U.S. EPA | WATER INFRASTRUCTURE OUTREACH

United States Environmental Protection Agency

# Condition Assessment of Underground Pipes

**April 2015**

**With excerpts from: Condition Assessment of Wastewater Collection Systems, EPA/600/R-09/049**

*EPA New England Water Infrastructure Outreach provides tools, examples, and technical assistance for water infrastructure operators and managers, local officials, and other decision-makers for more effective and sustainable water infrastructure management. For more information see http://www.epa.gov/region1/sso/toolbox.html*

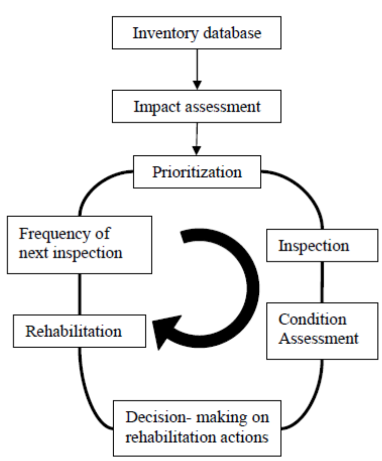
---

**Why perform a condition assessment of your underground infrastructure?** Every day in communities across the United States millions of gallons of human and industrial waste are sent through complex underground sewer systems that empty into wastewater treatment plants. These systems operate all day, every day, to convey polluted water to treatment plants that clean it, and contribute to a healthy environment for our families.

One of the challenges of maintaining these wastewater collection systems is that so much of the process takes place underground, out of view. Most municipal sewer systems are at least 60 years old and many communities have sewers that are older than 100 years.

Given the age of our sewer systems, many communities and utilities are turning their attention to assessing the condition of their underground pipes and associated infrastructure. A Condition Assessment is an investment these valuable community assets. It's also an investment in managing risk. Knowing the structural condition of your assets will allow you to avoid emergencies, prioritize repair and replacement projects, and plan for the future.

Condition Assessment is an ongoing process (see figure below from Condition Assessment of Wastewater Collection Systems, EPA/600/R-09/049). To assess the condition of a sewer system, data and information are gathered through observation, direct inspection, investigation, and indirect monitoring and reporting. An analysis of the data and information helps determine structural and operational issues, and performance of the system. Condition assessment also includes failure analysis to determine the causes of infrastructure failures and to develop ways to prevent future breakdowns. Condition assessment enhances the ability of utilities to make technically sound judgments regarding asset management.




Source: McDonald and Zhao, 2001

Some utilities presume that older pipe must be in poorer condition than newer pipe, which is not always the case. There are many examples showing 80 year old pipe in excellent condition and 30 year old pipe near failure. The only way to know for sure is to take a look - perform a condition assessment.

Knowing how your collection system really works will reveal maintenance and capacity issues before they become maintenance problems. Implementing a pro-active program based on information and systematic assessment leads to preventive maintenance decisions, rather than reacting to emergencies, and removes some of the politics and second-guessing from decision-making.

Performing a condition assessment has a cost, but being able to organize the assets of your system by maintenance and replacement needs is an essential step toward better management.

A variety of methods have been developed for performing condition assessments, but they generally follow a similar progression of steps: setting objectives for the condition assessment, identification of assets and available data, asset inspection, data analysis, and decision making. This is similar to EPA's Capacity, Management, Operations and Management (CMOM) program for collection systems. CMOM programs include defined goals, use of information-based approaches to set priorities, evaluation and insurance of adequate capacity, development of a dynamic, strategic approach to preventive maintenance and conducting periodic program audits to identify program deficiencies and ways to address those deficiencies.

**1. Program Development Introduction**

The first step when developing a condition assessment program is to determine what you want to achieve and how you want to use the program. Improved service, regulatory compliance, operation and maintenance ease, efficiency, risk management, and/or financial budgeting and forecasting, are among many goals of Condition Assessment programs. For many utilities, identification of high risk pipes or areas where a catastrophic failure could lead to extensive service disruptions and health or environmental damage is a priority. A risk-based condition assessment program would focus on specific pipes and areas that present these types of risk.

The design of the program should consider how the results of the condition assessment will be used to make decisions and achieve your goals. Key performance indicators (KPIs) - that will be used to determine progress - would be defined at this step. KPI's often focus on three categories: Service, Expenditure, and Investment. Preliminary objectives for performing a condition assessment could include: understanding the structural condition, performance, and/or progression of deterioration (i.e. remaining service life) of the assets.

Condition Assessment has costs and benefits, some of which are captured in the lists below.
Costs of condition assessment include:

- Equipment and labor costs to conduct field inspections, monitoring equipment and data collection
- Labor costs before and after field work for planning, data analysis and reporting
- Cost of service disruptions due to inspection work.

Specific benefits of a formal condition assessment program may include:

- Early identification of problems (resulting in use of less expensive repair methods)
- Reduced emergency consequences by identifying and addressing previously unknown problem areas
- Reduced O&M costs (e.g., by identifying and cleaning only the "dirty" pipes during operation and maintenance programs)
- Avoided emergency costs due to scheduled preventive maintenance
- Avoided service disruptions by up-front scheduling of preventive maintenance

- Avoided or mitigated Sanitary Sewer Overflows (SSOs) or pipeline breaks and associated costs from environmental and property damage
- Avoided public health costs
- Improved planning and prioritizing of rehabilitation and replacement projects
- Reduced backlogs of deferred maintenance
- Identification and prediction of future Capital Renewal needs
- More effective and efficient operations and maintenance.

**2. Asset Inventory**

In developing the condition assessment program, it is essential to compile an inventory of the assets to be assessed. The utility should understand the content and form of existing data, and should identify data gaps at this step. Existing data may be available but not in a good form. For example, manhole or pipe inspections may have been conducted several years prior, with the data stored in files or reports. Collecting and summarizing the data in a spreadsheet or database (see Section 4. below) would allow for checking, evaluating and arranging the information and identifying data gaps.

Inspection and testing records may include Inflow and Infiltration (I & I) studies: flow and smoke testing data, flow isolation studies, and/or dye tracer studies. Failure data from within the system or from research on similar conditions (e.g., soil bedding type, pipe material, age) in utility districts can be used to assess risk of failure. Existing data and the data gaps identified in this step are used to plan the inspection program.

A key difficulty in developing a rational inspection and condition assessment program is that some of the most critical elements of the sewer infrastructure are the most difficult and expensive to inspect. For example, large diameter sewers that have continuous and high levels of flow may make bypassing the sewer in order to perform an inspection difficult or impossible. They may contain large debris that hinders inspections unless the pipes are cleaned first, and they may not have been inspected for decades. Similarly, force mains, as critical elements with high consequence of failure, are more difficult to inspect. Addressing these critical areas first may front-load the costs of a condition assessment but the resulting risk reduction is worth the effort.

**3. Asset Assessment /Inspection**

The primary purpose of a condition assessment/ inspection is to define the current condition of an asset, in order to evaluate the progression of deterioration and to make informed decisions on managing maintenance, repair and potential replacement. A well- developed inspection plan will maximize the value of the program, while minimizing the cost of inspection.

A plan of work should be outlined at this phase to lay out the steps of the proposed inspection program. The inspection plan should focus on which assets to inspect, when they should be inspected, and what technologies will be used for inspection. There are many risk criteria that can be used to help determine where to conduct pipeline assessments, described below. As mentioned, inspections and follow up are intended to prevent failure, allowing for effective renewal of the assets.

**a. Selecting and Prioritizing Assets for Inspection**

It may be cost prohibitive to inspect every linear foot of a wastewater collection system on a short-term schedule, especially when confronting the need to inspect a large system with little prior inspection history. For this reason, many condition assessment programs use a planned approach to focus on high consequence/high risk pipes to begin the condition assessment program. Decisions on which assets to inspect should tie in with the goals of the program.

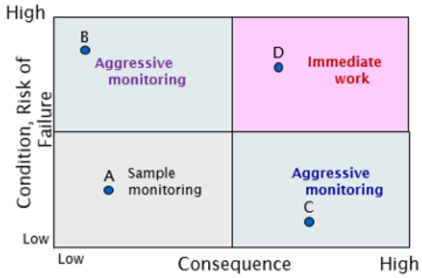
For example, if the goal is specifically to reduce wet weather flow, the focus will be on I & I, and inspections will be directed by flow monitoring data. If the goal is to reduce risk of structural failure in an aged system, the inspections will begin in areas of high consequence of failure.

In all cases, there will be a number of ways to prioritize assets for inspection. Most methods evaluate both **criticality** (consequence of failure, the impact of a failure in terms of repair cost, disruption to the public and economy, impairment of system operation, regulatory compliance, public health and safety, and damages to the environment) and **condition** (probability of failure). Assets can then be prioritized for inspection and follow up, maintenance, and/or rehabilitation based on the utility's knowledge of their criticality and condition ratings.

***Probability and Consequence***

Assets whose failure will result in greater impact to the community and/or environment are considered highly critical, and would be given a high **criticality** rating. Likewise, assets that have a high probability of failure (poor condition) would be assigned a high **condition** rating. Assets with a high criticality and a high condition rating should be very visible to managers and included in a capital improvement plan or the priority maintenance list. Pipes, pump stations and components with a lower criticality and condition rating would receive routine inspection and maintenance and a lower priority for repair or rehabilitation. Criticality - consequence assessment - is largely based on your knowledge of the system, and can be used to prioritize condition work. Condition assessment is described below, in Section 5.

*Relationship of risk-consequence to work program*




***Criticality***

Failure of any component of your collection system will impact the environment, transportation, business, the public, and the municipal resources, regardless of where it occurs. Assigning a criticality rating to an asset is usually a one-time event as the importance of the asset is unlikely to change significantly for some time. Having criticality information for your assets is useful information that will help you focus on the highest priority problems. There are many criteria that can help assess the criticality of collection system components. Below are common categories:

- Quantity of Flow
- Transportation/Business Impact
- Environmental Impact
- Public Health Impact
- Difficulty of Emergency Repair – Accessibility; Pipe depth; Ability to re-route flow

The simplest method for assigning criticality to your assets is on a scale of 1 to 5. The specific scale is not that important, but 1 to 5 is also used in the rating program for pipe condition developed by the National Association of Sewer Service Companies (NASSCO) described further in Section 5, below. Multiple circumstances impacting criticality or consequence ratings can lead to use of weighting factors and a more complicated assessment methodology. NASSCO also has an Appendix to the Pipeline Assessment and Certification Program (PACP) for Asset Management which has suggested formulas for criticality assessment with categories of Economic, Social and Environmental consequence.

***Criticality Rating based on Quantity of Flow***
The quantity of flow can be estimated based on the size of your pipes and the capacity of your pump stations. Larger pipes and force mains generally convey more flow than smaller pipes and would receive a higher criticality rating for this criteria. The smallest pipes would receive a (1) and the largest pipes a (5). However, if you know that pipes are oversized in certain areas of your system, you may want to adjust the rating.

***Criticality Rating based on Potential Environmental or Public Health Impact***
Any release of wastewater from a sewer can have an adverse impact on the environment or public health. If a sewer line is near a waterway or serves critical populations (schools, hospitals, densely populated areas, etc.), the potential impact is greater in those areas, and therefore would be given a higher criticality rating.

***Criticality Rating based on Transportation/Business Impact of Failure***
A pipe or pump station failure in a business district, under a rail line or interstate highway, or near a major thoroughfare, for example, would have a greater impact to traffic and community businesses than a pipe failure on a street less traveled. Accordingly, the greater the potential disruption the higher the criticality rating. For this criteria, a small pipe failure may cause the same disruption as a large pipe.

***Criticality Rating based on Difficulty of Access and Repair (Cost)***
Another criteria of criticality is how difficult it would be to repair the asset. If the pipe is difficult to repair in an emergency, there is a greater potential for increased impacts to the community and environment. Even if it is not an emergency, difficult repairs may take longer and contribute to longer disruptions and higher costs.

Each system can choose criteria that are based on the individual circumstances, however, the assets that scored high for all criteria would receive the highest criticality rating. Nonetheless, any asset that scored high for any single measure may warrant a second look.

**b. Asset Inspection**
Once assets have been catalogued for priority work, the type of inspections performed will depend on the objective of the condition assessment program. The selected inspection techniques need to be consistent with the type of asset to be inspected and provide the information and data required to support decision making.

Various methods of camera inspection, the primary one being Closed-Circuit Television (CCTV), are commonly used to inspect gravity sewers for structural defects. CCTV may also identify areas where clean water is leaking into the sewers, and flow monitoring is utilized to conduct more formal I & I studies or Sewer System Evaluation Surveys (SSES). Flow monitoring is also used to evaluate hydraulic capacity and determine hydraulic restrictions. The written plan of work should include details on how the inspections will meet the goals of the condition assessment program.

Regardless of how formal the condition assessment effort is, it should not be overlooked that every trip into the field is an opportunity to gather information. For example, when crews set up to jet or televise lines they should also assess the condition of the manholes used to access the pipes and any easements that the pipes run through. This is simple enough to do, but is often not done because condition assessment has not been the focus of a cleaning program. **For an example of a manhole inspection form go to Attachment A of this document.** For information on developing a manhole numbering system see ***"Developing a Manhole or Catch Basin Numbering System".***

## 4. Data Management

A successful condition assessment program requires that the data collected are organized, analyzed, and maintained in a database system. This important step not only allows a utility to manage, sort, evaluate and store the data, it helps to develop an understanding of trends. There are three general approaches to database management that have varying degrees of cost and complexity but all of which use commercially available software:

1. Software specifically designed for condition assessment and asset management.
2. Database software that is not specifically designed for condition assessment.
3. Spreadsheet software.

### *Condition Assessment/Asset Management Software*

There are numerous commercially available data management programs for condition assessment with a range in level of complexity and cost. The primary component is a storage location for data and defect coding on pipe segments both spatially and over time. Most commercially available systems also incorporate additional elements such as cost accounting, work order functionality, and spare parts inventory and ordering information.

Another useful feature is the incorporation of Geographic Information System (GIS) mapping functionality into the system. The GIS component manages the spatial information associated with the data, and can provide very powerful visualization and analytical capabilities such as proximity of assets to critical or sensitive features (such as hospitals or roads and railroads). Using spatial information in this way to prioritize work can be an effective tool for the utility to plan subsequent inspections and/or rehabilitation activities. The benefit of the commercially available programs is that they are designed specifically for the intended purpose. However, depending on complexity, the cost of the software and licensing can be significant.

Another type of commercially available software is designed to summarize the results of a CCTV pipe inspections and its defects data. This has become standard practice in the industry. NASSCO certifies CCTV operators and licenses software programs to be consistent using the Pipeline Assessment Certification Program (PACP), Manhole Assessment Certification Program (MACP), and Lateral Assessment Certification Program (LACP) rating systems (discussed below).

Pipeline inspection software is used during the pipeline inspection to accurately document the status of sewer pipe, storm drains, or water pipelines. The software gives access to text data, video, and still photos, all of which help the user identify and document the condition of the pipe or manhole. Defects can be quickly categorized by location, type, and severity. The software compiles this data into a searchable database which can be used to create customized printed reports and to analyze trends over time.

EPA helped develop two free software programs, one from the Maryland Center for Environmental Training called Total Electronic Asset Management Software (TEAMS), which has not been updated in many years, but offers an organized database for treatment plant and manhole, pipe and pumping systems based on Microsoft Access software, and Check Up Program for Small Systems (CUPSS) which is a self-contained system developed with a focus on small drinking water plants. Both of these programs can export data to spreadsheets, however, neither is based on NASSCO programs.

### *General Database Software*

Commercially available (generic) database software packages allow a utility to customize a database specific to their needs. The benefits to development of a utility-customized database system include the reduced initial licensing cost of the software, and the ability to code the specific factors of importance to the individual utility.

Many utilities would have database software as part of their professional software packages licensed for their operating system (e.g. spreadsheet, database, and word processing programs, and including existing computerized maintenance management systems (CMMS) that may already contain inventory information). Another benefit is that the utility would not incur additional annual maintenance fees associated with the condition assessment software described above**.** A drawback to this approach, however, is the significant up-front work and specialized expertise to design/customize a database system for the intended purpose.

***Spreadsheet Programs***

Similar to database programs, spreadsheet software is readily available, and likely already exists at most utilities. It is also the least costly of the three systems. A simple yet effective system can be designed to collect and store condition assessment data. However, spreadsheets can be cumbersome when many columns and sheets are involved and lack the sophisticated functionality of a database for querying and reporting. To download EPA–New England's condition assessment spreadsheet templates for pipelines and for manholes, go to "***Spreadsheet Tools*****"**.

**5. Data and Analysis**

The data from inspections should be used to begin to quantify the level of service being provided and any structural defects of the assets. Data alone, however, will not provide risk reduction or even highlight the significance of any of the findings. The follow-up steps include processing, evaluating and analyzing the inspection data, and using that information to make informed decisions.

There are two general methods used, based on the type of inspection performed. If CCTV or one of the other non-destructive technologies was used to identify structural or maintenance condition, analysis is generally performed by coding defects in accordance with one of the various methods available, such as NASCCO's P/M/LACP programs. If CCTV identifies I & I and/or if flow monitoring was employed as the inspection technology, an analysis of hydraulic capacity should be performed, using hydraulic modeling techniques and/or the SSOAP Toolbox.

***Structural Condition and Defects from CCTV***

CCTV structural inspection data generally includes coding of the defects based on both type and severity. Structural pipe defects, Operations and Maintenance (O&M) issues, and hydraulic restrictions discovered during the inspection need to be ranked by severity based on the potential to impact the system's proper operation, effective maintenance, and hydraulic capacity.

A set of standards to rank the severity of pipe defects found in an inspection was developed by the Water Resource Centre (WRC), in the United Kingdom. In 2001, NASSCO developed a set of coding standards based on the WRC system which have become the industry standard for coding pipe defects in the United States. NASSCO has training programs to certify and train inspection professionals in PACP, MACP, and LAPC.

NASSCO's coding system categorizes defects and features into five categories: continuous defects, structural defects, operational and maintenance, construction features, and miscellaneous features coding. For each type of defect, a combination of capital letters is used to describe the type of defect and a numeric assessment ranks the severity of the defect. For example, "FL" represents a longitudinal fracture and "CC" represents a circumferential crack. The numeric code ranks the severity of the identified defect.

Defect codes are recorded on a standardized form along with other system data, including defect type, continuous distance of the defect, severity, size, circumferential location (clock location), joint number, image/video reference number, and comments.

A brief description summarizing some of the PACP defect coding system is described below:

- **Continuous Defect Coding:** Continuous defect coding is made up of two separate coding classifications. The first is called “Truly” continuous defects - defects that run along the sewer and the second is “Repeated” continuous defects - continuous defects that occur at regular intervals along the pipe.
- **Structural Defect Coding:** Structural defect codes include many separate coding classifications. Codes define the type of defects that are related to structural degradation of the pipe due to various reasons such cracks (C), fractures (F), breaks (B), etc.
- **Operational and Maintenance Defect Coding:** O&M codes define the type of defects that are related to lack of maintenance such as deposits (D), roots (R), infiltration (I), etc.
- **Construction Features Coding:** Construction features codes indicate features located in or around the pipe system such as tap (T), intruding seal material (IS), etc.
- **Miscellaneous Features Coding:** Miscellaneous features coding includes many sub-coding classifications. This section uses coding to indicate miscellaneous (M) features in the pipe system. Under this subtitle, the miscellaneous designation is combined with other letters to further define the type of defect.

The PACP uses a numerical grading system to define the severity of pipe defects identified by the shorthand codes above. Condition grades for structural defects and O&M defects are assigned based on the risk of further deterioration or failure. The numerical system uses numbers ranging from 1 to 5 with 1 being a minor defect and 5 being a severe defect. The severity ranking considers the immediate defect, risk of failure, and rate of deterioration.

- Severity Grade 5 – Pipe segment has failed or will likely fail within the next five years - requires immediate attention.
- Severity Grade 4 – Pipe segment has severe defects - risk of failure within the next five to ten years.
- Severity Grade 3 – Pipe segment has moderate defects - deterioration may continue, at a ten to twenty year timeframe.
- Severity Grade 2 – Pipe segment has minor defects - pipe unlikely to fail for at least 20 years.
- Severity Grade 1 – Pipe segment has minor defects - failure unlikely in the foreseeable future.

To put the entire pipe rating together, the number of occurrences for each condition grade is calculated separately for both structural and O&M defects for each pipe segment. Each pipe segment will be assigned a segment grade based on the number of occurrences of each graded defect. The structural defects are added separately from the O&M grades, so each pipeline receives two separate grades.

The PACP also uses a **quick rating** system, which is a shorthand method of expressing the number of occurrences for the 2 highest grade levels. The quick grading system uses four numerical characters:

1. The first number is the highest severity grade occurring along the entire pipe length.

2. The second number is the total number of times that the highest severity grade was noted in all of the defects along the pipe length.

3. The third number is the next highest severity grade occurring along the pipe length.

4. The fourth number is the total number of the second highest severity grade occurrences, which is formatted the same way as the second character.

For example, a code of 3224 would mean that the pipe's worst severity grade for any defect was 3 (moderate defect) and that there were two defects identified with a severity of grade 3, and four grade 2 defects were identified in the pipe segment. This also summarizes that no grade 4 or 5 defects were found. The quick grading system allows the pipe defects to be summarized in an efficient manner.

This type of coding system provides a quick summary that helps in your efforts to prioritize information on which to base O&M, repair, and replacement decisions, as well as provide information towards identifying future needs. For further information about PACP go to www.NASSCO.org

***Flow Data (Hydraulics) in Condition Assessment***

Condition grading may indicate infiltration and the relative severity of the leakage, or, if the CCTV camera was underwater during the inspection when low or no flow conditions were expected, this may indicate that flow studies to determine the impact of I & I are needed. Since hydraulic capacity is a primary performance measure for a wastewater collection system, it may be obvious, based on dry weather and wet weather flows that I & I is a problem.

Besides CCTV evaluation, flow data gathered by flow meters has been used to guide sewer system management for decades. Flow data can be used as a tool in condition assessment either to identify areas for further CCTV inspection or to quantify the severity of I & I identified during CCTV work.

CCTV provides a snapshot of pipe condition, while data from flow metering is gathered over time. This data is useful in demonstrating system impacts from rainfall or elevated groundwater. It can help identify illegal inflow connections that are connected to the sewer system, or if laterals are leaking. It provides information necessary to calibrate a hydraulic model or refine I & I studies. A hydraulic model, such as the SSOAP toolbox, can be then be used as a tool to project overflow and/or surcharged conditions for various design storms.

In the absence of CCTV, flow meter data can provide a good indication of upstream pipe conditions if the tributary area is small. As the sewershed area monitored increases in size, flow data are less useful to predict condition of specific pipe segments. Flow meters provide numerical data to quantify flow for the area tributary to the metering location and therefore a well-defined sewershed tributary must be mapped out. Flow monitoring has real value in development of a database on long-term historic trends in order to determine seasonal variations and impacts of wet weather on the sewer system.

The traditional method of viewing flow data is hydrographs, which reveal information on sewer system condition upstream of flow meters. Alternatively, flow data can be viewed as scatter graphs (also known as scatter plots), which provide information on hydraulic conditions downstream, or in the vicinity of, a flow meter. Scatter graphs are created by plotting flow depth versus flow velocity data. When flow meters are working correctly, a normal pipe curve would result when data are plotted unless normal open channel flow is not occurring. In these cases, the scatter graph data can be used to identify such hydraulic restrictions as silt or obstacles, bottlenecks, and negative grade pipe, as well as surcharged conditions.

Wastewater treatment facilities can evaluate their influent flow data to get a handle on how their collection system as a whole responds to wet weather. Likewise, a pump station with a flow meter can provide data on its specific sewershed to estimate the influence of I & I. The following is a list of the most common evaluation terms that describe the assessment of I & I, the results of which indicate the need for priority inspection, if such data are available from individual sewersheds:

- **Average Daily Dry Weather Flow** includes the average flow from a sewershed: Base wastewater flow plus base infiltration.
- **Base Wastewater Flow** is estimated on the number and type of sewer users, water usage records, and predicted diurnal flow variations. It equates to only the wastewater flow.
- **Groundwater infiltration**, determined by subtracting the estimated Base Wastewater Flow from the Average Daily Dry Weather Flow, indicates whether the sewer system has excess leakage.
- Capture coefficient or fraction of the rainfall falling on a separated sewershed that enters the collection system as rainfall derived inflow or infiltration (RDII).
- **Relationship between rainfall and peak flows** also allows the manager to estimate whether wet weather leakage leads to excessive flows and capacity problems.

For further information on I & I see **"*Guide for Estimating Infiltration and Inflow*"**.

Including flow monitoring data in the condition data set provides trend information that can both indicate deterioration (if I & I is increasing) and help determine if performance measures are being attained. Flow data are also useful as a screening tool to determine problems areas of a system that require further study by other means.

**6. Decision Making**

Decision making based on the results of condition assessment of a sewer system entails understanding the possible risks and determining at what point a utility will intervene to avoid a failed condition that could result in an unacceptable cost and/or consequence. The follow-up decision making process to determine the priority ranking for repair or rehabilitation is the final step in the condition assessment process. Risk reduction results from acting on those repair/rehabilitation decisions.

The action to fix problems and upgrade the system is what leads to risk reduction. In addition to the criticality and condition data, which should now be stored in a spreadsheet or database, the utility can include supplemental data on long-term asset performance to aid in the decision making process. The following questions should be considered in decision making:

- For those assets identified in poor condition, what are the consequences, and which have the highest consequences, if they fail?
- To avoid failure, what are the alternatives?
- What are the costs to repair/rehabilitate/replace the assets?

The objective for the decision making model is to understand risk and to determine when to intervene to avoid undesirable economic, socio-economic, and/or environmental consequences. However, it is not possible to have a robust decision making model without obtaining sufficient condition data and an understanding the pipe or system failure modes.

In general terms, decisions on pipe rehabilitation/replacement can be made based on one or more of the following: engineering calculations, failure risk analysis, and remaining life estimation.

- **Failure Risk Analysis:** This is based on a forecast of asset deterioration over time. If a utility has condition data to support this type of forecast, then interventions can be implemented before an unacceptable level of service occurs. Repeated data collection and analysis over time and use of decay curves inform this ongoing assessment.
- **Engineering Calculations:** An example is the calculation of hydraulic capacity. Flow data can provide direct measurement of actual flow conditions; and then be interpolated using a hydraulic model to calculate hydraulic capacity of a pipe segment under current or projected conditions. If it does not meet the required design conditions or performance conditions, then replacement or rehabilitation is required.
- **Remaining Life Estimation:** Remaining useful life (RUL) estimation is used to characterize condition of buried assets. Remaining life is defined as the duration of time until an unacceptable condition exists or an asset no longer meets its primary function. Standard coding systems, as described in Section 5, are used to define condition and performance. For example, using NASSCO's PACP system, a pipe rating of '5' indicates a broken or collapsed pipe. The remaining life in this case is zero. With a pipe rating of '3' or '4', a manager may determine the remaining life is 5 to 10 years.

A variety of decision making models have been developed for pipeline assets. Using the remaining useful life, based on physical condition and O&M data from a condition assessment program, spreadsheets and databases can be customized for a manager to assess and prioritize assets in need of repair/rehabilitation and replacement. Costs are then applied, and budgeting and capital planning are used to develop the financial accounting to implement the program.

**7. Conclusion**

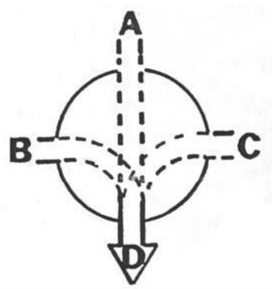
A pipe is usually rehabilitated because of degraded structural condition, or because of impacts on O&M, such as infiltration through cracks, roots, sediments, etc. Regardless of the reason for rehabilitation, improvements in O&M and structural integrity give a pipeline or pumping station a new lease on life. The compelling reason to perform condition assessment on the sewer collection system is to preserve the existing structure, reduce O&M costs, and avoid emergencies and the costs (social, economic, environmental) and political repercussions they entail.

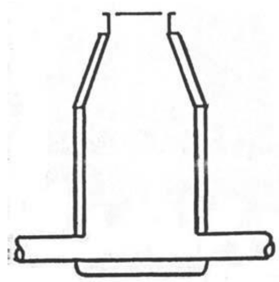
# Attachment A
# Example Manhole Inspection Report

MH NO. ___________ DATE _____________ TIME ______________ INSPECTOR _______

ELEVATION ________________ DEPTH TO INVERT _________________________ CLEANLINESS ___________________________

TYPE CONSTRUCTION _________________________ STREET REFERENCES ____________________________________



DEFECTS: (Cover, frame, grout, steps, shelf, pipes, or channels)

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |

(USE REVERSE SIDE FOR ADDITIONAL DEFECTS or INLETS TO BE NOTED.)

| | PIPE SIZE | LENGTH | TO/FROM MH# | EST. FLOW | TYPE FLOW |
|---|---|---|---|---|---|
| A- | | | | | |
| B- | | | | | |
| C- | | | | | |
| D- | | | | | |

REMARKS: (Include need for repairs)

_______________________________________________________________________________

_______________________________________________________________________________

**Overall Rating (Good, Fair, Poor)**