# SECTION 3 - SUMMARY OF KEY WATER DISTRIBUTION OPERATOR MATH FORMULAS

Most mathematics problems found on Grade I - IV level examinations are process control problems that are responsive to a host of math formulas that have been developed over a period of time to provide each operator with immediate control information with regard to the operation of his/her water plant or water distribution system.

The working formulas in this workbook have been arranged according to process application for easier identification and memorization. A **working formula**, compared to a root, or partially completed formula, is ready for use as written. Simply match up the working formula to the information given in a problem, then substitute the given information from the problem into the letter designations listed within each formula. From that point on, it's simply a matter of following established algebraic practice and crunching numbers until a final solution is finally arrived at. If you have trouble matching formulas with word problems, ask about the **Key Words to Formulas** tri-fold translation cards and **blue math summary card** that are both available at no charge.

It is important to memorize as many working formulas as possible before sitting for an examination to reduce your reliance on examination site handout sheets which often contain too few formulas, partial formulas, infrequently used formulas, or mixed water - wastewater formulas in no special order that do little to assistant your efforts. Occasionally, some formulas have even been written incorrectly.

The working formulas in this section of the workbook have also been published in the form of **algebraic pie wheels**, flash cards known as **FlashMATH!** publications, 90 - 150 minute **VHS mathematics video tapes** and **CD - ROMs**. All are designed for self-study.

## SECTION 3 - SUMMARY OF KEY DISTRIBUTION OPERATOR MATH FORMULAS

## General:

| | | | |
|---|---|---|---|
| 1. | **Lbs/Day** | = | (Vol, MGD) x ( Dosage, mg/l) x 8.34 lbs/gal) |
| 2. | **Dosage, mg/l** | = | $\frac{\text{( Feed, lbs/day )}}{\text{(Vol, MGD) x 8.34 lbs/gal)}}$ |
| 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.** | = | $\frac{\text{(0.785) x } (D^2\text{,ft})}{(3)}$ x (Height or Depth,ft) |
| | 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)** $= \dfrac{(\text{Vol, Gals/day})}{(\text{Population Served}) \times (\text{GPCD})}$

**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 x 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 = $\frac{(\text{Lbs/day})}{(\text{MGD}) \times (8.34 \text{ lbs/gal})}$

**65% HTH Feed, Lbs/day - Calcium Hypochlorite**

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

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

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

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

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

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

**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 )

## 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 = $\dfrac{(\text{ 1.0 - \% Removal })}{100}$ x **Log key x ( - )**

## SECTION 3 - SUMMARY OF KEY DISTRIBUTION OPERATOR MATH FORMULAS - Continued

Fluoridation:

1. Feed, Lbs/day = 

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

2. Adjusted Feed, Lbs/day = 

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

3. Dosage, mg/L = 

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

**1. Hydraulic (Water Column Height) Pressure :**

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

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

**Or,**

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

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

Pounds of Force On The Face of a Valve

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

**Or,**

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

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

Right Cylinders

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

**Change of Direction**

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

SCADA

1. **Feet of Water In A Tank :**

$$\text{Ft. Water} = \frac{(\text{Process Variable, mA} - 4.0\text{ mA})}{(20\text{ mA} - 4.0\text{ mA})} \times \text{Tank Height, ft.}$$

Live Signal

2. **mA Reading :**

$$\text{mA Reading} = \frac{(\text{Water Depth, Ft.})}{(\text{Tank Height, ft.})} \times (20\text{ mA})$$

## Pumps and Pumping:

**1. Pumping Rate:**

Volume, Gals = GPM x 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:**

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

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

% Overall Effic. (Pump/Motor) = ( Motor, % Effic. x 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:**

Drawdown, ft. = Pumping Level, ft. - Static Level, ft.

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

## SECTION 3 - SUMMARY OF KEY DISTRIBUTIONOPERATOR MATH FORMULAS - Continued

### Strength of Solutions:

1. **Chemical Feed Pumps:**

**GPD (Gals)** = **( Required Feed, Lbs/Day ) / ( Dry lbs/Gal )** = **( MGD ) x mg/L x 8.34 lbs/gal / ( Dry Lbs/gal )**

2. **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 )

3. Lbs/gallon = ( % Solution ) x 8.34 lbs/gallon x ( Specific Gravity ) / ( 100 )

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

5. Specific Gravity = ( 8.34 lbs/gallon **+** Chemical Wt., Lbs/gallon ) / ( 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 = ( Dry Chemical, Lbs ) / [ ( Dry Wt. Chemical, Lbs ) **+** ( Water, Lbs ) ] x 100

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

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

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 DISTRIBUTION OPERATOR MATH FORMULAS - Continued

**Velocity:**

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

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

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

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

4. Flow Conversions:

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

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

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

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

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:**

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

2. **Hazen - Williams**

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

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

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

   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:**

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

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 = $\frac{\text{(Total Exchange Capacity x Kilograins x 1,000 )}}{\text{( Total Hardness as } CaCO_3\text{, Grains/gallon )}}$

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

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

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

# Ion Exchange Formulas
**( Continued)**

**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** $= \dfrac{\text{( Blended Discharge Hardness, mg/L )}}{\text{( Initial Hardness, mg/L )}} \times 100$

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

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

## Lime - Soda Ash Softening

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

Laboratory:

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

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

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

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

5. Concentrations:

   ( Conc. 1 ) x ( Volume 1 ) = ( Conc. 2 ) x ( Volume 2 )

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

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

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

8. Temperature:

   F° = ( C° x 1.8 ) + 32°

   C° = $\frac{\text{( F° - 32° )}}{\text{( 1.8 )}}$

# ABBREVIATIONS

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

END

Updated: March, 2002