Guidelines For Condition Assessment And Rehabilitation Of Large Sewers

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1. General

1.1 Introduction

Sewer collection systems are essential elements of municipal services. To ensure a high level of reliability at the lowest possible cost, asset management systems and procedures that include effective methods for condition assessment and rehabilitation must be implemented.

This Guideline applies to large sewers (900 mm and larger) and provides owners and operators of sewer systems with suggested methods for managing the assessment and repair of large sewers. The subject areas covered in this Guideline include:

- Health and safety issues for inspection and repair
- Availability, applicability and limitations of existing technologies for inspection, condition assessment and rehabilitation
- Failure impact assessment
- Collection and management of reliable data
- Decision making based on sewer conditions and failure impact
- Projections of future sewer conditions
- Cost estimates for sewer and access hole inspection and repair.

The steps for the effective management of large sewers and their location in this Guideline are shown in Figure 1.1. In addition, the health and safety issues associated with work in the confined space of a sewer are provided in Section 2. Appendix A provides tables for converting defect codes from other rating systems to the Large Sewer Condition Code

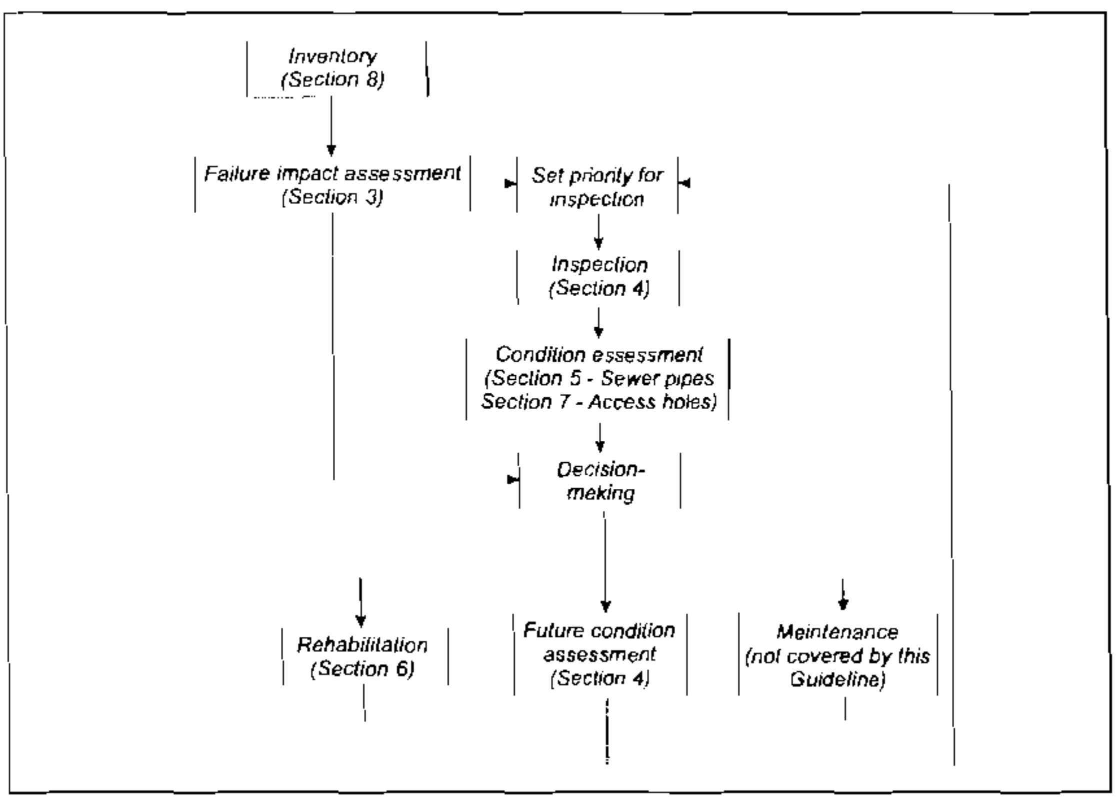

Figure 1.1. Steps for managing sewer assets

and Rating (LSCCR) system described in this Guideline. Appendix B contains additional information on estimating future conditions of sewers.

1.2 Scope

This Guideline applies to large gravity sewers, that is, sewers with a minimum pipe size of 900 mm (the minimum aceepted size for person entry)[22,51]. However, many aspects of the Guideline are applicable to sewers of smaller sizes.

The Guideline provides a systematic method for the structural defect rating of sewers, brick sewers and aceess holes and provides information about eurrent rehabilitation methods for large sewers.

The planning and scheduling of sewer rehabilitation will not depend entirely on the failure impact rating and the condition ratings described in this document. Other factors such as population growth, plans for installation of other buried services and road surface rehabilitation will also affect the timing of sewer rehabilitation.

The Guideline also provides a method for rating serviceability defects. The serviceability rating can be used to prioritize maintenance work. However, the decision-making about maintenance needs and appropriate techniques are beyond the scope of this Guideline.

1.3 Terminology

The principal terms used in this Guideline and their meanings are as follows:

Access hole: A structure that provides access to the sewer pipe for maintenance, inspection and rehabilitation. Access hole is used interchangeably with maintenance hole (or manhole — MH for short) and access structure.

Condition: The condition of a sewer pipe or access hole is expressed by six condition ratings as follows: 0 – excellent, 1 – good, 2 – fair, 3 – poor, 4 – bad, 5 – failure or imminent failure. Condition ratings are also referred to as condition states in theoretical models for predicting future sewer conditions (Appendix B).

When the pipe or aceess hole is in excellent eondition (or as good as new), no defects will be observed during an inspeetion and its eondition is represented by "0".

Defect: A defect is a physical or service deficiency. Defects may originate from the manufacturing or installation proeess, or may be a result of normal wear and tear or third party damage. Defects can be classified as either affecting structural integrity or affeeting serviceability.

Durability: Durability[37,17] is the ability of a pipe or aecess hole to satisfactorily withstand the effects of service conditions to which it is subjected. Or stated more simply, it is the ability of a pipe or access hole to resist wear and deterioration.

Embedment: Embedment is the backfill materials surrounding the pipe extending from the top of the pipe to the base of the trench and including bedding.

Failure: Failure of a pipe or access hole occurs when it is no longer able to function as intended. Failure of a sewer pipe means that the pipe is no longer able to convey sewage at its design capacity. Modes of failure vary with pipe materials. Condition 5 indicates failure or imminent failure.

Full-line inspection methods: These are inspection methods that are used for continuous inspection of a sewer pipe from one access hole to another.

In-line test methods: These are test methods used for localized areas, joints or lengths, usually with specialized tools. In-line testing usually involves person-entry.

Large sewers: Sewers of 900 mm and larger are defined as large sewers. This size is considered the minimum size for which person-entry is practical and safe.

Person-entry activities: These are any activities requiring a person to enter the sewer.

Pipe bedding: Pipe bedding is structural backfill material placed between the bottom of the pipe and the bottom of the trench.

Service life: Service life is the expected duration that a pipe or access hole will perform satisfactorily based on normal maintenance activities. (For other definitions of service life, refer to References 25,43, and 46.) Remaining service life is the life span of a structural element from the current time to the time of its failure. Design service life is the intended life span from the time of construction to the time of failure, based on the design criteria. Design service life is not a true indicator of the deterioration rate of the element materials or when the element will actually fail.

Serviceability: Serviceability is the capability of a pipe or access hole to perform the function for which it was designed while exposed to in-situ conditions.

Special-purpose inspection methods: These are inspection methods used for localized areas or lengths (not necessarily for the entire MH to MH length), or to access a particular defect.

2. Health and Safety

Sewers are dangerous work areas because they contain harmful gases, bacteria and other micro-organisms, and have insufficient oxygen supply, high humidity, odour and slippery working conditions. Furthermore, flows in many large sewers cannot be diverted so that inspection or rehabilitation can take place in the absence of flows.

Health and safety is paramount and must not be compromised. A safety plan is required for all person-entry activities inside a sewer pipe. Safety procedures must be developed and followed by all involved personnel. Before any inspection or rehabilitation work commences, safety procedures must be in place and trained personnel responsible for site safety must be identified. Fatalities can occur if appropriate safety procedures are not followed.

Although a national health and safety regulation does not exist in Canada, many provinces and municipalities have established their own regulations and procedures for confined space entry. Any municipality operating a sewer system is urged to establish suitable procedures in consultation with provincial authorities and other municipalities. For additional information, refer to the following documents:

- Ontario Regulation 213/91: The *Occupational Health and Safety Act*
- City of Toronto: *Confined Space Entry and Exit*, 1989
- Capital Regional District (Victoria, BC): *Section 3 – Work Procedure (WP) 13: Confined Space Entry Procedure*, CRD ENG Policy/Procedures Manual, 1998
- Region of Hamilton-Wentworth: *Confined Space Entry Procedure* (developed for a specific project), 1998
- Greater Vancouver Regional District: *Confined Space Guidelines*, 1999; *Confined Space Entry Guidelines for Sewer Entry*, 1994; *Personal Protective Equipment Policy Statement*, 1993 (all are included in tender documents for sewer work)
- City of Regina: *Confined Space Entry Program, City of Regina*, 1997.

Minimum requirements for confined space entry are:

- Proper training of above-ground and below-ground personnel participating in the inspection and rehabilitation of sewers
- Detailed contingency plans for work and rescue
- Assessment of potential hazards prior to access hole and sewer entry
- Availability of appropriate protective clothing and equipment (harness, life-lines, breathing apparatus, and hoisting and conveying equipment)
- Availability of appropriate tools and equipment that are in good working order
- Availability of emergency equipment (first-aid kit and fire extinguisher)
- Notification of appropriate rescue agencies (such as the fire department) prior to commencement of work
- Air quality testing and monitoring prior to and during person-entry
- Maintenance of adequate ventilation and lighting during person-entry

- Opening and continuous monitoring of the access holes immediately upstream and downstream from the work area

- Effective communication between the above-ground and below-ground personnel

- Constant maintenance of lifelines

- Safe control of surface traffic.

Sewers are hazardous work environments. Any person entering a sewer must be trained in work and safety requirements for confined-space entry.

3. Failure Impact Assessment

The impact of a failure of a large sewer depends on several factors and each sewer is unique. Decisions about sewer rehabilitation are based on two main considerations - the impact of failure and the condition of the sewer (Seetions 5 and 7).

Failure impact assessment is a way of assessing the consequences of failure of the different segments of a sewer system and the likelihood of failure based on the site eonditions where the sewer is loeated. Failure impact assessment is usually done independently of on-site inspeetion and eondition assessment.

The impact of failure is based on the likelihood of failure and the severity of consequences resulting from failure. For example, the likelihood of failure would be high if a fractured sewer were located in unstable soil conditions. The consequences resulting from a failure would be high if a sewer served a large area and no bypass capability existed.

The failure impact assessment rating is used in conjunction with the condition rating to provide a logical and systematic means for determining the priorities for snbsequent inspections and the eventual rehabilitation of sewers.

3.1 Failure Impact Assessment of Sewer Pipes

Table 3.1 shows the major factors that either affect the likelihood of failure or the severity of eonsequences resulting from failure. Local impact factors will vary from location to loeation whereas global impact factors will remain the same for individual MH to MH sewer segments or even for an entire urban area.

3.1.1 Failure impact determination

Numerieal values are used to represent the degree of impact should failure occur. Consistent assignment of values will provide useful information about the relative degree of failure impact of one sewer or sewer segment to another. When the impact of a factor is negligible or low, a value of 1 is assigned, and when the impact is medium or high, values of 1.5 and 3.0 respeetively are assigned (Table 3.2, page 8). Each failure impact factor has an established weighting faetor that is used in combination with the degree of failure impact in Eq. 3.1 to determine the weighted failure impact factor for a sewer.

Table 3.1. Major failure impact factors

Factor	Affecting the likelihood of failure	Affecting the severity of consequences resulting from failure	Local or global effect
Sewer location	•	•	Local
Embedment soil	•		Local
Sewer size		•	Global
Burial depth	•	•	Global
Sewer function	•	•	Global
Seismic zone	•		Global

Failure impact ratings serve two purposes:

1. They establish priorities for sewer inspection (Section 4) and condition assessment (sewer pipes - Section 5, access holes - Section 7)

2. They serve, in combination with condition rating, as the basis for decision-making for the timing for rehabilitation (sewer pipes - Section 6, access holes - Section 7)

The degree of failure impact of each of the major factors is defined in 3.1.2 to 3.1.7. The weighted failure impact factor I_w is then calculated by:

$$I_w = (0.2) f_l + (0.16) f_e + (0.16) f_s + (0.16) f_d + (0.16) f_f + (0.16) f_q \quad [3.1]$$

Once the weighted failure impact has been calculated, the impact rating R_{imp} is then determined using Table 3.3.

3.1.2 Sewer location

The impact of a sewer failure on the public and the environment is affected by its location.

Table 3.4 shows the sewer location factor f_l and the failure impact as a function of land use, traffic, access for repair, location relative to essential facilities and environmental zoning.

Figure 3.1 shows an example of assigning sewer location factors. A high sewer location factor has been assigned for the portion of the sewer within the airport perimeter and a low location factor assigned for the portion outside the airport.

Table 3.2. Failure impact factors and weights

Failure impact factor	Weighting factor	Symbol	Degree of failure impact		
			Low	Medium	High
Local					
Sewer location (Table 3.4)	0.2	f_l	1.0	1.5	3.0
Embedment soil (Table 3.5)	0.16	f_e	1.0	1.5	3.0
Global					
Sewer size (Table 3.6)	0.16	f_s	1.0	1.5	3.0
Burial depth (Table 3.7)	0.16	f_d	1.0	1.5	3.0
Sewer function (Table 3.8)	0.16	f_f	1.0	1.5	3.0
Seismic zone (Table 3.9)	0.16	f_q	1.0	1.5	3.0

Table 3.3. Failure impact rating

Weighted impact factor, I_w	Impact rating, R_{imp}
1.00	1
1.01 – 1.60	2
1.61 – 2.20	3
2.21 – 2.80	4
> 2.80	5

Table 3.4. Sewer location factor*

Aspects	Degree of failure impact		
	Low (f_l = 1.0)	**Medium (f_l = 1.5)**	**High (f_l = 3.0)**
Land use	Industrial	Residential	Commercial
Traffic intensity	1 or 2 lanes	3 to 5 lanes	6 lanes or more
Access for repair	Unrestricted	Limited	Restricted
Location (under or adjacent to)	Areas not covered in the next two columns	• high volume tourist areas • high risk installations or utilities	• high risk installations or utilities • railroads, rivers, canals or other bodies of water • buildings • primary access to emergency facilities • airports
Environmental	Non-sensitive areas	Environmental conservation zones	Environmental protected zones

* Modified from References 10 and 11

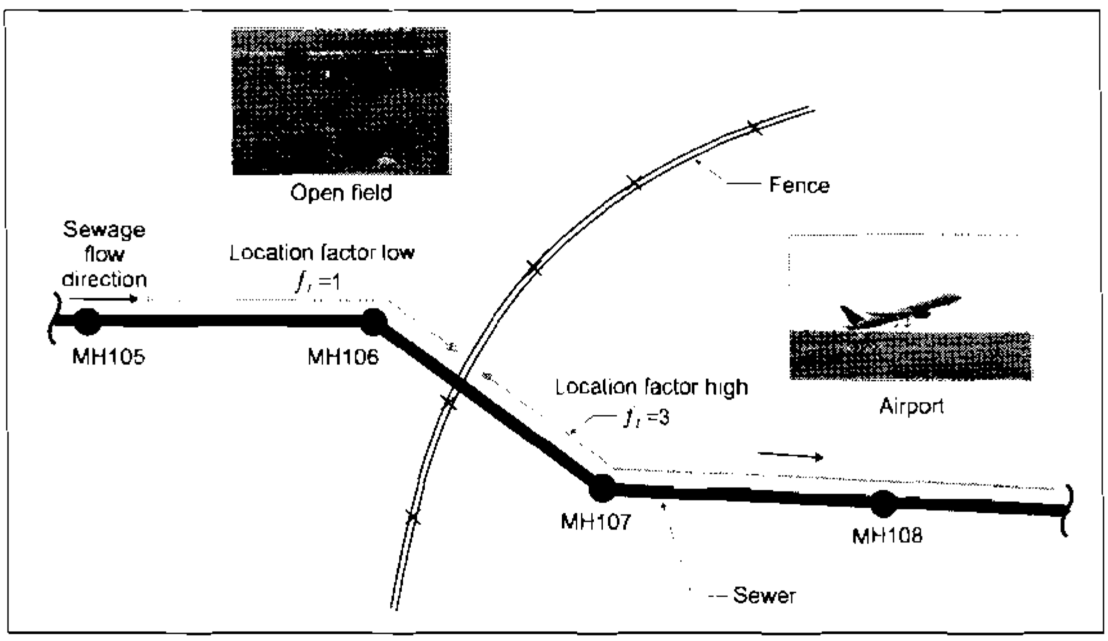

Figure 3.1. Sewer location factor example

3.1.3 Embedment soil

The characteristics of the embedment soils and the native soils in proximity to a large sewer are an indication of the susceptibility of the sewer to failure. For example, the combination of fine embedment soils, high water table and fractures or joint openings in the sewer pipe can result in erosion of the soils supporting the pipe.

Silts and fine sands are highly susceptible to erosion[3] (a phenomenon commonly referred as "piping") even when exposed to small hydrostatic heads (less than 1.5 m head) and this loss of support can lead to sewer failure. Table 3.5 shows the embedment soil factor f_s for various soil types.

Table 3.5. Embedment soil factor*

Embedment soil	Degree of failure impact	f_s
Medium to high plasticity clays All clays if sewer was constructed by tunnelling	Low	1.0
Low plasticity clays Fine to medium gravel Well graded sandy gravel Silts, silty fine sands or fine sands	Medium	1.5
Medium to coarse sands	High	3.0

*Based on Reference 52

3.1.4 Sewer size

Sewer size affects the selection of rehabilitation methods, the execution of the repairs, and the degree of contamination to the surrounding environment (soil or receiving waters) in the event of a failure. Generally, repair costs increase with increasing sewer size. Table 3.6 shows the sewer size factor f_z for various sizes of sewer.

3.1.5 Burial depth

The degree of difficulty for emergency repairs increases with increasing sewer depth. The difficulty of carrying out an inspection also increases with depth, as do health and safety concerns. Table 3.7 shows the sewer burial depth factor f_d for various depths.

Table 3.6. Sewer size factor*

Sewer diameter/vertical size (h), mm	Degree of failure impact	f_z
< 900	Low	1.0
900 – 1800	Medium	1.5
> 1800	High	3.0

* Based on Reference 15

Table 3.7. Burial depth factor*

Burial depth (h), m	Degree of failure impact	f_d
h ≤ 3	Low	1.0
3 < h ≤ 10	Medium	1.5
h > 10	High	3.0

* Based on Reference 15

3.1.6 Sewer function

The type of sewage conveyed in a large sewer impacts the degree of both the soil and/or receiving water contamination and the repair difficulty. In general, the failure of sanitary sewers poses a higher degree of impact than the failure of storm sewers[44]. Table 3.8 shows the sewer function factor f_f for different types of sewers.

3.1.7 Seismic zone

Earthquakes can cause more damage to defective pipe sections than to non-defective pipe sections. The ground vibrations diminish the soil support for the sewer, particularly for flexible pipe because it has a higher degree of reliance on soil support than rigid pipe.

Consideration of the seismic factor is not meant to eliminate damage to sewer systems during earthquakes, but rather to minimize the degree of damage in such events. Table 3.9 shows the seismic zone factor f_q for different seismic zones. Z_a is defined as acceleration-related zone and Z_v *is* defined as velocity-related zone[42].

3.2. Failure Impact Assessment of Access Holes

Access holes connect two or more sewer pipes together. These pipes can be of different sizes and depths and therefore the impact of their failures may be different. The impact rating of an access hole is defined as being equal to that of the adjoining sewer pipe with the most severe failure impact rating (Figure 3.2, page 12).

3.3 Using Failure Impact Ratings to Set Priorities

Impact rating maps (Figure 3.3, page 12) can be generated for sewer collection systems using the failure impact rating methodology explained in this Section. Failure impact maps will help not only for identifying priorities for inspection, condition assessment and rehabilitation, but also for planning new sewer extensions. For instance, an impact rating might be used to locate a new sewer away from high failure impact rating areas.

A comprehensive inspection plan is crucial for

Table 3.8. Sewer function factor*

Function	Degree of failure impact	f_f
Collector sewer, storm sewer	Low	1.0
Major trunk, sanitary or combined sewer	Medium	1.5
Major/regional interceptor, influent and effluent to/from wastewater treatment plant	High	3.0

*Modified from references 10 and 11

Table 3.9. Seismic zone factor[42]

Acceleration-related or velocity-related seismic zone, Z_a, Z_v	Degree of failure impact	f_q
0 - 2	Low	1.0
3 - 4	Medium	1.5
5 - 6	High	3.0

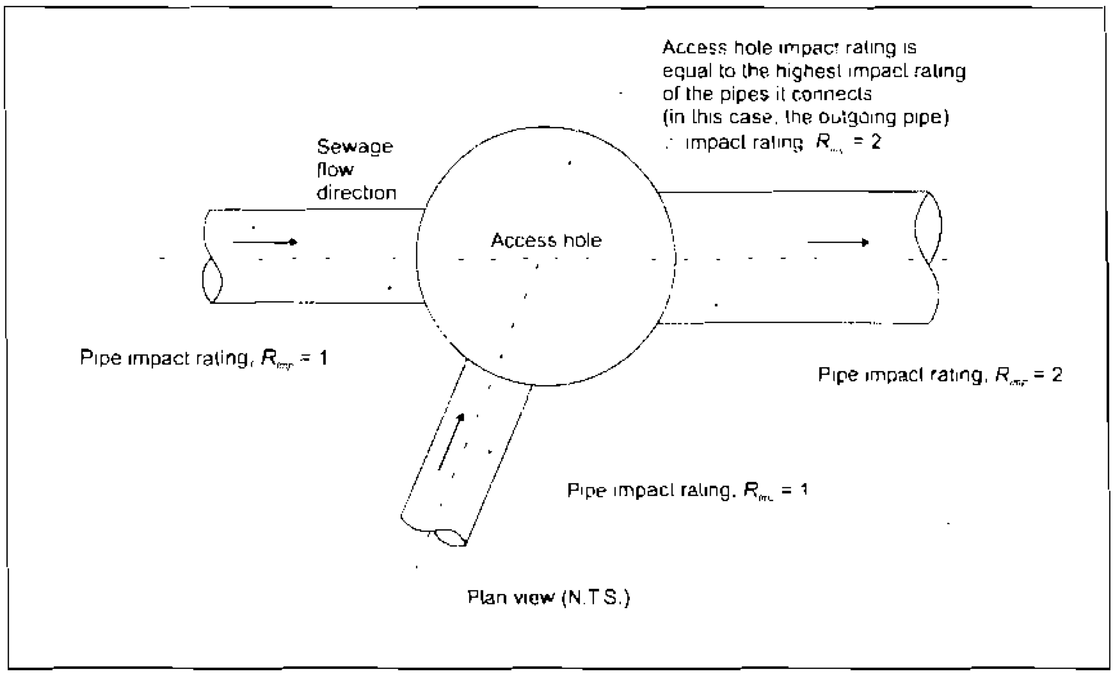

Figure 3.2. Access hole failure impact rating

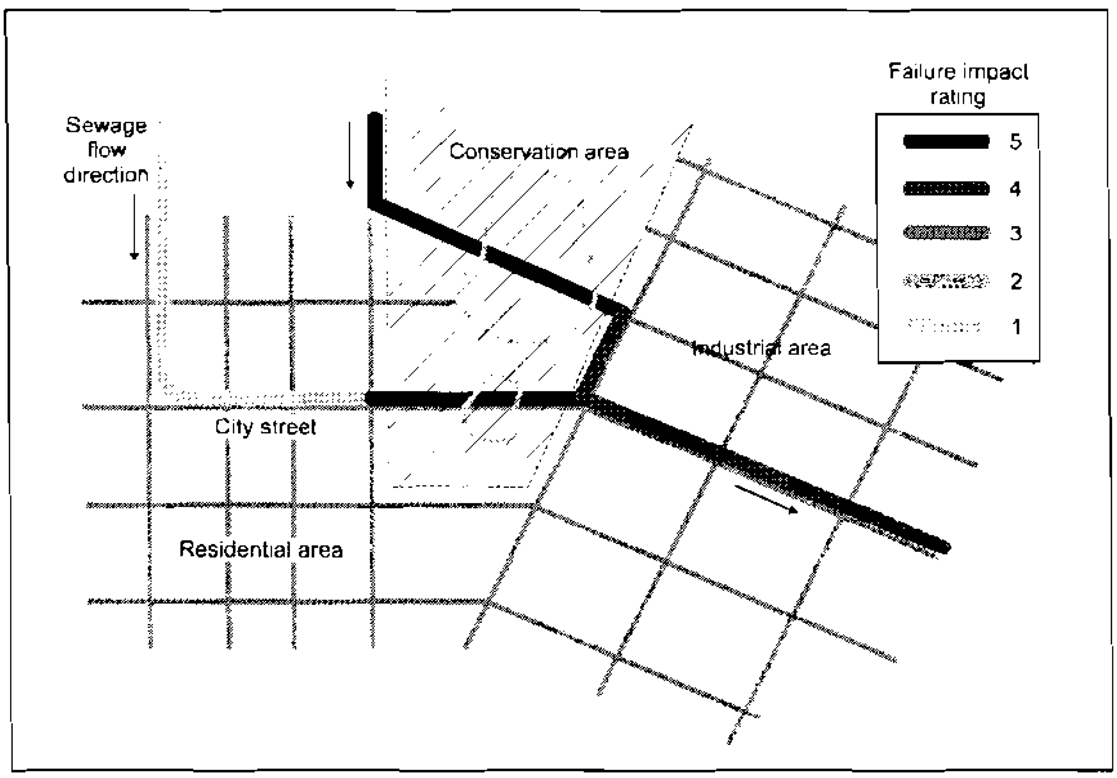

Figure 3.3. Sample sewer impact map

4. Inspection

the effective management of large sewers. Inspection is the first step of the condition assessment. The condition of a sewer system, in combination with the failure impact assessment presented in Section 3, is the basis for making repair decisions that minimize service disruptions and minimize costs.

Inspections provide information on the physical condition of the sewer and on rates of material deterioration. Inspection data help forecast future conditions of the sewer and help determine the need and timing for rehabilitation.

Optimal scheduling of inspections will result in savings and minimize the likelihood of sewer failure. This section provides recommendations for inspection frequencies as well as descriptions and rough cost estimates for various inspection techniques. Inspection methods described include "full-line" and "special-purpose" methods. Some commonly used "in-line" testing methods are also included.

4.1 Inspection Timing and Frequency

4.1.1 Initial inspection

Many sewers have defects of some kind. In some cases, the defects result from normal in-service deterioration. However, one study[11] determined that the majority of sewer defects are a result of poor workmanship. Another study based on the assessment of 180 km of sewers[44] determined that many defects arise during or shortly after construetion. These findings confirm the need for inspections of new sewers.

It is common practice for a municipality (or its delegate) to perform an inspection to confirm that a new sewer has been built in conformance to specifications. This inspection should also document any changes to the original design that occurred during construction (for examples, alignment changes, location of service connections, or additional access holes).

It is recommended that the initial inspection be the basis for a full condition assessment (Sections 5 and 7). In addition, because studies show many defects result from poor workmanship and because it may take some time for these defects to become obvious, it is recommended that an interim inspection of a new sewer be made prior to the end of the warranty period. The inspection should cover the entire length of the new or rehabilitated pipeline. This initial inspection will provide valuable baseline data that can be used for comparison in future condition assessments.

If an existing large sewer has never been inspected, an initial inspection should be performed as early as possible (regardless of the age of the sewer) to benchmark the sewer condition. This information can be used to determine maintenance and rehabilitation needs.

For sewer systems that have not been part of a comprehensive inspection plan, the following points can assist in setting priorities for first inspection:

1. Use the failure impact assessment method described in Section 3 to produce a failure impact rating map for all large sewers in the system.

2. Assign high priority to sewers of known (or suspected) problems sueh as: high inflow/infiltration (I/I), proximity to a water main rupture, ground disturbance from construction activity, or exposure to above-normal chemical concentrations.

3. Consider the schedule for road refurbishment or nearby water main replacement so that if replacement of the sewer pipe by the open-cut method is likely, it can be carried out before a new road surface is installed.

4. In high seismic risk zones, assign high priority to sewers installed in soils with high liquefaction characteristics.

4.1.2 Subsequent inspection

Optimal scheduling of inspection cycles is an important aspect of good management of large sewers. Many factors must be considered: the cost of inspection, the anticipated condition of the pipe based on the last inspection, the level of risk (or likelihood of failure), and the degree of difficulty required to complete an inspection.

Full-length inspection of large sewers should be carried out following the modified WRc (Water Research Centre, United Kingdom) approach shown in Table 4.1. The recommended inspection frequency depends not only on the physical condition state (Sections 5 and 7) but also on the failure impact rating of the sewer (Section 3).

The recommended inspection timings in Table 4.1 as well as those used by WRc and the City of Edmonton and others are prescriptive in nature. However, unlike other methods, the determination of the timing for the next inspection in Table 4.1 takes the failure impact rating into account. There are several reported attempts to develop inspection decision methods that are more quantitative and thus more specific to individual sewers. Some of these methods are described in Appendix B. It is recommended that inspection frequency guidelines in Table 4.1 be followed until a better quantitative method is developed and validated with field data.

4.2 Full-Line Inspection Techniques

Full-line inspection means the continuous inspection of a given length of sewer from MH to MH. The inspection techniques covered in this section are summarized in Table 4.2 and a brief description of each of the techniques is provided. Where project information is available, a cost range for the inspection is given. Actual costs of inspection will depend on sewer size and depth, distance between access holes, site and sewer conditions, and availability of inspectors locally.

In general, the quality of the inspection will be enhanced if the sewer has been cleaned prior to inspection.

Table 4.1. Inspection timing based on condition rating and failure impact rating

Condition rating	Failure impact rating (R_{imp})	Time to next inspection (years)
5	1 to 5	0*
4	5 1 to 4	0* 2 to 6
3	5 1 to 4	3 5 to 10
2	5 1 to 4	5 10 to 15
1 or 0	5 1 to 4	10 15 to 25

* Immediate rehabilitation required

Table 4.2. Full-line inspection techniques

Inspection method	Application limitations	Range of cost†
CCTV	Sewers up to 1500 mm diameter, above flowline only, quality decreases as cable length increases	$2 – $14/m
Sonar/CCTV	Some flow required, above and below flowline, quality decreases as cable length increases	$7 – $10/m
Person-entry	Sewers 900 mm diameter and larger, visual, above flowline only, health and safety concerns	$2 – $20/m
Stationary camera	Applicable only to pipe sections adjacent to access holes, above flowline only, used mainly for preliminary assessment	$100/MH

† Costs depend on actual job situations and tend to increase with the increase in pipe burial depth and sewer size
These costs are estimates only

4.2.1 Closed circuit television (CCTV)

Closed circuit television (CCTV) is an effective tool for the inspection of large sewers and it does not require person-entry. The inspection procedure involves moving a video camera through the sewer to record the condition of the interior surfaces of the sewer. Modern video technology, including 'pan-and-tilt' and 'fish eye', provides high-quality images of the sewer interior.

Certified CCTV operators use the video footage to record the type and location of defects. Corresponding condition assessment is carried out subsequently by viewing the inspection tape and the inspection report.

CCTV can only capture images of the portion of the pipe above the flowline and cannot provide quantitative deformation measurements. However, a skilled operator can detect features such as a hydraulic jump that may indicate a deformed pipe or deformed joint. If it is essential to inspect the pipe below the flowline using CCTV, dewatering of the sewer by means of bypass or bypass pumping will be required.

Most CCTV tools are suited for pipes up to 1500 mm in diameter[52]. The CCTV cameras are supported by tractors or floats and movement is controlled remotely by an operator on the surface. For the tractor application, the CCTV camera is placed on a moveable platform that allows the camera to be moved closer to a defect. Some cameras have the ability to pan-and-tilt, rotate or zoom to improve inspection quality. Extra lights are often attached to the tractor to improve visibility. The inspection apparatus can be assembled in the sewer or collapsed to fit through a standard access hole and expanded to full size inside the sewer. The tractors can negotiate bends, turn on their own axis and move through areas with debris. Inspections can be performed from access hole to access hole. If only one access point is available, inspection is carried out as the CCTV camera travels to the furthest location, and the inspection tractor is reversed to return to the entry point.

Before the tractor- or rig-camera system is used, the expected flowline is estimated. Spacers are placed on the rig to elevate the camera to the appropriate position prior to entry. If the flowline is too high, the camera will be submerged, rendering the survey ineffective. In areas where the flow level is high, the camera can be mounted on a float. In such cases, the extent of the circumference visible to the camera is diminished and if the flow velocity is high, movement of the float and camera may adversely affect the image quality.

There are some drawbacks to CCTV inspection. Depending on the situation, set-up can be a large portion of the overall inspection time. Although power supply cable is available up to 1000m long, image quality may deteriorate when cable longer than 500m is used[35]. For long cable lengths, a booster may be needed to improve image transmission. The drag weight of long cable also becomes a limiting factor.

Although CCTV is an effective means of inspecting large sewers, it is subject to operator interpretation and an operator may fail to identify defects for various reasons including inattention, fatigue or poor image quality. CCTV operators must have formal training and certification from a credible organization to ensure reliability and uniformity of defect coding. The North America Association of Pipeline Inspectors (NAAPI) offers training and certification for CCTV operators based on WRc (Water Research Centre, United Kingdom) standards.

In general, CCTV inspection cost increases with sewer depth because of increased set-up time and because of the additional cable length extending from the surface to the sewer. The cost of CCTV inspection varies from $2/m to $14/m[55] (not including sewer cleaning costs).

4.2.2 Sonar/CCTV

Sonar/CCTV combines the use of sonar to inspect the portion of the sewer below the flowline and CCTV to inspect above the flowline to give a complete picture of the sewer. The sonar images can reveal the true shape of the pipe, sedimentation build-up at the invert and defects in the pipe wall greater than 4 mm[21].

Like CCTV, this inspection technique requires specially trained personnel both to perform the inspections and to interpret the results. The set-up arrangement and length limitations are similar to those for CCTV. However, the inspection speed can be significantly lower than for CCTV inspection alone. As with CCTV inspection, the set-up time for combined sonar-CCTV inspection is usually long in relation to the actual inspection time. Inspection costs range from $6/m to $10/m for sonar only, and $7/m to $10/m for combination sonar and CCTV[55].

4.2.3 Person-entry inspection

Visual sewer inspection by trained personnel can provide qualitative and quantitative information about defects. For example, inspectors can note defects and deterioration, detect concrete de-lamination, measure pipe deflection, and take close-up photos. Person-entry inspection may be the sole type of inspection used or may be used to acquire additional information following a CCTV inspection. In preparation for person-entry inspection, it is useful to review past reports and to identify locations of particular concern.

Person-entry inspectors should receive formal training for visual condition assessment and certification to ensure consistency and comparability. In addition, person-entry inspectors must have special training for work in confined spaces. As described in Section 2, sewers are hazardous work areas and any person-entry activity requires strict adherence to safety procedures. The set-up time for person-entry inspection is lengthy due to health and safety requirements and the rate of inspection is affected by safety factors such as the duration of bottled air supply.

As for CCTV inspection, person-entry inspection can only observe defects above the flowline, and there is always the possibility of a subjective interpretation of defect type and severity. Person-entry inspection may not accurately establish the location of each defect. City of Edmonton costs for person-entry inspection range from $2/m to $20/m.

4.2.4 Stationary camera

Stationary cameras are used to obtain quick and first-hand indications of pipe defects in the vicinity of access holes. This technique is often used as a screening tool based on the premise that the sewer line condition is often poorest near the access holes[41]. Photos are taken from the access holes and therefore the distance from the access hole that can be checked depends on the quality of lighting and the zooming capability of the camera. The cost is approximately $100 per access hole.

4.2.5 New inspection technology

Several promising techniques are under development. One of these is Sewer Scanner and Evaluation Technology (SSET), developed in Japan and evaluated by the Civil Engineering Research Foundation (CERF). SSET uses a scanning technique in conjunction with an expert database system to automatically identify defect types on the interior surfaces of sewers[2, 23]

4.3 Special-Purpose Inspection Techniques

Special-purpose inspection techniques are those used for extraordinary situations (such as surcharged pipe) or are techniques specific to certain pipe materials. Table 4.3 summarises the techniques that are described in this section.

4.3.1 Rotary sonic device

Similar to the combined sonar-CCTV technique described in 4.2.2, the rotary sonic device can be used to measure deflections in a flexible sewer pipe or a lined pipe or to determine the loss of material from the interior surface of a pipe. Sonar operates by measuring the different travel velocities of sound in different materials[45]. Sonic devices can be used to inspect portions of the pipe both above and below the flowline, but not simultaneously. The rotary sonic device travels inside the pipe on carriers similar to those used for CCTV cameras and measures the deformation at any given point around the pipe. The cost of using a rotary sonic device ranges from $10 to $13/m [45] (excluding sewer cleaning and mobilization).

4.3.2 Diver inspection

Certified divers can be used to perform inspections in high flow conditions and in surcharged sections such as inverted siphon sections of large sewers. Visibility and extra difficulty in recording defect severity and location are limiting factors. Diver inspection is a high-risk person-entry inspection method with specialized safety requirements.

4.3.3 Système méchanique d'auscultation des conduites (MAC)

The MAC system is a test technique used for spot evaluation of the structural strength of pipe and the integrity of the pipe-soil structure[47]. The sewer must be dewatered before

Table 4.3. Special-purpose inspection techniques

Inspection method	Characteristics
Rotary sonic device	Proven technique, useful for deflection measurement of flexible pipe, used for sewers up to 1500 mm in diameter
Divers	High risk technique for surcharged sewers, limited effectiveness in high turbidity
MAC system	Proven technique, dewatering or low flows required
Infrared thermography	Developing technique, limited effectiveness in areas congested with buried utilities
Ground penetrating radar	Developing technique, soil-condition dependent