A SunCam online continuing education course

Water Treatment CIP Management

by

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Course Outline:

Water Treatment Systems
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

Water Treatment Systems

The purpose of a water treatment system is to improve the quality of water by eliminating contaminants. Water treatment systems include a series of treatment processes such as aeration, softening, filtration, and disinfection.

There are several different applications for water treatment, including:

- Drinking water (public distribution or private/industrial supply),
- Industrial process water (boiler, cooling tower, chemical make-up, etc.),
- Irrigation (landscaping, garden, farming, etc.),
- Water recreation (swimming pool, water park, etc.),
- Fish tanks, ponds, and farms,
- Environmental (river flow maintenance, saltwater intrusion control, etc.)
- Purified water (deionized, distilled, heavy, etc.)

This course will focus on water treatment systems for public drinking water distribution. Such water treatment systems are found in the following locations:

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

The water must be treated to become ***potable water***, which means water that is safe for drinking and for food preparation. Drinking water standards are defined in the Safe Drinking Water Act (SWDA), US Code Title 42, Sections 300f & 300g. Maximum contaminant levels are defined for physical, chemical, biological, and radiological substances.

Public water treatment systems must reduce contaminant concentrations below the SWDA standards, as well as complying with state and local regulations. Reliable treatment systems are crucial to human health. There are many incidents of contaminant breakthroughs that have resulted in many sick people and even deaths. See Table 1 for a summary of treatment approaches for each contaminant category.

Table 1: Water Treatment Techniques by Contaminant Category		
Contaminant Category	Example Contaminants	Common Treatment Techniques
Physical	Sediment, Large Organics, Grit	Screening Sedimentation Sand Filtration
Chemical	Nitrogen, Salts, Pesticides, Metals, Toxins Produced by Microorganisms, Medicines, Per- and Polyfluorinated Substances (PFAS)	Coagulation Membrane Filtration Sand Filtration Flocculation Ion Exchange Softening
Biological	Bacteria, Viruses, Protozoans, Parasites	Disinfection Membrane Filtration Sand Filtration
Radiological	Cesium, Plutonium, Uranium	Ion Exchange Membrane Filtration

Water 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.

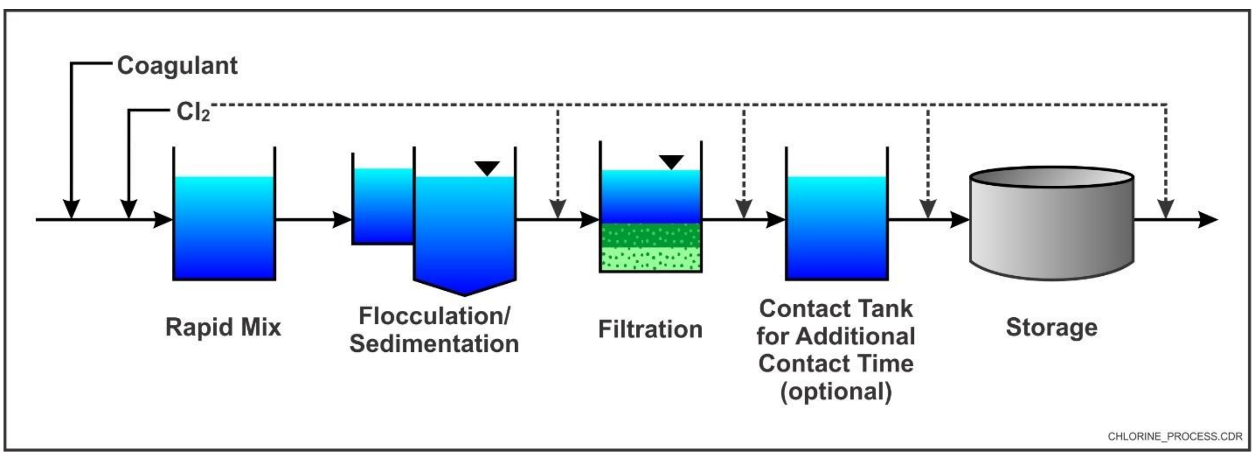


Figure 1: Water treatment system with sand filtration and chlorine disinfection.
Source: frtr.gov/matrix/Disinfection (public domain)

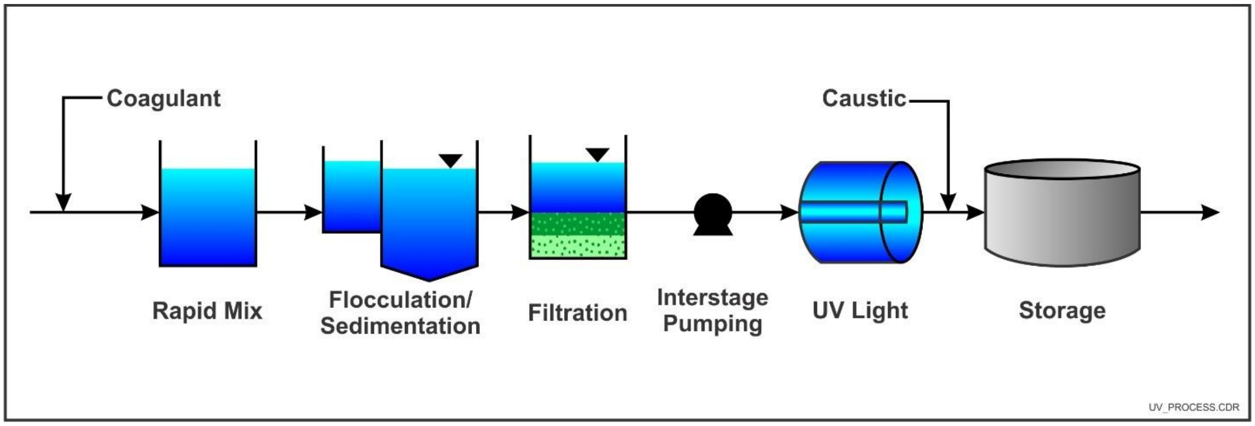


Figure 2: Water treatment system with sand filtration and UV disinfection.
Source: frtr.gov/matrix/Disinfection (public domain)

A large water treatment system is commonly referred to as a Water Treatment Plant (WTP), Water Treatment Facility (WTF), or Water Purification Facility (WPF). See Figure 3 for an example.

Figure 3: Aerial photo of a WTP. In the center are circular lime softener clarifiers. At the bottom is a row of sand filters. At the top are chlorine contact chambers.
Source: www.roseville.ca.us/news/what_s_happening_in_roseville/tour_our_water_treatment_plant_virtually_

The main method for removing pathogens is disinfection. Disinfection is typically the last treatment process before the finished water is sent to storage tanks and distribution. The following are common disinfection methods:

1. Free Chlorine (most common)
2. Chloramines
3. Chlorine Dioxide
4. Ozone
5. UV

The following is a list of potential raw water sources in the order of likelihood for biological contamination. Additional disinfection may be required for Items 5 through 7.

1. Ocean (offshore intake)	Least likely to have biological contamination
2. Deep well	.
3. Rainwater	.
4. Ocean (beach intake)	.
5. Shallow well	.
6. Surface water	.
a. Seepage spring	.
b. River	.
c. Lake	.
d. Canal	.
e. Pond	.
7. Reclaim/reuse water	Most likely to have biological contamination

Other types of contaminants (physical, chemical, and radiological) also need to be identified in the water source. Water treatment processes are often selected based on the water quality of the water source. For example, a WTP with a groundwater source with high levels of heavy metals can be treated with an ion exchange system with cation resin.

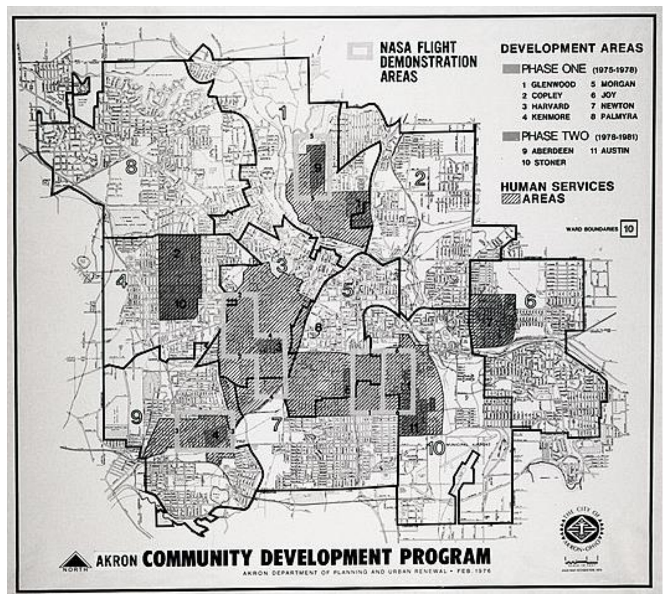
Final treated water (finished water) is often discharged into a concrete basin called a clear well. The finished water is then pumped into storage tanks which may be at the WTP site or located offsite. Water distributions systems transfer the finished water from to individual consumers/customers. The delivered water needs to be pressurized and kept safe for drinking.

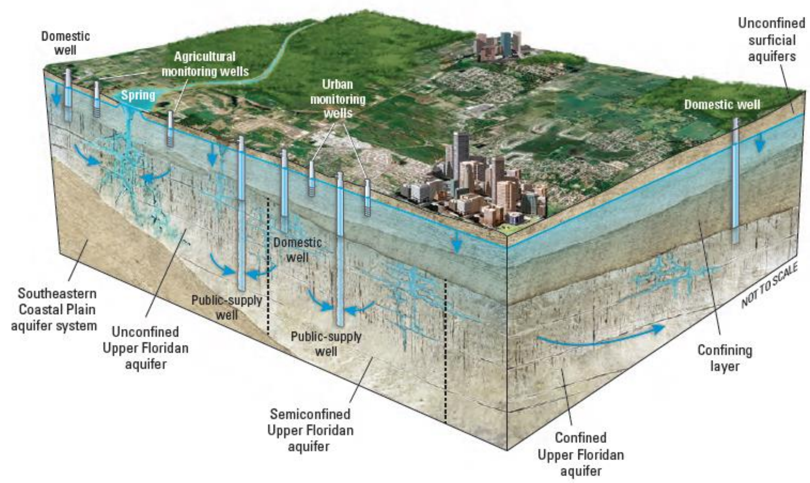
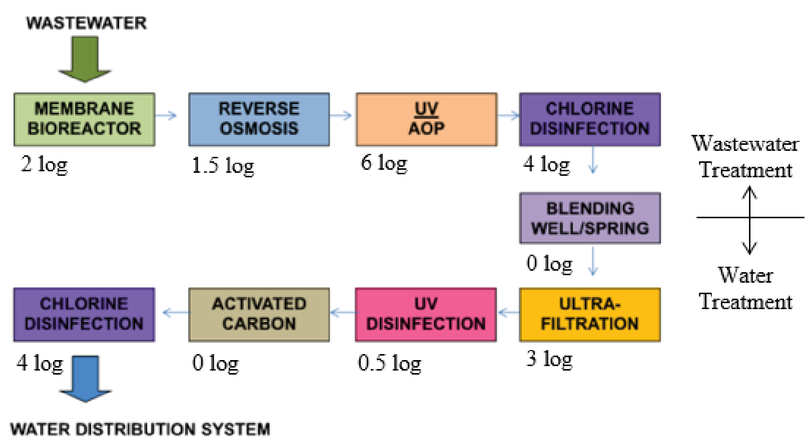
This course focuses on the management of a capital improvement program (CIP), also called a capital improvement plan, for large water treatment systems. Organizations often have similar CIPs for water distribution systems, wastewater treatment systems, and wastewater collection systems, which are addressed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

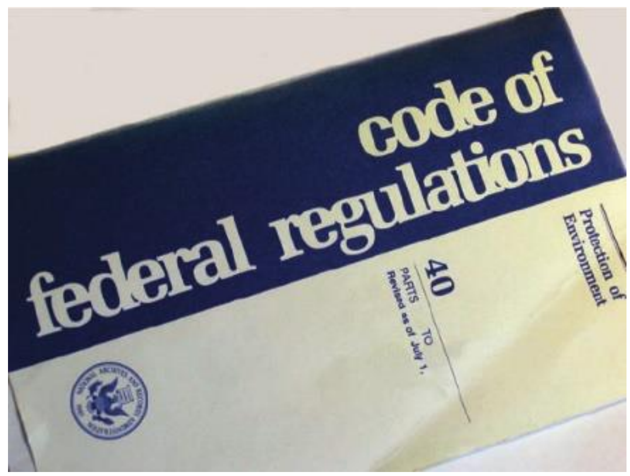
Motivations for Improvements

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

Table 2: Motivations for Water Treatment System Improvements		
Motivations	Description	Example
Develop-ment	Accommodate community growth or a new large user.	 Source: public domain
Climate Change	Protect from rising sea levels and saltwater intrusion for coastal WTPs. Storm hardening of structures. Prepare for water scarcity projections.	 Source: public domain

Water Source Changes	Water sources change over time. New sources may need to be added. Treatment processes are modified based on source water quality.	 Source: public domain
Water Reuse	To conserve water, wastewater and other used waters are recycled as potable water through advanced water treatment processes.	 Source: Example flow diagram for a direct potable reuse system
Water Quality Problems	Upgrades to improve finished water quality and prevent pollutant breakthrough. Assess the performance of existing treatment processes.	 Source: public domain

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, improve backup power, and provide alternative power sources.	 Source: public domain
Regulations	Compliance with new federal or state regulations. For example, recent PFAS (per- and polyfluoroalkyl substances) limits.	 Source: public domain
Funding	Utilize available federal or state funding.	 Source: public domain

Regulations and Standards

Safe Drinking Water Act
The Safe Drinking Water Act (SDWA) gives authority to the Environmental Protection Agency (EPA) to establish and enforce standards that public drinking water systems must follow, including maximum contaminant levels, treatment techniques, monitoring, and reporting requirements. EPA delegates primary enforcement responsibility (also called primacy) for public water systems to states and Indian Tribes.

40 CFR
Title 40 CFR includes regulations for the management of water treatment systems in the following Subchapters:

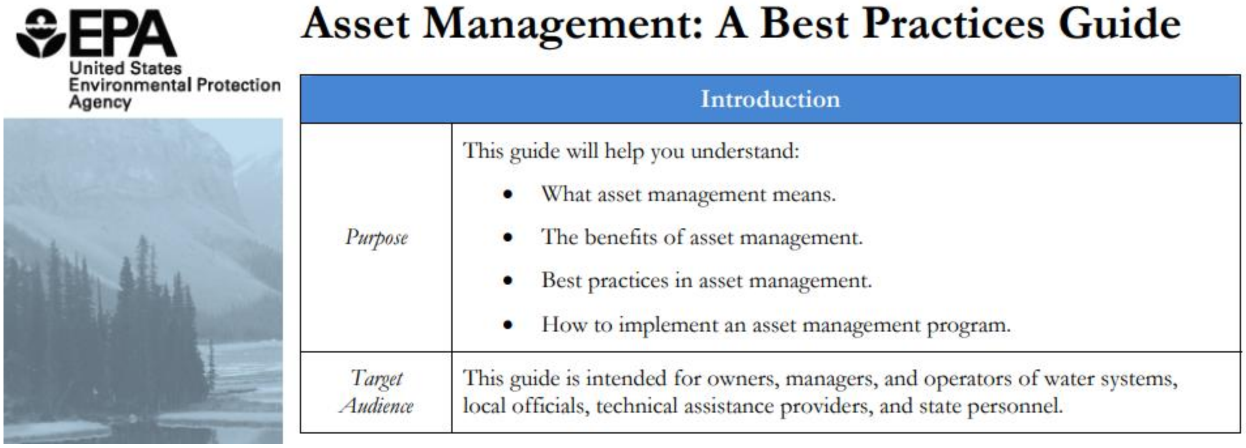
- 40 CFR 141: National Primary Drinking Water Regulations
- 40 CFR 142: National Primary Drinking Water Regulations Implementation

The focus of these regulations is on defining the acceptable contaminant levels in potable water, acceptable treatment methods, protection of water systems from fecal contamination, contaminant monitoring requirements, and reporting requirements.

The sentence in bold can be achieved by asset management and CIP management. Showing compliance with the CFR 40 standards is often required when applying for a grant or federal financial assistance.

Compliance Monitoring
The EPA and authorized states have the authority to monitor, inspect and audit the water quality in community water systems 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”, as shown in Figure 4.



EPA United States Environmental Protection Agency

Asset Management: A Best Practices Guide

Introduction	
Purpose	This guide will help you understand: • What asset management means. • The benefits of asset management. • Best practices in asset management. • How to implement an asset management program.
Target Audience	This guide is intended for owners, managers, and operators of water systems, local officials, technical assistance providers, and state personnel.

Figure 4: Cover page title for the Asset Management EPA paper.
Source: Public Domain

In this document, the EPA provides general principles for managing water treatment and distribution 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. See the flow chart in Figure 5 for the five core areas considered essential for asset management. The EPA document provides advice for assessing each of these areas (also called questions).

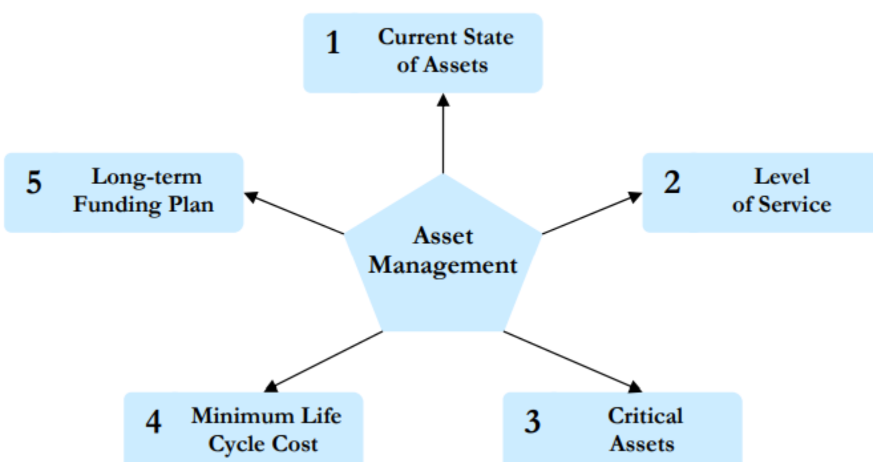


Figure 5: The Five Core Areas of an Asset Management Framework.
Source: Public Domain

Asset management should be implemented to achieve continual improvements through a series of “plan, do, check, act” steps. The above framework guides the planning step for asset management. The recommended steps are as follows:

- Plan: Five core questions framework (short-term), revise asset management plan (long-term)
- Do: Implement asset management program
- Check: Evaluate progress, changing factors and new best practices
- Act: Take action based on review results

A goal of asset management and improvement 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 6 for an EPA graphical depiction of balancing CIP project costs to emergency repair costs.

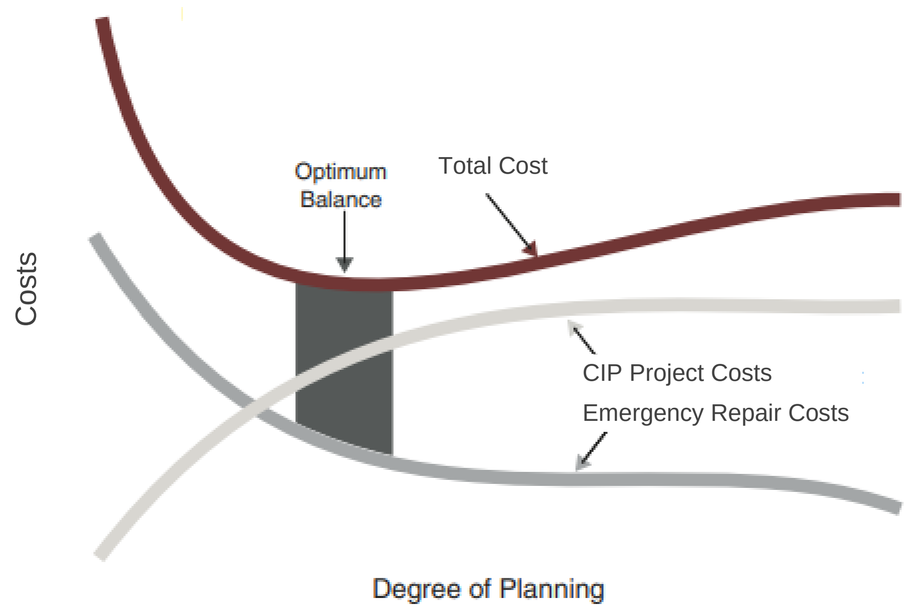


Figure 6: CIP planning chart showing the sum of emergency repair costs and CIP replacement costs based on the degree of planning. There is an optimum balance where just enough planning and CIP projects are done so the total cost is minimized.

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

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 water systems. Risk assessments are a part of CIP management.

States also provide funding for improvement initiatives, such as the replacement of lead pipes or 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 Water Works”, 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
Coating Failure	X			
Equipment Failure	X			
Zero Remaining Useful Life	X		X	
Observed Corrosion, Cracks, or Deflections	X			
Electrical Failure	X			Standby Power
Lack of Redundancy	X		X	
Process Upsets or Permit Violations		X		Public Health
Water Quality Improvement Desired		X		
Flow Demand Increase		X		
New Water Source Added		X		
Process Change or Chemical Change		X		Safety

Step 1 – Gather Information

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

- Drinking water ordinances, approved rates, and tariffs (focus on 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 water treatment system,
- Previous assessment reports,
- Process flow diagrams of treatment system (see Figure 7),
- Water quality data for water source (raw water) and treated water,
- 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).

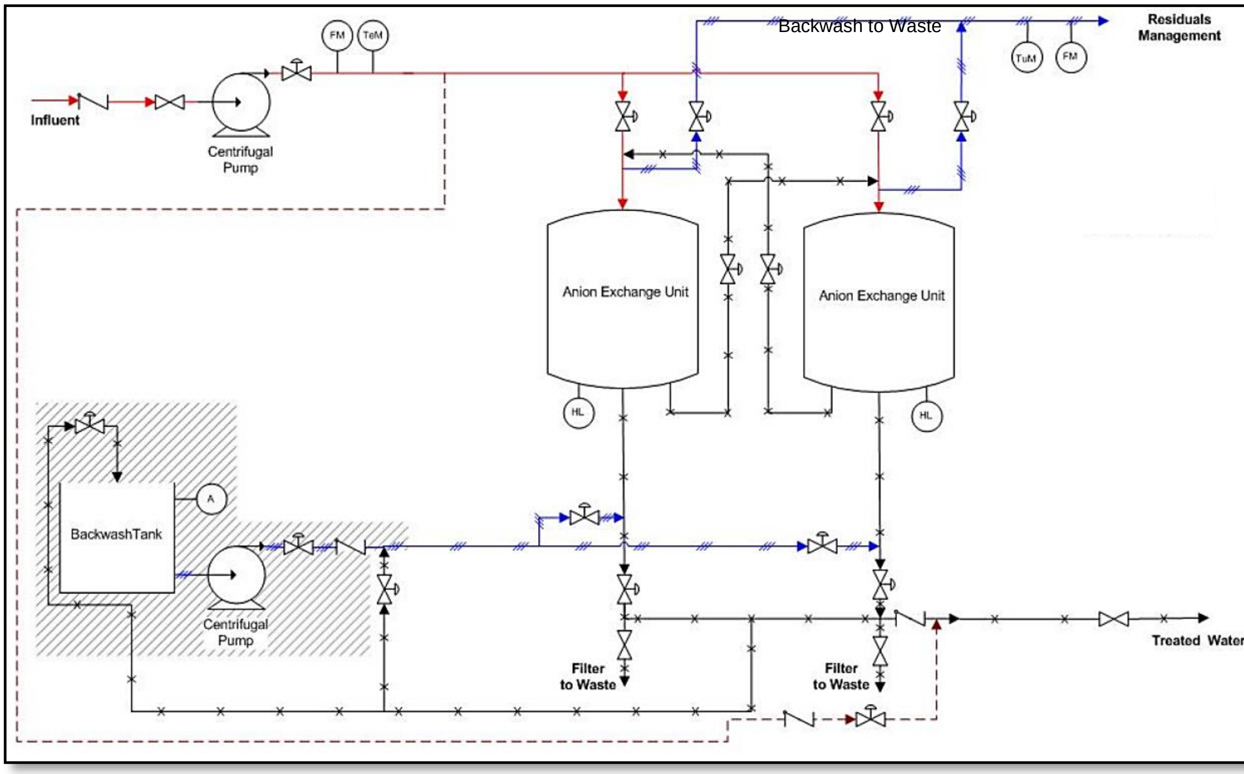


Figure 7: Example PFD with basic features. This drawing could be a starting point for creating a P&ID with control and communication details.

Source: www.epa.gov/sites/default/files/2019-07/documents/wbs-ixclo4-documentation-june-2019.pdf (public domain)

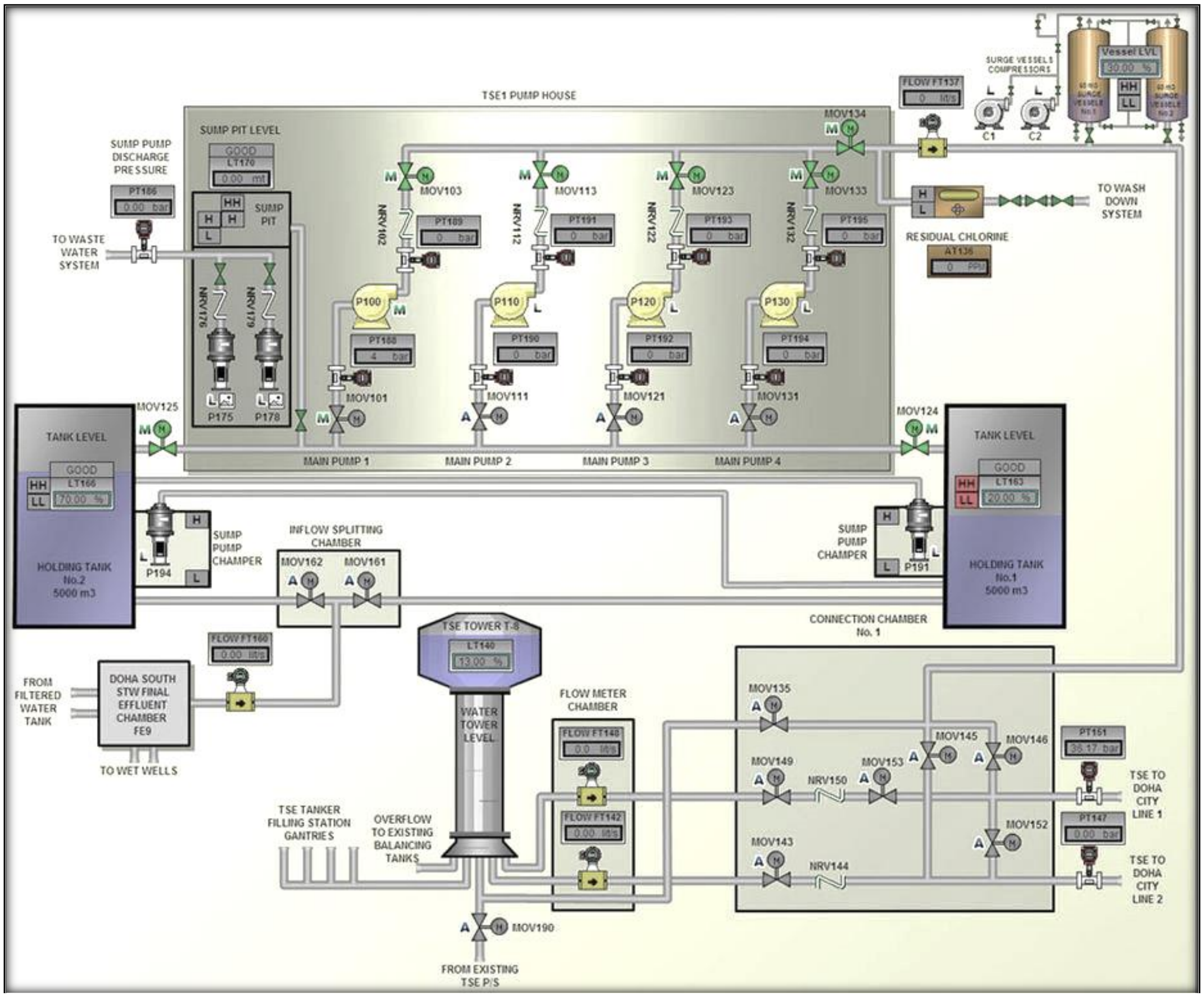


Figure 8: Example SCADA screen showing meter and instrument readings. A historian records these readings on regular intervals. This data helps with performance evaluations and water quality problem troubleshooting.

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 clear well pump station, there should be multiple assessment, including:

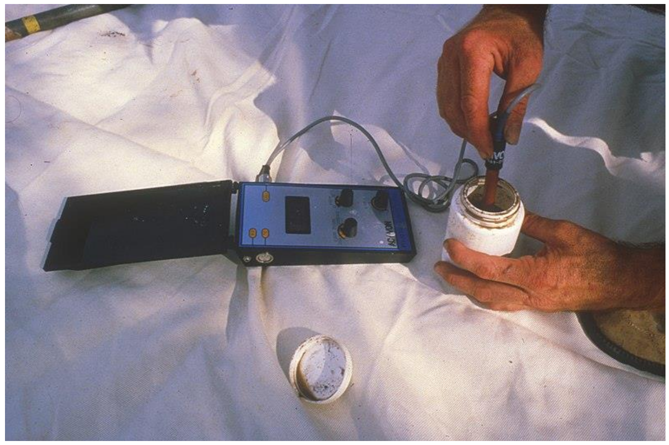
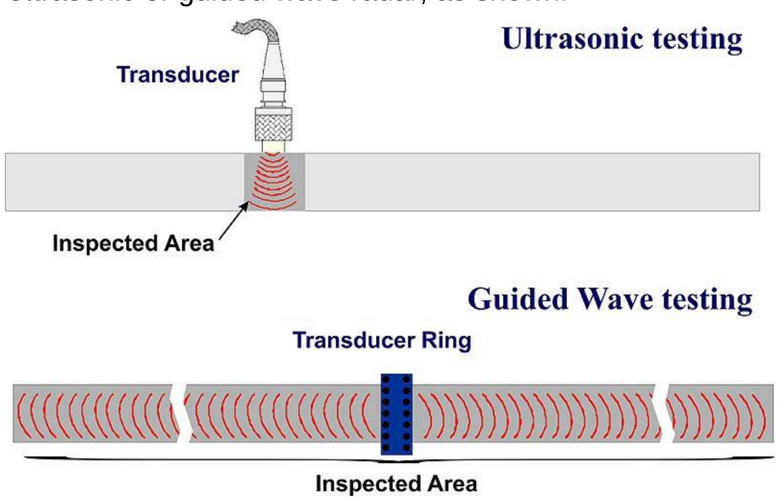
- Mechanical assessment of the pumps and valves (by a mechanical engineer),
- Electrical assessment for power and controls (by an electrical engineer), and
- Structural assessment of the anchorage, coatings, and concrete wet well (by a structural engineer).

The condition assessment process may involve the following steps:

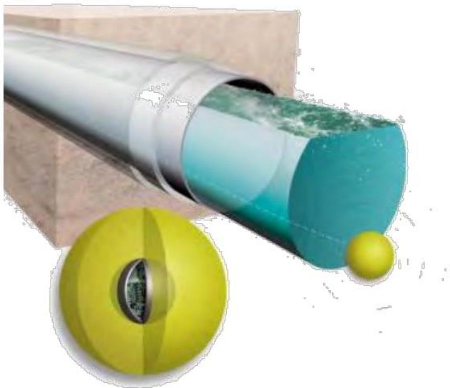
1. Review previous assessment scope and results,
2. Identify areas to assess,
3. Decide on assessment techniques,
4. Define scope of work and solicit a consultant,
5. Perform assessment work,
6. Estimate remaining useful life (see next section),
7. Compile results in a report, and
8. Utilize results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

For Step 3, there are many condition assessment techniques to choose from, as illustrated in Table 4. Some pipes and equipment are challenging to internally inspect for the following reasons:

- Critical equipment and pipes without redundancy cannot be taken down for more than a few hours without impacting the treatment water quality or volume,
- Many tanks need to be drained, sludge removed, and surfaces pressure washed for a proper condition assessment,
- Accessing the inside of many pipes requires removing fittings, valves, and/or cutting open the pipe, and
- Disinfection procedures need to be followed to minimize contamination risks and comply with regulations.

Table 4: Condition Assessment Techniques	
Component	Common Techniques
Piping (Exterior)	○ Soil corrosion analysis (for buried pipe)  Source: commons.wikimedia.org/wiki/File:CSIRO_ScienceImage_1740_Testing_soil_salinity.jpg, CSIRO, CC-BY-SA-3.0 ○ Leak detection techniques ○ Exterior visual inspection ○ Exterior coupon inspection (for PCCP pipe) ○ Exterior acoustic impact echo (for PCCP pipe) ○ Exterior electromagnetic scanning ○ Exterior bracelet probe ○ Ultrasonic or guided wave radar, as shown:  Source: commons.wikimedia.org/wiki/File:UT_vs_GWT.jpg, Sprialboy, CC-BY-SA-3.0

<table>
<tr>
<td>Piping (Internal)</td>
<td>
○ CCTV, as shown:

Source: https://www.northbay.ca/services-payments/water-wastewater/services/camera-inspections/, public domain
○ 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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Concrete Tanks	○ Visual Inspection (by tank manufacturer or structural engineer) including leaks, efflorescence buildup from leaks (see below), cracks, chips, discoloration, or uneven settling.  ○ Coupon inspection, as shown:  ○ Acoustic impact echo, as shown:  ○ Half-cell corrosion mapping ○ Ground-penetrating radar (GPR) ○ Cover meter test ○ Coating/lining thickness measurement ○ Leak testing

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<tr>
<td>Steel Tanks</td>
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- 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)

- Exterior ultrasonic scanning or spot checking, as shown:

- Coating/lining thickness measurement
- Leak testing

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

- Visual Inspection (by tank manufacturer or structural engineer)
- 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

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Pump Stations	○ Visual Inspection, as shown:  Source: www.cctexas.com/detail/onswtp-high-services-pump-building-no-3 (public domain) ○ Coating/lining thickness measurement, as shown:  Source: Author ○ Valve and instrument inspection and functional testing, as shown:  Source: Public Domain ○ Pump manufacturer inspection and function testing ○ Pipe testing (see techniques above) ○ Electrical power and controls assessment

Concrete Vaults	○ Visual inspection, as shown:  Source: www.portland.gov/water/backflow-prevention/backflow-assemblies (public domain) ○ Half-cell corrosion mapping ○ Coupon inspection ○ Acoustic impact echo ○ Valve and instrument inspection and functional testing
Steel Members in Mechanical Equipment	○ 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" allowance is common)

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

</td></tr>
<tr><td>Specialty Process Equipment
</td><td>

Visual inspection
Manufacturer inspection and functional testing
Electrical power and controls assessment

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</table>

<u>Example Problem 1</u>

Project engineer Andrea was tasked with assessing the condition of a steel tank for a solids contact clarifier at the local water treatment plant. She reviewed the shop drawings which show the tank wall is made of 1/2" thick carbon steel with L3x3x3/8 stiffener angles. A corrosion allowance of 1/16” is in the specifications.

Andrea recorded thickness measurements around the tank wall. She found an area with three depressions, as shown below with measurements in inches in green. Is the remaining steel acceptable at these locations?

Solution:

The tank wall should have a minimum thickness of 1/2" minus 1/16” = 7/16”, or 0.44”. All three of the readings (0.304”, 0.360”, and 0.428”) are less than the minimum thickness of 0.44”. Therefore, the remaining steel is inadequate and additional steel reinforcing is prudent to restore the original design integrity of the tank in this area.

Step 3 - Remaining Useful Life

Estimating the remaining useful life of components is very useful in making improvement decisions and for budgeting. Often this is done as part of the condition assessment scope from a consultant.

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. 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.
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 Water Treatment Equipment		
Component	Materials	Estimated Lifespan*
Submerged Steel and Equipment	Standard Coating	30
	Robust Coating	40
	Galvanized	40
	304 Stainless	50
	316 Stainless	60
Water Holding Structures, Tanks, and Wet Wells	Unlined Concrete	40
	Lined Concrete	50
	Coated Steel	60
	Glass Lined Steel	70
	304 Stainless	70
	316 Stainless	80
Chemical Tanks	Linear Polyethylene	10
	Crosslinked Polyethylene	20
	Lined Steel	30
	FRP	40
Drives, Bearings, Motors	Various	20
Pumps, Mixers, Blowers	Various	15
Membranes (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	30
	Copper	40
	Coated Steel	40
	DIP	50
	FRP	50
	PVC & CPVC	60
	HDPE & FRP	60
	PCCP	70
	Polymer Concrete	80
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
A condition assessment was recently performed on a 30 year old concrete structure (unlined) for a sand filter. The structure was found to be in “very good” condition. What is the estimated remaining useful life?

Solution:
The estimated lifespan is 40 years per Table 5, under Water Holding Structures, Unlined Concrete. Estimated remaining useful life is **12.5 years**, per this calculation:

Remaining Useful Life = (Lifespan – Age) x Condition Factor
= (40 – 30) x 1.25 = 12.5 years

Useful Life Worksheet
The EPA Guide entitled “Asset Management: A Handbook for Small Water Systems” suggests using a worksheet for recording and updating information needed for estimating the remaining useful life. See Figure 9 for an example.

Example **System Inventory Worksheet**

Date Worksheet Completed/Updated: 8/14/02

Asset	Expected Useful Life	Condition	Service History	Adjusted Useful Life	Age	Remaining Useful Life
Well 1 (1993)	30	Good		30	9	21
Well 1 pump	10	Good	Rehab (1996)	10	9	1
Well 2 (1993)	30	Good		30	9	21
Well 2 pump	10	Good	Rehab (1998)	10	9	1
Pumphouse (1993)	30	Good		30	9	21
Electrical components	10	Some corrosion	Rehab (1994)	10	9	1
Chlorinator (1993)	10	Good	Rehab (1998)	5	3	2
Storage tank 1 (1993)	40	Good	Rehab (2000) - $17,000	40	9	31
Storage tank 2 (1993)	40	Good	Rehab (2000) - $17,000	40	9	31
Storage tank 3 (2000)	40	Almost new		40	2	38
Distribution System:						
Hydrants (15)	40	Unknown		40	9	11
Valves (45)	40	Unknown	6 valves don't work	40	9	11
6-inch (PVC)	60	Unknown		60	9	51
4-inch (PVC)	60	Unknown		60	9	51
2-inch (PVC)	60	Unknown	Repair breaks (2/year)	60	9	51

Figure 9: EPA inventory worksheet for recording useful life data.

Source: www.epa.gov/safewater, EPA 816-R-03-016 (public domain)

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.)
- 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 10 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

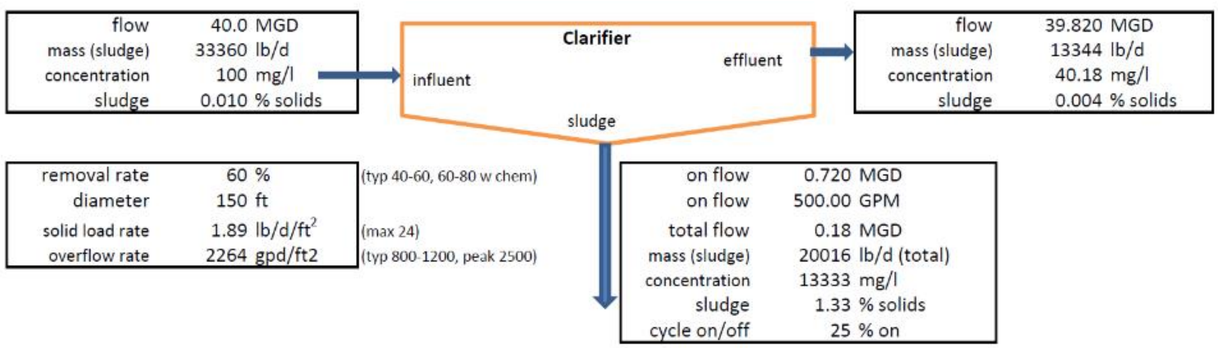

Figure 10: Example mass balance for a clarifier at peak flow. Note the mass of sludge entering the clarifier (33,360 lb/d influent) equals the mass leaving the clarifier (13,344 lb/d effluent plus 20,016 lb/d sludge).

- 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 6).
- 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 the removal of per- and polyfluoroalkyl substances (PFAs) by ion exchange with different media.
- Contaminant transport modeling for analyzing the fate of select pollutants through one or more treatment processes.
- 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 11 for an example of model results.

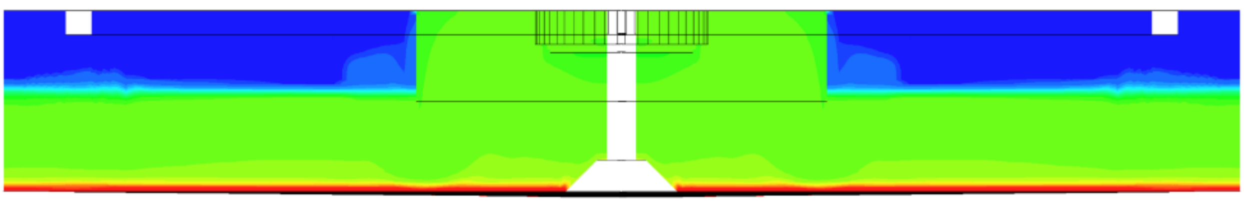

Figure 11: CFD model results for solids concentration of a clarifier. Colors are as follows: dark blue is 10 mg/L, light blue is 1,000 mg/L, green is 3,000 mg/L, and red is 6,000 mg/L.

<u>Step 4 – Field Testing:</u>

- 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 12.

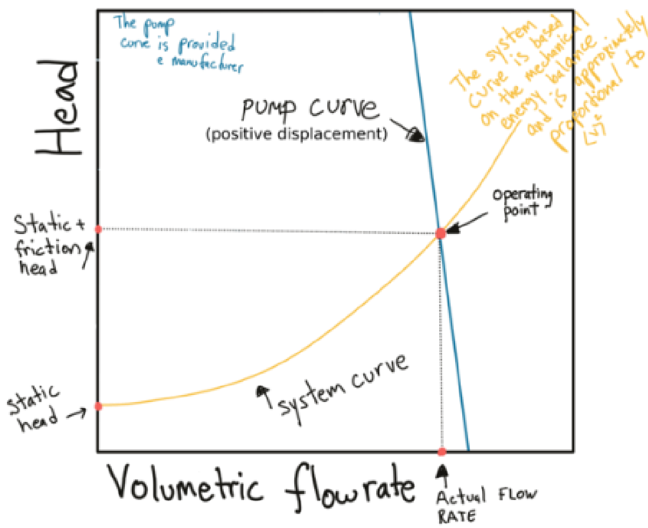

Figure 12: Pump and system curves with operating point based on field testing.
Source: commons.wikimedia.org/wiki/File:Operating_Curves_of_Positive_Displacement_pump.png, Steven Baltakatei Sandoval, CC-BY-SA-4.0

Step 5 – Report and Recommendations:

- Document performance assessment findings and conclusions.
- Create a performance summary table for each process, as shown in Table 6.
- Review performance assessment results with process experts and compile a list of potential modifications to improve performance.

Table 6: Performance Summary – Slow Sand Filters

Parameter	2022 Data [a]	Industry Standard [b]
Filtration rate (m/h) at Average Flow	0.20	0.08 – 0.24
Filtration rate (m/h) at Peak Flow	0.45	0.1 – 0.4
Maximum height of Supernatant water (m)	0.8	0.9
Bed Depth (m)	0.9	0.8 – 1.2
Effective media size (mm)	0.2	0.3 – 0.45
Support bed (m)	0.5	0.4 – 0.6
Turbidity Removal, Average	80%	60 to 85%
Turbidity Removal, Range	51 to 92%	40 to 95%
Effluent Turbidity, Average	0.4	<1.0 NTU
Effluent Turbidity, Range	0.05 to 2.2	N/A

Notes: a) Values in red are outside industry standard
b) Based on 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 to 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 13 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	Filters No. 1 to 8 Hypo Pumps	Raw Well No. 3	
Moderate		Lime Pumps & Mixers	Softeners No. 1 to 4 Acid Feed	Buried Piping	Cl2 Analyzer
Low		Aerators No. 1 & 2 Hypo Tanks	Raw Wells No. 1 & 2 Final Pumps	Raw Well No. 4	
Very Low			Storage Tanks	Lime Silo	Clear Well

Figure 13: 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 13 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

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

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 water treatment and distribution systems.

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 14 for an example Master Plan report table of contents.

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1.1.2 Town Wells and nano-Filtration Facility 1.3
1.2 WTP EXPANSION PROJECT DRIVERS 1.4
1.2.1 Regulatory 1.4
1.2.2 Growth 1.5
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3.4 MICROFILTRATION TREATMENT 3.5
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5.1.2 Alternative 2: Belt Press 5.3
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7.1.2 Alternative #2, Conventional Floc/Sed – Membrane Filtration – GAC 7.4
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8.0 COSTS **8.1**
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8.2 PRESENT WORTH 8.2

9.0 PROJECT RECOMMENDATIONS **9.1**

Figure 14: Example table of contents for a Master Plan report.

Source: http://www.wellingtoncolorado.gov/DocumentCenter/View/1598/masterplan-report-wo-figures-and-appendicies_combined-Bromley-9-12-17?bidId=, public domain

Step 7 - Project Selection

Previous steps helped identify the improvements needed. 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 7 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 7, 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**.

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 7: Example CIP Project Planning Table														
Proj. No.	Potential Project Name	Cost Estimate ($M)	New Develop-ment	Climate Change	Water Sources & Reuse	Water Quality	Remaining Useful Life	High Risk Ranking	Redund-ancy	Qualifies for Funding	Regulatory Needs	Other	No. of Motivations	Cost per Motivation
1	New Raw Water Well No. 6	$4.0	X	X	X				X				**4**	$1.0
2	Softener Rehabilitation	$1.2					X	X					2	$0.6
3	Filter Structure Rehabilitation	$0.8					X	X				Safety Concerns	3	$0.3
4	Clear Well Lining and Baffles	$0.6				X		X					2	$0.3
5	Reverse Osmosis Process Addition	$3.6	X		X	X				X	X		**5**	$0.7
6	Yard Piping Rehabilitation	$0.8					X	X					2	$0.4
7	Transfer Pump Station Replacement	$1.8					X	X	X				3	$0.6
8	New Ground Storage Tank	$2.1	X					X	X				3	$0.7
9	High Service Pump Station Upgrades	$0.7	X				X	X					3	**$0.2**
10	New Chemical Building	$2.2	X	X				X			X	City Council Agenda Item	**5**	$0.4
11	Hurricane Hardening	$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)	$20.6	$12.6	$7.7	$7.6	$4.2	$5.9	$11.1	$8.3	$5.1	$6.1	$5.2	-	-

Example Problem 3

Project Manager Baizhu helped prepare Table 7 and now needs help to select which projects to proceed, while staying within the budget of $8.0M. The goal is to proceed with the greatest number of projects that are highlighted **red** in the last two columns (most motivations and with the lowest cost per motivation). Help Baizhu decide which project(s) should be eliminated and what is the total cost?

Solution:

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

- $4.0M – 1, New Raw Water Well No. 6, 4 motivations
- $3.6M – 5, Reverse Osmosis Process Addition, 5 motivations
- $0.7M – 9, High Service Pump Station Upgrades, $0.2M per motivation
- $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

$11.2M - Total

All total exceeds the $8.0M budget by $3.2M. The following are options for proceeding:

1. Eliminate Project No. 1 to save $4.0M for total $7.2M.
2. Eliminate Project No. 5 to save $3.6M for total $7.6M.
3. Eliminate Projects No. 9, 10, and either 12 or 13. This results in less total number of projects to proceed, so is not further considered.

In comparing options 1 and 2, Project No. 5 has a greater number of motivations (5 versus 4) and a lower cost per motivation ($0.7M versus $1.0M). Therefore, Project No. 5 is a better choice to proceed based on information available.

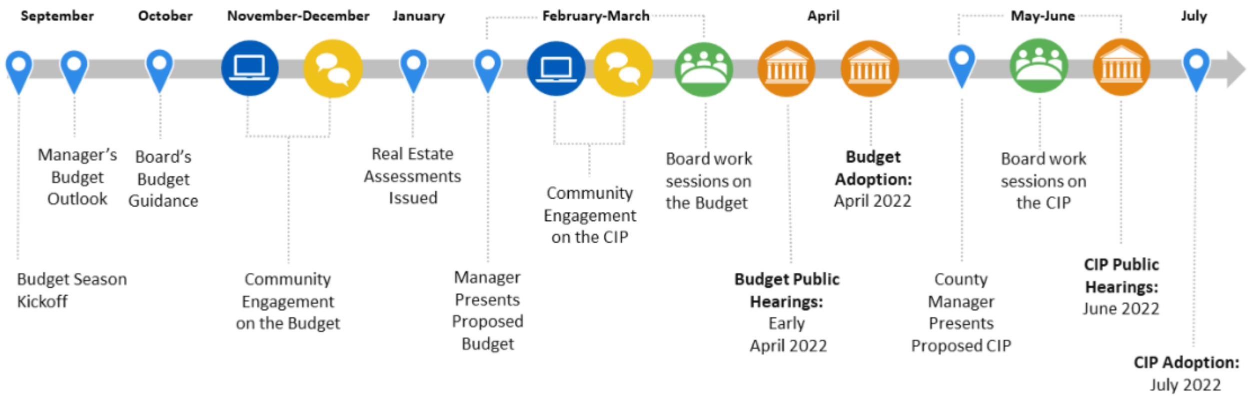
Recommendation is to eliminate Project No 1 and proceed with the following projects for a total cost of $7.2M:

- $3.6M – 5, Reverse Osmosis Process Addition, 5 motivations
- $0.7M – 9, High Service Pump Station Upgrades, $0.2M per motivation
- $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

$7.2M – Total

Spending Projections

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 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. The CIP Program Budget may require annual 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. To avoid major differences, careful scheduling and detailed spending projections for each project are required.

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. 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 8 for an example, which is also provided in excel format as free software with this course.

Table 8: 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	New Raw Water Well No. 6	$4.0	-	$0.10	$0.40	$0.20	$0	$0.10	$0.60	$0.60	$0.80	$0.50	$0.50	$0.20
2	Softener Rehabilitation	$1.2	-	$0.10	$0.10	$0	$0	$0.10	$0.20	$0.30	$0.30	$0.10	-	-
3	Filter Structure Rehabilitation	$0.8	-	$0.05	$0.05	$0	$0	$0.10	$0.30	$0.20	$0.10	-	-	-
4	Clear Well Lining and Baffles	$0.6	-	-	$0.05	$0.05	$0	$0	$0.10	$0.20	$0.10	$0.10	-	-
5	Reverse Osmosis Process Addition	$3.6	$0.05	$0.15	$0.20	$0.20	$0	$0	$0.20	$0.60	$0.80	$0.70	$0.50	$0.20
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	$0.50	$0.20	-
8	New Ground Storage Tank	$2.1	-	-	-	$0.20	$0.20	$0	$0	$0.20	$0.40	$0.60	$0.40	$0.10
9	High Service Pump Station Upgrades	$0.7	-	-	$0.10	$0.10	$0	$0	$0.10	$0.10	$0.20	$0.10	-	-
10	New Chemical Building	$2.2	-	$0.05	$0.05	$0.20	$0.10	$0	$0	$0.20	$0.30	$0.50	$0.60	$0.20
11	Hurricane Hardening	$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	$0.10	$0.10	$0.10	-	-	-	-	-
13	Instrumentation Upgrades	$0.3	-	$0.05	$0	$0	$0.05	$0.10	$0.10	-	-	-	-	-
14	Actuated Valve Replacements	$0.6	-	-	$0.02	$0.02	$0	$0	$0.06	$0.20	$0.20	$0.10	-	-
	Quarter Total	$20.6	$0.15	$0.60	$1.17	$1.17	$0.50	$0.70	$2.16	$3.35	$4.20	$3.50	$2.40	$0.70
	Annual Total		$3.09				$6.71				$10.80			

Example Problem 4

A City Utility Department has created the CIP spending schedule in Table 8. 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 $4.2M, for an excess of $0.7M. Although several projects could be shifted to reduce the total, the following is the only two projects that on its own can reduce the total by $0.7M or more:

- Project No. 1, "New Raw Water Well No. 6", with total $0.80M in Q1, 2025.
- Project No. 5, "Reverse Osmosis Process Addition", with total $0.80M in Q1, 2025.

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

Project No. 5 can be shifted to start in Q4 of 2023 (a delay of 3 quarters) which decreases the Q1 2025 spending to $3.4M.

Helpful References

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