Rehabilitation of Existing Sewerage Infrastructure

By

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ABSTRACT

This dissertation has been produced for the research section of the Environmental Protection MSc, from Sligo Institute of Technology. The overall objective of the study was to highlight Infiltration and Exfiltration in existing sewerage infrastructure, associated problems, investigation techniques, rehabilitation techniques and a case study.

As part of efficient treatment of sewage, separation of surface water and infiltration water from sewer networks is advantageous. Therefore, a high priority should be given to achieving watertight sewers. When sewers are sealed, as well as efficient treatment, exfiltration (leakage) is reduced which decreases the risk of groundwater contamination.

Rehabilitation of sewer lines can be used in many cases to achieve water tightness using trenchless technology, which can avoid construction and installation works, which would cause inconvenience to local residents and business people, especially in urban areas.

From investigations undertaken for the purposes of this report, it was found that the traditional method of installing new sewer networks or replacing existing pipes with a cut trench system is still the most common form of infrastructure upgrading. However, some local authorities, together with Civil Engineering Consultants have started to incorporate sewer rehabilitation as part of their overall designs. The Castlebar Environs Sewerage Scheme, included an existing sewer rehabilitation project, as part of the total contract. It was found that when old, damaged or leaking sewer pipes were rehabilitated it reduced groundwater infiltration, which in turn reduced the flows into the sewage treatment plant.

This dissertation gives examples of where rehabilitation may be considered, where it has been used and the advantages associated with his method of maintenance.

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1. INTRODUCTION

Water and sewage infrastructure, represent a significant investment for Central Government and Local Authorities in Ireland. Historically, the distribution networks for sanitary and water services have been located underground in pipes or ducts that are laid, repaired or replaced by trenching from the surface. In cities and urban areas, most of these distribution networks are located underneath roads. This often makes access difficult, particularly in areas congested with traffic and buildings.

As time passes and when pipeline infrastructure is not well maintained, inefficiencies occur. For example, in water distribution systems, this can lead to leakage and possible water shortages. In sewage systems, cracked and damaged pipes can cause wastewater seepage, leading to contamination of groundwater, and groundwater infiltration, resulting in increased intake at Wastewater Treatment Plants. These problems often give rise to related health and environmental impacts.

The oldest underground utility services are usually found close to the surface of the roads. Services installed later are usually found below or interwoven with the earlier installations. Construction and repair work carried out from the surface inevitably disrupts traffic, business and other services. This disruption has a negative impact on the local environment in terms of air quality, noise, and other pollution, as well as on local vegetation and buildings. This, in turn, diminishes the quality of life for local residents. The provision and maintenance of safe and efficient utility services requires more environmentally sound technologies and approaches to ensure public support, *(Read,. 1997)*.

Technologies, which minimise the requirement for surface excavation, can significantly reduce the environmental impacts of underground utility service installation, maintenance and repair. By minimising surface disruption, traffic congestion is significantly reduced, thereby reducing air and noise pollution.

Furthermore, these Technologies can take advantage of existing pipeline materials and can minimise wastes caused by earth and pavement excavation.

The basis of this dissertation is the systematic investigation of rehabilitation of drainage systems. Sewer systems are an important part of any nation's infrastructure and also, critical in maintaining public health. However, with drainage systems being largely out of sight (usually underground), neglect of the sewerage networks may often arise, leading primarily to pollution, sewer collapse, sewer flooding and blockage.

The dissertation will contain the following:

- **(i)** A general discussion on underground drainage systems;
- **(ii)** An outline of how to determine the performance of sewers;
- **(iii)** An outline of the environmental impact of damaged sewer systems;
- **(iv)** An analysis of the survey techniques and procedures for assessing deterioration and collapse of sewers;
- **(v)** A description the structural renovation & rehabilitation methods for damaged sewers;
- **(vi)** A discussion on a case study of survey and rehabilitation works at Castlebar, Co. Mayo.

Castlebar is the county town of Co Mayo. Mayo County Council carried out an extensive survey of Castlebar's drainage system in 2000. Following this survey, a € 3m Rehabilitation Contract is underway in the town. This Contract was undertaken as part of a sewage management programme for Mayo. Local authorities must abide by the requirements of the economic and environmental regulators in Europe and maintain EU environmental standards.

Whilst this dissertation is being completed a relationship will be established with two companies called USSR (Underground Systems & Sewer Repair) and USA

(Underground Survey & Analysis) who are currently being employed to carry out the Rehabilitation Contract.

The dissertation will also describe various surveying techniques being undertaken to assess the condition of Castlebar's drainage system. This will include Manhole surveys, which will determine the manhole condition, flow direction, pipe size and interconnectivity and CCTV Surveys which will check the overall condition of existing sewer lines.

The use of Global Positioning Systems (GPS) and Total Stations will assist in getting cover levels and exact positions of manholes. This section will also describe the overall advantages of using such equipment.

This dissertation shall also describe the process of sewer renovation and how the existing underground sewers can be maintained or replaced, even when the sewer is underneath roads, parks and buildings. Again, Castlebar Drainage System will be used as a case study. Site visits will be undertaken to assess the methods and progress used by USA and USSR.

2. CHARACTERISTICS OF SEWAGE

2.1. Introduction

Sewage can normally be classified as either domestic (sanitary) or industrial (trade). Domestic sewage originates from residences, commercial/retail developments and public institutions e.g. schools and colleges, whilst industrial sewage arises from industry. Usually large towns and cities have a mixture of domestic and industrial sewage which normally includes effluent from other sources i.e. dairies, laundries, bakeries and other light industrial processes.

Although there is a similarity in the basic content of the sewage in Western Europe, the volume and characteristics will vary between different areas due to water supply, water availability, population size, and the precise industrial waste. Data on sewage is usually limited to the 5-Day Biochemical Oxygen Demand test (BOD_5), Chemical Oxygen Demand (COD), Suspended Solids (SS) and Ammonia.

Usually, wastewater treatment plants were designed to a 20/30 standard i.e. 20 mg/l BOD and 30 mg/l SS, which was set by the UK Royal Commission on Sewage Disposal in 1912. This standard has since been superseded by the current quality standards in the Urban Wastewater Treatment Regulations (UWWT), which has the following limits, (*EPA., 1997*).

BOD : 25 mg/l
COD : 125 mg/l
SS : 35 mg/l

Sewage is a complex mixture of natural inorganic and organic matter with a small proportion of man-made substances. The main source of sewage is human excreta with smaller contributions from food preparation, personal washing and laundry. The chemical and physical nature of sewage can be further complicated by the inclusion of industrial wastes (composed of strong spent liquors from industrial processes) and comparatively weak wastewaters (from rinsing, washing, condensing and contaminated surface runoff), (*CIRIA., 1993*).

Ireland's wastewater services have historically been of varying standards and effectiveness. Until compliance to EU environment directives, different levels and types of treatment was evident in wastewater treatment plants across the country. e.g. sewage from wastewater from most of Dublin City, as well as parts of Fingal, South Dublin and Dun Laoghaire-Rathdown Council areas, was pumped to the Ringsend Treatment Works. It received preliminary and primary treatment at Ringsend before being discharged into Dublin Bay. However, following the installation of a new € 300 m wastewater treatment works at Ringsend, which was completed in 2003, (*Dublin City Council., 2003*).

2.1.1. Sewage Treatment in Ireland

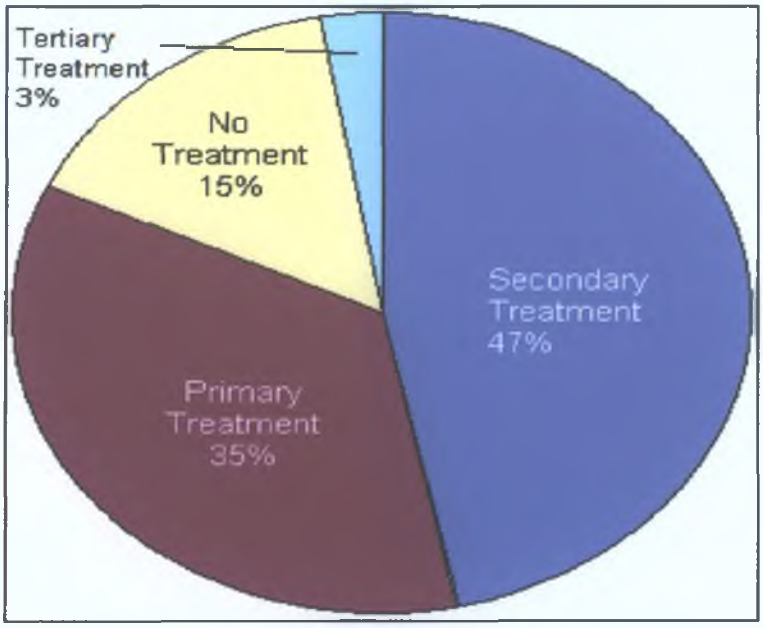

Fig 2.1 A Pie Chart showing the various treatment of domestic sewage in Ireland.

Percentage of population connected to sewers 68% approximately

No treatment	15.3%
Primary treatment	35.3%
Secondary treatment	46.7%
Tertiary treatment	2.7%

The remainder of the domestic sewage is treated in septic tanks connected to individual houses.

2.1.2. Overview of Wastewater Treatment

Wastewater treatment may involve physical, chemical and biological processes or combinations of these processes depending on the particular required standards.

The first stage of wastewater treatment takes place in the preliminary treatment area of a treatment plant. Materials such as oils, fats, grease, grit, rags and large solids are removed.

Primary settlement is usually the next stage. Horizontal or radial flow tanks are normally used to reduce the flow velocity, which allows some of the suspended matter to settle.

Biological treatment of wastewaters takes place in fixed media or suspended growth reactors using activated sludge, biofiltration, rotating biological contactors, constructed wetlands or a combination of these systems.

Chemical treatment is used to improve the removal abilities of suspend solids prior to the solids removal processor to adjust the properties of the components of wastewater before biological treatment. It can also be used for precipitating phosphorus together with biological phosphorus treatment.

Secondary settlement separates the sludge solids the outflow of the biological stage.

Tertiary treatment refers to processes that are used to reduce parameter values below the standards set out in national regulations. Tertiary treatment is often used to describe nutrient removal.

Sludge treatment is a significant part of wastewater treatment and involves the stabilisation and or thickening and dewatering of sludge prior to it's reuse or disposal, (*EPA., 1997*).

2.1.3. Overview of Water Quality

The most recent national overview of water quality in Ireland is provided in the Environmental Protection Agency (EPA) Report. It is entitled Water Quality in Ireland 1998 – 2000. It details the monitoring of rivers programme, which now extends to over 13,200 kilometres of river length. It identifies the quality classifications below.

Table 2.1 Water quality in Ireland (*EPA 2001*)

	1998 - 2000	1991 - 1994	1987 – 1990
Unpolluted (Class A)	70%	71.2%	77.5%
Slightly Polluted (Class B)	17%	16.8%	12%
Moderately Polluted (Class C)	12%	11.4%	9.5%
Seriously Polluted (Class D)	1%	0.6%	1%

The bulk of the rivers continue to show good quality and are suitable for the requirements of the most sensitive uses such abstraction for drinking, fishing and bathing, (*EPA., 2000*).

Both long term and recent trends and analysis indicate two particular developments:

- A further reduction in the extent of serious pollution
- A slight trend of increasing levels of pollution

The report attempted to identify the main areas responsible for the pollution of rivers. Table 1.2 below shows suspected pollution causes.

Table 2.2 River channel affected %

SECTOR	CLASS B Slightly Polluted	CLASS C Moderately Polluted	CLASS D Seriously Polluted
Agriculture	46.0%	44.5%	28.6%
Sewerage	28.8%	33.4%	16.9%
Industry	13.2%	15.0%	42.9%
Other	12.0%	7.10%	11.7%

2.2. The National Development Plan (NDP)

Based on the above results and analysis that the Government proposed the National Development Plan in 1998, allocating a total of € 3.68bn over the years 2000 - 2006 to Ireland's water and wastewater infrastructure. Particular emphasis is being placed on catchment areas of waters that have been designated as sensitive under the Urban Wastewater Treatment Directive, (*91/271/EEC*).

The NDP incorporates an almost threefold increase in capital spending on water services in the several years leading up to 2006 by comparison to the 1994 – 1999 period, (*National Development Plan., 2000*).

This money was allocated for the construction of 529 schemes consisting of:

- **(a)** The continuation of 79 major water and sewerage schemes, which were currently in planning stages or being installed in 1998;
- **(b)** 113 new schemes which, began installations during the years of 2000 – 2002;
- **(c)** 113 new schemes, which are currently being planned in preparation for construction during the National Development Plan;
- **(d)** The installation of 206 schemes under Serviced Land and Rural Towns and Villages Initiatives. This is extremely important as many new developments which occur in cities and their suburbs are usually connected to a local drainage system unlike many rural areas where many houses would not have the adequate infrastructure to be connected to neighbouring sewer lines.

The breakdown of € 3.6 billion over 2000 – 2006 is shown in Table 2.3

Table 2.3 Cost of water and waste scheme

EURO – MILLION	SCHEMES
€ 1398m	Waste Water Schemes
€ 482m	Water Supply Schemes
€ 699m	Rehabilitation and Management of Water and Waste Water Infrastructure
€ 589m	Water and Wastewater schemes to provide for infrastructure support
€ 533m	Rural Water Programmes

The European Union is also playing its part to ensuring the Development Plan goes ahead, they have allocated a total of € 319m through the Cohesion and European Regional Development Funds up to the year 2003.

This funding is essential if Ireland are to meet European standards and for the prevention of further environmental problems in Irelands natural watercourses.

2.2.1. Castlebar Co Mayo Drainage System

Among the programmes assigned for further development and reconstruction is Castlebar existing drainage system, which is being studied in this dissertation. On July 8, 2002, the then Minister for the Environment and Local Government, Mr. Noel Dempsey announced the largest ever-capital allocation of € 7,175,500 for the upgrading of rural water supply systems in County Mayo including Castlebar. This marked a significant increase of € 4,757,073 originally awarded under the National Development Plan the year before.

Through the completion of these schemes, the Government hopes to provide adequate wastewater services to meet the demand of economic and social development throughout Ireland, and to meet national and European standards in preventing water pollution.

3. LITERATURE REVIEW AND ENVIRONMENTAL LAW IN EUROPE & IRELAND

3.1. Literature Review

3.1.1. Background

The investigation for the Literature Review for this Project has found limited research on the effects of leaking sewers on groundwater in Ireland and the possible solutions. However, in the UK there have been quite a large number of investigations carried out and the pollution threat posed to groundwater by sewage and sewerage systems has been recognised for many years. An early incident in the UK, which drew attention to the risk, was the direct contamination of a Chalk well in southern Croydon between October and December 1937. This resulted in 341 cases of typhoid and at least 43 deaths (*Galbraith et al., 1987*). Leaking sewerage systems were not implicated in this incident but the potential for bacteriological contamination of groundwater supplies was highlighted.

Little is known about the risk of groundwater contamination from sewers and even less is known about which sewer's leak. This is generally true internationally, though some significant research has been carried out in Germany. What is known however, is that where sewer related bacteriological contamination of groundwater coincides with the breakdown of chlorination (or lack of chlorination) at a potable supply source, the effects on public health can be dramatic. Such incidents are rare, but where they have occurred (Naas, County Kildare), the health of the local population are affected. There is a need to discuss the scale of the problems associated with leaking sewers and the relevant repair techniques.

3.1.2. European Environmental Law

Environmental law is a relatively new area of interest within the European Union. It is an area, which has become more complex and substantial over the past number of years. At first the European Community's main objective was primarily to protect consumer's interest however as time went by more directives were drawn up with the aim to protect our rivers, seas and oceans. Over recent decades, it has become clear that our environment is under serious threat leading to the inevitable pollution of our natural water resources.

Example

On 31st December 1998 37 European Union cities with a population of 150 000 and more were discharging their wastewater which was also untreated into the natural environment. Another 57 countries were discharging a large proportion of effluent which was either untreated or without proper treatment. In addition, another interesting commission report was released in 2001.

3.1.3. Report - Com (2001) 685 Final

A commission report released on the 21st of November 2001 – implementation of council directive 91/271/EEC of 21 of May 1991 in relation to urban waste treatment as amended by the commission directive 98/15/EC on the 27 February 1998.

With the application of the directive on 31 December 1998, this report highlighted that many member states were successfully complying with the above directive and had continued to make substantial progress in relation to water quality. It was noted that there were substantial improvements with Europe's water resources as a whole.

However the following was noted in many member states:

a) That there was still a problem with wastewater not being properly treated and subsequently flowing into seas, which resulted in their pollution. Many national authorities had underestimated the level of treatment required for the treatment of wastewater.

b) Although good progress was being made since December 1998 many member states still had serious problems in implementing and meeting the deadlines outlined in the directive

The application of these directives has become a number one priority for the EU, so much so that they set up the EU's sixth environment action program.

3.1.4. The 6th Amendment Action Program

The 6th amendment action program was launched in 2001. This action program put forward four areas where the full attention of all member states was needed in making a difference to its environment.

1. Climate change
2. Protecting nature and biodiversity
3. Health and quality of life
4. Managing natural resources and tackling waste

(*europa., 2003*).

3.2. Current situation

This project will consider the following areas of sewerage services:

- Sewer pipe materials
- Sewer pipe design
- Manhole materials
- Manhole design and construction, historic and current practice
- Sewage pumping main materials

- Sewage pumping main design and construction, historic and current practice
- Requirements for testing sewers, manholes and sewage pumping mains
- Sewerage system maintenance

Most of the information relating to this was drawn from “Materials Selection Manual for Sewers, Pumping Mains and Manholes (*UK Water Industry Sewers and Water Mains Committee., 1993*) and (*Escritt., 1984*).

A questionnaire was sent to the Department of the Environment and the Local Authorities that are currently installing sewerage infrastructure. Following an interview with the DOE, it was shown that sewer rehabilitation was not a priority from department level. It was stated that process and collection system design, was decided by the relevant Local Authority. The Local Authorities that replied to the questionnaire stated that they did not consider sewer rehabilitation for large scale projects, rather small localised repairs on damaged sewers and in some cases water mains.

3.3. International Situation

3.3.1. USA

A great deal of literature from the USA regarding sewers and groundwater quality is related to sewer installation as a means of improving groundwater quality, since much of rural USA relies on septic tanks for sewerage disposal.
The earliest references found for sewers, as a source of ground water contamination was that of,

1. *Deutsch., 1963,*
2. *Kreitler et al., 1978,*
3. *Katz et al., 1980*
4. *Flipse et al., 1984,*
5. *US Environmental Protection Agency*

Deutsch describes two cases of leaking sewers polluting groundwater in Michigan in 1945 and 1952. In 1945, the Michigan Department of Health recommended that the city of Sturgis abandon its wells, or install a chlorination system, because of the proximity of sewers to wells and bacteriological contamination of ground water supplies. In 1952, a sewer on a small industrial plant in the Lansing area fractured, apparently from "frost-heave", permitting sewage to flow to a well. Therefore, six employees of the plant became ill.

Deutsch discussed the importance of the fresh groundwater resources of Michigan. He stated that 90 % of the rural and 70 % of the total population of the state outside of the Detroit city area were supplied from groundwater sources. Michigan showed contamination from many sources, including chemical and organic matter, entering many of the states aquifers. Leaking sewers, industrial and domestic wastes, septic tanks, surface waters, mine waters and airborne wastes all have been stated as sources of groundwater contamination in Michigan. Saline waters have also been introduced into some aquifers by overpumping or unrestricted flow from artesian wells, possibly by dewatering. Even with the contamination that has occurred, the total amount of ground water that has been affected is a small volume of the total resource. The legal authority to control most types of groundwater contamination in the state has been assigned by the Michigan legislature to the water resources commission, the department of conservation and the department of health also exercise water pollution control functions. (*Deutsch., 1963*).

The groundwater system beneath Long Island, New York has been studied in some detail, particularly with relevance to nitrate sources (*Kreitler et al., 1978; Katz et al., 1980; Flipse et al., 1984*). The evidence for sewers as a source of groundwater nitrate in urban areas of Long Island appears to be contradictory. *(Flipse et al., 1984)*, studied nitrate sources in a sewered housing estate and concluded that sewer leakage was probably negligible. However, all the other workers present evidence that sewers are a significant source of ground water nitrate in urban areas. The strongest evidence comes from a nitrogen isotope study by (*Kreitler et al., 1978*), where heavy isotope ratios under urbanised areas suggest that leakage from sewers is the major source of nitrate in the shallow unconfined aquifer. The Long Island aquifer system displayed problems for water as a source, probably because of the large population in Nassau and Suffolk Counties who reside over the unconfined aquifer. Nitrate contamination of groundwater on Long Island came from a number of different land use activities. Potential sources of nitrate include septic tank effluent or leaking sewer lines, commercial or industrial wastewater. Most of Long Island was once intensively farmed, however as urbanisation spread the importance of agriculture began to disappear from New York City (*Kreitler et al., 1978).*

Various studies from the USA indicate that organic compounds from sewer leakage are causing pollution in industrial areas (*Weimer., 1980; Avon and Bredehoeft., 1989; Kaback et al., 1989; Hanson., 1992*). Leaking sewers are also suspected as a CAUSE OF solvent and metals pollution of groundwater in industrial areas of the UK *(Burston et al., 1993*)

The US Environmental Protection Agency dedicates chapter of its book *Groundwater Pollution from Subsurface Excavations* to sewer leakage (*Anon., 1975*). It states that leakage is a common occurrence (especially from older sewers) but concludes that the actual effect of sewer leakage on groundwater quality is probably far less than the theoretical potential, owing to the clogging of soils and retardation of pollutants. The article suggests that better practices for laying sewers and monitoring will reduce the pollution threat.

3.4. Continental Europe

Much of the published research from Continental Europe into the effects of leaking sewers on groundwater comes from Germany. Other literature was traced from the Netherlands, Italy, Sweden and Switzerland. Among the first to recognise a connection between leaking sewers and groundwater contamination was,

1. *Hornef., 1983, 1985,*
2. *Merkal et al., 1988,*
3. *Mull et al., 1992,*
4. *Schleyer et al., 1992,*
5. *Dizer and Hagegdorf., 1991,*
6. *Toussaint., 1989,*
7. *Eiswirth and Hotzl.,1994,*

In Germany, (*Hornef., 1983, 1985*) appears to have been amongst the first to recognise the possible connection between leaking sewers and ground water contamination. (*Merkal et al., 1988*) estimated that 2% leakage of sewer flows occurred in the Munich Harlaching area, contributing phosphate, boron, total organic carbon and a variety of chlorinated solvents to groundwater. (*Mull et al., 1992*) similarly concluded that sewers were a source of ground water contamination in the Hanover area; 5 to 8 million m^3 per year, of sewage were found to be contaminating the aquifer in areas where the sewers lie permanently or temporarily above the high water table. High sulphate concentrations were found in groundwater in areas where sewerage entered the aquifer. In addition, boron and chlorinated solvents were detected, and nitrate levels were elevated. (*Toussaint., 1989*) also cites sewers as a source of chlorinated solvents. *(Schleyer et al., 1992*) state that the full extent of the potential hazard confronting groundwater in Germany from leaking sewers was only recently recently recognised. They estimate that 10% to 15% of the 285,000 km of public sewers and 600,000 km of private sewers in the former West Germany have exceeded their life expectancy. They estimate that approximately 300 million m^3 of wastewater seeps into groundwater each year.

At the International Congress on Pipe Construction in Hamburg, (*Anon., 1994*), it was estimated that about 300,000 km of pipes in western Germany transport a total of 8 billion m^3 of sewage per year. Of these sewers, about 12% are more than 75 years old, 26% are more than 50 years old and 54% are more than 25 years old. In 1990, a study by the German Association for Sewage works (ATV) stated that over 22% of the sewers were defective, and it is estimated that in the private sector the proportion might reach 40%. Of the 36,000 km of pipe in former East Germany, only 28% have been built over the last 25 years and researchers believe that up to 50% of pipework here is defective.

The most technical studies on sewer leakage conducted in Germany were those of (*Dizer and Hagegdorf., 1991*), and (*Eiswirth and Hotzl., 1994*). Dizer and Hagendorf reported on the chemical and microbiological quality of soil water adjacent to a leaking sewer and concluded that the quality is poorer adjacent to the leak. However, they conclude that bacteria, which have the potential to break down contaminants, are soon introduced into the soil. Eiswirth and Hotzl (1994) took a multi-disciplinary approach when investigating the feasibility of detecting sewer leakages in an old sewerage section and a specially constructed research sewerage system in Rastatt, southern Germany. They conclude that the closed-circuit television (CCTV) surveys cannot distinguish between those cracks and fractures that represent active or inactive leakage from sewer pipes.

In Switzerland, Schalekamp (1992) reported on groundwater contamination of Switzerland's most important groundwater resource, "Hardhof" at Zurich. Here, leaky sewers were found to cause groundwater contamination by bacteria and tetrachloroethene, especially during heavy rainfall. Such connections between groundwater contamination levels and rainfall have also been reported in the UK (*Lerner et al., 1989*). In the Netherlands at (*Hilversum, Schuurmans et al., 1981*) suggest that groundwater contamination beneath the town is related, in part, to sewer leakage. In a study of waterborne disease outbreaks in Sweden (*Anderson and Stenstorm., 1987*), infiltration of wastewater, mainly due to broken sewer pipes, was identified as the cause of seven outbreaks, the largest of which was due to a fractured sewer pipe located only 8m from the groundwater source. The distance between broken sewers and polluted sources was generally found to be between 6m and 30m. However, in one case in a fissured rock formation the distance exceeded 60m.

3.4.1. Inpipe

This increasing problem of sewerage pipelines that are in a poor condition and in desperate need of repair and replacement is not just confined to Ireland and other western European countries. Asia, Middle East, North America and Australia are all experiencing similar problems with renovating their drainage systems.

However, methods of repair and replacement by excavation work are considered costly and extremely disruptive. In recent times, a new technology using trenchless techniques has been made available to contractors. This new technology is seen as an efficient and economical alternative to sewer renovation, with minimal environmental impact to the surrounding area. Since the 1980's the use of trenchless technology rehabilitation techniques have increased considerably. There are now various rehabilitation technologies available. The choice of renovation system for any job application depends on an assessment of the existing drainage system and the likely cost. Money being spent on repairs to old pipe networks is growing year by year and therefore the technology of choice for rehabilitating existing sewer pipelines has proven to be the no dig – method, *(SSTT., 1997)*.

3.4.2. No–Dig Method

The No-did method is considered to both efficient and cost effective. This method is a pipe rehabilitation method developed by a company called "Inpipe" that are based in Sweden. "Inpipe" have been carrying out trenchless technology techniques since 1985. The result is that Inpipe now has the ability to provide the quickest installation practices with the lowest energy consumption in the world.

The Water Research Center (WRc) (*Sewerage Rehabilitation Manual., 2001*), is a document that provides guidelines to assist in the planning and design of works. This is done to improve the performance of the existing sewer systems, and in the strategic planning of operations and maintenance work. The manual was developed principally to meet the sewerage rehabilitation needs for the UK water industry. However, due to it's extensive detail, it has been applied to a number of other countries, including Ireland. The European Standard "Drain and Sewer Systems Outside Buildings: part five – Rehabilitation", (CEN 1997b), follows very similar procedures.

The *(SSTT., 2002)*, describes the preferred method of Trenchless installation and rehabilitation techniques in the Scandinavian countries. It describes the history of trenchless technology, as well as many technical aspects of modern civil engineering works of both water and wastewater pipes.

The UK Water Industry (*Manual of sewer condition Classification., 1998*) sets down the sewer condition classification from the National Water Council Standing Technical Committee on Sewers and water mains in association with the Department of the Environment. It outlines details on the compiling of "Header" information and details, condition details and codes including structural condition, service defects and construction features.

The EPA have also produced some studies for the protection of groundwater in Ireland, covering groundwater pollution from septic tanks and setting guidelines for the protection of groundwater.

3.5. European Environmental Law

Environmental law is a relatively new area of legal interest within the European Union. It is an area, which has increased in complexity and volume over the past number of years. At first, the European Union's main objective was primarily to protect consumer's interest. However, as time went by an increasing number of Directives were drawn up, with the aim to protect our environment, agriculture and human health. Over recent decades, our environment has become of increased concern due to various pollution incidents from industry, agriculture and domestic sources leading to the inevitable degradation of our water, air and land.

As Europe expands, with ten new accession countries having joined in May 2004, member states have became more integrated and increasingly involved in mutual affairs. This has resulted in many European countries having a similar legal approach in dealing with common environmental matters.

European member states have realised that our natural resources, particularly water resources, are not inexhaustible and that countries acting alone cannot always safeguard their own environment. As rivers flow from one country to another it is obvious that what will be discharged to an estuary in one country will be washed up on the shore of another. It is necessary that with the effective management procedures we can continue to benefit from uncontaminated water resources.

This has led the European Union members to harmonise their environmental laws towards a combined legal system. Member states have been setting environmental standards now for over thirty years ever since The EU saw the first environmental programme drawn up in Paris in 1972, (*EU 2003*). The council of the European Union, is the body responsible for this common approach.

3.5.1. Council of the European Union

Since 1972 the EU has become increasingly effective in setting standards through agreeing policies, passing various laws, and introducing measures to enforce them.

The Council has a number of important responsibilities:

1. It is the Union's legislative body for a wide range of EU issues, it exercises legislative powers in co-decision with the European Parliament.

2. It co-ordinates the broad economic politics of member states.

3. It concludes, on behalf of the EU, international agreements with one or many member states or international organisations e.g. world environmental organisations.

4. It shares budgetary authority with the parliament, which is important for the allocation of funds by the EU to various countries attempting to radically change their attitudes towards environmental care for e.g. Ireland's National Development Plan (NDP).

5. It takes the decisions necessary for farming and implementing the common foreign and security policy, based on general guidelines established by the European Council.

6. It co-ordinates the activities of Member States and adopts measures in the field of police and judicial co-operation in criminal matters, which is again useful in terms of implementing environmental laws and possible implications for people who breach legislation, (*EU., 2003*).

This common approach has resulted in new European environmental laws, which now consists of over two hundred separate pieces of legislation for the purposes of Europe's environmental protection.

This common legislation is transposed into national legislation throughout all the member states. Each member state government agree to these laws and policies at various conventions so there is no excuse for them not to ensure these environmental provisions.

This legislation will only be effective if each European country implement and enforce the environmental laws. The body that upholds the general interest of the Union is called the European Commission.

3.5.2. European Commission

The president and Members of the Commission are also elected by the Member States once the European Parliament has approved them.

The Commission is the driving force in the Unions institutional system:

1. It has the right to initiate draft legislation and presents legislative proposals to the parliament and the Council.

2. As the Union's executive body, it is responsible for implementing the European legislation (Directives, Regulations, Decisions etc), budget and other such programs adopted by the European Parliament.

3. It acts as a guardian of all the treaties and together with the Court of Justice, ensures that community law is properly withheld.

4. It represents the Union on the international front and negotiates international agreements.

The European Union's environmental role is also one of support, as it attempts to co-ordinate the efforts of member states. The European Union's legislation understands and respects the fact that national and local authorities in individual member states should decide on their priorities which also includes their own environmental issues. However, cases that come before the European Commission in relation to non-compliance are environmentally related. It is necessary that the Commission has the power to launch legal action against those countries guilty and if necessary, take them to the European Court of Justice.

From the European Union's Maastricht Treaty, new powers were given to the European Court of justice to penalise, through fines, member states that failed to comply with judgements of the court. This proved to be of fundamental importance in the European commission's objective to ensure the protection of Europe's environment.

To avoid such cases, European monitoring bodies for the European Commission check and confirm that Member State Governments are complying with the commitments they have made to the European Union.

3.5.3. European Standards EN752-2: 1997 Clause 8

In 1997 European standards regarding the performance of drainage systems were being questioned and EN752-2: 1997 Clause 8 was implemented. It recommended that the following information is collected and compared with performance requirement, (*europa., 2003*).

a) Flooding incidents
b) Pipe blockage incidents
c) Sewer collapse incidents
d) Disease injury or fatal incident to operators
e) Disease injury or fatal incident to members of public
f) Sewer damage incident
g) Compliance with discharge consent into and out of system
h) CCTV survey and visual inspection data
i) Sewerage related odour complaints incident
j) Hydraulic performance analysis
k) Performance of mechanical/electrical equipment
l) Results of test monitoring
m) Performance and conditions of flow control structure
n) Sewer surcharge incidents.

However, even with new legislation and awareness to an ever increasingly fragile environment within the European Union, there are still reports being released from various European monitoring bodies that suggest improvement is required. On the 31st December 1998, a total count of 37 European Union cities with a population of 150,000 or more were discharging wastewater into the natural environment. Another 57 cities were discharging a large proportion of effluent which was either untreated or without proper treatment. Also another relevant Commission report was released in 2001, the EU 6th Amendment Action Program, *(europa., 2001)*.

The 6th amendment action program was launched in 2001. This program put forward four areas where all member states had to prioritise measures in implementing sufficient environmental protection:

(1) Climate change.

(2) Protecting nature and biodiversity.

(3) Health and quality of life.

(4) Managing natural resources and tackling waste.

3.6. Irish Environmental Laws

The Republic of Ireland covers an area of land about 70,000 km^2 (*Ordinance Survey Ireland., 2003*). Census 2002 showed the population as 3,917,203 people (*Central Statistics Office., 2002*). The Irish coastline is deeply indented, particularly in the west. Its length, including estuaries is 5,630 km. Estuarine and coastal areas are significant receiving waters in that over 80% of the estimated waste load from urban sewage and from industry enter tidal waters, with the ten largest cities and towns situated adjacent to estuaries or the coast. There are 18 estuaries, or combination of estuaries, with contributing catchment areas of more than 500km^2, *(EPA., 2003)*.

At the time of Irelands accession to the European Community in 1973, environmental law was not developed in Ireland. Therefore, the country passed many pieces of legislation in the forms of Acts, Orders and Circulars in order to adjust to the European Community's Environmental Laws.

Ireland excelled in implementing the EC environmental laws in the context of air pollution. However, the country was challenged by the Commission about its failure in the implementation of pollution control in waste disposal, water and environment impact assessment. The majority of the problems originated with the local authorities. Difficulties in the implementation of environmental directives may have been a factor to the challenge.

In 1993 the Irish authorities admitted that they needed to regulate the escalating problem by introducing new legislation. The Environmental Protection Agency Act 1992 was passed.

3.7. The Environmental Protection Agency Act 1992

In relation to water protection the following terms were written
Under Section 4 of the EPA Act. The term "environmental protection" was to include:

(a) The prevention, limitation, elimination, or reduction of environmental pollution.

(b) The preservation of the quality of the environment. A definition of "environmental medium" is given to include land, soil, atmosphere and water.

Section 53 provided the possibility of Environmental Monitoring Programmes. This involves setting up databases, which would include information on water quality, ground waters, estuarial and coastal waters.

The act also enforced previous enactment's, with the introduction of an increase in fines and certain penalties.

With the introduction of the Environmental Policy Act in 1992 Ireland reconfirmed its commitment to the European commission to implement their directives in ensuring the protection of Europe's already fragile water environment, (*EPA., 2003*).

3.8. Urban Wastewater Treatment

3.8.1. Council directive 91/271/EEC (Urban Waste Water Treatment)

The Urban Wastewater Treatment Directive was drawn up to specifically protect the environment from the effects of domestic sewage, industrial wastewaters and surface water run off. The treatment of such waste is also of importance, as it achieves many of the objectives laid down for the Bathing Water Directives. Disposal to waters by dumping from ships, by discharge from pipelines or by any other means, were also to be phased out by 1998. Registration or authorisation to dump sewage sludge was to be introduced by 1998.

By the end of 2000 sewerage systems were to be provided for all towns with a population of 15,000 and above, and for towns and villages with a population of between 2,000 and 15,000 by 2005. Where areas have a population of 10,000 or more and the discharge of waste was to a particularly sensitive area, sewerage systems were to be introduced by the year 1998.

Sensitive areas were allocated to various regions of member states. The allocation of such areas was agreed by their own national and local authorities with the help of special guidelines laid down in Annex 11 of the Directive.

For example, a sensitive area would include surface waters with high nitrate content. Also, before waste entered its receiving waters it was to be given a level of treatment; primary, secondary, tertiary or appropriate and also the date at which the wastewater would receive its treatment should be recorded.

The level of treatment depends on the volume, type and the level of sensitivity of the receiving water - coastal, estuarine or freshwater, entering the local wastewater treatment plant. It was noted in the Directive that wastewater before discharge was to receive a minimum of secondary treatment. Some regions designated by member countries as less sensitive were to receive at least primary treatment. For such an area substantial evidence is needed to ensure the discharges would not affect the surrounding environment.

As part of the Directive, wastewaters from treatment plants are to be continuously monitored by member states national authorities and reports submitted to the European Commission for analysis.

The Department of the Environment is responsible for policy and legislation in relation to water quality issues and, together with local authorities , under the supervision of the EPA, must implement the following EU Directives.

- Bathing Waters (76/160/EEC).
- Dangerous Substances (76/464/EEC).
- Freshwater Fish (78/659/EEC).
- Shellfish Waters (79/923/EEC).
- Groundwaters (80/68/EEC).
- Drinking Water (80/778/EEC).
- Urban Waste Water Treatment (91/271/EEC).
- Nitrates (91/676/EEC).

4. SEWER DETERIORATION

4.1. Introduction

As with all underground pipelines, sewers must withstand the load of surrounding soil and water pressure as well as surface loads like the constant weight of traffic and overhead buildings. Over the years as surface infrastructure changes, the loads being exerted on these sewer pipelines can cause varying levels of damage. Where these pipelines were originally installed in different circumstances, now they have to be able to take huge pressure loads that were not originally anticipated. The condition and fabric of the sewer pipeline will inevitably begin to deteriorate over time through abrasion, chemical attack, damage from tree root intrusion and poorly made lateral connections, as well as soil support and the additional factor of surface loads, (*USA., 2003*).

The principal materials that have been used in the construction of sewers in the UK and Ireland are:

- Asbestos cement.
- Clay (salt glazed and vitrified).
- Concrete (reinforced and prestressed).
- Glass fibre reinforced plastic (GRP).
- Medium density polyethylene (MDPE).
- Steel.
- Unplasticised Polyvinyl Chloride (U-PVC).
- Brick and Masonry.
- Pitch fibre.

Some of these materials, (clay, brick and masonry) are traditional materials, and others i.e. (U-PVC and MDPE) are modern pipe materials.

U-PVC and concrete pipes comprise the majority of sewers found in the UK and Ireland. Brick and masonry made up the majority of the man-entry sized sewers constructed in the nineteenth century in the larger cities. The use of other materials i.e. GRP, MDPE and ductile iron is usually reserved for special circumstances, e.g. sewers that are constructed above ground, in boggy ground or where large ground movements are possible. U-PVC is also used extensively for land drainage, (*Materials Selection Manual for Sewers., 1993).*

Fig 4.1 Typical underground infrastructure in an urban area

Structural defects in sewers can be caused by numerous factors and whilst some deterioration occurs at the time of sewer construction other deterioration factors occur over a longer period of time. This deterioration may not be visible for many years as sewer pipelines are usually installed underground and this is where of the sewer lines deterioration occurs.

It is therefore necessary to understand the mechanisms that cause the deterioration of sewer lines, thus permitting any effluents, industrial waste and any other pollutants to be discharged into the groundwater. However, due to the sewer pipeline being underground, without the use of visual surveys conducted by CCTV (closed circuit television) evidence of exfiltration/infiltration is rarely found. It is necessary therefore that these pipelines should be accurately assessed and interpreted correctly and efficiently using CCTV.

The most common defects that might give rise to leakage are:

- Cracks, fractures.
- Joint displacement.
- Root intrusion.
- Deformation.
- Collapse.
- Reverse Gradients.
- Siltation.
- Blockage.
- Poorly constructed connections.
- Abandoned laterals left unsealed

Few of these defects will occur in isolation. For any incident of leaking sewage, a number defects may be present, arising from a single cause or many causes in sequence, (*WRc., 2001*).

Sewers are generally laid in the center of roadways in Irish towns and cities, with many of these sewers being in existence for more than 100 years, (*McGee., 1991*). Any maintenance or "rehabilitation", of these sewers often causes difficulty due to the impact of the associated disruption to commuters and business people.

Leaking sewers caused by cracks, poor joints or total sewer collapse will have social, environmental and economic costs. The public tends to become unhappy when remedial work is carried out, due to its impacts. Most people realise that that infrastructure needs to be maintained, but the short-term inconvenience during the works may sometimes aggravate people in the locality. This highlights the importance of effective public relations and a good traffic management plan, when carrying out works, (*Read and Vickridge., 1997*).

Infiltration, (groundwater entering the sewers), usually occurs in cracks, joints or sewer connections. The reverse can also take place, (exfiltration), where the liquid being transported in the sewer, leaks into the surrounding ground through these breaches.

Maintaining the integrity of the sewerage infrastructure is an important aspect of efficient wastewater management. Infiltration and exfiltration are processes that directly effect sewer network and treatment plant performance, receiving water and groundwater quality and in turn, it affects overall catchment water use.

Some of the problems that are associated with poor sewer integrity are.

- The age of urban sewer pipes, with some cities having sewer systems over 100years old.
- Poor construction quality, poor material quality, improper laying conditions, poor training, underestimation of the effects of unstable Geotechnical and structural conditions, continued disturbance by infrastructure provision including communication and utility cabling etc.
- Lack of appropriate or sufficient maintenance.
- Lack of appropriate investment in rehabilitation.
- High costs in construction and rehabilitation.
- Continued extension of the sewer systems with increasing pipe sizes, joints, manholes, inspection chambers etc. which collectively increases the chances of leakage into and out of the sewer (*McGhee., 1991*).

4.2. Sewer Deterioration

The rate of sewer deterioration depends on three main factors

1. The deterioration of sewer pipe material,
2. Changes that occur in the surrounding soil,
3. The interaction between the pipe and the soil.

4.2.1. Deterioration of sewer pipe material

Many sewer pipelines were constructed in the nineteenth and early twentieth centuries, particularly in areas of high population density. Sewer materials of these periods have been found to be durable under normal conditions, with a high level of good workmanship. This durability is only found as long as care has been taken to ensure that materials selected are suitable for the sewer environment for which they have been installed in. However, the joints and mortar used are often more prone to attack. The degradation of the sewer pipe material itself is unlikely to be the major cause of deterioration.

Chemical attack from certain types of groundwater and some industrial effluents can cause serious corrosion and erosion of the pipe and disastrously affect the pipe jointing material, which understandably is the most important feature of sewer pipes.

The organic material in the sewage effluent is broken down by natural microbiological reactions. The bacterial reactions can occur naturally in the sewer pipes when self cleansing velocities are not maintained, which in turn produce methane and hydrogen sulphide, (*McGhee., 1991*). Sulphide rich environments, a warm, humid environment, and a long retention time period create the perfect conditions for these microbiological reactions which induce the advanced corrosion of sewer pipe lines. An acid-producing bacteria known as thiobacillus is the principle cause of corrosion in a sewer system.

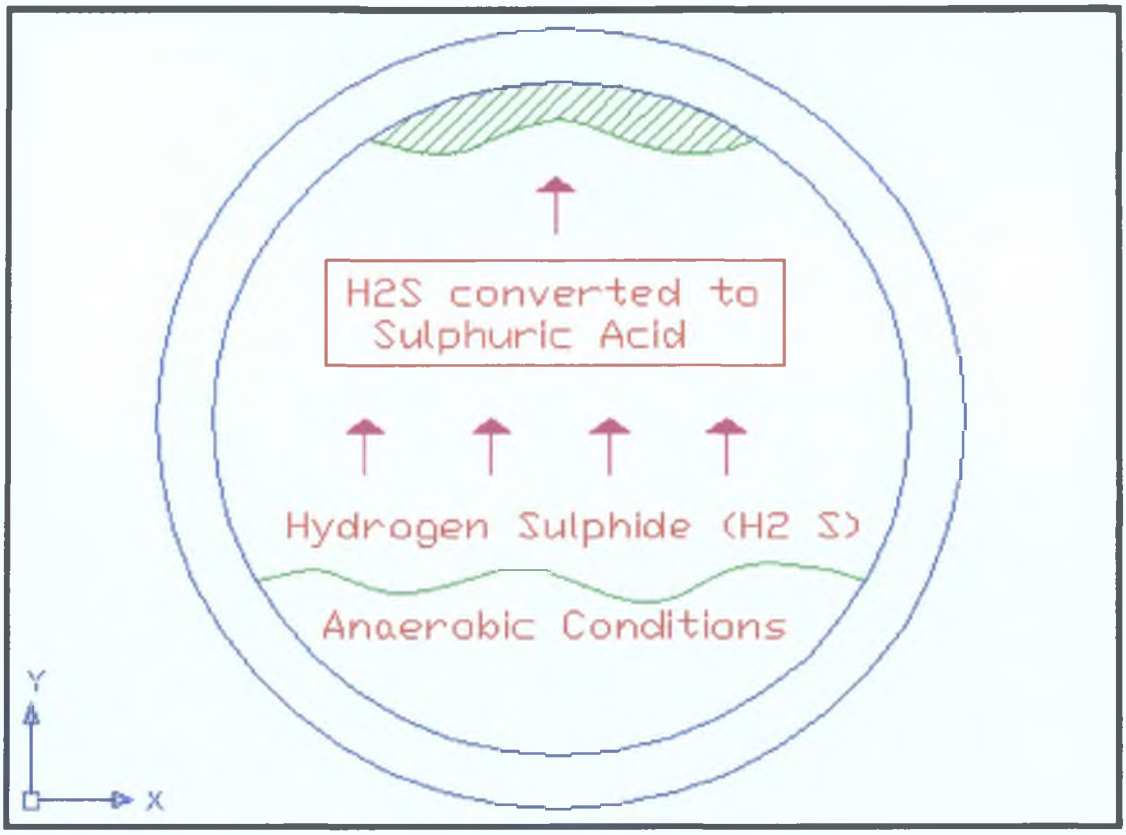

Fig 4.2 **Hydrogen Sulphide corrosion in sewers**

The degradation of a sewers pipe material can be rapid and take place within a couple of years of being first constructed due to the corrosion from microbiological action.

The corrosion of pipes can be reduced by various methods, including oxygen injection, to prevent anaerobic conditions, and lime dosing which neutralises possible acidic conditions. These measures however are not always satisfactory and may lead to extra operational expenses while managing the sewer system. The most effective measure is the selection of anticorrosive materials during the pipe rehabilitation process, which will be explained in detail in a later chapter.

4.2.2. Changes that occur in the surrounding soil

Pipe Bedding & Surround

When installing sewers it is important to include suitable bedding for the development of strength of the pipes, assuring it is laid to the proper grade and preventing subsequent settlement. Where the soil conditions may be unfavourable i.e. wet clays and organic soils the correct choice of bedding is particularly important, (*McGhee., 1991*).

Soil Types

The type of soil that a pipe may be laid in has a significant influence on the rate of deterioration of the pipe's condition and the extent of any fracture.

Silts and clays

Silts and clays are considered to be fine-grained soils, which have cohesion and plasticity i.e. the ability of a soil to mould. Silts and clays have low permeability in that water can pass through them relatively easily.

Silts

Silts are the product of the physical weathering of rocks and are composed of the same minerals as sand and gravel. Silts exhibit high cohesion, they are relatively permeable, and are easily eroded. Silts therefore can be transported with the movement of ground water and into sewers.

As can be seen from fig 4.3 self-supporting soil bridges can be erected around the defect thus decreasing the rate of deterioration of the sewer pipe. However, if the pipe is surcharged, or there is a heavy flow within the pipe, the flow of material might change direction and eventually destroy the soil bridge. (*WRc., 2001*)

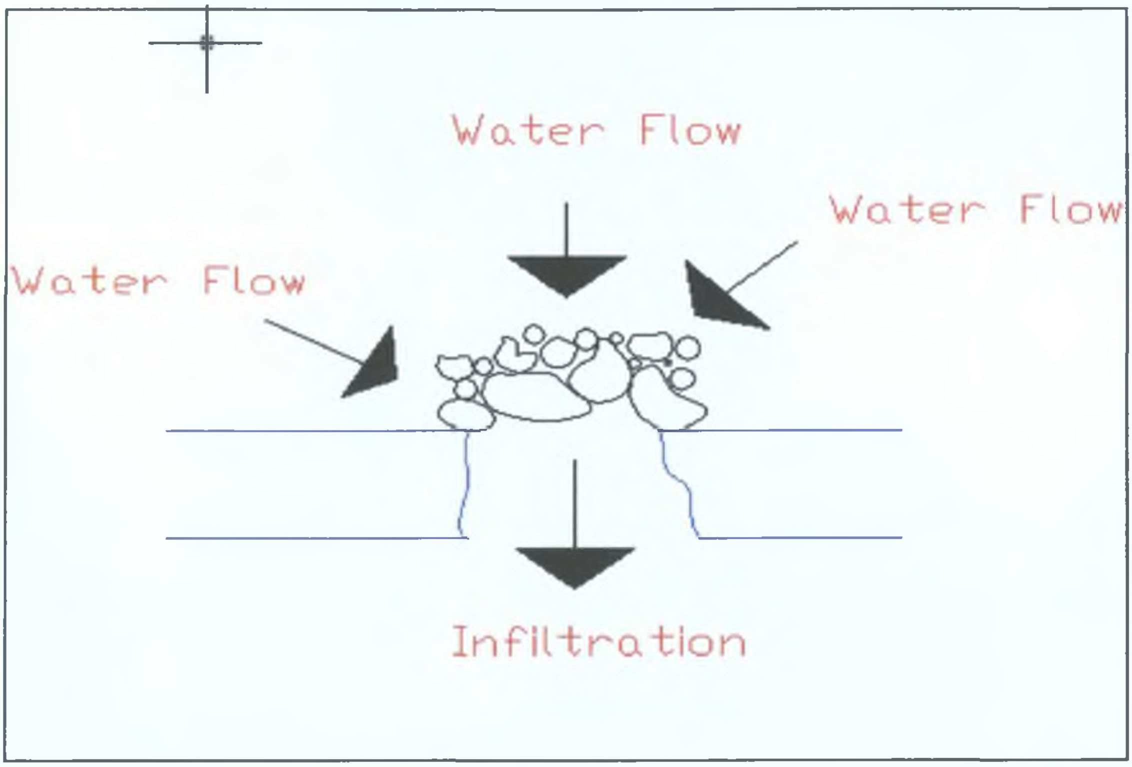

Fig 4.3 Self-supporting soil bridge around a damaged pipe.

Clays

Clays are finer materials than silts, and are created from the chemical weathering of rocks. Clays have high cohesion and their strength is increased with the decreasing of the surrounding water content. Clays are much less likely to be washed away in comparison to silts. Clays have low permeability and expand and shrink in relation to surrounding moisture.

If a void does not form, loss of fine soil by "washout" or erosion will inevitably cause a reduction in soil density and therefore, a reduction in support to the pipe. Once voids have formed, they may not be stable. They may increase in size and will tend to migrate upwards, particularly where there is a high water table. It is not uncommon, to find voids or areas of low strength soil at a higher level to the sewer, just under the road surface level. The problems of deteriorating sewers may not be just confined to only the sewers themselves, but can also affect other aspects of our infrastructure e.g. Roads, other utility services and buildings. Loss of pipe support can also occur when there is a flow of water of effluent through the bedding material, in a direction parallel with the pipe, this causes fines in the material to be washed away. An undermining effect will occur and the pipe may shear under the load of the backfill material. (*Vickridge., 1999*).

The soil content surrounding a sewer pipe can have great influence on the rate of deterioration within a sewer system. Also, the sewer hydraulics (surcharge) and the surrounding groundwater table can have a major effect on the degradation of a sewers pipeline.

4.2.3. The Interaction Between Pipes and the Soil

It must be remembered that the structure of a sewer is not just confined to the pipe. The structure must include the soil and the pipe. The resulting deterioration is caused by these two factors and their relationship with one another. When the soil that supports the pipe decreases in matter, the structure of the pipe will significantly loose its strength and will begin to deform. Most sewer materials that usually consist of concrete, clay and brick have little tensile strength.

4.2.4. Visible defects

The resulting deformation will cause cracks and fractures to develop at the highest point of bending stress – which usually occur in the invert and soffit. See Figs 4.4 and 4.5.

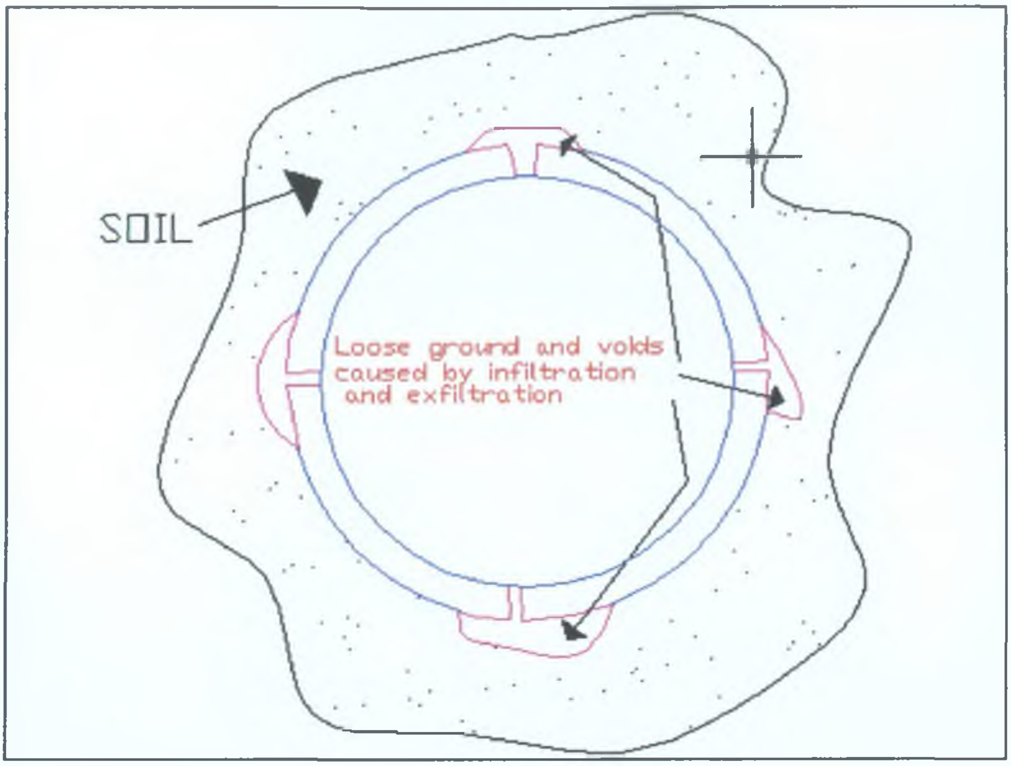

Fig 4.4 **Early stages of deformation**

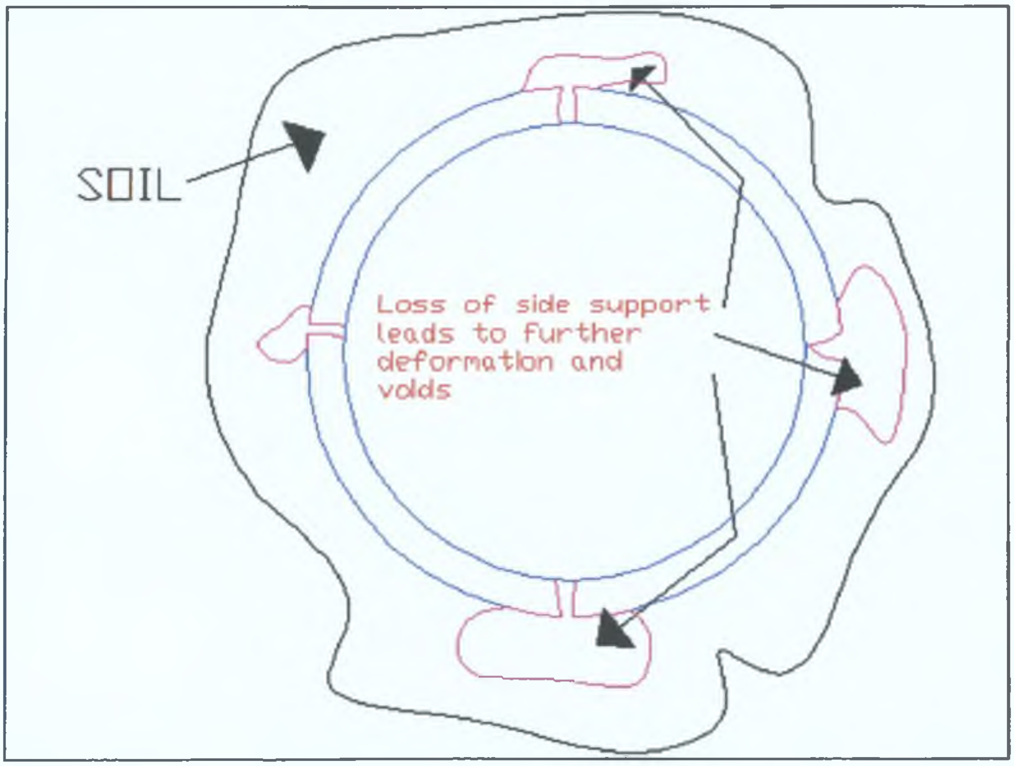

Fig 4.5 **Progressed stages of deformation**

4.3. Infiltration / Exfiltration

4.3.1. Infiltration

Infiltration is the entry of water into a sewer system through openings such as displaced or open pipe joints, cracks, fractures and breaks in the fabric of the main sewer, lateral connections and manhole chambers (*WRc., 2001*).

There are three basic types of infiltration:

1. **Groundwater infiltration**

   Groundwater infiltration occurs when the water table is above the sewer invert level, and therefore such infiltration is usually a seasonal phenomenon.

2. **Rainfall induced infiltration**

   Rainfall induced infiltration is caused by the temporary raising of the groundwater table. The potential for a large volume of rainwater infiltration into the sewer network depends on the time period and the amount of rainfall likely to fall.

3. **Tidal infiltration**

   Tidal infiltration occurs in areas where sewers are laid in tidally saturated ground. The timing of infiltration is dependant on the tidal cycles. Therefore, infiltration will be most likely be hazardous during the spring tides. Separate components of infiltration are detailed below.

   "Peak Infiltration Rate" is defined as the average of the minimum flow rate observed over a period of several days, during high (or "peak") groundwater conditions which usually occur in early spring after snow melt or soil thaw, and generally measured during low flow conditions (midnight to 6.00 a.m.) (*Inpipe., 2003*).

"Minimum Infiltration Rate" is defined as the average daily infiltration rate determined over a period of several days, during low (or "minimum") groundwater conditions.

"Annual Average Infiltration" is defined as the average daily infiltration rate determined over the entire calendar year.

"Total Annual Infiltration" is defined as the total infiltration volume over the entire calendar year.

"Tidal Infiltration Volume" is defined as the increase in infiltration which may occur when the groundwater table is temporarily elevated due to the impact of high tide. (*Commonwealth of Massachusetts Environmental Protection Bureau., 1993*).

4.3.2. The consequences of infiltration

Extraneous water entering a sewer system from the ground will usually contribute to the following effects.

1. Overburdened treatment plants.
2. Increased treatment costs.
3. Surcharged lines.
4. Pollution.

4.3.3. Cost effectiveness of Infiltration Reduction

Whilst infiltration may be present in most systems, the level and distribution of the infiltration may be such that the cost of investigations and removal can be greater than the cost of enlarging the system to take account of the additional flows. In order to assess the benefits of any proposed work the risks associated with leaking sewers need to be established.

Infiltration will usually cause four typical problems, which in turn will cost money.

(i) Unnecessary Pumping
(ii) Pipe Failure
(iii) Structural Collapse
(iv) Reduction of Pipe Capacity

However, in some catchments, where the level of infiltration is generally high or concentrated in a small proportion of the sewer network, there may be the potential for considerable cost savings by adopting the infiltration removal approach.

Initially this requires the costs associated with infiltration to be considered and the economic level of infiltration to be established. The approach requires the combined whole life costs (including social and environmental costs) of continuing to accept infiltration to be compared with the costs of reducing the infiltration. The exercise needs to be undertaken for various levels of infiltration reduction, e.g. 20%, 40%, 50% and 60% reduction. The most economic level of infiltration will be the target level of infiltration reduction where the combined costs are a minimum, (*Inpipe., 2003*).

The relative costs of infiltration reduction and continuing to accept infiltration (in terms of net present values), for various levels of infiltration, can be compared. The various costs are:

- The capital cost of infiltration reduction to a particular level. This will increase proportionally with the level of reduction and will become more expensive to reduce infiltration once the more obvious sources have been identified and eliminated.

- The cost of continuing to accept infiltration related flows, e.g. the cost to transport and treat the remaining infiltration, both in the sewer system and the sewage treatment plant.

This cost will depend upon the catchment / problem in question. Where costings are limited to operational functions, e.g. pump running, the costs will generally be proportional to the degree of infiltration. However, where capital works are required, possibly to increase capacity / storage to satisfy regulatory requirements, the costs will show a step change in the combined capital / operational costs.

- The total cost of infiltration, i.e. the combined costs of reducing infiltration and continuing to transport and treat the remaining infiltration.

The most economic level of infiltration reduction is where the combined costs are at a minimum.

The economic analysis may need to be repeated at various stages of the Infiltration Reduction Procedure as more reliable information becomes available. The analysis is likely to be brief at the initial planning / preliminary assessment stage, the aim being to establish if an infiltration approach which is likely to be cost effective.

If infiltration reduction appears to cost effective, or is required for regulatory purposes, it will be necessary to proceed to a more detailed investigation. More detailed economic analyses should then be undertaken once additional information becomes available. This will further refine the earlier assumptions and give a more detailed assessment of the most appropriate way forward.

In reality, the cost of continuing to deal with infiltration may include the cost of capital works to increase capacity / storage, possibly to satisfy regulatory requirements. Such capital schemes will show a step change in the combined capital / operational costs. (*WRc., 2001*).

4.3.4. Exfiltration

Just as infiltration takes place in the sewer pipeline, then the opposite may also happen. Where sewers are defective and are overloaded (surcharged), internal pressure in the forces sewerage out of the pipe and into the surrounding soil. As the pressure in the pipe subsides then the whole process is reversed and the sewage reenters the defected pipe bringing with it silt and clay.

These new or enlarged defects allow water and soil into the pipe accelerating the rate of soil loss deceasing the soils density, eventually the pipe will loose support within the soil material.

It should be noted that sewer systems are built for the reliable collection and transportation of rain and wastewater and the limitation of flooding events is one of the most important performance indicators. Nevertheless, the major driving forces for drainage construction have always been the safeguard of public health and the control of environmental pollution. Therefore, the water tightness of a drainage system is considered a basic requirement (*EN 752-2., 1995*).

Evidence of groundwater contamination as a result of sewer leakage in cities in the UK, is shown in a number of studies using standard ion chemistry, boron and isotopic ratios. (*Nazari et al., 1993; Lerner et al., 1994; Anderson et al., 1996*). In the Greater London area estimates suggest that a 5% loss occurs i.e. equivalent to a recharge rate of 20 – 25 mm/year (*Bishop et al ., 1998*) although rates of only 9 – 10 mm/year have been recorded in the Nottingham urban region (Yang et al., 2000). The potential dangers of sewer exfiltration have led the UK Environment

Agency to oppose the construction of new sewer systems within its most vulnerable groundwater Source Protection Zone regions.

4.4. Visible defects

Fractures and slight deformation of sewers.

4.4.1. Subsidence of sewers

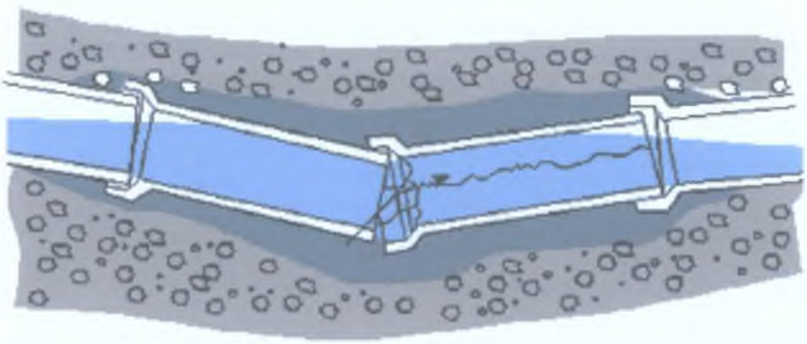

Fig 4.6 Subsidence within sewer pipes

Once deformation exceeds 10% the pipe becomes likely to collapse. The result is subsidence as the voids in the ground continue to increase. This causes ground collapses under the strain of heavy traffic and buildings.

Before the introduction of CCTV cameras, the main indicators of sewer pipe failure were persistent blockages or collapse. Collapse of surface infrastructure like roads and buildings occur where the pipe flow over the years carves out a cavern. If the flow is so intense and the soil type is a poor cohesive even in a relatively small pipe the subsidence caused could carve out a large hole.

4.5. Roots

Fig 4.7 Root intrusion within a sewer pipe.

Where a sewer is above the water table there is a risk of roots from nearby trees penetrating the sewer pipe. Root intrusion is not considered a serious structural fault but serious damage occurs when they exacerbate existing defects such as cracks. This may eventually cause blockages and surcharging within the sewer pipe, which will accelerate overall deterioration within the sewer pipe.

4.5.1. Multiple cracks and fractures

Multiple cracks and fractures are the direct result of vertical loading and uneven support. Fractures and cracks will deteriorate at a much faster depending on the type of soil surrounding the pipe, groundwater level and the hydraulic regime within the pipe.

4.5.2. Circumferential cracks and fractures

Circumferential cracks and fractures are mostly found near joints. Such cracks and fractures are regularly caused by uneven surface, which may have occurred when the pipes were being first laid. They like root intrusion are not serious defects but over time if undetected can cause leakage and eventually deterioration.

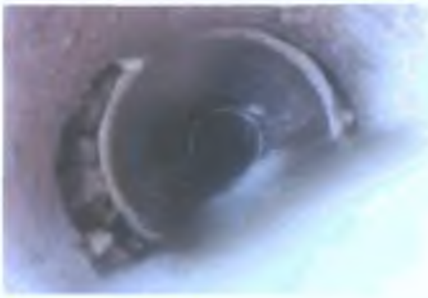

Fig 4.8 Circumferential cracks and fractures

4.5.3. Longitudinal cracks and fractures

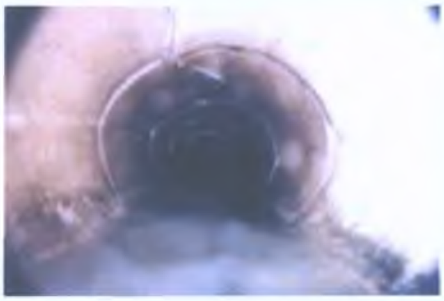

Fig 4.9 Longitudinal cracks and fractures within a sewer pipe

Longitudinal cracks involve cracks running the length of the pipe at 12 o'clock, 9 o'clock, 3 o'clock and 6 o'clock. Cracks visible at 12 o'clock are the most obvious whilst cracks at 9 o'clock and 3 o'clock only become visible as deterioration proceeds. Cracks at 6 o'clock are normally obscured by the flow within the sewer.

4.6. Conclusion

Sewer pipelines might begin with a relatively small defect but as time goes by the defect can decay significantly and lead to total collapse. The final collapse of the sewer can be just as easily be triggered off by something like nearby excavation work, an unusual high downfall of rain or construction going on nearby. Also, the collapse can be caused by human interference within the pipeline for example the surveying and cleaning of the line.

It must also be noted that the rate of deterioration within a sewer is never constant and that during the life of the sewer there will be various times where the sewer will be in worse condition than other times. However, the prevention of such collapse can be undertaken provided the sewer is surveyed at regular intervals during the sewer systems life.

The economic analysis may need to be repeated at various stages of the Infiltration Reduction Procedure as more reliable information becomes available. The analysis is likely to be brief at the initial planning/preliminary assessment stage, the aim being to establish if an infiltration approach is likely to be cost effective.

If infiltration reduction appears to feasible i.e. cost effective, or is indeed required for regulatory purposes, it will be necessary to proceed to a more detailed investigation. More detailed economic analyses should then be undertaken once additional information becomes available. This will further refine the earlier assumptions and give a more detailed assessment of the most appropriate way forward. An example of this can be seen in the case study section of this document.

5. UNDERGROUND SURVEYING AND DATA COLLECTION METHODS

5.1. Introduction

The development of underground services i.e. water mains, electricity, telecommunications and sewerage systems, has led to a high concentration of ducts and pipes etc, in urban roads, (usually 1 – 4m deep). Information on the condition of sewers is often not readily available, and even the location of certain services may not be known.

In order to develop cost effective maintenance procedures, up to date information on sewers should be available. The condition of large diameter pipes can be established by, man entry inspection techniques. For smaller diameter pipes, inspection can now be carried out by the use of CCTV (closed circuit television), which is cheaper, safer and tends to be more accurate than man entry surveys. Infrared thermography can be used for the external inspection of pipes without the disturbance of pipe surround material, (*USA., 2003*).

Identification of potential problems and prioritising maintenance work should be recorded, and one of the most effective ways of doing this is by establishing a database. The structure of a database should allow for easy updating of the records so that maintenance and changes to the system can be included as they occur. Together with the use of existing information, local knowledge and with a full survey of the sewerage system, an accurate database can be successfully created. The knowledge gained from the collected data should be sufficient to proceed with the planning of rehabilitation and upgrading of the particular drainage system.

5.2. Data / Information Required

5.2.1. For Manholes

A full SUS25 Survey usually includes the following (SUS 25 is a computer program used for sewer surveying and mapping).

- Manhole reference
- Grid reference (co-ordinates)
- Location (e.g. in road, in field, etc.)
- Cover and invert levels
- Pipeline reference, size and invert levels of all connections
- Function (foul, surface water, combined)

5.2.2. For pipelines

- Pipeline reference
- References for the upstream and downstream manholes
- Size of pipelines
- Pipe Material (e.g. brick, clayware, concrete, PVC-U etc.)
- CCTV Survey to show structural and condition of sewer pipe

5.2.3. For pump stations

- Number and capacity of pumps

- Pump operating sequences (e.g., duty/assist, duty/standby)
- Pump switch-on and switch-off levels (or details of other methods of operation)

The following are methods that can be used to get the sufficient data required to update and/or upgrade an existing drainage system. (*WRc., 1993*).

5.3. Underground Surveying Methods

5.3.1. Manhole Surveys

These are the simplest investigation techniques for locating areas where infiltration and may be occurring.

Manhole surveys are carried out by survey teams which were given maps to locate the relevant manholes. The maps are usually in the possession of the local authoritiy. The location of each manhole is recorded into a database and according to National Grid Co-ordinates. The equipment used is GPS (Global Positioning Systems) and can be incorporated into standard land surveying equipment i.e. Total stations. The leveling is carried out with automatic levels and staffs and benchmark figures are supplied by Ordnance Survey Ireland.

Details of the manhole condition can be obtained by removing the manhole cover. Vertical distance from the cover to the inverts are measured, with all of the pipes being sized and recorded. It is very useful to draw a sketch of the direction of flow of the sewer together with other relevant characteristics it may have. This information is then downloaded into the computer software package called SUS25 (explained later in this chapter). In SUS25 the sewer pipes can be connected by various manholes and thus plotted out to a desired scale by using a printer or plotter.

5.3.2. CCTV (Closed Circuit Television)

Detailed information on the overall condition of a sewer pipeline cannot be identified through manhole surveys. The Information regarding the location of many sewer lines will not be always available, as the sewers may have been constructed many years ago and "as-constructed" drawings relating to the relevant networks may be lost. Therefore, companies or sub-contractors employed to carry out rehabilitation work on urban drainage systems are often left with two dimensional information regarding the existing sewer line often however, the most critical feature of a sewer line is the third dimension. The third dimension is the depth, whose calculation can be essential during the rehabilitation process.

Therefore, CCTV (Closed Circuit Television) surveying was introduced for underground surveying worldwide. CCTV surveys are now widely used in the detailed evaluation of pipe networks. The structural assessment and classification of sewers, are at present mainly done based on the use of visual analysis.

The basic principle of CCTV inspections is that a camera is mounted onto a suitably sized tractor, which is then maneuvered in the pipeline from manhole to manhole from a remote control position. A CCTV camera is mounted on the tractor and the image from the camera is transmitted through an attached cable and is recorded onto a videocassette. The cable is connected up to a colour TV monitor that is installed in the control vehicle, which is usually parked over the manhole is being inspected. The entire survey of the sewer pipe can then be examined from the videotape, where the client can see the sewer pipes defects, infiltration points, flow rates and other features of the pipe.

Fig 5.1 CCTV camera mounted on a tractor

Ever since the first introduction of CCTV cameras in the 1970's for the inspection of drainage systems, the cameras ability to swivel 360° has become feature of the system. This allows the surveyor to inspect part of a sewer where there are difficult obstructions such as bends, obstructions or deformations and also making it possible to view all lateral connections regardless of their connection angle to the trunk line.

Through the use of CCTV cameras, the inspection of even the smallest of pipes can now be undertaken with great accuracy and precision. CCTV surveys have the potential to produce vast amounts of visual information. The gathered information can be analysed with reports written up highlighting defects found which may lead to potential problems in the future.

The CCTV survey recorded onto videotapes can then be stored in a database for possible use in the future. Some systems now have the software to copy the CCTV information from videotape to compact discs (CD). For storage purposes this can be an advantage as CD's take up far less storage space than videotapes. It can also an advantage for clients to receive the entire CCTV survey on CD rather than videotape especially when the job includes such a large drainage systems.

Faults and defects that can be identified through the use of CCTV cameras are as follows:

- Cracks – longitudinal and circumferential
- Collapses
- Blockages
- Broken pipes
- Defective and displaced joints and connections
- Evidence of abrasion and corrosion
- Siltation

- Encrustation
- Tree root intrusion
- Loss of mortar
- Deformations
- Infiltration
- All lateral connections and their degree of penetration
- Subsidence
- Chemical and physical attack

5.4. Cleaning

In some cases, particularly when dealing with old drainage systems it may not be possible to get a CCTV camera through the sewer which may be due to sewer collapse and obstruction. Special tools will then required to remove such obstructions. It is important that such equipment is readily available if severe delays to the CCTV survey are to be avoided.

5.5. Data Collection Methods

5.5.1. Computer Software

SUS25

SUS25 is a computer software package or database with a graphical interface where all information gathered during the manhole and topographical surveys are entered into SUS25. This results in the gathered information such as manhole locations, conditions, construction and pipe gradients being easily obtained from the SUS25 package.

The database is composed of a series of points or nodes, (drainage structures) such as manholes, junctions, pumping stations etc. Ordnance Survey maps can be imported and viewed as a backdrop with the sewer network in the foreground. When a node is added to the database, the program automatically assigns a reference to that node based on its easting and northing co-ordinates. (*ENGIS.,1997*)

5.5.2. Referencing System

For surveying purposes Ireland is divided into 25 squares by Ordinance Survey Ireland, as shown below:

A	B	C	D	E
F	G	H	J	K
L	M	N	O	P
Q	R	S	T	U
V	W	X	Y	Z

Fig 5.2

Each node is given a 10 digit reference. The system is best illustrated by the following example.

The National Grid Coordinates of this manhole are 227746.3 E, 190584.6 N

1st Digit 'S' - All of Ireland is 'S'

2nd Digit 'M' - All of Castlebar is 'M'

3rd & 4th Digits '15' - Derived from the ten thousand and one thousand metre Easting ordinates

5th & 6th Digits '91' - Derived from the ten thousand and one thousand metre Northing ordinates

7th Digit '5' - Derived from the hundred metre Easting ordinate

8th Digit '0' - Derived from the hundred metre Northing ordinate

9th & 10th Digits are arbtirary numbers assigned to nodes in each hundred metre grid.

The following are some of the main uses of the program.

Assimilation of quantities

- Total length of the sewers e.g. Castlebar
- Quantities of concrete pipe, PVC pipe etc.
- Amount of sewer in a given catchment

Assessing Conditions

- Current state of manhole covers
- Have the manholes the required step rungs?
- Manholes that are surcharging
- Sewers with a high flow rate
- Manholes that have been poorly constructed
- Infiltration

Reporting

A detailed report should be compiled. All manholes can be selected in a certain area and a report constructed on the condition of a series manholes s in a particular area.

Plotting

Plotting of a sewer network can be generated at any scale showing detailed information. Drawing with the cover & invert levels as well as pipe diameters can be produced.

5.5.3. Examiner

The Examiner database is a software package that has the ability to assess large volumes of data required during the CCTV survey. The Contractor can then produce reports that are compatible with Examiner. These reports are imported to Examiner and can form part of a large database for each job, and can be imported into a separate database. Once in Examiner the data can be used to the operator's preference.

There is a list displayed in Examiner of all surveys carried out. This list may be sorted in a variety of ways e.g. Road Name, Date, Pipe Size etc. When a survey is chosen there are 3 pages of information associated with it.

1. Header Page
2. Detail Page
3. Grading Page

The Header page contains information such as the video tape number, date of survey, distance between manholes etc. The Detail page is a record of observations made during the CCTV survey. All defect codes and video digits are on this page. (*USA Ltd., 2003*).

5.5.4. Main uses of Examiner:

Remedial Action

Searches can be made for sewers of certain categories. The biggest problems will involve sewers that have collapsed or have defects. Examiner can quickly locate these isolated cases and pick out the relevant surveys that can then be printed in a brief text format, report.

Sewer Condition

A system of grading sewers allows ease of sewer condition assessment. Grades numbers 1 & 2 indicate reasonable condition; grade 1 is perfect, grade 2 may indicate instances of minor defects such as cracks etc. Grades 3, 4 & 5 sewers, often require attention but each case needs to be examined in detail.

Examiner will assign a grade 5 value to any sewer which is deformed, but a PVC pipe which has deformed by 10% horizontally may be regarded as acceptable. A concrete pipe however, exhibiting a similar deformation will have fractured badly and may need to be repaired or replaced.

Structural "scores" are given in Examiner and these can help to quickly identify problem areas. The scores are derived from a value which is associated with each defect e.g. 60 points for a break, 15 for a longitudinal fracture. There are 3 types of score calculated in Examiner:

1. *Peak Score*: Highest number of points accumulated in a given metre.
2. *Mean Score*: Average number of points in a sewer length.
3. *Total Score*: Total number of points in a sewer length.

5.6. Conclusion

The methods outlined above provide a good means for assessing and recording the condition of sewer networks. The potential for mistakes reduced with the use of portable data loggers and computers. The technology related to the surveying of underground assets is continually evolving e.g. the use of infrared thermography and ultrasonics are becoming more commonly used by surveying contractors.

6. SEWER REHABILITATION

Following a CCTV Survey of a particular sewer pipeline, an engineer is usually employed, together with the survey contractor, (sometimes the same person), to examine all the visual footage from CCTV videotapes. Subsequently a judgment will be made as to the condition of each length of sewer pipe. To define and compare the structural performance of one part of the sewer to another, a process of assigning condition grades to each sewer length is then usually adopted. A choice will then be made on the most suitable rehabilitation method used.

6.1. Defect Calculation

Table 6.1 Table for grade given to condition of sewer (*SRM., 2002*)

GRADE	IMPLICATION	TYPICAL DEFECTS
5	Collapse or collapse imminent	Already collapsed deformation > 10%,cracked or fractured, extensive areas of missing sewer fabric
4	Collapse likely in the foreseeable future	Deformation 5 – 10% ,cracked or fractured, loss of level, dropped invert
3	Collapse likely in near future but further deterioration likely	Deformation 0 – 5%,Longitudinal cracking, Displaced bricks, Defective connections
2	Minimal collapse risk in short term but potential for further deterioration	Circumferential cracking, Moderate joint defects, No deformation but loss of mortar
1	Acceptable structural condition	No structural defects

The most severe defect along the individual sewer length is used to give a single condition grade for that particular sewer length.

NOTE:

Whether the grading is carried out by CCTV assessment or a defect point system, the overall grades assigned takes no account of the other external factors that may be influencing the accelerated rate of deterioration within the sewer pipe.

6.2. Background

Sewerage pipelines that are in a poor condition and in need of repair is an increasing problem in Ireland and other European countries. Asia, Middle East, North America and Australia are all experiencing similar problems with renovating their drainage systems, (*ISTT., 2003*).

However, methods of repair and replacement by excavation work are considered costly and extremely disruptive. In recent years a new technology using trenchless techniques have been made available to contractors. This technology is seen as an efficient and economical alternative to traditional sewer renovation using a cut trench method, with minimal environmental impact to the surrounding area.

Since the 1980's the use of trenchless technology rehabilitation techniques have increased considerably. There are now various trenchless rehabilitation systems available. The choice of renovation system for any job application depends on an assessment of the existing drainage system and the likely cost and the money being spent on repairs to old pipe networks is growing year by year.

Pipe restoration can be divided into four categories,

- **(i)** Hard
- **(ii)** Soft
- **(iii)** Hybrid
- **(iv)** Spray Applied

6.3. Hard Linings

Hard lining are generally made to suit the shape and size of the pipe being renovated. Where linings are placed directly into the sewer, this is known as sliplining, the lining material is jacked through an existing sewer pipeline with any resulting gaps being filled with grout. There are three main types of sliplining:

- Undersize
- Size for Size
- Upsize

An undersize lining is a pipe that will have a smaller diameter than the existing pipe to allow ease of repair. This is one of the oldest systems of existing pipe rehabilitation. The gaps that would occur between the new lining and the existing pipe would also be filled with a suitable grout. The disadvantages with this system was the new light weight pipe tended to float and the cross sectional area was reduced, which in turn reduced the hydraulic capacity of the sewer. Filling the pipes with water could over-come the floating problem, but hydraulic capacity could only be increased by replacing the original pipe.

The materials that were used were high-density polyethylene (HDPE) and medium-density polyethylene (MDPE) lengths of which were welded together on site.

In the 1980's Impact Moling were developed which allowed size for size and upsize sliplining to be carried out. The technology was developed by British gas and was subsequently used in the sanitary industry. Moles were hammer devices that were operated using compressed air, which pushed the pipes through the ground leaving a circular sleeve. The main disadvantages with this system, is the lack of directional control and the obstruction caused by laterals, which have to be removed before work can begin.

6.4. Soft Linings

Soft linings were introduced towards the end of the 1970's with one of the first systems being called Insituform. This system consisted of a resin-impregnated sock, which is placed into position through the existing pipe. The lining is the cured by using heating by hot water. Copeflex was a similar system that that was introduced to Europe at a later date. It consisted of coating the outside of a glass-reinforced polyester fibre bag. Once in position the bag was inflated by compressed air and heat was not required for curing. Problems occurred with this process however, as the impregnation was carried out by hand, which created irregular mixtures of the resin and poor quality control.

In Japan a number of similar techniques were developed which consisted of flexible linings, which are capable to withstand certain levels of earthquake damage. These Insituform type systems were mainly designed for the gas and drinking water supply networks.

6.4.1. Soft Lining Example - Inpipe Method (Used in Case Study)

Inpipe is a system which uses an inversion method for inserting a resin impregnated glass fibre sock into the pipe, which provided structural strength to the point that it could be a stand alone pipe, once the original was lined.

6.4.2. Installation Method

There are four stages to the installation method.

Stage 1

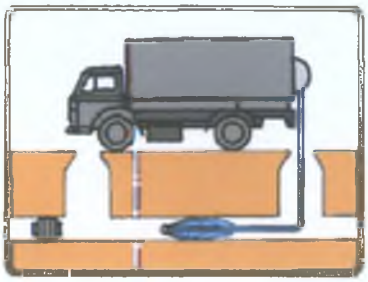

Fig 6.1 Impregnation of Glass Fibre Braid

Prior to any work being carried out on the sewer pipeline, cleaning, using water at high pressure should be undertaken. This is to ensure that there are no blockages, silt or other debris in the sewer pipeline. The soft liner at this stage, is a flexible uncured tube. The glass-fibre braid is impregnated under optimum conditions using a special polyester or vinylester resin.

Stage 2

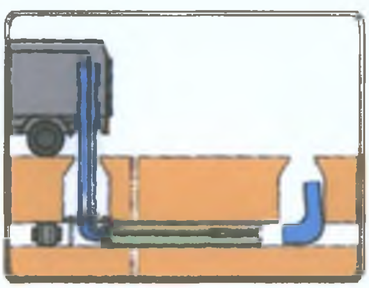

Fig 6.2 Inpipe Liner inverted into Manhole

The pre-formed Inpipe liner is inverted into the deteriorated sewer via an existing manhole, with the use of compressed air.

Stage 3

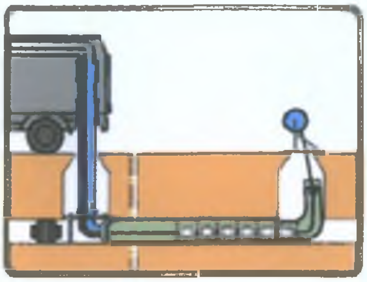

Fig 6.3 Inpipe Liner is Cured & Hardened

The Inpipe liner should now be pressed firmly against the wall of the existing sewer pipe. Compressed air is continuously pumped into the pipe just as a "train" of ultraviolet curing lights is drawn through the pipe. The function of the ultraviolet (UV) light is to rapidly cure and harden the Inpipe liner. With glass-fibre reinforcement the Inpipe liner is now a strong new pipe which would have the same strength as PVC pipes or greater.

Stage 4

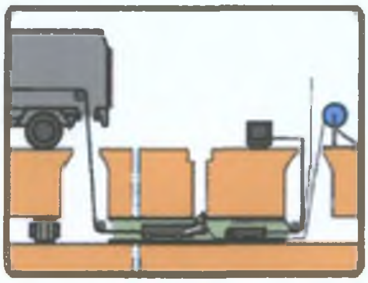

Fig 6.4 New Inpipe **Fig 6.5 New Inpipe Within Old Sewer Pipe**

Once the Inpipe liner has become hard the end sections of the liner are cut off and trimmed back to the original pipe and the annulus sealed off at the end using epoxy mortar. The new Inpipe is now an independent pipe minus joints and has the ability to withstand great pressure loads exerted onto it and also will not be affected by infiltrating groundwater that entered through the cracks in the original pipe.

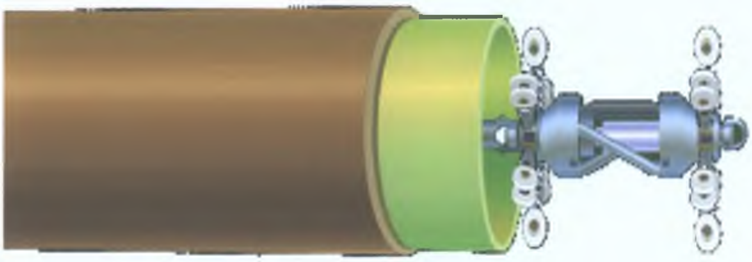

Fig 6.6 Preformed Inpipe Liner

6.4.3. Structural Abilities

Fig 6.7 Characteristics Of Inpipe

- The dimensions of the Inpipe liner ranges from 150 – 800 mm.

- The Inpipe liner is a pliable, seamless, glass fibre reinforced, composite liner. The liner is an advanced close–fit cured in place pipe lining system used specifically for gravity flow and pressurised supply pipes like sewer pipes.

- The Inpipe liner material has a very high level of strength, and is very flexible. This is important as it allows the Inpipe to have a maximum diameter within the originally damaged pipe.

- The glass-fibre reinforcement gives the Inpipe liner structural strength; this is needed in ensuring that there are perfectly sealed lateral connections within the sewer pipeline.

- The glass-fibre braid also ensures a corrosive resistant pipe, which was an essential catalyst in the deterioration of previous sewer. The braid also extends the shelf life of the Inpipe to 50 years.

- The installation/cure time is short.

- Most importantly is that the no-dig installation is via an existing manhole.

6.5. Environment

The Inpipe method seems to be environmentally friendly. Through the use of ultraviolet light is considered more efficient and cost effective than more conventional methods available. Inpipe use corrosive resistant material in the pipes, which meet with European environmental standards.

Where conventional methods used (e.g. excavation), one of the biggest problems was traffic delays. The air pollution emitted from vehicles stuck in traffic (e.g. Carbonmonoxide, Carbondioxide) can build up to dangerous levels especially in areas of high population densities. This can lead to adverse health conditions as well environmental problems. The Inpipe method on the other hand consists of a single vehicle equipped with all the necessary equipment and involves no excavation process. This leads to minimum traffic disruption and less of an impact on the surrounding environment. (*Inpipe., 2003*).

6.6. Conclusion

The Inpipe liner has a dimension range of between 150 – 800mm, this means that it's possible that Inpipe can be used to rehabilitate existing drainage systems at an economical price whilst also ensuring environmental standards. The economics of using Inpipe or other forms of trenchless technology, may be an important factor in deciding what system to use.

Inpipe has a theoretical service life of 50 years and can purportedly be installed in all weather conditions. This could be a big advantage to northern European countries like Ireland and England where high rates of rainfall occur.

There are obvious advantages in using soft lining rehabilitation methods but in certain circumstances it may be more advantageous to using traditional cut trench systems e.g. in rural areas.

7. HEALTH AND SAFETY FOR SEWER REHABILITATION

Occupational accidents cause death, disease and injury, which in turn give rise to personnel suffering. To avoid such unnecessary circumstances, safety equipment such as gas detectors, breathing devices, road cones and diversion signs as well as washing facilities, should be vital parts of the standard on-site equipment.

In the case of surveying and the subsequent rehabilitating of sewer pipelines, the employer or project manager of the job in question, should identify any possible areas that may be classified as a confined space. The key to efficient health and safety on a project is to follow the guidelines and procedures set out by the Health and Safety Authority.

7.1. Confined Spaces

Confined spaces are significantly more hazardous than normal workplaces. The hazards involved may not be unique to confined spaces, but are almost always exacerbated by the enclosed nature of the confined space. The resulting injuries are potentially fatal. A seemingly insignificant error or oversight while working in a confined space can result in a tragic accident with the possibility of multiple casualties. (*Health & Safety Authority., 2001*).

7.2. Occupational Safety And Health Legislation

7.2.1. The Safety, Health And Welfare At Work Acts, 1989, 1993

The Health & Safety Authority in Ireland was set up under the Safety, Health and Welfare Act 1989 as the national body responsible for all areas of occupational safety and health. The authority has set a number of guidelines and procedures, which employers of companies must adhere to. These regulations are enforced on the workforce by safety inspectors. Within Ireland there are eight regional locations where safety inspectors operate. The Health & Safety Authority include a variety of representatives that range from employers, which the authority integrates and works closely with and various other organisations like the trade unions and government.

7.2.2. The Safety In Industries Acts, 1955 & 1980

These acts were set up to specifically target the national workforce employed in such industries as the manufacturing, construction, docks and warehousing industries. Their detailed provisions can be used as indicators of what is acceptable for confined spaces, e.g.

- The size of the manhole opening into the confined space.
- The removal of fumes from the confined space.
- The use of safety harness by the persons working in the confined space.
- The checking of equipment on a monthly basis.
- The use of gas detectors and alarms in the confined spaces.
- Having trained people to deal with an emergency situation.

7.2.3. The Safety, Health And Welfare At Work (Chemical agents) Regulations, 1994

These regulations advise employers to closely monitor the atmospheres in the working area. The regulations also put an exposure limit for over 700 chemicals that the workers might be exposed to.

7.2.4. The European communities Act 1972

The European Communities Acts deal specifically with major accidents, hazards, noise, asbestos, lead and chemicals. Through the introduction of various regulations by the European Union, the Health and Safety Authority within Ireland must then enforce these acts.

7.3. Testing

The testing of confined space atmospheres must be carried out so that the area can be certified as safe to enter. Such tests can be carried out using gas detectors. A gas detector is capable of monitoring up to four gas types simultaneously. Using electrochemical sensors, the gas detector can be configured to check for the presence of flammable, (e.g. in the case of sewer pipelines the gas may be methane) or toxic fumes (e.g. hydrogen sulphide). The gas detector ensures that there are adequate oxygen levels in the confined space. As some vapors are heavier than air, it is necessary that readings within the confined spaces of a sewer are taken regularly and where flammable atmospheres are likely to occur gas detectors approved to a European Standard (e.g. BASEEFA) should be used. The gas detector is a light device but at the same time is durable and resistant to external factors such as water and dust. (*Health & Safety Authority., 2002).*

7.4. Maintenance and Calibration

Operators of gas detectors are recommended by the Health & Safety Authority to carry out monthly gas response checks and a recalibration interval of six months. This ensures that the gas detectors are maintained in accordance with the manufacturer's instructions. It is advised that the gas detectors are kept as near as possible or on to the employee during its use in confined spaces.

7.5. Limitations of Use

Table 6.1 Limitations of use

	Long Term Storage Limits		Operating Limits	
	MIN	MAX	MIN	MAX
TEMPERATURE	0° C	20° C	-10° C	50° C
PRESSURE	900mbar	1100mbar	900mbar	3bar
HUMIDITY (Non – Condensing)	15%RH	90%RH	0%RH	90%RH

7.6. Safety Health and Welfare at Work (Confined Spaces) Regulations, 2001

These Regulations impose requirements and prohibitions with respect to the safety and health of persons carrying out work in confined spaces, as defined in Regulation 2(1). They apply to all work activities involving confined spaces, with the exception of activities below ground at a mine and diving operations.

The Regulations also replace the provisions of section 38 of the Factories Act, 1955, as amended by section 21 of the Safety in Industry Act, 1980, the repeal of which is activated by the Safety, Health and Welfare at Work Act, 1989 (Repeal of Section 38 of Factories Act, 1955) (Commencement), Order, 2001, made under sections 1 (2) and 4 (3) of the Safety, Health and Welfare at Work Act, 1989.

7.7. Conclusion

Through the implementation of the relevant legislation, safety equipment - gas detectors and safety training - confined space courses, it is possible for the hazards associated with working in confined spaces, to be reduced. It is important that as employers exercise responsibility in relation to safety by ensuring that the workplace is as safe possible.

Prior to work being undertaken in a potentially dangerous environment i.e. sewer pipes, manholes etc, it is necessary that a safe system of work should be devised and used. This should set out the work to be done and precautions to be taken. Employees involved in the implementation of safe working practices should be given adequate instruction and supervision.

The system of work should be understood by all persons involved. Where a system of work is complex, it needs to be in writing. When written down, it is a formal record that all foreseeable hazards and risks have been considered in advance and that control measures have been established.

8. CASTLEBAR REHABILITATION (DRAINAGE ASSET SURVEY)

8.1. Introduction

On 17th January 2000 USA Ltd (Underground Surveying & Analysis) was employed by Mayo County Council to begin a contract to carry out a systematic investigation of Castlebar's drainage system. On completing the survey USA's sister company USSR (Underground Surveying & Sewer Rehabilitation) was employed to rehabilitate any sewer lines suffering from deterioration and collapse. The object of the contract was for Castlebar to have a high performance drainage system and thus prevent the pollution of surrounding water resources.

The cost of the contract has been valued at € 3 million and was scheduled to be completed by 2004. The Castlebar Contract is discussed in the case study for this dissertation, which is located in the appendix section. The appendix contains the catchment details, length of pipe network , the general defect summery of the network and details of an infiltration study that was carried out as part of a progress report, during the contract.

8.2. Location: - Castlebar, Co. Mayo, Ireland

Castlebar is the county town of County Mayo and is located on the Castlebar River, which flows into Lough Lannagh. Prior to any works being initiated on the existing Castlebar sewerage system, a survey of the Castlebar River was undertaken. It showed the treated effluent standards were good but storm water overflow losses in the catchment area and inadequate storm water capture in the treatment plant, collectively resulted in a deterioration of the river condition. The population of the town was approximately 12,000 people at the time of the 2002 census, with signs of growth due to the high number of new residential houses being built around the catchment.

8.2.1. Drainage Assets:

- Manholes 1373
- Outfalls 7
- Junctions 44
- Pump Stations 11
- High Point 2
- Other 12

48,975m of sewer pipelines – Combined, Foul & Storm
There are 11 no Pumping Stations mainly associated with development, which has taken place in the last 30 years. (*Tobin Consulting Engineers., 2003*).

8.3. Existing Information

A flow recording project was put into operation between 1997 and 1998. Two flow recording monitors were installed in the Castlebar Main Drainage System. In conjunction with the flow monitors a single raingauge was installed in the town. The flow monitors measured both depth of flow and velocity of flow at a pre-programmed interval of 2 minutes. An accuracy in the region of +/- 10% was expected provided the sewer has suitable hydraulic characteristics and adequate flow. The flow recording monitors were installed immediately upstream of the inlet to the Wastewater Treatment Works.

The original design Dry Weather Flow was **4200 m^3 / D** for the Wastewater Treatment Works. But the Flow survey found an average flow of **10743.30 m^3 /D**. (D = Day).

It was not possible to blame all of the increase of flow to the treatment plant to Infiltration. New development, additional sewer extensions and new connections to the existing sewer all contribute to the flows. *(Tobin., 2003).*

The sewer system in the town centre consists of combined sewers as wall as separated, with pipes ranging in diameter from 150mm to 675mm pipe. Sewer materials are generally earthenware and thought to have been laid in the early 1900's. As Castlebar has developed, the majority of new sewer pipes laid are made of uPVC and concrete, but problems may still exist in recently laid pipes. The consulting engineers recommended to the local authority that as much foul and surface water sewers be separated and a sewer survey with a view to a rehabilitation contract being undertaken. *(Tobin., 2003).*

By the summer of 2004 the rehabilitation contract was still underway but an ongoing infiltration reduction study showed an average reduction of infiltration **4500 m^3/ D** to **1500 m^3/ D** approx. (see Appendix, Infiltration Reduction Study).

8.4. Contract History

The surveying contract started on January 17th 2000 with cleaning of the sewers prior to the CCTV Survey. This was recommended by Tobin Consulting Engineers in the Castlebar Environs Sewerage Scheme, Design Review Report of March 1999.

8.4.1. Infiltration Study

As stated earlier, infiltration may lead to loss of pipe surround causing formation of voids, which can lean towards structural failure and collapse. Increased volumes and flows will also lead to increased pumping and treatment costs.

The following guideline has been used to estimate infiltration to the drainage system in Castlebar:

The CCTV Survey identifies infiltration in the following categories:

- Infiltration Gushing,
- Infiltration Running,
- Infiltration Seeping / Dripping,
- Encrustation,

(Where encrustation is evident, infiltration has caused these deposits and whilst the infiltration may not be visible by CCTV there may be still inflow to the system).

The results are based on a visual assessment from CCTV data and recordings and are estimated values, (see Appendix).

Note:

Not all of the housing estates have been surveyed, as they are not taken in charge by the Town Council. Sewers below 150mm diameter were not surveyed.

Four groups were required to carry out the survey work.

- Topographical Survey Team
- Manhole Inspection Team
- Sewer Cleaning Team
- CCTV Survey team

8.5. Topographical Survey Work

The topographical team were responsible for positioning and levelling all manhole / nodes in the drainage system.

Node =

- manhole
- Junction
- Vent column
- Outfall
- Overflow
- Pump station

The nodes were positioned to National Grid Co-ordinates using GPS (Global Positioning System).
Levelling was carried out using an automatic level and staff.
Heights were calculated to the O.S datum at Malin Head.
(Benchmark values supplied by the Ordnance Survey).

8.6. Manhole Inspection Work

The manhole inspection team surveyed the nodes, most of which were manholes. The structural and serviceability condition as well as safety features were noted. In many cases dye tests had to be performed to resolve doubts over sewer connectivity, particularly where CCTV work was not being carried out.

The manhole survey was carried out by employees of USA Ltd (Underground Surveying & Analysis).

8.7. Sewer Cleaning

Sewer cleaning commenced in mid January in conjunction with CCTV survey. At this stage of the contract, it became evident that a substantial amount of sewers would require cleaning. The cleaning of drains was carried out solely to enable the CCTV work to proceed without difficulties. The overall quantity of cleaning required and carried out was such that the overall serviceability of the system had been improved greatly. Cleaning proved to be the most difficult aspect of the contract as high levels of silt and debris were evident especially in the main trunk sewers. This subsequently led to high water levels and restricted flow. Secondary sewers had become infected due to this with silt evident.

For example, water levels of 60% - 80% of diameter were evident in the 675mm trunk sewer due to restrictions caused by debris; this debris has now been removed.

Pat Hinch Pipe & Drain Cleaning Ltd carried out all cleaning work.

8.8. CCTV Survey Work

CCTV work was carried out to establish the condition of the sewers between manholes. Sewers were surveyed using a Flexiscan camera system. The Flexiscan camera system has the ability to 'look around' so one is not restricted to a 'straight ahead' view only, with trained surveyors carrying out all of the survaying work.

VHS to date has been transferred All of the CCTV data recorded on to CD Rom Format, which is less bulky, easier and faster to access than using the traditional videocassettes and video recorders. (see appendix for photos).

Information displayed on screen at all times as follows:

I. View of pipe
II. Survey date
III. Pipe diameter
IV. Start manhole
V. Direction of flow

8.9. Defect Survey Summery

The Defect Survey was completed by USA Ltd, and Tobin Consulting Engineers compiled a list of works required for a proposed Sewer Rehabilitation Contract. The works that were required to rehabilitate the existing sewer were as follows;

- Inpipe Lining 9670m
- Localised Repair 700m
- Manhole Repair 157
- Cleaning 21650m
- CCTV Pre Cleaning 21650m
- CCTV Post Cleaning 21650m
- CCTV Post Repair 21650m
- Robotic Cutting Intrusions 300
- Reopen Connections 720
- Test and Seal 549

As can be seen from the above table a total of, **21650m** of pipeline was proposed to be relined. The contract started in 2002 and was due to finish in 2004.

8.10. Rehabilitation Methods

The main system used on the Castlebar Environs Sewerage Rehabilitation Contract is the IN-PIPE method (*detailed in section 7.5*). The contractor carrying out the works USSR Ltd and the Consulting Engineer, Tobin Consulting Engineers Ltd agreed on this method of insitu pipe repair, prior to the contract starting. In certain areas a different methods could be used, if circumstances required e.g. if a pipe collapse occurred, then a cut trench may be required.

The problem areas identified in the drainage asset survey were correlated and used as a list of repair work for the rehabilitation crews. A monthly site meeting was held between the Contractor, Consulting Engineer and the Client – Mayo

County Council. These meetings highlighted the works completed, rate of works, cost analysis and any problems or additional works that my arise during the course of the contract. The Resident Engineer that supervised the works on behalf of the Consulting Engineer contacted relevant people e.g. the area and town engineers, regarding areas being worked on and traffic arrangements, on a weekly basis.

8.11. Rehabilitation Process

As with surveying prior to any rehabilitation works being carried out, the pipe in question must first be cleaned. The cleaning process was not as time consuming as it was prior to the sewer surveying. Most of the debris had been removed on the earlier occasion and therefore the Inpipe lining system could commence.

8.12. Conclusion

The contract works progressed without any major problems and with little inconvenience to the general-public, businesses and traffic. This was due to the unobtrusive means of sewer repair. The only sign of works that was visible to the public was a truck parked over a Manhole in the roadway. In certain circumstances, works would be undertaken at night to reduce the possibility disruption.

Infiltration rather than exfiltration was the most common problem associated with damaged and degraded sewer pipes in Castlebar. Although almost 10,000 m of the sewer network was lined, there will continue to be a certain amount of infiltration in the system. This will mainly come from private estates, business areas where the local authority has no jurisdiction and future connections into the sewer network, which may be carried out using improper tools and methods. Methods of making connections to a live sewer may be an area of interest for further study. However, the latest infiltration study in April 2004, showed a decrease from over 4500 m^3/D to just under 1500 m^3/D, with still a substantial part of the contract to be completed.

9. GROUNDWATER CONTAMINATION FROM SEWAGE

9.1. Characteristics for Contamination Incidents

This section assesses the characteristics of sewerage systems in areas in the UK where sewage related groundwater contamination has been identified. There is limited information on similar incidents occurring in Ireland, however, Naas in County Kildare had a related problem in the late 1980's. It shows examples of where damaged or poorly maintained sewer pipes may be associated with groundwater pollution incidents and the ill effects that they may have on the environment and consumers.

9.2. Incident 1 - London Road, Amersham

The water source at Amersham was contaminated by a leaking sewer in 1989. When the water was sampled, it was shown to have bacteriological contamination and the water source was temporarily closed. The source of the contamination was shown to be a surcharged sewer. The polluted groundwater did not enter the public water network and therefore did not cause any public health problems.

The water supply well and borehole was constructed around 1900 on a Chalk aquifer. The distance of the sewer from the borehole is relatively short, which suggests that the contamination occurred in the inner source protection zone. However, the sewage contamination may have found an easy route to deep levels in the aquifer through one or more disused boreholes, at the same site as the sewer. This seems possible due to the source well and borehole had a deep lining.

The sewage leak seems to have occurred from an out of use lateral sewer used by a meat processing factory. The sewer connection had been broken but not capped and the blockages caused surcharging which leaked from the unsealed lateral. The clayware pipes were found to have no structural damage. No flooding occurred which indicated that the sewage seeped through the ground into the groundwater. This incident illustrates the need of sealing lateral connections. The sewer was renovated after the incident. (*Halliday & Lerner., 1992*).

9.3. Incident 2 Bramham, Yorkshire

In 1980 the public water supply Magnesian Limestone aquifer in northern England was affected by sewer contamination. Bramham is one of the villages that lie on a narrow belt of Limestone running North to South in Yorkshire. In 1980 Bramham and some other local villages were served by four Yorkshire Water Authority boreholes supplying water from this aquifer.

In July 1980, Leeds Department of Environmental Health received the first reports of incidences of illness from communities served by the Bramham boreholes. Within a few days 3000 cases of gastro-enteritis were recorded. The source of the problem was shown to be feacal contamination of one of the boreholes, which showed both feacal coliforms and E.Coli. The borehole was 6.71m of 0.3m diameter solid casing and 11.58 slotted casing underneath. The total depth of the borehole was 38.05m, but an alternative water source was then found and that borehole was abandoned.

The source of the pollution was shown to be a leaking sewer. Tests showed that poor sewer connections was to blame. Tracers were used to measure the distance the contamination travelled and it was approximately 100m and took 8 hours to travel the distance. There were two main reasons that for the contamination of the groundwater supply:

- Inadequate interpretation of bacterial indicators after the commissioning of the polluted borehole.
- Chlorination breakdown in the water supply.

The sewerage system in the area was residential and some businesses and was served by both combined and separated system. The sewer pipes were 150, 200 and 225mm clay ware with cast iron used for river crossings. (*Short., 1988*).

9.4. Incident 3 Naas, County Kildare

In October 1991, a public water supply, serving approximately 1500 households in the town of 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 source of the incident at Naas was a new borehole known as Sunday's Well, located in what is now a housing estate bearing the same name. An existing well, 10m from the borehole was the original water source for the town. The new borehole was commissioned in December 1990, supplying the town with 300,000 gallons of groundwater per day.

Problems shown at the Sunday's Well source started on the 7 October 1991 when a consumer complained about a bad smell in the water after it was boiled. The complaints became more common so the source was then examined and it was shown to have contamination from sewage. The water analyses showed presumptive coliforms of 10^9 / ml and E.Coli of 10^7 / ml. The pollution was traced to a blockage in the sewer close to the groundwater borehole from where the sewage leaked into the water source.

The water supply was chlorinated but seems to have been inadequate to deal with a high concentration of polluting matter. Two weeks after the pollution incident the borehole was super chlorinated which illuminated the contamination.

The Naas incident showed how quickly that a groundwater source can become contaminated from leaking sewers and the serious consequences for public health. (*Garrett., 1992*).

9.5. Incident 5 Thames Gravels Acquifer, London

This incident related to suspected sewage related groundwater contamination. The local ground make up consists of alluvial layers over Chalk. The water source consists of 7 chalk boreholes and the surrounding area is bordering a river and a canal to the south. There are several open water channels and large areas of lying water.

One borehole at the site was affected by microbiological contamination, which is located on the North Western corner of the site. The borehole construction is made up of a 750mm casing, grouted to 25m with a 110m deep open hole below. The water level is approximately 13.5m below ground level.

When the first pumping tests were being carried out on the borehole, the coliform count was approximately 400 / 100ml of water. Between 1985 and 1995 *E.coli* contamination was shown to be approximately 200 / 100ml of water for many of the boreholes. High levels of bacteriological contamination were present when incidences of heavy rainfall occur. This may be linked to sewer surcharging in combined flow systems that cannot adequately deal with high storm flowrates. The responsible water company proposed that the contamination source may have been 10m to 100m from the borehole but the water source was treated with chlorine and no public health incidents were reported. (*CIRIA., 1993*).

10. CONCLUSION

The EU report (our common future report, 1997) shows Sustainable Development is "a development which meets today's requirements without jeopardising future generations prospects of meeting their needs".

Based on the evidence, the continuous upgrading of any urban drainage system should be under taken as part of a sewerage management system. Through the use of computerised databases, CCTV Surveys and efficient methods of rehabilitation, it has become easier to access, monitor and repair or replace sewer systems as required. With the installation of most new Capital Drainage Schemes, the works are completed within a few years and consideration of future costs should be concentrated on such aspects as maintenance.

The information available concerning groundwater contamination from leaking sewers shows that they are a relatively rare occurrence, especially in Ireland. Most of the incidents noted in the UK occurred in the chalk aquifer in the south east of England. The large population and the extensive use of the aquifer as a water source probably contributed to the incidences.

Public Health will be affected when water supplies are contaminated with sewage as can be seen from the Naas incident, illness will almost certainly occur and death may take place. This highlights the need to monitor and maintain existing sewer network systems.

The disruption that will be caused by conventional repair and maintenance methods i.e. trench dig, makes surveying and rehabilitation using non-intrusive systems i.e. trenchless technology more desirable to both Local Authorities and the general public. Sewer maintenance, which may take place with minimal disruption, will also be more attractive from a service point of view as repair works will not seem as big a job as it used to be. The reduction in infiltration that was shown in the case study for this dissertation highlighted that when sewer rehabilitation is used as part of an overall maintenance plan it will have beneficial environmental protection characteristics. The case studies reduction of groundwater infiltration of 3000 m^3/D will include the following advantages:

- Increased storm capacity in the treatment plant
- Fewer untreated overflows going into receiving rivers
- Reduced ware on pumps
- Reduced Electricity costs
- Increased capacity in sewer networks

This Dissertation has shown some of the many choices in sewer rehabilitation on the market in Europe. In Ireland however, choice may be limited to what rehabilitation contractors have available. Although methods and technology are becoming more advanced a client may require customised repair work. It is still fair to say, that the options available for sewer rehabilitation are such that a suitable method can be found for most individual cases.

From the gathered evidence, there is no reason to believe that groundwater contamination will take place if all proper precautions are taken during pipeline installation. Newly constructed pipelines using modern materials and techniques should produce a maintenance-free, sealed environmentally protecting sewerage system.

It seems that age is one of the primary characteristics in the performance of a sewage system. The contamination incidents that were recorded seemed to be associated with older networks. However, it is not uncommon to have a sewer network consisting of pipelines of varying age. From information gained from Consultants, Contractors etc, it appears that the most common point of Infiltration and Exfiltration is at the pipe joints. Although modern pipes have rubber joint connections, which may have increased the seal integrity generally, it still can be a weak point in a pipeline.

Ground conditions and the usage of the pipes may also be a contributing factor to pipeline integrity. If the surrounding ground has poor structural capacity and a pipeline is installed without the necessary procedures, it is almost certain that the pipeline will move in the ground over time, which leads to breaches in the pipe. Private sewers tend to be installed with less attention to building regulations and guidelines. Without due care problems are more likely to occur over time, which may be after a local authority has taken over the maintenance of the private pipeline.

If a Local Authority decides on rehabilitation work to an existing sewer system, Trenchless Technology is now a realistic option by the use of GIS (Geographic Information Systems). This Dissertation has described some of the methods available to a Client, but there are many options for particular circumstances. A factor that may influence the choice of rehabilitation techniques, is the life span of a particular system. The type of waste being conveyed in a pipeline will affect this e.g. chemical and biological attack, joint integrity and abrasion resistance.

As a sewer network ages, pipeline records may not be maintained. Mapping of a network can be a pain staking expensive exercise, so it is important that a continuing record system is put in place once a particular type of maintenance system is put in place. Knowledge of sewer infrastructure is desirable so that a chosen monitoring and improvement system is the most cost effective system available. Pipe integrity does not last forever, and the "out of site out of mind" approach must be abandoned if Infiltration and Exfiltration are to be managed as part of an environmental management plan.

As highlighted from the literature review, there is limited knowledge on sewer rehabilitation using Trenchless Technology, in the Department of Environment. It is generally over looked by Local Authorities and Consulting Engineers when designing sewerage and drainage schemes for urban areas in Ireland. With the exception of the Castlebar Environs Sewerage Scheme, there is no large-scale sewer rehabilitation project currently under way in Ireland. The funding that is currently provided for capital water and sewerage schemes, is generally for the traditional trench dig methods. Complying with the European Commission regulations regarding the minimising pollution caused by sewage discharges into waters, Local Authorities seem to be overlooking the problems associated with sewerage dereliction. Sewers should be considered an important asset to an economy and as with any other asset, it must be maintained to an acceptable standard.

However, it should also be noted that the Irish government has shown its will to comply with National and European legislation through its successful systematic investigation of other urban drainage systems within Ireland. With the allocation of € 3.67 billion through the National Development Plan (NDP) over the years 2000 - 2006 to Ireland's water and wastewater infrastructure, recommendations from consultants for the rehabilitation of various urban drainage systems are likely to take place.

The implementation of the National Development Plan will demonstrate that Ireland's water infrastructure is a vital component of all the country's economic performance, Should ensure that the country is able to meet the demands of its growing economy. It will also have the added effect of achieving an appropriate balance between the requirement of that economy and the protection of the Ireland environment.

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12. GLOSSARY

CCTV - Closed circuit television.

Cracks - Crack lines visible along the length and/or circumference.

EU - European Union.

Exfiltration - Escape of flow from sewer into surrounding ground.

Flow Attenuation - The process of reducing the peak flow rate in a sewer system by redistributing the same volume of flow over a longer period of time.

Flow Reduction - The process of decreasing flows into a sewer system or removing a proportion of the flow already in a sewer system.

Fractures - Cracks visibly open along the length and/or circumference with the pieces still in place.

Infiltration - Entry of groundwater into sewer.

Lateral - Any pipe connected to a sewer.

Rehabilitation - All aspects of upgrading the performance of existing sewer systems.

Renewal - Construction of a new sewer, on or off the line of an existing sewer, the basic function and capacity of the new sewer being similar to those of the old.

Renovation - Methods by which the performance of a length of sewer is improved by incorporating the original sewer.

Repair - Rectification of damage to the structure of the sewer and the reconstruction of short sections, but not the reconstruction of the whole of the pipeline.

Replacement - Construction of a new sewer, on or off the line of an existing sewer.

13. APPENDIX No. 1

13.1. Catchment Details

Catchment No. 1

Catchment No. 1 – Serviced by 675mm Trunk Sewer running North of Castlebar River. All sewers serviced by the Trunk Sewer running from Manhole sm14904403 located outside Castlebar UDC Offices to Manhole sm15915006 at Castlebar Treatment Works.

Diameter 450mm – 675mm

Catchment 1 covers the following areas:

Ballynaboll North / South
Knockacroghery
Snugborough
Rathbaun
Pontoon Road
Knockthomas
Carrowncurry
Town Centre

This is a mainly combined system with separate foul and surface water lines found in newer estates i.e. Knockaphunta Park, Manor Village, Garryduff, Rathbaun, The Grove, Watersville, Rossmore, Greenfields.

Statistics

The following statistics summarise the make up of the catchment:
Total No. of Nodes = 1,059 which may be broken down as:

- Manholes 999
- Outfalls 4
- Junctions 44
- Pump Stations 6
- High Point 1
- Other 5

Total Length of Sewers 32,780 m

Materials

- Concrete = 10,300 m
- PVC = 17,500 m
- Clay = 2,900 m
- Asbestos = 1,600 m
- Cast Iron = 480 m

Sizes

- 150mm = 14 km
- 225mm = 13 km
- 300mm = 2.5 km
- 375mm = 0.4 km
- 450mm = 0.5 km
- 525mm = 0.1 km
- 600mm = 0.1 km
- 675mm = 0.9 km

Catchment 1 is the larger of the two catchment areas and is serviced by a 675mm Trunk Sewer. As can be seen from the statistics uPVC is the most common material found in Catchment 1. This can be attributed to the number of estates that have been constructed in the catchment area. Earthenware pipes are predominately found in the older sections of the town.

A general summary of the items of note follows:

13.1.1. Pipe Size Reductions

This has happened in certain areas where developers and others have removed old pipes and replaced them with smaller ones over the years, thereby reducing the capacity of the drainage pipes.

- **Ring Road**

sm14894805 to sm14894904 reducing from a 300mm to 225mm
The 225mm sewer section runs to the junction with Pavillion Road at sm14906001 where it returns to 300mm. (note: There is only a 12m section of 300mm sewer on the Ring Road, the remainder is 225mm).

- **Spencer Street**

sm14906208 to sm14906204 reducing from 375mm to 225mm
The 375mm incoming pipe is a connection from the 450mm Storm sewer on Spencer Street. This will need to be separated.

- **Castle Street**

sm14906420 diameter reduces from 450mm to 375mm and remains at 375mm to sm14907503 (132 metres). Water level in 375mm sewer approximately 55%.
Sm14907503 incoming 375mm reducing to 300mm cast iron at river crossing and remaining at 300mm to its connection to the 675mm sewer at sm14907598 (buried) on Lucan Street.

Note: sm14907503 is a Storm Overflow Manhole with the overflow in constant use during heavy rainfall.

- **Richard Street** (at junction with Upper Charles Street)

sm14908611 - Incoming 225mm from Richard Street, incoming 150mmm from Upper Charles Street, outgoing 150mm VC pipe for 18 metres to 300mm at sm14908604.

- **Lower Charles Street** (entrance to The Grove)

sm14908609 outgoing 375mm reducing to 300mm between manholes sm14908609 and sm14908608 (3 metres) sm14908608 on the 675mm sewer.

- **Pontoon Road** (Davitts Terrace junction)

sm14917111 - incoming 300mm from Pontoon Road, incoming 225mm from Turlough Road - outgoing 225mm for 50 metres returning to 300mm at sm14916001.

- **Turlough Road** (opposite Carrowncurry)

sm14918205 - 300mm and 150mm incoming to 225mm outgoing
sm14918203 - 225mm incoming to 150mm outgoing downstream for 100 metres and returning to 225mm at manhole sm14917108.

13.1.2. Combined Storm Overflows

There were 4 no. Combined Storm Overflow (CSO) chambers located in Catchment 1 The location of each are as follows:

Newtown / Shamble Street	sm14903514
Castle Street Car Park	sm14907503
Duke Street	sm14904308
Rowan Drive	sm15901911

The above Combined Storm Overflows (CSO) is in constant use during periods of heavy rainfall, notably the Castle Street Car Park CSO and Rowan Drive CSO.

The level of siltation and debris in the 675mm Trunk Sewer is may be contributing to the constant use of the CSO. After cleaning has been completed the overflows can be monitored during storm events to evaluate the effect of cleaning.

It was noted that during periods of heavy rainfall the 675mm sewer surcharges in all manholes upstream of the Treatment Works. On the 27th September 2000 cleaning of the 675mm sewer was abandoned, due to the water level increase during heavy rainfall. Covers lifted in The Oaks and Rowan Drive showed the level of water at approximately 200 – 300mm below the covers.

13.1.3. Defect Summary

There are 6 no. Pumping stations located in Catchment 1. Their locations are as follows:

South of Castlebar River

- Knockaphunta Park (Private Estate not in charge)
- Westport Road (County Council)
- Aglish Estate (Private Estate not in charge)

North of Castlebar River

- Belvedere Court (UDC)
- GarryDuff Park (UDC)
- Castlehill Park (MCC)

Problems have been identified in Castlehill Park Pumping Station where manholes in the immediate vicinity are constantly surcharged.

An inspection of the Pumping Station was required to determine whether groundwater infiltration or malfunctioning pumps are causing the manholes in the vicinity to surcharge.

13.1.4. Defect Summary

The sections of sewers listed in the following pages have an internal condition grade of 3, 4 or 5 and suffer from one or more of the following defects:

Fractures	Breaks	Infiltration
Root Ingress	Faulty Connections	Intruding Connections
Encrustation Surcharging		Deformed

The following is brief summary of areas where remedial / rehabilitation works are required in Catchment 1.

- **Lower Chapel Street**

Lower Chapel Street is serviced by a 150mm & 225mm Concrete sewer. The sewer is in very poor structural and service condition (service condition applies to debris, roots, intruding connections and any other obstacles/obstructions which impede flows) and is in urgent need of remedial works as identified by CCTV.

- **Manor Park, Westport Road**

A recently constructed system not in charge, work is required to several areas due to heavy infiltration to the pipelines. The drainage system consists of mainly 225mm UPVC pipe.

- **Pontoon Road**

The 150mm – 225mm sewer on Pontoon Road has numerous structural / service defects. An intruding connection to the sewer line outside Rossmore Estate requires attention. Grease buildup on the pipe walls was also evident as a result of surcharging due to restrictions in the pipe. The 150mm concrete sewer at the junction with Turlough Road towards Rossmore requires some remedial works.

- **Newport Road**

The 225mm – 300mm Concrete sewer on Newport Road requires remedial works due to infiltration, breaks, faulty / intruding connections.

- **Spencer Street**

The 225mm concrete sewer on Spencer Street is in need of remedial works. Heavy infiltration has occurred at joints and connections with structural defects (breaks and fractures) have been identified by CCTV. Approximately 330 metres of the sewer upstream of Rock Square require remedial works.

- **Turlough Road**

Consisting of 150mm VC sewer and 300mm concrete sewer. Structural damage is evident to the junction with the Pontoon Road. Remedial works will be required on the 150mm section of sewer.

- **Westport Road**

Infiltration is evident to the 225mm Asbestos Cement sewer serving the Westport Road area. A section of this sewer remains to be cleaned and surveyed. The sewer line inspected showed infiltration, breaks and faulty / intruding connections. Remedial works will be required on this sewer. Access to a large section of this sewer is difficult due to its location in gardens to rear of houses. Surcharging of the sewers on the Westport Road occurs during periods of heavy rainfall.

Foul connections were made to the surface water line on the Westport Road and needed to be removed.

- **Rathbaun Road**

A section of 150mm Earthenware sewer on Rathbaun Road requires attention due to breaks and intruding connections to the sewer restricting flows.

13.1.5. Manhole Inspection - Catchment 1

The internal inspection of 999 manholes on the foul and combined drainage system showed that 67 manholes were in need of remedial works.

The following criteria was used in determining the need for remedial works:

- Infiltration
- Chamber and/or benching needing attention

The following is a breakdown of defects listed:

41 manholes - Infiltration Seeping
12 manholes - Infiltration Running
3 manholes - Infiltration Gushing

11 manholes require structural repairs to the chamber or benching

20 manholes requiring remedial works are in the following Private Estates:

Table 13.1 Manholes In Private Estates Requiring Rehabilitation

Manor Park	Knockaphunta Park	Glenfort	Knights Park
The Oaks	Garryduff Court	Foxfield	Watersville

47 manholes requiring remedial works in the Public Domain are located in the following areas:

Table 13.2 Manholes In Public Areas Requiring Rehabilitation

Blackfort Close	Pontoon Road	Rathbaun Road	Spencer Street
Clydagh Park	Charles Street	Rathbaun Drive	Pound Street
Newport Road	Westport Road	Riverside	The Grove

The list applies to internal condition of manholes where urgent attention is required. Damaged or broken covers, shafts etc., are also evident and would be detailed in the Main Manhole Survey Report.

13.1.6. Infiltration - Guide

Table 13.3 Calculations Used To Quantify Infiltration

INFILTRATION SEEPER / DRIPPER	0.75 litres / minute
INFILTRATION RUNNER	3.00 litres / minute
INFILTRATION GUSHER	6.00 litres / minute
ENCRUSTATION	0.25 litres / minute

The following is a breakdown of infiltration and infiltration type found in Catchment 1 from the CCTV Survey carried out to date.

Table 13.4 CCTV Survey – Pipeline Infiltration

INFILTRATION TYPE	QUANTITY	LITRES PER MINUTE	TOTAL
Infiltration Gushing	65	6 litres / minute	390.0
Infiltration Running	247	3 litres / minute	741.0
Infiltration Seeping / Dripping	520	0.75 litres / minute	390.0
Encrustation	670	0.25 litres / minute	167.5
			Total: 1688.5

Table 13.5 Summary of Tables 7.4 & 7.5 for Catchment 1.

Infiltration to pipelines	1688.5 litres per minute
Infiltration to Manholes	87.00 litres per minute
Estimated Inflow	1775.5 litres per minute

106,530 litres per hour

2,556,720 litres / 24 Hours

(Estimated Inflow over 24 hour period based on CCTV information and on dry weather flows).

14. APPENDIX No. 2

14.1. Catchment No. 2

Catchment No. 2 – Serviced by 450mm Trunk Sewer running South of Castlebar River. All sewers serviced by the Trunk Sewer running from Manhole sm15902299 located at rear of houses on McHale Road to sm15915006 at Castlebar Treatment Works.

Diameter - 450mm Concrete Pipe.

Catchment 2 covers the following areas:

Saleen
Drunconlan
Gorteendrunagh
Moneenbradagh
Industrial Estate (Baxter etc)

This is a combined system in the Station Road area with separate foul and surface water lines found in newer estates i.e. Springfield, Chestnut Grove, Maryland, Davitt College, Fortlands, Fortfield, Rosslee.

Statistics

The following statistics summarize the make up of the foul and combined sewers in catchment 2:

Total Number of Nodes = 390, which are broken down as follows:

Manholes	374
Outfalls	3
Pump Stations	5

High Point	1
Other	7

Total Length of Foul & Combined Sewers = 13,563 metres

Materials:

Concrete	3,736 m
PVC	8,645 m
Clay	1,182 m

Sizes:

150mm	6,800 m
225mm	4,500 m
300mm	500 m
375mm	561 m
450mm	1,202 m

Catchment 2 is the smaller of the two catchment areas and is serviced by a 450mm Trunk Sewer. As can be seen from the statistics UPVC is the most common material found in Catchment 2. This can be attributed to the number of estates that have been constructed in the catchment area. Earthenware pipes are predominately found in the older sections of the town.

14.1.1. Combined Storm Overflows

There were 2 no. Combined Storm Overflow chambers identified in Catchment 2. The location of each is as follows:

Curragh Estate	(sm14897401)
Station Road	(sm14907503)

14.1.2. Pump Stations

5 number Pumping Stations have been identified in Catchment 2. Their locations area as follows:

- Tara Court
- Baxter (Balla Road)
- Baxter (Moneen Industrial Estate)
- Chestnut Grove
- Moneen Industrial Estate (cottages)

Sewers in the vicinity of Chestnut Grove Pumping Station are constantly surcharged. An inspection of the wet well and the pumps is required to identify the cause of surcharging.

14.1.3. Defect Summary

The following is a brief summary of areas where remedial / rehabilitation works are required in Catchment 2.

The sections of sewers listed in the following pages have an internal condition grade of 3, 4 or 5 and suffer from one or more of the following defects:

Fractures	Breaks	Infiltration
Root Ingress	Faulty Connections	Intruding Connections
Encrustation	Surcharging	Deformed

- **Moneen Road**

The 300mm concrete sewer on the Moneen Road is in very poor structural and service condition. Fractures, breaks and deformed sections of sewer are evident. Infiltration to the sewer is also prevalent.

- **N5 Ring Road**

The 450mm concrete sewer located adjacent to Furniture World is in poor condition with infiltration, breaks and fractures evident.

- **Station Road**

Serviced mainly by a 225mm Earthenware pipe this section of sewer has numerous fractures, breaks, defective connections and infiltration.

- **Moneen Industrial Estate**

This section of concrete sewer is in poor structural and service condition. The pipe has disintegrated in places due to chemical attack.

The above is a brief summary of the problems uncovered by the CCTV investigation.

14.1.4. Manhole Inspection

The internal inspection of 390 manholes on the foul and combined drainage system showed that approximately 49 number manholes were in need of remedial works.
The following criteria was used in determining the need for remedial works:

- Infiltration
- Chamber and/or benching needing attention

The following is a breakdown of defects listed:

15 manholes	-	Infiltration Seeping
4 manholes	-	Infiltration Running
2 manholes	-	Infiltration Gushing

28 manholes require structural repairs to the chamber or benching.

These manholes are located generally in the following areas:

Chestnut Grove
Curragh
Moneen Industrial Estate
Fortlands
Fairway

14.1.5. Infiltration Guide

Table 14.7 Calculations Used To Quantify Infiltration

INFILTRATION SEEPER / DRIPPER	0.75 litres / minute
INFILTRATION RUNNER	3.00 litres / minute
INFILTRATION GUSHER	6.00 litres / minute
ENCRUSTATION	0.25 litres / minute

The following is a breakdown of infiltration and infiltration type found in Catchment 2 from the CCTV Survey carried out to date.

Table 14.8 CCTV Survey – Pipeline Infiltration

INFILTRATION TYPE	QUANTITY	LITRES PER MINUTE	TOTAL
Infiltration Gushing	8	6 litres / minute	48.0
Infiltration Running	56	3 litres / minute	168.0
Infiltration Seeping / Dripping	353	0.75 litres / minute	264.0
Encrustation	467	0.25 litres / minute	116.75
			Total: 596.75

Table 14.9 Manhole Survey – Manhole Infiltration

INFILTRATION TYPE	QUANTITY	LITRES PER MINUTE	TOTAL
Infiltration Gushing	2	6 litres / minute	12.0
Infiltration Running	4	3 litres / minute	12.0
Infiltration Seeping / Dripping	15	0.75 litres / minute	11.25
			Total 35.25

Table 14.10 Summary of Tables 14.8 & 14.9 for Catchment 2

Infiltration to pipelines	596.75 litres / minute
Infiltration to Manholes	35.25 litres / minute
Estimated Inflow	632.0 litres / minute

37,920.0 litres / h 910.08 m^3 / D

(Estimated Inflow over 24 hour period based on CCTV information and on dry weather flows).

14.2. Summary Of Catchments 1 & 2

(Based on Dry Weather Flows)

Estimated Inflow in Catchment 1: 2,556.72 m^3 / D

Estimated Inflow in Catchment 2: 910.08 m^3 / D

Total Estimated Infiltration: 3,466.8 m^3 / D

Wastewater Treatment Works original design Dry Weather Flow:

4200 m^3 / D

Flow Survey average results: 10743.30 m^3 / D.

14.3. Moneen Stream (Estimated Inflow from Stream)

(Dry Weather Flow 10% to 15% Pipe Diameter) **518.4 m^3**

Based on the Colebrook-White equation which is :-

$$1 / \sqrt{f} = -4 \log (K_s / 3.7d + 1.255 / R\sqrt{f})$$

=>

K_s = absolute roughness of pipe in mm. (This approximates to the dimensions of the particles or granularity of the material causing roughness).

R = Reynolds Number. (A dimensionless number related to viscosity and the boundary layer).

14.4. Photographs & Maps

The attached photos show some of the rehabilitation works in operation, and the accompanying maps show the layout of the Castlebar sewer network with the existing sewer pipes being colour coded:

- Green shows existing foul sewers
- Red shows existing combined sewers
- Blue shows rehabilitation works carried out to June 2004

14.5. Infiltration Study

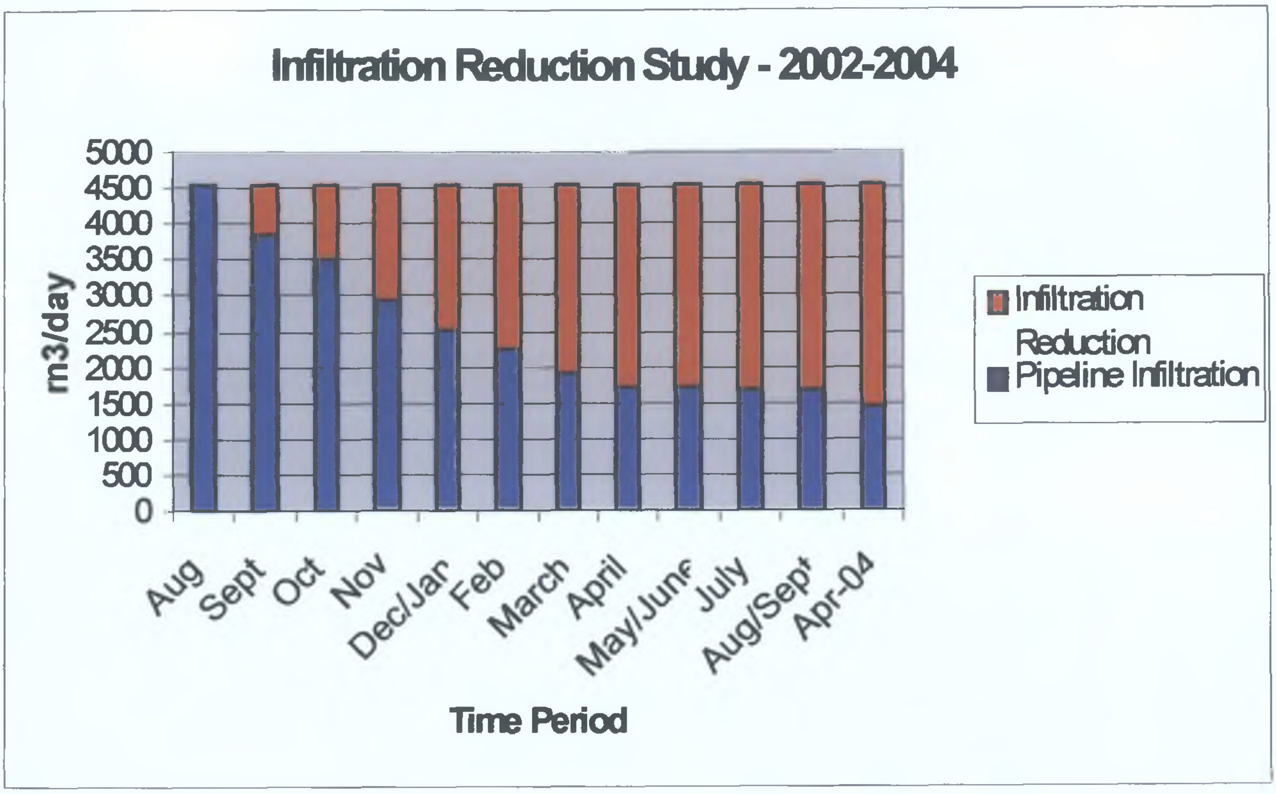
The Attached bar chart shows the Infiltration Reduction Study up to April 2004. The Blue colour shows the infiltration rate and the Red shows the infiltration reduction. The **X** axis shows the time in months and the **Y** axis gives the volume of infiltration in m^3 x 1000.

Photo 1.

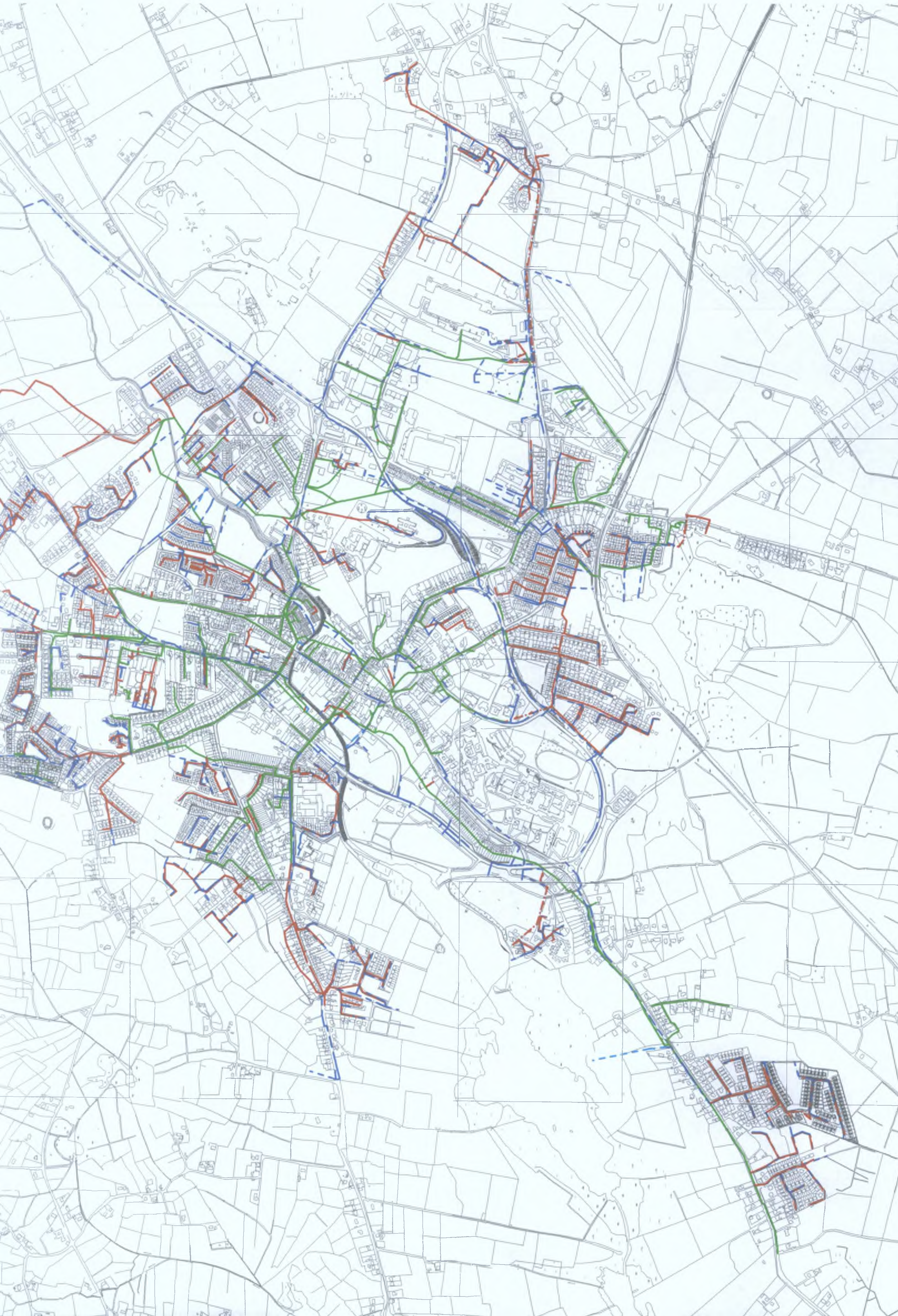
Typical rehabilitation truck working over manhole.

Photo 2.

Typical open cut trench.


Infiltration Reduction Study - 2002-2004
m3/day
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Aug
Sept
Oct
Nov
Dec/Jan
Feb
March
April
May/June
July
Aug/Sept
Apr-04
Time Period
Infiltration Reduction
Pipeline Infiltration

IT Sligo



IT Sligo