iSTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGY RESOURCE CENTRE	
	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	CONDITION ASSESSMENT AND REHABILITATION PLANNING	LAST UPDATED JULY2009

This section of the TRC begins with an overview of the nature of pipeline networks and the effects of pipe degradation on network performance. The remainder of the section contains information on activities which should be carried out by pipeline network owners and operators before embarking on new installation, replacement or rehabilitation programmes. These activities all form part of what is now commonly termed an Asset Management Plan (AMP) and such plans are fast becoming an essential tool for modern utilities facing the challenges of planning and implementing massive network rehabilitation programmes.

Many of these topics are highly specialised disciplines and the Guidelines should be seen as brief introductions to each topic. Click the More> link to access the individual topic subsection.

More detailed information and expertise can be found in the relevant Conference Papers and Bibliography associated with this section.

The section offers Guidelines on the topics listed below:

1. PIPELINE NETWORKS, PIPES AND PIPE PROBLEMS – AN OVERVIEW
   This section provides background information on the various types of pipeline networks, the types of pipes used and the degradation processes which impact network performance and drive the rehabilitation/renewal process. More>
2. ASSET MANAGEMENT OVERVIEW
   This is a brief summary of the purpose, essential components, and methodology of the planning process with particular reference to the incorporation of Trenchless Technologies. More>
3. PIPELINE LOCATION AND CONDITION ASSESSMENT – EXISTING INFORMATION SOURCES
   This section reviews the types of information available from a study of existing network records and the criteria for deciding whether further information is required via direct inspection in order to make an informed decision. More>
4. PIPELNE LOCATION AND CONDITON ASSESSMENT – FIELD TECHNIQUES.
   This section reviews field location and inspection techniques which can be used to supplement existing information and improve the technical viability and cost effectiveness of the decision. The section covers both traditional and new/experimental methods. More>
5. REHABILITATION/RENEWAL PLANNING AND METHOD SELECTION
   This section summarises current thinking on methods of deciding, whether, when and how to rehabilitate/renew based on the available information. It also introduces the available options for repair, replacement, and renovation. More>

INTRODUCTION

Pipeline networks have played a vital role in the development of the world economy and the maintenance of public health. However since the majority of the most critical networks are buried their existence and condition has been essentially invisible to the general public. Parts of these networks, particularly those lying beneath our major cities are more than 100 years old and it is a tribute to the engineering capabilities of our forefathers that they have largely continued to perform their function.

The first evidence that significant parts of the UK sewer network were seriously degraded was obtained by the brave souls who traversed by man entry some of the UK's Victorian brick sewers. Large sink holes, measured by reference to "the number of buses they could swallow", had begun to appear in urban thoroughfares and the cause was clearly collapse of the ageing brick sewers. With the advent of CCTV cameras that could be pulled /driven through pipes too small for man entry, the full extent of the problem became increasingly apparent and it was also clear that old water supply pipes and gas mains posed problems of similar magnitude.

It was also clear that the cost and social//commercial disruption involved in replacing these ageing assets by conventional open cut excavation methods would be horrendous. What was needed was an alternative approach to the problems and in the early 1980's the concept of Trenchless Technologies for pipe replacement and rehabilitation was born. The formation of the ISTT in 1986 was intended to provide a means of facilitating the international development and utilisation of the new technologies and this website is intended be a key contributor to that objective.

In the three decades since the first No Dig conference held in London in 1985 the Trenchless industry and the pipe rehabilitation market it serves have experienced rapid growth. The annual conferences of the ISTT and its affiliate societies have recorded and reported this growth in terms of the emergence of new technologies and examples of their use on major projects.

PIPELINE NETWORKS

1. Water Supply, Waste Water and Drainage Networks

These networks originate at a water source such as a lake, river, well field or desalination plant. The raw water is transported by long distance transmission mains/aqueducts to a water treatment plant or storage facility for irrigation systems. The treated potable water is transported by local transmission mains to a storage tank or distribution point and then via distribution mains and service pipes to domestic, institutional, commercial and industrial users. The water is processed within the user's premises and generates wastewater which is transported by a network of laterals and collector mains to a waste water treatment plant. The treated water is then discharged to the sea or river via an outfall pipe or re-circulated as "grey" water for non potable applications.

An associated drainage water network collects excess surface water from paved areas and roofs etc and discharges into the sea or a river. In older systems the run off from domestic and commercial premises is combined with the wastewater for transport to the treatment plant. In modern systems the drainage water is kept separate from the waste water to avoid surcharging or treatment plant overload during storms etc.

An indication of the scale of these networks is given in Table 1.1 which summarises total network lengths for a number of international markets together with projected capital expenditure for network rehabilitation in the period 2005 to 2016. Table 1.2 summarises the key characteristics of these networks in terms of the diameter and types of pipes used and network operating conditions.

Table 1.1 – Estimated Network Lengths and Projected Capital Expenditure S For Water And Waste Water Lines In Some Major Markets

REGION	POPULATION MILLION	WASTE WATER		WATER	
		NETWORK LENGTH KM	CAPEX 2005-16 EU MILION	NETWORK LENGTH KM	CAPEX 2005-16 EU MILLION
UNITED KINGDOM	60	354000	36000	334413	31500
EUROPE WEST	391	1598000	195800	2887754	123912
EUROPE EC ACCESSIONS	236	143525	20060	318050	8869
EUROPE EASTERN	318	236296	3345	772181	4175
N AMERICA	300	1287450	102000	1440000	92000

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Table 1.2 – Typical Pipe Materials Diameters and Operating Conditions Used in Water Supply And Waste Water Networks

CONTENT	TYPR	DIAM M	DIAM IN	BAR	PSI	MA7ERIAL
WATER	LONG DISTANCE TRANSMISSION	IM TO 4M	36 RAW TO 144	3 TO 30	50 TO 450	PCCP,RCP, STEEL, DUCTILE IRON, FRP,
POT ABLE WATER	LOCAL TRANSMISSION	0.5M TO 2M	18 TO 72	3 TO 16	50 TO 250	PCCP.RCP,STEEL,DUCTILE,PE, MOPVC, UPVC,FRP,AC
	DISTRIBUTION MAINS	0.1M TO 0.4M	4 TO 16	3 TO 10	50 TO 150	STEEL, DUCTILE IRON, CAST IRON HDPE,UPVC ,MOPVC, AC
	SERVICE PIPES	0.02M TO 0.05M	0.75 TO 2	3 TO 10	50 TO 150	STEEL,COPPER,PE,PP ,
SEWERAGE	LATERAL	0.1 TO 0.15M	4 TO 6	G	G	VITRIFIED CLAY,URC AND SRC, PLASTICS
	COLLECTOR MAIN	0.15 TO 1M	6 TO 36	G	G	
	TRUNK SEWER	0.6 T02M	24 TO 72	G	G	
RECYCLED WATER	GRAY WATER TRANSMISSION LINES	0.6 TO 1M	24 TO 36	3 TO 10	50 TO 150	PCCP PLASTICS
	IRRIGATION DISTRIBUTION	0.15M	6	3 TO 10	50 T0 150	PVC

Wastewater pipes are typically subject to longitudinal and circumferential cracking caused by excess or localised vertical loads .which may eventually lead to collapse and blockage. Even before collapse such fractures together with joint failure can result in the waste water leaking out of the pipe (Exfiltration) or groundwater leaking into the pipe (Infiltration). Exfiltration can wash away bedding and backfill causing voids and total pipeline collapse plus health hazards. Infiltration, particularly during floods, can significantly increase the quantity of flow in the pipe which can surcharge the pipeline causing leakage of sewage or overload the treatment facilities necessitating the illegal discharge of untreated waste water to the sea and waterways leading to environmental damage

2. Gas and Hazardous Liquids Transmission and Distribution Networks

These networks transport oil and gas and related products from extraction facilities to local storage. The gas is then transported by long distance transmission lines to distribution points which supply a network of distribution lines to domestic industrial and commercial users. Oil is transported by long distance transmission lines to refineries and oceanic export terminals. Further networks from refineries deliver products such as gasoline, aviation fuels and by products such as Ammonia to users.

In comparison with municipal water networks these lines carry high value products at high transportation cost and the consequences of failure in terms of public safety and environmental impact are very high. Pipe and pipeline performance and condition are therefore subject to stringent statutory regulation, inspection and monitoring by Government agencies. Fig 1.1 is a schematic of these networks while table 1.3 lists the principal types, diameters and operating conditions. Fig 1.2 is an estimate of network lengths in the USA and Table 1.4 an estimate of gas transmission network lengths for various world markets.

Fig 1.1 – Schematic Of Typical Networks For Transport Of Oil, Gas and Hazardous Liquids.

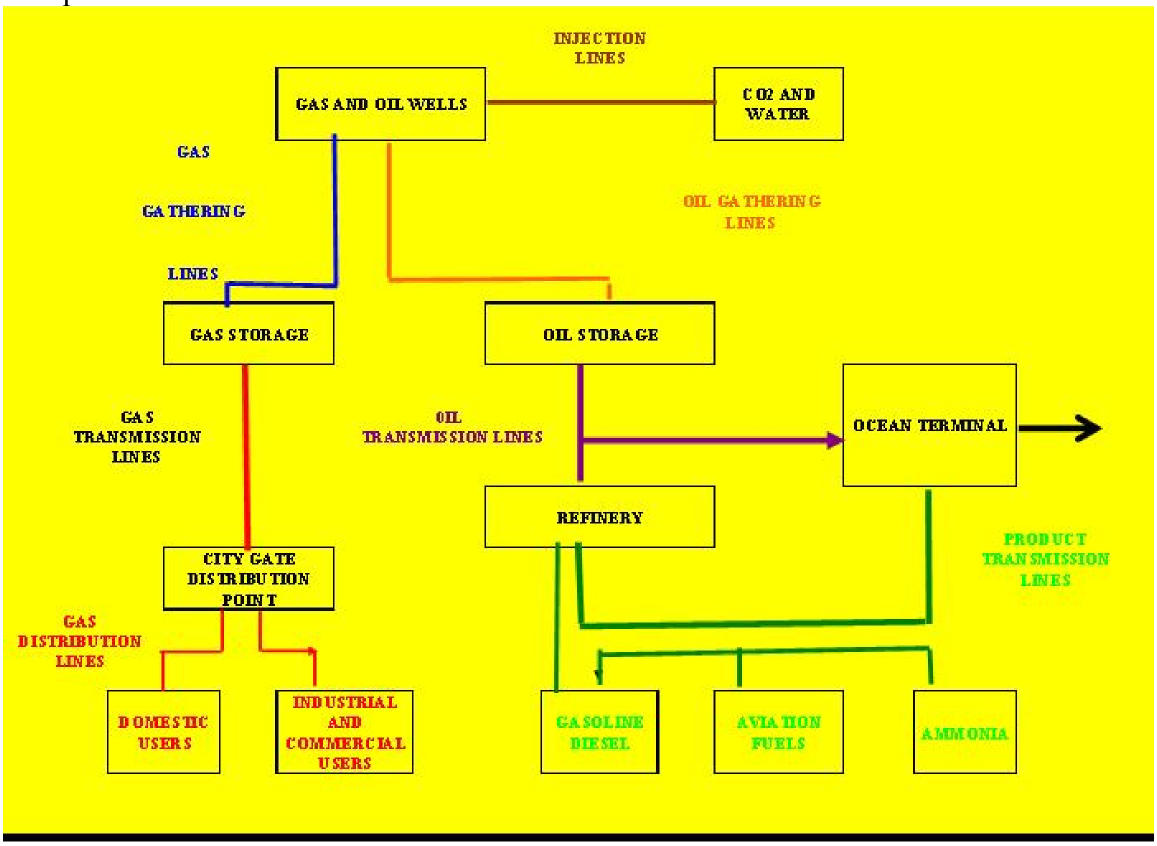


Table 1.3 – Summary of pipe, materials, diameters and operating pressures for Oil Gas and Hazardous Liquids Networks

SECTOR	SUB TYPE	GAS OR FLUID	FROM	TO	DIAM RANGE	PRESSURE CLASS BAR	MATERIALS
NATURAL GAS	GATHERING LINES	GAS	WELL	STORAGE	100 to 300		STEEL FRP
	TRANSMISSION LINES	GAS	STORAGE	CITY GATE	150 TO 1500	16-100	STEEL
	DISTRIBUTION LINES	GAS	CITY GATE	CONSUMER	100 to 300	.1-5	STEEL, DI, PE
	SERVICE LINES	GAS	SERVICE CONNECTION	METER	25 to 100		PE,COPPER
HAZARDOUS LIQUID							
	INJECTION LINES	WATER CO2	TANK	WELL	100 to 300	10-50	STEEL, FRP
	GATHERING LINES	OIL	WELL	TANK			STEEL, FRP
	TRANSMISSION LINES		TANK	REFINERY OCEAN TERMINAL	150 TO 1200	16-100	STEEL
	PRODUCT TRANS MISSION LINES	GASOLINE DIESEL AVIATION FUEL AMMONIA etc	REFINERY	CUSTOMER OR OCEAN TERMINAL	150 -1200	16-50	STEEL

Fig 1.2 – Estimate Of Oil, Gas and Hazardous Liquids Network Lengths In North America

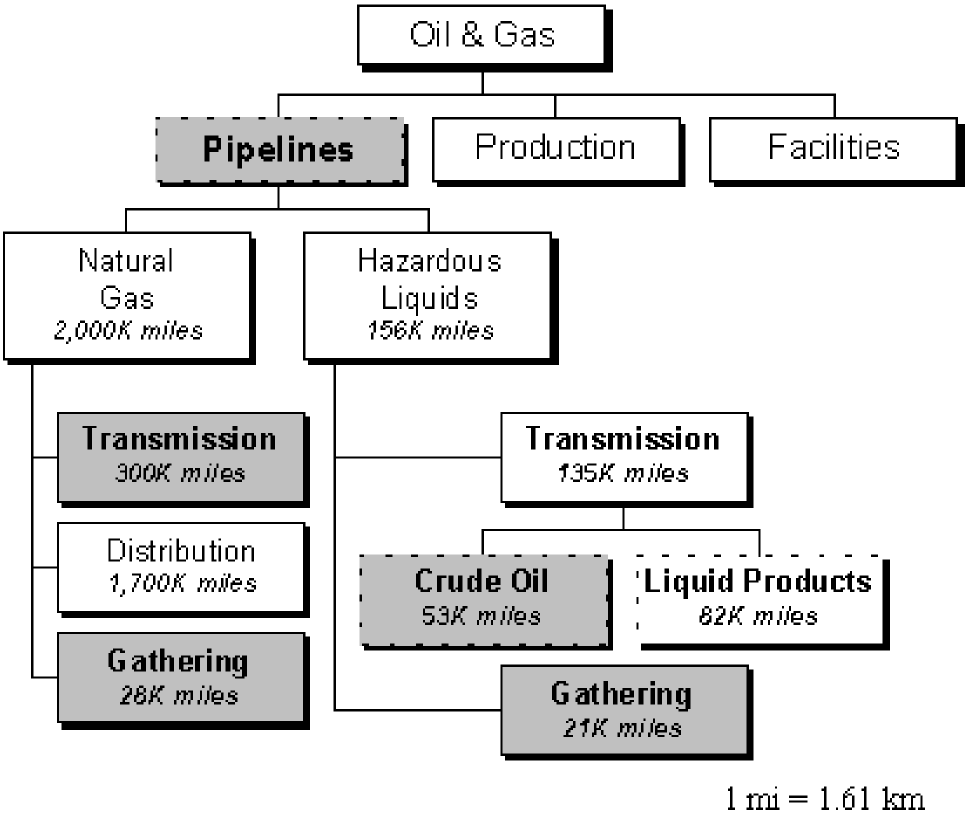


Table 1.4 – Estimate of Lengths of Gas Transmission Networks in Selected Markets

		LENGTH	**LENGTH**	
	TERRITORY	**KM**	**%**	
	UK	**17579**	**3%**	
	EUROPE	**144914**	**24%**	
	RUSSIA	**24227**	**4%**	
	MIDDLE EAST AND NORTH AFRICA	**28236**	**5%**	
	ASIA	**35615**	**6%**	
	SUB TOTAL	**232992**	**38%**	
	USA	**378250**	**62%**	
	TOTAL	**611242**	**100%**	

The cross country gas and oil transmission networks are constructed using welded steel pipes which are protected from internal and external corrosion by sophisticated coatings and cathodic protection systems. They are serviced by specialist contractors and are not normally considered to be part of the pipe rehabilitation industry represented by ISTT members. However the municipal gas distribution networks involve ageing cast and ductile iron pipelines which fail due to internal/external corrosion allowing the escape of gas with severe economic, environmental and public safety consequences.

In the UK the application of trenchless technologies to the rehabilitation of cast iron gas mains preceded the development of the water and wastewater specific techniques. In fact several of the technologies normally associated with water mains (e.g. Pipe Bursting and close fit PE Lining) were originally developed for the rehabilitation/replacement of leaking gas mains. The gas distribution networks occupy the same sub surface space as the water mains and hence can benefit from trenchless technologies in a similar manner to water mains.

Another area of the oil and gas market which utilises these technologies is the internal lining of oil and gas field collection networks. In many cases the pipe used for oil and gas injection/collection in oil fields is lined with close fit PE to prevent future internal corrosion of the steel pipe in the network.

3. Power and Telecom Networks

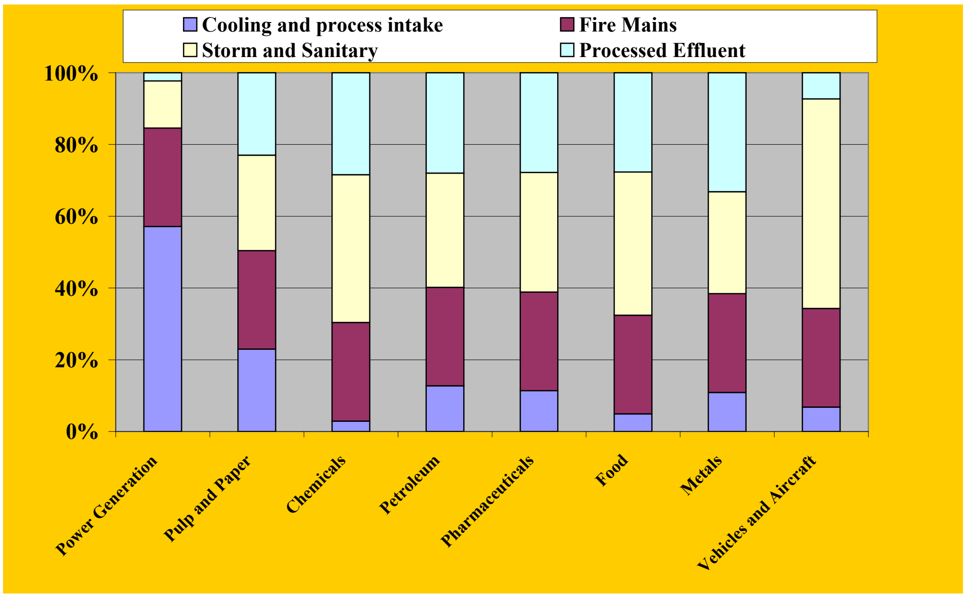
Electric Power and Telecommunications cables are generally installed in networks of underground conduits. In some cases trenchless techniques can be used to install suitably armoured cables directly below ground using directional drilling.

INDUSTRIAL PIPELINE NETWORKS

Industrial sites have extensive pipeline networks including

A. Potable and process water supply
B. Cooling water supply and removal
C. Product lines
D. Fire mains
E. Sewerage and effluent lines

The graphic Fig1.3 shows a typical distribution of industrial lines by purpose and industrial sector. Many of the techniques developed for water/sewerage and gas distribution in the municipal sector can also be used for some of the pipe rehabilitation needs in an industrial environment.



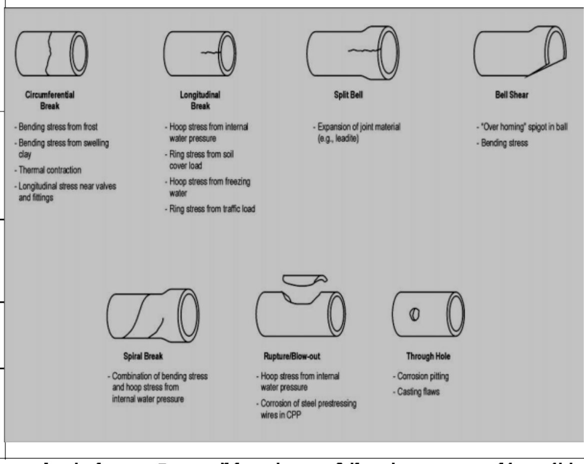
AN OVERVIEW OF PIPE TYPES

Channels, both open and closed, for the conveyance of water and waste have been in use since Roman times. However the first use of purpose built pipes was probably in the mid-nineteenth century, including cast iron for water mains, and insitu brick construction for sewers. Some of these early pipes are still in service today, which is a testament to their quality and the skills of our engineering forefathers. In the ensuing years, new types of pipe have been introduced on the basis of perceived advantages, which have not always been realised, and in some cases, such products are showing signs of failure in less than ten years. As new products have gained market share across all utilities, older ones have been discontinued and withdrawn. Examples are the replacement of cast with ductile iron, and the cessation of asbestos cement pipe manufacture, due to health concerns.

		DIAMETER RANGE mm		PERIOD OF INSTALLATION		GRAVITY	PRESSU RE
Cement based	**Unreinforced concrete**	**150**	**600**	**early 1900s**	**To date**	✓	
	Steel reinforced concrete	**150**	**1200**	**early 1900s**	**To Date**	✓	
	Concrete pressure pipe	**250**	**3660**	**1940's**	**To date**		✓
	asbestos cement	**150**	**1050**	**1930.s**	**1980.s**	✓	✓
Ferrous pipes	**Steel**	**15**	**4000**	**1850.s**	**To date**		✓
	Ductile iron	**75**	**1600**	**1960s**	**To date**		✓
	Cast Iron pit	**75**	**1500**	**1850,s**	**1940,s**		✓
	Cast Iron spun	**75**	**1500**	**1930's**	**1950's**		✓
Ceramic	**Vitrified Clay**	**100**	**1000**	**Early 1900.s**	**To date**	✓	
	In Situ Brick	**600**	**4000**	**mid 1800.s**	**1940**	✓	
Thermoplastic	**Polyethylene**	**100**	**1600**	**1980,s**	**to date**		✓
	UPVC	**100**	**1200**	**1970's**	**To date**	✓	✓
	MOPVC	**100**	**600**	**1995**	**To Date**		✓
Glass Fibre Reinforced Thermoset Resin	**Pressure to 10 bar**		**2750**				
	Gravity and pressure to 6 bar	**300**	**4000**	**1960's**	**To Date**	✓	✓
	Pressure to 17 bar		**2400**				
Polymer Concrete		**200**	**3500**	**1990s**	**To date**	✓	

Table 1 (above) lists all the pipe types installed over the past 150 years in terms of diameter range, period of installation, and main application area. Table 2 (below) summarises the types of defects which can affect the performance of pipe networks, and are the primary drivers of rehabilitation programs. The remainder of the section discusses the types of pipe in more detail, with particular emphasis on the older materials which account for most of the current rehabilitation activity.

Summary of the Most Typical Structural Failure Modes For Commonly Used Pipes

TYPICAL FAILURE MODES FOR COMMONLY USED PIPES			
MATERIAL		STRUCTUAL FALURE MODES	
Cast Iron (CI)	Small diam (<375 mm)	• Circumferential breaks, split bell, corrosion through holes	
	Medium diam (375-500 mm)	• Same as small, plus longitudinal breaks and spiral cracking, blown section	
	Large diam (>500 mm)	• Longitudinal breaks, bell shear, corrosion through holes	
Ductile Iron (DI)	• Corrosion through holes at defects in external or internal protective coatings		
Steel	• Corrosion through holes, large diameter pipes are susceptible to collapse		
Polyvinyl Chloride (PVC)	• Longitudinal breaks due to excessive mechanical stress Susceptible to impact failure in extreme cold condition Excessive deformation due to.incorrect bedding or backfill		
High Density Polyethylene	• Joint imperfections, mechanical degradation from improper installation methods, susceptible to vacuum collapse for lower pressure ratings		
Asbestos Cement (AC)	• Circumferential breaks, pipe degradation in aggressive water or soils and septic swerage • Longitudinal splits		
Unreinforced concrete (URC)	longitudinal cracks due to excess external loads,concrete degradation in aggressive swerage or soils, invert abrasion		
Steel Reinforced Concrete(SRC)	As URC plus degradation of reinforcement due to loss of concrete cover in aggreive soils or sewerage		
Concrete Pressure Pipe (CPP)	• Pipes with pre-stressed wires may experience ruptures due to loss of pre-stressing upon multiple wire failure. Pipe degradation in particularly aggressive soils, corrosion of pipe canister, concrete damage due to improper installation methods		
Vitrified Clay (VC)	Longitudinal and bell cracks due to excess external loads		

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TRADITIONAL PIPE MATERIALS

CEMENT BASED PIPE

Un-reinforced and Steel reinforced concrete pipes are widely used in sewer and storm water networks to convey waste water. They are normally available in Standard sizes from 300 mm to 2,500 mm using bell and spigot joints with flexible rubber sealing rings. In the USA non-circular pipes are also available.

The primary design requirement is for the buried pipe to sustain external loads, such as hydrostatic (from groundwater) fill, and traffic loads, without excessive deformation or collapse. Their structural capability is normally defined by a three edge crushing test. When equipped with a restrained joint, steel reinforced pipes can also be used for low internal pressure applications.

Concrete pipes can be subject to external corrosion in aggressive soils, and internal corrosion from certain types of sewage. In steel reinforced pipes, such corrosion can attack the reinforcement, leading to spalling of the concrete cover and rapid failure. A particular problem in warm climates, with low flow velocities, is the generation of hydrogen sulphide from septic sewage. This is converted by bacteria to sulphuric acid, which attacks the crown of the pipe leading to eventual collapse. Modern practice is to design sewers to avoid septicity, and to protect the inner surface of the pipe with a polymeric lining.

Even in the absence of corrosion, concrete pipes may fail due to excessive loads, not allowed for in the design, or due to a change in surface conditions. Joint failure may also occur, due to degradation of the joint rings, or excessive shear loads. All of these problems can be detected from internal CCTV inspection, and coded and scored to assign a structural grade, from 1 (Good condition) to 5 (At serious risk of collapse).

Concrete Pressure Pipes were developed in the USA in the 1940's, to meet the need for large diameter long distance water transmission mains. They consist of a steel cylinder embedded in cement mortar, with a layer of steel reinforcement. This is pre-stressed during manufacture, and supports the hoop stresses, generated by the internal pressure load. PCPP pipes are available in diameters up to 3.5 m, and working pressures up to 30 bars. Like all cement based pipes, PCPP can be subject to both internal and external corrosion, which may lead to corrosion of the reinforcement, and burst failure. In addition, some types of pre-stressing wire have been found to be subject to hydrogen embrittlement and premature failure.

The failure of this type of pipe can be spectacular and costly in terms of the loss of supply and consequential damage. Special techniques have been developed to detect potential problems before failure occurs, and either replace or strengthen the high risk sections. These methods include a form of remote field eddy current inspection, and acoustic monitoring.

Also available are Polymer concrete pipes and GRC glass reinforced concrete pipes which utilise modern materials to improve the basic characteristics and performance under different conditions of concrete based pipes.

The final type of cement based product is Asbestos Cement Pipe, which was manufactured from the 1930's until the 1980's. Production then ceased in the USA and Europe, due to concerns over the effect of asbestos fibre on the health of workers in the production plants. It was primarily used for water mains in North America and Europe, and as a gravity sewer pipe in markets such as the Middle East. In general the product has performed fairly well as a water main. In the absence of any evidence of health risk from the consumption of water carried in the pipes, Asbestos Cement Pipes are still in use in many areas. Urgent replacement is normally limited to situations where acid water or aggressive soils cause premature failure. This is caused by softening of the cement matrix, and debonding of the fibres. This is normally detected by laboratory evaluation of sample pipes, but a technique based on pipe coupons has also been developed.

The use of Asbestos Cement for sewage has been more problematic. The product is particularly vulnerable to corrosion from septic sewage, which was fairly common in the regions where the main use for this purpose was prevalent.

VITRIFIED CLAY (VC) PIPES

Vitrified Clay pipes were first manufactured in the USA in the early 1800s. They are manufactured by mixing together a blend of clays, which are then cast to form a pipe, glazed and fired. The larger scale production of clay pipe in the United States was started in 1849 by the firm of Hill, Merrill and Company in Middlesbury, Ohio (near Akron). Their first product was hexagonal water pipe. Soon they began making round clay sewer pipes. Early on, the bell & spigot joints were added/formed manually onto the cylindrical shafts, formed from mechanical presses. Over the next 20-25 years, the overall process became almost fully mechanised.

Until the 1950s, clay pipes were joined with a bell and spigot joint, which was filled with cement mortar during installation. However, this type of joint was very rigid, and tended to crack and leak if there was any ground movement. It was therefore replaced with a flexible rubber ring and the problem was largely eliminated.

VC pipes are now available in diameters up to 1,200 mm, and the range includes specially designed pipes for jacking. The great advantage of the product is its high resistance to corrosion, which has led to its widespread use in septic and other aggressive sewage conditions. The main problems are failure of the older type of joint and cracking and structural failure due to excessive loads.

BRICK SEWERS

Many of the early interceptor sewers in Europe and the USA were constructed insitu using bricks and mortar. High standards of craftsmanship were required to construct circular and elliptical pipes in diameters up to 4 m. For sewers to be made of brick, certain features had to be respected – more specifically:

- Due to the inherent rough surface of the resulting wall, the sewers had to be larger to offset the inherent larger roughness co-efficient.
- To physically construct brick sewers, structural forming was needed – again, adding somewhat to the resulting sewer's size.
- As experience was gained, it was recognised that the mortar between the bricks was the weak link; i.e., the mortar was subject to erosion and softening by corrosive acids.

As the pros/cons of brick sewers were understood, the impetus for other newer and longer-lasting pipe materials arose.

The weak point of this method of construction was the cement mortar joints which were often attacked by aggressive sewage and abrasion from flowing silt. It was the collapse of his type of sewer in the northern cities of the UK, which triggered the assessment of sewer condition and the subsequent rehabilitation programmes.

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3. METALLIC PIPES

CAST IRON
Cast-iron pipe began to become available in the mid-1700s for municipal water service. The first large-scale use of cast-iron pipe for distribution of water occurred in 1664 at Versailles, France. A 15-mile cast-iron main was installed from Marley-on-Seine to the palace at Versailles; the system is still in service today. The bell-and-spigot joint was developed by Sir Thomas Simpson in 1785 (London) for cast-iron pipe and has been in use ever since. The early versions used 'butt' joints sealed with metal bands.

The first cast-iron pipe manufactured in the United States was produced in a foundry in Weymouth, New Jersey, in the early 1800s. The city of Philadelphia began installing cast-iron pipe in its water distribution system (approximately 1804-1810) to replace some deteriorated old spruce log wood pipe (reinforced at the ends with bands of wrought iron). In fact, Philadelphia was the first American city to use cast-iron pipe exclusively – due to its greater longevity, and the higher water pressure that it could handle. For years, the higher quality cast-iron pipe made was cast with a 'P', indicating that the pipe met the rigorous standards of Philadelphia's water system.

Until the early 1940s the pit cast process was used, but this was gradually superseded by a Centrifugal casting process which remained in use until the advent of ductile iron in the 1960's.

Cast iron pipes suffer from both internal and external corrosion, and the effects of this on system performance, is the principle driver for water main rehabilitation in the developed world. Internal corrosion of cast iron, is often accompanied by a build up of corrosion product, (Tuberculation) which adversely affects pressure and flow capacity, and water quality in terms of both contamination and aesthetics (colour, odour, and taste) Eventually the pits cause leakage and structural failure. External corrosion in aggressive soils also causes pitting leakage, and structural failure.

Cast iron pipes produced from 1930 onwards were cement mortar lined during production to prevent internal corrosion. In the 1950's, this process was adapted to allow the insitu protection of pipes in service This process and its resin based successors, are the most widely used renovation technologies for water mains.

STEEL
The high strength and ready availability of steel, has led to its widespread use in pressure pipe applications. The earliest steel pipes were formed from segments with riveted seams, before subsequent developments allowed use of welded seams and seamless tubes. The susceptibility of this material to corrosion, led to the use of factory or site applied cement mortar lining on the inner surface, and coal tar epoxy coatings on the outer surface.

Protected steel pipes exhibit good durability providing the protection system is appropriate to the corrosion characteristics of the soil. If the outer surface coating fails, then enhanced local corrosion will cause pin holing and eventual wall penetration. Similar effects occur due to internal coating failure. It should be noted, that steel is a highly ductile material, which fails gradually rather than by bursting?

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4. MODERN PIPE MATERIALS

DUCTILE IRON

Ductile Iron was introduced in the early 1960's, as a replacement for cast iron. Changes in the metallurgy of the iron allowed large increases in the design strength. This, coupled with the high ductility of the material, allowed higher internal pressure capability, with considerably reduced wall thickness. However, Ductile Iron is just as susceptible to corrosion as cast iron, but can fail much earlier, due to the thin wall. The product must therefore be protected, both internally, and externally, in most situations.

Internal protection is normally achieved through use of a factory applied, cement mortar lining. External protection originally involved a coal tar epoxy coating, which was supplemented in aggressive soils by a polyethylene sheet over wrap. More recently, sophisticated coatings, involving tin or zinc layers, plus epoxy, have been used.

Over the last few years, there has been a considerable increase in the corrosion failure of ductile iron, gas and water pipes, and the adequacy of the polyethylene sheet protection, has been questioned.

THERMO PLASTIC PIPES

PVC Based

The first use of PVC in pipes occurred in the 1950's, and within twenty years, the product had achieved a significant share in the sewer, gas, and water main market. However in the UK, problems with brittleness, led to spectacular failures in solvent jointed pipes, and a change in formulation, was needed. In the USA, the initial formulation was correct, and the brittle failures avoided. These events led to substantial differences in attitude to the product in the UK, and in the USA. More recent developments, have allowed a gradual increase in long term, flexural modulus, and tensile design strength, resulting in the use of pipes with thinner walls. Molecularly Oriented PVC, (MO PVC) was introduced in 1995, and more recently, a version which can be fusion welded, like polyethylene, has been introduced. The product is used for sewer, water, and gas pipes, and has the advantage of low weight, combined with freedom from corrosion.

Polyethylene (PE)

Polyethylene pipes were first produced in the early 1980's, and have since gained a major share of the pressure pipe market. The high ductility, low weight, and ease of handling, enabled more efficient installation. However, the key advantage is the use of Butt Fusion Welding to join individual 30 meter pipes into a continuous pipeline of one kilometre, or more. The product is available in diameters up to 1.6 meters, and pressure capability of up to 16 bars. Like PVC, the material has been steadily improved, with the introduction of PE 100 resin, allowing the use of thinner walls for a given pressure capability. However, due to differences in design approach in the USA, this benefit has not yet been exploited. More recently XLPE (Cross-linked Polyethylene) pipe has been introduced, which is designed to improve the performance characteristics of the pipe by improving heat resistance, durability, chemical resistance and flexibility.

Other developments in the field have included the introduction of 'Protective skin' PE pipes which utilise an underlying PE pipe as the carrier pipe for a pipeline installation. This main pipe is protected by an outer layer of tougher plastic that is designed to be sacrificial so that, particularly where trenchless installation techniques are used, should any damage occur to the outer surface of the pipe this is absorbed by the protective cover, leaving the inner product pipe in full design condition.

GLASS FIBRE REINFORCED THERMOSET RESIN BASED PIPES

These are all based on a combination of Epoxy or Vinyl Ester resin, sand filler, and continuous or chopped glass fibres. Although the literature seems to recognise two types of pipe, there is some confusion over the definition of these types. The term Reinforced Thermoset Pipe (RTP) is frequently used to describe all types of pipe with these ingredients. The other term, Reinforced Plastic Mortar (RPM) is also used by some manufacturers to describe the same kind of pipe, and as yet there is no consistent recognised definition for this product.

There are two basic manufacturing processes. In the filament winding process, the pipe is manufactured by wrapping a continuous length of resin impregnated glass fibre 'roving' around a rotating mandrel, until the desired wall thickness as been built up. The angle of wind can be varied to achieve the required blend of hoop and longitudinal strength. The pipe is then oven cured to develop maximum strength.

In the alternative method of manufacture, all the materials are added to a cylindrical mould, which is then spun at high speed to distribute and compact the ingredients prior to oven curing.

Both types of pipe can be used for both pressure and gravity applications, and are also widely used for Microtunnelling and Sliplining.

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5. PLASTIC PIPE PROBLEMS

Since plastic-based pipes are comparatively new, it can be argued that there has been insufficient time for any inherent material degradation mechanism to appear. Nearly all field failures of PE pipe have been attributed to poor fusion and installation practices. The use of PE by the gas industry has generated an extensive programme of tests, which have helped to build confidence for other uses, and have generated Codes of Practice and Guidelines, to facilitate rigorous quality assurance procedures.

Once the initial formulation and solvent joint problems were resolved, the use of PVC followed a similar path to PE. Failures were mainly attributed to point loads due to poor bedding and installation. PVC is perhaps more susceptible to this problem than PE due to its lower ductility. PVC is also susceptible to premature fatigue failure under some conditions.

Thermoset resin based pipes have generally performed well. The only reported problems are excessive deflection due to faulty design, and/or inadequate bedding, and the potential for strain corrosion failure in some environments.

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	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	ASSET MANAGEMENT PLANNING OVERVIEW	LAST UPDATED JULY 2009

1. INTRODUCTION

The collection and interpretation of information on existing collections of assets such as buried pipelines can be complex and demanding in terms of financial and human resources. This can involve networks of several thousand km of pipes of different types ages and condition. Utilities faced with these challenges are turning to a recently developed approach termed Asset Management Planning (AMP)

ASSET MANAGEMENT PLANNING is a disciplined and structured approach to the management, of physical assets and is essentially designed to answer the following questions:

1. What are the assets, and where are they located?
2. How much are they worth – including replacement costs?
3. What is their current condition, based on;
   a. Performance data
   b. Maintenance history
   c. Failure incidents
   d. Age
   e. Results of specific condition assessments
4. What is the estimated remaining service life?
5. What is the maintenance strategy – typically, the reactive response to failure?
6. What is the rehabilitation strategy – pro active work, to limit future failures?
7. What are the target minimum service levels – set internally, and/or, by an external regulator?
8. What are the relevant future performance requirements?

The following definition of Asset Management has been proposed by consultants Camp Dresser McKee: “Asset Management is a systematic process of maintaining, upgrading, and operating physical assets Cost Effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organised, logical approach to decision making. Thus, Asset Management provides a framework for handling both short-and long-range planning.”

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2. HISTORICAL BACKGROUND

An early, comprehensive, adoption of the term 'asset management' in the engineering profession was during privatisation of water utilities in Great Britain in the 1980s. In order to establish equitable pricing, those looking to run the privatised companies had to develop detailed asset management plans, identifying how they would ensure the maximum return on the public investment, already made in the infrastructure of the utilities they were to acquire.

In 1993, 'asset management' made its way into the public works lexicon, when the Australian Accounting Standards Board, issued the Australian Accounting Standard 27 (AAS27). This required municipalities to capitalise and depreciate infrastructure assets, rather than expense them against earnings. Thus, infrastructure – roads, sewers, fire hydrants and the like – the domain of the engineer, was now a complex set of problems for accountants to manage. Many US utilities have historically already adopted this type of accounting convention, either to comply with revenue bond funding covenants, or because they were subject to public utility commission regulations, or guidance. However, the advance resulting from the work of the New Zealand National Asset Management Steering Group, and the Institute of Public Works Engineering of Australia, was to advance this concept, beyond solely a paper accounting transaction. Those groups developed a framework that acknowledges that current actions can, and do, affect the useful life and cost effectiveness of asset investments.

In 1999, the General Accounting Standards Board, in the USA, issued statement 34, (GASB 34) which sought to provide users of governmental financial statements, with a more complete picture of the assets, and liabilities. Other seminal events in the evolution of asset management in the US include the publication of "Infrastructure 2000", which identified a systematic and growing gap in the need for infrastructure funding and the available amount of such funding. The report found that the need for repair and replacement funding was especially critical. Then in January, 2001 the US Environmental Protection Agency issued a draft rule known as CMOM (Capacity, Management, Operations, and Maintenance). CMOM, while specific to wastewater collection systems, was significant because it was the first pending regulation that might require that asset management programmes be implemented within affected departments of public works and municipal utilities. Subsequently, Congressional legislation, extending the authorisation for the State Revolving Fund, programmes for water and wastewater, has incorporated language that requires asset management, as a condition of eligibility.

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3. DIFFICULTIES EXPERIENCED

In the eyes of the American Public Works Association, "the issue of managing jurisdiction's [infrastructure] assets is no longer just an engineering problem. Lawyers, planners, accountants, analysts, citizens all, have a role to play. A fully implemented public works asset management system, will allow decision makers to explore how each action – e.g., operating and maintaining existing facilities, as well as building new ones – is likely to influence both current budgets and long-term regional well being." This interdisciplinary view of asset management is enforced by the General Accounting Office (GAO), which makes a strong case that an effective asset management program, requires integration of data and decision making, across the accounting, engineering, finance, maintenance, and operations functions of an organisation.

Studies in Canada and the US have revealed some of the common difficulties public works, utilities, and municipal officials have faced in implementing asset management including:

a) Too much maintenance and condition data is required.
b) Inadequate standards of analysis exist for valuing assets and establishing condition assessments.
c) There is a lack of cost-effective, non-invasive, and non-destructive inspection and condition assessment tools.
d) Software tools are too complicated.
e) The value of asset management cannot be realised during a typical election cycle.
f) An asset management plan could increase the short-term revenue requirements of an organisation when its intent is to decrease the cost of operation. However, costs savings are long term.
g) “This is a pain…we already do this stuff!”

Overcoming these problems can be a major difficulty for small to medium sized utilities and can seriously impair the progress of their rehabilitation programmes.

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4. ASSET MANAGEMENT PLANNING FOR BURIED PIPELINE NETWORKS

Asset Management Planning is a major specialist discipline which is extensively documented in books, manuals, and conference papers. In addition a number of major Consulting Engineering Practices provide specialist services in this field. In the USA one or two of these companies have collaborated with the EPA in the preparation and delivery of training programmes. At the time of writing, one of these was published on the internet as a PDF of a 400 slide PowerPoint Presentation (available through the ISTT Email: info@istt.com) and provides an excellent overview of the state of the art in this field.

One word of warning: Asset Management is a valuable tool but its value depends on the quality and quantity of information available and the ability of the utility, in terms of financial and human resources to implement it. Start with the basics of inventory and indirect condition assessment, and only move to the more exotic techniques when you are confident you can make full use of the advice and methodologies generated.

NOTE: Most of the questions listed in the Introduction are also considered in more detail subsequent sections of the Guidelines for this topic.

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<tr><td>TRENCHLESS TECHNOLOGY GUIDELINES</td><td>THIRD EDITION</td></tr>
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1. INTRODUCTION

Water, wastewater, gas, power and telecoms utilities throughout the developed world face a major challenge in the rehabilitation of their ageing buried service networks. In meeting the challenge, utility engineers are required to make a series of informed decisions which must be based on information about the buried pipeline, duct and cable infrastructures which is as accurate, complete and up to date as possible.

Information on the existing pipeline networks is used in a number of ways:

1. To describe the extent, asset value, and current condition of the network for financial and regulatory reasons. An example is the emergence of GASB34 in the USA, which requires utilities to include a realistic asset value and renewal/replacement expenditure provision for buried infrastructure in their annual accounts.
2. To enable decisions to be made on the need for rehabilitation/renewal and to prioritise those sections with the most urgent need. In most cases the total cost of a work programme far exceeds the available funds and a phased approach over many years is required.
3. To enable selection of the least-cost, technically viable rehabilitation/ renewal method for each section of the network. The use of renovation technologies which utilise the existing pipe in a structural composite must be based on accurate assessment of the condition of the pipe.
4. To avoid damage to existing networks caused by conflict with rehabilitation and other construction activities taking place in the same underground space

Each use has different requirements in terms of the extent and accuracy of the information required. Since the cost of obtaining the information increases rapidly with its extent and accuracy it is important to try to match these levels to the type of use. This concept is explored in the discipline of Sub Surface Utility Engineering (SUE) a process developed by the USDOT Federal Highways Administration as a means of reducing the costly effects of collateral damage to existing buried infrastructure in road construction projects. The process has three main components

A) SUBSURFACE UTILITY DESIGNATING:
Uses surface geophysical techniques to determine the existence and approximate horizontal position of underground utilities. The geophysical techniques include various methods, such as pipe and cable locators, magnetic

method, metal detectors, Ground Penetrating Radar (GPR), acoustic emission method, etc.

B SUBSURFACE UTILITY LOCATING:
Uses minimally intrusive methods of excavation, such as vacuum excavation and surveying instruments, to allow the precise horizontal and vertical position and profile of the underground utility line to be documented.

C DATA MANAGEMENT:
Surveying utility information to project tolerances and reducing it onto the project design and construction documents. A critical component of this data management involves analyzing all available utility record information with the results of the designating and locating process. Computer Aided Design and Drafting (CADD) and database management technologies are applied to assure the quality, value and utility of the data collected.

The DOTFHA define four quality levels related to the accuracy and completeness of the information derived from the SUE process:

Quality Level D: This is the most basic level of information and comes solely from existing utility records. It may provide an overall "feel" for the congestion of utilities, but it is often highly limited in terms of comprehensiveness and accuracy. Its usefulness should be confined to project planning and route selection activities.

Quality Level C: It is presently the most commonly used level of information. It involves surveying visible aboveground utility facilities, such as manholes, valve boxes, posts, etc., and correlating this information with existing utility records. When using this information, it is not unusual to find that many underground utilities have been either omitted or erroneously plotted. Its usefulness, therefore, should be confined to rural projects where utilities are not prevalent, or are not too expensive to repair or relocate.

Quality Level B: It is the first level where SUE information is used. It involves "designating" and is usually sufficient to accomplish preliminary engineering goals. Decisions can be made on where to place storm drainage systems, footers, foundations, and other design features in order to avoid conflicts with existing utilities. Slight adjustments in the design can produce substantial cost savings by eliminating utility relocations.

Quality Level A: It is the highest level of accuracy presently available. It involves "locating" and provides precise plan and profile information for use in making final design decisions. By knowing exactly where a utility is positioned in three dimensions, the designer can often make small adjustments in elevations or horizontal locations and hence avoid the need to relocate utilities. Additional information such as utility material, condition, size, soil contamination, and paving thickness, also assists the designer and utility owner in making decisions during the early stages of the project

Although SUE is aimed at collecting information for just part of a network the same principles can be applied to the collection of information needed to compile an Asset Inventory for the complete network which is the first step in formulating an Asset Management Plan.

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2. DIRECT AND INDIRECT INFORMATION

Information on the location, characteristics, and condition of underground networks can be obtained in two ways:

A Desk Study – based on the evaluation of existing historical data such as:

1. As-Built drawings and subsequent modifications combined with specification and performance documentation for the pipes used on the project. Local variations in pipe layout made during construction to avoid sub surface obstacles etc should be carefully recorded.
2. Burst/failure records analysed by location, type, age and type of pipe.
3. Maintenance Records recording the nature of bursts, leaks and other performance problems together with its exact location (GIS) and any observations made by the maintenance crew on the appearance of the failed pipes.
4. Customer complaints – particularly those concerning water quality and system pressure and flow issues.
5. System tests –any leakage or similar tests performed on sections of the network.

This information is equivalent to the designating stage of SUE at quality levels C and D

A Field Study – based on the use of field location inspection and test procedures to generate new and additional information, as described in next section. This is equivalent to the locating stage of SUE at quality levels A and B

A prudent operator will of course try to make the most cost effective and accurate use of both sources of information to arrive at the best decision. However there are many utilities which argue that the additional "fine tuning" on a rehabilitation decision gained from the results of most of the sophisticated inspection technologies currently available may not be worth the additional expenditure and disruption involved. There are also major differences in the technical and cost effectiveness of the various techniques depending on the pipe material.

Table 1 summarises the information required to make a rehab/renew decision and the desk (indirect) and field (direct sources) available for each item.

Interpretation of Desk Study Data

Information from the desk study may be considered sufficient to allow a decision on rehabilitation requirements to be reached without additional field inspection. This is frequently associated with a set of fairly subjective principles such as "Rehabilitate all asbestos cement pipes in the network beginning with the oldest".

The data can also be subject to **statistical analysis** to try to correlate the frequency of recorded pipeline problems with specific network characteristics such as pipe type and age, water/flow chemistry (if applicable), soil type and operating conditions. This is best based around a Geographical Information System (GIS) which allows the problems and the network variables to be associated with specific pipe locations in a network map. In principle the approach allows identification of sub populations of pipes (also called cohorts) with the highest failure potential to be prioritised for rehabilitation. There are many references available to this approach and a number of **computer models** have been developed to aid analysis. Examples of such models include:

- Asset Map and Fail net (France)
- KANEW and UtilNets (Germany)
- WRc cluster method linked to Waterfowl (UK)
- CARE S and CARE W – EU Project

Many water utilities currently implement this approach via **a scoring system** which allocates points to sections of the network, based on a selection of the characteristics discussed above, with weighting factors to allow for issues such as the consequences of failure. Selection of pipes for rehab is then based on threshold levels of the points score.

Table 1: INFORMATION SOURCES FOR BASIC PIPE CONDITION AND LIKELY PERFORMANCE

CATEGORY	INFORMATION	INFORMATION SOURCES	
		EXISTING INFORMATION	NEW INVESTIGATION OPTIONS
BASIC PIPE DATA	Dimensions – OD, ID, and wall thickness	As built drawings, bid specification, pipe supply documentation	Pressure Pipes – direct measurement of OD and thickness by ultrasonics or from UP Tap coupon
	Pipe material and performance spec	As built drawings or bid/supply documents	Visual inspection of exposed pipe Evaluation of removed samples
	Pipe lengths and joint type	As built drawings or bid/supply documents	Visual inspection
	Age	Supply and installation dates from contract records	
	Corrosion Protection	Bid/Supply documentation	Visual inspection of pipe exterior CCTV or man entry inspection of interior
	Manufactured bends and fittings	As built drawings or bid/supply documents and suppliers catalogues	CCTV or man entry inspection of interior
PIPELINE GEOMETRY	location and severity of bends inc vertical bends	As built drawings plus amendments due to site variations	CCTV or man entry inspection of interior
	Profiles	as built drawings	CCTV or man entry inspection of interior
	Access points	Manhole drawings	Site survey to identify locations for excavation of access pits for pressure pipes
SURFACE AND SUB SURFACE ENVIRONMENT	Location and type of other buried utilities and structures	As built drawings Maintenance crew reports	Discussions ,one call system Mapping using GPR, EM etc Trial holes
	Nature of bedding	Installation Specification Observations of maintenance crews	Visual inspection at excavations
	Nature of backfill/soil	Installation Specification Observations of maintenance crews	Visual inspection at excavations
	Surface Features above pipeline e.g. roads, buildings, trees etc		Visual inspection of pipeline route using checklist and photo/CCTV record Aerial Survey
OPERATING CONDITIONS	Sewers – design fill/ traffic and hydrostatic loads	Original specifications and as built drawings. Pipe purchase records	Check for changes since installation
	Pressure Pipes – design, maximum, and average operating pressures Possibility of vacuum and surge	Original Specifications and as built drawings. Pipe purchase records	Check for changes
STRATEGIC AND LOGISTICS ISSUES	Need for Bypass	Sewer Flow Records	Accessibility of upstream sewer to handle back up during rehab/renewal.
	Need for temporary supply	Network layout drawings	Hydraulic modelling to assess impact of rehab on adjacent parts of network
	Maximum out of service time	Company policy	Analyse requirements of key users
STRUCTURAL CONDITION SEWERS	Performance indicators	Records of Blockage, flooding and collapse.	
	Structural Defects	Existing CCTV survey data	New CCTV inspection and deformation measurements. Smoke and dye testing
	Excessive deformation	Existing CCTV survey data	
	Silting and Root Ingress	Maintenance record	
	Manhole Condition	Maintenance records	Visual inspection
HYDRAULIC	Hydraulic adequacy	Records of surcharging etc	New hydraulic models

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CATEGORY	INFORMATION	INFORMATION SOURCES	
		EXISTING INFORMATION	NEW INVESTIGATION OPTIONS
CONDITION SEWERS	Infiltration and infiltration	Existing measurements and studies	Specialist studies
STRUCTURAL CONDITION - WATER MAINS	Performance indicators	Customer Complaints re quality, pressure and service interruption Burst records Leakage data Maintenance records	Water quality sampling Pressure and flow tests
	Condition of pipe wall – ferrous pipes	Maintenance records and observations Records of evaluation of any pipes removed	External Visual inc pit depth measurement Ultrasonic electromagnetic Coupon removal – Sample Removal
			Internal Visual (man entry) CCTV Intelligent pig (Hydroscope)
	Condition of pipe wall – Asbestos Cement pipes	Burst history Excess fibres in water	External visual inspection Phenolphthalein test on samples Measurement of wall softening on samples
	Condition of Pipe Wall – UPVC	Burst History	Methylene chloride and mechanical tests on samples
HYDRAULIC CONDITION WATER MAINS	Performance Indicators	Complaints re low flows/pressures	Flow/pressure tests Hydraulic Models

3. THE NEED FOR A FIELD STUDY

The most common reason for the use of a field study is to plug the information gaps associated with past (and sometimes current) inadequate record keeping. Sadly this is often the case with the smaller utilities which lack the resources to adopt a comprehensive Asset Management Plan. The USEPA have tried to ease this problem by issuing a series of simple guidance documents on topics such as Asset Inventory.

An example of a frequently encountered problem is the inadequacy of "as built drawings" which are usually incomplete, incorrect or otherwise inaccurate because:

a) They were not accurate in the first place and merely reflect the planned location of the installation rather than the actual route determined by site circumstances.

b) On older sites there may have been several utility owners, architects/engineers and contractors installing facilities and burying objects for decades in the area. Seldom are the records placed in a single file and often they are lost. There is almost never a comprehensive composite drawing.

c) References are frequently lost and records relate to distances/directions from surface objects which no longer exist or have been changed.

d) Lines, pipes and tanks are removed from the ground but not from the drawings.

This problem can be resolved by using the geophysical designating techniques described in the next section and if necessary the locating techniques requiring asset exposure by conventional or vacuum excavation.

Similarly direct inspection techniques can be used to generate a more detailed assessment of asset condition as described in the next section.

The use of additional inspection can also be justified if it leads to a different decision which allows a more cost effective rehabilitation solution to be used. An example is assessment of the structural condition of a pipe to determine whether a semi or non-structural renovation methods can be used. The types of inspection technology available are fully described in a separate section of these guidelines.

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	PIPE LOCATION AND CONDITION ASSESSMENT - FIELD TECHNIQUES	LAST UPDATED JULY 2009

1. INTRODUCTION

A wide range of techniques is available to locate buried pipes and assess their condition. Designating and locating techniques are summarised in Table 1 below. Inspection techniques from simple visual inspection to highly sophisticated electromagnetic techniques are summarised in Table 2. The most widely used technologies are described in more detail in subsequent sections of this document.

TABLE 1: FIELD DESIGNATING AND LOCATING TECHNIQUES FOR BURIED PIPELINES

Methods		Principle of the method	Interpretation of the data	Application information
Electro-magnetic methods (EM)	Pipe and Cable Locator	A transmitter emits an electromagnetic wave (radio frequency, normally ranging from 50 Hz to 480 kHz) to the ground or directly to the pipe and a receiver detects secondary waves generated by the underground utility.	The receiver detects the reflected wave and gives an indication such as a “beep” or a visual sign on the screen for an operator to detect the horizontal position of the underground utility.	Only metallic objects can be detected. - Various application techniques (Conductive, Inductive, Passive, Sonde insertion, Tracing wire/metallic marking tape). - Good for tracing utilities. - Crew size of 1~2 people. -
	Terrain conductivity	A transmitter induces an electromagnetic wave into the ground and a receiver measures both the primary and resulting secondary magnetic fields.		Typically metallic objects can be detected. Can detect other features associated with ground conductivity -Effective depth is typically 5 m (15 ft) or so. - Good for searching utilities -Crew size of 1 person. –
	e-Line Locator	Same as pipe and cable locator but digging a hole and installing an E-Line through a mechanical fitting is		-Used for plastic gas pipe. - Exact location of pipe is required. - Relatively expensive.

		required		
	Metal Detectors	A transmitter emits an AC magnetic field into the ground and a receiver analyzes the resulting magnetic field.	A receiving unit detects the peak magnetic field and emits a noise, alerting the operator to the presence of the metallic object.	- Metallic objects can be detected. - Applicable for shallow manhole lids, valve box covers and so on. - Crew size of 1 person. - With some types of equipment, the results can be mapped using contouring programs

Methods		Principle of the method	Interpretation of the data	Application information
Electro magnetic methods (EM)	Electronic Marker System (EMS)	A locator transmits electromagnetic signal to the electronic markers and a receiver detects the reflected signal from the electronic markers	The location is indicated with both visual reading and audible tone.	- Usually installed for non-metallic utilities. - Different frequency of electro markers for different type of utility.
	Ground Penetrating Radar (GPR)	The radar sends electromagnetic waves (commonly between 10 - 1,000 MHz) and receives reflected waves from subsurface material. Responds to changes in electrical properties (dielectric and conductivity).	The data to interpret is changes in the materials' electrical properties, through which GPR waves travel. The interpretation is to be made with computer programs by skilled geologists.	Both metallic and non - metallic utilities may be imaged. - Rule of thumb: from surface up to 6 feet of depth and in very low conductive soils and highly different impedances, a round utility whose diameter in inches does not exceed the depth in feet can be imaged.
Magnetic Methods		It measures the intensity of the earth's magnetic field. Deviation of magnetic intensity caused by ferrous objects is detected by the equipment.	The different intensity of the magnetic field captured by two sensors creates a beep sound or high numeric number on the screen for an operator to detect the existence of metallic object.	- Useful for detecting and tracing ferrous (steel or iron) utilities. - Crew size of 1 person. - Good for searching for vertical and point-source metallic utility structures (e.g. well casings, manhole lids). - Effective depth: 1.5 to 3 (5 to10 ft) for vertical structures; 0.6 m (2 ft) for horizontal structures.

Acoustic Emission Method	An acoustic transducer applies sound waves into utility line. The sound waves travel along the utility lines and special sensors on the ground detect the sound waves that reach the surface.	Special sensors such as geophones or accelerometers are used to detect the sound emitted from the pipe.	- The method is useful for designating plastic pipe (typically water/gas pipe). - The method can service up to 300 m (1,000 ft) distance for gas pipe and 150 m (500 ft) for water pipe. - Crew size of 1~2 people.

GROUND PENETRATING/ PROBING RADAR (GPR)

This method is based on the same principles as the RADAR (**RA**dio **D**irection **A**nd **R**anging) developed in the 1930's to detect above ground distant objects such as aircraft, shipping vehicles birds rainstorms etc. The methods depend on the transmission of electromagnetic energy, usually in the form of a pulse and the detection of a small amount of that energy reflected from the target. The time delay of the reflection indicates the range of the target.

Buried objects may also be detected by radar methods and have been the subject of electromagnetic probing for longer than have above-ground objects. Work reported in the fifteen years after 1910 was devoted to the electromagnetic identification of underground regions of dissimilar conductivity (e.g. ore deposits) or absorption compared with their surroundings, using non-pulsed methods. The first pulsed experiments were reported in 1926 when the depths of rock strata were determined by time-of-flight methods. It was noted that any dielectric variations, not necessarily related to conductivity variations, could give rise to reflections and that, further, it was easier to implement directional sources than was the case for seismic methods.

Over the next 50 years, radar pulsed techniques were developed for a range of specialised applications such as:

- Ice thickness measurement;
- Fresh water depth measurement;
- Salt deposit thickness;
- Desert sand layer investigations;
- Buried plant location;

The emphasis of these method has been with deep penetration, sometimes up to a few kilometres, which requires emissions at frequencies of a few or tens of MHz, requiring large antennas with the accompanying restriction of low resolution of the objects or interfaces detected. The detection of shallow objects such as utilities lying in the first few metres of the Earth's surface requires much higher emission frequencies of up to 1000 MHz. The generation and reception of electromagnetic impulses at these high frequencies poses many problems and this severely restricted the usefulness of the early commercial GPR systems aimed at the detection of buried utilities.

The detection of buried utilities with GPR imposes the following constraints on the design of an effective GPR system:

- utilities are typically located within the first 1.5 m of the surface
- There is a wide variation in size and, materials (metallic and non metallic)

- they may be in close proximity to other plant
- they may occupy a wide range of soil types with different properties affecting the absorption and velocity of propagation of E—M waves
- ground conditions may vary rapidly in a survey area including variations in water content and the presence of imported backfill

All of these factors make it difficult to achieve good penetration combined with adequate resolution and this problem has led to inconsistency in the output of the first generation of commercial GPR location systems. In order to resolve these problems a Joint Research Initiative (ORFEUS) involving six European organisations has been funded by the European Commission with the following objectives:

- To provide a step change in the depth penetration and spatial resolution of GPR used for surveys carried out from the ground surface.
- To design a prototype innovative GPR-based real-time obstacle detection system for steerable bore-heads of Horizontal Directional Drilling (HDD) pipe and cable laying systems, so that they can operate more safely below ground.
- To increase knowledge of the electrical behaviour of the ground, by means of in-situ measurements to enhance understanding of the sub-soil electrical environment and to provide information for scientifically based antenna design.

The consortium running the project comprises representatives of the major water and gas utilities across Europe, one of the world's leading developers of GPR systems, designers and operators of one of the world's leading Horizontal Directional Drilling (HDD) companies and leading European academics, all supported by a recognised authority in GPR technology and its applications. The progress of this project is reported in (Manacorda et al, Rome 2007) and (Raclavsky et al, Moscow 2008).

In (Lund, San Diego 2007) the principles of Computer Aided Radar Tomography (CART) and Ground Penetrating Radar (GPR) are reviewed and hardware based on each system described in detail.

CART Array comprises 17 antennae (9 transmitters and 8 receivers)

Detailed view of Array

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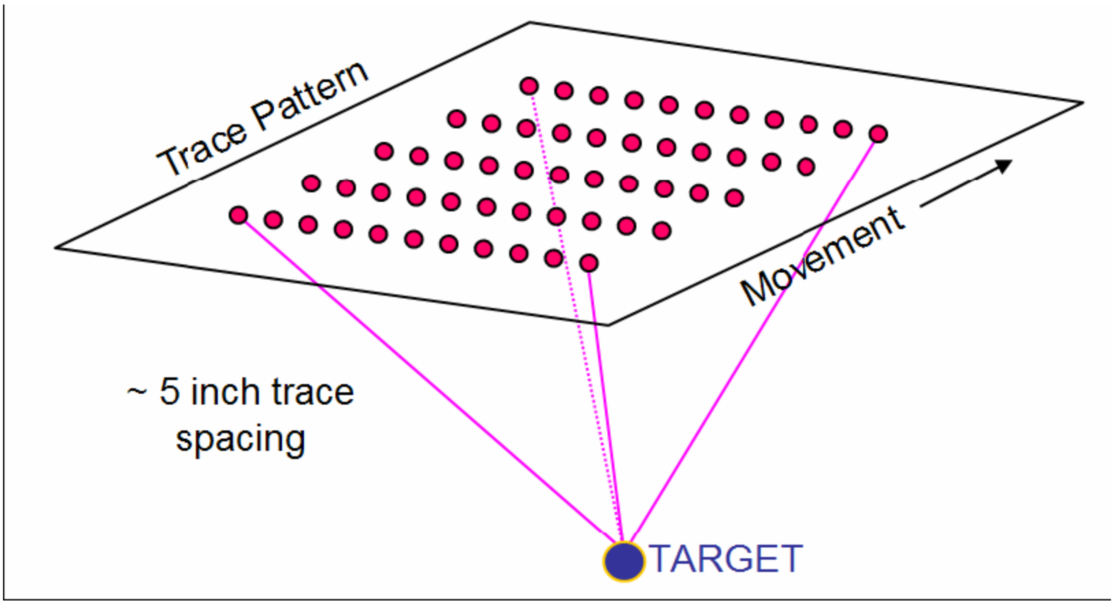
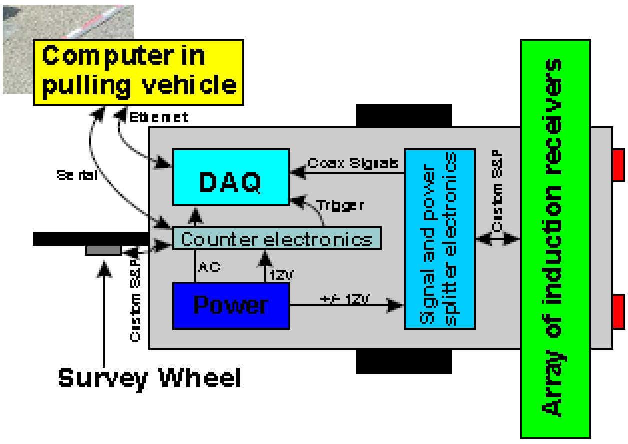
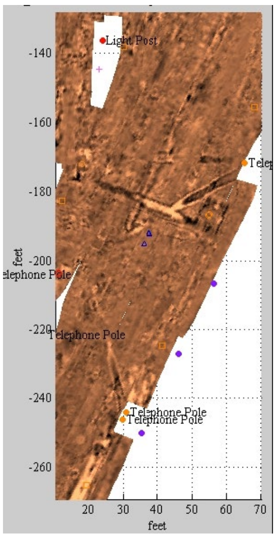
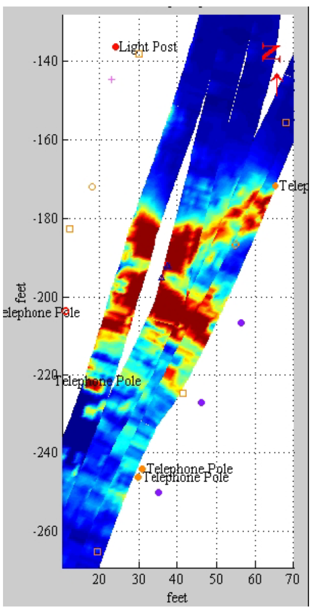


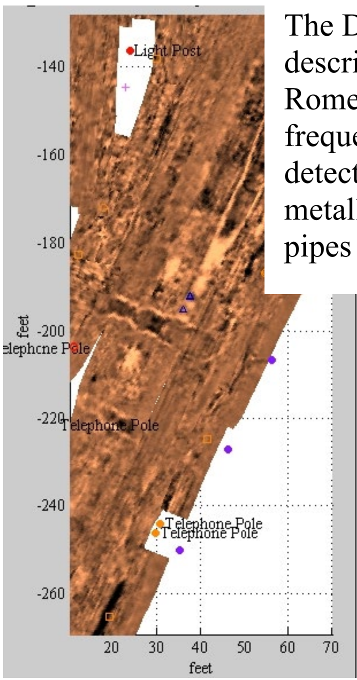
Laser Geodimeter used to measure precise location of Array via a Prism mounted on the array



Array of Induced Receivers (AIR) technology is used to detect electrically conductive pipes and the array of 16 Triaxial Coil Magnetometers can receive wide range of EM frequencies in all three planes. The EM signal is either applied directly to the pipe or induced by an Induction Sphere.







The Detector Duo system described by (Simi et al Rome 2007) uses a dual frequency antenna which can detect shallow and deep metallic and non metallic pipes in a single scan.

TABLE 2: FIELD CONDITION ASSESSMENT TECHNIQUES FOR BURIEDPIPELINES

TYPE	NAME	PRNCIPAL
LEAK DETECTION (PRESSURE PIPES)	LEAK NOISE CORRELATOR	Detects and locates by triangulation the sound of escaping liquid
	SAHARA TECHNOLOGY	Device attached to umbilical cord continuously detects sound of leakage as it is propelled/pulled through operating pressure pipe. Has also been use to detect trapped air in sewage force mains
LEAK DETECTION (GRAVITY PIPES)	CCTV OBSERVATION	Inward leaks (infiltration) can be observed on CCTV surveys
	SMOKE TESTING	Smoke is pumped into a sewer and then the surface path of the sewer is visually monitored for evidence of escaping smoke
FLOW AND CAPACITY MEASUREMENT (SEWERS)	FLOW AND LEVEL MONITORING	For sewers flow and level monitoring devices are installed at manholes etc

FLOW AND PRESSURE MEASUREMENT (WATER MAINS)	**MEASUREMENT OF FLOW RATES AND OPERATING PRESSURES**	**For water mains flow rates and pressures are monitored at fire hydrants and access points located at key positions in the network**
EXTERNAL INSPECTION TECHNIQUES	EXTERNAL VISUAL INSPECTION	The pipe is inspected at locations where it is exposed and the surface condition noted including the presence and condition of any corrosion protection.
	PIT DEPTH MEASUREMENT	Direct measurement of corrosion pit depth and distribution on ferrous pipes.
	ULTRASONICS	Ultrasonic inspection to determine wall thickness.
	COUPON REMOVAL	Use of under pressure tapping technology to remove a small coupon for laboratory evaluation.
	PIPE SAMPLE REMOVAL	Removal of full pipe samples for laboratory evaluation.
INTERNAL INSPECTION TECHNIQUES	INTERNAL VISUAL INSPECTION	Direct inspection in man entry pipe to Locate and identity visual defects such as cracks, blockages, collapses etc
	CCTV SURVEY AND SSET	Use of CCTV camera to identify and classify pipe defects. Most modern techniques (SSET) use fish eye lenses to give full 180 degree view of pipe wall and computer based recording and evaluation of defects leading to assignment of condition grade (1-5). Variant uses digital zoom lens to survey manholes and sections of pipe just upstream and downstream from manhole location
	SONAR	Supplement to CCTV inspection to assess flooded sections e.g inverts where camera is unable to observe
	LASER PROFILING	Means of assessing exact pipe profile/ shape by projecting a laser image and comparing it with the CCTV image of the pipe at the same location. Most effective technique to assess pipe deformation for liner design purposes. Can also be used to measure degree of erosion/corrosion of pipe walls

ADVANCED and EXPERIMENTAL TECHNIQUES	ELECTRO - MAGNETIC METHODS	Uses remote eddy current and similar electromagnetic effects to determine wall thickness and pit depths of ferrous pipes by passing an electromagnetic device through the pipe. Can also be used on the outside of exposed pipe sections
	LINEAR POLARISATION RESISTANCE	
	ACOUSTIC MONITORING	Detects and locates the sounds associated with the failure of pre-stressing wires etc
	ULTRASONIC EVALUATION	Ultrasonic device mounted on "PIG" which is pulled or propelled through pipe

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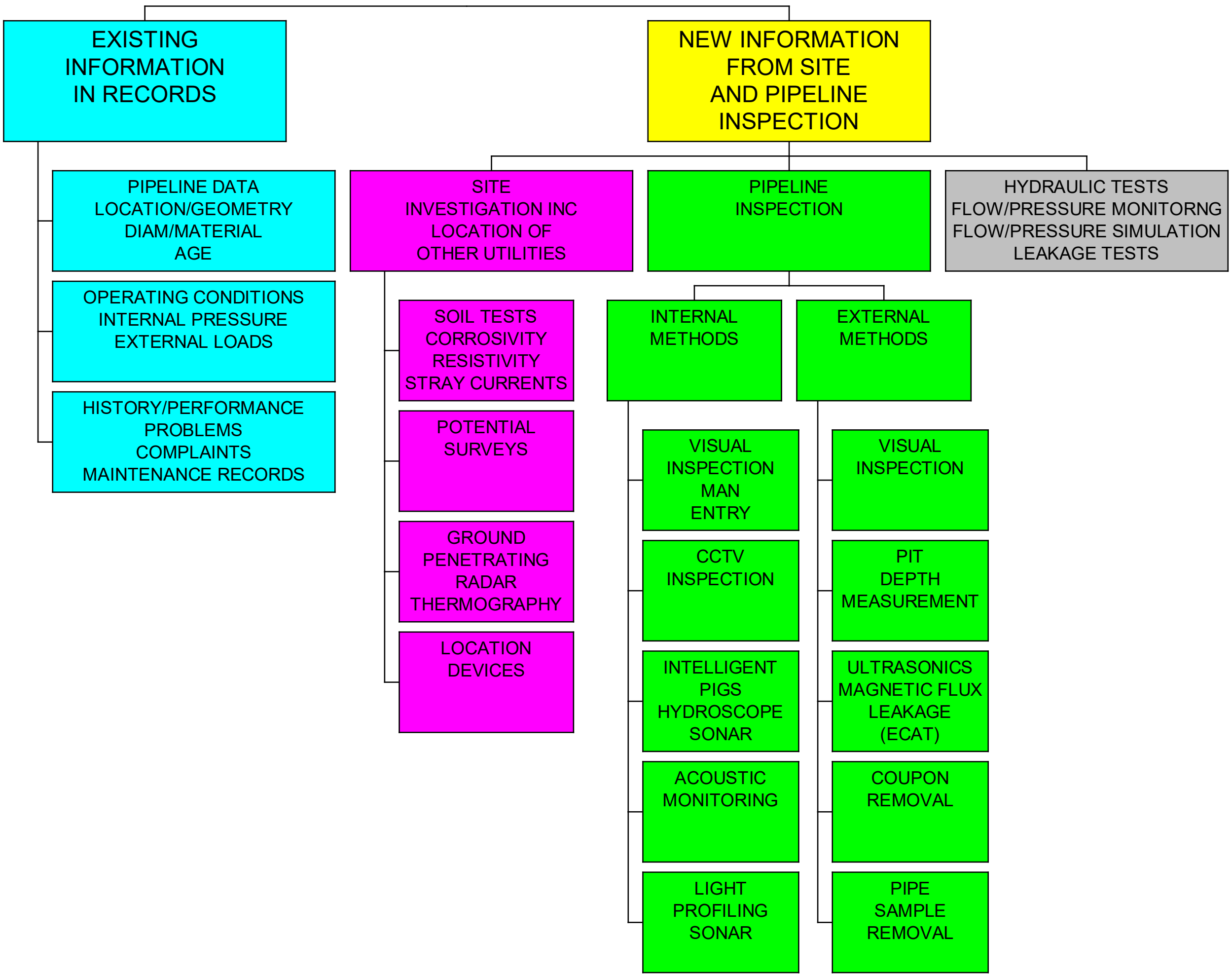
FIG 1.1 -INFORMATION SOURCES



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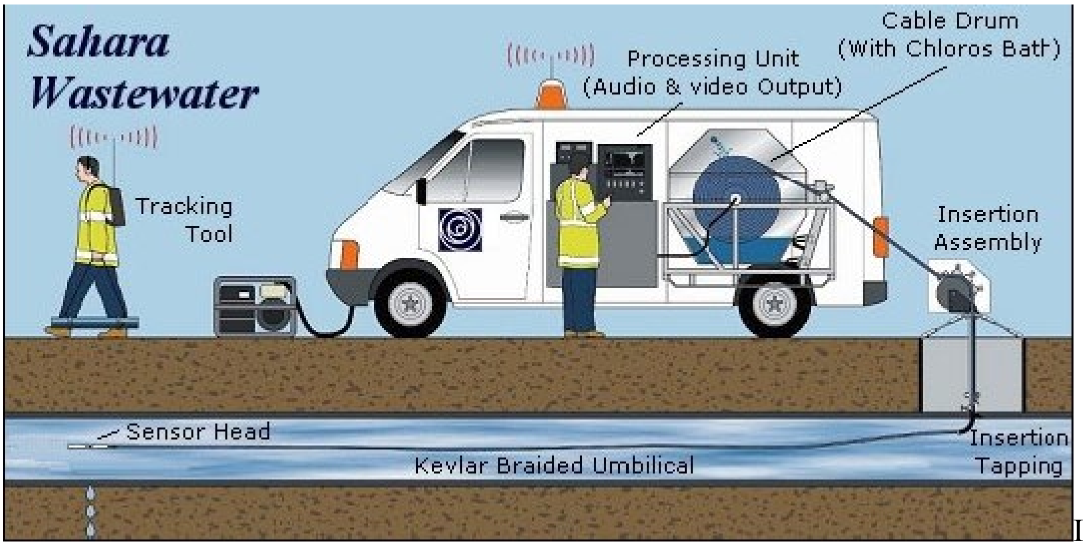
TRADITIONAL METHODS

LEAK DETECTION TECHNOLOGIES

Leakage of fluids either out of (exfiltration) or into (Infiltration) a pipe is normally associated with progressive deterioration in pipe condition at pipe joints and/or structural defects. The movement of fluid can also cause removal of pipe bedding and backfill materials leading to further structural degradation and eventual failure.

In pressure pipelines the leakage of fluids at high pressure generates noise which can be used to detect and locate the leak. The simplest approach used a manual listening device which is held against the pipe and the ear of the operator. This has now been replaced by Pipe Noise Correlators in which multiple microphones are used to detect the noise and determine its exact location.

The SAHARA Technology uses a noise detection device attached to an umbilical which allows the device to be inserted into the pressurised pipe and then traverse it while providing a continuous record of leak noise data. The system was designed for use in water transmission mains but has most recently been used in sewer force mains (Knight et al San Diego 2007).



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In gravity lines leakage is normally detected during CCTV Survey. Infiltration can be observed directly as inflow. The existence and location of potential leakage paths can be confirmed by smoke tests. Infiltration can also be quantified by flow measuring techniques.

EXTERNAL INSPECTION TECHNIQUES

A. VISUAL INSPECTION

These techniques make use of existing points at which the pipe may be exposed or points at which it is deliberately exposed for the purposes of inspection. In the case of metallic pipelines the inspection checks for signs of corrosion and any damage to external protection. However, most commonly these techniques provide an opportunity to apply a number of related external inspection technologies as listed below.

B. PIT DEPTH MEASUREMENT
On metallic pipelines such as cast and ductile iron and steel it is possible to measure the extent of external corrosion by assessing the depth and distribution of corrosion pits. It is first necessary to expose the metal surface by removing any corrosion product and then mark a suitable grid on the surface. A simple gauge is then used to measure individual pit depths.

C. ULTRASONIC INSPECTION
On metallic pipelines manually operated ultrasonic equipment can be used to measure the remaining wall thickness of the pipe and to some extent the amount of pitting. However, special techniques are needed with cast iron pipes due to the in homogeneity of the wall, which can give rise to false internal reflections. The simple form of this technique is based on a hand held device but more sophisticated systems operating from a travelling PIG inside the pipeline are also available and used for continuous inspection of high value pressure lines such as oil and gas transmission lines

D. COUPON REMOVAL AND EVALUATION
This technique involves use of under-pressure tapping equipment to remove a coupon (50 mm diameter) from the pipe wall while it is in service. Examination of the coupon gives an indication of the type and extent of corrosion and in combination with measurement of external Pipe diameter it can also be used to determine the internal diameter of the pipe. In the case of asbestos cement pipe the coupon can be tested in a compression rig and the results used to determine the residual strength of the pipe wall.

E. PIPE SAMPLE REMOVAL AND EVALUATION
This is the most effective and accurate method to determine the precise nature and extent of degradation but since it involves closing down the section of pipe it is also the most expensive and disruptive. However some argue that part of the expense is justified by the detection of faulty line valves.

Typically a one metre long sample is extracted every 250 metres, and sent to the laboratory for evaluation. A careful and rigorous procedure is followed in which the corrosion product is removed and the weight change recorded and then direct measurement of internal and external pits carried out. This method is often used to calibrate the results of non-destructive testing. The UK water companies have used this method on many thousands of samples and established a database of relevant information.

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3. INTERNAL INSPECTION TECHNIQUES

1. VISUAL INSPECTION
In man entry size pipes this involves closing down the line and then manually inspecting the pipe wall to determine the degree of corrosion and other defects. The inspector would normally carry a video recorder and dictation device to retain the data.

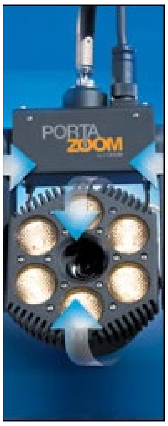
In non-man entry pipes the inspection is carried out by a close circuit TV (CCTV) survey as described below.

2. CCTV SURVEY

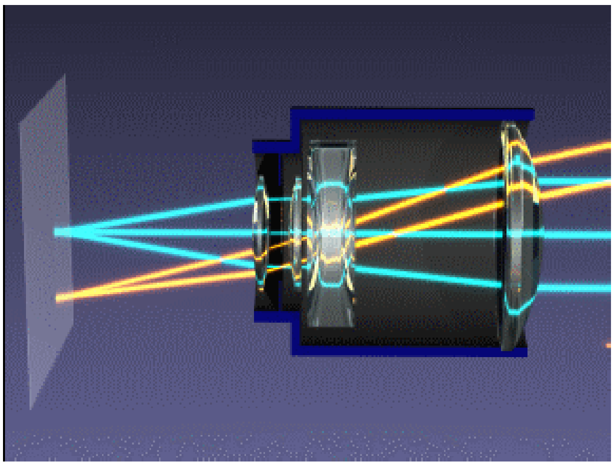
A wide range of miniaturised video equipment is available, which can be mounted on a small tractor device or sled, and driven or pulled through the pipe while recording an image of the pipe wall. This is the main technique used to assess the condition of brick concrete and vitrified clay sewers using a standard method of coding the observed defects, to enable lengths of pipe to be assigned a structural grade from 1-5 (1 best and 5 worst).

In more recent developments the camera has a pan and tilt capability to enable closer inspection of defects or lateral openings. Special software is available to control the progress of the survey and process the incoming data. The most sophisticated equipment (SSET) uses a special type of "fish eye" lens, which allows simultaneous observation of sections of wall both behind and in front of the camera, and then automatic processing of the data to give a structural grade.

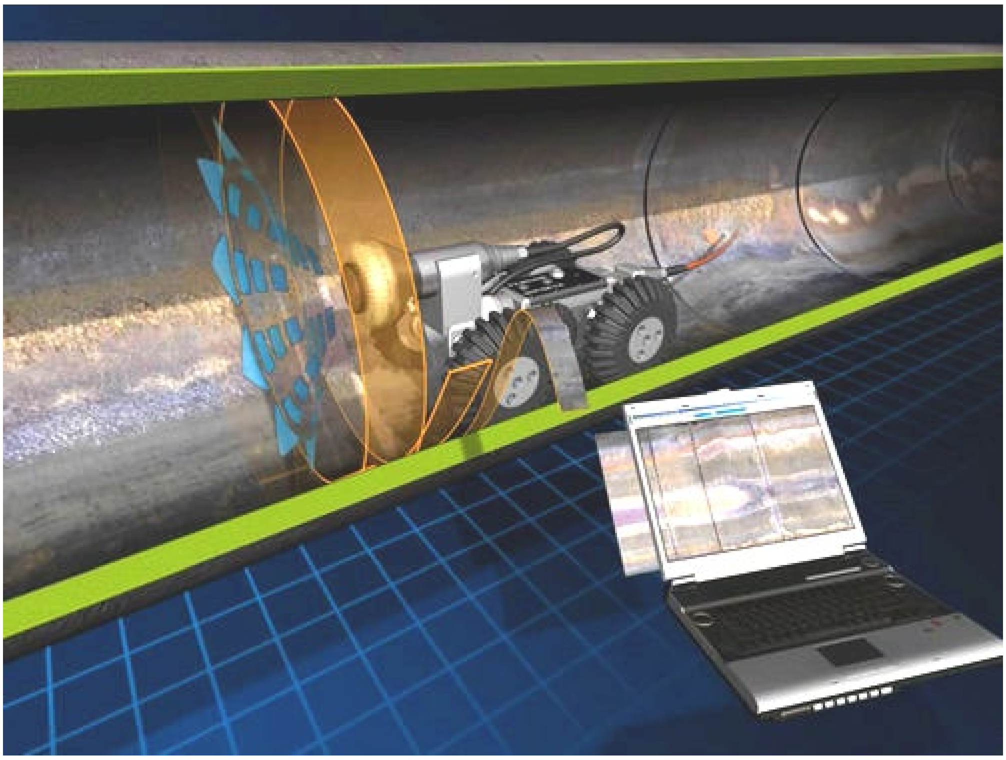
Another recent development (Samarakoon San Diego 2007) is the use of a camera with a zoom lens which can be lowered into a manhole and used to observe the condition of the manhole and a short length of the main pipe both upstream and downstream from the manhole. This is much cheaper and less disruptive than normal CCTV survey and can be used to identify the need for flushing and sectors which require the more normal CCTV survey.



Zoom Cameras for use in manholes



In addition to structural defects such as longitudinal and circumferential cracks, the survey can also determine the location and condition of lateral openings and the condition of joints based on observation of live infiltration. Equipment is also available to survey laterals over distances of up to 20 metres when launched into the lateral from inside the main pipe. In the early days of sewer rehab the decision to renovate or replace a section of sewer was entirely based on information from the CCTV survey. However, more recently in the UK the decision to rehabilitate is based on the performance of the pipe as a sewer, rather than the degree of degradation it has suffered. It should be pointed out that, whilst it may be possible to utilise a CCTV system in any pipeline, the majority of the work is completed in sewer systems, as most pressure pipes would need to be decommissioned before any inspection could be done, although this does not preclude CCTV being used in pressure pipes.



A schematic of a full pipe internal survey.

3. SONAR

These methods are used as a supplement to the CCTV inspection of sewers, in situations where the sewer is heavily silted or flowing. They provide information on the condition of the pipe beneath the surface of the sewage and/or silt layer. The equipment is frequently mounted on the same tractor as the CCTV equipment so the results can be integrated.

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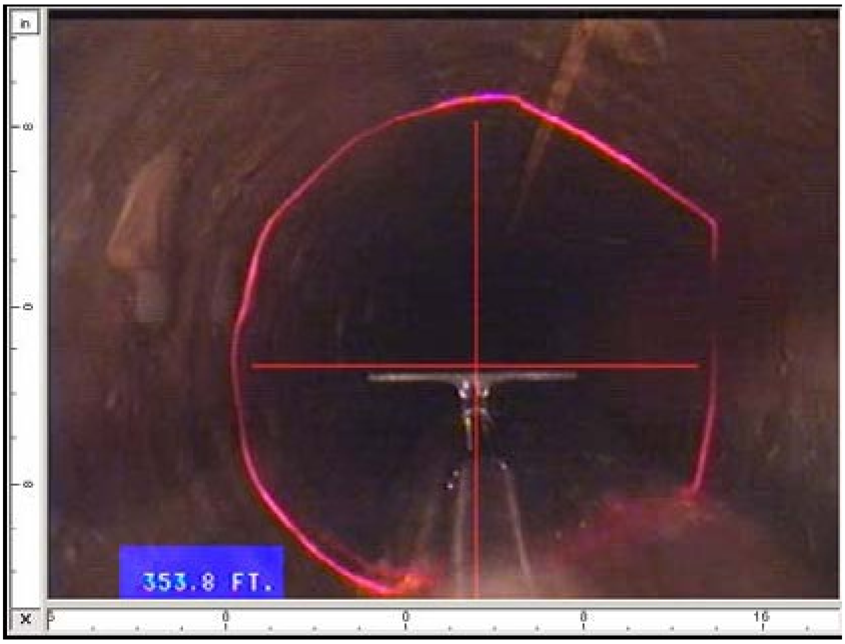
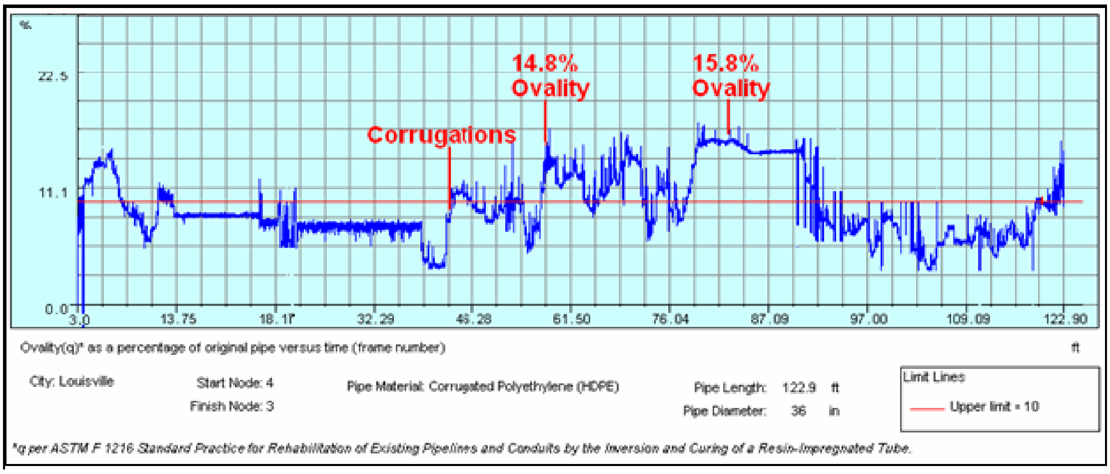
4. LASER PROFILE

This device can be mounted on the same sled or tractor as the CCTV camera and projects a laser image of the pipe profile which can be observed from the CCTV camera.



Typical Laser profiling image



Ovality Report from a Laser Profile

This technique is used to determine the dimensions and shape of a sewer profile and in particular any ovality or vertical deflection, caused by the interaction of sewer defects and external loads. This information is important since it affects the design of any liner system that might be considered.

The technique can also be used to measure any material loss from the pipe wall and hence determine the extent of corrosion and reduction in cover to steel reinforcement in SRC Pipes.

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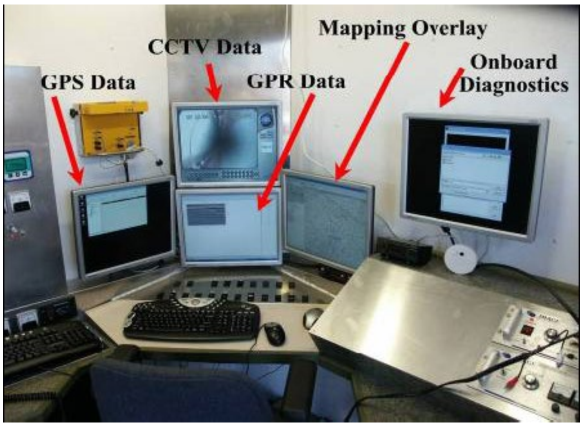
5. MULTIPLE DATA COLLECTION TECHNOLOGIES FOR SEWERS

(Wilson et al , Nashville 2006) describe the advantages of collecting data from a number of internal inspection technologies mounted on the CCTV inspection robot. For sewers the range of data includes:

1. data collection viaadvanced CCTV cameras;
2. sonar arrays;
3. in-pipe and ground level ground penetrating radar;
4. in-pipe 3-D mapping using GPS equipment.

Robot equipped with multiple inspection technologies.



Data Monitoring desk.

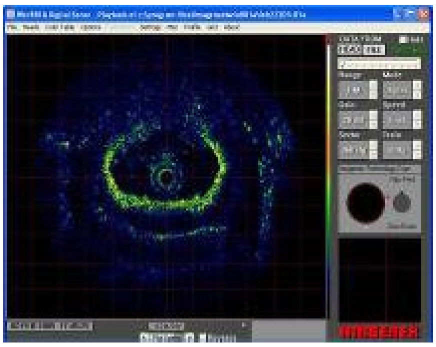


Image from sonar Array

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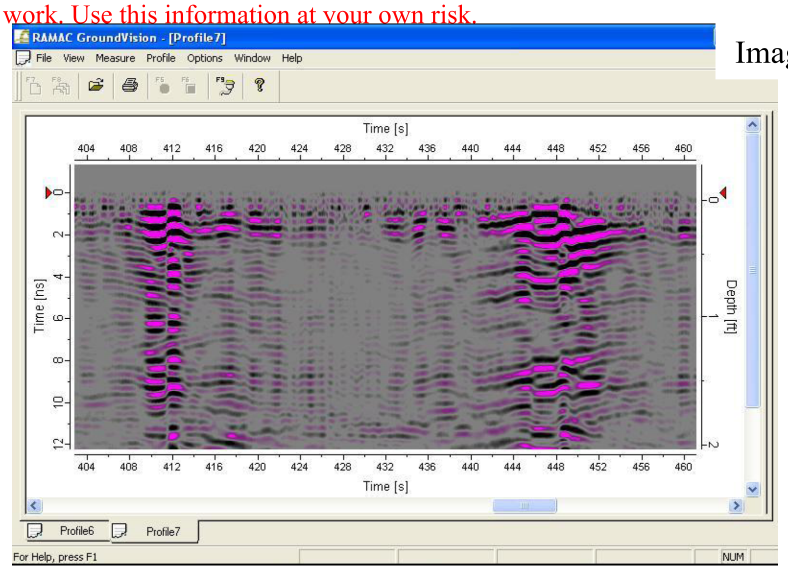


Image from Robot mounted GPR.

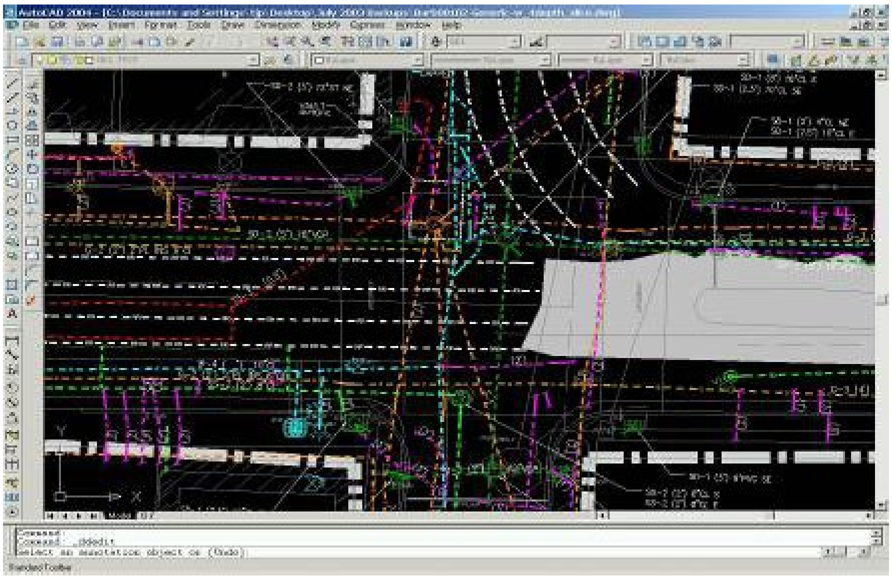
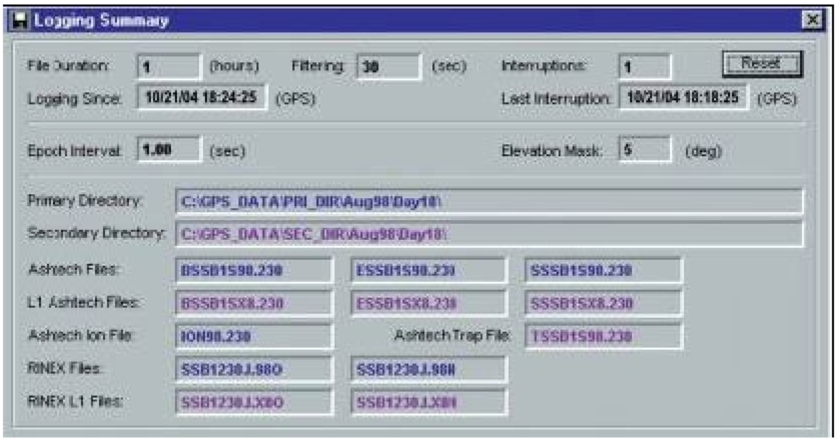
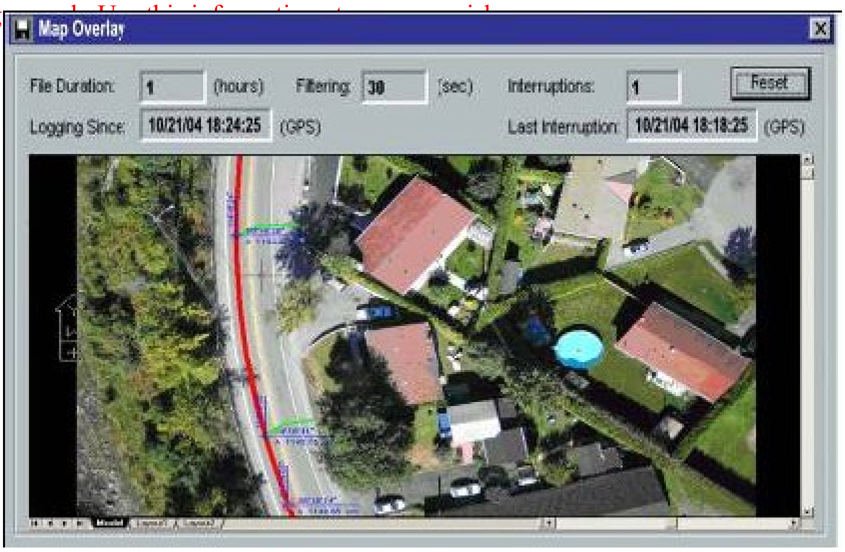


Image from surface GPR scan



Muliple Data Log linked to GPS

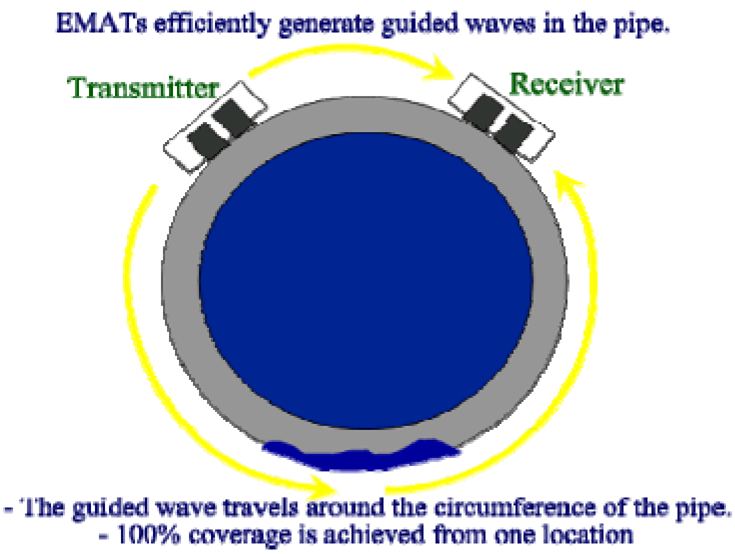


Map Display

5. IMPACT ECHO MEASUREMENT

This method for the non-destructive testing of concrete pipe structures is based on the use of impact generated stress (or sound) waves that propagate through the concrete and are reflected by internal flaws and external boundaries. Impact echo can be used to determine the location and extent of flaws such as cracks, delaminations, and voids in plain and reinforced concrete pipe conduits.

A form of wave measurement that is quickly gaining notoriety is Ultrasonic Testing (UT) with Multiple Electro Magnetic Acoustic Transducers (EMAT). Ultrasonic Testing is the use of high-frequency sound waves to detect imperfections or to locate changes in material properties of solid objects. Because of its capabilities and reliability, UT is one of the fastest growing non-destructive testing techniques. It is the method of choice for critical applications where full volumetric inspection is required, especially when there is only limited access to the object being inspected. The EMAT and the metal test surface interact and generate an acoustic wave within the material as illustrated below.



6. ACOUSTIC MONITORING TECHNIQUES

Acoustic monitoring can be used for two purposes:

a) To detect and locate leakage which is frequently associated with degradation in pipe joints and voidage in adjacent fill (see above in section on leakage detection)

b) To detect and locate the degradation and failure of the pre-stressing wires in Pre-stressed Concrete Pressure Pipes (PCPP)

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4. ADVANCED and EXPERIMENTAL TECHNIQUES

ELECTROMAGNETIC METHODS

These techniques induce an electromagnetic field in the pipe wall from a transmitter and determine the extent to which the field is changed in amplitude and/or frequency by its passage through the pipe wall. The signal is then evaluated by sophisticated computer software to produce a plot of local thickness variation. There are a number of different techniques.

In REMOTE FIELD TECHNOLOGY (RFT), the signal is induced into the pipe by an internally or externally placed coil (exciter), which is energised by a low frequency voltage. This generates eddy currents and magnetic flux lines, which radiate as an electromagnetic field from the exciter. At a distance of about three pipe diameters, the field in the pipe wall is stronger than the field within the pipe, and sensors positioned in this 'remote field region' can detect minor variations in the field strength. The signal arriving at the detector is typically very small (only a few micro volts) and very sensitive electronics are required for its measurement.

BROAD BAND ELECTRO MAGNETIC (BBEM) induction techniques record data over a broad range of frequencies and consequently should have advantages over RFT. The principle of BBEM is to transmit a signal that covers a broad frequency spectrum (i.e. perhaps 3 decades). The received signal resulting from a broadband transmission contains more information, and allows detection and quantification of various wall thicknesses as well as the effective conductivity of the complex through-wall components of the pipe. Instruments for acquiring BBEM data are based on the time-domain electromagnetic techniques (TDEM) initially developed in the 1970s, where the transient decay of the magnetic field is measured following the interruption of current flow in the transmitter coil. This technology has now been extensively modified for pipe diameters of 100 mm and greater. However, Low Frequency Electromagnetic (LFEM) has some advantages over BBEM in that it is consequently faster and can be more cost-effective.

The methods also differ in their dependence on the distance of the sensor from the pipe wall and the effect of corrosion products. The least sensitive method is BBEM, which can use a hand held transmitter and sensor, or a special version of the equipment can be lowered into a micro-excavation and held just above pipe surface. The other techniques use equipment mounted on an assembly, which facilitates scanning of either a circumferential or a longitudinal strip of the pipe or maintaining the sensor at the correct distance from the pipe wall. This type of equipment can also be mounted on an Intelligent Pig and used to scan the inside of the pipe. The PIG is either propelled through the pipe by fluid pressure or pulled with a winch. This provides data covering a continuous section of pipe wall between access points, so is the most accurate and comprehensive means of assessing pipe condition. However, it does involve shutting down the pipe and, in the case of water mains, dealing with the effects of disturbing the corrosion product layer.

Use of this technique can be expensive and time consuming, and a number of contractors in the USA have attempted to justify the cost by setting them against the savings, which can be obtained by postponing rehabilitation or using a less expensive renovation technique. A number of attempts can be made in the USA to achieve the inspection contract, which recognises the savings and expenditure and sets it against reduced costs in new treatment works.

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LINEAR POLARISATION RESISTANCE

A number of methods have been suggested to allow correlation of the corrosion of metallic pipes with the corrosivity of the soil. These include the pipe to soil potential, Pearson surveys, remote resistivity and direct current voltage gradient. However, the most advanced technique appears to be linear polarisation resistance technique (LPR), which is based on laboratory measurement of the polarisation resistance of soil samples taken near metal pipes and is used to determine their corrosion rates in various soil types. By knowing the polarisation resistance, R_p, an estimate of the corrosion rate of metal pipes can be made to allow an estimate of their lifetime and their future propensity to fail and leak. Although the limitations of LPR are known, it is a practical and low cost method for corrosion assessment, and has been successfully applied in combination with extreme value statistics to determine the performance of many critical mains in Australia.

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5. USE OF INSPECTION RESULTS

THE ROLE OF CONDITION MONITORING

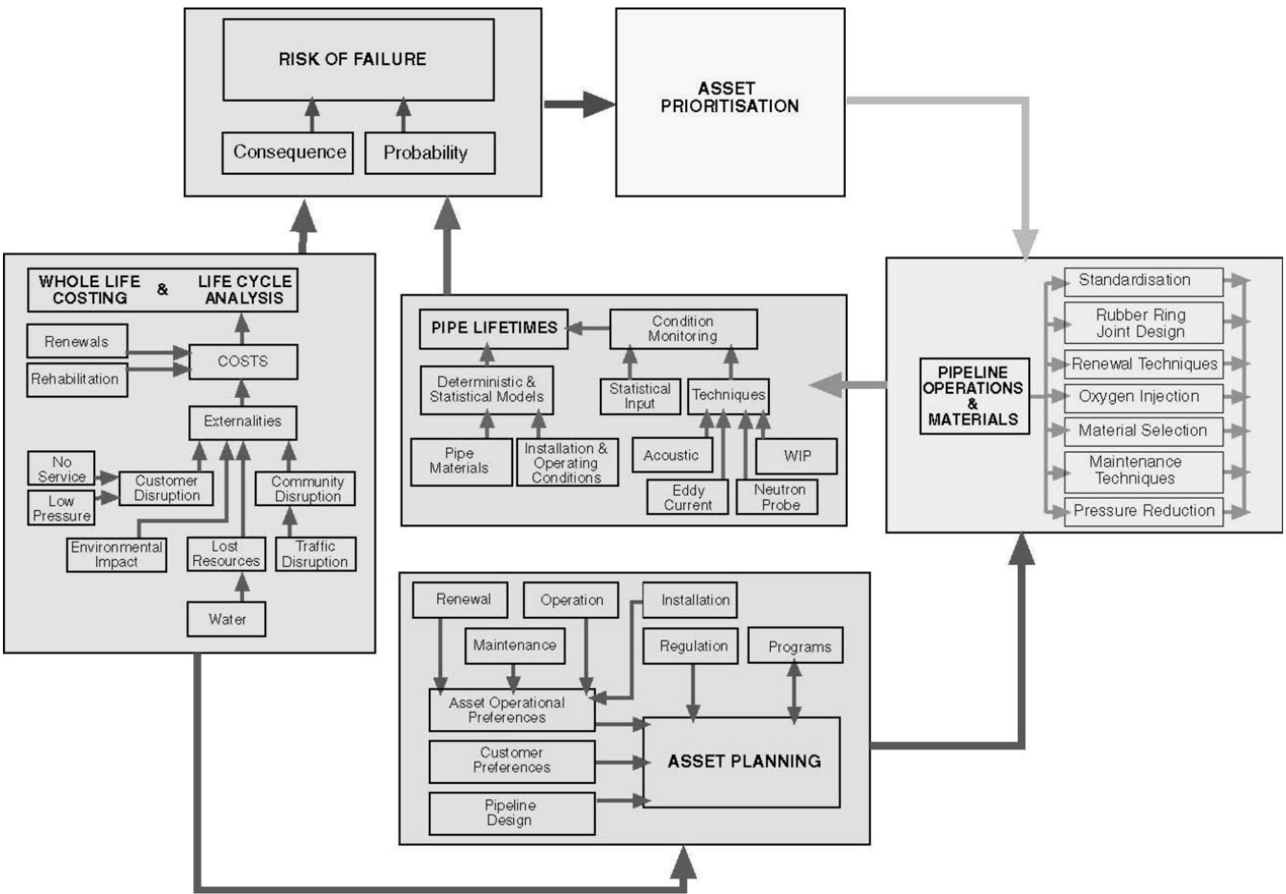
The development of asset planning and prioritisation models has highlighted the need for accurate failure data for the range of pipeline materials installed in a utility network working under varied installation and operating conditions. Either this failure data can be developed at a cohort level or where possible for individual assets, depending entirely upon the amount of statistical or empirical data that is available to allow models to be generated. The assessment of the failure probability or condition of a pipeline is central to any decision with regard to its upgrading or replacement and condition monitoring is a critical factor in confirming the lifetimes to be used in asset planning or prioritisation (Burn et al., 2001).

The increasing need for more reliable data during condition monitoring of pipelines has prompted infrastructure managers to start looking for enhanced alternatives to CCTV. Although, in most instances the extra costs associated with these techniques has precluded their use, except in those areas where the consequence of failure is a critical factor in the pipeline operation. (*IWA 2 World Water Congress 15-19 Oct 2001, Berlin, Germany.)*

CONDITION MONITORING TECHNIQUES

The condition monitoring technique required to assess the condition of an individual pipe asset is pipe-type-specific, and to a lesser extent, location specific. To allow assessment of the remaining life of a pipeline or to establish its probability of failure, information is required on a significant number of factors, which vary from pipe type to pipe type, but may include, pipe wall thickness, pipe wall defects, pipe deflection, soil support conditions, soil movement index and soil corrosivity. For pressure pipelines, these systems have concentrated on assessment of a single property such as remaining wall thickness or the presence of leaks, whereas for sewer systems the use of multi-sensor systems has been investigated. However, pressure pipelines require significant information on a number of properties to allow condition or lifetime assessment. Consequently, the development of multi-sensor systems for pressure pipelines that can be inserted through a hydrant (or gland valve) or used from the ground above the pipe would seem to be necessary. The reasons for this lack of development of in-pipe systems for pressure pipelines stem from a large number of difficulties associated with product and quality issues, due to the disturbance of say sediments in water pipes, the need to maintain continuity of supply and the lack of easy access into the pipeline, or the explosive nature of the product, hence the need to insert the system through a valve, such as a fire hydrant.

The relationship between the various types of inspection results and the components of an AMP for water mains, for example, are illustrated in the diagram below.



1. INTRODUCTION

In previous sections above, it has been seen how an asset management plan may be implemented. The condition of the network is first assessed by some of the inspection technologies described. Depending on the type of pipe, engineers can identify system performance failures caused by pipe defects. A decision can then be made as to which sections of pipe need rehabilitation or replacement, and a time scale appropriate to the type of degradation. The next step is to identify all possible rehabilitation solutions, and then choose the method that solves the problem, at the lowest cost. Of course a suitable acronym must be used, this being LCTVS [Least Cost Technically Viable Solution].

A technically viable rehabilitation solution must meet the following criteria:

a) It must solve the problem in a manner which maintains all the required performance parameters of the system.
b) It must continue to solve the problem for the design life of the rehabilitated system.
c) It must comply with any relevant codes, standards or regulations.
d) It must be capable of implementation at an acceptable level of risk and achieve adequate quality.
e) It must allow future maintenance by the Utility work force.

There are many ways of approaching the process of selecting methods which meet these criteria, and each utility tends to evolve a method which suits their company culture, the expertise of their employees, and the scale of their pipeline network. The methods used may be based on:

- Advice from technology vendors and contractors -
  This is inevitably and understandably biased towards a company's specific offerings.
- Advice from Consulting Engineers -
  This of course depends on the level of knowledge and experience of the particular Engineers involved.
- An existing company philosophy which supports or excludes a particular group of rehabilitation options -
  This is highly subjective and frequently based on the biased views of a favourite contractor or technology guru.

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2. THE LOGICAL APPROACH

A more logical approach to method selection, is set out below, and involves the following stages:

- Identify the key performance problems, and the defects in the pipes which are causing them.
- List all of the rehabilitation or replacement options that are capable of solving these problems.
- Starting from the lowest cost solution, compare the characteristics of the solutions, with the requirements of the application.
- Retain as a short list for bidding those solutions which are technically viable.

Many utilities make use of decision matrices or 'Trees' to structure and formalise the selection process. Many examples of such trees can be found in the available literature, many of them reflecting the particular interests and biases of the utility involved. Ultimately any utility that wishes to use a decision matrix should evolve its own, using published examples as a starting point. All such trees are based on providing answers to a series of structured questions. Each answer directs the user to the next question and eventually to a set of possible solutions.

Examples of such decision trees used for water mains and sewers are described below where they are used as a means of identifying the key issues in method selection.

Water Main Decision Tree

A typical tree used for water mains is discussed in AWWA's Manual M28, 'The Rehabilitation of Water Mains' which was updated in 2001.

The purpose of this tree is to identify alternative solutions to new installation or off-line replacement, whether undertaken by conventional open trench methods or trenchless technologies such as HDD. The tree therefore evaluates the technical viability of using the methods which make use of the existing pipe or the void in the ground which it occupies. These include on-line Replacement, and non-, semi-, and fully structural renovation. The deliverable from use of the tree is a list of technically viable solutions comprising one or more of the groups listed above. Only in the case of non-structural renovation does the table identify a specific technology.

The tree has three main branches which correspond to the primary drivers for water main rehabilitation, namely:

- Structural Problems
- Low Flow/pressure
- Water Quality

Fig 5.1 (below) shows part of this tree. One of the most important questions requires an assessment of the effect of the rehab technology used on the future structural integrity of the pipe. The answer to this question depends on the causes of the structural problem. If it is some form of external corrosion, then renovation processes based on internal lining will not prevent further degradation. The answer is then to use replacement or fully structural lining options. If it is internal corrosion and the pipe is still sufficiently sound at the time of renovation then non- or semi-structural renovation may be appropriate.

Another key question relates to hydraulic performance. The user is expected to assess the likely impact of the various rehab options on the hydraulic performance of the line based on the usual hydraulic models. The aim is to determine the minimum bore which will meet the current flow requirements using a roughness co-efficient (C-value) appropriate to the various rehab options, and hence determine whether any of the renovation options are viable.

At the end of each branch are the solutions boxes which offer on-line replacement and where possible renovation.

The other main branches relate to pipes which do not have structural problems but do have either low flow/pressure, leakage or/water quality problems. The first question determines whether the problem is hydraulic or water quality based. If the problem is water quality, the next question relates to the type of water carried and recommends non-structural lining with cement lining excluded in the case of aggressive water. The hydraulic branch of the tree first checks whether the renovated pipe will be hydraulically adequate. If no, then replacement options are recommended, if yes, the next question relates to leakage. If the pipe does not have excessive leakage, then non-structural lining is recommended on the assumption that the hydraulic problems are caused by tuberculation etc. If the pipe does have excessive leakage, then replacement, semi/fully structural lining or joint seals are the listed options.

SECONDARY SELECTION FACTORS

In most cases the tree identifies a number of rehabilitation solutions which can restore and maintain the structural and hydraulic integrity of the pipe. However some of these solutions can be eliminated by comparing their application envelope and limitations with the operating conditions and geometry of the pipe. Other key selection criteria include:

- Horizontal and Vertical Bends – processes differ in their ability to negotiate manufactured bends.
- Maximum Installation length – can be a factor where access to the pipe is restricted.
- Site Footprint – size and amount of plant and surface space requirements for liner handling can be a factor in congested urban situations.
- Service Outage factors – some processes allow same day return to service which may remove the need for bypass/temporary supplies.
- Service Connections and fittings (branches, valves etc) – all semi/fully structural lining processes currently require local excavation to reinstate service connections and fittings, and the density of these has a major effect on costs.
- Standard of cleaning – some lining processes depend on achieving a high standard of cleaning and this can be difficult in some circumstances.
- Risk of damage from cleaning – processes such as epoxy and PU lining require aggressive cleaning methods which can damage pipe.
- Proximity of other utilities and structures – can be a problem with pipe bursting.

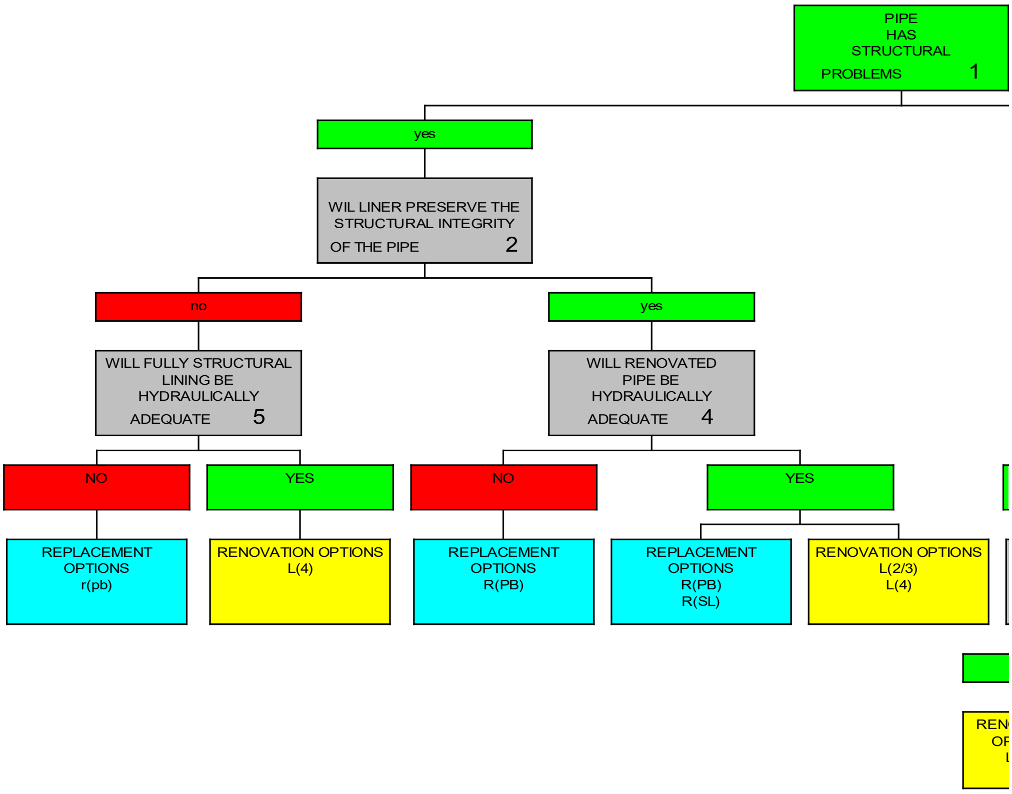
Application of these criteria will reduce the number of technically viable options to one or more trenchless technologies plus of course open cut replacement. The utility then has two alternatives:

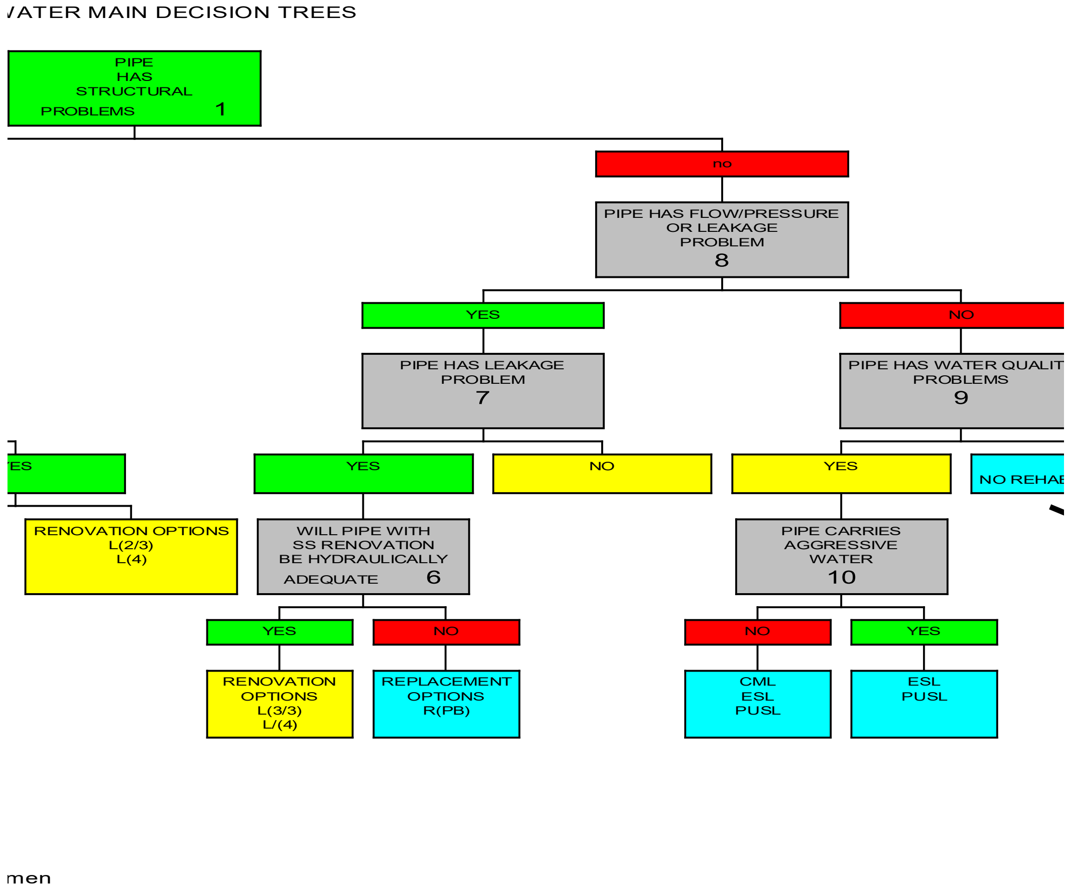
a) Continue with the selection process by comparing probable direct and social costs for each solution.

b) Allow bids based on use of any or all of the selected technologies and accept the lowest bid and hence the technologies on which that bid is based.

Utilities which have partnering arrangements with contractors have a third alternative, which is to require the contractor to choose the technology.

FIG 5.1WATER MAIN DECISION





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SEWER DECISION TREE – EXAMPLE

The method selection tree shown below was adapted from a tree used by a major city in the USA. Like the water main tree it works on the principle of eliminating methods based on answers to a series of questions, so that the technically viable solutions are those surviving at the end of the process. The questions relate to both system performance and pipe condition issues and to pipeline characteristics which influence method selection.

The first question relates to capacity and hydraulic performance, and would be answered on the basis of overflow/surcharge experience and hydraulic models. Inadequate capacity triggers selection of either conventional or trenchless replacement options, but little guidance is offered on the criteria for choosing between these.

The next question asks whether the only defects are leaks at joints and/or cracks. The answer to this would be based on both analysis of CCTV surveys and Infiltration/Inflow and/or exfiltration studies. A 'Yes' response prompts selection of local grouting or joint seals if joints are the main problem, and leak sealing methods if leakage is due to more general defects.

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Further questions used to eliminate rehabilitation methods include:

- The existence of bends
- The size of the pipe, man entry or smaller
- The possibility to divert flow or bypass
- The acceptability of external lateral reinstatement

Additional selection will depend on access, hydraulic capacity, structural condition, questions common to final method selection in many cases. The Sewer Renovation Selection Chart provides further specific information to inform the selection process.

FIG 3.4 SEWER REHAB DECISION TREE

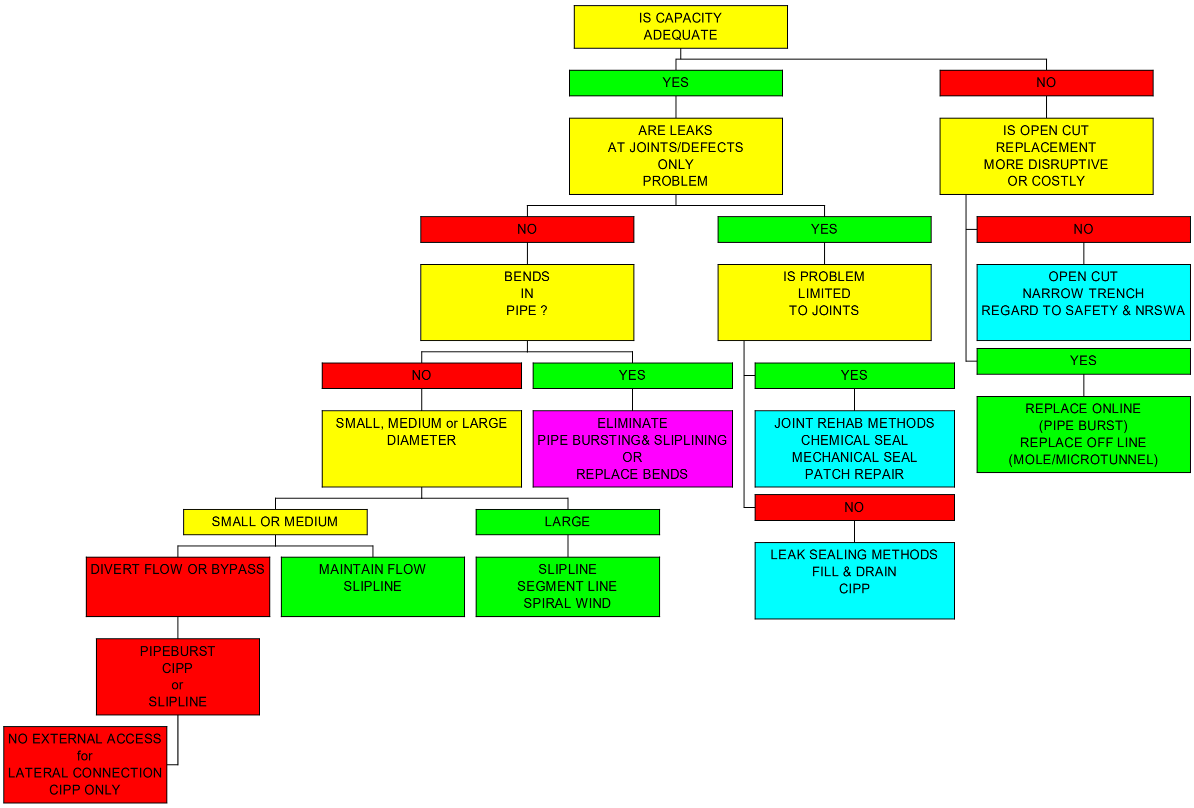

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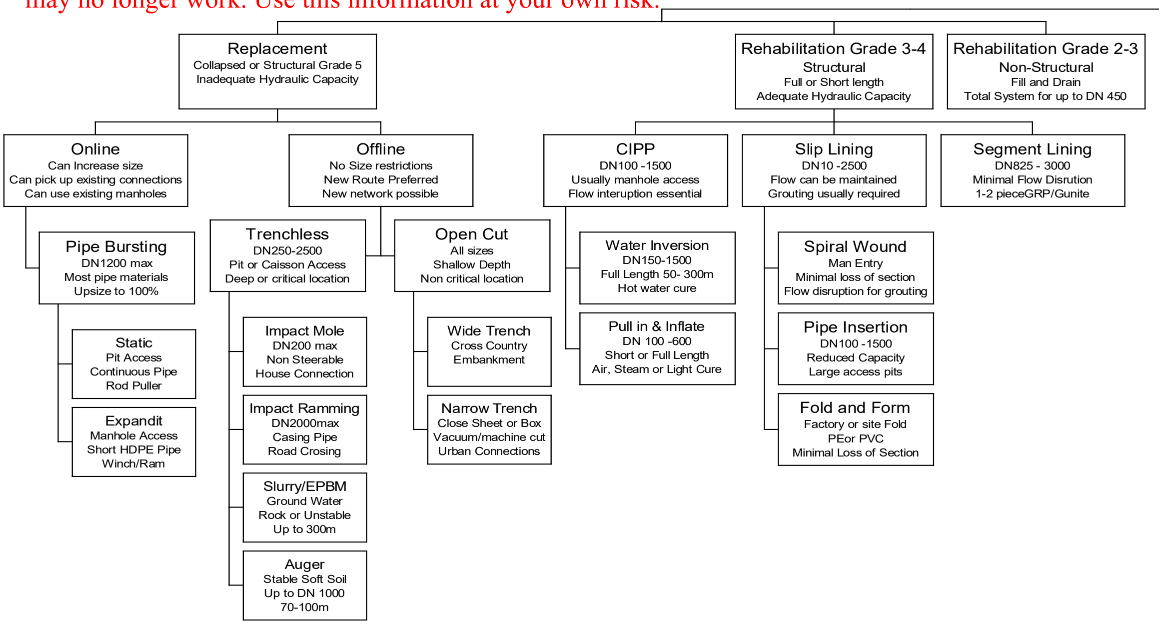
Fig 3.5 Sewer Renovation Selection Chart



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