

# Inflow and Infiltration Guidance Document



**MOONSHOT**  
MISSIONS



Great Lakes  
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*Prepared by Moonshot Missions*



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# Inflow and Infiltration Module

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# Executive Summary

This Inflow and Infiltration (I&I) Module is designed as a comprehensive guide for wastewater utilities to understand, assess, and mitigate I&I in their sewer collection systems. I&I can lead to increased treatment costs, sewer backups, sanitary sewer overflows (SSOs), and compromised treatment plant performance, particularly in aging infrastructure and regions anticipating wetter climates like the Great Lakes.

This document focuses on maintenance best practices, asset management, GIS integration, and prioritization frameworks to help utilities efficiently allocate resources. The document is further supported by case studies from Madison and Milwaukee, Wisconsin, illustrating successful regional and municipal approaches to I&I reduction.

This module serves as a technical and strategic roadmap, enabling utilities to proactively address I&I challenges and enhance the resilience and efficiency of their wastewater systems.

## Chapter 1: Introduction

### 1.1 Background

Inflow and infiltration (I&I) can be a major concern for wastewater utilities and their collection systems. Negative impacts on utilities from I&I include: increased flow, increased treatment and maintenance costs, diluted sewage inflow to the treatment plant which can alter the treatment process, increased likelihood of sewage backup into homes due to the stressed capacity of the treatment system, and increased likelihood of sewage overflows.

Addressing I&I is particularly critical in regions like the Great Lakes, where climate models predict a wetter and warmer future (Angel, et.al., n.d). This shifts the focus from cost savings to risk management, as increasing rainfall and groundwater levels exacerbate I&I issues. If left unaddressed, I&I could lead to the critical failure of treatment plants and collection systems, resulting in a threat to public health and the environment.

Proactively managing I&I now, rather than delaying action, enhances utility resiliency. Aging collection systems are particularly vulnerable, as the likelihood and costs of I&I increase with time. Utilities nationwide are working to mitigate the impacts of existing I&I and prevent future occurrences through targeted solutions and infrastructure improvements.

### 1.2 Objective

The primary goals of this documents are to:



1. Provide an overview of sources of I&I in wastewater collection systems
2. Outline assessment and evaluation tools for utilities to identify the sources and impacts of I&I in their systems, and
3. Outline cost-effective strategies and solutions to prevent I&I.

The assessment tools and solutions will also be supported by case studies of successful implementation as well as potential funding sources to help reduce the financial impact of implementing solutions.

## Chapter 2: Inflow and Infiltration Overview

### 2.1 Sources of I&I

I&I occurs when stormwater and groundwater enter the sewage collection system through inflow or infiltration. Inflow can enter the system directly through leaking manhole covers, sewer cleanouts, or roof drain or other private property connections. Combined sewer systems, by design, experience significant amounts of inflow during storm events which can result in combined sewer overflows when the storage capacity of the system is reached, and sewage and runoff are both discharged. Infiltration refers to groundwater and/or stormwater that seeps into collection system pipes through cracks, holes, or joints caused by aging sewer laterals or sewer mains or through root intrusion into pipes. Appendix A includes a tool to help utilities evaluate and prioritize the different sources of I&I to help streamline the tracking and solution implementation.

#### 2.1.1 *Inflow*

Inflow consists of non-sewage water that directly enters the sanitary sewer system. Common sources of inflow typically include stormwater and surface water runoff, but in some instances, it can come from improper connections made by property owners. Since wastewater and stormwater utilities don't always have the capacity to monitor inflow, especially from private connections, it can be difficult to narrow down where the excess flow is coming from.

##### 2.1.1.1 *Roof Drains*

Roof drains are systems designed to remove rainwater or snowmelt from a building and reroute that flow away from the structure. These systems typically consist of a drain body or gutter that collects water from the roof and directs it away through a downspout. Roof drains can contribute significantly to I&I if not properly managed. In some cases, roof drains are improperly connected directly to the sanitary sewer system, leading to excessive inflow during wet weather events, which can overwhelm the system. Additionally, roof drains that are not properly set up



can still cause I&I issues by directing water to poorly drained areas, which may result in flooding and eventual infiltration into the sewer system through cracks in sewer mains or laterals.

#### *2.1.1.2 Manhole Covers*

Manholes serve as access points to the sewer system to allow for proper maintenance and inspection of the infrastructure below. They typically consist of a cover, chimney, cone, shaft or chamber, and bottom. Manholes can be significant contributors to inflow and infiltration (I&I) due to improper design and construction, inadequate maintenance, and aging infrastructure. According to the U.S. Environmental Protection Agency (EPA), there are an estimated twenty million manholes in the United States, which equates to one manhole for every 400 feet of pavement (Bhatia, 2017).

Inflow through manhole covers is one of the most common causes of inflow. This typically occurs due to poorly sealed covers, often caused by old or broken seals or a damaged ring that does not provide proper sealing. When water flows over the top of the manhole cover, it can leak into the sewer system if the cover is not properly sealed. Manholes located in low-lying areas, such as ditches or the low points of streets with poor drainage, are particularly vulnerable, as water can collect on top of the cover and flow into the sewer system. This problem is exacerbated when the covers are not adequately sealed.

#### *2.1.1.3 Improper Connections*

Improper connections refer to any illegal or unauthorized connections to the sewer system other than the lateral itself. These connections typically occur on private property and introduce unwanted or non-sewage water into the sanitary sewer system. Common sources of improper connections include sump pumps, downspouts, and foundation drains. While improper connections are often private, public sources, such as stormwater cross-connections and catch basins improperly connected to the sanitary system, can also contribute to the problem.

Because these improper connections are usually located on private property, monitoring and detecting them is challenging. In many cases, property owners may not even be aware of the improper connections, especially if they were installed before the current owner took possession of the property.

#### *2.1.1.4 Sewer Lateral Cleanouts*

Sewer lateral cleanouts are installed on every private lateral connection to allow access to the lateral for cleaning or inspection. While many laterals in the Great Lakes region are located in the basement of properties and are protected from damage in inflow, some located outside are vulnerable to damage from lawn equipment, vehicles, or other equipment depending on where they are located. Damaged cleanout caps allow direct inflow into the sewer system from stormwater runoff and many homeowners are not aware of situations when their sewer lateral



cleanout caps are broken or missing, especially since this issue doesn't often lead to backups inside the home. Therefore, sewer cleanouts can be a significant source of inflow for years before the caps are replaced.

#### 2.1.1.5 CSS

Combined sewer systems (CSSs) are commonly found in the Great Lakes region, typically in older and larger cities. A CSS consists of both storm and sanitary sewers, which can create an immense burden on wastewater treatment plants (WWTPs) during wet weather events due to the excessive inflow of stormwater. Because most CSSs are older and generally pertain to larger cities, the infrastructure has a difficult time handling the influx of flows during wet weather events, often resulting in combined sewer overflows (CSOs).

CSOs occur when the WWTP and collection system reach their capacity, and operations staff have no choice but to redirect the untreated mixture of stormwater and sewage to a nearby waterway to relieve the collection system and prevent residential backups. CSSs are very challenging and expensive to modify and maintain. For instance, most of these combined systems run below heavily populated areas in major cities, and the cost to dig up and separate these systems completely is almost impossible from a financial perspective.

### 2.1.2 Infiltration

Infiltration refers to groundwater or stormwater that indirectly enters the collection system through cracked pipes and deteriorating infrastructure. However, stormwater can play an indirect role by percolating into the ground and becoming groundwater. During wet weather events, as the ground becomes saturated, groundwater enters the collection system through deteriorating infrastructure as pressure builds, following the path of least resistance. Additionally, when the water table is high, groundwater can still infiltrate the collection system even during non-wet weather events.

#### 2.1.2.1 Aging Pipeline

According to the American Society of Civil Engineers (ASCE) Infrastructure Report Card, the average age of sewer mains in the United States is about 45 years (Tabuchi, 2017). Pipes (specifically Vitrified Clay Pipes (VCP)) are prone to cracking and developing holes that allow infiltration of groundwater into the collection system. This can also increase the likelihood of clogged pipes which also contribute to a risk of capacity breach and backups in the system. Pipe joints are also susceptible to infiltration as the system ages and as activity above ground or disturbances below ground can eventually lead to gaps at the joints.

#### 2.1.2.2 Private Connections

Private connections, often referred to as laterals, are the sewer lines on private property that connect to the public sewer system. Property owners are typically responsible for maintaining



and repairing these laterals. However, since laterals are underground and out of sight, most property owners are unaware of their condition. As a result, inspections typically occur only when problems arise, such as sewer backups. Consequently, laterals can contribute significantly to I&I and often go unnoticed for many years before issues are addressed.

In older properties, laterals are commonly made from materials like clay or cast iron, which degrade over time and allow infiltration. Additionally, tree roots can penetrate these aging pipes, leading to cracks, collapses, and further infiltration. Because inspecting and maintaining laterals is costly, and many property owners are unaware of the need for it, infiltration through laterals frequently goes unnoticed until major repairs or replacements are required. This is especially common in older properties with aging infrastructure.

#### 2.1.2.3 *Manhole Structure*

Manholes are generally constructed from concrete or brick, and over time, these materials can develop cracks or deteriorate. This is especially common in regions like the Great Lakes, where freeze-thaw cycles cause ground movement. As the structure begins to crack, groundwater can infiltrate through the damaged areas, particularly during wet weather events when the ground becomes saturated, and water follows the path of least resistance.

## Chapter 3: Inflow and Infiltration Assessment and Evaluation

### 3.1 Key Indicators

When determining if a collection system is experiencing I&I, there are several key indicators that are useful to track and quantify to understand the scale of I&I including:

1. Increased flow to the treatment plant during and after wet weather events.
2. Longer pump running times for lift stations in the collection system.
3. Increased blocks or clogs in pipes throughout the system.
4. Sanitary bypassing or overflows during wet weather events.
5. Sewage backups into homes during or after wet weather events.

If the collection system is experiencing any of these indicators, a utility should consider taking action to first determine the source and amount of I&I and then work on developing solutions to mitigate the I&I.

### 3.2 Determining the Source of I&I

Determining the source of I&I is a very important step in reducing the amount of I&I in the collection system. The most common sources of I&I are discussed in sections above and the



following techniques can be applied to determine where these sources are occurring in the system. Each technique is discussed further in sections below and an overview of the techniques and their advantages and disadvantages are included in the table below. [Appendix A](#) includes a spreadsheet to help utilities prioritize the methods for tracking I&I depending on the suspected or priority sources.

**Table 1. I&I Tracking Methods**

| TRACKING METHOD                     | COST | ADVANTAGES                                                                                                                                                              | DISADVANTAGES                                                                                                                                                                                                                                  | SOURCE OF I&I DETECTED                                                                                                                                                                                  |
|-------------------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>LIFT STATION PUMP MONITORING</b> | \$   | <ul style="list-style-type: none"> <li>• Cost effective</li> <li>• Simple to implement with existing data</li> </ul>                                                    | <ul style="list-style-type: none"> <li>• Only provides a general idea of I&amp;I source locations</li> <li>• Only applicable to collection systems with several lift stations</li> </ul>                                                       | <ul style="list-style-type: none"> <li>• Roof drains</li> <li>• Storm sewer cross connection</li> <li>• Sump pumps/foundation drains</li> <li>• Aging Pipeline</li> <li>• Manhole Structures</li> </ul> |
| <b>MANHOLE INSPECTIONS</b>          | \$\$ | <ul style="list-style-type: none"> <li>• Cost effective provided there is available utility staff</li> <li>• Provides specific locations with I&amp;I issues</li> </ul> | <ul style="list-style-type: none"> <li>• Can be time consuming depending on size of collection system</li> <li>• Does not provide information on infiltration</li> </ul>                                                                       | <ul style="list-style-type: none"> <li>• Manhole covers</li> <li>• Manhole structures</li> </ul>                                                                                                        |
| <b>SMOKE TESTING</b>                | \$   | <ul style="list-style-type: none"> <li>• Cost effective</li> <li>• Provides information on sections of system with I&amp;I issues</li> </ul>                            | <ul style="list-style-type: none"> <li>• Can be time consuming depending on size of collection system and size of sections tested at once.</li> <li>• Does not provide specific locations of I&amp;I sources, just general overview</li> </ul> | <ul style="list-style-type: none"> <li>• Roof drains</li> <li>• Storm sewer cross connections</li> <li>• Sump pump/foundation drains</li> <li>• Manhole covers</li> <li>• Aging pipeline</li> </ul>     |



|                               |        |                                                                                                                                              |                                                                                                                                                       |                                                                                                                                                                              |
|-------------------------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>DYE TESTING</b>            | \$     | <ul style="list-style-type: none"> <li>• Cost effective</li> <li>• Provides information on sections of system with I&amp;I issues</li> </ul> | <ul style="list-style-type: none"> <li>• Can be time consuming depending on size of collection system and size of sections tested at once.</li> </ul> | <ul style="list-style-type: none"> <li>• Faulty lateral connection</li> <li>• Cracked lateral</li> </ul>                                                                     |
| <b>SEWER SYSTEM CLEANING</b>  | \$\$   | <ul style="list-style-type: none"> <li>• Benefits the collection system while tracking I&amp;I</li> </ul>                                    | <ul style="list-style-type: none"> <li>• Time consuming depending on size of collection system.</li> </ul>                                            | <ul style="list-style-type: none"> <li>• Aging pipeline</li> <li>• Manhole structure</li> </ul>                                                                              |
| <b>SMART SEWER MONITORING</b> | \$\$\$ | <ul style="list-style-type: none"> <li>• Allows collection of real time data and continuous monitoring</li> </ul>                            | <ul style="list-style-type: none"> <li>• Costly</li> <li>• Limited to only select portions or system or select structures</li> </ul>                  | <ul style="list-style-type: none"> <li>• Aging pipeline</li> <li>• Manhole structure</li> <li>• Manhole covers</li> </ul>                                                    |
| <b>SEWER SYSTEM CCTV</b>      | \$\$\$ | <ul style="list-style-type: none"> <li>• Provides specific locations of I&amp;I into the system</li> </ul>                                   | <ul style="list-style-type: none"> <li>• Costly to implement at a system wide level</li> </ul>                                                        | <ul style="list-style-type: none"> <li>• Aging pipeline</li> <li>• Manhole structure</li> <li>• Storm sewer cross connection</li> <li>• Faulty lateral connection</li> </ul> |

### 3.2.1 Lift Station Pump Monitoring

If the collection system includes multiple lift stations, a good first step in narrowing down the source of I&I is to review the pump data at each lift station. If lift stations are equipped with flow meters, it is essential to compare wet and dry weather data. In instances where lift stations do not have flow meters, comparing pump run times can be another effective method for identifying I&I. If any pumps are running significantly longer during wet weather than during dry weather, this is a strong indication of I&I in that portion of the collection system.

Some important considerations when using pump run times instead of flow data include ensuring that proper wet well drawdown occurs when the pumps are running and that the pumps are not air-bound or clogged. If these issues exist, they can result in faulty or irrelevant data regarding I&I. An example spreadsheet to record and track pump station and rain data is included in [Appendix B](#).



### 3.2.2 Manhole Inspections

Because manholes are a common source of inflow for collection systems, completing comprehensive manhole inspections through the system is another helpful and cost-effective option for tracking sources of I&I. Although this process can be time consuming, it can be done utilizing staff time without many additional resources. Manhole inspections should include the evaluation of all components of the manhole, including the lid and frame as well as the frame connection. The condition of the manhole interior can be captured with a camera or by visual inspection with the proper equipment and confined space entry permits. An example inspection form is included in [Appendix C](#) to use as a guide for conducting manhole inspections.

If the utility is equipped with digital files of their manholes and collection system, it can be very beneficial to include this form in the digital files to keep a record of manholes needing attention. It is also helpful to establish a ranking system to give manholes a priority order for addressing the issues identified during the manhole inspections. The inspection form in [Appendix C](#) includes an example ranking system for manhole inspections.

### 3.2.3 Smoke Testing

Smoke testing is an effective way of tracking sources of I&I that are not as immediately obvious as large gaps or holes in manholes and sewer pipes. Through the use of non-toxic, simulated smoke blown into the system at a manhole, sources of I&I can be realized by monitoring the location of the smoke rising through the system. This method often helps identify roof drains or other private connections to the system as well as manholes with smaller gaps that might not be identified during a manhole inspection alone. If there is a way for smoke to rise to the surface of the ground, this method can also help identify sections of pipe underground that have gaps allowing I&I.

A smoke test is most effective when applied to smaller sections of pipe at a time (between one or two manholes). In order to do this, an inflatable plug is inserted into one end of the pipe through the manhole and a manhole one or two sections down is plugged at the opposite pipe. A blower is then inserted on top of the second manhole to blow smoke into the system and if there are gaps, smoke will be visible. This process can then be repeated in other sections of the system. Running a smoke test typically costs from \$0.15-\$0.50/LF, including the equipment and labor (Superior Sewer Company, n.d.). An example Smoke Test inspection form is included in [Appendix D](#) (City of Baton Rouge, n.d.).

### 3.2.4 Dye Testing

Dye testing is similar to smoke testing in that it can help narrow down sections of the collection system that are subject to I&I. It is often used following a smoke test to confirm the results or target even more specific areas for results. In a dye test, non-toxic dye is mixed with water and



pumped into a groundwater or stormwater source that is being evaluated. Sewer manholes downstream of the stormwater infrastructure being evaluated are monitored for the appearance of the dye in the system. While this method can be time consuming if there are many areas to be evaluated, it is a cost-effective monitoring tool, costing only labor of the utility staff and the low cost of the dye.

### *3.2.5 Sewer System Cleaning*

Regularly cleaning and maintaining the sewer system is one of the most effective ways to identify and mitigate I&I. Cleaning removes debris that builds up in the system, which can cause flow backups and reduce hydraulic capacity. It also allows personnel to inspect the integrity of the collection system through routine visual inspections. These inspections help assess the condition of the infrastructure and can pinpoint specific areas where I&I is occurring. Once identified, these areas can be prioritized for maintenance and repairs, helping to reduce I&I.

### *3.2.6 Monitoring and Modeling*

While manual manhole inspections and lift station pump monitoring are beneficial and cost-effective options for determining the source of I&I, there are several technologies available to further streamline I&I tracking by offering real-time flow monitoring and automated data collection. These smart sewer monitoring devices allow users to collect regular and continuous data at points of interest throughout the system. The installation and use of smart monitoring devices would be most beneficial following a smoke or dye test or after reviewing lift station data to better understand areas of concern throughout the system. The data gathered from the smart sewer monitoring implemented can be used to determine the amount of I&I getting into the system from different sections of the collection system. Many of these devices are portable and can be installed on different manholes for specific ranges of time in order to collect data from across the collection system.

Flow volume data may also be used to model the system and quantify rainfall-derived inflow & infiltration (RDII) volumetric totals. The associated flow hydrographs may be used to separate the base dry weather flow to determine the rainfall dependent I&I and characterize the predominant RDII type in the metered area of the sewer system (inflow vs. infiltration). If provided, their associated [scatter graphs](#) (plotting flow depth vs. velocity) may be used to more quickly characterize flow conditions within sewers such as whether high flow depths at meter locations are more likely the result of SSOs as opposed to downstream blockages. RDII models can also help utilities understand the response time of their systems to rainfall and when they can expect peak flows based on the predicted rainfall amount and intensity.



### 3.2.7 Sewer System CCTV

Closed Circuit Television (CCTV) is an incredibly useful tool for tracking sources of I&I through the collection system. Recording the condition of the sewer pipes using CCTV can inform utilities about gaps at joints in the system or holes in the pipes. Using CCTV can also help identify portions of the system that are blocked or clogged. CCTV survey work is often done through a contracted firm and charged per hour or foot of pipe surveyed. While this method for tracking sources of I&I is very accurate and helpful to identify specific locations allowing I&I, it can be costly to CCTV an entire system. Using this method may be more beneficial after following some of the other methods discussed to get a general idea of sections of the system where I&I may be occurring.

### 3.2.8 On-Site Inspections

For improper or illicit connections such as roof drains, sump pumps, or foundation drains, on-site inspections may be required. [Section 4.4](#) includes options for public outreach and disconnection programs to help reach private property owners that may have improper connections. Once the initial outreach and connection has been made, utilities can offer on-site inspections to help the owner understand the issues and to help work together towards solutions to remove the improper connection and reconnect it to the appropriate drainage location.

## 3.3 Determining Amount of I&I

Quantifying the amount of I&I entering the system is an important step for utilities to take when working to understand and address I&I issues. This is useful information to have to understand the scale of I&I issues as well as to report I&I volumes for permitting needs. There are several types of wastewater flow to take into account when determining I&I volumes including:

- Sanitary flow: Direct sewage from users.
- Infiltration: Groundwater flow entering the system through cracks or gaps.
- Inflow: Stormwater flow entering the system.

**Table 2.** Determining the Amount of I&I

| TYPE OF FLOW         | CALCULATION METHOD                                                                                                                                                                                                                                                    | TIME PERIOD FOR CALCULATION                                                                                                                                                 |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>SANITARY FLOW</b> | <ol style="list-style-type: none"><li>1. Volume of inflow to the treatment plant minus the groundwater infiltration (calculation below).</li><li>2. Determining the water usage volume from the flow meters in the system (this assumes that water usage is</li></ol> | <ol style="list-style-type: none"><li>1. During at least a two week dry period.</li><li>2. During period where water usage on lawns or irrigation is less likely.</li></ol> |



|                       |                                                                                                                               |                                                                                                                        |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
|                       | approximately equal to the amount of sanitary flow in the system).                                                            |                                                                                                                        |
| <b>INFILTRATION</b>   | Averaging nighttime flows during study period and subtracting any known significant industrial or commercial nighttime flows. | During at least a two week dry period with high groundwater.                                                           |
| <b>INFLOW</b>         | Subtracting the average sanitary flow and infiltration calculated from the total volume of inflow at the treatment plant.     | During a rainy period. Flow data should be compared to dry weather data immediately before the rainfall.               |
| <b>PEAK INFLOW</b>    | The largest flow difference between rainfall event flow and dry weather flow before the event.                                | One hour period.                                                                                                       |
| <b>TOTAL INFLOW</b>   | Direct Inflow + Delayed Inflow                                                                                                | Total time of increased flow to the treatment plant.                                                                   |
| <b>DIRECT INFLOW</b>  | Total flow following a rain event minus the base sanitary flow and groundwater infiltration.                                  | Time difference between the start of rainfall and the start of increased flow to the treatment plant.                  |
| <b>DELAYED INFLOW</b> | Total flow following a rain event minus the base sanitary flow and groundwater infiltration.                                  | Time difference between the start of increased flow to the treatment plant and the return to base flow and conditions. |

For additional information on calculating I&I volumes, refer to the EPA published guide at [this link](#) (EPA, 2014).

Monitoring and modeling activities discussed in [Section 3.2.6](#) are important tools when working to determine the amount and types of I&I in the system. An example spreadsheet provided by H2Ometrics is included in [Appendix E](#) to help quantify the RDII volumetric totals and better characterize the system's response to rainfall.



# Chapter 4: Inflow and Infiltration Solutions and Implementation

## 4.1 Sewer Rehabilitation

Traditionally, sewer rehabilitation has been a costly and time-consuming process, involving significant construction to excavate old pipes and manholes, which often disrupts traffic, businesses, and daily public activities. Traditional methods require physically digging up deteriorated infrastructure and replacing it, a process that can take many months to complete and significantly impact communities.

However, with the emergence of modern technology, more efficient and cost-effective rehabilitation methods have become available. These newer approaches, known as "trenchless" technologies, allow for repairs and upgrades to be made within the existing infrastructure without extensive excavation. Trenchless methods are faster, less disruptive, and often cheaper than traditional open-cut replacement. These techniques can address I&I as well as extend the lifespan of the infrastructure and minimize the impact on the surrounding environment. There are multiple different rehabilitation methods and each of them offer certain advantages and disadvantages.

### 4.1.1 Open-Cut Pipe Replacement

Open-cut pipe replacement is the most traditional method of pipe rehabilitation, involving the excavation of a trench to replace sections of pipe. Due to the labor-intensive process and the disruptions associated with this method, it is often not the first choice for pipe rehabilitation and can be extremely expensive. However, there are instances where open-cut repair is the only viable option, such as for large-diameter pipes or cases where structural damage is too significant for other methods to be effective.

**Table 2.** Advantages and Disadvantages of Open-Cut Pipe Replacement

#### Advantages

Suitable for significant damaged piping and allows for the removal and replacement of pipes, joints, and other connection points at the same time. Longer service life and ability to replace pipes with new materials that are more resilient to corrosion and root intrusion.

#### Disadvantages

The process is labor-intensive and requires significant excavation, shoring, and backfilling, leading to high overall costs compared to trenchless alternatives. Disrupts surface areas, including roadways, sidewalks, and landscapes.



Allows for installation of larger pipe diameters to accommodate higher hydraulic capacities.

Excavating, replacing, and restoring can take longer than other trenchless methods, impacting project timelines and increasing inconvenience for the community.

#### 4.1.2 Sewer Lining

Sewer lining, also known as Cured-in-Place Pipe (CIPP), is a trenchless technology used for sewer rehabilitation that is cost-effective and minimizes the need for extensive excavation. The process begins with thoroughly cleaning the sewer line, followed by televising the line with a camera (CCTV) to ensure the pipe is suitable for lining. After cleaning, a flexible resin-impregnated liner is inserted into the pipe, typically through a manhole, and pulled or inverted through to the other end, often another manhole. Once the liner is in place, it is inflated and cured using hot water, steam, or UV light. This process hardens the liner, creating a new, durable pipe within the existing damaged pipe, all without the need for large-scale excavation.

CIPP offers several benefits, as it can be done from manhole to manhole and usually does not require additional excavation. Additionally, service laterals can typically be reconnected to the sewer main using a robotic cutting tool, rather than manual excavation. However, CIPP installation can be challenging, and if not done correctly, it may affect the long-term performance of the rehabilitated pipe.

**Table 3.** Advantages and Disadvantages of Sewer Lining

| Advantages                                                                                                                                                             | Disadvantages                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Minimal impact on pipe capacity reduction.                                                                                                                             | Installation complications can cause the liner to wrinkle and improperly cure, which can affect the long term-term performance.             |
| Minimal or no excavation is required, resulting in fewer disruptions to traffic and residents, making it a cost-effective alternative to traditional pipe replacement. | The curing process can be complicated and can lead to additional installation costs if specialized equipment is needed.                     |
| Versatile for pipes with varying diameters and bends.<br>Lifespan is typically 30 to 50 yrs.                                                                           | Limited for very large diameter pipes. Typical ranges for CIPP are 2 to 110 inches in diameter.<br>Limited for severely deteriorated pipes. |
| Easy service lateral reconnection that does not require excavation.                                                                                                    |                                                                                                                                             |

#### 4.1.3 Slip Lining

Slip lining is a trenchless technology that involves inserting a smaller pipe inside the existing pipe, rather than applying a lining like CIPP. Once the new pipe is pulled through and positioned,



grout is applied to seal the space between the old and new pipes. The process starts with thoroughly cleaning and inspecting the existing pipe, similar to the preparation for CIPP. Common materials used for slip lining include high-density polyethylene (HDPE), fiberglass-reinforced plastic (FRP), and PVC. While slip lining can be done from manhole to manhole for small diameter pipes over short distances, it often requires a larger access point to be excavated to accommodate the equipment and liner installation. Additionally, slip lining typically requires excavation to reconnect service laterals, making it a more intensive process.

**Table 4. Advantages and Disadvantages of Slip Lining**

| <b>Advantages</b>                                                                                                                                                | <b>Disadvantages</b>                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Minimal excavation is required, resulting in fewer disruptions to traffic and residents, making it a cost-effective alternative to traditional pipe replacement. | Reduced initial pipe diameter which can create capacity issues.                                                                                    |
| Compatible with a variety of materials: concrete, clay, and cast iron.                                                                                           | Limited flexibility outside of straight sections of pipe. Additionally slip lining is not suitable for piping with multiple diameters.             |
| Can extend the life of the existing pipe by decades.                                                                                                             | The grouting process can be complex and must be done correctly; otherwise, the new pipe may not be stable, leading to potential future challenges. |
|                                                                                                                                                                  | Requires excavation for reconnecting service laterals.                                                                                             |

#### 4.1.4 Pipe Bursting

Pipe bursting is a trenchless technology used to replace existing pipes by breaking them apart while simultaneously pulling a new pipe into place. The process typically involves pulling a tapered expansion head, or bursting head, through the old pipe. As the expansion head moves through, it fractures the existing pipe and pushes the broken pieces into the surrounding soil, making room for the new pipe. Common materials used for the new pipe in pipe bursting include high-density polyethylene (HDPE), polyvinyl chloride (PVC), and ductile iron.

Pipe bursting requires an access point larger than a manhole due to the size of the equipment and the sections of pipe that need to be pulled through. In most cases, this necessitates some construction to dig an access pit, though it is still far more efficient than traditional open-cut replacement. The process can be noisy and disruptive and may cause ground movement during the bursting operation. The main advantage of pipe bursting over other trenchless technologies is its ability to increase the pipe diameter, allowing for greater hydraulic capacity.



**Table 5. Advantages and Disadvantages of Pipe Bursting**

| Advantages                                                                                     | Disadvantages                                                                                                                                           |
|------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Less excavation required than traditional sewer replacement.                                   | Not suitable if the existing pipe is completely collapsed.                                                                                              |
| The ability to increase pipe capacity by upsizing the diameter to accommodate increased flows. | Potential ground movement due to the intensity of the process can cause disruptions, including noise and vibration, which may affect community members. |
| Suitable for replacing a variety of old pipe material such as clay, cast iron, and concrete.   | Requires a larger access point than a manhole and sometimes may require construction.                                                                   |
|                                                                                                | Limited flexibility outside of straight sections of piping.                                                                                             |
|                                                                                                | Requires excavation for reconnecting service laterals.                                                                                                  |

#### *4.1.5 Point Repair*

Most previous methods have focused on end-to-end repair, but that is not always necessary if there are only a few problematic sections of the pipeline. When infiltration is occurring in specific areas, point repair technologies can be applied instead of rehabilitating the entire pipeline, resulting in significant cost savings. This approach is typically used to address issues such as cracks, joint separations, and root intrusions. Various techniques are available for point repair, including spot lining, grout injection, mechanical repair, and robotic repair.

#### *4.1.6 Manhole Rehabilitation*

Manholes are one of the most common and exposed exterior components of the sewer system, making them a significant source of I&I. Manholes are susceptible to both inflow from stormwater flowing over the lids as well as groundwater infiltration through cracks, joints, and other structural defects. The main sources of I&I in manholes include leaking covers and frames, structural cracks and joint failures, and corrosion. Due to their various components, several different approaches can be taken to prevent I&I.

##### *Sealing and Coating Liners*

Sealing and coating involve applying epoxy or cementitious coatings to the inside of the manhole structure to seal cracks and deteriorated surfaces. These coatings not only seal leaks but also protect against corrosion, especially in environments with high levels of sewer gases like hydrogen sulfide.



### *Chimney Seals*

Chimney seals are applied to the manhole cover and frame components to prevent surface water inflow. This typically involves installing a flexible rubber sleeve that fits tightly around the chimney section (the upper part of the manhole) and is secured by stainless steel bands.

### *CIP Lining*

Similar to the CIP process used for sewer pipes, manholes can be lined with cured-in-place (CIP) liners on the inside of the structure. CIP liners are typically resin-impregnated materials that cure in place. The process involves cleaning, installing the liner, and curing it using hot water, steam, or UV light.

### *Chemical Grouting*

Grouting is an older but proven approach that involves applying chemical grout to seal internal leaks, joints, and cracks where infiltration is occurring. Additionally, grout can be injected into the soil surrounding the manhole to fill voids and stabilize the structure.

### *Frame and Cover Replacement*

Since many manholes were installed decades ago, replacing frames and covers with newer, watertight designs can significantly reduce I&I, especially in low-lying areas where flooding frequently occurs.

### *External Sealing*

External sealing is more labor-intensive than other methods because it requires excavation around the manhole, unlike interior rehabilitation. However, it is sometimes necessary, especially in areas with high groundwater levels. The process involves excavating around the manhole and applying a waterproof membrane around its exterior to prevent infiltration.

**Table 6.** Advantages and Disadvantages of Manhole Rehabilitation Methods

| METHOD                    | ADVANTAGES                                                                                                                                                                                                | DISADVANTAGES                                                                                                                                                                                                                        |
|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CEMENTITIOUS LINER</b> | <ul style="list-style-type: none"><li>• Cost-effective and relatively quick to apply.</li><li>• Adds structural strength to deteriorated areas.</li><li>• Can be layered to increase thickness.</li></ul> | <ul style="list-style-type: none"><li>• Less flexible than other liners and may crack if significant ground movement occurs.</li><li>• Limited resistance to aggressive chemical environments without additional coatings.</li></ul> |
| <b>EPOXY LINER</b>        | <ul style="list-style-type: none"><li>• Provides a smooth, impermeable surface resistant to corrosion and chemicals.</li><li>• Long-lasting and durable.</li></ul>                                        | <ul style="list-style-type: none"><li>• More expensive than cementitious liners.</li><li>• Requires thorough surface preparation for proper adhesion.</li></ul>                                                                      |



|                                    |                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                            |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CHIMNEY SEALS</b>               | <ul style="list-style-type: none"> <li>• Prevents surface water inflow through manhole covers and frames.</li> <li>• Easy to install and cost-effective.</li> </ul>                                                                                                           | <ul style="list-style-type: none"> <li>• Only addresses inflow at the manhole top; does not solve infiltration issues in other parts of the manhole.</li> </ul>                                                                            |
| <b>CIP</b>                         | <ul style="list-style-type: none"> <li>• Provides structural reinforcement to the manhole.</li> <li>• Effective in sealing cracks and joints.</li> <li>• No excavation required, minimizing surface disruption.</li> </ul>                                                    | <ul style="list-style-type: none"> <li>• May not fully address severe external groundwater infiltration.</li> <li>• Installation requires curing time (steam, UV, or hot water).</li> </ul>                                                |
| <b>CHEMICAL GROUTING</b>           | <ul style="list-style-type: none"> <li>• Can be injected to fill voids and stop leaks without full excavation.</li> <li>• Effective for sealing joints and cracks.</li> </ul>                                                                                                 | <ul style="list-style-type: none"> <li>• May not provide long-term structural strength.</li> <li>• Potential for grout to migrate or wash away over time.</li> </ul>                                                                       |
| <b>FRAME AND COVER REPLACEMENT</b> | <ul style="list-style-type: none"> <li>• Effectively prevents surface water inflow through poorly fitting or damaged covers.</li> <li>• Improves access for maintenance.</li> <li>• Can be upgraded to watertight or pressure-rated designs for flood-prone areas.</li> </ul> | <ul style="list-style-type: none"> <li>• Requires some excavation to replace the frame and adjust the surrounding surface.</li> <li>• May not address deeper structural issues or infiltration from other parts of the manhole.</li> </ul> |
| <b>EXTERNAL SEALING</b>            | <ul style="list-style-type: none"> <li>• Directly addresses groundwater infiltration from the outside.</li> <li>• Provides a durable, watertight barrier around the manhole.</li> </ul>                                                                                       | <ul style="list-style-type: none"> <li>• Requires excavation, which is costly and disruptive.</li> <li>• Not suitable in areas with limited access for excavation equipment.</li> </ul>                                                    |

## 4.2 Private Lateral Rehabilitation

Private laterals are one of the most significant and challenging sources of I&I to address. Studies, such as one conducted by the Madison Metropolitan Sewerage District (Brown and Caldwell, 2021), have shown that up to 70% of I&I can originate from private laterals. Since property owners are typically responsible for maintaining these pipes, many delay repairs due to the high cost, opting for rehabilitation only when absolutely necessary. While some states have laws that allow utilities to work on private laterals, in most cases, the responsibility lies with the property owner.

To encourage proactive rehabilitation, some utilities offer incentive programs that cover a portion of the repair costs. More information on the implementation of programs like this is included in [Section 4.4.3](#).



Lateral rehabilitation techniques are similar to those used in broader sewer rehabilitation efforts and include methods such as [slip lining](#), [pipe bursting](#), [CIPP](#), and [traditional open cut repairs](#).

## 4.3 Green Infrastructure

Green infrastructure is an effective approach to controlling I&I through stormwater management. It works by diverting stormwater away from sewer systems, promoting better infiltration into the ground, and providing storage for excess water during wet weather events to help reduce sanitary sewer overflows (SSOs). In addition to being a cost-effective alternative to gray infrastructure, green infrastructure enhances natural beauty and, in some cases, offers public recreational spaces. These benefits make it a sustainable and multifunctional solution for I&I reduction management.

**Table 7.** Types of Green Infrastructure

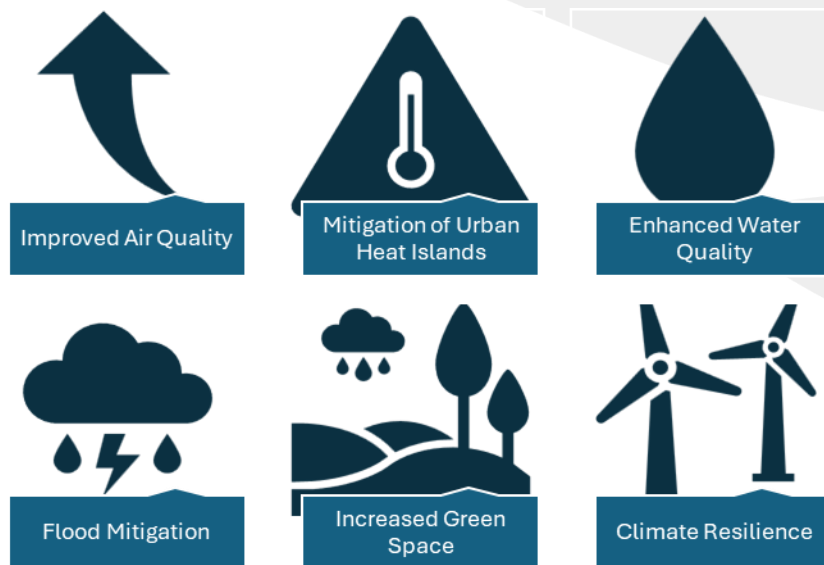
| TYPE OF GI                  | COMMON METHODS                   | FORM OF I&I REDUCTION                                                                                                                                                                  |
|-----------------------------|----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BIORETENTION SYSTEMS</b> | Rain gardens, bioswales          | Captures and filters stormwater through vegetation and soil, slowing down runoff and reducing the amount of water that reaches the sewer system. Also helps remove contaminants.       |
| <b>GREEN ROOFS</b>          | Vegetated roofs, rooftop gardens | Absorbs rainfall, reducing the volume of water that runs off roofs and into sewer systems. Helps decrease peak flows during storm events.                                              |
| <b>VEGETATED SWALES</b>     | Grass swales, tree-lined swales  | Slows and treats stormwater, promoting infiltration and reducing the amount of runoff that enters the sewer system.                                                                    |
| <b>CONSTRUCTED WETLANDS</b> | Wetland basins, marshes          | Treats and slows stormwater, reducing the volume and speed of water entering the sewer. Helps manage peak flow and infiltration.                                                       |
| <b>URBAN TREE CANOPY</b>    | Street trees, park trees         | Intercepts rainwater through tree roots, reducing runoff and increasing soil infiltration before water reaches the sewer system.                                                       |
| <b>RETENTION PONDS</b>      | Wet ponds, stormwater basins     | Retains stormwater onsite, slowly releasing it to reduce peak flows. Helps to settle out pollutants and reduce the volume of water entering the sewer system during heavy rain events. |

### 4.3.1 Environmental Justice

Utilizing GI to enhance public engagement also provides significant benefits to disadvantaged parts of the community facing environmental justice (EJ) challenges. Communities with EJ



concerns are often the most vulnerable to the impacts of I&I, as infrastructure in these areas is typically less reliable compared to more affluent neighborhoods. GI not only helps beautify neglected or abandoned parts of the city but also addresses environmental justice concerns while reducing the risks associated with CSOs. Engaging with the public, particularly in EJ areas, empowers residents to have a voice in shaping the landscape of their community. Some specific EJ benefits of GI include:



**Figure 1.** Environmental Justice Benefits of GI

## 4.4 Disconnection Programs and Public Outreach

Because a significant portion of I&I can come from private properties and illicit connections, disconnection programs and public outreach are important to help reduce and sustain the reduction of I&I in a collection system. If the public is informed about the consequences of illegal connections to the sewer system and is provided with options or assistance for disconnecting, the amount of infiltration making its way to the collection system can be greatly reduced.

Because many of the private connections to the sewer systems occur in Combined Sewer Systems, more specific programs and initiatives are covered in [Chapter 3 of the CSO Module](#). An overview of these programs is provided below.

### 4.4.1 Public Awareness Programs

Public outreach is important to:

1. Inform the public of the consequences of I&I.
2. Provide actions that the public can take to help reduce infiltration from their property.

3. Communicate the efforts and value of the work that the utility is providing to keep the system running and reduce I&I.
4. Learn from the public on challenges they face relating to I&I.

Public awareness of I&I can take many different forms depending on the needs and specific concerns of the community planning to implement a public awareness program. Some options for public outreach include:

- Notices on stormwater or utility bills
- Presentations at community meetings
- Website information
- Email outreach
- Fliers and door hangers
- Signs around the community
- Information booths at festivals or other community events

The information included in this outreach will also change depending on the communities specific I&I issues. Some examples of information to share with the public include:

- Approximate flow of I&I in the system
- Sources of I&I throughout the community
- Information on consequences of I&I in the system and the cost of additional wet weather flow
- Information on actions that the utility is taking to eliminate or mitigate I&I
- Share information about rain barrel or disconnection programs (more information on these is included in sections below)

#### *4.4.2 Disconnection Programs*

There are a number of specific programs that utilities can implement to help reduce the amount of I&I getting into the collection system through private properties. These include:

- Rain barrel programs
- Sump pump disconnection programs
- Downspout disconnection programs

While these programs are largely more applicable to Combined Sewer Systems, they can be useful for separate systems, specifically the rain barrel programs, to reduce the overall stormwater runoff coming from a property and potentially making its way into the collection system. These programs are covered in more detail in [Chapter 3 of the CSO Module](#).



#### 4.4.3 Pipe Check Programs

Many homeowners are unaware that they are responsible for the sanitary sewer lateral from their home and are therefore likely unaware of potential issues with their lateral. Unknown connections to the lateral or cracks in the pipe caused by roots or other structural problems could be leading to flooding in their basement and contributing to I&I in the collection system. To raise awareness of the public's responsibility for their lateral and to help them assess and fix potential issues, utilities can implement pipe check programs. These kinds of programs can include a wide range of incentives for participation including:

- Discount on the utility bill
- Utility can pay for portion of any work required based on pipe inspection

Through the program, homeowners can choose through a list of utility-approved contractors to conduct an inspection of their home's lateral. Following the inspection, the contractor will provide information on the required repairs and depending on the incentives offered by the program, will inform the homeowner of the amount they are due. Once the work is completed, the homeowner will pay their portion and the utility will pay the rest or will provide a discount to the utility bill, depending on how the program is set up. For more information and a video on a successful program, follow this [link](#) to the Milwaukee Metropolitan Sewerage District website.

### 4.5 Prioritization

One of the most important aspects of addressing I&I is prioritizing which repairs or projects should be implemented over others. Not all sources of I&I contribute equally to the system's challenges. For instance, a cracked pipeline in an area with high groundwater will consistently contribute a significant volume of I&I, as groundwater will seep into the system even during dry weather. In contrast, a roof drainage system will only contribute during wet weather events.

Since every collection system is unique, many factors must be considered when prioritizing repairs, and the priorities will likely differ for each utility. Therefore, it is crucial for each utility to determine a prioritization approach tailored to its specific collection system and treatment facility. Key factors to consider when prioritizing include volume of impact, frequency, cost impact, and ease of resolution.

The goal of prioritization is to help a utility identify the largest sources of I&I, understand the costs associated with addressing the issue, and estimate the effort and resources required to resolve it. Properly prioritizing I&I repairs and solutions enables utilities to make cost-effective decisions with the greatest potential for I&I reduction. For an interactive prioritization tool that helps utilities better address their I&I challenges and solutions, see [Appendix F](#).



## 4.6 Maintenance Best Practices

### 4.6.1 Asset Management

Addressing I&I challenges begins with developing an asset management plan, which involves creating a detailed inventory of the collection system's components, such as pipe age, material, condition, and lift station components. This inventory enables utilities to track and schedule inspections, maintenance, and rehabilitation activities. Proper monitoring of asset condition and age helps identify I&I sources, prioritize maintenance, and plan repairs, ensuring proactive management of infrastructure.

Maintaining detailed records of inspections, maintenance activities, and past incidents is essential for providing historical context and supporting data-driven decision-making. One of the best ways of tracking asset management is through the use of a computerized maintenance management system (CMMS). CMMS is software that centralizes maintenance information and facilitates the processes of maintenance operations. CMMS software may be used as a tool to schedule and track preventive maintenance.

Supplementing asset management information with data on flow rates, rainfall, and lift station pump performance allows for a more comprehensive evaluation of I&I issues and informs targeted reduction strategies.

An effective asset management plan also identifies critical assets and develops a risk profile, aiding in prioritization of repairs and replacements. A well-maintained inventory should include key details, such as equipment type, location, age, material, manufacturer, and expected life expectancy. This approach supports routine maintenance, capital planning, and long-term funding solutions.

An asset management plan can be broken down into six core components (Camden County Municipal Utilities Authority, 2015):





**Figure 2.** Asset Management Plan Components

#### 4.6.2 GIS

While all utilities typically have some form of mapping or drawings of the collection system, information can become outdated or lost over time due to personnel changes or undocumented modifications. Paper copies are particularly vulnerable to loss or damage, especially when used in the field for maintenance and repairs. Geographic Information Systems (GIS) offer an electronic user-friendly solution for preserving mapping, record-keeping, and enhancing asset management. GIS enables digital and precise mapping of sewer networks, including the locations of manholes, sewer lines, storm drains, and other critical infrastructure.

With GIS, utilities can organize documentation of the collection system, allowing field operators to access information on a tablet or phone. This ensures that data is current, repairs and maintenance are documented in real time, and vital information is preserved. By integrating GIS with an asset management plan, utilities can significantly improve their ability to track and address I&I challenges.

#### 4.6.3 Monitoring (Smart Sewers)

Smart sewer monitoring involves the use of various advanced sensors strategically placed throughout the collection system to provide real-time data collection and analysis of flows and levels. This approach is one of the most effective ways to track and pinpoint I&I. With advanced software programs, real-time data on flows, levels, pressure, temperature, and precipitation can be analyzed to help utilities make data-driven and precise decisions about locating and addressing I&I. These programs can graph and compare wet and dry weather data, as well as

analyze historical data to identify trends. Sensors are typically installed in manholes and pump stations to monitor conditions in real time.

In addition to providing continuous real-time data, these systems enable operators to better monitor the system during wet weather events, allowing for quicker responses to reduce the likelihood of SSOs, CSOs, and basement backups.

Beyond I&I monitoring, smart sewers can also optimize collection system maintenance. Rather than using the traditional time-based cleaning and maintenance approach, smart sewer monitoring can determine maintenance frequency based on real-time system conditions. For example, a pump station wet well may be on an annual cleaning schedule, but data might show elevated levels of debris and grease due to decreased pump efficiency. Operators can then adjust the cleaning schedule from annually to quarterly or as needed, prolonging the life of the equipment, reducing energy usage, and maximizing the hydraulic capacity of the sewer system.

Smart sewer systems can also be integrated with asset management and GIS programs to further optimize maintenance, inventory management, and repair of the collection system. While the initial investment in these technologies may be significant, the potential for quick payback and substantial long-term cost savings is significant due to reduced energy and treatment costs, compliance with regulatory requirements, and extended equipment lifespans.

#### *4.6.4 General Maintenance*

Regularly cleaning, televising, inspecting, and performing general maintenance on sewer systems and their components is vital not only for the longevity of the system but also as one of the most effective and proactive approaches for tracking and monitoring I&I. Incorporating these practices and integrating the information gathered during each maintenance activity into GIS and the utility asset management program is an extremely effective and organized approach for optimizing the sewer maintenance process and tracking I&I.

##### *Sewer Cleaning*

Sewer cleaning involves using high-pressure water jetting or mechanical rodding equipment to remove blockages, sediment, grease, and other debris that can clog the sewer system and reduce hydraulic capacity. This process is typically followed by televising the sewer line to identify structural issues, such as cracks and joint failures, which may contribute to infiltration. Best practices for sewer cleaning include:

- Implementing a routine cleaning schedule for high-priority areas, such as those prone to blockages or with a history of I&I issues.
- Cleaning before performing CCTV inspections to ensure the camera can clearly identify defects.



- Documenting each portion of the system cleaned, including the type of debris removed and any other relevant observations.

### *Televising (CCTV)*

CCTV inspections involve using a camera to visually inspect the inside of sewer pipes for cracks, joint failures, root intrusion, and other defects contributing to I&I. As mentioned above, it is best to combine sewer cleaning and televising to ensure there is no debris obstructing the camera, allowing for a clear view of the pipeline. Best practices for CCTV inspections include:

- Performing inspections after cleaning to ensure clear visibility of the pipeline.
- Integrating inspection data into the GIS system to track pipe conditions and maintenance history.

### *Catch Basin Cleaning*

Catch basins play a vital role in stormwater management by collecting rainwater and snowmelt and directing it to a stormwater outlet, rather than allowing excess clear water to flow into and infiltrate the sanitary sewer. This also helps prevent roads and yards from flooding during heavy precipitation events. While catch basins are beneficial in reducing I&I, they can have adverse effects if not properly maintained. They are prone to accumulating sediment, leaves, and other debris, which can block the outlet and lead to overflows, potentially contributing to I&I by infiltrating the ground around the sanitary sewer system or entering through manholes. Best practices for catch basin cleaning include:

- Cleaning catch basins annually, with increased frequency in areas prone to flooding or heavy leaf accumulation.
- Using vacuum or manual cleaning methods, depending on basin size and location.
- Monitoring for illegal stormwater connections to the sanitary sewer.

**Table 8:** General Maintenance Schedule

| METHOD                 | ACTIONS                                                                                                                           | FREQUENCY                                                                                                       |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| <b>SEWER CLEANING</b>  | Remove debris, grease, sediment, and roots using high-pressure jetting or mechanical rodding. Inspect for damage during cleaning. | Annually for high-priority areas, every 3-5 years for others, or as needed based on system performance.         |
| <b>CCTV INSPECTION</b> | Perform visual inspection inside pipes using a camera to identify defects like cracks, joint failures, and root intrusion.        | Every 5-7 years for routine assessment, more frequently in high-risk areas. Conduct inspections after cleaning. |



|                             |                                                                                                                                        |                                                                                                           |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| <b>CATCH BASIN CLEANING</b> | Remove debris, sediment, and trash from catch basins to prevent blockages. Monitor for illicit stormwater connections.                 | Annually, with increased frequency (bi-annually) in areas prone to heavy debris accumulation or flooding. |
| <b>MANHOLE INSPECTION</b>   | Check for signs of deterioration, leaks, or infiltration at manhole covers, joints, and walls. Perform smoke or dye testing if needed. | Every 3-5 years, or more often in areas with known I&I issues.                                            |

## Chapter 5: Case Studies

### 5.1 Madison, WI

| UTILITY NAME                                  | SERVICE AREA     | POPULATION SERVED | NUMBER OF MUNICIPALITIES SERVED | TREATMENT SIZE  |
|-----------------------------------------------|------------------|-------------------|---------------------------------|-----------------|
| <b>MADISON METROPOLITAN SEWERAGE DISTRICT</b> | 187 square miles | 407,000           | 25                              | Average: 36 MGD |

### Background

The Madison Metropolitan Sewerage District (District) is a regional wastewater collection and treatment utility that accepts wastewater from 24 Cities, Villages and Towns (municipalities) in Dane County, WI. Each of the Municipalities own and operate their own sanitary sewer collection systems and discharge to regional interceptor sewers owned and operated by the District.

Recent years have seen intense storms with flooding that has resulted in stormwater (inflow) and groundwater (infiltration) getting into the sanitary sewer system. The August 2018 storm event, while an extreme event, identified that the district and its municipalities are vulnerable to the impacts of inflow and infiltration (I/I) as basement backups and sanitary sewer overflows (SSOs) occurred in some areas where the sanitary sewers were inundated with excessive clear water.

The district has been working on reducing I/I through periodic interceptor rehabilitation projects such as lining or replacing leaking public sewers. However, quantifying the benefits has been difficult due to limited flow monitoring, and these types of projects often have little to no impact on overall reduction in I & I.



The district therefore embarked on a Regional I/I Reduction Program that allows the District the ability to get ahead of the looming problem related to the continued aging of sanitary sewer collection system. Inspections are rare, and deteriorated private sewer laterals are significant sources of I/I.

By year 2030, 25 percent of private sewer laterals in Dane County will be at least 70 years old. The expected increase in I/I from these laterals poses a threat to the capacity of the district's regional sewer system if their condition is not addressed.

## Goal

I/I reduction provides value to the district and surrounding communities over time by increasing resilience to changing weather patterns, deferring needs for expensive capacity increases, improving system performance, and meeting regulatory requirements.

## Planning/Strategy

In 2020, the district hired a consultant to begin work on an I/I reduction program plan and formed a technical advisory committee comprised of six representatives from municipalities to provide input on developing an overall I/I reduction program framework. The group worked by consensus to develop a program strategy. An important result of the technical advisory committee's work regards allocation of spending. Regional programs typically look to optimize solutions and target areas that will yield the greatest net benefit for the cost.

## Implementation

The I/I Reduction Program Implementation Strategy includes major steps to be taken, with a timeline and budget shown in Attachment 1. An outline of these steps are described as follows:

- **Monitoring Program:** The District to develop a flow monitoring plan. This effort began with an upgrade to the district's collection system hydraulic model so that it better reflects dynamic I/I conditions and can be used to identify high priority flow monitoring of tributary areas suspected of exceeding the I/I Reduction Program standards. This effort will also result in a flow monitoring plan that recommends phased locations for installing and maintaining monitors.
- **Adopt Changes to Sewer Use Ordinance (SUO):** Implementation of the recommended I/I Reduction Program required some modifications to the district's existing SUO. Changes include reference to the I/I Reduction Program, the requirement for municipal work plans, and an expressed limit on I/I daily volume.
- **Establish Technical Support Capabilities:** The District is establishing technical support capabilities for municipalities seeking to comply with the I/I standards or otherwise reduce I/I in



their collection systems. Support could include providing general technical information useful to all communities, such as investigation and design guidelines, or specifically to a single community that has requested assistance. In the case of an individual community request, the district would pass on the costs associated with that assistance to that community. The timing of this activity would be such that technical support would be available in time for assistance with developing the municipalities' work plan.

- **Establish Education Support Capabilities:** The District developed general and targeted educational materials concerning I/I reduction in the form of web page material, templates for direct contact mailers, and informational brochures.
- **Begin Enforcement Process:** The commencement of enforcement would not occur until after data have been collected to confirm an area exceeds the I/I standards and any changes to the District's SUO have taken effect. It is likely that this would not occur until Year 2027, or the seventh year of the program.

## 5.2 Milwaukee, WI

| UTILITY NAME                             | SERVICE AREA | POPULATION SERVED | NUMBER OF MUNICIPALITIES SERVED | TREATMENT SIZE   |
|------------------------------------------|--------------|-------------------|---------------------------------|------------------|
| MILWAUKEE METROPOLITAN SEWERAGE DISTRICT | 423          | 1,100,000         | 29                              | Average: 150 MGD |

### Background

The Milwaukee Metropolitan Sewerage District (MMSD) serves approximately 1.1 million people across 29 municipalities. The treatment plants treat an average of 150 MGD and experience up to 5 to 6 times the sewer capacity during rainfall events due to inflow and infiltration (I&I) in the system. MMSD has implemented I&I reduction programs to specifically target private property sources of I&I entering the sanitary sewer system and managing water where it falls.

Through the PPII program, Milwaukee MMSD has achieved a reduction of 108 MG removed annually from the sanitary sewer as of late 2024. Under the Green Infrastructure programs, 158.2 million gallons of clear water can be captured and kept out of the collection system per rain event.



## Goal

The goal of the PPI&I reduction program is to reduce the amount of rainwater, groundwater, and runoff entering the sanitary sewer system, thereby reducing the risk of basement backups of sanitary sewer waste. Reducing I&I will also benefit the environment and overall watershed by reducing the risk of overflows of untreated water to the waterways and helping to keep the collection system under capacity, even during heavy rainfall events.

## Planning/Strategy

The primary focus of the PPI&I reduction program is on private property sources of I&I, including sanitary sewer laterals and foundation drains. In order to partner with private property owners more effectively, MMSD conducts outreach and continuously hosts events and other initiatives to keep the public engaged and informed about the programs and opportunities available to them to help reduce I&I and their risk of backups in their homes. Some of the public engagement strategies that MMSD uses in their I&I reduction efforts include:

- Hosting Public engagement meetings within the project area
- Pipe Check Program
  - Sewer lateral replacement program
  - Foundation drain disconnection program
- Rain barrel workshops
- Green infrastructure throughout the community
- Hosting educational events
- Website updates for public notification

## Implementation

MMSD has implemented several programs to help homeowners and the community learn how to manage water on their properties and provide funding to implement corrective measures to reduce I&I in the sanitary sewer collection system through large publicly bid projects and by providing funding directly to homeowners.

Separately from the PPII program, MMSD also offers several green infrastructure programs that homeowners and community members can participate in. These include, but are not limited to; rain barrel and rain garden programs for homeowners to install and maintain a rain barrel on their property and other resources for homeowners to manage water on their properties. Overall, the green infrastructure program encourages the installation of and educates on green infrastructure through the community. These programs have been successful in reducing I&I in



the collection system and saving homeowner's money on much needed repairs to keep their homes protected.

• **Pipe Check Program:** MMSD's Pipe Check Program helps homeowners identify issues with their sanitary sewer laterals, foundation drains connected to the sanitary sewer system, or other issues that are causing I&I from their property to get into the sanitary sewer system. The program starts with education, including information about I&I and homeowner lateral ownership. MMSD keeps the public informed about the program and the issues that the program addresses through website updates and direct outreach. MMSD requires the following conditions to be eligible for the Pipe Check program:

- Located within the MMSD service area
- One or two-family home
- Site visit conducted by an approved contractor
- W-9 form submitted to MMSD, as the value of the work completed through the program is taxable
- Signed participation waiver
- Approved contractor completes all of the required work identified in the site visit

The homeowner is responsible for contacting the contractor, paying for any site visit fees, and paying the remaining portion of the work identified in the site visit. Milwaukee provides a list of approved contractors and will pay the Pipe Check program flat rate financial incentive amount directly to the contractor when the work is completed. The homeowner will then be billed for the remaining balance and will pay the contractor directly. Lastly, MMSD will send the homeowner a 1099 form at the end of the year for tax purposes.

The total cost of the work and the financial incentive that the homeowner receives are dependent on the scope of work, as identified by the approved contractor during a site visit, and that can vary for each home. Funding for the PPII program is through the MMSD capital budget funded by property tax and non-member billings.

- **Sanitary Sewer Lateral Replacement:** One of the primary goals of the Pipe Check program is to identify and address aging sewer laterals that are causing increased I&I in the collection system. The approved contractor, selected by the homeowner, will make a site visit to the home, camera the lateral to conduct a condition assessment, and if structural issues are found, the contractor will recommend a full lateral replacement (from inside clean out to connection at municipal main), as required by the Pipe Check program. The lateral repair is typically completed using pipe bursting or open cut excavation, to eliminate root and groundwater intrusion by installing a completely new pipe. This provides along term solution for the property owner, and reduced I&I for all stakeholders.



- **Foundation Drain Disconnection Program:** Another of the major goals of the Pipe Check program is to identify foundation drains that are still connected to the sanitary sewer system and get them disconnected. MMSD estimates that homes built before 1954 are more likely to have foundation drains connected to the sanitary sewer system that should be disconnected. Through the Pipe Check program, homeowners can hire an approved contractor to inspect and disconnect their foundation drains. This is typically completed by removing the drain valve, disconnecting the drains, and installing a sump pump to drain to the yard in a suitable location. MMSD also offers educational opportunities to homeowners regarding the operation and maintenance of their sump pumps to ensure that they are working correctly to protect the home against flooding.
- **Municipal Program:** Under the Municipal side of the PPII, MMSD provides funding to the 29 municipalities to identify meter sheds that are reactive to groundwater and/or wet weather events and complete large-scale publicly bid PPII reduction projects. The municipality identifies the project areas, and the property owners in these projects are requested to participate in the program for the betterment of the community. The types of work completed under the municipal program include, but are not limited to, the disconnection of foundation drains and installation of sump pumps, sanitary lateral replacement/restoration, and downspout disconnection. The determination of 1099 is left up to the municipality. Municipal projects require extensive outreach and education to achieve an impactful level of project buy-in as property owners are not required to participate.
- **Rain Barrel Program:** As part of MMSD's efforts to reduce I&I and help homeowners protect their homes, they offer a rain barrel program to provide education and free rain barrels to participating homeowners. By participating in the rain barrel workshops, homeowners can receive one free rain barrel per household and will learn how to install, maintain, and use their barrel effectively. Even without participating in the program, homeowners can benefit from the education provided on MMSD's website and during other public outreach events. If a homeowner chooses to purchase and install a rain barrel on their own, they can get tips on selecting the right rain barrel, how and where to install them, and information on maintaining them. Rain barrels have been used as a entry level educational tool at MMSD for more than 20 years.
- **Green Infrastructure:** MMSD has a suite of green infrastructure (GI) programs that install (GI) on public and private property to help reduce the amount of stormwater entering storm and sanitary sewers and reduce the risk of flooding. By managing water where it falls with GI, MMSD can help to reduce I&I and benefit the community in other ways. Green



infrastructure not only retains rainwater, keeping it out of the collection system, but it also helps filter pollutants, provide habitat, and beautify the community. MMSD has introduced the following examples of green infrastructure throughout the community:

- Bioswales
- Rain gardens
- Green roofs
- Porous pavements
- Native landscaping (long rooted native plants)
- Tree canopy restoration

## Results

Through these and other programs, MMSD hopes to continually engage the community within the service area. Community engagement encourages more education, more participation in various MMSD programs, and better results for all stakeholders. Through the PPII program, MMSD has reduced the amount of I&I in the system by over 100 MG annually.



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## Appendix Items

Appendix A: I&I Tracking Steps. Please use [this link](#) to view and download!

Appendix B: Pump Data for I&I Tracking. Please use [this link](#) to view and download!

Appendix C: MH Inspection Form. Please use [this link](#) to view and download!

Appendix D: Smoke Test Inspection Form. Please use [this link](#) to view and download!

Appendix E: H2Ometrics-RDII Computations and Formulas. Please use [this link](#) to view and download!

Appendix F: I&I Prioritization Tool. Please use [this link](#) to view and download!

