Introduction to Wastewater Treatment
Grades 3&4 – Week 2 Course #2201

Fleming Training Center
February 11 - February 15, 2019
Monday, February 11, 2019
8:30 Review Exam 1
9:00 Activated Sludge Part II
11:00 Lunch
12:00 Activated Sludge Part II cont.
1:30 Intro to Wastewater Math

Instructor
Bri Begley

Tuesday, February 12, 2019
8:30 Intro to Lab and Sampling
10:00 Intro to QA/QC, Standard Methods, and SOPs
12:00 Lunch
1:00 Microscopic Exam

Instructor
Bri Begley

Wednesday, February 13, 2019
8:30 Sludge Thickening, Digestion, and Dewatering
11:00 Lunch
12:00 Effluent Disposal
1:30 Administration and Management

Instructor
Bri Begley

Thursday, February 14, 2019
8:30 Pumps and Equipment Maintenance
10:00 NPDES Overview
11:00 Lunch
12:00 Plant Tour (TBD)

Instructor
Bri Begley

Friday, February 15, 2019
8:30 End of Course Review
11:00 Lunch

Instructor
Bri Begley
# Introduction to Wastewater Treatment Grades 1 - 4

## Week 2

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Section 1

Activated Sludge

Part II
Activated Sludge: Part II

Introduction to Wastewater

Recap from Part I

- Activated Sludge:
  - Mixture of influent (primary clarifier effluent) and microorganisms; bacteria, protozoa, metazoan, insects, fungi

- This fundamental process is the heart of activated sludge treatment

  Organics + O₂ + nutrients + inert matter → CO₂ + H₂O + new microorganisms + additional inert matter

Components of all Activated Sludge

1. Flocculent Slurry of Microorganisms Solids in the Aerator
2. Quiescent Settling of Solids in Clarifier
3. Return of Settled Solids to the Aerator (RAS)
4. Excess Solids Wasted from the System (WAS)

Activated Sludge Process Design

- Plug-flow (conventional)
- Step Feed
- Contact Stabilization
- Bardenpho
- Kraus
- Pure Oxygen
- Complete mix
- Extended aeration
- Oxidation ditches
- High-rate aeration

Pounds Formula !!!!

- Real life and guaranteed test Question.

- How many pound of MLSS are in the aeration basin?

- Size MG * MLSS mg/L * 8.34 (lbs/gal) = pounds(lbs)

  10 MG * 2500 mg/L * 8.34 = 208,500 lbs
Biological Reactors
- Biological reactors provide oxygen and mixing that promote contact with waste
- RAS maintains the microorganism population

Over Aeration
- Adding dissolved oxygen to the mixed liquor creates the highest single electrical demand at most activated sludge facilities
  - Can account for 40-70% of the total power demand at a typical plant
- Over aerated basins at DO levels of 6 mg/L or more can shear the floc and waste energy.

Pure Oxygen System
- Chattanooga, TN
  - Pure oxygen systems use mechanical mixers similar to a complete mix plant but in a covered tank

Aeration Systems
- Surface aerators
- Diffused aeration systems
- Hybrid devices

Surface Aerators
- Surface Aerator
  - Horizontal Rotor Surface Aerator
  - High-speed surface aerator
  - Surface Aerator
  - (Also subsurface mixers)
Surface Aerator

- For surface aerators, the most common way to control the DO and mixing is through the use of variable-speed motors.
- Typically, a two-speed motor is used.
- Often generates splashing and mist.
- Aspirators

Diffused Aeration System

- Air System
- Filters
- Valves & Controls
- Blower & Motor
- Piping
- Diffusers
  - Coarse Bubble: Non-Porous
  - Fine Bubble: Porous
    - Ceramic
    - Domes/Disks
    - Plates
    - Tubes

Diffused Aeration System

- Because the terms “fine bubble diffuser” and “coarse bubble” diffuser are often not clearly defined, the use of these designations can be very confusing.

Membrane Diffuser

Biological Reactor

Aeration tapers off through reactor
Mixing with Aeration, Conventional

- Single Roll
- Double Roll

Aeration

- Maintenance is required on aeration systems air filters
- A dirty air filter will be the most probable cause for a drop in blower output
- This can be determined by reading the differential pressure between the intake and the discharge of the filter or using a manometer
- When using a manometer (mercury filled), if the reading increases more than two or more inches from the initial reading, the air filter should be cleaned
- Shut off the blower and tag and lock out for safety

Influent Flow vs. Air Flow

Off/On Aeration (Pulsed, Cyclic, Phased)

- Increasingly used for nutrient removal
- Aeration equipment is cycled "ON" and then "OFF" to select for different types of bacterial metabolism
- Aerobic, Oxic- free oxygen is present, used for CBOD removal and a must for ammonia & phosphorus removal
- Anoxic- no free oxygen, but there is the combined oxygen nitrate & nitrite (NO$_3$ & NO$_2$) for CBOD removal and Total Nitrogen removal
- Anaerobic- fermentation is beginning, no free oxygen, no NO$_3$ & NO$_2$, but there are other forms of combined oxygen like SO$_4$, CO$_2$-HCO$_3$-CO$_3$, needed for phosphorus removal

Centrifugal RAS Pump

- Return sludge results high MLSS and fast treatment
- It is very important to have the RAS enter the biological reactors at a point where thorough mixing occurs
- There are 2 methods of RAS rates:
  - Constant return rates
  - Rate based on % of influent flow

Return Activated Sludge Systems
Waste Sludge Options

- The amount of sludge wasted from the process affects all the following:
  - Growth rate of microorganisms
  - Oxygen consumption
  - Mixed liquor settleability
  - Nutrient quantities needed
  - Occurrence of foaming/frothing
  - Possibility of nitrification
  - Effluent quality

Waste Sludge Options

- Increasing the wasting rate will:
  - Decrease the MLSS concentration
  - Decrease the MCRT
  - Increase the F:M ratio
  - Increase the SVI

Wasting Rates

- MLVSS that need to be wasted accumulate primarily from new cell production by the microorganisms.
- If you fail to waste the correct amount, you will unintentionally waste solids by losing suspended solids in the effluent.
  - A gradual increase in the amount of solids over the weirs of the secondary clarifier is usually an indication that the WAS is too low.
  - If the WAS is not adequate, the microorganisms may starve, the F:M will decrease, sludge blanket and MLSS will increase and the effluent may deteriorate after a period of time.
- The most important feature of a WAS pumping system is its flexibility to allow different wasting rates.
- Develop a wasting strategy that works best for your facility.

Process Control

We know a lot, but poor performance does occur.
How do you control your activated sludge process?

- How do you get the results you want?
- What results do you want?

Process Control

- If the process is right the results will be right
- Operators use the tools provided to adjust the Activated Sludge process, i.e. the environment that the bugs live in, so the bugs make good effluent

Process Control

- Process Control Goal
- Stable Process that meets regulatory requirements
- Know the plant and process
- Monitor the process
- Adjust the process

Process Variables: Influent

- Influent
  - Flow:
    - Normal
    - Low=weekend
    - High=rainwater flooding
  - Type of Pollutant:
    - Organic: CBOD, FOG, Chlororganic compounds, hydrocarbons, Organic nitrogen or ammonia
    - Concentration of the pollutants
    - pH
    - Temperature

Process Variables: Facilities

- Facility Design
- Flow Pattern and Sewage Feed Point
- Type of treatment units: primary clarifier, aeration basins, secondary clarifiers, selectors, filters, recycle, RAS, WAS, manual or automatic control and adjustment
- Number of treatment units

Process Control Tools

- Adjust
  - Air: flow(cf), Dissolved Oxygen(DO), concentration (mg/L)
  - Return rate: percent of influent flow, gallons, lbs
  - Waste rate: gallons, lbs
  - Mode of operation: most powerful operator tool but most plants are not designed for this change
  - Number of units used: clarifiers, aeration tanks, blowers
  - Rate and location of sewage feed: mode of operation
  - Influent control: industrial pretreatment, I/I control, these two often take time
### Process Monitoring Methods

- Human senses
- Visual appearance, odors, noise, mixing
- Process tests
  - Flow, D.O., pH, temp., alkalinity, ORP, turbidity
  - Settler, Sludge judge
  - MLSS, MLVSS
  - Centrifuge spins, TSS meter
  - Microscopic evaluation
  - Oxygen Uptake Rate, Specific Oxygen Uptake Rate

### Process Control

What aerator test "now" will assure you of good effluent? When that water reaches the effluent several hours latter.

![Diagram](image)

- Aerator
- Clfr
- Return Activated Sludge
- Effluent

**You choose the method that assures you that effluent will meet permit.**

- NPDES permit
  - Part II.A.4 Proper Operations and Maintenance
    - "...adequate process controls..."
    - Though almost hidden, this is a Permit requirement
- Find a method that works for you and use it!

**Trouble Shooting**

- Every plant experiences trouble from time to time. Having a Process Control Baseline is important in these events.

### Observations, Aeration Basin

- Odors
  - Fresh plowed field
  - Hog pen
- Turbulence
  - Boiling, dead spots
- Foam and Scum
  - Fresh, crisp, light-colored foam
  - Billowing white foam
  - Thick, scummy, dark foam
- Balanced Flow to All Units

### Sensory Process Control

- Clarifier Issues
  - Bulking, sludge quality
  - Billowing, hydraulic overload
  - Clumping, denitrification
  - Ashing/Pin Floc, old sludge
  - Straggler Floc, young sludge

### Observations- Influent/Effluent

- Odors, color, solids
Foam

Start-up, Recovery, Billowing White Foam

Old Sludge, Thick, Scummy, Dark Tan

Prehistoric Sludge, Black, Thick, Stable

Light Crisp Unstable Foam

Foam

Nocardia

Industrial Surfactant Foam

“Normal” Foam

“Fresh, crisp, light-colored foam”

Observations, Clarifier

Rising clumps – Denitrification

Solids Wash Out- High Flow

Bulking- Filaments

Filamentous Scum, M. Parvicella

Activated Sludge Part 2
Observations, Clarifier

- Ashing: Old Sludge
- Age/Denitrification
- Pristine Effluent

Observations, Effluent

- Clear Mountain Stream
- vs.
- Ooops, not a good day

Process Control Testing

**Good Data = Good Decisions**

- **Sampling Factors:**
  - Timely
  - Representative
- **Testing Factors:**
  - Timely
  - Unbiased
  - Accurate
- **Types:**
  - D.O., pH, temp, alkalinity
  - ORP, turbidity, conductivity
  - Settlesmer, Sludge judge
  - MLSS, MLVSS
  - Centrifuge spins,TSS meter
  - Oxygen Uptake Rate, Specific Oxygen Uptake Rate
  - Microscopic evaluation

Process Control Tests

- Flow Rates, accurate flow measurements of premier importance.
- Locations
  - Influent Q
  - RAS,WAS, other
- Dissolved oxygen
  - Aeration tank effluent
  - Profiles - longitudinal,vertical
  - RAS may be helpful
  - OUR/SOUR

Process Control, continued

- **pH**
  - Indicator of toxicity
  - Related to Alkalinity
  - Indicator of nitrification problems
- **Temperature**
  - Use D.O. meter
  - Affects speed of bacterial metabolism, or perhaps no metabolism!
  - Most common impact is slowing of nitrification, so we allow MLSS to be higher in the winter.

Process Control, continued

- **Alkalinity**
  - Necessary for complete nitrification
- **ORP-Oxidation Reduction Potential, Redox**
  - pH meter with ORP probe
  - Indicated the oxidative state of the solution
  - Most useful where treatment processes continue and DO is 0.0mg/L
- **Turbidity**
  - Indicator of completeness of flocculation
Process Control, continued

- Settlometer
  - Use settlometer not graduated cylinder
  - Indicator of clarifier performance
  - How well the biomass settles, compacts, and clears
  - May give mixed signals
- Sludge Judge- Profile of the clarifier
- MLSS, MLVSS, Centrifuge spins, TSS meter
  - Indicators of biomass inventory
- Microbiological Exam

Sludge Judge, Core Taker

- Sludge Judge
  - Depth of blanket- from bottom of clarifier to the top of the sludge layer
  - Depth to blanket - from the top water level down to the top of the sludge blanket
  - Core Sample – the entire contents of the sampler into a bucket

Settlometer- benchtop clarifier

- Key Readings
  - 5 min. - indicates how well the sludge settles
  - 30 min.- indicates how well the sludge compacts
  - Clarity of the supernatant- indicates how well the sludge flocculates and clears
  - Blanket quality- flocculation and settling impacts
  - Rise time- indicates how long it may take for the clarifier to clump
- Other Indications
  - Record each 5 min. reading for 30 min., then each 10 min. reading for the next 30 min.
  - Graph the data, calculate Settled Sludge Concentration. Set RAS rate.

Settlometer – Use a wide mouth container

- (Photo of a settlometer comparison)
  - Identical MLSS
  - Three short settlometers had SSV30 = 400
  - The graduated cylinders had SSV30 = 600
  - Takeaway: Narrow cylinders hinder settling

5 min. Normal, Dispersed

10 min.
15 min.

30 min.

30 min. –
Right side has dispersed growth, settles poorly

Clarity of Supernatant

Clear Supernatant = Good effluent

Left: sample from aerator
Right: sample from clarifier feedline

Settlometer, Blanket Observation

- Blanket Observation
- Granular, Compact, Fluffy, Feathery
- Large, Small
- Blanket, Individual Particles
- Clear or Cloudy
- Edge
  - Crisp, spongy, feather-edged, homogeneous

Settlometer, Blanket Observation

- Filamentous Bacteria
- Blanket Coning associated with filaments
- Also very clear supernatant
- Check Sludge Volume Index (SVI)
  - Calculation that indicates the tendency of aerated solids to thicken or become concentrated during sedimentation/thickening process
  - Greater than 150 may be filaments
  - Greater than 200 probably is filaments

One Environmental Protection Agency
Settlometer - Rise Time

- **Rise Time**
- Allow the Settlometer to sit until the settled blanket floats
- Short time to rise (<60 min) = high potential for clarifier clumping
- Long time to rise (>120 min) = far less potential for lumping
- Look closely to see nitrogen gas bubbles

Settometer

- **Reasons for NO Settling:**
  - Dispersed Growth
  - Biomass Dead

- **Reasons for Slow Settling:**
  - Young Biomass
  - Too much Biomass
  - Filaments

Settled Sludge Concentration

- Calculated from SSV (Settled Sludge Volume)
- Time zero = MLSS mg/L
- Use 5-10 minute readings
- \[ \text{SSC} = \frac{\text{MLSS} \times 1000}{\text{SSV}} \]
- Knee area represents the “maximum” thickness that is reasonably possible for the RAS

Settometer, Graphs

Graph the actual settled volumes, then construct the Settled Sludge Concentration.

Settometer, Worksheets
Example Settleometer Test

More Process Control Tests – Biomass Solids

- Quicker Tests to do MCRT calculations.
  - Centrifuge - Al West
  - TSS Meter, even faster
- Microscopic Exam - useful to check floc quality, filamentous bacterial presence and type (Phase Contrast) and a secondary indicator of sludge age

Biomass Solids
- Biomass (MLSS) Inventory Tests
  - MLSS - gravimetric
  - Centrifuge - quicker, Sludge Units
  - TSS meter - even quicker
  - Test three locations, sometime four
  - Aeration basin
  - RAS
  - Clarifier Core
  - Sometimes Effluent TSS is used

Mixed Liquor Suspended Solids
- Most Common Advanced Lab test for Process Control
- Process Control goal is to maintain a constant MLSS based on historic performance
- Looks at only Aerator

Biomass Inventory/MCRT
- Inventory of Biomass should answer three questions:
  1. How much sludge is in the system?
  2. Where is it located?
  3. How long has it been there?
- Experience has shown us certain mean cell residence times will give us certain effluent qualities.
- With these answers, process control is easy

Solids Inventory and Control
Solids

- As BOD is reduced, additional microorganisms are produced. The microorganisms grow and reproduce as they remove food/pollutants from the water.
- To keep a balanced system, what grew today must be removed.
- Measuring flow and solids concentration allows calculation of mass balances.

Solids Inventory

<table>
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<th></th>
<th>Secondary Influent</th>
<th>MLVSS</th>
<th>Secondary Effluent</th>
</tr>
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<tbody>
<tr>
<td>Q_{in}</td>
<td>Q_{eff}</td>
<td>Q_{in}+Q_{eff}</td>
<td></td>
</tr>
<tr>
<td>TSS_{in}</td>
<td>MLVSS</td>
<td>TSS_{eff}</td>
<td></td>
</tr>
<tr>
<td>BOD_{in}</td>
<td>RAS</td>
<td>WAS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q_{RAS}</td>
<td>Q_{WAS}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TSS_{RAS}</td>
<td>TSS_{WAS}</td>
<td></td>
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Solids Wasted

- WAS, lbs/day = \((TSS_{in}, \text{mg/L}) (Q_{in}, \text{MGD})(8.34\text{lbs/gal})\)
- Example: WAS flow of 200 gpm with a WAS TSS of 8050 mg/L
- How many pounds of WAS are wasted per day?

F:M Ratio

- One of the most important process control parameters is maintaining the optimum amount of solids to remove BOD from influent wastewater.
- BOD = “food”
- Activated sludge solids = “microorganisms”
- \(F:M\) Ratio
  - Food (BOD, lbs/day) divided by Microorganisms (MLVSS, lbs)
F:M Ratio

\[ F: M = \frac{(\text{BOD}_{\text{infl}}, \text{mg/L})(Q_{\text{infl}}, \text{MGD})(8.34 \text{ lbs/gal})}{(\text{MLVSS}, \text{mg/L})(\text{AeratorVol}, \text{MG})(8.34 \text{ lbs/gal})} \]

**Target F:M values**
- Conventional = 0.2 – 0.5
- Nitrifying less than or equal to 0.10
- Extended Aeraton = 0.05-0.15

F:M based on BOD measurements does not give immediate process control feedback, 5 days late at best!
- Running averages of F:M provide useful monitoring input
- F:M can be based on COD measurements when immediate process feedback is required

**F:M Example**

<table>
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<th>BOD&lt;sub&gt;infl&lt;/sub&gt;</th>
<th>145 mg/L</th>
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<tr>
<td>Q&lt;sub&gt;infl&lt;/sub&gt;</td>
<td>15 MGD</td>
</tr>
<tr>
<td>MLVSS</td>
<td>2500 mg/L</td>
</tr>
<tr>
<td>AeratorVolume</td>
<td>2 MG</td>
</tr>
</tbody>
</table>

\[ F: M = \frac{(145 \text{ mg/L})(15 \text{ MGD})(8.34 \text{ lbs/gal})}{(2500 \text{ mg/L})(2 \text{ MG})(8.34 \text{ lbs/gal})} = 0.44 \]

**F:M Ratio**

- Excess sludge to waste:
  - Excess M to waste = Current M – Food (Microorganisms) F:M Target

**F:M Calculations**

- Desired MLVSS, lbs = BOD or COD lbs
- Desired F:M ratio
- Desired MLSS, lbs = Desired MLVSS lbs
- %Vol. Solids, as decimal
- SS, lbs to waste = Actual MLSS, lbs – Desired MLSS, lbs

**F:M Ratio BOD/MLSS Changes?**

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<th>Calculated F:M</th>
<th>Result</th>
<th>Action</th>
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<td>Less than target F:M</td>
<td>Too many microorganisms in process</td>
<td>Increase wasting rate</td>
</tr>
<tr>
<td>Greater than target F:M</td>
<td>Not enough microorganisms in process</td>
<td>Reduce wasting rate</td>
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**Excess Sludge to Waste Example**

Given the following data, use the desired F:M ratio to determine the lbs SS to be wasted:
- Aeration Vol = 1,300,000 gal
- MLSS = 2980 mg/L
- %VS = 70%
- BOD = 115 mg/L

- Desired F:M = 0.15 lbs BOD/day/lb MLVSS
- Desired MLVSS, lbs = BOD, lbs
  - Desired F:M ratio
    - F:M Target
  - SS, lbs to waste = Actual MLSS, lbs – Desired MLSS, lbs

**Excess Sludge to Waste Example**

- Given the following data, use the desired F:M ratio to determine the lbs SS to be wasted:
  - Aeriation Vol = 1,300,000 gal
  - MLSS = 2980 mg/L
  - %VS = 70%
  - BOD = 115 mg/L

- Desired F:M = 0.15 lbs BOD/day/lb MLVSS
- Desired MLVSS, lbs = BOD, lbs
  - Desired F:M ratio
    - [115 mg/L](3.19 MGD)(8.34)
    - 0.15
    - = 20,396.86 lbs desired MLVSS
**Excess Sludge to Waste Example**

Given the following data, use the desired F:M ratio to determine the lbs SS to be wasted:

- Aeration Vol = 1,300,000 gal
- Q_{in} = 3,190,000 gpd
- BOD = 115 mg/L
- Desired F:M = 0.15

**Desired MLSS, lbs** = Desired MLVSS, lbs

\[
\text{% Vol Solids, as decimal} = \frac{20,396.86 \text{ lbs}}{0.70} = 29,138.37 \text{ lbs desired MLSS}
\]

SS, lbs to waste = Actual MLSS, lbs − Desired MLSS, lbs

\[
= (2980 \text{ mg/L})(1.3 \text{ MG})(8.34) − 29,138.37 \text{ lbs} = 32,309.16 \text{ lbs} − 29,138.37 \text{ lbs} = 3170.79 \text{ lbs to waste}
\]

**MCRT**

- **Mean Cell Residence Time**
- The average time a given unit of cell mass stays in the biological reactor.
- Higher MCRTs create higher MLSS concentrations
- Lower MCRTs create lower MLSS concentrations

MCRT, days = Suspended Solids in System, lbs / SS Leaving System, lbs/day

**MCRT**

- Given the following data, use the information below to determine the MCRT, days:
  - Aeration Vol = 1.5 MG
  - Final Clar Vol = 0.11 MG
  - PE Flow = 3.4 MGD
  - WAS Pump Rate = 60,000 gpd
  - MLSS = 2460 mg/L
  - WAS SS = 8040 mg/L
  - SE SS = 18 mg/L
  - CC SS = 1850 mg/L

MCRT = \[
\frac{(2460 \text{ mg/L})(1.5 \text{ MG})(8.34) + (1850 \text{ mg/L})(0.11 \text{ MG})(8.34) + (18 \text{ mg/L})(3.4 \text{ MGD})(8.34)}{(8040 \text{ mg/L})(0.06 \text{ MG})(8.34) + (18 \text{ mg/L})(3.4 \text{ MGD})(8.34)}
\]

\[
= 3973.6 \text{ lbs MLSS}  + 1697.19 \text{ lbs CCSS} = 32471.79 \text{ lbs}
\]

\[
\text{4023.216 lbs/d WAS + 510.408 lbs/d SE SS} = 4533.624 \text{ lbs/d}
\]

\[
= 7.2 \text{ days}
\]
**MCRT**

- Given the following data, use the information below to determine the MCRT, days (same as previous, just missing the CCSS sample):
  - MLSS = 2460 mg/L
  - WAS SS = 8040 mg/L
  - SE SS = 18 mg/L
  - Aeration Vol = 1.5 MG
  - Final Clar Vol = 0.11 MG
  - PE Flow = 3.4 MGD
  - WAS Pump Rate = 60,000 gpd

- MCRT = \( \frac{2460 \text{ mg/L}}{1.5 \text{ MG} + 0.11 \text{ MG}} \cdot 8.34 \) \( \text{ (8040 mg/L)(0.06 MGD)(8.34) + (18 mg/L)(3.4 MGD)(8.34)} \)

\[ \begin{align*}
\text{MCRT} &= \left( \frac{2460 \text{ mg/L}}{1.61 \text{ MG}} \right) \cdot 8.34 \\
&= 33031.404 \text{ lbs} \\
&= 7.3 \text{ days}
\end{align*} \]

**DO Requirements**

- For low-BOD wastewater, the minimum airflow rate is often based on mixing rather than DO requirements.
- Typically, oxygen requirements are met when the DO in the mixed liquor is at 1.5 mg/L, but many plants do more.

- Reference manuals will often recommend ranges of 1-3 mg/L or 1.4 mg/L, and state 1.0 mg/L is needed for BOD removal and 2.0 mg/L is needed for Ammonia removal, but in real life plants will operate at lower levels.
- And for nutrient removal air is often cycled off allowing DO to drop to 0.0 mg/L for short periods of time.

**Low DO**

- Signs that low-DO conditions may be present:
  - Odors
  - Dominance of “low-DO” filamentous bacteria
  - Turbid effluent
  - Gray or black mixed liquor
  - H. Hydrossis- Low DO filaments thrive at DO levels in the range of 0.3-0.7 mg/L day in and day out. It is the continuous low that is the problem

**Uniform Mixing**

- Reactors should be monitored to ensure mixing is uniform
**Septic Sludge**

- **Location:** almost any basin
- **Reason:** too long without air, improper mixing, often a design issue
- **Symptoms:** Odors, clumping, poor treatment
- **Solutions:** pinpoint the reason and correct it.
  - Increase oxygen, mixing, wasting, clean pipelines, pumps, valves
  - Correct flow: RAS, WAS, other

**Toxic Discharge**

- Aerator DO suddenly way up!
- **SOUR- Specific Oxygen Uptake Rate, way down or 0.0 mg/hr/g MLVSS**
- Some causes: high/low pH, toxic chemicals, metals, pesticides, oils
- Actions: hold and treat off line, maintain air, reduce/stop wasting, up MLSS,

**Trouble Shooting**

- Trouble shooting observations and data
- Influent, In the Plant, Effluent
- Trouble shooting steps:
  - Check operational data and logs ~ three weeks of data
  - Talk to other operators and on other shifts
  - Review recent adjustments and tests
  - Check for variation in:
    - Influent
    - Plant equipment
    - Activated Sludge Biology
  - Act according to the majority of signals
  - Allow 2-3 MCRT’s for protozoa predominance to stabilize

**Elevated Effluent TSS – The most common violation**

- **Bulking Sludge-** the sludge blanket settles poorly and/or it rises and overflows the effluent weir fouling the effluent.
- **Hydraulic Overload-** I/I, “Bilowing Sludge”
- **Glutted System-** waste biomass quality
- **Slime Bulking-** India ink test,
  - “nutrient deficiency
  - Cation Ratio - Ca, Mg, Na, K
  - Filaments - ID and fix

**Elevated Effluent TSS –**

- Clarifier Clumping - the settled blanket denitrifies and nitrogen gas rises floating part or all of the settled blanket.
  - Increase RAS
  - Increase WAS
  - Increase Aerator DO
  - Denitrify somewhere else ~ in the aerator

**Clarifier Denitrification**

- Clarifier “Clumping”
- Generally from Denitrification, could be septic
- Skimmers often remove the clumps, but may not
- Books recommend:
  - SSV<sub>60</sub> blanket stays down
  - SSV<sub>120</sub> blanket may begin to rise
  - If it floats at 60, waste or increase RAS
Clarifier Covered in “Ash”, Pin Floc

- Pin Floc may occur when:
  - Denitrification is beginning to occur in the clarifier
  - F:M is extremely low and beyond normal extended aeration old over-oxidized mixed liquor
  - Mixed liquor contains excessive levels of grease
  - Floc Shear

Clarifier Effluent - Straggler Floc

- Straggler Floc
  - Generally light colored, large, fluffy particles
  - Could be caused by filaments, check with microscope
  - Generally high F:M or short MCRT

Elevated Effluent SBOD, TSS - Turbidity

- Possible Causes
  - Shock Load: high flow, industrial discharge, collection system cleaning, internal load ~ solids processing,
  - Check: baseline and current Process Control Data

- Evaluate and Act
  - Adjust DO if low, verify viable biomass (MLVSS), change mode of operation, start or stop parallel basins, change discharges from slug to 24/7

Temperature Impacts

- “Grade 4” Package Plant
  - Above ground steel construction results in more dramatic temperature impacts.

- Summer, Generally:
  - Need higher DO and lower MLSS

- Winter, Generally:
  - Need lower DO and higher MLSS

Low effluent pH

- Is influent pH low also?
  - Correct with chemicals
  - Check effluent alkalinity
  - Alkalinity low:
    - Supplement with chemicals
    - Begin denitrification within the plant

Nitrification

Biological conversion of ammonia to nitrate
Nitrogen Cycle

- The activated sludge process can also be operated to remove nitrogen and/or phosphorus.

Eutrophication

- Eutrophication is an increase in chemical nutrients (compounds containing nitrogen or phosphorus) in an ecosystem, and may occur on land or in water.
- However, the term is often used to mean the resultant increase in the ecosystem’s primary productivity (excessive plant growth and decay), and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.
- Once algae blooms, it will die off and as the algae decay bacteria will consume it and use up all the oxygen.

Nutrients

- Algal blooms can be caused by excess nutrient levels
- Aquatic and marine dead zones can be caused by an increase in chemical nutrients in the water, known as eutrophication.
- Chemical fertilizer is considered the prime cause of dead zones around the world

Eutrophication

- Gulf of Mexico
  - Currently the most notorious dead zone is a 8,543 mi² region in the Gulf of Mexico, where the Mississippi River dumps high-nutrient runoff from its vast drainage basin, which includes the heart of U.S. agribusiness, the Midwest.
  - The drainage of these nutrients are affecting important shrimp fishing grounds.
  - This is equivalent to a dead zone the size of New Jersey.

Reversal of Dead Zones

- Dead zones are reversible.
- The Black Sea dead zone, previously the largest dead zone in the world, largely disappeared between 1991 and 2001 after fertilizers became too costly to use following the collapse of the Soviet Union and the demise of centrally planned economies in Eastern and Central Europe.
- Fishing has again become a major economic activity in the region.
Nitrification

- A bacterial process that converts ammonia nitrogen to nitrate and consumes alkalinity.

\[ \text{NH}_4^+ + 1.5 \text{O}_2 \xrightarrow{\text{Nitrosomonas}} \text{NO}_2^- + 2 \text{H}^+ + \text{H}_2\text{O} + \text{Energy} \]

\[ \text{NO}_2^- + 0.5 \text{O}_2 \xrightarrow{\text{Nitrobacter}} \text{NO}_3^- + \text{Energy} \]

Process Modes for Nitrification

- Activated sludge process
- Trickling filter
- Rotating biological contactor (RBC)
- Oxidation pond
- Land treatment (overland flow)
- Wetland treatment (Hyacinth cultures)

Nitrification vs. pH

- A pH between 7.5 and 8.5 is considered optimal.

Alkalinity and pH

- Alkalinity is a key parameter in nitrifying systems.

- To adequately control pH
  - Calculate the total amount of alkalinity required
  - Calculate the additional alkalinity that must be added

Nitrification vs. Temperature

- The optimum wastewater temperature range is 60-95°F (15-35°C) for good nitrification.

Nitrification

- Most processes will require an MCRT of 4 days or more to nitrify.

- If a plant has to recover from a toxic shock load, killing the nitrifying bacteria, allow several weeks for a full recovery.
Nitrification

- Nitrification typically requires 25% more oxygen than conventional processes.
- Factors influencing nitrification:
  - DO
  - Alkalinity/pH
  - MCRT
  - Temperature

Denitrification

- Denitrification can occur unintentionally causing operational difficulties.
- Denitrification can cause rising sludge problems.

Advantages of denitrification:
- Use of nitrate returns some of the extra oxygen needed, recycle oxygen
- A portion of the alkalinity removed by nitrification is returned, recycle alkalinity
- Use less electricity
- Use less chemicals
- Slightly less biomass produced
- Generally better effluent

Partial Nitrification, elevated nitrite

- A bacterial process that converts ammonia nitrogen to nitrate and consumes alkalinity.
- $\text{NH}_4^+ + 1.5 \text{O}_2 \rightarrow \text{NO}_2^- + 2 \text{H}^+ + \text{H}_2\text{O} + \text{Energy}$
- $\text{NO}_2^- + 0.5 \text{O}_2 \rightarrow \text{NO}_3^- + \text{Energy}$
- Nitrification: 5:1 chlorine demand; Loss of disinfection so elevated e-coli.
- Spares chlorine: one part Nitrate
CHAPTER 8

Nitrification

8.1 General

8.1.1 Applications
8.1.2 Process Selection

8.2 Suspended Growth Systems

8.2.1 Single - Stage Activated Sludge
8.2.2 Two - Stage with Activated Sludge Nitrification

8.3 Fixed - Film Systems

8.3.1 Trickling Filters
8.3.2 Activated Biofilter (ABF) Process
8.3.3 Submerged Media
8.3.4 Rotating Biological Contactors
NITRIFICATION

8.1 General

8.1.1 Applications

Nitrogen exists in treated wastewater primarily in the form of ammonia which is oxidized to nitrate by bacteria. This process requires oxygen and can exert a significant oxygen demand on the receiving water.

Nitrification shall be considered when ammonia concentrations in the effluent would cause the receiving water to exceed the limitations established to prevent ammonia toxicity to aquatic life, or when the effluent ammonia quantity would cause the dissolved oxygen level of the receiving stream to deplete below allowable limits. The degree of treatment required will be determined by the NPDES permit limit.

8.1.2 Process Selection

Calculations shall be submitted to support the basis of design. The following factors should be considered in the evaluations of alternative nitrification processes:

a. Ability to meet effluent requirements under all environmental conditions to be encountered, with special emphasis on temperature, pH, alkalinity, and dissolved oxygen.

b. Cost (total present worth)

c. Operational considerations, including process stability, flexibility, operator skill required, and compatibility with other plant processes.

d. Land requirements.

8.2 Suspended Growth Systems

8.2.1 Single - Stage Activated Sludge

This section details the requirements for activated sludge systems designed to both remove carbonaceous matter and oxidize ammonia.
8.2.1.1 Process Design

Design must provide adequate solids retention time in the activated sludge system for sufficient growth of nitrifying bacteria. A safety factor of 2.5 or greater should be used to calculate the design mean cell residence time or sludge age. This safety factor must be large enough to provide enough operational flexibility to handle diurnal, peak, and transient loadings. The calculation of the solids retention time shall consider influent BOD, TSS, BOD$_5$/TKN (Total Kjeldahl Nitrogen) ratio and kinetic parameters. The kinetic parameters can be taken from the literature, similar installations, or pilot plant studies. The effect of temperature on the kinetics must be considered since nitrification will not proceed as rapidly during winter months.

8.2.1.2 Special Details

The following requirements are in addition to those included in Chapter 5, "Clarifiers", and Chapter 7, "Activated Sludge":

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O$_2$ per pound total Kjeldahl nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO$_2$ produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as CaCO$_3$ per pound NH$_3$-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.

f. Clarifier and return sludge pumping must be designed with the capability to allow operation over a range of solids retention times. Flexibility should be provided to prevent denitrification in the clarifier from low D.O. levels in the sludge blanket. This could cause violations of other effluent limits (i.e., suspended solids).
8.2.2 Two-Stage with Activated Sludge Nitrification

This section details the requirements for systems in which carbonaceous BOD is removed in the first stage and ammonia is oxidized by activated sludge in the second stage. BOD removal in the first stage could be by activated sludge, trickling filters, or physical-chemical treatment.

8.2.2.1 Process Design

The first stage shall be designed using the requirements of the appropriate chapters, such as activated sludge, trickling filters, and clarifiers. To promote a sludge with good settling characteristics in the second stage clarifier, some carbonaceous BOD shall enter the second stage aeration basin. This allows a less conservative design of the first stage as long as total BOD removal is sufficient. The requirements for the process design of the second stage are the same as those presented previously for the single-stage nitrification system.

8.2.2.2 Special Details

The following details are in addition to those in Chapter 5, "Clarifiers," Chapter 6, "Fixed Film Reactors," and Chapter 7, "Activated Sludge."

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O₂ per pound total Kjeldahl nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO₂ produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as CaCO₃ per pound NH₃-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.
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This section details the requirements for systems in which carbonaceous BOD is removed in the first stage and ammonia is oxidized by activated sludge in the second stage. BOD removal in the first stage could be by activated sludge, trickling filters, or physical-chemical treatment.

8.2.2.1 Process Design

The first stage shall be designed using the requirements of the appropriate chapters, such as activated sludge, trickling filters, and clarifiers. To promote a sludge with good settling characteristics in the second stage clarifier, some carbonaceous BOD shall enter the second stage aeration basin. This allows a less conservative design of the first stage as long as total BOD removal is sufficient. The requirements for the process design of the second stage are the same as those presented previously for the single-stage nitrification system.

8.2.2.2 Special Details

The following details are in addition to those in Chapter 5, "Clarifiers," Chapter 6, "Fixed Film Reactors," and Chapter 7, "Activated Sludge."

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O$_2$ per pound total Kjeldahl nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed nitrogen to calculate the oxygen requirements for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO$_2$ produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as CaCO$_3$ per pound NH$_3$-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.
f. Clarifier and return sludge pumping must be designed with the capability to allow operation over a range of solids retention times. Flexibility should be provided to prevent denitrification in the clarifier from low D.O. levels in the sludge blanket. This could cause violations of other effluent limits (i.e., suspended solids).

8.3 Fixed - Film Systems

8.3.1 Trickling Filters

8.3.1.1 Process Design

Recirculation is required to provide a constant hydraulic loading on the medium.

a. Single - Stage

This section details the requirements for a trickling filter that is designed for both carbonaceous BOD removal and ammonia oxidation. Design shall be based on the organic loading expressed as pounds BOD per 1,000 cubic feet. The design loading rate shall be justified from literature, similar installations, or pilot plant data for a particular depth and type of filter medium. Design shall consider temperature effects on ammonia removal and organic loading rates, and any proposal to attain nitrification in a single-stage rock media trickling filter will be more closely scrutinized than with other types of media.

b. Two - Stage

This section details the requirements of using a trickling filter for nitrification which is preceded by a trickling filter, activated sludge system, or physical - chemical treatment for carbonaceous BOD removal. Design must be based on either a surface area loading expressed as square feet per pound NH₄-N oxidized per day or a volumetric loading expressed as pounds NH₄-N per 1,000 cubic feet per day. Loading rates must be justified from literature, similar plants, or pilot plant data. The effects of temperature on loading rates and ammonia oxidation must be considered in the design.

8.3.1.2 Special Details

The following requirements are in addition to those in Chapter 5, "Clarifiers," and Chapter 6, "Fixed Film Reactors."

a. Clarifiers will be required for second-stage trickling filters for nitrification.
b. Higher specific surface area and lower void ratio media may be used for second-stage trickling filters providing nitrification.

8.3.2 Activated Biofilter (ABF) Process

8.3.2.1 Process Design

Process design shall be based on the literature, similar installations, or pilot plant data. The design shall consider the effects of temperature, pH, and aeration basins.

8.3.2.2 Special Details

a. Sufficient oxygen must be provided for both carbonaceous BOD oxidation and ammonia oxidation. Use 4.6 pounds O₂ per pound total Kjeldahl nitrogen to calculate the oxygen requirement for nitrification, in addition to the oxygen needed for BOD removal.

b. Aeration basin design dissolved oxygen shall be greater than or equal to 2.0 mg/l.

c. Diurnal peak mass flow rates of BOD and total Kjeldahl nitrogen must be considered in the aeration system design.

d. The pH levels must be controlled within the range of 6.5 to 8.4. Nitrification is optimized in the upper portion of this range (7.9 to 8.4) but pH levels in the range of 7.6 to 7.8 are recommended since CO₂ produced will be released from the wastewater.

e. Nitrification requires alkalinity, 7.1 pounds as CaCO₃ per pound NH₃-N oxidized. The wastewater must be shown to have sufficient alkalinity or chemical treatment must be considered to provide adequate alkalinity.

f. Clarifier and return sludge pumping must be designed with the capability to allow operation over a range of solids retention times. Flexibility should be provided to prevent denitrification in the clarifier from low D.O. in the sludge blanket. This could cause violations of other effluent limits (i.e., suspended solids).
8.3.3 Submerged Media

8.3.3.1 General

This section includes all designs for fixed-film reactors using stones, gravel, sand, anthracite coal, or plastic media or combinations thereof in which the medium is submerged and air or oxygen is used to maintain aerobic conditions. Pilot plant testing or a similar full-scale installation with a minimum of 1 year of operation is required before consideration will be given to a submerged design. No design will be considered unless the following can be demonstrated:

a. Reliable operation
b. Ability to transfer sufficient oxygen
c. Ability to handle peak flows without washout of medium
d. Methods of separating suspended solids from effluent, removing waste sludge, and stabilization and dewatering of waste sludge
e. Media resistance to plugging

8.3.3.2 Process Design

Data for design and calculations shall be submitted upon request to justify the basis of design.

8.3.4 Rotating Biological Contactors

8.3.4.1 Process Design

Process design shall be based on the surface area loading expressed as gallons per day per square foot. Design surface area loading shall consider the number of stages, temperature, BOD concentration entering and leaving each stage, and ammonia concentration entering and leaving each stage. Calculations shall be submitted upon request to justify the basis of design.

8.3.4.2 Special Details

The following requirements are in addition to those set forth in Chapter 5, "Clarifiers," and Chapter 6, "Fixed Film Reactors."
a. Standard media (100,000 square feet per shaft or less) shall be used until influent BOD concentration is less than manufacturer's recommendation for high-density media (150,000 square feet per shaft or more). High-density media may be used for influent BOD concentrations less than manufacturer's recommendation for high-density media.

b. Clarifiers will be required following rotating biological contactors that follow a secondary process.
Activated Sludge Vocabulary – Part 2

1. ________________________________ refers to the clouds of billowing sludge that occur throughout secondary clarifiers and sludge thickeners when the sludge does not settle properly. In the activated sludge process, this is usually caused by filamentous bacteria or bound water.

2. The anoxic biological reduction of nitrate nitrogen to nitrogen gas is called_____________________. It is an anoxic process that occurs when nitrite or nitrate ions are reduced to nitrogen gas and nitrogen bubbles are formed as a result. The bubbles attach to the biological floc in the activated sludge process and float the floc to the surface on the secondary clarifiers. This condition is often the cause of rising sludge observed in the secondary clarifiers or gravity thickeners.

3. The abbreviation for Food to Microorganism ratio, ________________ is a measure of food provided to bacteria in an aeration tank.

4. The rate at which organisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions is known as ___________________________. It is also referred to as the organic strength of the wastes in the water.

5. The suspended solids in the mixed liquor of an aeration tank are called ____________________________.

6. A ______________ is a device used to break the air stream from the blower system into fine bubbles in an aeration tank.

7. The measure of time a particle of suspended solids has been retained in the activated sludge process is known as ____________________________.

8. The process of __________________________ describes the clumping together of very fine particles into larger particles (floc) caused by chemicals called coagulants.

9. The organic or volatile suspended solids in the mixed liquor of an aeration tank are called ____________________________. This volatile portion is used as a measure or indication of the microorganisms present.

10. The expression of the average time that a microorganism will spend in the activated sludge process is ____________________________.

11. Liquid removed from settled sludge is called _____________________________. This liquid is usually returned to the influent wet well or to the primary clarifier.

12. The aerobic process of __________________________ occurs when bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate).
13. ____________________________ occurs in secondary clarifiers of activated sludge plants when the sludge settles to the bottom of the clarifier, is compacted, and then starts to rise to the surface, usually as a result of denitrification.

14. The ____________ is a calculation that indicates the tendency of activated sludge solids (aerated solids) to thicken or to become concentrated during the sedimentation/thickening process.

Word Bank:

- Coagulation
- Denitrification
- F:M ratio (or F/M ratio)
- Supernatant
- Mixed Liquor Suspended Solids (MLSS)
- Bulking
- Rising Sludge
Activated Sludge Review Questions – Part 2

1. The amount of time that microorganisms spend in the activated sludge process before they are wasted is called the _______.
   a. Total residual chlorine
   b. MLSS
   c. MCRT
   d. WAS

2. Conventional activated sludge processes are designed to remove soluble carbonaceous BOD from wastewater.
   a. True
   b. False

3. Return activated sludge is typically pumped back to which of the following?
   a. The headworks
   b. Primary clarifier
   c. Influent side of a biological reactor
   d. Effluent side of a biological reactor

4. The measure of biochemical or organic strength of wastewater is referred to as _______.
   a. Total residual chlorine
   b. TSS
   c. BOD
   d. F:M

5. The mean cell residence time for most conventional activated sludge processes is typically _______.
   a. 5 – 15 days
   b. 5 – 15 hours
   c. 20 – 30 days
   d. 20 – 30 hours

6. Billowy, white foam is usually a sign of old, over-oxidized sludge in the aeration basin. True or False?
   a. True
   b. False

7. Nitrification is a two-step process. At the end of the second and final step, to what has ammonia been oxidized?
   a. Nitrite
   b. Nitrate
   c. Ammonium hydroxide
   d. Nitric acid
8. Which of the following is one of the most important process control parameters used to maintain the optimum amount of solids to remove BOD from influent wastewater, and which incorporates both the amount of BOD and the quantity of microorganisms in the water?
   a. MCRT
   b. F:M Ratio
   c. Biomass Inventory
   d. Settleometer

9. The settleometer “rise time” is the time it takes for the sludge blanket to float to the surface. What is the most likely cause of a rising sludge blanket in the settleometer?
   a. Gasification
   b. Denitrification
   c. Bulking
   d. Excessive aeration

10. Off/On aeration is increasingly being used for nutrient removal. True or False?
    a. True
    b. False

11. The amount of sludge wasted (WAS) from the activated sludge process affects all of the following except:
    a. Growth rate of microorganisms
    b. Mixed liquor settleability
    c. Effluent quality
    d. Influent quality

12. Which of the following statements is not true?
    a. Increasing the wasting rate will decrease the MLSS concentration
    b. Increasing the wasting rate will decrease the MCRT
    c. Increasing the wasting rate will decrease the F:M ratio
    d. Decreasing the wasting rate will increase the MLSS concentration

13. Thick, scummy, dark tan foam and a “hog pen” odor in the aeration basin are signs that the activated sludge process is working effectively. True or False?
    a. True
    b. False

14. In the winter, activated sludge systems commonly require lower DO levels and higher MLSS concentrations due to the decreased temperature. True or False?
    a. True
    b. False

15. Which of the following statements is not true regarding nitrification in an activated sludge system?
    a. A pH of 6.5 – 7.5 is considered optimal
    b. Alkalinity is a key parameter
    c. The optimum wastewater temperature range is 60 – 95°F (15 – 35°C)
    d. Most processes require an MCRT of 4 days or more to nitrify
Section 2

Introduction to

Wastewater Math
Introduction to Sedimentation Math

Detention Time

Example 1
The flow to a sedimentation tank 50 ft long, 30 ft wide, and 10 ft deep is 2.45 MGD. What is the detention time in the tank, in hours?

Tank Volume:

\[ \text{Volume} = (L)(W)(d) \]

\[ \text{Vol.} = (50\text{ft})(30\text{ft})(10\text{ft}) = 15,000 \text{ ft}^3 \]

\[ \text{Vol.} = (15,000 \text{ ft}^3)(7.48 \text{ gal/ft}^3) = 112,200 \text{ gal} \]

Flow Rate:

\[ \text{Flow} = \text{MGD} \rightarrow \text{gph} \]

\[ = \left(2.45 \text{ MGD/Day}\right)\left(\frac{1 \text{ Day}}{24 \text{ hrs}}\right)\left(\frac{1000000 \text{ gal/1 MGD}}{1 \text{ MGD}}\right) \]

\[ = 102083.3333 \text{ gph} \]

Detention Time, hrs = \[
\frac{\text{Volume of Tank, gal}}{\text{Flow, gph}}
\]

\[ = \frac{112200 \text{ gal}}{102083.3333 \text{ gph}} \]

\[ = 1.10 \text{ hrs} \]

Weir Overflow Rate

Weir Overflow Rate is commonly expressed in gpd/ft

Example 2
A rectangular clarifier has a length of 70 ft and a width of 50 ft. What is the weir overflow rate in gpd/ft when the flow is 2.71 MGD?

Flow Rate:

\[ \text{Flow} = \text{MGD} \rightarrow \text{gpd} \]

\[ = \left(2.71 \text{ MGD/Day}\right)\left(\frac{1 \text{ Day}}{24 \text{ hrs}}\right)\left(\frac{1000000 \text{ gal/1 MGD}}{1 \text{ MGD}}\right) \]

\[ = 2710000 \text{ gpd} \]

Weir Length:

\[ \text{Perimeter} = 2(L) + 2(W) \]

\[ = 2(70\text{ft}) + 2(50\text{ft}) = 240\text{ft} \]

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

\[ = \frac{2710000 \text{ gpd}}{240\text{ft}} \]

\[ = 11304.1667 \text{ gpd/ft} \]
Weir Overflow Rate
Example 2
A rectangular clarifier has a length of 70 ft and a width of 50 ft. What is the weir overflow rate in gpd/ft when the flow is 2.71 MGD?

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

\[ \frac{2.71,000,000 \text{ gpd}}{240 \text{ ft}} = 11291.67 \text{ gpd/ft} \]

Surface Overflow Rate

Surface Overflow Rate, gpd/ft
\[ \frac{\text{Flow, gpd}}{\text{Area, ft}^2} \]

Example 1
A circular clarifier has a diameter of 68 ft. What is the surface overflow rate in gpd/ft² if the primary effluent flow is 2.93 cfs?

\[ \text{Area} = \pi \left( \frac{D}{2} \right)^2 \]
\[ = (0.785)(68 \text{ ft})^2 = 3629.84 \text{ ft}^2 \]

\[ \text{Surface Overflow Rate, gpd/ft}^2 = \frac{\text{Flow, gpd}}{\text{Area, ft}^2} \]
\[ = \frac{1,893,576.96 \text{ gpd}}{3629.84 \text{ ft}^2} = 521.67 \text{ gpd/ft}^2 \]
Wastewater Sedimentation Math

1. The flow to a circular clarifier is 3,940,000 gpd. If the clarifier is 75 ft in diameter and 12 feet deep, what is the clarifier detention time in hours?

2. A circular clarifier has a diameter of 50 feet. If the primary clarifier influent flow is 2,260,000 gpd, what is the surface overflow rate in gpd/sq.ft.?

3. A rectangular clarifier has a total of 210 ft. of weir. What is the weir overflow rate in gpd/ft when the flow 3,728,000 gpd?

4. A secondary clarifier, 55-ft in diameter, receives a primary effluent flow of 1,887,000 gpd and a return sludge flow of 528,000 gpd. If the MLSS concentration is 2640 mg/L, what is the solids loading rate in lbs/day/sq.ft. on the clarifier?
5. A circular primary clarifier has a diameter of 60 feet. If the influent flow to the clarifier is 2.62 MGD, what is the surface overflow rate in gpd/sq.ft.?

6. A secondary clarifier, 70 feet in diameter, receives a primary effluent flow of 2,740,000 gpd and a return sludge flow of 790,000 gpd. If the mixed liquor suspended solids concentration is 2815 mg/L, what is the solids loading rate in the clarifier in lbs/day/sq.ft.?

7. The flow to a secondary clarifier is 5.1 MGD. If the influent BOD concentration is 216 mg/L and the effluent BOD concentration is 103, how many lbs/day BOD are removed daily?

8. The flow to a sedimentation tank 80 feet long, 30 feet wide and 14 feet deep is 4.05 MGD. What is the detention time in the tank, in hours?
**Introduction to Chemical Dosage Math**

Feed Rate, Mass, Loading Rate  
aka “Pounds Formulas”

**Chemical Application**

* Different chemicals are added to locations of wastewater system to maintain the system  
* The amount of chemicals needed is determined by dosage level desired and the purity of the chemicals used  
  * If the purity of the chemical is not mentioned then it is assumed to be 100% available or 1.0 in decimal form for use in formulas

**Chemical Application**

* There are three possible formulas to calculate dosage rates:  
  * Feed Rate, lbs/day  
  * Mass, lbs  
  * Loading Rate, lbs/day  
* All three calculate pounds, but feed rate is the only one that factors in the percent purity of the chemical being applied

**Chemical Application**

* Chlorine application is achieved by applying one of two types of hypochlorite  
  * Sodium hypochlorite  
    * NaOCl  
    * Bleach  
    * 5-15% concentration  
  * Calcium hypochlorite  
    * Ca(OCl)\(_2\)  
    * High test hypochlorite (HTH)  
    * 65% concentration

**Feed Rate**

* When dosing a volume of wastewater, a measured amount of chemical is required

\[
\text{Feed rate, } \frac{\text{lb}}{\text{day}} = \frac{(\text{dose})(\text{flow})(8.34 \text{ lb/gal})}{\% \text{ purity}}
\]

**Example 1**

* A collections system wants to feed calcium hypochlorite with a purity of 65%. The required dose is 8 mg/L for a flow of 3 MGD. How many pounds per day of disinfectant must be fed?

\[
\frac{\text{lb}}{\text{day}} = \frac{(\text{dose})(\text{flow})(8.34 \text{ lb/gal})}{(8 \text{ mg/L})(3 \text{ MGD})(8.34 \text{ lb/gal})}
\]

\[
\frac{\text{lb}}{\text{day}} = \frac{0.65}{307.94} = 307.94 \text{ lb/day}
\]
Mass and Loading Rate

* Same as feed rate without the % purity
* If percent purity of a chemical is not provided, it assumed to be 100% pure

\[
\text{Mass, lbs} = (\text{volume, MGD}) \cdot (\text{conc.}, \frac{\text{lb}}{\text{gal}}) \cdot (8.34 \frac{\text{lb}}{\text{gal}})
\]

\[
\text{Loading rate, lb/day} = (\text{flow, MGD}) \cdot (\text{conc.}, \frac{\text{lb}}{\text{gal}}) \cdot (8.34 \frac{\text{lb}}{\text{gal}})
\]

Dose

* To determine dose, we will need to rearrange the Feed Rate or Mass formula

\[
\frac{\text{lb day}}{\% \text{ purity}} = (\text{dose})(\text{flow})(8.34)
\]

\[
(\% \text{ purity}) \cdot \frac{\text{lb day}}{\% \text{ purity}} = (\text{dose})(\text{flow})(8.34)
\]

\[
\frac{\text{lb day}}{\text{dose}} = \frac{(\text{flow})(8.34)}{\% \text{ purity}}
\]

Example 2

* A collection system feeds 65 lb/day of 65% calcium hypochlorite. If the flow is 1.6 MGD, what dose, in mg/L, of disinfectant will result?

\[
\text{Dose} = \frac{(\% \text{ purity})(\text{lb day})}{\text{flow}(8.34)(\text{gal})}
\]

\[
\text{Dose} = \frac{(0.65)(65 \text{ lb/day})}{(1.6 \text{ MGD})(8.34 \text{ lb/gal})}
\]

\[
dose = 3.17 \text{ mg/L}
\]

Example 3

* An operator needs to make 10 gallons of a bleach dilution with a concentration 25 mg/L. The bleach on hand has a concentration of 100 mg/L. How many gallons of the concentrate must be used to achieve the dilution?

\[
C_1 \times V_1 = C_2 \times V_2
\]

\[
(25 \text{ mg/L})(10 \text{ gal}) = (100 \text{ mg/L})(V')
\]

\[
\frac{(25 \text{ mg/L})(10 \text{ gal})}{100 \text{ mg/L}} = V
\]

\[
2.5 \text{ gal} = V
\]

Intro to Wastewater Math
Chemical Dosage/Wastewater Disinfection Math

1. Calculate the chlorine feed rate in lbs/day for a chlorine dosage of 6 mg/L at a flow of 100,000 gal/day.

2. Determine the chlorinator setting (lbs/day) needed to treat a flow of 8.2 MGD with a chlorine dose of 4.5 mg/L.

3. What is the chlorinator feed rate in lbs/day if the chlorine dosage is 8 mg/L and the flow is 500,000 gal/day?

4. A total chlorine dose of 6.8 mg/L is required to treat a particular wastewater. If the flow is 1.3 MGD and the calcium hypochlorite has 65% available chlorine, calculate the lbs/day of hypochlorite required.

5. To neutralize a sour digester, one pound of lime is added for every pound of volatile acids in the digester sludge. If the digester contains 195,000 gallons of sludge with a volatile acid level of 2,100 mg/L, how many pounds of lime should be added?
6. The chlorinator is set to feed 26.5 lbs of chlorine per 24 hours for a plant flow of 1.2 MGD. Calculate the chlorine residual for a chlorine demand of 1.85 mg/L.

7. What is the demand of your wastewater if you are feeding 133 lbs/day of chlorine and the flow rate is 2 MGD? The chlorine residual after a 30 minutes contact time is 1.5 mg/L.

8. A chlorine contact tank with a volume of 20,000 gallons receives an average flow of 1000 gal/min. If the minimum contact time is 15 minutes, is this tank above or below the minimum time?

9. How many pounds of HTH (65% available chlorine) are required to make 35 gallons of 5% available chlorine bleach? (Assume bleach is 8.34 lbs/gal.)

10. How many pounds of 65% HTH are used to make 10 gallons of 5% solution?
**Introduction to Activated Sludge Math**

**Loading Rate (“Pounds”) Formula**
- BOD, COD, or SS Loading

The BOD concentration of the wastewater entering an aerator is 215 mg/L. If the flow to the aerator is 1,440,000 gpd, what is the lbs/day of BOD loading?

\[(\text{Concentration, mg/L}) \times (\text{Flow, gpd}) \times (8.34 \text{ lbs/gal}) = \text{lbs/day}\]

\[(215 \text{ mg/L}) \times (1.44 \text{ MGD}) \times (8.34) = 2582 \text{ lbs/day}\]

**Mass (“Pounds”) Formula**
- Solids Inventory in the Aeration Tank

If the MLSS concentration is 1100 mg/L, and the aeration tank has a volume of 525,000 gallons, how many pounds of suspended solids are in the aeration tank?

\[(\text{Concentration, mg/L}) \times (\text{Volume, gal}) \times (8.34 \text{ lb/gal}) = \text{Mass, lbs}\]

\[(1100 \text{ mg/L}) \times (0.525 \text{ MG}) \times (8.34 \text{ lb/gal}) = 4816 \text{ lbs MLSS}\]

**Wasting Rate**
- An operator calculates that 15,000 lbs MLSS are desired in the aeration tank. If the aeration tank vol is 800,000 gal and the MLSS conc is 2720 mg/L, how many lbs MLSS should be wasted?

\[(\text{MLSS, mg/L}) \times (\text{Aer Vol, gal}) \times (8.34 \text{ lb/gal}) = \text{lbs MLSS}\]

\[(2720 \text{ mg/L}) \times (0.8 \text{ MG}) \times (8.34) = 18,148 \text{ lbs MLSS}\]

Now compare actual versus desired lbs MLSS:

18,148 lbs actual – 15,000 lbs desired = 3148 lbs MLSS to be wasted

**F:M Ratio**
- An activated sludge aeration tank receives a primary effluent flow of 2.42 MGD with a BOD of 170 mg/L. The MLVSS is 1980 mg/L and the aeration tank volume is 350,000 gallons. What is the current F:M ratio?

\[\frac{\text{BOD, lbs/day}}{\text{MLVSS, lb}}\]

Expanded formula:

\[\frac{(\text{BOD, mg/L}) \times (\text{Flow, MGD}) \times (8.34 \text{ lbs/gal})}{(\text{MLVSS, mg/L}) \times (\text{Aer Vol, MG}) \times (8.34 \text{ lbs/gal})}\]

Note: The expanded formula is not included in the ABC formula book.

\[\text{F:M Ratio} = \frac{(170 \text{ mg/L}) \times (2.42 \text{ MGD}) \times (8.34 \text{ lbs/gal})}{(1980 \text{ mg/L}) \times (0.35 \text{ MG}) \times (8.34 \text{ lbs/gal})} = 0.59\]
Mean Cell Residence Time

- Also called Solids Retention Time (SRT)
- Represents the average length of time an activated biosolids particle stays in the activated biosolids system.
- MCRT/SRT is based on suspended solids leaving the system
- When calculating the lbs MLSS, both the aeration tank and final clarifier volumes are normally used.
- Basically 4 Pounds Formulas

Mean Cell Residence Time

- Determine the MCRT given the following data:
  - Aer. Vol. = 1.5 MG
  - Fin. Clar. Vol. = 0.11 MG
  - P.E. Flow = 3.4 MG
  - WAS Pumping Rate = 60,000 gpd
  - MLSS = 2460 mg/L
  - WAS SS = 8040 mg/L
  - S.E. SS = 18 mg/L
  - CCSS = 1850 mg/L

Mean Cell Residence Time

- In ABC Formula Book:
  
  \[
  \text{MCRT or SRT, days} = \left( \frac{\text{MLSS (lbs/g)}}{\text{Aer. Vol. (MG)}} \right) \left( \frac{8.3 \text{ lbs/L}}{} \right) + \left( \frac{\text{CCSS (mg/L)}}{\text{Fin. Clar. Vol. (MG)}} \right) \left( \frac{8.3 \text{ lbs/L}}{} \right)
  
  \text{WAS SS (mg/L)/WAS MGD} \left( \frac{8.3 \text{ lbs/L}}{} \right) + \left( \frac{\text{S.E. SS (mg/L)}}{\text{Plan Flow (MGD)}} \right) \left( \frac{8.3 \text{ lbs/L}}{} \right)
  
  \text{Solids in the System}
  
  \text{Solids Leaving the System}
  
  \text{Note: CCSS = Average Clarifier Core SS Concentration}

MCRT = 7.2 days
Activated Sludge Math

1. The flow to an aeration tank is 750,000 gpd. If the BOD content of the wastewater entering the aeration tank is 230 mg/L, how many pounds of BOD are applied to the aeration tank daily?

2. An aeration basin is 130 ft long, 50 ft wide, and holds wastewater to a depth of 15 ft. If the aeration basin has an MLSS concentration of 2300 mg/L, how many pounds of MLSS are under aeration?

3. The WAS flow at a 5 MGD capacity plant is 300 gpm, and the WAS TSS is 7500 mg/L. How many pounds of WAS are wasted each day?

4. An activated sludge aeration tank receives a primary effluent flow of 1.5 MGD with a BOD concentration of 175 mg/L. The mixed liquor volatile suspended solids is 2100 mg/L and the aeration tank volume is 400,000 gallons. What is the current F:M ratio?
5. An activated sludge system has a total of 30,000 lbs of MLSS. The suspended solids leaving the final clarifier in the effluent is 400 lbs/day. The pounds suspended solids wasted from the final clarifier is 2800 lbs/day. What is the MCRT in days?

6. Determine the MCRT given the following information:
   - Aeration tank = 1,500,000 gallons
   - Final clarifier = 100,000 gallons
   - Flow = 4,000,000 gallons per day
   - WAS pump rate = 71,000 gallons per day
   - MLSS = 2400 mg/L
   - S.E. SS = 19 mg/L
   - CCSS = 1850 mg/L
   - WAS = 6700 mg/L
Section 3

Introduction to Wastewater

Laboratory and Sampling
Introduction to Sampling and Wastewater Laboratory

Why Sample?
• Meet compliance requirements
• Process control
• Ensure public safety and protect the environment

Sampling and Analysis Plan
• Good sampling practices + Competent sample analysis = Quality data for process control

Sampling Plan
• There are many questions to consider before actually collecting a sample
• The answer to these questions will help you put together a sampling plan
  1. Why is the sample being collected?
  2. What tests need to be run on the sample?
  3. Where is the sample going to be collected from?
  4. How is the sample going to be collected?
  5. When does the sample need to be collected/analyzed?
  6. Who is going to analyze the sample?

Reliable sampling data are obtained by collecting samples:
• At the right location
• In the correct manner
• At the right time

Automatic Sampling Device
• Timesaver
• Composite: set to collect specific volumes over a period of time
• Refrigerated and thoroughly mixed
• Clean intake line regularly to prevent growth of bacteria or algae
Preventative Sampler Maintenance

• Pump tubing replacement
• Suction line replacement
• Container replacement
• Diagnostic routines
• Volume calibration
• Desiccant replacement

Samplers

• Sampling devices may include weighted buckets, beakers, or other containers attached to a rod or chain.

Can you clean it?!

Samplers – Approved or Not?

Considerations

• Collection
• Volume
• Storage and preservation
• Sample points
• Sampling frequency

• Include Sampling Plan in SOP

Sample Types

• The two types of samples typically taken for an activated sludge process are:
  – Grab
  – Composite

Grab Samples

• Single volume of water
• Representative of water quality at exact time and place of sampling
• Grab samples are used to test for unstable parameters that could change if the sample were allowed to stand for any length of time
  ◦ DO
  ◦ pH
  ◦ Chlorine residual
  ◦ Temperature
  ◦ E. coli and/or fecal coliform

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  ◦ Temperature
  ◦ E. coli and/or fecal coliform

Considerations

• Collection
• Volume
• Storage and preservation
• Sample points
• Sampling frequency

• Include Sampling Plan in SOP
Composite Sample
• Representative of average water quality of location over a period of time
• Series of grab samples mixed together
• Determines average concentration
• Not suitable for all tests
• Types of composite samples:
  1. Fixed volume or time composite
  2. Flow proportioned

Example of Flow-Proportioned Sample Collection

<table>
<thead>
<tr>
<th>Time</th>
<th>Flow</th>
<th>Sample Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00 am</td>
<td>18 MGD</td>
<td>180 mL</td>
</tr>
<tr>
<td>10:00 pm</td>
<td>12 MGD</td>
<td>120 mL</td>
</tr>
</tbody>
</table>

Composite Sample
• Refrigerated and thoroughly mixed
• Measure flow and sample volume
• BOD, total N, settleable solids
• NEVER use composite sample for bacterial analysis
Sampling Guidelines

- Representative
- Proper container
- Do not contaminate the lid
- Preservative/dechlorinating agent
  - If bottle already has preservative or dechlorinator in it, don’t over fill or rinse out

➢ If you have questions regarding volume, container or holding times, check 40 CFR 136 Table II or contact the lab if you have an outside lab do your analysis

Sample Labeling

Location: 196 E. Main Street, Springfield, TN
Date / Time: 9/22/2018 @ 8:15 AM
Sampled by: BS (Bob Smith)
Comments: grab sample
pH < 2 with H2SO4 and stored at 4°C

Chain of Custody

- Written record to trace possession and handling of samples from collection to reporting
  - In case of legal litigation
- Used when sending out samples to contract lab
- Should identify who handled sample from collection to transport to storage to analysis to destruction
  - Including dates, times, initials, addresses, etc.

Sample Volume

- Depends on test procedure
- Headspace for mixing
- Preservative
- QA/QC comparisons

Sampling Point Selection

- Flow well mixed
- Exclude large particles (>1/4 inch)
- Exclude floating matter
- Readily accessible & in safe area
Subsurface Sampling

- Grasp container at base
- Plunge bottle mouth down into water
  - To avoid introducing any floating material
- Position mouth of bottle into current and away from hand
- Tip bottle slightly upward to allow air to exit so bottle can fill

Homemade Depth Sampler

- Collection from basins, tanks, lakes, reservoirs
- Pre-marked steel cable
- Pre-measured/marked rope
  - non-smearing ink/paint
- A jerk on the cord will remove the stopper and allow the bottle to fill

Sample Points

Process Control

- Tests frequently performed by operators to quickly obtain the results and make any necessary process adjustments
- Required by NPDES permit
- Not reported
  - Keep records

NPDES Permit

1.1 NUMERIC AND NARRATIVE EFFLUENT LIMITATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Standard Value (Mg/l)</th>
<th>Concentration</th>
<th>Comparison</th>
<th>Concentration</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>Sec. 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“The permittee shall at all times properly operate and maintain all facilities and systems (and related appurtenances) for collection and treatment which are installed or used by the permittee to achieve compliance with the terms and conditions of this permit. Proper operation and maintenance also includes adequate laboratory and process controls and appropriate quality assurance procedures.”
Tools for Success

- Refer to 40 CFR 136 for approved methods
- Latest revision went into effect on September 27, 2017
- Standard Methods for the Examination of Water and Wastewater
- The 23rd edition is the latest edition - But there is often a lag time

Process Monitoring and Control Tests

- \( \text{cBOD}_5 \)
- MLSS
- MLVSS
- Centrifuge (spin) Test
- Microscopic Examination
- SOUR
- Temp
- Depth of Blanket
- Thirty-minute settleometer
- SVI
- pH
- DO
- Nitrogen
  - Ammonia
  - Nitrate
  - Nitrite
  - Total Kjeldahl (TKN)

Biochemical Oxygen Demand (BOD)

- The BOD test is used to measure the sample’s organic strength.
- Measures the amount of oxygen required by a sample during the five days of incubation
  - Incubated at 20 ± 1°C for 5 days ± 6 hours in the dark

History of BOD

- Thames River - London, England
  - Waste dumped in Thames River took 5 days to reach ocean

- The Royal Commission on River Pollution, which was established in 1865, and the formation of the Royal Commission on Sewage Disposal in 1898, led to the selection in 1908 of \( \text{BOD}_5 \) as the definitive test for organic pollution of rivers.
- Five days was chosen because this was supposedly the longest time that river water took to travel from source to ocean in UK.
History of BOD

• This 5-day BOD test result may be described as the amount of oxygen required for aquatic microorganisms to stabilize decomposable organic matter under aerobic conditions.
• A 5-day duration for BOD determination has no theoretical grounding but is based on historical convention.

Biochemical Oxygen Demand (BOD)

• The total BOD includes both carbonaceous BOD and nitrogenous components.
• If your permit requires CBOD only, you must add nitrification inhibitor
  – This prevents the oxidation of nitrogen compounds
• In the US and Canada, the BOD of domestic wastewater typically ranges from 100 to 250 mg/L.
• Industrial wastewater can have much higher levels of BOD.

Biochemical Oxygen Demand (BOD)

• Typically a composite sample
• Not useful for process control
• Need minimum of 3 dilutions and run a duplicate every 20th sample (or fewer)
  • Influent and effluent are considered separate samples, so if you run BOD 5 days/week, that would be considered 20 samples within that week.

BOD<sub>5</sub> Procedure

1. Measure initial D.O.
   – DO measured by Winkler method (titration) or using a meter and electrode.
2. Incubate sample for 5 days
3. Measure final D.O.
4. The BOD<sub>5</sub> is the amount of D.O. used up over the 5-day period.

BOD<sub>5</sub>

• BOD<sub>5</sub> analysis must be done under these conditions:
  – Must be in the dark at 20°C ± 1°C
  – Initial D.O.<9.0 mg/L (blanks and samples)
  – pH range of 6.5-7.5
  – Must have an existing microbiological population. If not, sample must be “seeded”
  – Min. sample depletion 2 mg/L and final D.O. of 1 mg/L
  – Max depletion of blanks is 0.2 mg/L
Biochemical Oxygen Demand (BOD)

**REQUIREMENTS FOR VALID BOD<sub>5</sub> RESULTS**

- **Blank depletion** must be \( \leq 0.2 \text{ mg/L DO} \)
- **Initial DO** must be \( \leq 9.0 \text{ mg/L} \)
- Samples must deplete at least 2.0 mg/L DO
- Samples must have at least 1.0 mg/L DO remaining at the end of the incubation period

**BOD Calculation**

- Initial DO = 8.2 mg/L
- Final DO = 4.5 mg/L
- Sample Volume = 6 mL

\[
BOD = \frac{((\text{Initial DO, mg/L}) - (\text{Final DO, mg/L}))[300 \text{ mL}]}{\text{ml of Sample}}
\]

\[
BOD = \frac{(8.2 \text{ mg/L}) - (4.5 \text{ mg/L})[300 \text{ mL}]}{6 \text{ mL}}
\]

\[
BOD = \frac{-1110}{6}
\]

\[
BOD = 185 \text{ mg/L}
\]

**BOD Equations**

- **Unseeded**

\[
BOD = \frac{((\text{Initial DO, mg/L}) - (\text{Final DO, mg/L}))[300 \text{ mL}]}{\text{ml of Sample}}
\]

- **Seeded**

\[
BOD = \frac{((\text{Initial DO, mg/L}) - (\text{Final DO, mg/L}) - \text{Seed Correction Factor, mg/L})[300 \text{ mL}]}{\text{ml of Sample}}
\]

**Ultimate BOD**

- The ultimate BOD is the total amount of dissolved oxygen it would take to completely break down all the organic material in a sample over an infinite amount of time.

- BOD consumed + BOD remaining = Ultimate BOD
Chemical Oxygen Demand

- The COD test is used for more rapid assessment of organic strength.
- The COD test measures oxidizable organic matter
  - ...susceptible to oxidation by a strong chemical oxidant
- Can be useful for process control:
  - Test yields data in 2 to 4 hours
  - BOD typically lower than COD
  - Ratio must be established for a specific plant

Suspended Solids

- Amount of material suspended in sample
  - Suspended solids are a combination of settleable solids and those that will remain in suspension
- To control activated sludge processes and account for solids inventories, we need to know the suspended solids at various stages through the process
- The SS test measures the amount of solids in suspension that can be removed by filtration
  - The sample is filtered through a pre-weighed filter paper and dried in an oven at 103-105°C

Mixed Liquor Suspended Solids (MLSS) Calculation

- Use the following data to determine the MLSS for this sample.
  - Weight of filter and dry solids = 0.5955 g
  - Weight of filter = 0.4021 g
  - Sample volume = 50 mL

- \( SS, \text{mg/L} = \frac{(A-B)(1,000,000)}{Sample \text{ Volume, mL}} \)
- Where
  - A = final weight of pan, filter and residue, in grams
  - B = weight of prepared filter and pan, in grams

MLSS Calculation

- Weight of filter and dry solids = 0.5955 g
- Weight of filter = 0.4021 g
- Sample volume = 50 mL

\[
\text{MLSS, mg/L} = \frac{(A-B)(1,000,000)}{\text{Sample Volume, mL}}
\]
\[
\text{MLSS} = \frac{(0.5955 - 0.4021)(1,000,000)}{50 \text{ mL}}
\]
\[
\text{MLSS} = 0.1934(1,000,000)
\]
\[
\text{MLSS} = 3868 \text{ mg/L}
\]
Suspended Solids

- Results of SS tests are used to determine secondary process removal efficiencies, SRT, F:M, and solids loading.

MLVSS

- MLVSS is typically performed immediately following the SS test
- The filter paper and solids from the SS test are burned at 550ºC in a muffle furnace
- Indicates the portion of microorganisms in biomass
  - Usually 80-85% of MLSS

MLSS vs. MLVSS

(Mixed Liquor Suspended Solids vs. Mixed Liquor Volatile Suspended Solids)

Food to Microorganism Ratio

- F:M = \( \frac{BOD_{mg/L}}{MLVSS,lb} \)

- See formula book or refer back to previous slides for BOD and MLVSS calculations

- Loading Rate, lb/day
  \[ = (Flow, MGD)(Concentration, mg/L)(8.34 lb/gal) \]

- Note: The following slides will be combining equations

F:M Ratio (Food to Microorganism Ratio)

- F:M = \( \frac{(BOD_{infl}, mg/L)(Q_{infl}, MGD)(8.34 lbs/gal)}{(MLVSS, mg/L)(Aerator Vol, MG)(8.34 lbs/gal)} \)

F:M Ratio

- Target F:M values
  - Conventional = 0.2 – 0.5
  - Nitrifying less than or equal to 0.10
- F:M based on BOD measurements does not give immediate process control feedback
- Running averages of F:M provide useful monitoring input
- F:M can be based on COD measurements when immediate process feedback is required
  - Target F:M COD = \( \frac{Target \ F:M_{BOD}}{BOD:COD} \)
F:M Example

| BOD_{inf} | 145 mg/L |
| Q_{inf} | 15 MGD |
| MLVSS | 2500 mg/L |
| Aerator Volume | 2 MG |

- F:M = \frac{\text{BOD}_{inf} \times Q_{inf} \times \text{MLVSS}}{\text{Aerator Vol} \times \text{MLVSS}} \times \frac{8.34 \text{ lbs/gal}}{8.34 \text{ lbs/gal}}
- F:M = \left(145 \text{ mg/L} \right) \left(15 \text{ MGD} \right) \left(2500 \text{ mg/L} \right) \left(2 \text{ MG} \right) = 0.44

F:M Ratio

<table>
<thead>
<tr>
<th>Calculated F:M</th>
<th>Result</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than target F:M</td>
<td>Too many microorganisms in process</td>
<td>Increase wasting rate</td>
</tr>
<tr>
<td>Greater than target F:M</td>
<td>Not enough microorganisms in process</td>
<td>Reduce wasting rate</td>
</tr>
</tbody>
</table>

- Excess sludge to waste:
  - Excess M to waste = Current M - F: (Food) (Microorganisms) F:M Target

Three different formulas:
- Desired MLVSS, lbs = BOD or COD, lbs Desired F:M ratio
- Desired MLSS, lbs = Desired MLVSS, lbs % Vol. Solids, as decimal
- SS, lbs to waste = Actual MLSS, lbs - Desired MLSS, lbs

Centrifuge Spin Test

- The spin test can be used to get a quick estimate of SS concentrations.

Microscopic Examination

- Microscopic examinations should be performed immediately after sample collection
- Provides valuable information on the biological characteristics and health of the activated sludge process
- Gives warning of process problems, such as poor settling or the presence of a toxic or inhibitory material

1. Place a drop of mixed liquor on a slide
2. Place a cover slide on top
- A healthy activated sludge will have a tight floc structure and many organisms present
**Sludge Age Indicator**

- Predominance of ciliates and rotifers indicates the process is operating well.
- Predominance of rotifers and worms indicates that sludge is old.

**Oxygen Uptake Rate (OUR)**

- Quickly indicates biological activity.
- The microorganisms are consistently using DO to oxidize organic matter for new cell growth and energy.
- Rate of oxygen used varies considerably with:
  1. Age of the solids
  2. Incoming organic load
- Excess food = reproduce quickly.
- Use up oxygen at a high rate, this results in a high OUR.
- As the food supply is used up or the microorganisms are affected by a toxic condition, the growth rate decreases, therefore the OUR would be low.

---

**Example:**

- Initial DO = 6.1 mg/L
- Final DO = 1.4 mg/L
- Time = 4.5 min

**OUR, mg/L/min =**

\[
\text{OUR, mg/L/min} = \frac{\text{Oxygen Usage, mg/L}}{\text{Time, min}}
\]

**OUR, mg/L/hour =**

\[
\text{OUR, mg/L/hour} = \frac{6.1 - 1.4}{4.5} = 1.04 \\
= 1.04 \times \frac{60}{60} = 62.7 \text{ mg/L/hour}
\]

Must multiply by 60 because it’s asking for HOURS, not minutes.
**SOURRE**

- Specific Oxygen Uptake Rate

\[
\text{SOUR, (mg/g)/hr} = \frac{OUR, \text{mg/L/min} \times 60 \text{ min}}{MLVSS, \text{g/L (1 hr)}}
\]

---

**Temperature**

- Microorganisms will respond to temperature changes

---

**Thirty-Minute Settleometer**

- To produce a good quality effluent, the activated sludge must settle well in the final clarifiers.
- The thirty-minute settleometer test indicates how well the mixed liquor will settle in the clarifiers.

---

**Thirty Minute Settleometer**

- The purpose of the 30-min test is to indicate the solids – liquid separation capability of the sludge that is going to the secondary clarifiers
  1. Take a 2-L sample of well-mixed mixed liquor and pour it into the settleometer as soon as possible after taking sample
  2. Allow it to settle for 30 minutes and record the level of the sludge blanket
- Note the color and clarity of the liquid and if there are any gas bubbles
- SVI can be determined with this number along with your MLSS, mg/L

---

**Sludge Volume Index (SVI)**

- Sludge Volume Index (SVI) - The ratio of the volume (in milliliters) of sludge settled from a 1000-mL sample in 30 minutes to the concentration of mixed liquor (in milligrams per liter [mg/L]) multiplied by 1000.

\[
\text{SVI, mL/g = \left(\frac{\text{Settled Sludge Vol, mL/L}}{1,000}\right) \times \text{MLSS, mg/L}}
\]

- The proper SVI range for your plant is determined at the time your final effluent is in the best condition regarding solids and BOD removals and clarity.
  - Preferable range is 50-150 mL/gram
pH

• Power of hydrogen
  – Measurement of the hydrogen ion concentration
  – $\text{pH} = -\log [H^+]$
  – Each decrease in pH unit equals a 10x increase in acid
• Scale runs from 0 to 14, with 7 being neutral
• Probe measures millivolts, then converts into pH units
  – Temperature affects millivolts generated, therefore you need a Automatic Temperature Compensator (ATC)
• If the pH of the mixed liquor varies too far from neutral (pH = 7.0), microorganisms may become inhibited or may start to die.

Dissolved Oxygen

• We must know the oxygen concentration in the aeration tanks to control it for optimum performance
  – Both BOD and nitrification are aerobic processes
• Two options for testing DO
  – DO probe and meter
  – Winkler method

Nitrogen

• If your plant is required to nitrify (convert ammonia-nitrogen to nitrate-nitrogen), you must also include ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen in your sampling
• By measuring these parameters, you can determine the efficiency of your plant and therefore make adjustments to your process

Chlorine Residual

• Two most common tests:
  1. Amperometric titration
     • Less interferences such as color and/or turbidity
  2. DPD (N,N-diethyl-p-phenylenediamine)
• Analysis should be performed ASAP
• Exposure to sunlight or agitation of the sample will cause a reduction in the chlorine residual

Chlorine Residual

• Approved Methods:
  – Amperometric titration
  – Iodometric titration – starch endpoint
  – Back titration
  – DPD - FAS
  – Spectrophotometric, DPD
  – Electrode
• NOTE: DPD color comparator is NOT an approved method
Chlorine Residual
- DPD colorimetric method is the most commonly used
  - Add powder pillow
  - Swirl sample for 20 seconds to mix
  - Wait three minutes (Hach method)
  - Place it into colorimeter and take reading

Alkalinity
- Capacity of water to neutralize acids
- Due to presence of hydroxides, carbonates and bicarbonates
- Many chemicals (alum, chlorine, lime) alter water alkalinity
  - Alum and chlorine destroy
  - Lime adds
  - Nitrification and denitrification also affect alkalinity
- Titration using H₂SO₄ to pH endpoint
- Expressed as mg/L CaCO₃

Turbidity
- Turbidity is a quick (less than 30 minutes) control test that can be used to determine the quality of the treatment plant effluent.

Coliform Bacteria
- MPN of coliform bacteria are estimated to indicate the presence of bacteria originating from the intestines of warm-blooded animals
- Coliform bacteria are generally considered harmless
  - But their presence may indicate the presence of pathogenic organisms

Coliform Bacteria
- Comprises all the aerobic and facultative anaerobic gram negative, nonspore-forming, rod-shaped bacteria that ferment lactose within 48 hours ~ 35°C
- 2 groups Coliform bacteria:
  - Fecal
  - Non-fecal
- The fecal group can grow at higher temperatures (45 °C) than the non-fecal coliforms

Sampling
- Clean, sterilized borosilicate glass or plastic bottles or sterile plastic bags
- Leave ample air space for mixing
- Collect samples representative of wastewater tested
- Use aseptic techniques; avoid sample contamination
- Test samples as soon as possible
Approved Methods

- Coliform (fecal)
  - Number per 100 mL
- Membrane filtration (SM9222 D-2006)
- E. coli
  - Number per 100 mL
- Membrane filtration
  - m-ColiBlue24®
  - Modified mTEC agar (EPA Method 1603)
- Multiple tube/multiple well (Colilert®) (SM9223 B-2004)

Membrane Filtration

1. Use sterilized forceps to place a sterile, absorbent pad in a sterile petri dish. Replace the lid on the dish.
2. Insert an ampule two or three times into the broth. Break open an ampule of m-ColiBlue24 solution and place in a sterile petri dish.
3. Set up the Membrane Filtration Apparatus. With sterile forceps, place a membrane filter grid-side up into the assembly.
4. Shake the sample vigorously to mix. Pour 100 mL of sample or diluted sample into the apparatus. Place the sample flask containing the sample, filter the sample through the filter for three times with 20 to 30 mL of sterile balanced dilution water.

Membrane Filtration Equipment

- Water bath or air incubator operating at appropriate temperature
- Vacuum pump
- Alcohol burner
- UV sterilizer or boiling water bath
- 10-15 X dissecting microscope; should have fluorescent illuminator

Membrane Filtration Supplies and Glassware

- Sterile graduated cylinder
- Sterile pipets
- Sterile MF filtration flask
- Sterile dilution water
- Sterile sample vessels
- Samples containing chlorine must be treated with 3% sodium thiosulfate solution
- mFC Broth
Fecal Coliform

- A 100 mL volume of sample is filtered through a 47-mm membrane filter using standard techniques.
- Filter is transferred to a 50-mm petri plate containing an absorbent pad saturated with mFC Broth.
- Invert filter and incubate at **44.5±0.2°C** for 24 ± 2 hrs.
- Fecal coliform density reported as number of colonies per 100 mL of sample.
  - Fecal coliforms appear blue.
  - Colonies = colony forming unit = cfu.
- NPDES permit limit: monthly average of 200 cfu/100 mL; daily maximum of 1000 cfu/100 mL.

E. coli m-ColiBlue24®

- Incubation is at **35 ± 0.5°C** for 24 ± 2 hrs.
- *E. coli* density reported as number of colonies per 100 mL of sample.
- *E. coli* appear blue.
- NPDES permit limit typically has a monthly average of 126 cfu/100 mL.
- Samples and equipment known or suspected to have viable *E. coli* attached or contained must be sterilized prior to disposal.

Escherichia coli (E.coli) m-ColiBlue24® with Membrane Filtration

- Maximum hold time is 8 hrs at < 10°C.
- Ideal sample volume yields 20-60 colonies.
- Run a minimum of 3 dilutions.
- Samples <20 mL, add 10 mL sterile dilution water to filter funnel before applying vacuum.
- Sanitize funnel between samples.
- Count colonies.
- Verify using 10-15 X binocular wide-field microscope.

E. coli m-ColiBlue24®

- Maximum hold time is 8 hrs at < 10°C.
- Ideal sample volume yields 20-60 colonies.
- Run a minimum of 3 dilutions.
- Samples <20 mL, add 10 mL sterile dilution water to filter funnel before applying vacuum.
- Sanitize funnel between samples.
- Count colonies on membrane filters.
- Verify using 10-15 X binocular wide-field microscope.
Expected Reactions of Various Microorganisms

- Total coliforms will produce a red colony
  - Enterobacter species
    - E. cloacae
    - E. aerogenes
  - Klebsiella species
    - K. pneumoniae
  - Citrobacter species
    - C. freundii
- *Escherichia coli* will produce a blue colony
  - *E. coli* O157:H7 will not produce a blue colony, but will grow as a red colony

**Escherichia coli (E.coli)**
Modified mTEC agar
(EPA Method 1603)
Modified mTEC Agar with Membrane Filtration

**EPA Method 1603**
- Membrane Filter – modified mTEC agar
- Filter sample dilutions through a 47mm diameter sterile, white, grid marked filter (0.45µm pore size)
- Place sample in a petri dish with modified mTEC agar
- Invert dish and incubate for 35 ± 0.5°C for 2 hours
  - Resuscitates injured or stressed bacteria
- Then incubate at 44.5 ± 0.2°C for 22 hours
- After incubation, remove the plate from the water bath or dry air incubator

**Method 1603**
- Count and record the number of red or magenta colonies (verify with stereoscopic microscope)
- See the USEPA microbiology methods manual, Part II, Section C, 3.5, for general counting rules

**Method 1603**
- QC Tests:
  - Initial precision and recovery
  - Filter sterility check
  - Ongoing precision and recovery
  - Method blank
  - Matrix spike
  - Filtration blank
  - Negative control
  - Media sterility check
  - Positive control

**Method 1603**
- Initial precision and recovery
  - Should be performed by each lab before the method is used for monitoring field samples
- Ongoing precision and recovery
  - Run after every 20 field and matrix spike samples or one per week that samples are analyzed
  - Matrix spike
    - Run 1 per 20 samples
  - Negative control
  - Analyze whenever a new batch of media or reagents is used
  - Positive control
  - Analyze whenever a new batch of media or reagents is used
Method 1603
• Filter sterility check
  • Place at least one membrane filter per lot of filters on a tryptic soya agar (TSA) plate and incubate for 24 ± 2 hours at 35ºC ± 0.5ºC.
  • Absence of growth indicates sterility of the filter
• Run daily
• Method Blank
  • Filter a 50-mL volume of sterile buffered dilution water and place on a modified mTEC agar plate and incubate
  • Absence of growth indicates freedom of contamination from the target organism
• Run daily
• Filtration Blank
  • Filter a 50-mL volume of sterile buffered dilution water and place on a TSA plate and incubate for 24 ± 2 hours at 35ºC ± 0.5ºC
  • Absence of growth indicates sterility of the buffer and filtration assembly
• Run daily

Method 1603
• Media sterility check
  • The lab should test media sterility by incubating one unit (tube or plate) from each batch of medium (TSA, modified mTEC and verification media) as appropriate and observing for growth
  • Absence of growth indicates media sterility
• Run daily

Colilert® & Colilert-18®
• MPN Method
  • Most Probable Number
• Add substrate to a 100 mL sample
• If making dilutions, use sterile DI water, not sterile buffered water.

Colilert® & Colilert-18®
• Shake sample vigorously
• Wait for bubbles to dissipate
• Pour into QuantiTray

Colilert® & Colilert-18®
• Seal sample in Quanti-Tray
• Incubate at 35±0.5°C for 18 hrs (Colilert-18) OR 24 hrs (Colilert)
Colilert® & Colilert-18®

- Examine tray for appropriate color change
- Yellow is an indicator of total coliforms

For more information

- For Colilert®: IDEXX Laboratories, www.idexx.com
- For mTEC Agar and mColiBlue-24® media: Hach Company, www.Hach.com
- EPA Method 1603: E.coli In Water By Membrane Filtration Using Modified membrane-Thermotolerant Escherichia coli Agar (Modified mTEC), September 2002, EPA-821-R-09-007

All Bacteriological Checks

- Temperatures are documented twice daily at least 4 hours apart, while samples are being incubated
- Thermometers are certified at least annually against NIST thermometers
- Reagents for storage requirements and expiration dates
- E. coli colonies identified correctly
- Calculations are correct
- Holding Times are met
  - Sample collection
  - Analysis start
  - End times

Geometric Mean

- Reported on netDMR
- NPDES definition:
  - The geometric mean of any set of values is the nth root of the product of the individual values where “n” is equal to the number of individual values.
  - For the purposes of calculating the geometric mean, values of zero (0) shall be considered to be one (1)

- You have run your E. coli samples for the month and need to figure your geometric mean
- Your results are as follows:
  - 60 cfu
  - 100 cfu
  - 0 cfu
  - 0 cfu
Geometric Mean

- Geometric Mean – $(X_1)(X_2)(X_3)\ldots(X_n)^{1/n}$

- Step 1: $1/n \rightarrow 1$ divided the number of test results. For our example above, there are four test results.
  - $1 \div 4 = 0.25$ (write this number down, you will use it in Step 3)

- Step 2: Multiply all of the test results together and punch the $=$ button on the calculator. **Remember to count 0 as a 1**.
  - $60 \times 100 \times 1 \times 1 = 6000$ (Do Not clear out your calculator)

- Step 3: Punch the $y^x$ button and then type in the number from Step 1, then punch $=$.
  - $6000 \times y^x 0.25 = 8.8011$

Now, try one on your own:

- 20, 20, 210, 350

- $\frac{1}{4} = 0.25$

- $(20)(20)(210)(350) = 29,400,000$

- $(29,400,000)^{0.25} = 73.6$

- Geometric Mean = 73.6

Tools for Success

- **40 CFR 136.6 (Flexibility to Modify Methods)**
- **Hach® EPA compliant methods**
  - [http://www.hach.com/epa](http://www.hach.com/epa)
  - Confirm method of analysis (WW or DW)
  - equivalent, acceptable or approved (EPA compliant)
- **Fleming Training Center website**
- **Standard Methods for Water and Wastewater Analyses** (consensus body approved methods)
- **State of TN, Design Criteria for Sewage Works** (Technical/Engineering Documents)

- **Tools for Success**
  - Standard Operating Procedures
    - Yearly review/signature
    - Update
    - Training
  - Review of log books
    - Instrument calibration (daily)
    - Temperature
    - Maintenance
    - Sampler
    - Standard preparation
    - Calibration
  - Lab instruments – yearly maintenance check (or more frequently)
    - including thermometers and weights
  - Flow measurement devices – yearly maintenance check
Any Questions?
CHAPTER 3

Laboratory, Personnel, Maintenance Facilities and Safety Design

3.1 General

3.2 Laboratory Facilities

3.2.1 General
3.2.2 Space Requirements
3.2.3 Design
3.2.3.1 Location
3.2.3.2 Layout

3.3 Personnel Facilities

3.4 Maintenance Facilities

3.4.1 Maintenance Shop
3.4.2 Storage Requirements
3.4.3 Yard Requirements

3.5 Safety Design

Appendix 3-A On-site Checklist
LABORATORY, PERSONNEL, MAINTENANCE FACILITIES & SAFETY DESIGN

3.1 General

Suggested considerations are presented in this chapter for laboratory, personnel, maintenance facilities, and safety. If testing is contracted out (particularly for lagoon systems) minimal maintenance facilities will only be required.

3.2 Laboratory Facilities

3.2.1 General

A guide to provision of laboratory facilities is the EPA publication Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities, EPA-430/9-74-002.

Lab work involves a significant portion of a small facility's work tasks. Each facility should estimate work tasks by obtaining the following documents:

a. "Minimum sampling schedule" should be obtained from the Permit Section of the Division of Water Pollution Control, containing compliance parameters from NPDES Permit as well as operation test.


d. Tennessee "Laboratory Equipment and Supplies for Wastewater Treatment Plants." Contact the Julian Fleming Training Center in Murfreesboro.

3.2.2 Space Requirements

Specific laboratory facilities should be based on the needs of the treatment plant. Minimum suggested space for one MGD facilities is:

- Floor space of 200 sq. ft.
- Percent of floor space required for bench area is 40%
- Cabinet volume of 200 cubic foot.
These figures apply to a typical treatment plant monitoring program. If laboratory testing will be performed for other sources, such as industrial discharges, receiving waters, and sewer overflows, appropriate space increases should be provided. If some of the plant monitoring tests are performed at other facilities, the space required could be significantly less.

3.2.3. Design

The following factors should be key considerations in design of plant laboratories:

- Flexibility, which provides for changes in use requirements
- Adaptability, for changes in occupancy requirements
- Expandability, for changes in space requirements

3.2.3.1 Location

The laboratory should be located at ground level and easily accessible to all sampling points. To assure sufficient environmental control, the laboratory should be located away from vibrating machinery, corrosive atmospheres, or equipment which might have adverse effects on the performance of laboratory instruments or the analyst.

3.2.3.2 Layout

New lab layouts should be modeled after proven exemplary layouts. Efficient laboratory operation depends largely on the physical layout of the laboratory. The physical layout includes items such as working area arrangement, the number and location of sinks and electrical outlets, the arrangement of laboratory equipment, materials of construction, and lighting. The details of the layout can affect the accuracy of the laboratory tests. For example, tests that include identification of a colorimetric end point, as in heavy metals determinations, can be drastically affected by the type of lighting and the finishes on laboratory facilities.

The following factors should be considered when laying out a laboratory:

a. A northern exposure is preferred for colorimetric analysis.

b. Adequate lighting should be provided. Color-corrected fluorescent lighting is suggested.

c. Wall and floor finishes should be nonglare-type and light in color. Flat-finish wall paint is suggested.
Floor finishes should be of a single color for ease of locating small items that have been dropped.

d. Floor covering, in addition to being nonglare, should be easy to clean and comfortable.

e. Doors shall have large glass windows for visibility into and out of the laboratory. There should be no obstructions near the doors.

f. Aisle width between work benches should be at least 4 feet. Adequate spacing should be provided around free-standing equipment, workbenches, and file cabinets to facilitate cleaning.

g. Storage space for reagent stock should be under workbenches. Reagent containers removed from storage areas under workbenches are less likely to be dropped than reagent containers removed from storage in the inconvenient and hard-to-reach areas above the workbenches. Only items that are infrequently used or chemicals of a nonhazardous nature should be stored above workbenches. Strong acids or bases should be stored within convenient reach of the laboratory personnel, preferably beneath or adjacent to the fume hood.

h. Sufficient cabinet and drawer space should be provided for the storage of equipment and supplies. Wall cabinets should be no more than 30 inches above the workbench top so that the contents of the top shelving can be reached. The base cabinets under the workbenches should contain a combination of drawers and storage spaces for large items. All cabinets and drawers should be acid resistant.

i. One sink with a large gooseneck faucet, large enough to wash laboratory equipment, should be provided for every 25 to 30 feet of bench length. One sink should be sufficient when total bench length is less than 25 feet. The sink should be made of chemical-resistant material.

Cup sinks, also of chemical-resistant material, should be provided at strategic locations on the bench surface to facilitate laboratory testing. The number of cup sinks depends largely on the type of tests that will be run; the general rule is one cup sink for every 25 to 30 feet of bench length. Cup sinks should be alternated with the wash sinks at 12- to 15-foot intervals.
Where workbench assemblies are provided in the center of the laboratory, a trough-type sink down the center of the workbench may be provided in lieu of cup sinks. A hot and cold water tap should be placed at approximately every 5 to 10 feet along the trough.

The use of an automatic dishwasher should be considered. Where dishwashers are provided, some of the sinks can be replaced by cup sinks.

j. Electrical receptacles should be provided at strategic points for convenient and efficient operation of the laboratory. Duplex-type receptacles should be spaced at intervals along benches used for laboratory tests. Strip molding receptacles may be used. All receptacles must be elevated to prevent spills from entering the receptacles.

k. Gas and vacuum fixtures should be provided at convenient locations.

l. Bench tops should be suitable for heavy-duty work and resistant to chemical attack. Resin-impregnated natural stone and other manmade materials provide such a surface and should be used.

m. Bench surfaces should be approximately 36 inches high for work done from a standing position and 30 inches high for work done while sitting.

n. Bench surfaces should be approximately 30 inches wide.

o. Equipment arrangement should be given special consideration in laying out the laboratory facility in conjunction with the facility's owner and operators. Plumbing, and/or electrical connections should be provided for units such as the distillation apparatus, drying ovens or other wall-mounted equipment. Pieces of equipment used for making common tests should be in proximity.

For example, the drying oven used in making total, suspended, and dissolved solids tests should be close to the muffle furnace for use in determining total volatile solids and volatile suspended solids from the samples dried in the drying oven. The drying oven and the muffle furnace should be near the
balance table because the balance is used in the weight determinations for the various solids tests.

p. Safety is a prime consideration of a laboratory. The first aid kit, fire extinguisher, eye wash, and emergency shower should be near the main working area of the laboratory. If the safety shower is not provided in a separate shower stall, a floor drain should be nearby.

q. Sources of loud or startling noises, such as alarms or composite sampling equipment, should be located at sites remote or otherwise isolated from the laboratory.

r. The analytical balance should be on a separate table at least 30 inches long and 24 inches deep. The table should not transmit vibrations that would adversely affect the operation of the balance.

s. A separate table is desirable for microscopes. This table should be about 30 inches long, 24 inches deep, and 27 inches high.

t. Fume hoods, if provided, should be near the area where most laboratory tests are made.

u. All labs which run BOD₅ require air-conditioning to achieve a sufficiently high, stable D.O. in the dilution water.

Laboratories should be separately air-conditioned, with external air supply for 100-percent makeup volume. Separate exhaust ventilation should be provided. Window air-conditioning should not blow directly on the analytical balance or furnaces.

v. Panic hardware should be provided for doors opening to the outside to allow for rapid exiting in an emergency.

### 3.3 Personnel Facilities

Personnel facilities are generally located in the administration building. This building serves the needs of the supervisory staff, the operation and maintenance personnel, and often the laboratory staff. Sewer maintenance personnel may also share the administration building. However, facilities for the laboratory and operations and maintenance staff need not be provided in the administration building, even though this is customary.
A wastewater treatment plant staffed for 8 hours or more each day should contain support facilities for the staff. Toilets shall be provided in conformance with applicable building codes. The following should be provided:

a. **Wash-up and changing facilities:** Showers, lockers, sinks, and toilets sufficient for the entire staff at design conditions. A heated and ventilated mudroom is desirable for changing and storage of boots, jackets, gloves, and other outdoor garments worn on the job. Each staff member should have separate lockers for street clothes and plant clothes. Separate wash-up and changing facilities should be available for men and women, with the exception of the mudroom.

b. **Eating Facilities:** A clean, quiet area with facilities for storage and eating of light meals.

c. **Meeting facilities:** A place to assemble the plant staff and visitors. In many cases, meeting facilities and the eating facilities will be the same.

d. **Supervisors' facilities:** A place where discussion and writing can be carried out in private. A desk station should be provided for data entry.

Facilities should be provided for the storage of analytical methods and records, catalogs, as-built plans, operation and maintenance manual(s), etc.

Small mechanical treatment plants that are not manned 8 hours per day need not contain all of the personnel facilities required for larger plants, but shall contain a lavatory, and a storage area.

### 3.4 Maintenance Facilities

To assure adequate maintenance of equipment, convenient maintenance facilities should be available. Such facilities generally include a maintenance shop, a garage, storage space, and yard maintenance facilities.

Access to nearby municipal garages and other maintenance centers should be considered. Duplication of facilities should be avoided where possible.

#### 3.4.1 Maintenance Shop

A separate maintenance shop should be designated where treatment plant equipment and vehicles can be repaired. The maintenance shop should be provided with the following facilities:
a. Work space with adequate area and lighting, including a workbench with vise.

b. Conveyances to move heavy items from the point of delivery to the appropriate work space.

c. Storage for small tools and commonly used spare parts.

d. Adequate power outlets and ratings for the equipment.

3.4.2 Storage Requirements

Storage space should be provided for paints, fuels, oils and lubricants, grounds maintenance equipment, spare parts, and collection system equipment.

In larger facilities, it may be desirable to have a separate storage building for things such as paints, fuel, oils and lubricants, spare parts, and yard supplies. For storage of flammable materials, the requirements of the uniform building code shall be met. In smaller facilities, it might be desirable to combine storage with the shop or garage so that the stored material can be protected against unauthorized use.

Where underground tanks are to be used to store controlled substances, the Division of Ground Water Protection shall be contacted regarding Underground Storage Tank (UST) requirements.

3.4.3 Yard Requirements

A landscaped yard helps to soften the visual impact of a treatment facility. Shrubs and trees judiciously located can screen unsightly areas from public view. Care must be taken that the plantings do not become a hindrance to operation. Deciduous leaves falling in clarifiers can hinder skimming and add unnecessarily to the digester loading. Roots from trees too close to pipes can cause clogging. Fencing should be adequate to prevent unauthorized or unattended entry.

3.5 Safety Design

The field of wastewater treatment has always been one of the most hazardous fields of employment. This fact is accented by job-related deaths and accidents which happen each year. Safety designs are needed which should be supplemented by yearly inspections to gain awareness.

Adequate provisions shall be included in the design of all wastewater treatment facilities to minimize exposure of facility personnel and visitors to safety hazards.
Treatment facilities shall be designed in full compliance with the Occupational Safety and Health Standards of the State of Tennessee, Division of Occupational Safety and Health (TOSHA).

Pertinent safety design requirements as well as safety design practices are included in the attached on-site checklist for wastewater treatment plants (Appendix 3-A).

To gain awareness each operator should have other safety resources such as:

1.) Safety & Health in Wastewater Systems (MOP-1 by WPCF)
2.) Individual safety manual adopted by each plant's safety committee.
3.) Safety meetings with city.

Any unsafe practices or incidents should be reported to TOSHA and each facility's safety committee. As a last resort, complaints can be made anonymously by the operator or any other concerned citizen.
Appendix 3-A

On-Site Checklist

STANDARD SAFETY

1. Personnel Protective Clothing:
   a. Safety helmets (for operators and visitors)
   b. Ear protectors for high noise areas
   c. Goggles
   d. Gloves
   e. Rubber boots with steel toes

2. Safety Devices Available for Use:
   a. Non-sparking tools in areas where flammable or explosive gases may be present
   b. Fire extinguishers readily available
   c. Oxygen deficiency/explosive gas indicator
   d. Self-contained breathing apparatus near entrance to chlorine room, away from fan discharge
   e. Safety harness
   f. First aid kits readily available
   g. Ladders to enter manholes or wetwells (fiberglass or wooden for around electrical work)
   h. Traffic control cones
   i. Safety buoy at activated sludge plants
   j. Live preservers for around lagoons
   k. Portable crane/hoist
3. General Plant Safety:
   a. Railing around all tanks, with openings chained off
   b. No uncovered pits or wells
   c. Explosion-proof fixtures, where needed
   d. Equipment guards in place
   e. Emergency telephone numbers posted
   f. Proper flammable liquid storage
   g. Covered trash cans
   h. Ladders have safety cages or equipped with safety slide rail
   i. Portable hoists for equipment removal; e.g., pumps, aeration equipment

4. Are plant personnel immunized for typhoid and tetanus?

5. No cross connections exist between a potable water supply and a non-potable source:
   a. Pump and mixer seals
   b. Digester heating system make-up water
   c. Vacuum filter water sprays
   d. Chemical mixing tank
   e. Chlorinator water source
   f. Yard hydrants
   g. Properly installed backflow preventers

6. If anaerobic digesters are used, are the following present?:
   a. Pressure/vacuum relief valves
   b. "No smoking" signs
   c. Explosimeter
   d. Drip trap
   e. Flame traps within 25' of the flame source
7. **Electrical Safety:**
   a. All electrical circuitry enclosed and identified
   b. Electrical test equipment available, such as a voltmeter and amperage meter
   c. Rubber mats present for electrical work
   d. The personnel are familiar with the electrical work to be performed
   e. All personnel are trained in electrical safety, such as lockout procedures
   f. Warning and/or caution signs present
   g. Rubber gloves available
   h. Ground fault interrupter used

8. **Chlorine Safety:**
   a. NIOSH-approved self-contained 30 minute air pack
   b. All standing chlorine cylinders are chained in place
   c. All personnel are trained in the use of chlorine
   d. Chlorine repair kit is available
   e. Chlorine leak detector tied into the plant alarm system
   f. Ammonia for checking chlorine leaks is present
   g. Ventilator fan with an outside switch is present
   h. Safety precautions posted
   i. Doors open outward and are equipped with "panic" hardware
9. Process Chemical Safety:
   a. Respirator to protect the operator against dust inhalation, when needed
   b. All personnel are trained to handle the chemicals properly
   c. Proper safety clothing for the chemical to be handled, such as rubber aprons, boots and gloves for handling ferric chloride
   d. Has complied with the Tennessee Department of Labor, Hazardous Chemical Right To Know Law, T.C.A. 50-3-2001 thru 2019.
   e. Emergency Action Plan on file with local Fire Department and appropriate Emergency Agency
   f. Containment of chemical storage areas, including curbing and floor drains to appropriate areas

10. Laboratory Safety:
   a. Eye wash and shower station is present
   b. Fume hood is present
   c. All chemicals properly labeled and stored
   d. Laboratory safety devices such as pipette suction bulbs
INNOVATIVE SAFETY

1. Warning Signs:
   a. Non-potable water
   b. Chlorine hazard
   c. No smoking
   d. High Voltage
   e. "Watch your step" signs in certain areas
   f. Exit signs
   g. Piping signs

2. Safety programs

3. Operators provided with a shower and a locker for their work clothes

4. Are the operators trained in first aid and CPR?
Sampling and Laboratory Vocabulary

1. A ____________________________ (aka proportional) sample is a collection of individual samples obtained at regular intervals, usually every 1 or 2 hours, during a 24 hour period.

2. A ____________________________ sample is a single sample of water collected at a particular time and place that represents the composition of water only at that time and place.

3. Another word for sterile is ____________________________. You use this type of technique when collecting samples for bacterial analysis.

4. ____________ is an expression of the intensity of the basic or acidic condition of a liquid. It is also described as the measurement of the hydrogen ion concentration, or the power of Hydrogen.

5. The purpose of the ____________________________test is to indicate the solids – liquid separation capability of the sludge that is going to the secondary clarifiers.

6. The device used to sterilize laboratory equipment, DI water, or media: ____________________________

7. ____________________________ can be automated or improvised devices, and may include weighted buckets, beakers, or other containers attached to a rod or chain.

8. Tests frequently performed by operators to quickly obtain the results and make any necessary process adjustments are known as ____________________________. Results of these tests are not reported each month, but the data should be documented in-house.

9. ____________________________ is a measure of the clarity or cloudiness of water, and is expressed in NTUs.

10. This test is used to determine a sample’s organic strength by measuring the amount of oxygen required by a sample during a five day incubation period: ____________________________

11. The ____________________________ test is used for more rapid assessment of organic strength (results in 2 hours instead of 5 days with BOD).

12. Results from the ____________________________ measures the amount of solids in suspension that can be removed by filtration (and is a combination of settleable solids and those that will remain in suspension). The sample is filtered through a pre-weighed filter paper and dried in an oven at 103-105ºC.

13. The term ____________________________ refers to all the aerobic and facultative anaerobic gram negative, nonspore-forming, rod-shaped bacteria that ferment lactose within 48 hours ~ 35ºC. There are 2 groups: Fecal and Non-fecal.

14. During ____________________________, water passes through a filter, while bacteria are trapped or captured on the surface of the filter.
15. ____________________ refers to the closeness of two or more measurements to each other. This is not to be confused with Accuracy, which refers to the closeness of a measured value to a standard or known value

**Word Bank**

Composite

Precision

Membrane filtration

Process control tests

Biochemical Oxygen Demand (BOD)

Aseptic

Autoclave

Coliform

Turbidity

Chemical Oxygen Demand (COD)

pH

Samplers (Sampling devices)

Suspended Solids Test

Grab

Thirty minute settleometer
Sampling and Laboratory Review Questions

1. What is the name of the device used to sterilize laboratory equipment, DI water, or media? And what is the standard time and temperature that is generally used for sterilization?

2. If you had a question regarding a sample hold time, for example, how long a sample could be stored before analysis, where would you look to find this information?

3. Using the answer from question #2, give the maximum hold times for the following types of tests:
   a. Bacterial tests = ____________________ hours
   b. Aquatic Toxicity tests = ____________________ hours
   c. Oil and grease (FOG) tests = ____________________ days

4. Why would you need to seed a BOD sample?

5. BOD samples must be kept in an incubator at ___________ degrees C for the duration of the test. Valid results require a Blank depletion of less than ___________. Samples must deplete at least ___________. And the Initial DO must be less than or equal to ___________.

6. Describe the difference between a grab sample and a composite sample.
7. To perform the Suspended Solids test, the sample is filtered through a pre-weighed filter paper and dried in an oven at _________________ degrees C.

8. Which of the following methods is **not approved** for analyzing chlorine residual?
   a. Amperometric titration
   b. Spectrophotometric, DPD
   c. Electrode
   d. DPD color comparator

9. Interpret the following microscopic evaluation results:
   a. Predominance of ciliates and rotifers =
   b. Predominance of rotifers and nematodes (worms) =
   c. An abundance of amoebas =

10. Name two chemicals that will use up or destroy alkalinity in the water.

11. What is the typical (keep in mind that not all permits are the same) NPDES permit limit for Fecal Coliform?

   When testing for Fecal Coliforms, samples are incubated at _________________ degrees C for _________________ hours.

12. NPDES permits typically (keep in mind that not all permits are the same) have an *E. coli* limit as a geometric mean of _________________ . When testing for *E. coli* using the mColiBlue24 method, samples are incubated at _________________ degrees C for _________________ hours.
13. When testing for *E.coli* using the Colilert or Colilert 18 methods, interpret the following results:
   
a. Yellow coloration = ________________________________
   
b. Yellow + Fluorescence = ________________________________

14. Write out what the following QA/QC abbreviations stand for:
   
a. DOC = _____________________________________________
   
b. MDL = _____________________________________________
   
c. ICV = _____________________________________________
   
d. CCV = _____________________________________________
   
e. LRB = _____________________________________________
   
f. LFM = _____________________________________________
Section 4

Introduction to QA/QC, Standard Methods, and Standard Operating Procedures (SOPs)
Introduction to QA/QC
Standard Methods
Standard Operating Procedures (SOPs)

Introduction to Wastewater Class

Standard Methods
• 1880’s movement for “securing the adoption of more uniform and efficient methods of water analysis”
• Drinking water only until 1925
• 1933 joint publication
  – Standard Methods of the Examination of Water and Sewage

Standard Methods
• Methods believed to be best available
• Recommendations of specialists, ratified by large number of analysts and other experts
• Truly consensus standards
• Offers valid and recognized basis for control and evaluation

Standard Methods
• Standard Methods for the Examination of Water and Wastewater
• Often a lag time between 40 CFR 136 approved methods and Standard Methods
• Look at Editorial Revision date on method, not latest Edition of SM

Code of Federal Regulations (CFR)
• The purpose of the CFR is to present the official and complete text of agency regulations in one organized publication and to provide a comprehensive and convenient reference for all those who may need to know the text of general and permanent Federal regulations

Code of Federal Regulations (CFR)
• The CFR is divided into 50 titles representing broad areas subject to Federal regulation
  • Each title divided into chapters
  • Each chapter divided into parts
  • Each part divided into sections

  • Wastewater: 40 CFR 136

  • CFR can supersede Standard Methods
Code of Federal Regulations (CFR)

- CFR will list approved methods for testing
- Includes:
  - Standard Methods
  - EPA methods
  - Hach methods
  - Etc.
- Always check to make sure you are using an approved method!

40 CFR 136 Method Update Rule

- This rule modifies the testing procedures approved for analysis and sampling under the Clean Water Act. The changes adopted in this final rule fall into the following categories: New and revised EPA methods (including new and/or revised methods published by the Standard Methods Committee... updated versions of currently approved methods; methods reviewed under the alternate test procedures (ATP) program; clarifications ...and amendments to the procedure for determination of the method detection limit to address laboratory contamination and to better account for intra-laboratory variability.
- QA/QC
- You Have Heard it All Before

2017 Update of 40 CFR 136

Clean Water Act Methods Update Rule for the Analysis of Effluent

- Standard Methods approved by date (editorial revision) not Edition
- Section 136.7 Quality Assurance and Quality Control

Federal Register August 28, 2017, effective September 27, 2017

Section 136.7 Lab QA

- “...suitable QA/QC procedures...”
- “...QA/QC procedures are generally included in the method or may be found in the methods compendium...” (Ex. Standard Methods)
- “The permittee/lab shall follow these QA/QC procedures, as described in the method or methods compendium.” (Ex. Standard Methods)
- “If the method lacks QA/QC...”

Three QA Options

- A. ...follow equivalent EPA procedures
- B. Refer to QA/QC in consensus organization compendium. (Follow Standard Methods) Didn’t we have that on the previous slide?
- C. Follow the 12 Steps where applicable.
- The 13th step requires an SOP (standard operating procedures)

12 Quality Control Elements

1. DOC – demonstration of capability
2. MDL – method detection level
3. URB/MB – method blank
4. LFB – laboratory fortified blank (standard)
5. LFM/LFMD – laboratory fortified matrix/duplicate (spike)
6. Internal standards, surrogate standards or tracer – only applies to organic analysis and radiochemistry
7. Calibration - initial and continuing
8. Control charts or other trend analysis
9. Corrective action – root cause analysis
10. QC acceptance criteria
11. Definition of a batch (preparation and analytical)
12. Minimum frequency for conducting all QC elements
13. Unwritten 13th Step – SOP – Standard Operating Procedures need to be written and followed for all lab sampling and analysis
Not all of these items apply to all tests, there are many exceptions!
Can you defend what you do?
• How do you interpret your Permit language or the Rule?
• Can you defend that interpretation, will a judge or jury support you?
• What do Regulators say and what is written?
  • Is it clear?
  • Don’t be afraid to ask Why?
  • Don’t be afraid to ask for directives in writing

What You Are Already Doing
• Most Labs are doing lots of QA/QC stuff – especially contract labs
• Write down what you do....SOP
• Summarize QC Data
  – Table Form
  – Average, Max, Min.
  – Control Charts

Demonstration of Capability (DOC)
• DOC once for each analyst
• Standard Methods 1020.B.1
  • As a minimum, include a reagent blank and at least 4 LFBs at a concentration between 10 times the MDL and the midpoint of a calibration curve.
  • Something to keep along with these records is a signed form (documentation) that analyst has read and understands all appropriate SOPs and Methods.

Method Detection Level (MDL)
• Estimation of the detection limit for variety of physical and chemical methods
• EPA defines as: “the minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results”
• What tests does this apply to?
  • Ammonia, Chlorine and Total Phosphorus
• How often?
  • Annually – but at least every 13 months
  • Ongoing data collection and MDL validation is now required quarterly

What is an MDL study?
• It is a calculation that statistically gives the lowest concentration that a lab/facility can “see,” or detect an analyte
• Not practical for many analyses
• As detector sensitivity improves, the background contamination of the lab, consumable supplies, and equipment can be more important in determining the detection limit than the sensitivity of the instrument

How MDL Studies are Performed
• Procedure uses method blanks, as well as spiked samples to calculate MDL
• MDLₜ: value calculated from the spiked samples
  – 8/year (2/quarter)
• MDLₘ: value calculated from the method blanks
  – No additional sample required, use your routine method blanks
• MDL = the higher of the two numbers
MDL Calculations

- Samples used to calculate MDL should be performed throughout the year, not on a single date
  - Run spiked replicates in at least 3 separate preparation and analysis batches
  - Samples analyzed every quarter, but calculation performed only once a year
- Lab has the option to pool data from multiple instruments to calculate one MDL that represents multiple instruments

Laboratory Reagent Blank (LRB)
- Also known as Method Blank
- Standard Methods 1020.B.5
  - A reagent blank (method blank) consists of reagent water and all reagents that normally are in contact with a sample during the entire analytical procedure (distillation, incubation, etc.)
- What tests does this apply to?
  - Ammonia, BOD/cBOD, Chlorine, Total Phosphorus and TSS
  - How often?
  - Depends on method QA/QC

Laboratory Fortified Blank (LFB)
- Standard Methods 1020.B.6
  - A laboratory-fortified blank is a reagent water sample to which a known concentration of the analyte of interest has been added
  - Sample batch = 5% basis = 1 every 20 samples
  - At least once a month
  - Use an added concentration of at least 10 times the MDL, or less than or equal to the midpoint of the calibration curve
- What tests does this apply to?
  - Ammonia, BOD/cBOD, Chlorine, Total Phosphorus, TSS
  - For samples that need to be analyzed on a 5% basis or once for every 20 samples follow these criteria:
    - If a permit stated that 3 analyses per week, we would allow for a LFB to be analyzed at least once per month.
    - If a permit stated 5 analyses per week, we would suggest twice a month.
    - Once per month would be the minimum requirement.

Laboratory Fortified Matrix and Duplicate (LFM/LFMD)
- Also called a Matrix Spike/Matrix Spike Duplicate (MS/MSD)
- Shows if there are interferences in the effluent matrix
- What tests does this apply to?
  - Ammonia and Total Phosphorus
- How often?
  - For samples that need to be analyzed on a 5% basis or once for every 20 samples follow these criteria:
    - If a permit stated that 3 analyses per week, we would allow for a LFB to be analyzed at least once per month.
    - If a permit stated 5 analyses per week, we would suggest twice a month.
    - Once per month would be the minimum requirement.

Laboratory Fortified Matrix and Duplicate (LFM/LFMD)
- Also known as a Spike and Spike dup
- Standard Methods 1020.B.7
  - A laboratory matrix (LFM) is an additional portion of a sample to which a known amount of the analyte of interest is added before sample preparation
  - The LFM is used to evaluate analyte recovery in a sample
  - Sample batch = 5% basis = 1 every 20 samples
  - At least once a month
  - Add a concentration less than or equal to the midpoint of the calibration curve
  - Preferably the same concentration as the LFB (laboratory fortified blank)

Duplicate (Dup)
- Not a part of the 12 Steps of QA, an addition from the State of TN
- Why is this important?
  - Precision refers to the closeness of two or more measurements to each other
- Standard Methods 1020.B.8
  - As a minimum, include one duplicate sample with each sample set or on a 5% basis
- Standard Methods 1020.B.12
  - Calculate the RPD (relative percent difference)
  - Equal to or less than 20% RPD
Duplicate (Dup)

• What tests does this apply to?
  • BOD/CBOD, chlorine, pH, DO, TSS and Settleable Solids
• How often?
For samples that need to be analyzed on a 5% basis or once for every 20 samples follow these criteria: (10% would be once every 10 samples for TSS)
  • If a permit stated that 3 analyses per week, we would allow for a LFB to be analyzed at least once per month.
  • If a permit stated 5 analyses per week, we would suggest twice a month.
  • Once per month would be the minimum requirement.

Initial Calibration Verification & Continuing Calibration Verification

• ICV
  • Standard Methods 1020.B.11.b
  • Perform initial calibration using at least three concentrations of standards for linear curves.
  • Calibrate meter (DO, pH or ISE) or verify scale, colorimeter/spectrophotometer and thermometers.

• CCV
  • Standard Methods 1020.B.11.c
  • Analysts periodically use a calibration standard to confirm that the instrument performance has not changed significantly since initial calibration.
  • Verify calibration by analyzing one standard at a concentration near or at the mid-point of the calibration range.
  • Verify the calibration (especially if preset by manufacturer) at beginning of day, after every 10 readings and at the end of the batch.
  • Daily

Control Charts

• Accuracy Control Charts
  • Standard Methods 1020.B.13.a
  • The accuracy chart for QC samples (e.g., reagent blanks, LFBs, calibration check standards and LFMIs) is constructed from the average and standard deviation of measurements.
  • The accuracy chart includes upper and lower warning levels (WL) and upper and lower control levels (CL).
  • Common practice is to use ±2σ and ±3σ limits for the WL and CL, respectively, where σ represents standard deviation.

• Precision Control Charts
  • Standard Methods 1020.B.13.b
  • The precision chart also is constructed on the average and standard deviation of a specified number of measurements (e.g., %RSD [relative standard deviation] or RPD) for a replicate or duplicate analyses of the analyte of interest.

Corrective Action

• Standard Methods 1020.B.15
  • QC data that are outside the acceptance limits or exhibit a trend are evidence of unacceptable error in the analytical process.
  • Take corrective action promptly to determine and eliminate the source of error.
  • Do not report data until the cause of the problem is identified and either corrected or qualified (see Table 1020.II).
  • The corrective action plan needs to be in your SOP for each method on what to do if your QC tests fail or are out of range.
  • If you have a “boo boo”, write down how you fixed it.
  • Any issues should be recorded and a sentence on how it can be prevented, if possible, in the future.
  • Common problems and their corrections should be covered in your Standard Operating Procedures (SOP).
  • If you see things frequently, you can give them qualifiers that are noted in your SOP.

QC Acceptance

• Have in SOP for each method the acceptance ranges for standards, duplicates, spikes, etc. and make sure they match the method requirements.
  • If not mentioned in method, these are the accepted criteria for QC:
    – Blank < reporting limit
    – LFB ± 15%
    – MS/MSD ± 20%
    – ICV/CCV ± 10%
    – RPD ± 20%
**Batch Size & QC Frequency**

- Each “Batch” could be daily, every 10 samples or every 20 samples
- Check method
- If you sample only once a month, need to run QC each time
- QC Frequency is usually lumped in with the definition of a “batch” and should be in the SOP of some kind

**Ammonia SM4500-NH₃ D -2011**

- Standard Methods
  - 4500-NH₃ A.1 – In general, direct manual determination of low concentrations of ammonia is confined to drinking waters, clean surface or groundwater and good-quality nitrified wastewater effluent.
  - 4500-NH₃ D.1.b. – Sample distillation is unnecessary
- Tennessee recommends that one sample is run yearly to compare the distilled and undistilled results and that the results are within 20% of each other.
- Note – if distilled sample and undistilled sample are below detection limit, you cannot calculate the percent difference.

**Ammonia SM4500-NH₃ D -2011**

- DOC
- MDL
- LRB
- LFB
- LFM/LFMD
- ICAL/CCV
- Control Charts
- Corrective Action
- QC Acceptance
- Batch Size
- QC Frequency

**BOD₅/cBOD₅ SM5210 B – 2011 & Hach Method 10360**

- DOC
- LRB
- LFB
- Dup
- ICAL/CCV
- Control Charts
- Corrective Action
- QC Acceptance
- Batch Size
- QC Frequency

**BOD₅/cBOD₅ SM5210 B – 2011 & Hach Method 10360**

- Method Blanks
  - Real people language: analyze dilution water
  - Preferably one at the beginning and one at end
  - Run daily (every day of test set up)
  - Target value is less than 0.20 mg/L (preferably less than 0.10 mg/L)

**pH SM4500-H⁺ B – 2011 Electrometric Method**

- DOC
- Dup
- ICAL/CCV
- Corrective Action
- QC Acceptance
- Batch Size
- QC Frequency
TSS SM2540 D – 2011
Dried at 103-105°C

• DOC
• LRB
• LFB
• Dup
• ICAL
• MDL (blanks only)
• Corrective Action
• QC Acceptance
• Batch Size
• QC Frequency

Temperature SM2550 B – 2010
Thermometric Measurement

• ICAL
  – Have thermometers verified **annually** by an NIST thermometer
• Corrective Action
• QC Frequency

**Standard Operating Procedure**

• Here’s that “13th Step”, your SOP
• All procedures must be documented in some type of SOP
• It can be very simple but must provide the information necessary for someone who is not familiar with the test to perform it
  – Step by step instructions on how and where to collect the samples and then how to run the test
• It must include the QC Acceptance Criteria, the definition of a “Batch” and the minimum frequency of QC checks

**Standard Operating Procedure (SOP)**

• Describes the analytical method
• Sufficient detail that someone unfamiliar with the method could perform it and get satisfactory results
• Can include pictures (Ex: where samples are collected)
• It must include the QC Acceptance Criteria, the definition of a “Batch” and the minimum frequency of QC checks

**Standard Operating Procedure (SOP)**

• Should include:
  – Title of reference
  – Method #
  – Summary
  – Definitions
  – Interferences
  – Safety considerations
  – Equipment and supplies
  – Preservation and storage requirements
  – QC information
  – Etc...

**Standard Operating Procedure (SOP)**

• Annually:
  – Review/Update
    • Make any necessary adjustments
    • Changes to facility?
    • Changes to staff?
  – Document new Revision
  – Training
    • Have all analysts review/read
    • Have analysts sign off that they have done refresher
    • Documentation
Bench Sheets

- Where the analyst records the test results
- Even though data is transferred to the DMR, bench sheets are still an official record
- At a minimum, it should include:
  1. Date
  2. Time
  3. Analyst's initials
  4. Name of test/Method #
  5. Sample results
  6. Lot #s
Documentation

- Review of log books
  - Instrument calibration (daily)
  - Temperature
  - Maintenance
  - Sampler
  - Standard preparation
  - Calibration
- Lab instruments - yearly maintenance check (or more frequently)
  - Including thermometers and weights
- Flow measurement devices – yearly maintenance check

Any Questions?
Section 5

Microscopic Exam
Microscopic Exams

Wastewater Microbiology

The First Light Microscopes

• Around 1590 Zaccharias and Hans Janssen experimented with lenses in a tube, leading to the forerunner of the microscope and the telescope
• In the late 1600's, Anton van Leeuwenhoek was the first to see bacteria, yeast, and many other microbes using a microscope

Microscopes

• 2 types generally used
  1. Compound
     • High-magnification
     • 40x to 1000x
     • Monocular or binocular
  2. Stereoscopic or Dissecting
     • Lower magnification
     • 8x to 40x
     • Use for counting bacterial colonies (membrane filtration)
     • For objects too thick or large to be seen with higher magnifications, but too small for the naked eye

Microscopes

• Magnification usually written as a number followed by “x”
  – “x” stands for “times life size”
  – Ex: 10x means 10 times life size
• Magnification will be marked on the side of the objective lens

Microscopes

• All compound microscopes contain lens system consisting of:
  1. Objective lens
     • Produces the image (magnified)
     • Usually 4X, 10X, 40X
  2. Ocular (eyepiece)
     • Also magnifies the image (usually 10x)
     • May contain a pointer or counting grid
• Total magnification = magnification of ocular lens multiplied by magnification of objective lens
  – Ex: 40X (objective lens) x 10X (ocular lens) = 400X magnification

Section 5

TDEC Fleming Training Center

Microscopic Exam
**Compound Microscopes**

- **Objective lenses:**
  - 4x low power objective or “scanning objective”
  - 10x medium power objective
  - 40x high power objective
  - 100x “Oil immersion lens”
    - Use of immersion oil with this objective will increase resolving power (resolution)
    - Resolution = makes details clear and distinguishable

- **Moveable Stage**
  - With clips to hold the slide

- **Course Adjustment Knob**
  - Moves the stage in larger increments
  - Use with scanning objective (10x)
  - Never use this knob with 40x or 100x objectives

- **Fine Adjustment Knob**
  - Moves the stage in very small increments
  - Focusing

**Light source**
- “Illuminator” or lamp built into base
  - Adjustable light intensity
  - Mirror beneath stage, separate lamp required for illumination
  - Brightfield: light rays passed through a condenser that directs rays through specimen

- **Diaphragm**
  - Rotating disc diaphragm: different holes through which light passes
  - Iris diaphragm: aperture size is regulated by an adjustable arm on the side of the diaphragm’s case

**Procedure**

1. Always carry microscope with 2 hands: one on the arm and one under the base for support
2. Clean ocular and objective
   - Only use lens paper!
3. Rotate 4x scanning objective into place
4. Open iris diaphragm fully
5. Use coarse adjustment knob to bring slide closer to lens
6. Once you can see the object, use fine adjustment knob to sharpen the focus
7. While watching from the side, rotate to next higher objective
   - Only a minor adjustment with the fine adjustment knob should be needed to focus.
8. Repeat the above step until you get to the high power objective
   - Only use fine adjustment knob at this point!
9. If using immersion oil, move objectives until it is between 40x and 100x. Add one drop of oil onto slide, then slowly finish rotating 100x into position
Procedure (continued...)

• When you are finished with your exam, clean oil off of objective!
• To store scope:
  – move to low power objective
  – raise stage, wrap cord around base
  – lower stage gently to secure cord
  – add protective cover

Tips

• Always clean the lenses before beginning
• Always watch from the side when changing objectives
  – Never force the objective into place
• Watch from the side while making major adjustments with coarse knob to avoid ramming stage into objective lens
• Continually vary the light intensity to find the correct level
  – Excessive light eliminates color and contrast
  – You may need to increase light with higher objectives
• If you are seeing dark spiky things, it’s probably your eyelashes – try moving a little closer

Sample Collection

• Potential sampling areas
  • Aeration Basin
  • Suspect problematic areas
  • Mixed Liquor
  • WAS
  • RAS

Sample Collection

• 100 mL plastic bottles
• Select:
  • Mixed liquor from effluent side
  • Discharge from secondary clarifier center well
  • RAS pump discharge
  • Foam samples (if suspect)
  • Wastewater Influent/Effluent samples

How to Prepare a Wet Mount Slide

1. Clean slide & cover slip
2. Shake sample bottle, transfer 50 mL to beaker
3. Drop of sample to slide center
4. Hold cover slip at 45° above sample
5. Slide slip toward sample drop
6. Allow sample to spread to cover slip edge

How to Prepare a Wet Mount Slide

7. Drop slip into place on sample
8. Press slip w/ pencil eraser to spread
9. Absorb excess sample with tissue
10. ID the slide with appropriate markings
Slide Prep, Staining
• Clean slide & cover glass
• Drop of sample in center of slide
• Spread/smear sample w/ glass rod
• Air-dry (do not use a heat source...hair-dryer)
• Stain per Standard Methods, following protocol, or manufacturer instructions

Staining Types
• Gram stain
• Neisser stain
• India Ink reverse stain
• Polyhydroxybutyrate stain
• Crystal Violet Sheath stain

Gram Stains, How-To
1. Prepare thin smear of sample-air dry
2. Stain 1 minute w/ Gentian Violet - rinse 1 sec in water
3. Stain 1 minute w/ Gram’s Iodine solution, rinse well
4. Add Decolorizing agent drop-by-drop for 25 seconds, Blot dry

Gram Stains, How-To (continued...)
5. Stain w/ Safranin Solution for 1 minute
6. Examine using 1000X mag under oil immersion
   – Blue-Violet is Positive
   – Pink-Red is Negative

Microorganism Review

Bacteria
• Convert dissolved organic material
  – Phosphates
  – Sugars
  – Proteins
  – Starches
• Comprise about 95% of activated sludge
  – Most are soil bacteria
• Aerobic, Anaerobic, Facultative
• Sphere (coccus), rod (bacillus), and spiral (spirillum)
Filaments (Filamentous Bacteria)
- Some filaments OK for floc formation
  - Forms a backbone of sorts
- Grow in long thread-like strands
- If you have excessive filaments:
  - Check DO levels > 1 PPM
  - Nutrients (N, P, FE)
  - pH
- No Filaments?
  - Check F/M ratio
  - Check DO, reduce if > 3.0 PPM

Protozoa
- Abundant & diverse in activated sludge process
- Inactive?
  - Toxic shocks?
- No Protozoa?
  - F/M too high: Reduce wasting, increase return
  - Low to normal F/M: Increase DO, toxic shock
- Healthy protozoa, but dispersed floc?
  - Reduce mixing, reduce aeration

Amoebae
- Earliest organism that show-up in activated sludge process
- Associated with “young sludge”
- Feed by pseudopodia (false feet)
  - Engulf small of organic matter
- Often encyst themselves in wastewater

Flagellates
- Tail-like structure which whips back & forth for mobility
- Activated sludge activator
- Some feed on bacteria and small algae
- Others feed on soluble organic nutrients
  - Dominate early in treatment process when nutrients are high
  - Compete with bacteria

Free & Stalked Ciliates
- Highly prized in wastewater activated sludge
- Associated w/ good settleability
- Low suspended solids
- Organism in sweeping motion
- Sweeping effect by ciliates gather small particles to form floc
- Settle rapidly
- Requires good bright microscopy to see these organisms
- Phase contrast may offer better visibility

Free & Stalked Ciliates
Free Swimming Ciliates
Stalked Ciliates
**Rotifers**

- Rotary sweeping organism that pull small particles into mouth
- Constant movement
- Wastewater plants may prefer larger numbers in activated sludge process
- Better settling
- In some wastewater, higher numbers mean old sludge and more wasting needs
- Best viewed with bright microscopy at 300X to 400x

**Nematodes**

- Roundworms that feed on organic matter and bacteria
- Associated with old sludge
- Substantial numbers usually a sign to increase wasting rates
- Some are predators feeding upon protozoa, rotifers
- Best viewed upon Bright Microscopy at 300X

**Algae/Fungi**

- Lagoon or pond type organisms
- Contribute to SS
- Add oxygen in sunlight
- Control or harvest is essential
- Best viewed with bright microscopy at <400X
- Phase contrast helps identify species

**Scope Care & Maintenance**

- Never touch lens
- Never leave slide on stage when not in use
- Always remove oil from objective
- Stage should be clean
- Do not tilt microscope when using oil
- Keep microscope covered when not in use
- Store in cabinet when not in use
- Regular professional service

**Troubleshooting**

- Image is too dark!
  - Adjust the diaphragm, make sure your light is on
- Only half of my viewing field is lit, it looks like there's a half-moon in there!
  - You probably don't have your objective fully clicked into place

**Troubleshooting (continued...)**

- There's a spot in my viewing field, even when I move the slide the spot stays in the same place!
  - Your lens is dirty.
  - Use lens paper, and only lens paper to carefully clean the objective and ocular lens.
  - The ocular lens can be removed to clean the inside
Troubleshooting (continued...)

• I can’t see anything under high power!

➢Remember the steps: if you can’t focus under scanning and then low power, you won’t be able to focus anything under high power
Section 6

Sludge Thickening, Digestion and Dewatering
Sludge Thickening, Digestion, and Dewatering

- or -

Now What Do We Do With It?

Process Overview

1. Solids from preliminary treatment are sent to landfill
   - Screenings (coarse solids), grit, scum
2. Primary and secondary solids are most often treated onsite
   - Primary sludge usually is grey and slimy with an offensive odor
   - Sludge from activated sludge and trickling filter has brown, flocculant appearance, both digest readily
3. Sludge from chemical precipitation with metal salts
   - Usually dark in color and may be gelatinous
   - Decomposes slowly and may give off large amounts of gases

Sludge Thickening, Digestion, and Dewatering

- Thickening
- Gravity
- Gravity belt
- Dissolved Air Flotation (DAF)
- Stabilization
- Anaerobic digestion
- Aerobic digestion
- Dewatering
- Centrifuge
- Plate and frame
- Belt filter press
- Vacuum filter
- Drying beds

Sludge Thickening

Main component of sludge is water

~90% or more before treatment
Gravity Thickening

- Most effective on primary sludge
- Detention time is around 24 hours
- Thickening tank looks like a primary circular clarifier
- Monitored for blanket depth and sludge concentration
- Affected by temperature of sludge
- Increased temperature will increase biological activity and gas production

Gravity Belt Thickener

- Concentrates solids on a porous horizontal belt
- Sludge usually preconditioned with polymer
- Water drawn by gravity through the belt
- Can thicken secondary sludge to 4–7% solids

Dissolved Air Flotation Thickening (DAF)

- Two components:
  1. Saturator - dissolves air into water under pressure
  2. Pressure saturated water introduced to the flotation unit
  3. Air bubbles attach to the solids and carry them to the surface - they accumulate as a float (This is the separation of solids/liquids stage)
  4. Solids (“Float cake”) continuously removed by scraping
  5. Drainage of intestinal water from the float above the water level increases solids concentration (This is the thickening stage)
Dissolved Air Flotation Thickening (DAF)
- Principle factor affecting thickening during flotation = Drainage of float layers above the water level

- Cake 2-4% solids vs 3-5% solids with polymer

Biosolids Stabilization (Digestion)
Reduce volume
Stabilize organic matter
Eliminate pathogenic organisms

Stabilization
- Helps to avoid odor problems
- Prevents breeding of insects
- Reduces the number of pathogenic organisms

- Sludges can be stabilized 2 ways:
  1. Anaerobically (in anaerobic digester, sludge heated and organics hydrolyzed into methane (CH₄), CO₂, and H₂O, and volatile solids reduced)
  2. Aerobically (in unheated digester, producing CO₂ and H₂O, and reducing volatile solids)

General Overview
Before digestion of 100 pounds of sludge: 75% Volatile, 25% Fixed Solids

<table>
<thead>
<tr>
<th>75 Lbs VS</th>
<th>25 Lbs Fixed</th>
</tr>
</thead>
</table>

After a 65% reduction in Volatile Solids there is less sludge remaining to process

| 50 Lbs of CH₄, CO₂, H₂O | 25 Lbs VS | 25 Lbs Fixed |
Biosolids Stabilization

Anaerobic Digestion

- Anaerobic Digestion reduces wastewater solids from a sticky, smelly mixture to a mixture that is relatively odor free, dewaterable and capable of being disposed of without causing a nuisance.
- In this process organic solids in the sludge are liquefied, the solids volume is reduced, and valuable methane gas is produced in the digester by the action of two different groups of bacteria living together in the same environment.
  1. Saprophytic organisms, commonly referred to as "acid formers."
  2. "Methane producers" use the acid produced by the saprophytes

Anaerobic Digestion

- 2-phase process:
  - Acid formers - Facultative bacteria convert organic matter to volatile acids, CO₂, and H₂S
  - Methane producers - Anaerobic bacteria convert acids to CH₄ and CO₂
    - The methane producers are not as abundant in raw wastewater as are the acid formers.
    - The methane producers desire a pH range of 6.6 to 7.6 and will reproduce only in that range.
  - 28-40% carbon dioxide, 60-72% methane
  - Minimum methane for reuse is 62%
  - Sludge retention time is 30-60 days

Anaerobic Digestion

- The object of good digester operation is to maintain conditions in the digester for growing (reproducing) populations of both acid formers and methane fermenters.
- You must do this by controlling:
  - Loading rate of food supply (organic solids/COD)
  - Volatile acid/Alkalinity ratio
  - Mixing
  - Temperature

Anaerobic Digestion

- Removes 50-65% VS and 85-99% of pathogens
- Wastewater solids and water are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen.
- The purpose of sludge digestion is to decrease the bulk of sludge to facilitate handling, to decompose enough of the organic matter to avoid creating a nuisance and to separate the liquid from the solids to facilitate drying.
- At least two general groups of bacteria act in balance: Saprophytic Bacteria and Methane Producers break down the acids to methane, carbon dioxide, and water.

Temperature Ranges

- Heated units operate ~ 90-95°F
- An anaerobic digester may be operated in one of three temperature zones or ranges, each of which has its own particular type of bacteria.
  - Cold temperature - Psychrophilic bacteria
  - Medium temperature - Mesophilic bacteria
  - Hot temperature - Thermophilic bacteria

Sludge Thickening, Digestion, and Dewatering

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Psychrophilic Bacteria

- The lowest range (in an unheated digester) utilizes Psychrophilic (cold temperature loving) bacteria.
- The psychrophilic upper range is around 68°F (20°C).
- Digestion in this range requires from 50 to 180 days, depending upon the degree of treatment or solids reduction required.

Mesophilic Bacteria

- Organisms in the middle temperature range are called the Mesophilic (medium temperature loving) bacteria.
- Thrive between about 68°F (20°C) and 113°F (45°C).
- The optimum temperature range is 85°F (30°C) to 100°F (38°C), with temperatures being maintained at about 95°F (35°C) in most anaerobic digesters.
- Digestion at 95°F may take from 5 to 50 days or more (normally around 25 to 30 days), depending upon the required degree of volatile solids reduction and adequacy of mixing.

Thermophilic Bacteria

- Organisms in the third temperature range are called Thermophilic (hot temperature loving) bacteria and they thrive above 113°F (45°C).
- The optimum temperature range is considered 120°F (49°C).
- The time required for digestion in this range falls between 5 and 12 days, depending upon operational conditions and degree of volatile solids reduction.
- However, the problems of maintaining temperature, sensitivity of the organisms to temperature change, and some reported problems of poor solids - liquid separation are reasons why only a few plants have actually been operated in the thermophilic range.

Changing Temperatures

- You can’t change temperature and expect a quick change in bacteria population and therefore a shorter digestion time.
- An excellent rule for digestion is never change the temperature more than one degree a day to allow the bacterial culture to become acclimated (adjust to the temperature changes).

Anaerobic Digestion

- Several products end up in the digester that are not desirable because the bacteria can’t effectively use or digest them, and they can’t be readily removed by the normal process.
  - Petroleum products and mineral oils
  - Rubber goods
  - Plastics (back sheets to diapers)
  - Filter tips from cigarettes
  - Hair
  - Grit (sand and other inorganics)

Anaerobic Digestion

- When wastewater solids are first added to a new digester, naturally occurring bacteria attack(eat) the most easily digestible food available, such as sugar, starches, and soluble nitrogen.
- The anaerobic acid producers change these foods into organic acids, alcohols, and carbon dioxide, along with some hydrogen sulfide.
- The pH of the sludge drops from 7.0 to about 6.0 or lower.
- An acid regression stage then starts and lasts as long as six to eight weeks.
Anaerobic Digestion
- During this time ammonia and bicarbonate compounds are formed, and the pH gradually increases to around 6.8 again, establishing an environment for the methane fermentation or alkaline fermentation phase.
- Organic acids are available to feed the methane fermenters.
- Larger quantities of methane gas are produced as well as carbon dioxide, and the pH increases to 7.0 to 7.2.
- Once alkaline fermentation is well established, strive to keep the digesting sludge in the 7.0 to 7.2 range.

Feeding Anaerobic Digester
- Better operational performance occurs when the digester is fed several times a day, rather than once a day because you are avoiding temporary overloads on the digester and you are using your available space more effectively.
- Several pumpings a day not only helps the digestion process, but maintains better conditions in the clarifiers, permits thicker sludge pumping, and prevents coning in the primary clarifier hopper.
- Never pump thin sludge or water to a digester.
- A sludge is considered thin if it contains less than 5% solids (too much water).
- Thick a sludge as possible = operating sludge pump for several minutes each hour (at a rate not to exceed 50 GPM)

Cross-Section of an Egg-Shaped Digester

Anaerobic Digesters
- Fixed Cover Tanks
  - Holds a larger volume of gas
  - Must be equipped with pressure and vacuum relief valves to break the vacuum or bleed off excessive pressure to protect from structural damage
  - If air is drawn into tank, explosive conditions could develop
- Floating Cover Tanks
  - Moves up and down with tank level and gas pressure
  - Flotation chamber: in the roof of cover, prevents cover from sinking
  - Less danger of explosives
  - Better control of supernatant withdrawal
  - Better control of scum blankets
Anaerobic Digesters - Covers

Source: Operation of Municipal Wastewater Treatment Plants, Vol III, Sixth Ed., p. 30-14

Anaerobic Digestion – Normal Ranges

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge retention time</td>
<td>30 – 60 days (Heated)</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>90 – 95 ºF (Heated)</td>
</tr>
<tr>
<td>Volatile Solids Loading</td>
<td>0.04 – 0.1 lb VM/day/ft³</td>
</tr>
<tr>
<td>% Methane in gas</td>
<td>60 – 72%</td>
</tr>
<tr>
<td>% Carbon Dioxide in gas</td>
<td>28 – 40%</td>
</tr>
<tr>
<td>pH</td>
<td>6.8 – 7.2</td>
</tr>
<tr>
<td>Volatile acids: alkalinity ratio</td>
<td>≤ 0.1</td>
</tr>
<tr>
<td>Volatile solids reduction</td>
<td>40 – 60%</td>
</tr>
</tbody>
</table>

* For every 1 lb. of VM destroyed, 12-18 ft³ of gas is produced.

Anaerobic Digestion

- Volatile Acids to Alkalinity Ratio
  \[
  \text{Ratio} = \frac{\text{volatile acids concentration, mg/L}}{\text{alkalinity concentration, mg/L}}
  \]
- Most important factor to monitor
- Can be used to control operation of anaerobic digester
- Very sensitive indicator of process condition
- One of the first indicators that the digester is going sour
- Must monitor alkalinity in lab
- Indication of the buffer capacity of the digester
- High buffer capacity desired & achieved by a low ratio

Acid-Alkalinity Relationship

<table>
<thead>
<tr>
<th>Condition</th>
<th>V.A./ALK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum</td>
<td>0.05 - 0.1</td>
</tr>
<tr>
<td>Stress</td>
<td>0.3 - 0.4</td>
</tr>
<tr>
<td>Deep Trouble</td>
<td>0.5 - 0.7</td>
</tr>
<tr>
<td>Failure</td>
<td>0.8 and above</td>
</tr>
</tbody>
</table>

- Once ratio reaches 0.5, serious decreases in the alkalinity usually occur
- Concentration of CO₂ will start to increase

Acid-Alkalinity Relationship

- As long as volatile acids remain low and the alkalinity stays high, anaerobic sludge digestion will occur in digester
- Measure volatile acid/alkalinity relationship at least 2x/week
- Plot the volatile acid/alkalinity relationship against time and watch for any adverse trends
- If ratio starts to rise = problem developing – your 1st sign!
- Action steps:
  1. Extend mixing time
  2. Control heat more evenly
  3. Decrease raw sludge feed rates
  4. Decrease digested sludge withdrawal rates

Acid-Alkalinity Relationship

- Mixing
  - Puts microorganisms in contact with food
  - Controls pH, distributes buffering alkalinity
  - Distributes heat throughout the tank
  - Mixing combined with heating speeds up the digestion rate
Anaerobic Digestion

Mechanical mixing – most common method:
- Shaft-driven propeller extended down into sludge
- Susceptible to wear
- Cleaning and replacement necessary

Other methods:
- Propeller with draft tube
- Bubble-gun type
- Jet mixing

Anaerobic Digestion

<table>
<thead>
<tr>
<th>Anaerobic Digestion – Sludge Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loss of alkalinity</strong></td>
</tr>
<tr>
<td>&lt; 4% Solids</td>
</tr>
<tr>
<td>Decreased Sludge retention time</td>
</tr>
<tr>
<td>Increased heating requirements</td>
</tr>
<tr>
<td>Decreased volatile acid/alkalinity ratio</td>
</tr>
<tr>
<td>4 – 8% Solids</td>
</tr>
<tr>
<td>Normal Operation</td>
</tr>
<tr>
<td>&gt; 8% Solids</td>
</tr>
<tr>
<td>Poor mixing</td>
</tr>
<tr>
<td>Organic overloading</td>
</tr>
<tr>
<td>Decreased volatile acid/alkalinity ratio</td>
</tr>
</tbody>
</table>

Anaerobic Digestion

- Foaming
  - Problems: odors, excess pressure on cover, plugs gas piping system
  - Cause: Gas production at startup with insufficient solids separation (Insufficient digestion)
  - Prevention: Adequate mixing before foaming starts

Anaerobic Digestion: Neutralizing a Sour Digester

- A digester can be compared with your own body.
  - Both require food; but if fed too much will become upset.
  - Excess acid will upset both.
- Sour digester?
  - Lime
    - Lime is added at a 1:1 ratio, 1 lb of lime for every 1 lb or volatile acid
  - Soda ash
  - Transfer alkalinity from secondary digester to primary

Neutralizing a Sour Digester

- The recovery of a sour digester can be accelerated by neutralizing the acids with a caustic material such as anhydrous ammonia, soda ash, or lime, by transferring alkalinity in the form of digested sludge from the secondary digester.
  - Such neutralization reduces the volatile acid/alkalinity to a level suitable from growth of the methane fermenters and provides buffering material which will help maintain the required volatile acid/alkalinity relationship and pH.
  - If digestion capacity and available recovery time are great enough, it is probably preferable to simply reduce loading while heating and mixing so that natural recovery occurs.
Neutralizing a Sour Digester

- When neutralizing a digester, the prescribed dose must be carefully calculated.
- Too little will be ineffective, and too much is both toxic and wasteful. In considering dosage with lime, the small plant without laboratory facilities could use a rough guide a dosage of about one pound of lime added for every 1000 gallons of sludge to be treated.
- Stuck Digester - A stuck digester does not decompose organic matter properly.
- The digester is characterized by low gas production, high VA/alk relationship, and poor liquid-solids separation.
- A digester in a stuck condition is sometimes called a “sour” or “upset” digester.

Gas Production

- The anaerobic digestion process (depending on the characteristics of the sludge) produces
  - B-12 ft³ of gas for every pound of volatile matter added
  - 12-18 ft³ for every pound of volatile matter destroyed
- When methane fermentation starts and the methane content reaches around 60%, the gas will be capable of burning.
- Methane production eventually should predominate, generating a gas with 65-70% methane and 30-35% carbon dioxide by volume.
- Digester gas will burn when it contains 56% methane, but is not usable as a fuel until the methane content approaches 62%.

Gas Production

- Digester gas is used in plants in various ways:
  - For heating and mixing the digesters
  - Heating the plant buildings
  - Running engines
  - Air blowers for the activated sludge process
  - Electrical power for the plant
- Note: It is dangerous to start a digester when it is only partially full due to explosive conditions created by the mixture of air and methane

Supernatant and Solids

- Two separate digestion tanks or 1 tank with 2 divided sections
- Tank 1: Primary digester
  - Heating, mixing, breakdown of raw sludge
  - Binding property of sludge is broken = water released
- Tank 2: Secondary digester
  - Holding tank for separation of the solids from the liquor
  - Settled solids compact = minimal water in sludge dewatering system

Biosolids Stabilization

Aerobic Digestion

- Purpose: to extend decomposition of solids and regrowth of organisms to a point where available energy in active cells and storage of waste materials are low enough and material is stable enough for ultimate disposal
- Extended aeration of wastewater
  - Wastes stabilized by long-term aeration of about 10-20 days
  - Check pH weekly and adjust if less than 6.5
  - Lower equipment costs than anaerobic (but higher energy costs)
  - Less noxious odors at DO ≥ 1 mg/L
  - Better on secondary sludge than primary sludge
  - Sludge has higher water content
  - By products: residual solids, CO₂, H₂O, SO₄⁻, NO₃⁻
Aerobic Digestion

- Aerobic digesters are operated under the principle of extended aeration from the activated sludge process relying on the mode or region called endogenous respiration.
- Aerobic digestion consists of continuously aerating the sludge without the addition of new food, other than the sludge itself, so the sludge is always in the endogenous region.

Comparison Between Anaerobic and Aerobic Digestion

<table>
<thead>
<tr>
<th>Anaerobic Digestion</th>
<th>Aerobic Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not use aeration</td>
<td>Aeration equipment—oxygenation, mixing</td>
</tr>
<tr>
<td>Fresh wastes</td>
<td>Partially stabilized solids</td>
</tr>
<tr>
<td>Putrefaction</td>
<td>Produces fewer odors</td>
</tr>
<tr>
<td>Concentrates sludge</td>
<td>Higher water content sludge</td>
</tr>
<tr>
<td>Produces solids, water, etc.</td>
<td>Produces residual solids, water, etc</td>
</tr>
<tr>
<td>Liquids that are difficult to treat</td>
<td>Liquids that are easier to treat</td>
</tr>
</tbody>
</table>

Aerobic Digestion – Normal Ranges

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detention time (days)*</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Volatile Solids Loading (lb/ft³/day)</td>
<td>0.1 – 0.3</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>1.0** to 2.0</td>
</tr>
<tr>
<td>pH</td>
<td>5.9 – 7.7</td>
</tr>
<tr>
<td>Volatile Solids Reduction</td>
<td>40 – 50%</td>
</tr>
</tbody>
</table>

*To meet Class B standards for pathogen reduction, SRT ≥ 60 days at 20°C or ≥ 60 days at 15°C
**Strive to maintain DO level of 1.0 mg/L

Sludge Dewatering

- Dewatering reduces sludge moisture and volume to allow for more economical disposal
  1. Mechanical Dewatering:
     - Centrifuge*
     - Plate and Frame Press
     - Belt Press
     - Vacuum Filter*
  2. Drying Beds
  3. Blacktop Drying Beds
  4. Sludge Lagoon/Withdrawal to Land

Centrifuge

- Used to thicken or dewater raw or secondary sludges
- Sludge fed at constant rate into rotating horizontal bowl
- Solids separated from liquid and compacted by centrifugal force (1000 – 2000 rpm)
- Condition of sludge cake and the quality of the centrate are regulated by:
  - Sludge feed rate
  - Bowl speed
  - Chemical conditioners
    - Dosage rates
    - Pool depth
Plate-and-Frame

- Solids are pumped in batches into spaces between plates
- 200 – 250 psi pressure applied to squeeze out water
- At end of cycle (1.5 – 4 hours), plates are separated and solid drops out onto conveyor
- Pressure filtration that forces liquid through the filter media

Plate-and-Frame

- Modified plate and frame that is vacuum assisted
- Steam heated at 163.4°F for 30 min
- Entire process takes about 4 hours

Belt Filter Press

- Principle of filtration
- Low power use
- Reliable
- Continuous operation
- Two long belts that travel over a series of rollers
- Sludge applied to free water zone (much water will drain off here)
- Solids then squeezed between a series of rollers (and more water is removed)
- Remaining solids are scraped from the belt
- Belts are washed and the process repeats
**Belt Filter Press**

- Problem: Washout
  - “belt blinding” or “plugging” – result of inadequate belt washing or chemical blinding
  - Manually clean belts with high-pressure hose to restore at least some of the drainage
  - Polymer dose and belt speed too low
  - Hydraulic load too high

- Problem: Cake solids too wet
  - Belt speed too high
  - Belt tension too low

**Vacuum Filter**

- Dewatering aerobically or anaerobically digested sludge requires washing the sludge first and then conditioning it with chemicals
- Elutriation = washing of digested sludge with either fresh water, plant effluent, or other wastewater
  - To remove fine particulates and/or alkalinity
  - Reduces demand for conditioning chemicals and improves settling/filtering
- Sludge pumped into a tank around a partially submerged rotating drum
- Drum rotates, vacuum collects solids on surface
- Vacuum removes excess water
- Vacuum is then released and solids are removed

**Drying Bed**

- Simplest of all methods
- Sludge deposited in layer on sand bed or other surface with drain
- Dewatering occurs by drainage and evaporation
- Drying bed constructed with underdrain system covered with coarse, crushed rock
  - Over rock is layer of gravel, then layer of pea gravel covered with 6-8 inches of sand
  - Time required is affected by climate, depth of solids, and type of solids
  - Sometimes drying beds are covered while others have vacuum assisted drainage
- Blacktop Drying Bed is a variation

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**Source:** Operation of Municipal Wastewater Treatment Plants, Vol III, Sixth ed., p. 33-64
From Digesters

1. Fewer (most probable number) of fecal coliforms per gram of total solids

40 CFR 503 – Pollutant Limits

- Land applier is required to keep records of the amounts of each regulated pollutant applied to the site over time to ensure that the maximum allowable amounts are not exceeded.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Monthly applied concentration (milligrams per kilogram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>41</td>
</tr>
<tr>
<td>Cadmium</td>
<td>39</td>
</tr>
<tr>
<td>Copper</td>
<td>1600</td>
</tr>
<tr>
<td>Lead</td>
<td>200</td>
</tr>
<tr>
<td>Mercury</td>
<td>17</td>
</tr>
<tr>
<td>Nickel</td>
<td>400</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
</tr>
<tr>
<td>Zinc</td>
<td>2000</td>
</tr>
</tbody>
</table>

- Dry weight basis.

40 CFR 503 – Pathogen Reduction

- If the sludge is prepared for land application or surface disposal, it must comply with applicable pathogen reduction requirements.

1. Class A
   - Class A pathogen reduction alternatives render the sewage sludge virtually pathogen free after treatment

2. Class B
   - Class B pathogen reduction alternatives significantly reduce but do not eliminate all pathogens

40 CFR 503 – Vector Attraction Reduction

- Vectors are animals and insects (e.g., rodents, flies, birds) that might be attracted to sewage sludge and, therefore, could transmit pathogenic organisms (if any are present) to humans.

- Vector attraction reduction is to reduce the attraction of vectors (flies, mosquitoes, and other potential disease-carrying organisms) to the biosolids or sludge.

- 1 of 10 options specified in part 503 to achieve vector attraction reduction must be met when biosolids are applied to land.
40 CFR 503 – Vector Attraction Reduction

1. Reduce the mass of volatile solids by a minimum of 38%
2. Demonstrate vector attraction reduction with additional anaerobic digestion in a bench-scale unit
3. Meet a specific oxygen uptake rate for aerobically treated biosolids
4. Use aerobic processes at greater than 40°C (avg. temp 45°C) for 14 days or longer (during biosolids composting)
5. Add alkaline materials to raise the pH under specified conditions

40 CFR 503 – Vector Attraction Reduction (continued)

5. Reduce the moisture content of biosolids that do not contain unstabilized solids from other than primary treatment to at least 75% solids
6. Reduce the moisture content of biosolids with unstabilized solids to at least 90%
7. Inject biosolids beneath the soil surface within a specified time, depending on the level of pathogen treatment
8. Incorporate biosolids applied to or placed on the land surface within specified time periods after application to or placement on the land surface

40 CFR 503 Regs

- If your wastewater plant has a design influent flow rate equal to or greater than 1 million gallons per day, or serves a population of 10,000 or more, or Class I Sludge management facilities (State of Tennessee Industrial Pretreatment Program) you must report annually to the permitting authority.
- Annual reports cover information and data collected during the calendar year (January 1 to December 31) and are due February 19, every year and submitted to the permitting authority, which is the EPA Regional IV Office for Tennessee.
CHAPTER 12

Sludge Processing and Disposal

12.1 General

12.1.1 Definition
12.1.2 Total Systems Approach To Design
12.1.3 Recycle Streams
12.1.4 Multiple Units
12.1.5 Sludge Pumps
12.1.6 Sludge Piping

12.2 Sludge Production

12.3 Thickening

12.3.1 General
12.3.2 Gravity Thickeners
12.3.3 Flotation Thickeners
12.3.4 Centrifugal Thickeners
12.3.5 Other Thickeners

12.4 Conditioning

12.4.1 General
12.4.2 Chemical

12.5 Digestion

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12.6 Composting

12.7 Sludge Dewatering

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12.7.2 Sludge Drying Beds
12.7.3 Mechanical Dewatering

12.8 Sludge Storage Lagoons

12.9 Sludge Disposal
SLUDGE PROCESSING AND DISPOSAL

12.1 General

12.1.1 Definition

Sludge is a broad term used to describe the various aqueous suspensions of solids encountered during treatment of sewage. The nature and concentration of the solids control the processing characteristics of the sludge. Grit screenings and scum are not normally considered as sludge and therefore are not discussed in this section.

12.1.2 Total Systems Approach to Design

The most frequently encountered problem in wastewater treatment plant design is the tendency to optimize a given subsystem, such as sludge dewatering, without considering the side effects of this optimization on the overall plant operation and treatment costs.

Sludge handling processes can be classified as thickening, conditioning, stabilization, dewatering, and disposal. Numerous process alternatives exist within each of these categories. Each unit process should be evaluated as part of the total system, keeping in mind that the objective is to use that group of processes that provides the most cost-effective method of sludge disposal.

The analysis should include a materials balance to identify the amounts of material which enter, leave, accumulate, or are depleted in the given process and the system as a whole. Energy requirements should also be provided to aid in determining capital and operating costs of the total system.

12.1.3 Recycle Streams

Recycle streams from the process alternatives, including thickener overflow, centrate, filtrate, and supernatant, should be returned to the sewage treatment process at appropriate points to maintain effluent quality within the limits established. Volume and strength of each recycle stream should be considered in the plant design. Sidestream treatment should be provided if the load is not included in the plant design or if the side stream will upset the treatment process. Equalization of side streams should be considered to reduce instantaneous loading on the treatment process.

12.1.4 Multiple Units

Multiple units and/or storage facilities should be provided so that individual units may be taken out of service without unduly interrupting plant operation.
12.1.5 Sludge Pumps

12.1.5.1 Capacity

Pump capacities should be adequate to maintain pipeline velocities of 3 feet per second. Provisions for varying pump capacity are desirable.

12.1.5.2 Duplicate Units

Duplicate units shall be provided where failure of one unit would seriously hamper plant operation.

12.1.5.3 Type

Plunger pumps, progressing cavity pumps, or other types of pumps with demonstrated solids handling capability should be provided for handling raw sludge.

12.1.5.4 Minimum Head

A minimum positive head of 24 inches (or the manufacturer's recommendation) should be provided at the suction side of centrifugal-type pumps and is desirable for all types of sludge pumps. Maximum suction lifts should not exceed 10 feet (or the manufacturer's recommendation) for plunger pumps.

12.1.5.5 Sampling Facilities

Unless sludge sampling facilities are otherwise provided, quick-closing sampling valves should be installed at the sludge pumps. The size of valve and piping should be at least 1-1/2 inches.

12.1.6 Sludge Piping

12.1.6.1 Size and Head

Sludge withdrawal piping shall have a minimum diameter of 8 inches for gravity withdrawal and 6 inches for pump suction and discharge lines. Where withdrawal is by gravity, the available head on the discharge pipe should be at least 2 feet and preferably more, with provisions to backflush the line.
12.1.6.2 Slope

Gravity piping shall be laid on uniform grade and alignment. Slope on gravity discharge piping should not be less than 3 percent.

12.1.6.3 Cleaning

Provision should be made for draining and flushing suction and discharge lines. Where sludge pumps are available, piping should be such that suction lines can be backflushed with pump discharge or rodded. Glass-lined or equivalent pipe should be considered for raw sludge piping and scum lines.

12.1.6.4 Corrosion Resistance

Special consideration shall be given to the corrosion resistance and continuing stability of pipes and supports located inside digestion tanks.

12.2 Sludge Production

The sludge production rates listed in the literature have often been shown to be underestimated. The sludge production rates (SPR) listed below in Table 12-1 have been determined from various studies and provide a more realistic basis for designing solids handling facilities. These values shall be used for design unless other acceptable data is submitted.

<table>
<thead>
<tr>
<th>Type of Treatment</th>
<th>SPR (lb BOD removed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Activated Sludge</td>
<td>0.85</td>
</tr>
<tr>
<td>Extended Aeration</td>
<td>0.75</td>
</tr>
<tr>
<td>Contact Stabilization</td>
<td>1.00</td>
</tr>
<tr>
<td>Other Activated Sludge</td>
<td>0.85</td>
</tr>
<tr>
<td>Trickling Filter</td>
<td>0.75</td>
</tr>
<tr>
<td>Roughing Filters</td>
<td>1.00</td>
</tr>
</tbody>
</table>
12.3 Thickening

12.3.1 General

The cost-effectiveness of sludge thickening should be considered prior to treatment and/or disposal.

12.3.1.1 Capacity

Thickener design should provide adequate capacity to meet peak demands.

12.3.1.2 Septicity

Thickener design should provide means to prevent septicity during the thickening process. Odor consideration should be considered.

12.3.1.3 Continuous Return

Thickeners should be provided with a means of continuous return of supernatant for treatment. Provisions for side-stream treatment of supernatant may be required.

12.3.1.4 Chemical Addition

Consideration should be given to the use of chemicals or polymer to improve solids capture in the thickening process. This will not normally increase the solids level of the thickened sludge.

12.3.2 Gravity Thickeners

12.3.2.1 Stirring and skimming

Mechanical thickeners should employ pickets on rake arms for continuous gentle stirring of the sludge. Skimmers should be considered for use with biological sludges.

12.3.2.2 Depth and Freeboard

Tank depth shall be sufficient so that solids will be retained for a period of time needed to thicken the sludge to the required concentration and to provide storage for fluctuations in solids loading rates. The thickener should be operated to avoid denitrification. At least two feet of freeboard shall be provided above the maximum water level.
12.3.2.3 Continuous Thickening

Variable-speed sludge draw-off pumps may be provided so that thickening can be continuous, or an adjustable on-off time clock control for pulse withdrawal may be used with constant-speed pumps to improve control over the thickening.

12.3.2.4 Solids and Surface Loading Rates

The engineer shall provide the design basis and calculations for the solids and surface loading rates and the support calculations upon request. Thickener solids loading rates vary with the type of sludge. Some typical solids loading rates are given below in Table 12-2. These values shall be used for design unless other acceptable data are submitted. For loading rates of other type sludges, refer to Table 5.2 of the EPA Process Design Manual-Sludge Treatment and Disposal.

<table>
<thead>
<tr>
<th>Type of Sludge</th>
<th>(lb/day/sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>20-30</td>
</tr>
<tr>
<td>Activated sludge</td>
<td>5-6</td>
</tr>
<tr>
<td>Trickling filter</td>
<td>8-10</td>
</tr>
<tr>
<td>Primary and activated combined</td>
<td>6-10</td>
</tr>
<tr>
<td>Primary and trickling filter</td>
<td>10-12</td>
</tr>
</tbody>
</table>

Surface loading rates of 400 gallons per day per square foot (gpd/sq ft) or less will normally result in septic conditions. To prevent septic conditions, surface overflow rates should be maintained between 500 and 800 gpd/sq ft. For very thin mixtures or WAS only, hydraulic loading rates of 100-200 gpd/sq ft are appropriate. An oxygen-rich water source, such as secondary effluent, shall be available as a supplemental flow to the thickener to achieve the necessary overflow rates.

The diameter of a gravity thickener should not exceed 80 feet.
12.3.2.5 Bottom Slope

Bottom slopes shall be sufficient to keep the sludge moving toward the center well with the aid of a rake. Generally, the slope should be greater than conventional clarifiers. A floor slope of 2-3 inches per foot is recommended.

12.3.3 Flotation Thickeners

Flotation thickeners are normally used to concentrate waste activated sludge.

12.3.3.1 Air-Charged Water

The thickener underflow is generally used as a source of water for the air-charging units, although primary tank effluent or plant effluent may also be used.

12.3.3.2 Design Sizing

The engineer shall provide the design basis for sizing the units and for the support calculation. Design sizing should be based on rational calculations, including: total pounds of waste sludge anticipated, design solids and hydraulic loading of the unit, operating cycle in hours per day per week, removal efficiency, and quantity and type of chemical aids required. Flotation thickeners are normally sized by solids surface loadings.

Typical design loadings range from 1.0 to 2.5 pounds per hour per square foot. (See Table 12-3, for typical solids loading rates to produce a minimum 4% solids concentration.)

12.3.3.3 Hydraulic Loading Rates

If polymers are used, hydraulic loading rates of 2.5 gpm/sq ft or less should be used. The hydraulic loading rates shall be lower if polymers are not used. Hydraulic loading rates shall be based on the total flow (influent plus recycle). The design of any thickened sludge pump from DAF units should be conservative. Frequently, polymer conditioned sludge will result in a solids concentration greater than 4%. Pumps shall be capable of handling a sludge of at least 5% thickness.
### TABLE 12-3

TYPICAL DAF THICKENER SOLIDS LOADING RATES NECESSARY TO PRODUCE A MINIMUM 4 PERCENT SOLIDS CONCENTRATION

<table>
<thead>
<tr>
<th>Type of sludge</th>
<th>No chemical addition</th>
<th>Optimum chemical addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary only</td>
<td>0.83 - 1.25</td>
<td>up to 2.5</td>
</tr>
<tr>
<td>Waste activated sludge (WAS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>0.42</td>
<td>up to 2.0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.6 - 0.8</td>
<td>up to 2.2</td>
</tr>
<tr>
<td>Trickling filter</td>
<td>0.6 - 0.8</td>
<td>up to 2.0</td>
</tr>
<tr>
<td>Primary + WAS (air)</td>
<td>0.6 - 1.25</td>
<td>up to 2.0</td>
</tr>
<tr>
<td>Primary + trickling filter</td>
<td>0.83 - 1.25</td>
<td>up to 2.5</td>
</tr>
</tbody>
</table>

12.3.4 Centrifugal Thickeners

12.3.4.1 Pretreatment

Any pretreatment required is in addition of that required for the main wastewater stream. For example, separate and independent grit removal may be needed for the centrifuge feed stream.

Disc nozzle centrifuges require pretreatment of the feed stream. Both screening and grit removal are required to reduce operation and maintenance requirements. Approximately 11% of the feed stream will be rejected in pretreatment, consideration should be given to the treatment of this flow. It is usually routed to the primary clarifier.

Basket centrifuges do not require pretreatment and are recommended in small plants (1.0-2.0 MGD) without primary clarification and grit removal.

Solid bowl decanter centrifuges require grit removal in the feed stream and are a potentially high maintenance item.
12.3.4.2 Chemical Coagulants

Provisions for the addition of coagulants to the sludge should be considered for improving dewatering and solids capture.

12.3.4.3 Design Data

The engineer shall provide the design basis for loading rates and support calculations. Both hydraulic and solids loading rate limitations should be addressed.

12.3.5 Other Thickeners

Other thickener designs will be evaluated on a case-by-case basis. Pilot plant data shall be provided by the design engineer upon request.

12.4 Conditioning

12.4.1 General

Pretreatment of the sludge by chemical or thermal conditioning should be investigated to improve the thickening, dewatering, and/or stabilization characteristics of the sludge.

The effects of conditioning on downstream processes and subsequent side-stream treatment should be evaluated. Thermal conditioning will concentrate the BOD level of the side stream. Its treatment must be considered in calculating organic loadings of other units.

12.4.2 Chemical

Type of chemical, location of injection, and method of mixing should be carefully considered to ensure obtaining anticipated results. Pilot testing is often necessary to determine the best conditioning system for a given sludge.

12.5 Digestion

12.5.1 Anaerobic Digestion

12.5.1.1 General
a. Operability

Anaerobic digestion is a feasible stabilizing method for wastewater sludges that have low concentrations of toxins and a volatile solids content above 50%. It should not be used where wide variations in sludge quantity and quality are common. Anaerobic digestion is a complex process requiring close operator control. The process is very susceptible to upsets as the microorganisms involved are extremely sensitive to changes of their environment. Frequent monitoring of the following parameters is required:

(i) pH (6.4 - 7.5 recommended)
(ii) volatile acids/alkalinity ratio (always 0.5 or greater)
(iii) toxics (volatile acids, heavy metals, light metal cations, oxygen, sulfides, and ammonia)
(iv) temperature (within 1°F of design temperature)
(v) recycle streams (BOD, SS, NH₃, phenols)

The importance of avoiding digester upsets cannot be overlooked. The methane-producer bacteria have a very slow growth rate and it will take two weeks or more to resume normal digester performance.

b. Multiple Units

Multiple units should be provided. Staged digestion design may be used, provided the units can be used in parallel as well as in series. Where multiple units are not provided, a lagoon or storage tanks should be provided for emergency use so that digestion tanks may be taken out of service without unduly interrupting plant operation. Means of returning sludge from the secondary digester unit to the primary digester should be provided. In large treatment plants where digesters are provided, separate digestion of primary sludges should be considered.

c. Depth

The proportion of depth to diameter should provide for the formation of a supernatant liquor with a minimum depth of 6 feet. Sidewall depth is generally about one-half the diameter of the digester for diameters up to 60 feet, and decreases to about one-third the diameter for diameters approaching 100 feet.
d. Maintenance Provisions

To facilitate emptying, cleaning, and maintenance, the following features are required:

(i) Slope

The tank bottom shall slope to drain toward the withdrawal pipe. A slope of between 1 inch per foot and 3 inches per foot is recommended.

(ii) Access Manholes

At least two access manholes should be provided in the top of the tank, in addition to the gas dome. One opening should be large enough to permit the insertion of mechanical equipment to remove scum, grit, and sand. A separate side wall manhole should be provided at ground level.

(iii) Safety

Nonsparking tools, rubber-soled shoes, safety harness, gas detectors for flammable and toxic gasses and the hose type or self-contained type breathing apparatus shall be provided.

e. Pre-thickening of sludge may be advantageous, but the solids content shall be less than 8% to ease mixing problems.

12.5.1.2 Sludge Inlets and Outlets

Multiple sludge inlets and draw-offs and multiple recirculation suction and discharge points should be provided to facilitate flexible operation and effective mixing of the digester contents, unless adequate mixing facilities are provided within the digester. One inlet should discharge above the liquid level and be located at approximately the center of the tank to assist in scum breakup. Raw sludge inlet points should be located to minimize short-circuiting to the supernatant drawoff.

12.5.1.3 Tank Capacity

a. General

Two cultures of bacteria are primarily involved in anaerobic digestion: acid formers and methane formers. Capacity of the digester tank shall be based on the growth rate of the methane-formers, as they have extremely slow growth rates.
b. Solids Basis

Where the composition of the sewage has been established, tank capacity should be computed from the volume and character of sludge to be digested. The total digestion tank capacity should be determined by rational calculations based upon factors such as volume of sludge added, its percent solids and character, volatile solids loading, temperature to be maintained in the digesters, and the degree or extent of mixing to be obtained. These detailed calculations shall be submitted to justify the basis of design.

Where composition of the sewage has not been established, the minimum combined digestion tank capacity outlined below shall be provided. Such requirements assume that the raw sludge is derived from ordinary domestic wastewater, a digestion temperature is maintained in the range of 85° to 100° F, there is 40 to 50 percent volatile matter in the digested sludge, and that the digested sludge will be removed frequently from the process.

(i) Completely Mixed Systems

For heated digestion systems providing for intimate and effective mixing of the digester designed for a constant feed loading rate of 150 to 400 pounds 1,000 cubic feet of volume per day in the active digesting unit. The design average detention time in completely mixed systems shall have sufficient mixing capacity to provide for complete digester turnover every 30 minutes.

(ii) Moderately Mixed Systems

For digestion systems where mixing is accomplished only by circulating external heat exchanger, the system may be loaded up to 40 pounds of volatile solids per 1,000 cubic feet of volume per day in the active digestion units. This loading may be modified upward or downward, depending upon the degree of mixing provided. Where mixing is accomplished by other methods, loading rates will be determined on the basis of information furnished by the design engineer.
c. Population Basis

Where solids data are not available, the following unit capacities shown in Table 12-4 for conventional, heated tanks shall be used for plants treating domestic sewage.
The capacities should be increased by allowing for the suspended solids population equivalent of any industrial wastes in the sewage. The capacities stated apply where digested sludge is dewatered on sand drying beds and may be reduced if the sludge is dewatered mechanically or otherwise frequently withdrawn.

<table>
<thead>
<tr>
<th>Type of Plant</th>
<th>Moderately Mixed Systems</th>
<th>Completely Mixed Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>2 to 3</td>
<td>1.3</td>
</tr>
<tr>
<td>Primary and Trickling Filter</td>
<td>4 to 5</td>
<td>2.7 to 3.3</td>
</tr>
<tr>
<td>Primary and Activated Sludge</td>
<td>4 to 6</td>
<td>2.7 to 4</td>
</tr>
</tbody>
</table>

For small installations (population 5,000 or less) the larger values should be used.

12.5.1.4 Gas Collection System

a. General

All portions of the gas system, including the space above the tank liquor, storage facilities, and piping shall be so designed that under all normal operating conditions, including sludge withdrawal, the gas will be maintained under positive pressure. All enclosed areas where any gas leakage might occur shall be adequately ventilated.

b. Safety Equipment

All necessary safety facilities shall be included where gas is produced. Pressure and vacuum relief valves and flame traps, together with automatic safety shutoff valves, are essential. Water-seal equipment shall not be installed on gas piping.
c. Gas Piping and Condensate

Gas piping shall be of adequate diameter and shall slope to condensation traps at low points. The use of float-controlled condensate traps is not permitted. Condensation traps shall be placed in accessible locations for daily servicing and draining. Cast iron, ductile iron, and/or stainless steel piping should be used.

d. Electrical Fixtures and Equipment

Electrical fixtures and equipment in enclosed places where gas may accumulate shall comply with the National Board of Fire Underwriters' specifications for hazardous conditions. Explosion-proof electrical equipment shall be provided in sludge-digestion tank galleries containing digested sludge piping or gas piping and shall be provided in any other hazardous location where gas or digested sludge leakage is possible.

e. Waste Gas

Waste gas burners shall be readily accessible and should be located at least 50 feet away from any plant structure, if placed near ground level, or may be located on the roof of the control building if sufficiently removed from the tank. Waste gas burners shall not be located on top of the digester. The waste gas burner should be sized and designed to ensure complete combustion to eliminate odors.

f. Ventilation and Cover

Any underground enclosures connecting with digestion tanks or containing sludge or gas piping or equipment shall be provided with forced ventilation. Tightly fitting, self-closing doors shall be provided at connecting passageways and tunnels to minimize the spread of gas. A floating cover should be provided instead of a fixed cover for increased operational flexibility and safety.

g. Metering

Gas meters with bypasses should be provided to meter total gas production and utilization.
h. Pressure Indication

Gas piping lines for anaerobic digesters should be equipped with closed-type pressure indicating gauges. These gauges should read directly in inches of water. Normally, three gauges should be provided, one to measure the main line pressure, a second to measure the pressure upstream of gas-utilization equipment, and the third to measure pressure to wasteburners.

Gas-tight shutoff and vent cocks shall be provided. The vent piping shall be extended outside the building, and the opening shall be screened to prevent entrance by insects and turned downward to prevent entrance of rainwater. All piping shall be protected with safety equipment.

i. Gas Utilization Equipment

Gas-burning boilers, engines, and other gas utilization equipment should be located at or above ground level in well-ventilated rooms. Gas lines to these units shall be provided with suitable flame traps.

12.5.1.5 Heating

a. Insulation

Digestion tanks should be constructed above the water table and should be suitably insulated to minimize heat loss.

b. Heating Facilities

Sludge may be heated by circulating the sludge through external heaters or by units located inside the digestion tank.

(i) External Heating

Piping should be designed to provide for the preheating of feed sludge before introduction to the digesters. Provisions should be made in the layout of the piping and valving to facilitate cleaning of these lines.

Heat exchanger sludge piping should be sized for heat transfer requirements.
(ii) Internal Coils

Hot water coils for heating digestion tanks should be at least 2 inches in
diameter and the coils, support brackets, and all fastenings should be of
corrosion-resistant material. The use of dissimilar metals should be
avoided to minimize galvanic action. The high point in the coils should be
vented to avoid air lock.

(iii) Other Methods

Other types of heating facilities will be considered on their own merits.

c. Heating Capacity

Sufficient heating capacity shall be provided to consistently maintain the
digesting sludge temperature to within 1°F (0.6°C) of the design
temperature. An alternate source of fuel should be available and the boiler
or other heat source should be capable of using the alternate fuel if
d digester gas is the primary fuel. Thermal shocks shall be avoided. Sludge
storage may be required to accomplish this.

d. Hot Water Internal Heating Controls

(i) Mixing Valves

A suitable automatic mixing valve should be provided to temper the boiler
water with return water so that the inlet water to the heat jacket or coils
can be held to below a temperature (130° to 150°F) at which sludge caking
will be accentuated. Manual control should also be provided by suitable
bypass valves.

(ii) Boiler Controls

The boiler should be provided with suitable automatic controls to maintain
the boiler temperature at approximately 180°F to minimize corrosion and
to shut off the main fuel supply in the event of pilot burner or electrical
failure, low boiler water level, or excessive temperature.

(iii) Thermometers

Thermometers shall be provided to show temperatures of the sludge, hot
water feed, hot water return, and boiler water.
12.5.1.6 Mixing

Facilities for mixing the digester contents shall be provided where required for proper digestion by reason of loading rates, or other features of the system.

12.5.1.7 Supernatant Withdrawal

a. Piping Size

Supernatant piping should not be less than 6 inches in diameter, although 4-inch lines will be considered in special cases.

b. Withdrawal Arrangements

(i) Withdrawal Levels

Piping should be arranged so that withdrawal can be made from three or more levels in the tank. A positive unvalved vented overflow shall be provided.

(ii) Withdrawal Selection

On fixed-cover tanks the supernatant withdrawal level should preferably be selected by means of interchangeable extensions at the discharge end of the piping.

(iii) Supernatant Selector

If a moveable supernatant selector is provided, provision should be made for at least one other draw-off level located in the supernatant zone of the tank in addition to the unvalved emergency supernatant draw-off pipe. High-pressure backwash facilities should be provided.

(iv) Sampling

Provisions shall be made for sampling at each supernatant draw-off level. Sampling pipes should be at least 1-1/2 inches in diameter.

(v) Supernatant Handling

Problems such as shock organic loads, pH, and high ammonia levels associated with digester supernatant shall be addressed in the plant design. Recycle streams should be bled continuously back to the treatment process.
12.5.2 Aerobic Sludge Digestion

12.5.2.1 Mixing and Aeration

Aerobic sludge digestion tanks shall be designed for effective mixing and aeration. Minimum mixing requirements of 20 cubic feet per minute per 1,000 cubic feet for air systems and 0.5 horsepower per 1,000 cubic feet for mechanical systems are recommended. Aeration requirements may be more or less than the mixing requirements, depending on system design and actual solids loading. Approximately 2.0 pounds of oxygen per pound volatile solids are needed for aeration.

If diffusers are used, types should be provided to minimize clogging and designed to permit removal for inspection, maintenance, and replacement without dewatering the tanks, if only one digester is proposed.

12.5.2.2 Size and Number of Tanks

The size and number of aerobic sludge digestion tank or tanks should be determined by rational calculations based upon such factors as volume of sludge added, its percent solids and character, the degree of volatile solids reduction required and the size of installation with appropriate allowance for sludge and supernatant storage.

Generally, 40 to 50 percent volatile solids destruction is obtained during aerobic digestion. To ensure a stabilized sludge which will not emit odors, the volatile solids content should be less than 60 percent in the digested sludge. Calculations shall be submitted upon request to justify the basis of design. The following design parameter ranges should be considered the minimum in designing aerobic digestion facilities.

a. Hydraulic Detention Time

Hydraulic detention time at 20°C should be in the range of 15 to 25 days, depending upon the type of sludge being digested. Activated sludge alone requires the lower detention time and a combination of primary plus activated or trickling filter sludges requires the high detention time. Detention times should be adjusted for operating temperatures other than 20°C.
b. Volatile Solids

The volatile solids loading shall be in the range of 0.1 to 0.2 pound of volatile solids per cubic foot per day.

c. Dissolved Oxygen

Design dissolved oxygen concentration should be in the range of 1 to 2 mg/l. A minimum of 1.0 mg/l shall be maintained at all times.

d. Mixing Energy

Energy input requirements for mixing should be in the range of 0.5 to 1.5 horsepower per 1,000 cubic feet where mechanical aerators are used; 20 to 35 standard cubic feet of air per minute per 1,000 cubic feet of aeration tank where diffused air mixing is used on activated sludge alone; and greater than 60 cubic feet per minute per 1,000 cubic feet for primary sludge alone and primary plus activated sludge.

e. Storage

Detention time should be increased for temperatures below 20°C. If sludge cannot be withdrawn during certain periods, additional storage capacity should be provided. Plants smaller than 75,000 gpd should have storage capacity of 2 cubic foot per population equivalent served.

12.5.2.3 Supernatant Separation

Facilities should be provided for separation or decantation of supernatant. Provisions for sidestream treatment of supernatant should be considered.

12.6 Composting

Composting operations will be considered on a case-by-case basis, provided that the basis for design and a cost-effective analysis are submitted by the engineer.

12.7 Sludge Dewatering

12.7.1 General

Drainage from drying beds and centrate or filtrate from dewatering units should be returned to the sewage treatment process at appropriate points preceding the secondary process. The return flows shall be returned downstream of the influent sample and/or flow measuring point and a means shall be provided to sample return flows. These organic loads must be considered in plant design.
12.7.2 Sludge Drying Beds

12.7.2.1 Area

It is recommended that wastewater systems have a hybrid sludge disposal method because of the seasonal downtime associated with drying beds. The amount of rainfall normal for our state makes the use of sludge drying beds insufficient at times.

Consideration shall be given to the location of drying beds to avoid areas where moisture in the air is higher than normal (i.e., adjacent to rivers where morning fog is common).

In determining the area for sludge drying beds, consideration shall be given to climatic conditions, the character and volume of the sludge to be dewatered, type of bed used, and methods of ultimate sludge disposal. Design calculations shall be submitted upon request to substantiate the area used.

Drying bed design should be based on square feet per capita or pounds of sludge solids per square foot per year. Table 12-5 presents the range of values that should be used, these values are for drying anaerobically digested sludges. Additional area is required for wetter sludges such as those resulting from aerobic digestion; therefore, use the higher number of the required range.

Table 12-5 DRYING BED DESIGN CRITERIA*

<table>
<thead>
<tr>
<th>Type of Sludge</th>
<th>Open Beds Per Capita (sq ft/capita)</th>
<th>Covered Beds Solids (lb/sq ft/yr)</th>
<th>Covered Beds Per Capita (sq ft/capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>1.0 to 1.5</td>
<td>27.5</td>
<td>0.75 to 1.0</td>
</tr>
<tr>
<td>Attached Growth</td>
<td>1.25 to 1.75</td>
<td>22.0</td>
<td>1.0 to 1.25</td>
</tr>
<tr>
<td>Suspended Growth</td>
<td>2.50</td>
<td>15.0</td>
<td>2.00</td>
</tr>
</tbody>
</table>

*The design engineer should rely on his experience and the plant location.

These criteria are a minimum.
12.7.2.2. Percolation Type

a. Gravel

The lower course of gravel around the underdrains should be properly graded to range in size from 1/4-inch to 1-inch and should be 12 inches in depth, extending at least 6 inches above the top of the underdrains. It is desirable to place this in 2 or more layers. The top layer of at least 3 inches should consist of gravel 1/8 inch to 1/4 inch in size. The gravel shall be laid on an impervious surface so that the filtrate will not escape to the soil.

b. Sand

The top course shall consist of at least nine inches of sand with a uniformity coefficient of less than 3.5. For trickling filter sludge, the effective size of the sand shall be between 0.8 to 3.0 millimeter. For waste activated sludge, the effective size of the sand shall be between 0.5 to 0.8 millimeter. For combinations, use the lower size range.

c. Underdrains

Underdrains should be clay pipe, concrete drain tile, or other underdrain acceptable material and shall be at least 4 inches in diameter and sloped not less than 1 percent to drain. Underdrains shall be spaced between 8 and 20 feet apart. The bottom of the bed shall slope towards the underdrains. Consideration should be given to placing the underdrain in a trench.

12.7.2.3 Impervious Types

Paved surface beds may be used if supporting data to justify such usage are acceptable to the Department. The use of paved beds for aerobically digested sludge is generally not recommended.

12.7.2.4 Walls

Walls should be watertight and extend 15 to 18 inches above the ground surface. Outer walls should be curbed to prevent soil from washing onto the beds.

12.7.2.5 Sludge Removal

Not less than two beds should be provided and they should be arranged to facilitate sludge removal. Concrete truck tracks should be provided for all
percolation-type sludge beds with pairs of tracks for the beds on appropriate centers. If truck access is by way of an opening in the drying bed wall, the opening shall be designed so that no sludge will leak out during the filling process.

12.7.2.6 Sludge Influent

The sludge pipe to the beds should terminate at least 12 inches above the surface and be arranged so that it will drain. Concrete splash plates shall be provided at sludge discharge points.

12.7.3 Mechanical Dewatering

12.7.3.1 Methods and Applicability

The methods used to dewater sludge may include use of one or more of the following devices:

a. Rotary vacuum filters

b. Centrifuges, either solid bowl or basket type

c. Filter presses

d. Horizontal belt filters

e. Rotating gravity concentrators

f. Vacuum drying beds

g. Other "media type" drying beds

The technology and design of sludge dewatering devices are constantly under development; therefore, each type should be given careful consideration. The applicability of a given method should be determined on a case-by-case basis, with the specifics of any given situation being carefully evaluated, preferably in pilot tests. The engineer shall justify the method selected using pilot plant data or experience at a similar treatment plant.
12.7.3.2 Considerations

Considerations in selection should include:

a. Type and amount of sludge
b. Variations in flow rate and solids concentration
c. Capacity of the equipment
d. Chemicals required for conditioning
e. Degree of dewatering required for disposal
f. Experience and qualifications of plant staff
g. Reliability
h. Operation and maintenance cost
i. Space requirements

12.7.3.3 Storage

Adequate storage shall be provided for all systems.

12.8 Sludge Storage Lagoons

Refer to Chapter 9, Ponds and Aerated Lagoons, for the requirements of sludge storage lagoons.

12.9 Sludge Disposal

The ultimate disposal of sludge through various methods (i.e., landfilling, land application) is subject to the regulations and/or guidelines of the Tennessee Division of Water Pollution Control (DWPC). Approval by DWPC is required prior to initiation of the selected disposal alternative.
1. The primarily organic solid product produced by wastewater treatment processes that can be beneficially recycled is called __________________________. (This term replaces the word ‘sludge’ when referring to wastes that have been treated. In contrast, sludge is unprocessed and generally unsuitable for beneficial use.)

2. This group of bacteria is referred to as “acid formers” and they convert the organic or volatile matter into volatile acids during anaerobic digestion. __________________________

3. Aerobic digesters rely on __________________________, the situation that occurs when bacteria oxidize some of their own cellular mass instead of new organic matter that they would adsorb or absorb from their environment.

4. The process of __________________________ reduces sludge moisture and volume to allow for more economical disposal.

5. The washing of digested sludge with either fresh water, plant effluent, or other wastewater is called __________________________. The objective is to remove (wash out) fine particulates and/or the alkalinity in the sludge. This process reduces the demand for conditioning chemicals and improves settling or filtering characteristics of the solids.

6. The water leaving a centrifuge after most of the solids have been removed is called the __________________________.

7. __________________________ describes the treatment process in which wastewater solids and water (about 5% solids, 95% water) are placed in a large tank (known as a digester) and bacteria decompose the solids in the absence of oxygen.

8. During the anaerobic digestion process, two groups of bacteria work together in sequence. The saprophytic organisms establish first and produce volatile acids that will then be consumed by the __________________________.

9. The measure of the capacity of a solution or liquid to neutralize acids or bases is called __________________________. This is the measure of the capacity of water or wastewater for offering a resistance to changes in pH. (*The volatile acid/alkalinity relationship is an indication of this with regards to digester contents.)

10. During __________________________, sludge to be treated is placed in a large aerated tank where aerobic microorganisms decompose the organic matter in the sludge. This digestion process may be used to treat only WAS, or trickling filter sludge and primary (raw) sludge, or waste sludge from activated sludge treatment plants designed without primary settling.

11. Cold temperature bacteria: __________________________

          Medium temperature bacteria: __________________________
High temperature bacteria: 

12. The most important factor to monitor with anaerobic digesters is the _________________. When this ratio starts to increase, corrective action must be taken immediately to prevent a sour digester.

13. This serves as the foundation of all regulatory policies regarding Biosolids: ________________

**Word Bank**

- Aerobic digestion
- Biosolids
- Saprophytic organisms
- Anaerobic digestion
- Thermophilic bacteria
- Psychrophilic bacteria
- Mesophilic bacteria
- 40 CFR 503
- Methane fermenters
- Centrate
- Dewatering
- Volatile acid/Alkalinity ratio
- Endogenous respiration
- Buffering capacity
Sludge Thickening, Digestion, and Dewatering Review Questions

1. Briefly explain what is happening during anaerobic digestion.

2. What happens if you add too much raw sludge to the digester?

3. Why is it hazardous to start a digester when it is only partially full?

4. A thick a sludge as possible may be pumped to the digester by operating the sludge pump for several minutes per hour, at a rate not to exceed _____, to clear the sludge hopper.

5. What causes foaming in an anaerobic digester and what steps would you take to prevent foaming from occurring?
6. List some common problems associated with a belt filter press and what can be done to attempt to fix those problems.

7. An operator is doing a routine inspection and notices that the floating cover on the anaerobic digester is tilting. What could be causing this condition?

8. 40 CFR 503 Regulations specify maximum levels of fecal coliform allowed in finished biosolids to meet Pathogen Reduction requirements for land application.

List the fecal coliform criteria for:

Class A biosolids = __________________

Class B biosolids = __________________

9. Laboratory tests show that the volatile acids/alkalinity ratio in your anaerobic digester is beginning to rise. You recognize that this is the first sign of a major problem, what do you do next?
10. Why would you add lime to a digester?

11. What kinds of materials accumulate in digesters and reduce the active volume for digesting sludge?

12. What DO level should be maintained in aerobic digesters?

13. Centrifuges are commonly used to dewater what type of sludges? What factors regulate the quality of the sludge cake/slurry and the centrate from a centrifuge?

14. What are the 3 main requirements regulated by 40 CFR 503 with regards to land applied biosolids?
DESCRIPTION

Biosolids are primarily organic materials produced during wastewater treatment which may be put to beneficial use. An example of such use is the addition of biosolids to soil to supply nutrients and replenish soil organic matter. This is known as land application. Biosolids can be used on agricultural land, forests, rangelands, or on disturbed land in need of reclamation.

Recycling biosolids through land application serves several purposes. It improves soil properties, such as texture and water holding capacity, which make conditions more favorable for root growth and increases the drought tolerance of vegetation. Biosolids application also supplies nutrients essential for plant growth, including nitrogen and phosphorous, as well as some essential micro nutrients such as nickel, zinc, and copper. Biosolids can also serve as an alternative or substitute for expensive chemical fertilizers. The nutrients in the biosolids offer several advantages over those in inorganic fertilizers because they are organic and are released slowly to growing plants. These organic forms of nutrients are less water soluble and, therefore, less likely to leach into groundwater or run off into surface waters.

There are several methods to apply biosolids. The selection of the method depends on the type of land and the consistency of the biosolids. Liquid biosolids are essentially 94 to 97 percent water with relatively low amounts of solids (3 to 6 percent). These can be injected into the soil or applied to the land surface. Specialized vehicles are used to inject biosolids into the soil, as shown in Figure 1. These tankers have hoses leading from the storage tank to injection nozzles which release the biosolids.

FIGURE 1 BIOSOLIDS INJECTION EQUIPMENT

Modified tanker trucks are used for surface application (Figure 2). Biosolids applied to the land surface are usually incorporated into the soil with conventional farm equipment.

It is often economical to reduce the volume of biosolids prior to transportation or storage. The amount of water in biosolids can be reduced through mechanical processes such as draining, pressing, or centrifuging, resulting in a material composed of up to 30 percent dry solids. This material will be the consistency of damp soil. Dewatered biosolids do not require any specialized equipment and can be applied with conventional agricultural equipment, such as manure spreaders pulled by tractors.
Figure 3 shows the spraying of biosolids, an application method primarily used in forested or reclamation sites. Liquid biosolids are sprayed from a tank towed by a truck or other vehicle.

The Environmental Protection Agency’s 40 CFR Part 503, Standards for the Use and Disposal of Sewage Sludge (the Part 503 Rule), requires that wastewater solids be processed before they are land applied. This processing is referred to as “stabilization” and helps minimize odor generation, destroys pathogens (disease causing organisms), and reduces vector attraction potential. There are several methods to stabilize wastewater solids, including:

- Adjustment of pH, or alkaline stabilization.
- Digestion.
- Composting.
- Heat drying.

The Part 503 Rule defines two types of biosolids with respect to pathogen reduction, Class A and Class B, depending on the degree of treatment the solids have received. Both types are safe for land application, but additional requirements are imposed on Class B materials. These are detailed in the Part 503 Rule and include such things as restricting public access to the application site, limiting livestock grazing, and controlling crop harvesting schedules. Class A biosolids (biosolids treated so that there are no detectable pathogens) are not subject to these restrictions.

In addition to stabilization, the Part 503 Rule sets maximum concentrations of metals which cannot be exceeded in biosolids that will be land applied. These are termed Ceiling Concentrations. Part 503 also establishes Cumulative Pollutant Loading Rates for eight metals which may not be exceeded at land application sites. A third set of metals criteria is also included in Part 503, known as Pollutant Concentrations. If these concentrations are not exceeded in the biosolids to be land applied, the Cumulative Pollutant Loading Rates do not need to be tracked. Table 1 shows the three sets of federal limits applicable to biosolids to be land applied.
The term *Exceptional Quality* is often used to describe a biosolids product which meets Class A pathogen reduction requirements, the most stringent metals limits (Pollutant Concentrations), and vector attraction reduction standards specified in the Part 503 Rule. Vectors (flies, mosquitoes, rodents, birds, etc.) can transmit diseases directly to humans or play a specific role in the life cycle of a pathogen as a host. Vector attraction reduction refers to processing which makes the biosolids less attractive to vectors thereby reducing the potential for transmitting diseases. Exceptional Quality biosolids products are as safe as other agricultural and horticultural products and may be used without site restrictions.

**APPLICABILITY**

Land application is well-suited for managing solids from any size wastewater treatment facility. As the method of choice for small facilities, it offers cost advantages, benefits to the environment, and value to the agricultural community. However, biosolids produced by many major metropolitan areas across the country are also land applied. For example, biosolids from the Blue Plains Wastewater Treatment Facility serving the District of Columbia and surrounding communities in Virginia and Maryland have been land applied since the plant began operation in 1930. The cities of Philadelphia, Chicago, Denver, New York, Seattle, and Los Angeles all land apply at least part of their biosolids production.

Land application is most easily implemented where agricultural land is available near the site of biosolids production, but advances in transportation have made land application viable even where hauling distances are greater than 1,000 miles. For example, Philadelphia hauls dewatered biosolids 250 miles to reclaim strip-mines in western Pennsylvania and New York City ships some of its biosolids over 2,000 miles to Texas and Colorado.

**ADVANTAGES AND DISADVANTAGES**

Land application offers several advantages as well as some disadvantages that must be considered before selecting this option for managing biosolids.

**Advantages**

Land application is an excellent way to recycle wastewater solids as long as the material is quality-controlled. It returns valuable nutrients to the soil and enhances conditions for vegetative growth. Land application is a relatively inexpensive option and capital investments are generally lower than other biosolids management technologies. Contractors can provide the necessary hauling and land application equipment. In addition, on-site

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**TABLE 1  MAXIMUM METAL CONCENTRATIONS**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Ceiling Concentration (mg/kg)</th>
<th>Cumulative Pollutant Loading Rates (kg/hectare)</th>
<th>Pollutant Concentrations (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>75</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Cadmium</td>
<td>85</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Copper</td>
<td>4,300</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>Lead</td>
<td>840</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Mercury</td>
<td>57</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>75</td>
<td>NL</td>
<td>NL</td>
</tr>
<tr>
<td>Nickel</td>
<td>420</td>
<td>420</td>
<td>420</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Zinc</td>
<td>7,500</td>
<td>2,800</td>
<td>2,800</td>
</tr>
</tbody>
</table>

NL = No limit

spatial needs can be relatively minor depending on the method of stabilization selected.

Disadvantages

Although land application requires relatively less capital, the process can be labor intensive. Even if contractors are used for application, management oversight is essential for program success. Land application is also limited to certain times of the year, especially in colder climates. Biosolids should not be applied to frozen or snow covered grounds, while farm fields are sometimes not accessible during the growing season. Therefore, it is often necessary to provide a storage capacity in conjunction with land application programs. Even when the timing is right (for example, prior to crop planting in agricultural applications), weather can interfere with the application. Spring rains can make it impossible to get application equipment into farm fields, making it necessary to store biosolids until weather conditions improve.

Another disadvantage of land application is potential public opposition, which is encountered most often when the beneficial use site is close to residential areas. One of the primary reasons for public concern is odor. In worst case situations, municipalities or counties may pass ordinances which ban or restrict the use of biosolids. However, many successful programs have gained public support through effective communications, an absolutely essential component in the beneficial use of biosolids.

Environmental Impacts

Despite many positive impacts to the environment, land application can have negative impacts on water, soil, and air if not practiced correctly.

Negative impacts to water result from the application of biosolids at rates that exceed the nutrient requirements of the vegetation. Excess nutrients in the biosolids (primarily nitrogen compounds) can leach from the soil and reach groundwater. Runoff from rainfall may also carry excess nutrients to surface water. However, because biosolids are a slow release fertilizer, the potential for nitrogen compounds to leach from biosolids amended soil is less than that posed by the use of chemical fertilizers. In areas fertilized by either biosolids or chemicals, these potential impacts are mitigated by proper management practices, including the application of biosolids at agronomic rates (the rate nutrients are used by the vegetation.) Maintenance of buffer zones between application areas and surface water bodies and soil conservation practices will minimize impacts to surface water.

Negative impacts to soil can result from mismanagement of a biosolids land application. Federal regulations contain standards related to all metals of concern and application of biosolids which meets these standards should not result in the accumulation of metals to harmful levels. Stringent record keeping and reporting requirements on both the federal and state level are imposed to prevent mismanagement.

Odors from biosolids applications are the primary negative impact to the air. Most odors associated with land application are a greater nuisance than threat to human health or the environment. Odor controls focus on reducing the odor potential of the biosolids or incorporating them into the soil. Stabilization processes such as digestion can decrease the potential for odor generation. Biosolids that have been disinfected through the addition of lime may emit ammonia odors but they are generally localized and dissipate rapidly. Biosolids stabilization reduces odors and usually results in an operation that is less offensive than manure application.

Overall, a properly managed biosolids land application program is preferable to the use of conventional fertilizers for the following reasons:

- **Biosolids are a recycled product, use of which does not deplete non-renewable resources such as phosphorous.**
- **The nutrients in biosolids are not as soluble as those in chemical fertilizers and are therefore released more slowly.**
- **Biosolids applicators are required to maintain setbacks from water resources and are often subject to more stringent soil conservation and erosion control practices, nutrient**
management, and record keeping and reporting requirements than farmers who use only chemical fertilizers or manures.

**C** Biosolids are closely monitored.

**C** The organic matter in biosolids improves soil properties for optimum plant growth, including tilth, friability, fertility and water holding capacity. They also decrease the need for pesticide use.

A joint policy statement of the U.S. Department of Agriculture, the U.S. Food & Drug Administration, and the U.S. Environmental Protection Agency states, “...the use of high quality biosolids coupled with proper management procedures, should safeguard the consumer from contaminated crops and minimize any potential adverse effect on the environment” (U.S. EPA, 1981).

**DESIGN CRITERIA**

Design criteria for land application programs address issues related to application rates and suitable sites. Design criteria for physical facilities (such as stabilization) that are part of land application programs are discussed in separate fact sheets. Biosolids, site, and vegetative characteristics are the most important design factors to consider.

Biosolids must meet regulatory requirements for stabilization and metals content. In addition, nutrient content and physical characteristics, such as percent solids, are used to determine the appropriate application rate for the crop that will be grown and the soil in which the crops will be grown.

Site suitability is determined based on such factors as soil characteristics, slope, depth to groundwater, and proximity to surface water. In addition, many states have established site requirements to further protect water quality. Some examples include:

**C** Sufficient land to provide areas of non-application (buffers) around surface water bodies, wells, and wetlands.

**C** Depth from the soil surface to groundwater equal to at least one meter.

**C** Soil pH in the range of 5.5 to 7.5 to minimize metal leaching and maximize crop growing conditions.

Site suitability is also influenced by the character of the surrounding area. While odors and truck traffic may not be objectionable in an agricultural area, both will adversely impact residential developments and community centers close to fields where biosolids are applied.

The type of vegetation to be grown is also a design consideration. Vegetation, like soil characteristics, will generally not exclude biosolids application since most vegetation will benefit from the practice. However, the type of vegetation will impact the choice of application equipment, the amount of biosolids to be applied, and the timing of applications. The effect of vegetation on the choice of application equipment is discussed above in the description of this technology. The amount of biosolids that may be applied to a site is a function of the amount of nutrients required by the vegetation and the amount of metals found in the biosolids. Table 2 summarizes the application frequency, timing, and rates for various types of sites.

Another factor to be considered in designing a land application program is the timing of applications. Long periods of saturated or frozen ground limit opportunities for application. This is an important consideration in programs using agricultural lands; applications must be performed at times convenient to growers.

**Typical Biosolids Application Rate Scenario**

The recommended minimum amount of nitrogen needed by a typical corn crop to be grown in New Jersey is 120 pounds per acre per year. Biosolids containing 3 percent nitrogen could be applied at up to 5.4 dry tons per acre if used to supply all the nitrogen needed by the crop (i.e., no other nitrogen fertilizers used.) A city producing 10 dry tons of biosolids per day would require access to almost 700 acres of corn. If the biosolids contained only 1.5 percent nitrogen, twice as many tons could be applied per acre, requiring only half as many acres to land apply the same amount of biosolids generated.
to the farmer and must not interfere with the planting of crops. Most application of biosolids to agricultural land occurs in the early spring or late fall. As a result, storage or an alternate biosolids management option must be available to handle biosolids when application is not possible. Forest lands and reclamation sites allow more leeway in the timing of applications. In some areas of the United States, application can proceed year round. Application is most beneficial on agricultural land in late fall or early spring before the crop is planted. Timing is less critical in forest applications when nutrients can be incorporated into the soil throughout the growing period. Winter application is less desirable in many locales. Rangelands and pasturelands also are more adaptable to applications during various seasons. Applications can be made as long as ground is not saturated or snow covered and whenever livestock can be grazed on alternate lands for at least 30 days after the application. The timing of single applications in land reclamation programs is less critical and may be dictated by factors such as regulatory compliance schedules.

**PERFORMANCE**

In 1995, approximately 54 percent of wastewater treatment plants managed biosolids through land application, an increase of almost 20 percent from information reported in 1993 (WEF, 1997 and U.S. EPA, 1993.) The vast majority of these land application programs use agricultural land, with minor amounts applied to forest lands, rangelands, or land in need of reclamation.

The use of land application increased steadily in the 1980s for several reasons, including decreasing availability and increasing costs associated with landfill disposal. Research also helped refine procedures for proper land application. Meanwhile, implementation of the Nationwide Pretreatment Program resulted in significant improvements in biosolids quality. The 1993 adoption of the Part 503 Rule created a structure for consistent application procedures across the nation. The regulations were developed with input from the U.S. Department of Agriculture, the U.S. Food and Drug Administration, biosolids generators, environmental groups, the public, state regulators, and academic researchers. Conservative assumptions were used to create regulations to “protect public health and the environment from all reasonably anticipated adverse effects” (U.S. EPA, 1993).

Land application is a reliable biosolids management option as long as the system is designed to address such issues as storage or alternate management for biosolids during periods when application cannot take place due to unfavorable weather or field conditions. Public opposition rather than technical constraints is the most common reason for discontinuing land application programs.

### TABLE 2  TYPICAL BIOSOLIDS APPLICATION SCENARIOS

<table>
<thead>
<tr>
<th>Type of Site/Vegetation</th>
<th>Schedule</th>
<th>Application Frequency</th>
<th>Application Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural land</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>April, May, after harvest</td>
<td>Annually</td>
<td>5 to 10 dry tons per acre</td>
</tr>
<tr>
<td>Small grains</td>
<td>March-June, August, fall</td>
<td>Up to 3 times per year</td>
<td>2 to 5 dry tons per acre</td>
</tr>
<tr>
<td>Soybeans</td>
<td>April-June, fall</td>
<td>Annually</td>
<td>5 to 20 dry tons per acre</td>
</tr>
<tr>
<td>Hay</td>
<td>After each cutting</td>
<td>Up to 3 times per year</td>
<td>2 to 5 dry tons per acre</td>
</tr>
<tr>
<td>Forest land</td>
<td>Year round</td>
<td>Once every 2 - 5 years</td>
<td>5 to 100 dry tons per acre</td>
</tr>
<tr>
<td>Range land</td>
<td>Year round</td>
<td>Once every 1 - 2 years</td>
<td>2 to 60 dry tons per acre</td>
</tr>
<tr>
<td>Reclamation sites</td>
<td>Year round</td>
<td>Once</td>
<td>60 to 100 dry tons per acre</td>
</tr>
</tbody>
</table>

“In fact, in all the years that properly treated biosolids have been applied to the land, we have been unable to find one documented case of illness or disease that resulted.”

Martha Prothro, Former Deputy Assistant Administrator for Water, U.S. Environmental Protection Agency.


OPERATION AND MAINTENANCE

Land application systems generally use uncomplicated, reliable equipment. Operations include pathogen reduction processing, dewatering, loading of transport vehicles, transfer to application equipment, and the actual application. Operations and maintenance considerations associated with pathogen reduction processing are discussed in other fact sheets. The other operations require labor skills of heavy equipment operators, equipment maintenance personnel, and field technicians for sampling, all normally associated with wastewater treatment facilities.

In addition, the biosolids generator is responsible for complying with state and local requirements as well as federal regulations. The biosolids manager must be able to calculate agronomic rates and comply with record keeping and recording requirements. In fact, the generator and land applier must sign certification statements verifying accuracy and compliance. The generator should also allocate time to communicate with farmers, landowners, and neighbors about the benefits of biosolids recycling. Control of odors, along with a viable monitoring program, is most important for public acceptance.

COSTS

It is difficult to estimate the cost of land application of biosolids without specific program details. For example, there is some economy of scale due to large equipment purchases. The same size machine might be needed for a program that manages 10 dry tons of biosolids per day as one managing 50 dry tons per day; the cost of that machine can be spread over the 10 or 50 dry tons, greatly affecting average costs per dry ton. One source identified costs for land application varying from $60 to $290 per dry ton (O’Dette, 1996.) This range reflects the wide variety in land application methods as well as varying methods to prepare biosolids for land application. For example, costs for programs using dewatered biosolids include an additional step whereas costs for programs using liquid biosolids do not reflect the cost of dewatering. They do, however, include generally higher transportation costs.

Despite the wide range of costs for land application programs, several elements must be considered in estimating the cost of any biosolids land application program:

C Purchase of application equipment or contracting for application services.
C Transportation.
C Equipment maintenance and fuel.
C Loading facilities.
C Labor.
C Capital, operation and maintenance of stabilization facilities.
C Ability to manage and control odors.
C Dewatering (optional).
C Storage or alternate management option for periods when application is not possible due to weather or climate.
C Regulatory compliance, such as permit applications, site monitoring, and biosolids analyses.
C Public education and outreach efforts.

Land must also be secured. Some municipalities have purchased farms for land application; others apply biosolids to privately held land.

Some operating costs can be offset through the sale of the biosolids material. Since the biosolids
reduce the need for fertilizers and pH adjustment, farmers sometimes pay to have biosolids applied to their lands.

REFERENCES

Other Related Fact Sheets

Odor Management in Biosolids Management
EPA 832-F-00-067
September 2000

Centrifugal Dewatering/Thickening
EPA 832-F-053
September 2000

Belt Filter Press
EPA 832-F-00-057
September 2000

Filter Press, Recessed Plate
EPA 832-F-00-058
September 2000

Alkaline Stabilization of Biosolids
EPA 832-F-00-052
September 2000

Other EPA Fact Sheets can be found at the following web address:


**ADDITIONAL INFORMATION**

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DESCRIPTION

Current options for managing wastewater biosolids in the United States include both beneficial reuse technologies (such as land application, landfilling with biogas recovery, and energy recovery through incineration) and non-reuse options, including landfilling. While implementing some type of beneficial reuse is the preferred method for managing wastewater biosolids, this is not always practical. For example, land acquisition constraints or poor material quality may limit beneficial reuse options. In these situations, landfilling of biosolids may be a viable alternative.

Biosolids landfilling options include disposal in a monofill (a landfill that accepts only wastewater treatment plant biosolids), or in a co-disposal landfill (a landfill that combines biosolids with municipal solid waste). Although co-disposal landfilling is more common than monofilling, biosolids typically represent only a small percentage of the total waste in a co-disposal landfill (WEF, 1998).

Landfill disposal of biosolids should not be confused with use of biosolids to amend final cover material at landfills. This practice is a form of land application in which biosolids are added to soil to enhance conditions for growing cover vegetation. The EPA fact sheet Land Application of Biosolids addresses the use of biosolids in rehabilitating disturbed lands.

Biosolids Monofilling

Biosolids monofilling consists of preparing the site, transferring the biosolids to the site, and covering the biosolids with a layer of cover material. Depending on the concentration of pollutants in the biosolids, site preparation may include installing a liner to prevent contaminants from migrating downward into the site soil. The three most common methods of monofilling wastewater biosolids are the trench, area, and ramp methods.

Trench monofilling (Figure 1) involves excavating a trench, placing the biosolids in the trench, and then backfilling the trench to return the soil to its original contours. Monofill trenches can be narrow or wide, depending on the solids concentrations of the biosolids to be filled. Narrow trenches (typically less than 3 m [approximately 10 ft] wide) are generally used for disposal of biosolids with a low solids content. Wide trenches (typically greater than 3 m [approximately 10 ft] wide) are used for disposal of biosolids with a solids content of 20 percent or more. If the biosolids contain less than 20 percent solids, they will not support the machinery used to place the cover material over the trench.

Application rates for trenches less than 3 m in width are approximately 2,270-10,580 m³/ha (1,200-5,600 yd³/acre). Typical application rates for wider trenches range from 6,000-27,000 m³/ha (3,200-14,500 yd³/acre) (U.S. EPA, 1978).

The trench method provides efficient use of available land space. However, this method is
generally not used at sites that require a liner because of the potential to damage the liner during trench excavation.

In the area method, biosolids are placed in a natural or excavated depression, or they are mixed with soil and placed on top of the existing soil layer. Biosolids to be landfilled in this manner are generally stabilized prior to landflling because these sites do not always apply daily cover. The area method is particularly well suited to areas where bedrock or ground water are shallow, and excavation (as is required for the trench method) is difficult. However, this method requires substantial amounts of soil for fill and results in changes to the local topography.

The ramp method involves spreading and compacting the biosolids along a slope. The soil higher on the slope is pushed over the top of the biosolids as a cover material.

**Applicable Regulations**

Landfilling of biosolids in monofills is regulated by the Environmental Protection Agency under Subpart C of 40 CFR, Part 503, Standards for the Use and Disposal of Sewage Sludge as surface disposal. The Part 503 Regulations establish maximum concentrations of arsenic, chromium, and nickel in biosolids to be landfilled in a monofill without a liner. The limits vary with distance to property lines as presented in Table 1. If the concentration of any of these pollutants exceeds the criteria, the facility must be lined. The regulations also allow establishment of site-specific pollutant limits at the discretion of the permitting authority.

<table>
<thead>
<tr>
<th>Distance from Boundary of Active Biosolids Unit to Property Line, m</th>
<th>Pollutant Concentration (Dry Weight Basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic mg/kg</td>
<td>Chromium mg/kg</td>
</tr>
<tr>
<td>0 to less than 25</td>
<td>30</td>
</tr>
<tr>
<td>25 to less than 50</td>
<td>34</td>
</tr>
<tr>
<td>50 to less than 75</td>
<td>39</td>
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<tr>
<td>75 to less than 100</td>
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<td>100 to less than 125</td>
<td>53</td>
</tr>
<tr>
<td>125 to less than 150</td>
<td>62</td>
</tr>
<tr>
<td>Equal to or greater than 150</td>
<td>73</td>
</tr>
</tbody>
</table>

Source: Part 503 Regulations

**Co-Disposal Landfilling**

Co-disposal landfilling involves combining wastewater solids with municipal solid waste and placing the mixture in a permitted landfill. Generally, a layer of municipal solid waste is spread near the working face of the landfill. Wastewater solids are then spread over the municipal waste and the two are thoroughly mixed using typical landfill machinery. The ratio of waste to wastewater solids is dependent, in part, on the solids content of the wastewater solids. Ten percent biosolids to 90 percent solid waste (by volume) is common. The mixture is then compacted and covered with a daily cover.

**Applicable Regulations**

The design and operation of co-disposal landfills is regulated by EPA under Subpart I of 40 CFR, Part 258, Criteria for Municipal Solid Waste Landfills. Standards set forth in the Part 258 Regulations address general requirements, pollutant limits, management practices, operational standards for
pathogens and vector attraction, and monitoring, record keeping, and reporting requirements.

Accepting wastewater solids at a co-disposal landfill generally does not add significant regulatory hurdles or permit constraints to the landfill operator. In addition, co-disposal typically does not result in additional operational requirements for the landfill other than the mixing the biosolids and waste prior to placement in the permanent cell.

**APPLICABILITY**

Landfilling is generally considered for wastewater biosolids management when land application or other beneficial reuse is not possible. Typical scenarios that lead to selection of landfill disposal rather than beneficial reuse include:

- Land acquisition constraints;
- High concentration of metals or other toxins in the biosolids; or
- Odorous material that may create a public nuisance if managed through other options.

Solids concentrations of the biosolids are also a factor in determining whether landfilling is a viable disposal option. For biosolids monofills, the solids concentration should be 15 percent or greater. Although soil may be mixed with biosolids to increase the solids concentration to this level, this may not be cost effective. Biosolids are usually stabilized prior to monofilling.

As a general rule, municipal solid waste landfills will not accept materials with solids content less than about 18 percent. The operator will generally perform a paint filter test on the biosolids prior to allowing them to be deposited due to the regulatory prohibition of materials containing free liquids. The paint filter test is described in detail in EPA publication SW-846, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, Method 9095. In addition to the paint filter test for free liquids, a Toxicity Characterization Leaching Procedure (TCLP) must also be performed to verify that the biosolids are non-hazardous. Passing this test is generally not a problem for biosolids. The TCLP method (Method 1311) is defined in EPA SW-846.

Finally, economics also factor into any decision to manage biosolids through landfilling. Landfill tipping fees can be less than the full cost of land application or other reuse options. Because tipping fees change in response to market conditions, a periodic reassessment of solids management decisions is recommended.

**ADVANTAGES AND DISADVANTAGES**

**Advantages**

- Landfilling is suitable for biosolids with high concentrations of metals or other toxics.
- Landfills may require smaller land area than land application.
- Landfilling improves packing of solid waste and increases biogas production.
- Landfills may be the most economical biosolids management solution, especially for malodorous biosolids.

**Disadvantages**

- Landfilling biosolids eliminates their reuse potential and is contrary to the EPA national beneficial reuse policy.
- Landfilling requires extensive planning, including selection of a proposed landfill site, and operation, closure, and post closure care of the site.
- Operation, maintenance, and post closure care of landfills are labor intensive.
- Landfill sites have a potential for groundwater contamination from leachate.
- Decomposition of biosolids in a landfill produces methane gas which must be collected and reused or disposed of by flaring or venting. Energy can be recovered...
through methane capture systems to offset the cost of the necessary collection system.

- Landfills have a potential for odor generation.

**Environmental Impacts**

There are several potential environmental impacts associated with landfilling of wastewater biosolids. Leachate from the landfill may transport nitrate, metals, organics, and/or pathogens to groundwater if the landfill site has not been properly selected or if the liner has been damaged. In addition, rainfall runoff from an active landfill may carry contaminants to nearby surface waters. Specific impacts will vary among landfill locations.

Other potential impacts from these landfills include impacts on traffic volume, land use, air quality, public health, aesthetics, wildlife, and habitats of endangered species. Adverse impacts should be mitigated during the site selection process or by specific measures in the design (U.S. EPA, 1979).

**DESIGN CRITERIA**

Design of monofills and co-disposal landfills includes selecting an appropriate site, evaluating wastewater solids quality, and approving a method of operation. Preliminary planning is followed by detailed design, site development, site operation and maintenance, and closure.

**Site Evaluation**

Landfill sites must meet the siting criteria established by either the Part 503 (for monofills) or the Part 258 regulations (for co-disposal landfills). Both regulations contain similar requirements, including:

- A landfill shall not be developed if it is likely to adversely affect a threatened or endangered species.
- The landfill cannot be located in a wetland unless a special permit is obtained.
- A landfill cannot restrict the flow of a 100-year flood event.
- The landfill must not be located in a geologically unstable area.
- The landfill must be located 60 m (200 ft) or more from a fault area that has experienced displacement in Holocene time.
- If the landfill is located in a seismic impact zone, it must be designed to resist seismic forces.
- The landfill must be located at least 300 m (1,000 ft) from an airport runway.

Some states have additional siting criteria, including setbacks from property lines, public or private drinking water wells, surface drinking water supplies, and buildings or residences.

**Preliminary Planning**

The preliminary planning phase for landfill design should include a determination of the biosolids characteristics and an estimate of the average biosolids quantity. Once the biosolids quantity is determined, the area required for the landfill site, as well as its probable lifespan, can be calculated. Generally, a site should provide 10 to 20 years of operational capacity.

Other factors to consider during preliminary planning include haul distance and route from point of generation to the facility; topography; surface water and soils; geology; groundwater; vegetation; meteorology; environmentally sensitive areas; archaeological and historical significance; site access; final site use; and cost. Each of these issues could affect the final location of the landfill.

**Site Development**

Once the landfill site is determined, initial site development can begin. During the initial development of the landfill site, utilities such as water, sewer, and electricity must be provided for daily operations. In addition, support facilities such as an equipment garage, office building, and...
leachate pumping stations may need to be constructed.

The landfill design must also include site-specific criteria to meet environmental requirements. These requirements include mitigating the environmental impacts of runoff, infiltration of water through the landfill and into the underlying soil, and gas generation. Depending on regulatory requirements, the landfill may also require a lining. Design considerations for these impacts are discussed below.

**Mitigation of Runoff**

EPA requires that surface water runoff from an active landfill be collected and disposed of in accordance with NPDES requirements (WEF, 1998). The runoff collection system must be designed to contain a 25-year, 24-hour storm.

**Infiltration**

As water percolates through a landfill, it may become contaminated as it dissolves various soluble components of the biosolids. The resulting leachate must be contained and treated to eliminate the potential for groundwater pollution and/or public health problems. Methods for controlling leachate include implementing proper drainage, installing a liner, allowing the leachate to attenuate naturally, or collecting and treating the leachate. A leachate collection system may consist of a drainage layer (usually sand or geonet), leachate collection piping, a sump or series of sumps, and manholes.

**Gas Generation**

The anaerobic decomposition of biosolids in a landfill contributes to the generation of “natural” gas consisting primarily of methane (45 to 55 percent) and carbon dioxide. Methane is explosive in the atmosphere at concentrations of 5 to 15 percent. Either passive or active gas collection systems can be effective in preventing the accumulation and possible migration of landfill gas.

A passive collection system consists of perforated collection pipes and header pipes placed just below the landfill cap to collect and vent gas to the atmosphere. Active systems consist of a series of gas wells drilled into the waste or a series of horizontal trenches and a blower to collect the gas. Active gas collection systems are used to control odors at a site and may also be used to recover energy from the methane. If cost effective, the methane recovered from the landfill gas may be used in boilers or space heaters, or in turbines to generate electricity. It may also be upgraded to pipeline-quality gas.

**Landfill Liner**

Another critical design consideration is facility lining. Three types of materials are typically used for landfill liner systems. They include low permeability soil (clay), geosynthetic clay liners (GCL), and geomembrane liners. The Part 503 regulations require a maximum hydraulic conductivity of $1 \times 10^{-7}$ cm/s (2$\times 10^{-7}$ ft/min) for a monofill liner (when a liner is required). The Part 258 regulations require all co-disposal landfills to have a composite liner. The top component of the liner must consist of a minimum 30-mil flexible membrane liner, while the bottom component must consist of at least a 60 cm (2 ft) thick layer of compacted soil with a hydraulic conductivity of $1 \times 10^{-7}$ cm/s (2$\times 10^{-7}$ ft/min). The flexible membrane component must be installed in direct and uniform contact with the compacted soil.

Both natural and synthetic liners have advantages and disadvantages. While synthetic liners are virtually impermeable to liquids, they do not have the self-healing characteristics of natural liners. Natural liners have slightly higher permeability than synthetic liners, but are less susceptible to possible subbase changes.

**OPERATION AND MAINTENANCE**

Each municipal solid waste landfill is required to have an operation and maintenance (O&M) plan that describes its procedures. Monofills are encouraged to maintain a similar plan. Operational considerations addressed in these plans include:

- Hours of operation.
- Material weighing procedures.
Traffic flow and unloading procedures.

Cover material excavation (or purchase), stockpiling, and placement.

Maintenance procedures and schedules.

Inclement weather operations.

Environmental monitoring and control practices.

Management and reporting required under the Part 503 and Part 258 regulations include maintaining activity, performance, and cost records, as well as required regulatory reports. Activity records may include equipment and personnel accounts, biosolids receipts, cover material quantities, etc.

Regular O&M activities at a landfill containing biosolids may involve the following: providing periodic cover for the biosolids; capping sections (or “cells”) of the landfill once they are full; monitoring the site to ensure that leachate from the landfill does not contaminate groundwater; and closing the landfill site when it has reached its capacity. These O&M activities are discussed in more detail below.

**Periodic Cover**

Cover materials are used at landfills to manage vectors, control odors, increase compaction, decrease settling, and minimize wind erosion. If the landfill site does not have sufficient available soil, cover material must be obtained off-site and transported to the facility. At the end of each working day 15 cm (6 in) of cover is spread over the compacted waste. An intermediate cover 30 cm (1 ft) thick is applied when the cover material will be exposed for more than one month but less than six months. If the cover material is to be exposed for more than six months, final cover with a minimum thickness of 60 cm (2 ft) is required.

**Cell Closure**

Landfills are typically developed in phases to minimize the area exposed to rainfall and the rate of leachate production. Based on the site topography and the calculated amount of waste to be landfilled, an area with an expected life of two to five years is developed for each phase. As an active cell nears its capacity, a new cell is constructed.

**Site Monitoring**

Both the Part 503 and Part 258 regulations stipulate that landfills shall not contaminate an aquifer. Most states require groundwater monitoring at landfill sites. EPA has also established monitoring requirements for methane gas because of the explosive hazard. Monitoring is required during the active life of the landfill and for three years following closure of the landfill.

**Site Closure/Capping**

When a landfill cell has reached capacity, a final cap is placed to prevent infiltration of rainwater and reduce leachate generation. The layers of the cap, from bottom to top, include the following:

- **Subgrade Layer** - Used to contour the landfill and provide a base for construction of subsequent layers.
- **Gas Control Layer** - Transports gas to a venting system.
- **Hydraulic Barrier** - Limits infiltration of water to the landfilled waste.
- **Drainage Layer** - Collects and transports water that percolates into the final cover.
- **Biotic Layer** - Protects the hydraulic barrier from intrusions by animals or plants.
- **Filter Layer** - Prevents the migration of fines from the vegetative support (surface) layer to the drainage layer.
- **Surface Layer** - May be either a soil capable of supporting vegetation or an armored protection layer.

The thickness and performance standards for each layer may vary depending on the approving authority. Post closure monitoring of the cap
should include monitoring of settlement, cover soil integrity, grading, vegetation conditions, sediment and erosion controls, gas controls, and security fencing.

The Part 503 and Part 258 Regulations require the owner/operator of a landfill to submit a closure plan at least 180 days prior to closure of the facility. The closure plan should describe both closure and post closure activities including maintenance of the leachate collection system, monitoring of methane gas production, and limiting public access to the site, all required for three years following closure.

The final intended use of a closed landfill should be identified during the design phase to ensure that appropriate decisions are made regarding cover material, grading, monitoring, and stormwater management. Typical uses for closed landfills include athletic fields, game courts, golf courses, playgrounds, picnic areas, and open spaces where there is not a need for extensive tree planting.

COSTS

It is difficult to estimate the cost of landfilling biosolids without individual program details. For example, land acquisition costs vary from region to region, and liners may or may not be required. Other factors that impact the cost of landfilling of biosolids include:

- Capacity of landfills serving the area.
- Haul distance.
- Method of leachate treatment and disposal.
- Method of gas collection, disposal or reuse.
- Post closure use.
- Purchase and maintenance of equipment.
- Regulatory compliance, such as preparation of reports, site monitoring, and biosolids analysis.
- Local labor rates.
- Importation of cover material if on-site quantity is insufficient.

In 1994, the municipalities of Las Vegas, Henderson, and the Clark County Sanitation District in Nevada were disposing all biosolids in a privately owned and operated facility 25 miles from the municipalities. The total solids production of 545 wet Mg/day (600 wet tons/day) was mechanically dewatered to a range of 10 to 33 percent solids. The cost for disposing of these solids was approximately $10/wet Mg ($11/wet ton), including transportation by a contract hauler and landfill tipping fee.

As part of a regional biosolids management plan developed in 1994, the municipalities evaluated the option of building their own biosolids monofill. Potential sites, ranging from less than 16 km (10 mi) to up to 80 km (50 mi) away, were selected based primarily on their distance from the municipalities. Other site evaluation criteria included topography, hydrology, land use, availability of utilities, and other social/environmental concerns. The monofill capacity was estimated at 31 million m³ (40 million yd³), based on accommodating the total annual solids production for a period of 30 years. The amount of land required for the monofill and space for solids processing was estimated to be approximately 200 ha (500 acres). The estimated cost for this alternative ranged from $25.71/wet Mg ($28.32/wet ton) for the closest site to $28.32/wet Mg ($31.20/wet ton) for the most remote site.

REFERENCES

Other Related Fact Sheets

Odor Management in Biosolids Management
EPA 832-F-00-067
September 2000

Centrifugal Dewatering/Thickening
EPA 832-F-053
September 2000

Belt Filter Press
EPA 832-F-057
September 2000
Filter Press, Recessed Plate
EPA 832-F-00-058
September 2000

Alkaline Stabilization of Biosolids
EPA 832-F-00-052
September 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owm/mtb/mtbfact.htm


**ADDITIONAL INFORMATION**

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P.O. Box 1670
Marina, CA 93933

Virginia Department of Environmental Quality
Hassan Vakili
629 East Main Street
Richmond, VA 23219

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Office of Water
EPA 832-F-03-012
June 2003

For more information contact:
Municipal Technology Branch
U.S. EPA
1200 Pennsylvania Ave, NW
Mail Code 4204M
Washington, D.C. 20460
What every operator should know about biosolids management for land application

Steve Wilson

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Principles</th>
<th>Practical considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory requirements</td>
<td>Title 40, Code of Federal Regulations, Part 503</td>
<td>The 1993 40 CFR Part 503 Rule and technical support documents serve as the foundation of all regulatory policies. State or local jurisdictions can be more conservative in some cases, but never less stringent.</td>
</tr>
<tr>
<td></td>
<td>Various state and local rules</td>
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</tr>
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</table>
| Terminology                      | Biosolids versus sewage sludge                                            | **Biosolids** are the primarily organic solid product of wastewater treatment that can be beneficially used. **Sludge** or **sewage sludge** is unprocessed (i.e., unstabilized) and generally unsuitable for beneficial use.  
The Part 503 rule does not use the term **biosolids**, but subsequent guidance and state-level policies have recognized the distinction between **sludge** and **biosolids** and use this terminology. |
| Product standards                | Rules and guidance define acceptable (risk-based) chemical characteristics focusing on metals.  
Pathogen reduction and stabilization (vector attraction reduction) standards also are defined. | Metal (pollutant) limits are defined in the Part 503 rule. Metals rarely are limiting in beneficial use programs because pretreatment programs have been so effective. But operators always should check data for verification.  
Pathogen reduction will be to Class A or Class B standards depending on process technology. Class B product reuse has management practice limits to protect operator and public health.  
Stabilization standards, such as the minimum 38% volatile solids reduction through digestion, minimize odors during product handling and reuse and help minimize complaints. |
| Agronomic rates                  | Application rates are determined to match the amount of available nitrogen applied to the amount needed by crops. | Available nitrogen is calculated in units of pounds per dry ton. This value is converted to a wet (or as-applied) basis in either wet tons or gallons per acre in line with fertilizer recommendations for the crop being grown. Many guidance documents and even online spreadsheets are available to assist in making these calculations (see below). Spreader equipment then is calibrated to deliver this amount of material per unit of field. |
| Marketability                    | Class B biosolids generally are delivered at no cost or for a nominal fee; the land owner benefits from the fertilizer value.  
Class A products may be marketed more aggressively and sometimes are sold to offset production costs. Quality may be more important. | Product quality parameters include  
■ meeting or exceeding all regulatory requirements,  
■ lack of visible trash or foreign material,  
■ low odor potential,  
■ "soil-like" consistency (i.e., manufactured topsoil or compost), and  
■ dust-free product with uniform particle size (for dried products). |
Knowledge | Principles | Practical considerations
--- | --- | ---
Monitoring | Part 503 and state rules dictate sampling frequencies, parameters, and methodology. | Testing generally includes Part 503 metals (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc), nutrients (total Kjeldahl nitrogen, ammonium–nitrogen, nitrate–nitrogen, and phosphorus), and percent-total and percent-volatile solids.
For Class A products, additional testing is required to demonstrate pathogen reduction to minimal (1000 MPN/g dry solids) levels.
Reporting | Agencies must report process control details (to verify pathogen and vector attraction reduction), biosolids quantities, pollutant concentrations, nutrient values, and biosolids disposition information on an annual basis. | At a minimum, a biosolids “preparer” must submit an annual report to the U.S. Environmental Protection Agency (EPA) for the previous year by February 19. Where authority has been delegated to states, the report goes to the state regulatory agency. Dual reporting to both state and EPA is not uncommon.
The preparer must certify that all regulatory requirements have been met. In some cases, a contract “applier” must submit a separate report certifying land application practices. The preparer always should verify that a separate applier has met all requirements.
Resources | Comprehensive guidance and training is available readily from several sources. | A short list of sources includes the following:
- The Water Environment Federation provides access to state regulatory contacts, technical resources, and other documents at www.wef.org/biosolidsnews.
- EPA lists a wealth of links and information at http://water.epa.gov/polwaste/wastewater/treatment/biosolids.
- EPA also posts the Plain English Guide to the Part 503 Rule at http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm.
Networking | Become active in your regional or local biosolids community. | Regional biosolids communities include the Northwest Biosolids Management Association (Seattle), the North East Biosolids Recycling Association (Tamworth, N.H.), the Mid-Atlantic Biosolids Association (Philadelphia), the California Association of Sanitation Agencies (Sacramento, Calif.), and WEF Member Association biosolids committees.
Promoting public support | Share information. | News releases about program successes benefit public understanding by sharing positive biosolids recycling news.
Potential for public opposition | Be aware. | An Internet search for “biosolids” reveals the extent of unsupported, unscientific, negative information that is out there for the uninformed to use as the basis for their first impression of biosolids recycling. It’s important to understand what kind of faulty information the public may be exposed to.
Research and emerging issues | Support research. | Questions about fundamental biosolids benefits and controls – not to mention emerging constituents, personal care products, and other microconstituents – abound. Consider funding research with local universities directly through your agency or as a regional association member.

Steve Wilson is a chief scientist in the Portland, Ore., office of Brown and Caldwell (Walnut Creek, Calif.).
Section 7

Effluent Disposal
Effluent Disposal

Intro to Wastewater

Disposal by Dilution

- Treatment required prior to discharge:
  - Stabilize waste
  - Protect public health
  - Meet discharge requirements

- Site specific
- Most common method of effluent disposal

Disposal by Dilution

- Diffusers
- Cascading outfalls
  - Increase D.O.
  - Remove chlorine
  - Remove sulfur dioxide
  - Surface discharge

Land Treatment Systems

- When high-quality effluent or even zero-discharge is required, land treatment offers a means of reclamation or ultimate disposal
- Land treatment = the controlled application of wastewater to the land surface to achieve a designed degree of treatment through physical, chemical, and biological processes within the plant-soil-water matrix.
  - Soil texture, soil structure, permeability, infiltration, available water capacity, and cation exchange capacity
  - Adsorption and precipitation are the main processes involved in the retention of wastes in the soil
Land Treatment Systems

- Simulate natural pathways of treatment
- Use soil, plants, and bacteria to treat and reclaim wastewater
- Treatment is provided by natural processes as effluent moves through soil and plants
- Some of wastewater is lost by evaporation and transpiration
- Remainder returns to hydrologic cycle through surface runoff or percolation to groundwater

Hydrologic Cycle

Land Application System

- Treatment prior to application
- Transmission to the land treatment site
- Storage
- Distribution over the site
- Runoff recovery system
- Crop systems

Land Application System

- Evapotranspiration
- Percolation
- Surface Runoff
- Land Disposal Site
- Storage Reservoir
- Treated Plant Effluent

3 Major Land Treatment Processes

1. Slow rate
   - Irrigation, ridge-and-furrow, border strip flooding
   - Vegetation uses portion of flow, some goes to groundwater
   - Organic wastes removed by filtration and adsorption
   - Designed for no surface runoff

2. Rapid infiltration
   - Moderately and highly permeable soils by spreading basins or sprinklers (vegetative cover not used)
   - Treated effluent collected by drain tiles and discharged to surface water or it enters groundwater

3. Overland flow
   - Highly permeable soils, applied at upper reaches of grass covered slopes, flows over vegetation, surface runoff collected

Site Considerations

- Control of ponding problems
- Percolation
- Crop selection
- Drainage tiles
- Install PVC laterals below ground
- Potential odor release with spray systems
- Routine inspection of equipment
- Plan “B” in case system fails
- Nitrogen is the major limiting factor
Wastewater Reclamation: Land Application

- Irrigation most common:
  - Ridge and furrow
  - Sprinklers
  - Surface/drip systems
  - Border strip flooding
  - Overland flow
  - Wetlands treatment

Irrigation

- Method depends on crop grown, 3 groups:
  1. Forage crops (ex: grasses and alfalfa)
  2. Field crops (ex: corn)
  3. Forests
- Water & nutrients enhance plant growth for beneficial use
- Water removed by:
  - Surface evaporation & plant transpiration
  - Deep percolation to subsoil

Irrigation - Spray Systems

3 categories:
1. Solid set (Fixed)
   - Buried or on surface
   - Cultivated crops or woodlands
2. Portable
3. Continuously moving
   - Moving - center pivot

- Maximum slope in TN (TN Design Criteria 16.1.4):
  - Row crops 8%
  - Forage crops 15%
  - Forests 30%

Irrigation - Spray Systems

- Most common land treatment in US
- Spray: fixed or moving
- Surface spreading: controlled flooding or ridge & furrow
- Climate affects efficiency
  - If ground freezes, subsurface seepage is greatly reduced.
  - Therefore storage of treated wastewater may be necessary
  - Ex: lawns, parks, golf courses, pastures, forests, fodder crops (corn, alfalfa), fiber crops, cemeteries
**Irrigation – Ridge & Furrow**

- Ridge and Furrow = a series of interconnected ditches (furrows) which allow for the distribution, infiltration, and treatment of wastewater
- Wastewater flows through furrows between rows of crop
- Wastewater slowly percolates into soil
- Wastewater receives partial treatment before it is absorbed by plants

**Irrigation – Ridge and Furrow**

Source: [fao.org](http://fao.org)

Source: [colostate.edu](http://colostate.edu)

**Irrigation – Removal Efficiencies**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% Removal</th>
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<tbody>
<tr>
<td>BOD</td>
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</tr>
<tr>
<td>COD</td>
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</tr>
<tr>
<td>Suspended Solids</td>
<td>98</td>
</tr>
<tr>
<td>Nitrogen</td>
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</tr>
<tr>
<td>Phosphorus</td>
<td>95</td>
</tr>
<tr>
<td>Metals</td>
<td>95</td>
</tr>
<tr>
<td>Microorganisms</td>
<td>98</td>
</tr>
</tbody>
</table>

**Overland Flow**

- Spray or surface application
- 6-12 hours/day
- 5-7 days/week
- 2-8% slope
- Slow surface flow treats wastewater
- Water removed by evaporation & percolation
- Runoff collection
Overland Flow

• Wastewater is applied intermittently at top of terrace
• Runoff collected at bottom (for further treatment)
• Treatment occurs through direct contact with soil
  • Sedimentation, filtration, and biological oxidation

Overland Flow

• Highly impermeable soils
• High nitrogen removal (70-90%)

Distribution Methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Low energy costs</td>
<td>Difficult to achieve uniform distribution</td>
</tr>
<tr>
<td></td>
<td>Minimize aerosols and wind drift</td>
<td>Moderate erosion potential</td>
</tr>
<tr>
<td>Gated Pipe</td>
<td>Same as General, plus</td>
<td>Same as General, plus</td>
</tr>
<tr>
<td></td>
<td>Easy to clean</td>
<td>Potential for freezing and settling</td>
</tr>
<tr>
<td>Slotted or Perforated Pipe</td>
<td>Same as General</td>
<td>Same as Gated Pipe, plus</td>
</tr>
<tr>
<td></td>
<td>Small openings clog</td>
<td>Most difficult to balance hydraulically</td>
</tr>
<tr>
<td>Bubbling Orifices</td>
<td>Same as General, plus</td>
<td>Same as General, plus</td>
</tr>
<tr>
<td></td>
<td>Not subject to freezing/sediment</td>
<td>Difficult to clean when clogged</td>
</tr>
<tr>
<td></td>
<td>Only the orifice must be leveled</td>
<td></td>
</tr>
<tr>
<td>Low-pressure Sprays</td>
<td>Better distribution than surface methods</td>
<td>Moderate subject to clogging</td>
</tr>
<tr>
<td></td>
<td>Less aerosols than sprinkler</td>
<td>More aerosols and wind drift than surface methods</td>
</tr>
<tr>
<td>Sprinklers</td>
<td>Most uniform distribution</td>
<td>High energy costs</td>
</tr>
</tbody>
</table>

Suitable Grasses

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Perennial or Annual</th>
<th>Rooting Characteristics</th>
<th>Method of Establishment</th>
<th>Growing Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reed canary</td>
<td>Perennial</td>
<td>sod</td>
<td>seed</td>
<td>120-210</td>
</tr>
<tr>
<td>Tall fescue</td>
<td>Perennial</td>
<td>bunch</td>
<td>seed</td>
<td>90-120</td>
</tr>
<tr>
<td>Rye grass</td>
<td>Annual</td>
<td>sod</td>
<td>seed</td>
<td>60-90</td>
</tr>
<tr>
<td>Redtop</td>
<td>Perennial</td>
<td>sod</td>
<td>seed</td>
<td>60-90</td>
</tr>
<tr>
<td>KY bluegrass</td>
<td>Perennial</td>
<td>sod</td>
<td>seed</td>
<td>30-75</td>
</tr>
<tr>
<td>Orchard grass</td>
<td>Perennial</td>
<td>bunch</td>
<td>seed</td>
<td>15-60</td>
</tr>
<tr>
<td>Common Bermuda</td>
<td>Perennial</td>
<td>sod</td>
<td>seed</td>
<td>30-45</td>
</tr>
<tr>
<td>Coastal Bermuda</td>
<td>Perennial</td>
<td>sod</td>
<td>sprig</td>
<td>30-60</td>
</tr>
<tr>
<td>Dallis grass</td>
<td>Perennial</td>
<td>bunch</td>
<td>seed</td>
<td>60-120</td>
</tr>
<tr>
<td>Bahia</td>
<td>Perennial</td>
<td>sod</td>
<td>seed</td>
<td>29</td>
</tr>
</tbody>
</table>

Suitable Grasses

• Well established plant cover is essential for efficient performance of overland flow
• Primary purpose of plants is to facilitate treatment of wastewater
• Planting a mixture of different grasses usually gives best results
• Ryegrass used as a nurse crop; grows quickly until other grasses are established
Suitable Grasses

- Cool Season Grass – plant from Spring through early Summer or early Fall to late Fall
- Warm Season Grass – generally should be planted from late Spring through early Fall
- Planting time affected by expected rainfall, location, climate, grass variety, etc.
- Amount of seed required to establish cover depends on:
  - Expected germination
  - Type of grass
  - Water availability
  - Time available for crop development

Overland Flow – Removal Efficiencies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>92</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>92</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>70-90</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>40-80</td>
</tr>
<tr>
<td>Metals</td>
<td>50</td>
</tr>
</tbody>
</table>

- Treatment by oxidation and filtration
  - SS removed by filtration through vegetative cover
  - BOD oxidized by microorganisms in soil and on vegetative debris
  - Nitrogen removal by denitrification and plant uptake

Rapid Infiltration

- Primary objective is to recharge the groundwater
- Wastewater is applied to spreading basins or seepage basins and allowed to percolate through the soil
- No plants are used or desired

Land Treatment Limitations

- Sealing soil surface due to high SS in final effluent
  - More common in clay soils
  - Disk or plow field to break mats of solids
  - Apply water intermittently and allow surface mat to dry and crack
  - Build up salts in soil
    - Salts are toxic to plants
    - Leach out the salts by applying fresh water
    - Rip up the soil 4 – 5 ft deep to encourage percolation

- Top– Picture of a seepage basin in Nevada
- Bottom - Large volumes of reclaimed water, which have undergone advanced secondary treatment, are reused through land-based applications in a 40-square-mile area near Orlando, Florida.
Land Treatment Limitations

- Excessive nitrate ions reach groundwater
- Rain can soak soil so that no treatment is achieved
- Do not apply nitrate in excess of crop’s nitrogen uptake ability
- Excessive nitrate in groundwater can lead to methylmoglobinemia (blue baby syndrome)
- Too much nitrate consumed by child leads to nitrate in stomach and intestines where nitrogen is absorbed into bloodstream and it bonds to red blood cells preventing them from carrying oxygen.
- Baby becomes oxygen deprived, turns blue and suffocates

Water Quality Indicators

- Receiving water measurements = tests used to determine the effect of discharge on the receiving waters and on the beneficial uses (water supply, recreation, fishery) of the receiving waters after effluent has mixed with receiving waters
- To measure impact:
  - Take a measurement upstream (not affected) and downstream (affected) and compare the two results
  - “Oxygen profile” (Dissolved oxygen) to get a good measure of the effect of the effluent
  - Measure the DO at several different cross sections downstream from discharge to find out where the lowest DO level occurs

Water Quality Indicators

- To determine impact, the following questions must be answered:
  1. What are the characteristics upstream?
  2. Temperature
  3. Dissolved oxygen (DO)
  4. What are the characteristics downstream?
  5. If upstream and downstream are different, does the discharge cause the difference?
  6. Are the downstream characteristics in violation of established standards or objectives
  7. If downstream is in violation, did the discharge cause it?

Water Quality Indicators – DO profile

Monitoring Requirements

<table>
<thead>
<tr>
<th>Area</th>
<th>Test</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effluent and groundwater or seepage</td>
<td>BOD</td>
<td>Two times per week</td>
</tr>
<tr>
<td></td>
<td>Fecal coliform</td>
<td>Weekly</td>
</tr>
<tr>
<td></td>
<td>Total coliform</td>
<td>Weekly</td>
</tr>
<tr>
<td></td>
<td>Flow</td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td>Nitrogen</td>
<td>Weekly</td>
</tr>
<tr>
<td></td>
<td>Phosphate</td>
<td>Weekly</td>
</tr>
<tr>
<td></td>
<td>Suspended solids</td>
<td>Two times per week</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Daily</td>
</tr>
<tr>
<td></td>
<td>Total dissolved solids (TDS)</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>Total P</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>Chloride</td>
<td>Monthly</td>
</tr>
<tr>
<td>Vegetation</td>
<td></td>
<td>- - - variable depending on crop - - -</td>
</tr>
<tr>
<td>Soils</td>
<td>Conductivity</td>
<td>Two times per month</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Two times per month</td>
</tr>
<tr>
<td></td>
<td>Cation Exchange Capacity (CEC)</td>
<td>Two times per month</td>
</tr>
</tbody>
</table>
Water Quality Indicators

- Plant effluent analyzed prior to discharge:
  - In-stream: pH, D.O., temperature
  - In laboratory: BOD, COD, suspended solids, fecal coliforms, E. coli, N, P

- Disposal by dilution may require analysis of receiving stream upstream & downstream
- WET testing (Whole Effluent Toxicity)

Whole Effluent Toxicity (WET) Testing

- Whole Effluent Toxicity (WET) test refers to the combined toxic effect to aquatic organisms from all pollutants contained in a wastewater effluent
- Looks at the effluent as a single component
- WET tests measure wastewater’s effects on specific test organisms’ ability to survive, grow and reproduce
- Acute toxicity
- Short term, lethal effects
- “End of pipe” conditions
- Chronic toxicity
- Long term, sub-lethal effects
- Mixed water conditions
- More sensitive test

Whole Effluent Toxicity (WET) Testing

- NPDES permit limits found in Sections 3.4, 3.5
- Methods for compliance with NPDES permits in 40 CFR 136.3
- Test organisms:
  - Water flea (Ceriodaphnia dubia)
  - Invertebrate crustacean
  - Fathead Minnow (Pimephales promelas)
  - Vertebrate fish
CHAPTER 16

Design Guidelines for Wastewater Treatment Systems Using Spray Irrigation

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16.1.4 Topography
16.1.5 Soils

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16.2.2 Soil Mapping
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SPRAY IRRIGATION
LAND TREATMENT SYSTEMS

16.1 General

16.1.1 General

This chapter provides guidelines and criteria for the design of surface spray irrigation land treatment systems.

The wastewater loading rate is limited by the maximum amount of a particular wastewater constituent that can be applied to a specific site. For wastewater from municipalities, the limiting design factor is usually either the hydraulic capacity of the soil or the nitrogen content of the wastewater. For industrial wastewater, the limiting design factor may be the hydraulic capacity of the soil, nitrogen or any other wastewater constituent such as metals, organics, etc.

16.1.2 Applicability

Spray irrigation wastewater treatment systems must be designed and operated so that there is no direct discharge to surface waters. Treatment consists of evaporation directly to the atmosphere, by transpiration to the atmosphere via vegetation uptake and by percolation to groundwater. A State of Tennessee Operation Permit (SOP) is required for operation of spray irrigation land treatment systems.

16.1.3 Location

The spray irrigation treatment site should be relatively isolated, easily accessible and not susceptible to flooding. The site can be developed on agricultural land and/or forests or can include parks, golf courses, etc. Site location shall take into account dwellings, roads, streams, etc. A site evaluation by the Division of Water Pollution will be required before review of the Engineering Report and/or application for an SOP.

16.1.4 Topography

Maximum grades for wastewater spray fields should be limited to 8% for row crops, 15% for forage crops and 30% for forests. The greater the slope the greater potential for lateral subsurface drainage, ponding and extended saturation of the soil. Depressions, sink holes, etc., are to be avoided.

16.1.5 Soils

The infiltrative capacity of soil is a critical factor to be considered when designing any type of spray irrigation system. If the profile of a particular soil considered for spray irrigation extended to a significant depth without a restrictive horizon (most limiting layer), the ability to load that soil per unit area would be relatively high.
On the other extreme, if a soil being considered for spray irrigation has a shallow restrictive horizon, the ability to load that soil would be lower relative to the deeper soil. Depth to restrictive horizon, soil permeability and slope of the restrictive horizon are factors that control the amount and rate at which ground water can exit an area. If the amount of treated effluent applied to an area, in combination with rainfall over the area and groundwater moving into the area, exceed the soil profile’s ability to transmit the water away from the application area, surface runoff of wastewater effluent will likely occur.

Evaluation of a soil area’s suitability for spray irrigation should take into consideration limiting aspects of the soil profile. Sites with shallow restrictive horizons overlain by low permeability soils represent one of the more limited scenarios for spray irrigation and the application rate and/or application area should be suitably modified.

Also critical when designing systems in soils with shallow restrictive horizons are the presence and location of hydrologic boundaries such as drainage ways and waterways. These hydrologic boundaries provide an outlet for ground water discharge. Not only is it critical to identify these features in consideration of appropriate setbacks/buffers, it is also critical to factor in their role in the overall hydrologic cycle of the landscape.

Horizons along which lateral flow would be expected include, but are not necessarily limited to: bedrock, fragipans, and zones with high clay percentage overlain by more permeable soil.

Spray irrigation design submittals should take into consideration all factors influencing the infiltrative capacity of the soil and the ability of the soil and site to transport ground water away from the application area. Spray pattern designs must properly utilize the site soil and topography. It should be noted that the use of historical information from existing systems installed and operated in similar soils, with documented loading rates, landscape positions and design conditions similar to the proposed system may be applicable. Therefore, soils that have been highly compacted and/or disturbed, such as old road beds, foundations, etc., must be excluded when evaluating suitable areas for surface spray irrigation systems.

### 16.2 Soil Investigations

#### 16.2.1 General

Preliminary soil investigations should be done to identify areas best suited for surface spray irrigation. The proposed surface spray area must be mapped at sufficient accuracy to identify each soils series (or lowest possible level of soil classification) present and the boundary location between series. Once those areas are identified, the more detailed procedures outlined below will be employed.

It is required that all soil investigations be performed by a soil scientist currently on the Ground Water Protection list of approved soil scientists/soil consultants.

For spray irrigation wastewater treatment systems, moderately permeable and well-drained soils are desirable. However, the use of any soil is acceptable if it meets the following four (4) criteria:
1. The applied effluent loading rate does not exceed the applicable hydraulic loading rate in Table 16-1. The applicable hydraulic loading rate is determined by a detailed site evaluation in which the site is mapped utilizing soil borings and pits to determine the physical properties of soil horizons and soil map units.

2. The applied effluent maximum loading rate does not exceed 10% of the minimum NRCS saturated vertical hydraulic conductivity ($K_{SAT}$) for the soil series or 0.25 GPD/SF whichever is least. Note: this may have to be lowered based upon the results of the nutrient loading rate calculation per Equation 16-1.

3. The soil does not have a restrictive horizon within its top twenty (20) inches.

4. The soil is well drained, or capable of being drained.

   It is desirable to have a minimum depth of twenty (20) inches of undisturbed soil above a restrictive horizon (eg., rock, fragipan, high water table, etc.)
## TABLE 16-1
Hydraulic Loading Rates (GPD/SF) – For Spray Irrigation Systems


<table>
<thead>
<tr>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>GRADE</th>
<th>HYDRAULIC LOADING RATE*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SHAPE</td>
<td>BOD ≤ 150 mg/L</td>
<td>GPD / SF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BOD ≤ 30 mg/L</td>
<td>GPD / SF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Sand, Loamy Coarse Sand</td>
<td>NA</td>
<td>NA</td>
<td>0.80</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sand</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Loamy Sand, Fine Sand, Loamy Fine</td>
<td>Single Grain</td>
<td>Structureless</td>
<td>0.40</td>
</tr>
<tr>
<td>Sand, Very Fine Sand, Loamy Very</td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Fine Sand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Sandy Loam, Sandy Loam</td>
<td>Massive</td>
<td>Structureless</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Plate</td>
<td>Weak</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate, Strong</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Blocky, Granular</td>
<td>Weak</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate, Strong</td>
<td>0.70</td>
</tr>
<tr>
<td>Loam</td>
<td>Massive</td>
<td>Structureless</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Plate</td>
<td>Weak, Moderate, Strong</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Angular, Blocky</td>
<td>Weak</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Granular, Subangular</td>
<td>Moderate, Strong</td>
<td>0.60</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>Massive</td>
<td>Structureless</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Plate</td>
<td>Weak, Moderate, Strong</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Angular, Blocky</td>
<td>Weak</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Granular, Subangular</td>
<td>Moderate, Strong</td>
<td>0.60</td>
</tr>
<tr>
<td>Sandy Clay Loam,</td>
<td>Massive</td>
<td>Structureless</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effluent Disposal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay Loam, Silty Clay Loam</td>
<td>Weak, Moderate, Strong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------------</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky, Granular, Subangular</td>
<td>Weak</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky, Granular, Subangular</td>
<td>Moderate, Strong</td>
<td>0.60</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sandy Clay Clay, Silty Clay</th>
<th>Weak, Moderate, Strong</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive, Structureless, Platy</td>
<td>Weak, Moderate, Strong</td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky, Granular, Subangular</td>
<td>Weak</td>
<td>0.20</td>
</tr>
<tr>
<td>Angular, Blocky, Granular, Subangular</td>
<td>Moderate, Strong</td>
<td>0.30</td>
</tr>
</tbody>
</table>

* Maximum allowable is 0.25 GPD/SF; however all hydraulic loading rates may be adjusted based upon special site specific evaluations approved by TDEC. These soils are considered unacceptable for spray irrigation.
16.2.2 Soil Mapping

The mapping procedure will usually begin with the property/land being generally evaluated to delineate or separate areas with suitable characteristics. This procedure will save time and money since some areas will be too shallow, too wet, too steep, etc. Adequate ground control is mandatory for all sites. The ground control is necessary to reproduce the map if needed. All located coordinates (soil map boundaries and pit locations) must be shown on the final Water Pollution Control (WPC) Soil Map.

Soil data collection shall be based upon one, or combination of the following:

1. Grid staking at intervals sufficient to allow the soils scientist to attest to the accuracy of the map for the intended purpose;

2. Mapping of pits and critical auger locations using dual frequency survey grade Global Positioning System (GPS) units.

3. Other controls adequate to map the location of pits, physical features, and separations.

4. Grid stakes and GPS data points must be locatable to within two (2) feet of distance shown.

5. The ground control has to correlate to the exterior boundaries of the property so as to show the location of the soils areas within the bounds of the project and must be certified by a Registered Land Surveyor per TCA 62-18-102(3).

The soil scientists are responsible for conducting a sufficient number of borings that, in their professional opinion, will allow them to certify the soils series (or lowest possible level of soil classification) present, identify boundaries between series, and describe each soil horizon as to color, depth to restrictive horizon, and depth to rock. Any redoximorphic features observed are to be described. This delineation should be based upon the texture and structure of the soils to a depth of forty-eight (48) inches or restrictive horizon whichever is shallower.

After the mapped soils area is established and marked, soil borings to a minimum depth of forty-eight (48) inches or restrictive horizon, whichever is shallowest, shall be taken at sufficient intervals to identify and map the boundaries of the soils series (or lowest possible level of soil classification) present on the site. The exact number and location of borings will be determined by the soils scientist in consultation with the design engineer. Sufficient borings should be made to identify any dissimilar soils accounting for more than 10 percent of the total proposed surface spray irrigation area.

The soil scientist shall excavate an adequate number of pits to determine the typical profiles and soils characteristics that are expected for all soils mapped. It is recommended that a minimum of two (2) pits per acre in polygons of qualifying soils be excavated; however, the actual number and location of pits will be left to the best professional judgment of the soil scientist. If less than two (2) pits per acre are utilized, the soil scientist must include the rationale in notes on the WPC Soil Map.
The pit description must be entered onto a pedon sheet and submitted with the soils map and engineering report. The “Soil Description” should include all of the information contained on form NRCS-Soils-232G (5-86), U.S. Department of Agriculture, Natural Resources Conservation Service (as shown in Chapter 17, Appendix D).

In their description of the pit profiles, the soil scientists must describe the soil’s structure, texture, color, and any redoximorphic features present. They should also describe root depth and presence of macropores, etc. The series name or lowest possible level of soil classification will be recorded. The depth to hard rock using an auger or a tile probe must be specified if the depth is less than forty-eight (48) inches and estimated if greater than forty-eight (48) inches. The auger borings and soil backhoe pits should be located, numbered and shown on the WPC Soil Map. The soil scientist will be required to prepare and sign a detailed certification statement for each site evaluated as follows:

Water Pollution Control Soil Map Completed by:

Signature    Date

John/Jane Doe, Soils Consultant

The following statement should appear on the map:

“I, (Soils Consultant’s Name) affirm that this Water Pollution Control Soil Map has been prepared in accordance with accepted standards of soil science practice and the standards and methodologies established in the NRCS Soil Survey Manual and USDA Soil Taxonomy. No other warranties are made or implied.”

Soil profile information and pit excavation, as described in these design criteria, are additional requirements deemed necessary to properly assess an area’s suitability for surface spray irrigation.
16.2.3 Soil Definitions

**Soil Horizons (layers):** Soil is made up of distinct horizontal layers; these layers are called horizons and display vertical zones. They range from rich, organic upper layers (humus and topsoil) to underlying rocky layers (subsoil, regolith and bedrock).

Soil horizons develop due to the nature of soil formation. Soil is the product of the weathering of parent material (i.e. bedrock), accompanied by the addition of organic matter. The method for naming the soil horizons is quite simple as the Figure 16.1 shows. In the simplest naming system, soils horizons are designated O (organic), A (topsoil), B (mineral soil), C (weathered parent material), and R is the unweathered rock (bedrock) layer that is beneath all the other layers. The horizons of most importance to plant growth and forest health are the O and A horizons. The litter layer found covering the soil is also of interest because it provides most of the organic matter found in the O and A horizons.
The Litter Layer is the topmost layer on the forest floor. It consists of leaves, needles, and other non-decomposed material on the forest floor. While this is not considered part of the soil, it is interesting to measure the depth of the litter layer when sampling the soil. The depth of the litter layer can vary greatly even within a particular site. Because of this, several measurements are required to attempt to characterize litter layer depth. The litter layer can be considered part of the overall soils depth.

The O-Horizon primarily consists of decomposed organic matter and has a dark rich color, increased porosity, and increased aggregate structure (larger soil “clumps”). The depth of the O horizon is measured from the surface of the soil (after the litter layer has been cleared away) to the point where the darker organic color changes to a slightly lighter colored soil that contains increased mineral particles in addition to organic matter.
The transition from the O to the A horizon can also be recognized by a significant increase in the mineral soil particles. In many urban soils, the O horizon may very thin if it exists at all. The O horizon can also be considered part of the overall soils depth.

The A-Horizon is the mineral “topsoil” and consists of highly weathered parent material (rocks), which is somewhat lighter in color than the O horizon due to a decrease in organic matter. The particles in the A horizon are more granular and “crumb-like”. Seeds germinate and plant roots grow in this layer. It is made up of humus (decomposed organic matter) mixed with mineral particles. The depth of the A horizon is measured from the region of color changes from the dark O horizon to the transition to the B horizon. The transition to the B horizon can be identified by increased clay content (see below) and the absence of organic material: no root hairs, small pieces of needle, etc.

The most thorough soil study involves analysis on separate O and A horizon samples. This requires separating and storing O and A horizon samples. It also involves completing the entire soil analysis on both the O and A samples. If this is not possible, the O and A samples can be combined (or composited) and the analysis can be completed on the O and A sample together.

The B-Horizon is also called the subsoil - this layer is beneath the A horizon and above the C horizon. It contains clay and mineral deposits (like iron, aluminum oxides, and calcium carbonate) that it receives when soil solution containing dissolved minerals drips from the soil above.

The B horizon is identified by increased clay content which makes the soil hold together when moist. A simple test for clay content is to moisten a small handful of soil and attempt to smear a small portion up the forefinger. Soils high in clay will hold together and form a “ribbon”, soils with more sand and silt will be granular and fall apart. It is lighter in color and often may be reddish due to the iron content.

The C Horizon (layer beneath the B Horizon) consists of porous rock (broken-up bedrock, bedrock with holes). It is also called regolith or saprolyte which means "rotten rock." Plant roots do not penetrate into this layer; very little organic material is found in this layer.

The R-Horizon is the unweathered rock (bedrock) layer that is beneath all the other layers. For the purposes of drip dispersal designs, the R horizon is considered an impermeable layer.


These surveys are made for various land use that requires detailed soils information.
Map scale should be one (1) inch equals one hundred (100) feet or a scale that will allow the map to fill a 24” x 36” plan sheet. These maps should have adequate cartographic detail to satisfy the requirements of project. The WPC Soils Map is essentially a special map that shows a very high degree of soil and landscape detail. Baseline mapping standards for these WPC Soil Maps prepared in support of surface spray irrigation should be a first order survey in accordance with the current edition of the Soil Survey Manual, United States Department of Agricultural, October 1993. Soil profile information and pit excavation, as described in these design criteria are additional requirements deemed necessary to properly assess an area’s suitability for surface spray irrigation. These maps should be clearly marked or labeled as “Water Pollution Control Soil Map”.

**Soil map unit.** A unique collection of areas that have common soil characteristics and/or miscellaneous physical and chemical features.

**Soil scientist.** A person having the experience and education necessary to measure soil properties and classify soils per *Soil Taxonomy*, synonymous with the term “soil consultant”.

**Soil series.** A group of soils having similar properties; the lowest level of soil classification.

**Most limiting horizon.** A horizon in the soil (bedrock or fragipan) that either provides the greatest impediment to or completely stops, the downward movement of liquids through the soil.

### 16.3 Preapplication Treatment Requirements

#### 16.3.1 General

Wastewater spray irrigation systems have a demonstrated ability to treat high strength organic wastes to low levels. However, such systems require a high degree of management with particular attention paid to organic loading rates and aeration of the soil profile between wastewater applications.

The Division of Water Pollution requires that all domestic and municipal wastewaters receive biological treatment prior to irrigation.

This is necessary to:

a. Protect the health of persons contacting the irrigated wastewater.

b. Reduce the potential for odors in storage and irrigation.

Some industrial wastewaters may be suitable for direct land treatment by irrigation under intensive management schemes. The Division of Water Pollution Control will evaluate such systems on a case-by-case basis.
16.3.2 BOD and TSS Reduction, and Disinfection

Preapplication treatment standards for domestic and municipal wastewaters prior to storage and/or irrigation are as follows:

a. Sites Closed to Public Access

All wastewater must be treated to a level afforded by lagoons which are designed in accordance with Chapter 9.

Disinfection is generally not required for restricted and fenced access land treatment sites. The Division of Water Pollution Control may, however, require disinfection when deemed necessary.

b. Sites Open to Public Access

Sites open to public access include golf courses, cemeteries, green areas, parks, and other public or private land where public use occurs or is expected to occur. Wastewater that is spray irrigated on public access sites must not exceed a 5-day Biochemical Oxygen Demand and Total Suspended Solids of 30 mg/L, as a monthly average. Disinfection to reduce E. coli bacteria to 23 colonies/100 mL is required.

The preapplication treatment standards for wastewater that is to be applied to public access areas will be reviewed by the Division of Water Pollution Control on a case-by-case basis. More stringent preapplication treatment standards may be required as the Division of Water Pollution Control deems necessary. The Division of Water Pollution Control recommends that the engineer give preference to pretreatment systems that will provide the greatest degree of reliability.
16.3.3 Treatment and Storage Ponds

The storage pond and irrigation pump station must be hydraulically separate from the treatment cells (i.e., pumping must not affect hydraulic detention time in these cells). The Division of Water Pollution Control recommends the use of Chapter 9 of the Design Criteria for Sewage Works, as well as the United States Environmental Protection Agency's October 1983 Design Manual: Municipal Wastewater Stabilization Ponds as a reference for design of preapplication treatment ponds.

16.4 Inorganic Constituents of Treated Wastewater

Inorganic constituents of effluent from preapplication treatment should be compared with Table 16-2 to insure compatibility with land treatment site soils and cover crops.
Table 16-2
Recommended Values for Inorganic Constituents in Wastewater Surfaced Applied to Land

<table>
<thead>
<tr>
<th>Potential Problem and Constituent</th>
<th>No Problem</th>
<th>Increasing Problem</th>
<th>Severe Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (Standard Units)</td>
<td>6.5 – 8.4</td>
<td>&lt;5.0 or &gt;9.0</td>
<td></td>
</tr>
<tr>
<td><strong>Permeability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Conductivity (mho/cm)</td>
<td>&gt;0.50</td>
<td>&lt;0.50</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>Sodium Adsorption Ratio (a)</td>
<td>&lt;5.0</td>
<td>5.0 – 9.0</td>
<td>&gt;9.0</td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Conductivity (mho/cm)</td>
<td>&lt;0.75</td>
<td>0.75 – 3.0</td>
<td>&gt;3.0</td>
</tr>
<tr>
<td><strong>Anions:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicarbonate (meq/L)</td>
<td>&lt;1.5</td>
<td>1.5 – 8.5</td>
<td>&gt;8.5</td>
</tr>
<tr>
<td>(mg/L as CaCO₃)</td>
<td>&lt;150</td>
<td>150 – 850</td>
<td>&gt;850</td>
</tr>
<tr>
<td>Chloride (meq/L)</td>
<td>&lt;3.0</td>
<td>3.0 – 10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>(mg/L)</td>
<td>&lt;100</td>
<td>100 – 300</td>
<td>&gt;300</td>
</tr>
<tr>
<td>Fluoride (mg/L)</td>
<td>&lt;1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cations:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia (mg/L as N)</td>
<td>&lt;5.0</td>
<td>5.0 – 30</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Sodium (meq/L)</td>
<td>&lt;3.0</td>
<td>3.0 – 9.0</td>
<td>&gt;9.0</td>
</tr>
<tr>
<td>(mg/L)</td>
<td>&lt;70</td>
<td>70 or greater</td>
<td></td>
</tr>
<tr>
<td><strong>Trace Metals</strong> (mg/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>&lt;10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>&lt;0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td>&lt;0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>&lt;0.5</td>
<td>0.5 – 2.0</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td>Cadmium</td>
<td>&lt;0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>&lt;0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td>&lt;0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>&lt;0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>&lt;10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>&lt;10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithium</td>
<td>&lt;2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>&lt;0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molybdenum</td>
<td>&lt;0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>&lt;0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selenium</td>
<td>&lt;0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>&lt;4.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Sodium Adsorption Ratio (SAR) = \( \frac{Na^{+1}}{SQR (Ca^{2+} + Mg^{2+}) / 2} \)

Where, Na+1, Ca+2, and Mg+2 in wastewater are expressed in milliequivalents per liter(meq/L).

SQR represents “Square Root of”
16.5 **Protection of Irrigation Equipment**

Prior to pumping to the spray field distribution system, the wastewater must be screened to remove fibers, coarse solids, oil and grease which might clog distribution pipes or spray nozzles. As a minimum, screens with a nominal diameter smaller than the smallest flow opening in the distribution system should be provided. Screening to remove solids greater than one-half (½) the diameter of the smallest sprinkler nozzle is recommended by some sprinkler manufacturers. The planned method for disposal of the screenings must be provided.

Pressurized, clean water for backwashing screens should be provided. This backwash may be manual or automated. Backwashed screenings should be captured and removed for disposal. These screenings should not be returned to the storage pond(s) or preapplication treatment system.

16.6 **Determination of Design Application Rates**

16.6.1 **General**

One of the key steps in the design of a spray irrigation system is to develop a "design application rate" in gallons per day per square foot (GPD/SF). This value is derived from either the hydraulic (water) loading rate (Lwh) based upon the most restrictive of (1) the NRCS hydraulic conductivity data and the texture and structure (per Table 16-1), or (2) the nutrient (nitrogen) loading rate (Lwn) calculations to determine design wastewater loading(s) and, thus, spray irrigation field area requirements.

16.6.2 **Design Values**

The most limiting horizon, of each soil series shall be identified. Any surface condition which limits the vertical or lateral drainage of the soil profile shall also be identified. Examples of such conditions are shallow bedrock, a high water table, aquitards, and extremely anisotropic soil permeability. Design considerations relative to the soils per Section 16.1.5 must be used.

Sites with seasonal high groundwater less than twenty-four (24) inches deep may require drainage improvements before they can be utilized for spray irrigation land treatment. The design hydraulic conductivity at such sites is a function of the design of the drainage system.
16.7 Determination of Design Wastewater Loading

16.7.1 General

The design wastewater loading is a function of:

- Precipitation.
- Evapotranspiration.
- Design hydraulic conductivity rate.
- Nitrogen loading limitations.
- Other constituent (i.e., organic/BOD) loading limitations.
- Groundwater and drainage conditions.
- Average and peak design wastewater flows.
- Soil denitrification rates
- Rate of nitrogen uptake in site vegetation

Therefore, developing the design wastewater loading is an iterative process. The Lwh value is determined by a detailed site evaluation and will be dependent upon the soil characteristics as shown in Table 16-1 and pictorially represented in Figure 16.2. This loading is then compared to the Lwn loading limitations (reference Section 16.8). If the initial Lwh value exceeds the Lwn value, the design wastewater loading resulting from the nitrogen reduction evaluation described in Section 16.8 becomes the design loading rate.

**FIGURE 16.2**
16.8 Nitrogen Loading and Crop Selection and Management

16.8.1 General

Nitrate concentration in percolate from wastewater spray irrigation systems will be limited via a State Operation Permit (SOP) to not exceed 10 mg/L nitrate-nitrogen at the site property line. Percolate nitrate concentration is a function of nitrogen loading, cover crop, and management of vegetation and hydraulic loading. The design wastewater loading determined from using the criteria stipulated in 16.1.5 for hydraulic loading rates must be checked against nitrogen loading limitations.

16.8.2 Nitrogen Loading

In some instances, the amount of wastewater that can be applied to a site may be limited by the amount of nitrogen in the wastewater. A particular site may be limited by the nitrogen content of the wastewater during certain months of the year and limited by the infiltration rate during the remainder of the year.

16.8.3 Organic / BOD Loading

When wastewater is high strength (above 150 mg/L BOD), the organic loading rate should be limited as follows based upon the soil:

- 10,000 pounds of BOD per acre per year for Clays.
- 15,000 pounds of BOD per acre per year for Loams.
- 20,000 pounds of BOD per acre per year for Sandy.

(Reference: Dr. Robert Rubin, NC State University, who cited work by Phillips and Carlile)
Equation 16-1 is used to calculate, on a monthly basis, the allowable hydraulic loading rate based on nitrogen limits:

**(Equation 16-1)**

\[
L_{wn} = \frac{C_p (P_r - P_{ET}) + U(4.413)}{(1 - f)(C_n) - C_p}
\]

Where:

- **L_{wn}** = allowable monthly hydraulic loading rate based on nitrogen limits, inches/month
- **C_p** = nitrogen concentration in the percolating wastewater, mg/L.
  This will usually be 10mg/L Nitrate-Nitrogen
- **P_r** = Five-year return monthly precipitation, inches/month
- **P_{ET}** = potential evapotranspiration, inches/month
- **U** = nitrogen uptake by cover, lbs/acre/year pounds/acre/year
  (value should not exceed 100 lbs/acre/year)
- **C_n** = Nitrate-Nitrogen concentration in applied wastewater, mg/L
  (after losses in preapplication treatment)
- **F** = fraction of applied nitrogen removed by denitrification and volatilization.

The values of **L_{wh}** and **L_{wn}** are compared for each month. The lesser of the two values will be used to determine the amount of acreage needed.

**NOTES:**

- A “**C_n**” value of less than 23 mg/L will become a permit condition.
- The allowable vegetative uptake “**U**” of nitrogen on the drip area will be limited to an uptake rate of 100 pounds per acre per year unless trees are the vegetation.
- The “**F**” values for denitrification have been estimated based upon data supplied by the University of Tennessee and Oak Ridge National Laboratory. Denitrification rates (f) ranging from 25% in January and February to 35% in July and August are very conservative, but are defendable based upon the literature. Denitrification rates are assumed to vary linearly with the temperature and the actual rates are likely to be higher than the default values shown in Table 16-1.
- Conversion Factor - 4.413 mg-acre-inch/liter-lb. The equation and factor are from the TDHE Design Criteria for Sewage Works (April 1989).
The factor comes from assuming that one pound of contaminant of concern is diluted within a volume of water equal to one acre-inch. For Example calculation see Chapter 17, Appendix 17-A. For the derivation of this factor see Chapter 17, Appendix 17-C.
Table 16-2 shows the default values for Lwn calculations. Other values may be used provided adequate rationale and documentation is presented to, and approved by the Division of Water Pollution Control.

### TABLE 16-2

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Pr&lt;sup&gt;(1)&lt;/sup&gt; Inches / Month</th>
<th>PET&lt;sup&gt;(2)&lt;/sup&gt; Inches / Month</th>
<th>N Uptake&lt;sup&gt;(3)&lt;/sup&gt; Percent / Month</th>
<th>f Denitrification&lt;sup&gt;(4)&lt;/sup&gt; Percent / Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN</td>
<td>7.62</td>
<td>0.10</td>
<td>1%</td>
<td>25%</td>
</tr>
<tr>
<td>FEB</td>
<td>6.72</td>
<td>0.27</td>
<td>2%</td>
<td>25%</td>
</tr>
<tr>
<td>MAR</td>
<td>8.85</td>
<td>0.97</td>
<td>4%</td>
<td>27%</td>
</tr>
<tr>
<td>APR</td>
<td>6.59</td>
<td>2.30</td>
<td>8%</td>
<td>29%</td>
</tr>
<tr>
<td>MAY</td>
<td>6.13</td>
<td>3.59</td>
<td>12%</td>
<td>31%</td>
</tr>
<tr>
<td>JUN</td>
<td>5.52</td>
<td>4.90</td>
<td>15%</td>
<td>33%</td>
</tr>
<tr>
<td>JUL</td>
<td>6.85</td>
<td>5.44</td>
<td>17%</td>
<td>35%</td>
</tr>
<tr>
<td>AUG</td>
<td>4.73</td>
<td>5.00</td>
<td>15%</td>
<td>35%</td>
</tr>
<tr>
<td>SEP</td>
<td>5.54</td>
<td>3.79</td>
<td>12%</td>
<td>34%</td>
</tr>
<tr>
<td>OCT</td>
<td>4.47</td>
<td>1.98</td>
<td>8%</td>
<td>32%</td>
</tr>
<tr>
<td>NOV</td>
<td>6.11</td>
<td>0.82</td>
<td>4%</td>
<td>29%</td>
</tr>
<tr>
<td>DEC</td>
<td>7.55</td>
<td>0.27</td>
<td>2%</td>
<td>26%</td>
</tr>
</tbody>
</table>

(1) Based upon Table A-3 – 5-year return monthly precipitation
(2) Based upon Table A-2 – Potential Evapotranspiration
(3) Based upon Table A-5 – Monthly Nitrogen Uptake by Vegetation
(4) Applied Nitrogen Fraction Removed by Denitrification / Volatilization

**Note:** Appendix 16-B shows Equation 16-1, using the default values.
16.8.4 Cover Crop Selection and Management

Row crops may be irrigated with wastewater via spray irrigation only when not intended for direct human consumption. Livestock must not be allowed on wet fields so that severe soil compaction and reduced soil infiltration rates can be avoided. Further, wet grazing conditions can also lead to animal hoof diseases. Pasture rotation should be practiced so that wastewater spray application can be commenced immediately after livestock have been removed. In general, a pasture area should not be grazed longer than 7 days. Typical regrowth periods between grazings range from 14 to 35 days. Depending on the period of regrowth provided, one to three spray applications can be made during the regrowth period. At least 3 to 4 days drying time following an application should be allowed before livestock are returned to the pasture. Unmanaged, volunteer vegetation (i.e., weeds) is not an acceptable spray irrigation field cover. Disturbed areas in forest systems must be initially grassed and replanted for succession to forest.

Spray irrigation field cover crops require management and periodic harvesting to maintain optimum growth conditions assumed in design. Forage crops should be harvested and removed several times annually. Pine forest systems should be harvested at 20 to 25 year intervals. Hardwood forest systems should be harvested at 40 to 60 years. It is recommended that whole tree harvesting be considered to maximize nutrient removal. However, wastewater spray irrigation loadings following the harvesting of forest systems must be reduced until the hydraulic capacity of the site is restored. Spray field area to allow for harvesting and the regeneration cycle should be considered by the design engineer.

While high in nitrogen and phosphorus, domestic and municipal wastewaters are usually deficient in potassium and trace elements needed for vigorous agronomic cover crop growth. High growth rate forage crops such as Alfalfa and Coastal Bermuda will require supplemental nutrient addition to maintain nitrogen uptake rates assumed in design. Industrial wastewaters considered for irrigation should be carefully evaluated for their plant nutrient value.

16.9 Land Area Requirements

16.9.1 General

The land area to which wastewater is spray irrigated is termed a "field". The total land requirement includes not only the field area, but also land for any preapplication treatment facilities, storage reservoir(s), buffer zone, administration/maintenance structures and access roads. Field and buffer zone requirements are addressed in this Section. Land area for storage reservoirs is discussed in Section 16.10. All other land requirements will be dictated by standard engineering practices and will not be addressed in this document.
16.9.2 Field Area Requirements

The area required for the field is determined by using the following equation:

\[
A = \frac{(Q_y + V)C}{Lwd} \quad \text{(Eq. 16-2)}
\]

Where:

- \( A \) = Field area, acres
- \( Q_y \) = Flow, MG per year
- \( V \) = Net loss or gain in stored wastewater due to precipitation, evaporation and/or seepage at the storage reservoir, gallons per day
- \( Lwd \) = Design hydraulic loading rate, in/year
- \( C = \frac{1,000,000 \text{ gal} \times \frac{\text{ft}^3}{\text{MG}} \times 12 \text{ in} \times \frac{\text{acre}}{43,560 \text{ ft}^2}}{7.48 \text{ gal} \times \text{ft}} = 36.83 \)

The first calculation of the field area must be made without considering the net gain or loss from the storage reservoir. After the storage reservoir area has been calculated, the value of \( V \) can be completed. The final field area is then recalculated to account for \( V \). The Appendix includes the use of Equation 16-2.

16.9.3 Buffer Zone Requirements

The objectives of buffer zones around land treatment sites are to control public access, improve project aesthetics and, in case of spray irrigation, to minimize the transport of aerosols. Since development of off-site property adjacent to the treatment site may be uncontrolable, the buffer zone must be the primary means of separating the field area from off-site property. Table 16-3 gives minimum widths of buffer zones for varying site conditions:
### Table 16-3
On-Site Buffer Zone Requirements

<table>
<thead>
<tr>
<th>SURFACE SPREAD</th>
<th>SPRINKLER SYSTEMS (Edge of Impact Zone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Boundaries</td>
<td>Open Fields</td>
</tr>
<tr>
<td>100 Feet</td>
<td>300 Feet</td>
</tr>
<tr>
<td>On-Site streams, ponds and roads</td>
<td>50 Feet</td>
</tr>
</tbody>
</table>

#### 16.10 Storage Requirements

16.10.1 General

The design of a wastewater spray irrigation land application system must take into account that wastewater application will be neither continuous nor constant. Provisions must be made for containing wastewater when conditions exist such that either wastewater cannot be applied or when the volume of wastewater to be applied exceeds the maximum application rate. The minimum storage requirement should be sixty (60) days at design flow unless engineering rationale can be presented and approved by the Division of Water Pollution Control that justifies less storage capacity.

The storage requirement may be determined and/or evaluated by either of two methods. The first method involves the use of water balance calculations and is illustrated in Appendix A. The second method involves the use of a computer program that was developed based upon an extensive NOAA study of climatic variations throughout the United States. The program entitled EPA-2 would probably be the most appropriate of the three programs available. For information on the use of the computer program, contact the National Climatic Center of NOAA at (704) 259-0448.
16.10.2 Estimation of Storage Requirements Using Water Balance Calculations

The actual wastewater that is available is compared to the actual amount that can be applied. Any excess wastewater must be stored. The actual wastewater volume must be converted to units of depth for that comparison. Equation 16-3 will be used:

\[ W_p = \frac{Q_m \times C}{A_p} \]  

(Eq. 16-3)

Where:

- \( W_p \) = depth of wastewater, in inches
- \( Q_m \) = volume of wastewater for each month of the year, in million gallons
- \( C = \frac{1,000,000 \text{ gd} \times \frac{\text{ft}^3}{\text{MG}} \times \frac{\text{acre}}{7.48 \text{ gal}} \times \frac{12 \text{ in}}{43,560 \text{ ft}^2}}{\text{ft}} = 36.83 \)
- \( A_p \) = field area, in acres

The months in which storage is required are cumulated to determine the maximum amount of total storage needed. The use of the method is illustrated in Appendix A.

The maximum storage amount in inches, over the field area, is converted to a volume, in cubic feet. A suitable depth is chosen and a storage basin surface area is calculated.

This storage basin will be affected by three factors: precipitation, evaporation and seepage. These three factors are determined and the result is \( V \), which is then introduced back into equation 16-2. A new, final field area is calculated and a corresponding new storage volume is determined.

In Tennessee, the maximum seepage is 1/4 inch per day. This amount can be used unless the storage basin will be constructed so that a lesser seepage rate will result. In some cases, where an impervious liner will be constructed, the seepage rate will be zero.

16.11 Distribution System

16.11.1 General

The design of the distribution system is a critical aspect of the land application. The field area and the storage volume were derived with the assumption that wastewater would be evenly distributed. For high strength wastes or wastes with high suspended/settleable solids, sprinkler applications are performed. Sprinklers will distribute these wastes more evenly over the treatment area whereas surface application may result in accumulation of solids and odors near the application point.
16.11.2 Surface Spreading

With surface spreading, wastewater is applied to the ground surface, usually by perforated pipe or by an irrigation-type ditch, and flows uniformly over the field by gravity. The uniform flow is critically dependent upon a constant slope of the field, both horizontal and perpendicular to the direction of flow. Several other factors are of importance:

a. Uniform distribution cannot be achieved on highly permeable soils. The wastewater will tend to percolate into the soil that is nearest to the point of application.

b. A relatively large amount of wastewater must be applied each time so that wastewater will reach all portions of the field. The dosing must account for the fact that the field area nearest the point of application will be wetted for a longer period of time and, thus, will percolate more wastewater.

c. Erosion and/or runoff may be a problem. Since a surface discharge will not be allowed to occur, a return system may be necessary.

16.11.3 Sprinkler Spreading

Sprinkler systems can be classified into one of three general categories: (1) solid set, (2) portable and (3) continuously moving.

The following factors should be considered during design:

a. The hydraulic conditions within the distribution system must be given a thorough review. Head losses through pipes, bends, nozzles, etc., must be balanced so that the wastewater is uniformly applied to the field.

b. Design must consider the effects of cold weather. Nozzles, risers, supply pipes, etc., must be designed to prevent wastewater from freezing in the various parts.

c. Wind can distort the spray pattern. Also, aerosols may be carried off the field area. A properly designed buffer zone should alleviate most of the aerosol problems. Also, the O&M manual can include a provision which would prevent spraying when the wind velocity is high enough to carry wastewater off the field area.

d. Crop selection is important. The higher humidity level may lead to an increase in crop disease.

e. Higher slopes can be used than in surface spreading. Also, slopes do not need to be constant. Further, the type of crop is nearly unlimited. Forests can be irrigated.
with solid set sprinklers. Forage crops can be irrigated with any of the three basic types of systems.

f. The system layout must take into consideration the method that will be used for harvesting the crop.

16.12 Spray Irrigation of Wastewater from Gray Water Facilities

16.12.1 General

This Section provides criteria for facilities that produce a "gray water" wastewater. These facilities include coin-operated laundries, car washes and swimming pool backwash filters. Wastewater disposal requirements are not as complex as are those for domestic wastewater. An engineering report which provides information on the design of the facilities must be submitted to the Division of Water Pollution Control.

16.12.2 Site Location

16.12.2.1 The Division of Water Pollution Control must inspect and approve the proposed site prior to any construction being undertaken.

16.12.2.2 The site must be chosen such that the operation of the system will not affect surrounding property owners. No surface runoff or stream discharge will be allowed.

16.12.3 Design Flow

Since these are service enterprises, the amount of wastewater that is generated is directly related to the desire of people to use the facilities. Thus, an estimate of the number of potential users (and frequency) is extremely important.

Various factors must be taken into consideration:

a. A rural setting would tend to have a shorter daily usage period than would an urban location.

b. An area that is predominately single-family houses would tend to have a lesser usage rate for laundries and car washes than would an area with apartment complexes.

c. The amount of water that washing machines use will vary among manufacturers and models. The Division recommends the use of water-saving machines.
The design engineer should use 250 gpd/washer for laundries and 700 gpd/bay for car washes unless more reliable data is available.

16.12.4 Pretreatment

16.12.4.1 General

Facilities that produce gray water have different pretreatment requirements, designed not only to the type of facility but also to the specific establishment.

16.12.4.2 Laundries

a. All laundry wastewater (does not include sanitary wastes) shall pass through a series of lint screens. A series will consist of five screens, starting with a screen with 1-inch mesh and ending with a screen that is basically equivalent to a window screen.

b. Since some detergents produce a wastewater with a pH in the range of 11.0 to 11.5, some type of pH adjustment may be necessary. This may occur as a retrofit if the vegetation in the spray plots is being stressed by the high pH.

c. Disinfection will generally not be required unless the operation of the facilities will result in a potential hazard to the public. The need for disinfection will be determined by the Division of Water Pollution Control on a case-by-case basis.

16.12.4.3 Car Washes

a. All car wash wastewater shall pass through a grit removal unit. The flow-through velocity shall be less than 0.5 feet per second. The grit removal unit shall be constructed to facilitate the removal of grit.

b. The use of detergents with a neutral (or nearly neutral) pH is recommended. The use of high-pH detergents may require neutralization if the vegetation is being stressed by the high pH.

16.12.4.4 Swimming Pools

a. A holding tank/pond shall be provided to receive the backwash water from the swimming pool filters. The solids shall be allowed to settle to the bottom before the supernatant is removed for disposition on the spray plots.
b. Dechlorination may be required if the vegetation on the plots is being stressed by the chlorine in the water.

c. If the entire pool volume is to be emptied, by using the spray plots, the rate shall be controlled so as to not exceed the application rate that is specified in Section 16.7.

16.12.5 Field Requirements

16.12.5.1 The maximum wastewater that can be sprayed on a site is based either on the nitrogen content of the wastewater or an amount equal to 10% of the infiltration rate of the most restrictive layer of soil which shall be determined by the design engineer with input from a qualified soil scientist.

16.12.5.2 The application of wastewater shall alternate between at least two separate plots. Each plot shall not receive wastewater for more than three consecutive days and must have at least three days rest between applications. Reserve land area of equivalent capacity must be available for all gray water systems.

16.12.5.3 Ground slopes shall not exceed 30%. Extra precautions must be taken on steep slopes (15-30%) to prevent runoff and erosion.

16.12.5.4 The field shall be covered with a good lawn or pasture grass unless an existing forested area is chosen. The ground cover should be a sturdy perennial that will resist erosion and washout. Forested areas should be chosen so that installation of sprinkler equipment will not damage the root systems of the trees and will not produce runoff due to the usual lack of grass in forested areas.

16.12.6 Application Equipment

16.12.6.1 Sprinklers shall be of a type and number such that the wastewater will be evenly distributed over the entirety of a plot. Information on sprinklers shall be included in the engineering report. In forest plots, sprinklers shall be on risers which shall be tall enough to allow the wastewater to be sprayed above the undergrowth. Sprinklers shall be of the type that are not susceptible to clogging.

16.12.6.2 All piping (excluding risers) shall be buried to a depth that will prevent freezing in the lines. An exception to this burial requirement can be made in the case where piping will be laid in forested areas. Burial in this case may be difficult, expensive and may kill some trees. All risers shall be designed such that wastewater will drain from them when wastewater is not being pumped. This can be accomplished by either draining all lines back into the pump sump or by placing a gravel drain pit at the base of each riser. Each riser would necessarily be equipped with a weep hole. Particular attention
must be given during the design so that the entire subsurface piping does not drain into these pits.

16.12.6.3 The engineering report must contain hydraulic calculations that show that each nozzle distributes an equivalent amount of wastewater. Differences in elevation and decreasing pipe sizes will be factors which need to be addressed.

16.12.6.4 The piping must be of a type that will withstand a pressure equal to or greater than 1-1/2 times the highest pressure point in the system. The risers should be of a type of material such that they can remain erect without support. The pipe joints should comply with the appropriate ASTM requirements. Adequate thrust blocks shall be installed as necessary.

16.12.6.5 A sump shall be provided into which the wastewater will flow for pumping to the spray plots. The pump can be either a submersible type, located in the sump, or a dry-well type, located immediately adjacent to the sump in a dry-well. The pump shall be capable of pumping the maximum flow that can be expected to enter the sump in any 10-minute period. The pump shall be operated by some type of float mechanism. The float mechanism shall activate the pump when the water level reaches 2/3 of the depth of the sump and should de-activate the pump before the water level drops to the point to where air can enter the intake.

If the distribution system is designed to drain back into the sump, the sump shall be enlarged to account for that volume.

If desired, the sump for laundries can also contain the lint screens. The screens shall, in any case, be constructed so that they cannot be bypassed. They shall be built so that they can be easily cleaned. A container shall be provided for disposal of the lint which is removed from the screens.

16.12.6.6 The pipe from the facility to the sump shall be large enough to handle the peak instantaneous flow that could be realistically generated by the facility. Flow quantities, head loss calculations, etc., shall be included in the engineering report.

16.12.7 Operation of System

16.12.7.1 The operator shall insure that wastewater is applied to alternate plots on a regular basis.

16.12.7.2 Monthly operating reports shall be submitted to the appropriate field office of the Division of Water Pollution Control. The parameters to be reported shall be delineated by field office personnel but should include, as a minimum, dates of spray plot alternation.
16.12.7.3 The owner of the system shall apply for and receive an operating permit from the Division of Water Pollution Control prior to initiation of operation of the system.

16.12.7.4 The system operator shall inspect and maintain the pump and sprinklers in accordance with manufacturer's recommendations. An operations manual shall be located at the facility for ready reference.

16.12.7.5 The operator shall inspect the wastewater facilities on a regular basis. The inspection shall include the spray plots to determine whether or not runoff and/or erosion are or have occurred, the spray patterns of the sprinklers, the physical condition of the system (looking for damage due to adverse pH conditions, etc.)

16.12.7.6 The spray plots shall be mowed on a regular basis to enhance evapotranspiration. Grass height shall not exceed 6-inches.

16.12.7.7 The lint screen at laundries shall be cleaned on a schedule that is frequent enough to prevent upstream problems due to head loss through the screens. Disposition of the lint shall be in accordance with applicable requirements.

16.12.7.8 The grit traps at car washes shall be cleaned at a frequency that is sufficient to keep the trap in its designed operating condition.

16.12.7.9 If the car wash is equipped with an automatic wax cycle, the operator shall be especially attentive to the possibility of wax build-up on the sump, pump and all downstream piping.

16.12.7.10 The operator shall insure that the car wash facility is not used as a sanitary dumping station for motor homes or for washing trucks/trailers that are used for hauling livestock. If necessary, the facility shall be posted with signs which clearly indicate this prohibition.

16.12.7.11 The sludge holding tank/pond at a swimming pool facility shall be cleaned at a frequency that is sufficient to prevent solids from being carried over into the pump sump. Cleaning shall be performed in a manner that will minimize re-suspending the solids and allowing them to enter the pump sump.

16.13 Plan of Operation and Management

A Plan of Operation and Management (POM) is required before an Operation Permit (SOP) can be issued. The Plan is written by the owner or the owner's engineer during construction of the slow rate land treatment system. Once accepted by the Division, the Plan becomes the operating and monitoring manual for the facility and is incorporated by reference into the Permit.
This manual must be kept at the facility site and must be available for inspection by personnel from the Tennessee Department of Health and Environment.

This POM should include, but not be limited to, the following information:

16.13.1 Introduction

a. System Description:

1. A narrative description and process design summary for the land treatment facility including the design wastewater flow, design wastewater characteristics, preapplication treatment system and spray fields.

2. A map of the land treatment facility showing the preapplication treatment system, storage pond(s), spray fields, buffer zones, roads, streams, drainage system discharges, monitoring wells, etc.

3. A map of force mains and pump stations tributary to the land treatment facility. Indicate their size and capacity.

4. A schematic and plan of the preapplication treatment system and storage pond(s) identifying all pumps, valves and process control points.

5. A schematic and plan of the irrigation distribution system identifying all pumps, valves, gauges, sprinklers, etc.

b. Discuss the design life of the facility and factors that may shorten its useful life. Include procedures or precautions which will compensate for these limitations.

c. A copy of facility's State Operation Permit.

16.13.2 Management and Staffing

a. Discuss management's responsibilities and duties.

b. Discuss staffing requirements and duties:

1. Describe the various job titles, number of positions, qualifications, experience, training, etc.

2. Define the work hours, duties and responsibilities of each staff member.
16.13.3 Facility Operation and Management

a. Preapplication Treatment System:
   1. Describe how the system is to be operated.
   2. Discuss process control.
   3. Discuss maintenance schedules and procedures

b. Irrigation System Management:
   1. Wastewater Application.

   Discuss how the following will be monitored and controlled. Include rate and loading limits:
   
   (a) Wastewater loading rate (inches/week)
   (b) Wastewater application rate (inches/hour)
   (c) Spray field application cycles
   (d) Organic, nitrogen and phosphorus loadings (lbs/acre per month, etc)

   2. Discuss how the system is to be operated and maintained.

   (a) Storage pond(s)
   (b) Irrigation pump station(s)
   (c) Spray field force main(s) and laterals

   3. Discuss start-up and shut-down procedures.

   4. Discuss system maintenance.

      (a) Equipment inspection schedules
      (b) Equipment maintenance schedules

   5. Discuss operating procedures for adverse conditions.

      (a) Wet weather
(b) Freezing weather
(c) Saturated Soil
(d) Excessive winds
(e) Electrical and mechanical malfunctions

6. Provide troubleshooting procedures for common or expected problems.

7. Discuss the operation and maintenance of back-up, stand-by and support equipment.

c. Vegetation Management:

1. Discuss how the selected cover crop is to be established, monitored and maintained.

2. Discuss cover crop cultivation procedures, harvesting schedules and uses.

3. Discuss buffer zone vegetative cover and its maintenance.

d. Drainage System (if applicable):

1. Discuss operation and maintenance of surface drainage and runoff control structures.

2. Discuss operation and maintenance of subsurface drainage systems.

16.13.4 Monitoring Program

a. Discuss sampling procedures, frequency, location and parameters for:

1. Preapplication treatment system.

2. Irrigation System:

   (a) Storage pond(s)

   (b) Groundwater monitoring wells

   (c) Drainage system discharges (if applicable)

   (d) Surface water (if applicable)
b. Discuss soil sampling and testing:

c. Discuss ambient conditions monitoring:

1. Rainfall
2. Wind speed
3. Soil moisture

d. Discuss the interpretation of monitoring results and facility operation:

1. Preapplication treatment system.
2. Spray fields.

16.13.5 Records and Reports

a. Discuss maintenance records:

1. Preventive.
2. Corrective.

b. Monitoring reports and/or records should include:

1. Preapplication treatment system and storage pond(s).
   (a) Influent flow
   (b) Influent and effluent wastewater characteristics
2. Irrigation System.
   (a) Wastewater volume applied to spray fields.
   (b) Spray field scheduling.
   (c) Loading rates.
4. Drainage system discharge parameters (if applicable).
5. Surface water parameters (if applicable).


7. Rainfall and climatic data.
CHAPTER 17

Design Guidelines for Wastewater Dispersal Using Drip Irrigation

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Appendix 17-C   Derivation of Conversion Factor for Equation 17-2
DRIP DISPERSAL TREATMENT

17.1 General

17.1.1 General

This chapter provides guidelines and criteria for the design of drip dispersal systems for domestic wastewater effluent treated to a level of secondary treatment. It is not applicable to spray irrigation, overland flow or rapid infiltration. The design engineer should use best professional judgment (BPJ) to produce a system that will be robust and sustainable for many years.

17.1.2 Applicability

Drip dispersal systems are designed and operated to allow the soil to provide final treatment of the wastewater prior to its introduction to groundwater. Dispersal and treatment occurs via physical, chemical and biological processes within the soil and through evapotranspiration and nutrient uptake by plant matter.

The ultimate goal is to create a treatment and dispersal system that will return the treated water to the environment while protecting ground water and surface waters from excessive pollution. Water does not disappear in the soil column, it evaporates into the atmosphere, is used by plants and/or organisms, or moves through the soils to ground water or into water courses. There are many factors to be considered when designing drip dispersal systems, such as the quality of treated effluent being applied, depth of soils, and retention time in the soils before water returns to either ground water or surface water. The development of these guidelines utilized general assumptions, best professional judgment (BPJ) and empirical data.

The infiltrative capacity of soil is a critical factor to be considered when designing any type of subsurface sewage disposal system. However, equal consideration should be given to other factors that control the overall lateral movement of groundwater within the soil profile.

If the profile of a particular soil considered for drip dispersal extended to a significant depth without a restrictive horizon (most limiting layer), the ability to load that soil per unit area would be relatively high. On the other extreme, if a soil being considered for drip dispersal had a shallow restrictive horizon, the ability to load that soil would be lower relative to the deeper soil. Depth to restrictive horizon, soil permeability and slope of the restrictive horizon are factors that control the amount and rate at which ground water can exit an area. If the amount of treated effluent applied to an area, in combination with rainfall over the area and groundwater moving into the area, exceed the soil profile’s ability to transmit the water away from the application area, mounding and runoff will occur.

Evaluation of a soil area’s suitability for drip dispersal should take into consideration limiting aspects of the soil profile. Level sites with shallow restrictive horizons overlain by low permeability soils represent one of the more limited scenarios for drip dispersal and the application rate and/or application area should be suitably modified.

Also critical when designing systems in soils with shallow restrictive horizons are the presence and location of hydrologic boundaries such as drainage ways and waterways.
These hydrologic boundaries provide an outlet for ground water discharge. Not only is it critical to identify these features in consideration of appropriate setbacks/buffers, it is also critical to factor in their role in the overall hydrologic cycle of the landscape.

Horizons along which lateral flow would be expected include, but are not necessarily limited to: bedrock, fragipans, and zones with high clay percentage overlain by more permeable soil.

**Drip dispersal design submittals should take into consideration all factors influencing the infiltrative capacity of the soil and the ability of the soil and site to transport ground water away from the application area.** It should be noted that the use of historical information from existing systems installed and operated in similar soils, with documented loading rates, landscape positions and design conditions similar to the proposed system may be applicable. Therefore, soils that have been highly compacted and/or disturbed, such as old road beds, foundations, etc., must be excluded when evaluating suitable areas for drip dispersal systems.

**17.1.3 Slopes and Buffers**

**Slopes** - Slopes up to and including 50% slope with suitable soils may be considered for drip dispersal. Depending upon the overall shape of the slope (concave, convex or linear on the planar and profile view) the design engineer may have to make adjustments in the aspect ratio of the drip lines on the slope, the loading rate, or both to ensure that all applied effluent will move down gradient and/or into the underlying formations without surfacing. It is important to note that when the proposed drip field area slopes are greater than 30%, the design engineer may need to obtain a geologic investigation conducted by a geologist or geotechnical engineer evaluating the slip potential of the slope under operating conditions. When slopes increase above 10 percent, wastewater flow down the slope (parallel to the slope) may control the hydraulic design of the system.

For land application areas with slopes between 10 percent and 50 percent and with a restrictive horizon less than 48 inches, the design engineer should calculate the percentage saturation of the soil column at the narrowest portion of the cross-sectional area of the dispersal area perpendicular to the direction of flow. This landscape loading rate analysis will determine the saturation depth at design load and flow of the most restrictive cross-section in the down gradient flow path within and beyond the drip field. The aspect of ratio of the drip field should be adjusted or the loading rate reduced as necessary to ensure that surfacing does not occur.

**Buffers** - Treatment and dispersal system components should be located so as to protect potable water supplies and distribution systems and surface waters. The design engineer is responsible to identify setbacks on construction drawings. Setbacks from water bodies, water courses, and sink holes will be a function of local subsurface geology and quality of the applied effluent. It is important to note that varying site conditions may require different distances of separation. The distances may increase or decrease as soil conditions so warrant as determined by a qualified professional (engineer, soil scientist, geologist, etc.).

If site buffers are different from Table 17-1, then the design engineer must provide rationale used for the recommended site buffers which must be approved by the Tennessee Department of Environment and Conservation.
17.1.4 Soils

In general, moderately permeable and well-drained soils are desirable. However, the use of any soil is acceptable if it meets the following four (4) criteria:

1. The applied effluent loading rate does not exceed the applicable hydraulic loading rate in Table 17-2. The applicable hydraulic loading rate is determined by a detailed site evaluation in which the site is mapped utilizing soil borings and pits to determine the physical properties of soil horizons and soil map units.

2. The applied effluent maximum loading rate does not exceed 10% of the minimum NRCS saturated vertical hydraulic conductivity ($K_{SAT}$) for the soil series or 0.25 GPD/SF whichever is least. Note: this may have to be lowered based upon the results of the nutrient loading rate calculation per Section 17.5.2.

3. The soil does not have a restrictive horizon within its top twenty (20) inches.

4. The soil is well drained, or capable of being drained.

---

**TABLE 17-1**

<table>
<thead>
<tr>
<th>Site Feature</th>
<th>Buffer Distance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Septic Tank and/or Dosing Chamber (Feet)</td>
<td>Dispersal Field (Feet)</td>
</tr>
<tr>
<td>Wells and Springs</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Dwellings and Buildings</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Property Lines</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Underground Utilities</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Septic Tank</td>
<td>NA</td>
<td>5</td>
</tr>
<tr>
<td>Gullies, Ravines, Blue Line Streams, Drains, Drainways, Cutbanks, and Sinkholes</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Closed Depressions</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Soil Improvement Practice</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

*To be determined by the design engineer and approved by the Division of Water Pollution Control.
### TABLE 17-2
Hydraulic Loading Rates (GPD/SF) – For Drip Dispersal Systems

<table>
<thead>
<tr>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>SHAPE</th>
<th>GRADE</th>
<th>HYDRAULIC LOADING RATE*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GPD / SF BOD ≤ 30 mg/L</td>
</tr>
<tr>
<td>Coarse Sand, Loamy Coarse Sand</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Coarse Sandy Loam</td>
<td>Massive</td>
<td>Structure less</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>Platy</td>
<td>Weak</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Blocky, Granular</td>
<td>Moderate, Strong</td>
<td>0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loam</td>
<td>Massive</td>
<td>Structure less</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Platy</td>
<td>Weak</td>
<td>Weak</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granular, Sub angular</td>
<td>Moderate, Strong</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt Loam</td>
<td>Massive</td>
<td>Structure less</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Platy</td>
<td>Weak</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky, Granular, Sub angular</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>Massive</td>
<td>Structure less</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Clay Loam</td>
<td>Platy</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky, Granular, Sub angular</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy Clay, Silty Clay</td>
<td>Massive</td>
<td>Structure less</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Platy</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angular, Blocky</td>
<td>Weak</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granular, Sub angular</td>
<td>Moderate, Strong</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Maximum allowable hydraulic loading rate is 0.25 GPD/SF; however, all hydraulic loading rates may be adjusted based upon special site specific evaluations approved by TDEC.

These soils are considered unacceptable for drip dispersal.

It is desirable to have a minimum depth of twenty (20) inches of undisturbed soil above a restrictive horizon which may need to be increased as slope increases. This is necessary to provide adequate installation depth and buffer below the drip line. (For example, see Figure 17.1).

**FIGURE 17.1**

Even if a soil meets the depth requirements it may not be suitable due to the texture and/or structure. If a soil shows signs of wetness within a depth of 20 inches of the soil surface, it will most likely require a soil improvement practice such as an interceptor or drawdown drain. The location and size of the drains and buffers must be factored into the total area required for the drip dispersal system.

17.1.5 Line Spacing

In an attempt to achieve even distribution of the wastewater and maximum utilization of the soil, it is recommended that the emitter line spacing and emitter spacing be at 2-foot spacing. Depending upon site conditions (soil type, slope and reserve area) the Department of Environment and Conservation may allow spacing to increase to ensure that each emitter supplies a minimum wetted area of not more than ten (10) square feet (i.e., 5-foot line spacing with 2-foot emitter spacing or 10-foot line spacing with 1-foot emitter spacing).

17.1.6 Line Depth

Drip dispersal lines should be placed at depths of six (6) to ten (10) inches below the surface. The drip lines should be laid level and should run with the contour.
### 17.2 Soil Investigations

#### 17.2.1 General

Preliminary soil investigations should be done to identify areas best suited for subsurface wastewater drip dispersal. The proposed drip dispersal area must be mapped at sufficient accuracy to identify each soils series (or lowest possible level of soil classification) present and the boundary location between series. Once those areas are identified, the more detailed procedures outlined below will be employed. It is required that all soil investigations be performed by a soil scientist currently on the Ground Water Protection list of approved soil scientists/soil consultants.

#### 17.2.2 Soil Mapping

The mapping procedure will usually begin with the property/land being generally evaluated to delineate or separate areas with suitable characteristics. This procedure will save time and money since some areas will be too shallow, too wet, too steep, etc.

Adequate ground control is mandatory for all sites. The ground control is necessary to reproduce the map if needed. All located coordinates (soil map boundaries and pit locations) must be shown on the final Water Pollution Control (WPC) Soils Map.

Soil data collection shall be based upon one, or combination of the following:

1. Grid staking at intervals sufficient to allow the soils scientist to attest to the accuracy of the map for the intended purpose;
2. Mapping of pits and critical auger locations using dual frequency survey grade Global Positioning System (GPS) units.
3. Other controls adequate to map the location of pits, physical features, and separations.
4. Grid stakes and GPS data points must be locatable to within two (2) feet of distance shown.
5. The ground control has to correlate to the exterior boundaries of the property so as to show the location of the soils areas within the bounds of the project and must be certified by a Registered Land Surveyor per TCA 62-18-102(3).

The soil scientists are responsible for conducting a sufficient number of borings that, in their professional opinion, will allow them to certify the soils series (or lowest possible level of soil classification) present, identify boundaries between series, and describe each soil horizon as to color, depth to restrictive horizon, and depth to rock. Any redoximorphic features observed are to be described. This delineation should be based upon the texture and structure of the soils to a depth of forty-eight (48) inches or restrictive horizon whichever is shallower.

After the mapped soils area is established and marked, soil borings to a minimum depth of forty-eight (48) inches or restrictive horizon, whichever is shallowest, shall be taken at sufficient intervals to identify and map the boundaries of the soils series (or lowest possible level of soil classification) present on the site. The exact number and location of borings will be determined by the soils scientist in consultation with the design engineer. Sufficient borings should be made to identify any dissimilar soils accounting for more than 10 percent of the total proposed drip dispersal area.
The soil scientist shall excavate an adequate number of pits to determine the typical profiles and soils characteristics that are expected for all soils mapped. It is recommended that a minimum of two (2) pits per acre in polygons of qualifying soils be excavated; however, the actual number and location of pits will be left to the best professional judgment of the soil scientist. If less than two (2) pits per acre are utilized, the soil scientist must include the rationale in notes on the WPC Soil Map. The pit description must be entered onto a pedon sheet and submitted with the soils map and engineering report. The “Soil Description” should include all of the information contained on form NRCS-Soils-232G (5-86), U.S. Department of Agriculture, Natural Resources Conservation Service (as shown in Appendix D).

In their description of the pit profiles, the soil scientists must describe the soil’s structure, texture, color, and any redoximorphic features present. They should also describe root depth and presence of macropores, etc. The series name or lowest possible level of soil classification will be recorded. The depth to hard rock using an auger or a tile probe must be specified if the depth is less than forty-eight (48) inches and estimated if greater than forty-eight (48) inches. The auger borings and soil backhoe pits should be located, numbered and shown on the WPC Soils Map. The soil scientist will be required to prepare and sign a detailed certification statement for each site evaluated as follows:

Water Pollution Control Soils Map Completed by:

Signature       Date

John/Jane Doe, Soils Consultant

The following statement should appear on the map:

“I, (Soils Consultant’s Name) affirm that this Water Pollution Control Soils Map has been prepared in accordance with accepted standards of soil science practice and the standards and methodologies established in the NRCS Soil Survey Manual and USDA Soil Taxonomy. No other warranties are made or implied.”

Soil profile information and pit excavation, as described in these design criteria, are additional requirements deemed necessary to properly assess an area’s suitability for drip dispersal.

17.2.3 Definitions:

**Soil Horizons (layers):** Soil is made up of distinct horizontal layers; these layers are called horizons and display vertical zones. They range from rich, organic upper layers (humus and topsoil) to underlying rocky layers (subsoil, regolith and bedrock).

Soil horizons develop due to the nature of soil formation. Soil is the product of the weathering of parent material (i.e. bedrock), accompanied by the addition of organic matter. The method for naming the soil horizons is quite simple as the Figure 17.2 shows.
In the simplest naming system, soils horizons are designated O (organic), A (topsoil), B (mineral soil), C (weathered parent material), and R is the un-weathered rock (bedrock) layer that is beneath all the other layers. The horizons of most importance to plant growth and forest health are the O and A horizons. The litter layer found covering the soil is also of interest because it provides most of the organic matter found in the O and A horizons.
The **Litter Layer** is the topmost layer on the forest floor. It consists of leaves, needles and other non-decomposed material on the forest floor. While this is not considered part of the soil, it is interesting to measure the depth of the litter layer when sampling the soil. The depth of the litter layer can vary greatly even within a particular site. Because of this, several measurements are required to attempt to characterize litter layer depth. The litter layer can be considered part of the overall soils depth.

The **O-Horizon** primarily consists of decomposed organic matter and has a dark rich color, increased porosity, and increased aggregate structure (larger soil “clumps”). The depth of the O horizon is measured from the surface of the soil (after the litter layer has been cleared away) to the point where the darker organic color changes to a slightly lighter colored soil that contains increased mineral particles in addition to organic matter. The transition from the O to the A horizon can also be recognized by a significant increase in the mineral soil particles. In many urban soils, the O horizon may very thin if it exists at all. The O horizon can also be considered part of the overall soils depth.
The **A-Horizon** is the mineral “topsoil” and consists of highly weathered parent material (rocks), which is somewhat lighter in color than the O horizon due to a decrease in organic matter. The particles in the A horizon are more granular and “crumb-like”. Seeds germinate and plant roots grow in this layer. It is made up of humus (decomposed organic matter) mixed with mineral particles. The depth of the A horizon is measured from the region of color changes from the dark O horizon to the transition to the B horizon. The transition to the B horizon can be identified by increased clay content (see below) and the absence of organic material: no root hairs, small pieces of needle, etc.

The most thorough soil study involves analysis on separate O and A horizon samples. This requires separating and storing O and A horizon samples. It also involves completing the entire soil analysis on both the O and A samples. If this is not possible, the O and A samples can be combined (or composited) and the analysis can be completed on the O and A sample together.

The **B-Horizon** is also called the subsoil - this layer is beneath the A horizon and above the C horizon. It contains clay and mineral deposits (like iron, aluminum oxides, and calcium carbonate) that it receives when soil solution containing dissolved minerals drips from the soil above.

The B horizon is identified by increased clay content that makes the soil hold together when moist. A simple test for clay content is to moisten a small handful of soil and attempt to smear a small portion up the forefinger. Soils high in clay will hold together and form a “ribbon”, soils with more sand and silt will be granular and fall apart. It is lighter in color and often may be reddish due to the iron content.

The **C Horizon** (layer beneath the B Horizon) consists of porous rock (broken-up bedrock, bedrock with holes). It is also called regolith or saprolute which means "rotten rock." Plant roots do not penetrate into this layer; very little organic material is found in this layer.

The **R-Horizon** is the un-weathered rock (bedrock) layer that is beneath all the other layers. For the purposes of drip dispersal designs, the R horizon is considered an impermeable layer.

**Water Pollution Control (WPC) Soils Map.** A first order survey as defined in the Soil Survey Manual, United States Department of Agriculture, October 1993. These surveys are made for various land use that requires detailed soils information. Map scale should be one (1) inch equals one hundred (100) feet or a scale that will allow the map to fill a 24” x 36” plan sheet. These maps should have adequate cartographic detail to satisfy the requirements of project. The WPC Soils Map is essentially a special map that shows a very high degree of soil and landscape detail. Baseline mapping standards for these WPC Soils Maps prepared in support of drip dispersal should be a first order survey in accordance with the current edition of the Soil Survey Manual, United States Department of Agricultural; October 1993. Soil profile information and pit excavation, as described in these design criteria are additional requirements deemed necessary to properly assess an area’s suitability for drip dispersal. These maps should be clearly marked or labeled as “Water Pollution Control Soils Map”.

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Soil map unit. A unique collection of areas that have common soil characteristics and/or miscellaneous physical and chemical features.

Soil scientist. A person having the experience and education necessary to measure soil properties and classify soils per Soil Taxonomy, synonymous with the term “soil consultant”.

Soil series. A group of soils that have similar properties; the lowest level of soil classification.

Most limiting horizon. A horizon in the soil (bedrock or fragipan) that either provides the greatest impediment to or completely stops the downward movement of liquids through the soil.

17.2.4 Special Soil/Geologic Considerations

For sites with slopes between 30% and 50%, TDEC may request, a special investigation (performed by a qualified professional, such as a geologist, geo-tech engineer, engineering geologist, etc.) to be conducted to evaluate those sites. To adequately complete these determinations the following information should be provided.

- Strike and dip angle of underlying bedrock
- Depth to either hard rock and partly weathered rock
- Type of rock (limestone, shale, etc.)
- Soil particle-size class designation to a depth of six (6) feet or to hard rock whichever is less
- Slippage potential of slope
- Certification statement signed by a qualified professional that addresses all of the above characteristics.

For sites with slopes between 30% and 50%, in addition to meeting all other soil suitability requirements, the site should also meet the following requirements:

- Have a vertical depth of at least twenty (20) inches of soil above the rock layer.
- Not have a predominant particle size class of fragmental or sandy-skeletal.

17.3 Determination of Design Application Rates

17.3.1 General

One of the key steps in the design of a drip dispersal system is to develop a "design application rate" in gallons per day per square foot (GPD/SF). This value is derived from either the hydraulic (water) loading rate (Lwh) based upon the most restrictive of (1) the NRCS hydraulic conductivity data and the texture and structure (per Table 17-2), or (2) the nutrient (nitrogen) loading rate (Lwn) calculations to determine design wastewater loading(s) and, thus, drip field area requirements.
17.3.2 Design Values

The most limiting horizon, of each soil series (or lowest possible level of soil classification) shall be identified. Any surface condition that limits the vertical or lateral drainage of the soil profile shall also be identified. Examples of such conditions are shallow bedrock, a high water table, aquitards, and extremely anisotropic soil permeability. Design considerations relative to the soils per Section 17.1.4 must be used.

Sites with seasonal high groundwater less than twenty-four (24) inches deep may require drainage improvements before they can be utilized for slow rate land treatment. The design hydraulic conductivity at such sites is a function of the design of the drainage system.

17.4 Determination of Design Wastewater Loading

17.4.1 General

The design wastewater loading is a function of:

a. Precipitation.
b. Evapotranspiration.
c. Design hydraulic conductivity rate.
d. Nitrogen loading limitations.
e. Other constituent loading limitations.
f. Groundwater and drainage conditions.
g. Average and peak design wastewater flows.
h. Soil denitrification rates
i. Rate of nitrogen uptake in site vegetation

Therefore, developing the design wastewater loading is an iterative process. The Lwh value is determined by a detailed site evaluation and will be dependent upon the soil characteristics as shown in Table 17-2 and pictorially represented in Figure 17.3. This loading is then compared to the Lwn loading limitations (reference Section 17.5). If the initial Lwh value exceeds the Lwn value, the design wastewater loading resulting from the nitrogen reduction evaluation described in Section 17.5 becomes the design loading rate.
17.5 Nitrogen Loading and Crop Selection and Management

17.5.1 General

Nitrate concentration in percolate from wastewater irrigation systems will be limited via a State Operation Permit (SOP) to not exceed 10 mg/L nitrate-nitrogen at the site property line. Percolate nitrate concentration is a function of nitrogen loading, cover crop, and management of vegetation and hydraulic loading. The design wastewater loading determined from using the criteria stipulated in 17.1.4 for hydraulic conductivity must be checked against nitrogen loading limitations.

17.5.2 Nitrogen Loading

In some instances, the amount of wastewater that can be applied to a site may be limited by the amount of nitrogen in the wastewater. A particular site may be limited by the nitrogen content of the wastewater during certain months of the year and limited by the infiltration rate during the remainder of the year.
Equation 17-2 is used to calculate, on a monthly basis, the allowable hydraulic loading rate based on nitrogen limits:

\[
L_{wn} = \frac{C_p (Pr - PET) + N(4.413)}{(1 - f)(C_n) - C_p} \quad \text{(Equation 17-2)}
\]

Where:

- \( L_{wn} \) = allowable monthly hydraulic loading rate based on nitrogen limits, inches/month
- \( C_p \) = nitrogen concentration in the percolating wastewater, mg/L. This will usually be 10mg/L Nitrate-Nitrogen
- \( Pr \) = Five-year return monthly precipitation, inches/month
- \( PET \) = potential evapotranspiration, inches/month
- \( U \) = nitrogen uptake by cover, lbs./acre/year
- \( N \) = nitrogen uptake by cover, lbs./acre/month
- \( C_n \) = Nitrate-Nitrogen concentration in applied wastewater, mg/L (after losses in pre-application treatment)
- \( f \) = fraction of applied nitrogen removed by denitrification and volatilization.

The values of \( L_{wh} \) and \( L_{wn} \) are compared for each month. The lesser of the two values will be used to determine the amount of acreage needed.

NOTES:

- A “\( C_n \)” value of less than 23 mg/L will become a permit condition.
- The allowable (default value) vegetative uptake “\( U \)” of nitrogen on the drip area will be an uptake rate of 100 pounds per acre per year unless trees or other vegetation are acceptable to, and permitted by WPC.
- The “\( f \)” values for denitrification have been estimated based upon data supplied by the University of Tennessee and Oak Ridge National Laboratory. Denitrification rates (\( f \)) ranging from 25% in January and February to 35% in July and August are very conservative, but are defendable based upon the literature. Denitrification rates are assumed to vary linearly with the temperature and the actual rates are likely to be higher than the default values shown in Table 17-2.
- Conversion Factor - 4.413 mg-acre-inch/liter-lb. The equation and factor are from the TDHE Design Criteria for Sewage Works (April 1989). The factor comes from assuming that one pound of contaminant of concern is diluted within a volume of water equal to one acre-inch. For the derivation of this factor see Appendix 17-C.
Table 17-3 shows the default values for Lwn calculations. Other values may be used provided adequate rationale and documentation is presented to, and approved by the Department of Environment and Conservation.

**TABLE 17-3**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Pr(1) Inches / Month</th>
<th>PET(2) Inches / Month</th>
<th>N Uptake(3) Percent / Month</th>
<th>f Denitrification(4) Percent / Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN</td>
<td>7.62</td>
<td>0.10</td>
<td>1%</td>
<td>25%</td>
</tr>
<tr>
<td>FEB</td>
<td>6.72</td>
<td>0.27</td>
<td>2%</td>
<td>25%</td>
</tr>
<tr>
<td>MAR</td>
<td>8.85</td>
<td>0.97</td>
<td>4%</td>
<td>27%</td>
</tr>
<tr>
<td>APR</td>
<td>6.59</td>
<td>2.30</td>
<td>8%</td>
<td>29%</td>
</tr>
<tr>
<td>MAY</td>
<td>6.13</td>
<td>3.59</td>
<td>12%</td>
<td>31%</td>
</tr>
<tr>
<td>JUN</td>
<td>5.52</td>
<td>4.90</td>
<td>15%</td>
<td>33%</td>
</tr>
<tr>
<td>JUL</td>
<td>6.85</td>
<td>5.44</td>
<td>17%</td>
<td>35%</td>
</tr>
<tr>
<td>AUG</td>
<td>4.73</td>
<td>5.00</td>
<td>15%</td>
<td>35%</td>
</tr>
<tr>
<td>SEP</td>
<td>5.54</td>
<td>3.79</td>
<td>12%</td>
<td>34%</td>
</tr>
<tr>
<td>OCT</td>
<td>4.47</td>
<td>1.98</td>
<td>8%</td>
<td>32%</td>
</tr>
<tr>
<td>NOV</td>
<td>6.11</td>
<td>0.82</td>
<td>4%</td>
<td>29%</td>
</tr>
<tr>
<td>DEC</td>
<td>7.55</td>
<td>0.27</td>
<td>2%</td>
<td>26%</td>
</tr>
</tbody>
</table>

(1) Based upon Table A-3 of Chapter 16 – 5-year return monthly precipitation
(2) Based upon Table A-2 of Chapter 16 – Potential Evapotranspiration
(3) Based upon Table A-5 of Chapter 16 – Monthly Nitrogen Uptake by Vegetation
(4) Applied Nitrogen Fraction Removed by Denitrification / Volatilization

**Note:** Appendix 17-B shows Equation 17-2, using the default values.
17.6 Plan of Operation and Management

Each decentralized wastewater treatment system utilizing drip effluent dispersal should be covered by a Plan of Operation and Management (POM). For public utility systems, a General POM applicable to all of the utility’s facilities and covering the items discussed below will suffice. The POM is written by the owner or the owner's engineer and once accepted by the Division of Water Pollution Control, the POM becomes the operating and monitoring manual for the facility. This manual should be kept on file by the facility owner and should be available for inspection by personnel from the Tennessee Department of Environment and Conservation.

This Plan should include, but not be limited to, the following information unless previously submitted via the permit application process:

17.6.1 Introduction

a. System Description:
   1. A narrative description and process design summary for the land treatment facility including the design wastewater flow, design wastewater characteristics, pre-application treatment system and drip fields.
   2. A map of the land treatment facility showing the pre-application treatment system, drip fields, buffer zones, roads, streams, drainage system discharges, monitoring wells, etc.
   3. A map of the collection system including gravity lines, force mains and pump stations tributary to the land treatment facility. Indicate their size and capacity.
   4. A schematic and plan of the pre-application treatment system identifying all pumps, valves and process control points.
   5. A schematic and plan of the irrigation distribution system identifying all pumps, valves, gauges, etc.

b. Discuss the design life of the facility and factors that may shorten its useful life. Include procedures or precautions that will compensate for these limitations.

17.6.2 Management and Staffing

a. Discuss management's responsibilities and duties.

b. Discuss staffing requirements and duties:
   1. Describe the various job titles, number of positions, qualifications, experience, training, etc.
   2. Define the work hours, duties and responsibilities of each staff member.
   3. Describe the location of operational and maintenance personnel relative to the location of the treatment system.

17.6.3 Facility Operation and Management

a. Pre-application Treatment System:
1. Describe how the system is to be operated.
2. Discuss process control.
3. Discuss maintenance schedules and procedures.
4. Discuss the use of telemetry

b. Drip Dispersal System Management:

1. Wastewater Application. Discuss how the following will be monitored and controlled. Include rate and loading limits.
   (a) Wastewater loading rate
      (gallons per day per square foot or inches/week)
   (b) Drip dispersal field application cycles
2. Discuss how the system is to be operated and maintained.
   (a) Storage pond(s), where utilized.
   (b) Irrigation pump station(s)
   (c) Drip dispersal field force main(s) and laterals
3. Discuss start-up and shut-down procedures.
4. Discuss system maintenance.
   (a) Equipment inspection schedules
   (b) Equipment maintenance schedules
5. Discuss operating procedures for adverse conditions.
   (a) Electrical and mechanical malfunctions
6. Provide troubleshooting procedures for common or expected problems.
7. Discuss the operation and maintenance of back-up, stand-by and support equipment.

c. Drainage System (if applicable):

1. Discuss operation and maintenance of surface drainage and run off control structures.
2. Discuss operation and maintenance of subsurface drainage systems.

17.6.4 Monitoring Program

a. Discuss sampling procedures, frequency, location and parameters for:
   1. Pre-application treatment system.
   2. Drip Dispersal System:
      (a) Storage pond(s), where utilized
      (b) Groundwater monitoring wells
      (c) Drainage system discharges (if applicable)
      (d) Surface water (if applicable)
b. Discuss soil sampling and testing:

c. Discuss ambient conditions monitoring:
   1. Rainfall
   2. Soil moisture

d. Discuss the interpretation of monitoring results and facility operation:
   1. Pre-application treatment system.
   2. Drip dispersal fields.

17.6.5 Records and Reports

a. Discuss maintenance records:
   1. Preventive.
   2. Corrective.

b. Monitoring reports and/or records should include:
   1. Pre-application treatment system and storage pond(s).
      (a) Influent flow
      (b) Influent and effluent wastewater characteristics
   2. Drip Dispersal System.
      (a) Wastewater volume applied to drip dispersal fields.
      (b) Loading rates.
   4. Drainage system discharge parameters (if applicable).
   5. Soils data.
   6. Rainfall and climatic data.
**Effluent Discharge, Reclamation, and Reuse Vocabulary**

1. The term __________________________ is used to describe any rivers, streams, lakes, estuaries, or oceans into which wastewater effluent is discharged. Direct discharge into these waters is the most common reuse method.

2. Chemicals are added to a sample in the field to prevent the water quality indicators of interest from changing before the analysis can be conducted in the laboratory; this is known as a ____________________________.

3. A _____________ sample is a single sample of water collected at a particular time and place that represents the composition of the water only at that time and place.

4. A collection of individual samples obtained at regular intervals – usually every one or two hours during a 24 hour period - which are combined to form a representative sample is known as a ____________________________ sample.

5. The process in which an organism takes in oxygen for its life processes and gives off carbon dioxide is called ____________________________.

6. The process by which water vapor is released to the atmosphere from living plants; includes the total water removed by plants and by evaporation from soil, snow, and water surfaces. ____________________________

7. The most common form of land treatment for effluent disposal is ____________________________, which includes ridge and furrow, sprinklers, surface/drip systems, and border strip flooding.

8. A type of irrigation method, ____________________________ is a series of interconnected ditches (furrows) which allow for the distribution, infiltration, and treatment of wastewater.

9. Another form of irrigation, ____________________________ are broken into 3 categories: solid set (fixed), portable, or continuously moving.

10. This form of irrigation is used on highly impermeable soils; where wastewater is applied intermittently at top of terrace, slowly runs down the slope, and runoff is collected at the bottom for further treatment: ____________________________

11. One way to gauge the impact that effluent discharge is having on the receiving waters is to measure DO at several different cross sections downstream from the discharge to determine the lowest level; this is called a ____________________________.
12. The point, location, or structure where wastewater discharges from a sewer, drain, or other conduit is called the __________________________. These locations will be identified and numbered in your NPDES permit.

**Word Bank**

Composite
Irrigation
Surface waters
Ridge and furrow
Dissolved Oxygen profile (aka Oxygen profile)
Overland flow
Evapotranspiration
Respiration
Spray systems
Grab
Fixed sample
Outfall
Effluent Discharge, Reclamation, and Reuse Review Questions

1. What is the most common method of effluent discharge, reclamation, and reuse?

2. List other common methods of wastewater discharge, reclamation, and reuse.

3. Tennessee does not allow rapid infiltration due to the risk of rapid groundwater discharge. Why would that be a problem?

4. How would you measure the impact of discharge on receiving waters?

5. What water quality indicators can be monitored or determined by in-stream measurements?

6. What water quality indicators are usually determined by samples collected in the field and then analyzed in the laboratory?

7. According to the TN Design Criteria, wastewater that is spray irrigated on public sites (such as golf courses, cemeteries, green areas, parks, etc.) must not exceed a BOD₅ and TSS of _______ mg/L, as a monthly average. Disinfection to reduce E. coli bacteria to _________ colonies/100 mL is required.
Description

Land (surface) treatment systems (figures 1 and 2) are permitted in some states, but are not widely used because of their large land area requirements exacerbated by code-required setbacks. For example, a spray irrigation system requires about four times the area of an individual home lagoon. When these systems are used, large buffer areas and fencing may be required to ensure minimal human exposure. Also, given the nature of these systems, all requirements include disinfection and significant pretreatment before application. In wet and cold areas, an additional basin for storage or a larger dosing
tank is necessary to eliminate possible runoff from the application area. The most used variation of these systems is the spray irrigation system (figure 3).

Spray irrigation systems distribute wastewater evenly on a vegetated plot for final treatment and discharge. Spray irrigation can be useful in areas where conventional onsite wastewater systems are unsuitable due to low soil permeability, shallow water depth table or impermeable layer, or complex site topography. Spray irrigation is not often used for residential onsite systems because of its large areal demands, the need to discontinue spraying during extended periods of cold weather, and the high potential for human contact with the wastewater during spraying. Spray irrigation systems are among the most land-intensive disposal systems. Drifting aerosols from spray heads can be a nuisance and must be monitored for impact on nearby land use and potential human contact. Buffer zones for residential systems must often be as large as, or even larger than, the spray field itself to minimize problems.

In a spray irrigation system, pretreatment of the wastewater is normally provided by a septic tank (primary clarifier) and aerobic unit, as well as a sand (media) filter and disinfection unit. Some states do not require the aerobic unit if the filter is used. The pretreated wastewater in spray irrigation systems is applied at low rates to grassy or wooded areas. Vegetation and soil microorganisms metabolize most nutrients and organic compounds in the wastewater during percolation through the first several inches of soil. The cleaned water is then absorbed by deep-rooted vegetation, or it passes through the soil to the ground water.

Rapid infiltration (RI) is a soil-based treatment method in which pretreated (clarified) wastewater is applied intermittently to a shallow earthen basin with exposed soil surfaces. It is only used where permeable soils, which generally can accept a conventional OWTS, are available. Because loading rates are high, most wastewater infiltrates the subsoil with minimal losses to evaporation. Treatment occurs within the soil before the wastewater reaches the ground water. The RI alternative is rarely used for onsite wastewater management. It is more widely used as a small-community wastewater treatment system in the United States and around the world.

The third and last type of land surface treatment is the overland flow (OF) process. In this system, pretreated wastewater is spread along a contour at the top of a gently sloping site that has minimum permeability. The wastewater then flows down the slope and is treated by microorganisms attached to vegetation as it travels by sheet flow over very impermeable soils until it is collected at the bottom of the slope for discharge. This system (figure 4) requires land areas similar to the spray
irrigation system. However, surface water discharge requirements (e.g., disinfection) from the OF system must still be met. Overland flow, like rapid infiltration, is rarely used for onsite wastewater management.

**Typical applications**

Spray irrigation (SI) is normally considered at site locations that do not permit a conventional SWIS because of relative impermeability and shallow depths caused by restrictive conditions (e.g., ground water or impermeable bedrock or fragipan). SI is normally the final step in the treatment sequence as the effluent is reintroduced to the environment. Most states require advanced treatment and disinfection prior to SI treatment.

**Design assumptions**

After pretreatment, which at a minimum should be a typical ISF effluent followed by disinfection, the treated wastewater is conveyed to a holding tank with a pump and controls that deliver it to the sprinkler system. The sprinklers spread the wastewater over a predetermined area at specific times. In wet climates or frozen soil conditions, an additional holding (storage) basin or larger dosing tank is required to prevent irrigation during periods when the wastewater would not be accepted by the soil for treatment and intended environmental incorporation. Regulations for buffer requirements from Texas, Virginia, and Pennsylvania are incorporated into table 1. Typically, the features listed below and their peripheral buffer zones are fenced to prevent exposure.

Application rates vary. Texas determines design rates based on evaporation, Virginia bases rates on soil texture, and Pennsylvania uses a combination of soil depth and slope. From a performance code approach, the application rate should be based on protecting the receiving surface/ground waters. It should be based on wastewater characteristics, critical constituent required concentrations (at a monitoring location where a specific quality standard must be met), and the characteristics of the site (i.e., features that will mitigate wastewater contaminants in order to meet the constituent concentration at the point of use).

In practical terms, all three states require the same pretreatment sequence, which yields SI influent of approximately 5, 5, 25, and 4 mg/L of CBOD, TSS, TN, and TP, respectively, in addition to a fecal coliform (FC) level of about 10 cfu/100 mL (if the disinfection step is working properly). Passage through 1 foot of unsaturated soil should for a few years remove most CBOD, TSS, TP, and FC; therefore, nitrogen will be the

<table>
<thead>
<tr>
<th>Feature</th>
<th>Buffer distance (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property lines</td>
<td>10 - 100</td>
</tr>
<tr>
<td>Roads, driveways</td>
<td>25</td>
</tr>
<tr>
<td>Dwellings</td>
<td>0 - 100</td>
</tr>
<tr>
<td>Streams and lakes</td>
<td>25 - 100</td>
</tr>
<tr>
<td>Wells and water supplies</td>
<td>100</td>
</tr>
<tr>
<td>Recreation areas</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: North Carolina DEHNR, 1996.
constituent of most concern. During the growing season, removal should be feasible by crop uptake and, to a lesser degree, ammonia volatilization.

Therefore, the hydraulic and nitrogen loading rates for a specific site are the primary design parameter. Also, these systems are rarely considered for permeable soils. The design approach described below is for this set of circumstances.

Spray irrigation systems are designed to treat wastewater and evenly distribute the effluent on a vegetated lot for final treatment. The application rate is determined by two major factors: hydraulic loading and nutrient loading (usually nitrogen is the limiting factor). The application rate is designed to meet the capacity of the soil to accept the effluent hydraulically and subsequently allow it to drain through the soil. The application rate can be varied according to the permeability of the soil. In Pennsylvania and Virginia, this method results in application rates of 0.6 to 2.5 cm/week. Lower rates can greatly improve nitrogen removal. The treated wastewater is spread over the required application area through a sprinkler or drip irrigation system.

Sprinklers are generally low-angle (7 to 13 degrees), large-drop-size nozzles designed to minimize aerosols. Application areas must be vegetated (with crops not intended for human consumption) and have slopes that preclude runoff to streams. The type of vegetation determines the nitrogen loading capacity of the site, but the hydraulic capacity depends on climate and soil characteristics. Additional nitrogen losses may occur through denitrification (only about 25 percent due to the low BOD:N ratio) and ammonia volatilization (about 10 percent if soil pH is high; less to none if it is acidic).

Spray irrigation of wastewater effluent must be timed to coincide with plant uptake and nutrient use. Temperature factors in some areas of the country may preclude the use of spray irrigation during certain times of the year. The wastewater may need to be stored in holding tanks during the coldest period of the year, because plant growth is limited and the nitrogen in effluent discharged during this time will be mineralized and unavailable for plant uptake.

Some SI systems irrigate only one or two days per week so that the soil can drain and aerate between applications. Others spray twice during the night or in the early morning to minimize inconvenience to the homeowner and to minimize the potential for human contact.

The width of the required buffer zone depends on the slope of the site, the average wind direction and velocity, the type of vegetation, and the types of nearby land uses. For wastewater produced by a single-family home, the minimum recommended SI plot area, including buffer zones, is commonly about 2 acres (0.81 hectares) in Pennsylvania and Virginia.

**Performance**

Studies that sample both the soil below the spray field and its runoff show that spray irrigation systems work as well as other methods of managing wastewater. Spray irrigation systems are designed for no degradation; therefore, hydraulic and nutrient loading rates are based on the type of vegetation used and the hydraulic properties of the soils. If the vegetation cannot assimilate the amount of nitrogen applied, for example, then nitrogen removal to reduce the nitrogen content of the effluent prior to spray irrigation may be required. The overall efficiency of a spray irrigation system in removing pollutants will be a function of the pollutant removal efficiencies of the entire treatment process and plant uptake.

There have been few documented cases of health problems due to the spray irrigation, but use of proper buffer zones is crucial. One benefit of spray irrigation is savings on potable water because the wastewater is used for irrigation.

**Management needs**

Construction factors include site preparation and installation of runoff controls, irrigation piping, return systems, and storage facilities. Since sustained wastewater infiltration is an important component of successful system operation, it is critical that construction activity be limited on the application site. Where stormwater runoff can be significant, measures must be taken to prevent excessive erosion, including terracing of steep slopes, contour plowing, no-till farming, establishment of grass border strips, and installation of sediment control basins. Earthworking operations should be conducted in
such a way as to minimize soil compaction. Soil moisture should generally be low during these operations. High-flotation
tires are recommended for all construction vehicles.

The soil profile must also be managed to maintain infiltration rates by avoiding soil compaction and maintaining soil
chemical balance. Compaction and surface sealing (caused by harvesting equipment and development of fine layers from
multiple wastewater applications) can reduce soil infiltration and increase runoff.

Local regulatory agencies may require ground water monitoring to evaluate system performance. Soil fertility and chemical
balance should be evaluated periodically to determine if soil amendments are necessary. Trace elements may also be
analyzed to monitor possibly toxic accumulations.

Residuals produced by slow-rate land application systems are limited to harvested crops and crop residues that are not for
human consumption. Agricultural crop applications require the most intensive management, while forest application
requires the least management. Management tasks may include soil tillage, planting and harvesting of crops, nutrient
control, pH adjustment, and sodium and salinity control. No special equipment, other than the appropriate agricultural
equipment, is required. Typical pump, controls, and basin requirements prevail for the dosing system.

Virginia’s O/M requirements for onsite spray irrigation systems (not including pretreatment unit processes) include the
following:

- **Monthly.** Walk over spray area and examine for
  - Ponding of effluent
  - Bad odors
  - Damage to spray heads
  - Surfacing liquids
  - Vegetation problems
  - Surface soil collapse

- **Quarterly.** Conducted by a qualified, semi-skilled operator
  - Proper spray sequence
  - Proper pump function
  - Proper liquid levels

- **Biannually**
  - Erosion
  - Storage unit capacity

- **Annually.** Effluent sampling by a certified laboratory
  - Test water supplied to spray irrigation area for pH, total Kjeldahl nitrogen, fecal coliform bacteria, chlorine, TSS, and BOD
  - Reports of analyses are to be submitted by the laboratory to the local/district health department within 10 days of
    the completion of the analyses.

A management contract with an approved operator or operations firm is also required.
Risk management issues

No crops grown on the SI application area should be consumed by humans. Buffer zones should minimize aerosol exposure. Spray irrigation systems with sufficient storage capacity are essentially unaffected by major flow variations. A water balance should be conducted to determine the need under the climate conditions, soils, and application rates and patterns of each rate. Similarly, toxic shock loadings should be largely dissipated in the preceding pretreatment steps, but phytotoxic compounds may still be a concern at the application site. Spray irrigation cannot function during saturated or frozen conditions, and the pretreated influent must be stored until proper vegetative uptake (usually nitrogen) conditions return. Power outages will affect the upstream pretreatment processes rather than the SI system, even though the system must have power to function.

However, by the time the wastewater effluent is discharged by the sprinklers, the water should be sufficiently treated so as not to pose health risks. There have been no documented cases of health problems due to the spray irrigation of properly treated wastewater. However, drifting aerosols from the spray heads should be monitored for impact on nearby land uses. A benefit of spray irrigation is the use of effluent, instead of potable tap water, to water the landscape.

Costs

Construction costs of SI systems are very high if the generally required pretreatment is included, especially if both an aerobic unit and a sand filter treating septic tank effluent are included. Such a system could easily cost $20,000 or more.

O/M costs for the SI system alone primarily include labor (15 to 20 hours per year), power (for pumps and other pretreatment needs) and materials (e.g., chlorine, if chosen). O/M costs are estimated at more than $500 per year, given the entire treatment train suggested by figure 3. If the aerobic treatment unit is not required ahead of the sand filter, and a UV disinfection unit is used, this cost may reduce to $300 to $400 annually.

References


**Wastewater Technology Fact Sheet**

Rapid Infiltration Land Treatment

**DESCRIPTION**

Rapid Infiltration (RI), which is also known as soil aquifer treatment, is one of the three major land treatment techniques that uses the soil ecosystem to treat wastewater. However, the RI process can treat a much larger volume of wastewater on a much smaller land area than other land treatment concepts. In RI systems, wastewater is applied to shallow basins constructed in deep and permeable deposits of highly porous soils. Wastewater application can be by flooding, or occasionally by sprinklers. Treatment, including filtration, adsorption, ion exchange, precipitation, and microbial action, occurs as the wastewater moves through the soil matrix. Phosphorus and most metals are retained in the soil while toxic organics are degraded or adsorbed.

As wastewater percolates through the soil, it can be collected, or it can flow to native surface water or groundwater aquifers. Where the groundwater table is relatively shallow, the use of underdrains allows control of groundwater mounding and recovery of the renovated water. In areas with deeper groundwater, wells are used to recover the renovated water. This recovered water can be for irrigating crops or for industrial uses. This is known as “beneficial reuse.” Water that is not recovered can recharge groundwater aquifers. The typical hydraulic pathways for water treated by RI are shown in Figure 1.

**Common Modifications**

Concerns regarding increased nitrogen levels in aquifers near RI systems have prompted several modifications to the general system design. RI sites may be located next to rivers or other surface water bodies, particularly if hydrogeological studies show that the percolate will flow to the surface water system and will not impact the general groundwater quality. When using underdrains or wells, an alternative is to design for a discharge rate that only slightly exceeds the percolation rate. This prevents any adverse impact on the adjacent groundwater. It is also possible to use special management approaches that maximize the nitrification and denitrification reactions, or to recycle the portion of the percolate with the highest nitrate concentration.

**APPLICABILITY**

RI is a simple and low cost wastewater treatment concept that has been used for more than 100 years. It is applicable for either primary or secondary effluent, and it has been used for treating municipal and some industrial wastewaters. Industries which have successfully used RI to treat their wastewater...
include breweries, distilleries, food processing plants, paper mills, and wool scouring plants.

RI can be used in a variety of different climates and at varied site locations. Unlike other land treatment and aquiculture concepts, RI systems do not have any special seasonal constraints, and they have been successfully operated throughout the winter months in the northern United States and southern Canada. RI is also very flexible in terms of site location. Unless groundwater recharge and recovery is intended, the most desirable sites are located immediately adjacent to surface waters to minimize any impact on the general groundwater quality. An underdrained system can be located wherever suitable soil and groundwater conditions exist.

There are more than 350 RI systems operating in the United States. However, the potential difficulty in identifying appropriate sites for the construction of RI systems and more stringent standards that must be met before the effluent can be applied to RI basins have led to a decrease in the use of RI as a treatment process for primary wastewater. Instead, many of the systems currently in use in the U.S. are used to polish secondary effluent. Other systems serve primarily as a wastewater disposal method, or as a method to replenish groundwater supplies. For example, the Landis Sewerage Authority in New Jersey operates an 3,100 m³/day (8.2 MGD) advanced wastewater treatment facility (AWTF). After being processed in the AWTF, all of the water is discharged back to the groundwater through a RI basin, recharging the aquifer. RI basins have also recently been installed to dispose of treated effluent from an industrial area consisting of a hospital and a retirement home in Chester County, Pennsylvania. There are several basins covering a total of 1.2 ha (3 acres) in the system, and wastewater is applied by spraying it into each basin on a rotating schedule. Once the basins have reached their design effluent capacity, they are allowed to dry. The effluent then infiltrates through the soil and into the groundwater, further improving its quality and recharging the aquifer (Satterthwaite and Associates, 2003).

The town of Lake George, New York, has been using a RI system for over 60 years. The use of RI basins at Lake George stems from a 1942 New York state law that forbids discharge of wastewater to Lake George or any of its tributaries. Therefore, in order to dispose of its wastewater, the town discharges to natural basins consisting of more than 30 m (100 ft) of glacial sand deposits. The wastewater then percolates into the soil. After percolation, the sand is raked and/or rototilled to aerate the soil, and the beds can be reused.

Currently, the Lake George WWTP discharges 1.3 MGD during the summer, and between 0.5-0.6 MGD in the winter. Treatment consists of equalization, clarification, and trickling filters. After secondary settlement, wastewater is discharged to one of 26 RI basins. Each basin is filled to just below the spillway, and the water is then allowed to infiltrate into the soil. During peak flow periods in the summer, approximately one basin is filled per day. The basins take approximately 5 days to drain, and then each basin is raked and is ready for reuse.

Because of the concerns that using these basins could load high concentrations of nitrogen and phosphorous into the groundwater, the town’s NPDES permit requires groundwater monitoring for increased nutrient concentrations. Nitrogen can be a particular problem during the winter months when nitrogen-fixing bacteria are less active.

**ADVANTAGES AND DISADVANTAGES**

**Advantages**

- Gravity distribution methods consume no energy.
- No chemicals are required.
- RI is a simple and economical treatment.
- The process is not constrained by seasonal changes.
- Effluent is of excellent quality.
- The process is very reliable with sufficient resting periods.
- RI provides a means for groundwater recharge, controlling groundwater levels, recovering renovated water for reuse or discharge to a particular surface water.
body, and temporary storage of renovated water in the aquifer.

- The process is suitable for small plants where operator expertise is limited.

**Disadvantages**

- As typically operated, RI systems will not usually meet the stringent nitrogen levels required for discharge to drinking water aquifers.

- Requires long term commitment of a significant land area for treatment, with minimal secondary benefits such as are possible with other natural treatment systems (i.e., crop or forest production, habitat enhancement, etc.).

- Requires annual removal of accumulated deposits of organic matter on the infiltration surfaces in the basins.

- May require occasional removal and disposal of the top few inches of soil to expose clean material.

- Clogging can occur when influent is received at high application rates from algal laden facultative lagoons and polishing ponds.

**DESIGN CRITERIA**

Most RI failures are due to improper or incomplete site evaluation. Therefore, the primary design consideration for an RI system is site selection. Soil depth, soil permeability, and depth to groundwater are the most important factors in site evaluation. All of these factors must be very carefully evaluated during site investigation, regardless of system size, to ensure a successful design.

Once a suitable site has been selected, hydraulic loading rates, nitrogen loading rates, organic loading rates, land area requirements, hydraulic loading cycle, infiltration system design, and groundwater mounding must all be taken into account in designing the RI system. General design parameters for RI systems are shown in Table 1.

As described above, the RI process is entirely dependent on the soil and hydrogeological characteristics at a particular site, and these characteristics must be carefully considered before choosing the site for a RI system. The soil must have sufficient hydraulic capacity to allow the wastewater to infiltrate, then percolate and move either to the groundwater or into underdrains. Any fine textured top soil must be removed from the site so as to utilize the underlying coarse soils as the basin bottom and percolation media. In addition, the top 1.5-3 m (5-10 ft) of soil beneath the basin must be unsaturated at the start of the flooding cycle to allow the expected treatment to occur. There must be suitable subsurface conditions (i.e., slope and/or hydraulic gradient) to ensure that the percolate can flow away from the site at expected rates. The use of RI basins on fill material is not recommended because of potential damage to soil structure and hydraulic capacity during

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin Infiltration Area</td>
<td>0.3-5.5 ha/10^3 m^3/d (3-56 acres/MGD)</td>
</tr>
<tr>
<td>Hydraulic Loading Rate</td>
<td>6-90 m/yr (20-300 ft/yr)</td>
</tr>
<tr>
<td></td>
<td>[6-92 m^3/m^2/yr (150-2250 gal/ft^2/yr)]</td>
</tr>
<tr>
<td>BOD Loading</td>
<td>22-112 kg/ha/d (20 to 100 lb/acre/d)</td>
</tr>
<tr>
<td>Soil Depth</td>
<td>at least 3-4.5 m (10-15 ft)</td>
</tr>
<tr>
<td>Soil Permeability</td>
<td>at least 1.5 cm/hr (0.6 in/hr)</td>
</tr>
<tr>
<td>Wastewater Application Period</td>
<td>4 hrs to 2 wks</td>
</tr>
<tr>
<td>Drying Period</td>
<td>8 hrs to 4 wks</td>
</tr>
<tr>
<td>Soil Texture</td>
<td>coarse sands, sandy gravels</td>
</tr>
<tr>
<td>Individual Basin Size</td>
<td>0.4-4 ha (1-10 acres)</td>
</tr>
<tr>
<td>(at least 2 basins in parallel)</td>
<td></td>
</tr>
<tr>
<td>Height of Dikes</td>
<td>0.15 m (0.5 ft) above maximum expected water level</td>
</tr>
<tr>
<td>Application Method</td>
<td>flooding or sprinkling</td>
</tr>
<tr>
<td>Pretreatment Required</td>
<td>primary or secondary</td>
</tr>
</tbody>
</table>

construction. Exceptions may be possible for very coarse textured soils, but only if the hydraulic capacity is tested in a full scale fill. Performance limitations relate to removal of nitrogen, as discussed previously.

Some system designs include an underdrain, which is used to collect renovated water. In order for percolating water to move down through the soil and into an underdrain, the soil must be saturated. Therefore, the use of an underdrain pipe network for percolate recovery is not feasible unless the native groundwater is less than 3 m (10 ft) deep beneath the bottoms of the basins. This should allow for soil saturation during the flooding cycle.

Once the proper site is chosen, a preliminary estimate of the treatment area required for an RI system can be made with the following equation:

\[ A = (0.250)(Q)/(L)(P) \]

Where: \( A \) = RI treatment area in acres; \( Q \) = wastewater flow, gal/d; \( L \) = annual hydraulic loading into the basin, ft/yr (typical range 6-90 m [20-300 ft]; higher values for coarse soils and secondary treated wastewater); \( P \) = number of weeks per year the system is operated.

If the RI system operates on a year-round basis, the equation reduces to:

\[ A = (0.0048)(Q)/(L) \]

This is an estimate of the basin treatment area. The total site area would also include dikes and berms, access roads, etc.

Design of an RI basin must include mechanical equipment. Typical equipment associated with RI systems includes distribution piping or troughs, pumps, underdrain piping (if used), well piping and pumps (if used), and storage tanks or lined basins (if needed). Sprinklers or pumped groundwater recovery will require appropriate energy sources.

**PERFORMANCE**

RI systems produce effluent of excellent quality with sufficient travel distance through soil. The use of primary versus secondary level influent influences the hydraulic loading rate but not the expected performance of the system. Table 2 shows expected removal percentages for typical pollution parameters using RI.

**OPERATION AND MAINTENANCE**

RI has excellent reliability. With proper operation and management, several systems in the northeastern United States have operated continuously for more than 50 years without problems.

**Operation**

Preapplication treatment can be used to reduce the concentration of excess solids in the wastewater prior to introduction of the wastewater into the RI basin. Use of secondary effluent will allow a higher hydraulic loading rate and therefore a smaller RI basin system. RI basins receiving influent at high application rates from algal laden facultative lagoons and polishing ponds often experience rapid clogging.

Proper operation of a RI system requires a periodic cycle of flooding and drying of each basin at the site. First, wastewater is added to a dry bed in the “flooding” stage. The length of the flooding stage is determined by the design infiltration rate and the treatment requirements. After the bed is flooded for the appropriate period, it is allowed to dry. During the drying stage, wastewater infiltrates into the soil or is evaporated out into the atmosphere. The drying period is essential to restore aerobic conditions in the soil profile and to allow for desiccation and decomposition of the organic solid matter retained on the soil surface. The drying period can range from several hours to several

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>95 to 99 percent</td>
</tr>
<tr>
<td>TSS</td>
<td>95 to 99 percent</td>
</tr>
<tr>
<td>TN</td>
<td>25 to 90 percent</td>
</tr>
<tr>
<td>TP</td>
<td>0 to 90 percent</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>99.9 to 99.99+ percent</td>
</tr>
</tbody>
</table>

weeks depending on the flooding period selected and the type of wastewater applied. Typically, the drying period is at least equal to the flooding period and may be twice as long. In cold climates, the drying period may be extended and the flooding period shortened during the winter months to compensate for the lower rate of treatment during that season.

**Maintenance**

The same maintenance requirements used at any earthen basin are applicable to RI systems. Special requirements for RI systems pertain to preserving the design infiltration capacity of the basins. The operator should perform daily inspections and record drainage time for the basins so that the infiltration rate can be tracked. Restoration of the infiltrative surface may be necessary when the infiltration rate decreases. Accumulated organic deposits are typically removed at least annually, and the infiltration surface is raked, disked or tilled to restore infiltration capacity. On a more extended interval, it may be necessary to remove the top few inches of soil to expose clean material. These maintenance activities should only occur when the basin bottom is dry to avoid soil compaction. Dikes and berms should also be monitored for signs of decay or erosion.

**COSTS**

With suitable soil and hydrogeologic conditions, RI systems can produce a percolate that is essentially equal in quality to that produced by more conventional advanced wastewater treatment processes, at a fraction of the cost. General equations for estimating preliminary costs for construction and O&M of RI systems are shown in Table 3. The following assumptions were made in developing the equations:

- Costs are based on May 2001 data (ENR Index 6318).
- Basin construction costs include field preparation, no seasonal storage, assumed hydraulic loading of 60 m/yr (200 ft/yr) [61 m³/m²/yr (1496 gal/ft²/yr)], gravel service roads, and stock fence around site perimeter.
- O&M includes the annual tillage of infiltration surfaces, and the repair of dikes, fences, and roads every 10 years.
- Construction for underdrained case also includes drain pipes at 2.5 m (8 ft) depth on 120 m (400 ft) spacing, with drains connecting to an interception ditch at the edge of the site.
- Construction of the recovery well case includes gravel packed well, vertical turbine pumps, simple shelter over well, and a 15 m (50 ft) vertical pumping head.
- Special O&M for underdrains includes jet cleaning of pipes every five years, and annual cleaning of interceptor ditch.
- Equations in Table 3 are valid for up to 3785 m³/d (10 MGD) wastewater flow and use the following notation: C = costs in million of dollars; Q = wastewater flow in MGD.

Costs of preliminary treatment, monitoring wells, and transmission from preliminary treatment facility to the RI site are not included.

**TABLE 3 COST ESTIMATION EQUATIONS**

<table>
<thead>
<tr>
<th></th>
<th>Construction ($)</th>
<th>Operation and Maintenance ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I Rapid Infiltration - No Underdrains, No Recovery Wells</td>
<td>C=0.580(Q)⁰.⁸⁸₈</td>
<td>C=0.054(Q)⁰.⁷₅₆</td>
</tr>
<tr>
<td>Case II Rapid Infiltration with 50 ft Deep Recovery Wells</td>
<td>C=0.597(Q)⁰.⁸₅₇</td>
<td>C=0.058(Q)⁰.⁷₅₆</td>
</tr>
<tr>
<td>Case III Rapid Infiltration with Underdrains</td>
<td>C=0.683(Q)⁰.⁸₈₆</td>
<td>C=0.075(Q)⁰.⁶⁴¹</td>
</tr>
</tbody>
</table>

Source: Crites, et al., 2000
REFERENCES

Other Related Fact Sheets

Slow Rate Land Treatment
EPA 832-F-02-12
September 2002

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owm/mtb/mtbfact.htm


ADDITIONAL INFORMATION

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Office of Water
EPA 832-F-03-025
June 2003

For more information contact:

Municipal Technology Branch
U.S. EPA
ICC Building
1200 Pennsylvania Ave., NW
7th Floor, Mail Code 4204M
Washington, D.C. 20460
**Wastewater Technology Fact Sheet**  
**Slow Rate Land Treatment**

**DESCRIPTION**

Slow rate (SR) land treatment is the controlled application of primary or secondary wastewater to a vegetated land surface. It is the oldest and most widely used form of land treatment. The nutrients and the water in partially treated wastewater contribute to the growth of a wide variety of crops, the maintenance of parks, pasture lands, and forests. SR systems can produce a very high quality percolate but also require the largest land area compared to the other land treatment concepts. On a worldwide basis, thousands of systems use wastewater for irrigation in variations of the SR process.

In the SR process, wastewater infiltrates and percolates from the vegetated soil surface and flows through the plant root zone and soil matrix. Water may percolate to the native groundwater or to underdrains or wells for water recovery and reuse of the effluent. Underdrains serve to prevent groundwater mounding under the site, to control groundwater flow, and to minimize movement of leachate onto adjacent property. Figure 1 illustrates the principal hydraulic pathways of water applied in SR systems.

SR systems use standard irrigation methods to distribute the water to agricultural fields, pastures, or forest lands. SR systems can be classified as either slow rate infiltration systems (Type 1) or crop irrigation systems (Type 2). The design objective of slow rate infiltration systems is to maximize wastewater treatment while minimizing land area. Crop irrigation systems are designed to meet crop water needs, which typically requires the use of a larger land area.

**APPLICABILITY**

The simplicity of land treatment makes it an attractive technology compared with other wastewater technologies.

A large forested sprinkler, slow rate irrigation system, constructed in the early 1980s, in Dalton, Georgia, highlights the applicability of land treatment systems. Dalton is known as the “carpet capital of the world” with 87 percent of its total municipal flow attributed to the carpet industry. The total site contains 3,640 hectares (9,000 acres) with about 1,860 hectares (4,605 acres) of forest being irrigated. The terrain varies from flat to relatively steep (some areas have up to a 40 percent grade) with soil depths of 0.5 to 1.2 m (1.5 to 4 feet). The three secondary treatment plants that feed secondary effluent to the site generate a combined flow of 33 million gallons per day (MGD) (Nutter, 2000).

**FIGURE 1 HYDRAULIC PATHWAYS FOR SLOW RATE LAND TREATMENT**

The choice of application method depends upon site conditions and wastewater characteristics. In Dalton, lint caused clogging problems in the sprinkler system but improved industrial pretreatment and screening at the pumping stations remediated this problem. In general, advantages of sprinkler application over gravity methods include:

- More uniform distribution of water and greater flexibility in application rates.
- Applicable to most crops.
- Less susceptible to topographic constraints and reduced operator skill and experience.

Gravity methods that utilize shallow flooding of carefully graded fields is generally applicable only for row crops and pastures on relatively flat, uniform terrain.

ADVANTAGES AND DISADVANTAGES

Advantages

SR systems, like other land treatment methods, may be an economical system for wastewater treatment in locations where sufficient land is available at a suitable price. Specific advantages of this technology include:

- Significantly reduced operational, labor, chemical, and energy requirements compared to conventional wastewater treatment systems.
- Economic return from the use and re-use of water and nutrients to provide marketable crops.
- Little or no disposal or effluent production.
- Recycling and reuse of water reduces water distribution and treatment costs for crop irrigation.

Disadvantages

SR systems require a thorough investigation of site suitability before implementation. Land area requirements are significantly greater for SR systems than for conventional wastewater treatment plants and other land treatment methods, such as rapid infiltration and overland flow systems. Slow rate application may not be feasible in most suburban and urban areas. Land requirements include the application area, roads, and winter storage during cold weather if seasonal crops are grown or if frozen soil conditions develop. Temporary storage may also be required for harvesting and maintenance activities.

The removal of pathogens and other pollutants is very effective in SR systems when properly designed and managed. The complex removal mechanisms involved with land treatment processes make site selection a critical part of the design. Specific problems associated with poor site selection include:

- Soil structure dispersion resulting from high dissolved salts concentration.
- Runoff and erosion for sites with steep slopes or lack of adequate erosion protection.
- Inadequate soil or groundwater characterization resulting in operational hydraulic problems.

DESIGN CRITERIA

Proper soils and an adequate land area are paramount criteria when considering SR systems. Table 1 shows the general design parameters for SR systems. The SR process is most suitable for soils of low to medium permeability. Land requirements for this technology are relatively large, but can decrease as the level of influent water quality or degree of pre-treatment increases.

Vegetation serves to reduce nutrient concentrations by uptake, to control erosion, and to maintain or increase infiltration rates.

Considerations for vegetative selection include:

- Suitability of climate and soil conditions.
- Consumptive water use and water tolerance.
TABLE 1 DESIGN CRITERIA

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Area</td>
<td>56 to 560 acres/MGD</td>
</tr>
<tr>
<td>Application Rate</td>
<td>2 to 20 ft/yr</td>
</tr>
<tr>
<td></td>
<td>(0.5 to 4 in/wk)</td>
</tr>
<tr>
<td>BOD Loading</td>
<td>0.2 to 5 lb/acre/d</td>
</tr>
<tr>
<td>Soil Depth</td>
<td>at least 2 to 5 ft</td>
</tr>
<tr>
<td>Soil Permeability</td>
<td>0.06 to 2.0 in/hr</td>
</tr>
<tr>
<td>Lower Temperature Limit</td>
<td>25 deg F</td>
</tr>
<tr>
<td>Application Method</td>
<td>sprinkler or surface</td>
</tr>
<tr>
<td>Pretreatment Required</td>
<td>preliminary &amp; secondary</td>
</tr>
<tr>
<td>Particle Size (for sprinkler applications)</td>
<td>Solids less than 1/3 sprinkler nozzle</td>
</tr>
</tbody>
</table>


- Nutrient uptake and sensitivity to wastewater constituents.
- Economic value and marketability.
- Length of growing season.
- Ease of management.
- Public health regulations.

Design considerations for the sprinkler system include:

- Field conditions (shape, slope, vegetation, soil type).
- Climate.
- Operating conditions.
- Economics.

Design slopes should be less than 15 percent to promote infiltration rather than surface runoff.

References 1, 2, and 6 provide detailed design guidance for SR systems. For planning purposes, a rough estimate of the total land area required for an SR system can be developed using the following equations:

For warm climates and/or 12 month per year operation:

\[
A = 190(Q)
\]

Cold climates and/or 6 month per year operation:

\[
A = 280(Q)
\]

Where: \( A = \) total site area, acres

\( Q = \) design flow, MGD

These equations are valid up to a design flow of about 10 MGD, and include an allowance for a temporary storage pond or access roads. Pretreatment is not included.

**PERFORMANCE**

Performance of SR systems in reducing BOD, TSS, nitrogen, phosphorus, metals, trace organics, and pathogens is generally very good. Table 2 shows expected removals for typical pollution parameters by SR systems. Nitrogen removal occurs through vegetative uptake, biological reduction through nitrification/denitrification in soil, and ammonia volatilization.

**Limitations**

Land treatment of wastewaters by the SR process is limited by several factors, including climate, the slope of the land, and soil conditions. Wastewater application may need to be reduced during wet weather periods, creating a need for an adequate storage volume during such periods. In cold climates, frozen soil conditions may also slow application during the winter months.

**TABLE 2 EFFLUENT QUALITY**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Percent Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>90 to 99+ percent</td>
</tr>
<tr>
<td>TSS</td>
<td>90 to 99+ percent</td>
</tr>
<tr>
<td>TN</td>
<td>50 to 90 percent</td>
</tr>
<tr>
<td>TP</td>
<td>80 to 99 percent</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>99.99+ percent</td>
</tr>
</tbody>
</table>

disadvantages include high land requirements and potential odor and vector problems if adequate pretreatment is not employed. Other limitations of the SR process include:

- Crop water tolerances.
- Nutrient requirements.
- Sprinkling limitations (wind conditions, clogging of nozzles).
- May need pretreatment for solids, oil, and grease.

**OPERATION AND MAINTENANCE**

Proper operation and maintenance (O&M) is required for SR land treatment systems to perform as intended. In general, labor requirements for land treatment systems will be less than those for conventional wastewater systems. When crop harvesting is required, there will be a greater requirement for labor. Monitoring requirements can include applied wastewater, groundwater, soil, and vegetation. Vegetation grown on SR systems is usually harvested on a routine basis. Dikes and berms for ponds require regular investigation to check for burrowing animals or decay/destruction of the structure and liner material. Systems that use sprinklers should have a regular inspection and cleaning schedule, including regular draining of lines and pipes in seasonal operation to avoid corrosion. Pumps, valves, and other mechanical elements require routine maintenance, including lubrication.

**COSTS**

Capital costs for land treatment systems include (Crites, Reed, and Bastian, 2000):

- Transmission.
- Pumping.
- Preapplication treatment.
- Storage.
- Field preparation.
- Distribution.
- Recovery.
- Land.

There will be operation and maintenance costs with all of these areas except land purchase and preparation. Other O&M costs may include monitoring, site and crop management, and harvesting. Other costs may include buildings, roads, relocation of residents, and purchase of water rights.

A preliminary estimate of costs for planning purposes can be obtained using the following equations.

**Slow Rate, Sprinklers, Underdrained**

Construction costs ($) \[ C = (3.187)Q^{0.9331} \]

O & M Costs ($/yr) \[ C = (0.1120)Q^{0.8176} \]

**Slow Rate, Sprinklers, Not Underdrained**

Construction Costs ($) \[ C = (1.71)Q^{0.999} \]

O & M Costs ($/yr) \[ C = (0.205)Q^{0.5228} \]

Where: \( C \) = costs in millions of dollars

\( Q \) = design flow, MGD

These costs are valid up to about a flow of 10 MGD. Increase construction costs by about 5 percent for solid-set sprinklers; decrease construction costs by about 5 percent for center pivot sprinklers. Increase O & M by 5 percent for center pivot sprinklers; decrease by 5 percent for solid-set. Underdrain costs assume a six foot deep pipe network. A 75-day storage pond is included in these cost estimates, but pretreatment and land costs are not.
REFERENCES

Other Related Fact Sheets

Rapid Infiltration Land Treatment
EPA-832-F-02-018
September 2002

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owm/mtb/mtbfact.htm


ADDITIONAL INFORMATION

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Brown and Caldwell
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Effluent Disposal

Sherwood Reed
Environmental Engineering Consultants
50 Butternut Road
Norwich, VT 05055

The mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Office of Water
EPA 832-F-02-012
September 2002

For more information contact:

Municipal Technology Branch
U.S. EPA
ICC Building
1200 Pennsylvania Avenue, NW
7th Floor, Mail Code 4204M
Washington, D.C. 20460

2002
THE YEAR OF
CLEAN WATER
Celebration of Commitment

MTB
Excellence in compliance through optimal technical solutions
MUNICIPAL TECHNOLOGY BRANCH
Effluent Disposal
2012 Guidelines for Water Reuse

An updated authoritative reference for facilitating further development of water reuse practices

Chapter 1–Introduction
Discusses the objectives and overview of the guidelines, as well as the motivation for water reuse and the terminology.

Chapter 2–Planning and Management Considerations
The steps that should be considered in the planning stage as part of an integrated water resources plan are presented, followed by an overview of key considerations for managing reclaimed water supplies.

Chapter 3–Types of Reuse Applications
A discussion of reuse for agricultural, industrial, environmental, recreational, and potable supplies is presented, as well as an expanded discussion of indirect and direct potable reuse.

Chapter 4–State Regulatory Programs for Water Reuse
An overview of legal and institutional considerations for reuse, an updated summary of existing state standards and regulations, as well as suggested minimum guidelines for water reuse.

Chapter 5–Regional Variations in Water Reuse
Summarizes current water use in the U.S. and discusses expansion of water reuse nationally to meet water needs, and includes variations in regions. Case studies in the U.S. are also introduced.

Chapter 6–Treatment Technologies for Protecting Public and Environmental Health
Overview of the treatment objectives for reclaimed water and a discussion of the major treatment processes that are fundamental to the production of reclaimed water.

Chapter 7–Funding Water Reuse Systems
Discussion of how to develop and operate a sustainable water system using sound financial decision-making processes that are tied to the system’s strategic planning process.

Chapter 8–Public Outreach, Participation, and Consultation
Outline of strategies for informing and involving the public in water reuse system planning and reclaimed water use. New social networking tools that can be tapped to aid with this process are also discussed.

Chapter 9–Global Experiences in Water Reuse
Describes the growth of advanced reuse globally, and provides information on principles for mitigating risks, enabling factors for expanding water reuse, and new case studies that can provide informed approaches.

Background
Recognizing the need to provide national guidance on water reuse regulations and program planning, the U.S. Environmental Protection Agency (EPA) developed comprehensive, up-to-date water reuse guidelines in support of regulations and guidelines developed by states, tribes, and other authorities. The Guidelines for Water Reuse debuted in 1980, and was updated in 1992, 2004, and now 2012. Water reclamation and reuse standards in the U.S. are the responsibility of state and local agencies—there are no federal regulations for reuse.

Need for Updated Guidance
As of the publication of the updated guidelines in September 2012, 30 states and one U.S. territory have adopted water reuse regulations. In addition, 15 states have guidelines or design standards that govern water reuse. The updated guidelines serve as a national overview of the status of reuse regulations, and clarify some of the variations in the regulatory frameworks that support reuse in different states and regions across the Nation.

Document Availability
This document is available via the internet: http://www.waterreuseguidelines.org/
Section 8

Treatment Plant Administration

and Management
TREATMENT PLANT ADMINISTRATION AND MANAGEMENT

NEED FOR UTILITY MANAGEMENT
- Public or private, large or small, it’s a complex and challenging job
- Protection from environmental disasters with a minimum investment of money
- External concerns (public citizens) vs. challenges within the utility
  - Ethical and responsible decisions
  - Personnel
  - Resources
  - Equipment
  - Preparing for the future

FUNCTIONS OF A MANAGER
- Planning
- Organizing
- Staffing
- Directing
- Controlling

- In small communities, the utility manager may be the only one who has all these responsibilities

PLANNING
- One of the most important functions
- Building the resources and financial capability to provide for future needs
  - Future growth
  - Industrial development
  - Plant capacity
  - Level of treatment

- Short term and long term goals
- Should include input from: operational personnel, local officials, and the public

PLANNING (O & M)
- Operational Standpoint
- To maintain design functionality (capacity)
  - Does the system perform as designed?
- Proactive or reactive?
  1. Corrective Maintenance
  2. Preventative Maintenance
  3. Predictive Maintenance

- Proactive can be scheduled and long-term Capital Improvement Programs (CIP) planned/budgeted

PLANNING (O&M)
- Corrective Maintenance (Reactive)
  - Emergency
  - Reliance on reactive maintenance will always result in poor system performance
- 2 types of emergencies:
  1. Normal
     - Sewer blockages
     - Can be reduced by effective maintenance program
  2. Extraordinary
     - High-intensity rainstorm, floods, earthquakes
     - Can be minimized by planned maintenance program and development of comprehensive emergency response plan
PLANNING (O&M)

- Preventative Maintenance (Proactive)
  - Programmed, systematic approach
  - Will always result in improved system performance
  - Ex: lubrication of motors is frequently based on running time

- Major elements of good PM program:
  - Planning and scheduling
  - Records management
  - Spare parts management
  - Cost and Budget control
  - Emergency repair procedures
  - Training program

- Predictive Maintenance (Proactive)
  - Method of establishing baseline performance data, monitoring performance over time, observing changes so failure can be predicted
  - Goal: reduce Corrective and Emergency maintenance, thereby reducing system failures that result in stoppages and overflows

- Goal of managing maintenance: minimize investments of labor, materials, money, and equipment
  - Major capital investments
  - Reliability is critical

ORGANIZING

- Deciding who does what work and delegating authority to appropriate persons
- Utility should have a written organizational plan and written policies
  - Show who reports to whom
  - Job descriptions
- Authority = the power and resources to do a specific job or to get that job done
- Responsibility = answering to those above in the chain of command to explain how and why you used your authority
- Delegation = the act in which power is given to another person
- Accountable = employee must ensure the manager is informed of results or events

- Employees should not be asked to accept responsibilities beyond their level of authority
- Authority and responsibility must be delegated properly to be effective

- 3 components present = successful delegation
  1. Proper job assignments
  2. Authority
  3. Responsibility

- Follow-up is important
STAFFING
- Should have established procedures for:
  - Hiring
  - Analyzing staffing needs
  - Qualifications profile, Advertising, Interviewing
  - Training
  - New employee and ongoing
  - Safety is extremely important, but not sole benefit
    - Protection of public’s investment
    - Employee pride and recognition
    - Certification
    - Supervisor training
  - Evaluating job performance
  - Written evaluation strongly recommended for documentation
  - Set goals

COMMUNICATION
- Both written and oral communication skills are needed to effectively organize and direct the operation of wastewater plant
- 2 part process:
  - Info must be given
  - Info must be understood (good listening skills)
- Communicating with employees, your governing body, and the public
  - Annual report
    - One of the most involved writing projects
    - Review of what and how the utility operated the past year
    - Include goals for next year

COMMUNICATION
- Conducting Meetings
- Public Relations
  - Utility Operations
    - Public image
    - Open communication
  - Mass Media
  - Being Interviewed
  - Public Speaking
  - Consumer Inquiries
    - Customer calls are frequently your first indication that something may be wrong
    - Education can be a valuable tool
    - Franklin videos: flushable wipes, grease
  - Plant Tours

FINANCIAL MANAGEMENT
- Budgeting is perhaps the most challenging task for many managers
- Must understand how the money was spent over the last year, the needs of the utility, and how the needs should be prioritized
- Must have a Repair/Replacement Fund
- Wastewater treatment rates
- Capital Investments and funding in the future
- Financial Assistance

SAFETY
- Regardless of size, utility must have a safety program
  - Basic elements include: safety policy statement, safety training and promotion, accident investigation and reporting
- Regulatory agencies
  - OSHA (TOSHA)
- First Aid
- Hazard Communication/Right To Know Laws
  - 29 CFR 1910.1200
  - SDS
- Confined Space Entry Procedures
- Reporting
- Training

SECURITY MEASURES
- Investing in security and infrastructure improvements
- Security of critical wastewater infrastructure
  - Sanitary and Storm sewers is one of America’s most valuable resources
- Vulnerabilities include:
  - Pumping and Lift Stations
  - Manholes
  - Chemical and fuel storage areas
  - Outfall pipes
ETHICS

- Performing illegal acts is always unethical. However, unethical acts are not always illegal.
- What is ethics?
  - Moral principles and rules of conduct
  - The point of ethics is to benefit people
  - Correct ethical actions are those that one does out of consideration for others
  - How people ought to treat each other
  - Ethical concepts are based on the assumption that everyone acts with consideration of all
  - Everyone benefits when we act ethically towards others

Examples of illegal and unethical activities:
- Providing false information on an application for a job or certification exam
- Cheating on your certification exam
- Copying certification exam questions
- Dry-labbing (writing down results without actually performing the test)
- Falsifying results and reports
- Intentionally discharging toxic wastes to receiving waters
- Harassing other employees
- Requiring operators to use unsafe equipment, work under unsafe conditions, or occupy confined space with an unsafe atmosphere

Ask yourself: “Would I be uncomfortable with my actions if they were reported in the newspaper?”

Other areas where operators will encounter ethical situations:
- Collecting samples
- Preparation of reports
- Sabotaging someone else’s work
- Recommending a vendor or consulting engineer
- Employee performance evaluations
- Cheating on an exam

Whistleblowing = the act of reporting illegal activity to an authority

Codes of Ethics
- Trustworthiness
- Respect
- Responsibility
- Caring
- Justice
- Civic virtue and citizenship
- Interactions between operators and the public
- Interactions among operators
- Approved professional conduct
- Service by operators to protect the public and the environment

An operator’s certificate may be revoked when:
- Operator has not used reasonable care, judgement, or application of his/her knowledge in performance of their duties
- Intentional or negligent
- Operator is incompetent to perform those duties
- Operator has practiced fraud or deception
- Obtained certificate through fraud, deceit, or submission of inaccurate data regarding qualifications
- False, inaccurate data on reports or lab analysis
Any Questions?
Administration and Management Vocabulary

1. __________________ is the power and resources to do a specific job or to get that job done.
2. The act of __________________ is defined as deciding who does what work and delegating authority to the appropriate persons.
3. Answering to those above in the chain of command to explain how and why you have used your authority is defined as __________________.
4. A __________________________ is a brief (10-20 minutes) safety meeting held every 7 – 10 working days.
5. Moral principles and rules of conduct define the concept of __________________. An operator’s certification may be revoked if they do not act with this concept in mind.
6. When a manager gives power/responsibility to an employee, and the employee ensures that the manager is informed of results or events, that employee is demonstrating ____________________.
7. ____________________________ is the act in which power is given to another person in the organization to accomplish a specific job.
8. ____________________________ maintenance is proactive and is defined as a programmed, systematic approach to maintenance activities.
9. The nation’s ____________________________ provides the essential services that underpin American society and serve as the backbone of our nation’s economy, security, and health. This includes the Water and Wastewater Systems Sector, which includes water distribution and sewage collection systems.
10. Identifying system components, estimating disaster effects on those components, estimating customer demand for service following a disaster, and identifying key system components that would be primarily responsible for a system failure are all key steps that should be taken when conducting a __________________ analysis.
11. The act of reporting illegal activity to an authority is called ____________________.
12. ____________________________ maintenance is a method of establishing baseline performance data, monitoring performance criteria over a period of time, and observing changes in performance so that failure can be predicted and maintenance can be performed on a planned, scheduled basis.

Word Bank:

Accountability
Organizing
Preventative
Whistleblowing
Critical Infrastructure
Predictive

Ethics
Accountability
Responsibility
Tailgate Safety Meeting
Authority
Vulnerability
Review Questions – Administration and Management

1. Utility Management is a complex and challenging job because, in part, it involves protecting the town from environmental disasters with a minimum investment of money.
   a. True
   b. False

2. Planning involves building the resources and financial capability to provide for future needs, therefore it only incorporates long term goals.
   a. True
   b. False

3. Proper planning should include input from whom?
   a. Operational personnel
   b. Local officials
   c. Public
   d. All of the above

4. Which of the following types of maintenance are considered proactive?
   a. Corrective
   b. Preventative
   c. Predictive
   d. All of the above
   e. Both b. and c.

5. Sewer blockages are an example of an “extraordinary” type of emergency.
   a. True
   b. False

6. Emergency Response Plans (also called Emergency Operating Plans) involve coordinating and communicating with local agencies to assess vulnerabilities and provide for a recovery operation in the case of a natural or human disaster.
   a. True
   b. False

7. Consumer inquiries are often an operator’s first indication that something may be wrong in your collection system.
   a. True
   b. False

8. Safety is the sole benefit to employee training.
   a. True
   b. False
9. Which of the following would be the most challenging and important managerial consideration for successfully managing a wastewater plant?
   a. Budgeting
   b. Public relations
   c. Annual report
   d. Preventative Maintenance Plan

10. The security of America’s critical wastewater infrastructure is extremely important, and includes both sanitary and storm sewers.
   a. True
   b. False

11. Pumping and Lift Stations and Manholes would be considered “vulnerabilities” in a security risk assessment.
   a. True
   b. False

12. Moral principles and rules of conduct could be used to best describe what trait that operators must demonstrate?
   a. Determination
   b. Self-reliancy
   c. Ethics
   d. Considerate

13. Which of the following is not an example of an illegal and unethical activity that operators could encounter in their daily jobs?
   a. Dry-labbing
   b. Intentionally discharging toxic wastes to the receiving stream
   c. Harassing other employees
   d. Arriving 15 minutes late to work
   e. Requiring a subordinate to enter an unsafe confined space

14. Cheating on your certification exam is an example of unethical behavior.
   a. True
   b. False

15. An operator’s certificate may be revoked if the operator is found to have written false or inaccurate data on a report or lab analysis.
   a. True
   b. False
Section 9

Pumps and Equipment

Maintenance
WASTEWATER PUMPS AND EQUIPMENT MAINTENANCE

Types of Pumps
• Classified by character of material handled:
  - Raw wastewater
  - Grit
  - Sludge
  - Effluent

General Considerations
• Centrifugal pumps: wastewater
• Piston or diaphragm pumps: heavy solids
• Gear and piston pumps: high pressures
• Turbine or propeller pumps: mixing air or chemicals

Types of Pumps
• Positive-Displacement Pumps
  • Metering pumps – sometimes used to feed chemicals
  • Piston pump
  • Screw pump
• Velocity Pumps
  • Vertical turbine
  • Centrifugal
  • Most common type in wastewater lift stations

Positive-Displacement Pumps
• Sludge & chemical feed pumps
• Less efficient than centrifugal pumps
• Cannot operate against a closed discharge valve

Positive-Displacement Pumps
• Reciprocating (piston) pump - piston moves back and forth in cylinder, liquid enters and leaves through check valves
Positive-Displacement Pumps

- Rotary pump - Use lobes or gears to move liquid through pump

Screw Pumps

- Screw pumps are used to lift wastewater to a higher elevation
- This pump consists of a screw operating at a constant speed within a housing or trough
- The screw has a pitch and is set at a specific angle
- When revolving, it carries wastewater up the trough to a discharge point

Incline screw pumps handle large solids without plugging

Velocity Pumps

- Spinning impeller or propeller accelerates water to high velocity in pump casing (or volute)
- High velocity, low pressure water is converted to low velocity, high pressure water

Vertical Wet Well Pumps

- Has a vertical shaft, diffuser-type centrifugal pump with the pumping element suspended from the discharge piping.
- The needs of a given installation determines the length of discharge column
- The pumping bowl assembly may connect directly to the discharge head for shallow sumps, or may be suspended several hundred feet for raising water from wells
- Vertical turbine pumps are used to pump water from deep wells and may be of the single-stage or multistage type

Velocity Pump Design Characteristics

- Axial - flow designs
  - Propeller shaped impeller adds head by lifting action on vanes
  - Water moves parallel to pump instead of being thrown outward
  - High volume, but limited head
  - Not self-priming

Velocity Pump Design Characteristics

- Radial flow designs
  - Water comes in through center (eye) of impeller
  - Water thrown outward from impeller to diffusers that convert velocity to pressure
  - The discharge is perpendicular to the pump shaft
Velocity Pump Design Characteristics

- Mixed-flow designs
- Has features of axial and radial flow
- Works well for water with solids

Centrifugal Pump

- Basically a very simple device: an impeller rotating in a casing
- The impeller is supported on a shaft, which in turn, is supported by bearings
- Liquid coming in at the center (eye) of the impeller is picked up by the vanes and by the rotation of the impeller and then is thrown out by centrifugal force into the discharge

Most Common Centrifugal Pumps

- Horizontal non-clog type
- Vertical ball bearing type
- Propeller type

Advantages of Centrifugal Pumps

- Wide range of capacities
- Uniform flow at a constant speed and head
- Low cost
- Ability to be adapted to various types of drivers
- Moderate to high efficiency
- No need for internal lubrication

Disadvantages of Centrifugal Pumps

- Efficiency is limited to very narrow ranges of flow and head
- Flow capacity greatly depends on discharge pressure
- Generally no self-priming ability
- Can run backwards if check valve fails and sticks open
- Potential impeller damage if pumping abrasive water

Let’s Build a Centrifugal Pump

- First we need a device to spin liquid at high speeds – an impeller
  - This is the heart of our pump
- As the impeller spins, liquid between the blades is impelled outward by centrifugal force
- As liquid in the impeller moves outward, it will suck more liquid behind it through this eye, provided it is not clogged.
  - If there is any danger that foreign material may be sucked into the pump, clogging or wearing of the impeller unduly, provide the intake end of the suction piping with a suitable screen
Impeller

- Bronze or stainless steel
- Closed; some single-suction have semi-open; open designs
- Inspect regularly
- As the impeller wears on a pump, the pump efficiency will decrease

Let’s Build a Centrifugal Pump

- Now we need a shaft to support and turn the impeller
  - It must maintain the impeller in precisely the right place
  - But that ruggedness does not protect the shaft from the corrosive or abrasive effects of the liquid pumped, so we must protect it with sleeves slid on from either end.

Shaft and Sleeves

- Shaft
  - Connects impeller to pump; steel or stainless steel
  - Should be repaired/replaced if grooves or scores appear on the shaft
- Shaft Sleeves
  - Protect shaft from wear from packing rings
  - Generally they are bronze, but various other alloys, ceramics, glass or even rubber-coating are sometimes required.

Let’s Build a Centrifugal Pump

- We mount the shaft on sleeve, ball or roller bearings
  - If bearings supporting the turning shaft and impeller are allowed to wear excessively and lower the turning units within a pump’s closely fitted mechanism, the life and efficiency of that pump will be seriously threatened.
  - 2 types: Oil-lubricated, Grease lubricated
  - Keep the right amount of the right lubricant in bearings at all times.

Bearings

- Anti-friction devices for supporting and guiding pump and motor shafts
- Get noisy as they wear out
- If pump bearings are over lubricated, the bearings will overheat and can be damaged or fail
  - Tiny indentations high on the shoulder of a bearing or race is called brinelling
  - When greasing a bearing on an electric motor, the relief plug should be removed and replaced after the motor has run for a few minutes. This prevents you from damaging the seals of the bearing.
- Types: ball, roller, sleeve

Bearings

- Inspect and lubricate bearings-grease
  - If possible, remove bearing cover and visually inspect grease.
  - When greasing, remove relief plug and cautiously add 5 or 6 strokes of the grease gun.
  - Afterward, check bearing temperature with thermometer.
  - If over 220°F (104°C), remove some grease.
Let's Build a Centrifugal Pump

To connect with the motor, we add a coupling flange.

- Our pump is driven by a separate motor, and we attach a flange to one end of the shaft through which bolts will connect with the motor flange.
- If shafts are met at an angle, every rotation throws tremendous extra load on bearings of both pump and the motor.
- Flexible couplings will not correct this condition if excessive.

Common Pump & Motor Connections

- Direct coupling
- Angle drive
- Belt or chain
- Flexible coupling
- Close-coupled

Couplings

- Connect pump and motor shafts
- Lubricated require greasing at 6 month intervals
- Dry has rubber or elastomeric membrane
- Calipers and thickness gauges can be used to check alignment on flexible couplings

Misalignment of Pump & Motor

- Excessive bearing loading
- Shaft bending
- Premature bearing failure
- Shaft damage
- Checking alignment should be a regular procedure in pump maintenance.
  - Foundations can settle unevenly
  - Piping can change pump position
  - Bolts can loosen
  - Misalignment is a major cause of pump and coupling wear.

Let's Build a Centrifugal Pump

- Now we need a “straw” through which liquid can be sucked.
- Insure that the pipe does not put strain on the pump’s casing.
- The horizontal pipe slopes upward toward the pump so that air pockets won’t be drawn into the pump and cause loss of suction.

Let's Build a Centrifugal Pump

- We contain and direct the spinning liquid with a casing.
- Housing surrounding the impeller; also called the volute.
- Designed to minimize friction loss as water is thrown outward from impeller.
- Usually made of cast iron, spiral shape.

See that piping puts absolutely no strain on the pump casing.
Let’s Build a Centrifugal Pump

• Now our pump is almost complete, but it would leak like a sieve
  • As water is drawn into the spinning impeller, centrifugal force causes it to flow outward, building up high pressure at the outside of the pump (which will force water out) and creating low pressure at the center of the pump (which will draw water in)
  • Water tends to be drawn back from pressure to suction through the space between the impeller and casing – this needs to be plugged

• So we add wearing rings (aka wear rings) to plug internal liquid leakage
  • Restrict flow between impeller discharge and suction
  • Leakage reduces pump efficiency
  • Installed to protect the impeller and pump casing from excessive wear
  • Provides a replaceable wearing surface
  • Inspect regularly

Let’s Build a Centrifugal Pump

• To keep air from being drawn in, we use stuffing boxes
  • We have two good reasons for wanting to keep air out of our pump
    • We want to pump water, not air
    • Air leakage is apt to cause our pump to lose suction
  • Each stuffing box we use consists of a casing, rings of packing and a gland at the outside end
    • A mechanical seal may be used instead

Stuffing Box

• Parts include:
  • Packing
  • Lantern ring
  • Gland follower

Lantern Rings aka Seal Cages

• Perforated ring placed in stuffing box
• A spacer ring in the stuffing box that forms seal around shaft, helps keep air from entering the pump and lubricates packing

Packing vs. Mechanical Seals

• If a pump has packing, water should drip slowly
• If it has a mechanical seal, no leakage should occur
Packing Rings
• Provides a seal where the shaft passes through the pump casing in order to keep air from being drawn or sucked into the pump and/or the water being pumped from coming out.

![Graphite Seal Ring]

Packing Rings
• If new packing leaks, stop the motor and repack the pump.
• Pumps need new packing when the gland or follower is pulled all the way down.
• The packing around the shaft should be tightened slowly, over a period of several hours to just enough to allow an occasional drop of liquid (20-60 drops per minute is desired).
• Leakage acts as a lubricant.
• Stagger joints 180º if only 2 rings are in stuffing box, space at 120º for 3 rings or 90º if 4 rings or more are in set.

Packing Rings vs. Mechanical Seal
• Advantages
  • Less expensive, short term
  • Can accommodate some looseness

• Disadvantages
  • Increased wear on shaft or shaft sleeve
  • Increased labor required for adjustment and replacement

Mechanical Seals
• Located in stuffing box
• Prevents water from leaking along shaft; keeps air out of pump
• Should not leak
• Consists of a rotating ring and stationary element
• The operating temperature on a mechanical seal should never exceed 160°F (71°C)
• Mechanical seals are always flushed in some manner to lubricate the seal faces and minimize wear
• The flushing water pressure in a water-lubricated wastewater pump should be 3-5 psi higher than the pump discharge pressure.

Mechanical Seal vs. Packing Rings
• Advantages
  • Last 3-4 years, which can be a savings in labor
  • Usually there is no damage to shaft sleeve
  • Continual adjusting, cleaning or repacking is not required
  • Possibility of flooding lift station because a pump has thrown its packing is eliminated; however mechanical seals can fail and lift stations can be flooded

• Disadvantages
  • High initial cost
  • Great skill and care needed to replace
  • When they fail, the pump must be shut down
  • Pump must be dismantled to repair
Centrifugal Pump Operation

- Pump Starting:
  - Impeller must be submerged for a pump to start
  - Should never be run empty, except momentarily, because parts lubricated by water would be damaged
  - **Foot valve helps hold prime**
  - Discharge valve should open slowly to control water hammer
  - In small pumps, a check valve closes immediately when pump stops to prevent flow reversal
  - In large pumps, discharge valve may close before pump stops

Centrifugal Pump Operation

- Pump shut down for extended period of time:
  - Close the valve in the suction line
  - Close the valve in the discharge line
  - Drain the pump casing

Flow Control

- Flow usually controlled by starting and stopping pumps
- Throttling flow should be avoided - wastes energy
- Variable speed drives or motor are best way to vary flow
- Variable speed pumping equipment can be adjusted to match the inflow rate

Monitoring Operational Variables

- Pump and motor should be tested and complete test results recorded as a baseline for the measurement of performance within the first 30 days of operation
Monitoring Operational Variables

• Suction and Discharge Heads
  • Pressure gauges
• Bearing and Motor Temperature
  • Temp indicators can shut down pump if temp gets too high
  • Check temp of pump by feel

Monitoring Operational Variables

• Vibration
  • Detectors can sense malfunctions causing excess vibration
  • Operators can learn to distinguish between normal and abnormal sounds

Monitoring Operational Variables

• Likely causes of vibration
  • Bad bearings or bearing failure
  • Imbalance of rotating elements, damage to impeller
  • Misalignment from shifts in underlying foundation
  • Improper motor to pump alignment

Monitoring Operational Variables

• Speed
  • Cavitation can occur at low and high speeds
  • Creation of vapor bubbles due to partial vacuum created by incomplete filling of the pump

Inspection and Maintenance

• Inspection and maintenance prolongs life of pumps
• Checking operating temperature of bearings
• Checking packing glands
• Operating two or more pumps of the same size alternatively to equalize wear
• Check parallel and angular alignment of the coupling on the pump and motor
  • A feeler gauge, dial indicator calipers are tools that can be used to check proper alignment
• Necessary for warranty
• Keep records of all maintenance on each pump
• Keep log of operating hours

Cavitation is a noise coming from a centrifugal pump that sounds like marbles trapped in the volute
A condition where small bubbles of vapor form and explode against the impeller, causing a ping sound
Best method to prevent it from occurring is to reduce the suction lift
Inspection: Impellers

- Wear on impeller and volute
- Cavitation marks
- Chips, broken tips, corrosion, unusual wear
- Tightness on shaft
- Clearances
- Tears or bubbles (if rubber coated)

Pump Won’t Start?

- Incorrect power supply
- No power supply
- Incorrectly connected
- Fuse out, loose or open connection
- Rotating parts of motor jammed mechanically
- Internal circuitry open

Pump Safety

- Machinery should always be turned off and locked out/tagged out before any work is performed on it
- Make sure all moving parts are free to move and all guards in place before restarting
- Machinery creating excessive noise shall be equipped with mufflers.

Pump Safety: Wet Wells

- Confined spaces
- Corrosion of ladder rungs
- Explosive atmospheres
- Hydrogen sulfide accumulation
- Slippery surfaces

Pump Facts

- Sewer pumps used in a lift station shall be capable of passing at least a 3 inch diameter sphere
- Pump suction and discharge opening shall be no less 4 inches in diameter
- Each pump must have its own intake line
- Wet wells should be designed to avoid turbulence near the intakes
- The velocity in the suction line of a pump should not exceed 6 fps
- The velocity in the discharge line of a pump should not exceed 8 fps

Pump Facts

- Ventilation in wet wells shall provide for at least 12 complete air changes per hour if continuous and 30 changes per hour if intermittent
- Ventilation in dry wells shall provide for at least 6 complete air changes per hour if continuous and 30 changes per hour if intermittent
Pump Facts

• The maximum recommended suction lift for a pump in a pumping station is 15 feet
• Minimum force main size is 4 inches
• A gasoline powered centrifugal pump in good condition can lift water (suction lift) up to 18 inches of mercury
  • 20 feet of possible suction lift
• Head is the amount of energy possessed by water at any point in a hydraulic system
  • Feet divided by 2.31 equals psi (pounds per square inch) in head

Types of Pumps Found in Collection Systems

• Incline screw pump
• Centrifugal
• Pneumatic ejectors
• Piston
• Close-coupled
• Submersible
• Progress cavity
• Flexible stator and rotor

Beware of Electricity

• Be careful around electrical panels, circuits, wiring, & equipment
  • Serious injury
  • Damage costly equipment
  • Basic working knowledge is key

Tools, Meters & Testers

• Ammeter: records the current or amps in circuit
  • Most are clamp on type
• Megger: checks insulation resistance on motors, feeders, grounds, and branch circuit wiring
  • Motors should be megged at least once a year
• Ohmmeter: measures resistance in a circuit.
  • An ohmmeter is used only when the electric circuit is off or de-energized
  • Tests fuses, relays, resistors and switches.
• Multimeter: checks for voltage
  • By holding one lead on ground and the other on a power lead, you can determine if power is available
  • You can also tell if it is AC or DC and the intensity or voltage (110, 220, 480 or whatever) by testing the different leads
Need for Maintenance

- Performance and life of pumps and other equipment affected by:
  - Water
  - Dust
  - Humidity
  - Heat and cold
  - Vibration
  - Corrosive atmosphere

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Electrical Protective Devices: Fuses

- Protect control panel from excess voltage or amperage
- Fusible metal strip melts and breaks circuit
- One-time use devices
  - Should never be jumped or bypassed
  - When removing any fuse, a fuse puller should be used

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Transformer

- Allows energy to be transferred in an AC system for one circuit to another
- Used to convert high voltage to low voltage
  - High voltage is 440 volts or higher
- Standby engines should be run weekly to ensure that it is working properly
- Relays are used to protect electric motors

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Electrical Protective Devices: Circuit Breaker

- Protect electrical systems from short circuiting
- Switch opens when current or voltage out of range
- Unlike fuse, can be reset

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Need for Maintenance

- Inspect & maintain electrical equipment annually.
- Inspection should include:
  - Thorough examination
  - Replacement of worn & expendable parts
  - Operational checks & tests
  - Fuses and circuit breakers are protective devices used to protect operators, main circuits, branch circuits, heater, motors and various other electrical equipment.
**D.C. versus A.C.**

- Direct current (D.C.) is flowing in one direction only and is essentially free from pulsation.
- DC is seldom used in lift stations and wastewater treatment plants except in motor-generated sets, some control components of pump drives and standby lighting.
- DC is used exclusively in automotive equipment, certain types of welding equipment, and a variety of portable equipment.
- All batteries are DC.
- Alternating current (A.C.) is periodic current that has alternating positive and negative values.
  - AC are classified as:
    - Single phase
    - Two phase
    - Three phase or polyphase

**Batteries**

- An electric battery is a device for the transformation of chemical energy into electric energy.
- A primary battery is a battery that the chemical action is irreversible, like a flashlight battery.
- A storage battery is one that the chemical action is almost completely reversible, like a car battery.
- The most common battery is the lead-acid type.
- Another common type of battery is the nickel-cadmium type.

**A.C. Induction Motor**

- Most common pump driver in wastewater pump stations.
- Motors pull the most current on start up.
- Malfunction due to:
  - Thermal overload (40°C max.)
  - Contaminants
  - Single phasing
  - Old age
  - Rotor failure

**Single-phase vs Three-phase**

- Single-phase power is found in lighting systems, small pump motors, variable portable tools and throughout our homes.
  - It is usually 120 volts or 240 volts.
  - Single phase means only one phase of power is supplied to the main electrical panel at 240 volts and the power supply has three wires or leads.
    - 2 of these leads have 120 volts each, the other lead is neutral and usually coded white, which is grounded.
  - Three-phase power is generally used with motors and transformers found in lift stations and wastewater treatment plants.
  - Generally all motors above 2 horsepower are three-phase.

**Motor Components**

- In order to prevent damage, turn the circuit off immediately if the fuse on one of the legs of a three-phase circuit blows.
- An electric motor changes electrical energy into mechanical energy.
- Power factors can be improved by:
  - Changing motor loading
  - Changing the motor type
  - Using capacitors.
  - Also referred to as a condenser and it will also store electricity when it is charged.
Motors
• Routine cleaning of pump motors includes:
  • Checking alignment and balance
  • Checking brushes
  • Removing dirt and moisture
  • Removal of obstructions that prevent air circulation
  • Cool air extends the useful life of motors
  • A motor (electrical or internal combustion) used to drive a pump is called a prime mover
  • The speed at which the magnetic field rotates is called the motor synchronous speed and is expressed in rpm

Motors
• If a variable speed belt drive is not used for 30 days or more, shift the unit to minimum speed setting
• Emory cloth should not be used on electric motor components because it is electronically conductive and may contaminate parts
• Ohmmeters used to test a fuse in a motor starter circuit
• The most likely cause of a three-phase motor not coming to speed after starting – the motor has lost power to one or more phases

Compressors
• Increase the pressure of air or gas
• Common uses:
  • Wastewater ejectors
  • Pump control systems (bubblers)
  • Water pressure systems
  • Portable pneumatic tools

Compressors
• Inspect suction filter at least monthly
• Daily in dusty areas such as construction zones
• Inspect safety valves weekly
• Lubrication
  ◦ Oil bearings
  ◦ Oil cup, grease fittings, crankcase reservoir
  ◦ Change oil every 3 months (unless otherwise specified)
• Inspect belt tension
• Clean dirt, oil & grease at least monthly
• Drain condensate daily using valve on air receiver
• Examine operating controls

Valves
• Controlling device in piping systems to stop, regulate, check, or divert flow of liquids or gases
• Types of valves found in a pumping station
  • Butterfly – used on suction and discharge
  • Gate – used on suction and discharge
  • Plug – used on suction and discharge
  • Swing or ball check – used on discharge
  • Knife – used on suction and discharge
  • Wafer – used on discharge

Valves
• Gate valve:
  ◦ Open valve fully; reverse & close one-half turn
  ◦ Operate all large valves at least yearly
  ◦ Inspect valve stem packing for leaks; tighten if needed
  ◦ Close valves slowly in pressure lines to prevent water hammer
Valves

- Check valves: discharge of pump to provide positive shut off from force main pressure & prevent force main from draining back into wet well

Check Valve

Valves

- Butterfly valves: often clog on sewer lines when installed to carry stormwater or wastewater
- Plug valves: less susceptible to plugging; sludge pumping

Lubrication

- Purposes:
  - Reduce friction between two surfaces
  - Remove heat due to friction
  - Oils in service becomes acidic & may cause corrosion, deposits, sludging, etc.
- Oils & greases:
  - Can create fire hazard
  - Clean up spills immediately
  - Don’t contaminate

Building Maintenance

- Only one person should be in charge on any maintenance program.
- Keep facility clean, store tools in proper place
- Type of maintenance needed influenced by age, type & use of building
- Maintenance program includes:
  - Floors & roofs
  - Heating, cooling & ventilation
  - Lighting
  - Plumbing
  - Windows

Bearings

- Screw pumps are supported by 2 bearings, a ball or roller bearing above the flights & a sleeve bearing in the WW

Bearings

- Usually last for years if serviced properly
- Failures:
  - Fatigue – excessive load
  - Contamination
  - Brinelling – improper mounting
  - Electric arching – leakage; short circuiting
  - Misalignment
  - Cam failure
  - Lubrication failure – dirty; too much; not enough; wrong kind

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Pump Vocabulary Words

1. **Amperage** – the strength of an electric current measured in amperes.
2. **Axial-Flow Pump** – a pump in which a propeller-like impeller forces water out in the direction parallel to the shaft. Also called a propeller pump.
3. **Bearing** – anti-friction device used to support and guide a pump and motor shafts.
4. **Brinelling** – The tiny indentations that occur high on the shoulder of the bearing race or bearing. A type of bearing failure.
5. **Casing** – the enclosure surrounding a pump impeller, into which the suction and discharge ports are machined.
6. **Cavitation** – a condition that can occur when pumps are run too fast or water is forced to change direction quickly. A partial vacuum forms near the pipe wall or impeller blade causing potentially rapid pitting of the metal.
7. **Centrifugal Pumps** – a pump consisting of an impeller on a rotating shaft enclosed by a casing having suction and discharge connections. The spinning impeller throws water outward at high velocity, and the casing shape converts this velocity to pressure.
8. **Circuit** – the complete path of an electric current, including the generating apparatus or other source; or a specific segment or section of the complete path.
9. **Circuit Breaker** – a safety device in an electric circuit that automatically shuts off the circuit when it becomes overloaded.
10. **Closed-Coupled Pump** – a pump assembly where the impeller is mounted on the shaft of the motor that drives the pump.
11. **Current** – The movement or flow of electricity.
12. **Diffuser Vanes** – vanes installed within a pump casing on diffuser centrifugal pumps to change velocity head to pressure head.
13. **Double-Suction Pump** – a centrifugal pump in which the water enters from both sides of the impeller. Also called a split-case pump.
14. **Foot Valve** – a check valve placed in the bottom of the suction pipe of a pump, which opens to allow water to enter the suction pipe but closes to prevent water from passing out of it at the bottom end. Keeps prime.
15. **Frame-Mounted Pump** – a centrifugal pump in which the pump shaft is connected to the motor shaft with a coupling.
16. **Fuse** – a protective device having a strip or wire of fusible metal that, when placed in a circuit, will melt and break the electric circuit if heated too much.
17. **Impeller** – the rotating set of vanes that forces water through the pump.
18. **Jet Pump** – a device that pumps fluid by converting the energy of a high-pressure fluid into that of a high-velocity fluid.
19. **Jogging** – the frequent starting and stopping of an electric motor.
20. **Lantern Ring** – a perforated ring placed around the pump shaft in the stuffing box. Water from the pump discharge is piped to this ring. The water forms a liquid seal around the shaft and lubricates the packing.
21. **Mechanical Seal** – a seal placed on the pump shaft to prevent water from leaking from the pump along the shaft; the seal also prevents air from entering the pump.
22. **Megger** – an instrument used for checking the insulation resistance on motors, feeders, bus bar systems, grounds, and branch circuit wiring.
23. **Mixed-Flow Pump** – a pump that imparts both radial and axial flow to the water.
24. **Packing** – rings of graphite-impregnated cotton, flax, or synthetic materials, used to control leakage along a valve stem or a pump shaft.
25. **Packing Gland** – a follower ring that compressed the packing in the stuffing box.
26. **Positive Displacement Pump** – a pump that delivers a precise volume of liquid for each stroke of the piston or rotation of the shaft.

27. **Prime Mover** – a source of power, such as an internal combustion engine or an electric motor, designed to supply force and motion to drive machinery, such as a pump.

28. **Radial-Flow Pump** – a pump that moves water by centrifugal force, spinning the water radially outward from the center of the impeller.

29. **Reciprocating Pump** – a type of positive-displacement pump consisting of a closed cylinder containing a piston or plunger to draw liquid into the cylinder through an inlet valve and forces it out through an outlet valve.

30. **Resistance** – the property of a conductor or wire that opposes the passage of a current, thus causing electrical energy to be transformed into heat.

31. **Rotary Pump** – a type of positive-displacement pump consisting of elements resembling gears that rotate in a close-fitting pump case. The rotation of these elements alternately draws in and discharges the water being pumped.

32. **Single-Suction Pump** – a centrifugal pump in which the water enters from only one side of the impeller. Also called an end-suction pump.

33. **Stuffing Box** – a portion of the pump casing through which the shaft extends and in which packing or a mechanical seal is placed to prevent leakage.

34. **Submersible Pump** – a vertical-turbine pump with the motor placed below the impellers. The motor is designed to be submersed in water.

35. **Suction Lift** – the condition existing when the source of water supply is below the centerline of the pump.

36. **Velocity Pump** – the general class of pumps that use a rapidly turning impeller to impart kinetic energy or velocity to fluids. The pump casing then converts this velocity head, in part, to pressure head. Also known as kinetic pumps.

37. **Vertical Turbine Pump** – a centrifugal pump, commonly of the multistage, diffuser type, in which the pump shaft is mounted vertically.

38. **Voltage** – the electrical pressure available to cause a flow of current (amperage) when an electric circuit is closed.

39. **Volute** – the expanding section of pump casing (in a volute centrifugal pump), which converts velocity head to pressure head.

40. **Water Hammer** – the potentially damaging slam that occurs in a pipe when a sudden change in water velocity (usually as a result of too-rapidly starting a pump or operating a valve) creates a great increase in water pressure.

41. **Wear Rings** – rings made of brass or bronze placed on the impeller and/or casing of a centrifugal pump to control the amount of water that is allowed to leak from the discharge to the suction side of the pump.
**Pumps, Motors, and Equipment Maintenance Vocabulary**

1. A _______________________ is a safety device in an electric circuit that automatically shuts off the circuit when it becomes overloaded. The device can be manually reset.
2. _____________________ describes the tiny indentations (dents) that occur high on the shoulder of the bearing race or bearing. A type of bearing failure.
3. A ___________________ is a protective device having a strip or wire of fusible metal that, when placed in a circuit, will melt and break the electric circuit if heated too much. High temperatures will develop in the fuse when a current flows through the fuse in excess of that which the circuit will carry safely.
4. The formation and collapse of a gas pocket or bubble on the blade of an impeller or the gate of a valve is known as ___________________. The collapse of this gas pocket or bubble drives water into the impeller or gate with a terrific force that can cause pitting on the impeller or gate surface. This is accompanied by loud noises that sound like someone is pounding on the impeller or gate with a hammer.
5. ________________ is the electrical pressure available to cause a flow of current (amperage) when an electric circuit is closed.
6. The frequent starting and stopping of an electric motor is called ________________.
7. The term________________ describes the movement or flow of electricity.
8. A ________________ is an instrument used for checking the insulation resistance on motors, feeders, bus bar systems, grounds, and branch circuit wiring.
9. ________________ is the strength of an electric current measured in amperes. The amount of electric current flow, similar to the flow of water in gallons per minute.
10. ________________ is that property of a conductor or wire that opposes the passage of a current, thus causing electrical energy to be transformed into heat.
11. A ________________ is the complete path of an electric current, including the generating apparatus or other source; or a specific segment or section of the complete path.
12. A ________________ is an anti-friction device that is used to support and guide a pump and motor shaft.
13. The________________________ is a check valve placed in the bottom of the suction pipe of a pump, which opens to allow water to enter the suction pipe, but closes to prevent water from passing out of it at the bottom end. It keeps the prime.
14. The rotating set of vanes that force water through the pump are known as the ________________.
15. The ________________ is a perforated ring placed around the pump shaft in the stuffing box. Water from the pump discharge is piped to this ring. The water forms a liquid seal around the shaft and lubricates the packing.
16. A ________________ seal is placed on the pump shaft to prevent water from leaking from the pump along the shaft; the seal also prevents air from entering the pump.
17. Rings of graphite-impregnated cotton, flax, or synthetic materials that are used to control leakage along a valve stem or a pump shaft are called _____________________.
18. A _______________________ pump consists of an impeller on a rotating shaft enclosed by a casing having suction and discharge connections. The spinning impeller throws water outward at a high velocity, and the casing shape converts this velocity into pressure.
19. The expanding section of a pump casing which converts velocity head to pressure head is the ________________.

20. A ______________________________ pump delivers a precise volume of liquid with each stroke of the piston or rotation of the shaft.

21. The term _____________________________ describes the potentially damaging slam that occurs in a pipe when a sudden change in water velocity (usually the result of too-rapidly starting a pump or operating a valve) creates a great increase in water pressure.

22. _______________ rings are made of brass or bronze and placed on the impeller and/or casing of a centrifugal pump to control the amount of water that is allowed to leak from the discharge to the suction side of the pump.

**Word Bank**

- Amperage
- Brinelling
- Bearing
- Cavitation
- Centrifugal
- Circuit
- Circuit Breaker
- Current
- Foot Valve
- Fuse
- Impeller
- Jogging
- Lantern Ring
- Mechanical
- Megger
- Packing
- Positive Displacement
- Resistance
- Velocity
- Voltage
- Volute
- Water Hammer
- Wear
Pumps and Motors Review Questions

1. Leakage of water around the packing on a centrifugal pump is important because it acts as a(n):
   a. Adhesive
   b. Lubricant
   c. Absorbent
   d. Backflow preventer

2. What is the purpose of wear rings in a pump?
   a. Hold the shaft in place
   b. Hold the impeller in place
   c. Control amount of water leaking from discharge to suction side
   d. Prevent oil from getting into the casing of the pump

3. Which of the following does a lantern ring accomplish?
   a. Lubricates the packing
   b. Helps keep air from entering the pump
   c. Both (a.) and (b.)

4. Closed, open, and semi-open are types of what pump part?
   a. Impeller
   b. Shaft sleeve
   c. Casing
   d. Coupling

5. When tightening the packing on a centrifugal pump, which of the following applies?
   a. Tighten hand tight, never use a wrench
   b. Tighten to 20 foot pounds of pressure
   c. Tighten slowly, over a period of several hours
   d. Tighten until no leakage can be seen from the shaft

6. Excessive vibrations in a pump can be caused by:
   a. Bearing failure
   b. Damage to the impeller
   c. Misalignment of the pump shaft and motor
   d. All of the above

7. What component can be installed on a pump to hold the prime?
   a. Toe valve
   b. Foot valve
   c. Prime valve
   d. Casing valve
8. The operating temperature of a mechanical seal should not exceed:
   a. 60°C
   b. 150°F
   c. 160°F
   d. 71°C
   e. c and d

9. What is the term for the condition where small bubbles of vapor form and explode against the impeller, causing a pinging sound?
   a. Corrosion
   b. Cavitation
   c. Aeration
   d. Combustion

10. The first thing that should be done before any work is begun on a pump or electrical motor is:
    a. Notify the state
    b. Put on safety goggles
    c. Lock out the power source and tag it
    d. Have a competent person to supervise the work

11. Under what operating condition do electric motors pull the most current?
    a. At start up
    b. At full operating speed
    c. At shut down
    d. When locked out

12. As the impeller on a pump becomes worn, the pump efficiency will:
    a. Decrease
    b. Increase
    c. Stay the same

13. How do the two basic parts of a velocity pump operate?

14. What are two designs used to change high velocity to high pressure in a pump?
15. In what type of pump are centrifugal force and the lifting action of the impeller vanes combined to develop the total dynamic head?

16. Identify one unique safety advantage that velocity pumps have over positive-displacement pumps.

17. What is the multistage centrifugal pump? What effects does the design have on discharge pressure and flow volume?

18. What are two types of vertical turbine pump, as distinguished by pump and motor arrangement, which are commonly used to pump ground water from wells?

19. What type of vertical turbine pump is commonly used as an inline booster pump?

20. What is the most common used of positive-displacement pumps in water plants today?

21. What is the purpose of the foot valve on a centrifugal pump?
22. How is the casing of a double-suction pump disassembled?

23. What is the function of wear rings in centrifugal pumps of the closed-impeller design? What is the function of the lantern rings?

24. Describe the two common types of seals used to control leakage between the pump shaft and the casing.

25. What feature distinguishes a close-coupled pump and motor?

26. What is the value of listening to a pump or laying a hand on the unit as it operates?

27. When do most electric motors take the most current?

28. What are three major ways of reducing power costs where electric motors are used?
29. What effect could over lubrication of motor bearings have?

30. Why should emery cloth not be used around electrical machines?

31. What are the most likely causes of vibration in an existing pump installation?

32. What can happen when a fuse blows on a single leg of a three-phase circuit?

33. What is the first rule of safety when repairing electrical devices?
**Equipment Maintenance Review Questions**

1. What are some of the uses of a voltage tester?

2. How often should motors and wirings be megged?

3. An ohmmeter is used to check the ohms of resistance in what control circuit components?

4. What are the **two** types of protective/safety devices found in main electrical panels or control units?

5. What is the **most common pump driver** used in lift stations?

6. Why should inexperienced, unqualified, or unauthorized persons and even qualified and authorized persons be extremely careful around electrical panels, circuits, wiring, and equipment?

7. Under what conditions would you recommend the installation of a screw pump?

8. What is the **purpose** of packing?
9. What is the purpose of the lantern ring?

10. How often should impellers be inspected for wear?

11. What is the purpose of wear rings?

12. What causes cavitation?

13. How often should the suction filter of a compressor be cleaned?

14. How often should the condensate from the air receiver be drained?

15. What is the purpose of lubrication?

16. What precautions must be taken before oiling or greasing equipment?
17. If an ammeter reads higher than expected, the high current could produce
   a. “Freezing” of motor windings
   b. Irregular meter readings
   c. Lower than expected output horsepower
   d. Overheating and damage equipment

18. The greatest cause of electric motor failures is
   a. Bearing failures
   b. Contaminants
   c. Overload (thermal)
   d. Single phasing

19. Flexible shafting is used where the pump and driver are
   a. Coupled with belts
   b. Difficult to keep properly aligned
   c. Located relatively far apart
   d. Required to be coupled with universal joints

20. Never operate a compressor without the suction filter because dirt and foreign materials will cause
   a. Deterioration of lubricants
   b. Effluent contamination
   c. Excessive water
   d. Plugging of the rotors, pistons or blades
Section 10

NPDES Overview
No. «PERMIT_NUMBER»

Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES)

Issued By

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER RESOURCES
William R. Snodgrass - Tennessee Tower
312 Rosa L. Parks Avenue, 11th Floor
Nashville, Tennessee 37243-1102


Discharger: «Permittee_Name»
«Project_Name»

is authorized to discharge: «EFFLUENT_DESCRIPTION»

from a facility located: in «City», «County», Tennessee

to receiving waters named: «RECEIVING_STREAM»

in accordance with effluent limitations, monitoring requirements and other conditions set forth herein.

This permit shall become effective on:

This permit shall expire on:

Issuance date:

for Jennifer Dodd
Director
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1.0. EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

1.1. NUMERIC AND NARRATIVE EFFLUENT LIMITATIONS

The City of City is authorized to discharge to the . Discharge 001 consists of municipal wastewater from a treatment facility with a design capacity of MGD. Discharge 001 shall be limited and monitored by the permittee as specified below:

Notes: The permittee shall achieve removal of CBOD₅ and TSS on a monthly average basis. The permittee shall report all instances of releases, overflows and/or bypasses. See Part 2.3.3.a for the definition of overflow and Part 1.3.5.1 for reporting requirements.

Unless elsewhere specified, summer months are May through October; winter months are November through April.

See Part 1.2.3 for test procedures.

See Part 3.4 for biomonitoring test and reporting requirements. See next page for percent removal calculations.

Total residual chlorine (TRC) monitoring shall be applicable when chlorine, bromine, or any other oxidants are added. The acceptable methods for analysis of TRC are any methods specified in Title 40 CFR, Part 136 as amended. The method detection level (MDL) for TRC shall not exceed 0.05 mg/l unless the permittee demonstrates that its MDL is higher. The permittee shall retain the documentation that justifies the higher MDL and have it available for review upon request. In cases where the permit limit is less that the MDL, the reporting of TRC at less than the MDL shall be interpreted to constitute compliance with the permit.

The wastewater discharge must be disinfected to the extent that viable coliform organisms are effectively eliminated. The concentration of the E. coli group after disinfection shall not exceed 126 cfu per 100 ml as the geometric mean calculated on the actual number of samples collected and tested for E. coli within the required reporting period. The permittee may collect more samples than specified as the monitoring frequency. Samples may not be collected at intervals of less than 12 hours. For the purpose of determining the geometric mean, individual samples having an E. coli group concentration of less than one (1) per 100 ml shall be considered as having a concentration of one (1) per 100 ml. In addition, the concentration of the E. coli group in any individual sample shall not exceed a specified maximum amount. A maximum daily limit of 487 colonies per 100 ml applies to lakes and exceptional Tennessee waters. A maximum daily limit of 941 colonies per 100 ml applies to all other recreational waters.

There shall be no distinctly visible floating scum, oil or other matter contained in the wastewater discharge. The wastewater discharge must not cause an objectionable color contrast in the receiving stream.
The wastewater discharge shall not contain pollutants in quantities that will be hazardous or otherwise detrimental to humans, livestock, wildlife, plant life, or fish and aquatic life in the receiving stream.

Sludge or any other material removed by any treatment works must be disposed of in a manner that prevents its entrance into or pollution of any surface or subsurface waters. Additionally, the disposal of such sludge or other material must be in compliance with the Tennessee Solid Waste Disposal Act, TCA 68-31-101 et seq. and the Tennessee Hazardous Waste Management Act, TCA 68-46-101 et seq.

Nothing in this permit authorizes take for the purposes of a facility’s compliance with the Endangered Species Act. (40 C.F.R. 125.98(b)(1)).

For the purpose of evaluating compliance with the permit limits established herein, where certain limits are below the State of Tennessee published required detection levels (RDLs) for any given effluent characteristics, the results of analyses below the RDL shall be reported as Below Detection Level (BDL), unless in specific cases other detection limits are demonstrated to be the best achievable because of the particular nature of the wastewater being analyzed.

For CBOD$_5$ and TSS, the treatment facility shall demonstrate a minimum of % removal efficiency on a monthly average basis. This is calculated by determining an average of all daily influent concentrations and comparing this to an average of all daily effluent concentrations. The formula for this calculation is as follows:

$$\text{1 - average of daily effluent concentration \over average of daily influent concentration} \times 100\% = \% \text{ removal}$$

The treatment facility will also demonstrate % minimum removal of the CBOD$_5$ and TSS based upon each daily composite sample. The formula for this calculation is as follows:

$$\text{1 - daily effluent concentration \over daily influent concentration} \times 100\% = \% \text{ removal}$$

1.2. MONITORING PROCEDURES

1.2.1. Representative Sampling

Samples and measurements taken in compliance with the monitoring requirements specified herein shall be representative of the volume and nature of the monitored discharge, and shall be taken after treatment and prior to mixing with uncontaminated storm water runoff or the receiving stream. Appropriate flow measurement devices and methods consistent with accepted scientific practices shall be selected and used to insure the accuracy and reliability of measurements of the volume of monitored discharges. The devices shall be installed, calibrated and maintained to insure that the accuracy of the measurements is consistent with accepted capability of that type of device. Devices selected shall be capable of
measuring flows with a maximum deviation of less than plus or minus 10% from the true discharge rates throughout the range of expected discharge volumes.

Samples and measurements taken in compliance with the monitoring requirements specified above shall be representative of the volume and nature of the monitored discharge, and shall be taken at the following location(s):

Influent samples must be collected prior to mixing with any other wastewater being returned to the head of the plant, such as sludge return. Those systems with more than one influent line must collect samples from each and proportion the results by the flow from each line.

Effluent samples must be representative of the wastewater being discharged and collected prior to mixing with any other discharge or the receiving stream. This can be a different point for different parameters, but must be after all treatment for that parameter or all expected change:

a. The chlorine residual must be measured after the chlorine contact chamber and any dechlorination. It may be to the advantage of the permittee to measure at the end of any long outfall lines.

b. Samples for *E. coli* can be collected at any point between disinfection and the actual discharge.

c. The dissolved oxygen can drop in the outfall line; therefore, D.O. measurements are required at the discharge end of outfall lines greater than one mile long. Systems with outfall lines less than one mile may measure dissolved oxygen as the wastewater leaves the treatment facility. For systems with dechlorination, dissolved oxygen must be measured after this step and as close to the end of the outfall line as possible.

d. Total suspended solids and settleable solids can be collected at any point after the final clarifier.

e. Biomonitoring tests (if required) shall be conducted on final effluent.

### 1.2.2. Sampling Frequency

Where the permit requires sampling and monitoring of a particular effluent characteristic(s) at a frequency of less than once per day or daily, the permittee is precluded from marking the “No Discharge” block on the Discharge Monitoring Report if there has been any discharge from that particular outfall during the period which coincides with the required monitoring frequency; i.e. if the required monitoring frequency is once per month or 1/month, the monitoring period is one month, and if the discharge occurs during only one day in that period then the permittee must sample on that day and report the results of analyses accordingly.
1.2.3. Test Procedures

a. Test procedures for the analysis of pollutants shall conform to regulations published pursuant to Section 304 (h) of the Clean Water Act (the "Act"), as amended, under which such procedures may be required.

b. Unless otherwise noted in the permit, all pollutant parameters shall be determined according to methods prescribed in Title 40, CFR, Part 136, as amended, promulgated pursuant to Section 304 (h) of the Act.

c. Composite samples must be proportioned by flow at time of sampling. Aliquots may be collected manually or automatically. The sample aliquots must be maintained at ≤ 6 degrees Celsius during the compositing period.

d. In instances where permit limits established through implementation of applicable water criteria are below analytical capabilities, compliance with those limits will be determined using the detection limits described in the TN Rules, Chapter 0400-40-03-.05(8).

e. All sampling for total mercury at the municipal wastewater plant (application, pretreatment, etc.) shall use Methods 1631, 245.7 or any additional method in 40 CFR 136 with a maximum detection limit of 5 ng/L.

1.2.4. Recording of Results

For each measurement or sample taken pursuant to the requirements of this permit, the permittee shall record the following information:

a. The exact place, date and time of sampling;

b. The exact person(s) collecting samples;

c. The dates and times the analyses were performed;

d. The person(s) or laboratory who performed the analyses;

e. The analytical techniques or methods used, and;

f. The results of all required analyses.

1.2.5. Records Retention

All records and information resulting from the monitoring activities required by this permit including all records of analyses performed and calibration and maintenance of instrumentation shall be retained for a minimum of three (3) years, or longer, if requested by the Division of Water Resources.
1.3. REPORTING

1.3.1. Monitoring Results

Monitoring results shall be recorded monthly and submitted monthly using NetDMR. Submittals shall be no later than 15 days after the completion of the reporting period. If NetDMR is not functioning, a completed DMR with an original signature shall be submitted to the following address:

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER RESOURCES
COMPLIANCE & ENFORCEMENT SECTION
William R. Snodgrass - Tennessee Tower
312 Rosa L. Parks Avenue, 11th Floor
Nashville, Tennessee 37243-1102

If NetDMR is not functioning, a copy of the completed and signed DMR shall be mailed to the City Environmental Field Office (EFO) at the following address:

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER RESOURCES
City Environmental Field Office
1301 Riverfront Parkway, Suite 206
City, Tennessee 37402

In addition, any communication regarding compliance with the conditions of this permit must be sent to the two offices listed above.

The first DMR is due on the 15th of the month following permit effectiveness.

DMRs and any other information or report must be signed and certified by a responsible corporate officer as defined in 40 CFR 122.22, a general partner or proprietor, or a principal municipal executive officer or ranking elected official, or his duly authorized representative. Such authorization must be submitted in writing and must explain the duties and responsibilities of the authorized representative.

For purposes of determining compliance with this permit, data provided to the division electronically is legally equivalent to data submitted on signed and certified DMR forms.
1.3.2. Additional Monitoring by Permittee

If the permittee monitors any pollutant specifically limited by this permit more frequently than required at the location(s) designated, using approved analytical methods as specified herein, the results of such monitoring shall be included in the calculation and reporting of the values required in the DMR form. Such increased frequency shall also be indicated on the form.

1.3.3. Falsifying Results and/or Reports

Knowingly making any false statement on any report required by this permit or falsifying any result may result in the imposition of criminal penalties as provided for in Section 309 of the Federal Water Pollution Control Act, as amended, and in Section 69-3-115 of the Tennessee Water Quality Control Act.

1.3.4. Monthly Report of Operation

Monthly operational reports shall be submitted on standard forms to the appropriate Division of Water Resources Environmental Field Office in Jackson, Nashville, City, Columbia, Cookeville, Memphis, Johnson City, or Knoxville. Reports shall be submitted by the 15th day of the month following data collection.

1.3.5. Bypass, Release and Overflow Reporting

1.3.5.1. Report Requirements

A summary report of known instances of sanitary sewer overflows, releases, and bypasses shall accompany the Discharge Monitoring Report (DMR). The report must contain the date(s), estimated duration in hours, estimated quantity of wastewater in gallons, and if applicable, the receiving stream for each instance of sanitary sewer overflow, release, or bypass. For each sanitary sewer overflow and release, the report shall identify (using the permittee’s naming conventions) the next downstream pump station. For each sanitary sewer overflow, the report shall also identify whether it was a dry weather overflow.

The report must also detail activities undertaken during the reporting period to correct the reported sanitary sewer overflows and releases.

On the DMR, the permittee must separately report: the total number of sanitary sewer overflows for the reporting month and the cumulative total for the previous 12 months; the total number of dry-weather overflows for the reporting month and the cumulative total for the previous 12 months; the total number of releases for the reporting month; and the total number of bypasses for the reporting month. On the DMR, sanitary sewer overflows are coded “SSO, Dry Weather and SSO, Wet Weather” and releases are coded “Release [Sewer], Dry Weather and Release [Sewer], Wet Weather.” Estimated total monthly volume for each type of event will be reported as gallons per month. Each release due to improper operation or maintenance shall be reported as such. Each discrete location of a sanitary sewer overflow or a release shall be reported as a separate value. A sanitary sewer
overflow or release occurring at one location over a period of up to 24 hours shall be reported as one occurrence. A sanitary sewer overflow or release occurring at one location over a period more than 24 hours shall be reported as the appropriate number of occurrences.¹

1.3.5.2. Anticipated Bypass Notification

If, because of unavoidable maintenance or construction, the permittee has need to create an in-plant bypass which would cause an effluent violation, the permittee must notify the division as soon as possible, but in any case, no later than 10 days prior to the date of the bypass.

1.3.6. Reporting Less Than Detection; Reporting Significant Figures

A permit limit may be less than the accepted detection level. If the samples are below the detection level, then report “BDL” or “NODI =B” on the DMRs. The permittee must use the correct detection levels in all analytical testing required in the permit. The required detection levels are listed in the Rules of the Department of Environment and Conservation, Division of Water Resources, Chapter 0400-40-03-.05(8).

For example, if the limit is 0.02 mg/l with a detection level of 0.05 mg/l and detection is shown; 0.05 mg/l must be reported. In contrast, if nothing is detected reporting “BDL” or “NODI =B” is acceptable.

Reported results are to correspond to the number of significant figures (decimal places) set forth in the permit conditions. The permittee shall round values, if allowed by the method of sample analysis, using a uniform rounding convention adopted by the permittee.

1.4. COMPLIANCE WITH SECTION 208

The limits and conditions in this permit shall require compliance with an area-wide waste treatment plan (208 Water Quality Management Plan) where such approved plan is applicable.

¹ For example, if a sanitary sewer overflow discharges continuously from 1 pm until 3 am the following morning, the event shall be reported as a single violation. Similarly, if the same sanitary sewer overflow discharges intermittently for the same time period, it should be reported as one violation. By contrast, if the same sanitary sewer overflow did not end until 3 pm two days later, it should be reported as three violations.
1.5. REOPENER CLAUSE

This permit shall be modified, or alternatively revoked and reissued, to comply with any applicable effluent standard or limitation issued or approved under Sections 301(b)(2)(C) and (D), 307(a)(2) and 405(d)(2)(D) of the Clean Water Act, as amended, if the effluent standard, limitation or sludge disposal requirement so issued or approved:

a. Contains different conditions or is otherwise more stringent than any condition in the permit; or

b. Controls any pollutant or disposal method not addressed in the permit.

The permit as modified or reissued under this paragraph shall also contain any other requirements of the Act then applicable.

1.6. SCHEDULE OF COMPLIANCE

Full compliance and operational levels shall be attained from the effective date of this permit.
2.0. GENERAL PERMIT REQUIREMENTS

2.1. GENERAL PROVISIONS

2.1.1. Duty to Reapply

Permittee is not authorized to discharge after the expiration date of this permit. In order to receive authorization to discharge beyond the expiration date, the permittee shall submit such information and forms as are required to the Director of the Division of Water Resources (the "director") no later than 180 days prior to the expiration date. Such forms shall be properly signed and certified.

2.1.2. Right of Entry

The permittee shall allow the director, the Regional Administrator of the U.S. Environmental Protection Agency, or their authorized representatives, upon the presentation of credentials:

a. To enter upon the permittee's premises where an effluent source is located or where records are required to be kept under the terms and conditions of this permit, and at reasonable times to copy these records;

b. To inspect at reasonable times any monitoring equipment or method or any collection, treatment, pollution management, or discharge facilities required under this permit; and

c. To sample at reasonable times any discharge of pollutants.

2.1.3. Availability of Reports

Except for data determined to be confidential under Section 308 of the Federal Water Pollution Control Act, as amended, all reports prepared in accordance with the terms of this permit shall be available for public inspection at the offices of the Division of Water Resources. As required by the Federal Act, effluent data shall not be considered confidential.
2.1.4. Proper Operation and Maintenance

a. The permittee shall at all times properly operate and maintain all facilities and systems (and related appurtenances) for collection and treatment which are installed or used by the permittee to achieve compliance with the terms and conditions of this permit. Proper operation and maintenance also includes adequate laboratory and process controls and appropriate quality assurance procedures. This provision requires the operation of backup or auxiliary facilities or similar systems, which are installed by a permittee only when the operation is necessary to achieve compliance with the conditions of the permit. Backup continuous pH and flow monitoring equipment are not required.

b. Dilution water shall not be added to comply with effluent requirements to achieve BCT, BPT, BAT and or other technology based effluent limitations such as those in State of Tennessee Rule 0400-40-05-.09.

2.1.5. Treatment Facility Failure (Industrial Sources)

The permittee, in order to maintain compliance with this permit, shall control production, all discharges, or both, upon reduction, loss, or failure of the treatment facility, until the facility is restored or an alternative method of treatment is provided. This requirement applies in such situations as the reduction, loss, or failure of the primary source of power.

2.1.6. Property Rights

The issuance of this permit does not convey any property rights in either real or personal property, or any exclusive privileges, nor does it authorize any injury to private property or any invasion of personal rights, nor any infringement of federal, state, or local laws or regulations.

2.1.7. Severability

The provisions of this permit are severable. If any provision of this permit due to any circumstance, is held invalid, then the application of such provision to other circumstances and to the remainder of this permit shall not be affected thereby.

2.1.8. Other Information

If the permittee becomes aware of failure to submit any relevant facts in a permit application, or of submission of incorrect information in a permit application or in any report to the director, then the permittee shall promptly submit such facts or information.
2.2. CHANGES AFFECTING THE PERMIT

2.2.1. Planned Changes

The permittee shall give notice to the director as soon as possible of any planned physical alterations or additions to the permitted facility. Notice is required only when:

a. The alteration or addition to a permitted facility may meet one of the criteria for determining whether a facility is a new source in 40 CFR 122.29(b); or

b. The alteration or addition could significantly change the nature or increase the quantity of pollutants discharged. This notification applies to pollutants, which are subject neither to effluent limitations in the permit, nor to notification requirements under 40 CFR 122.42(a)(1).

2.2.2. Permit Modification, Revocation, or Termination

a. This permit may be modified, revoked and reissued, or terminated for cause as described in 40 CFR 122.62 and 122.64, Federal Register, Volume 49, No. 188 (Wednesday, September 26, 1984), as amended.

b. The permittee shall furnish to the director, within a reasonable time, any information which the director may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit, or to determine compliance with this permit. The permittee shall also furnish to the director, upon request, copies of records required to be kept by this permit.

c. If any applicable effluent standard or prohibition (including any schedule of compliance specified in such effluent standard or prohibition) is established for any toxic pollutant under Section 307(a) of the Federal Water Pollution Control Act, as amended, the director shall modify or revoke and reissue the permit to conform to the prohibition or to the effluent standard, providing that the effluent standard is more stringent than the limitation in the permit on the toxic pollutant. The permittee shall comply with these effluent standards or prohibitions within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified or revoked and reissued to incorporate the requirement.

d. The filing of a request by the permittee for a modification, revocation, reissuance, termination, or notification of planned changes or anticipated noncompliance does not halt any permit condition.

2.2.3. Change of Ownership

This permit may be transferred to another party (provided there are neither modifications to the facility or its operations, nor any other changes which might affect the permit limits and conditions contained in the permit) by the permittee if:
a. The permittee notifies the director of the proposed transfer at least 30 days in advance of the proposed transfer date;

b. The notice includes a written agreement between the existing and new permittees containing a specified date for transfer of permit responsibility, coverage, and liability between them; and

c. The director, within 30 days, does not notify the current permittee and the new permittee of his intent to modify, revoke or reissue, or terminate the permit and to require that a new application be filed rather than agreeing to the transfer of the permit.

Pursuant to the requirements of 40 CFR 122.61, concerning transfer of ownership, the permittee must provide the following information to the division in their formal notice of intent to transfer ownership: 1) the NPDES permit number of the subject permit; 2) the effective date of the proposed transfer; 3) the name and address of the transferor; 4) the name and address of the transferee; 5) the names of the responsible parties for both the transferor and transferee; 6) a statement that the transferee assumes responsibility for the subject NPDES permit; 7) a statement that the transferor relinquishes responsibility for the subject NPDES permit; 8) the signatures of the responsible parties for both the transferor and transferee pursuant to the requirements of 40 CFR 122.22(a), “Signatories to permit applications”; and, 9) a statement regarding any proposed modifications to the facility, its operations, or any other changes which might affect the permit limits and conditions contained in the permit.

2.2.4. Change of Mailing Address

The permittee shall promptly provide to the director written notice of any change of mailing address. In the absence of such notice the original address of the permittee will be assumed to be correct.

2.3. NONCOMPLIANCE

2.3.1. Effect of Noncompliance

All discharges shall be consistent with the terms and conditions of this permit. Any permit noncompliance constitutes a violation of applicable state and federal laws and is grounds for enforcement action, permit termination, permit modification, or denial of permit reissuance.

2.3.2. Reporting of Noncompliance

a. 24-Hour Reporting

In the case of any noncompliance which could cause a threat to public drinking supplies, or any other discharge which could constitute a threat to human health or the environment, the required notice of non-compliance shall be provided to
the Division of Water Resources in the appropriate Environmental Field Office within 24-hours from the time the permittee becomes aware of the circumstances. (The Environmental Field Office should be contacted for names and phone numbers of environmental response team).

A written submission must be provided within five days of the time the permittee becomes aware of the circumstances unless the director on a case-by-case basis waives this requirement. The permittee shall provide the director with the following information:

i. A description of the discharge and cause of noncompliance;

ii. The period of noncompliance, including exact dates and times or, if not corrected, the anticipated time the noncompliance is expected to continue; and

iii. The steps being taken to reduce, eliminate, and prevent recurrence of the noncomplying discharge.

b. Scheduled Reporting

For instances of noncompliance which are not reported under subparagraph 2.3.2.a above, the permittee shall report the noncompliance on the Discharge Monitoring Report. The report shall contain all information concerning the steps taken, or planned, to reduce, eliminate, and prevent recurrence of the violation and the anticipated time the violation is expected to continue.

2.3.3. Overflow

a. Sanitary sewer overflows, including dry-weather overflows, are prohibited.

b. The permittee shall operate the collection system so as to avoid sanitary sewer overflows and releases due to improper operation or maintenance. A “release” may be due to improper operation or maintenance of the collection system or may be due to other cause(s). Releases caused by improper operation or maintenance of the permittee’s collection and transmission system are prohibited.

c. The permittee shall take all reasonable steps to minimize any adverse impact associated with releases.

d. No new or additional flows shall be added upstream of any point in the collection or transmission system that experiences greater than 5 sanitary sewer overflows or releases (greater than 5 events per year)^2 or would otherwise overload any portion of the system. Unless there is specific enforcement action to the contrary,

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^2 When determining if a location experiences chronic sanitary sewer overflows or releases the term “event(s)” includes dry weather overflows, wet weather overflows, dry weather releases and wet weather releases.
the permittee is relieved of this requirement after: 1) an authorized representative of the Commissioner of the Department of Environment and Conservation has approved an engineering report and construction plans and specifications prepared in accordance with accepted engineering practices for correction of the problem; 2) the correction work is underway; and 3) the cumulative, peak-design, flows potentially added from new connections and line extensions upstream of any chronic overflow or release point are less than or proportional to the amount of inflow and infiltration removal documented upstream of that point. The inflow and infiltration reduction must be measured by the permittee using practices that are customary in the environmental engineering field and reported in an attachment to a Monthly Operating Report submitted to the local TDEC Environmental Field Office. The data measurement period shall be sufficient to account for seasonal rainfall patterns and seasonal groundwater table elevations.

e. In the event that chronic sanitary sewer overflows or releases have occurred from a single point in the collection system for reasons that may not warrant the self-imposed moratorium of the actions identified in this paragraph, the permittee may request a meeting with the Division of Water Resources EFO staff to petition for a waiver based on mitigating evidence.

2.3.4. Upset

a. "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

b. An upset shall constitute an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limitations if the permittee demonstrates, through properly signed, contemporaneous operating logs, or other relevant evidence that:

i. An upset occurred and that the permittee can identify the cause(s) of the upset;

ii. The permitted facility was at the time being operated in a prudent and workman-like manner and in compliance with proper operation and maintenance procedures;

iii. The permittee submitted information required under "Reporting of Noncompliance" within 24-hours of becoming aware of the upset (if this information is provided orally, a written submission must be provided within five days); and

iv. The permittee complied with any remedial measures required under "Adverse Impact."
2.3.5. **Adverse Impact**

The permittee shall take all reasonable steps to minimize any adverse impact to the waters of Tennessee resulting from noncompliance with this permit, including such accelerated or additional monitoring as necessary to determine the nature and impact of the noncomplying discharge. It shall not be a defense for the permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this permit.

2.3.6. **Bypass**

a. "**Bypass**" is the intentional diversion of waste streams from any portion of a treatment facility. "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.

b. Bypasses are prohibited unless all of the following 3 conditions are met:

i. The bypass is unavoidable to prevent loss of life, personal injury, or severe property damage;

ii. There are no feasible alternatives to bypass, such as the construction and use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass, which occurred during normal periods of equipment downtime or preventative maintenance;

iii. The permittee submits notice of an unanticipated bypass to the Division of Water Resources in the appropriate Environmental Field Office within 24 hours of becoming aware of the bypass (if this information is provided orally, a written submission must be provided within five days). When the need for the bypass is foreseeable, prior notification shall be submitted to the director, if possible, at least 10 days before the date of the bypass.

c. Bypasses not exceeding permit limitations are allowed only if the bypass is necessary for essential maintenance to assure efficient operation. All other bypasses are prohibited. Allowable bypasses not exceeding limitations are not subject to the reporting requirements of 2.3.6.b.iii, above.

2.3.7. **Washout**

a. For domestic wastewater plants only, a "washout" shall be defined as loss of Mixed Liquor Suspended Solids (MLSS) of 30.00% or more. This refers to the MLSS in the aeration basin(s) only. This does not include MLSS decrease due to solids wasting to the sludge disposal system. A washout can be caused by improper operation or from peak flows due to infiltration and inflow.
b. A washout is prohibited. If a washout occurs the permittee must report the incident to the Division of Water Resources in the appropriate Environmental Field Office within 24 hours by telephone. A written submission must be provided within five days. The washout must be noted on the discharge monitoring report. Each day of a washout is a separate violation.

2.4. LIABILITIES

2.4.1. Civil and Criminal Liability

Except as provided in permit conditions for "Bypassing," "Overflow," and "Upset," nothing in this permit shall be construed to relieve the permittee from civil or criminal penalties for noncompliance. Notwithstanding this permit, the permittee shall remain liable for any damages sustained by the State of Tennessee, including but not limited to fish kills and losses of aquatic life and/or wildlife, as a result of the discharge of wastewater to any surface or subsurface waters. Additionally, notwithstanding this Permit, it shall be the responsibility of the permittee to conduct its wastewater treatment and/or discharge activities in a manner such that public or private nuisances or health hazards will not be created.

2.4.2. Liability Under State Law

Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties established pursuant to any applicable state law or the Federal Water Pollution Control Act, as amended.
3.0. PERMIT SPECIFIC REQUIREMENTS

3.1. CERTIFIED OPERATOR

The waste treatment facilities shall be operated under the supervision of a certified wastewater treatment operator and the collection system shall be operated under the supervision of a certified collection system operator in accordance with the Water Environmental Health Act of 1984.

Paragraph 1a-c applies if the STP does NOT have an approved pretreatment program:
Paragraph 2a-c applies if the pretreatment program is inactive:
Paragraph 3a-d applies if the STP has an approved or developing pretreatment program:
Paragraph 4a-c applies if the STP has a dormant pretreatment program:

3.2. POTW PRETREATMENT PROGRAM GENERAL PROVISIONS

As an update of information previously submitted to the division, the permittee will undertake the following activity.

(If developing, replace the above sentence with the one below, and delete the 120-day IWS submission requirement in 3.2.a.viii.)

Requirements of Section 3.2 shall apply after the division director or pretreatment coordinator has approved the pretreatment program by letter.

1a. The permittee shall submit the results of an Industrial Waste Survey (IWS) in accordance with 40 CFR 403.8(f)(2)(i), including any industrial users (IU) covered under Section 301(i)(2) of the Act. As much information as possible must be obtained relative to the character and volume of pollutants contributed to the POTW by the IUs. This information will be submitted to the Division of Water Resources, Pretreatment Section within one hundred twenty (120) days of the effective date of this permit, unless such a survey has been submitted within 3 years of the effective date. Development of a pretreatment program may be required after completion of the industrial user review. All requirements and conditions of the pretreatment program are enforceable through the NPDES permit.

2a. The current pretreatment program is in the inactive stage. The program will remain inactive as long as no significant industries discharge into the collection system. Should a significant industrial user request permission to discharge into the City system, then the City must request that the division reactivate the pretreatment program. This must be done prior to the industrial discharge taking place.
4.0. DEFINITIONS AND ACRONYMS

4.1. DEFINITIONS

“Biosolids” are treated sewage sludge that have contaminant concentrations less than or equal to the contaminant concentrations listed in Table 1 of subparagraph (3)(b) of Rule 0400-40-15-.02, meet any one of the ten vector attraction reduction options listed in part (4)(b)1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 of Rule 0400-40-15-.04, and meet either one of the six pathogen reduction alternatives for Class A listed in part (3)(a)3, 4, 5, 6, 7, or 8, or one of the three pathogen reduction alternatives for Class B listed in part (3)(b)2, 3, or 4 of Rule 0400-40-15-.04.

A "bypass" is defined as the intentional diversion of waste streams from any portion of a treatment facility.

A “calendar day” is defined as the 24-hour period from midnight to midnight or any other 24-hour period that reasonably approximates the midnight to midnight time period.

A "composite sample" is a combination of not less than 8 influent or effluent portions, of at least 100 ml, collected over a 24-hour period. Under certain circumstances a lesser time period may be allowed, but in no case, less than 8 hours.

The "daily maximum concentration" is a limitation on the average concentration in units of mass per volume (e.g. milligrams per liter), of the discharge during any calendar day. When a proportional-to-flow composite sampling device is used, the daily concentration is the concentration of that 24-hour composite; when other sampling means are used, the daily concentration is the arithmetic mean of the concentrations of equal volume samples collected during any calendar day or sampling period.

“Discharge” or “discharge of a pollutant” refers to the addition of pollutants to waters from a source.

A “dry weather overflow” is a type of sanitary sewer overflow and is defined as one day or any portion of a day in which unpermitted discharge of wastewater from the collection or treatment system other than through the permitted outfall occurs and is not directly related to a rainfall event. Discharges from more than one point within a 24-hour period shall be counted as separate overflows.

“Degradation” means the alteration of the properties of waters by the addition of pollutants, withdrawal of water, or removal of habitat, except those alterations of a short duration.
“De Minimis” - Degradation of a small magnitude, as provided in this paragraph.

(a) Discharges and withdrawals

1. Subject to the limitation in part 3 of this subparagraph, a single discharge other than those from new domestic wastewater sources will be considered de minimis if it uses less than five percent of the available assimilative capacity for the substance being discharged.
2. Subject to the limitation in part 3 of this subparagraph, a single water withdrawal will be considered de minimis if it removes less than five percent of the 7Q10 flow of the stream.
3. If more than one activity described in part 1 or 2 of this subparagraph has been authorized in a segment and the total of the authorized and proposed impacts uses no more than 10% of the assimilative capacity, or 7Q10 low flow, they are presumed to be de minimis. Where the total of the authorized and proposed impacts uses 10% of the assimilative capacity, or 7Q10 low flow, additional degradation may only be treated as de minimis if the Division finds on a scientific basis that the additional degradation has an insignificant effect on the resource.

(b) Habitat alterations authorized by an Aquatic Resource Alteration Permit (ARAP) are de minimis if the Division finds that the impacts, individually and cumulatively are offset by impact minimization and/or in-system mitigation, provided however, in ONRWs the mitigation must occur within the ONRW.

An “ecoregion” is a relatively homogeneous area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

The "geometric mean" of any set of values is the \( n^{th} \) root of the product of the individual values where “n” is equal to the number of individual values. The geometric mean is equivalent to the antilog of the arithmetic mean of the logarithms of the individual values. For the purposes of calculating the geometric mean, values of zero (0) shall be considered to be one (1).

A "grab sample" is a single influent or effluent sample collected at a particular time.

The "instantaneous maximum concentration" is a limitation on the concentration, in milligrams per liter, of any pollutant contained in the wastewater discharge determined from a grab sample taken from the discharge at any point in time.

The "instantaneous minimum concentration" is the minimum allowable concentration, in milligrams per liter, of a pollutant parameter contained in the wastewater discharge determined from a grab sample taken from the discharge at any point in time.
The "\textit{monthly average amount}\" shall be determined by the summation of all the measured daily discharges by weight divided by the number of days during the calendar month when the measurements were made.

The "\textit{monthly average concentration}\", other than for \textit{E. coli} bacteria, is the arithmetic mean of all the composite or grab samples collected in a one-calendar month period.

A "\textit{one week period}\" (or "\textit{calendar-week}\") is defined as the period from Sunday through Saturday. For reporting purposes, a calendar week that contains a change of month shall be considered part of the latter month.

"\textit{Pollutant}\" means sewage, industrial wastes, or other wastes.

A "\textit{quarter}\" is defined as any one of the following three-month periods: January 1 through March 31, April 1 through June 30, July 1 through September 30, and/or October 1 through December 31.

A "\textit{rainfall event}\" is defined as any occurrence of rain, preceded by 10 hours without precipitation that results in an accumulation of 0.01 inches or more. Instances of rainfall occurring within 10 hours of each other will be considered a single rainfall event.

A "\textit{rationale}\" (or "fact sheet") is a document that is prepared when drafting an NPDES permit or permit action. It provides the technical, regulatory and administrative basis for an agency’s permit decision.

A "\textit{reference site}\" means least impacted waters within an ecoregion that have been monitored to establish a baseline to which alterations of other waters can be compared.

A "\textit{reference condition}\" is a parameter-specific set of data from regional reference sites that establish the statistical range of values for that particular substance at least-impacted streams.

A "\textit{release}\" is the flow of sewage from any portion of the collection or transmission system owned or operated by the permittee other than through permitted outfalls that does not add pollutants to waters. In addition, a "release" includes a backup into a building or private property that is caused by blockages, flow conditions, or other malfunctions originating in the collection and transmission system owned or operated by the permittee. A "release" does not include backups into a building or private property caused by blockages or other malfunctions originating in a private lateral.

A "\textit{sanitary sewer overflow (SSO)}\" is defined as an unpermitted discharge of wastewater from the collection or treatment system other than through the permitted outfall.

"\textit{Sewage}\" means water-carried waste or discharges from human beings or animals, from residences, public or private buildings, or industrial establishments, or boats,
together with such other wastes and ground, surface, storm, or other water as may be present.

“Severe property damage” when used to consider the allowance of a bypass or SSO means substantial physical damage to property, damage to the treatment facilities which causes them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass or SSO. Severe property damage does not mean economic loss caused by delays in production.

“Sewerage system” means the conduits, sewers, and all devices and appurtenances by means of which sewage and other waste is collected, pumped, treated, or disposed.

“Sludge” or “sewage sludge” is solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.

A “subecoregion” is a smaller, more homogenous area that has been delineated within an ecoregion.

“Upset” means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

The term, "washout" is applicable to activated sludge plants and is defined as loss of mixed liquor suspended solids (MLSS) of 30.00% or more from the aeration basin(s).

“Waters” means any and all water, public or private, on or beneath the surface of the ground, which are contained within, flow through, or border upon Tennessee or any portion thereof except those bodies of water confined to and retained within the limits of private property in single ownership which do not combine or effect a junction with natural surface or underground waters.

The "weekly average amount", shall be determined by the summation of all the measured daily discharges by weight divided by the number of days during the calendar week when the measurements were made.

The "weekly average concentration", is the arithmetic mean of all the composite samples collected in a one-week period. The permittee must report the highest weekly average in the one-month period.
4.2. **ACRONYMS AND ABBREVIATIONS**

1Q10 – 1-day minimum, 10-year recurrence interval
30Q20 – 30-day minimum, 20-year recurrence interval
7Q10 – 7-day minimum, 10-year recurrence interval
BAT – best available technology economically achievable
BCT – best conventional pollutant control technology
BDL – below detection level
BOD₅ – five day biochemical oxygen demand
BPT – best practicable control technology currently available
CBOD₅ – five day carbonaceous biochemical oxygen demand
CEI – compliance evaluation inspection
CFR – code of federal regulations
CFS – cubic feet per second
CFU – colony forming units
CIU – categorical industrial user
CSO – combined sewer overflow
DMR – discharge monitoring report
D.O. – dissolved oxygen
*E. coli* – *Escherichia coli*
EFO – environmental field office
LB(lb) – pound
IC₂₅ – inhibition concentration causing 25% reduction in survival, reproduction and growth of the test organisms
IU – industrial user
IWS – industrial waste survey
LC₅₀ – acute test causing 50% lethality
MDL – method detection level
MGD – million gallons per day
MG/L(mg/l) – milligrams per liter
ML – minimum level of quantification
ml – milliliter
MLSS – mixed liquor suspended solids
MOR – monthly operating report
NODI – no discharge
NPDES – national pollutant discharge elimination system
PL – permit limit
POTW – publicly owned treatment works
RDL – required detection limit
SAR – semi-annual [pretreatment program] report
SIU – significant industrial user
SSO – sanitary sewer overflow
STP – sewage treatment plant
TCA – Tennessee code annotated
TDEC – Tennessee Department of Environment and Conservation
TIE/TRE – toxicity identification evaluation/toxicity reduction evaluation
TMDL – total maximum daily load
TRC – total residual chlorine
TSS – total suspended solids
WQBEL – water quality based effluent limit
State of Tennessee NPDES Permit Vocabulary

1. Treated sewage sludge: _________________________

2. An intentional diversion of waste streams from any portion of a treatment facility: ________________

3. An exceptional incident in which there is unintentional and temporary noncompliance with technology-based effluent limitations because of factors beyond the reasonable control of the permittee: ___________________

4. The 24-hour period from midnight to midnight: ___________________________

5. A combination of not less than 8 influent or effluent portions, of at least 100 mL, collected over a 24-hour period: ________________________________

6. A loss of mixed liquor suspended solids (MLSS) of 30% or more from the aeration basin(s): ________________________________

7. A limitation on the average concentration in units of mass per volume of the discharge during any calendar day: ___________________________

8. The addition of pollutants to waters from a source: _____________________________ (Also referred to as “discharge of a pollutant.”)

9. A type of sanitary sewer overflow defined as one day or any portion of a day in which unpermitted discharge of wastewater from the collection or treatment system other than through the permitted outfall occurs and is not directly related to a rainfall event: ________________________________

10. The alteration of the properties of waters by the addition of pollutants, withdrawal of water, or removal of habitat, except those alterations of a short duration: ___________________________

11. The n<sup>th</sup> root of the product of the individual values where “n” is equal to the number of individual values: ____________________________. For calculating purposes, values of zero shall be considered to be one.

12. A single influent or effluent sample collected at a particular time: ___________________________

13. An unpermitted discharge of wastewater from the collection or treatment system other than through the permitted outfall: ___________________________

14. The summation of all the measured daily discharges by weight divided by the number of days during the calendar month when the measurements were made: ________________________________

15. Discharge Monitoring Report, the first of which is due on the 15<sup>th</sup> of the month: ___________________________

16. The arithmetic mean of all the composite or grab samples collected in a one-calendar month period (other than for E.coli): ________________________________
17. Water-carried waste or discharges from human beings or animals, from residences, public or private buildings, or industrial establishments, or boats, together with such other wastes and ground, surface, storm, or other water as may be present: ________________________________

18. The period from Sunday through Saturday: ________________________________. For reporting purposes, a calendar week that contains a change of month shall be considered part of the latter month.

19. Sewage, industrial wastes, or other wastes are all considered: ________________________________

20. Solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works: ________________________________. It includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge.

21. One of the following three-month periods: January 1 - March 31, April 1 - June 30, July 1 - September 30, and/or October 1 - December 31 ______________________________

22. Any occurrence of rain, preceded by 10 hours without precipitation that result in an accumulation of 0.01 inches or more: ________________________________. Instances of rainfall occurring within 10 hours of each other will be considered a single rainfall event.

Word Bank:

Degradation
Washout
Biosolids
Sewage
Sludge or sewage sludge
Discharge
DMR
Sanitary Sewer Overflow (SSO)
Pollutants
Geometric mean
Calendar day

Rainfall event
Dry weather overflow
Quarter
Upset
One week period or Calendar week
Bypass
Grab sample
Composite sample
Monthly average concentration
Daily maximum concentration
Monthly average amount
Section 11

Answers to
Vocabulary and Review Questions
Section 1 Activated Sludge Part 2 Answers

Vocabulary:
1. Bulking
2. Denitrification
3. F:M (or F/M)
4. Biochemical Oxygen Demand (BOD)
5. Mixed Liquor Suspended Solids (MLSS)
6. Diffuser
7. Sludge Age
8. Coagulation
9. Mixed Liquor Volatile Suspended Solids (MLVSS)
10. Mean Cell Residence Time (MCRT)
11. Supernatant
12. Nitrification
13. Rising Sludge
14. Sludge Volume Index (SVI)

Review Questions:
1. C
2. A
3. C
4. C
5. A
6. B
7. B
8. B
9. B
10. A
11. D
12. C
13. B
14. A
15. A

Section 2 Intro to Wastewater Math Answers

Sedimentation Math Answers:
1. 2.41 hours
2. 1151.59 gpd/sq.ft.
3. 17,752.38 gpd/ft
4. 22.39 lbs/day/sq.ft.
5. 927.11 gpd/sq.ft.
6. 21.55 lbs/day/sq.ft.
7. 4806.34 lbs/day
8. 1.49 hrs

Chemical Dosage/Disinfection Math Answers
1. 5.00 lbs/day
2. 307.75 lbs/day
3. 33.36 lbs/day
4. 113.42 lbs/day
5. 3415.23 lbs
6. 0.8 mg/L
7. 6.47 mg/L
8. 20 min, above DT
9. 22.45 lbs
10. 6.42 lbs

Activated Sludge Math Answers:
1. 1438.65 lbs/day
2. 13989.43 lbs
3. 18.77 lbs/day
4. 0.31
5. 9.38 days
6. 6.86 days

Section 3 Introduction to Laboratory and Sampling Answers

Vocabulary:
1. Composite
2. Grab
3. Aseptic
4. pH
5. Thirty Minute Settleometer
6. Autoclave
7. Samplers
8. Process Control Tests
9. Turbidity
10. BOD
11. COD
12. Suspended Solids Test
13. Coliform
14. Membrane Filtration
15. Precision

Review Questions:
1. Autoclave, 121 degrees C for 15 min at 15 psi
2. 40 CFR 136, Table II
3. 8 hours, 36 hours, 28 days
4. If there is no existing bacterial population, for example: if samples were collected after disinfection, if nitrification inhibitor has been added, or if a toxic load was suspected in the plant.

5. 20, 0.2 mg/L, 2.0 mg/L, 9.0 mg/L

6. Grab sample is a volume of water, representative of the water quality at that exact time and place of sampling. A composite sample is a combination of not less than 8 influent or effluent portions, of at least 100 mL, collected over a 24-hour period. In certain circumstances, a lessre time period may be allowed, but in no case less than 8 hours. A composite sample is a series of grab samples mixed together, representative of the average water quality over a period of time.

7. 103 -105 degrees C

8. D.

9. (a) Process is operating well, good settling sludge (b) Old sludge, increase wasting (c) Young sludge, lots of food (BOD), insufficient biomass. Could indicate plant start-up or recovery after an upset.

10. Alum and chlorine

11. 200 cfu/100 ml, 44.5 +/- 0.2 degrees C, 24 +/- 2 hours

12. 126 cfu/100 ml, 35 +/- 0.5 degrees C, 24 +/- 2 hours

13. (a) positive for total coliforms (b) positive for E.coli

14. 
   a. Demonstration of capability
   b. Method Detection Level
   c. Initial Calibration Verification
   d. Continuing Calibration Verification
   e. Laboratory Reagent Blank (aka Standard)
   f. Laboratory Fortified Matrix (aka Spike)

Section 6 Sludge Thickening, Digestion, and Dewatering Answers

Vocabulary:
1. Biosolids
2. Saprophytic
3. Endogenous Respiration
4. Dewatering
5. Elutriation
6. Centrate
7. Anaerobic Digestion
8. Methane Fermenters
9. Buffering Capacity
10. Aerobic Digestion
11. Psychrophilic, Mesophilic, Thermophilic
12. Volatile Acid/Alkalinity Ratio
13. 40 CFR 503
Review Questions:
1. During anaerobic digestion, organic solids in the sludge are liquefied, the solids volume is reduced, and valuable methane gas is produced in the digester by the action of 2 different bacteria groups: saprophytic organisms (acid formers) and methane formers.
2. The acid fermenters will predominate, driving the pH down and creating an undesirable condition for the methane fermenters. The digester will go sour or acid. This could lead to foaming or frothing.
3. Explosive conditions created by a mixture of air and methane in partially full digesters
4. 50 GPM
5. Foaming is caused by an imbalance between the acid-forming bacteria and the methane-fermenting bacteria. This imbalance results in active gas production while solids separation has not progressed far enough (insufficient digestion).

To prevent it from occurring, ensure the contents are well mixed from bottom to top at all times. (short answer)

- Maintain a constant temp
- Feed sludge at regular, short intervals
- Exercise caution when breaking up scum blankets
- Do not overdrain sludge from digester
- Keep contents well mixed from bottom to top at all times

6. Problem: Washout caused by belt blinding, polymer dose, belt speed being too low, or hydraulic load too high. Belt blinding or plugging can be the result of inadequate belt washing or chemical blinding. Manually clean belts with high-pressure hose to restore at least some of the drainage.
   Problem: Cake solids too wet. Belt speed could be too high – lower belt speed. Belt tension could be too low – raise belt tension.

7. Water could be in the floating cover compartment (this could come from condensation or rain water), you would do a visual inspection of the flotation chamber to look for water or sludge, siphon or pump out any water or sludge and repair the leak.
   The weight distribution could be off/uneven, in this case you would check the location of the weights and check the buoyancy chamber for leakage. If movable ballast or weights are provided, move them around until the cover is level.
   If excess scum has accumulated around the edge, you would need to clean with chemicals or degreasing aids and hose down with water.

8. Class A Less than (<) 1,000 MPN per gram of total dry solids
   Class B Less than (<) 2 million MPN or cfu/gram of total dry solids

9. Extend mixing time, Control heat more evenly, Decrease raw sludge feed rates, Decrease digested sludge withdrawal rates
10. To neutralize it if the digester is going sour. This will only raise the pH however, and not correct the initial cause of the problem.

11. Petroleum products and mineral oils
   - Rubber goods
   - Plastics (back sheets to diapers)
   - Filter tips from cigarettes
   - Hair
   - Grit (sand and other inorganics)

12. 1.0 mg/L

13. Raw or Secondary sludges.
   Quality is regulated by: Sludge feed rate, Bowl speed, Chemical conditioners

14. (1) Pollutant Limits – Metals. The first parameter of the 3 that must be assessed to determine overall sludge quality is the level of pollutants.
   (2) Pathogen Reduction. The second parameter in determining sewage sludge quality is the presence or absence of pathogens (i.e., disease causing organisms), such as Salmonella bacteria, enteric viruses, and viable helminth ova.
   (3) Vector Attraction Reduction. The degree of attractiveness of sewage sludge to vectors is the third parameter of sewage sludge quality.

Section 7 Effluent Disposal Answers

Vocabulary:
1. Surface Waters
2. Fixed Sample
3. Grab
4. Composite
5. Respiration
6. Evapotranspiration
7. Irrigation
8. Ridge and Furrow
9. Spray Systems
10. Overland Flow
11. D.O. profile
12. Outfall

Review Questions:
1. Discharge into surface waters
2. (1) Discharge to land by use of irrigation – slow rate, rapid infiltration, overland flow
   (2) Groundwater recharge basin
   (3) Underground discharge
3. It could contaminate groundwater aquifers. Due to Karst topography, cracks in limestone provide direct route of infiltration to groundwater and therefore no treatment is achieved and groundwater may become contaminated.
4. Take a measurement upstream (not affected) and downstream (affected) and compare the two results, and then perform a DO profile.
5. Dissolved oxygen, pH, Temperature
6. Biochemical oxygen demand (BOD), Suspended solids (SS), Total coliform and fecal coliform bacteria, Nutrients (Nitrogen and Phosphorus)
7. 30 mg/L BOD, TSS
   23 colonies/100 mL for E. coli

Section 8 Administration and Management Answers
Vocabulary:
1. Authority
2. Organizing
3. Responsibility
4. Tailgate Safety Meeting
5. Ethics
6. Accountability
7. Delegation
8. Preventative
9. Critical Infrastructure
10. Vulnerability
11. Whistleblowing
12. Predictive

Review Questions:
1. A
2. B
3. D
4. E
5. B
6. A
7. A
8. B
9. A
10. A
11. A
12. C
13. D
14. A
15. A

Section 9 Pumps and Equipment Maintenance Answers
Vocabulary:
1. Circuit Breaker
2. Brinelling
3. Fuse
4. Cavitation
5. Voltage
6. Jogging
7. Current
8. Megger
9. Amperage
10. Resistance
11. Circuit
12. Bearing
13. Foot Valve
14. Impeller
15. Lantern Ring
16. Mechanical
17. Packing
18. Velocity
19. Volute
20. Positive Displacement
21. Water Hammer
22. Wear

Pumps and Motors Review Questions:
1. B
2. C
3. C
4. A
5. C
6. D
7. B
8. C
9. B
10. C
11. A
12. A
13. A spinning impeller accelerates water to a high velocity within a casing, which changes the high-velocity, low-pressure water to a low-velocity, high-pressure discharge.
14. Volute casing and diffuser vanes
15. Mixed-flow pump (the design used for most vertical turbine pumps)
16. If a valve is closed in the discharge line, the pump impeller can continue to rotate for a time without pumping water or damaging the pump.
17. A multistage centrifugal pump is made up of a series of impellers and casings ( housings) arranged in layers, or stages. This increases the pressure at the discharge outlet, but does not increase flow volume.
18. Shaft-type and submersible-type vertical turbines.
19. A close-coupled vertical turbine with an integral sump or pot.
20. Positive-displacement pumps are generally used in water plants to feed chemical into the water supply.
21. The foot valve prevents water from draining when the pump is stopped, so the pump will be primed when restarted.
22. The bolts holding the two halves of the casing together are removed and the top half is lifted off.
23. Wear rings prevent excessive circulation of water between the impeller discharge and suction area. Lantern rings allow sealing water to be fed into the stuffing box.
24. (1) Packing rings are made of graphite-impregnated cotton, flax, or synthetic materials. They are inserted in the stuffing box and held snugly against the shaft by an adjustable packing gland. (2) Mechanical seals consist of two machined and polished surfaces. One is attached to the shaft, the other to the casing. Spring pressure maintains contact between the two surfaces.
25. The pump impeller is mounted directly on the shaft of the motor.
26. An experienced operator can often detect unusual vibration by simply listening or touching. Vibration, especially changes in vibration level, are viewed as symptoms or indicators of other underlying problems in foundation, alignment and/or pump wear.
27. During start-up.
28. (1) Increase system efficiency; (2) spread the pumping load more evenly throughout the day; (3) reduce power-factor charges
29. The bearings may run hot, and excess grease or oil could run out and reach the motor windings, causing the insulation to deteriorate.
30. The abrasive material on emery cloth is electrically conductive and could contaminate electrical components.
31. Imbalance of the rotating elements, bad bearings and misalignment
32. A condition called single-phasing can occur, causing the motor windings to overheat and eventually fail.
33. Make sure the power to the device is disconnected. This is critical since rubber gloves, insulated tools and other protective gear are not guarantees against electrical shock.

Equipment Maintenance Review Questions:
1. A voltage tester can be used to test for voltage, open circuits, blown fuses, single phasing of motors and grounds.
2. At least once a year and twice a year if possible
3. Coils, fuses, relays, resistors and switches
4. Fuses and circuit breakers
5. A.C. induction motor
6. You can seriously injure yourself or damage costly equipment.
7. They can handle fluctuating flows with large solids and rags.
8. To keep air from leaking in and water leaking out where the shaft passes through the casing.
9. To allow outside water or grease to enter the packing for lubrication, flushing, and cooling and to prevent air from being sucked or drawn into the pump
10. Every 6 months or annually, depending on pumping conditions; if grit, sand or other abrasive material is being pumped, inspections should be more frequent
11. They protect the impeller and pump body from damage due to excessive wear.
12. Cavitation can be caused by a pump operating under different conditions than what it was designed for, such as off the design curve, poor suction conditions, high speed, air leaks into suction end and water hammer conditions.
13. The frequency of cleaning a suction filter on a compressor depends on the use of a compressor and the atmosphere around it. The filter should be inspected at least monthly and cleaned or replaced every three to six months. More frequent inspections, cleanings and replacements are required under dusty conditions such as operating a jackhammer on a street.

14. Daily

15. To reduce friction between two surfaces and to remove heat caused by friction.

16. Shut it off, lock it out and tag it so it can’t be started unexpectedly and injure you.

17. D

18. C

19. C

20. C

Section 10  NPDES Overview

Vocabulary:
1. Biosolids
2. Bypass
3. Upset
4. Calendar day
5. Composite sample
6. Washout
7. Daily maximum concentration
8. Discharge
9. Dry weather overflow
10. Degradation
11. Geometric mean
12. Grab sample
13. Sanitary Sewer Overflow (SSO)
14. Monthly average amount
15. DMR
16. Monthly average concentration
17. Sewage
18. Calendar week or One week period
19. Pollutants
20. Sludge or Sewage sludge
21. Quarter
22. Rainfall event