Water Treatment Process

Troubleshooting Guide

for

Class A and Class B Operators

Supplement to

Small Water Systems Training Manual

9/2005

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Chlorination Troubleshooting Questions

1. On a gas chlorinator, the Injector vacuum reading is low. Injector water supply is 70 PSI. What Is the probable cause ?

    a. Insufficient water pressure at the orifice
    b. CPRV (chlorine pressure regulating valve)
    c. injector orifice needs adjustment
    d. flow restricted though the Injector orifice

2. ssure gauge from the chlorine cylinder reads 90 b. The gauge on the chlorinator reads 8 b. The chlorine residual is dropping. What is the probable cause?

    a. faulty injector (no vacuum)
    b. restriction in supply system
    c. chlorine cylinder is going empty
    d. CPRV is dirty and plugged

3. On a gas chlorinator, the injector vacuum reading is low. The injector water supply is 70 psi, the probable cause is?

    a. excessive back pressure al the application point
    b. CPRV (chlorine pressure regulating valve dirty
    c. wrong orifice in the injector
    d. flow restricted through the injector orifice

4. What Is the corrective action to be taken in the question above?

    a. change out orifice
    b. adjust injector orifice
    c. clean the CPRV with acid
    d. decrease water pressure to Injector

5. Pressure in the chlorine header reads 110 lbs. The gauge on the chlorinator reads 5 lbs. Chlorine residual is dropping. What Is the probable cause?

    a. Injector throat is plugged (no vacuum)
    b. restriction in water supply system
    c. pig tail on the chlorine cylinder is froze up
    d. CPRV is plugged

6. A liquid chlorine spill can be controlled with?

    a. $Ca\ (OH)_2$
    b. NaOH
    c. H_2O
    d. H2 SO4

7. When a chlorinator will feed OK at maximum output, but will not control at low rates, the most probable cause is:

    a. the vacuum regulator valve is closed or stuck
    b. the flow of water is too low
    c. clogged throat
    d. plugged restrictor

Disinfection By-Product Troubleshooting Questions

1. Which one of the following would lead to the least amount of trihalomethane information ?

    a. a high concentration of natural organics
    b. a high water temperature
    c. high pH
    d. low pH

2. You have a minor THM problem and decide to add ammonia to the filter effluent. You are concerned about taste and odor problems. Therefore you should add ammonia at a ratio, which will produce which compounds?
    a. Monochloromines
    b. Dichloromines
    c. Dichloromines
    d. Chlorophenols
    e. Haloacetic Acids

Lime Softening Troubleshooting Questions

1. You are operating a lime softening plant which produces a finished water with a total hardness of 80 mg/l as Ca CO3, and a Langelier Index of +0.6, What is the problem?

    a. the finished Water is aggressive
    b. too much CO2 was added
    c. the finished water hardness is too low
    d. the finished water will be scale forming

2. What caused the problem in the question above?

    a. the pH was too low
    b. the excessive CO_2 increased the L. I.
    c. too much blending
    d. excessive calcium carbonate

3. You are using pH to determine lime addition in a lime softening plant. The pH meter indicates a pH of 10 but after you have added lime you determine that the dose was excessive. What is the most probable cause?

    a. The water contained an excessive amount of pH
    b. PH was actually 9
    c. The water contained excessive alkalinity
    d. The meter read 10 when it was actually much higher
    e. The lime slaker has malfunctioned

Stabilization and Taste and Odor Troubleshooting

1. Black water complaints may be caused by

    a. corrosion of copper lines
    b. corrosion of ductile iron pipes
    c. sulfide corrosion of iron lines
    d. microbial activity

Problem: Marshy, or woody odor. Use this to answer questions 50, 51, and. 52.

2. Possible cause

    a. increase in organisms in water supply
    b. increase in Actinomycetes in water supply
    c. bacteria increase
    d. algae increase

3. Required check

    a. check for nitrates
    b. check for coliform
    c. check for organisms
    d. check for algae

4. Possible solution

    a. increase chlorination
    b. add activated carbon
    c. apply algaecide
    d. apply potassium permanganate

Filtration Troubleshooting Questions

1 Persistent filter blinding may be overcome by

a. changing media
b. changing or adjusting coagulant
c. improving backwash
d. using filter aids

2. Mud ball formation in a filter bed may be caused by

a. low surface scour rates
b. improper coagulation
c. sludge removal rates
d. rapid mix speed

4. What should you do if test results indicate a filter mud ball volume of 2.6%

a. Nothing, this is good
b. Add a polymer
c. Reduce the coagulant dose
d. "Bump" the filter gravel
e. Extend the backwash duration.

5. When a filter wash is uneven, the spots violently over washed might result in which of the following?

a. Damage to sludge removal equipment
a. Cause the sand grains in this area to cement together.
b. Cause an increase in the sand effective size.
c. Overturn the gravel layer, allowing sand to displace it.

6. When cold water starts to warm up, a condition that can occur in the media of a filter is called,

a. Mudballing
b. Jet action
c. Bed shrinking
d. Air binding

7. Air binding of a filter can be caused by,

a. The reduction of pressure resulting from operating under a negative head
a. An increase in the temperature of the water during filtration
b. The release of oxygen by algae collected within the filter
c. All of the above

8. Some idea of the amount of filter media growth can be indicated by.

   a. Periodic sieve analysis of the media
   b. Periodic measurements of the distance from the top of the clean filter to the trough weir
   c. Periodic determinations of the percent solubility of the media in hydrochloric acid
   d. All of the above

Sedimentation Troubleshooting Questions:

1. You operate a surface water plant that uses an up-flow clarifier, has a raw water pH of 7.4 and an alkalinity of 260 mg/l. Each spring as the weather changes, you have a severe taste and odor problem. What change might you consider for the clarifier to minimize this problem?

   a. Add additional coagulant and polymer
   b. Increase the amount of activated carbon in the slurry
   c. Change the through-put rate to the Clarifier
   d. Increase the sludge blanket depth
   e. Increase the amount of prechlorination

2. In and up-flow clarifier, when you want to increase the depth of the slurry, without increasing its volume or density, what would you do?

   a. Increase the rising rate
   b. Raise the weirs
   c. Slowly decrease the flow rate to the Clarifier
   d. Rapidly increase the flow rate to the Clarifier
   e. Rapidly increase the overflow rate

3. It is in the middle of the summer and you are having a breakdown in the coagulation process in our up-flow clarifier due to algae, this problem occurs only in the late afternoon, with periods of good operation before and after this problem period. What changes should you make during the problem periods to improve the finished water quality?

   a. Allow the Sludge blanket to build
   b. Increase the amount of activated carbon in the slurry
   c. Increase the slurry level
   d. Increase the sludge blanket depth
   e. Reduce the sludge blanket depth

Coagulation and Flocculation Troubleshooting Questions:

1. An inspection of your Coagulation/Flocculation filtration plant yielded the following problems. Match the corrective action for each condition cited.

   Observed Conditions (match with number below)

   1. Floc as it enters the basin is large and sheared
   2. Water has a milky appearance with a bluish tint
   3. Floc size increases in the flocculation basin then starts to break up.
   4. Floc rapidly settles in the first part of the sedimentation basin.

   Corrective Actions

   a. Mixing intensity of the downstream flocculator is too high
   b. Excessive Coagulant dosage
   c. Excessive alum dosage
   d. Flash mixer is set too high

   a. d,b,a,c
   b. a.c.d.b
   c. c.d.a.b
   d. d,c,a,b

2. You have adverse changes in the raw water temperature. It would be best to adjust the flash mixer but this is not possible in your plant. Which action below would be the most appropriate?

   a. Reduce the amount of coagulant chemical
   b. Increase the amount of coagulant chemical
   c. Increase the pH with soda ash
   d. Add an ionic filter aid chemical polymer
   e. Adjust the mixing intensity of the flocculator

3. You have observed that the floc as it enters the flocculation basin is not well dispersed throughout the flow. What is the most likely problem?

   a. No problem, it will ix as it gets to the sedimentation basin
   b. Flash mixer too slow
   c. Coagulant dose too high
   d. Feed rate too high
   e. Polymer addition needs to be increased

4. You raw water alkalinity increased from 230 mg/l to 235 mg/l and the pH to 7.9. Your chlorine residual then dropped below acceptable limits. What is the most likely cause of this condition?

    a. Excess alkalinity reacted with the chlorine
    b. Chlorine has been converted to hypochlorous acid
    c. Chlorine has reacted with mineral compounds that raised the pH
    d. There has been an increase in hypochlorite

5. You have been using dry cationic polymer as a coagulant aid at a solution concentration of 5%. You converted to using an anionic dry polymer at the same concentration and it would not feed properly. What is the most probable cause?

    a. Excessive molecular weight
    b. Excessive mixing
    c. Mixing time not long enough
    d. Too little polymer viscosity
    e. Chlorine interference

Guide #1 Hypochlorinator

Observation	Probable Cause	Check	Remedy
1. Inconsistent Bleach Feed	1. Feed tube has an accumulation of carbonate scale. 2. Lack of Cleaning.	1. Remove kinks, bends or sags in line. 2. Feed pump or tubing has carbonate accumulations	1. Clean pump and tubing with muriatic acid solution and flush with vinegar more frequently 2. Pump solution through pump, lines, and valve to clean.
2. Low Chlorine Residual	1. Improper Dosage 2. Chlorine solution has lost strength, (light, heat or long storage time.) 3. Destruction of chlorine residual by inorganic reducing compounds, i.e. Fe++, Mn++, H2S or by organic material.	1. Check Feed Rate 2. Check storage location, condition or exposure to sunlight or heat. 3. Perform water quality checks, i.e. temperature, pH, turbidity, reducing inorganic agents and TOC increases.	1. Clean deposits from bottom of basins. 2. Flush sediments from system.
3. Poor Coliform Kills	1. Poor mixing 2. Insufficient dose 3. Insufficient contact time 4. Short circuiting 5. Chlorine is in the form of chlororganics and chloramine	1. Clean injection points 2. Check Chlorine dose 3. Calculate CT values	1. adjust inadequate dosage. 2. Move feed points
4. Unit not Feeding Properly	1. Equipment malfunction	1. Check to see that there is hypochlorite solution 2. Check internal mechanisms, i.e damaged diaphragm, weak springs, and gaskets. 3. Check integrity of drive belt and belt tension 4. Check poppet valve	1. Refill solution tank 2. Clean mechanical drives. 3. Replace damaged parts.

Guide #2 Gas Chlorination			
Observation	**Probable Cause**	**Check**	**Remedy**
1. Injector Vacuum Reading Low	1. Flow restrictions. 2. Improper water pressure.	1. Remove kinks, bends or sags in line. 2. Pump or tubing has carbonate accumulations 3. Injector water supply system does not supply needed pressure. 4. Check vacuum over a full range of flows, i.e. low, half and full.	1. Clean pump and tubing with muriatic acid solution and flush with vinegar more frequently 2. Pump solution through pump, lines, and valve to clean. 3. Pump or line may have restriction. Ensure proper pump output is proper in reference to pump curve.
2. Leakage of Chlorine (see Response Procedures below)	1. Damaged gasket. 2. Loose connection	1. Check Joint Connections 2. Check around valve stems 3. Check at valve discharge outlet.	1. Replace gasket or tighten connections. 2. Reset vacuum in accordance with manufacture's recommendations
3. Chlorinator will not Reach Maximum Output	1. Faulty Injector (no vacuum). 1. Flow Restrictions in supply. 2. Leaks in system. 3. Wrong Orifice (too small.)	1. Check for restrictions at orifice. 2. Check supply system for restrictions 3. Examine size opening of orifice	1. Remove obstructions 2. Leaks can be identified with spray ammonia mist or with ammonia soaked rag. 3. Make needed repairs to system. 4. Replace orifice if too small
4. Chlorinator will feed OK at Maximum Output but will not control at low rate	1. Vacuum regulating valve is malfunctioning. 2. If equipped with Chlorine Pressure Reducing Valve (CPRV) it is malfunctioning	1. Remove valve and clean. 2. Check for any damage to valve components	1. Repair diaphram and valve components. 2. Clean CPRV cartridge, CPRV diaphragm and CRPV gaskets.

Guide #2 Gas Chlorination

Observation	Probable Cause	Check	Remedy
1. Chlorine will not feed	1. Chlorine Cylinder empty 2. Flow restrictions 3. Damaged Piping.	1. Pressure form cylinder should be between 20 and 40 psi.	1. Replace cylinder if empty. 2. Remove restrictions or repair damaged piping.
1. Leakage of Chlorine (see Response Procedures below)	1. Damaged gasket. 2. Loose connection	1. Check Joint Connections	1. Replace gasket or tighten connections. 2. Reset vacuum in accordance with manufacture's recommendations
1. Variable vacuum control. Formerly working well, now will not go below 30%.	1. Problem with CPRV	1. CPRV is likely obstructed	1. Clean CPRV
1. Variable vacuum control. Reaches full feed, but will not go below 50% feed. CPRV OK	1. Signal Vacuum is too high	1. Remove valve and clean. 2. Hole in Diaphram	1. Replace diaphragm. 2. Clean dirty filter disks. 3. Clean converter nozzle.
1. Variable vacuum control. Will not go to full fee. Gas pressure is OK and CPRV is OK.	1. Plugged (rate valve) restrictor 2. Air leak in signal	1. check at rate valve outlet connection	1. Remove restriction. 2. Repair air leak.
1. Freezing in Rotameter	1. Chlorine rate too high 2. Restriction in orifice	1. check at rate valve outlet connection	1. Lower feed rate 2. Remove restriction
1. Rotameter float will not fall to bottom in off or in operating position. 2. Rotameter float does not rise or fall smoothly when control knob is rotated.	1. Leaks in diaphragm or scared surfaces in pressure regulating valve. 2. Obstruction or dirt in V-notch plug 3. Feed Rate is too high	1. Check diaphragm and sealing surfaces for leaks. 2. Disassemble V-notch assembly	1. Clean or replace parts as needed.
1. No injector vacuum at gas inlet to injector; operating and discharge pressures are OK	1. Injector check valve is not opening	1. Disassemble and examine for damage to diaphragm or for obstruction	1. Repair or replace as needed.

Guide #3 Direct Mount Gas Chlorination

Observation	**Probable Cause**	**Check**	**Remedy**
1. Water in Chlorine Metering Tube.	1. Deposits in seat of check valve 2. Check valve distorted by high pressure.	1.Examine check valve and check valve seat.	1. Clean deposits from check valve seat with muriatic acid. 2. Replace distorted valve.
1. Water venting to atmosphere.	1. Excess pressure in vacuum regulator.	1. Examine vacuum regulator operation	1. Pull regulator and allow chlorinator to pull air until dry. 2. Reposition vacuum regulator and observe for proper operation.
1. No indication on flow meter when vacuum is present.	1. Vacuum leak due to bad or brittle vacuum tubing, connections, rate valve, O-rings or gasket on top of flow meter.	1. Check for leaks. 2. Disassemble rate valve. 3. Examine parts for wear of obstructions.	1. Tighten connections and observe for proper operation. 2. Disassemble and remove obstructions. 3. Replace damaged parts.
1. There is and indication on flow meter but air is present not chlorine gas.	1. Gasket below meter tube is leaking. 2. Vacuum regulator obstructed	1. Check for leaks. 2. Check for obstructions in regulator.	1. Tighten connection. 2. Replace damaged elements. 3. Remove obstructions from regulator.

Guide #4 DBP - Source Water Changes			
Observation/Metric	**Probable Cause**	**Check**	**Remedy**
1. DBP Significant Excursion and increase in TOC in Source Water following **Wet Weather**. **TOC, SUVA** **PH, Alkalinity** **Flow Rate** **Temperature** **Turbidity**	1. Heavy Rainfall, flooding, or or algae bloom. 2. Source Water turnover. 3. Surface water is intruding into groundwater supply.	1. Rainfall, reservoir level or flow increases. 2. Temperature changes that cause water stratification mixing, 4. For high seasonal temperatures causing upwelling of organic materials 5. Alkalinity and pH.	1. Run jar test for coagulant changes or for enhanced coagulation to reduce incoming TOC. 2. Identify alkalinity and pH changes for possible adjustment. 3 Perform more frequent TOC monitoring and initiate removal actions.
1. DBP Significant Excursion and some increase in TOC in Source Water following **Dry Weather** event **Bromide Concentration** **TOC** **PH, Alkalinity and TDS** **Temperature** **Flow Rate/ Detention Times** **Turbidity**	1. Brackish water Intrusion. 2. Ground Water quality changes due to aquifer water level decline	1. Check Bromide levels in Source Water. 2. Perform water quality checks, i.e. temperature, pH, turbidity, reducing inorganic agents and for TOC increases.	1. Run jar test for coagulant changes or for enhanced coagulation to reduce incoming TOC. 2. Identify alkalinity and pH changes for possible adjustment.
1. DBP Significant Excursion after **Source Water Supply Changes** incorporated. **TOC, SUVA,** **pH and Temperature**	1. Source water supplies have different levels of TOC.	4. Determine water quality from source water points.	3. adjust coagulant dosage based on jar test. 4. Move to other source water feed points

Troubleshooting Guide #5 DBP – Process Upsets in Water Treatment Plant			
Observation/Metric	**Probable Cause**	**Check**	**Remedy**
1. DBP Significant Excursion is noticed following changes in **Coagulation Practices**. **pH** **Coagulant Dose** **Polymer Dose** **Alkalinity** **TDS** **Flow Rate**	1. Coagulant or Flocculation equipment malfunction. 2. Coagulant and/or pH not adjusted for source water conditions. 5. Feed pump failure or operation at improper rates 6. Flow rate has significantly changed resulting in changes to water quality held in storage. 7. There has been a change in coagulant or coagulant aid.	1. Equipment maintenance records, calibrations and settings. 5. Feed equipment, coagulant dose applied and pH trends. 6. Changes in alkalinity or higher levels of TDS in source water. 7. Check for changes in coagulant or coagulant aid	1. Repair and recalibrate feed equipment as needed. 2. Identify alkalinity and pH changes for possible adjustment (high pH will adversely affect coagulation.) 3. Run enhanced coagulation jar tests and reset chemical addition.
1. DBP Significant Excursion is noticed following changes in **Chlorination Practices**. <u>**Total and Free Chlorine Residuals**</u> **Temp, pH, Turbidity and TOC**	1. Changes in dosing at a plant location is producing higher levels of DBPs. 2. Chlorine dose is too high for conditions.	1. Check Bromide levels in Source Water. 2. Perform water quality checks, i.e. temperature, pH, turbidity, reducing inorganic agents and for TOC increases.	1. Plot chlorine demand curve and reset dosage to achieve desired residual. 2. Adjust chlorine dose based on pH.
1. **Prechlorination** has been initiated to control tastes or odors. **Free Chlorine Dose/Residual**	1. Prechlorination is causing premature DBP reactions prior to removal of TOC.	1. Determine DBP formation potential.	1. Move point of chlorine application.

Troubleshooting Guide #5 DBP - Process Upsets in Water Treatment Plant (continued)			
Observation	**Probable Cause**	**Check**	**Remedy**
			1.
1. DBP Significant Excursion noticed with Changes in **Chlorine Residual** in plant processes with no chlorine dose increases **Free Chlorine Residual** **pH** **TOC, Turbidity** **Flow Rate** **Detention Times in Basins**	1. Source water quality has changed. 2. Plant flow has significantly changed, decreasing detention detention times through plant facilities. 3. pH has changed resulting in more reactive disinfectant.	1. Determine source water quality. 2. Check for equipment failures, chlorine feed calibration and for improper chlorine feed rates. 3. Chlorine feed rates are not being flow paced.	2. Decrease chlorine feed to establish necessary in-plant residuals 3. Repair and/or recalibrate equipment. 4. Calibrate chlorine monitoring equipment, including hand held test equipment.
1. DBP Significant Excursion noticed combined with upset in **Sedimentation Basin**. **Sludge Blanket Depth** **Clarifier Effluent Turbidity** **Flow Rate** **Weir Conditions for Short Circuiting** **Velocity Currents**	1. Excess sludge build up in settling basin causing resolublization of organics. 2. Carry over of organic solids has occurred and is combining with chlorine forming DBPs. 3. Higher flow has decreased the amount of organics removed in the sedimentation tank,	1. Check current sludge blanket levels and previous records to determine if carryover has occurred. 2. Check hydraulic loading rates to clarifier to determine if short circuiting has occurred 3. Check weirs for solids carryover.	1. Lower sludge blanket levels in the sedimentation tank. 2. Clean weirs as needed. 3. Ensure that baffles are in place and properly set.

Guide #6 **DBP - Process Upsets in Water Treatment Plant (continued)**			
Observation	**Probable Cause**	**Check**	**Remedy**
	1.	1.	1.
1. DBP Significant Excursion noticed with **Filter Performance** problem. **Filter Effluent Turbidity** **Chlorine Residual in Filters** **Filter Turbidity Spikes following backwash** **Filter Loading rates and duration** **Length of Filter Runs** **GAC EBCT and TOC removal efficiency**	2. There has been a turbidity or colloidal breakthrough associated with longer filter run(s) or backwash return.. 3. High chlorine residual was retained in filters for an extended period. 4. Filters were significantly overloaded by higher flow rates. 5. GAC filter adsorptive capacity is exhausted.	2. Check length of filters runs, turbidity and head loss at backwash. 2. Check Coagulation and Flocculation Process. 3. Check Sedimentation operation. 4. Check for hydraulic filter overloading 6. A filter has been taken off-line causing others to run at too high a rate. 7. Chlorine is being added ahead of GAC filter	2. Verify proper backwash and headloss operation, adjust Backwash Cycle as needed. 3. Make prefilter process control adjustments as required.
1. DBP are higher coming out of **Clearwell**. **Flow Rate** **Detention Time in Clearwell.** **<u>Continuous Plant (not batch) operation.</u>** **TOC or Turbidity increases out of clearwell.**	1. There are dead zones in the clearwell. 2. There is excessive sediment in clearwell.	1. Check hydraulic detention time in clearwell. 2. Check maintenance records for last sediment removal.	1. Reduce storage volume. 2. Clean sediment from clearwell
1 DBP are higher following **Maintenance** activities. **Residual Chlorine Levels at select points in distribution system**	1. Flow patterns or retention times have been disrupted 2. Sediment has been re-transported into treatment processes.	1. Check Maintenance Records	1. Re-establish proper equipment operation.

Guide #7 DBP - Water Distribution System Contributors

Observation	Probable Cause	Check	Remedy
1. DBP Significant Excursion occurs in **Distribution System** at select points **Free/Combined CL Residual**	1. Water age is excessive allowing reaction between free chlorine and TOC.	1. Determine water age in water distribution system.	1. Initiate corrective flushing program. 2. Install automatic flush valves
1. DBP Significant Excursion are occurring in Distribution System following long period of E**xtended Hot Weather**. **Free/Combined CL Residual** **HPC**	1. Biogrowth in distribution system is concentrating organic materials that are reacting with free chlorine.	1. Check for chorine residual. 2. Determine Free Chlorine potion of total chlorine (> 80%) 3. Perform HPC.	1. Increase flushing frequencies. 2. Superchlorination may be needed followed by change to chloramines as disinfectant..
1. DBP Significant Excursion occur in isolated areas of **Low Flow or in Areas with Dead End Pipelines.** **Free/Combined CL Residual** **HPC** **System Pressure Analysis** **Water Age Calculations**	1.Biogrowth in distribution system is concentrating organic materials that are reacting with free chlorine producing DBPs. 2. Pipelines are experiencing tuberculation. 3. System valves are closed increasing water age in some isolated pipelines.	1. Check for chorine residual. 2. Determine Free Chlorine potion of total chlorine (> 80%) 3. Perform HPC. 4. Perform system pressure test.	1. Increase flushing frequencies. 2. Superchlorination may be needed followed by change to chloramines as disinfectant. 3. Ensure that all system valves are open. 4. May need to pig lines to restore hydraulic efficiency.

Troubleshooting Guide #7 DBP - Water Distribution System Contributors (continued)			
Observation	**Probable Cause**	**Check**	**Remedy**
1. DBP Significant Excursion occur in isolated areas of **Near Water Storage Tanks.** **Free/Combined CL Residual** **HPC** **Water Age Calculations** **Water Tank Temperatures.** **Water Tank Levels** **Tank Fill and Turnover Calculations.**	1. Sediment accumulations in water storage tank is concentrating organic material and reacting with free chlorine producing DBPs. 2. Stratification and turnover of stagnant water in tank has occurred. 3. Changes in tank levels have occurred because of hydraulic demands.	1. Check maintenance records for last sediment removal. 2. check tank temperatures for water stratification. 3. Perform tank fill and turnover calculations.	1. Ensure that tank is properly filling and emptying and that no stratification is occurring; tank levels should be changing daily with at least 2/3 of tank water changing over.
1. DBP Significant Excursion occur after M**aintenance, Repair or Start Up of Distribution Pipelines**. **Free/Combined CL Residual** **Flushing Frequency and Locations.**	1. Flow patterns have been disrupted and/or sediment transported. 2. Excess chlorine has entered water system following repair or startup.	1.Check maintenance records for last water main repairs or new main startup. 2. Check t o ensure that system valves are in open position.	1. Re-institute flushing in affected areas.

Table 1

Most Common Locations of Chlorine Leaks

No.	Location
1.	Chlorine Valve packing gland.
2.	Chlorine Valve seat.
3.	Chlorine Valve inlet threads.
4.	Broken valves or stems.
5.	Fusible Valve threads.
6.	Fusible metal of plug.

Table 2

Use of Chemical Absorption for Large Chlorine Leaks

Absorption Agent	Pounds of Chemical Per size container		Gallons of Water Per size container	
	150 lb	1 Ton	150 lb	1 Ton
NaOH Sodium Hydroxide	188	2500	60	800
Na2CO3 Soda Ash	450	6000	150	2000
CaOH2* Hydrated Lime	188	2500	188	2500

* Must be agitated to be absorbed

Table 3

Repairing Chlorine Leaks

No.	Location and Type of Leak	Response (All safety requirements observed)
1.	Valve Stem Leak	Tighten Packing nut or gland.
2.	Container Leak	Close container valve and leak stops.
3.	Container leaking liquid.	Roll container so gas escapes instead of liquid
	Container Valve will not stop leak	Apply outlet plug or cap
5.	Container leak can not be stopped	Use emergency capping device required
6.	If it is not possible to direct chlorine into operation; remove cylinder and isolate	Call supplier for assistance

Guide #8 Coagulation Flocculation

Observation	Probable Cause	Check	Remedy
1. Influent changes in Turbidity and Color 2. Influent changes in Alkalinity, PH or Temperature changes.	1. Turbidity in source water has increased/decreased without appropriate change in chemical dosing. 2. Significant change in temperature since last chemical dose change 3. Mechanical adjustment needed in mixing or flocculation speeds.	1. Check Water Quality Parameters such as alkalinity, pH and Temperature 2. Check Coagulant Dosing based on jar test 3. For changes in temperature check flash mixer for proper dispersion and mixing speed. 4. For changes in temperature check Flocculator Mixing Speeds	1. Adjust Coagulant dose 2. Consider coagulant aids 3. Adjust alkalinity as needed; requires .35 mg/l lime for each mg/l of alum added. 4. Make process change to flash mixer 5. Make process change to flocculator mixing intensity. (see Velocity Gradient Requirements)
1. Effluent Water Quality changes in Turbidity and Color 2. Effluent changes in Alkalinity, PH or Temperature	1. Source Water Quality Changes. 2. Process Malfunction.	1. Verify process performance in coagulant feed rates and flash mixer operation 2. Perform Jar Test. 3. Verify Response.	1. Make appropriate process changes as in remedies above. 2. Adjust coagulant dosage. 3. Consider coagulant aids 4. Chemically adjust pH
1.Poor Floc formation such as dispersion, size and break up.	1. pH of source water has changed. 2. Alkalinity being consumed by coagulant	1. pH of source water 2. Alkalinity of source water. 3. Holding time in coagulation tank	1. Adjust pH to target levels indicated by jar test. 2. Adjust alkalinity 3. Make process adjustments
4. Some floc forms but does not settle.	1. Polymer feed is too low. 2. Process control problem with mixing and dispersion of coagulant	1. Determine Coagulant/Polymer feed based on jar test. 2. Perform mixing analysis (See Below)	1. Make appropriate chemical adjustments. 2. Make appropriate mixing adjustments

Velocity Gradient, Detention Time and Paddle Tip Speed For Coagulation/Flocculation Processes

1. Velocity Gradient

$$G = \left\{ \frac{P}{V\mu} \right\}^{1/2}$$

G = Velocity Gradient (fps/ft)
P = Power to Water in (ft-lb/sec) Note: multiply HP by 550
V = Volume of Basin (cu. ft.)
μ = Dynamic Viscosity of Water from Table:

Temp. Water (F°)	**Dynamic Viscosity (μ)** (10^{-5})
40	3.23
50	2.73
60	2.36
70	2.05

Table 5

Acceptable Ranges for Velocity Gradients for Coagulant Mixing and for Flocculation

Process	Acceptable Range for G (ft-sec/ft)	Acceptable Detention Time
Coagulation Rapid Mix	700 – 1,000	15 to 60 sec.
Flocculation 1st Basin	50 – 100	20 to 30 min.
Flocculation 2nd or 3rd Basin	20 - 50	

Importance of Flocculator Paddle Speed

Tip speed of flocculator paddles should range from 0.5 to 2.0 fps

Use stop watch and approximate distance traveled by paddle (V (fps) = d (ft)/ t (sec).)

Guide #9 Flocculation

Observation	Probable Cause	Check	Remedy
1. Source Water Quality Changes after optimal coagulant doses have been determined		**Flocculator Effluent Condition**	
		High Coagulation pH with Optimal color removal	1. Increase Acid Feed. 2. Decrease Alkalinity adjustment in raw water
		High Coagulation pH without Optimal color removal	1. Increase Coagulant. 2. Decrease Acid feed to maintain optimum pH
		Low Coagulation pH with Optimal color removal	1. Decrease Acid Feed. 2. Increase Alkalinity Adjustment in raw water.
		Low Coagulation pH without Optimal color removal	1. Decrease Acid if below optimal pH zone 2. Increase coagulant and alkalinity.
		Loss of Acid Feed	1. Increase coagulant to achieve optimal pH.
		Optimal pH without Optimal color removal	1. Increase coagulant, decrease acid or increase alkalinity.
		Optimal pH and color removal With floc carryover	1. Decrease Coagulant 2. Increase Polymer 3. Increase removal of settled floc 4. Decrease flow-through velocities in treatment unit
		High Turbidities and coagulant residuals in settled water	1. Check for floc carryover 2. Adjust polymer feed to enhance settling 3. Perform Jar Test

Table 6

Desirable Floc Characteristics

No.	Floc Characteristics
1.	Firm and compact about the size of a pin head.
2.	Water that is clear between floc particles
3.	Floc particles that appear to settle in slow motion.

Table 7

Coagulants Used in Water Treatment and Their Optimal Applications

No.	Coagulant Chemical Name and Formula	pH Ranges	Optimal Use
1.	Aluminum Sulfate $Al_2(SO_4)_3 \bullet 18 H_2O$	5.6 – 6.8 below 5.5 Up to 7.5 Up to 10,5	Optimal Range For High Color For High Minerals For Use With Lime
2.	Ferric Sulfate $Fe_2(SO_4)_3$	3.5 – 5.5	Optimal Range Forming Heavy Floc Warm Water
3.	Ferrous Sulfate $FeSO_4 \bullet 7 H_2O$	3.5 to 5.5 above 9	Optimal Range Effective with Lime Bivalent Fe ion oxidizes to trivalent with aeration or Cl
4.	Ferrous Chloride $FeCl_3 \bullet 6 H_2O$	5.5 to 11.0	Optimal Range
5.	Sodium Aluminate $NaAlO_2$	Alkaline Conditions	Highly Colored Water Highly Turbid Water Reduces Hardness

Guide #10 Sedimentation

Observation	Probable Cause	Check	Remedy
1. Turbidity in Influent	1. Coagulation/Flocculation Failure.	1. Check Coagulant Dosing 2. Check flash mixer for proper dispersion and mixing speed. Check Flocculator Mixing Speeds 3. Perform Jar Tests	1. Adjust Coagulant dose 2. Make process change to flash mixer 3. Make process change to flocculator mixing intensity.
2. Turbidity with upward movement and colloidal like suspensions	1. Sludge removal frequency too long. 2. Sludge removal rate is inadequate.	1. Sludge blanket should have clear liquid to a depth of 3'. 2. Check for possible thermal stratification. 3. Check for wind currents.	1. Change frequency of sludge removal. 2. For wind problems tank may need baffling.
3. Floc settles at inlet and in first half of basin	1. Coagulant dose is too high.	4. Perform jar test 5. In horizontal flow units over 50% of sludge will settle in first third of basin	6. Adjust coagulant dosage. Lowest Turbidity after 5 min in jar test.
4. Cloudiness in settled water at Launders	1. Sludge removal is insufficient.	1. Measure blanket depth using Sounder.	3. Remove sludge more frequently. 4. For low solids sludge removal should be set at 5 to 15 minutes each hour. 5. For high solids condition sludge removal rate should be continuous.
5. Sludge is watery	1. Too high removal rate of sludge.	1. Sludge removal frequency 2. Perform V/V Test; slurry in <u>reaction zone</u> should be 5% to 20% solids in 5-10 min in a graduated cylinder test. (Upflow Unit)	3. Decrease sludge removal frequency. Alum sludge concentration ranges from .25 to 10% solids (low to high.)

Guide #10 Sedimentation

Observation	Probable Cause	Check	Remedy
1. Sludge is dense and close to surface. 2. Sludge is bulking.	1. Too low removal rate of sludge	1. Sludge blanket depth. 2. Condition of sludge 3. Perform V/V Test; sludge from <u>discharge zone</u> should be 90% to 98% solids in 5-10 min in a graduated cylinder test. (Upflow Unit)	1. Increase frequency of pumping rate
1. Water Levels at Launders are too high 2. Water levels at Launders are uneven	1. Algae and/or debris build up.	1. Launders and V notches	1. Remove Blockages 2. Chlorinate periodically to remove algal growth.
1. Sedimentation basins operate at different efficiencies 2. Outlets basins exhibit different clarities.	1. Uneven Flow distribution	1. Break up of floc at basin inlet. 2. Short Circuiting in basin.	1. Adjustment or repair of flow split mechanism 2. Adjustment of weir elevations 3. Cleaning of weirs
1. Turbidity increase only at high flow	1. Hydraulically Overloaded basin 2. Poorly maintained weirs.	1. Check Surface Overflow Rate 2. Check Weir Loading Rate 3. Check Detention Time 4. Check Flow Velocity.	1. Install or adjust baffle plates 2. Make process changes 3. Clean Weirs
1. Sedimentation process unable to achieve less than 5 NTU.	1. Influent turbidity is greater than 10 NTU.	1. Upstream Processes 2. Changes in source water quality.	1. Adjust coagulation process or add polymer; inlet turbidity should be brought down to below 5 NTU. Filter removal is typically 1 log reduction.

Table 8

Permissible Sedimentation Tank Surface Overflow Rates And Other Critical Operating Parameters

Type of Treatment Employed	Allowable Overflow Rate (gpm/sf)
Alum Floc	0.4 – 0.7
Lime Softening	0.4 – 1.4
Tube Settlers	1.0 – 3.0
Plate Settler	2.0 – 6.0
Upflow Clarifier	0.7 – 1.8
Lime Upflow Clarifier	0.7 – 2.2
Detention Time	1.5 to 4 hrs
Velocity (fpm)	1.0 – 3.0 fpm
Weir Loading Rate	6.9 – 9.7 gpm/ft.

Guide #11 Filtration

Observation	**Probable Cause**	**Check**	**Remedy**
1. Turbidity Increasing Rapidly 2. Color Increasing 3. Head Loss Changing Rapidly 4. Frequent Backwahsing	1. Change in source water quality. 2. Upset in Coagulation/Flocculation Process 3. Hydraulic Overloading	1. Increase Sampling Frequency of Raw Water 2. Perform Jar Test 3. check hydraulic and weir loading rates.	1. Adjust Coagulant as indicated by jar test. 2. Change to different coagulant as indicated by jar test. 3. Check mixing and flocculator speeds (see Coagulation/Flocculation) 4. Increase chlorination dose if used for color removal (note DBP must be considered.) 5. 5. Increase backwash rate to remove higher levels of turbidity
1. Media Depth Shrinkage	1. Media carryover into wash water trough during backwash 2. Backwash Rate too high. 3. Media Boils are causing loss of media.	1. Check for loss by using a burlap bag to filter effluent and checking for media deposits in clearwell 2. Determine media shrinkage by measurement from top of basin and comparing with previous measurement. 3. Check backwash rate. Media expansion should be 20% to 25% of depth of media. Measure while backwash is activated.	1. Adjust backwash rate to achieve proper expansion. To achieve cleaning rate will be between 10 to 25 GPM (15 is average rate) per sq. foot of surface area. (Note: 1 GPM is approximately 1.6 inches per minute of rise.) 2. Media loss that results in unacceptable turbidity levels will need to be replaced.
		4. Measure media depth and statification and Inspect support media gravel for media boils.	

Observation	Probable Cause	Check	Remedy
1. Media not Clean after Backwash	1. Media not fully expanded. 2. Improper backwash flow rate. 3. Surface scour rates is too short.	1. Observe media expansion. 2. Record surface wash rate and duration.	1. Adjust media expansion within proper range. To achieve cleaning rate will be between 10 to 25 GPM (15 is average rate) per sq. foot of surface area. (Note: 1 GPM is approximately 1.6 inches per minute of rise.) 2. Adjust backwash rate and duration within proper range. 3. Adjust Surface scour rate and duration into proper range.
1. Coagulants Observed on Filter Service and not removed during Backwash	1. Coagulants Over Fed 2. Coagulants not mixed properly 3. Coagulants have adhered to surface	1. Perform Jar Test 2. Check flash mixer and flocculator speed	1. Adjust Coagulants 2. Make mixing/flocculation speeds (see Coagulation Section)
Algea Build up on filter sidewalls and wash water troughs.	1. No or low chlorine residual. 2. Debris accumulation. 3. Change in water quality.	1. Check for algae and debris build up	1. Adjust chlorine dosage.
1. Mudball Formation in Filter Beds. 2. Cracks and clogging in Filter Bed.	1. Improper Backwashing. 2. Poor Sedimentation. 3. Poor Coagulation.	1. Observe Surface Wash/Air Scour. 2. Observe Backwash duration and rate. 3. Observe Filter Bed expansion.	1. Adjust Backwash Cycle. 2. Adjust Coagulation/Flocculation Process. 3. Check Sedimentation operation.
1. Loss of Filter capacity, unequal rates of filtration, dirty spots on filter surface.	1. Air Binding. 2. Failure of Media 3. Damage to Underdrain	1. Perform check for migration of gravel by probing. 2. Evaluate Media by excavation 3. Determine depth to interfaces 4. Perform Sieve Analysis	1. Verify proper backwash and headloss operation. Air Binding can be caused by high head loss caused by too long of operation cycle. 2. Replenish or replace media.

Table 9

Operating Parameters for
Filter Media Cleaning

Backwash Method	Wash Water Rate (GPM/Sq. Ft.)	Wash Water Duration (Min)	Air Scour Rate (scfm/sq. ft.)	Air Scour Rate Duration (Min.)
Upflow Water Wash (1 Step)	15 to 23	3 to 15	-	-
Upflow Low Rate Water Wash With Initial Air Scour (2 Step)				
1. Air Scour	-	-	1 to 2	3 to 5
2. Low Rate Water Wash	5 to 7.5	3 to 5	-	-
Upflow High Rate Water Wash With Initial Air Scour (2 Step)				
1. Air Scour	-	-	2 to 5	3 to 5
2. High Rate Water Wash	15 to 23	3 to 5	-	-
Concurrent Upflow Water Wash With Initial Air Scour (2 Step)				
1. Concurrent Air and Water First	6.3 to 7.5	5 to 10	6 to 8	5 to 10
2. Water Wash only	6.3 to 15	5 to 10	-	-
Upflow Water Wash With Surface Wash (3 Steps)				
1. Surface Wash only	0.5 to 2.0	1 to 3	-	-
2. Low Rate Water Wash	5 to 7.5	5 to 10	-	-
3. High Rate Water Wash	15 t0 23	1 to 5	-	-

Table 10

Effects of Air Binding in Filter Operation

Filtration Media Type	Maximum Loading Rate (GPM/Sq ft)	Air Binding Loading Rate (GPM/Sq ft)
Sand	2	1.0 to 1.5
Dual Media	4	2.0 to 3.0
Deep Bed (depth > 60")	6	3.0 to 4.5

Table 11

Chemical Treatment for Removing Media Deposits

Chemical Deposit	**Application**
Alum or Organic Deposits	1. Use 1 to 3 lbs/Sq. Ft. Flaked NaOH 2. Allow to stand 6 to 12 hours 3. Backwash to waste
Calcium Carbonate Deposits	1. Determine concentrations of HCL or Carbonic Acid that is effective for removing deposits. 2. Ensure that it will not attack metal surfaces 3. Allow to stand 6 to 12 hours 4. Backwash to waste
Iron, Manganese and Calcium Carbonate Deposits	1. Use 2% Sulfur Dioxide solution. 2. Allow to circulate through filter for several hours until deposits are dissolved. 3. Operate filter to waste until acid and deposits are not visible.

Guide #12 **Reverse Osmosis**			
Observation	**Probable Cause**	**Check**	**Remedy**
1. Low Product Water or accelerated differential pressure build up due to turbidity.	1. Excessive turbidity to Unit. 2. Filter media breakthrough or cartridge filter failure 3. Inadequate Cleaning of membrane. 4. Fined suspended solids on face of membrane and on feed concentrate mesh spacer.	1. Turbidity loading to Unit. 2. Cleaning cycle (initiated when flux decreases by 15% of rated value or differential pressure is 15% above rated value.) 3. Perform Silt Density Index (SDI) and Modified Fouling (MFI) Index. These should be between 0 and 2. 4. Check effluent from filtration system.	1. Turbidity should be limited to below 1 NTU to RO unit. 2. Indexes out of range will require higher level of Turbidity removal. 3. Initiate more frequent cleaning of membrane. 4. Correct filtration problems
2. Low Product Water or accelerated differential pressure build up due to minerals.	1. Mineral scaling from carbonates, sulfates, silica, Ferric (Fe+++) , or H2S. 2. Elemental sulfur and iron oxide deposits on membrane.	**1. Perform Water Quality Tests for: Hardness (CH and NCH), Iron/Manganese and Hydrogen Sulfide.**	1. Convert carbonate hardness to CO2 by adding acid. 2. Remove NCH by softening. 3. Add polyphosphates or silicates to prevent scaling, 4. Remove Iron/Manganese by greensand or chloination/dechlorination, (no aeration.) 5. H2S can be removed by degasification. 6. Initiate more frequent cleaning of the membrane using citric acid,.

Reverse Osmosis (Continued)			
Observation	**Probable Cause**	**Check**	**Remedy**
3. Low Product Water Flow Rate, Higher Salt Rejection, High operating pressure.	1. Membrane Compaction	1. Operating pressure should be less than 500 psi.	1. Replace Membrane.
4. High Product Flow Rate with Lower Salt Rejection.	1. Membrane Hydrolysis.	1. Check pH and Temperature to determine if they are within operating limits.	1. Injection of colloid 189 will sometimes extend membrane life. 2. Replace Membrane

Table 12

Fouling Indexes for Reverse Osmosis Systems

Fouling Index	**Range (s/L^2)**
MFI	**0 to 2**
SDI	**0 to 2**

Guide #13 Stabilization			
Observation	**Probable Cause**	**Check**	**Remedy**
1. Customer Complaints for color, taste and odor.	1. Chemical changes in water quality caused by biological actions. 2. High levels of iron. Manganese or hydrogen sulfide in water.	**Perform corrosion indices checks.** 1. Perform water quality analysis at plant and in distribution system. 2. See Speciation Tastes and Odors.	**pH or alkalinity adjustment as determined by corrosion indices.** 1. Consider additional water treatment of additions of polyphosphates or silicates.
2. Frequent distribution system leaks caused by pipe failure.	1. Pitting and dissolution of metal from internal pipe surfaces. 2. Chemical dissolution of binding material in asbestos pipe.	1. Examine pipe samples for internal corrosion. 2. Examine pipe coupons. 3. Perform corrosion indices and water quality analysis as indicated above.	1. See remedies #1 above. **2. Pipe replacement may be necessary.**
3. Excessive pumping costs, low pressures and high water losses (>15%).	1. Tuberculation deposits in water mains. 2. Scaling in pipelines .	**1. Check for high levels of DO** 2. Low non-scouring flow rates and high water age. 3. Check for closed system valves	1. See remedies #1 above. **2. Pigging of lines may be necessary to restore flow.**
3. High coliform counts not controllable with typical chlorine dosing techniques. 4. Loss of chlorine residuals unrelated to system breaks,	1. Sedimentation and growth of biofilm in dead lines, 2. Sediment build up in water tanks.	1. Chlorine residual testing in tanks and remote areas. 2. HPC testing at tank sites. 3. Determination of water age and pipe flushing velocities.	1. Clean deposits from bottom of basins. 2. Flush sediments from dead end lines. 3. Initiate more aggressive disinfection control procedures.

Guide #14 Taste and Odor Control (Speciation)

Observation	Probable Cause	Check	Remedy
1. Customer Complaints for Foul Taste and odors accompanied by black particulate matter	1. High levels of iron. Manganese or hydrogen sulfide in water.	1. Perform water quality analysis at plant and in distribution system.	**1. Aeration and filtration.** 2. Consider additional water treatment of additions of polyphosphates or silicates.
2. Customer Complaints for organic type tastes and odors.	1. Algae if surface water plant. 2. Can also be caused by pesticides or volatile compounds such as gas or petroleum products. 3. Overdosing of polymer.	1. Perform water quality analysis at plant and in distribution system.	1. Increase chlorination. 2. Add GAC treatment. 3. Add Potassium Permanganate. 4. Adjust Polymer feed.
3. Customer Complaints of fishy, grassy, or sewage type odors.	1. Algae if surface water plant. 2. Bacterial contamination if groundwater plant. 3. Both SW and GW potential inreases in bacteria.	1. Perform water quality analysis at plant and in distribution system.	1. Increase chlorination. 2. Add GAC treatment. 3. Add Potassium Permanganate.
4. Customer Complaints of marshy, woody, musty or earthy odors. 5. Customer Complaints of Swampy tastes and odors.	1. Likely source is Actinomycete Organisms for marshy and wood tastes if unrelated to season. 2. Likely source is leave decay if the occurrence is in the fall.	1. Perform water quality analysis at plant and in distribution system.	1. Use of activated carbon before chlorination
6. Customer Complaints of sweet and aromatic tastes and odors..	1. Likely source is Phenols that react with chlorine..	1. Perform water quality analysis at plant and in distribution system.	2. Can be removed by aeration and addition of activated carbon before chlorination

Table 14

Types of Corrosion Mechanisms in Water Systems

Type of Corrosion	Description	Significance
Galvanic	Dissimilar metals in contact in water.	Frequently occurs in service lines. Can result in leaks or build up in pipelines.
Pitting	Caused by scratches or imperfections in metal pipe.	Can result in localized corrosion leading to holes in pipe.
Tuberculation	Caused by metal ion transfer and development of electrolytic cell formation inside pipe.	Can result in large mineral and iron oxide deposits that impede water flow.
Crevice	Occurs at joints where there is little water movement.	Can result in development of pin holes at crevices.
Biological	Results from reactions of pipe materials and bacterial metabolism.	Responsible for most taste and odor problems caused by corrosion.
Dealloying	Preferential removal of one alloy from a metal.	Weakens pipe and can result in pipe failure.

Table 15

Typical Customer Water Complaints Caused by Corrosion

Customer Complaint	Probable Cause
Red Water or reddish brown staining of fixtures and laundry.	Corrosion of iron pipes or presence of iron in water.
Bluish stains on fixtures.	Corrosion of copper service lines.
Black Water	Sulfide corrosion of iron or copper lines.
Foul tastes and odors.	By-products of microbial activity facilitated by corrosive conditions
Loss of Pressure	Excessive scaling, tuberculation, pitting and galvanic corrosion.
Lack of Hot Water	Mineral deposits of heating elements caused by scale.
Short Service Life of Household Plumbing	Rapid deterioration of pipes caused by corrosive conditions.

Table 16

Marble Test

Effects of Adding Marble	Water Stability	Saturation (CaCO3)
PH and Alkalinity Increase	Corrosive	Water is Under Saturated
PH and Alkalinity Decrease	Scale Forming	Water is Supersaturated
PH and Alkalinity are the Same	Stable	Water is Saturated

Relationship between pH and Alkalinity For Stable Water

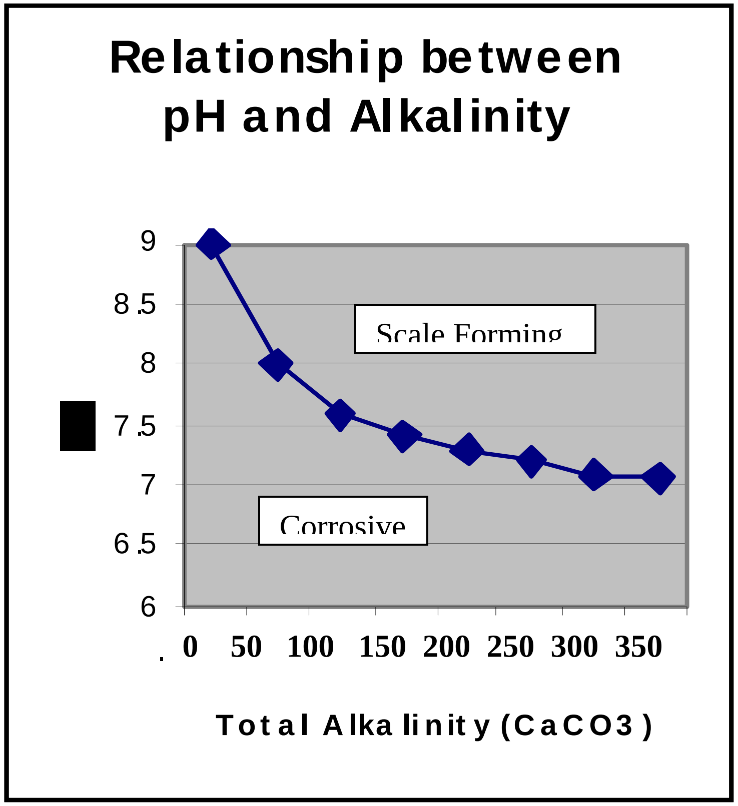


Table 15

Corrosion Indices Used in Water Treatment

Index	Parameters (measured as $CaCO_3$)	Significance
Langlier Saturation Index (LSI) LSI = pH - pHs	Total Alkalinity Calcium Hardness Total Dissolved Solids On-Site pH On-Site Temperature	LSI > 0; Water is Supersaturated and tends to precipitate LSI = 0; Water is Saturated and stable LSI < 1; Water is Undersaturated and corrosive
Aggressive Index (AI) AI = pH + log (A x H)	Total Alkalinity Hardness On-Site pH	AI > 12; Water is non-aggressive AI = 10 to 12; Water is moderately aggressive AI < 10; Water is very aggressive
Ryzner Stability Index (RSI) RSI = 2 pHs - pH	Total Alkalinity Calcium Hardness Total Dissolved Solids On-Site pH On-Site Temperature	RSI < 6.5; Water is Supersaturated and tends to precipitate RSI = 6.5 to 7.0; Water is Saturated and stable RSI > 7.0; Water is Undersaturated and corrosive.
Riddick's Corrosion Index (CI) $CI = 75/Alk((CO_2 + \frac{1}{2})(H - Alk) + Cl^- + 2N) \times (10/SiO_2)\left(\frac{DO + 2}{Sa + DO}\right)$	CO_2 (mg/l) Alkalinity Hardness Cl^- (mg/l) N (mg/l) DO (mg/l) Saturation DO (mg/l)	CI; 0 – 5 Scale Forming CI; 6 - 25 Non Corrosive CI; 26 – 50 Moderately Corrosive CI; 51 – 75 Corrosive CI; 76 – 100 Very Corrosive CI; 100+ Extremely Corrosive
Driving Force Index (DFI) $DFI = \frac{Ca^{++} \times CO_3}{Kso \times 10^{10}}$	Calcium CO_3^- Kso = Solubility product of $CaCO_3$	DFI > 1; Water is Supersaturated and tends to precipitate DFI = 1; Water is Saturated and stable DFI < 1; Water is Undersaturated and corrosive.

Guide #15 Water Distribution System Upsets

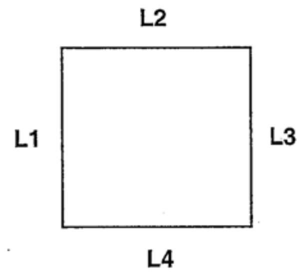
Observation	Probable Cause	Check	Remedy
1. Water appears dirty, highly colored or turbid.	1. Water treatment upset. 2. Water main break and system flushing.	1. Treatment Plant and Distribution Records. 2. Flushing or fire hydrant flow testing. 3. Perform water quality check to identify problem.	1. Correct water treatment problems. 2. Flush fire hydrants and blow off valves.
2. Water appears milky.	1. Shut down of water mains. 2. Air leaking into high service or booster pumps at packing. 3. Water main break. 4. Inoperative check valve allowing air to enter system.	1. System repair records. 2. Likely pumps and check valves.	1. Make system repairs.
3. Musty tastes and organic odors in water.	1. Water treatment problems. 2. Disinfection at new mains, tanks or reservoirs. 3. Turnover of water in storage tanks. 4. Stagnant water in dead end lines. 5. Chlorine is in the form of chlororganics and chloramine	1. Source water changes. 2. High chlorine levels from disinfection at new facilities. 3. Changes in weather conditions causing turnover in water tanks. 3. Check for high THM levels. 4. Check for low free chlorine and high combined chlorine residuals.	1. Clean deposits from bottom of basins. 2. Flush sediments from system. 3. Maintain free chlorine residuals.

Water Distribution System Upsets (Continued)			
Observation	**Probable Cause**	**Check**	**Remedy**
4. Chlorinous tastes and odors in water.	1. Change in chlorine dosing at water treatment plant. 2. Changes in chlorine forms in distribution system.	1. Check plant operational chlorine dosing records. 2. Check for low free chlorine and high combined chlorine residuals.	1. Adjust chlorine feed. 2. Free residual chlorine should be > 85% of total chlorine; flush to restore balance.
5. Soapy, chemical or hose taste to water or light blue color.	1. Cross Connection at Customer location. 2. Unprotected hose bib or irrigation line.	1. Inspect plumbing connections.	1. Install appropriate backflow preventor.
6. Positive total coliform test.	1. Improper sampling technique. 2. Inadequate chlorine residual. 3. Main break or cross connection 4. Growth of biofilm in system.	1. Review staff training and sampling protocol. 2. Make chlorine residual system checks. 3. Check system repair records. 4. Check for cross connections. 5. Perform HPC sampling at tanks and dead ends.	1. Staff training. 2. Increase chlorine residual at plant as indicated. 3. Perform system flushing as indicated. 4. May require superchlorination.

Perimeter / Circumference

Square or Rectangle:

$$Perimeter = L1 + L2 + L3 + L4$$



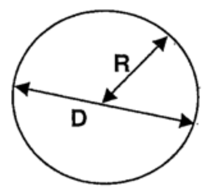
Circle:

$$Circumference = \pi D$$

or

$$Circumference = \pi \ x \ (2R)$$

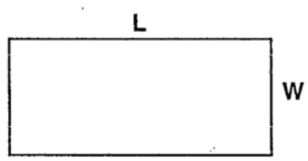
Where $\pi = 3.14$



Area

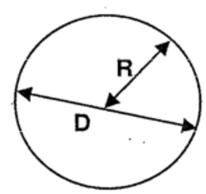
Square or Rectangle:

$$A = L \ x \ W$$



Circle:

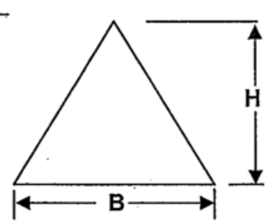
$A = \pi R^2$ **or** $A = 0.785 \ D^2$



Where $\pi = 3.14$

Triangle:

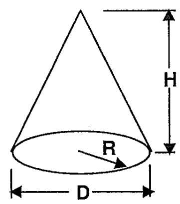
$$A = \frac{B \ x \ H}{2}$$



Volume

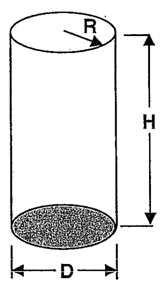
Cone:

$$V = \frac{\pi R^2 H}{3} \quad \textbf{or} \quad V = \frac{0.785\, D^2 H}{3}$$



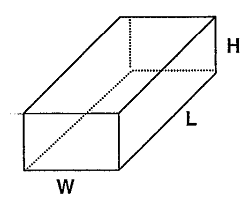
Cylinder:

$$V = \pi R^2 H \quad \textbf{or} \quad V = 0.785\, D^2 H$$



Cube:

$$V = L \times W \times H$$



Formula/Conversion Table
for Water Treatment and Water Distribution Exams

Alkalinity, as mg $CaCO_3$/L $= \dfrac{(\text{Titrant Volume, mL}) \times (\text{Acid Normality}) \times (50{,}000)}{\text{Sample Volume, mL}}$

Amps = Volts/Ohms

Area of Circle $= (\Pi/4) \times (\text{Diameter}^2)$ or $(\Pi) \times (\text{Radius}^2)$

Area of Cone (lateral area) $= (\Pi) \times (\text{Radius}) \times \sqrt{\text{Radius}^2 + \text{Height}^2}$

Area of Cone (total surface area) $= (\Pi) \times (\text{Radius}) \times (\text{Radius} + \sqrt{\text{Radius}^2 + \text{Height}^2}\ )$

Area of Cylinder (total outside surface area) = [Surface Area of End #1]+ [Surface Area of End #2] + $[(\Pi) \times (\text{Diameter}) \times (\text{Height or Depth})]$

Area of Rectangle $= (\text{Length}) \times (\text{Width})$

Area of a Right Triangle $= \dfrac{(\text{Base}) \times (\text{Height})}{2}$

Average (arithmetic mean) $= \dfrac{\text{Sum of All Terms}}{\text{Number of Terms}}$

Average (geometric mean) $= (X_1 \times X_2 \times X_3 \times X_4 \times X_n)^{1/n}$ The *n*th root of the product of *n* numbers

Chemical Feed Pump Setting, % Stroke $= \dfrac{(\text{Desired Flow}) \times (100\%)}{\text{Maximum Flow}}$

Chemical Feed Pump Setting, mL/min =

$$\frac{(\text{Flow, MGD}) \times (\text{Dose, mg/L}) \times (3.785\ \text{L/gal}) \times (1{,}000{,}000\ \text{gal/MG})}{(\text{Liquid, mg/mL}) \times (24\ \text{hr/day}) \times (60\ \text{min/hr})}$$

Circumference of Circle $= (\Pi) \times (\text{Diameter})$

Composite Sample Single Portion $= \dfrac{(\text{Instantaneous Flow}) \times (\text{Total Sample Volume})}{(\text{Number of Portions}) \times (\text{Average Flow})}$

Degrees Celsius = (Degrees Fahrenheit - 32) $\times$ ($^5/_9$) or $\dfrac{(F^\circ - 32)}{1.8}$

Degrees Fahrenheit = (Degrees Celsius) $\times$ ($^9/_5$) + 32 or (Celsius) $\times$ (1.8) + 32

Detention Time $= \dfrac{\text{Volume}}{\text{Flow}}$

Electromotive Force (E.M.F), volts = (Current, amps) $\times$ (Resistance, ohms) or E =IR

Feed Rate, lbs/day $= \dfrac{(\text{Dosage, mg/L}) \times (\text{Capacity, MGD}) \times (8.34\ \text{lbs/gal})}{(\text{Purity, decimal percentage})}$

$$\text{Feed Rate, gal/min (Fluoride Saturator)} = \frac{(\text{Plant capacity, gal/min}) \times (\text{Dosage, mg/L})}{(18{,}000\ \text{mg/L})}$$

$$\text{Filter Backwash Rise Rate, in/min} = \frac{(\text{Backwash Rate, GPM/sq ft}) \times (12\ \text{in/ft})}{(7.48\ \text{gal/cu ft})}$$

$$\text{Filter Drop Test Velocity, ft/min} = \frac{\text{Water Drop, ft}}{\text{Time of Drop, min}}$$

$$\text{Filter Flow Rate or Backwash Rate, gpm/sq ft} = \frac{\text{Flow, gpm}}{\text{Filter Area, sq ft}}$$

$$\text{Filter Yield, lbs/hr/sq ft} = \frac{(\text{Solids Loading, lbs/day}) \times (\text{Recovery, \% / 100\%})}{(\text{Filter operation, hr/day}) \times (\text{Area, sq ft})}$$

Flow Rate, cfs = (Area, sq ft) $\times$ (Velocity, ft/sec) or $Q = AV$ where: Q = flow rate, A = area, V= velocity

Force, pounds = (Pressure, psi) $\times$ (Area, sq in)

$$\text{Gallons/Capita/Day} = \frac{\text{Volume of Water Produced, gpd}}{\text{Population}}$$

$$\text{Hardness, as mg } CaCO_3\text{/L} = \frac{(\text{Titrant Volume, mL}) \times (1{,}000)}{\text{mL of Sample}}$$ Only when the titration factor is 1.00 of EDTA

$$\text{Horsepower, Brake} = \frac{(\text{Flow, gpm}) \times (\text{Head, ft})}{(3{,}960) \times (\text{Decimal Pump Efficiency})}$$

$$\text{Horsepower, Motor} = \frac{(\text{Flow, gpm}) \times (\text{Head, ft})}{(3{,}960) \times (\text{Decimal Pump Efficiency}) \times (\text{Decimal Motor Efficiency})}$$

$$\text{Horsepower, Water} = \frac{(\text{Flow, gpm}) \times (\text{Head, ft})}{3{,}960}$$

$$\text{Hydraulic Loading Rate} = \frac{\text{Total Flow Applied}}{\text{Area}}$$

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs}) \times (100)}{(\text{Hypochlorite Solution Needed, gal}) \times (8.34\ \text{lbs/gal})}$$

$$\text{Leakage, gpd} = \frac{\text{Volume, gallons}}{\text{Time, days}}$$

Mass, lbs/day = (Flow, MGD) $\times$ (Concentration, mg/L) $\times$ (8.34 lbs/gal)

Milliequivalent = (mL) $\times$ (Normality)

$$\text{Molarity} = \frac{\text{Moles of Solute}}{\text{Liters of Solute}}$$

$$\text{Normality} = \frac{\text{Number of Equivalent Weights of Solute}}{\text{Liters of Solution}}$$

$$\text{Number of Equivalent Weights} = \frac{\text{Total Weight}}{\text{Equivalent Weight}}$$

$$\text{Number of Moles} = \frac{\text{Total Weight}}{\text{Molecular Weight}}$$

$$\text{Reduction in Flow, \%} = \frac{(\text{Original Flow - Reduced Flow}) \times (100\%)}{\text{Original Flow}}$$

$$\text{Removal, \%} = \frac{(\text{In} - \text{Out}) \times (100)}{\text{In}}$$

$$\text{Slope, \%} = \frac{\text{Drop or Rise}}{\text{Distance}} \text{ x } 100$$

$$\text{Solids Concentration, mg/L} = \frac{\text{Weight, mg}}{\text{Volume, L}}$$

$$\text{Solids, mg/L} = \frac{(\text{Dry Solids, grams}) \times (1{,}000{,}000)}{\text{Sample Volume, mL}}$$

$$\text{Specific Gravity} = \frac{\text{Specific Weight of Substance, lbs/gal}}{\text{Specific Weight of Water, lbs/gal}}$$

$$\text{Surface Loading Rate, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Area, sq ft}}$$

Three Normal Equation $= (N_1 \text{ x } V_1) + (N_2 \text{ x } V_2) = (N_3 \text{ x } V_3)$, where $V_1 + V_2 = V_3$

Two Normal Equation $= N_1 \text{ x } V_1 = N_2 \text{ x } V_2$, where N = concentration, V = volume or flow

$$\text{Velocity, ft/sec} = \frac{\text{Flow Rate cu ft / sec}}{\text{Area, sq ft}} \text{ or } \frac{\text{Distance, ft}}{\text{Time, sec}}$$

Volume of Cone $= (1/3) \times (\Pi/4) \times (\text{Diameter}^2) \times (\text{Height})$

Volume of Cylinder $= (\Pi/4) \times (\text{Diameter}^2) \times (\text{Height})$

Volume of Rectangular Tank $= (\text{Length}) \times (\text{Width}) \times (\text{Height})$

Watts $= (\text{Volts}) \times (\text{Amps})$

$$\text{Weir Overflow Rate, gpd/ft} = \frac{\text{Flow, gpd}}{\text{Weir Length, ft}}$$

$$\text{Wire-to-Water Efficiency, \%} = \frac{\text{Water Horsepower, HP}}{\text{Power Input, HP or Motor HP}} \text{ x } 100$$

$$\text{Wire-to-Water Efficiency, \%} = \frac{(\text{Flow, gpm}) \times (\text{Total Dynamic Head, ft}) \times (0.746 \text{ kw/hp}) \times (100)}{(3{,}960) \times (\text{Kilowatt Demand}) \times (\text{Pump Efficiency})}$$

Alkalinity Relationships:

Result of Titration	Hydroxide Alkalinity as $CaCO_3$	Carbonate Alkalinity as $CaCO_3$	Bicarbonate Concentration as $CaCO_3$
	Alkalinity, mg/L as $CaCO_3$		
P = 0	0	0	T
P < ½T	0	2P	T – 2P
P = ½T	0	2P	0
P > ½T	2P – T	2(T – P)	0
P = T	T	0	0

*Key: P – phenolphthalein alkalinity; T – total alkalinity

Conversion Factors:

1 acre = 43,560 square feet
1 acre foot = 326,000 gallons
1 cubic foot = 7.48 gallons
1 cubic foot = 62.4 pounds
1 cubic foot per second = 0.646 MGD
1 foot = 0.305 meters
1 foot of water = 0.433 psi
1 gallon = 3.79 liters
1 gallon = 8.34 pounds
1 grain per gallon = 17.1 mg/L
1 horsepower = 0.746 kW or 746 watts or 33,000 ft. lbs./min.
1 mile = 5,280 feet
1 million gallons per day = 694 gallons per minute
1 million gallons per day = 1.55 cubic feet per second (cfs)
1 pound = 0.454 kilograms
1 pound per square inch = 2.31 feet of water
1% = 10,000 mg/L
Π or pi = 3.14

Abbreviations:

cfs	cubic feet per second	MGD	million gallons per day
DO	dissolved oxygen	mL	milliliter
ft	feet	ppb	parts per billion
g	grams	ppm	parts per million
gpd	gallons per day	psi	pounds per square inch
gpg	grains per gallon	Q	flow
gpm	gallons per minute	SS	suspended solids
in	inches	TOC	total organic carbon
kW	kilowatt	TSS	total suspended solids
lbs	pounds	VS	volatile solids
mg/L	milligrams per liter		

Fundamentals of Management for Water Treatment Operators

Manager's Duties

- Plan
- Organize
- Staff
- Direct
- Monitor and Control

Plan

Planning

- Identifying managerial activities that prepare the department, division or organization for the future
- Ensuring that the decisions regarding men, materials and machines achieve the organization's objectives
- Must be performed before other managerial functions

Planning Components

- Establishing goals and objectives
- Setting priorities
- Identifying and comparing options and alternatives
- Devising both short-term and long-term strategies
- Identifying and choosing between options
- Setting Policies and Procedures to achieve goals

Planning Concerns

Present Resources
- Budget (Monies)
- Human Resources (Staff)
- Assets (Facilities and Equip.)

Future Resources

Financial Capability

Facility Rehab and Replacement

New Facility Needs

Staffing

Some Important **Planning Responsibilities** and Limitations Imposed on Manager

- **Provide exact answers using inexact information**
- **Provide solutions within defined schedule and budget**
- **Focus on priority objectives not on the details**
- **Constantly convince upper management and employees while implementing the plan**
- **Set levels of achievable performance, reasonable standards and methods for monitoring results with sometimes less than cooperative workforce**
- **Create an environment for employee input and innovation while meeting schedules and budgets**
- **Develop both short-term and long-term plans under ever-changing conditions**
- **Maintain competence and technical skills in self and with existing employees with little or limited support**
- **Integrate dept. goals with those of larger organization**

Organize

Critical **Organizing Tasks**

- Deciding Who Does What, When, How and Where
- Identifying the Reporting Relationships to the Appropriate Staff Member
- Effectively Directing Limited Resources

Examples of Plans for **Organizing Work**

- **Organizational Plans** Defining Dept. Structure and Reporting Requirements
- **Financial Plans** such as budgets and financial forecasts which track and allocate funds
- **Written Policies, Procedures and Standards** that organize or direct employee actions
- **Employee Staffing, Training and Succession** Plans that ensure capable workforce
- **Environmental Management Plans** that dictate precautions, detection and response actions
- **Equipment Replacement Rehabilitation** Plans
- **Emergency Management Plans** for Responding

The Organizational Plan

The Organizational Plan
Primary Plan of an Organization

Defines organization’s structure, the system of activities and authority relationships

1. Establishes Unity of Command
2. Identifies Clear Lines of Authority
3. Defines the Divisions of Labor
4. Identifies Employee and Group Responsibilities
5. Identifies Formal Lines of Communications

Organizational Plan and the Principles of **Unity of Command**

No Subordinate reports to more than one supervisor at one time

- Minimizes duplication and conflict
- Decreases confusion and establishes accountability
- Prevents diffusion of responsibility
- Improves communication resulting in mutual understanding among supervisors and staff
- Results in increase effectiveness of resources

The Organizational Plan Principles of **Lines of Authority**

Identifies Those Responsible for Designating how Organizational Resources will be used to Perform a Task.

Formal Authority (Organizational Position)

Informal Authority (Willingness to Follow)

The Organizational Plan Managerial **Authority and Types of Power**

- Legitimate Power – Based Formal Authority based on Organizational Position
- Coercive Power – Perception of Supervisor's ability to Punish
- Reward Power – Based on Supervisor's ability to Reward
- Reference Power – Based on subordinate's desire to follow a charismatic leader
- Expert Power – Based on subordinate's Perception of Superior's expertise, knowledge or skill and thus willingness to follow

The Organizational Plan Principles of **Division of Labor**

- Departmentalization – how department is broken down into distinct related units or groups
- Span of Control – who reports to whom and the lines of communications that are used
- Degree of Centralization – where decisions are made
- Delegation – Transfer of power from superior to subordinate
- Work Function - Line (responsible for direct command in performing work tasks) and Staff (responsible for advice and support)

Financial Plans

Types of Financial Plans

- Budgets
  - Operating Budget
  - Personal Services Budget
  - Capital Improvement Plan
- Rate Planning based on the Cost of Providing Services (Cost of Service Study)
- Borrowing Plans such as Bonds and Short Term Securities

Budget Preparation in a Water Utility

Purpose and Use of a Budget

- All businesses rely on proper budgeting and financial management to control expenses
- Growth, Aging of Facilities and Equipment, External Constraints and Environmental Regulations affect the Budget
- A Budget can be a short or long-term plan that anticipates future expenditures based on estimated variables
- A Budget prioritizes financial needs using actual expenses and trends from prior year(s) in "line items"
- The line items are then monitored to keep expenses in line and determine future needs

Major Types of Budgets used by Utilities

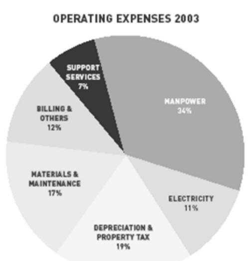
- **Operation and Maintenance (O&M) Budget**
- **Personal Services (PS) Budget**
- **Capital Improvements Plan (CIP)**

Use of a Line Item Budget

	Column #	1 Budget Exp.	2 Budget	3 Projections	4 Request
Act # 100	Item Supply & Equip	Previous Yr 5-Yr. AVE	Current Yr. Curr-Previous	Yr'ly Projection Proj-Prop	Budget Request Request Bud-Req
120	Maint Supplies	$13,900 2.5%	$14,700 10.6%	$15,380 4.6%	$ 15,800 7.4%
130	Small Tools	$6,500 0.6%	$ 6,700 3.1%	$6,432 (1.1%)	$ 6,500 (3.0%)
140	Safety Equip	$3,200 1..3%	$ 3,300 3.1%	$14,700 459%*	$ 3,300 0.0%
	Totals	$23,600 2.3%	$24,700 4.1%	$36,512 54.7%	$25,600 3.6%

*140 Extraordinary Expense Necessary to Replace Confined Space DO Meter

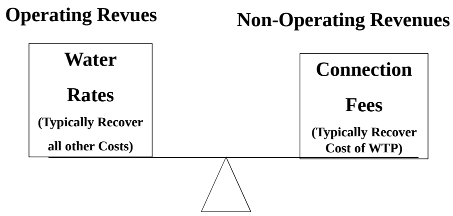
Example of Operating Expenses for Typical Water System



Sources of Revenues for a Water System

- Operating Revenues
  - Water sales
  - Connection Fees
  - Impact Fees
  - Late payments
  - Reconnection fees
- Non-Operating Revenues
  - Interest on checking acct.
  - Interest on reserve acct.
  - Equity Buy-In fees
  - Capital Recovery Fees

Major Sources of Utility Revenue are Rates and Connection Fees



Capital Improvement Plan (CIP) Development Process

- Identification of the needs for capital improvements
- Development of the CIP (typically 20 years)
- Prioritization of capital projects
- Scheduling of the Projects (typically 5 year horizon)
- Identification of Funding Sources
- Determining Borrowing Schedules

The Capital Improvement Plan (CIP)

Major Capital Improvement Program **CIP Categories**

- Source Water Improvements (Wells)
- Water Treatment Improvements
- Water Storage and Pumping Improvements
- Water Transmission Improvements
- Water Distribution Improvements
- Replacement and Rehabilitation
- Relocation of Pipelines
- Pipeline Improvements including Upsizing
- New Development
- Water Service (Meters and Appurtenances)

CIP Project Management using a Five Year (Short-Term) Window

- **ESSENTIAL:** Project needed to meet water demand from new development or essential for the maintenance of the water system.. Water demands or infrastructure conditions if not completed there is the risk of being unable to provide water to its new and existing customers. These Projects are included in the First year Schedule.
- **REQUIRED:** A project that is important for providing water service to customers yet timing of construction is not as critical as an essential project. Required projects are generally found in the last four years of the plan. External factors such as the pace of new development or the condition of existing infrastructure may delay or accelerate the timing of project construction. These Projects are included in the 5-yr. window.
- **DEFERRABLE:** Projects are not immediately critical to the operation of the water system. Expenditures in this category generally require a business case study or specific criteria to be met before spending can occur. Contingent spending is deferrable and covers emergency replacement. These projects are long-term and are placed beyond window.

CIP Line Item Budget Example

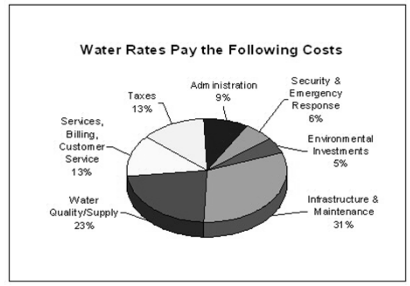
← Typically 5 Yrs. →

FERC Acct	Major Category	Current YR	FY 2006	FY 2007	Project Total
100	**Water Treatment Improvements**				
1	Filter #6 Improvements	$230,000	$474,000	$538,0000	$1,242,000
2	Clarifier #3 Upgrade		$ 67,000		$ 67,000
	100 Totals	$230,000	$541,000	$538,000	$1,309,000
500	**Water Transmission Improvements**				
3	Main Street Ext.		$24,700	$365,000	
	200 Totals		$24,700	$365,000	$389,700
Capital Budget Totals		$230,000	$565,700	$903,000	$1,698,700

Setting Water Rates (AWWA M1)

- **Step 1: Determine the full cost of doing business by calculating your costs.**
- **Step 2: Determine your current revenues.**
- **Step 3: Consider your reserve requirements to ensure you have enough funds to cover your asset rehabilitation**
- **and repair costs as well as unexpected costs during the next 5 years.**
- **Step 4: Calculate how much money you need to collect from customer charges to cover your costs and fully fund your reserve**
- **account.**
- **Step 5: Evaluate appropriate rate structures and distribute the variable costs component to the various customer classes in accordance with their requirements for service.**
- **Step 6: Implement the rates.**
- **Step 7: Review and adjust your rates so they recover from each class of customer, within practical limits, the cost to serve them**

Typical Component Costs Funded by a Utility Water Rate



Customer Related Costs of Providing Water Service

- **Supply and Transmission Costs –** average cost of supply and transmission to customer, i.e. electricity, chemicals & labor
- **Commodity Cost -** Costs that vary proportionately with the amount of water provided under average consumption; typically based on size of meter (proportioned by meter size)
- **Capacity Cost -** Costs that are incurred to meet the maximum demand (Peak demands have much higher costs)
- **Customer Related Cost -** The costs that are associated with serving customers independent of the amount of water they use
- **Public Fire Protection.** The cost of hydrants and the over-sizing of water mains and reservoirs to provide fire flows.
- **Taxes, Surcharges and GF Transfers.** Costs include state & city utility taxes, customer billing audits utility maintenance.

Typical Additional Financial Components Included in Rates

- Debt Service Coverage (Bonds Outstanding)
- Cash Funding of the Capital Improvement Program (Typically ~30%)
- Rate Stabilization Fund (Minimizes Rate Shock)
- Cash Targets Maintained (Available Working Capital)
- Variable Rate Debt for Short-Term Securities (Commercial Paper)

Cost of Service Study used in Designing Rates

- **Determine current expenses for residential, commercial and industrial classes of customers.**
- **Estimate short and long-term facility needs based on identified development, historical trends and economic indicators.**
- **Establish Construction Schedules, Capital Needs (cash flows), cash, interest payments and interest ratios to be maintained required by Bond Resolutions.**
- **Estimate operating revenue and non-operating expenses**
- **Rates are allocated to individual classes of customers that fairly allocates charges to those using the service**

Personal Services Budget

Preparing a **Personal Services Budget**

- List Employee Roster of Full Time and Part Time Equivalents (line item)
- Identify Pay Grade, Anticipated Pay Grade and Anticipated Base Pay
- Determine Direct Yearly Compensation
- Sum Total

Other **Personal Service Expenses** Included in PS Budget

- Temporary Salaries
- Overtime Pay
- Working Out or Class Straight Time
- Other Personnel Expenses
- Other Employee Allowances (Bonuses)
- Health Insurance

Management Strategies for Rate Protection

- **Locate, correct and eliminate illegal taps**
- **Perform water audits and institute leak detection programs, Water loss levels should be < 90%.**
- **Check water meters for efficiency and institute cost effective replacement programs**
- **Train meter readers in leak and illegal connections**
- **Evaluate User fees, deposits and other charges**
- **Improved timeliness and effectiveness of customer collections policies**
- **Add new customers to existing underutilized facilities**
- **Initiate Cooperative purchases for metes, pipe and standard purchases**

Staff

Staffing Components in a Water Utility

- Determine the Effective Number of Staff to Fill Available Positions (Personal Services Budget)
- Recruit and Hire Qualified Personnel
- Select, Retain and Train Employees
- Provide Opportunities for Advancement
- Evaluate Employee Performance and Discipline and Discharge when necessary

Recruitment and Hiring of Personnel

Sequence of **Hiring Procedures**

- Develop Job Related Position Specifications
- Recruit and Advertise Position
- Review Job Applications (screen of Applicants that meet job criteria) and set Desired Pool of Canditates
- Conduct Phone Interview (optional) and Screen
- Administer Oral and/or Written Test to Applicants
- Perform Background Review(s) of Top Candidate(s)
- Perform Drug testing
- Perform Physical (Must have written procedures for Physical Requirements)
- Offer Job to Successful Applicant

Recruiting for a Job Applicant

- **Prepare a Written Specification for the Requirements of the Job**
- **The Specification should be Job related and appropriate for the job; too many requirements or specializations will limit job applicants**
- **Determine the range of Compensation and ensure that the funds have been Budgeted; A compensation should be commensurate with experience, training and abilities to perform**
- **Review and List Job Duties for appropriateness**
- **Selection Process must comply with EEOC requirements**
- **Application Procedures should be specified and a closing date provided.**

Selection Criteria Requirements

- All Selection Criteria must be job-related.
- The questions you ask during interviews must be relevant to the job
- There is a natural tendency to be comfortable with people like us; jettison and not your personal preferences

Protected Classes of Employees
Equal Employment Opportunity Commission (EEOC)

- Race
- Gender
- Disabled persons
- Persons over 40 years of age
- Religion Affiliations
- Political Affiliations

Examination Selection Criteria

- Applicant's Knowledge and Skills
- Abilities to Perform Job-Related Activities
- Relevant Job Related Questions
- Relevant Experience and Training

Choosing Qualified Applicants

- Eliminate Those Who do not meet job specifications
- Choose Those Who are Best Qualified
- Rank Most Qualified and Choose Pool to Interview
- In larger organizations Human Resources will perform the first cut
- Document your reasons for selecting applicants
- Identify areas where clarification needed

Prepare Interview Questions and Acceptable Answers in Advance and in Writing

- Draw Up a List of Job-Related Questions That Will be Consistently Asked of All Applicants (Open vs. closed ended questions)
  - During the Interviews, Briefly Note the Answers Each Applicant provides.
- Review the Background Information, Job Application and Resume for Each Applicant to ensure that the Applicant meets Job Requirements
- It is customary to give both oral and written examinations
- It is advisable to use a team to chose the applicant
- The team may include Protected Classes to eliminate biases

Documentation Required in Hiring Process

- Personnel actions or a written record detailing actions
- When you did it and Why you did it
- Manager Must be aware:
  - **That you might be called upon to defend your actions in a hearing or in court**
  - **Good records serve to refresh your memory about past events—don't depend upon memory**

Welcoming New Employees

Introduction of New Employee

- Provide Written and Explain Organizational Policies and Practices

Compensation	Benefits and Health Ins.
Attendance Expectations	Drug Policy
Work Rules	Training and Promotions

- Introduce the new employee to co-workers
- Tour the work area(s)
- Provide **<u>Safety Training</u>** as soon as possible
- Explain Probationary Period

Evaluating Employee Performance

Employee Performance Evaluations

- Performed by Most Organizations
- Usually performed on An Annual Basis
- To be relevant should use frequent **status reviews (**Quarterly)
- Most Organizations use Management by Objectives (MBO's)
- The Purpose of a Performance Evaluation is to Improve Employee Performance
- Performance Evaluations can result in Employee Dissatisfaction

Performance Evaluation Process

- Supervisor completes the Performance Evaluation form
- The Supervisor Schedule a private meeting with Employee
- Supervisor and Employee review and discuss the evaluation
- Employee signs (acknowledgement of having seen and discussed)
- Employee is given a copy of the evaluation
- Evaluation is Placed in Personal File
- Some Organizations use a “360º” Evaluation

Performance Improvement Plan

A “Performance Improvement Plan” is a collaborative agreement between a supervisor and an employee to meet specific performance goals, and provide status reports within a specified time frame.

- Results in more opportunities to provide employees with positive feedback by recognizing performance and contributions
- Provides written performance standards and schedules to remove ambiguity
- Increases trust between the employee and the manager
- Identifies obstacles in meeting performance resulting in timely solutions
- Provides opportunities for coaching and feedback in solving performance problems

Necessary Management Components for Addressing Employee Discipline

Dealing With Employee Discipline Requires:

- Attention; Longer the problem lingers the more work is required to correct the problem
- Tact; Reward in Public and Discipline in Private
- Skill; Purpose of Discipline is to change behavior not to punish offender; employee multiple methods
- Stamina; Discipline Problems are not solved the first time out of the box
- Documentation; Without documentation there was no discipline problem

Reasons Cited for Correcting Unacceptable Behavior with Discipline

- No discipline problem ever solves itself; It becomes worse with time if left uncorrected.
- The sooner the problem is dealt with, the better the outcome will be.
- If the problem isn’t effectively dealt with, Morale of other employees is adversely affected reducing effectiveness
- Unacceptable Behavior sets the examples for others to follow compounding the problem

Common Organizational Disciplinary Processes

- **Most Organizations have a Written Disciplinary Policy that guides Employer Disciplinary Actions**
- **Most employers require a verbal warning (document) or consultation for minor infractions that occur**
- **For more serious violations or reoccurrence of a minor infractions after a verbal warning was issued, a written warning is issued; this is an official action that goes in the employee’s personal file (document)**
- **For repeated offences or major violations, punitive measures begin with the written (reprimand)**
- **Termination can be imposed at any time should the infraction be serious enough or infractions of a continuing nature, or a combination of actions occur.**

Disciplinary Meeting Steps

- If they respond inappropriately, you must restate the problem and explain that you are trying to find a positive solution that is acceptable to everyone.
- Close With a Positive Comment

Dealing with a Problem Employee

- **Maintain a constructive, calm, approach**
- **Create a private environment**
- **Listen very carefully and respond professionally**
- **Keep your language appropriate but direct**
- **Stay focused in the present**
- **Clearly and concisely state the problem with documented times and dates of occurrence(s)**
- **Explain that you are trying to find a positive solution that is acceptable to everyone.**
- **Aim for a permanent solution**
- **Close With a Positive Comment**
- **Record the discussion and the major items discussed**

Directing

Components of Directing

- Motivating
- Communicating
- Leading
- Coaching and Appraising
- Interpreting Organizational Goals and Objectives
- Managing Conflict

Manager/Supervisor Leadership Abilities

- Communicates Effectively and Listens
- Coaches and Motivates Employees
- Delegate Work Tasks Appropriately
- Holds Employees and/or Groups Accountable for Their Performance
- Manages Using Performance Data and accepted Evaluation Tools
- Leads by Example

Most Critical Management Functions

- Delegating Effectively
- Accomplishing Work Generally Through Others
- Ensuring Work Effectiveness and the Quality of Work Performed
- Ensuring that Work meets Quality Expecations
- Being Visible ("Managing by Walking Around") and Engaged (Performing Progress Status visits and Job Completion Follow-Ups)

Common Reasons for Management Resistance to Delegation

Primary! <u>Manager can not Delegate Responsibility</u>

- **Loss of Control**
- **Belief That Manager can do the job Better**
- **Managers believe that Employee is not as well qualified, trained or experienced**
- **Managers are afraid of mistakes that they will be ultimately responsible for**
- **Lack of confidence in subordinate judgment or dedication to doing quality work**
- **Comfort (Comfort Zone) confidence and/or satisfaction in performing a task**

Use of Teams to Improve Performance

Use of **Teams** to Improve Performance

Good Application

- **Provide group judgment on a specific issue or question**
- **Promote cooperation among employees**
- **Promote work coordination**
- **Carry out a specific function or purpose**
- **Provide advice to management**

Poor Application

- **Purpose and responsibilities are not well defined**
- **When timeliness is important**
- **When issues should not be compromised**
- **When decisions do not require study**
- **When no rules (charter) or procedures are set and records are not maintained**

Communication

Types of Communication

Communication may be verbal, non-verbal or written

- Formal Communication through Chain of Command is generally upward and downward
- Informal Communication is generally lateral direction
- Grapevine Communication is the probability of occurrence, gossip chain (both information and misinformation), cluster chain (diffusion and misinterpretation of information)

Communication Process

Sender ← **Feedback** → Receiver

Thinking Encoding Transmitting Perceiving Decoding Understanding

Communication Filters

Sender ↔ **Receiver**

- Fatigue
- Distractions
- Lack of Interest
- Lack of Concentration
- Preconceived Ideas or Prejudices
- Irrational Behavior, Harsh Words or Threats
- Instructions that are not clear, include Jargon or are too Complex

Problem Solving - Using Rudyard Kipling's Six Honest Serving Men

1. What
2. Why
3. When
4. How
5. Where
6. Who

Effective Problem Solving Steps Used by Managers

1. Realization that Problem Exists
2. Concise Statement of the Problem
3. Problem Analysis
4. Generation of Solutions
5. Selection of Best Alternative
6. Implementing Solution
7. Monitoring and Adjusting
8. Evaluating Results

Supervising Employees

Individual/Group Job Success Factors

- **Supervisory Leadership Abilities (Discussed Previously)**
- **Employee Readiness to Perform Tasks**
  - **Confidence based on training and experience**
  - **Work Attitudes and Beliefs**
  - **Knowledge, Skills and Applicable Training**
- **Resource Availability**
  - **Proper Tools and Diagnostic Equipment**
  - **Condition of and Effectiveness Equipment and Technology**
  - **Availability and Efficiency of Spare Parts Management**
- **Effectiveness of Work Procedures**
  - **Management Attitudes and Understanding**
  - **Management Support**
- **Existence of Employee Recognition and/or Rewards**

Critical Success Components for Managing Employees

- Objective Decisions
- Consistent and Uniform Treatment of Employees
- Decisions made in the interest of getting the job done on time while maintaining quality
- Decisions Based on the Ability of the employee to perform the job (with reasonable accommodation)
- Motivating Employee Performance

Objectivity in Decision Making

- Basing Decisions of Factual Information; it is a manager's responsibility to ensure that relevant data is collected to provide this information
- Be cognizant of influencing factors, e.g. environment and conditions surrounding the work
- Include the employee in decisions
- Solicit feedback to better understand the issues
- Utilize employee input and suggestions; employees typically know the job best
- Communicate directly with employees where possible

Consistent Treatment of Employees

- Handle Employee assignments, recognition and discipline equitably; mediocrity should not be rewarded
- Each Employee should be treated the same
- Unequal treatment of employees destroys morale and increases distrust
- OJT and outside Training Opportunities should be open to all employees.
- Overtime should be addressed with written procedures that ensures equity
- Genuine interest in employee progression, well-being and safety promotes cooperation

Decisions must be Related to the Employee's **Ability to Perform the Job**

- Decisions are based on the employee qualifications (demonstrated by training and experience) to perform the specific job tasks.
- Employees should be assigned to work with different crews and supervisors where possible to avoid the perception of special treatment
- Discrimination on the basis of physical characteristics of a person e.g.. size, gender, or appearance is illegal

Motivating Employees through **Job Enrichment**

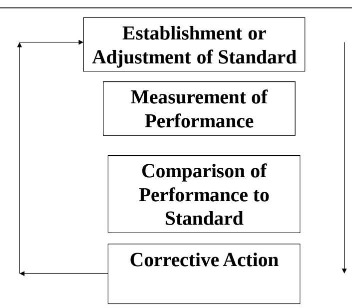
- Combining fractionalized tasks Job tasks to make them more meaningful to employees
- Giving employees more responsibility for quality or customer interaction
- Increasing employees leeway in the set up of jobs and use of tools and equipment
- Providing frequent feedback to employees so they know how they are doing
- Assessment and assistance with the employee's growth needs
- Higher expectations will produce higher results.

Opportunities for Increasing Job Effectiveness through **Job Redesign**

- When starting up or building a new plant
- During innovation or technological change
- When markets, products or services change
- When a reorganization occurs
- During periods of growth or downsizing
- When jobs are needed for a special position
- When the workforce or labor market changes
- When there are performance, quality, safety or satisfaction problems

Control

Control Process



Use of Control Systems

- To Standardize Performance
- To Safeguard Assets
- To Standardize Quality
- To Set Limits for Delegated Authority
- For Planning Operations
- To Balance Organizational Programs
- To Motivate Employees

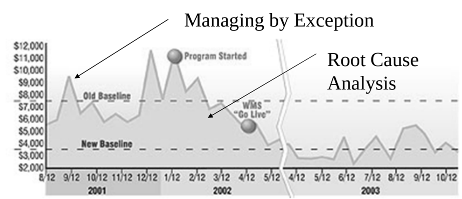
Typical Management Controls

- Control Charts
- Performance Reviews
- Spending vs. Budget Comparisons
- Profit and Loss Statements
- Monthly Reports
- Inspections/Audits

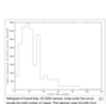
Characteristics of Effective Controls

- Simplicity and Units that are understandable (time or cost)
- Concentration of major activities or points (80/20 rule) and are not overused
- Emphasize the "management by exception" principle
- Provide Timely and Pertinent Information
- Evidence that Information is used to to correct deviation by those that receive it
- Controls are periodically reviewed

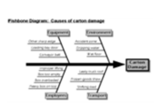
Typical Control Chart for **Reductions in Overtime**



Application of Ishikawa's 7 Tools of Quality (Let Data Speak)

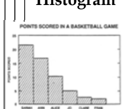


Histogram

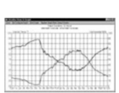


Fishbone Diagram

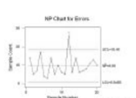
Check Sheet



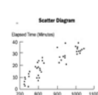
Pareto Diagram



Graph



Control Chart



Scatter Diagram

Common Methods of Improving Effectiveness in a Water Utility

- Total Productive Maintenance (eliminate wait states)
- Tearing Down Division/Department Silos (eliminate ineffective divisions or specializations in labor)
- Documenting and Reducing Non-productive Work (40/60 rule)
- Using Applied Technology, Automation and Controls
- Increasing Span of Management Control (reducing levels of management and increasing employees managed)
- Eliminating Unnecessary Emergency Staffing
- Outsourcing Non-Core Work accompanied with labor Reassignment to productive areas

Computer Aided Controls

- Process Control for plants, storage and transmission
- Cost controls such as enterprise capital and O&M budget spreadsheets
- Resource control such as inventory and personnel
- Productivity and and efficiency control such as Work Management Systems

Idealized Digital Environment (Rarely Exists)

Re-entry of Data

Unusable Information

Duplication of Records

Silos of Information

Ineffective and Outdated Policies

Controlling Employees

Concepts of **Management Responsibility** and **Employee Accountability**

- Manager Assigns and Delegates work tasks
- The manager establishes how the completed work is to be measured and reported
- Manager identifies the Employee's Performance
- Manager compares the performance to a standard
- The Employee is responsible for performing the task
- The employee is Accountable For the Results
- If there were obstacles to performance, the employee must describe them to management

Responsibility and Accountability for Work Performance Contrasted

Managerial Duties

- **Responsible for Delegating the work tasks**
- **Responsible for the quality and scheduling of the work**
- **Responsible for how the completed work is measured and reported**
- **Responsible for Comparing the performance to a standard**
- **Responsible for Identifying the Employee's Performance**

Employee Duties

- **Responsible for performing the assigned task**
- **Responsible for completing report on work performed**
- **Accountable for meeting the desired quality of the work performed**
- **Responsible for reporting obstacles to management**

Responsibility for the work can not be delegated!

Principles of Inventory Control

Reasons for Inventory

- Ensure that Parts and Materials used meet Standards
- Timeliness of Work Production and Elimination of Wait States
- To act as Buffers against Variation in Supplies and Demands
- Protection against Uncertainty
- Economies of Scale

Types of Inventory

- Raw Materials (warehouse)
- Spare Parts (warehouse)
- Work in Progress (assemblies)
- Pipeline (in transit such as materials or parts carried on work vehicles)
- Cycle Stock (set aside for high demand)
- Safety Stock (in excess of needed kept as hedge)
- Support Stock (nuts, bolts, bulbs, common fittings)

Inventory Costs

- Storage and Handling
- Insurance
- Spoilage, Pilferage and Damage
- Obsolescence
- Property Taxes
- Warehouse Maintenance and Depreciation
- Procurement and Processing
- Administration

Inventory Management

Effectively managing the flow of parts and materials by identifying the causes in variations in average demand while minimizing inventory costs.

- **Economic Order Quantity** (1915 F.W. Harris at Westinghouse) **(EOQ)**

$$\text{EOQ} = \sqrt{\frac{\textbf{2 x Ave Yr Demand x \$ per Order}}{\textbf{Holding Cost (\$ per Yr)}}}$$

(demand is uniform, lead time is zero, no quantity discounts, no constraints on storage capacity)

- **Reorder Levels** (based on use and quantity discounts)
- **Safety Stock** (based on service levels priorities)

Policies, Standards and Procedures

Policy and Procedures Definitions

Policy

- The intent and management philosophy for dealing with a given set of circumstances or conditions
- Intended to guide thinking and decision-making by employees
- It is under policy that the plan is developed

Procedures

- Rules, steps or standards for how work is performed

Use of Procedures

- Procedures are operating instructions for employees to use when performing repetitive work.
- They achieve four purposes:
  - promote standardization of work (SOPs)
  - used to train employees in effective methods
  - ensure acceptable management control
  - increase work effectiveness and reduce cost
- Procedures can be unwritten but written are preferable

Definition and Characteristics of an Effective **Standard**

A Standard is a criteria that is accepted as the minimum value or lowest quality that is desirable to be achieved.

- Understandable
- Timely
- Suitable and Economical
- Although a Standard is fixed, it can be modified by a manager when it better fits the conditions

Standard Operating Procedures **(SOP)**

- Standard Operating Procedures (SOPs) may be written for any business activity
- Most Commonly used for how work operating or maintenance work is to be performed
- Procedures describe, what, where, who, and when and are typically written in a sequence of steps
- Most utilities lack written procedures and this results in accelerated equipment failure, waste of resources, process excursions and ineffective response to problems

Components of an **Effective SOP** Program

- **SOPs are in written form and provided to those affected**
- **Detailed instructions are discouraged over standard methods sheets that are in pictorial and written form**
- **There are written procedures for discarding obsolete procedures and draft changes are circulated among those affected**
- **Existing and new Procedures are reviewed for effectiveness**
- **Procedures are enforced by all that are affected but flexibility and job simplification is encouraged**
- **There is a designated, responsive and trained procedure writer**

Monitor

Work Management

Development of an Effective Work Management Monitoring System

- **Work is categorized**
- **Work Standards that include time and quality are developed**
- **Work is Assigned based on Standards to Individuals or Crews**
- **Work is Completed, Data Recorded (and Inspected)**
- **Work Data is compared to acceptable standards**
- **Deviations of Acceptable Performance is identified**
- **Problems that inhibit performance are eliminated**
- **Maintenance Equipment Histories are often an outcome of a successful work management program**

Preventative Maintenance Programs

Types and Acceptable Ranges for a Preventative Maintenance Program

- **Predictive Maintenance (~ 60%)**
  - **- Vibration Monitoring - Infrared Heat Monitoring**
  - **- Electrical Monitoring (Volts and Amps)**
  - **- Flows & Pressure Monitoring - Laser Alignment**
  - **- Wear/Corrosion Monitoring - Ultrasonic Testing**
- **Preventative Maintenance (~ 40%)**
  - **- Performed on Regular Schedule**
  - **- Performed by Hours of Use**
- **Planned Maintenance**
  - **- Performed based on History**
  - **- Performed based on Performance Drop**
- **Breakdown Maintenance (< 20%)**

3% to 10% of original Equipment cost is spent on Maintenance in US

Evolution of a Total PM Program

Phase 1 Install PM System

Phase 2 Stabilize Mean Time Between Equipment Failures

Phase 3 Lengthen Equipment Life

Phase 4 Restore Periodically Restore Deterioration

Phase 4 Predict Equipment Life

T I M E

Energy Management Programs

Energy Monitoring and **Energy Surveys**

- The Goals are Twofold, reduce energy and/or reduce costs
- Identifies the amount Energy used in a facility by major equipment
- Identifies Energy Costs and Tariffs
- Evaluates Alternatives for Reducing Energy Use
  - **Identify how energy is used**
  - **Identify points of wasted energy**
  - **Identifies opportunities for improving operating techniques**
  - **Identifies Savings by Replacing Inefficient Equipment**
- Identifies Cost Effectiveness of Energy Alternatives

Components of a Typical Electric Bill

- Basic Service Fee ($/mo)
- Demand Charge ($/kW) (Typically based on Highest 15 minutes/year)
- Power Factor ($/kvar)
- Energy Charge ($/kWh)

Listing of Energy Consuming Equipment in Water Plant

Process #	Process Name
1	Raw Water Pumping
2	Screens
3	Rapid Mixers
4	Flocculation
5	Sedimentation
6	Filtration & Backwash
7	Chemical Treatment
8	Ozonation
9	Disinfection
10	Distribution Pumping
11	Sludge Thickening
12	Sludge Conditioning
13	Sludge Dewatering

	Process or Operation												
Electrotechnologies	1	2	3	4	5	6	7	8	9	10	11	12	13
Well pumps	X									X			
Water pumps	X									X			
Traveling screens		X											
Blowers/fans						X		X					
Agitators/mixers			X	X	X		X	X	X			X	
Clarifier drives					X		X				X		
Sludge pumps					X	X	X				X	X	X
Process water pumps						X	X	X	X				X
Compressors								X					
Chemical pumps			X			X	X		X			X	
Chemical mixers			X			X	X					X	
Conveyors		X					X						
Centrifuges											X		X
Belt filter press													X
Vacuum pumps						X							X
Hydraulic drives													X
Evaporators									X				X
Drainage Pumps	X			X	X				X	X			
Cranes/hoists	X	X							X	X			
Ozone generators								X					

Energy Requirements by Process

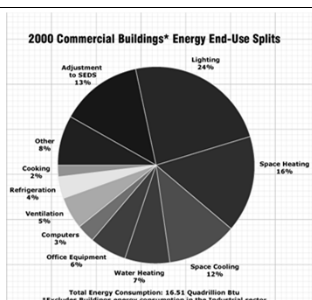
Typically 80 – 85% of Energy Use in a Water Treatment System is for Pumping

Item/Plant Production	1 MGD	5 MGD	10 MGD	20 MGD	50 MGD	100 MGD
Raw Water Pumping	121	602	1205	2410	6027	12055
Rapid Mixing	41	176	308	616	1540	3080
Flocculation	10	51	90	181	452	904
Sedimentation	14	44	88	175	438	876
Alum Feed System	9	10	10	20	40	80
Polymer Feed System	47	47	47	47	47	47
Lime Feed System	9	11	12	13	15	16
Filter Surface Wash Pumps	8	40	77	153	383	767
Backwash Water Pumps	13	62	123	246	657	1288
Treated Water Pumping	1205	6027	12055	24110	60273	120548
Chlorination	2	2	2	2	4	8
Residuals Pumping	4	20	40	80	200	400
Thickened Solids Pumping	N/A	N/A	N/A	123	308	616
Total (kWh/day)	1483	7092	14057	28176	70384	140685

Reducing Energy Use or Costs with Pumping Equipment

- **Shifting Power Consumption from On-peak to Off-peak hours (Demand Limiting)**
- **Adding Storage for Off peak/Emergency pumping**
- **Use of Efficient Pumping Programs**
- **Replacing older motors with high efficiency motors (cost 15 – 20% more).**
- **Adding or replacing eddy-speed drives with variable frequency drives (VFDs)**
- **Using Effective Instrumentation and Controls.**
- **Managing operations by the efficient use of available storage and high-efficiency motors**
- **Operating Emergency Generators for Peak-Clipping when no or little storage is available.**
- **Shifting Rates to Another Category (Master Metering)**

Energy Use for Space Heating & Cooling and Lighting are Major Users in Commercial Building



Brief History of Scientific Management in US

Management Science in US

- Adam Smith – *Wealth of Nations*, 1776
- Fredrick Taylor - *Principles of Scientific Management*, 1911
- Henry Fayol – *Theory of Administration*, 1918
- Elton Mayo - *Hawthorne Studies*, 1924 - 1927
- Walter Shewhart, Statistical Quality Control, 1931
- Frank & Lilian Gilbreth, Ergonomics, Mgmt./Psychology
- Abraham Maslow, BF Skinner, Fredrick Hertzberg
- Douglas MacGregor – *Human Side of Enterprize*
- William Knudson – Industrial Mobilization WW2, 1940
- Douglas MacAurther and Japanese Manf. (1945 - 1950)
- Quality Management, Demming, Juran and Ishikawa
- Phillip Crosby - US TQM Experience, 1980's
- Current Practice: Six Sigma, Balanced Scorecard
- Quality Influences in Globally, in US and in Public Sector

Adam Smith
Wealth of Nations, Scotland, 1776

- Identified transition from agriculture to manufacturing
- Through a policy of governing laissez faire (let alone,) the goods produced will be those that people want
- Labor talents and capital assets will be naturally applied where they contribute to production of desirable goods and services.
- This policy would naturally result in labor earning higher wages.
- The resulting demand would lead to increased production that would eventually lead to a greater supply and lower prices
- Economic reward would be sustained **on their own by self interest**
- individuals, acting in their own self-interest ("**invisible hand**"), would determine the economic activities that brought them the greatest reward
- This policy would maximize the economic well-being of society
- Society would create wealth through manufacture, services and trade.

Charles Babbage, England
On the Economy of Manufactures, 1832

- Father of Operations Research
- "Every Fact is Useful information"
- Developed Statistical Tables for Use in Predicting the amount of resources needed in production
- Studied manufacturing processes from needle making to tanning
- Developed basic design for computer

Henry Fayol, France
Theory of Administration, 1918
Fourteen Requirements

1. Division of work
2. Authority
3. Discipline
4. Unity of Command
5. Unity of Direction
6. Subordination of Individual
7. Remuneration and Recognition of Worth
8. Chain of Command
9. Order
10. Centralization
11. Equity in Employee Relations
12. Stability and Tenure
13. Initiative; Workers must be productive
14. Espirit de Corps

Fredrick Taylor, US
Principles of Scientific Management, 1911

- **1874 Assistant Machinist at Bethlehem Steel Corp.**
- **Mechanical Engineering Stevens Inst. of Technology (Correspondence)**
- **President of ASME 1906, Prof at Dartmouth**
- **Four Principles**
  1. **Study of Tasks (time and motion)**
  2. **Select and Train Employees**
  3. **Gain Worker Cooperation**
  4. **Divide work into Mgmt and Labor**
- **Best Results come from Partnership Labor/Mgmt.**
- **(Note: He was fired from B. Stl and ASME rejected his publications)**

Elton Mayo, US
Hawthorne Studies, 1924-1927

- How working environment affects employee production.
- Best known for Lighting experiments at Western Electric; (no correlation found)
- Studied fatigue and rest with 6 women/12 wks.
  - increased rest
  - lack of management coercion
  - responsibility for production

  <u>Increased Production by 20% even after Study was completed</u>!

The Pygmalion Effect

- The improvement in employee performance that results from raising a manager's expectations about the employee's performance.
- The Pygmalion Effect works when managers communicate high expectations to employees.
- Conversely, low manager expectations produces lower employee performance.

Walter Shewart, US
Statistical Control Techniques, 1931

- PDSA Cycle: Plan Do Study Act
- The cycle draws its structure from the notion that constant evaluation of management practices -- as well as the willingness of management to adopt and disregard unsupported ideas --are keys to the evolution of a successful enterprise
- importance of adapting management processes to create profitable situations
- In order to aid a manager in making scientific, efficient, economical decisions, he developed Statistical Process Control methods.
- Sampling at Various Points in Process adapted during WWII

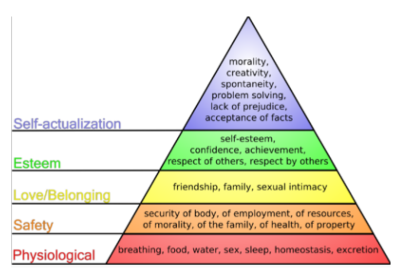
Frank & Lilian Gilbreth, 1924
Marriage of Mgmt./Psychology

- Development of Science of Ergonomics
- <u>Study of Work Tasks for Productivity Improvement</u>
- Study of Processes and Development of Control Charts (Frank died in 1924)
- *Psychology of Management,* 1914, stressed the importance of human relations, recognition of differences, justice and happiness in the workplace (Lilian not listed as author)
- Assisted US government with conversion of factories during WWII

Abrahm Maslow
A Theory of Human Motivation, 1943

- Hierarchy of Needs
  - Physiological: most pre-potent or strongest of human needs when unsatisfied
  - Safety, Love, Affection, and belongingness
  - Esteem and Self-actualization higher needs
- Higher needs emerge as lower ones are satisfied
- Emerge in different order in different people
- A satisfied or gratified need is not a satisfier of behavior

Maslow Hierarchy of Needs



William Knudson – 1940-1945 Industrial Mobilization WWII

- **Danish immigrant started career in boat industry**
- **Started on shop floor at Ford Motors and in 1911 became Director of Production; left for same job at GM after run-ins with Henry Ford; GM surpassed Ford**
- **Increased Production at GM plants by developing equipment standards, decentralizing operations and using outside suppliers, and attention to Customer**
- **Tapped by FDR to manage Industrial Mobilization during WWII**
- **Modernized plants idled by depression, replaced obsolete equipment, improved delivery systems, set production goals, monitored quality and retrained workforce revitalizing US output..**

Douglas McGregor

- MIT Sloan School of Management
- Human Side of Management published in 1960
- Theory X: Authoritarian, boss knows best and Theory Y: Workers Responsible and most Knowledgeable
- Generally accepted that Theory Y was the more effective form of management

Brief Comparison of Theory X Theory Y

Theory X

- People dislike work and must be coerced
- People like to be told what to do
- Tight controls are needed
- Punishment for outliers is important

Theory Y

- Work is a natural state
- If the job is satisfying then good results will follow
- Group behavior will lead to optimal solutions

Douglas MacAurther, 1945 Rebuilding of Japanese Industry

- perform a full-scale overhaul of its social, political and moral fabric
- loosened restraints on political expression
- bolstered labor's right to organize
- Expanded the education of women
- Dismantled the conglomerate "zaibatsus" forming more competitive "keiretsus"
- Today there are 6 major Keiretsus in Japan, Mitsubishi (Automotive, Petro, Beverages) is one of these
- Invited Quality Managers Duran and Deming

Japanese Industrial Culture

- **Feudal State to Economic Superpower in 35 years**
- **Culture – Job is identity to Larger Entity**
- **Job Instills feeling of prestige**
- **Pay raises and promotions automatic and tied to seniority**
- **Shushkin koyo (lifetime employment) is guaranteed; training is essential but new tech. threatens system**
- **Workers belong to Production Teams and every member is responsible for work**
- **Managers preserve harmony and cooperate with workers**
- **Government subsidizes 2/3 wages for layoffs or factory shutdowns**
- **Since 1990, 10% companies use merit system for executives tied to performance goals**

J. Edwards Deming

Some Theories of Sampling, 1950

- Use of Statistical Theories to identify and minimize defects; Plan, Do, Check, Act
- Quality can be improved only if top management participates in the quality program and is part of the solution
- Developed his "14 Points," the key actions management must take to ensure quality, productivity, and success.

Deming's 14 Points for QM

1. Create Constancy of purpose to improve products and service
2. Adopt a new leadership philosophy for change
3. build quality into the product and eliminate inspection
4. Award business on minimized total cost
5. Constantly improve production, services, quality, productivity and decrease costs.
6. Institute training on the job to make use of all employees.
7. Redefine leadership to help people and machines improve
8. Drive out fear so everyone works effectively
9. breakdown barriers between departments
10. Eliminate slogans, or targets for new levels of productivity without providing methods.
11. Eliminate work standards (quotas) and numbers or numerical goals
12. Remove barriers to pride of workmanship and abolish annual or merit rating, MBOs or management by numbers.
13. Institute education and self-improvement programs
14. Clearly define top management's permanent commitment to quality and productivity

Deming's Seven Deadly Sins

1. Lack of constancy of purpose to plan product and service that will keep the company in business and provide jobs.
2. Emphasis on short-term profits and short term thinking,
3. Personal review system, or evaluation of performance, merit rating, annual review,,or annual appraisal
4. Job hopping and mobility of management:.
5. Use of visible figures only for management, and/or little or no consideration for known or unknown pertinent facts
6. Excessive medical costs.
7. Excessive costs for warranties and consultants working for contingency fees.

Japan's Deming Award

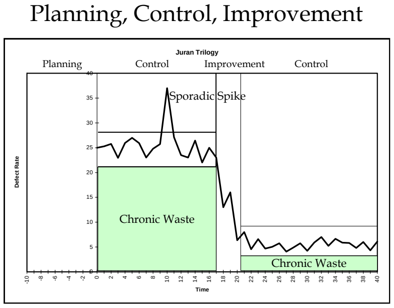
- Instituted in 1951 by Japanese Union of Scientist and Engineers and still in use today
- Uses 10 major evaluation criteria:

1. Policy	6. Use of Information
2. Organization	7. Quality Management
3. Education	8. Quality Assurance
4. Quality Process	9. Result of Program
5. Standardization	10. Future Plans

Joseph Juran
Improvements Japanese Quality, 1954

- Resistance to Change and Parento Principle ("80 - 20 Rule")
- credited for adding the human dimension to quality management
- Juran promoted "Quality Circles" in 1960
- "Juran's trilogy," an approach to cross functional management that is composed of three managerial processes: planning, control, and improvement

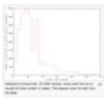
Juran Trilogy
Planning, Control, Improvement



Kaoru Ishikawa, Japan
Contemporary of Deming
"Seven Tools of Quality"

1. Histograms,
2. Cause and Effect Diagrams (Fishbone)
3. Check Sheets
4. Pareto Diagrams
5. Graphs
6. Control Charts
7. Scatter Diagrams.

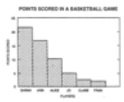
Ishikawa – Eg. 7 Tools of Quality



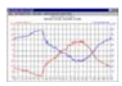
Histogram

Fishbone Diagram

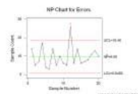
Check Sheet



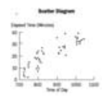
Pareto Diagram



Graph



Control Chart



Scatter Diagram

Ishikawa's Quality Circles

1. All employees should clearly understand the aim of the company in order to introduce and promote CWQC.
2. The features of CWQC of the whole company, of departments, and of branches should be clarified. People should have confidence in these features.
3. The effective PDCA (plan-do-check-act) cycle should rotate in the whole company, in branches, in plants, and in workshops for at lease three to five years. Statistical quality and process analyses should be adequately carried out, and upstream control should be developed and effectively used.
4. The company should have the capability of establishing a long term plan of CWQC and of carrying it out systematically.
5. The walls between departments-or sectionalism-should be broken down, and cross functional management should be effectively carried out.
6. Everyone should act with confidence, believing that his or her work will bear fruit.

BF Skinner
Science and Human Behavior, 1953

- **In operant conditioning, behavior affected by its consequences but the process is not trial-and-error learning, (discrimination and differentiation)**
- **Operant reinforcement both shapes and maintains behavior even after an operant is removed**
- **Schedules of reinforcement are important in maintaining behavior.**
  - **fixed reinforcement (Piece-rate pay)**
  - **variable reinforcement (Gambling)**
- **Reinforcers may be positive, negative or extinguishing.**
  - **a positive reinforcer acts when it is presented.**
  - **a negative acts reinforcer acts when it is withdrawn.**
  - **an extinguishing reinforcer acts when no response occurs.**
- **Negative Reinforcement has unwanted consequences**

Fredrick Herzberg, 1975 Two-Factor Hygiene Theory

Hygiene Factors

- Pay
- Fringe Benefits
- Relationship with co-workers
- Physical Environment
- Supervisor-Employee Relations

Motivation Factors

- Achievement
- Recognition
- Work Identity
- Responsibility
- Promotion
- Growth

Myers-Briggs Type Indicator MBTI

- Developed by Mother-Daughter in 1942
- Sorts for Personality Types not for Ability to Perform Job or for Job Selection!
- Useful in Career Counseling, Teaching, Group Dynamics, Employee Training, Leadership Training, and Personal Development
- Scientific Basis is highly suspect with reliability and repeatability often low

Phillip Crosby
Quality is Free, 1979

- Quality is defined as conformance to requirements not goodness, the system for causing quality is prevention not appraisal, the performance standard must be Zero Defects, not "that's close enough" and the measurement of quality is the Price of Nonconformance, not indices.

Crosby Maturity Grid

Business Maturity

- **Stage I: Uncertainty**
- **Stage II: Awakening**
- **Stage III: Enlightenment**
- **Stage IV: Wisdom**
- **Stage V: Certainty**

Measurement Categories

- **Management under-standing and attitude**
- **Quality organization status**
- **Problem handling**
- **Cost of quality as % of sales**
- **Quality improvement actions**
- **Summation of company quality posture**

Causes Cited for Failures of TQM Programs

- Lack of Integration
- Leadership Apathy
- Fuzzy Concepts
- Unclear Goals
- Purist Attitudes and Technical Zealots
- Failure to Breakdown Interior Barriers
- Incremental vs. Exponential Change
- Ineffective Training
- Focus on Product Quality

TQM in US
Malcolm Baldrige Award 1987

- Patterned after Deming Prize in Japan; Public Law 100-107
- Named posthumously after Malcolm Baldrige, Sec. Of Commerce under Ronald Regan
- Help Stimulate US Business to improve quality
- Recognize achievement and provide example to others
- Establish Guidelines for Business, Industry and Government
- Provide Guidance to others

Malcolm Baldrige Award Major Categories

1. Leadership
2. Information & Analysis
3. Strategic Quality Planning
4. Human Resource Utilization
5. Quality Assurance of Products & Services
6. Quality Results
7. Customer Satisfaction

Robert Kaplan and David Norton Balanced Scorecard 1990

Balanced Scorecard as a Management System

- enables organizations to clarify their vision and strategy and translate them into action
- It provides feedback around both the internal business processes and external outcomes in order to continuously improve strategic performance and results.
- It views the organization from <u>four</u> perspectives, the Learning, Business Customer and Financial Perspective

Ron Williams, 3-M, 1995

Self Directed Work Teams

- **teams are natural work groups that work together to perform a function or produce a product or service**
- **Teams do the work and take on the management functions formerly performed by supervisors and managers.**
- **This allows managers to teach, coach, develop and facilitate rather than simply direct and control.**
- **The traditional Taylor model, "reducing a process to individual steps" is restructured around whole processes.**
- **There is interdependence and joint responsibility for outputs, those closest to the jobs help design the job.**
- **<u>Requires Organizational Commitment!</u>**

Reported Benefits of Self Directed Work Teams (500 Organizations)

- Improved quality, productivity and service.
- Greater flexibility.
- Reduced operating costs.
- Faster response to technological change.
- Fewer, simpler job classifications.
- Better response to workers' values.
- Increased employee commitment to the organization.
- Ability to attract and retain the best people.

Jack Welsh, 2000 GE's Six Sigma σ Program

(6σ = Deviation or 99.9997 conf.)

Theme Description

1. Genuine Focus on Customer
2. Data and Fact Driven Management
3. Process Focus Management Improvement
4. Proactive Management
5. Boundaryless Collaboration
6. Drive for Perfection

Six σ Methods and Tools

- Continuous Improvement
- Process Design/Redesign
- Statistical Process Contol
- Analysis of Variance
- Process Management
- Design of Experiments
- Creative Thinking
- Voice of the Customer
- Balanced Scorecards, Innovation, Process, Customer and Financial

Quality Management in Public Sector

- *Reinventing Government.* Osborn and Gaibler, 1993
  - Compensation Systems reward Longevity over Performance
  - Line Item Budgeting encourages spending, hording of resources and departmental sub optimization
  - Monopolies result in higher costs and lack of attention to customer desires

Global Quality Management ISO 9000 & ISO 14000

- **1959, US develops Quality Program Requirements, standard for military procurement detailing suppliers requirements**
- **1962, NASA similarly develops Quality System Requirements for its suppliers and applied these techniques on the project "travel to the moon"**
- **1968, NATO adopts the Allied Quality Assurance Procedures specifications for the procurement of NATO equipment**
- **1971, British Standards Institution (BSI) published the first UK standard for quality assurance, BS 9000.**
- **After several revisions ISO 9000 developed for Global use in 1987, also ISO 14000 for Environmental Mgmt.**

Management Requirements ISO 9000 Standards

- Management Responsibility
- Quality System
- Order Entry
- Design Control
- Document and Data Control
- Purchasing
- Control of Customer Supplied Products
- Product Identification and Tractability
- Process Control
- Inspection and Testing Control of Inspection, Measuring, and Test Equipment
- Inspection and Test Status
- Control of Nonconforming Products
- Corrective and Preventive Action
- Handling, Storage, Packaging, and Delivery
- Control of Quality Records
- Internal Quality Audits

OMB Requirements for use of Quality Principles under Safe Drinking Water Act

- **Identification of each population addressed by any estimate of public health effects,**
- **Identification of the expected risk or central estimate of risk for the specific populations,**
- **each appropriate upper-bound or lower-bound estimate of risk;**
- **each significant uncertainty identified in the process of the assessment of public health effects and studies that would assist in resolving the uncertainty; and**
- **peer-reviewed studies that support, are directly relevant to, or fail to support any estimate of public health effects and the methodology used to reconcile inconsistencies in the scientific data.**

Energy Use for Space Heating & Cooling and Lighting are Major Users in Commercial Building