A SunCam online continuing education course

Collection System CIP Management

by

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Course Outline:

Collection System Infrastructure
Need for Infrastructure Improvements
Regulations and Standards
Capital Improvement Planning
Long-Term Planning
Project Selection
Budget Planning
Infrastructure Data Management
Hydraulic Modeling
Sewer Condition Assessment
Infiltration & Inflow Reduction
Sewer Rehabilitation
Helpful References
Examination

Collection System Infrastructure

A wastewater collection system is comprised of the following main infrastructure:

- **Private laterals** from residential, commercial, and industrial users.
- **Gravity sewers** that convey wastewater from private laterals.
- **Interceptors, trunk lines, or deep tunnels** that convey wastewater from gravity sewers to regional pump stations or to the wastewater treatment plant (WWTP).
- **Manholes** (access structures) that allow maintenance of sewers.
- **Lift stations** that collect and convey wastewater from gravity sewers.
- **Regional pump stations** that convey wastewater from lift stations to the WWTP.
- **Force mains** that transfer wastewater from lift stations and regional pump stations to regional pump stations or to the WWTP.

See Figure 1 for an example collection system, also called a conveyance system.

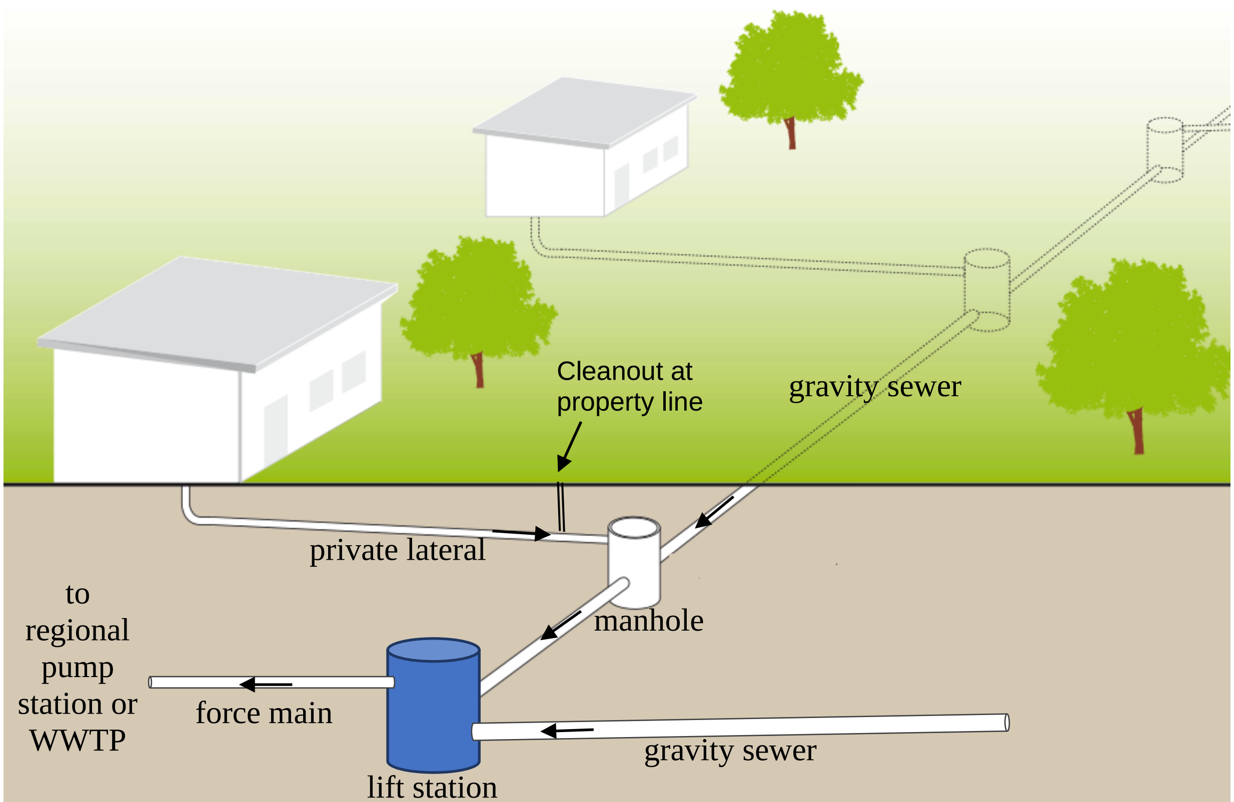


Figure 1: Schematic showing several wastewater collection system.
Source: https://commons.wikimedia.org/wiki/File:Schematic_of_the_Conventional_Gravity_Sewer.jpg
(c) Tilley, E., Ulrich, L., et al; CC BY-SA 3.0 (modified)

It is possible to design a collection system with only gravity sewers and no lift stations. However, the gravity sewers require a consistent downward slope, and as the sewer pipes get longer, the deeper down the pipes need to be installed. Large diameter deep tunnels can be utilized to collect and convey the flow by gravity. These deep pipes are expensive to construct and are difficult to maintain.

So, engineers utilize lift stations to allow for the conveyance of wastewater in shallow pipes (force mains) of a smaller diameter. Lift stations and force mains provide flexibility in routing pipes around or over features such as rivers, lakes, mountains, valleys, landmarks, and sensitive environmental areas. See Figure 2 for an example.

Figure 2: A force main crossing over a canal with an air relief valve in blue.
Source: Author

Normally multiple lift stations will pump wastewater into a common force main pipeline rather than keeping the force mains separate, since a single pipeline is more economical. The pipe size grows in diameter as it picks up the flow from additional lift stations until reaching the destination, which is often the headworks of the WWTP.

In large collection systems, there may be a regional pumping station that accepts flow from multiple lift stations and boosts the force main pressure to convey the wastewater to the WWTP. It is common to use the term Master Pump Station or Booster Pump Station. An example of a network of lift stations and force mains is shown in Figure 3.

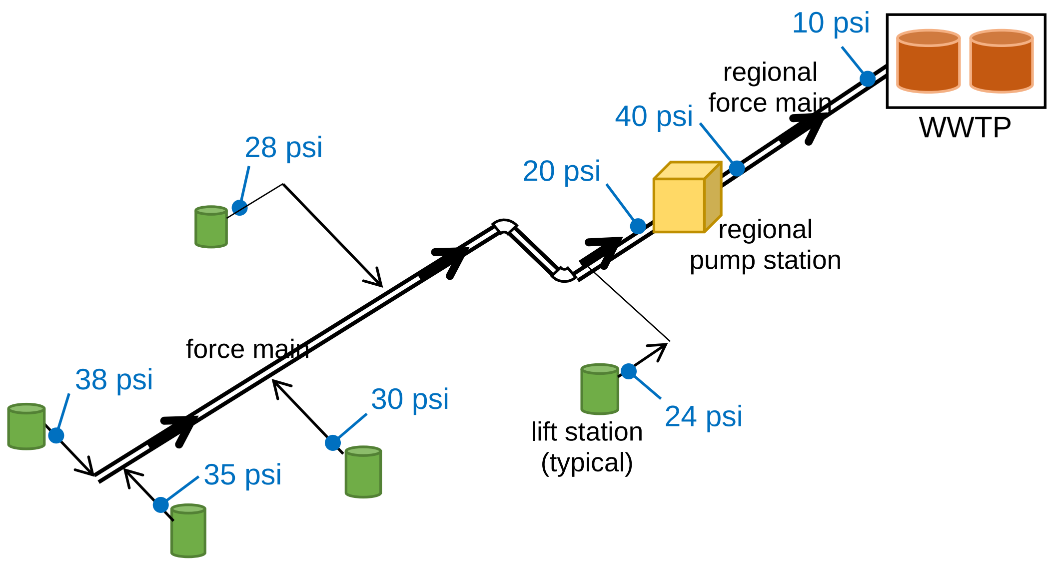


Figure 3: Force main schematic showing design pressures at each facility.
Source: Author

Collection systems are found in the following locations:

- Municipalities (cities, towns, villages),
- Counties,
- Sewerage districts of multiple municipalities and unincorporated areas,
- Large private residential communities,
- Large commercial complexes or business parks,
- Large industrial complexes or industrial parks, and
- Military bases.

This course focuses on the management of a capital improvement program (CIP), also called a capital improvement plan, for collection systems. Organizations often have similar CIPs for treatment facilities and water distribution systems.

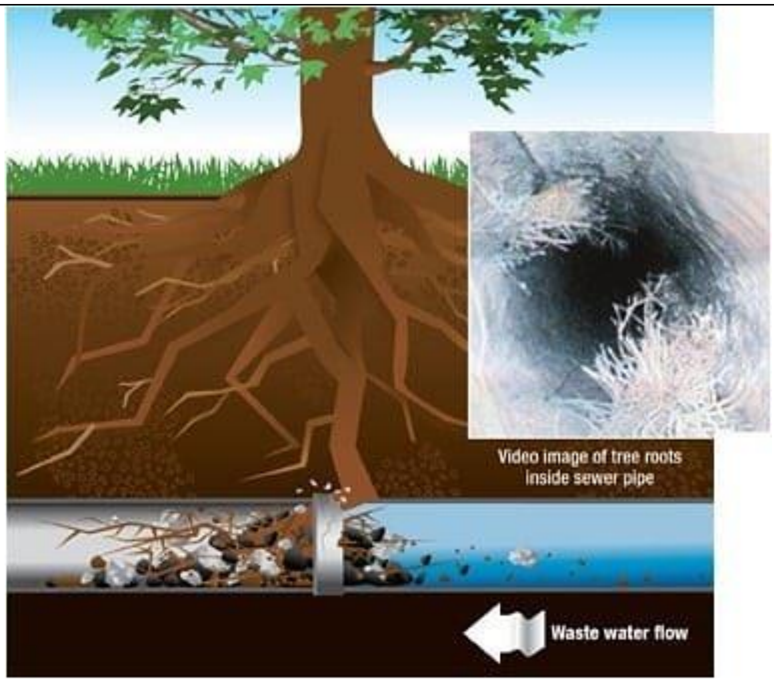
Need for Infrastructure Improvements

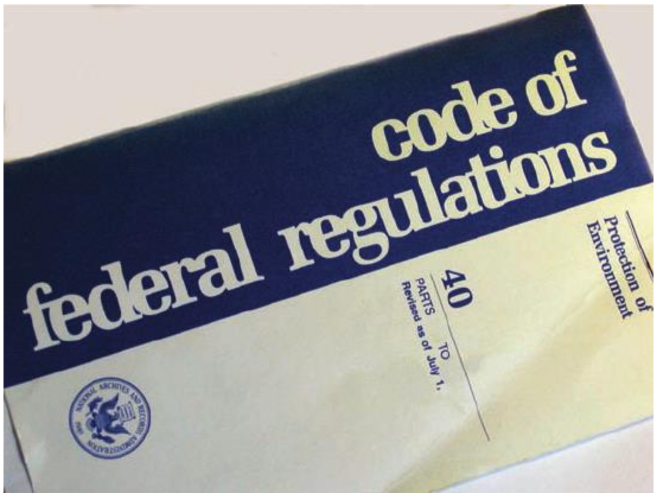
Collection systems need regular improvements for the reasons listed in Table 1.

Table 1: Reasons for Collection System Improvements

Reason	Description	Example
Develop-ment	Accommodate collection system expansion for community growth or a new large user. Developers may be responsible for funding or constructing the sewer upgrades.	 Source: public domain

Hydraulics	Correct hydraulic restrictions and thereby prevent backups and overflows.	 Source: commons.wikimedia.org/wiki/File:Sewer_overflowing_in_street_(outskirts_of_Johannesburg)_(2946285671).jpg, SuSanA Secretariat, CC-BY-2.0
Structural Failures	Prevent or repair structural failures such as breaks or collapses of pipes, wet wells, manholes, etc. Review historical data to identify force mains with frequent leaks and breaks. Add likelihood of failure (LOF) to consequence of failure (COF) for risk scoring.	 Source: public domain

I&I	Reduce inflow and infiltration (I&I) which increases over time. Flow monitoring and closed-circuit television (CCTV) inspection can identify pipes with high I&I flows, such as from root intrusion.	 Source: public domain
Age	Replace aged items and older materials to reduce the risk of failures. Lifespan (yrs) of pipes: Cast iron, 60 Concrete, 50 Ductile iron, 60 Galv. Steel, 40 HDPE, 80 PVC, 70.	 Source: https://commons.wikimedia.org/wiki/File:Belgick%C3%A1_(Praha),_rekonstrukce_(009).jpg, Juandev, CC-BY-SA-3.0

Regulations	Compliance with new federal or state regulations.	 Source: public domain
Funding	Utilize available federal or state funding.	 Source: public domain
Road Projects	Sewer improvements done in conjunction with road improvements (or other projects), thereby saving pavement restoration costs.	 Source: https://commons.wikimedia.org/wiki/File:Kitchener_downtown_cycling_grid,_Joseph_and_Gaukel_streets.jpg, Julius177, CC-BY-SA-4.0

Regulations and Standards

Clean Water Act

Regulations for industrial wastewater pretreatment started in 1972 as the Federal Water Pollution Control Act, which is now known as the Clean Water Act (CWA). The main goals of the CWA are to prevent the discharge of pollutants into the nation's navigable waters and to achieve fishable and swimmable water quality levels. The CWA established and directed the Environmental Protection Agency (EPA) to develop and implement regulations for limiting pollutants discharged to surface waters. With the CWA authority, the EPA promulgated Title 40 of the U.S. Code of Federal Regulations (40 CFR).

40 CFR

Title 40 CFR includes regulations for the management of sewer collection systems in the following Subchapters:

- 40 CFR 33 to 49: Subchapter B entitled "Grants and Other Federal Assistance"
- 40 CFR 100 to 149: Subchapter D entitled "Water Programs"

The most stringent requirements are in Subchapter B which are only required if the state or local agency is applying for a grant or other federal financial assistance. However, most collection systems receive federal assistance either directly through grant applications or indirectly through state funding that ultimately comes from federal funding. Therefore, collections systems are typically managed to comply with all the 40 CFR requirements.

In 40 CFR, the main themes related to collection system management are as follows:

- Sewer rehabilitation programs for the reduction of infiltration and inflow (I&I or I/I),
- Reduction of combined sewer overflows,
- Cross-connection control to protect drinking water systems from microbial contamination,
- Separation of storm sewer systems from domestic sewer systems, and
- Proper planning, operations, and maintenance of collection systems.

NPDES Permits

As detailed in 40 CFR 122, the EPA has the legal authority to manage the National Pollutant Discharge Elimination System (NPDES) Program for regulating direct discharges to surface waters. Either the EPA region or an authorized state environmental agency will issue the NDPES permit. NPDES permits include conditions for collection system management. These permit conditions are based on general regulations such as 40 CFR 122.41(e):

> *"The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with the conditions of this permit."*

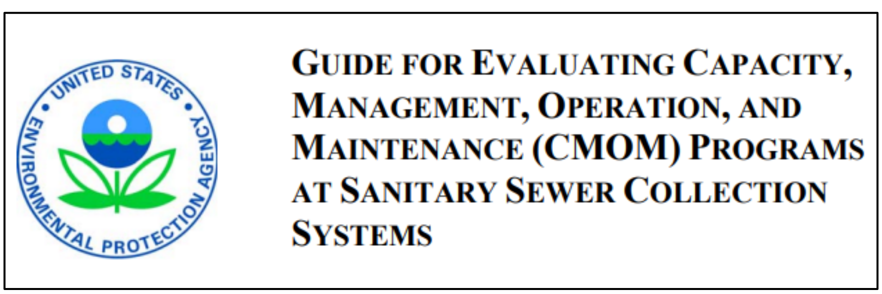
Permit violations can result in fines, compensation to residents and businesses, environmental restoration, and requirements to implement programs prevent recurring violations.

Compliance Monitoring

The EPA and authorized states have the authority to inspect and audit collection systems for compliance with NPDES permit conditions. Guidance for conducting compliance reviews is provided in the 2017 EPA guidance document entitled "NPDES Compliance Inspection Manual".

EPA CMOM

In 2005, the EPA issued a 126 page guidance document entitled "Guide for Evaluating Capacity, Management, Operations and Maintenance (CMOM) Programs for Sanitary Sewer Collection Systems", as shown in Figure 4.


UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

GUIDE FOR EVALUATING CAPACITY, MANAGEMENT, OPERATION, AND MAINTENANCE (CMOM) PROGRAMS AT SANITARY SEWER COLLECTION SYSTEMS

Figure 4: Cover page title for the CMOM EPA guidance document.
Source: Public Domain

In this document, the EPA defines a “CMOM Program” for managing a collection system. CMOM program practices are as follows:

- Designing and constructing for operation and maintenance (O&M)
- Knowing what comprises the system (inventory and physical attributes)
- Knowing where the system is (maps and location)
- Knowing the condition of the system (assessment)
- Planning and scheduling work based on condition and performance
- Repairing, replacing, and rehabilitating system components based on condition and performance
- Managing timely, relevant information to establish and prioritize appropriate CMOM activities
- Training of personnel

The four key elements of a CMOM program are as follows:

1. Collection System Management
2. Collection System Operation
3. Collection System Maintenance
4. Collection System Capacity Evaluation

Capital Improvement Program (CIP) management involves each the four elements.

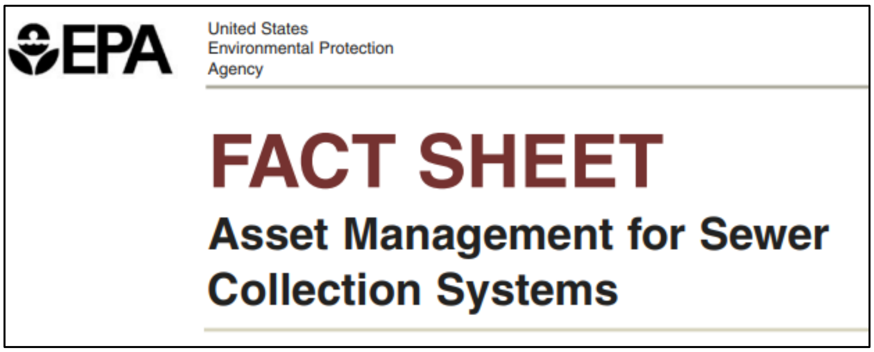
A checklist is provided in the EPA document for evaluating the completeness of a CMOM program. The checklist is a list of questions that require responses and documentation. A few of the relevant questions are as follows:

- Does the owner or operator have a CIP that provides for system repair/replacement on a prioritized basis?
- What is the collection system’s average annual CIP budget?
- What percentage of the maintenance budget is allotted to the following:
  - Predictive maintenance (tracking design, life span, and scheduled parts replacement),
  - Preventative maintenance (identifying and fixing system weakness which, if left unaddressed, could lead to overflows),
  - Corrective maintenance (fixing system components that are functioning but not at 100% capacity/efficiency),
  - Emergency maintenance (reactive maintenance, overflows, equipment breakdowns).

- Does the collection system experience problems related to I/I? How do these problems manifest themselves? (Manhole overflows, basement flooding, structure, SSOs)
- How does the owner or operator prioritize investigation, repairs and rehabilitation related to I/I?
- What methods are considered to remedy hydraulic deficiencies?
- Does the Continuing Sewer Assessment Plan include a schedule for investigative activities?
- Is the plan regularly updated?
- What procedures are used in determining whether the capacity of existing gravity sewer system, pump stations and force mains are adequate for new connections?
- Is any metering of flow performed prior to allowing new connections?
- Is there a hydraulic model of the system used to predict the effects of new connections?
- Is there any certification as to the adequacy of the sewer system to carry additional flow from new connections required?

EPA Asset Management

In 2002, the EPA issued a 16 page fact sheet entitled "Asset Management for Sewer Collection Systems", as shown in Figure 5.


EPA
United States
Environmental Protection
Agency

FACT SHEET
Asset Management for Sewer
Collection Systems

Figure 5: Cover page title for the Asset Management EPA fact sheet.
Source: Public Domain

In this document, the EPA provides general principles for managing collection systems. The term "asset management" is defined as managing infrastructure capital assets to minimize the total cost of owning and operating them, while delivering the service levels that customers desire. It is successfully practiced in collection systems to improve operational, environmental, and financial performance.

The Fact Sheet explains the need for collection system rehabilitation based on the average age of sewers across the United States. It explains how preventative (or proactive) improvements cost less than emergency (or reactive) repairs up to an optimal ratio. A goal of asset management is to perform just enough proactive improvements to stay in the optimal ratio range.

State Requirements

Each state has administrative codes with more detailed requirements, including collection system design and management policies. These codes vary greatly by state. Many states require risk assessments be performed for critical infrastructure, including wastewater systems. Risk assessments are a part of CIP management.

Capital Improvement Planning

Most owners of collection systems have a capital improvement program (CIP) as part of the overall asset management. Without asset management, the collection system would run until major failures occur resulting in permit violations, public discord, and costly emergency repairs. With asset management, regular work is done on the collection system and major failures are minimized, as shown in Figure 6.

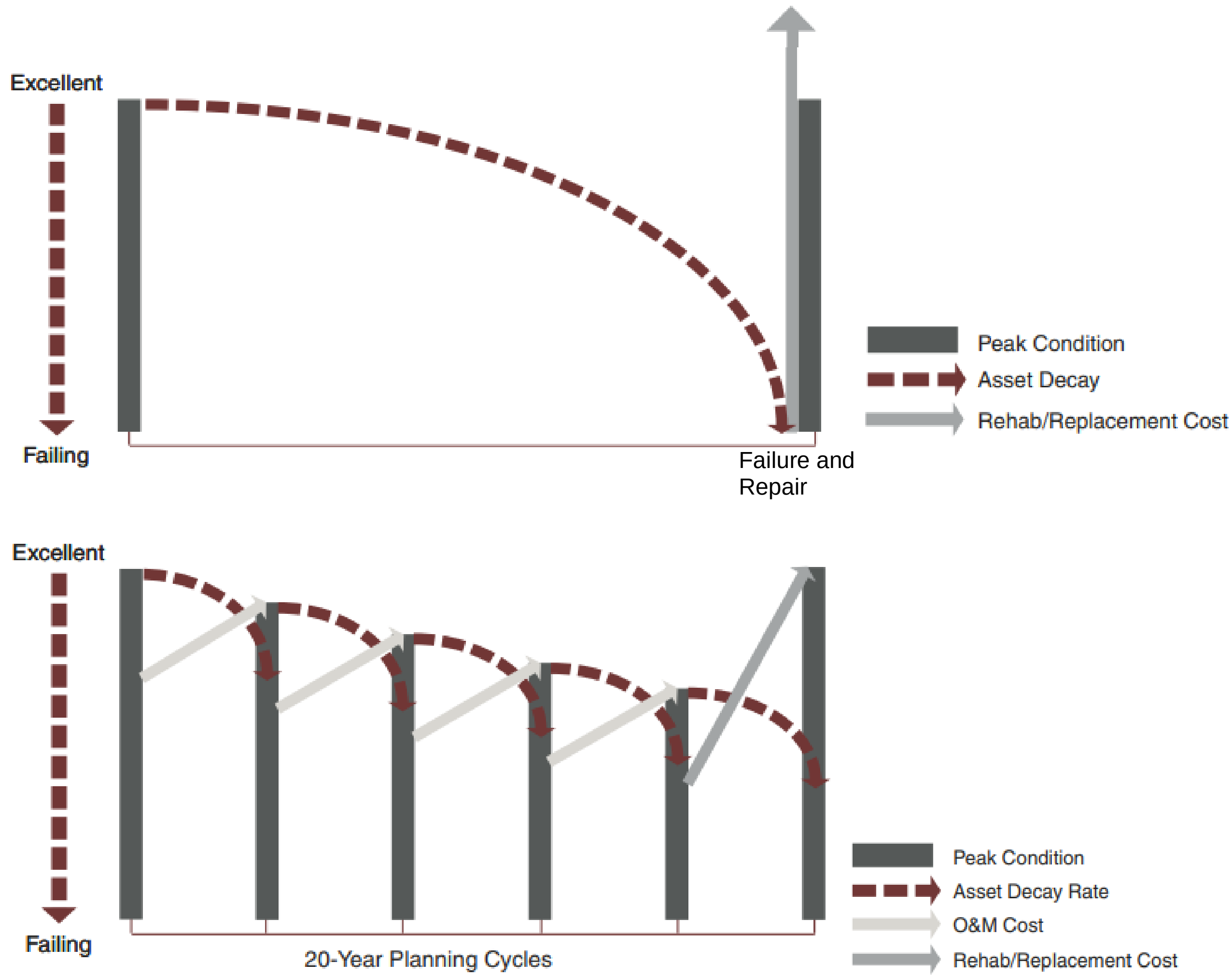


Figure 6: Top: Run-to-Failure Management Model. Once a failure occurs, that part of the system is quickly replaced at a premium cost. Bottom: Asset Management Model. The collection system is regularly maintained with an annual O&M budget (O&M Cost arrows). The final "Rehab/Replacement Cost" arrow on the right represents the CIP project cost to rehabilitate or replace a prioritized area of the collections system.

Source: www.epa.gov/sites/default/files/2015-10/documents/assetmanagement.pdf, public domain

Asset management often includes the sewer collection system, wastewater treatment facilities, water distribution system, and water treatment facilities. Key elements of asset management are as followings, with the items in bold directly related to CIP management:

- Performance goals
- Information management
- Asset identification and valuation
- **Failure impact evaluation and risk management**
- **Condition assessment**
- **Capacity assessment and hydraulic modeling**
- **Rehabilitation and replacement planning (master planning)**
- Maintenance analysis and planning
- Financial management
- Continuous improvement and auditing

The following are key documents to maintain for CIP management:

- Sewer use ordinance,
- Management policies and procedures,
- CIP reports, tables, and schedules
- Financial report with annual CIP budget,
- Past projects database,
- Master Plan for the collection system,
- Maps or geographic information system (GIS) of collection system including sewers, manholes, pump stations, and force mains (see Figure 7),
- Hydraulic model (see Figure 8),
- Performance measures for inspections, cleaning, repair, and rehabilitation,
- Flow monitoring records,
- Records of breaks, leaks, overflows, and user complaints, and
- As-built plans / record drawings.

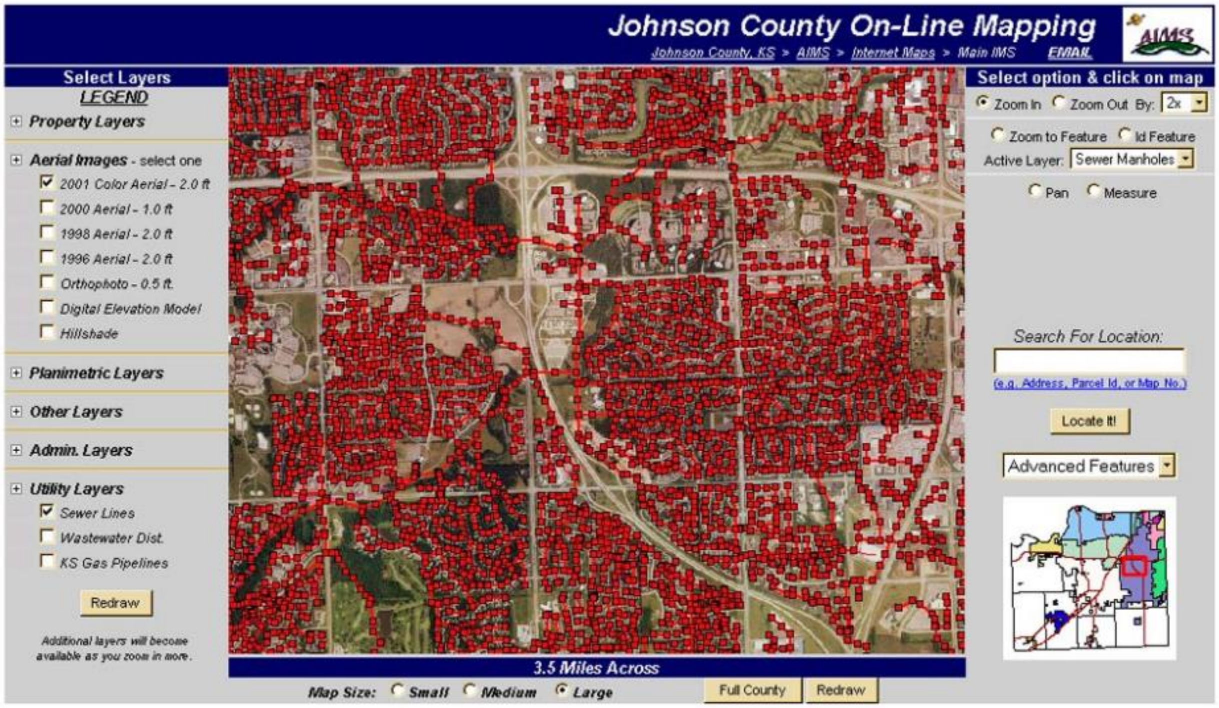


Figure 7: Example of a geographic information system (GIS) with sewers as red lines and manholes as red dots.
Source: www.epa.gov/sites/default/files/2015-10/documents/assetmanagement.pdf, public domain

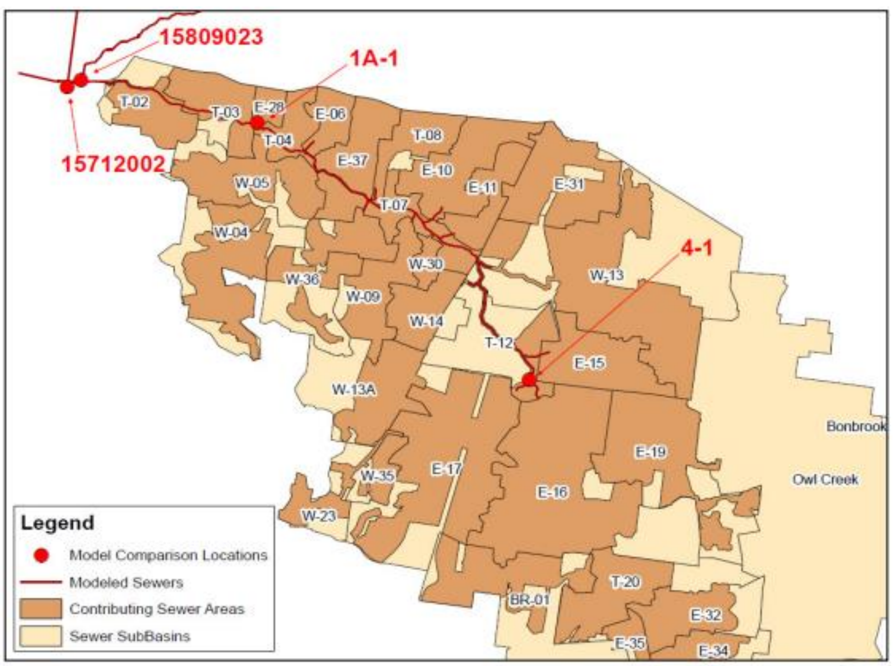


Figure 8: Example of a hydraulic model for the interceptor sewers in red.
Source: www.brentwoodtn.gov/Home/ShowDocument?id=3697, public domain

There are several different CIP organizational structures, with just a few depicted in Figure 9. Often engineering consultants will perform CIP work such as maintaining the hydraulic model, creating a master plan with recommended improvements, and designing CIP projects as engineer-of-record. Sometimes a separate asset management company will operate and maintain the collection system, including performing the CIP projects with or without consultants.

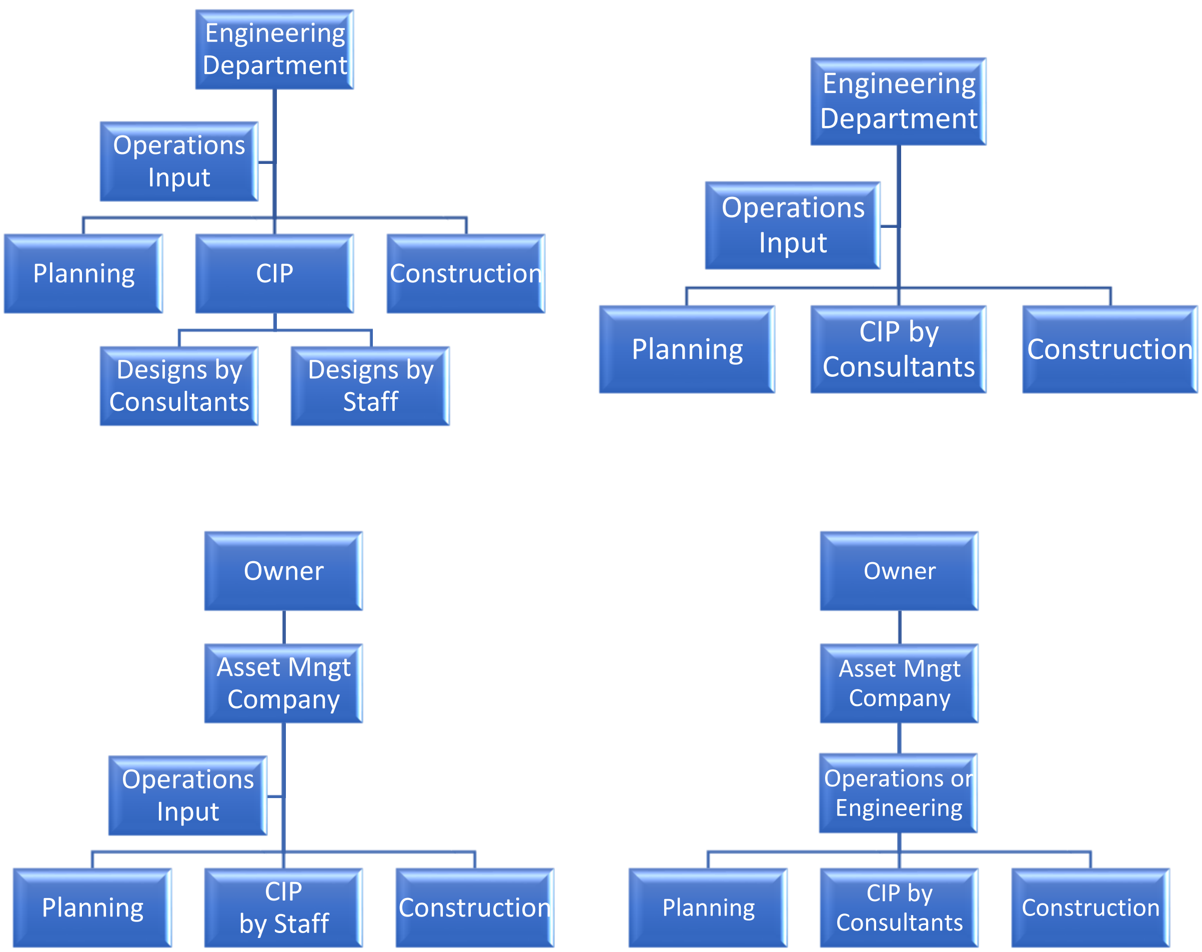


Figure 9: Four different possible organizational structures with CIP projects.

Source: Author

Long-Term Planning

The goal of infrastructure replacement planning is to schedule CIP projects such that the cost of replacement (or rehabilitation) is balanced against the accelerating cost to maintain the assets, while avoiding unacceptable declines in levels of service. See Figure 10 for a graphical depiction of balancing CIP project costs and maintenance and repair costs.

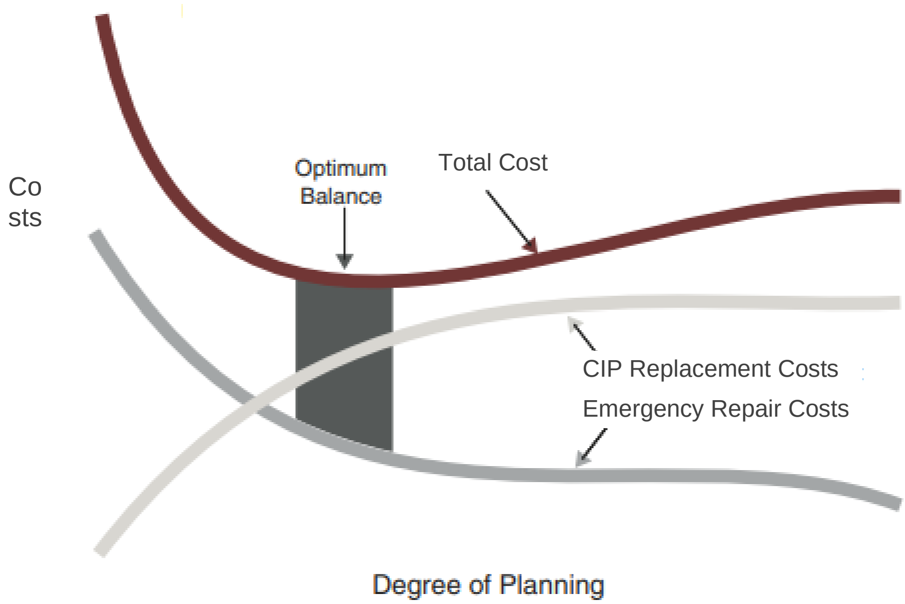


Figure 10: CIP planning chart showing the sum of emergency repair costs and CIP replacement costs based on the degree of planning. There is an optimum balance where just enough planning and CIP projects are done so the total cost is minimized.

Source: www.epa.gov/sites/default/files/2015-10/documents/assetmanagement.pdf, modified, public domain

Estimating the cost of CIP replacement projects is relatively straight forward. However, estimating the emergency repair costs is more difficult as it involves predicting the likelihood of failure of assets in the collection system such as sewers, lift stations, and force mains. To help in this regard, see Figure 11 for a graphical depiction of sewer deterioration over time which suggest replacement at 80 percent of useful life. Although that is a useful rule-of-thumb, it is best to perform regular condition assessments to estimate the useful life remaining, likelihood of failure (LOF), and consequence of failure (COF) of all significant assets in the collection system. Figure 12 shows the results of a useful life remaining assessment.

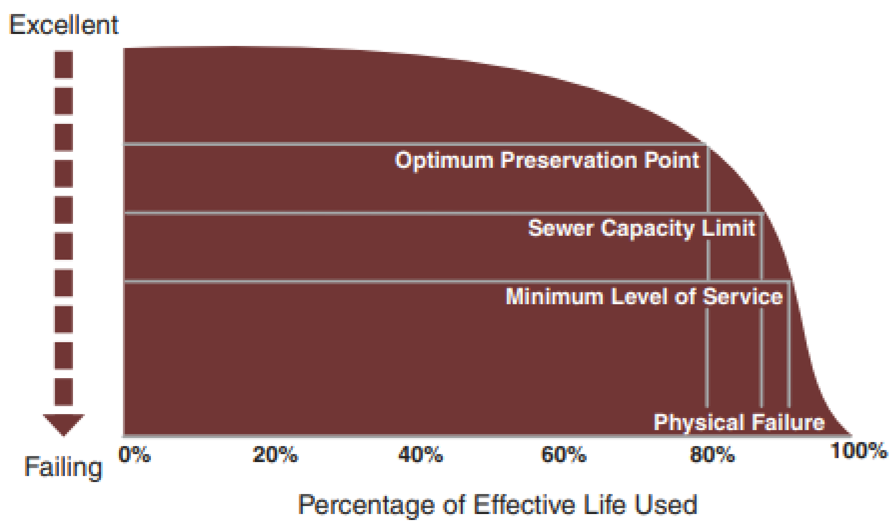


Figure 11: EPA sewer replacement planning chart indicating that CIP projects should aim to replace or rehabilitate sewers at 80 percent of their useful life.

Source: www.epa.gov/sites/default/files/2015-10/documents/assetmanagement.pdf, public domain

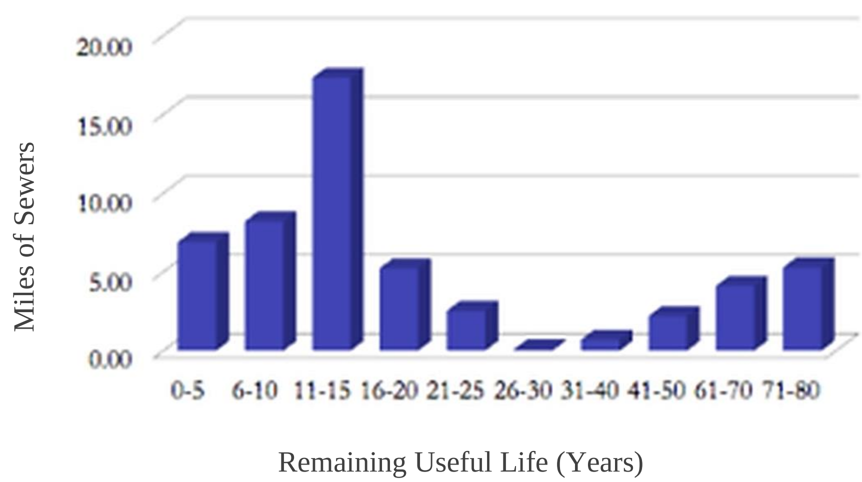


Figure 12: Sewer system age chart showing most of the pipes will reach the expected end of useful life within the next 15 years.

Source: www.eastgr.org/221/Public-Works

Based on the age of the sewers, it is common to select an annual target for percent rehabilitation (or replacement) of gravity sewer pipes. For example, a target rehabilitation of **4% per year** would rehabilitate all sewers in approximately 25 years.

Master Planning

A collection system master plan should be created and updated regularly to help guide the long term planning of CIP projects. The purpose is to identify improvements that will address existing deficiencies and meet projected needs throughout the service area for years to come. A master plan report commonly includes the following topics:

- Service Area Boundary and Zones
- Collection System Overview
- Growth Projections
- Hydraulic Modeling Results
- Condition Assessment Results
- I&I Reduction Plan
- Recommended Improvements
- Prioritization of Improvements
- Recommended Additional Studies

Figure 13: Example of a cover page for a Master Plan Report.

Source: www.fayetteville-ar.gov/DocumentCenter/View/17526/2014-Wastewater-Collection-System-Master-Plan-Update, public d.

Project Selection

CIP program management involves the regular selection of improvement projects to proceed with design or construction. The selection process typically involves the following steps:

1. Gain operations and maintenance ideas and “wish lists”
2. Review latest Master Plan for recommended improvements
3. Review recent condition assessments, I&I assessments, hydraulic model results, risk rankings, leak, and break histories, planned road projects, planned developments, and funding opportunities (may be accounted for in master plan)
4. Group potential projects by Service Areas or Zones
5. Estimate the cost for each potential project
6. Create a table of potential projects and motivations (see Table 2 and free software with this course)
7. Sum the total cost and cost for each budget category
8. Compare costs to budgets
9. Sum the number of motivations for each potential project and prioritize
10. Decide on projects to proceed based on priority and budget
11. Schedule out projects based on resources and budgets

Here is an example of an approved annual CIP budget for a collection system, broken into categories or packages:

- $2M – Zone 1
- $3M – Zone 2
- $3M – Zone 3
- $4M – Zone 4
- $2M – I&I Reduction
- $1M – Lift Station Rehabilitation
- $2M – Regional Pump Station Rehabilitation
- $1M – Multi-Zone and Other Improvements
- **$18M – Total Budget**

Potential projects that cost more than the package budget have the following options:

- Split into multiple smaller projects and only the first project advanced
- Budget can be passed to the next year and combined with that year’s budget
- Budget can be used from another package with justification and approval
- Budget can be increased with justification and approval

Table 2: Example Project Motivation Table

Zone	Proj. No.	Potential Project Name	Cost Estimate ($M)	New Develop-ment	Hydraulics Correction	High Risk Ranking	I&I Reduction	>80% of Useful Life	>100% of Useful Life	Leak & Break History	Qualifies Funding	Road Project	Other	No. of Motivations
1	1a	North Shore Dr Sewer Lining	$1.0				X				X			2
	1b	Peterson Ave Road Widening	$2.4									X		1
	1c	**Grande Isles New Sewer System**	**$1.5**	**X**								**X**	**City Council Agenda Item**	**3**
2	2a	Highway 66 Redundant Interceptor	$6.2		X									1
	2b	High View Development New Sewers & Lift Station	$4.1	X								X		2
3	3a	Lift Station No. 21 Rehabilitation	$0.5					X						1
	3b	**Jupiter Dr. Force Main Replacement**	**$5.2**			**X**		**X**		**X**				**3**
4	4a	Regional Pump Station Expansion	$8.0	X										1
	4b	**Lift Station No. 12 Rehabilitation**	**$0.6**			**X**		**X**	**X**					**3**
	4c	Cottage River HDD Crossing	$3.6		X								Riverbank Restoration	2
	4d	**N. 68th St Sewer Lining**	**$1.5**				**X**	**X**	**X**		**X**			**4**
Multi	**M1**	**Aged Manhole Lining**	**$0.8**				**X**	**X**			**X**			**3**
	M2	Aerial Crossing Repairs	$4.1			X		X						2
	M3	Air Relief Valve Replacements	$0.6					X		X				2
		Total	$40.1	$13.6	$9.8	$9.9	$3.3	$13.3	$2.1	$5.8	$3.3	$8.0	$5.1M	-

Example Problem 1

Engineer Eric helped prepare Table 2 and now needs help select which project(s) to proceed for I&I reduction, while staying within the budget of $2M for that category. Help Eric list the options and provide a recommendation.

Solution

The three I&I Reduction problems are as follows:

- $1.0 - 1a, North Shore Dr Sewer Lining, 2 motivations
- $1.5 - 4d, N. 68th St Sewer Lining, 4 motivations
- $0.8 - M1, Aged Manhole Lining, 3 motivations

All projects cannot be done within budget. The following are options for proceeding:

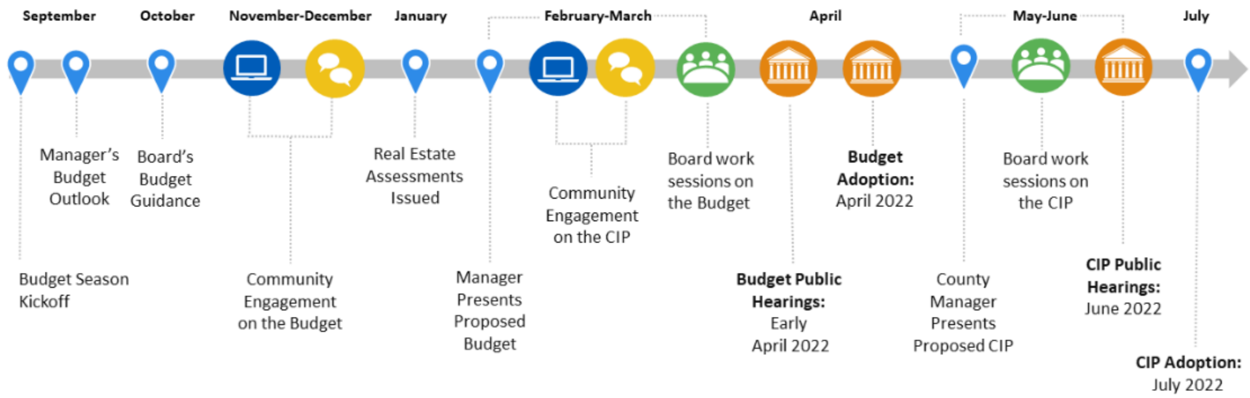
1. Proceed with project 4d since it has the highest priority (number of motivations).
2. Proceed with projects 1a and M1 so that two projects can proceed, and more budget ($1.8M) is utilized.
3. Proceed with project 4d, break up project M1 into a $0.5M project (M1a) and $0.3M project (M1b), and proceed with project M1a. A total of $1.9M budget is utilized.

Recommendation:

- Proceed with project 4d and M1a so that the highest priority project is proceeded and the most budget is utilized.

Budget Planning

Annual CIP budgets are typically approved through a lengthy process like this example:



Projects typically last 1 to 5 years, from design to startup, so the project cost does not occur in a single year. Thus, a long term budget is also required, with projected annual spending over the upcoming 4, 5 or 6 years. This is often called a CIP Program Budget. The CIP Program Budget may require annual approval in addition to an annual CIP Spending Budget. Ideally, the next year's Spending Budget would match the projection in the previous year's CIP Program Budget. To avoid major differences, careful scheduling and detailed budget projections for each project are required.

The following steps can be used create a basic CIP Program Budget:

1. Create a schedule for each project. Projects are often broken down into the following phases:
    a. Study or Conceptual Design
    b. Final Design
    c. Bidding/Procurement
    d. Construction
2. Develop a construction cost estimate for each project. Assign a cost to each phase. Often the design cost is estimated at 10% of the construction cost.
3. Create a table or schedule of all projects.
4. Enter the project costs for each design phase and divide the costs by year and/or quarter.

See Table 3 for an example of a table style CIP budget and schedule, which is also provided in excel format as free software with this course.

Table 3: Example CIP Budget Schedule
(Phase coloring: study, design, bid, construction) (All costs in $M)

Zone	Proj. No.	Potential Project Name	Cost Estimate ($M)	2023				2024				2025			
				Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	1a	North Shore Dr Sewer Lining	$1.0	-	-	$0.05	$0.05	$0	$0	$0.2	$0.2	$0.3	$0.2	-	-
	1b	Peterson Ave Road Widening	$2.4	$0.1	$0.1	$0.1	$0	$0	$0.3	$0.4	$0.6	$0.6	$0.2	-	-
	1c	Grande Isles New Sewer System	$1.5	$0.05	$0.05	$0.1	$0	$0	$0.2	$0.2	$0.4	$0.4	$0.1	-	-
2	2a	Highway 66 Redundant Interceptor	$6.2	-	-	$0.2	$0.3	$0.2	$0	$0	$0.8	$1.2	$1.4	$1.6	$0.5
	2b	High View Development New Sewers & Lift Station	$4.1	-	-	$0.1	$0.2	$0.2	$0	$0	$0.6	$0.8	$1.0	$1.0	$0.2
3	3a	Lift Station No. 21 Rehabilitation	$0.5	-	-	-	$0.03	$0.02	$0	$0	$0.05	$0.1	$0.2	$0.1	-
	3b	Jupiter Dr. Force Main Replacement	$5.2	-	$0.1	$0.2	$0.2	$0	$0	$0.6	$1.0	$1.3	$1.4	$0.4	-
4	4a	Regional Pump Station Expansion	$8.0	$0.1	$0.1	$0.2	$0.4	$0.3	$0	$0	$1.2	$1.6	$2.0	$1.8	$0.3
	4b	Lift Station No. 12 Rehabilitation	$0.6	-	-	-	$0.03	$0.02	$0	$0	$0.05	$0.2	$0.2	$0.1	-
	4c	Cottage River HDD Crossing	$3.6	-	$0.1	$0.1	$0.1	$0.1	$0	$0	$0.5	$0.7	$0.9	$0.9	$0.2
	4d	N. 68th St Sewer Lining	$1.5	$0.05	$0.05	$0.1	$0	$0	$0.2	$0.2	$0.4	$0.4	$0.1	-	-
Multi	M1	Aged Manhole Lining	$0.8	$0.05	$0.05	$0	$0	$0.1	$0.2	$0.3	$0.1	-	-	-	-
	M2	Aerial Crossing Repairs	$4.1	$0.1	$0.2	$0.2	$0	$0	$0.6	$0.8	$1.0	$1.0	$0.2	-	-
	M3	Air Relief Valve Replacements	$0.6	-	-	$0.02	$0.02	$0	$0	$0.06	$0.2	$0.2	$0.1	-	-
Quarter Total			$40.1	$0.45	$0.75	$1.37	$1.33	$0.94	$1.50	$2.76	$7.10	$8.80	$8.00	$5.90	$1.20
Annual Total				$3.90				$12.30				$23.90			

Example Problem 2

A County Utility Department has created the CIP project budget schedule in Table 3. However, the approved Budget Program does not allow spending of more than $8.0 million in any quarter. Which project schedules be shifted to meet this requirement, assuming all projects must start between Q1 and Q4 of 2023.

Solution

The only quarter with spending in excess of $8 M is Q1 of 2025 with $8.8 M. Although several projects could be shifted to reduce the total, the following is the only project that on its own can reduce the total by $0.8 M or more:

- Proj. No. 4a "Regional Pump Station Expansion", change to start on Q3 of 2023 instead of Q1 of 2023. The Q1 of 2025 total budget drops by $1.6M.

Infrastructure Data Management

Knowing details of the collection system is critical for identifying and prioritizing potential projects. This means the data needs to be gathered, saved, organized, and utilized regularly. Figure 14 shows some of the main data structures.

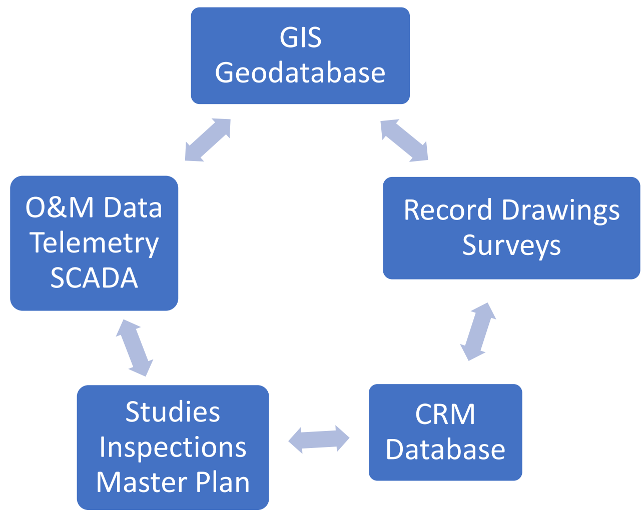


Figure 14: Basic data structures that help in CIP management.
CRM stands for customer relationship management.

Source: Author

GIS

GIS (Geographic Information System) has the power to make information easily accessible. GIS can draw information from all the data structures listed in Figure 14, and more. GIS is a computer software system that analyzes and displays information with geographic references.

For example, collection system features can be on layers in GIS, including pipes, manholes, lift stations, etc., as shown in Figure 15. If you click on a particular manhole there will be information such as invert elevation and age. Also, links can be added to relevant documents such as record drawings, photographs, and maintenance records.

GIS can graphically show information such as break history on a map with areas of high breaks shaded. Also, pipe ages can be shown in different colors. See Figure 16 for an example. This approach is commonly called a "hot spot" map.

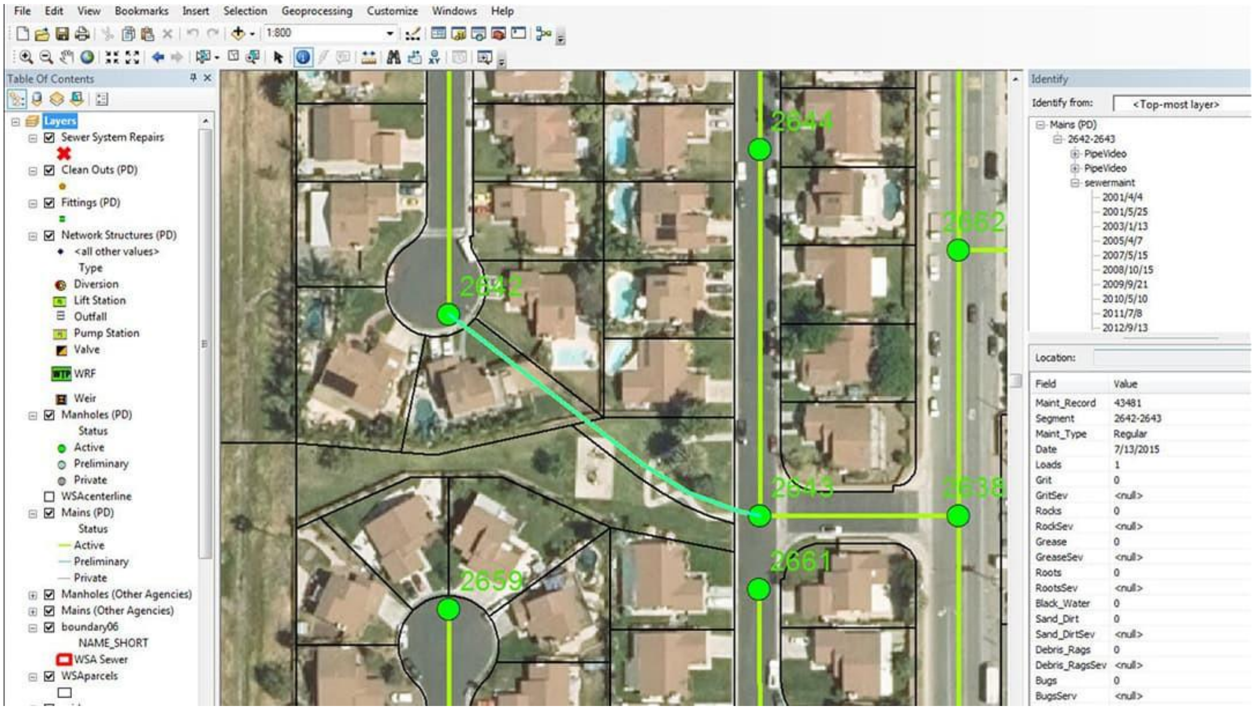


Figure 15: Example of a GIS map with sewer features in green.

Source: https://www.padredam.org (public domain)

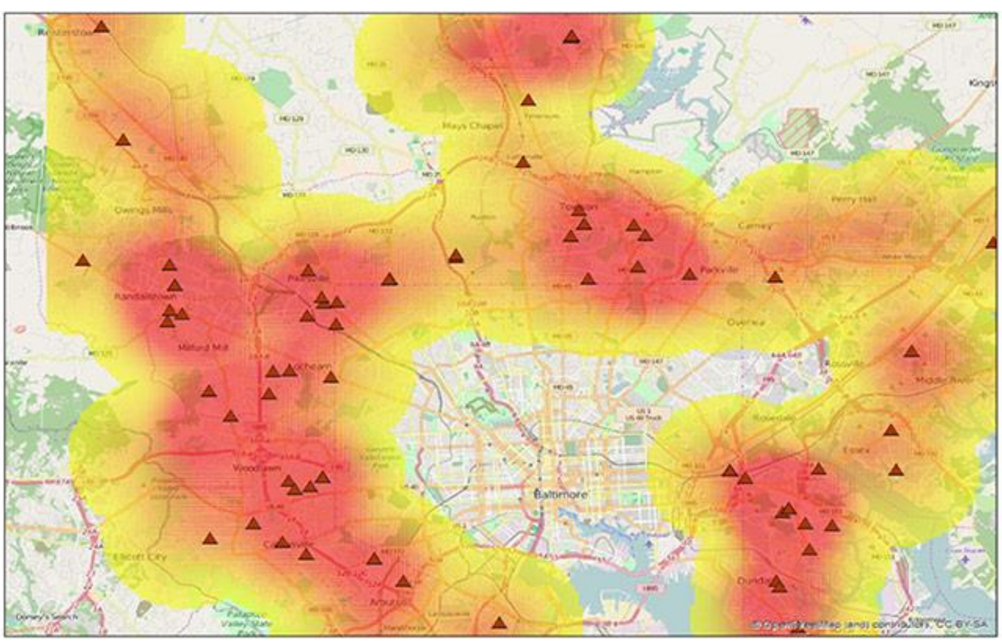


Figure 16: GIS map with overflow events as triangles and density of overflows shaded.

Source: www.baltimorecountymd.gov/departments/information-technology/gis/ (public domain)

Hydraulic Modeling

A hydraulic model is a useful tool for assessing the hydraulics of a collection system and thereby identifying CIP improvement projects. Hydraulic models commonly assess the following:

- Capacity remaining for sewers, pump stations, and force mains
- Pipes and manholes at risk of backup or overflow (see Figure 17)
- Sewers with low or high velocities
- Force mains with high pressure and low or high velocity
- Force main pressures for tie-in connections
- Points of failure with no redundancy
- Hydraulic restrictions or bottlenecks
- Infiltration and inflow (I&I) flowrate estimate and impact
- Optimize pipes and pump stations for proposed improvements
- Ideal locations and capacities for inter-connects to other systems

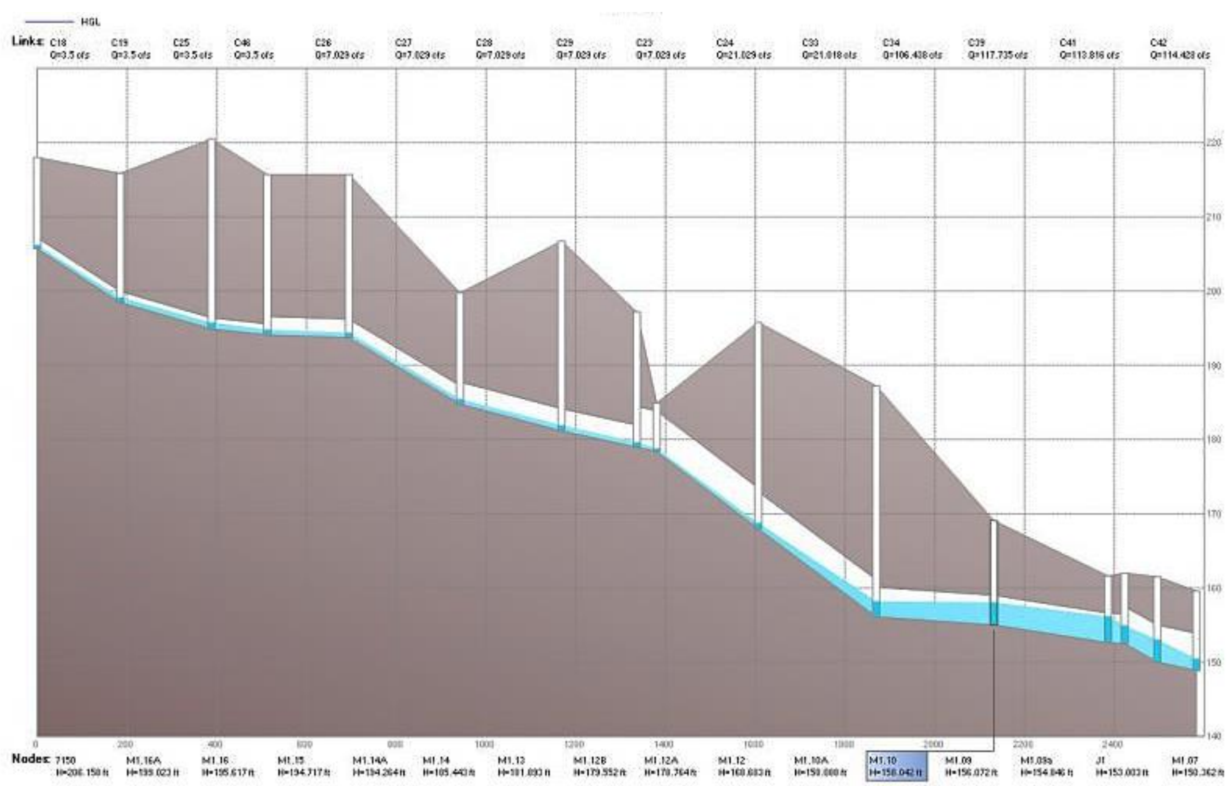


Figure 17: Sewer model results in profile view during a peak flow event.
Source: www.burlingtonvt.gov/stormwater/HandH_Model_Update (public domain)

<u>Steady-state versus Dynamic</u>
There are two main approaches to running a model simulation:

1. Steady-state modeling:
    a. Assumes total flow coming in equals total flow going out. There is no accumulation or overflow of sewage. Steady-state means the variables are constant with respect to time.
    b. For example, a model simulation with a constant output that equals the average flow to the WWTP and user input flows that add to that output.
    c. Advantages: low cost, simple, easy to calibrate, and reliable for average flows during dry weather.
2. Dynamic modeling:
    a. Allows for temporary buildup in the system when inputs do not equal outputs. The simulation can determine how long it takes to reach a stable condition and any backups or overflows in the meantime.
    b. For example, a model simulation with user input flows based on average meter readings plus I&I input flows that differ in each zone according to I&I measurements during a 10-years storm event. The output flow varies until the system reaches an equilibrium.
    c. Advantages: simulates storm scenarios, can project future events, helps identify I&I reduction improvements, simulates overflow events, and reliable for wet weather flows which often controls during design.

<u>Flow Inputs</u>
A dynamic model typically has the following flow inputs:

- User flows from residential, commercial, and industrial connections. Residential and commercial flows can be estimated based on water meter readings with a percent loss, such as 5%. Industrial connections typically have meters at the connection.
- Dry weather infiltration from groundwater that enters the collection system. This can be estimated by reviewing diurnal lift station flows or taking field flow readings during times when user flows are near zero, such as from 2 am to 4 am.
- Wet weather I&I from stormwater that inflows and infiltrates into the collection system. This can be estimated by reviewing lift station flows or taking field flow readings during wet weather events and interpolating to nominal storm events such as a 10-year or 20-year storm.

Calibration and Validation

Calibration is the process of modifying the model so that the results more closely align with actual flow readings. Validation is comparing the model results to actual flow readings and assigning an accuracy grade, such as 15% accuracy. Figure 18 shows a comparison of the model results (red) with actual field readings (blue). The difference is 6% on average, which represents a 6% accuracy for wet weather depth. Other variables such as flow rate would have different accuracies. If the model accuracies are deemed too high, the model can be modified such as by increasing the I&I, and the simulation ran again, which is called calibration.

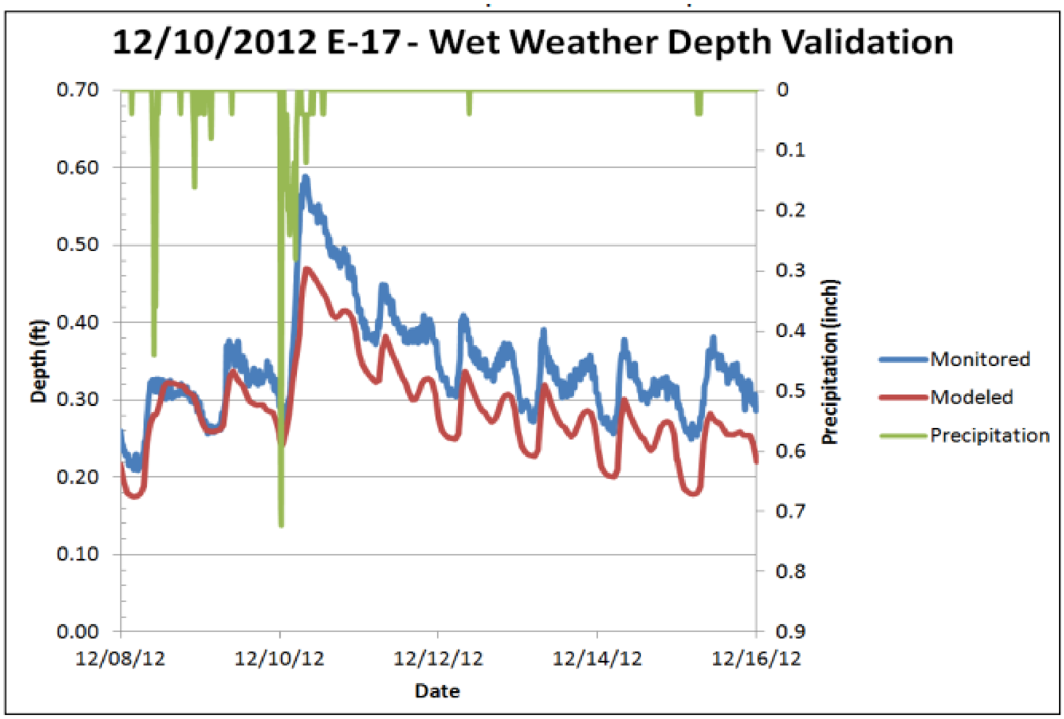


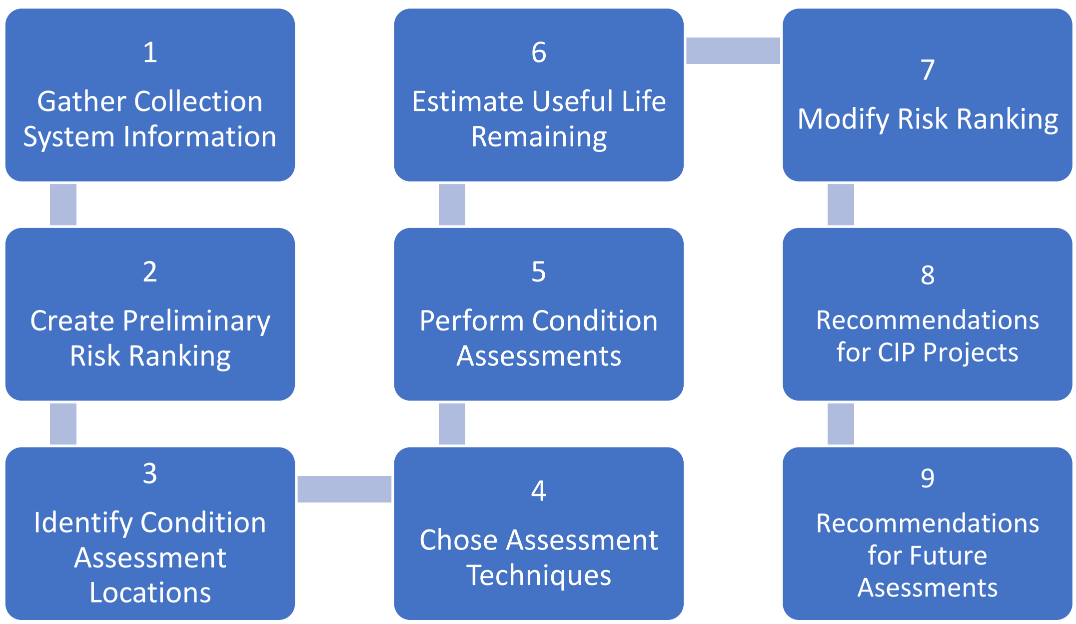
Figure 18: Example model results in red and field monitored readings (blue).

Source: www.brentwoodtn.gov/Home/ShowDocument?id=3697, public domain

Sewer Condition Assessment

Sewer condition assessments help make smart decisions for replacing or rehabilitating aged or failing components in a collection system. As a collection system ages, the benefit for regular condition assessments increases. The goal is not to inspect every single component, but to inspect a sufficient quantity to be representative of the areas of concern and thereby allow smarter decisions for rehabilitation planning.

The condition assessment process may involve these steps:



In Step 2, a consequence of failure (COF) value is assigned to each pipe segment. In Step 7, condition assessment results are used to assign a likelihood of failure (LOF) for each pipe segment.

For Step 4, there are many condition assessment techniques to choose from, as illustrated in Table 4.

Table 4: Condition Assessment Techniques

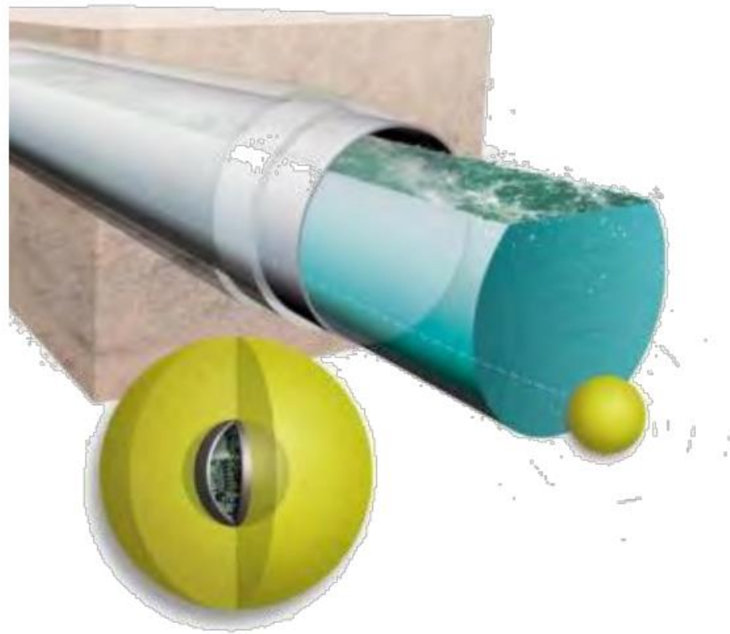
Component	Common Techniques
Laterals	○ Smoke testing, as shown:  Source: https://www.sumtersc.gov, public domain ○ CCTV, as shown:  Source: https://www.northbay.ca/services-payments/water-wastewater/services/camera-inspections/, public domain ○ Exterior inspection

Gravity Sewers & Interceptors	○ Smoke testing ○ CCTV ○ Exterior inspection, as shown:  Source: https://pipelinepds.com/residential-services/sewer-line-repairs, public domain ○ Acoustic impact echo, as shown: 

Force Mains (Exterior)	○ Soil corrosion analysis ○ Leak detection (various techniques) ○ CCTV ○ Exterior visual Inspection ○ Exterior coupon inspection, as shown:  ○ Exterior acoustic impact echo (for PCCP pipe) ○ Exterior electromagnetic scanning ○ Exterior ultrasonic scanning or spot checking, as shown:  ○ Exterior guided radar scanning ○ Exterior bracelet probe

<table>
<tr>
<td>Force Mains
(Internal)</td>
<td>

- Interior acoustic ball, as shown:



Source: https://your.kingcounty.gov/dnrp/library (public domain)

- Internal electromagnetic, as shown:

Source: www.denverwater.org/tap/diving-in-to-inspect-pipes-from-the-inside-out (p.d.)

- Internal magnetic flux
- Internal laser
- Internal ultrasonic pig

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Manholes and Vaults	○ Visual inspection, as shown:   Source: commons.wikimedia.org/wiki/File:Manhole_invert.jpg Pam Broviak, CC-BY-SA-2.0 ○ Half Cell Corrosion Mapping ○ Coupon inspection ○ Acoustic impact echo
Air Relief Valves (ARVs)	○ Visual Inspection, as shown:  ○ Valve manufacturer inspection and testing ○ Functional testing

<table>
<tr>
<td>Lift Stations &
Pump Stations</td>
<td>
○ Visual Inspection, as shown:

○ Half Cell Corrosion Mapping
○ Coupon inspection
○ Acoustic impact echo
○ Coating/lining thickness measurement, as shown:


○ Pump manufacturer inspection and testing
○ Functional testing
○ Pump performance testing
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Immediate Repairs
Some inspection results may require immediate action to avoid an imminent failure. See Figure 19 for an example of a section of pipe where the interior scanning suggested the wires were corroded and broken. The pipe section was exposed, and the results were confirmed. A replacement section and coupling were ordered, and the section of pipe replaced to avoid a catastrophic failure. A study was started by a consultant to develop a long term solution of rehabilitation or replacement of the pipe.

Figure 19: A section of prestressed concrete cylinder pipe (PCCP) with wire damage discovered by internal electromagnetic scanning.

Source: www.denverwater.org/tap/diving-in-to-inspect-pipes-from-the-inside-out (public domain)

Risk Ranking
For step 7, the assessment results are used to assign a likelihood of failure (LOF) for each pipe segment, often on a scale of 1 to 100. The LOF is added to the COF (consequence of failure) to get a total risk value for each pipe segment. The risk values are sorted by highest risk to help identify CIP project recommendations in Step 8. See Figure 20 for plot of COF versus LOF, also called a risk matrix.

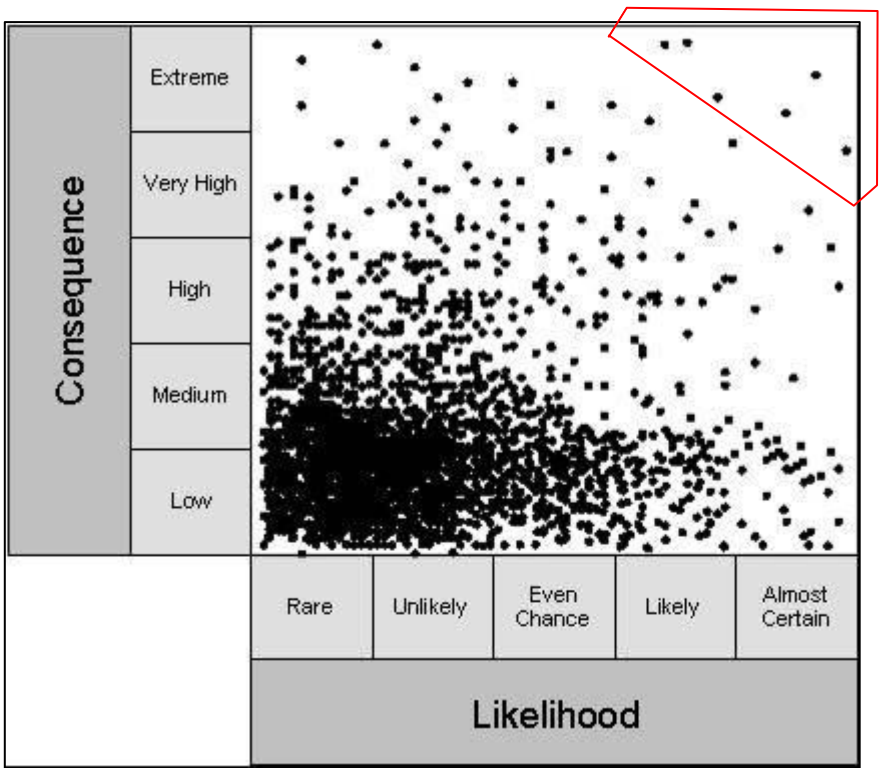

Figure 20: A risk matrix with each dot representing a pipe segment in a collection system. The dots in the red area in the upper right have the highest total risk.

Source: www.denverwater.org/tap/diving-in-to-inspect-pipes-from-the-inside-out (public domain)

Often the COF is considered of more importance than the LOF. In such cases, an importance factor (IF) is used when calculating the total risk, per this formula:

Total Risk = IF * COF + LOF

For example, an importance factor of 1.5 means the COF is one and a half times as important as the LOF.

Infiltration & Inflow Reduction

Every collection system has some amount of Infiltration and Inflow (I&I or I/I). Here are the common definitions of these terms:

- **Infiltration** is when groundwater seeps into sewers through holes, cracks, joints, taps, fittings, valves, etc. Infiltration is a nearly constant flow.
- **Inflow** is when stormwater flows into sewers through inappropriate connections such as roof drains, foundation drains, and cross-connections with storm sewers. Inflow also enters through holes in manhole covers, hatches, vents, and conduits. Inflow fluctuates from near zero during dry weather to high peak flows during wet weather.

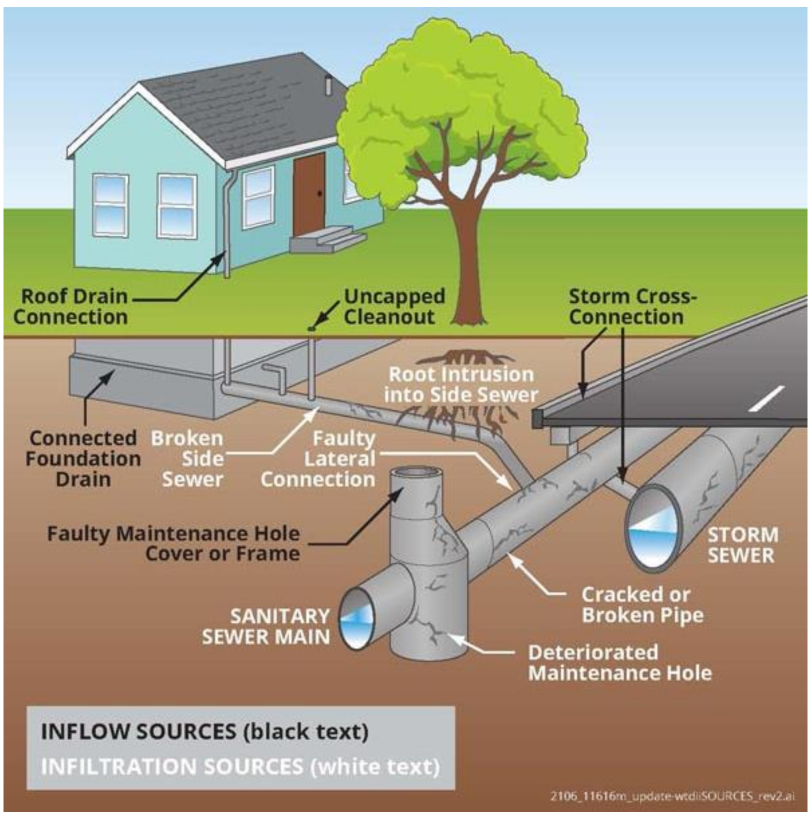

Figure 21: Common examples of Inflow (black) and infiltration (white).

Source: https://kingcounty.gov/services/environment/wastewater/ii/what.aspx

An effective way to control I&I is to form an I&I reduction program with an annual budget. The following are elements of an I&I program:

1. Perform a benchmarking assessment
    - For example, EPA recommendations (EPA 2014):
        - Inflow > 275 gpd/capita
        - Infiltration > 120 gpd/capita

2. Set a target for annual rehabilitation (linear feet or percent)
    - Percent example, 4% of total sewer length per year
        - Time to rehab all sewers = 100% / 4%/yr = 25 years
    - Linear feet example: 4% of 100,000 ft = 25,000 ft/yr

3. Set an annual budget
    - For example: 25,000 ft/yr x $200/ft = $5M

4. Field investigations such as:
    - Flow monitoring
    - CCTV
    - Smoke testing
    - Manhole inspections

5. Prioritize sewers or sewersheds
    - I&I rankings based on field investigations, age, material, etc.
    - Often an entire sewershed (a group of sewers flowing through a single path, see Figure 22) is given an I&I priority designation

6. Define rehabilitation projects
    - Often projects include rehabilitation of sewers in one or more sewersheds
    - Cured-in-Place-Pipe (CIPP) lining is the most common rehabilitation method for I&I reduction

7. Schedule projects based on annual budget
    - See the Table under the Section "Budget Planning"

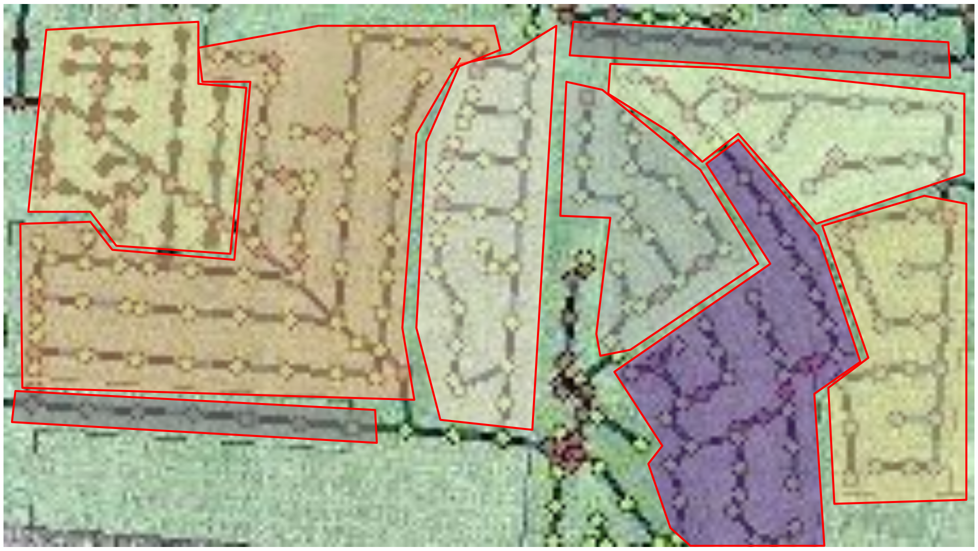

Figure 22: GIS map with sewersheds highlighted in red. When defining a sewershed, it is helpful to make the area as large as possible with the flow still going through a single path such as a manhole or lift station.

Source: Author

Example Problem 3

A field crew installed a temporary meter to measure the sewer flow rate for a sewershed with 300 residents. The data shows an average flow of 10,000 gpd during dry weather and 40,000 gpd for a storm event. Is this within EPA recommendations?

Solution

Since the additional flow is from a storm event, it is considered infiltration. The EPA recommendations are for the infiltration to be less than 120 gpd/capita. The infiltration per capita can be calculated as follows:

$$\text{Infiltration} = (Q_{wet} - Q_{dry}) / \text{Residents} = (40{,}000 - 10{,}000) / 300 = 100 \text{ gpd/capita}$$

The measured infiltration is less than 120 gpd/capita and is therefore within the EPA recommendations.

Sewer Rehabilitation

An engineering analysis should be done to determine the best method of rehabilitation for existing sewers. The following table provides typical rehabilitation techniques for gravity sewers. CIPP lining has proven very effective in extending the life of existing gravity sewers, and is often the assumed technique for planning purposes.

Table 5: Sewer Rehabilitation Techniques

Technique	Sewer Type	Diameter Range	Description & Example
Cementitious Coating	G, MH	> 30”	Shotcrete, gunite, or spin cast concrete sprayed on interior
Polymer Coating	G, FM, MH	> 6”	Spray on interior after pigging and flushing
Cured-in-place Pipe (CIPP)	G, L, FM, MH	> 4”	A liner with resin is inflated inside the pipe and heated to cure.
Thermo-formed Pipe	G, L, FM, MH	> 4”	“Fold and form” PVC or PE liner is pulled into the pipe and filled with steam.
Grout-in-place Pipe	G, L, FM, MH	> 4”	A liner with resin is inflated inside the pipe and heated to cure.
Joint Grouting	G, L, MH	> 4”	An inflatable packer is set at the joint, inflated, and grout is injected.
Sliplining	G, L, FM	> 4”	Pull a smaller pipe within the larger existing pipe and seal the annular space.
Pipe Bursting	G, L, FM	> 4”	A bursting tool and new pipe pulled through the existing pipe.
Spiral Wound Pipe	G, FM	> 6”	Continuous strips of PVC or HDPE are wound and overlapped and sealed.
Interior Sleeve Repair	G, FM	> 6”	A stainless sleeve with grout is guided to the damaged area and expanded using air. The grout expands and seals gaps.
Exterior Sleeve Repair	G, L, FM	All	Expose pipe at damaged area, clean the pipe surface, and install the sleeve.
Partial Replacement	G, L, FM	All	Isolate the section of pipe, cut, remove, and install new pipe with couplings.
Notes: 1) Abbreviations: Gravity Sewer (G), Lateral (L), Force Main (FM), Manhole (MH)			

Questions to explore when considering replacement or rehabilitation of a sewer:

- When was the asset installed?
- Is there a history of infiltration, inflow, leaks, breaks, or overflows?
- Has there been an inspection or condition assessment?
- Can the anticipated deterioration rate and eventual failure be predicted?
- If so, what is the estimated residual life until rehabilitation or replacement is necessary?
- Could best management practices and maintenance extend the time to failure?
- Can the asset be rehabilitated? How much would this extend the time to failure?
- What is the capital and life-cycle cost of replacement versus rehabilitation?
- Is the asset technically or commercially obsolete, or otherwise not needed?
- Is there an upcoming road project where replacement work can be combined?
- Are there planned improvements or developments in the area?
- How does this asset prioritize compared to other assets needing replacement?

Helpful References

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