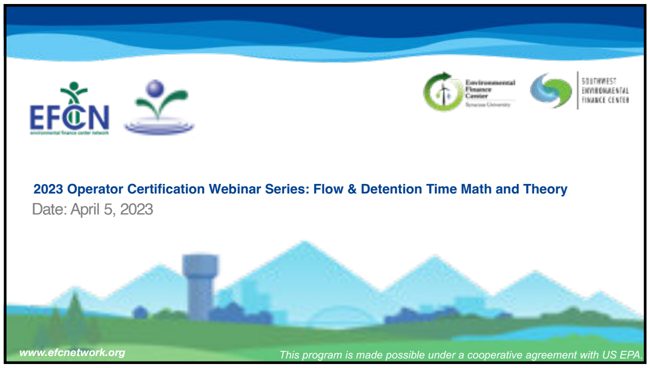

Environmental Finance Center
Syracuse University
SOUTHWEST ENVIRONMENTAL FINANCE CENTER
2023 Operator Certification Webinar Series: Flow & Detention Time Math and Theory
Date: April 5, 2023
www.efcnetwork.org
This program is made possible under a cooperative agreement with US EPA.

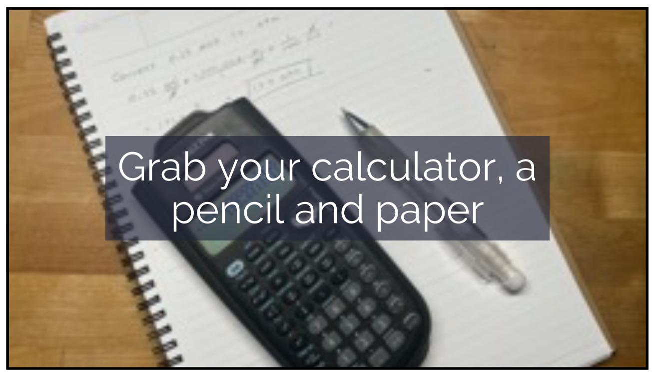
1


Operator Certification

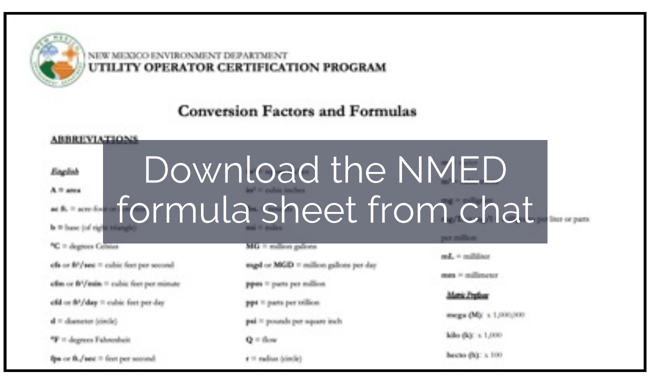
2


Flow Rates &
Detention Time

3


Grab your calculator, a
pencil and paper

4


NEW MEXICO ENVIRONMENT DEPARTMENT
UTILITY OPERATOR CERTIFICATION PROGRAM
Conversion Factors and Formulas
ABBREVIATIONS
Download the NMED
formula sheet from chat

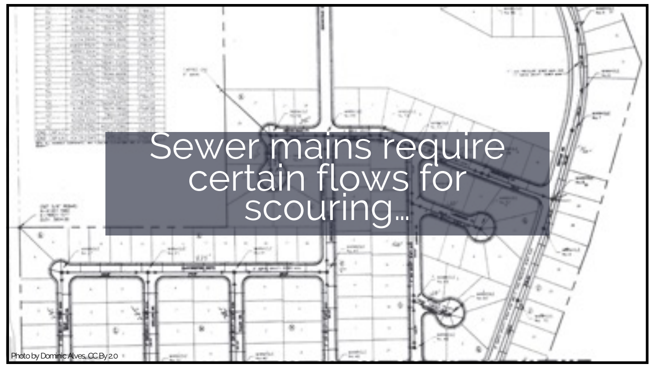
5


Why are flow rate and
detention time so
important?

6


Because they're used a lot.

7


Sewer mains require certain flows for scouring…
Photo by Dominic Alves, CC By 2.0

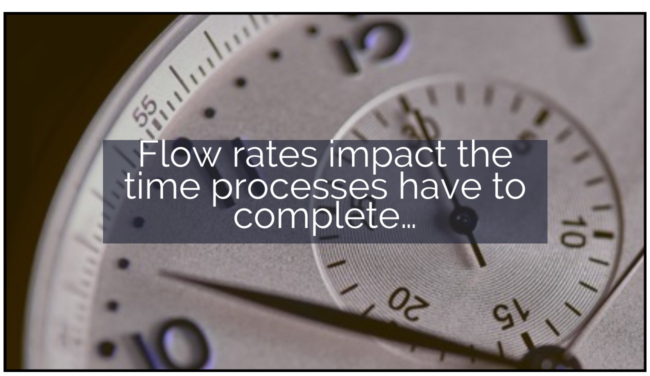
9


Treatment plants are built to accommodate specific flow ranges

10


Treatment Processes Require Time…

11


Flow rates impact the time processes have to complete…

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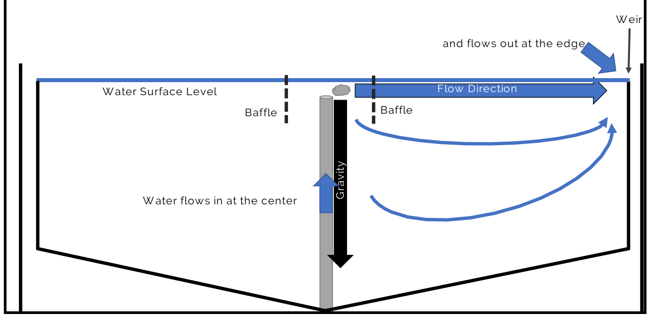
A simplified circular clarifier…



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A Quick Refresher

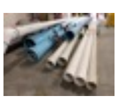
Volumes & Areas

17

17

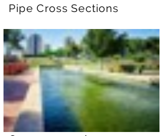
Areas

How you measure surfaces and cross sections



Pipe Cross Sections

Clarifier Surface Area



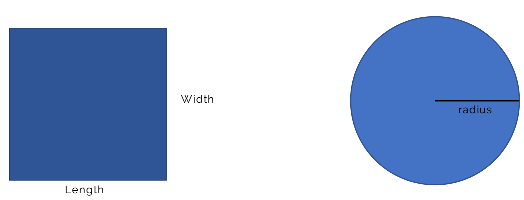
Open reservoir area

How much lawn you have to mow

18

18

Area: 2 dimensions (units²)



Area of a rectangle = Length x Width

Area of a circle = $\pi \times r^2$

19

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Area: Common Conversions:

1 square foot = 144 square inches
1 acre = 43,560 square feet

Useful Linear Conversions:

1 inch = 2.54 centimeters = 0.0254 meters
1 meter = 39.37 inches
1 mile = 5280 feet
1 mile = 1.61 kilometers = 1610 meters

20

20

Area: Common Conversions:

1 square foot = 144 square inches

Convert 12 square ft to square inches:

$$12\ ft^2 \times 144\frac{in^2}{ft^2} = 1728\ in^2$$

And back again…

$$1728\ in^2 \times \frac{1\ ft^2}{144\ in^2} = \frac{1728\ (in^2)(ft^2)}{144\ in^2} = 12\ ft^2$$

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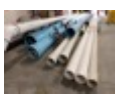
Volumes

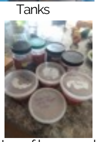
Water and other fluid substances take on the shape of their container

Tanks



Pipes

Clarifiers



Jars of homemade salsa

Excavations

Basins

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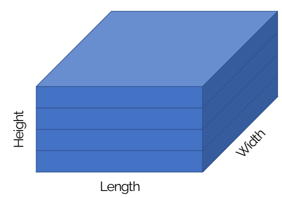
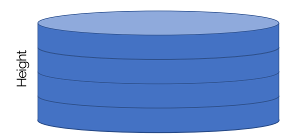
22

Volume: 3 dimensions ($units^3$) (or l or gal)





Area of a rectangle = Length x Width

Volume of a box = Length x Width x Height

Area of a circle = $\pi \times r^2$

Volume of a cylinder = $\pi \times r^2 \times$ Height

23

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Volume: Common Conversions

1 cubic foot = 7.481 gallons
1 cubic yard = 27 cubic feet
1 gallon = 3.785 liters
1 cubic meter = 1,000 liters
1 liter = 1,000 milliliters
1 acre foot = 43,560 cubic feet

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24

How many gallons are there in 1000 cubic meters?

1 cubic foot = 7.481 gallons
1 cubic yard = 27 cubic feet
1 gallon = 3.785 liters
1 cubic meter = 1,000 liters
1 liter = 1,000 milliliters
1 acre foot = 43,560 cubic feet

25

25

How many gallons are there in 1000 cubic meters?

1 cubic foot = 7.481 gallons
1 cubic yard = 27 cubic feet
1 gallon = 3.785 liters
1 cubic meter = 1,000 liters
1 liter = 1,000 milliliters
1 acre foot = 43,560 cubic feet

Solution: $1000\ \cancel{m^3} \times 1{,}000 \frac{\cancel{l}}{\cancel{m^3}} \times \frac{1\ gal}{3.785\ \cancel{l}} = 264{,}200\ gal$

26

New pieces of the puzzle

Velocity & Flow Rate
Include a Time Element

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Time Refresher: Common Conversions

1 minute = 60 seconds
1 hour = 60 minutes = 3600 seconds
1 day = 24 hours = 1440 minutes
1 year = 365 days = 8760 hours

28

How many minutes are there in a year?

1 minute = 60 seconds
1 hour = 60 minutes = 3600 seconds
1 day = 24 hours = 1440 minutes
1 year = 365 days = 8760 hours

29

How many minutes are there in a year?

1 minute = 60 seconds
1 hour = 60 minutes = 3600 seconds
1 day = 24 hours = **1440 minutes**
1 year = **365 days** = **8760 hours**

Solution: $365\ \cancel{d} \times 24 \frac{\cancel{hr}}{\cancel{d}} \times 60 \frac{min}{\cancel{hr}} = 525{,}600\ min$

OR

$8760\ \cancel{hr} \times 60 \frac{min}{\cancel{hr}} = 525{,}600\ min$

OR

$365\ \cancel{d} \times 1440 \frac{min}{\cancel{d}} = 525{,}600\ min$

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So, what is velocity?

The the distance (or length) something travels in a given time – you're answering **"how fast"**

$\frac{\textbf{distance}}{\textbf{time}}$ $\frac{ft}{sec}$ or **fps**

- feet per second (ft/sec, or **fps**)
- meters per second (m/sec, or **mps**)

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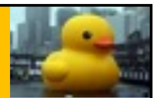
Calculate Velocity



A small rubber ducky gets sucked into a force main that is 520 feet long. It comes out the end in 142 seconds. How fast is sewage flowing through your force main?
(assuming sewage is flowing the same speed as the ducky)

V = distance / time
V = 520 ft / 142 sec
V = 3.7 ft/sec

(A) 378 ft/sec
(B) 73,840 ft/sec
(C) 0.28 ft/sec
(D) 3.7 ft/sec

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So, on to flow – what is it?

The volume flowing through something in a given time – you're answering **"how much"**

$$\frac{\textbf{volume}}{\textbf{time}} \quad \frac{ft^3}{sec} \quad \text{or} \quad \textbf{cfs}$$

- Gallons per minute (gal/min, or **gpm**)
- Cubic feet per second (ft^3/sec, or **cfs**)
- Gallons per day (gal/day or **gpd**)
- Million gallons per day (mil. gal/day or **MGD**)

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Flow

We figure out flow with two pieces of information:

1) The velocity the liquid is traveling at (for example, in **ft/sec)**
2) The cross section of the fluid, or it's area (for example, in **ft^2**)

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The basic flow formula:

Flow = Velocity x Area

or

Q = V x A

Variables:

Q = **Flow**
V = **Velocity**
A = Cross section **Area of the flow**

v (ft/sec) x A (ft^2) = Q (ft^3/sec)

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Pressurized Pipes

Drinking water mains and force mains are pressurized.

The pipe interior cross section area = the water cross section area

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Calculate Flow

Sewage in a 12" diameter force main is moving at 2.8 ft/sec. What is the sewage flow through the force main in cfs?

Our Formula: **Q = V x A**

$$V = 2.8\,\frac{ft}{sec}$$

$$A = \pi r^2 = \pi \times (0.5\,ft)^2 = 0.785\,ft^2$$

$$Q = 2.8\,\frac{ft}{sec} \times 0.785\,ft^2 = 2.2\,\frac{ft^3}{sec} = 2.2\,cfs$$

(A) 8.9 cfs
(B) 4.4 cfs
(C) 2.2 cfs
(D) 3.7 cfs

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Unpressurized Pipes

With the exception of force mains, sewers are **NOT pressurized**.

In that case you need the cross section and velocity **of the effluent**

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Velocity - Unpressurized

Our Formula: $Q = V \times A$

You are trying to verify that your 12" gravity mains maintain a minimum scouring velocity of 2 ft/second at peak flows. Inspection shows that they are half full at peak flow and flow is calculated to be 300 gpm. What is the velocity, and do you meet your goal of obtaining a velocity above 2.0 ft/sec?

Pipe D = 1 ft

$Area = A = (\pi \times r^2) \div 2$ (Pipe is only half full!)

$Area = A = (\pi \times 0.5ft^2) \div 2$

$Area = A = (0.785ft_2) \div 2$

$\mathbf{Area = A = 0.393ft^2}$

$Flow = Q = 300\ gpm$

But we need cubic feet per second.

$300 \frac{gal}{min} \times \frac{1}{60} \frac{min}{sec} = 5 \frac{gal}{sec}$

$5 \frac{gal}{sec} \times \frac{1}{7.48} \frac{ft^3}{gal} = \mathbf{0.67 \frac{ft^3}{sec}}$

Solve for Velocity:

$0.67 \frac{ft^3}{sec} = V \times 0.393ft^2$

$\left(0.67 \frac{ft^3}{sec}\right) \div 0.393ft^2 = V$

$V = 1.7 \frac{ft}{sec}$

(A) 0.16 ft/sec
(B) 1.7 ft/sec
(C) 2.12 ft/sec
(D) 763 ft/sec

(A) Yes, enough velocity to scour pipes
(B) No, not enough velocity to scour pipes

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Calculating velocity, flow & area

$Q = V \times A$ so $A = \frac{Q}{V}$ and $V = \frac{Q}{A}$

$$\frac{\textbf{flow}}{\textbf{area}} \quad \frac{\left(\frac{ft^3}{sec}\right)}{ft^2} = \frac{ft}{sec}$$

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Flow: Common Conversions

1 cfs = 448.8 gallons per min (gpm)
1 cfs = 646,300 gallons per day (gpd)
1 MGD = 694.4 gpm
1 MGD = 1.545 cfs
1 MGD = 1,000,000 gpd
1 cfs = 0.646 MGD

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Convert 1 cfs to MGD

$1 \frac{ft^3}{sec} \times 60 \frac{sec}{min} \times 1440 \frac{min}{day} \times \frac{1}{7.481} \frac{gal}{ft^3} \times \frac{1}{1{,}000{,}000} \frac{MG}{gal} = ?$

$1 \frac{ft^3}{sec} \times 60 \frac{sec}{min} \times 1440 \frac{min}{day} \times \frac{7.481}{1} \frac{gal}{ft^3} \times \frac{1}{1{,}000{,}000} \frac{MG}{gal} = 0.65 \frac{MG}{day}$

$$= 0.65\ MGD$$

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Average Annual Daily Flow

Month	Total Flow (MG)
1	50
2	55
3	45
4	50
5	45
6	55
7	50
8	55
9	45
10	50
11	45
12	55
Total	**600.00**

Average Annual Daily Flow = $\frac{\text{Total Flow for Period}}{\text{Total \# of Days}}$

Average Annual Daily Flow = $\frac{600\ MG}{365\ D}$

Average Annual Daily Flow = 1.643 $\frac{MG}{D}$ (or 1.6 MGD)

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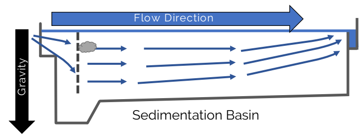
Detention Time

- The time water or effluent stays in a given reservoir or treatment process.



$$Detention\ Time = \frac{Volume}{Flow}$$ Units must be compatible

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What's going on in there?

A primary sedimentation example

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Primary Sedimentation

What's the purpose: Removal of readily settleable solids, reducing suspended solids content in the effluent.

How is it happening: water velocity is slowed so small particles have time to clump together and sink. Flocculants may be added to aid and speed the process.

Effluent: Cleaner effluent flows out of a weir at the surface

Solids: sink to the bottom of the tank and are removed mechanically

What's the impact: Removing BOD and TSS. Between 50-70% of TSS and 25 to 40% of BOD can be removed in efficient systems. Removal is a function of detention time and constituent concentration.

But it takes time: Fine solids reaching primary sedimentation need time to flocculate – or coalesce, and sink

Typical Ranges: Primary sedimentation detention time typically falls into the 1.5-hour to 2.5-hour range but may be shorter if less suspended solids need removal.

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Calculating Detention Time

7

Our formula: $Detention\ time = \frac{Volume}{Flow}$ (Units must match!)

Find the detention time in hours for the following sedimentation basin with **two** clarifiers, with an average overflow rate of 20,000m3/day:

Each clarifier's dimensions:
L = 42m
W = 6m
H = 5m
Sidewater Depth = 4m

Calculate Detention time:

$$Detention\ Time = \frac{2016\ m^3}{20{,}000\ \frac{m^3}{day}} = 0.1008\ day$$ **NEED HOURS!**

$$Detention\ Time = 0.1008\ day \times 24\ \frac{hrs}{day} = \mathbf{2.24\ hrs}$$

$$Detention\ Time = 2016\ m^3 \times \frac{1}{20{,}000}\ \frac{days}{m^3} \times 24\ \frac{hrs}{day} = \mathbf{2.24\ hrs}$$

Find the Volume:

$$Volume = 2 \times (42m \times 6m \times 4m) = \mathbf{2016\ m^3}$$

Metcalf & Eddy, 5TH Edition, McGraw Hill, 2014, Example 5-9

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What's next?

An intro to removal rates

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Primary Sedimentation Removal Rate

Our formula: $R = \frac{t}{a + bt}$

R = expected removal efficiency (%)
t = nominal detention time
a, *b* = empirical removal constants

Item	a	b
BOD	**0.018**	**0.020**
TSS	0.0075	0.014

$$R(BOD) = \frac{2.42\ hrs}{0.018 + (0.020 \times 2.42\ hrs)}$$

$$R(BOD) = \frac{2.42}{0.0664}$$

$$R(BOD) = 36\%$$

Metcalf & Eddy, 5[TH] Edition, McGraw Hill, 2014, Figure 5-45

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Primary Removal Rate

Our formula: $R = \frac{t}{a + bt}$

R = expected removal efficiency (%)
t = nominal detention time
a, *b* = removal constants:

Item	a	b
BOD	0.018	0.020
TSS	**0.0075**	**0.014**

$$R(TSS) = \frac{2.42\ hrs}{0.0075 + (0.014 \times 2.42\ hrs)}$$

$$R(TSS) = \frac{2.42}{0.04138}$$

$$R(TSS) = 58\%$$

Metcalf & Eddy, 5[TH] Edition, McGraw Hill, 2014, Figure 5-45

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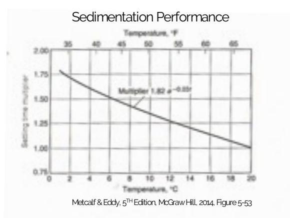
Quick Note: Temperature Impacts Required Detention Time

Colder temperatures tend to slow processes



Metcalf & Eddy, 5[TH] Edition, McGraw Hill, 2014, Figure 5-53

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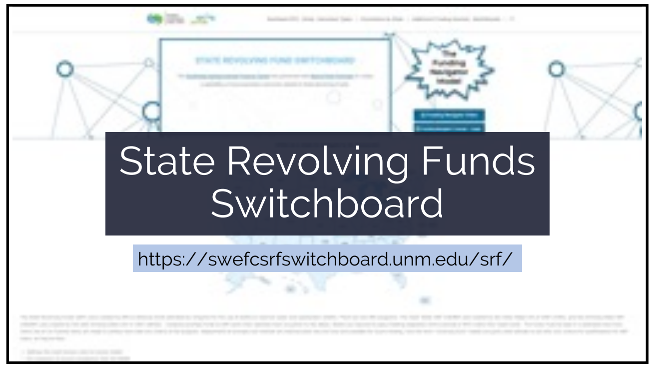

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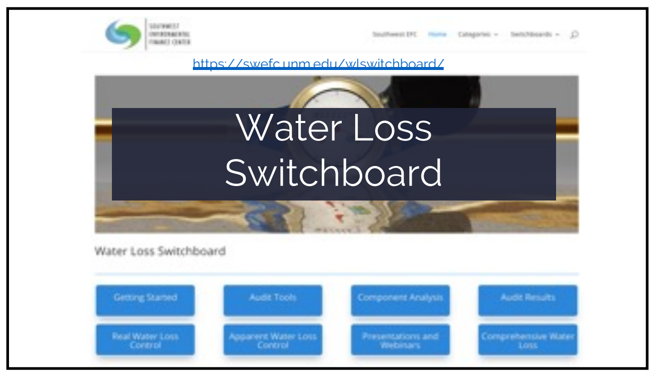

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