A SunCam online continuing education course

Wastewater Treatment CIP Management

by

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Course Outline:

Wastewater Treatment Summary
Motivations for Improvements
Regulations and Standards
Improvement Planning Process:

1. Gather Information
2. Condition Assessment
3. Remaining Useful Life
4. Performance Assessment
5. Risk Assessment
6. Update Master Plan
7. Project Selection

Spending Projections
Helpful References
Examination

Wastewater Treatment Summary

The purpose of a wastewater treatment system is to reduce pollutants to acceptable levels prior to discharge. Wastewater treatment systems include a series of treatment processes such as equalization, screening, aeration, clarification, filtration, disinfection, and solids handling.

There are several different applications for wastewater treatment, including:

- Public wastewater treatment:
    - Receives wastewater from public collection system
    - Direct discharge to environment (lake, stream, deep well, etc.)
    - Reuse of treated wastewater (irrigation, non-potable supply, purple water, direct or indirect potable reuse, etc.)
- Industrial wastewater treatment:
    - Pretreatment and indirect discharge to a POTW (publicly owned treatment works)
    - Direct discharge to environment (lake, stream, deep well, etc.)
    - Reuse of treated wastewater (irrigation, non-potable supply, boiler or cooling tower make-up, etc.)
- Private residential wastewater systems:
    - Septic system, trickle filtration, drain field, etc.

This course will focus on public wastewater treatment systems, which can be found in the following locations:

- Municipalities (cities, towns, villages),
- Counties,
- Utility districts covering multiple municipalities and unincorporated areas, and
- Military bases.

Most applications directly discharge wastewater into the environment, which means the wastewater must be treated to remove pollutants to acceptable levels and monitored daily for compliance. Common treatment methods are summarized in Table 1.

Table 1: Wastewater Treatment Methods by Category			
Category	Treatment Method	Traditional Process	Main Configurations
Physical	Equalization	Primary	Aboveground, basin, wet well
	Screening	Primary	Fine, course, basket, mechanical
	Grit Removal	Primary	Vortex, hydrocyclone, chain & bucket, aeration
	Sedimentation	Primary	Circular or rectangular clarifiers
	Flotation	Primary, Secondary	Dissolved air (DAF), gravity
	Media Filtration	Primary, Tertiary	Sand filters, downflow, upflow
	Membrane Filtration	Tertiary	MF, UF, NF, RO
	Oil-Water Separator	Primary	Oil interceptor, coalescing, gravity
	Adsorption	Tertiary	Activated carbon, fixed bed
	Evaporation	Tertiary	Pond, mechanical, falling film
	Air Stripping	Tertiary	Packed tower, degasifier, steam
Chemical	pH Neutralization	Tertiary	Base or acid addition, two-stage
	Chemical Precipitation	Tertiary	Flash-mix and settling
	Coagulation/ Flocculation	Secondary, Tertiary	Polymer or coagulant addition, mixing, and settling
	Oxidation-Reduction	Secondary, Tertiary	Chromium, cyanide, iron, arsenic, mercury, selenium removal
	Ion Exchange	Secondary, Tertiary	Anion, cation, fixed bed, moving bed, one or two-stage
	Electrodialysis	Secondary, Tertiary	ED stack, batch, or continuous
Biological	Bioaugmentation	Secondary	Biological additives
	Suspended Growth	Secondary	Activated sludge, oxidation ditch, SBR
	Attached Growth	Secondary	Trickling filter, RBC, packed bed, MBBR
	Membrane Bioreactor	Secondary	iMBR, sMBR, MF, UF
	Anaerobic Processes	Secondary, Solids	Upflow filter, fluidized bed, UASB, digester, anoxic selector
	Lagoons	Secondary, Tertiary	Multi-stage, stabilization ponds
	Constructed Wetlands	Secondary, Tertiary, Solids	Free surface or subsurface flow, horizontal or vertical flow, zero discharge

Wastewater treatment systems can be summarized with block flow diagrams which show the major treatment processes and how they interact. Example block flow diagrams are shown in Figures 1 and 2.

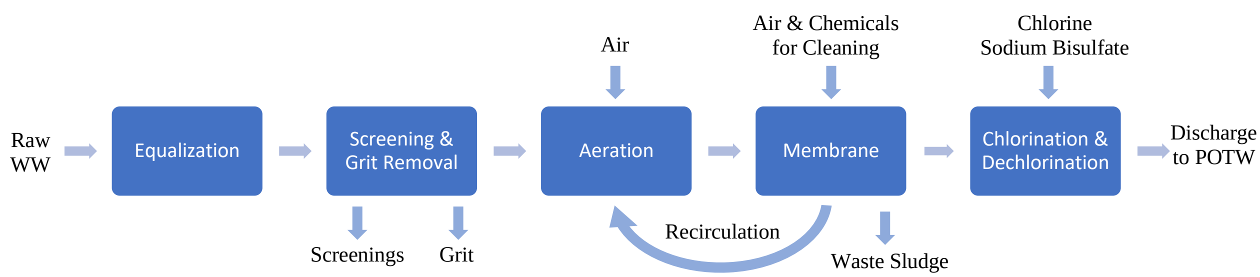


Figure 1: Wastewater treatment system with a membrane bioreactor (MBR) process.
Source: Author

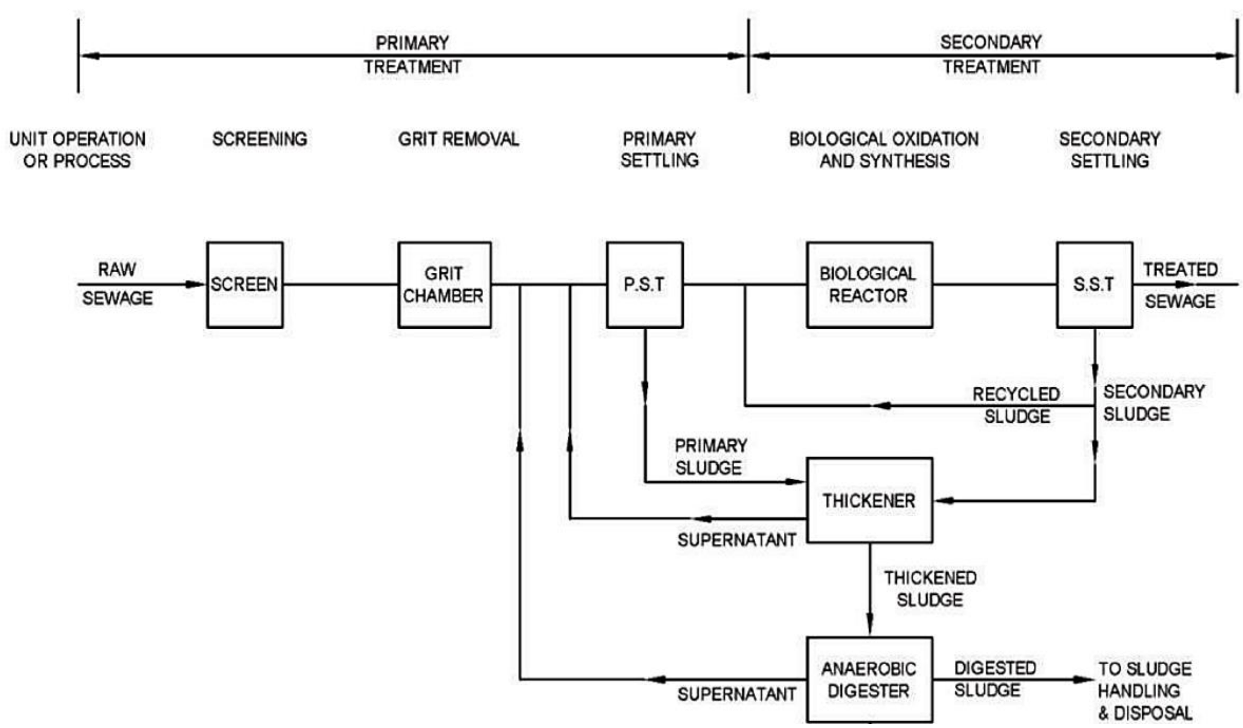


Figure 2: Wastewater treatment system with primary and secondary processes.
P.S.T. is primary sedimentation tank and S.S.T. is secondary sedimentation tank.
Source: "Manual on Sewerage and Sewage Treatment" 2nd Ed, by India Ministry of Urban Development (public domain)

A large wastewater treatment system is commonly referred to as a Wastewater Treatment Plant (WWTP), Water Reclamation Plant (WRP), or Water Reclamation Facility (WRF). See Figure 3 for an example.

Figure 3: Stickney WRP in Chicago, considered the largest WWTP in the world. The wide rectangular tanks have aeration for biological treatment. The circular tanks are primary and secondary clarifiers.

Source: commons.wikimedia.org/wiki/File:Stickney_Water_Reclamation_Plant.jpg, Airborne Chicago to Baltimore, CC-BY-SA-2.0

Pollutant breakthroughs can very quickly have a negative impact on the receiving water body, aquatic life, and nearby water supply systems. Therefore, wastewater treatment systems are to be maintained, operated, and upgraded as required to ensure continuous compliance with regulations and specific permit conditions.

A capital improvement program (CIP), sometimes called a capital improvement plan, focuses on improvements to the physical infrastructure to prevent failures and to meet treatment goals. Thus, a CIP plays a critical role in protecting the environment.

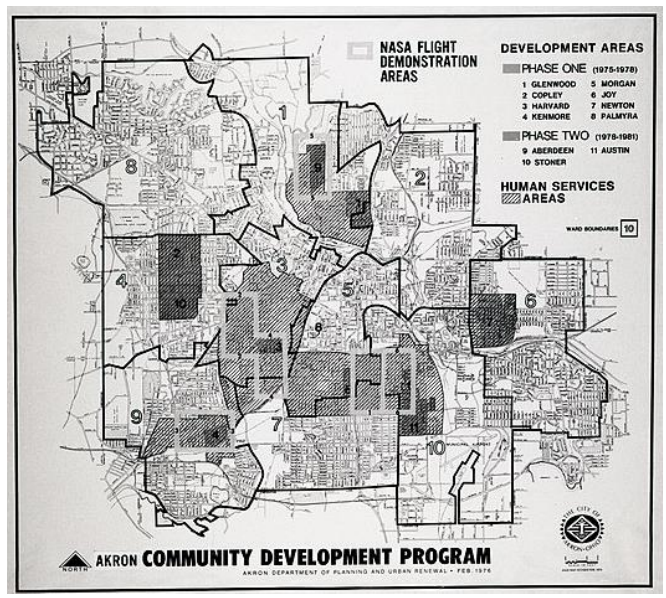
This course focuses on the management of a CIP for wastewater treatment systems. Utility organizations often have similar CIPs for water distribution systems, water treatment systems, and wastewater collection systems, which are each addressed in separate courses.

Capital improvements are individual projects that modify assets to better meet treatment objectives and maintain high levels of service. A CIP manages multiple projects and plans for future projects. The purpose of a CIP is to carry out asset management objectives related to improving physical components for maintaining high levels of customer service.

Motivations for Improvements

Wastewater treatment systems need regular improvements for the reasons listed in Table 2. These reasons are called motivations or drivers.

Table 2: Motivations for Wastewater Treatment System Improvements

Motivations	Description	Example
Develop-ment	Accommodate community growth or a new large user.	 Source: public domain
Climate Change	Protect from flooding, rising sea levels, and saltwater intrusion for coastal WTPs. Storm hardening of structures. Prepare for water scarcity projections.	 Source: commons.wikimedia.org/wiki/File:Dry_Creek_-_Flood_Aerial_-_Crop.jpg, DaveTN, CC-BY-SA-4.0

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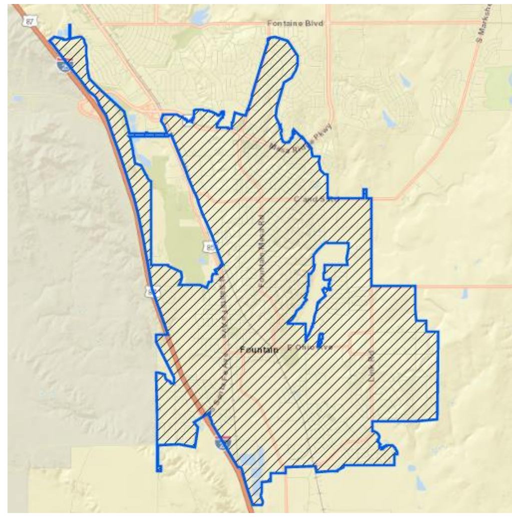
<tr>
<td>Service Area Changes</td>
<td>Sewershed modified to match watershed.

Nearby utility district acquired or merged to form a metro district.</td>
<td>
Source: public domain</td>
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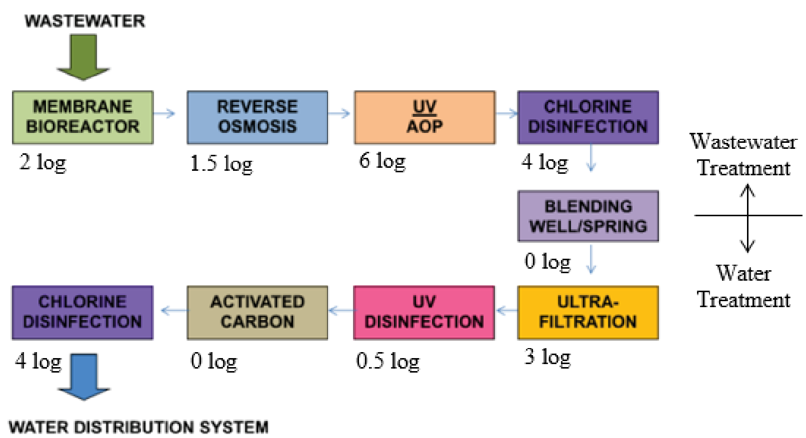
<td>Water Reuse</td>
<td>To conserve water, wastewater is recycled (or reclaimed) after advanced water treatment processes.</td>
<td>

Source: Example flow diagram for a direct potable reuse system</td>
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<td>Effluent Water Quality Problems</td>
<td>Upgrades to improve effluent quality and prevent pollutant breakthrough. Assess the performance of existing treatment processes.</td>
<td>
Source: public domain</td>
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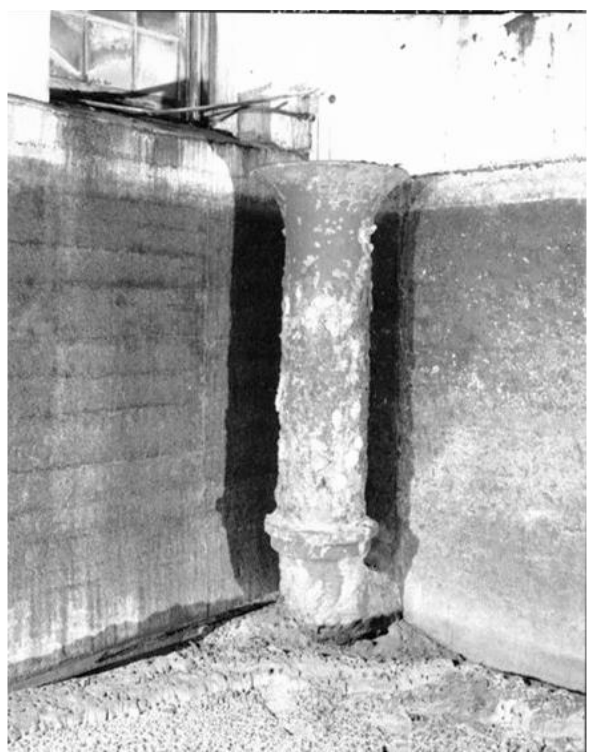
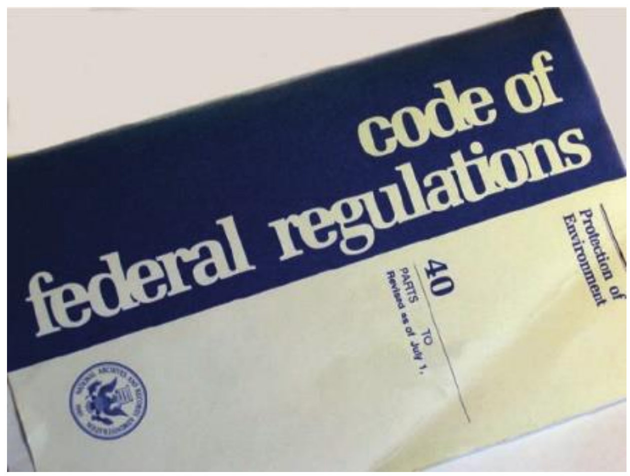
Prevent Structural Failures	Prevent or repair structural failures at tanks, wells, platforms, pipes, and buildings. Add likelihood of failure (LOF) and consequence of failure (COF) for risk scoring.	 Source: public domain
Age	Replace aged items and older materials to reduce the risk of failures. Estimate remaining useful life as lifespan minus age, with adjustment for condition.	 Source: public domain

Redundancy	Provide standby units, add overflows and bypasses, spare parts, improve backup power, and provide alternative power sources.	 Source: public domain
Regulations	Compliance with new federal or state regulations. For example, recent phosphorus and nitrogen limits.	 Source: public domain
Funding	Utilize available federal or state funding.	 Source: public domain

Regulations and Standards

Clean Water Act

National regulations for wastewater treatment began in 1972 as the Federal Water Pollution Control Act, which is now known as the Clean Water Act (CWA). This established and directed the Environmental Protection Agency (EPA) to develop and implement regulations for limiting pollutants discharged to surface waters. 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.

40 CFR 401

The EPA has the legal authority to manage the National Pollutant Discharge Elimination System (NPDES) Program for regulating direct discharges to surface waters, as prescribed in 40 CFR 401 (Code of Federal Regulations). NPDES permits are issued to POTW WWTPs and direct industrial dischargers.

The EPA regulates the discharge of 65 categories of pollutants for both direct and indirect discharges. Many of these pollutant categories are too broad to be tested directly. Therefore, the EPA broke down the list into 126 priority pollutants, each of which can be tested directly. The priority pollutant list is in 40 CFR 401.15 and 423, Appendix A. These are also refed to as toxic pollutants.

In addition, several conventional and non-conventional pollutants have strict discharge limitations, as listed in Figure 4. Part of the permitting process is to determine the discharge limits based on regulations and details on the receiving water body.

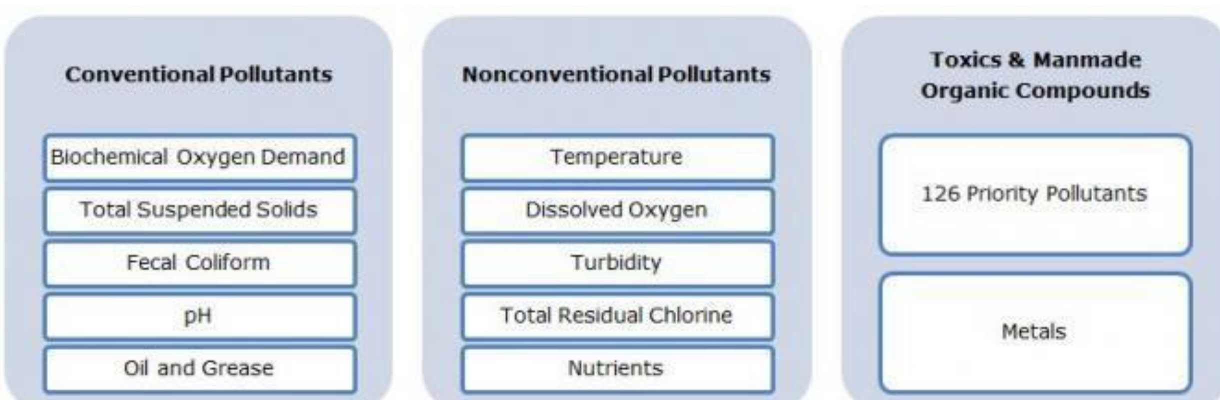


Figure 4: Pollutants commonly included in discharge permits.
Source: https://epd.georgia.gov/forms-permits/watershed-protection-branch-forms-permits/wastewater-permitting/permit-conditions

Compliance Monitoring
The EPA delegates primary enforcement responsibility (also called primacy) for wastewater treatment systems to authorized states and Indian Tribes. Most states have the responsibility to permit, monitor, inspect and audit the effluent water quality for compliance with operating permit conditions and 40 CFR standards.

EPA Asset Management
In 2007, the EPA issued a short paper entitled "Asset Management: A Best Practices Guide". In this document, the EPA provides general principles for managing water systems. The term "asset management" is defined as managing infrastructure capital assets to minimize the total cost of owning and operating them, while achieving service level goals.

See the chart in Figure 5 for the five core questions considered essential for asset management.

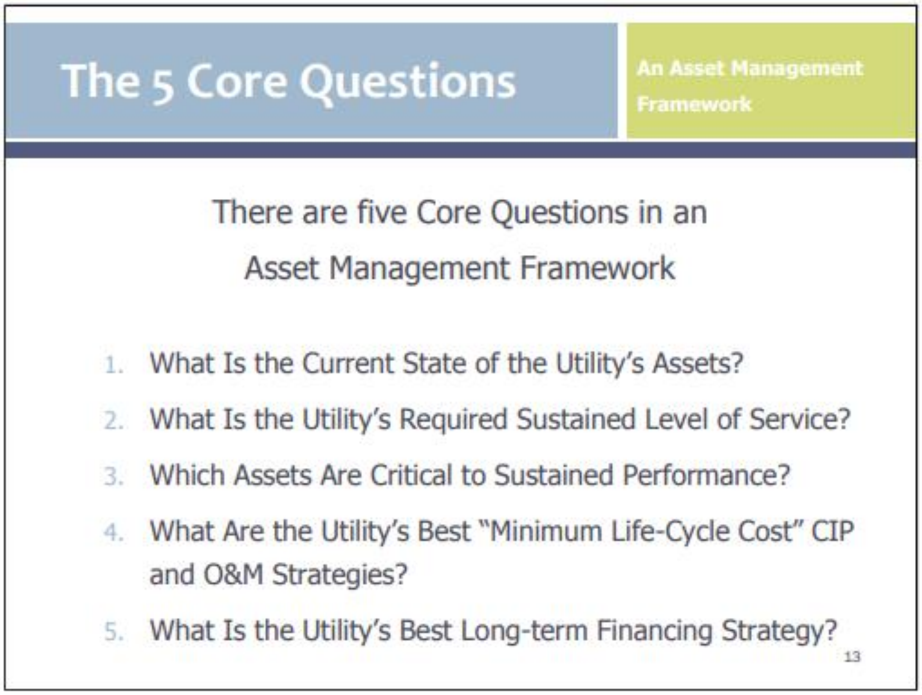


Figure 5: The Five Core Questions for an Asset Management Framework.
Source: www.epa.gov/sites/default/files/2015-10/documents/assetmgt101.pdf (Public Domain)

A goal of asset management and improvement planning is to schedule CIP projects such that the cost of improvement projects is balanced against the accelerating cost to maintain aging assets, while avoiding unacceptable declines in levels of service.

Lifecycle Costs

Smart decisions should be made early in the design process to minimize operations and maintenance (O&M) costs over the lifecycle of the treatment process, as depicted in Figure 6. As detailed design progresses, opportunities for reducing lifecycle cost diminish. For this reason, studies, alternatives comparisons, and basis of design reports are done early in the design process.

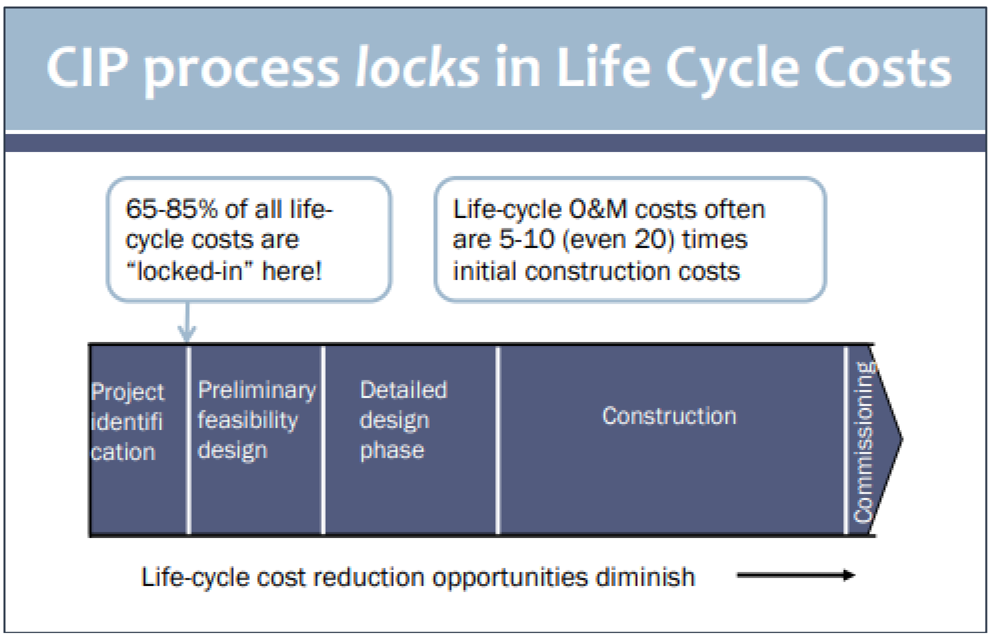


Figure 6: The Five Core Questions for an Asset Management Framework.
Source: www.epa.gov/sites/default/files/2015-10/documents/assetmgt101.pdf (Public Domain)

Lifecycle cost refers to the total cost of ownership over the life of an asset, including maintenance, energy usage, operation labor, chemical use, and waste disposal. Many treatment processes require significant operations and maintenance costs. So, when comparing alternatives, the full lifecycle cost should be considered. Often a time period of 20 years is used for treatment systems.

The lifecycle cost can be calculated using the present worth approach. The formula is as follows:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ Maintenance * PWF - Salvage\ Value$$

where: $PWF = Present\ Worth\ Factor = \frac{(1+i)^T - 1}{i*(1+i)^T}$

$i = interest\ rate$

$T = number\ of\ years$

State Requirements

Each state has administrative codes with more detailed requirements, including treatment 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.

States also provide funding for improvement initiatives, such flood protection and the removal of Per- and Polyfluorinated Substances (PFAS). Funding opportunities should be reviewed regularly, and project schedules adjusted to obtain project funding when possible.

Ten States Standards

The "Recommended Standards for Wastewater Facilities", also known as the Ten States Standards, is adopted by many state administrative codes. The Ten States Standards provides design standards for treatment system components.

See the last Section for references that provide additional standards and guidelines.

Improvement Planning Process

CIP program management involves a planning process to identify and select improvement projects for proceeding with design. The following chart shows common steps in this planning process. Each of the seven steps is addressed in proceeding sections.

This process is repeated periodically, such as every 3 to 5 years. In the other years, an abbreviated project selection process is done to help address urgent issues that arise.

Assessment Comparison

There are three main assessments needed for the planning process:

1. Condition assessments focus on the physical condition of the components.
2. Performance assessments determine the treatment efficiency and compare it to treatment goals, water quality objectives, and industry standards.
3. Risk assessments identify potential failures and the impacts of these failures.

Table 3 indicates which assessments are recommended for different situations.

Table 3: Recommended Assessments for Different Situations				
Situation	Recommended Assessment			
	Condition	Performance	Risk	Other
Electrical Failure	X			Standby Power
Equipment Failure	X			
Observed Corrosion, Cracks, or Deflections	X			
Zero Remaining Useful Life	X		X	
Coating Failure	X			
Process Change or Chemical Change		X		Safety
Flow Demand Increase		X		
New Water Source Added		X		
Effluent Quality Improvement Desired		X		
Process Upsets or Permit Violations		X		Toxicity Test
Lack of Redundancy			X	

Step 1 – Gather Information

The following are documents to maintain for CIP management and review as part of each improvement planning process:

- Sewer ordinances, approved rates, and tariffs (especially recent changes),
- CIP management policies and procedures,
- CIP project reports, tables, and schedules,
- Financial report with annual CIP budget,
- Growth projections for service areas,
- Funding opportunities,
- Regulatory changes (recent and upcoming),
- Permit violations and water quality problems,
- Past projects database,
- Latest Master Plan for the wastewater treatment system,
- Previous assessment reports,
- Process flow diagrams of treatment system (see Figure 7),
- Raw wastewater and effluent water quality data,
- SCADA (Supervisory Control And Data Acquisition) data such as flow meters, sensors, and equipment run times (see Figure 8),
- Operations and maintenance staff improvement ideas and “wish lists”,
- Operations and maintenance records, and
- As-built plans (record drawings).

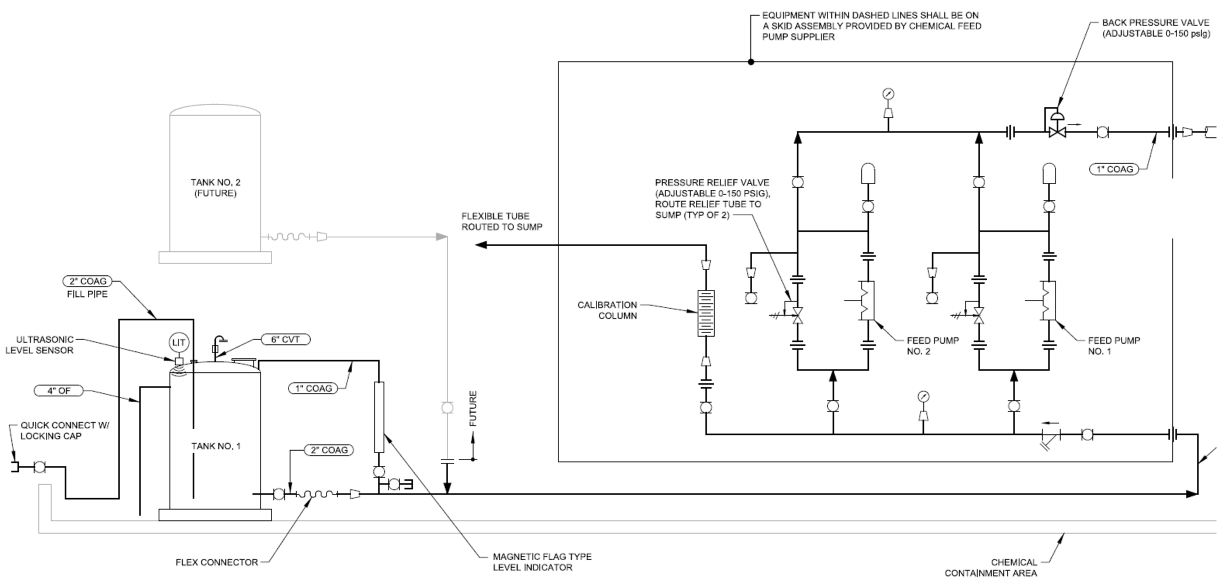


Figure 7: Example PFD for a chemical feed system.

Source: Author

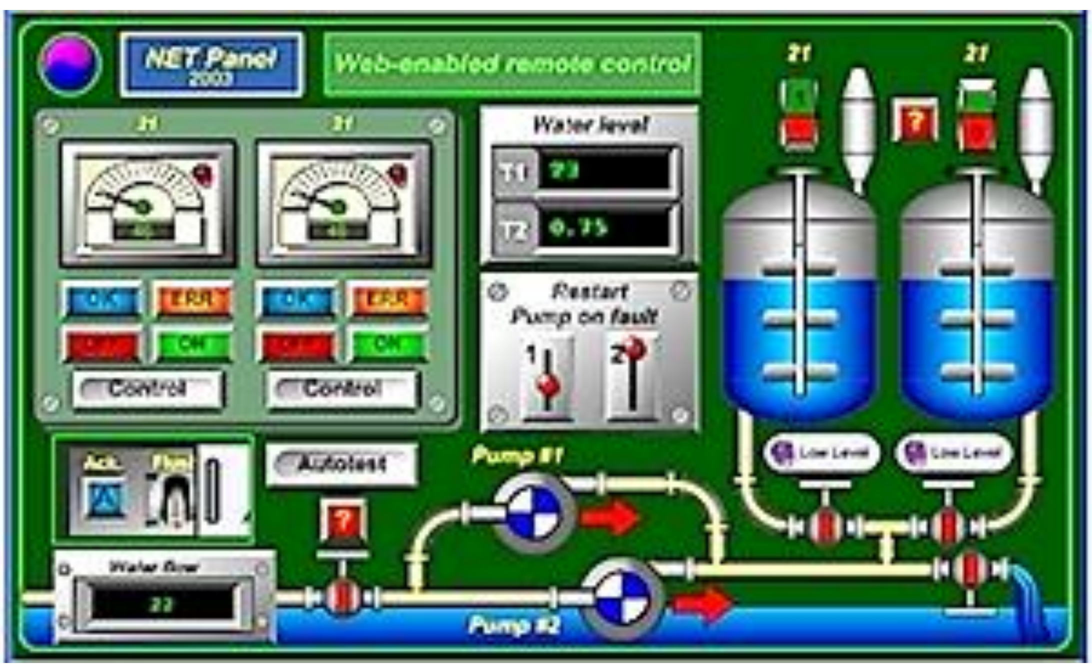


Figure 8: Example SCADA screen including meter and instrument readings. A historian records these readings on regular intervals. This data helps with performance evaluations and process troubleshooting.

Source: public domain

Step 2 - Condition Assessment

Condition assessments help make smart decisions for replacing or rehabilitating aged or failing components. The goal is to identify structural and mechanical weaknesses and to estimate the remaining useful life of components. As components age, the benefit of regular condition assessments increases.

The more detailed the condition assessment the more information available for making improvement project decisions. Having discipline specific assessments is better than a general assessment by a single engineer. For example, for a chemical feed system, there should be multiple assessments, including:

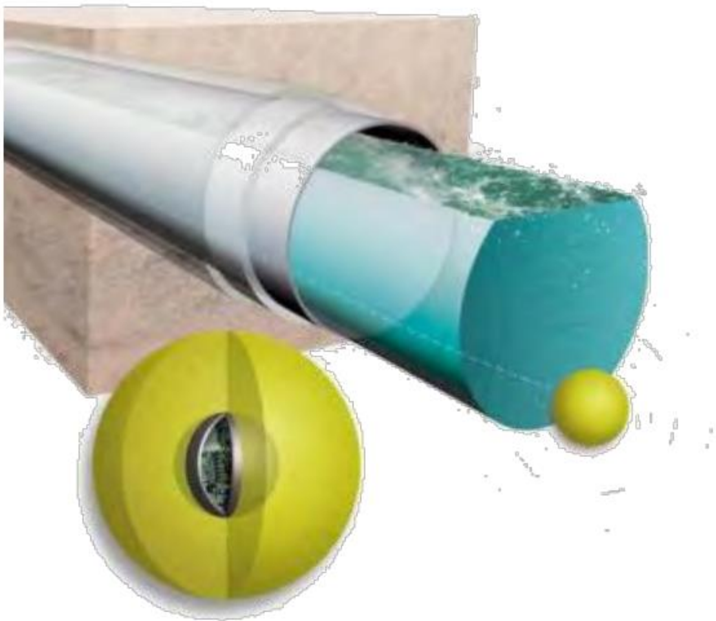
- Structural assessment of the anchorage, coatings, and tank (by a structural engineer).
- Mechanical assessment of the pumps and valves (by a mechanical engineer),
- Electrical assessment for power and controls (by an electrical engineer), and

The condition assessment process may involve the following steps:

1. Review previous assessment scope and results,
2. Identify areas to assess,
3. Decide on assessment techniques,
4. Define scope of work and solicit a consultant,
5. Perform assessment work,
6. Estimate remaining useful life (see next section),
7. Compile results in a report, and
8. Utilize results for risk ranking and prioritization of improvements.

For Step 3, there are many condition assessment techniques to choose from, as illustrated in Table 4.

Table 4: Condition Assessment Techniques	
Component	Common Techniques
Piping (Exterior)	○ Soil corrosion analysis (for buried pipe), as shown:  Source:commons.wikimedia.org/wiki/File:CSIRO_ScienceImage_1739_Testing_soil_pH.jpg CSIRO, CC-BY-SA-3.0 ○ Leak detection techniques ○ Exterior visual inspection, as shown:  Source: www.denverwater.orgi/tap/diving-in-to-inspect-pipes-from-the-inside-out (p.d.) ○ Exterior coupon inspection (for PCCP pipe) ○ Exterior acoustic impact echo (for PCCP pipe) ○ Exterior electromagnetic scanning ○ Exterior bracelet probe ○ Ultrasonic or guided wave radar

Piping (Internal)	○ Camera inspection (CCTV), as shown:  Source: www.cityofmadison.com/engineering/sanitary-sewer/programs-initiatives/closed-circuit-television-program, public domain ○ Interior acoustic ball, as shown:  Source: https://your.kingcounty.gov/dnrp/library (public domain) ○ Internal electromagnetic ○ Internal magnetic flux ○ Internal laser ○ Internal ultrasonic pig

Concrete Tanks	○ Visual Inspection (by tank manufacturer or structural engineer) including leaks, efflorescence buildup from leaks (see below), cracks, chips, discoloration, or uneven settling.  ○ Acoustic impact echo, as shown:  ○ Ground-penetrating radar (GPR) rebar mapping, as shown:  Source: commons.wikimedia.org/wiki/File:Gpr-concrete-imaging.jpg, Vadams, CC-BY-SA-3.0 ○ Half-cell corrosion mapping ○ Coupon inspection ○ Cover meter test ○ Coating/lining thickness measurement ○ Leak testing

Steel Tanks	○ Visual Inspection (by tank manufacturer or structural engineer):  Source: stillwater.org/page/home/government/current-projects/water-utilities-engineering-projects/water-projects/water-storage-tank-inspection-evaluation (public domain) ○ Ultrasonic thickness measurements, as shown:  ○ Coating/lining thickness measurement  Source: Author ○ Leak testing

<table>
<tr><td>FRP Tanks</td><td>

Visual Inspection (by tank manufacturer or structural engineer)


Source: www.epa.gov/ust/release-prevention-underground-storage-tanks-usts (p.d.)

Measure depth of corrosion pits and stress cracks
Flatness measurement of floor and flanges with straight edge
Thickness measurements with Ultrasonic or Microwave
Grind surface and test for chemical penetration
Peel off strength test
Loss of ignition test
Barcol hardness test
Acetone sensitivity test
Mechanical stress analysis

</td></tr>
<tr><td>Pump Stations</td><td>

Visual Inspection, as shown:


Source: commons.wikimedia.org/wiki/File:Pompownia_wielun_miejska_oczyszczalnia_sciek%C3%B3w_II_hala_pomp.JPG, Stefan.p21, CC-BY-SA-3.0

Coating/lining thickness measurement
Valve and instrument inspection and functional testing
Pump manufacturer inspection and function testing
Pipe testing (see techniques above)
Electrical power and controls assessment

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Concrete Vaults	○ Visual inspection, as shown:  Source: commons.wikimedia.org/wiki/File:ManholePMG_gobeirne.jpg, Greg O'Beirne, CC-BY-2.5 ○ Half-cell corrosion mapping ○ Coupon inspection, as shown:  Source: Author ○ Acoustic impact echo ○ Valve and instrument inspection and functional testing

<table>
<tr><td>Steel Members in Mechanical Equipment</td><td>

Visual inspection for corrosion (shown below), wear, deflection, and weld failure:

Source: Author
Compare ultrasonic thickness measurements to the design thickness values from original shop drawings
Identify components with a loss of steel greater than the corrosion allowance (1/16” to 1/8” allowance is common)

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<tr><td>Specialty Drives for Clarifiers and Other Equipment</td><td>

Vibration Test:

Accelerometer
Mount on the drive base and measure the filtered vibration spectra versus frequency and the vibration phase in three perpendicular planes
Typical Limit: 3.0 mils peak to peak displacement

Noise Test:

Sound Level Meter
Hold 3 feet from the drive and measure for each of the 8-octave band mid-points. Repeat on each side of the drive.
Typical Limit: 85 dBA

Amp Draw Test:

Read the amperage draw of the motor during operation and compare with design value. An electrician may be required.

Speed Change Test:

If possible, vary the speed of the drive to the low and high range, and repeat the above tests.

Electrical power and controls assessment

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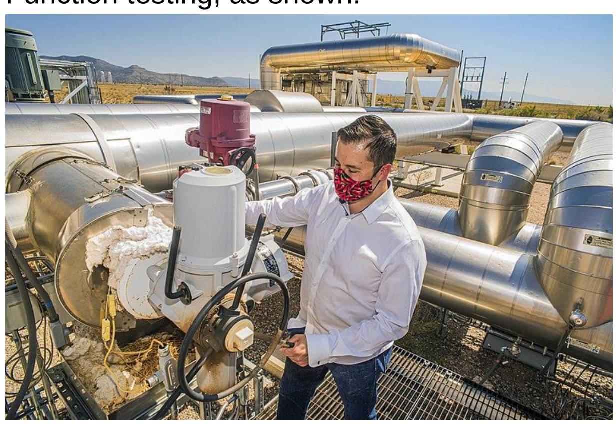
Specialty Process Equipment	○ Visual inspection, as shown:  Source: commons.wikimedia.org/wiki/File:Dissolved_Air_Flotation_DAF.jpg, Kroftaengineering1, CC-BY-SA-4.0 ○ Manufacturer inspection and functional testing ○ Electrical power and controls assessment
Valves	○ Visual inspection ○ Function testing, as shown:  Source: Public Domain

Example Problem 1

Project engineer Amanda has asked a vendor for assistance in the condition assessment of various wastewater treatment plant components. The vendor said the specialize in ultrasonic and ground penetrating radar (GPR) techniques. Based on Table 4, which of the following components could the vendor assist with:

- Steel piping
- Concrete tanks
- Concrete vaults
- Fiberglass tanks
- Steel tanks
- Mechanical drives
- Pumps
- Blowers
- Valves

Solution:

Based on Table 4, the vendor could likely assist with assessing the following:

- Steel piping (ultrasonic thickness)
- Concrete tanks (GPR rebar mapping)
- Fiberglass tanks (ultrasonic thickness)
- Steel tanks (ultrasonic thickness)

Step 3 - Remaining Useful Life

Estimating the remaining useful life typically involves the following steps for each component:

1. Assign an expected useful life (lifespan) based on the type of component. Consult with the original manufacturer.
    a. See Table 5 for typical lifespans, which should be modified for the actual conditions such as corrosive soils, chemical exposure, exposure to severe weather, etc.
    b. Components exposed to wastewater typically have a shorter lifespan than those exposed to clean water.
    c. Components exposed to raw wastewater typically have a shorter lifespan than those exposed to wastewater than has been pH neutralized or biologically treated.
2. Determine the year of manufacture, installation, or startup.
3. Calculate current age:
    Age = Current Date – Installation Date
4. Perform a condition assessment. If the assessment does not include the remaining useful life, the following steps can be used.
5. Assign a “Condition Factor” as follows:

Condition	Factor
Like New	1.50
Very Good	1.25
Good	1.10
Average	1.00
Poor	0.50
Very Poor	0.25

6. Calculate “Remaining Useful Life” (years) per this formula:
    Remaining Useful Life = (Lifespan – Age) x Condition Factor
        Max. Value = Lifespan
        Min. Value = 0

Table 5: Typical Lifespans for Wastewater Treatment Equipment		
Component	Materials	Estimated Lifespan*
Submerged Steel and Equipment	Standard Coating	20
	Robust Coating	30
	Galvanized	30
	304 Stainless	40
	316 Stainless	50
Wastewater Holding Structures, Tanks, and Wet Wells	Unlined Concrete	30
	Lined Concrete	40
	Coated Steel	40
	Glass Lined Steel	60
	304 Stainless	60
	316 Stainless	70
Chemical Tanks	Linear Polyethylene	10
	Crosslinked Polyethylene	20
	Lined Steel	30
	FRP	40
Drives, Bearings, Motors	Various	20
Pumps, Mixers, Blowers	Various	15
Membranes (MF, UF, NF, RO)	Various	5
Cartridge Filters	Filter	1
	Housing	10
Heat Exchangers	Various	20
Chemical Feed Systems	Various	15

Ion Exchange Resin	Cation	10
	Anion	5
Pressure Piping	Galvanized Steel	20
	Copper	30
	Coated Steel	30
	DIP	40
	FRP	40
	PVC & CPVC	50
	HDPE & FRP	50
	PCCP	60
	Polymer Concrete	70
Valves	Manual	40
	Automated	20
Buildings	Wood	40
	Metal, PEMB	60
	Concrete	100
	Brick	100
Electrical Equipment (MCCs, Switchgears, Transformers, etc.)	Various	30
Control Panels	Indoor	40
	Outdoor	20
Standby Generator	Indoor	40
	Outdoor	20
(*) Lifespan = Years of service prior to major rehabilitation or replacement, assuming normal maintenance		

Example Problem 2

Engineer William performed a condition assessment on 20 year old concrete structure (lined) for an aeration basin. The structure was found to be in "very good" condition. What is the estimated remaining useful life?

Solution:

Bill determines that the estimated lifespan of the aeration basin is 40 years per Table 5, under Wastewater Holding Structures, Lined Concrete.

The estimated remaining useful life is **25 years**, per this calculation:

Remaining Useful Life = (Lifespan – Age) x Condition Factor

= (40 – 20) x 1.25 = 25 years

Step 4 - Performance Assessment

A performance assessment aims to evaluate the efficiency of the treatment process and identify modifications that can improve the treatment process and effluent water quality. Since each process is unique, each performance assessment is also unique. Process experts including the equipment manufacturer should be consulted to plan out the details of a performance assessment.

Common steps in a performance assessment are as follows:

1. Gather Information
2. Desktop Study
3. Modeling (Optional)
4. Field Testing (Optional)
5. Report and Recommendations

Step 1 – Gather Information:

- Review all recent process flow diagrams for the treatment plant and compile them as needed.
- Confirm the process flow diagrams match the latest operations. Walk the plant to confirm all relevant processes have been incorporated and markup as needed.
- Gather historic information related to the process of concern, such as:
    - Flow rates
    - Pump start and stop times
    - Instrument readings such as water levels, pressures, and concentrations
    - Chemical feed rates and concentrations
    - Influent and effluent water quality parameters (pH, alkalinity, solids, etc.)
    - Permit violations and process upsets
- Review any previous design reports or process studies.

Step 2 – Desktop Study:

- Perform a flow balance and mass balance for the unit process. This will provide insight into how flow and solids pass through the clarifier.
  - See Figure 9 for an example mass balance done in excel.
  - A basic mass balance equation is as follows:

    $Q_{influent} * C_{influent} = Q_{sludge} * C_{sludge} + Q_{effluent} * C_{effluent}$

    where Q = flow rate
    C = suspended solids concentration

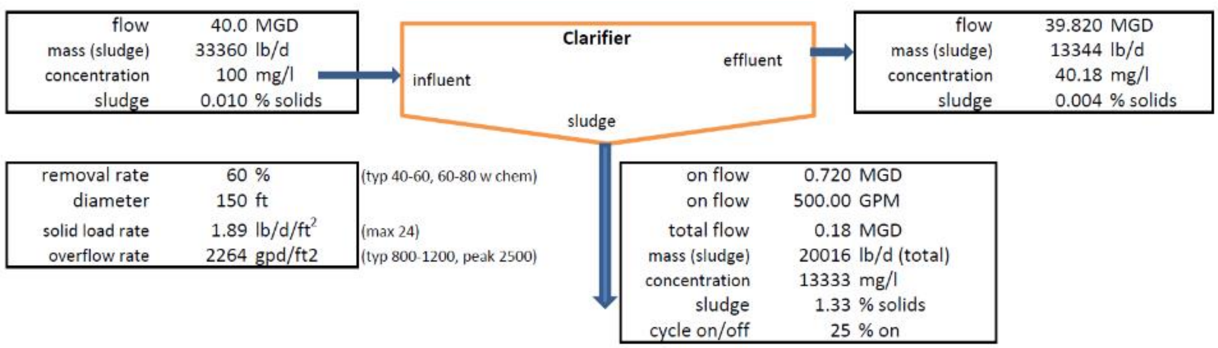


Figure 9: Example mass balance for a clarifier at peak flow. Note the mass of sludge entering the clarifier (33,360 lb/d influent) equals the mass leaving the clarifier (13,344 lb/d effluent plus 20,016 lb/d sludge).

- Calculate important performance parameters at average and peak flow conditions. Common parameter formulas are as follows:
  - Surface overflow rate = influent flow rate / surface area
  - Detention time = tank volume / influent flow rate
  - Solids loading rate = solids rate / surface area
  - Weir overflow rate = effluent flow / length of weir
  - Pollutant/solids removal rate = 1 – effluent conc. / influent conc.
  - Side water depth = water surface elevation - base of tank wall elevation
  - Chemical dosage (mg/L) = feed rate (lb/d) / (flow rate (MGD) x 8.34)
- Compare the calculated parameters to industry standards (see Table 7).
- Review with process experts and/or the equipment manufacturer to identify concerns and potential process modifications that could improve performance.

<u>Step 3 – Modeling:</u>

- Treatment simulator for calculating theoretical treatment efficiencies.
  - For example, running a simulator for nitrification and de-nitrification with biological treatment using the software called BioWin.
- Contaminant transport modeling for analyzing the fate of select pollutants through one or more treatment processes.
  - For example, modeling the removal of zinc through one or more processes based on chemical equations and water quality parameters.
- Computational fluid dynamics (CFD) modeling for the following:
  - Mixing effectiveness,
  - Identifying dead zones with poor circulation,
  - Peak flow rate capacity and pollutant loading rate capacity,
  - Improvements to minimize velocity vectors, and
  - Improvements to prevent carryover of settled sludge.
  - See Figure 10 for an example of CFD model results.

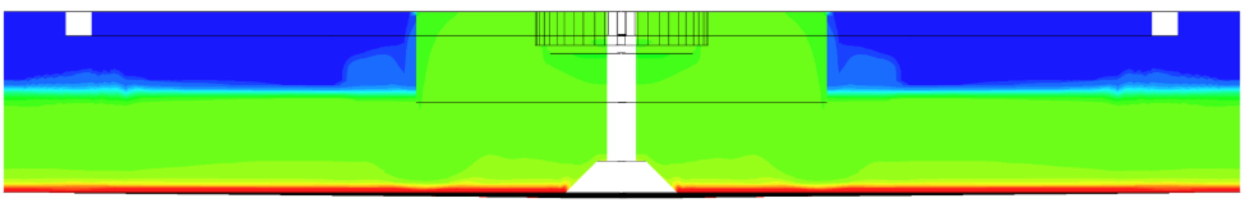


Figure 10: CFD model results for solids concentration of a secondary clarifier. Colors are as follows: dark blue is 10 mg/L, light blue is 1,000 mg/L, green is 3,000 mg/L, and red is 6,000 mg/L.

Step 4 – Field Testing:

- Field testing can expand on desktop study and modeling results by checking assumptions and confirming conclusions. Someone field testing is needed to gain information needed for modeling.
- Field testing can help identify root causes of poor performance.
- To help decide which tests should be undertaken, consider any parameters that are outside the industry standards, as identified in the desktop study. Choose tests that have the greatest chance of helping resolve the problems.
- For pumps, check the operating point using flow and pressure readings, and plot with the manufacturer's pump curve, as shown in Figure 11.

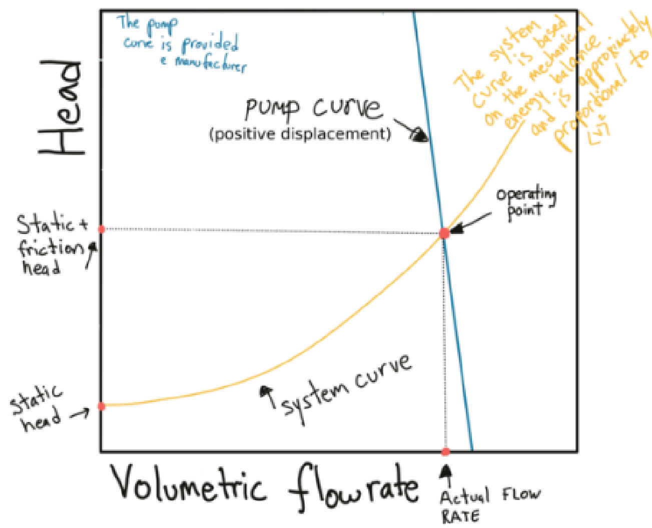
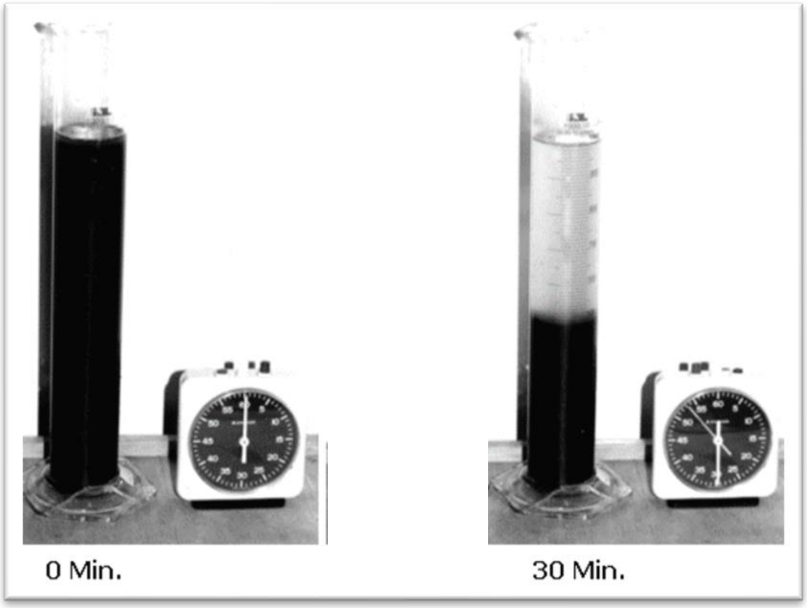


Figure 11: Pump and system curves with operating point based on field testing.
Source: commons.wikimedia.org/wiki/File:Operating_Curves_of_Positive_Displacement_pump.png, Steven Baltakatei Sandoval, CC-BY-SA-4.0

- See Table 6 for field tests that can help assess the performance of a clarifier.
- A common test for secondary clarifiers is the settling test shown in Figure 12.
- A core sampler (also called a sludge judge) can be used to understand the sludge blanket depth, and to produce a plot as shown in Figure 13.

Table 6: Field Tests for Wastewater Clarifier Performance Assessment			
Test	Instrument	Overview	Type of Clarifier
Tracer Test	Fluorescent Dye and Spectro-fluorometer	Dye is introduced just upstream of the clarifier and samples are obtained from the effluent at time intervals. Create a flow curve by plotted concentration over time. Samples can be taken at vertical intervals to view flow patterns within the clarifier.	All
Current Test	Drogue (X-vaned flow catcher)	Lower the drogue into the clarifier at different depths with a float. Track the movement over time of the float to identify strong currents within the clarifier.	All
Microscope Viewing	Microscope	Exam biological floc in a microscope to determine types and abundance of biota. If filaments are observed, consider process modifications.	Secondary
Settling Test	Settleometer or Graduated Cylinder	Measure settled sludge volume over 30 minutes as shown in Figure 12. Measure solids in the supernatant. Mix before the test and repeat to understand the impact of flocculation. Calculate the sludge volume index (SVI) and compare it to industry standards. Create a flux curve and state point analysis chart.	Secondary
Sludge Blanket Level	Core Sampler	Lower core sampler to the floor and close bottom valve. Raise to view sludge depth. Repeat at intervals along the clarifier radius.	All
Vertical Solids Profile	Suspended Solids Analyzer	Use core sampler to take sludge samples at vertical intervals (6” or 12”) and test for suspended solids. Make a vertical plot such as Figure 13.	Gravity Thickener
Chemical Jar Testing	Gang Stirrer and Turbidimeter	Place influent samples in multiple containers with different chemical concentrations. Flocculate and measure settle solids volume and effluent solids concentration or turbidity after 30 minutes.	Chemical Enhanced



$$\text{SVI (mL/g)} = \frac{\text{Settled Sludge Volume (mL/L)}}{\text{Mixed Liquor Suspended Solids (g/L)}} \times 1{,}000$$

Figure 12: Settling test showing the original sludge volume (left) and settled sludge volume after 30 minutes (right). The SVI formula is included for convenience.

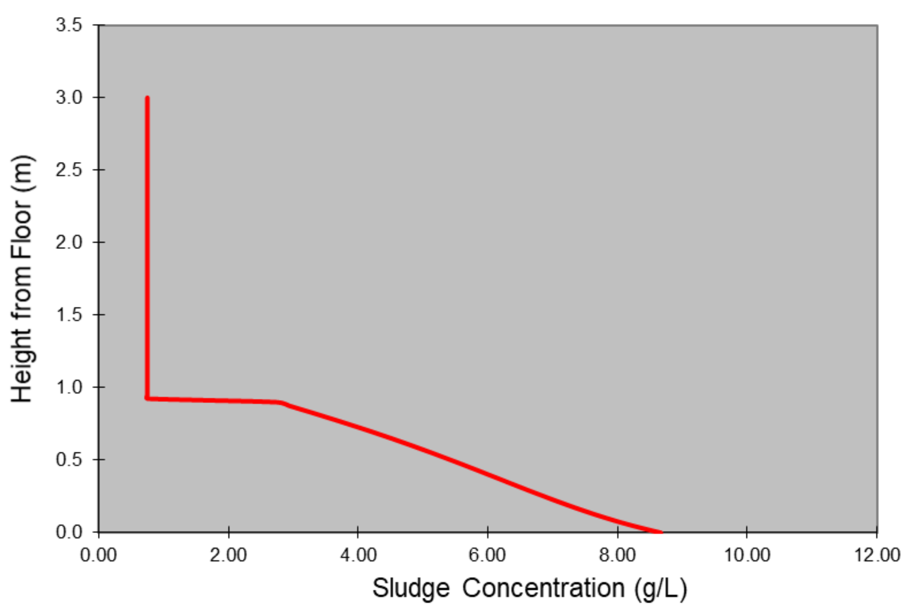


Figure 13: Example vertical solids profile for a gravity thickener.

Step 5 – Report and Recommendations:

- Document performance assessment findings and conclusions.
- Create a performance summary table for each process, as shown in Table 7.
- Review performance assessment results with process experts and compile a list of potential modifications to improve performance.

Table 7: Performance Summary
Primary Clarifiers

Parameter	2023 Data [a]	Industry Standard [b]
Overflow Rate (gpd/ft^2) at Average Flow	860	600 to 1200
Overflow Rate (gpd/ft^2) at Peak Flow	1800	1000 to 2500
Solids Loading Rate (lb/d/ft^2)	11	12 to 20
Weir Overflow Rate (gpd/ft)	8,000	10,000 to 20,000
Detention Time (hrs)	2.5	2.0 to 3.0
Side Wall Depth (ft)	10	10 to 14
TSS Removal Rate, Average	45	40 to 60
BOD Removal Rate, Average	25	20 to 50
Sludge Removal Concentration (% Solids)	1.6%	1 to 4

Notes: a) Values in red are outside industry standard
b) Sources should be stated, such as Ten States Standards

Step 5 - Risk Assessment

A risk assessment will identify likely failures and the potential impacts of each failure. This is sometimes called a reliability assessment. Failure is an inclusive term encompassing any malfunction or system upset, including structural, mechanical, electrical, controls, hydraulic, and treatment efficiency failures. Basically, any potential failure that can be prevented by a capital improvement project is considered in the risk assessment.

The result of a risk assessment is a numerical ranking of components from lowest to highest risk. This is called a “Risk Ranking”. High risk components should be prioritized for improvement projects that will reduce the risk.

The following are suggested steps for a risk assessment:

1. Review condition assessment and remaining useful life data,
2. Assign likelihood of failure (LOF) values to each component (scale 1 to 100),
3. Prioritize treatment processes from most essential to least essential for meeting the treatment goals,
4. Review redundancy and standby power available for each process,
5. Assign consequence of failure (COF) values to each component (scale 1 to 100),
6. Sum the LOF and COF values to obtain the Total Risk scores.

See Figure 14 for an example plot of COF versus LOF, also called a risk matrix.

Consequence of Failure

Likelihood of Failure	Very Low	Low	Moderate	High	Very High
Very High					
High		Exposed Piping	Grit Removal Polymer Feed	Effluent Pumps 1 & 2	
Moderate		Flow Meters Instruments	De-chlorination Blowers	Buried Piping	Chlorine Feed
Low		Primary Clarifiers Hypo Tanks	Disinfection Chamber Screens	Secondary Clarifiers	
Very Low			EQ Tank	Aeration Basin	Outfall

Figure 14: A risk matrix with major components added.
Items in red are considered highest priority, followed by yellow, then green.

Source: Author

Often the COF is considered of more importance than the LOF. This can be seen in Figure 14 as there are more red boxes in the high and very high categories of COF than LOF. To account for this, an importance factor (IF) can be used when calculating the total risk, per this formula:

Total Risk = IF * COF + LOF

<u>Example Problem 5</u>
A chemical feed pump is assigned a COF of 30, a LOF of 50, and an importance factor of 1.25. What is the Total Risk score?

Solution:
The Total Risk is 87.5 based on the following calculation:

Total Risk = IF * COF + LOF = 1.25 * 30 + 50 = 87.5

Step 6 - Update Master Plan

A master plan should be created and updated regularly to help guide the long term planning of CIP projects. The purpose is to summarize assessment results and identify improvements that will address deficiencies and help meet treatment goals for many years into the future. Often a common Master Plan is made for both the treatment plant and collection system.

A master plan report commonly includes the following topics:

- Treatment System Overview
- Treatment Goals and Permit Limits
- Summary of Water Quality Data and Trends
- Growth Projections
- Regulatory Changes
- Condition Assessment Results
- Remaining Useful Life Data
- Performance Assessment Results
- Risk Assessment Results
- Improvement Alternatives Analysis
- Recommended Improvements
- Cost Estimates
- Recommended Additional Studies

See Figure 15 for an example Master Plan report table of contents.

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- B Guelph WWTP Capacity Assessment
- C Sewer Use By-law Review
- D Wastewater Reuse
- E Evaluation and Prioritization Results
- F Future Expansion Considerations
- G Public Advisory Committee Material
- H Agency Consultation
- I Public Consultation

Figure 15: Example table of contents for a Wastewater Treatment Master Plan report.

Source: https://guelph.ca/wp-content/uploads/Wastewater-Treatment-Master-Plan.pdf, public domain

Step 7 - Project Selection

This step is for selecting which projects should proceed to design at this time and for scheduling of future projects while staying within budget limitations.

The following are suggested steps for project selection:

1. Create a table of potential projects and motivations (see Table 8 and free software with this course),
2. Sum the number of motivations (also called drivers) for each potential project (greater = high priority),
3. Estimate the cost for each potential project (often in Master Plan),
4. Sum the cost for each budget category and the total cost,
5. Compare total cost to budget,
6. Decide on projects to proceed based on motivations and cost estimates, and
7. Schedule out projects based on resources and budgets (see next section).

In Table 8, the last two columns “No. of Motivations” and “Cost per Motivation” can be used to help select projects for proceeding. Projects with the most motivations and with the lowest cost per motivation are highlighted **red**. Regulatory requirements may require proceeding with projects with high cost and few motivations.

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

1. Split into multiple smaller projects and advance only the first project/phase
2. Budget can be passed to the next year and combined with that year’s budget
3. Budget can be used from another package with justification and approval
4. Budget can be increased with justification and approval

Table 8: Example CIP Project Planning Table

Project No.	Potential Project Name	Cost Estimate ($M)	New Develop-ment	Climate Change	Water Reuse	Effluent Water Quality	Remaining Useful Life	High Risk Ranking	Redund-ancy	Qualifies for Funding	Regulatory Needs	Other	No. of Motivations	Cost per Motivation
1	Influent Pump Station Expansion	$3.0	X						X				2	$1.5
2	Grit Removal Rehabilitation	$1.2					X	X					2	$0.6
3	Aeration Basin Rehabilitation	$0.8					X	X				Safety Concerns	3	$0.3
4	Clarifier Mechanism Replacement	$0.6				X		X					2	$0.3
5	Plant Water Reuse System	$1.0			X					X			2	$0.5
6	Yard Piping Rehabilitation	$0.8					X	X					2	$0.4
7	Transfer Pump Station Replacement	$1.8	X				X	X	X				**4**	$0.5
8	Selector Tank Addition	$2.1	X			X					X		3	$0.7
9	Phosphorus Removal Addition	$3.0				X				X	X		3	$1.0
10	New Chemical Building	$2.2	X	X				X			X	City Council Agenda Item	**5**	$0.4
11	Flood Protection Improvements	$1.5		X						X		City Council Agenda Item	3	$0.5
12	Isolation Valve Additions	$0.4							X			Correct Lack of Isolation	2	**$0.2**
13	Instrumentation Upgrades	$0.3				X		X				Highest COF	3	**$0.1**
14	Actuated Valve Replacements	$0.6					X	X					2	$0.3
	Total ($M)	$19.3	$9.1	$3.7	$1.0	$6.0	$5.2	$8.3	$5.2	$5.5	$7.3	$5.2	-	-

Example Problem 3

Project Manager Randy helped prepare Table 8 and now needs help to select which projects to proceed, while staying within the budget range of $4.0M to $4.5M. The goal is to proceed with the greatest number of projects that are highlighted **red** in the last two columns. Help Randy decide which project(s) should be eliminated and what is the total cost?

Solution:

The projects highlighted **red** are as follows:

- $1.8M – 7, Transfer Pump Station Replacement, 4 motivations
- $2.2M – 10, New Chemical Building, 5 motivations
- $0.4M – 12, Isolation Valve Additions, $0.2M per motivation
- $0.3M – 13, Instrumentation Upgrades, $0.1M per motivation

$4.7M – Total

The total exceeds the $4.5M budget by $0.2M. The following are options for proceeding:

1. Eliminate Project No. 12 to save $0.4M for total $4.3M.
2. Eliminate Project No. 13 to save $0.3M for total $4.4M.

In comparing options 1 and 2, Project No. 13 has a greater number of motivations (3 versus 2) and a lower cost per motivation ($0.1M versus $0.2M). Therefore, Project No. 13 is a better choice to proceed based on information available.

Recommendation is to eliminate Project No. 12 and proceed with the following projects for a total cost of $4.3M:

- $1.8M – 7, Transfer Pump Station Replacement, 4 motivations
- $2.2M – 10, New Chemical Building, 5 motivations
- $0.3M – 13, Instrumentation Upgrades, $0.1M per motivation

$4.3M – Total

Spending Projections

Projects typically last 1 to 5 years, from design to startup, so the project costs are spread over multiple years. Thus, a long-term CIP Program Budget is required which is based on projected spending (also called a cash flow projection) over the upcoming years. Every year, the CIP Program Budget may require approval in addition to an annual CIP Spending Budget. Ideally, the upcoming year's Spending Budget would be equal to or slightly greater than the latest spending projection, also called a cash flow projection. Careful scheduling and detailed spending projections for each project can help prevent major differences between projections and actual cash flow.

The following steps can be used to 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.
    a. Assign a cost to each phase.
    b. 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 quarter.
    a. See Table 9 for an example, which is also provided in excel format as free software with this course.
5. Add the estimated costs for each quarter and each year.
    a. These totals can be rounded up to form the program budgets, which is the maximum spending per quarter and year.
    b. The values can be updated quarterly to confirm projections are within budget.

Table 9: Example CIP Spending Schedule
(Phase coloring: study, design, bid, construction) (All costs in $M)

Proj. No.	Potential Project Name	Cost Estimate ($M)	2023				2024				2025			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Influent Pump Station Expansion	$3.0	-	$0.10	$0.20	$0.10	$0	$0.10	$0.30	$0.30	$0.70	$0.50	$0.50	$0.20
2	Grit Removal Rehabilitation	$1.2	-	$0.10	$0.10	$0	$0	$0.10	$0.20	$0.30	$0.30	$0.10	-	-
3	Aeration Basin Rehabilitation	$0.8	-	$0.05	$0.05	$0	$0	$0.10	$0.30	$0.20	$0.10	-	-	-
4	Clarifier Mechanism Replacement	$0.6	-	-	$0.05	$0.05	$0	$0	$0.10	$0.20	$0.10	$0.10	-	-
5	Plant Water Reuse System	$1.0	-	$0.10	$0.10	$0	$0	$0.10	$0.30	$0.30	$0.10	-	-	-
6	Yard Piping Rehabilitation	$0.8	-	-	-	$0.10	$0.05	$0	$0	$0.05	$0.20	$0.20	$0.20	-
7	Transfer Pump Station Replacement	$1.8	$0.10	$0.10	$0	$0	$0.20	$0.30	$0.40	$0.40	$0.20	$0.10	-	-
8	Selector Tank Addition	$2.1	-	-	-	$0.20	$0.20	$0	$0	$0.20	$0.40	$0.60	$0.40	$0.10
9	Phosphorus Removal Addition	$3.0	-	$0.10	$0.20	$0.10	$0	$0.10	$0.30	$0.30	$0.70	$0.50	$0.50	$0.20
10	New Chemical Building	$2.2	$0.05	$0.05	$0.20	$0.10	$0	$0	$0.20	$0.20	$0.60	$0.50	$0.30	-
11	Flood Protection Improvements	$1.5	$0.05	$0.05	$0.10	$0	$0	$0.20	$0.20	$0.40	$0.40	$0.10	-	-
12	Isolation Valve Additions	$0.4		$0.05	$0.05	$0	$0.10	$0.10	$0.10	-	-	-	-	-
13	Instrumentation Upgrades	$0.3	$0.05	$0	$0	$0.10	$0.10	$0.05	-	-	-	-	-	-
14	Actuated Valve Replacements	$0.6	-	-	$0.02	$0.02	$0	$0	$0.06	$0.20	$0.20	$0.10	-	-
	Quarter Total	$19.3	$0.25	$0.70	$1.07	$0.77	$0.65	$1.15	$2.46	$3.05	$4.00	$2.80	$1.90	$0.50
	Annual Total		$2.79				$7.31				$9.20			

<u>Example Problem 4</u>
The City Wastewater Department has created the CIP spending schedule in Table 9. However, the approved Budget Program does not allow spending of more than $3.5M in any quarter. All projects must start in 2023. Which single project can be delayed to comply with the spending cap?

Solution:
The only quarter with spending more than $3.5M is Q1 of 2025 with $4.0M, for an excess of $0.5M. Although several projects could be shifted to reduce the total, the following are the only projects that on their own can reduce the total by $0.5M or more:

- Project No. 1, “Influent Pump Station Expansion”, with total $0.7M in Q1, 2025.
- Project No. 9, “Phosphorus Removal Addition”, with total $0.7M in Q1, 2025.
- Project No. 10, “New Chemical Building”, with total $0.6M in Q1, 2025.

Projects No. 1 & 9 would need to be shifted to start in Q1 of 2024, which is not acceptable since all projects must start in 2023.

Project No. 10 can be shifted to start in Q4 of 2023 (a delay of 3 quarters) which decreases the Q1 2025 spending to $3.4M. This is the solution.

Helpful References

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