flows from the new development.

- An eleven week winter flow survey in the Grand Canal Tunnel Sewer catchment showed marked differences between infiltration rates in the two main trunk sewer tributaries: the 9B (Clondalkin) Sewer and the 9C (Blanchardstown) Sewer. Flow plots for the full survey period are included in Appendix A. In the 9B Sewer, the base infiltration is low, at around 5 or 10% of total dry weather flow. In the 9C Sewer, it is significantly higher, at around 40 or 50% of dry weather flow. The effects of rainfall-induced infiltration are clearly shown in both systems, which are essentially separate foul sewers. The fast response to rainfall (peaks of up to 5 times average) indicates the presence of inflow.

2.4 International Experience of Inflow and Infiltration

The nature of the UK's sewerage system is similar to that of Ireland's (a mixture of older combined systems with newer separate areas) and an understanding of the UK's approach to I/I problems is beneficial. Literature from elsewhere in Europe indicates a similar level of understanding and experience to that in the UK.

In the USA, the great majority of sewer systems are intended to be fully separate and since the 1970s much effort has been expended in attempts to eliminate excessive I/I. There is a great deal of literature available describing I/I reduction programmes in American cities.

Sewerage systems in Australia and New Zealand are generally similar to those in the USA but major I/I reduction work has been more limited. Some major I/I studies have been undertaken in Hong Kong and Singapore in recent years.

2.4.1 United Kingdom Experience

In the UK, water services are provided by a number of private companies whose actions are regulated by the Office for Water Services (OFWAT). Since privatisation in 1989, investment has been delivered in five-year cycles known as Asset Management Plan (AMP) periods. Major improvements to sewage treatment, combined sewer overflows and property flooding have been achieved. However, the programme constraints imposed by the AMP process, combined with the scale of the workload, are such that the majority of capital works have been designed to deal with existing levels of inflow/infiltration.

The report, *Control of infiltration to sewers (CIRIA, 1996),* describes a questionnaire survey of infiltration problems in the UK. Of the 1,646 catchments included in the survey, 28% were reported to have greater than 25% infiltration and 9% to have more than 50% infiltration. The report describes a method for estimation of infiltration and a procedure for establishing the cost effectiveness of infiltration reduction.

A subsequent report, *Dry weather flow in sewers, (CIRIA, 1998),* presented an analysis of long term dry weather flow data from 95 sites in England and Wales. Infiltration ranged from 0% to 89% of total measured dry weather flow, with a mean of 45%. For purely domestic catchments, the 45% level is equivalent to 115 to 120 litres/capita/day. The report includes guidance on alternative methods of infiltration assessment depending on the available data.

Sewers for Adoption (Water UK/WRc, 5th edition 2001) is a design and construction guide for developers who want their new sewers to be ‘adopted’ (i.e. taken in charge) by the water company. The guide requires a design flow of 4000 litres/unit dwelling/day for gravity sewers serving new residential developments. The derivation of this figure effectively allows for 10% infiltration, which equates to 120 litres/capita/day.

Drains have been recognised as a potentially significant source of infiltration in many areas of the UK but no corrective action has been reported in this sector *(Control of infiltration to sewers, CIRIA, 1996*). A research project has recently been commissioned to investigate this issue further.

With the aim of improving water quality at EC identified bathing waters, spills from storm tanks at numerous sewage treatment works around the UK’s coast have been required to be limited to an average of 3 per bathing season. Understanding the range of infiltration present during the summer months has been found to be an important factor in optimising design of the storm tanks to achieve the new standards. A design study for a 3 spills storm tank at a WwTW on the south coast of England *(Poole, WaPUG Spring Meeting, 2002)* analysed five years of flow and rainfall data. Infiltration was found to vary seasonally but was more strongly influenced by the preceding rainfall. The amount of infiltration was also found to be influenced by the amount of rain that fell as much as 3 months earlier.

The benefits of long-term flow monitoring data were also demonstrated by an investigation carried out prior to award of a Private Finance Initiative (PFI) contract for a WwTW at Edinburgh, Scotland *(Friend and Hill, WaPUG Spring Meeting, 2001).* On average, infiltration amounted to some 60% of the dry weather flow and seasonal variations were noted. The PFI payment system was based on flows receiving full treatment at the WwTW and for the total payment over the 25 years concession period, approximately half is infiltration based. Infiltration values on dry days over a twelve-month period were plotted against both the number of preceding dry days and the Antecedent Precipitation Index (API30) values (API30 is a factored total of the rainfall that fell during the 30 days prior to the dry day). The analysis found that the lowest infiltration did not necessarily occur after the largest number of dry days or when the API30 value was lowest.

The considerable investment in CSO improvements in the UK in recent years has highlighted the importance of understanding rainfall-induced infiltration and representing it correctly in sewerage models. Where storage is proposed as a solution for reducing CSO spill frequency, the required volume may be underestimated if the model does not adequately represent the ‘recession’ of flows after a rainfall event. The typical five to ten week flow survey carried out to verify a sewerage model has been found, in many cases, to be insufficient for understanding infiltration variation to the extent needed for design.

2.4.2 United States of America Experience

The *US Environmental Protection Agency (EPA) 1975 Guidelines* required cities to eliminate excessive I/I in order to qualify for grants to improve collection systems or build new wastewater treatment plants. The threshold infiltration rate was set at 1500 gpd/in-mile or approximately 140 litres/day per mm diameter – kilometre length and communities were required to remove any infiltration in excess of this (for comparison, the US EPA standard for new construction is 18.5 litres/day per mm-km). This requirement has led to considerable work being undertaken and as a result there is a great deal of literature from the USA regarding I/I. The vast majority of sewerage systems are separate so WwTWs are not designed to accommodate storm flows. Historically there has been a high emphasis on the removal of inflow from both public and private sources. More recently, the drive to reduce combined sewer overflow spills has also focused attention on reduction of inflow.

A number of case studies suggest that I/I programmes have, for various reasons, often been ineffective or not cost effective. However, more recent work (Merrill, Lukas, Swarner and Klusman, 2001) suggests that detailed and good quality flow monitoring (ADS monitoring for low flows), together with modelling of individual I/I components, is helping to target priorities and therefore lead to a more cost effective and successful removal programme.

Success rates of I/I reduction are highly variable. The City of Nashville reported in 1994 that I/I reduction in five pilot basins ranged from 49 to 86 percent. In Seattle, Washington, a complete sewer rehabilitation programme in a pilot project area of 4ha achieved a total I/I reduction rate of 60%. A review of USA practice (Wade, *Controlling Inflow and Infiltration in Wastewater Collection Systems*, *1999*) found that it was “rare that I/I reduction rates exceed 50%” but that “most cities can expect cost recovery within a 3 to 5 year period.”

One of the most difficult factors involved in removing significant quantities of I/I from sewer systems is the large percentage of sources that are located on private property. In Cincinnati, Ohio, a major programme to reduce rainfall induced I/I provided reimbursement of up to $3,000 to each participating private property owner for re-routing storm flows and eliminating their discharge to the foul sewer *(Niehaus, 1995).* Over 10,700 unauthorised storm connections were identified, with a total removal cost of $16m. Savings in capital and operating costs were estimated at over $300m. The two most common types of inflow sources removed were roof drain connections and driveway drains. A change in the law was required to permit the funding of sewer improvements on private properties but the resulting strategy was definitely found to be a “win-win” approach.

A similar programme in St Paul, Minnesota was described in a guidance note on *Inflow Reduction for CSOs (US EPA, 1999)*. An estimated 20% of CSO volume came from roof drains. As a result of a $40 rebate for voluntary redirection and other efforts, some 18,000 homes redirected their roof drains over a three-year period.

Introducing similar funding schemes to the Dublin Region should only be done after cost-benefit analysis has been done to demonstrate that they would be worthwhile. Such analysis would need to compare the levels of I/I measured and the likely reduction that could be achieved (the benefits), with the funding amounts offered and the likely take-up of the scheme (the costs). The first step in this process is implementation of the I/I/E Reduction Procedure recommended as a short-term measure in Section 4, to define the potential benefits.

In Indianapolis, Indiana, frequent basement flooding was experienced, generating over 1,000 residential complaints. Rapid development compounded the problem by further taxing the hydraulic capacity of the sewer system and a sewer moratorium was threatened. Flow monitoring in 400 sub-catchments found that only 27% of the system contributed 80% of the I/I. This allowed rehabilitation efforts to be focused on the high priority areas for the quickest results. Construction of a new relief sewer was avoided with savings of $21m.

2.4.3 Experience Elsewhere

An extensive programme of infiltration studies was carried out in eight catchments in Singapore during the 1990s to identify sewers most at risk of structural deterioration *(Sharpe and Turner, WaPUG Spring meeting, 1999).* The separate foul sewer networks were mainly constructed in the 1970s. Detailed hydraulic models were built in each catchment and a total of 178 flow monitors were used with an average sub-catchment size of 32.5ha. Model calibration was used to identify the separate I/I components of base infiltration, rainfall induced infiltration and storm inflow. Infiltration was ranked using a l/s per mm-km analysis. Dry weather infiltration contributed between 0% and 57% additional flow. Storm inflow contributions more than doubled the peak dry weather flow in a 1-year return period event in some catchments. In the worst two catchments, storm inflow increased peak dry weather flow by a factor of 10 in a five-year return period storm event.

A pilot study in Hong Kong *(Atkins China, 2001)* for Inflow and Infiltration reduction investigated a study area with a population of 1.34 million. The realisation that capacity taken up by infiltration could instead be reserved for future population growth was a key driver for the study. The study employed flow and rainfall monitoring, sewer modelling, CCTV surveys and cost models to identify the most cost effective levels of I/I reduction. Rehabilitation work to reduce I/I was found to be cost effective in all but one of the 34 catchment areas in the pilot study area.

The *New Zealand Infiltration and Inflow Control Manual (NZ Water and Wastes Association, 1996)* highlights “three major issues which have an important influence on successful I/I control.” These include “flow measurement (both before and after remedial works), the careful investigation of sub-catchments to locate the worst problem areas, and house lateral rehabilitation.”

2.4.4 Summary of International Experience

It is evident that I/I/E is a worldwide problem with DWF percentage flows similar to those being experienced in the Dublin region. Due to the difficulty in identifying exfiltration, most investigative work has been directed towards inflow and infiltration.

The most successful approach is to use detailed and good quality flow monitoring, together with modelling of individual I/I components. Priorities are thus targeted and therefore produce a more cost effective and successful reduction/removal programme. This approach is being recommended for I/I/E policy in the Dublin region.

Reduction/removal rates are very variable, and should not be applied to the Dublin region without some pilot study into local problems. However the 80:20 principle applies (80% of I/I contributed by 20% of the system), again emphasising the worth of the structured approach being proposed in the policy.

Faults in private drainage systems contribute greatly to the I/I/E problem, and therefore drainage policy should concentrate on policing private connections.

It is recognised worldwide that I/I/E is a difficult and expensive problem to address, and therefore the most cost-effective approach is to avoid it in the first place. Policy should therefore also concentrate on good quality construction and supervision to maximise the life of the drainage assets. This principle is being recommended in the Regional drainage policies, in particular that for New Development.

2.5 Causes of Inflow and Infiltration

Inflow and infiltration can be caused by a wide variety of sewer system faults and ground conditions. In essence, I/I can be considered as the presence of rainwater/groundwater/seawater coinciding with sewer system faults allowing entry of the water.

2.5.1 Causes of Infiltration

Infiltration can occur where existing sewers undergo material and joint degradation, which results in entry paths for water. This degradation can be progressive, so that repair of, for instance, all faulty joints, may be followed by further degradation of different, formerly sound joints and renewed infiltration requiring further repair. Infiltration can also occur in new sewers where these, or the connected laterals, are poorly designed or constructed.

Factors that influence the occurrence and extent of infiltration include:

- Ground movement – caused by mining activity, construction work, change in overlying ground use, ground loss from around the sewer due to infiltration through damaged pipes.
- Soil type – will affect the drainage of water and movement of the pipe. Silts, sands and gravels generally have a high permeability allowing rapid erosion of soil particles. Clays have much smaller pore spaces and a greater resistance to this process.
- Pipe type and quality of construction – traditional materials are durable but the joints and mortar can be more prone to attack.
- Chemical attack – can be caused by standing sewage turning septic or illegal/un-licensed discharge of trade effluents to sewer or to groundwater.
- Groundwater – location, movement and response to rainfall. The mechanism of soil erosion is accelerated by high groundwater levels.
- Hydraulic regime – erosion of soil is dependent on flows through the defect and hence cycles of infiltration or exfiltration caused by periods of surcharge within the sewer are important.
- Pipeline bedding – highly permeable bedding can affect the local natural drainage paths; the use of cut-offs within the bedding prevents rapid flows along the sewer trench, which can result in erosion of backfill.
- Type and extent of land development – use of sustainable drainage systems (SuDS) in new developments.
- Age of sewerage system – materials and methods of design and construction have changed over the years.
- Quality of sewer system maintenance – workmanship and materials used for sewer repairs, replacement or re-lining; sealing/isolation of abandoned lateral sewers.
- Ownership – drains that are intended to remain in private ownership are not subject to the same standards of construction or maintenance as publicly owned sewers.
- Leakage from water mains – foul sewers are usually laid at a greater depth than potable water mains, reduction in potable water leakage rates may reduce infiltration.

The *Sewerage Rehabilitation Manual (4th edition, WRc, 2001)* provides a detailed explanation of the factors that result in infiltration, exfiltration and eventually sewer collapse. The three stages of collapse are referred to as initial defect; followed by deterioration and finally collapse, brought about by a number of contributing factors.

A thorough description of the causes of infiltration is given in *Control of infiltration to sewers (CIRIA, 1996).* The report describes types of sewerage systems particularly at risk from infiltration:

- sewers laid in poor ground conditions
- sewers lying below the water table
- sewers situated in estuarine or marine environments
- lateral connections to private properties
- systems where poor workmanship was employed during construction
- foul sewers situated below leaking water mains and storm sewers.

Sewerage systems are most easily characterised by:

- the age of the system
- local ground conditions
- factors specific to the system usage.

Migration of infiltration has been found to be a problem in some infiltration reduction programmes. This can occur where sewer rehabilitation removed the previously existing infiltration flow paths, resulting in localised raising of the groundwater level and flows of groundwater to un-rehabilitated sections of sewer, which previously were not leaking.

2.5.2 Causes of Inflow

Causes of inflow are less complex because the water enters the sewer system directly. Factors that influence the occurrence and extent of inflow include:

- Topography;
- State of the stormwater system – e.g. missing or damaged manhole covers, faulty flap valves on CSO outfall pipes, cross connections from storm sewers, presence of land drainage connections;
- Capacity of the stormwater system in comparison with experienced flows;
- Illegal stormwater connections – on new developments if work is not checked before sewers are taken in charge; in existing areas where new house extensions, patios or driveways are drained to the foul sewer;
- Low or unsealed foul gully traps allowing surface water to enter foul system.

2.6 Estimation of Inflow and Infiltration

It has been said that "you can't manage what you can't measure" and this is certainly applicable to I/I in sewerage systems. However, measurement of infiltration has sometimes proved difficult in the past and results have been affected by poor quality or insufficient data or by a lack of understanding of I/I components.

Evidence from the USA *(Merrill et al, 2001; Swarner and Thompson, 1999; Keefe, 2000),* where considerable effort is invested in I/I reduction, suggests that recent I/I investigations have been more successful than those in the past. These recent studies have employed detailed flow and rainfall monitoring combined with hydraulic modelling to understand the relative contributions of individual I/I components in wet and dry weather. This has helped to target available funds to where they can have the biggest cost saving impact.

However, different methods are appropriate at different stages of an investigation and initial estimates must be based on whatever data is available. The aim of this section is to describe a range of methods that may be applied at different stages as appropriate. For the purposes of analysis, the methods are described under two categories: dry weather flow and rainfall induced flow.

2.6.1 Dry Weather Flow

Sources of infiltration and inflow in dry weather are listed in Table 2.1. Two CIRIA reports: *Control of infiltration to sewers (1996)* and *Dry weather flow in sewers (1998)* describe various methods for estimating the quantity of base, or dry weather, infiltration in a sewerage system and much of the following is based on the findings of these two research studies.

The basic definition of dry weather flow (DWF) is **all flow in a sewer except that caused directly by rainfall**. The average daily DWF is given by:

$$DWF = PG + I + E$$

where

DWF = dry weather flow (m3/day)
P = population served
G = average domestic wastewater contribution (m3/capita/day)

I = infiltration (m3/day)
E = industrial effluent discharged in 24 hours (m3/day)

This formula gives an average flow rate that in practice will vary through the day. E is sometimes deemed to include metered commercial discharges.

The following sections describe methods for estimating dry weather infiltration in a catchment. The methods increase in complexity along with the level of data that is available or collected.

2.6.1.1 No Data

In the absence of any other data for sewerage systems in areas with high groundwater levels, it is suggested that infiltration is assumed to be 45% of total DWF (including infiltration). In other words:

I = 45% of (PG+I+E)

Alternatively, if I is expressed in terms of (PG+E):

I = 80% of (PG+E)

The average value of 45% was identified in *Dry weather flow in sewers*, *(CIRIA, 1998),* following an analysis of long-term dry weather flow data from 95 sites in England and Wales. Conditions influencing infiltration are likely to be generally similar in Ireland and, in the absence of any similar research covering Irish catchments, the same value is considered appropriate. For purely domestic catchments, the 45% level is equivalent to 115 to 120 litres/capita/day.

In theory I should be expressed as 81.8% of (PG+E). However 80% is satisfactory for this estimation process.

2.6.1.2 Data from Local Catchments with Similar Conditions

Where data is available from local catchments with similar conditions (i.e. similar age, pipe materials, subsoil type etc), this gives a better estimate of long-term infiltration. Data is best analysed in terms of litres/day per mm diameter – km length.

> The 2001 to 2004 Greater Dublin Strategic Drainage Study covered 18 foul/combined sewerage catchments with a combined population of 1.4m (about 1/3 of the total state population). A major programme of flow measurement (480 flow monitors and 270 raingauges) and sewerage modelling in these catchments provided an opportunity for an initial assessment of infiltration, albeit on a 'snapshot' basis due to the short term sewer flow surveys. It should also be noted that monitoring was undertaken in both summer and winter conditions. The results contained in Appendix A, are of the initial Grand Canal Flow Survey, undertaken between December 2001 and February 2002.
>
> The infiltration information in Appendix B resulted from flow surveys undertaken between June and September 2002. Infiltration in each monitored subcatchment was expressed in terms of percentage of DWF and was also related to system extent in terms of litres/day per pipe surface area. The measured infiltration rates ranged from 0 to 104% of DWF, and from 0 to 16558 $l/d/m^2$. Appendix B lists the results for each flow monitor and catchment.

2.6.1.3 Flow Survey Data

Two methods of estimating infiltration are proposed in *Control of infiltration to sewers (CIRIA, 1996).*

Method 1 – Minimum Flow Calculation

The first method involves examination of dry weather flows during the early hours of the morning when the domestic sewage contribution is at its lowest. Flow survey data for a dry weather day will provide values of average dry weather flow and minimum nighttime flow. At the time of minimum flow, it is assumed that approximately 10% of wastewater production (or PG+E) is present.

Deducting minimum night time flow from average dry weather flow eliminates infiltration, I, and so:

PG + E = (Ave – Min) / F, where

Ave = Average flow over 24 hours (measured)
Min = Minimum night time flow (measured)
F = Factor (typically 0.9)

Infiltration, I is then given by:

I = Ave – (PG+E)

Estimation of infiltration by this method is sensitive to the value used for the factor F. In upstream parts of sewer catchments, F is thought to be approximately 0.9 but attenuation will decrease the value in the downstream reaches of larger systems. The effect of attenuation of the dry weather flow profile is shown in Figure 2.2.

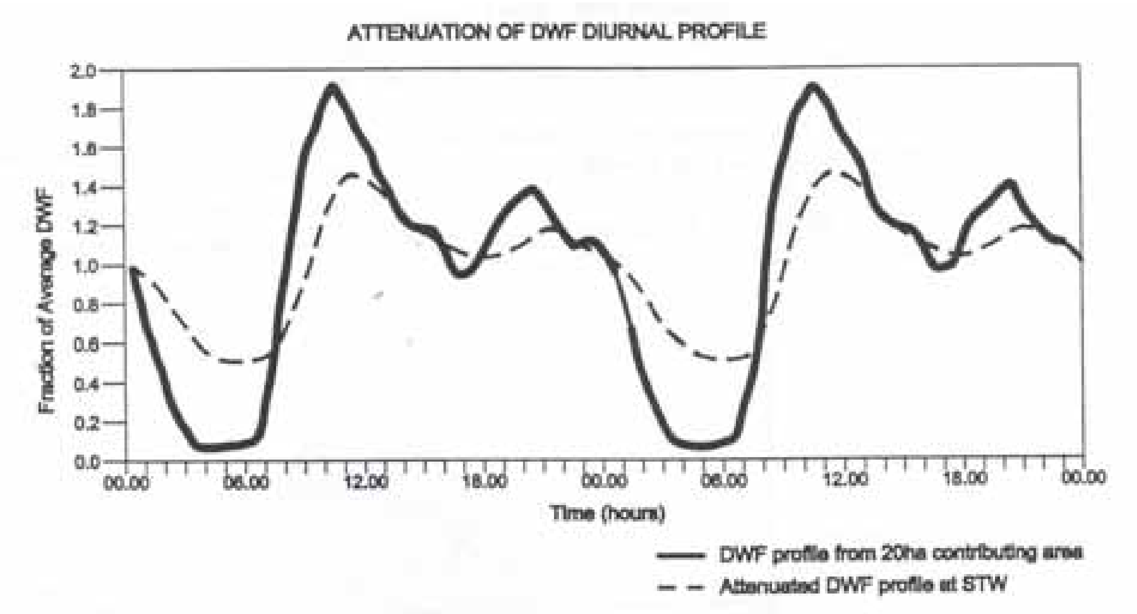

Figure 2.2 Attenuation of DWF diurnal profile *(Control of infiltration to sewers (CIRIA 1996))*

F should also take into account flows from industrial premises which may be working 24-hour days or discharging effluent overnight, e.g. from cleaning processes.

It can also be difficult to make a sufficiently accurate estimate of minimum flow at sites where flows are low and flow rates are only available in litre/second increments. ADS or equivalent-type flow monitors can provide better measurement of low flows. Alternatively, a temporary flume with ultrasonic depth measurement could be used.

Method 2 – DWF Calculation

An alternative approach is to calculate the values of PG and E and deduct from a measured value of dry weather flow (PG+I+E) over a 24-hour period.

There is a link between water consumption and wastewater generation – it has been estimated that about 95% of water used is returned to the sewer network. A value for G can therefore be obtained from water consumption figures. In the absence of local data, a value for G of 140 - 150 litres per capita per day could be assumed. Factors that may affect future trends in per capita water consumption include household size, water metering, and population age structure and climate change.

The accuracy of the calculation of E will depend on the level of data available for discharges by industries into sewers. Discharge licences usually state a maximum discharge rate, which may not be produced in practice. If possible, metering records should be obtained in order to calculate the amount discharged during a 24-hour period.

In addition to domestic and metered industrial sources, dry weather flow is also generated by a whole range of commercial establishments such as shops, offices, schools and pubs. Some town or city centre catchments may include a significant proportion of commercial flows and it is important to be clear about how these are accounted for in the above calculation. One option is to use water consumption records to derive a higher 'equivalent' G figure that includes for commercial flows. Alternatively, commercial flows could be included in the E figure by estimating volumes of wastewater production for individual sources (typical annual volumes for various sources are given in *Dry weather flow in* sewers *(CIRIA, 1998)*. The size of the catchment will determine which method is appropriate.

Records of incoming flow at a sewage treatment works are a commonly available source of data for obtaining a value of DWF. A period with no rain of at least seven days is usually considered sufficient to ensure that the effects of rainfall-induced flows are eliminated. However, this period may vary with catchment type and antecedent wetness. Figure 2.3 shows a typical pattern of flow recession after rain – the last rain occurred about 09:00 on day 1 of the plot. The indirect rainfall effects continue for a week until a constant diurnal pattern is achieved.

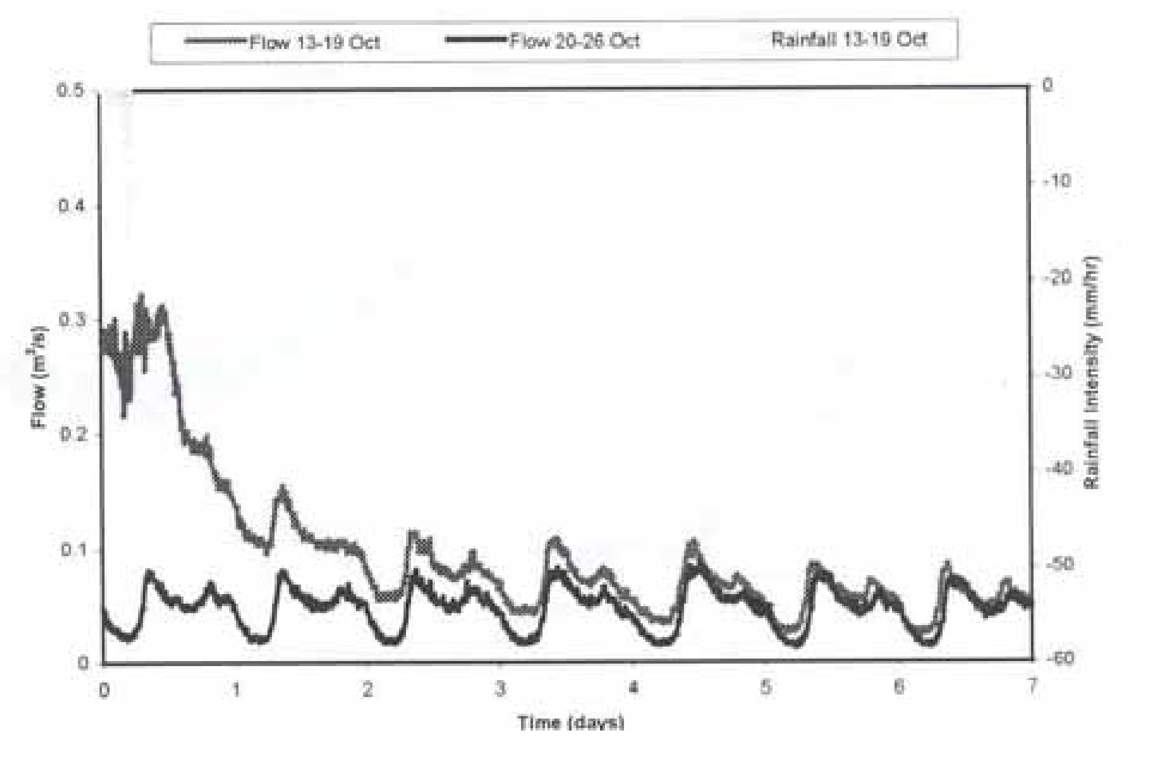

Figure 2.3 Flow Recession after Rain *(Dry weather flow in sewers (CIRIA 1998))*

The UK Institute of Water Pollution Control *(IWPC, 1975)* defined dry weather flow as

The average daily flow to the treatment works during seven consecutive days without rain following seven days during which the rainfall did not exceed 0.25mm on any one day.

Where there is a significant industrial component, the flow on five working days should be used. To overcome the problem of seasonal variation (see next section), the UK National Water Council *(NWC, 1979)* defined DWF as:

The median flow in dry weather, i.e. the median value over 24hrs of all days when rain did not exceed 1mm (in four quarters of the year).

In practice, the length and accuracy of the available flow and rainfall data will determine how much confidence can be placed in the estimate of dry weather infiltration. The benefits of long-term data are discussed in the following section.

2.6.1.4 Long Term Flow and Rainfall Data

For both methods described above, it is important to appreciate the potential for long-term variation due to antecedent rainfall. Studies have found that the flow at any given moment can reflect about 6 months of prior rainfall *(Merrill et al, 2001).* Seasonal variations in base infiltration are common in certain catchments due to seasonal variation in groundwater levels. Figure 2.4 shows diurnal profiles for two dry weather days for the same site in January and October. After removal of the infiltration component, Figure 2.5 shows that the two diurnal profiles are almost identical.

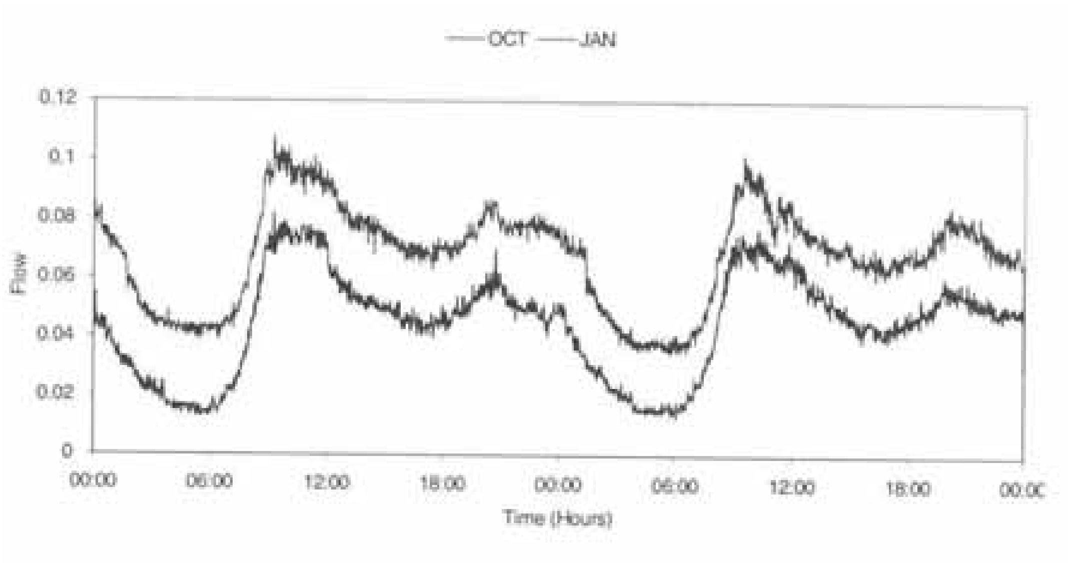

Figure 2.4 Seasonal Variation in Infiltration *(Dry weather flow in sewers (CIRIA 1998))*

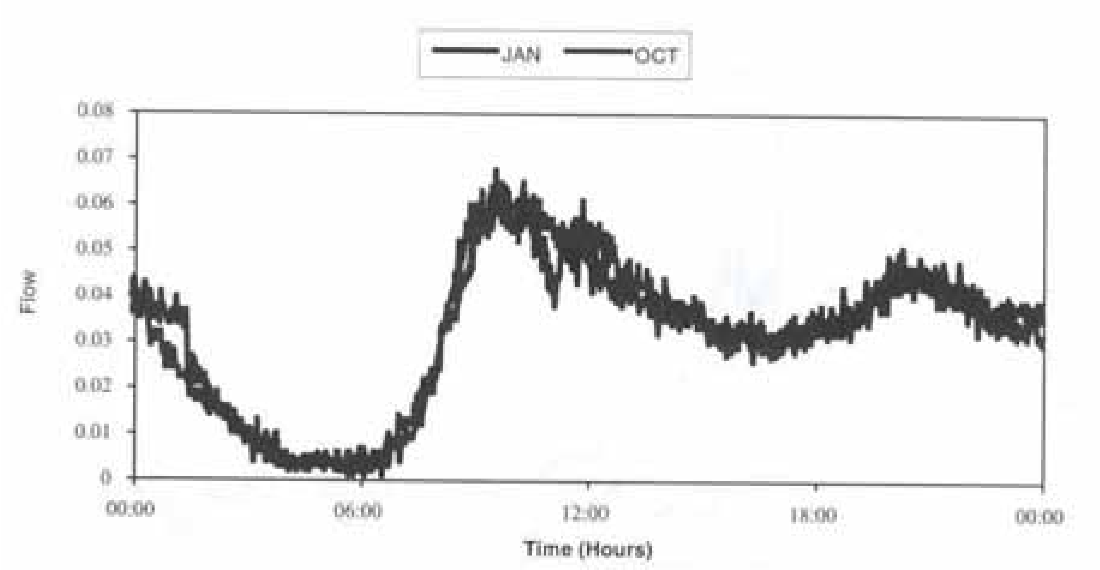

Figure 2.5 Diurnal Profiles after Removal of Infiltration *(Dry weather flow in sewers (CIRIA 1998))*

In assessing infiltration, the benefits of long term flow and rainfall data cannot be over-emphasised and the longest possible record should be obtained. A simple spreadsheet-type model of dry weather infiltration based on antecedent rainfall *(Poole, WaPUG Spring Meeting, 2002)* may be beneficial in cases where infiltration is known to vary significantly and its level affects the design of new infrastructure. At worst, a long term record will reveal a range of values within which base infiltration is known to lie – a useful aid to decision making and of much greater benefit than an estimate based on a single short term (e.g. 5 to 10 weeks) flow survey.

2.6.1.5 Ammonia Data

Dry weather flow in sewers (CIRIA, 1998) describes how an additional check on infiltration can be made if quality monitoring, usually at a WwTW inlet works, has included measurement of ammonia concentration. The research found that ammonia loads per capita for domestic wastewater appeared to be relatively constant across different catchments - an average concentration of 47 mg/l is suggested. Infiltration can be estimated by finding the flow rate necessary to adjust the measured ammonia concentration to this expected average value. This method should, however, only be used as a check and with caution as significant anomalies have been found in some catchments.

2.6.1.6 Sewerage Modelling

A hydraulic model of the sewerage system allows many of the limitations of the methods described above to be overcome. The advantages for estimation of dry weather infiltration include the following:

- the attenuation of domestic dry weather flow can be found at any point in the system by applying a standard diurnal profile to relatively small sub-catchment areas (1 – 5 ha) – this overcomes the uncertainty over the choice of value for F in Method 1 described above;
- model construction commonly requires collection of population data, household numbers, household size, water consumption, trade effluent licences, trade effluent monitoring records, tide levels, pump run times – all of which are relevant for understanding dry weather flow and for the calculation of PG+E in Method 2 described above;
- models are usually verified using flow measurements taken at various points within the catchment, allowing infiltration to be assessed at each flow monitor location.

However, care is needed when using existing models to assess infiltration:

- older models often contain only a single dry weather flow value at each node or conduit, i.e. the components of DWF are not separately identified;
- verification of dry weather flows may not have been considered important by a modeller primarily concerned with assessing flooding in a combined system;
- the quality of the dry weather flow verification is dependent on the modeller’s understanding of dry weather flow in sewers, the extent and quality of the data collected and the validity of any assumptions made;
- assumed values for G are commonly too high (perhaps due to misleading guidance in modelling specifications or design manuals), leading to an underestimate of infiltration;
- models are usually verified on the basis of a single short term (5 – 10 weeks) flow survey
    - a period long enough to eliminate the effects of rainfall induced flows may not have occurred during the survey
    - base infiltration may have been influenced by rainfall occurring before the measurement period started
    - selected dry weather days may have been influenced by tourist numbers, industrial shutdown periods, tidal effects or public holidays.

- older models may be unrepresentative due to large-scale development, new industry or structural deterioration of sewers.

Based on the above, there are clearly advantages in constructing a new hydraulic model to assess infiltration but this should be justified on a cost-benefit basis by means of an initial estimate using one of the simpler methods described in the preceding sections.

For diurnal variation of purely domestic dry weather flow, dimensionless profiles for modelled areas of 2 to 5 ha are given in *Dry weather flow in sewers (CIRIA, 1998).* Guidance on modelling dry weather flow was given in *WaPUG User Note No.33 (1996)* but recent improvements in modelling software have increased the ways in which dry weather infiltration can be modelled. For example, a time varying profile can be applied to groundwater infiltration flows and tidal variations in infiltration can be simulated.

2.6.2 Rainfall Induced Flow

Sources of rainfall-induced infiltration and inflow are given in Table 2.1. Due to the variety of sources and entry mechanisms, the measurement of volumes of these flows can be a complicated process. In a sewer system designed or required to be fully separate, such as many of those in the USA, all storm response would be considered as I/I and the total I/I could be assessed by means of flow measurements.

However, a typical urban catchment in Ireland may contain some combined and partially separate sewer systems in older areas with fully separate systems elsewhere. In separate areas, the system may contain mis-connections of storm to foul and vice-versa. In these circumstances, the complexities are such that a hydraulic model, verified with flow survey data, offers the only practical means of determining contributing areas.

Recent advances in modelling techniques, combined with good quality flow survey data, allow the separate identification and representation of dry weather infiltration, rainfall induced infiltration and rainfall induced inflow. System performance under different conditions can be tested using design storms or long-term historical rainfall records. Whatever the reason for wanting to reduce I/I, understanding the relative contribution of the different components allows reduction efforts to be targeted effectively.

The modelling of rainfall-induced infiltration is complex and there is little guidance currently available other than that provided with modelling software. The process should realistically be considered as one of calibration rather than verification but it has been reported *(Allitt, 2002)* that "with sufficient storms and sufficiently long periods of reliable data it is possible to achieve a very high degree of confidence in the way in which this (rainfall induced infiltration) is modelled. This then gives confidence in the way in which the flows might be extrapolated with higher return period storms."

2.7 Costs of Inflow and Infiltration

An assessment of flow records at a WwTW may have identified that base infiltration is 50% of total dry weather flow – is this a problem? Is it worth spending any money to investigate further? Is it worth spending money on an I/I study? Is it worth spending money on reducing infiltration or inflow? How much infiltration should be removed? Authorities responsible for sewerage systems will be faced with having to make decisions concerning I/I and such decisions invariably have to be justified in terms of cost.

It is important to be able to demonstrate the cost benefits of an I/I programme from the earliest stage of the investigation through to the end. A staged approach to the I/I investigation allows a cost appraisal to be undertaken at each stage and thus determine whether further work is necessary.

In order to make rational decisions regarding expenditure on measuring, locating and removing I/I from a sewerage system, it is necessary to establish:

- the net present value (NPV) cost of the system if existing levels are accepted;
- the net present value (NPV) cost of the system with reduced I/I;

- the cost of reducing I/I.

In most cases, there will be a level of I/I at which the combined whole life costs of: (a) reducing the I/I to that level; and, (b) accepting the remaining I/I are at a minimum. A scheme that succeeds in reducing I/I to this level is therefore the optimum cost solution. Determination of the most economic level of I/I reduction depends on accurate estimation of both the quantity of inflow and infiltration (Section 2.6) and its associated costs.

2.7.1 Cost of Accepting Inflow and Infiltration

2.7.1.1 Operating Costs

A typical combined sewer system deals with storm flows by spilling at CSOs and by utilising storm tanks at the WwTW. In such a system, base infiltration may have the most significant impact due to increased operating costs at pumping stations and treatment works. These costs are incurred continuously, irrespective of weather conditions, and are therefore important when calculated on a whole life basis.

Pumping costs – power costs can be estimated from knowledge of the flow rate and pumping head at pumping stations on the network and at the WwTW. In calculating annual costs, account should be taken of any known seasonal variation in the base infiltration level. *Control of infiltration to sewers (CIRIA, 1996)* describes an approach for calculating annual pumping power costs.

Treatment costs – many of the operational costs at WwTWs will not be greatly affected by the additional flow from infiltration. The main costs arise from aeration, pumping and chemical addition. In practice, it can be difficult to calculate the true extra cost of dealing with infiltration at a WwTW and each WwTW has to be assessed on an individual basis. The most straightforward cost to calculate is that of pumping – costs associated with infiltration can be significant if there are multiple stages of pumping at the WwTW. In principle the aeration cost is determined by the BOD load, which should not be changed by the presence of infiltration. Chemical addition is affected by many catchment specific factors and costs will have to be assessed on an individual basis. Ingress of seawater can create corrosion and odour problems from generation of hydrogen sulphide and sulphuric acid.

2.7.1.2 Maintenance Costs

Infiltration can cause fine material from around the outside of sewers to enter the pipes. This can lead to: structural failure; accumulation of fines in sewers, wet wells and WwTWs, and pump wear from abrasion. Unfortunately, although elimination of infiltration could be considered as prolonging the effective life of existing pipes, estimating the cost associated with these impacts is not practical.

2.7.1.3 Capital Costs

Reduction of I/I may eliminate the need for capital works or reduce the capital costs due to smaller pipe sizes, storm tanks or treatment process units. Capital costs associated with infiltration need to be assessed on a case-by-case basis. As stated in the previous section, it is important to understand the relative contributions of the different components of total I/I. The type of capital scheme under consideration will then determine which component should be targeted for maximum cost impact.

- A sewage transfer scheme may be designed to transfer flow to a new WwTW. Flow to Full Treatment (FFT) may be set at 3PG+I+3E so all infiltration is passed forward through the system to the WwTW. Reducing the base infiltration sufficiently to allow a smaller pipe size to be used could have a significant effect over a long transfer distance. There would also be reduced pumping and treatment costs.
- Storm storage tanks are commonly provided to reduce the frequency of CSO spills. Rainfall induced infiltration can affect the volume of storage required to meet spill frequency requirements, e.g. where the CSO is impacting on a bathing water. Reduction of rainfall-induced infiltration could lead to reduced storage tank costs.

- In a separate sewer system, where flooding or CSO spills in storm conditions should not occur, reduction of inflow from sewer mis-connections may be sufficient to avoid the need for sewer upsizing to pass forward the higher-than-designed-for flows.

At WwTWs, the unit processes most sensitive to hydraulic loading are preliminary and primary although some secondary and tertiary processes will also be flow sensitive.

Cost estimates for capital works should be derived using current civil engineering cost databases or manuals. Basic graphs of 'cost per l/s' versus 'flow in l/s' can be derived for treatment works. For pumping stations, a series of curves can be plotted for different pumping heads. For pipework costs, curves can be generated for gravity mains and rising mains and for a range of depths. These graphs give a useful visual impression of the cost impact of changes in flow rate.

2.7.1.4 Other Costs

The problems caused by I/I, as described in the Introduction, may also have environmental and social costs. Where an improvement scheme is required to alleviate these problems, the capital cost of the scheme can be taken as the cost of accepting I/I. If improvements are not carried out, the environmental and social costs should be evaluated.

Control of infiltration to sewers (CIRIA, 1996) refers to various economic techniques available for valuing these issues. However, even if such costs are not formally evaluated, an appreciation of their existence may be sufficient to swing the balance in favour of I/I reduction.

2.7.2 Costs of Reducing Inflow and Infiltration

In some cases, a single major point source of infiltration, such as a damaged sewer at a river crossing, may be known. In these circumstances, the cost of reducing the infiltration will be relatively low, being primarily that of sewer repair or replacement. However, in many catchments, the distribution of I/I will be throughout the system and measurement and source location will also be required. A planned, structured investigation will ensure the cost effectiveness of any I/I reduction work carried out.

Reduction of I/I may include the following elements:

- Study
  - management of investigation
  - initial data collection and assessment
  - estimation of I/I
  - hydraulic modelling
  - scheme development
  - cost calculations
  - reporting
- Site measurement of I/I
  - flow and rainfall monitoring
  - local flow gauging
  - river/tide/groundwater level gauging
- Source detection
  - CCTV survey
  - manhole inspection
  - isolation testing
  - dilution gauging / salinity testing
  - dye and smoke testing
  - jetting

- Reduction of inflow
  - re-direction of inflow sources to separate surface water system, soakaway or outfall
  - repair/maintenance of flap-valves on CSO outfalls
  - Sealing of manhole covers
- Reduction of infiltration
  - renovation (pointing/chemical grouting or lining/repairs)
  - replacement (open-cut or trenchless techniques).

Each of these elements has an associated cost and the realistic estimation of these costs is important to ensure that the correct (i.e. most economic) level of I/I reduction can be identified. Flow and CCTV work may involve additional preliminary costs for sewer jetting or arranging safe access to manholes.

Reference to published cost databases will provide some of the cost information required (e.g. sewer renovation and replacement) but the remainder is more likely to come from analysis of recent survey contract costs (e.g. flow and CCTV surveys) or a build-up of labour and material costs for minor works. Sections 2.6 and 2.7 describe techniques for site measurement, source detection and reduction of I/I.

There are a small number of catchments in which I/I removal could cause detrimental effects. For example, the presence of I/I can:

- ensure that sewer self cleansing velocities are achieved in periods of low flow;
- reduce the risk of septicity in pumping station wet wells and detention tanks during periods of low flow;
- help to improve sewage treatment works processes by diluting strong flows upstream of the works.

Where these operational risks occur, a cost should be estimated and included in the analysis.

2.7.3 Optimum Cost Solution

A strategy for dealing with I/I should aim to identify the most economic level of I/I by seeking the point at which total costs (accepting and reducing) are a minimum – the optimum cost solution. This can be expressed in terms of either an absolute level of infiltration (or inflow for a particular return period) or as a percentage of infiltration removed. Figures 2.6 and 2.7 give examples of both options.

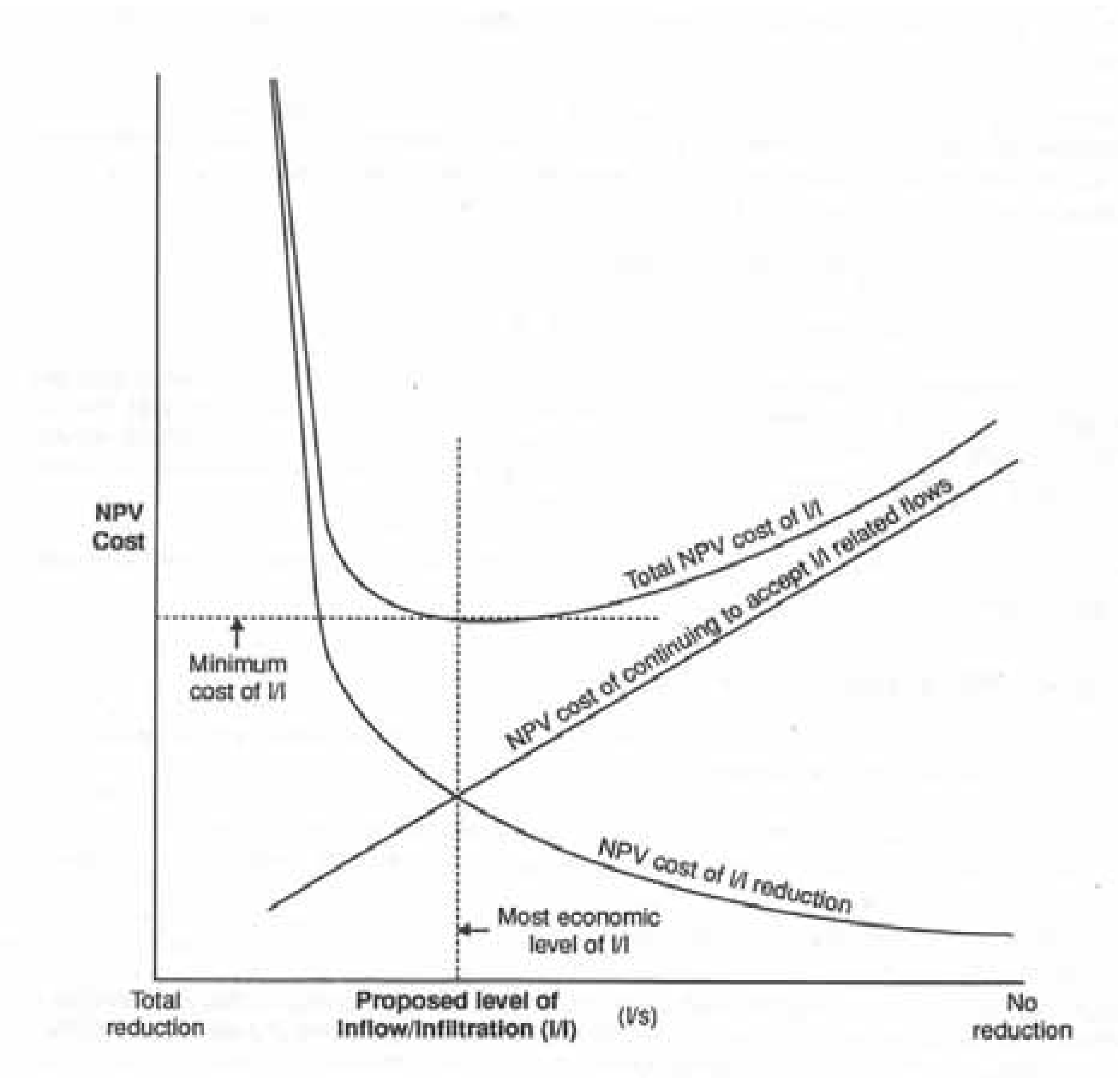

Figure 2.6 – The Most Economic Level of I/I Reduction

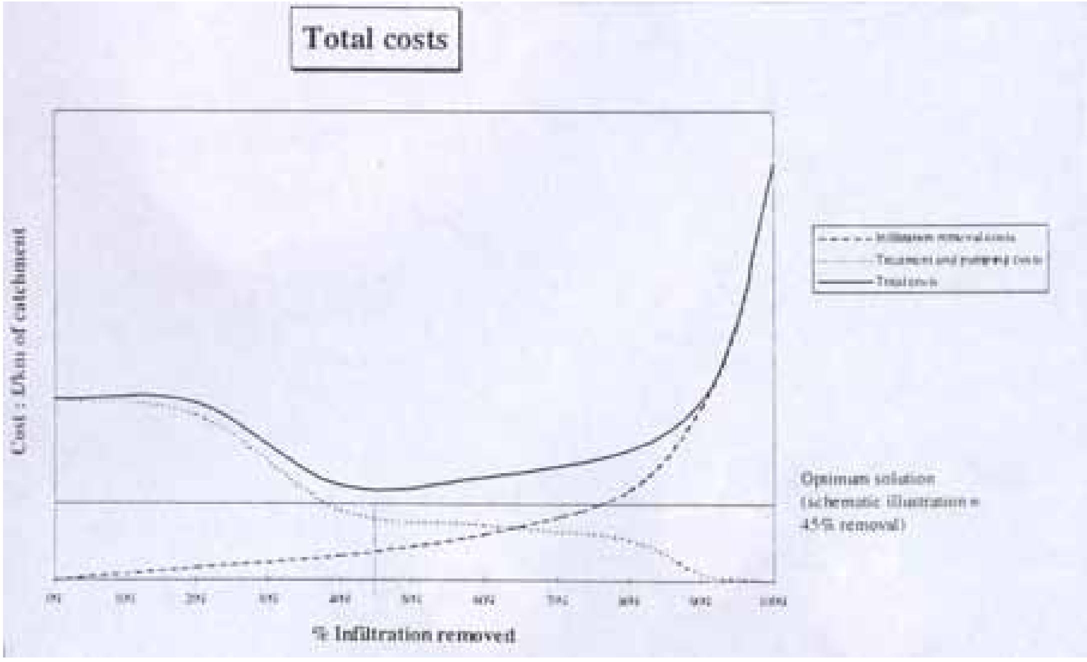

Figure 2.7 Optimum Cost Solution *(Control of infiltration to sewers (CIRIA 1997))*

In the early stages in the investigation, the distribution of I/I within the catchment is unlikely to be known and it is therefore difficult to estimate reduction costs. However, studies have shown that in many cases the distribution of infiltration has been shown to follow the Pareto principle. This states that for an 80/20 distribution, 80% of the problem will originate from 20% of the area. *Control of infiltration to sewers (CIRIA 1996)* refers to studies of catchments surveyed with CCTV, which have shown the Pareto principle to apply in the majority of cases with a range of 70/30 to 90/10. The principle is illustrated in Figure 2.8.

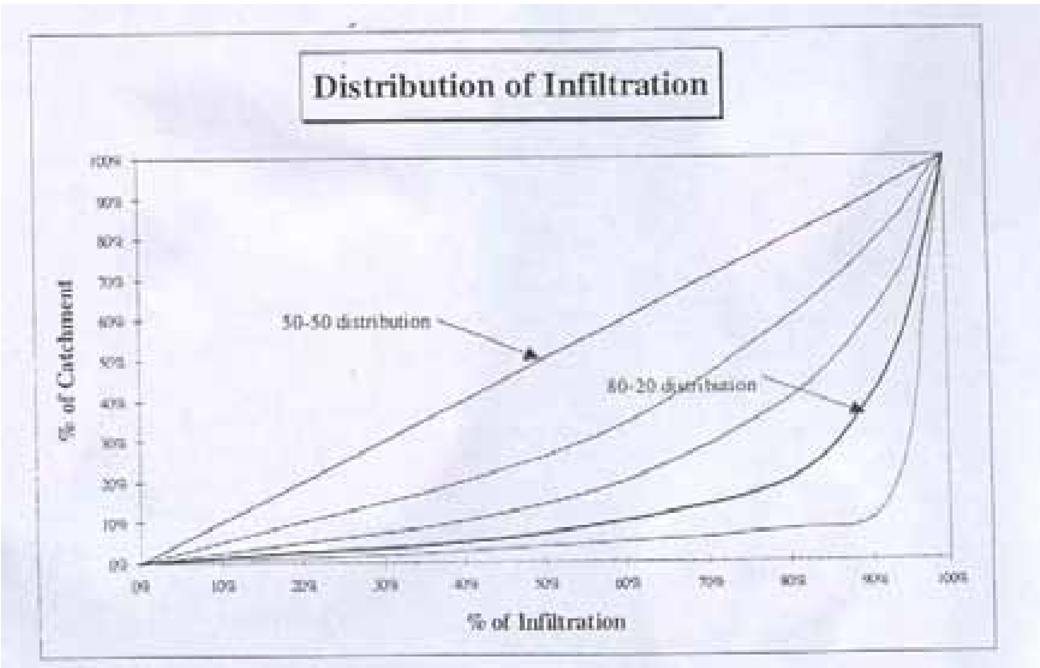

Figure 2.8 Distribution of Infiltration *(Control of infiltration to sewers (CIRIA 1997))*

On this basis, an 80/20 distribution could be assumed for an initial cost estimate to assess the need for progressing an I/I study into a second phase.

2.8 Survey Techniques for Inflow and Infiltration

Inflow and infiltration can occur anywhere in a sewer network, including private lateral sewers. However, as discussed in the previous section, I/I does not normally occur uniformly throughout the sewerage system. Location surveys need not, therefore, involve full, in-depth coverage of the whole network. A rational, structured survey approach is needed, firstly to identify the areas where the worst problems occur, and secondly to locate specific sources within those areas. The survey process may prove to be iterative, depending on the available resources and the size of the area under investigation.

2.8.1 Flow Surveys

Flow surveys are the most effective method of gaining an initial understanding of the distribution of I/I problems within a catchment. Data from any long term or permanent flow measurement sites (e.g. at WwTWs, pumping stations or where trunk sewers cross local authority boundaries) should be used as a starting point. Long term data, assuming it is reliable, has the advantage of providing information on seasonal / long term variation in infiltration. Such data is generally rarely available, or is only at one or two sites within a catchment.

Flow surveys undertaken for verification of sewer models (e.g. built for drainage area planning) usually have a good coverage of flow monitors through a catchment but are normally ‘short term’, i.e. a minimum of 5 weeks. These surveys, the primary aim of which is to record storm responses, may be extended to say, 15 or 20 weeks if there are insufficient rainfall events in the initial period. For assessment of inflow, short-term survey periods are acceptable. For assessment of infiltration, a long dry spell (at least a week) is useful to eliminate the short-term effects of rainfall. Beyond that, the longer the survey period the better.

Whilst maximum use should therefore be made of any existing flow survey data, a new, planned flow survey, specifically designed to identify I/I, has considerable advantages. *Control of infiltration to sewers (CIRIA 1996)* gives two methodologies for carrying out flow surveys for locating infiltration:

- Single Stage Survey
- Multi Stage Survey.

2.8.1.1 Single Stage Approach

A single stage survey covers a whole catchment in detail in one step. Direct comparison is possible between sub-catchments. The number of flow monitors required to cover the whole catchment in detail, together with the time required to record sufficient data, means that this can be an expensive approach.

Ideally, for a single stage survey to be effective, it needs to be undertaken in worst-case conditions (e.g. when groundwater levels and infiltration levels are at their highest). In some catchments, these conditions are more a function of antecedent rainfall than they are of season so it can be difficult to plan the best time for a survey.

Owing to the relative ease of locating direct inflows, a single stage survey should be sufficient to locate areas of high inflows, and to prioritise areas for further detailed location.

2.8.1.2 Multi-Stage Approach

The multi-stage approach takes longer, but uses fewer monitors than the single stage method. It identifies areas of high I/I by a series of surveys, each progressively concentrating on smaller catchment areas. A disadvantage of this type of flow survey is that conditions (i.e. groundwater, tides, rainfall) change between surveys so it is not possible to directly compare the relative contributions from specific areas.

2.8.1.3 Long Term Flow Monitoring

Establishment of long term flow monitoring for the duration of the investigations, e.g. at a number of key strategic points in the system, enables long term variations to be measured and provides a means of comparing relative contributions from sub-catchments. A period of one full year is commonly used for this type of monitoring.

On-going long term monitoring of sewer flows throughout the network is desirable to monitor the effectiveness of any I/I reduction works, any deterioration in the network condition and the impact of new development.

2.8.1.4 Recommended I/I Flow Survey Procedure

The recommended procedure for flow surveys to locate I/I is:

1) Establish a framework of long term flow monitors and raingauges to measure long-term trends. These monitors will remain in place throughout the investigations (at least a year) and preferably after implementation of I/I reduction. It is clearly important that good sites are selected for monitoring, i.e. good hydraulic conditions, no ragging and no silt. Results from the first week or two should be studied carefully and monitors re-located if necessary. Existing measurement sites, e.g. at a WwTW, should be checked for accuracy.

2) Carry out a short-term flow survey with monitor coverage that is sufficient to verify a hydraulic model of the sewer system, e.g. to drainage area planning standard. Ideally, this flow survey will be undertaken at a time when ‘worst case’ conditions for infiltration are likely to be present. This survey should record at least three suitable rainfall events and allow an initial assessment of inflow at each monitoring site. An initial assessment of infiltration at each monitoring site should be made by interpreting a flow and rainfall plot of the full flow survey period (examples are contained in Appendix A from a survey of the Blanchardstown and Clondalkin trunk sewers).

3) Based on the levels of I/I measured in 1) and 2), carry out an economic appraisal as described in Section 2.7. If this justifies reduction of I/I, proceed with further stages of flow survey, focusing on areas where the worst problems have been identified (typically 20 to 30% of the network). In this way, the target areas are progressively narrowed down until they are small enough for other source detection techniques to become more cost effective.

Recorded values of inflow and infiltration should be shown on separate thematic maps of the sewerage catchment. Infiltration should be expressed in absolute terms (l/s), as a % of wastewater flow (PG+E) and in l/s per mm-diameter km length. Peak observed inflow can be expressed as a multiplier of wastewater flow (PG+E). (If expressed as a multiplier of dry weather flow (PG+I+E), the factor will vary depending on the level taken for infiltration, I.) Alternatively, the hydraulic model can be used to predict peak flows in a design storm, say 1 or 5 year return period, and this can be expressed as a multiplier of wastewater flow (PG+E).

2.8.2 Source Detection

2.8.2.1 Inflow Source Detection

As inflow enters the sewer system directly, e.g. via mis-connected surface water drains, sources are generally easier to detect than those of infiltration. By using a hydraulic model, in conjunction with flow survey data, the approximate impermeable area connected in a sub-catchment can be estimated.

An Impermeable Area Survey (IAS) will form the basis of inflow location. Four basic techniques are used to detect direct inflows:

- Dye Testing
- Smoke Testing
- Visual Inspections
- Jetting

Dye Testing

Dye testing involves flushing non-toxic dyes down known surface water drains and observing nearby foul/combined sewer manholes for traces of the dye entering the foul system. Possible sources such as roof downpipes, yard or road gullies are targeted.

Dye testing is a labour intensive process, as it requires every possible course to be tested individually. Many of the possible sources (such as roof down pipes, yard or basement drainage) will be located on private property with associated difficulties of access and liaison with the public. An area-wide public relations exercise to inform residents of the work and its purpose is beneficial in this respect. A good level of public awareness will also assist if it is decided that it is cost effective to remove the inflow source.

It is also possible to isolate and flood either foul or storm sewers with dye to identify cross connections. Visual inspection of adjacent sewers or watercourses being tested will be required to further identify possible sources.

Having identified sources, CCTV inspections may be required to confirm the actual point of connection into the sewer.

Smoke Testing

Smoke testing involves pumping non-toxic, non-staining coloured smoke into a sewer and observing any points where the smoke reaches the surface. A typical smoke test between manholes takes between 10-30 minutes (after establishment) and is regarded as a quicker means of locating direct connections than dye testing if conditions are right. However, smoke testing can be affected by climate conditions such as wind and rain. It is important that properties are properly inspected (including backyards) for signs of smoke.

As with dye testing, smoke testing is good for locating inflow sources but further techniques are necessary to locate the actual connection points to the sewer.

CCTV Inspection

The development of Close Circuit Television (CCTV) inspections over the last fifteen years has greatly improved the success rate of inflow location. CCTV inspections are used in conjunction with dye testing or jetting to positively identify connection points and prove cross connections.

CCTV inspections also have the added benefits for structural assessment and for locating potential additional inflow points not detected by other means. Depending on the condition of the sewer, additional works (with associated cost) may be required to carry out the CCTV inspection. These include, but are not limited to:

Cleaning	Sediment and grease deposits can hinder the movement of the CCTV camera through the sewer. Removal of these deposits will also make hydraulic improvements to the sewer.
Removal of Obstructions	Obstructions such as intruding tree roots, lateral connections and foreign objects such as sewer rods, traffic cones, etc can prevent movement of the CCTV camera through the sewer. Removal of these obstructions will require more significant works, e.g. use of specialist trenchless equipment.
Diversion of Flows	Large diameter, or steep sewers may require diversion of flows to allow the CCTV camera access. This can be particularly time consuming and expensive when large flows are involved.

Wet Weather Spot Flow Measurement and Property Inspections

Location of inflows or rainfall-induced infiltration may be quickly narrowed down to a small area by systematically spot-measuring flows during or immediately after rainfall using hand held flow measurement probes. This does, however, require resources to be available on stand-by so that they can be mobilised when wet weather occurs.

Inflow can occur during wet weather due to localised flooding, e.g. flooding in a yard area to a level higher than that of foul gully traps on the outside of buildings. Knowledge or records of regular flooding locations are needed to identify potential problem areas. Analysis of river and tide levels should be undertaken to assess the likelihood of inflow via CSO outfalls.

Jetting

Cleaning or jetting a storm sewer and observing nearby foul sewers can be a cheap and effective means of locating cross-connections to small diameter sewers or sewers with low baseflows. This work will also have the added hydraulic benefits of cleaning the sewer in question.

A summary of inflow source detection methods is provided in Table 2.3.

Method	Advantages	Disadvantages
Smoke Testing	Quick and simple Minimises time spent on private properties	Can depend on climatic conditions Does not locate point of connection
Dye Testing	Simple	Does not locate point of connection Time spent on private properties
Jetting	Simple Additional maintenance	Requires low flows in receiving sewer to make noticeable difference Does not locate point of connection
Visual Inspection (CCTV)	Also useful for structural assessment location of infiltration Locates point of connection	Does not locate source of inflow Flow diversion, cleaning, root cutting may be required
Wet Weather Inspections & Flow Monitoring	Locates sources that cannot be found in dry weather conditions Quick and relatively simple	Requires staff on stand-by

Table 2.3 Summary of Inflow Source Detection Methods

2.8.2.2 Infiltration Source Detection

Infiltration detection needs to be as comprehensive as possible and should include both public and private sewers. Location and repair of only selected sources or defects can cause localised changes to groundwater levels and 'migration' of infiltration, e.g. to un-repaired private lateral drains.

Access is not always straightforward when investigating private drains and lateral connections. It is also seldom possible to accurately quantify the amount of infiltration arising from a particular source. The increased difficulty in detection of infiltration (compared to inflow) is such that smaller investigation areas, i.e. as defined by monitor density in the preceding flow surveys, are likely to be required.

Methods commonly used to locate infiltration sources include:

- Smoke and Dye testing
- Visual Inspection
- Isolation testing
- Dilution Gauging.

Smoke and Dye Testing

Smoke testing has only very limited value in locating sources of infiltration as it should not be carried out in wet ground or when sewers are below the groundwater table (the smoke can be trapped in the ground). Damaged sewers in shallow, dry ground have been known to be successfully detected by smoke testing.

The use of dye testing is similarly limited but shallow sewers in dry, rapidly draining soils have been successfully investigated using this method.

Visual Inspection Techniques

Visual inspection techniques, e.g. CCTV or manhole inspection surveys, are the most useful means of locating infiltration-causing defects. The best time to carry out a visual survey is when conditions for infiltration are worst, i.e. when groundwater levels or (in coastal areas) tide levels are high. In any event, signs of infiltration such as pipe encrustation at pipe or manhole joints and open or displaced joints should also be considered as possible infiltration sources even if they are not actually running at the time of the survey.

Whilst the advancement of CCTV technologies over the last fifteen years has greatly improved the ability to inspect inaccessible mains, it is rarely possible to inspect the complete network, i.e. including all private lateral drains and sewers.

The main two visual inspection techniques are manhole and CCTV inspections. Neither method is quantitative, but both are useful for identifying possible infiltration sources. Infiltration noted from manhole inspections needs to be seen in context, as manholes make up only a small proportion of the sewer network.

The analysis of CCTV data for infiltration location differs from that for structural and service defects as outlined in the Sewer Rehabilitation Manual. Whilst many infiltration-causing defects are also structural defects, all possible infiltration sources need to be considered. These include:

- observed infiltration (referred to as ‘’runners’’ or ‘’gushers’’);
- open pipe joints;
- displaced pipe joints;
- encrustation at pipe joints; and,
- other structural defects.

The ‘Examiner’ CCTV software is commonly used to record these defects.

Isolation Testing

Isolation testing involves isolating a section of sewer and either observing flows or testing the sewer with either air or water pressure. In practice, however, there are numerous problems associated with testing of existing sewers, including:

- the need to divert flows while the test is carried out;
- the difficulty of isolating lateral connections;

- the effect of groundwater levels at the time of testing.

This method of source detection will quantify levels of infiltration (and exfiltration), but additional visual inspection is required to locate the point of entry and, overall, it is considered more suitable for testing of new sewers.

Dilution Gauging

This method of source location can be used to quantify saline infiltration in coastal areas by comparing chloride concentrations in the groundwater and that in the sewage. A similar technique using ammonia concentrations in the sewage is described in Section 2.6. However, this procedure is limited by the time and cost required to carry out analysis.

A summary of infiltration detection methods is provided in Table 2.4.

Method	Advantages	Disadvantages / Limitations
Smoke Testing	Quick and simple Minimal time spent on private properties	Limited by climatic conditions Does not locate point of connection to sewer Success dependent on depth, soil type and water table level
Dye Testing	Simple	Does not locate point of connection to sewer High level of work carried out on private properties Relatively time consuming Success dependent on depth, soil type and water table level
Visual Inspection (CCTV)	Also provides structural condition Locates point of connection	Flow diversion, cleaning, root cutting may be required
Isolation	Quantifies infiltration / exfiltration	Requires isolation of section of sewer to be tested (i.e. over pumping etc.)
Dilution Gauging	Quantifies infiltration	Requires specialist analysis

Table 2.4 Summary of Infiltration Detection Methods

2.8.3 Lateral Drains

Lateral drains on private property can be a significant source of inflow and infiltration problems for the following reasons:

- lateral drains are often laid at shallow depths and are susceptible to damage from surface activities such as building works;
- the routing of lateral drains is often adjacent to trees - there are no controls on planting of vegetation over private drains;
- changing land use can leave abandoned lateral drains left un-sealed;
- damaged or un-capped inspection points often remain undetected; and,

- there is less construction control of lateral drains and often lower construction standards.

Legal arrangements for access to private properties may hinder the ability of a Local Authority to repair or enforce repair of an identified I/I source. Whilst existing systems may be difficult to inspect, measures may be undertaken to ensure new systems are easier to protect, e.g. installation of inspection chambers at all property boundaries. This would enable convenient access to carry out post-construction inspections and maintenance in both directions along the lateral (i.e. towards the sewer main and towards the property).

The occurrence of defects in lateral drains causing a significant number of pollution incidents is noted in *CIRIA Report No.44 'Reliability of Sewers in Environmentally Vulnerable Areas'.* Two possible strategies are identified that could also help in reducing I/I problems.

1. All private drains connected to a building or structure should be, as part of a condition of sale, be surveyed and tested, and any defects detected rectified prior to the sale proceeding. This strategy has been successfully implemented in Australia.

2. Disused sewers should be properly sealed (at the main) upon change of land use or demolition of a building.

2.9 Inflow and Infiltration Removal

2.9.1 Removal of Inflow Sources

Once an inflow source is located and its connection point to the foul system has been identified, provision can be made to redirect the flow to a surface water sewer or receiving water. In many cases, this will be a straightforward gravity connection but there can be situations where the foul drainage system has been used because there is insufficient fall available to reach the local surface water sewer. This can occur, for example, in low-lying areas where the foul system is pumped. Access arrangements for undertaking the necessary construction work will be more straightforward in local authority owned areas than on private properties.

While separation of surface flows from foul sewer systems has obvious benefits, the additional regular discharges of urban surface water runoff to local watercourses will create new adverse environmental effects. Therefore, in line with the recommendations in the Environmental Management Policy, SuDS techniques should be implemented where possible when upgrading an existing surface water sewer network or retrofitting a new surface water system. Retrofitting source controls can be difficult in established urban areas but it may be possible to provide some measures prior to discharge to the watercourse.

In addition to roof downpipes, road gullies, yard and driveway drains, other inflow sources that can be removed include:

Missing, Damaged or Jammed Flap Valves

Flap valves are commonly installed on CSO outfalls, particularly in tidally affected areas. These can become jammed open by debris or damaged by the action of river or seawater. Reverse flow via CSO outfalls can lead to large amounts of unnecessary flow in the sewer system and saline problems at WwTWs.

Each outfall needs to be assessed, and where flap valves are required, they need to be incorporated into the maintenance regime with regular inspections to ensure that they work correctly.

Faulty Manhole Covers

Where manholes are located in floodable areas (e.g. in floodplains adjacent to watercourses), it is important that their covers properly seal. Replacement of cover, frame or both may be required to achieve this. It is also important in certain areas to routinely check that manhole covers are actually present – it is not unheard of for covers to be stolen or tampered with.

Low-lying Foul Gully Traps

Inflow from low-lying foul gully traps on buildings can be eliminated by raising the lip well above the surrounding area.

2.9.2 Removal of Infiltration Sources

The method selected to remove infiltration sources largely depends on the degree of infiltration to the sewer and the nature of the defects causing the infiltration. The presence of groundwater can be a major factor in the selection of the rehabilitation method. Techniques for repair, renovation and replacement of sewers and drains are contained in Appendix C.

2.9.2.1 Repair

Owing to the migratory nature of infiltration, repair of infiltration-causing defects is not generally recommended as a stand-alone solution to infiltration problems. However, it is applicable for sewers that are generally in a sound material condition with isolated major structural defects. Such sewers are likely to be relatively young (less than fifty years old) and will not exhibit extensive minor defects (such as cracking or fractures). The defects present are most likely to be due to poor construction.

The use of robotic units with CCTV allows individual defects to be sealed and tested without rehabilitating the whole section of sewer. Some robotic systems with CCTV also allow access up lateral connections to repair defects away from the main.

The techniques available for infiltration repair include:

Joint Sealing

Leaking pipe joints or minor defects may be sealed by pumping grout or silicate gel from inside the pipe through the defective joint. This will fill any voids that have formed on the outside of the pipe. Following injection the pipe joint can be pressure tested to prove the repair.

Testing of non-structural defects such as open and encrusted joints is carried out prior to sealing. If the pipe joint has already started to deteriorate, a structural repair method will be needed. In this case, stabilisation of the ground behind the joint may be required to fill any voids.

The presence of infiltration at the time of repair can be a major factor in determining the suitability of sealing method as flows can wash out the sealant materials. Silicate gels have proved to be particularly effective in this regard - leaking joints are sealed by expansion on the outside of the pipe, filling any voids.

Trenchless Repairs

Most trenchless sewer lining systems have developed point repair methods to repair individual structural defects without rehabilitating the whole section of sewer. This will minimise the hydraulic restrictions caused by the rehabilitation and is particularly useful for rehabilitating sewers that are of limited hydraulic capacity without using a disruptive open-cut repair method.

Some systems rely on a resin anchor injected into the defect to hold the patch in place. This can be an effective repair if the defect is large enough and infiltration present at the time of repair does not prevent the resin anchor setting. This can be a particular problem of resin-based lining and repair systems.

In the past, various repair patch systems have proved to be unsuitable for controlling infiltration. It is important to consider the following aspects when selecting a trenchless repair method to rehabilitate a leaking defect:

- how the repair patch is sealed at the ends of the repair to prevent infiltration migrating between the repair material and original sewer;
- how the repair patch is anchored to prevent longitudinal movement of the repair along the sewer between the patch and the linings;
- how the edges of the patch are finished off to prevent solids catching in the interface with the original sewer.

The bond between the sewer and the patch is particularly important to consider. Systems that rely on adhesion between the patch and the original sewer have not been particularly successful. The difficulty of these systems is the ability to obtain clean or dry enough surfaces (especially) to obtain a good bond between the patch and the original material.

Open Cut Repairs

In cases of severely deformed or damaged sewers, or those that are severely restricted hydraulically, the only way to repair the sewer will be to excavate the damaged section and replace with a new section of sewer. Although usually more expensive and disruptive, open cut repairs remove the defective section of sewer from the system. The key component of an open cut repair is the integrity of the joints made with the original sewer material.

2.9.2.2 Renovation

In the case of extensively damaged sewers, complete renovation of the whole sewer is the preferred option to ensure that infiltration does not migrate towards minor or non-structural defects and make them worse. Particular attention to the sealing of lateral connections is required for controlling infiltration entering at lateral junctions - flows can migrate along the sewer between the lining and parent pipe. This particularly applies to slip lining and folded or wound in liners where excavation and reconnection, or grouting and sealing, of lateral connections is required after they have been cut out. Some cured in place lining manufacturers do not guarantee a leak proof seal at lateral junctions without grouting.

Renovation techniques do reduce the cross-sectional area of the sewer, so it is important to be confident that there will be sufficient hydraulic capacity following renovation. If in doubt, an alternative method may be required. Lining is also unsuitable for excessively deformed or damaged sewers.

A summary of renovation techniques (from *Control of Infiltration to Sewers, CIRIA 1996*) is contained in Appendix C.

2.9.2.3 Replacement

Replacement is the most expensive and disruptive rehabilitation method but is the only option where hydraulic improvements are also required or the existing sewer is too damaged to permit renovation techniques. Control of groundwater is a particular problem with open cut sewer replacement construction, as the fact that infiltration is a problem means that the sewer is below the groundwater level (or at least can be at certain times).

Various forms of ‘trenchless’ sewer replacement techniques are available. However, these do require proper re-connection of lateral connections to ensure effective infiltration control. This can limit the benefits of ‘trenchless’ sewer replacement techniques.

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.

4 STRATEGY FOR DEALING WITH I/I/E

Inflow and infiltration/exfiltration can cause a range of problems in sewer systems and to manage these systems effectively, an overall strategy for dealing with I/I/E is required. This strategy should form part of a complete asset management approach and should include a combination of short, medium and long-term measures.

Overall, however, effective management of inflow and infiltration/exfiltration requires a long-term mindset. Since privatisation of water services in the UK, capital expenditure on wastewater infrastructure has been governed by five year spending cycles. Programme constraints often rule out the option of I/I/E reduction, even though an initial assessment has indicated its cost effectiveness. Although the structure of water services in Ireland does not currently suffer from this disadvantage, it is still important that there is general awareness of the long term planning required with regard to I/I/E.

4.1 Short Term Measures

The expression 'short term' is used in this context to refer to a one-off investigation, as opposed to on-going programmes or permanent measures. Such an investigation may take a number of years so 'short term' should not be mistaken for 'quick-fix'.

Whatever the initial trigger for concern over I/I/E, a procedure is required which will address the concern and aid the decision-making process. It is recommended that the approach outlined in the *Sewerage Rehabilitation Manual (SRM) (WRc, 4th Edition, 2001)* be adopted. The general principles of the SRM formed the basis for the *European Standard EN752-5: Drain and Sewer Systems Outside Buildings: Part 5 Rehabilitation.*

The **Infiltration Reduction Procedure** described in Appendix A of the SRM is appropriate for both inflow and infiltration/exfiltration, although only the term infiltration is used in the manual. The following extracts describe the stages and principles of the procedure.

The stages of the procedure are:

i. A preliminary assessment, to establish if infiltration reduction is likely to be feasible and cost effective;

ii. A detailed investigation, through a review of existing data and, where appropriate, the targeted collection of new data;

iii. The development of solutions;

iv. Implementation;

v. Post project appraisal.

The main principles of the infiltration reduction procedure during these stages are:

a. An iterative approach, to gradually focus in on the source of excessive infiltration;

b. The need to consider the potential cost effectiveness of infiltration reduction, at each decision point in the procedure.

The iterative approach is illustrated in Figure 4.1.

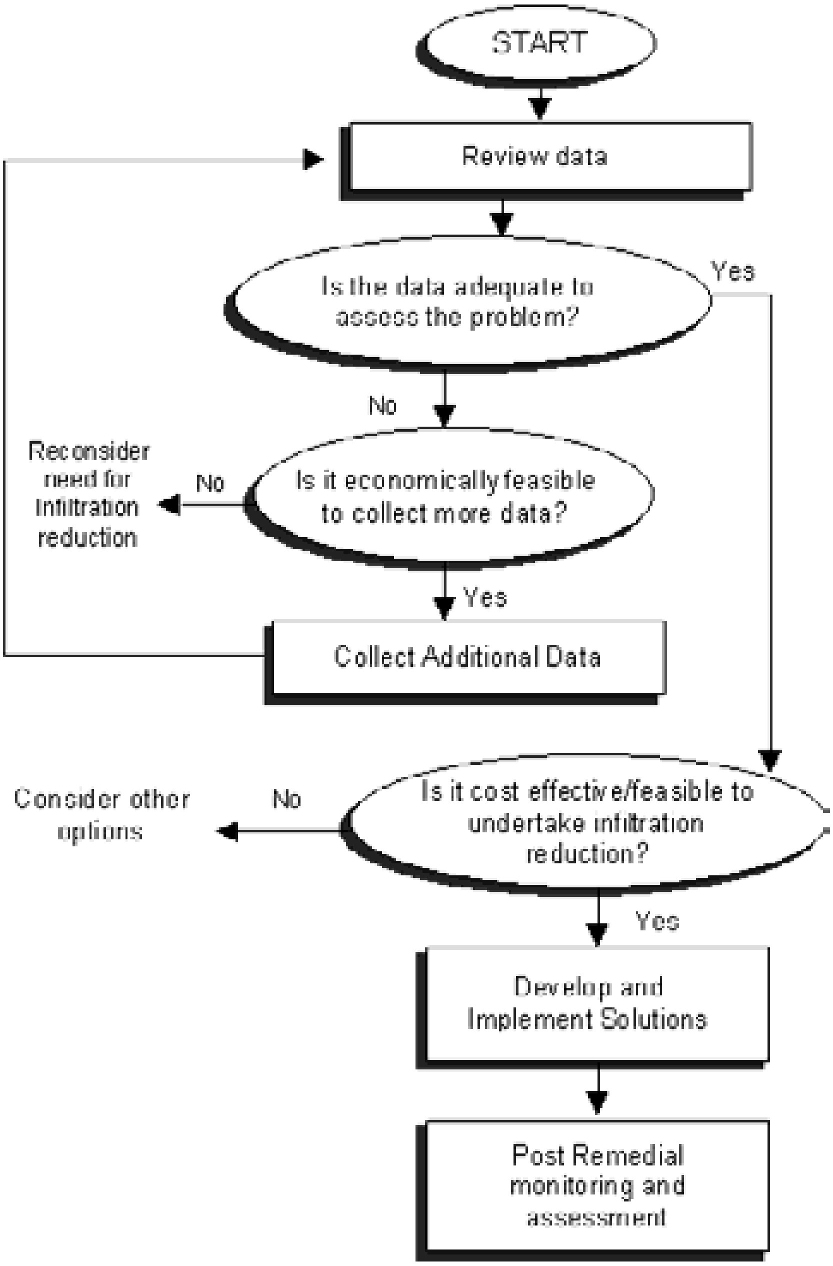

Figure 4.1 I/I/E Reduction Procedure – Iterative Approach

The process ensures that:

- the use of appropriate existing data is maximised and that additional data is only collected where it remains necessary to quantify and identify the location of infiltration;
- the cost of additional data collection is proportional to the potential savings from the proposed infiltration reduction;
- those investigations where infiltration reduction would not be a viable option are identified and, where appropriate, the investigation is terminated at the earliest opportunity.

The "Consider other options" caption in Figure 4.1 would be to retain the illegal flows and provide additional conveyance and treatment facilities.

The principles of cost optimisation were discussed in Section 2.7.

The 'preliminary assessment' and 'detailed investigation' stages mirror the SRM investigation procedure. The first stage can be undertaken in outline as part of the initial planning and the second stage as part of the hydraulic investigation.

The preliminary assessment should therefore include a pilot area for I/I/E reduction to establish the cost-effectiveness of such reduction programmes in the Dublin area. This pilot scheme should concentrate on the areas with various levels of I/I/E as identified by the GDSDS, starting with the worst areas and those with various types and age of development. The pilot study should include private drains to establish their effect on I/I/E in the overall system. The objective would be to establish typical rates of reduction actually achieved, together with the associated costs. Such information would then be used to manage the I/I/E reduction programme for the Region.

There are clear advantages to the 'holistic' approach of the full SRM procedure, i.e. consideration of all sewerage deficiencies in the catchment in order to maximise the benefits of any investment in system improvements. Indeed, it could be argued that the true costs of I/I/E cannot be evaluated without knowing all the deficiencies (hydraulic, environmental, etc.) in the system.

In addition, the benefits of a detailed hydraulic model of the sewerage system should not be underestimated when trying to quantify the individual components of I/I/E. The greater level of understanding provided by modelling means that resources available for I/I/E reduction are targeted more effectively.

However, although it is common for an I/I/E study to be triggered by the findings of a drainage area study, it is not essential that the two be done simultaneously. The preliminary assessment stage could be undertaken on its own to give an initial appreciation of I/I/E and the likely cost-effectiveness of reduction methods.

4.2 Medium Term Measures

Where there is evidence of inflow in a separate sewer system, a programme of identification and re-direction of mis-connections may prove to be cost effective (this should be demonstrated in the manner outlined in Section 2.7). Flow measurement surveys in supposedly fully separate foul sewers often record some degree of storm response. The most common sources of inflow are mis-connected roof downpipes, driveways and yard areas/patios. Roof downpipes from house extensions may be directed to the foul sewer even if the original house roof is drained correctly to a surface water sewer or soakaway.

An operations team can be set up to systematically identify and map these mis-connections. The timescale required will depend on the extent of the problem and the resources available. Solutions may range from simple re-direction of individual drains into the right sewer to larger schemes involving groups of properties. In private properties, the owner would normally be responsible for funding the remedial works. In some cases, an order may need to be imposed on the owner by the local authority to achieve the desired result.

A programme of this type requires considerable contact with the public. This should include informing the public of the reasons and aims of the programme in the broad sense, as well as during the operational phase. The former can be achieved by distributing publicity leaflets and the latter by means of a subsequent letter drop (e.g. 2 to 7 days before work begins in a particular area).

Lateral drains on private land may also be a significant source of infiltration/exfiltration in some catchments but the problem is more likely to be widespread due to general deterioration or poor workmanship. Replacing or repairing sewers and/or drains at the rear of properties in an urban area can be particularly difficult due to access and disruption. Nevertheless, there may be cases where particularly high point sources are traced to private properties and these can be addressed individually.

The requirement for survey of lateral drains as a condition of the sale of the building, and for proper sealing upon change of use or demolition of the premises, will contribute to the lessening of infiltration/exfiltration.

4.3 Long Term Measures

Data Collection and Management

A common problem encountered at the preliminary assessment stage of an I/I/E study is the lack of good quality long-term data of the type needed to draw conclusions about infiltration/exfiltration. Most sewage treatment works include flow measurement facilities of some sort but the collection and storage of the data is often suspect. Similarly at pumping stations, accurate long-term records can be difficult to obtain even though the facilities exist for measurement.

The value of long-term records has been stressed in previous sections and the establishment and maintenance of a system for the collection and storage of relevant data is strongly recommended. The most important data includes:

- sewage treatment works data – incoming flow and quality;
- flow at permanent flow monitor sites at strategic locations within large networks;
- pumping station data – pump run times/power usage;
- rainfall data;
- tide, river and groundwater level data.

There are, of course, many other areas where good records would be beneficial at the initial data review stage of an I/I/E investigation, e.g. flooding records, CCTV data, operational data, groundwater pollution data. However, the data in the list above is the most important and efforts should be focused on maintenance of a complete record of these values. For analysis of long-term variations in infiltration, daily data is adequate. Ideally, all data should be stored in digital database format within a Geographical Information System (GIS). The recommendations for the Regional Drainage GIS contain such proposals.

With this system in place, informed decisions can be made regarding I/I/E, either at the initial planning stage of a drainage area study / infiltration study, or preferably as part of on-going asset management. The existence of this information will also add value to the interpretation of other data such as CCTV and flooding records.

Sewerage Models

There is a growing realisation of the need for better management of existing sewerage assets. To achieve this, hydraulic models are increasingly seen as a potentially valuable tool.

Currently, models are invariably built for one-off studies to achieve a particular aim, such as solving a flooding problem or designing a sewage transfer scheme. On completion of the study, nothing more is done with the model and it becomes out-dated. However, the recent development of sewerage modelling software into a GIS-based approach means that the use of models for on-going asset management is becoming a more practical possibility.

As stated above, dealing with inflow and infiltration/exfiltration requires a long-term approach and on-going management of sewerage models would be consistent with this philosophy. Models verified originally using a single short-term flow survey can be updated and improved using long-term data. Updates can also be made following any remedial works undertaken to reduce I/I/E or capital works undertaken for any other reason. System performance can then be routinely assessed with some degree of confidence. Techniques for representation of I/I/E in sewerage models have improved considerably in recent years and the benefits of modelling for the ‘short term’ investigation stage have already been highlighted – a further shift in attitude is required to maximise the benefits of such models for long term asset management.

Asset Management

Since no sewerage system is leak free, then inflow/infiltration/exfiltration must be expected. The risk of occurrence must therefore be responsibly managed, as illustrated in Table 4.1.

For example the risk assessment of infiltration/exfiltration would involve a geological map, with a generic risk ranking system being developed based on the likely hydrogeological characteristics of the formation in which the sewers are to be placed, and hence the likelihood or otherwise of leaks having a harmful effect.

Factor	Risk	Management
Location of sewer	Pollution of groundwater from leakage	Minimise sewer construction near aquifers used for water sources. Impose stricter construction and testing requirements for sewers near vulnerable aquifers
Location of sewer	Inflow and infiltration from groundwater	Minimise sewer construction near water sources
Depth of sewer	Third party damage	Lay sewers and drains at minimum depth below other services
Age of sewer	Deterioration with age, previous poor quality	Target for renovation or replacement
Material of sewer	Deterioration with age, previous poor quality	Target for renovation or replacement
New construction of sewer	Poor quality design, materials and workmanship	Impose high quality specifications and rigorous checking regime
New construction of sewer	Inflow from mis-connections	Impose high quality specifications and rigorous checking regime
Existing construction of sewer	Inflow from mis-connections	Public education and inspections of suspect areas
Location of water supply network	Contamination by sewage entering pipework	Unlikely due to internal water supply pressure. Thorough cleansing and disinfection after maintenance of the water supply system
Location of groundwater	High water table interfacing with sewerage system	Minimise location of sewers near areas of high water table
Location of aquifers	Pollution of groundwater from leakage	Minimise sewer construction near aquifers used for water sources
Leakage from lateral drains	Drains in private ownership more likely to leak due to poor maintenance	Impose survey requirement as part of sale approval
Leakage from abandoned sewers and drains	More likely to leak due to lack of knowledge and ownership	Impose sealing requirement and rigorous checking
Water sources	Groundwater, especially that used for human consumption, will be contaminated	Impose requirement for registration of all water sources, and regular sampling and testing. Impose construction and inspection requirements for existing and new boreholes. Minimise groundwater sources in the vicinity of sewerage systems

Table 4.1 Management of I/I/E Risks

Practical requirements such as sewer location and depth will prevail in many instances, but the overall principles should be followed as good drainage design and construction practice. The imposition of high quality construction specifications and checking regime should be actioned, and are included in the New Development Policy.

The interaction between these factors and the risks they represent are best understood on a geographical basis. For that reason these factors are included in the proposals for the Regional Drainage GIS (RDGIS).

4.4 Summary of Measures

The combined set of measures for dealing with inflow and infiltration/exfiltration in sewerage systems is illustrated in Figure 4.2.

Short Term	Medium Term	Long Term
I/I/E Reduction Procedure (Appendix A of SRM, 4th Edition, WRc, 2001) Pilot study to establish cost-effectiveness in the Dublin Region Can be done separately, but there are advantages if carried out in conjunction with the SRM investigation procedure (drainage area study)	Misconnections programme to identify and remove sources of inflow in separate sewer systems Survey of lateral drains as part of building sale Building control of sealing of abandoned sewers In conjunction with public relations / community awareness programme	Establishment and maintenance of system for collection and storage of long-term data relevant to I/I/E management (permanent flow monitor data, rainfall data, sewage treatment works and pumping station data, tide/river/groundwater level and pollution data) through the RDGIS On-going maintenance of sewer system models

Figure 4.2 – Summary of Measures for Dealing with I/I/E

It is very evident that removal, or more realistically, significant reduction of I/I/E is a time-consuming and expensive process. It is far more cost-effective to avoid its occurrence in the first place. This can best be done by strictly controlling the quality of new and renovated sewerage installations, and by ensuring that best quality materials and construction techniques are used, to provide a long-lasting leak-free system. Connections must also be correctly made, and private drains and abandoned sewers managed to minimise the risk of leakage. Rigorous checking by Council Inspectors will ensure that sewerage construction will achieve its maximum life without defects.

The Regional Drainage Policy for New Development contains the procedures and specifications for implementing these requirements.

5 POLICY IMPLEMENTATION

This Section presents the guiding principles and methods by which the policy recommendations identified throughout the document can be practically implemented.

5.1 Details of Implementation

The proposed means of implementation are contained in Table 5.1.

Report Section	Policy Topic	Implementation Details
2.5.1	Reduce erosion of backfill through use of impermeable cut-offs within the bedding and surround	New water industry construction specification, as contained in New Development Policy.
2.5.1 2.9.1	Use of sustainable drainage systems (SuDS)	Principle is contained in New Development and Environmental Management Policies. Local control measures are most applicable to I/I/E.
2.5.1	Reduce I/I/E through improved specification and inspection of sewerage construction	New water industry construction specification, as contained in New Development Policy. Amendments to sewerage inspection procedures made in New Development Policy.
2.5.1 2.8.3 3.9 4.2	Reduce I/I/E through sealing/isolation of abandoned lateral drains	New water industry construction specification, as contained in New Development Policy. Amendments to sewerage inspection procedures made in New Development Policy.
2.5.1	Reduce I/I/E from private drains by requiring construction to public sewer standards	New water industry construction specification, as contained in New Development Policy.
2.8	Recommend I/I/E flow survey procedure	Drainage Departments to adopt proposed procedures.
2.8.3 3.9 4.2	Reduce I/I/E by requiring survey and renovation as condition of sale	Proposed requirement to be imposed by Drainage Department.
2.9.1	Reduce Inflow by maintaining flap valves and locating faulty manhole covers	Requirement for Council Maintenance Department.
2.9.1	Reduce Inflow by protecting low lying gully traps	Public education, included in New Development Policy on SuDS.
4.1	Short-term measures to reduce I/I/E	Adoption of principles of SRM by Drainage Department. Pilot Study to establish cost-effectiveness in the Dublin Region.

Report Section	Policy Topic	Implementation Details
4.2	Medium-term measures to reduce I/I/E	Set up mis-connections programme by Drainage Department.
4.3	Long-term measures to reduce I/I/E	Set up operational records system by Drainage and Operations Department, with data stored on RDGIS. On-going maintenance of sewer system models by Drainage Department. Set up and maintain risk factors for asset management on RDGIS. Impose tighter construction requirements and location constraints for sewerage near aquifers. Set up register of all water source boreholes and control locations near sewer systems.

Table 5.1 Policy Implementation Details

5.2 Actions and Responsibilities for Implementation

Implementation actions and responsibilities can be grouped as follows:

- Changing construction specification: Drainage Departments to agree changes within New Development Policy;
- Adoption of SuDS: Drainage Departments to agree under Environmental Management and New Development Policies;
- Inspection of private drains: Council Drainage Inspectorate to agree changes;
- Procedures for managing I/I/E: Drainage Departments to agree adoption of Infiltration Reduction Procedure from SRM;
- Establishing Cost-effectiveness of I/I/E reduction: Pilot study for the Dublin Region based on results from the GDSDS;
- Inspection of new construction: Council Drainage Inspectorate to agree more rigorous inspection regime, as contained in the New Development Policy;
- Maintenance of faulty flap valves and faulty manhole covers: reminder to Drainage Operations Department;
- Survey and renovation of lateral drains: Council Legal Department to impose as condition of sale of premises;
- Mis-connections programme: to be set up by Drainage Department and Drainage Inspectorate;
- Future maintenance of sewer system models: to be set up by Drainage Department;
- Risk factors for I/I/E: to be set up by Drainage Department as part of RDGIS;
- Register of water source boreholes: to be set up by Water Service Authorities under the new Water Bill;
- Restrictions on interface between water source boreholes and sewerage: Water Service Authorities and Drainage Departments to manage through RDGIS.

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Appendix A

Examples of Inflow and Infiltration

Appendix B

Base Infiltration in the GDSDS Foul Catchments

Appendix C

Summary Chart of Sewer Renovation Techniques

(from CIRIA Project Report for RP501 – Control of Infiltration to Sewers)