SECTION - 3
KEY WATER PLANT MATH FORMULAS

General:

1. **Lbs/Day** = (Vol, MGD) x (Conc., mg/l) x 8.34 lbs/gal)

2. **Dosage, mg/l** = $\frac{(\text{Feed, lbs/day})}{(\text{Vol, MGD}) \times 8.34 \text{ lbs/gal})}$

3. **Rectangular Basin Volume, cu. ft.** = (Length, ft) x (Width, ft) x (Height, ft)

   i) **Vol, Gals** = Multiply the above by the factor 7.48 gals/cu.ft.

4. **Right Cylinder Volume, cu. ft.** = (0.785) x (D^2, ft.) x (Height or Depth,ft)

   i) **Vol, Gals** = Multiply the above by the factor 7.48 gals/cu.ft.

5. **Conical Base Volume, cu. ft.** = $\frac{(0.785) \times (D^2, \text{ft}) \times (\text{Height or Depth,ft})}{3}$

   i) **Vol, Gals** = Multiply the above by the factor 7.48 gals/cu.ft.

6. **Trapezoid, Volume cu. ft.** = $\frac{(B_1 + B_2)}{2}$ x Height, ft x Length, ft.

   i) **Vol, Gals** = Multiply the above by the factor 7.48 gals/cu.ft.

7. **Removal, Percent** = $\frac{(\text{In - Out})}{\text{In}}$ x 100

8. **Decimal Fraction** = $\frac{(\text{Percent})}{100}$

GPCD means **Gallons Per Capita Per Day. A Capita is one (1) person.**

9. Gals/Day of Water Consumption, (Demand/Day) = (Population) x (Gals/Capita/Day)

Consumption Averages, per capita:

1. **Winter - 170 GPCD**
2. **Spring - 225 GPCD**
3. **Summer - 325 GPCD**

10. Gals/Capita/Day, Average Water Usage $= \dfrac{\text{(Vol, Gals/day)}}{\text{(Population, Served per day)}}$

11. Supply, Days (Full to Tank Dry) $= \dfrac{\text{(Vol, Gals/day)}}{\text{(Population Served) x (GPCD)}}$

12. GPD $= \dfrac{\text{(Meter Read 2, Gals - Meter Read 1, Gals)}}{\text{(Number of Days)}}$

13. GPH $= \dfrac{\text{(Volume, gallons)}}{\text{(Pumping Time, min. x 60 Min/Hr)}}$

14. Time, Hrs. $= \dfrac{\text{(Volume, gallons)}}{\text{(Pumping Rate, GPM x 60 Min/Hr)}}$

15. Supply, Hrs. (Full to Tank Dry) $= \dfrac{\text{(Storage Volume, Gals)}}{\text{(Flow In, GPM - Flow Out, GPM) x 60 min/hr.}}$

16. GPD Combined Consumption = (Pump In, GPD) + (Clearwell Storage Volume, GPD Used)

17. Percent (%) of Increase $= \dfrac{\text{(Larger Amount)}}{\text{(Smaller Amount)}} - 1.0 \times 100$

Chlorine Feed, Dosage/Demand/Residual:

Gas Chlorine Feed, Lbs/day

1. Lbs/Day = (Vol, MGD) x (Conc., mg/l) x (8.34 lbs/gal)

Dosage, mg/l = $\dfrac{(\text{Lbs/day})}{(\text{MGD}) \times (8.34 \text{ lbs/gal})}$

65% HTH Feed, Lbs/day - Calcium Hypochlorite

2. HTH, lbs/Day = $\dfrac{(\text{Vol, MGD}) \times (\text{Conc., mg/l}) \times (8.34 \text{ lbs/gal})}{(0.65)}$

Dosage, mg/l = $\dfrac{(\text{Lbs/day} \times 0.65)}{(\text{MGD}) \times (8.34 \text{ lbs/gal})}$

Lbs, 65% HTH = $\dfrac{(\text{Gals of Water} \times 8.34 \text{ lbs/gal}) \times \% \text{ Solution}}{(0.65)}$

5-1/4% - 12.5% Liquid Chlorine - Sodium Hypochlorite

3. Lbs/Gal = $\dfrac{(\text{Solution Percentage})}{100} \times 8.34 \text{ lbs/gal} \times \text{S.G.}$

GPD = $\dfrac{(\text{Vol, MGD}) \times (\text{Conc., mg/l}) \times (8.34 \text{ lbs/gal})}{(\text{Lbs/gal})}$

Dosage/Demand/Residual

4. Dosage, mg/l = (Demand, mg/l) + (Residual, mg/l)
5. Demand, mg/l = (Dosage, mg/l) - (Residual, mg/l)
6. Residual, mg/l = (Dosage, mg/l) - (Demand, mg/l)

MATH FORMULAS - Continued

C●t Calculations

1. **C●t = (Chlorine Residual, mg/L) x (Time, minutes**

2. **Time, minutes** $= \dfrac{(\text{C●t})}{(\text{Chlorine Residual, mg/L})}$

3. **Chlorine Residual, mg/L** $= \dfrac{(\text{C●t})}{(\text{Time, minutes})}$

4. Inactivation Ratio $= \dfrac{(\text{Actual System C●t})}{(\text{Table "E" C●t})}$

5. **C●t Calculated = T_{10} Value, minutes x Chlorine Residual, mg/L**

6. Log Removal $= \dfrac{(\mathbf{1.0}\ \mathbf{-}\ \text{\% Removal})}{100} \times$ **Log key x (-)**

Fluoridation:

1. **Feed, Lbs/day** $= \dfrac{(\text{MGD}) \times (\text{mg/L})}{\left(\dfrac{\%\ \text{Purity}}{100} \times \dfrac{\%\ \text{Fluoride}}{100}\right)} \times 8.34\ \text{lbs/gallon} \times \text{S.G.}$

2. **Adjusted Feed, Lbs/day** $= (\text{MGD}) \times \dfrac{(\text{Desired, mg/L} - \text{Existing mg/L})}{\left(\dfrac{\%\ \text{Purity}}{100} \times \dfrac{\%\ \text{Fluoride}}{100}\right)} \times 8.34\ \text{lbs/gallon} \times \text{S.G.}$

3. **Dosage, mg/L** $= \dfrac{\left(\text{Feed, Lbs/day} \times \dfrac{\%\ \text{Purity}}{100} \times \dfrac{\%\ \text{Fluoride}}{100}\right)}{(\text{MGD}) \times 8.34\ \text{lbs/gallon} \times \text{S.G.}}$

SECTION 3 - SUMMARY OF KEY WATER PLANT OPERATOR MATH FORMULAS - Continued

1. Hydraulic (Water Column Height) Pressure :

i) PSI = $\dfrac{(\text{Head, ft.})}{2.31 \text{ ft./PSI}}$

ii) PSI = Head, ft. x 0. 433 PSI/ft.

Or,

iii) Head, ft. = PSI x 2.31 ft./PSI

iv) Head, ft = $\dfrac{\text{PSI}}{0.433 \text{ PSI/ft.}}$

Pounds of Force On The Face of a Valve

2) Force, lbs = (Area, Sq. Inches) x PSI,

Or,

3) **Force, lbs = $(0.785)(\text{D, ft.})^2$ x 144 sq.in/sq.ft. x PSI.**

Tank Bottom Force and Buoyancy

Tank Bottom Forces:

Rectangular Basins

4) **Force, lbs = L, ft x W,ft, x H, ft, x 62.4 lbs/cubic foot**

Right Cylinders

5) **Force, lbs = $(0.785)(\text{D, ft.})^2$ x Height, ft. x 62.4 lbs/cu.ft.**

Pounds Per Square Foot on a Tank Bottom:

Rectangular Basins

6) **Force, lbs = $\dfrac{\text{L, ft x W,ft, x H, ft, x 62.4 lbs/cubic foot}}{(\text{Bottom Area, sq. ft.})}$**

Right Cylinders

7) **Force, lbs = $\dfrac{(0.785)(\text{D, ft.})^2 \text{ x Height, ft. x 62.4 lbs/cu.ft.}}{(\text{Bottom Area, sq. ft.})}$**

Change of Direction

8. Force, lbs (Any Bend) = **2 x [$\text{Area}_{\text{sq.in.}}$ x $\text{Pressure}_{\text{, Psi}}$] x (1/2 Sin Θ)**

SECTION 3 - SUMMARY OF KEY WATER PLANT OPERATOR MATH FORMULAS - Continued

Pumps and Pumping:

1. Pumping Rate:

$$\text{Volume, Gals} = \text{GPM} \times \text{Time, minutes}$$

$$\text{Rate, GPM} = \frac{(\text{Tank Volume, Gals})}{(\text{Time, minutes})}$$

$$\text{Time, minutes} = \frac{(\text{Tank Volume, Gals})}{(\text{Fill Rate, GPM})}$$

2. Pump Size:

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

$$\text{Brake Horsepower} = \frac{(\text{GPM}) \times (\text{Total Head, ft})}{(3{,}960) \times (\%\ \text{Efficiency})}$$

$$\%\ \text{Overall Effic. (Pump/Motor)} = (\text{Motor, \% Effic.} \times \text{Pump \% Effic.})$$

3. Pumping Cost:

$$\text{Cost, \$} = (\text{BHp}) \times (0.746\ \text{Kw/Hp}) \times (\text{Operating Hrs.}) \times \frac{\text{¢/Kw-Hr.}}{100}$$

4. Wells:

$$\text{Drawdown, ft.} = \text{Pumping Level, ft.} - \text{Static Level, ft.}$$

$$\text{Specific Capacity, GPM/ft.} = \frac{\text{Well Yield, GPM}}{\text{Drawdown, ft.}}$$

Strength of Solutions:

1. **Chemical Feed Pumps:**

GPD (Gals) = $\dfrac{\text{(Required Feed, Lbs/Day)}}{\text{(Dry lbs/Gal)}}$ = $\dfrac{\text{(MGD) x mg/L x 8.34 lbs/gal}}{\text{(Dry Lbs/gal)}}$

2. **Chemical Feed Rate:**

GPD = $\dfrac{\text{(Feed, ml/min. x 1,440 min/day)}}{\text{(1,000 ml/L x 3.785 L/Gal)}}$

GPM = $\dfrac{\text{(Feed, ml/min)}}{\text{(3,785 ml/Gal)}}$

ml/min = $\dfrac{\text{(GPD x 1,000 ml/L x 3.785 L/Gal)}}{\text{(1,440 min/day)}}$

ml/min = (GPM x 3,785 ml/Gal)

3. Lbs/gallon = $\dfrac{\text{(\% Solution)}}{\text{(100)}}$ x 8.34 lbs/gallon x (Specific Gravity)

4. Lbs Chemical = Specific Gravity x 8.34 lbs/gallons x Gallons of Solution

5. Specific Gravity = $\dfrac{\text{(8.34 lbs/gallon + Chemical Wt., Lbs/gallon)}}{\text{(8.34 lbs/gallon)}}$

6. Specific Gravity, Lbs/gallon = (S.G. x 8.34 lbs/gal) - (8.34 lbs/gal)

7. % Percent of Chemical in Solution = $\dfrac{\text{(Dry Chemical, Lbs)}}{\text{(Dry Wt. Chemical, Lbs) + (Water, Lbs)}}$ x 100

8. Two-Normal Equations:
   a) $C_1V_1 = C_2V_2$ b) $\dfrac{Q_1}{V_1} = \dfrac{Q_2}{V_2}$

9. Three Normal equations:
   a) $(C_1 V_1) + (C_2 V_2) = (C_3 V_3)$

SECTION 3 - SUMMARY OF KEY WATER PLANT OPERATOR MATH FORMULAS - Continued

Sedimentation Tanks and Clarifiers:

Hydraulic Cross-check Formulas:

1. Surface Loading Rate, GPD/sq ft. = (Total Flow, GPD) / (Surface Area, sq.ft.)
Design Data: 800 - 1,200 GPD/Sq.ft.

2. Detention Time, Hrs. = (Volume, gals) x (24 Hrs./day) / (Total 24 Hr. Flow, Gals/day)
Design Data: 1 - 4 Hours; Average 2.5 Hrs.

3. Flow, GPD = (Volume, gals) x (24 Hrs./day) / (Detention Time, Hrs.)

4. Weir Overflow Rate, GPD/L.F. = (Flow, GPD) / (Weir length, ft.)
Design Data: 10,000 - 40,000 GPD/LF; Average 20,000 GPD/L.F.

5. Circumference, ft = 3.141 (Pi) x Diameter, ft.

6. Solids Loading Rate, lbs/day/sq. ft. = (Solids into Clarifier, lbs/day) / (Surface Area, sq. ft.)

7. Sludge Solids, lbs = (Flow, Gals) x (8.34 lbs/gal) x (Sludge, %)

8. Raw Sludge Pumping, gpm = (Settleable Solids, ml/L) x (Plant Flow, GPM) / (1,000 mls/L)

9. Sludge Volume Index, mg/l (SVI) = (Settled Sludge Volume, ml/l) x (1,000 mg/G) / (Suspended Matter, mg/l)

10. mg/l = (ml x 1,000,000) / (ml sample)

SECTION 3 - SUMMARY OF KEY WATER PLANT OPERATOR MATH FORMULAS - Continued

Filtration:

1. **Filter Flow Rate:**

   Filtration Rate, GPM = (Filter Area, sq.ft.) x (GPM/sq.ft.)

2. **Filtration Rate, GPM/sq.ft. = $\dfrac{\text{(Flow Rate, GPM)}}{\text{(Filter Area, sq.ft.)}}$**

3. **Filtration Rate Rate, GPD = (Filter Area,sq.ft.) x (GPM/sq.ft.) x 1,440 min/day**

4. **Backwash Rate:**

   Backwash Pumping Rate, GPM = (Filter Area,sq.ft.) x (Backwash Rate, GPM/sq.ft.)

5. Backwash Volume, Gallons = (Filter Area,sq.ft.) x (Backwash Rate, gpm/sq.ft.) x (Time, min).

6. Backwash Rate, GPM/sq.ft. = $\dfrac{\text{(Backwash Volume, gpm)}}{\text{(Filter Area, sq.ft.)}}$

7. Backwash, GPM = (Filter Area, sq.ft.) x (Height, Rise/Fall/Drop, ft/min) x (7.48 gals/cu.ft.)

8. Rate of Rise, = (Height, Rise/Fall/Drop, ft/min) x (7.48 gals/cu.ft.) GPM/Sq. Ft.

9. Rate of Rise, GPM/sq.ft. = (Time, min) x (Height, ft.) x 7.48 gals/cu.ft.

Velocity:

1. **Q, cfs** $=$ **(Area, sq. ft.) x (Velocity, fps)**

$$\frac{(\text{GPM})}{(448.8\ \text{GPM/cfs})} = (0.785) \times (\text{D, ft})^2 \times \frac{(\text{Distance, ft.})}{(\text{Time, seconds})}$$

2. **Velocity. fps** $= \dfrac{(\text{Q, cfs})}{(\text{Area, sq. ft.})}$

3. **Area, sq. ft.** $= \dfrac{(\text{Q, cfs})}{(\text{Velocity, fps})}$

4. Flow Conversions:

Flow, GPM $=$ (Q, cfs) x (448.8 GPM/cfs)

5. Q, Cfs $= \dfrac{(\text{Flow, GPM})}{(448.8\ \text{GPM/cfs})}$

6. Pipe Diameter, Inches $= \sqrt{\dfrac{(\text{Area, sq.ft.})}{(0.785)}} \times 12$ inches/ft

7. Actual Leakage, GPD/Mile-inch $= \dfrac{\textbf{Leak Rate, GPD}}{\textbf{(Length, Mile) x (Diameter, inch)}}$

Note: **Minimum Flushing Velocity: 2.5 FPS**
Maximum Pipe Velocity: 5.0 FPS

Key Conversions: **1.55 cfs/mgd** **448.8 GPM/cfs**

Headloss Due to Friction:

1. **Darcy-Weisbach:**

   $$\text{Headloss, ft} = (f)\ \frac{L_{,ft} \times V^2}{D_{,ft} \times 2g}$$ (Use the Moody Diagram for "f")

2. **Hazen - Williams**

   $$Q\text{, gpm} = 0.28 \times C \times D^{2.63} \times S^{0.54}$$

   $$\text{"C" Factor} = \frac{\text{Flow, gpm}}{193.75\ (D,ft)^{2.63} \times (\text{Slope})^{0.54}}$$

   $$\text{HL/1,000 ft.} = \left(\frac{147.85 \times GPM}{C \times d^{2.63}}\right)^{1.852}$$

   $$V_{,fps} = 1.32 \times C \times R^{0.63} \left(\frac{H}{L}\right)^{0.54}$$

3. **Manning**

   $$C\text{, cfs} = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

   $$\text{Slope} = \left[\frac{CFS \times n}{1.49 \times A R^{2/3}}\right]^2$$

Ion Exchange:

1. **Calcium Hardness as mg/l $CaCO_3$ = (2.5) x (Calcium, mg/l)**

2. **Magnesium Hardness as mg/l $CaCO_3$ = (4.1) x (Magnesium, mg/l)**

3. **Total Hardness = Calcium + Magnesium Hardness as $CaCO_3$.**

4. **Convert Hardness from mg/l to grains/gallon:**

$$\text{Grains/gallon} = \frac{(\text{Total Hardness, mg/l})}{(17.1\ \text{mg/l/Grain})}$$

5. Total Exchange Capacity, Kilograins = (Resin Cap., kilograins/cu.ft.) x (Vol, cu.ft.)

6. Total Grains Capacity = Kilograins x 1,000

7. Gals of Soft Water per Service Run = $\dfrac{(\text{Total Exchange Capacity x Kilograins x 1,000})}{(\text{Total Hardness as } CaCO_3\text{, Grains/gallon})}$

8. By-Pass Water, GPD = $\dfrac{(\text{Flow, GPD}) \text{ x } (\text{Effluent Hardness, Gr/Gal})}{(\text{Influent Hardness, Gr/Gal})}$

9. By-Pass Water, % = $\dfrac{(\text{Discharge Hardness, mg/l})}{(\text{Initial Hardness, mg/l})}$ x 100

Ion Exchange Formulas
(Continued)

10. Salt, lbs = $\dfrac{\text{(Capacity, Grains) x (Salt, lbs)}}{\text{(1,000 Grains)}}$

11. Brine, Gals = $\dfrac{\text{(Salt Needed, lbs)}}{\text{(Salt, lbs/gallon)}}$

12. Hardness Removed, Grains = $\dfrac{\text{(Influent Hardness, mg/l - Effluent Hardness, mg/l)}}{\text{(17.1 mg/L/Grain)}}$

13. % of Soft Water By-pass = $\dfrac{\text{(Blended Discharge Hardness, mg/L)}}{\text{(Initial Hardness, mg/L)}}$ x 100

14. GPM By-Pass = $\dfrac{\text{(\% By-Pass)}}{100}$ x (Total Flow, GPM)

15. Total Flow Thru Softener, GPM = (Total Flow, GPM) - (By-Pass Flow, GPM)

Lime - Soda Ash Softening

16. Lbs Hardness Removed = (MGD) x (Dosage, mg/L x $\dfrac{\text{(Soda Ash - Mol Wt.)}}{\text{(Calcium Carbonate Mol. Wt.)}}$ x 8.34 lbs/gal

Jar Testing:

1. **Dosage, mg/l** $= \dfrac{\textbf{(Stock, ml) x 1,000 mg/gram x (Conc., Grams/L)}}{\textbf{(Sample Size, ml)}}$

2. **Grams/Liter** $= \dfrac{\textbf{(mg/l x 1,000 ml)}}{\textbf{(ml x 1,000 mg/l)}}$

3. **Alum Reacting, mg/l** $= \dfrac{\textbf{(1.0 mg/l Alum) x (Raw Alk., mg/l - Alk. Present, mg/l)}}{\textbf{(0.45 mg/l Alkalinity)}}$

4. Alkalinity Dosage, mg/l = (Total Alum, mg/l - Alum Reacting, mg/l)

5. Dilute Solution, mg/L $= \dfrac{\text{(mg of Alum dosage) x (1,000 ml/L)}}{\text{(1.0 ml/L)}}$

6. Grams $= \dfrac{\text{(mg) x (1.0 gram)}}{\text{(1,000 mg/l)}}$

7. mg/L $= \dfrac{\text{(Grams x 1,000 mg/L)}}{\text{(1.0 gram)}}$

SECTION 3 - SUMMARY OF KEY WATER PLANT OPERATOR MATH FORMULAS - Continued

Laboratory:

1. TSS (mg/l) $= \dfrac{\text{Paper Wt. and Dried Solids(g) - Paper Wt.(g)}}{(\text{ Milliliters [ml] of Sample })} \times 1{,}000{,}000$

2. Total Solids, mg/l $= \dfrac{(\text{ Residue, mg }) \times 1{,}000}{(\text{ ml sample })}$

3. Total Alkalinity, Mg/l $= \dfrac{(\text{ mls of titrant x Normality x } 50{,}000)}{(\text{ mls of Sample })}$

4. Langelier Index = (pH - pH, Saturated)

5. Concentrations:

$$(\text{Conc. } 1) \times (\text{Volume } 1) = (\text{Conc. } 2) \times (\text{Volume } 2)$$

6. mg/l $= \dfrac{(\text{ ml } \times 1{,}000{,}000)}{(\text{ ml sample })}$

   mg/l = ml x 1,000 ml/L

7. mg/l Total Solids $= \dfrac{(\text{ Residue, mg }) \times 1{,}000}{(\text{ ml sample })}$

8. Temperature:

$$F^\circ = (C^\circ \times 1.8) + 32^\circ$$

$$C^\circ = \frac{(F^\circ - 32^\circ)}{(1.8)}$$

ABBREVIATIONS

Ac-ft	Acre feet	M	Meter
AFC	Actual fluoride content	M	Mile
C°	Celsius	mg/l	Milligram per Liter
CCF	Hundred Cubic Feet	MGD	Million Gals/Day
Cf	Cubic feet (ft^3)	ml	Milliliter
CFS	Cubic Feet Per Second	msl	Mean Sea Level
F°	Fahrenheit	ppm	Parts per Million
Gal	Gallon(s)	Q	Flow, cu. ft/sec.
GPM	Gallons Per Minute	π	Pi (3.141)
GPD	Gallons Per Day	Sq. ft.	Square feet (ft^2)
GPH	Gallons Per Hour	Sq. Yd	Square Yards (ft^3)
GPCD	Gallons per capita per day	SWD	Side Wall Depth
H	Height	μ g/L	Microgram/Liter
Hp	Horsepower	V	Velocity
BHp	Brake Horsepower	V	Volume
Whp	Water Horse power		
KW-Hrs	Kilowatt hours		
Lbs	Pounds		
Lbs/Day	Pounds per day		
L	Liter		

END

Updated: March, 2002