Drinking Water Operations Wall Chart

HDR, in association with the AWWA, developed this new Drinking Water Operations wall chart to assist utility personnel with the daily operation and maintenance of water treatment and distribution systems.

A combination of reference tools and guidance information to improve system performance and achieve optimal water quality is presented in two categories: Treatment and Distribution.

The guidance information and all of the reference tools embody generally accepted calculations and practices used in the industry. This information was compiled to help utilities improve service to their consumers.

To request additional copies or view online resources for information referenced on this chart, please visit www.hdrinc.com/OpChart. This is the first edition of HDR's Drinking Water Operations wall chart. If you have suggestions or comments, please send those to us at water@hdrinc.com or call 1.800.366.4411 and ask for the National Water Program Coordinator.

TREATMENT (opposite side)

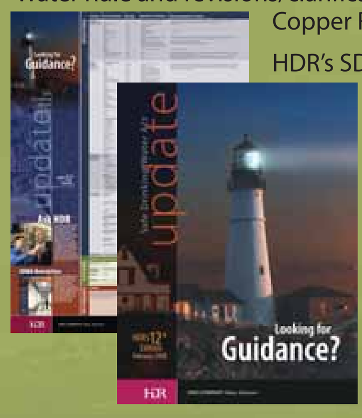
- Breakpoint Chlorination Curve - Optimizing Total Chlorine
- Jar Testing - Determining the Optimum Coagulant Dose
- Taste and Odor - Complaints and Corrective Actions
- Common Water Conversion Factors
- Top 10 Treatment and System Calculations

DISTRIBUTION SYSTEM

- Finished Water Calcite Stability - Managing Corrosiveness based on Calcium Carbonate
- Pumping and Energy Efficiency
- Water Loss Accounting
- Best Management Practices
  - Water Main Flushing Programs
  - Water Main Repair -10 Steps to Prevent Contamination
  - Storage Facilities - Maintaining and Protecting Water Quality

SDWA Regulatory Update Wall Chart, 12th Edition

HDR also produces the SDWA Regulatory Update – a poster-sized chart referencing all drinking water regulations, including a detailed listing of contaminants and maximum contaminant levels, health effects and monitoring requirements. The 12th edition (Feb. 2008) includes the latest information on the new Ground Water Rule and revisions/clarifications to the Lead and Copper Rules.



HDR's SDWA Newsletter is a quarterly publication that provides information on current and future SDWA regulations and new treatment approaches.

To request a copy or join our SDWA mailing list, contact sdwa@hdrinc.com.

HDR – Leaders in Water Solutions

Founded in 1917, HDR is an architectural, engineering and consulting firm that excels at helping clients manage complex projects and solve emerging challenges. Consistently ranked among *ENR's* Top 10 Water Firms, HDR is a leader in the water field. Our nationally respected professionals combine the latest technical innovations with practical solutions. Whether it's source water development or regulatory compliance, infrastructure management or sustainable operations, we help our clients identify the best course of action and deliver more value for their investment.

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DRINKING WATER OPERATIONS

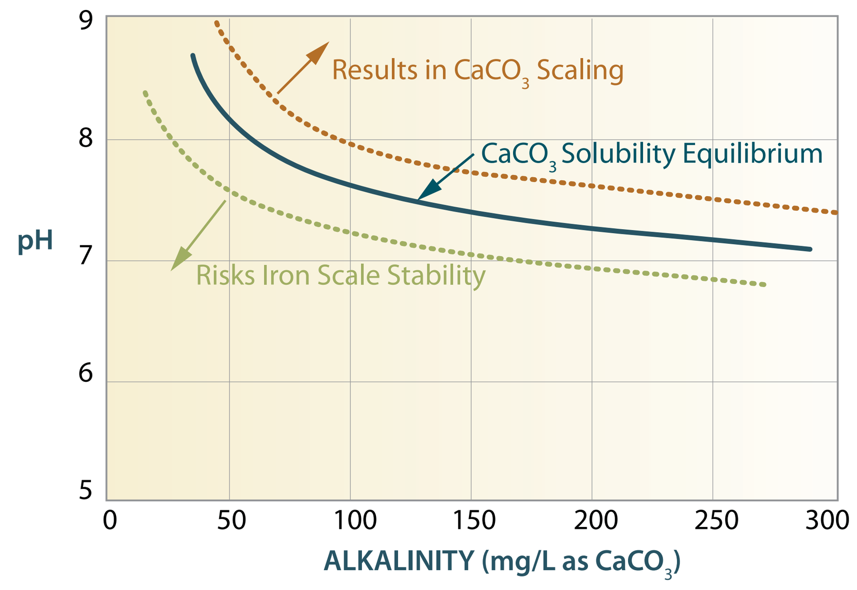
Treatment & Distribution

Tools to Improve System Performance and Achieve Optimal Water Quality

Finished Water Calcite Stability - Managing Corrosiveness based on Calcium Carbonate

Using pH - Alkalinity Relationship

The following approach to corrosion control is based on calcium carbonate saturation and can be useful to mitigate iron release and red water problems but may not be useful for lead and copper corrosion issues.



This graph may be used for estimating the corrosiveness of water. If the total alkalinity and pH values intersect at a point on the graph below the lower dotted line, the water may be considered corrosive. To reduce corrosion potential, raise the alkalinity and pH of the finished water by adding lime, caustic soda, sodium bicarbonate or soda ash until the point of intersection falls above the center solid curve. If the point of intersection falls above the top dotted curve, supersaturation is indicated and undesirable calcium carbonate deposits may be expected.

Langelier Saturation Index (LI)

One of the most common tests for determining the corrosivity of water is the Langelier Saturation Index (LI). The LI requires the following measurements: calcium hardness, total alkalinity, pH, total dissolved solids (TDS) and water temperature in centigrade. Once the tests have been performed, they are assigned a value from the following tables. Notice that hardness and alkalinity (C and D) both use the same table.

LI Formula

1. pH saturation (pHs) = A + B – C – D, then
2. LI = pH actual – pHs

Corrosive Characteristics	Langelier Index
Highly aggressive	< -1.0
Moderately aggressive	-1.0 to 0.0
Nonaggressive	>0.0

Water Temp (°C)	(A)
0	2.60
4	2.50
8	2.40
12	2.30
16	2.20
20	2.10
25	2.00
30	1.90
40	1.70
50	1.55
60	1.40
70	1.25
80	1.15

TDS mg/L	(B)
0	9.70
100	9.77
200	9.83
400	9.86
600	9.89
1,000	9.90

Calcium Hardness (C) or Total Alkalinity mg/L $CaCO_3$ (D)	(C) or (D)
10	1.00
20	1.30
30	1.48
40	1.60
50	1.70
60	1.78
70	1.84
80	1.90
100	2.00
200	2.30
300	2.48
400	2.60
500	2.70
600	2.78
700	2.84
800	2.90
900	2.95
1,000	3.00

Pumping and Energy Efficiency

The vast majority of energy consumption associated with water supply is due to raw water and finished water pumping. Over 80 percent of a typical plant's energy use is from these pumping systems. A sustainable facility will operate with these pumping systems optimized. The table to the right shows how your O&M staff can troubleshoot and optimize energy usage at your treatment and distribution facilities.

Issue or Symptom	Potential Cause	Action or Solution	Impact on Energy Efficiency or Energy Cost
1. Pump not developing design flow.	Throttling valve partially shut or impeller wear.	Check for partially shut valves and check impellers for wearing ring/impeller damage.	Throttling valves are an inefficient method of controlling flow because they increase head and power. Worn impellers or wearing rings can reduce pumping capacity and efficiency.
2. Pump testing shows poor wire to water efficiency.	a. Operating conditions have changed from original design. b. Inefficient variable speed drive (liquid rheostat with wound rotor motor, eddy current or hydraulic drive).	a. Determine operating point on pump curve. Then use variable speed, impeller change, or pump change to match new operating conditions. b. Change to variable frequency drive (VFD).	a. Operating on the pump curve significantly to the right or left of the efficiency "sweet spot" can result in poor efficiencies and potentially unstable operation. b. Modern VFDs have a loss of approximately 3% over the normal operating range of centrifugal pumps vs. 10-40% loss for drives mentioned under "Potential Cause."
3. Excessive energy used for pumping.	Throttling valve or pressure control valve used as control device.	Change to variable speed device like VFD.	Substantial reduction in head for any given flow and corresponding savings in energy.
4. Excessive flow output by pump causes operation far to the right on the pump curve and unstable operation.	Pump is over designed for actual operating conditions.	Use VFD, change impeller or consider using a smaller "jockey pump."	Operation on the far right of the pump curve is inefficient and can damage the pump.
5. Start/stop operation of pump causes high electrical demand charges.	No variable speed drive.	Install variable speed drive.	Continuous operation and a constant flow results in lower demand charges.
6. High energy costs during "on peak" energy periods.	High water demands usually occur during "on peak" energy hours in summer.	Take full advantage of storage in the system to trim "on peak" pumping.	Lower electricity charges even though daily pumping volume does not change.
7. Water utility is not getting paid for all of the water produced.	Water loss in the system or water accounting issue.	Conduct water audit followed by water loss detection/remediation program.	Lost water represents significant energy to treat and pressurize the water system.
8. Pump is short cycling.	Leakage is occurring back through the check valve.	Remove any obstructions or blockage and replace broken or badly worn parts.	Restores normal pump operation and energy efficiency.

Water Loss Accounting

Using the International Water Association (IWA)/AWWA Water Loss Accounting System (shown below) will help your utility develop a sound strategy to minimize the loss of valuable resources you work so hard to protect. Make it happen by implementing a Water Loss Reduction Program.

Step 1: Assess your losses
Use the standard terminology and auditing method (shown below) to determine your water losses.

Step 2: Identify system performance
How do your losses compare to other agencies'?

Step 3: Analyze your loss data
Develop a strategy based on the types of losses.

Step 4: Set targets, deadlines and implement
Adjust your strategy to meet your targets.

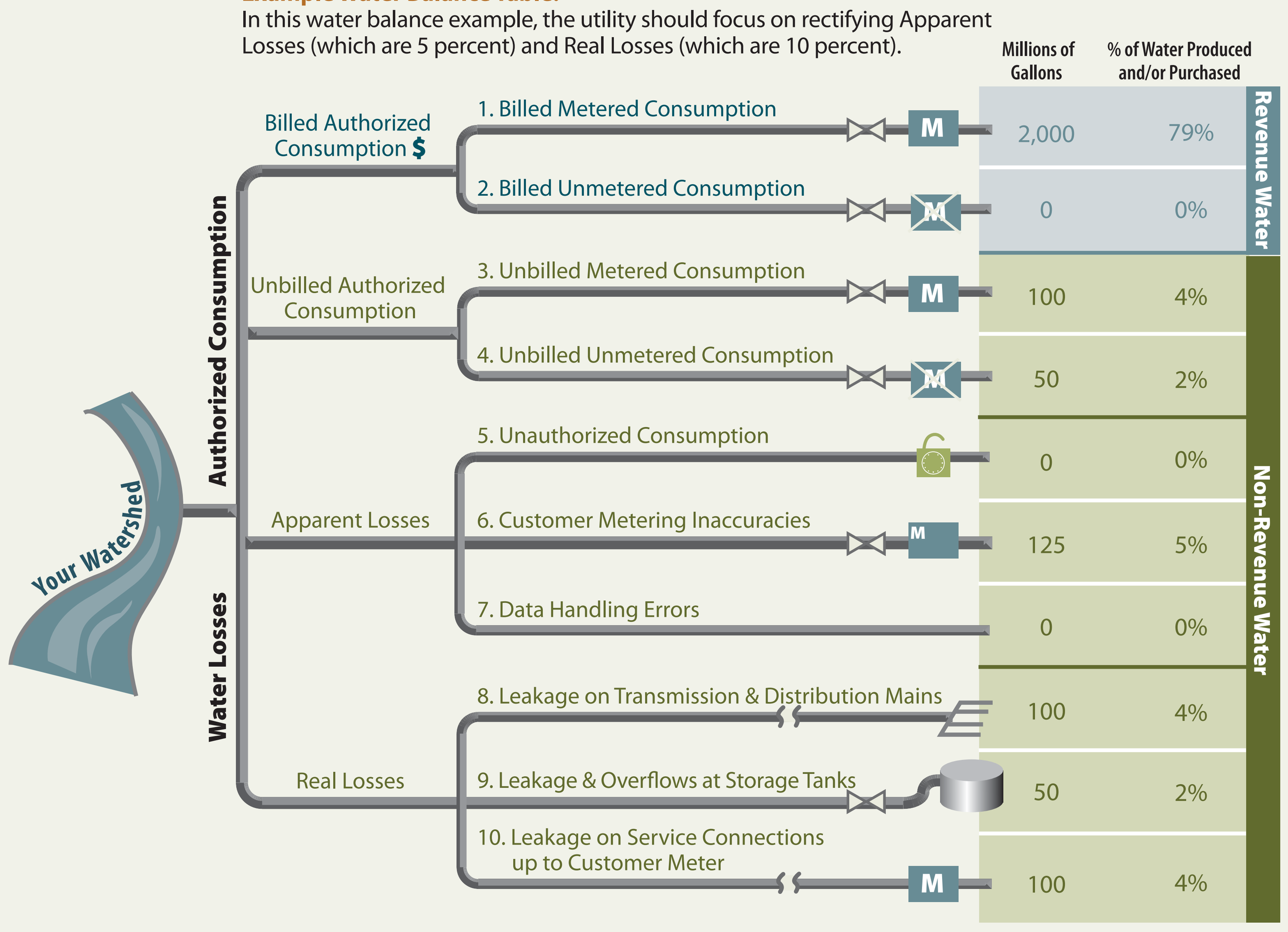
A "water balance" is an accounting of all water that is produced and/or purchased. It is useful for several purposes, including:

- Understanding the magnitude of system leakage
- Identifying lost revenue opportunities
- Calculating non-revenue water for demand forecasting

Water is assigned to the 10 numbered categories shown on the graphic. These 10 categories can be grouped in different combinations for various purposes.

- **Billed Authorized Consumption –** This is water that is billed and authorized by the utility and typically includes retailed and wholesaled water.
- **Unbilled Authorized Consumption –** It is standard practice not to charge for many uses in this category (e.g., flushing or fire fighting). However, it may be helpful to review uses in this category and assess whether any of them should be billed (e.g., contractor use).
- **Apparent Losses –** Water lost to theft, as well as "paper water losses" due to customer metering inaccuracies and data entry errors, are lost revenue opportunities.
- **Real Losses –** This is your system leakage. A certain level of leakage is unavoidable. Leakage beyond that level should be fixed so the physical infrastructure or the natural resource isn't burdened.

Example Water Balance Table:
In this water balance example, the utility should focus on rectifying Apparent Losses (which are 5 percent) and Real Losses (which are 10 percent).



Best Management Practices - Water Mains and Storage Facilities

Water Main Flushing Programs

Flushing Approaches

- Unidirectional Flushing (UDF)
  - Best applied for planned preventive maintenance practice
  - Should result in controlled hydraulic scouring of deposits
- Conventional
  - Best applied for reactionary "quick fix" practice
  - Should result in displacement of localized water

Key Implementation Steps for a Successful UDF Program

1. Define program goals, allocated resources and measures of success
   - Water quality improvement
   - System/asset assessment
2. Coordinate "stakeholders" and define associated responsibilities
   - Internal - Within utility
   - External - Fire department, customers
3. Obtain field equipment and necessary permits
4. Develop unskeletonized system maps
   - Hydrant and valve ID tags
   - Water, storm and sewer overlays
5. Develop and refine the flushing loops
6. Perform field reconnaissance and asset pre-inspection/maintenance
   - Physical and environmental constraints
   - Asset location, exercise and maintenance
   - Method of dechlorination
7. Inform customers and the public
   - Advanced notification
   - Field signage and leaflets
   - Special users, e.g., hospitals
8. Monitoring and information collection
   - Water quality, pressure and hydraulics
   - Resource needs and staff time

Key Elements for Long-Term UDF Program Optimization

- Integrate with other distribution system O&M practices
  - Reservoir cleaning
  - Main rehabilitation/replacement
- Develop data management plan
  - Data during flushing
  - Customer complaint tracking
  - Time to clear "dirty" water
- Program refinement - Prioritize locations and associated frequencies
  - Data assessment
  - Cost-benefit analysis

Photos courtesy of Woodinville Water District, Wash.

Water Main Repair - 10 Steps to Prevent Contamination

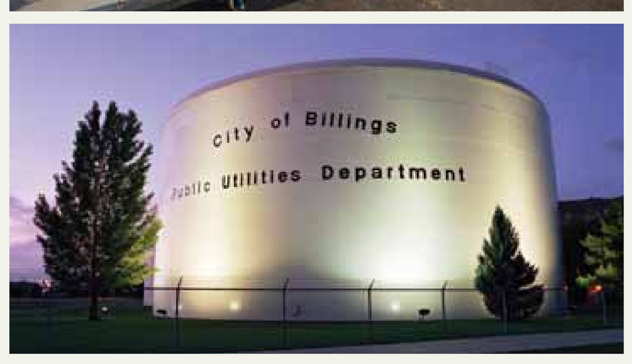
1. Minimize customer outage area and provide public notification of affected areas. Locate underground utilities.
2. Keep positive pressure at break site until pipe is exposed and trench is dewatered.
3. Dewater/prevent surface water from entering the excavation.
4. Clean and disinfect pipe repair materials before installation.
5. Disinfect pipe interior per AWWA standards by swabbing or spray.

6. Make repair with clean, disinfected tools and repair parts.
7. Pressurize and flush the immediate piping network until normal chlorine residuals are restored.
8. Collect and test water for chlorine residual and coliform bacteria per utility guidelines.
9. If sewage or chemicals may have entered the pipe, immediately contact your lab, state or local public health official for direction.
10. Prepare report that documents the repair type and field conditions, and close out the project.

Reference: AWWA Standard #C651-05, *"AWWA Standard for Disinfecting Water Mains"*

Storage Facilities - Maintaining and Protecting Water Quality

Below are general guidelines for managing finished water storage facilities and protecting water quality prior to delivery of water to customers. Please note that some states may have their own requirements for water storage facility operation and maintenance.



1. MONITORING - Needs to be conducted at the inlet, outlet and within the tank or reservoir. Consider measuring chlorine residual, bacteria, disinfection byproducts, pH and temperature. Online monitoring also is an option.

2. INSPECTING - Consider three types of inspections:
Routine — Daily or weekly, one person briefly viewing site and facilities.
Periodic — Monthly or quarterly, two staff making a more detailed inspection of facilities and site. May require climbing the tank to inspect penetrations, vents, hatches, etc.
Comprehensive — Three to five years, several staff or specialists, normally requiring drawdown of water and often combined with cleaning. Consider using divers.

3. MAINTAINING
a. Consider cleaning the tank or storage reservoir every 3 to 5 years.
b. Maintain an effective continuous coating and/or cathodic protection to extend life and protect water quality.
c. Keep vents and overflows in good working order.
d. Maintain screens, penetrations, ladders, security systems, fences, etc.

4. OPERATING - Two important considerations:
a. Use the water to keep it as fresh as possible
b. Turn the tank over to encourage mixing of the water and reduce short-circuiting

5. SECURING AND RESPONDING TO INTRUSION
a. Develop intrusion procedures and response plans.
b. Consider hardening the facilities with fences, lighting, cameras, intrusion alarms, etc.
c. Utilize secured entry procedures such as key cards, passwords, etc.

6. KEEPING GOOD ASSET RECORDS
a. Develop and maintain a comprehensive record of each storage facility, including shut down and drain procedures.
b. Document conditions with multiple approaches that include visual assessments, intrusion frequency, technical data on quality and conditions, special reports, monitoring data, etc.

Breakpoint Chlorination Curve - Optimizing Total Chlorine

Chlorine and Ammonia Chemistry

The reaction between chlorine (Cl_2) and ammonia (NH_3) is important for drinking water treatment. This reaction:

- Forms chloramines as a secondary disinfectant
- Removes (breakout) ammonia from water

When Cl_2 and NH_3 are mixed, the ratio of Cl_2 to NH_3 largely controls which products are formed and the quantity and composition of the residual disinfectant. The breakpoint curve plots this relationship.

The Breakpoint Curve

The breakpoint curve is divided into three zones. Each zone has its own characteristics relating the Cl_2:NH_3 ratio to:

- Residual chlorine
- Ammonia nitrogen
- Reaction products

The Cl_2:NH_3 ratio is typically expressed based on weight: mg/L Cl_2 to mg/L NH_3 measured as nitrogen (NH_3-N).

Zone 1 Cl_2:NH_3-N ratio is less than 5

The total Cl_2 residual increases at a rate less than the free Cl_2 applied. Chloramines are formed by the reaction of chlorine and ammonia. At a Cl_2:NH_3-N ratio of 5, the **hump** of the breakpoint curve is reached, producing the maximum concentration of combined chlorine. In Zone 1:

- Combined chlorine is formed from monochloramine (and dichloramine if pH < 7)
- Free ammonia decreases to zero at the hump
- Total ammonia nitrogen remains constant
- Monochloramine is the desired residual

Zone 2 Cl_2:NH_3-N ratio is between 5 and 7.6

The total Cl_2 residual rapidly drops to nearly zero. At a Cl_2:NH_3-N ratio of 7.6, the **breakpoint** is reached. Ammonia nitrogen is oxidized and consumed, forming nitrogen gas and non-ammonia nitrogen products. In Zone 2:

- Chloramines are destroyed
- Ammonia nitrogen decreases to near zero at the breakpoint

Zone 3 Cl_2:NH_3-N ratio is greater than 7.6

The total Cl_2 residual increases at the same rate as free Cl_2 addition. In Zone 3:

- Total chlorine residual equals free chlorine residual plus a small irreducible residual of combined chlorine.

Using the Breakpoint Curve

Guidelines: The treatment objective should be established prior to referring to the breakpoint curve. Typically, the objective is total chlorine (free + combined) residual. Once the desired residual is established, the breakpoint curve is used to determine the appropriate Cl_2:NH_3-N ratio. After determining the appropriate Cl_2:NH_3-N ratio, the chlorine or the ammonia dose for the desired total chlorine residual can be calculated.

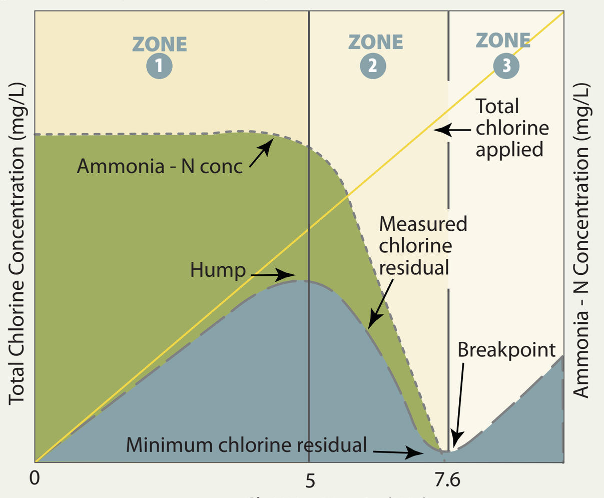
The actual breakpoint curve varies from water to water because of:

- Temperature, pH and alkalinity
- Competitive demands for Cl_2 from organic matter, iron, manganese and hydrogen sulfide. These demands will increase the Cl_2:NH_3-N ratio needed to form chloramines or breakout ammonia.

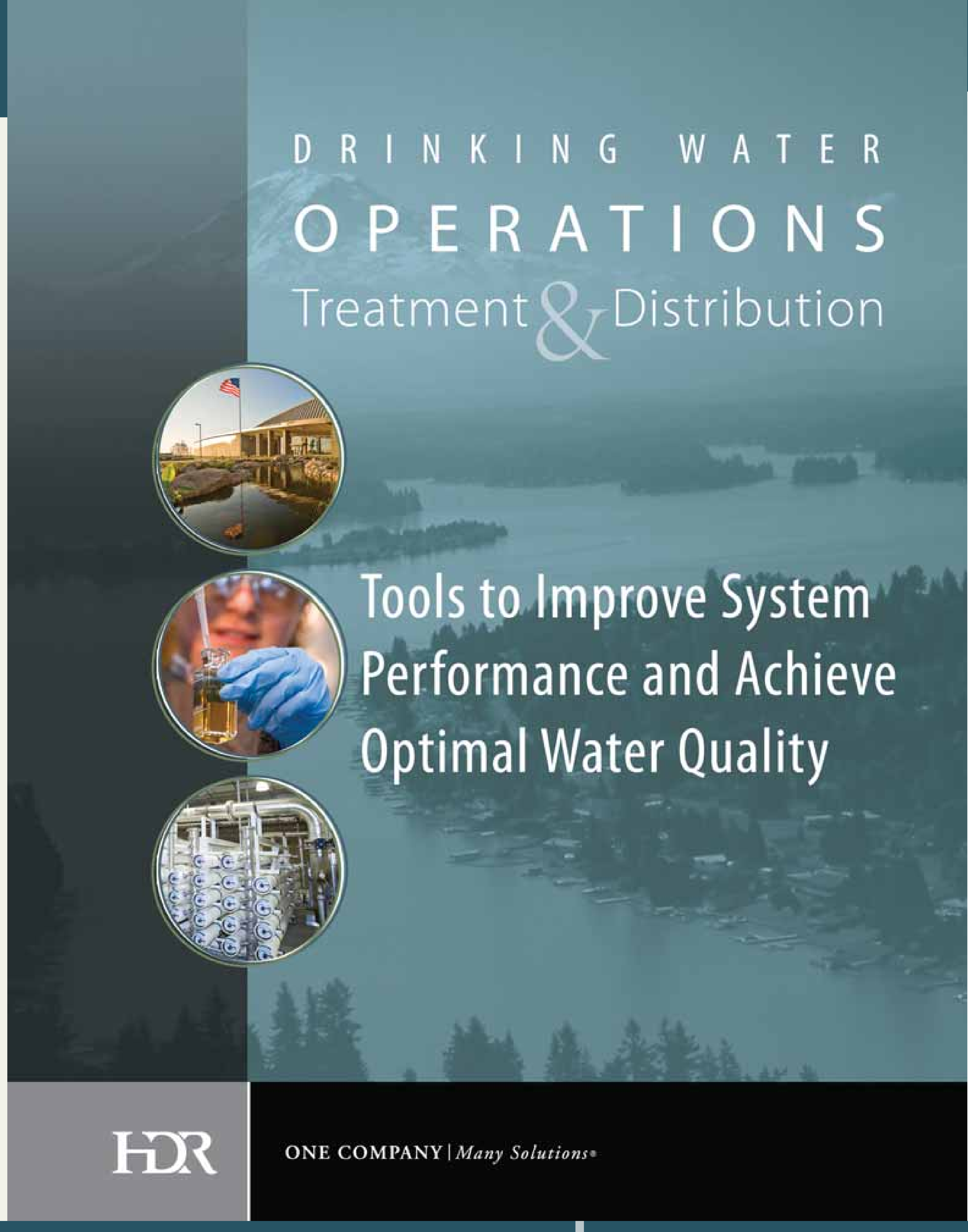
Typically, the actual Cl_2:NH_3-N ratio will be greater than theoretical values. The breakpoint curve for each water should be developed by bench testing.

Chloramine Formation: Chloramines are formed in Zone 1 of the breakpoint curve. Cl_2:NH_3-N ratios of between 3:1 to 5:1 are most effective. Lower ratios increase the risk of distribution system nitrification by unreacted ammonia; higher ratios risk loss of residual and odor problems.

Ammonia Removal: Ammonia nitrogen is oxidized at the breakpoint, Cl_2:NH_3-N ratio = 7.6. A greater ratio is typically required to overcome competitive demands and to provide sufficient chlorine residual (Zone 3). A 10:1 ratio is typically effective. Higher ratios (15:1 or greater) may cause odor problems.



Chlorine decay curve chart adapted from Handbook of Chlorination and Alternative Disinfectants, Fourth Edition, by George Clifford White, John Wiley & Sons, Inc., 1999.



Common Water Conversion Factors

1. Système International Prefixes

Multiply	By	To Obtain
mega (M)	1,000,000	the base unit
kilo (k)	1,000	the base unit
hecto (h)	100	the base unit
deka (da)	10	the base unit
deci (d)	0.1	the base unit
centi (c)	0.01	the base unit
milli (m)	0.001	the base unit
micro (μ)	0.000001	the base unit
nano (nn)	0.000000001	the base unit

2. US Customary Conversions

Multiply	By	To Obtain
acre-feet (acre-ft)	43,560	cubic feet (ft^3)
acre-feet	0.325851	million gallons (MG)
cubic feet (ft^3)	7.4805	gallons (gal)
cubic feet/second (ft^3/s)	448.831	gallons per minute (GPM)
cubic feet/second (ft^3/s)	0.6463	million gallons per day (MGD)
feet of water	0.4335	pounds per square inch (lb/in²)
horsepower (hp)	745.7	watts (W)
milligrams/liter (mg/L)	8.345	pounds/million gallons
milligrams/liter (mg/L)	0.0584	grains per gallon
percent solution	10,000	milligrams/liter (mg/L)
pounds/square in. (psi)	2.307	feet of water
kilowatts (kW)	1.341	horsepower (hp)

3. Metric Conversions

Multiply	By	To Obtain
foot (ft)	30.48	centimeter (cm)
meter (m)	3.2808	foot (ft)
square foot (ft²)	0.092903	square meters (m²)
pounds/square in. (psi)	0.06895	bars
pound (lb)	0.4536	kilograms (kg)
gallon (gal)	3.7854	liters (L)
cubic meter (m³)	264.2	gallons (gal)
gal/sq foot/min	40.7458	L/m²/min

Jar Testing - Determining the Optimum Coagulant Dose

Jar testing can be used to evaluate the effects of process changes (chemical dose changes, new chemicals, various points of chemical addition) in your plant or to optimize coagulation/flocculation processes, particularly during periods of changing raw water quality. Developing and practicing good jar test procedures will provide operators with an invaluable tool. Optimization testing for removal of turbidity, color, TOC, and iron and manganese can all be done in jars.

Step 1 – Plan Your Jar Test to Solve the Problem

- Define the issue you are trying to resolve - poor settling, change in raw water, TOC removal not good enough (DBPs too high), trying new chemicals.
- Define the variables you want to test to solve your problem - chemical dose, coagulation pH, mixing energy, settling time.
- Fill out the jar testing form with your test conditions (see Table 1).

Step 2 – Organize Equipment and Chemicals

- Clean jar test apparatus.
- Gather equipment - automatic pipette (10-mL), syringes (5-mL, 10-mL, and 25-mL), beakers, appropriate analytical equipment nearby, safety equipment (glasses & gloves) and MSDS sheets for chemicals used.
- Freshly mix chemicals in appropriate dilutions.

Most jar testers have 1- or 2-L jars, so neat chemical products must be diluted to get good results. Dilution should generally be done with distilled, deionized water (DDW) to prevent chemical reactions. To simplify dosing, the working solution strength should be 1,000 mg/L so that each mL will provide 1 mg/L dose to the water. When a 2-L beaker is used for the jar tests, 2 mL of working solution is equivalent to adding 1 mg/L. Working solutions should be prepared on the test day.

To calculate the amount of liquid chemical to add, you need the chemical's specific gravity (the density, or mass per unit volume) and the chemical strength as a percentage of active ingredient on a dry weight basis. Knowing these, the mass of active ingredient in each mL of "as delivered" product can be determined. *See Table 2 for typical chemical properties and dilution ratios.*

Step 3 – Collect Water Sample for Testing

- Collect sample from the right location - raw water with no chemicals added (before preoxidation) or water that enters the rapid mix or other location.
- Collect water just prior to testing - temperature is critical to the coagulation process. Use insulated container; 5 gallons is enough for one jar test. Mix the raw water sample before filling jars to counteract settling.

Step 4 – Select Mixing Times and Speeds

- Mixing times for rapid mix and flocculation should match the full-scale plant times, and mixing speeds should match full-scale velocity gradients (G, sec^{-1}) of rapid mix and flocculator.
- Default times should be consistent in each test. Typical defaults are 30 seconds rapid mixing and 15 minutes flocculation time.
- Default mixing speeds are 80 rpm for rapid mix and 30 rpm for flocculation.

Step 5 – Dose Each Jar

- Inject each pre-prepared syringe or pipette quickly.
- Add chemicals in the same order as they are added in the plant and in the same sequence as in the full-scale plant.
- Add chemicals in the sequence required by your test plan.
- Observe each jar quickly for floc. Compare observation to actual plant initial mix floc development and take notes on the data sheet.

Step 6 – Stop Mixing and Observe Settling or Filtration Results

- Conventional filtration plants – Allow settling time and observe settling. Consider developing a settling rate curve. Note amount of settled solids.
- Direct filtration plants – Note which jars appear to have the most floc and note size of floc. Filter samples from jars through a 0.45 μ filter to approximate filtration process and determine best jar to meet test plan objective.

Step 7 – Take Proper Measurements and Record Data

- Raw water sample - temperature just before treatment chemicals added, turbidity, pH and alkalinity
- Settled water - observations of floc development, turbidity (each jar), pH (each jar), other measurements of each jar to meet test plan

Table 1: Jar Test Data Sheet Example

Date: 5/18/2007	Plant Dosages	Raw Water Data	
Time: 11:00 AM	Coagulant ppm	pH 7.57 su	T Alkalinity 62 mg/L
Operator: Phil B.	Polymer ppm	Turbidity 29.8 NTU	Color 240 CU
	Oxidant	Temperature 11 °C	TOC 7.3 mg/L
	Other	UV254 0.307 1/cm	
Reason for running jar test:	Testing new chemical for TOC removal in a direct filtration membrane plant	Specific Gravity: 1.5	
Rapid Mix rpm: 300 / Time, sec: 30	Flocculation rpm: 20 / Time, min: 4	Settling time, min: 0 / Volume of each jar: 1 L	Filter: 0.45 μ "Millipore"

Jar Number	1		2		3		4		5		6	
Chemicals Added	ppm	mL added	ppm	mL added	ppm	mL added	ppm	mL added	ppm	mL added	ppm	mL added
Name - Sumaclear 1000 / Soln Concentration: Neat	0	0	1.5	1.0	3.0	2.0	7.5	5	15	10	75	50
Name:												
Soln Concentration 1,000 mg/L												
Floc Rating (1 is best)												
Description (None, Pin, Light, Medium, Heavy, Very Heavy)												
Filtered Water Turbidity	0.4		0.425		0.365		0.385		0.37		0.085	
Color	19		18.5		16.5		17		18		0	
pH	7.18		7.22		7.22		7.22		7.22		7.22	
Total Alkalinity	63		68.5		65		64		68		60	
UV 254	0.156		0.153		0.141		0.149		0.148		0.043	
TOC	6.15		6.01		5.75		6.09		6.17		2.49	

Table 2: Typical Bulk Solution Chemical Properties

Chemical[1]	Formula	Typical S.G.	Typical % Active*	Typical Concentration (mg/mL)	Amount to add to 1-L DDW for 1 mg/mL solution
Alum	$Al_2(SO_4)_3 \cdot 14(H_2O)$	1.3	48%	624	1.60
Polyaluminum Chloride	$Al_{12}(OH)_{12}Cl_{24}$	1.3	40%	520	1.92
Ferric Chloride	$FeCl_3$	1.4	40%	560	1.79
Ferric Sulfate	$Fe_2(SO_4)_3$	1.5	44%	660	1.52
Sodium Hydroxide	NaOH	1.5	50%	750	1.33
Sulfuric Acid	H_2SO_4	1.8	93%	1,674	0.60
Sodium Hypochlorite	NaOCl	1.2	12%	144	6.94
Polymer[2]	NA	1.1	100%	1,100	0.91

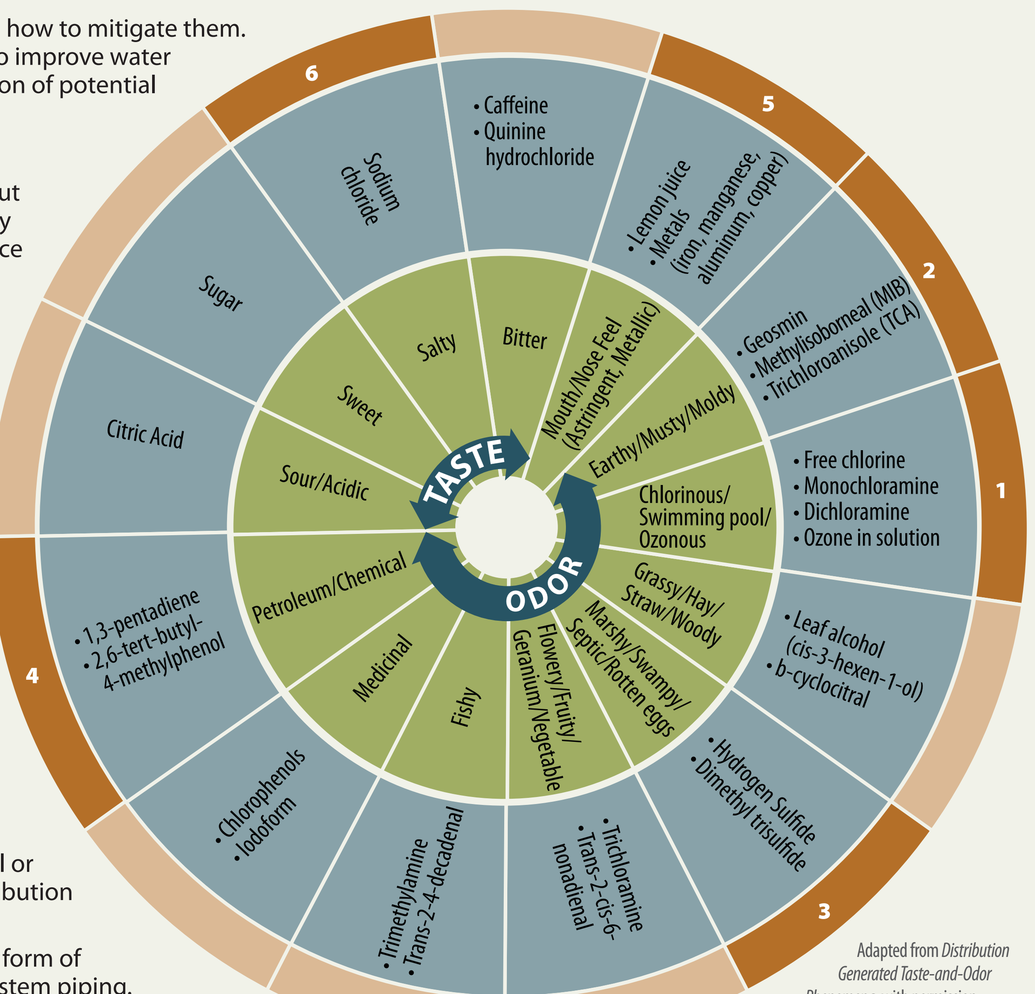
1. All chemicals are liquid. 2. Cationic polymer doses are often low, so it may be useful to make a 100 mg/L solution instead of 1,000 mg/L solution. In this way, each mL of working solution added to the 1-L beaker is equivalent to 0.1 mg/L. If making a 100 mg/L solution, multiply the last column by 10 and add this amount to the DDW. Some polymers should be added neat to give representative results, consult your polymer vendor. * % Active for coagulants refers to % dry weight of the indicated formula.

Taste and Odor - Complaints and Corrective Actions

Knowing how tastes and odors develop in a distribution system is the first step to determining how to mitigate them. The taste and odor wheel can help identify the likely sources and uncover a corrective action to improve water quality. The top six most frequent T&O issues are numbered on the wheel, and a brief description of potential corrective actions is included below.

Corrective Actions

1. Some chlorine taste and odor is noticeable, even at minimum residual disinfectant levels, but is generally not objectionable. Strong chlorine odor that may lead to complaints is generally caused by high chlorine concentration (at or near the maximum 4.0 mg/L) or by the presence of dichloramine.
   a. High chlorine concentration – Chlorine booster stations may be added to reduce the initial concentration of chlorine required to maintain a residual in the far reaches of the distribution system.
   b. Dichloramine – If desired distribution residual is free chlorine, then increasing chlorine dose will complete breakpoint chlorination and remove dichloramine. If desired distribution residual is chloramines, then reducing the chlorine-to-ammonia ratio will keep the chloramines as monochloramine and remove dichloramine.
2. Earthy or musty odor is likely caused by Geosmin and/or 2-Methylisoborneal (MIB), which are produced by algae in the raw water source. The odor intensity may change seasonally with higher odor during warmer periods or when more nutrients are available. The growth of algae in the raw water source may be lowered by reducing nutrients like nitrogen and phosphorous that are available in the water. Methods to remove Geosmin and MIB in the treatment plant include oxidation (chlorine dioxide, ozone, UV-peroxide) or adsorption (activated carbon – GAC or PAC).
3. Swampy or rotten egg odors may be caused by hydrogen sulfide present in some groundwater or formed if a residual disinfectant is absent. Addition of an oxidant like chlorine may help remove hydrogen sulfide. Aeration will also remove hydrogen sulfide; however, oxidation and filtration are most effective.
4. Petroleum or chemical odors may be caused by contamination of the source water by a spill or from leaching of chemicals from tank/pipe linings or gaskets. Odors originating in the distribution system may be avoided by complete curing of linings prior to introduction of water.
5. Metallic contaminants may originate in the source water, be added during treatment in the form of excessive metallic coagulant (alum, ferric sulfate), or result from corrosion of distribution system piping. Metals in the source water can be removed with oxidation and sedimentation/filtration. Proper coagulant control in the treatment plant will reduce carryover of metal ions. Metals originating in the distribution system can be controlled by replacing corroded pipes, proper corrosion chemistry (see Finished Water Calcite Stability) or flushing (see Best Management Practices).
6. Salty taste generally will not be perceived or considered objectionable when total dissolved solids and chloride concentrations are maintained below regulatory limits. Higher dissolved solids concentrations can be reduced with desalination treatment such as reverse osmosis.



Adapted from *Distribution Generated Taste-and-Odor Phenomena*, with permission. Copyright ©2002, Awwa Research Foundation and American Water Works Association.

LEGEND
Inner wheel *indicates category/description.*
Outer wheel *indicates most common sources of taste and odor for category.*
Outer reference number *corresponds to corrective action.*

Top 10 Treatment and System Calculations

1. Chlorine Feed Calculations

Gas Chlorine Feed		
Lbs/day	=	(Flow, MGD) x (Conc., mg/L) x (8.34 lbs/gal)
Dosage, mg/L	=	(Lbs/day) / [(Flow, MGD) x (8.34 lbs/gal)]
Sodium Hypochlorite		
Lbs/gal	=	[(Solution Percentage) x (8.34 lbs/gal) x Specific Gravity] / 100
Gal/day	=	[(Flow, MGD) x (Conc., mg/L) x (8.34 lbs/gal)] / (Lbs/gal)
Dosage/Demand/Residual		
Dosage, mg/L	=	(Demand, mg/L) + (Residual, mg/L)
Demand, mg/L	=	(Dosage, mg/L) - (Residual, mg/L)
Residual, mg/L	=	(Dosage, mg/L) - (Demand, mg/L)

2. Chemical Dosing

Feed, Lbs/day	=	[(Flow, MGD) x (Dosage, mg/L) x (8.34 lbs/gal)] / [(% Active Ingredient / 100) x (% Chemical / 100)]
Dosage, mg/L	=	[Feed, lbs/day x (% Active Ingredient / 100) x (% Chemical / 100)] / [(Flow, MGD) x (8.34 lbs/gal)]

3. Chemical Feed

Chemical Feed Pumps		
GPD	=	[(Flow, MGD) x (Dosage, mg/L) x (8.34 lbs/gal)] / (Dry lbs/gal)
Chemical Feed Rate		
GPD	=	[(Feed, mL/min) x (1,440 min/day)] / [(1,000 mL/L) x (3.785 L/gal)]
GPM	=	(Feed, mL/min) / (3,785 mL/gal)
mL/min	=	[(GPD) x (1,000 mL/L) x (3.785 L/gal)] / (1,440 min/day)
mL/min	=	(GPM) x (3,785 mL/gal)

4. Pumps and Pumping

Pump Size		
Brake Horsepower (BHp)	=	[(GPM) x (Total Dynamic Head, ft.)] / [(3,960) x (Efficiency*)] * Efficiency expressed as decimal
Overall Efficiency (Pump/Motor/Drive)	=	(Motor Efficiency*) x (Pump Efficiency*) x (Drive Efficiency*) * Efficiency expressed as decimal
Pumping Costs		
Cost, $	=	(BHp) x (0.746 kW/hp) x (Operating Hrs) x ($/kW-Hr)
Wells		
Drawdown, ft	=	(Pumping Level, ft) - (Static Level, ft)
Specific Capacity, GPM/ft	=	Well Yield, GPM / Drawdown, ft

5. CT Calculations

CT_{calc}	=	Disinfectant Residual (mg/L) x Detention Time (min) at peak hourly flow
$CT_{99.9}$ (3-log)	=	Can be read from tables E-1 through E-13 (EPA, 1991**) in Surface Water Treatment Rule Guidance Manual using pH and temperature of water
$CT_{required}$	=	(Log Inactivation Required) x ($CT_{99.9}$) / 3.0

Log inactivations are additive, e.g. 0.5 log + 1.0 log = 1.5 log

Inactivation Ratio $CT_{calc}/CT_{99.9}$		Log Inactivation		Percent Inactivation
0.17	=	0.5 log	=	68.4%
0.33	=	1.0 log	=	90%
0.50	=	1.5 log	=	96.8%
0.67	=	2.0 log	=	99%
0.83	=	2.5 log	=	99.7%
1.00	=	3.0 log	=	99.9%
1.33	=	4.0 log	=	99.99%

**Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources, EPA, 1991.

6. Filtration

Filter Flow Rate		
Filtration Rate, GPM	=	(Filter Area, sq ft) x (Filtration Loading Rate, GPM/sq ft)
Filtration Loading Rate, GPM/sq ft	=	(Filtration Rate, GPM) / (Filter Area, sq ft)
Filtration Rate, GPD	=	(Filter Area, sq ft) x (GPM/sq ft) x (1,440 min/day)
Backwash Rate		
Backwash Pumping Rate, GPM	=	(Filter Area, sq ft) x (Backwash Rate, GPM/sq ft)
Rate of Rise, ft/min	=	(Backwash Rate, GPM/sq ft) / (7.48 gal/cu ft)

7. Standard Membrane Calculations

Flux (J)		
Flux (J), GFD	=	(Feed Flow, GPD) / (Membrane Surface Area, ft²)
Temperature Corrected Flux 20°C		
Flux ($J_{20°C}$), GFD	=	(J, GFD) x ($e^{-0.0239(T_{°C}-20)}$)
Transmembrane Pressure		
Transmembrane Pressure, PSI	=	(Feed Pressure, PSI) - (Filtrate Pressure, PSI)
Permeability		
Permeability, GFD/PSI	=	($J_{20°C}$, GFD) / (Transmembrane Pressure, PSI)
Rejection		
Rejection, %	=	[1 - (Filtrate Concentration, mg/L / Feed Concentration, mg/L)] x 100
Recovery		
Recovery, %	=	[Beneficial Use Flow, GPM / Feed Flow, GPM] x 100

8. Velocity

Flow (Q), cfs	=	(Area, sq ft) x (Velocity, fps)
Velocity, fps	=	(Q, cfs) / (Area, sq ft)
Area, sq ft	=	(Q, cfs) / (Velocity, fps)

9. Hardness

Calcium Hardness as mg/L $CaCO_3$	=	(2.5) x (Calcium, mg/L)
Magnesium Hardness as mg/L $CaCO_3$	=	(4.12) x (Magnesium, mg/L)
Total Hardness as $CaCO_3$	=	Calcium Hardness as $CaCO_3$ + Magnesium Hardness as $CaCO_3$
Convert Hardness from mg/L to grains/gallon		
Grains/gallon	=	(Total Hardness as $CaCO_3$, mg/L) / (17.1 mg/L / grains/gal)

10. Jar Testing

Dosage, mg/L	=	[(Stock Volume, mL) x (1,000 mg/gram) x (Stock Conc., grams/L)] / (Sample Size, mL)
Dosage, Lbs/MG	=	[(Dosage, mg/L) x (3.785 L/gal) x (1,000,000 gal/MG)] / [(1,000 mg/g) x (454 g/lbs)]