Condition Assessment and Sewer Inspection (CASI) Methods – Guide Book

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Translated and modified from
Viemäreiden kuntotutkimusopas
Vesilaitosyhdistyksen monistesarja nro 50

Helsinki, Finland 2019

Distribution of original:
Julkaisun jakelu:

Vesilaitosyhdistys / Finnish Water Utility Association (FIWA)
Ratamestarinkatu 7 B
00520 Helsinki, Finland

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kotisivu www.vvy.fi

ISSN-L 2242-7279 (original, in Finnish)
ISSN 2242-7279 (original, in Finnish)

ISBN 978-952-6697-44-4 (original, in Finnish)

Helsinki, Finland 2019

DESCRIPTION SHEET			
Publisher	Finnish Water Utilities Association		
Author	Tiia Lampola, WSP Finland Oy Sakari Kuikka, SewCon Kuikka Oy		
Name and number of publication series	Publication series of Finnish Water Utilities Association n:o 50 (Vesilaitosyhdistyksen monistesarja nro 50)		
Subject of publicat-ion	Inspection methods for sewer pipes		
Availability	www.vvy.fi		
Abstract	Sewer inspections in Finland are mostly carried out using CCTV. Annually, less than 4 % of the total network length is inspected, which means that there is an approximate 25-year lifespan for a certain section of pipeline to be inspected. During that period, the condition of the sewers (and other pipelines) change considerably, with no repairing methods for breakages or inflow and infiltration being made. The renovation of pipelines is less than 0,5 % of the total length of water and sewer networks, meaning that the service life of a certain pipe section is as high as 200 to 300 years. This manual presents the condition assessment and sewer inspection (CASI) methods widely used globally. This information will increase both the amount and variability of inspection methods for water utilities, thus, improving the means of asset management. Also, the use of correct methods of inspection at the right time will help to focus on the accuracy and best ways for renovation, rehabilitation, and management actions. The tables of this manual present the most important and crucial aspects of the inspection methods. This will help water utilities, contractors, and consultancies to better assess managerial actions.		
Key words	Water supply, sewer inspection methods, asset management		
Financing	Finnish Water Utilities Association		
	ISBN 978-952-6697-44-4	*ISSN* 2242-7279	
	Pages 98	*Language* *Finnish*	*Confidentiality* *Public*
Distribution	Finnish Water Utilities Association, www.vvy.fi		
Print and year	Helsinki 2018		

KUVAILULEHTI			
Julkaisija	Suomen Vesilaitosyhdistys ry		
Tekijät	Tiia Lampola, WSP Finland Oy Sakari Kuikka, SewCon Kuikka Oy		
Julkaisun nimi	Viemäreiden kuntotutkimusopas		
Julkaisusarjan nimi ja numero	Vesilaitosyhdistyksen monistesarja nro 50		
Julkaisun teema	Viemäriverkkojen kuntotutkimukset omaisuudenhallinnan apuna.		
Saatavuus	Julkaisu on saatavissa Vesilaitosyhdistyksen verkkosivuilta.		
Tiivistelmä	Viemäriverkon kuntotutkimuksia tehdään Suomessa pääasiassa läpiajettavilla kameroilla, ns. CCTV-menetelmällä. Vuotuiset kuntotutkimusmäärät suomalaisilla vesilaitoksilla ovat tyypillisesti alle 4 % verkkojen kokonaismäärästä. Tämä johtaa siihen, että koko verkon tutkiminen kertaalleen vie yli 20 vuotta. Siinä ajassa verkkojen ominaisuudet ehtivät muuttua hallitsemattomasti, eikä esimerkiksi rikkoutumien ehkäisyyn ja vuotovesien hallintaan saada riittävästi tietoa. Verkkojen saneeraukseen kohdentuu vuosittain selvästi alle 0,5 % verkoista, mikä merkitsee sitä, verkon uusiutumisikä on tyypillisesti 200-300 vuotta. Tässä oppaassa tuodaan esille maailmalla käytettyjä kuntotutkimusmenetelmiä, joiden oikealla valinnalla saadaan lisättyä verkkojen kuntotutkimusmääriä nykyisestä, saadaan kohdennettua saneeraus- ja kunnossapitotoimenpiteet oikein ja tehokkaammin sekä saadaan arvokasta ja luotettavaa tietoa vesilaitosten omaisuudenhallinnan avuksi. Oppaassa on taulukoissa esitetty tärkeimmät ja keskeisimmät kuntotutkimusmenetelmiin liittyvät asiat, sisältäen mm. kunkin kuntotutkimustyypin käytön reunaehdot ja sovellettavuus verkkojen kuntotutkimuksissa. Lisäksi oppaassa on esitetty erilaisiin tarpeisiin soveltuvia menetelmiä.		
Avainsanat	viemäriverkot, kuntotutkimukset, omaisuudenhallinta		
Rahoittaja/ toimeksiantaja	Suomen Vesilaitosyhdistys ry		
	ISBN 978-952-6697-44-4	*ISSN* 2242-7279	
	Sivuja 98	*Kieli* suomi	*Luottamuksellisuus* Julkinen
Julkaisun jakelu	Vesilaitosyhdistys, www.vvy.fi		
Painopaikka ja -aika	Helsinki 2018		

BESKRIVNINGSBLAD			
Publicerat av	Finlands Vattenverksförening r.f.		
Författare	Tiia Lampola, WSP Finland Oy Sakari Kuikka, SewCon Kuikka Oy		
Publikationens titel	Guidebok om inspektion metoder för avlopp nätet		
Publikationsseriens titel och nummer	Vattenverksföreningens duplikatserie nr 50		
Publikationens tema	Inspektion metoder av avlopp för förvaltning av vattenförsörjning		
Tillgänglighet	Publikationen finns på Vattenverksföreningens webbsida.		
Sammanfattning	Avloppsnätet i Finland inspekteras oftast med en CCTV utrustning. Årliga inspektioner av rörledningar i det allmänna nätet är idag mindre än 4 %. Det innebär att rör inspekteras ca. var 25:e år. Under denna tid försämras avloppsnätet avsevärt och sprickor i rören leder till vattenläckage. Förvaltning av avlopps- och vattenledningar är klart mindre än 0,5 %, och betyder att det tar 200 till 300 år för att rör ska bli renoverade. Den här manualen presenterar flera olika rörinspektionsmetoder som används världen över. Med tillräcklig och högklassig information kan man välja den metoden som passar för ett specifikt rör. Med rätt taktik förbättras metoderna för att inspektera avlopps- och vattenledningar. Samtidigt får man mer information och förståelse för förvaltning av vattenförsörjningen. I de tabeller som man kan finna i den här manualen finns de mest viktiga och huvudsakliga metoderna för inspektion av avlopps- och vattenledningar.		
Nyckelord	avlopp nätet, kondition inspektion, förvaltning av vattenförsörjning		
Finansiär/ uppdragsgivare	Finlands Vattenverksförening r.f.		
	ISBN 978-952-6697-44-4	*ISSN* 2242-7279	
	Sidantal 98	*Språk* finska	*Konfidentialitet* offentlig
Distribution av publikationen	Vattenverksföreningen, www.vvy.fi		
Tryckort och år	Helsingfors 2018		

KURZBESCHREIBUNG	
Herausgeber	Vereinigung der Finnischen Wasserversorgungsbetriebe
Autoren	Tiia Lampola, WSP Finland Oy Sakari Kuikka, SewCon Kuikka Oy
Name und Nummer der Serie von Veröffentlichungen	*Serie von Veröffentlichungen* der Vereinigung der Finnischen Wasserversorgungsbetriebe Nummer 50 (Vesilaitosyhdistyksen monistesarja nro 50)
Gegenstand der Veröffentlichung	Methoden der Inspektion von Abwasser-Kanälen
Vertrieb	www.vvy.fi
Abstrakt	Die Inspektion von Abwasser-Kanälen erfolgt in Finnland meist in Form einer „CCTV Inspektion“. Pro Jahr werden weniger als 4 % des gesamten Kanal-Netzes inspiziert. Dies bedeutet, dass es bis zu 25 Jahren dauern kann, bis eine bestimmte Haltung untersucht wird. Während dieser Zeitspanne kann sich der Zustand einer bestimmten Leitung unkontrolliert verändern. Auch werden keinerlei Reparaturen für Beschädigungen oder Wasser-Ein- oder -Austritt während dieser Zeit vorgenommen. Weniger als 0,5 % der Gesamtlänge der Wasser- und Abwasser-Leitungen werden pro Jahr saniert, dies bedeutet, dass die Lebensdauer einer bestimmten Leitung ca. 200 bis 300 Jahre beträgt. Dieses Handbuch beschreibt die Zustandsprüfungen und Inspektionsmethoden, welche weltweit überwiegend eingesetzt werden. Damit wird für die Wasserversorger sowohl die Zahl also auch die Vielfalt der Inspektions-Methoden erweitert und somit die Möglichkeiten zur Netzwerk-Verwaltung verbessert. Auch das Wissen, welche Inspektions-Methode die richtige zum richtigen Zeitpunkt ist, verbessert den Fokus für die bestmögliche Reparatur oder Sanierung und weitere Planungs-Maßnahmen. Die Kapitel dieses Handbuch beschreiben die wichtigsten und entscheidenden Aspekte der Inspektions-Methoden. Hiermit können Wasserversorger, Kanal-Sanierungsfirmen und Ingenieur-Büros ihre Planungs-Maßnahmen effizienter und wirksamer durchführen.
Schlüssel-Begriffe	Wasserversorgung, Inspektion von Abwasser-Kanälen, Anlagenverwaltung
Finanzierung	Vereinigung der Finnischen Wasserversorgungsbetriebe
	ISBN 978-952-6697-44-4 · *ISSN* 2242-7279
	Seiten 98 · *Sprache* Finnisch · *Vertraulichkeit* Öffentlich
Vertrieb	Vereinigung der Finnischen Wasserversorgungsbetriebe, www.vvy.fi
Druck	Helsinki 2018

Contents

PREFACE

The “Condition Assessment and Sewer Inspection (CASI) methods” introduces current approaches that include and expand on the various ways in which to support water utilities for efficiently managing sewer and storm water sewer systems. The CCTV inspection is the most widely used method and their techniques, along with others, are outlined to demonstrate how to make condition assessment and sewer inspections (CASI) more efficient and reliable. New methods are not presented here to replace CCTV inspections but to increase the quantity of inspections and to help to better focus them. Also, with the new methods, it is possible to gain information faster for a better classification of the systems and by doing so, operational information of the systems can be obtained that can then be used, for example, to control and increase a system’s capacity issues.

Annually, less than four percent of the sewer system’s total length is inspected in Finland, which means that it takes more than 25 years to inspect each pipe once. The cost-benefit ratio is often quite low, since approximately 60 % of inspected pipelines are in good condition. The structural condition of pipes is not observed with CCTV; therefore it would require additional means to inspect them.

This guide pinpoints the effectiveness and quality control of pipeline pre-washing, which is required before the CCTV inspection. If the pre-wash process is inefficient it may increase inspection costs up to four times higher than usual.

The new pipeline inspection methods bring greater value to the asset management process for water utilities. Internationally, much research and development has been made in this field, resulting in new models and ways of inspecting sewer pipelines.

The transfer and management of data are very important features for water utilities as well. Under Finnish law (Water Services Act 119/2001) it is required of water utilities to be aware of, to control and, to manage their data systematically.

Official plans for training as well as for controlling and maintaining lists of competent persons in sewer and storm water system inspections must also be created and managed. This requires more detailed discussions between Finnish organizations, such as the Finnish Water Utilities Association (FIWA), the Ministry of the Environment, and schools, colleges, and universities.

This guide does not require or suggest changes to the CEN-standard and the Finnish guide from which it is based (“Viemäreiden TV-kuvauksen tulkintaohje”, *in Finnish*).

FIWA is responsible for keeping the original guide (“Viemäreiden kuntotutkimusopas”, *in Finnish*); updated by summoning experts within this field regularly.

1 INTRODUCTION

1.1 CURRENT SITUATION OF SEWER INSPECTIONS

There are approximately 50,000 km of sewers in Finland. The average age of a pipe network varies a lot. For example, in the Helsinki Region Environmental Service Authority's (HSY) area of operation the age of a pipe is approximately 36 years. The majority of sewer networks have been built since the end of WWII, in the 1950s to 1970s. According to the Finnish Water Utilities Association (FIWA), up to 80 to 90 % of water utility capital investment is given to water, sewer, and storm water network pipes (VVY, 2001; Välisalo et al. 2008).

Less than four percent of the total length of water supply pipelines are inspected annually, and renovation/rehabilitation actions even less frequently. The total volume of renovation/rehabilitation has declined from 2014 to 2016 for more than 50 % (Mika Rontu, FIWA, personal communication), which is very alarming. Also, the data from any type of network information systems, including data management, is quite often poor (Välisalo et al. 2008).

Condition assessment and sewer inspections (CASI) should be conducted within the intervals as determined by earlier sewer inspections. The first CASI should be conducted, and data saved, at the point of commissioning and acceptance. During the process of this guide, over a dozen experts in the field of CASI were interviewed, resulting in many different options for the length of the interval. A German study (Müller, 2007) recommends the first interval after acceptance to be 10 to 20 years. Inspection should also be conducted after the period of guarantee (typically two years in Finland). Inspections conducted at the beginning of the pipe's operation life are essential, since the data and information need initial-condition data (e.g. Ahmadi et al. 2014; Ahmadi et al. 2015). Table 1.1 shows an example of inspection intervals in a newly built pipeline (water, sewer, storm water) from the beginning to the end of its service life. Older pipelines (e.g. built in 1960s or 1970s), which have not been inspected at any time, have their own CASI intervals, which are shown in Table 1.2.

Tables 1.1 and 1.2 can be used to estimate the time intervals between CASI events. Below are also some examples of CASI's intervals. The service life of a pipeline is affected by several aspects, such as the properties of the pipe, soil, traffic, vegetation, a sewer water's quality and quantity, and so on. CASI should be considered as a continuous process with continuous data updates and management.

Table 1.1. New pipe: sewer inspection time intervals.

Time stamp, years	Explanation	Significance
0	Inspection of commissioning and acceptance	Initial data of the pipeline's condition. Subsequent inspections can be compared to this point. Data is saved, documented, and managed.
+ 2	Inspection after the period of guarantee is done.	Make sure that the pipeline is still in good (newly built) condition. If this is not the case, reparation is to be made and documented. Data is saved, documented, and managed.
+ 10	The first systematic inspection.	Data is saved, documented and managed. Analysis based on comparison of the earlier inspections.
Either: + 2 + 5 + 10	The second systematic inspection is made based on the earlier observations.	Data is saved, documented and managed. Analysis based on comparison of the earlier inspections.
Same as above. Continued until the service life is over.	Further inspections. Data updates, increases, and will be analyzed.	Data is saved, documented and managed. Analysis based on comparison of the earlier inspections.
End of service life.		Data is saved, documented and managed. Analysis based on comparison of the earlier inspections. Data and information is analyzed to improve asset management actions in other pipelines.

Table 1.2. Old pipelines with no prior-inspections .

Time stamp, years	Explanation	Significance
NOW	The first inspection of the pipeline.	Initial data of the pipeline's condition. The latter inspections can be compared to this point. Data is saved, documented, and managed.
either: + 2 + 5 + 10	The second systematic inspection is made based on the earlier observations.	Data is saved, documented and managed. Analysis based on comparison of the earlier inspections.
Same as above. Continued until the service life is over.	Further inspections. Data updates, increases, and will be analyzed.	Data is saved, documented and managed. Analysis based on comparison of the earlier inspections.
End of service life.		Data is saved, documented and managed. Analysis based on comparison of the earlier inspections. Data and information is analyzed to improve asset management actions in other pipelines.

Example 1. Concrete pipe (cylindrical), DN 300 mm, soil not frozen, only a small traffic load. Sewer inspections are conducted at:

- 0 years – the point of commissioning and acceptance, initial CASI;
- 2 years – after the period of guarantee;
- 12 years – systematic CASI – data is analyzed and follow-up period is approximated (in this example, no defects were found);
- 22 years, 32 years, 42 years etc., until the end of service life is reached;
- 79 years, end of service life following rehabilitation/renovation with an appropriate method.

Example 2. Concrete pipe (cylindrical), DN 300 mm, soil prone to freeze, mediocre traffic load. Sewer inspections are conducted at:

- 0 years – the point of commissioning and acceptance, initial CASI;
- 2 years – after the period of guarantee;
- 12 years – systematic CASI – data is analyzed and follow-up period is approximated (in this example, defects – such as small fractions – were found);
- 17 years (status quo);
- 22 years (small fractions enlarged, also some inflow appeared from joints):
  - the larger defects are repaired, another inspection is made to ensure quality;
- 27 years, 32 years etc., until the end of service life is reached;
- 50 years, end of service life following rehabilitation/renovation with an appropriate method.

Example 3. Concrete pipe (cylindrical), DN 300 mm, soil prone to freeze, mediocre traffic load. Sewer inspections are conducted at:

- 0 years – the point of commissioning and acceptance, initial CASI;
- 5 to 10 years – systematic CASI – data is analyzed and follow-up period is approximated;
- 15 years, 20 years etc., until the end of service life is reached;
- 22 years after the first inspection, end of service life following rehabilitation/renovation with an appropriate method.

CASI methods vary greatly from city to city and from town to town. This pinpoints the need to make stronger guidelines for inspection methods, terminology, condition classification, and rehabilitation/renovation methods. If the network information is high in quantity and it is geographically coded, the affects from a lack of data are minimal (Ahmadi et al. 2014; Ahmadi et al. 2015).

Figure 1.1 illustrates schematic outline of pipeline inspection (European Committee for Standardization, CEN, 2008).

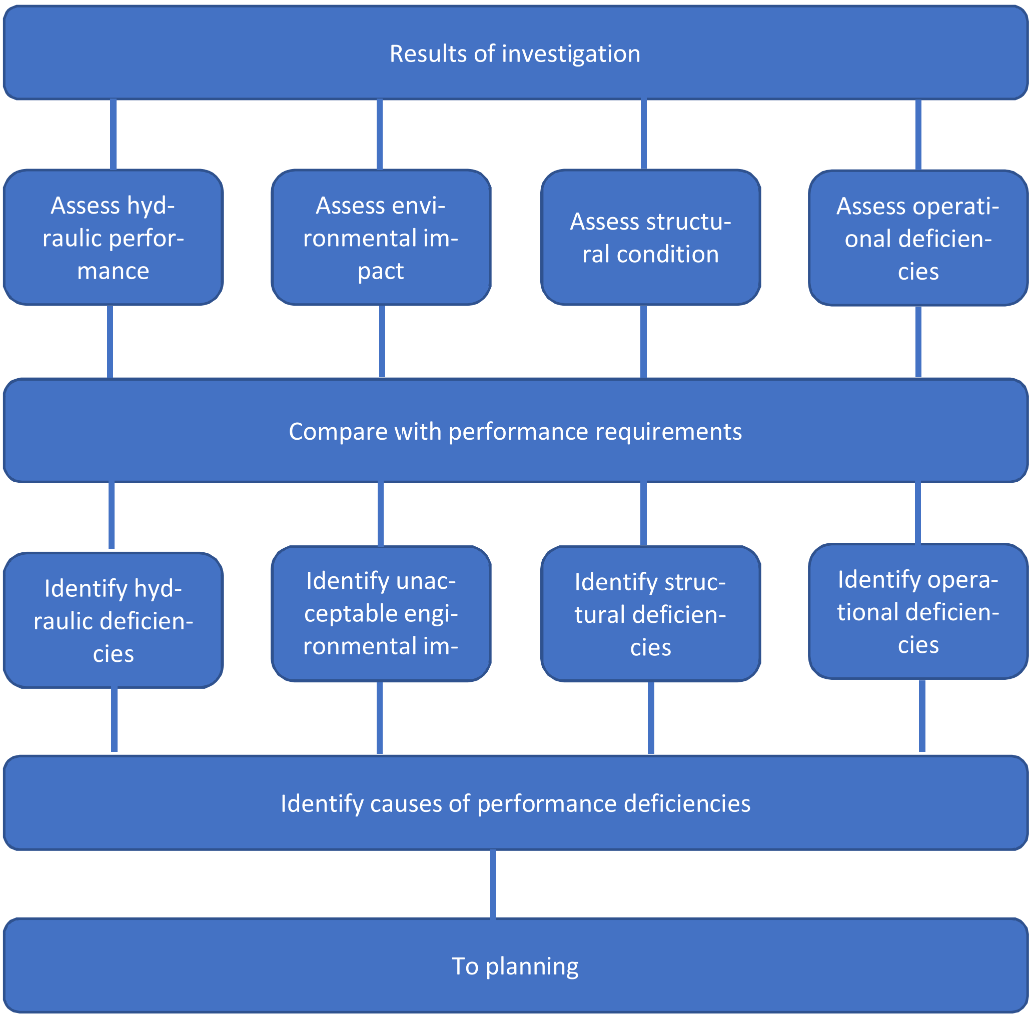


Figure 1.1. Process assessment for pipeline inspections (CEN, 2008).

Asset management and operational management needs at minimum, data from a pipeline's condition, its length, build date, material, and diameter. To assess the life cycle of a pipeline it is essential to obtain information about the installation method and its internal properties (Välisalo et al. 2008; Park & Kim, 2013; Laakso et al. 2015).

CASI for water utilities are made to improve: (i) budgeting and investments; (ii) fulfillment of legislation requirements; (iii) information for clients; (iv) information for critical parts of pipeline networks; (v) control of inflow and infiltration (I/I); (vi) planning process; and (vii) quality initial data for hydraulic modelling and prognoses.

One important factor, which supports the need for appropriate CASI methods, is the debris found in any pipeline. Figure 1.2 illustrates the effective capacity and design capacity of a pipeline (Rowe et al. 2004).

Figure 1.2. Illustration of the effective capacity and design capacity of a pipeline (Rowe et al. 2004).

1.2 ASSET MANAGEMENT OF WATER SUPPLY NETWORKS IN FINLAND AND IN OTHER PARTS OF THE WORLD

Even though water supply networks are an integral part of a city's infrastructure, asset management aspects of the networks have been quite inadequate and or insufficient in Finland (Välisalo et al. 2006). Also, risk assessments (Stone et al. 2002; Ana & Bauwens 2007; Halfawy et al. 2008; Stanić et al. 2012; Välisalo et al. 2013), critical assessments (Laakso et al. 2015) and other asset management, condition management and renovation management actions are scarcely used by Finnish water utilities. Table 1.3 lists key factors in Finnish water utilities' asset management aspects (Vaattovaara & Sipilä, 2005). Often the age and information of CCTV inspection are the only data obtained from sewers, which can result in incomplete information from the pipelines (Fenner, 2000; Stone et al. 2002; Ana & Bauwens 2007).

The age of the pipelines has been found to be an inadequate evaluation in the asset management process (Stone et al. 2002; McKim & Sinha, 1999; Ana & Bauwens 2007; Ana et al. 2009; Anderson et al. 2015). However, the most effective aspects are age, material, length, flow, debris, history of blockages, corrosivity of the soil, quality of the sewage, and height of ground water (Ana et al. 2009).

CCTV inspection alone is not able to produce enough data or enough reliable information of non-visual qualities of a pipeline (Nederlands Normalisatie-instituut 2003; Deutsche Vereinigung für Wasserwirtschaf 2006), such as structural condition or a theoretical life span. This means that often the decisions are made with poor, incomplete information since, in most of the cases only some of the structural information is available (Elachachi et al. 2006). The physical condition of pipelines, including recording, documenting and analyzing the data frequently, is maybe the most important data for asset management in water utility networks (McKim & Sinha, 1999). When a sewer inspection is made frequently and with the appropriate methods, most of the acute problems in the pipelines can be avoided (Kienow & Kienow, 2009).

Table 1.3. Asset management in Finnish water sector (Vaattovaara & Sipilä, 2005).

Water sector and asset management	• Physical capital assets comprise of large volumes, and there is no general information on its current condition. • Water sector is mainly in hands of municipalities. • Replacement investments have been very low. • Water and sewer pipes are over-sized. • A significant portion of experts in water sector are retiring soon.
Water sectors challenges and changes	• Water utilities are fewer but their size of operation is bigger. • Regional water sector. • Fusion of energy and water sector. • Privatisation of water utilities. • Growing need for renovation and rehabilitation. • More regulation in water sector. • More requirements for purification efficiency. • New concepts and financing.
Globalisation, pros and cons	• Undeveloped domestic market. • Research and development too small. • Great need for renovation and rehabilitation of assets. • Technologic level low in comparison to international companies.
Business and development of technology	• Business thinking and know-how are needed. • Development of new cooperation models. • Condition assessment, pipeline inspections, and rehabilitation/renovation technologies must be enhanced. • Data management and transfer must be developed further.

The slope (gradient), and especially negative slope (back slope) causes several problems in sewers. Current widely-used visual inspection methods do not necessary produce enough information in this area. A backward sloping section along a pipeline often has more debris or fat, oil, and grease (FOG) compounds. Figure 1.3 illustrates some typical sections of pipelines in sewers (Dirksen et al. 2014).

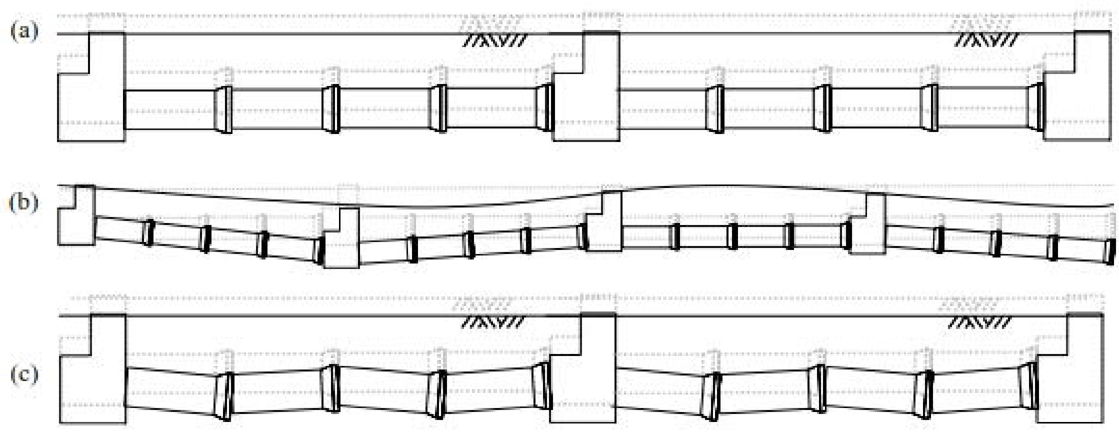


Figure 1.3. Illustration of three different sewer layouts (Dirksen et al. 2014).

Sewer deterioration models can be put in three main classes (Yang 2004): (i) physical models; (ii) AI models; and (iii) statistical models. Chapter 3.1 describes such models in more detail. Within the water utility sector, a heavier focus is often in risk management and asset management. For example, criticality assessment can be used, and the network can be classified as a whole unit for operational and rehabilitation management actions (Miles et al. 2007; Worthington & Homer, 2007; Kley & Caradot, 2013; Kley et al. 2013; Baah et al. 2015; Laakso et al. 2015).

The most often used sewer deterioration methods are based on network information alongside condition assessment inspections and historical reports. The newest methods use information from AI or self-learning, such as the decision tree method. The decision tree method has been found to be reliable tool for asset management for a medium-sized water utility (Winkler et al. 2018).

Globally, asset management of water supply networks has been under strong development for several years now (AWWA, 2001; Hafskjold et al. 2003). A focus on the needs of asset management has also been studied in Finland (Välisalo et al. 2008), with limited results so far. Figure 1.4 illustrates the socio-economic and environmental consequences from the defects of water supply network.

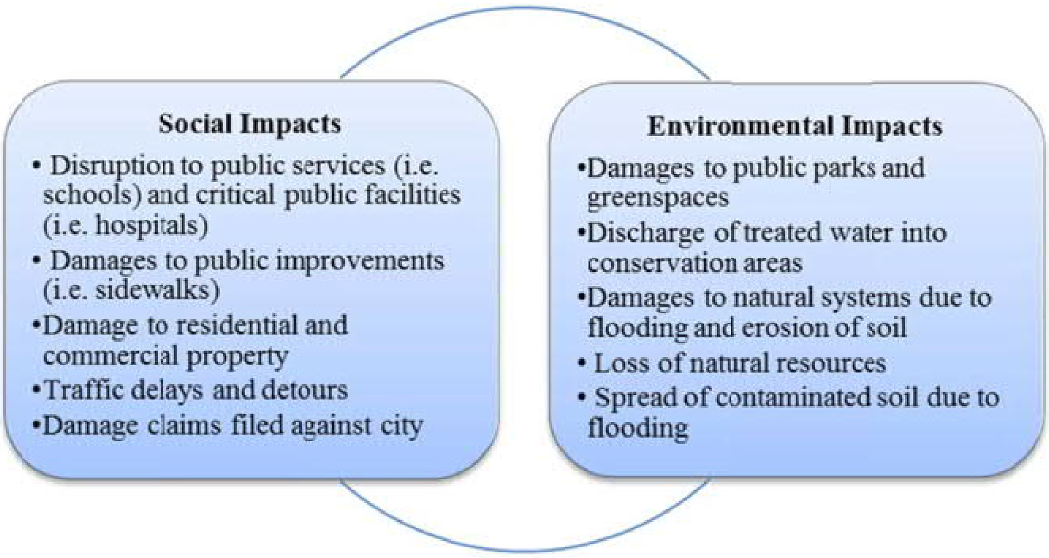


Figure 1.4. Social and environmental impacts of pipe failures (Ortega & Ross, 2012).

The One-Voice project, made in the US, aims to increase the knowledge of sewer pipelines and networks in order to achieve a better asset management, sufficient information regarding the condition of pipelines, an increase in pipeline owners' awareness, and the processes which cause pipeline deterioration. One-Voice helps all parties in data assessment, data management, collaboration, and condition assessment methods (Lewis et al. 2016).

The European Hydroplan-EU project aims at an increase in awareness of asset management in Europe. In the project, the Hydroplan-EU tool was piloted on a water utility's system (de Gueldre et al. 2007).

In Washington, D.C., a study of sewer condition assessment inspection methods, rehabilitation and renovation was undertaken. The study showed that the level of rehabilitation of sewer networks must be increased to almost double its current level based on a risk assessment evaluation. It was also found that the fewer the data and information for a given network, the worse less-accurate the asset management of pipelines would be (Anderson et al. 2015).

When asset management takes place, important questions to be considered are (Marlow et al. 2007): (i) what are the consequences if the pipeline is damaged? (ii) how much will renovation/rehabilitation cost?; (iii) what are the options?

Table 1.5. The expected life cycles of different sewer pipe materials, in years (Anderson et al. 2015; Kaukonen, 2018).

Material	USA	Finland
Asbestos cement (AC)	125	40-100
Brick (BR)	125	100
Cast Iron (CI)	75-100	up to 150
Concrete (reinforced)	75-100	75-100
Concrete (not-reinforced)	100	75-100
Corrugated steel	50	up to 120
Ductile iron	75-100	up to 150
HDPE	50	50-100
PVC	50	50-100
Steel iron	75-100	100

Data collection, management and usability requires planned actions also from the water utilities (Møller Rokstad et al. 2016). In Table 1.6 are listed the required information of pipelines (and their materials) during the expected life cycle (Stanić et al. 2012).

Table 1.6. The data required of a pipeline during the expected life cycle (Stanić et al. 2012).

	As built - pictures	Soil composition	Condition assessment	Observations from field
Location	x	x	x	x
Backfilling	x	x		
Funding of pipe	x	x		
Connections and joints	x		x	
Material	x			
Structural deterioration			x	
Ground water level				x
Roots in the pipes		x	x	x
Traffic load			x	x

Condition assessment I/I, CSO and SSO control

Inflow and infiltration (I/I) control is important in sewers, which may contain as much as 15 to 80 % of external water. I/I can dilute sewage water causing problems with the treatment processes at waste water treatment plants. The increased amount of sewage also increases pumping needs, resulting in a higher consumption of electricity and requires higher-volume sewer pipelines. Also, the amount of combined or separated sewer overflows (CSO and SSO, respectively) is affected by the amount of I/I in the sewer system (Karpf & Krebs, 2003; Kretschmer et al. 2008).

The I/I in the sewer network may be affected by the age of the pipeline, type of pipeline, level of ground water, location of the pipeline, etc. The methods with which the pipeline is built or inspected might also affect whether I/I is actually occurs or not (Dent et al. 2003).

When I/I is controlled, it is very important to prioritize rehabilitation/renovation and operational management actions (Dutt, 2003).

1.3 CAUSES OF PIPELINE DEFECTS

The defect of sewer systems causes many consequences (Table 1.7, Hahn et al. 2002).

Table 1.7. Summary of knowledge base (Hahn et al. 2002).

		Likelihood of failure					
		Overall Structural Defects					
Consequence of failure			MATERIAL DEGRADATION			Overall Operational Defects	
Socio-Economic Impacts	Reconstruction Impacts	STRUCTURAL DEFECTS	Interior corrosion	Exterior corrosion	Erosion	INFILTRATION	OPERATIONAL DEFECTS
Human health	Tunneling	Installation history	Material	Material	Material	Structural defects	Known root problems
Environmental	Resurfacing costs	Material	Wastewater temperature, BOD and corrosive chemicals	Soil acidity	Presence of debris	Soil type	Trees above line
Commerce	Access Redundancy	Age	Pipe structure	Stray currents in ground	Natural stream intake	Groundwater levels	Known debris problems
Traffic		Soil type	Wastewater velocity	Exterior coatings	Previous inspection assessment	Previous inspection assessment	Known overflows
		Groundwater levels	Previous inspection assessment	Cathodic protection			Known surcharging
		Surface loads		Previous inspection assessment			Previous inspection assessment
		Exfiltration					
		Previous inspection assessment					

Stanić et al. (2012) studied and listed comprehensively, factors in soil affecting and deteriorating the pipelines (Table 1.8). Table 1.9 lists typical defects in sewers (Thomson et al. 2004).

Table 1.8. Classification of the possible causes of ingress of soil and their information requirements (Stanić et al. 2012).

2.4. Ingress of soil	Cause	Information needed on cause	Where to get information
2.4.1. Improper pipe positioning	- improper quality of backfill	1. soil characteristics of backfill	a. from the constructor b. from the measuring
	- lack of supervision	1. who and if there was supervised	a. from the municipality
	- pipes barely connected	1. position of pipes	a. from the constructor b. from the inspection
2.4.2. Damaging during refilling/compaction	- cores material in backfill	1. soil characteristics of backfill 2. how it was compacted	a. from the constructor
	- lack of supervision	1. who and if there was supervised	a. from the municipality
2.4.3. Improper bedding/foundation	- improper consolidation of bedding	1. characteristics of bedding	a. from the constructor
	- improper foundation	1. soil characteristics of foundation	a. from the constructor
	- lack of supervision	1. who and if there was supervised	a. from the municipality
2.4.4. Wrongly constructed connections/joints	- lack of professionalism during construction	1. as-built report 2. inspection results	a. from the constructor
	- lack of supervision	1. who and if there was supervised	a. from the municipality
	- improvisation due to local conditions	1. as-built report 2. inspection results	a. from the constructor
2.4.5. Improper choice of pipe and joint type/material	- un/experienced engineers	1. checking of design protocol	a. inside the design company
	- lack of quality check	1. checking of final report	a. from the contractor
	- lack of appropriate data	1. checking the quality of initial data necessary for the design	a. sources of initial data: (e.g. material → manufacture)
2.4.6. Weakened structural elements	- low strength properties of plastic pipes	1. deformation of pipes	a. from the inspection (e.g. CCTV)
	- sever pipe deterioration	1. sever cracks, pipe brakes, infiltration	a. from the inspection (e.g. CCTV)
2.4.7. Groundwater table	- high groundwater table	1. measurement of groundwater table	a. from the measuring (ground water table)
	- aggressive ground water	1. ground water quality	a. from the measuring
2.4.8. Type/position and maintenance of trees in the area	- trees with deep roots	1. type of trees	a. from the local community
	- trees located close-by the sewer	1. location of trees	a. from the local community
	- good soil conditions	1. soil conditions	a. from the measuring
2.4.9. Inappropriate load transfer	- improper traffic load	1. nature and density of the traffic	a. from the municipality
	- load due to construction around the sewer	1. if proper measures were taken during construction 2. structure conditions	a. from the constructor b. from the inspection

Table 1.9. Typical defects of sewer pipes (Thomson et al. 2004).

Defect	C	AC	PCCP	CI	S	CL	Br	PVC	HDPE
Roots	x	x	x	x	x	x	x		x
FOG	x	x	x	x		x	x	x	x
Cracks	x	x				x			
Inner corrosion	x	x	x	x	x				
Outer corrosion			x	x	x				
I/I	x	x		x		x		x	
I/I of joints	x		x		x				
I/I of house connections				x					x
Wrong procedure				x				x	x
Wrong connection procedure		x		x		x			
Deformation					x			x	x
Other	1						2	3	4

C = Concrete, AC = Asbestos Cement, PCCP = Pre-stressed Cylindrical Concrete Pipe, CI = Cast Iron, S = Steel, CL = Clay, Br = Brick, PVC = PVC plastic, HDPE = High-Density PolyEthene, 1 = Seal defect, 2 = Missing bricks, 3 = House Connections, 4 = Pressure testing

1.4 A NEED TO UPDATE GUIDE BOOKS

Three guide books (*in Finnish*), ”Viemäreiden ja vesijohtojen TV-kuvauksen teettämisohjeet” (Guidelines to pipeline inspections. VVY, 1998), ”Viemäreiden TV-kuvauksen tulkintaohje” (Interpretation of CCTV inspections. VVY, 2005) and ”Viemärikaivojen kuntotutkimusohje” (Guidelines for manhole inspections. VVY, 2013), were published in Finland prior to this guide book. These books introduce only some of the methods and tools available for inspections in the sewer condition assessment process. Up-to-date information is therefore needed to improve and increase information and knowledge of CASI methods here in Finland. All the above-mentioned books need updated, more recnt projects to increase their usability in water utilities, cities, towns, and municipalities.

The CCTV method has been used in Finland since the end of 1970s. Previously published guide books are partly outdated and are somewhat narrowly focused. The need to update old guide books has been recognised by water utilities and the FIWA.

This guide presents new methods and tools for sewer (and other water supply pipeline) CASI. These tools allow for a more efficient and real-time CASI approach for water utilities, planners, contractors, municipalities, etc. The Standard SFS-EN 13508-2 describes the interpretation guidelines for CCTV inspections, and this guide book focuses more on describing the different techniques.

Several countries have updated their guide books for sewer pipeline inspection methods, such as Austria (Gangl et al. 2007), Norway (Norske Vann, 2018), USA (Feeney et al. 2009), and Australia (Queensland Government A ja B). In Germany, there are reports published which focus on mathematical deterioration models and coding of observations (defects) (Kley & Caradot, 2013; Kley et al. 2013). All above-mentioned guide books have kept updated knowledge in the field of sewer inspections. Those guide books have been used as references throughout this book.

International literature has lots of studies that analyse the CCTV inspection method: its pros and cons. Many studies have found that manual and visual inspection methods have many limitations and faults that should be settled in order to improve and increase both the quantity and quality of sewer inspections made today. Such limitations include human errors, machine errors and process deficiencies.

German studies (Hüben, 2002; Müller, 2006) found that the sewer inspection process produces highly variable results, despite the level of expertise the operator has. Figure 1.5 illustrates how the results and observations vary on a study in which 307 experts inspected the same pipeline (Müller, 2006). In that study, more than half of the results were at least somewhat different than the “actual” result.

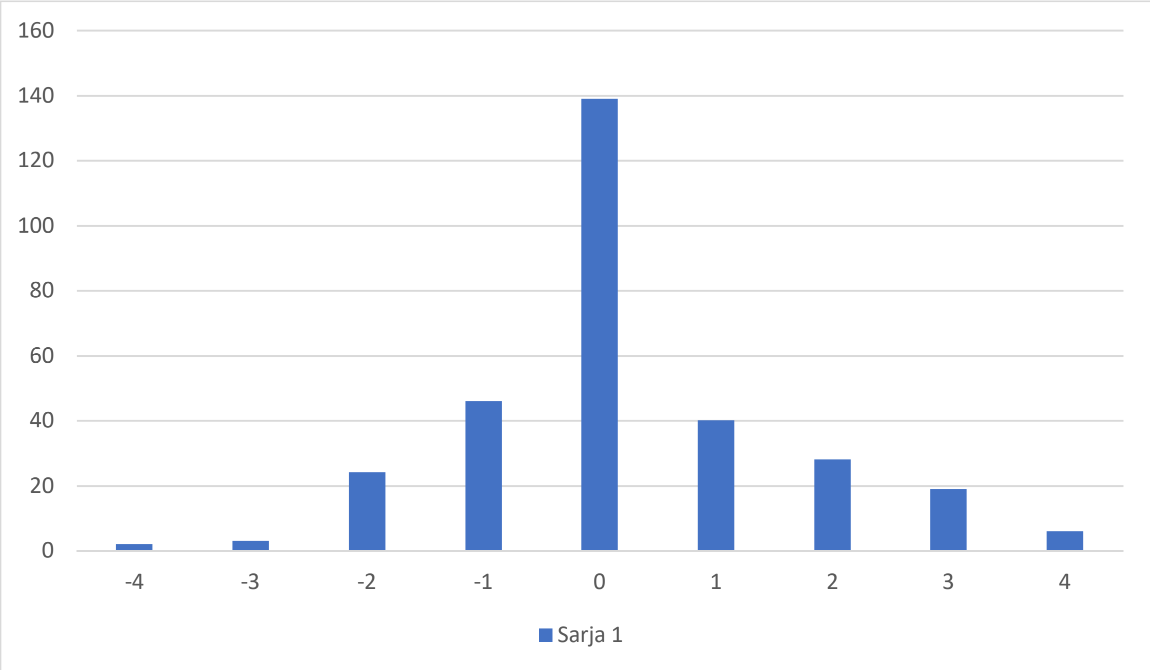


Figure 1.5. Variability of results and observations of 307 experts’ inspections (Müller, 2006).

An Austrian study showed that the variability of different companies’ results were big, even though the education of operators was similar (Figure 1.6, Gangl et al. 2007). This study showed that parts of the results and observations were insufficient and even wrong, and no company reached the expected quality level of 80 % of inspected pipelines.

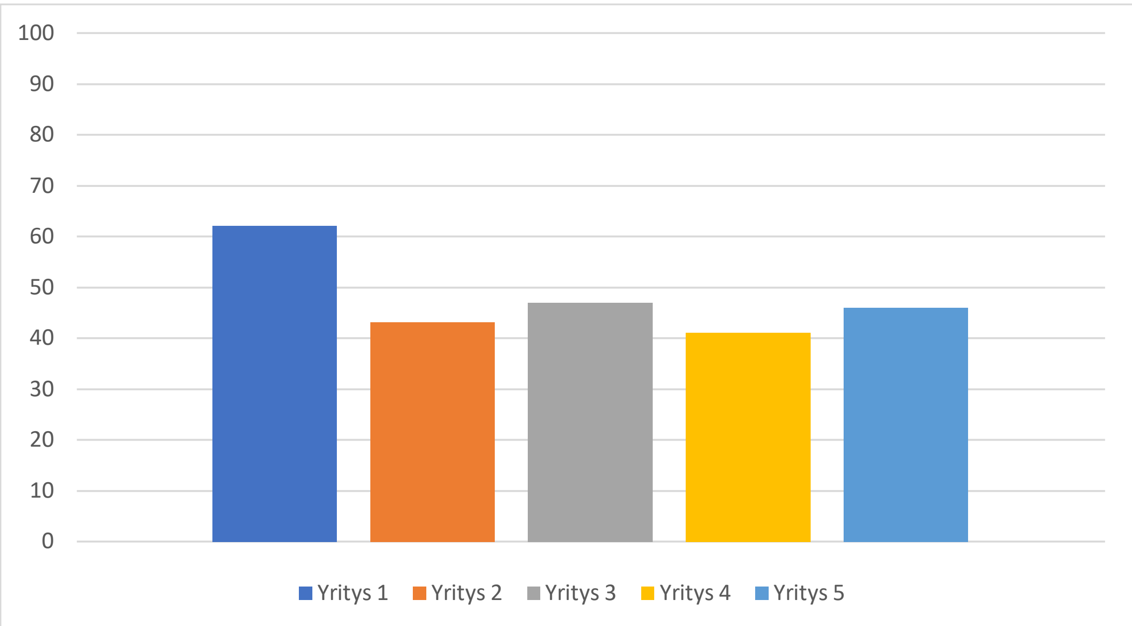


Figure 1.6. Variability between operator companies in Austria (Gangl et al. 2007).

A condition assessment of sewer pipelines has been under serious study to improve methods and tools for asset management (e.g. Makar, 1999; Allouche & Freure, 2002; Costello et al. 2007). These studies show that there is no single method/bundle of methods that cover all possible physical and chemical problems in sewers. It is very important to notice that there may be needed, several different combinations for CASI in one certain area. This guide book reviews and presents many methods and tools and their combinations for different needs.

Comprehensive knowledge and information is needed for engineers, politicians, etc. to get the best out of CASI along with reliable data, principles of planning, and economical values (Vanier, 2001).

The renewal age in Finnish water utilities varies from hundreds to even thousands of years, and it is highly dependable on tools with which the estimate is calculated (personal information, Mika Rontu, FIWA). This is unsustainable for water supply networks (pipelines) as, even in very optimal conditions a pipeline 200 year of age is only rarely possible.

1.5 METHODS OF THE UPDATE PROJECT

This guide book was financed by ISTT. The original guide book was financed by FIWA's Development Fund, several water utilities, and two operators. The project was conducted from January 1st 2018 to September 30th 2018, and the original publication ("Viemäreiden kuntotutkimusopas" *in* Finnish) was published on December 11th 2018.

A translation of the guide book was carried out by PhD, MSc Tiia Lampola (WSP Finland Oy), the English language was checked by MSc Peter Howett (WSP Finland Oy), and expertise checked by Mr. Jari Kaukonen (ISTT/WSP Finland Oy) and Sakari Kuikka (SewCon Kuikka Oy).

2 GENERAL REQUIREMENTS FOR SEWER INSPECTIONS

The quality and quantity of initial data is essential when CASI is undertaken. If either quantity and/or quality is insufficient, it becomes quite difficult to have the comprehensive knowledge for prioritization within the sewer network. However, most of the initial data can still be updated and improved upon, and many different methods are available for that process.

For example, the FME-program (Safe Software Inc.) is very useful for improving and increasing both quantity and quality of the initial data. Many geographic information programs, such as ArcGIS or QGIS, can be used. These programs can also help water utilities to better manage their network information based on the assumptions of other network information, such as the year of mounting, diameters, materials, etc. In HSY, the FME-program is widely used for both data management and to expand sewer systems (Sänkiaho & Lampola, 2018).

2.1 REQUIRED INITIAL DATA

When CASI are about to be made, it is paramount to have enough data and information about the sewer network. It is also important to have such data easily, quickly and efficiently available. Table 2.1 lists information that is needed prior to CASI. Table 2.1 also includes a list of methods to improve the initial data, if needed.

Table 2.1. Initial data for condition assessment and sewer inspections (CASI).

Initial data that has a significant role in sewer inspections	Significance of the data for sewer inspections	Means to improve the quantity and quality of the initial data
Geographic information	Identify the most critical points of the network. Identify the less critical points of the network. Identify manholes and other structures within a certain part of the network.	Digital GIS/NIS system. Using programs such as FME to improve and increase the amount of data. Improve and increase the data and information during the condition assessment process and sewer inspection methods.
Pipeline and manhole diameters and materials	Affects directly to the requirements of the method/tool to be used. Focus on certain type of pipelines/manholes. Manholes must be enough in size to insert the tools for a certain method.	The GIS/NIS information is improved along with other processes and works in the water utility's network. Using programs such as FME to improve and increase the data.

The GIS/NIS information must be qualified, since it is the most important data for CASI (prioritize, focus, program, etc.), which can be partly used at the inspection project or a separate project.

2.2 PRIORITIZE AND FOCUS ON A PARTICULAR PART OF THE NETWORK WITH A CERTAIN METHOD

Water utilities, the clients of water utilities, municipalities and politicians have different needs for data acquired from a sewage network. The following list contains different methods and means of CASI with regards to the data's purpose, for example, the renovation/rehabilitation process of a water utility's sewer network.

- Separation of a network's overall classification into different classes, factors and prescreening methods:
    - Using such a method requires a whole network to be inspected using certain procedures that attain a comprehensive knowledge of the network.
    - These procedures can include critical assessments, zoom-inspections, data-analyses and other statistical methods. These methods use the GIS/NIS information of a network, and other open source data during the analysis. Other important information may come from a person's memory/understanding, and this knowledge should be gathered as well.
    - The approach requires gathering a lot of fragmented data that would result in a large, somewhat difficult project. However, programs such as FME can be used to help the water utility companies in this phase.
    - The overall classification of a sewage network also yields information about the networks' condition, identifying which parts are in good shape and those that are in an acute need of inspection.
    - It is also faster and cheaper to get lists for more tedious inspection methods. These methods can prioritize and focus on the most defected parts of the sewer network.
- Flow measurements:
    - Flow measurements can be used to inspect I/I in catchments and sub-catchments of a sewer network. Measuring instruments can be placed in pumping stations, which gather flow rates over a certain geographical area.
    - Several methods are available for measuring a sewer's flow rate. Measuring methods for drinking water may not be usable for a sewer's flow rate measurement since the medium is somewhat different.
    - Level units are useful for estimating I/I in the sewer network due to raining. If a near-by water main is broken, flow measurement can also be used as a means identifying them.
    - Flow measuring methods for sewers include: magnetic flow meters, ultrasound measurements, measuring weirs, etc. However, the specific features of the sewer water (sewage) may, for example, increase clogging due to high amount of suspended matter and sediment.
- Sewer inspection with drive-through robots:
    - Pre-wash / pre-cleaning is required. Methods for pre-wash / pre-cleaning are presented in Chapter 2.6.
    - Sewer inspections with drive-through robots are quite slow and have many phases, which emphasize the use of the prescreening methods mentioned above. Thus, the slower processes can be focused on the pipelines with more statistical (or observed) defects.
    - These methods are using two different camera techniques: CCTV; which is widely used and, digital; which has increased use throughout this century.
    - Both CCTV and digital methods provide visual observations (of defects). The digital method also results in higher accurately in measurable and comparable observations.
    - With both above-mentioned methods it is very difficult to analyze the structural condition of pipelines.

- Laser scanning:
    - Pre-wash / pre-cleaning is required. Methods for pre-wash / pre-cleaning are presented in Chapter 2.6.
    - Often combined with CCTV or digital techniques, this again involves a drive-through inspection method, where several different tools are available.
    - Results in a 3D-model of the pipelines. Helps to analyze wall thickness, deformations, etc.
- Acoustic methods:
    - Several different types of methods exist based on the acoustic echo of tunnel materials.
    - For example, ground penetrating radar, sonar- and ultrasound methods.
    - Can be used above ground however, some methods need contact with the pipeline.
    - Structural conditions of pipelines are often available as a result.
    - Constraints on materials, diameters etc. might apply.
- Electrical and magnetic methods:
    - Based on analyzing electric current or magnetic flow.
    - For example, electrical leakage probes, ECT, and RFEC methods.
    - Structural conditions of pipelines are often available as a result.
    - Constraints on materials, diameters etc. might apply.

The above-mentioned methods and tools are presented in more detail in Chapter 3.

2.3 EDUCATION AND TRAINING IN CASI PROCESS

It is very important to update the education and training of all experts in the field of CASI of pipelines. Water utility companies are especially in need of improving their knowledge of available methods, improving asset management, prioritizing renovations/rehabilitations, managing I/I, etc. The contractors which provide those CASI methods need to also keep up-to-date with information about developments in the field. Pre-cleaning or pre-washing, in many cases, is a very important part of CASI: it is very important to acknowledge that the same method might not be adequate for every case.

To comply with the requirements, we suggest that an official party, such as the Ministry of Environment, should keep a register of competent parties and companies. This would ensure that everybody working with CASI is up-to-date with developments and methods used in the field. It will also increase and improve knowledge of asset management for water utility companies.

The course material should be compiled from available material (including this book, previously published Finnish books, other Nordic countries' books, and any other material, which is regarded suitable for the purpose). The material should not be kept static i.e. it should be kept updated. All the mentioned methods and tools need to be well written and explained in detail for each target group of the course so that each can have the best information available for their needs.

Training and courses for the various methods and tools would also need to be organized by the companies providing them. This book does not contain a detailed guide for the methods.

2.4 THE BIG PICTURE OF THE CASI PROCESS

A bigger picture of the CASI process contains several stages, as outlined in Figure 2.1 below.

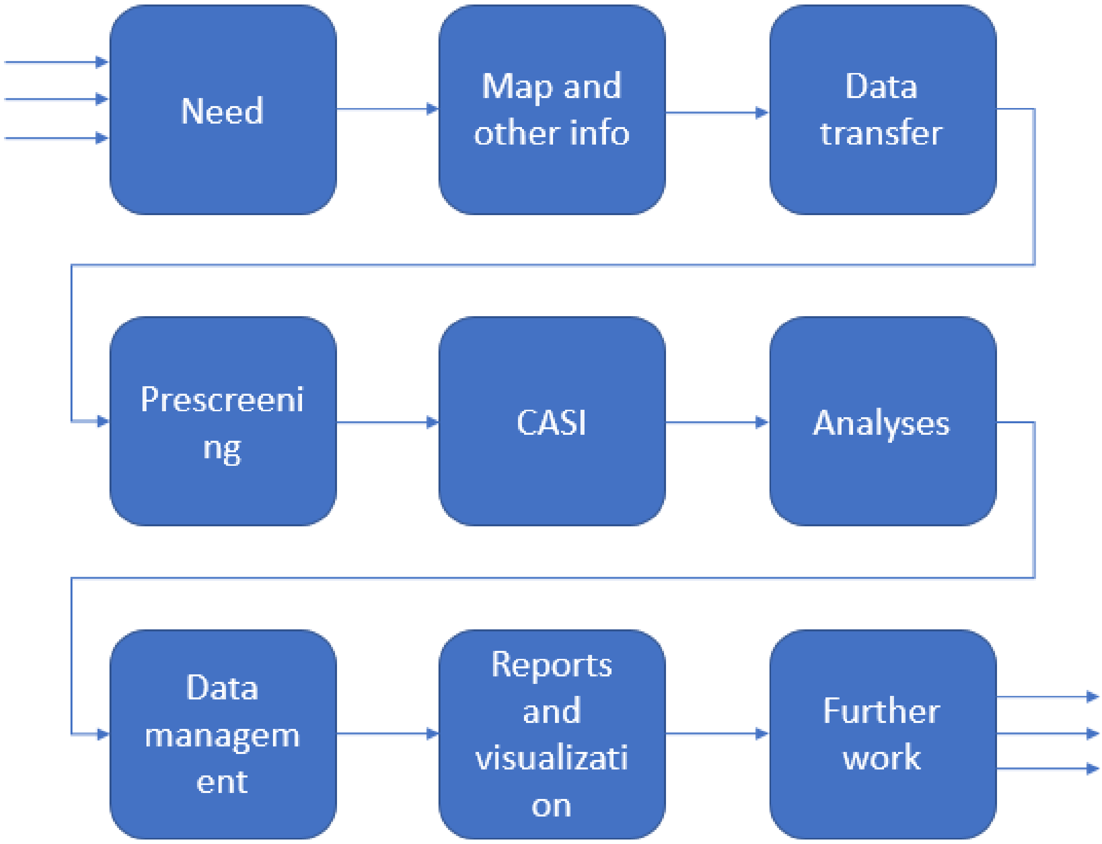


Figure 2.1. Condition assessment and sewer inspections (CASI) – different phases of the process.

Each of the phases in Figure 2.1 contains a multitude of factors, which affect the efficiency and accuracy of data for the CASI pipelines. This book presents methods and tools to be used throughout all the phases.

2.4.1 Need for CASI

The need for CASI comes typically from water utility companies, municipalities, contractors or clients. The need for such action might be planned (the rehabilitation of a street), or acute (the clogging of a sewer pipeline or the deterioration of a sewer).

2.4.2 Determination of the order

Traditionally in Finnish water utilities, the determination of the CASI order is made manually (by the personnel), which requires many hours of work. If the order is made manually many errors such as copying, may occur. Those errors can also cause challenges later in the data transfer phase.

2.4.3 Data transfer and its requirements

When the two initial phases of CASI are ready, data transfer and management occurs. It is important to get the data transferred easily, safely, and reliably from the water utility company to the contractor. Currently, manuals (printed on paper) or a transfer via a flash memory stick used which are slow and prone to error. Automated data transfer and management are also necessary to improve and ensure safety for the water utility companies as well.

2.4.4 Pre-screening methods for efficient CASI processes

Pre-screening methods that help CASI can be statistical (criticality assessment, other data analysis methods, hydraulic modelling) or physical (zoom-camera inspection from a manhole). All the pre-screening methods provide additional information for slower, and in many cases, more expensive methods.

2.4.5 Condition assessment and sewer inspection (CASI) methods

There are several different approaches to implement CASI for pipelines. It might require a lot of time to compare all the available methods and choose the right ones for the right case. This book presents several of those methods, including Tables, which can help water utilities to choose the right method for their needs.

Traditional CCTV inspection includes the manual operation of a robot camera along with recording the observations of defects, which are then manually reported. This method is quite slow compared to other methods available. However, it is a highly visual method, and it provides good information from the pipelines.

Some CASI methods require pre-work, such as pre-washing, plugging of the pipeline and/or flow control. When a successful condition assessment and sewer inspection is needed, the pre-work stage must also be effective.

Pre-wash of pipelines
Pre-washing of pipelines is often the slowest and most expensive phase of a CASI process. Quality control is often poor or lacking altogether. It is very important to have a reasonable quality control after pre-washing, since CASI can't provide effective results with a poorly washed stage. There are many different types of (jet) cameras that can be used and zoom-cameras via manholes provide a good tool for quality control.

2.4.6 Analysis of results

Manual observations along with manual reporting has been found to be unreliable and prone to error. Instructions and a decent road map for CASI is needed to ensure and improve the results. Newer techniques, such as digital cameras, can also help to provide better results for these processes. An automated analysis of the results will hopefully, soon begin to help significantly during this phase. There are several different approaches along these lines that are currently being carried out in Europe and in the USA.

2.4.7 Data management (and data transfer)

A fast, reliable and easy transfer of data is already possible. However, many of the water utility company's CASI programs are quite poor with these aspects. Typically, in Finland, it takes 1 week to 6 months to transfer the data from an inspection to the water utility company depending on many things, such as manual analysis and manual transfer. This is very unfortunate since accurate, real-time information and data transfer are available.

2.4.8 Reporting and visualizing the results from CASI

There is currently a high demand to standardize both reporting and visualizing the results obtained from CASI. However, this is not covered under the scope of this book. There is not available such a guide book at this moment.

2.4.9 Utilizing the results from CASI

The CASI process provides results of the sewer network for rehabilitation, renovation and management actions. All results obtained from CASI should be in such good quality that they are usable without any further processing.

2.5 DATA TRANSFER AND DATA MANAGEMENT AS A PART OF CASI

In Finland, there are two GIS/NIS systems used by water utility companies, namely Trimble NIS © and KeyAqua ©. Internationally, other systems exist such as DHI © and Esri ©.

Data transfer and data management are very important for the CASI processes. It must be possible to transfer data directly from the field measurements to the GIS/NIS system (and vice versa). The current systems are in great need for interface programs that would allow it to happen. Safety issues and data security must also be addressed.

Currently, by Finnish standards, the implementation and reporting of CASI takes many additional hours of manual labor due to human errors. The GIS/NIS systems should be:

- easy to use when providing the determination of areas;
- easy to select any type of network;
- automatically transfer the data to and from the water utility company and the contractor.

It is possible to develop a fast and dynamic system and program for data transfer and data management. The greatest need comes from the will of the water utility companies; it has already been shown that there is some need, but more is required to improve and advance the matter forward.

2.6 PRE-CLEANING AND PRE-WASHING

Pipelines must be cleaned and or washed prior to robot camera inspections. Before pre-washing, the pipeline's operational condition, as well as the structural integrity, must be evaluated to ensure that the pipeline is in such condition that pre-washing can occur. Often, pre-washing is carried out via jetting which can be harmful to certain types of pipe materials. These pre-inspections can be made for example, with a zoom-camera.

In a normal case, water pressure is in the pump is 80 to 150 bar, and the water jet sprays approximately 200 to 350 l/min. It is essential therefore, to use enough water and ensure that the correct type of nozzle is used.

If the proposed pipeline is highly corroded or structurally brittle, the pre-washing must be made with extra care. In such a case, ice pigging might be more ideal for the pre-cleaning of the pipe.

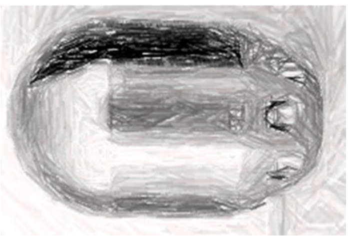
The type of nozzle must be chosen depending on the goal of the pre-washing/-cleaning. Sediment removal requires a different type of nozzle than fat, oil, and grease (FOG) or roots.

Table 2.2 lists parameters in washing/cleaning of the pipes.

Table 2.2. Parameters for washing/cleaning of pipes.

Pressure side				
Diameter of pipe, mm	pressure (bar)	amount of water l/min	diameter of the hose (inches)	water container m3
100 - 300	80 - 120	120 - 250	5/8”	3 >
350 - 600	100 - 150	280 - 380	1” - 1¼”	6 >
700 - 1000 >	120 - 180	400 - 500 >	1¼” - 1½” (2x1”)	8 >
Suction side				
Diameter of pipe, mm	suction m3/h	diameter of the hose (inches)	water container m3	
100 - 500	1800 - 3000	3”	3 >	
500 >	3200 >	4” - 5”	6 >	

Figure 2.2. Illustrations of the three types of nozzle.

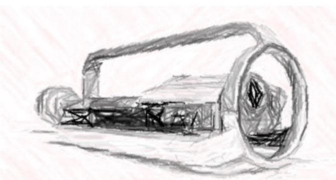


Circumferential cleaning.

Cleaning of base.

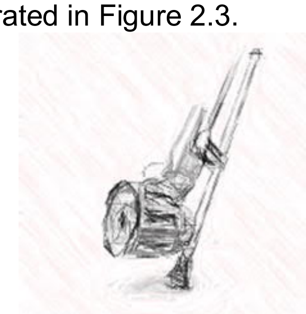
Root cutting.

Nozzle cameras and other cameras for quality control are illustrated in Figure 2.3.



JetCam®

Xpection®



QuickView®

Figure 2.3. Three camera configurations suitable for quality control.

Pre-washing of pipes has been in use for decades (Dinkelacker, 1992; Lorenzen et al. 1996). There are several methods and tools, from which man can choose the right types. Typically, jet nozzles can (Lorenzen et al. 1996):

- remove sedimentation;
- change the quality of sedimentation (which can cause pipe wall corrosion);
- remove sediments that would drift into the environment or water bodies;
- improve operation of a network even beyond the pre-washed pipeline.

Ice-water-slurry and sand-water-slurry are possible methods for cleaning pipelines. These methods are gentler on existing pipelines but also have their limitations.

Pre-screening methods can also be used for locating the parts of a pipeline network that need (pre)washing and/or cleaning. Most of the current cases of (pre)washing/cleaning are based on manual observations and there is no exact way to estimate the whole network's needs. Pre-screening methods are often only used over small areas. These actions must also be enhanced so that water utility companies have better knowledge of their networks (Campbell & Fairfield, 2008).

If pre-washing and cleaning is made with a mechanical scraper, etc. the mechanical stress can deteriorate the pipeline's inner walls, which may increase the effect of corrosion (Lorenzen et al. 1996), cause flooding (Dettmar & Staufer, 2005), and deterioration of a pipeline's flow properties (Cant & Trewq, 1998). Nozzles, water pressure, and other parameters are also affected (Medan et al. 2014; Medan & Ravai Nagy, 2015), most likely causing negative effects to the cleaning process.

Figures 2.4, 2.5, and 2.6 illustrate cameras with nozzles.

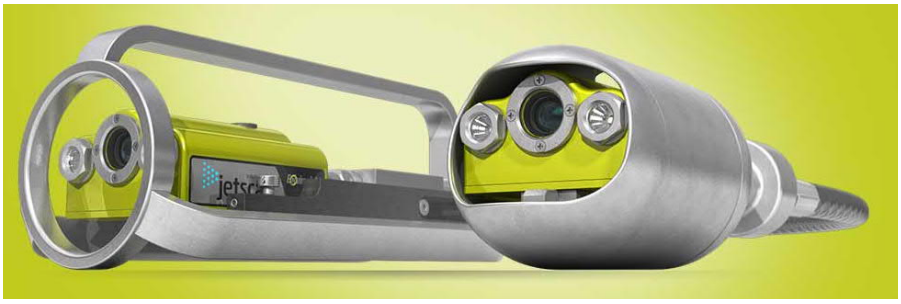


Figure 2.4 Envirosight JetScan® camera. https://www.envirosight.com/jetscan.php

Figure 2.5. iPEK nozzle camera. https://www.ipek.at/index.php?id=1001&L=ugsytsvmb


Figure 2.6. KEG nozzle camera. https://keg-pipe.com/en/sighted-nozzle.html

3 CONDITION ASSESSMENT AND SEWER INSPECTION (CASI) METHODS

Several different CASI standards are used around the world. In Finland the standard used is SFS-EN 13508-2. Prior to this book, interviews and discussions with experts from within the Finnish CASI market were carried out. They revealed that there is a clear need for more guidelines on processes for water utility companies. These guidelines would help to avoid unnecessary work and effectively locate the weakest parts of a network. This book is only the beginning of such a large project, as clear guidelines would also need to extend to cover the analyses of observations and provide example figures. Education and courses have also shown the potential and their importance for water utilities, planning agencies, contractors, municipalities etc. Courses are most effective when carried out by peer experts. Education and course needs are discussed in Chapter 2.3.

CASI methods can be classified in many ways. Figure 3.1 illustrates four different classifications.

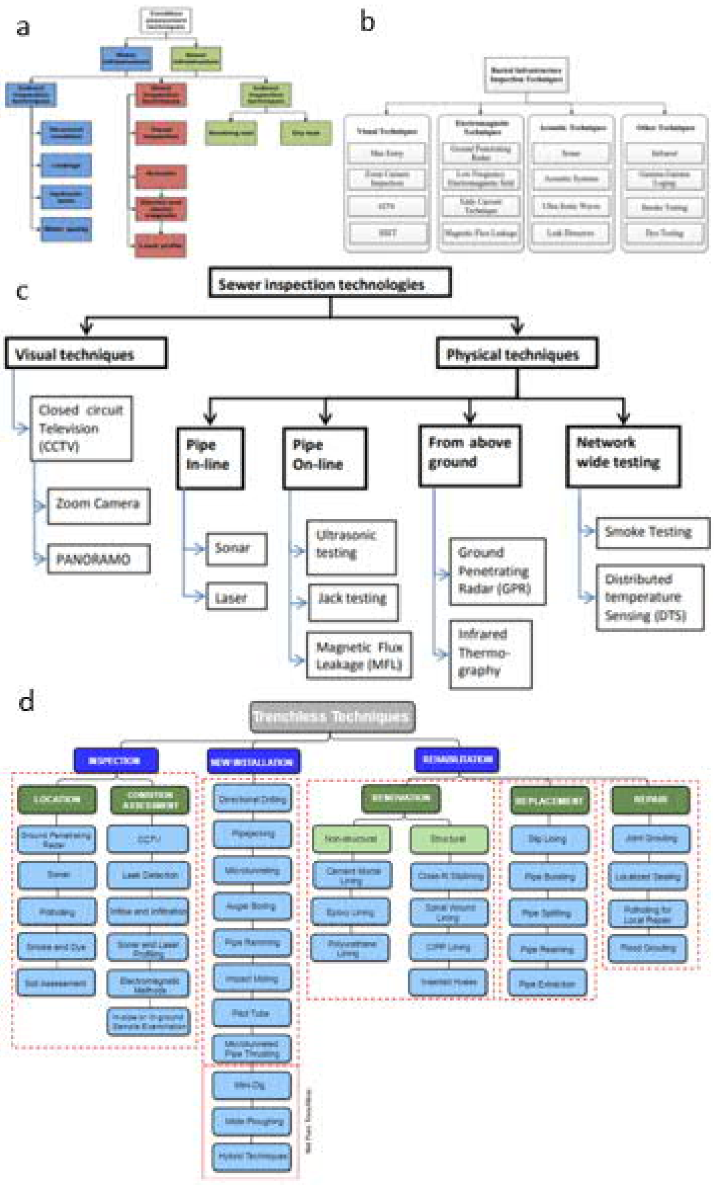


Figure 3.1. Four classifications of CASI methods. a) Atef, 2010; b) Daher, 2015; c) Kley et al. 2013; d) istt.com.

Table 1 (Appendix 1) lists CASI methods suitable for non-pressurized pipelines. Table 2 (Appendix 2) lists CASI methods suitable for pressurized pipelines (sewers and water mains).

Table 3.1. CASI pricing ($/m). Prizes are comparable for year 2001. (Zhao and Rajani, 2002).

CASI method	Prize $/m	Reference
CCTV	$2 - $10 / m	Zhao et al. 2001
CCTV with sonar	$7 - $10 / m	Zhao et al. 2001
Sewer diver (human)	$2 - $20 / m	Zhao et al. 2001
Manhole inspection	$100 / manhole	Zhao et al. 2001
Smoke testing	$1,9 - $3,8 / m	EPA 1975
Color testing	$3,1 - $6,3 / m	EPA 1975
Flood testing	$3,1 - $6,3 / m	EPA 1975

Large diameter pipelines have much fewer CASI methods available. Robotics and multi-analytical methods are continuously rising globally (Mirats Tur & Garthwaite, 2010).

Typical visual CASI is undertaken, as illustrated in Figure 3.2 (Dirksen et al. 2013).

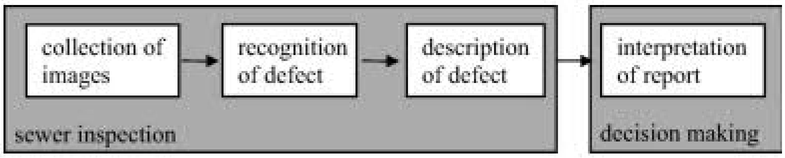


Figure 3.2. Flow diagram describing the sewer inspection process (Dirksen et al. 2013).

Although camera technology for CASI methods has improved throughout this century, the CCTV process has usually been carried out in the traditional way, with manual operation and observations (Sinha, 2014).

Up to 30 % of initial CCTV inspections have been shown to “disappear” during the second CCTV inspection phase, without any preparation and/or renovation; this shouldn’t be the case (Dirksen et al. 2010). Human errors are highly dependable on an operator’s skills, experience in the field, and concentration abilities. Technical errors are usually due to poor camera technology and lack of proper lighting (Chae et al. 2003; Müller & Fischer, 2007). Figure 3.3 illustrates observations from a study made in the Netherlands, showing the error classification of manual work in CASI (Dirksen et al. 2013). Figure 3.4 illustrates error classification in a study which compared experts’ analyses of observations (Dirksen et al. 2013).

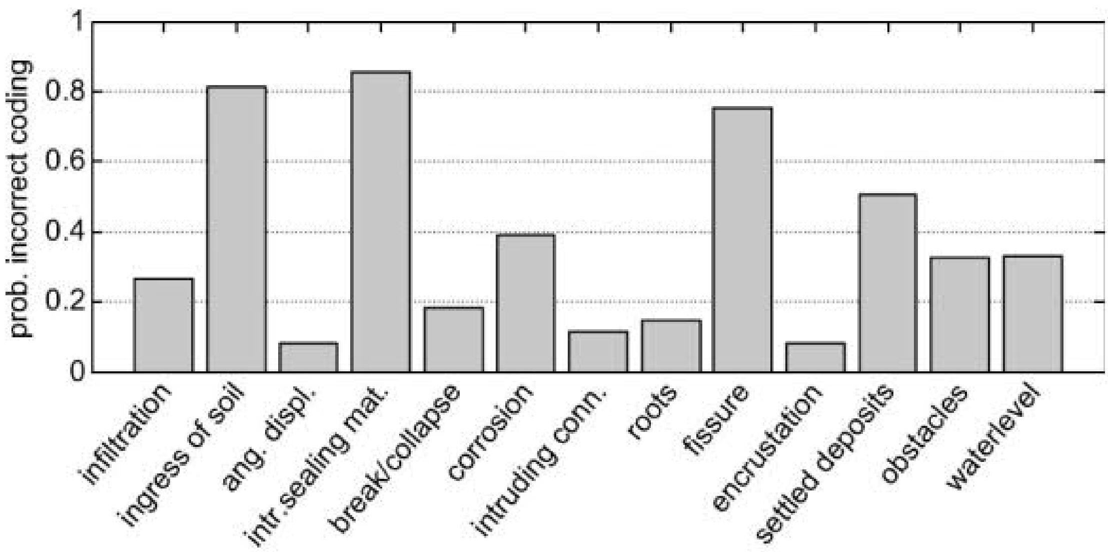


Figure 3.3. Probability of incorrect coding due to an inspector's examination of the results from the course 'Visual inspection of sewers' in the Netherlands (Dirksen et al. 2013).

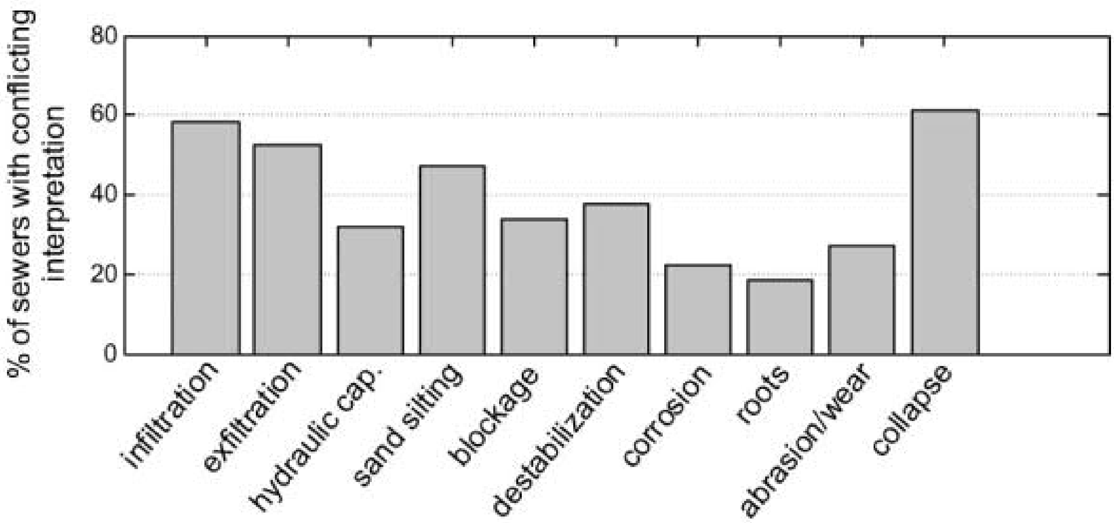


Figure 3.4. Percentage of sewers in which the interpretation of the inspection report by 4 to 6 different experts show a difference of at least two points (Dirksen et al. 2013).

Considering how widely used CCTV (with manual observations, interpretations, and analyses) has been used for over the last four decades, only some small steps have been made to enhance the process as a whole. If a pipeline is found to be in poor condition, statistically 80% of observations are correct. False negatives are approximately 20%, and false positives approximately 15%. With these observations, researchers have estimated that a statistical value "pipe in poor condition" is only 68% (Cararot et al. 2018).

Research has suggested various ways to improve and enhance CCTV analyses (Dirksen et al. 2013):

1) Classification of CASI observations must be simplified;
2) Human errors are possible to avoid if reporting is only made with pictures;
3) The client and contractor must develop mutual communication methods, and;

4) Pipelines require many methods and tools to make CASI, which would allow for good evaluations and estimations of structural integrity, for example.

CASI methods have been found to give (only) subjective information of pipelines, despite the operator's expertise. Since the most used CASI methods are quite unreliable and error prone, wrong decisions and choices are possible (McKim & Sinha, 1999; Koo & Ariaratnam, 2006; Müller & Fischer, 2007).

An automated analysis of CASI results would provide better results for: (i) spatial attributes from camera/analyzation; (ii) default recognition, and; (iii) classification of defaults (Müller & Fischer, 2007). Automated analyses have been studied and piloted in many countries (e.g. Yang et al. 2010).

Currently, almost 30 % of Canadian water supply networks are estimated to be in poor or very poor condition (Daher, 2015). Approximately 20 % of German water supply networks will require short-term or medium-term investments soon (Müller & Fischer, 2007). In the USA, annual rehabilitation/renovation investments are estimated to be as high as $15 billion to achieve a technically and economically reasonable condition of water supply networks (Daher, 2015). Annually in Europe, approximately five billion Euros are used for renovation and rehabilitation (Hafskjold et al. 2003).

CCTV inspections have been shown to result in poor reproducibility due to human errors, fatigue, subjectivity of analysis, and a process' polycyclic nature (Yang et al. 2010; Daher, 2015). A Canadian study (Feeney et al. 2009), showed that there are no standardized methods for the CASI process, which could help reduce the error factors. Similar results were found during project interviews.

The structural condition and hydraulic capacity of a pipeline has been found to be the most sort after 'extra knowledge' of the pipelines. It would help to prioritize and focus pipeline rehabilitation/renovation and condition assessment actions on those that need it the most. This is especially so for concrete pipes that suffer from corrosion and substance decrease due to biochemical corrosion from sulphuric acid and other sulphuric compounds. Visual CASI methods are not adequate methods for estimating the inner geometry of a pipeline and provide only apparent changes (Clemens et al. 2014).

There are several classification systems available. In the US, the NASSCO PACP and SCREAM™ classification systems were compared, and the comparison is shown in Table 3.2. Both methods are used with CCTV inspections.

Table 3.2. NASSCO PACP vs. SCREAM™. (Martel et al. 2010)
NASSCO PACP

Advantages	Disadvantages
• Broad and well-established coding process and training system across North America. • Readily available standardized coding and data recording software. • Good defect code classification system. • Simple and intuitive defect grading scale for operators.	• Standardized codes limit the degree of code customization and adaptations/improvements to coding system as technology evolves. • Three separate rating processes provide different condition interpretations for five coding families (see details in Appendix B). • Simplistic grading hinders definitive analysis cut-off points or sorting ranges when there are a large number of assets. • Scoring process is not integrated with other field inspection techniques. • No built-in or automated process that verifies the correct code was entered. Verification must be accomplished by a subsequent quality control review.

SCREAM™

Advantages	Disadvantages
• Flexible code customization to match historical or unique local nomenclature. • Defect codes have a base and maximum score between which the defect is scaled based on extent. • Code scores are specific to most popular pipe materials. • Rating process produces one condition score for each of four coding groups (see Appendix B). • Code system integrates with other inspection techniques.	• Access limited through software vendors and consultants; proprietary software. • Comprehensive code list mandates operator training. • Training and certification materials need more defect photo documentation. • No built-in or automated process to verify that the correct code was entered. Verification must be accomplished by a subsequent quality control review. • System is not widely used.

As seen in Table 3.2 there are big differences between the different classification methods (van der Steen et al. 2014).

The force mains from a pumping station form a very important group of pipelines in any sewer system. Force mains are often located in critical areas (under a water body, over large distances, etc.), which means that it is very important to have a better understanding of them to help water utility companies, municipalities and environmental agencies. So far in Finland there have not been any systematic CASI campaigns for force mains. Appendix 2 lists methods usable for the force mains and water mains (e.g. Bhaskar Dasari, 2016; Derr, 2010).

Automated analysis for CASI
It has been observed that a visual analysis can be improved and enhanced, if all the observations and analyses are unequivocal, and there is only one class for one type of defect. Classification would also be simplified if picture-only formats were used instead

of text written manually by the operator. An automated analysis of the results would also yield added value in CASI process (van der Steen et al. 2014).

Previously, computer capacity, memory, data transfer and many other techniques have been poor and slow. Nowadays, these are in a better state and several projects have already automated their analysis of CASI results, both in Europe and in North America.

Finnish research produced algorithms for an automated analysis of CASI; possibly the first in the world (Kannala et al. 2008). In HSY (Helsinki Region) there has been further developments with automated analysis for CASI (Lampola et al. 2017). Automation of digital and analogous inspection results have lately been extensively researched. For example in China (Wu et al. 2015); Exeter, UK (http://emps.exeter.ac.uk/engineering/research/cws/news-events/news/title_590136_en.html); Germany (www.esic.cloud); and the USA (Kumar, 2017).

3.1 PRE-SCREENING METHODS FOR CASI

3.1.1 Data analyses and other computational methods

Possibly the most important data recorded about the pipelines during CASI is the structural condition of the pipeline. Sewer deterioration models help water utility companies and other interested parties to plan renovation/rehabilitation and other management procedures. Such models are very useful if they have enough data for calibration, and the model is suitable for the initial data. It has been observed that deterioration models might be difficult to utilize, since the traditional CASI methods yield only indirectly data from the structural condition of pipelines. However, the sewer deterioration models are usable when prioritizing and targeting CASI methods within the network. For example, GompitZ, KanewZ and STATUS are all sewer deterioration models (Figure 3.5; Kley & Caradot, 2013; Rokstad ja Ugarelli, 2015; Caradot et al. 2017).

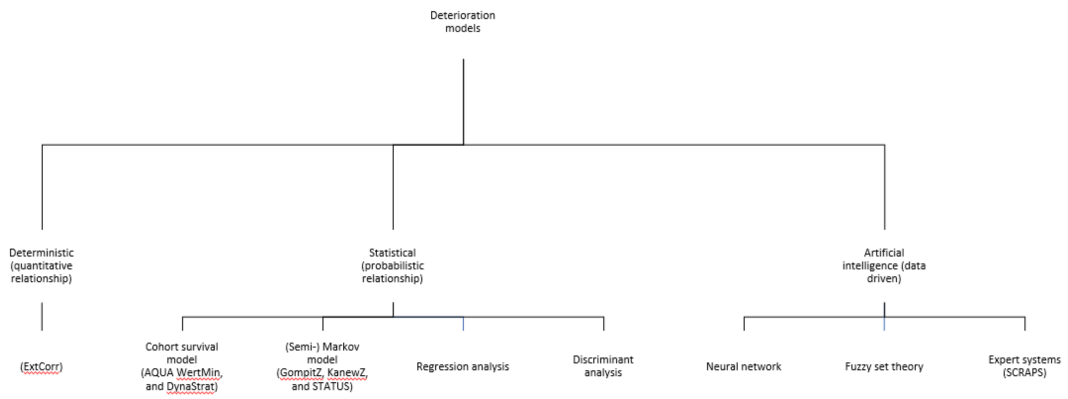


Figure 3.5. Sewer deterioration models (Kley & Caradot, 2013).

Data management and quality assurance are also very important factors during a sewer network asset management process. Table 3.5 lists several data needed. In addition to those mentioned in the table, the following data is required: (i) pipe form (circular, oval, etc.); (ii) chemical and physical conditions in pipelines and in pumping stations, (iii) flow conditions and variability; (iv) ground water height; (v) traffic load; (vi) age of pipelines; (vii) CSOs and SSOs and; (viii) management procedures of the pipelines (Fenner, 2000).

Figure 3.5. Requirements for a data management system (Fenner, 2000).

Requirements	Description
Accuracy	All pipe and channel sizes and other physical attributes are known and the connectivity of the system is confirmed
Completeness	All constructed works are identified with no gaps existing in the pipe and channel networks unless confirmed by field study
Spatially defined	The location of the network should be referenced to the cadastral or property and road base to the nearest meter for presentation of the data in a GIS and for accurate development of hydraulic models
Known system condition	Moves to condition based depreciation rather than straight line depreciation on design life make condition assessment essential
Data transfer	Information must be easily transferred to the format required by modern hydraulic modelling products and GIS software
Asset management	Business decision rules using asset condition (likelihood of failure) and asset criticality (consequences of failure) should be used to define proactive maintenance, inspection or rehabilitation programmes
Maintenance management	The drainage information system should link to a maintenance management system for recording incidents and for recording the nature of field operational work undertaken
Quality Assurance	The procedures for editing existing information or adding in more information need to be covered by sound QA and incorporate security on who can edit the data

Critical assessment is a very effective tool when water supply networks are being classified. This tool categorizes pipelines into critical and non-critical parts that can be used as the initial data during CASI process and asset management. In HSY two cycles of criticality assessment have been used, to help water utility companies prioritize their networks for CASI and for their management procedures. This analysis was made by buffering certain parameters and comparing their spatial data to the spatial data from the sewer and water pipelines. A critical index was used from 1 to 3 (1 = extremely critical, 2 = critical, and 3 = non-critical). Table 3.6 lists the parameters tested (Laakso et al. 2015).

Table 3.6. Water and sewer pipeline critical index. Parameters tested (Laakso et al. 2015).

Water/Sewer and critical index	Parameter tested
Water mains, critical index 1	Water mains from water treatment plants to water towers and significant pumping stations.
	Water mains leading to critical consumption points with no alternative route.
	Critical pipelines obtained from closing scenarios.
	Water mains under railroads with no protective pipe.
	Only water main to an area of significant size.
Water mains, critical index 2	Significant water mains that are not included in critical index 1.
	Pipeline under a building.
	Large water main under a significant road.
	Natural gas pipeline close to water main.
	Pipeline close to a critical underground facility.
Sewer, critical index 1	Tunnels.
	Trunk sewer pipes.
	Trunk sewer pipes and force mains in significant ground water areas.
	Sewer pipes close to important water points.
	Sewer lines under railroads.
	Force mains with no alternative route.
Sewer, critical index 2	Trunk sewers that are not included in critical index 1.
	Sewers located in nature conservation areas.
	Sewers that are lead proceeding under a water body.
	Sewer under a building.
	Sewer close to a protected stream.
	Sewer close to a beach.
	Sewer in significant ground water area.
	Trunk sewer located within a class 3 ground water body.
	Pipeline close to a critical underground facility.

3.1.2 CASI with zoom-camera

Zoom-cameras (such as QuickView®) can produce either still pictures or videos from a manhole to pipeline. The zoom-camera method does not require pre-cleaning or -

washing of the pipeline, and shows the operational condition of a pipeline with high accuracy. A zoom-camera is put in the manhole with a rod, and the pipeline is inspected either digitally or analogically with high definition zoom. It is possible to see 80 to 100 m with a zoom-camera. This method is only suitable for inspecting pipeline sections that are above water level (Feeney et al. 2009). For example, the INNO-KANIS project suggests the use of zoom-cameras as a qualifying method for the operational condition of sewers (Plihal et al. 2014).

The zoom-camera method is usable when inspecting pipelines from manhole to manhole, and inspection is done both downstream and upstream. The zoom-camera method does not substitute or decrease the need of CCTV inspections, but it can be used as a pre-screening method to help to focus on the parts of the network which are in the worst condition. Up to ten times more pipeline can be inspected with a zoom-camera method than with a CCTV method, and it is effective for manhole inspections as well (Table 3.7; Feeney et al. 2009).

Table 3.7. Inspection made with a zoom-camera (Feeney et al. 2009; this publication).

Sewer type	Only non-pressurized.
Material	All.
Dimension	150 mm ->.
Defects to be seen	Crevice, fissure, I/I, roots, overall estimation of pipeline’s inner wall, joints, connections.
Procedure	From manhole to manhole.
Currently available	Everywhere.
Pros	Fast CASI method. Efficient tool when prioritizing and classifying network.
Cons	Deformation and/or sedimentation affects negatively. Only available above water level. Cannot provide information of structural condition without laser scanning or such methods.
Unit price	Approximately 1-2 €/m including analysis of results (and data transfer to a cloud service).
Unit execution time	From a manhole, it takes less than a minute to inspect a pipeline. Up to kilometers per day of inspected pipelines.

Figures 3.6 and 3.7 illustrate different zoom-cameras available.

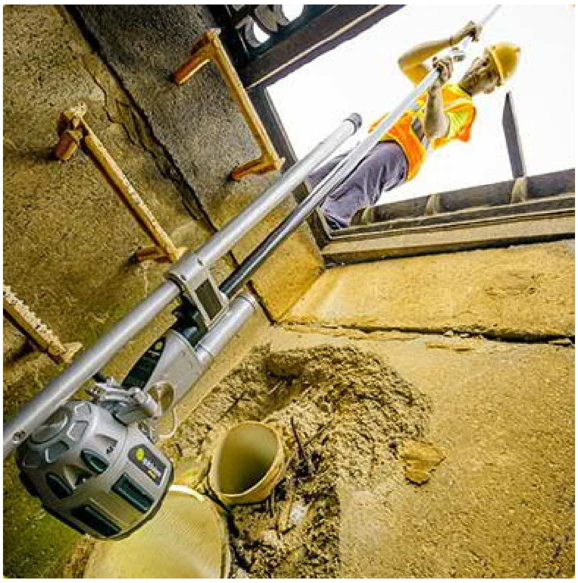


Figure 3.6. QuickView® camera. https://www.envirosight.com/quickview.php

Figure 3.7. A zoom-camera. https://www.messen-nord.de/products/drain-testing-and-inspection/drain-testing-and-inspection-manhole-camera-systems.html?L=1

3.3 CCTV IN THE CASI PROCESS

CCTV was developed in the 1960s in Germany. In Finland the CCTV method arrived in 1970s. Most currently used methods are reliant on this method.

To carry out a CCTV inspection, a camera mounted on a robot crawler is lowered from a manhole to a pipe. There are several methods in which to operate the crawler and camera. If a pipeline is large in diameter, or if it's partly filled with water, there are tools to put the camera on a raft and operate the inspection with it. Smaller diameter pipes can be inspected with a push-cam method where the camera is pushed to the pipeline (Feeney et al. 2009).

Taulukko 5.1. Ennen läpiajettavalla kameralla tehtävää tutkimusta tarvittavat tehtävät.

Ennen kuvaamisen suorittamista
Tarkasta, että kameran kaikki ominaisuudet toimivat;
- kameran paineistus, valot, kuvan terävyys, kääntömekanismi, kameran nostomekanismi, kaapelin kunto
- kalibroi säännöllisesti viettokaltevuuden mittaus järjestelmä
Kuvauksen jälkeen
- pidä kameralaitteisto puhtaana
- tarkasta kameran kaapelin kunto (pieni vuoto kaapelissa voi aiheuttaa ison vian kamerajärjestelmään)
HUOM! Tilaajan ei tarvitse hyväksyä epätarkkaa kuvaustulosta

CCTV inspection is often manual, and the operator stops and zooms (pan-and-tilt) the camera when a defect is detected. Defects are then reported as the distance from the starting manhole: pictures are also included. This procedure has been found to be considerably prone to error, with some defects being neglected or misanalysed. The expertise of the operator greatly affects the result, but still doesn't yield objective analyses of the pipeline inspection (McKim & Sinha, 1999; Kirkham et al. 2000; Feeney et al. 2009). A study made in the Netherlands showed a 25 % probability of a certain defect being neglected entirely (Dirksen et al., 2013). Despite errors and often vague results, the CCTV inspection is a very useful method in CASI process (Feeney et al. 2009).

CCTV inspection provides both video and a visual determination of the material of a pipeline. It is possible to recognize, locate and identify most of the defects, such as roots, which is why CCTV is the most used CASI method for water utility companies (Table 3.8; Feeney et al. 2009).

Similarly, as with zoom-cameras, the CCTV inspection only provides information above the water level (Feeney et al. 2009). The structural condition of the pipeline remains unclear, and it requires the use of other methods to inspect this further (Clemens et al. 2014).

Several new methods have been developed to help improve CCTV inspections and its results. Such methods include upgrades to robot crawlers, cameras, lighting, etc. (Feeney et al. 2009). Other tools have been connected and attached with the CCTV camera and crawler, such as radars (Olhoeft 2000), acoustic tools (Feng et al. 2012), sonars (Kirkham et al. 2000), laser scanning (Duran et al. 2003) or a combination of them all (Duran et al. 2007; EPA 2010).

Table 3.8. CCTV inspection's information. (Feeney et al. 2009; this book)

Sewer type	All pipelines, water mains, connection lines.
Material	All.
Dimension	150 mm ->.
Defects to be seen	Crevice, fissure, I/I, roots, overall estimation of pipeline's inner wall, joints, connections, corrosion.
Procedure	Inspection with a robot crawler.
Currently available	Everywhere.
Pros	Visual inspection.
Cons	Deformation and/or sedimentation affects negatively. Only information above water level. Cannot provide information of structural condition without laser scanning or such methods. Error-prone – human errors. Pre-washing and/or cleaning is required. Qualification of pre-washing is required but seldom done.
Unit price	2 - 15 € / m, requires proper pre-washing. Prewashing is the most arduous and costly part of the process.
Unit execution time	300 - 600 m / day.
Water mains	Water mains can be inspected with CCTV. However, hygiene must be taken into special account.

Digital CCTV

The digital CCTV method (DigiSewer®) has been in use since (approximately) the year 2000. It has been in use in some parts of the world, but there have been challenges with computational capacity, data transfer, etc. before now. Originally the digital CCTV was developed to help and improve the quality of the CCTV inspections. The digital CCTV method is based on the so-called multi-sensory technique, and provides a more accurate and objective result that is analogous to regular CCTV. DigiSewer® uses a fish eye lens camera that provides a 360º image of the inner wall of the pipeline. This method is somewhat faster than analogous CCTV inspection, since there are no stops and zooms (pan-and-tilt). What's different is that the results are analyzed after data collection is complete (Table 3.9; Allouche & Freure, 2002; Feeney et al. 2009, Daher 2015).

The panoramo®-system combines two high-resolution digital cameras (front and back), and it is operated with a robot crawler. Both cameras are equipped with a fish eye lens yielding an image field of view of 185º. This method results in images every 5 cm along the whole inner wall of the pipeline. Panoramo®-images have been found to provide highly accurate data, with up to 90 to 99 % accuracy (Müller & Fischer, 2007).

Table 3.9. Digital CCTV inspection's information (Feeney et al. 2009; this publication).

Sewer type	All pipelines, water mains, connection lines.
Material	All.
Dimension	150 mm - 1200 mm.
Defects to be seen	Crevice, fissure, I/I, roots, overall estimation of pipeline's inner wall, joints, connections, corrosion.
Procedure	Inspection with a robot crawler.
Currently available	Everywhere.
Pros	A third party can easily do the quality control of images. Digital measurements. Comparable results from one inspection to another. Automated analysis of results is possible with digital images. Faster than conventional CCTV inspection. Provides comprehensive image of a pipeline in digital form. Can be used in similar inspections as the conventional CCTV.
Cons	Deformation and/or sedimentation affects negatively. Only information above water level. Cannot provide information of structural condition without laser scanning or such methods. Pre-washing and/or cleaning is required. Qualification of pre-washing is required but seldom done.
Unit price	2 - 15 € / m, requires proper pre-washing. Pre-washing is the most arduous and costly part of the process.
Unit execution time	600-1000 m / day.
Water mains	Water mains can be inspected with digital CCTV. However, hygiene must be taken into an especial account.

Figures 3.8 – 3.14 shows several camera systems with robot crawlers.

Figure 3.8. MiniCam. https://docs.wix-static.com/ugd/673459_f36be7808398478b98c62f9fbcc67b98.pdf

Figure 3.9. CCTV camera, iPEK. https://www.ipek.at/index.php?id=694

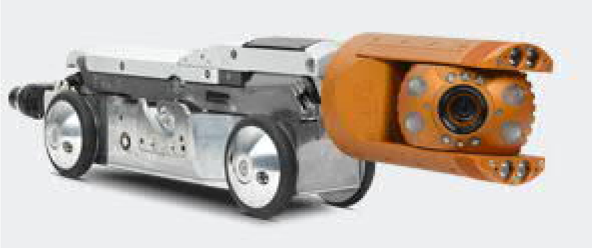


Figure 3.10. CCTV camera, IBAK. https://www.ibak.de/de/produkte/ibak_show/frontenddetail/product/t-76-hd/

Figure 3.11. DigiSewer® camera. https://nexxis.com.au/product/digisewer-190/

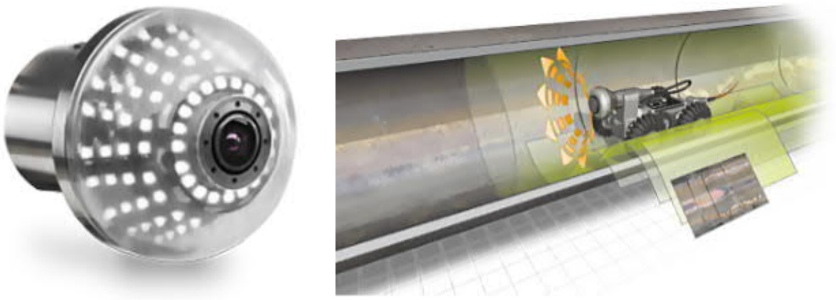


Figure 3.12. DigiSewer® camera. https://nexxis.com.au/product/digisewer-190/

Figure 3.13. Panoramo® camera. https://www.ibak.de/en/homepage/

Figure 3.14. Cues Inc. digital CCTV camera. https://cuesinc.com/equipment/digital-universal-camera-duc

3.6 LASER SCANNING AND ECHO-LOCATION CASI METHODS

3.6.1 Laser scanning

Laser scanning is a very useful method to estimate geometric changes along the inner wall of pipeline. It results in a point cloud, which can be used to analyze deformations, sagging, and wall thickness with a high accuracy. Laser scanning provides very high accuracy: less than 0.5 % errors were found in Clemens et al. (2000). A laser scanning tool is attachable to a robot crawler used for CCTV inspections (Table 3.10; Feeney et al. 2009; Clemens et al. 2014).

Table 3.10. Laser scanning of pipelines and manholes. (Feeney et al. 2009)

Sewer type	All pipelines, water mains, manholes.
Material	All.
Dimension	Approximately 150 mm - 800 mm.
Defects to be seen	Deformation, corrosion, accurate measurement of inner wall.
Procedure	Often attached to a CCTV crawler.
Currently available	Everywhere.
Pros	Provides more accurate information as compared to CCTV. 3D model of a pipeline/manhole.
Cons	Only above water level.
Unit price	Price is included in the CCTV crawler price. Analyses costs some extra,
Unit execution time	n. 300 m / day.

Figures 3.15 – 3.17 illustrates laser scanning tools.

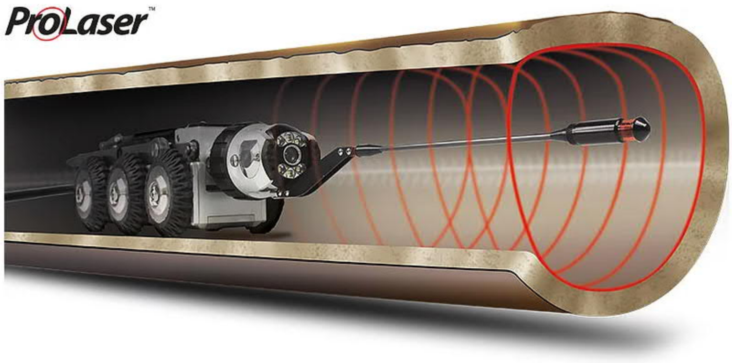


Figure 3.15. ProLaser. https://www.minicam.co.uk/prolaser

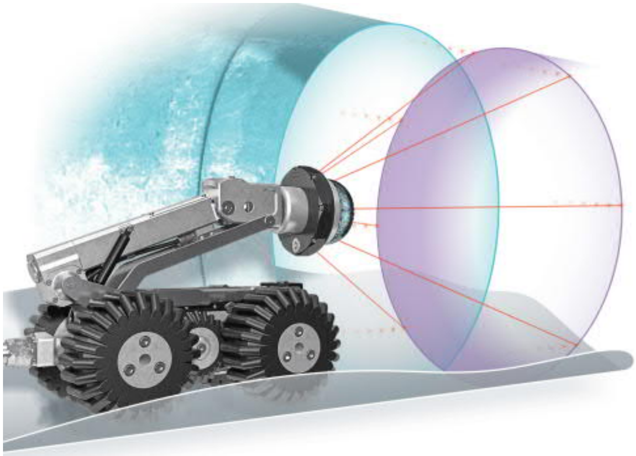


Figure 3.16. DigiSewer® camera. https://www.envirosight.com/dwnld/rvx_digisewer.pdf

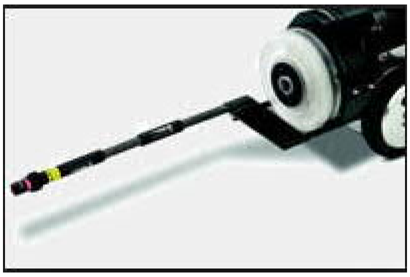


Figure 3.17. Panoramo® camera. https://www.ibak.de/en/produkte/ibak_show/frontenddetail/product/panoramo/

3.6.2 Ground penetrating radars

Ground penetrating radar (GPR) can be used above ground to inspect underground materials and structures. Originally, the US Army have developed this system, and GPR principles are similar to that of radar. Several different factors such as location, frequency, and time, can be analyzed with GPR sensors. GPR can be used to locate voids and collapses as well as identify the types of foundation pipelines. I/I can also be located with a GPR (Feeney et al. 2009; Daniels, 2005; Hao et al. 2012; Daher, 2015). GPR technology is also usable for inner wall inspections (Ékes et al. 2011; Ékes & Maier, 2012).

Electrical resistivity tomography (ERT) uses thousands of current-potential energy measurements from above ground, resulting in the visualization of electrical current in the ground. ERT can locate cracks, fissures, and other properties, and their continuities in the bed rock. The electro-current in the bed rock is mostly due to electrolytic ions (interstitial water) and it can vary several orders of magnitude in a small area (Figure 3.18; Korkealaakso, 2018).

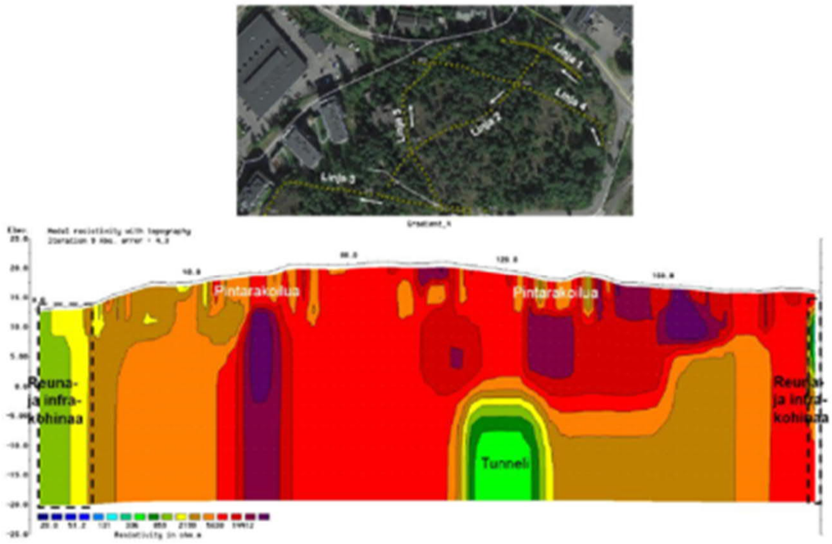


Figure 3.18. Ground resistivity measurements used in VTT Technical Research Centre of Finland LTD. (Korkealaakso, 2018)

Figures 3.19 – 3.24 illustrate several camera-combinations for radar-based inspections.

Figure 3.19. SewerVue®. http://sewervue.com/long-range-pipe-inspection-tracked-robot-surveyor.html

FIgure 3.20. Autonomous crawler. https://www.redzone.com/

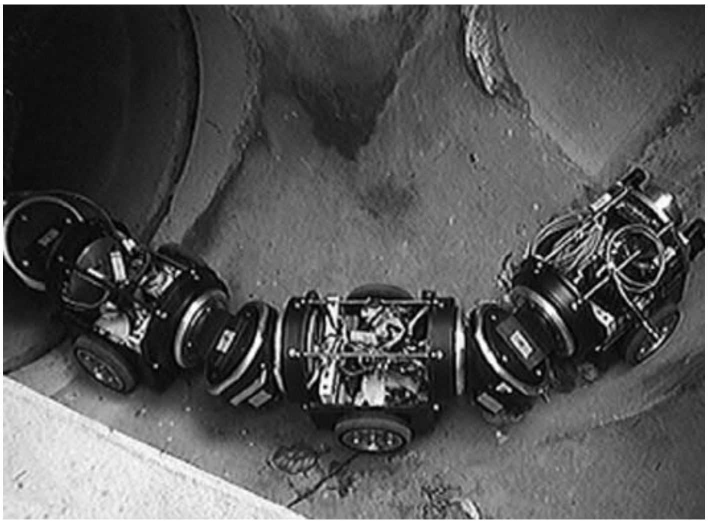


Figure 3.21. Autonomous crawler. https://www.academia.edu/18109939/Towards_autonomous_sewer_robots_the_MAKRO_project

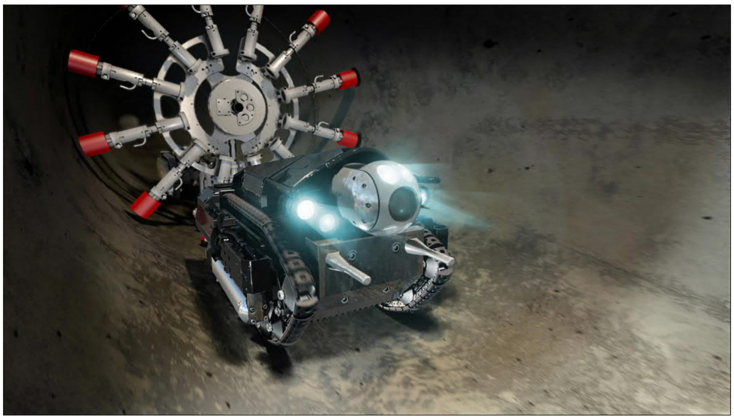


Figure 3.22. Pure Robotics' crawler. https://puretechltd.com/technology/purerobotics-pipeline-inspection-system/

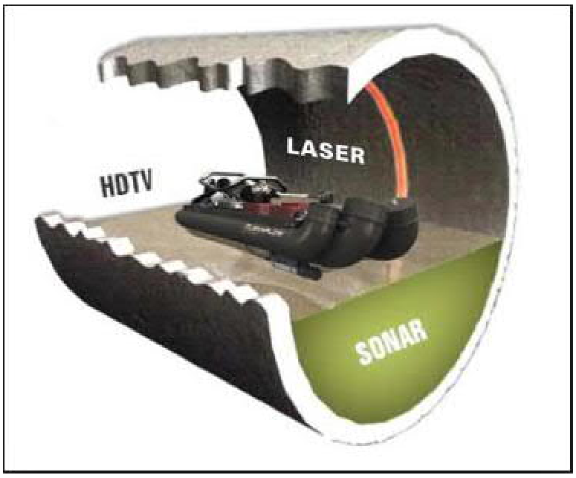


Figure 3.23. Multi-sensor pipeline inspection. https://caryloncorp.com/services/multi-sensor-pipeline-inspection/

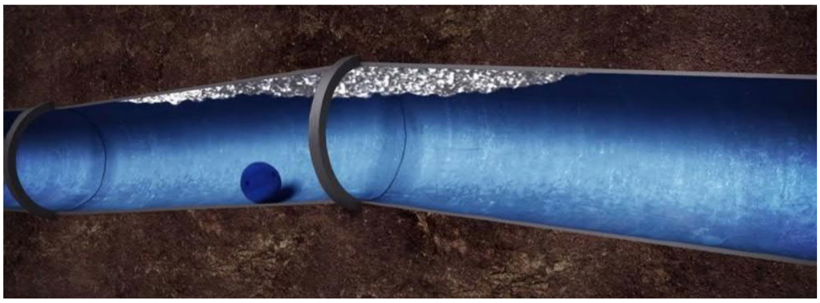


Figure 3.24. SmartBall®. https://puretechltd.com/articles/lyon-inspects-water-main-for-leaks-with-smartball/

3.6.3 Other methods

Gamma-gamma-loggers (GGL) have been developed to inspect concrete pillars and deep bore holes in the mining, oil, and gas industry. For this method, a gamma-gamma-rod, which has a Cesium-137 source, is used. Sensors are covered by lead to protect them from direct radiation. GGL is very good for inspecting concrete materials, and their structural densities. GGL can be used to estimate the structural conditions of concrete pipelines too, that show voids and other defects in the material (Feeney et al. 2009).

Infrared thermography (IRT) inspects thermal differences between materials/structures. IRT utilizes computational tools which visualize the thermal differences using different colors. This enables a user to see the inner walls of pipelines and their defects, such as I/I locations (Feeney et al. 2009). Unit price is approximately 5 € / m (Boshoff et al. 2009; Daher 2015).

The micro deflection (MD) method applies small, localized pressure increases to the pipe wall that can detect deformations and indirectly, its structural condition (Makar, 1999). MD can be used for brick, concrete and clay materials. MD is only partially usable for sewer and water main inspections since it only provides general information about the pipelines (Feeney et al. 2009).

3.7 ACOUSTIC CASI METHODS

Acoustic methods measure vibrations and/or sounds through a certain material. When used in sewer and watermain inspections, the results can help to locate defects.

Acoustic methods are often used to inspect pressurized pipelines (force mains and water mains), and they can be classified as: (i) I/I and/or leakage location; (ii) PCCP (prestressed concrete cylinder pipe) methods and; (iii) sonar- or ultrasound methods emitting a high pitch sound (Feeney et al. 2009).

Loggers (for I/I and/or leakages) utilize sound or vibration analyses in pressurized pipelines. Loggers are used with recorders, underwater microphones and geophones, and they are often used in water main inspections. Loggers have been around since 1980s. They can be installed permanently to water mains.

PCCP inspections include methods both for inner and outer wall inspections.

Sonar methods (Sound Navigation and Ranging) can be used to inspect under water pipeline walls, for example. Sonar is often combined with a CCTV raft. This method can be used in large diameter pipelines and tunnels (from 1500 mm to 3000 mm), and the water depth can vary from 6 to 60 m (Andrews 1998; Feeney et al. 2009).

Sonar utilizes acoustic pulses and it needs an emitter-and-sensor pair. The lag of the pulse from the emitter to the sensor indicates how far the inspected surface is from the emitter. If water supply networks are inspected, often a high frequency of 2 MHz is used, but lower frequencies (less than 200 kHz) are needed for structural inspections. The sonar method results in a very accurate surface (up to 3 mm resolution) model of a pipeline. Also, different materials yield different responses (Feeney et al. 2009).

Ultrasound methods (UM) for CASI have been developed recently, such as those at King's College, London. UM yields a very accurate surface result (Feeney et al. 2009). In the USA has been developed a UM combined with digital sewer inspection method (Lyer et al. 2011).

Impact Echo (IE) and **Spectral Analysis of Surface Waves** (SASW) are suitable methods for concrete materials. Both methods are based on the elastic effect of a material from a pneumatic hammer to the pipeline's wall. IE and SASW are effective in locating cracks, detached coatings, voids in the soil, and structural changes (Feeney et al. 2009).

Acoustic and ultrasound methods show (Table 3.11; Marshall & Loera, 2009):
- micro cracks;
- cracks;
- detached coating;
- pipeline's lower surface;
- pipeline's overburden;
- voids in the soil;
- pipeline's unnatural (faster) ageing;
- discontinuances of water pressure in force mains and water mains.

Table 3.11. Acoustic methods of CASI (Feeney et al. 2009; Bracken et al. 2009; Galleher Jr. et al. 2009; Paulson & Ngyen, 2010).

	In-Line loggers	Acoustic methods	Sonar/ultrasound
Sewer type	Force mains, water mains, non-pressurized sewers	Force mains	Force mains, water mains, non-pressurized sewers
Material	All	PCCP	All
Dimension	100 mm ->	450 mm ->	100 mm ->
Defects to be seen	Leakages, I/I	PCCP's defects	• micro cracks • cracks • detached coating • pipeline's lower surface • pipeline's overburden • voids in the soil • pipeline's unnatural (faster) ageing • discontinuances of water pressure in force mains and water mains
Procedure	Finding leakages and I/I in pressurized pipelines.	PCCP lines control and monitoring.	Under water mains, large pipelines, tunnels.
Currently available	Available.	Available.	Available.
Pros	Detects even minor leakages and I/I.	Good as a prescreening method.	Good for all materials and most of diameters.
Cons	Requires pressurized and moving water.	Only measures the general situation.	Only for under water pipelines and pipelines filled (partly) with water.
Unit price	NA	NA	NA
Unit execution time	NA	NA	NA

PCCP = Pre-stressed cylindrical concrete pipe; NA = not available

3.8 ELECTRICAL AND ELECTROMAGNETIC CASI METHODS

Electricity and electromagnetic currents can also be used to inspect pipelines. Eddy current testing (ECT), Remote Field Eddy Current (RFEC), and Remote Field Transformer Coupling (RTFC) methods are usable in iron/metallic pipes. ECT and RFEC methods use electric current and changes in the magnetic field. Magnetic Flux Leakage (MFL) method is used especially in the oil and gas industry to inspect metal loss and crack detection in iron and other metallic pipelines (Feeney et al. 2009; Psutka & Kong, 2009). Figure 3.25 illustrates a magnetic field inspection robot for pipelines, and Table 3.12 lists the pros and cons of these methods.

Figure 3.25. Magnetic field inspection robot. https://puretechltd.com/technology/purerobotics-pipeline-inspection-system/

ElectroScan method (ESM) was developed in Germany in 1999. It utilizes electrical currents to detect pipe defects. It can be used to inspect if there are leakages and I/I in non-metallic pipelines (clay, plastic, concrete, brick). However, the ESM cannot identify the cause of a defect or its location. Computational assessment can be used to locate the leakages and to estimate the causes. Unit price of ESM inspection is approximately 3 € / m (Tuccillo et al. 2011). ESM is especially useful in CASI of large diameter pipes (Moy et al. 2006).

ECT uses variable electric currents in the magnetic field yielding eddy currents in metallic pipes. This method measures small changes in the magnetic field and eddy currents, and qualities of pipelines are then analyzed. ECT can detect defects only from the surface of the pipeline (Feeney et al. 2009). It is good for small diameter pipes (less than 100 mm) (Daher, 2015).

RFEC was developed to conquer the limitations of ECT. This method can also detect defects in the inner part of pipeline's wall and uses a magnetic field with eddy currents (Feeney et al. 2009).

MFL is also useful when metallic pipes are inspected. It was developed during the 1920s and 1930s to help the oil and gas industry in asset management. In 1965 Tuboscope was developed for pipeline inspections. In this method, the magnetic field is analyzed with one or more magnets placed on the pipe's wall. It can detect fissures, a lack of welded joints, and points of pitting. It can only be used to inspect metallic pipes (Feeney et al. 2009).

Table 3.12. Electrical and magnetic methods (Feeney et al. 2009).

	Electrical leakage and I/I detection	ECT/RFEC	MFL
Sewer type	Force mains, water mains, non-pressurized sewers.	Force mains, water mains, non-pressurized sewers.	Force mains, water mains, non-pressurized sewers.
Material	non-metallic.	Metallic.	Metallic.
Dimension	75 mm ->.	50 mm ->.	50 mm – 1400 mm.
Defects to be seen	Fissures, leakage and I/I.	Loss of metallic substance, fissures, leakage, I/I, wall thickness.	Loss of metallic substance, cracks (any direction).

Procedure	To estimate leakage and I/I potential.	Water boilers' pipeline assessment	Petrochemical industry.
Currently available	Available.	Available.	Available with limitations.
Pros	Useful in inspecting house connections.	Many diameter pipes can be inspected. Defects can be located.	Oil and gas industry uses this.
Cons	Non-pressurized lines have to be filled with water prior to inspection.	Metallic pipes with limitations only.	Only very few cases in sewer inspections are known.
Unit price			
Unit execution time			

3.9 HOUSE CONNECTIONS AND THEIR INSPECTIONS

House connection lines are only rarely inspected. For instance, leakage and I/I can be significant through these lines, and their CASI should be increased considerably as compared to the current situation. Table 3.13 lists of CASI methods useful for inspections and pre-washing of house connection lines.

Table 3.13. Inspection and washing methods for house connection lines (Simicevic & Sterling, 2006).

Method	Description
▪ House-to-house survey	Locates cleanouts visible from the surface.
▪ Smoke testing	Locates pipes that are not very deep and have defects. Used often and on a large scale.
▪ Dye water flooding	Checks if the house is connected to the mainline. If so, another method can be utilized to identify the lateral layout if necessary.
▪ Mainline CCTV	Locates lateral-to-mainline connections along the mainline. Used frequently.
▪ Walkover sonde (on lateral CCTV, flexible rod or cleaning hose)	Identifies layout and depth of the pipe on its entire length (where the camera can pass). The most accurate method after open cut excavating.
▪ Rod probe from surface	Locates cleanouts where they are suspected to be. Used occasionally.
▪ Plumber's snake	Identifies layout of the pipe on its entire length, however difficult to work with in noisy conditions. Used less as other methods became available.
▪ Vacuum excavation	May be used to locate and check the depth of the pipe at selected points where it the lateral is believed to be laid, however mostly used for installation of cleanouts and opening of small pits where needed during lateral rehabilitation. Has become very popular for its ease of use and small footprint.
▪ Ground penetrating radar (GPR)	Identifies layout and depth of the pipe where the soil conditions are favorable and access to inside the lateral is difficult. Currently used rather infrequently but use increasing as cost of equipment drops and ease of use improves. Research is improving the resolution of utilities at greater depths in difficult soil conditions.
▪ Radar tomography (RT)	Can be used for locating (on a large scale) of sewer laterals if the surveyed area is accessible to a vehicle pulling a pool-table-size attachment. Creates 3D images showing utility lines and other features appearing at various depths.

4 OTHER METHODS LINKED TO PIPELINES CASI

4.1 MANHOLE INSPECTION METHODS (MIM)

Manhole inspection methods (MIM) include several CASI methods. However, in most of the cases, MIM only requires a visual inspection with pictures taken at the location. There are many MIM projects, which have focused on digital inspection methods. Such methods include CleverScan® and the Panoramo® manhole inspection camera. Table 4.1 lists known methods for MIM.

Table 4.1. Manhole inspection methods (MIM).

Method	Quality of results
CleverScan®	Good, video material, dimensional accuracy with digital images, point cloud of inspection.
Panoramo® manhole inspection camera	Good, video material, dimensional accuracy with digital images, point cloud of inspection.
CCTV equipment	Poor, only visual inspection.
Manual/visual inspection with picture taken using a standard camera	Mediocre.

Figures 4.1 – 4.3. Illustrates MIM equipment.

Figure 4.1. CleverScan®. http://cleverscan.com/

Figure 4.2. Panoramo® manhole inspection camera. https://www.mswmag.com/g/wef-tec-product-preview/2015/08/rapidview_ibak_north_america_panoramo_si

Figure 4.3. 3D color manhole scanning equipment. https://trenchlesstechnology.com/cues-introduces-first-wireless-3d-color-manhole-scanning-technology/

4.2 TUNNELS AND THEIR INSPECTION METHODS

Tunnels are a very important part of water and sewer networks throughout many cities and municipalities. Many CASI methods are available for tunnels' inspections however, there are both limitations and extra requirements for the equipment. For example, MPR and GPR methods are possible for the inspection of tunnels. Drone driven cameras (Figure 4.4) have also been developed and been put into use (in Spain and in the USA). Large diameter pipelines and tunnels can also be inspected by rafts, with all the equipment needed (Figure 4.5).

Figure 4.4. Drone with inspection equipment. https://www.thelocal.es/20151207/could-drones-soon-replace-workers-in-barcelonas-sewers

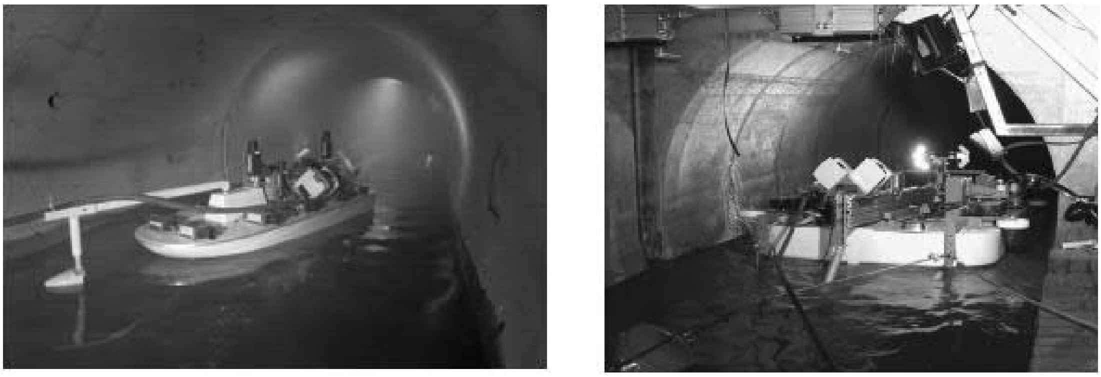


Figure 2 SEK prototype (left) and test of the SVM (right) in a real sewer

Figure 4.5. Raft with inspection equipment (Teichgräber et al., 2006).

4.3 INFORMATION AVAILABLE FROM PUMPING STATIONS

Data analysis methods are available as an indirect inspection method of the sewer (and water main) networks. In the Helsinki Region, the waste water division of HSY uses data analyses to estimate flow of the pumping stations and to evaluate the overall condition of the sewer network (HSY, 2017).

4.4 FLOW MEASUREMENTS

Flow measurements of sewer pipelines are often made with level measurements or velocity measurements. The flow through pipelines can then calculated with continuity equations. The proper method of flow measurement for each case must be evaluated carefully since, for example, pressurized pipelines, the amount of suspended matter and other such factors are the cause of the initial requirement for investigation. It is very important to ensure that the service life of batteries, the data transfer method, the data network, etc. are sufficient for use. Real-time flow measurements might endanger the service life of batteries for example (Feeney et al. 2009).

4.5 MEASUREMENTS OF WATER QUALITY

Water quality parameters, such as temperature, volume, the number of suspended solids, etc. help to evaluate the condition of the network upstream. Such methods can be continuous or one-time measurements. For example, Vuove-insinöörit Oy in Finland executes indirect inspections of sewer networks. These methods are useful as pre-screening methods when estimating the overall condition of sewer network.

4.6 SAMPLES TAKEN FROM A PIPE

During maintenance actions and connection procedures (for example), it is possible to take samples from along a pipeline's wall. These samples can be analyzed to get more information about a pipelines' quality and other properties. This information could be a "life-saver" and essential when estimating the overall condition of a network to get a more effective asset management for a water utility company. Even if samples are a good way to get information, the sampling should be taken carefully and without additional stress to the pipeline.

When a sample is taken, all the following data must be documented:

- material;
- age (build-in year);
- diameter (of the pipe);
- soil type (properties like corrosivity, stability, changes in use);
- load of the pipe (traffic, flow, water quality etc.);
- other data that is needed.

4.7 PRESSURE TESTING, SMOKE TESTING, COLOR TESTING

Pressure testing should be used when a sewer pipeline (or a set of pipes) is accepted. However, this type of testing is quite seldom used in sewers but is used in water mains. Pressure testing can be made with water or air. It should be noted that air penetrates smaller pores 20-fold more than water and thus, only water should be used in this method.

Smoke and color testing is useful when illegal or leaking joints and connections are suspected in a certain area. Those methods use safe substances to reveal possible deviations.

5 CASI METHODS IN DIFFERENT CASES

Good quality initial data from a sewer network is vitally important. Much of the initial data can be improved upon during the pre-screening process and/or CASI. A pre-screening method that incorporates data analysis can provide good enough information for CASI throughout all parts of the network. It is also possible to measure, for example, spatial information when carrying out CASI in the field.

There are methods from above ground, such as GPR, electrical resistivity tomography (ERT) and others, that can help to locate and analyze the pipelines condition indirectly, without accessing them. These methods also provide essential information about soil and other underground structures that might affect the condition of the sewers.

5.1 GRAVITY COLLECTORS

Appendix 1 lists CASI methods for gravity collectors.

Pre-screening methods suitable for gravity collectors include the critical assessment method, further data analytical methods, and zoom-inspection. Even if the data analytical methods are suitable, they are not enough on their own to use for CASI along those pipelines.

CASI methods include CCTV and digital CCTV with robot crawlers, laser scanning, sonar and ultrasound inspections, in-line I/I detection, electrical methods and flow measurements. Water quality measurements are suitable, too.

Table 5.2 lists methods suitable for gravity collectors, and Finnish companies providing those.

Table 5.2 CASI for gravity collectors and force mains, including list of companies (in Finland).

Method	Results of the method	Provider
Critical assessment	Classification of sewer and water networks. Spatial data analysis.	Universities, water utility companies, consultancies.
Zoom-camera inspection	Visual CASI method. Does not require pre-washing/cleaning of pipes. Good for pre-screening and operational condition assessment.	Delete Finland Oy Eerola-Yhtiöt Oy Lassila &Tikanoja Underground City Oy
CCTV	Visual CASI method. Pre-washing/cleaning required.	Delete Finland Oy Eerola-Yhtiöt Oy Hurrikaanit Oy Joen Loka Kaivopumppu Kulmala KM Pipe Oy Lahden Putkistokuvaus Oy Lassila &Tikanoja Oulun viemärihuolto Raision Pesuhuolto Oy RTK Palvelu SanMat Kunnossapito Oy Salon Imuautot Oy Seppo Eskelinen Oy Suokon imupalvelu Suurpää Oy Viemäritek Oy
Digital CCTV	Visual CASI method. Pre-washing/cleaning required Dimensional accuracy. Automated results analysis possible.	Delete Finland Oy Oy DigiSewer Productions Ltd Joen Loka Lassila &Tikanoja
Laser scanning	Accurate 3D model of the inner pipe.	Oy DigiSewer Productions Ltd Lassila &Tikanoja
Sonar method	Structural assessment of pipes. Soil properties around the pipe.	Loxus Technologies Ltd
Ultra sound method	Structural assessment of pipes.	Not available in Finland.
Electrical condition assessment		VTT / Korkealaakso Undergound City Oy
Water quality assessment	The amount of I/I and localization of sources.	Aquapriori Oy Vuove-Insinöörit Oy
Flow measurements	Local information of network. To estimate I/I in an area.	Aquapriori Oy Vuove-Insinöörit Oy Lots of providers
Data analyses using data from pumping stations	Blockages and I/I information almost in real-time. Indirect CASI method.	Perfektio Oy Avarea Oy Futurice Many other providers.

5.2 PRESSURE LINES, FORCE MAINS

Appendix 2 lists CASI methods suitable for force mains. Most of the methods provided are also suitable for water mains.

Force mains can be inspected by acoustic methods or with sensors flowing along the water pipe. Pre-screening methods suitable for gravity collectors include the critical assessment method, further data analysis, and zoom-inspections. Even if data analytical methods are suitable, they are not enough on their own to use as CASI along pipelines.

Table 5.2 lists methods suitable for force mains, and the Finnish companies providing those.

5.3 GENERAL INSPECTION WITH PRESCREENING METHODS

Pre-screening of water, sewer and storm water networks is possible with data analytical or physical methods. Those methods result in a criticality assessment, general condition assessment with information of operational condition of the sewers, and so on. The resulting data is then combined with network information (NIS, GIS, other format), failure and blockage information, and possibly information from open sources, such as from groundwater and surface water registries. Pre-screened data is then classified as critical pipes, pipes in poor condition, pipes with high I/I rate and so forth, depending on the process and programs used. That data helps to focus the more detailed condition assessment methods to areas where network is most probably in its worst condition. That data is then the basis of condition management and renovation programs following the prescreening phase.

For example, zoom inspection is one of the physical prescreening methods, which helps to screen whole networks in a relatively short time compared to more detailed pipeline inspection methods. This method is also suitable to estimate operational condition of the sewer and storm water network, because it is carried out without pre-cleaning phase.

5.4 REDUCING I/I IN THE SEWER AND STORMWATER PIPELINES

Methods to analyze I/I in sewers and storm water pipelines need initial data, such as accurate network information (NIS, GIS, other format), flow rate information from the pumping stations, CSO and SSO registries, and rain fall. The I/I can also be analyzed with indirect methods (such as Vuove method available in Finland), which analyze water quality parameters such as temperature, salinity, flow rate, and color.

This information is then combined and analyzed with the resulting aerial information of the pipelines; which are mostly affected by the I/I. That helps water utility to focus on those areas with more detailed CASI methods.

5.5 DATA COLLECTION FOR HYDRAULIC MODELLING

When a hydraulic model of the network is being made, there is a great need for accurate data, such as diameters, materials, GIS information and such. Here are listed some available methods for data management prior to hydraulic modelling:

- FME® platform is one useful method to gather and defragment network information. In this method, build year, material and diameter of the water, sewer, or storm water pipelines are estimated and unified;

- A zoom inspection method (such as QuickView®) is a very handy tool to estimate and collect data from networks since it is fast and does not require a pre-cleaning phase;
- Manhole inspections (such as CleverScan®) are important for I/I and capacity analyses of networks.

5.6 MINIMUM REQUIREMENTS OF SEVERAL CASI METHODS

This chapter lists the minimum requirements for several CASI methods, both Finnish and international sources have been used.

Tables 5.4 – 5.7 Lists requirements for each method.

Table 5.4 Requirements for zoom-camera.

Target	Pipelines, DN100 - DN2000	Pipelines, manholes, containers, other spaces
Battery	12 V.	Reloadable, changeable.
Camera	1280x720 (2,38 megapixel).	Color image.
Zooming properties	30:1 optic.	Digital x 12, 360:1 enlargement
Focusing	Manual / automatic.	
Lighting	Good enough.	Adjustable lightning.
Requirements	Moisture resistant, Oscillating quality.	
Handling of camera	With 6 m long rod.	
Stabilization	Floor-fixing to the bottom of manhole.	Floor-fixing to the ground.
Recording	Manual / analogous.	Automatic.
Data transfer	Via cloud-based system.	
Application	For camera and data transfer.	Zooming, lightning, data saving, coltage.
Information	Address, ID, date.	Time, length of data, GPS information.

Table 5.5. Requirements for nozzle cameras.

Target	Pipelines, DN200 - DN800.	Attachable to root cutter.
Camera	HD color camera.	
Battery	12 v.	Reloadable, changeable.
Lighting	LED.	Separate control.
Recording	Flash memory / 64 Gt.	Inner recording of camera / SDH max 32 Gt.

Table 5.6. CCTV with robot crawler.

Target	Pipelines, DN90 - DN2000	
Camera	CCD color camera	Luminous sensitivity 1 Lux
Accuracy range	Horizontal 530 TVL / PAL	Manual/automatic focus
Zoom	Manual	Automatic
Lighting	LED	Stepless control from 0 to 100 %
Recording	Flash memory	Inner recording of camera
Reporting	Manual/automatic data transfer	Analysis
Pan-Tilt	Stepless +/- 135 °	Up/down, sideways
Pressure requirement	1 bar	Pressure alarm
Laser scanning	option	
Back-camera		
Robot crawler	Min 4 wheel drive	Wheels changeable
Descending gradient sensor	Documented	
GPS emitter		
Cable drum	Automatic, cable min 200 m	Distance meter included

Table 5.7. Digital CCTV with robot crawler.

Camera	HD color camera.	Photo camera.
Resolution	Min 380 000 pixels.	
Lens of the camera	Viewing angle min 180 °.	
Lighting	LED.	Controllable.
Recording	To the equipment.	Flash memory.
For pipelines DN150 – DN800	Mechanical centring.	With application.
Images	Plan view of the inner pipe surface.	1-3 views.
Crawler	Min 4 wheel drive.	Wheels changeable.
Decending gradient sen-sor	Documented.	
Graphic image of pipe		
Precision	1 mm.	
Analysis of defects	Manually/automatically.	At the location or by a third party.
Cable drum	Automatic, cable min 200 m.	Distance meter included.

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APPENDIX