GRANITE STATE DESIGNERS & INSTALLERS
New Hampshires Association of Septic System Professionals

# WASTEWATER 101

University of Minnesota Onsite Sewage Treatment Program

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## UMN Onsite Program

Water Resource Center, Onsite Sewage Treatment Program (OSTP)

1. Education for Professionals started in 1974
2. Education for Homeowners & Small Communities started in early 1990s
3. Ongoing research and demonstration supporting educational efforts

## Minnesota

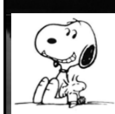
11,842

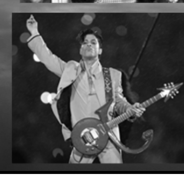
- Land of how many lakes?
- 6,564 rivers and streams
- Boasts the coldest temp in lower 48
  - Embarrass MN -60°F Feb1996
- Produces
  - General Mills
  - Minnesota Mining & Manufacturing



## Minnesota

- Celebrities
  - Prince, Bob Dylan, Jessica Lange, Judy Garland, Al Franken, Charles Schulz
- Movies
  - Fargo, Grumpy Old Men



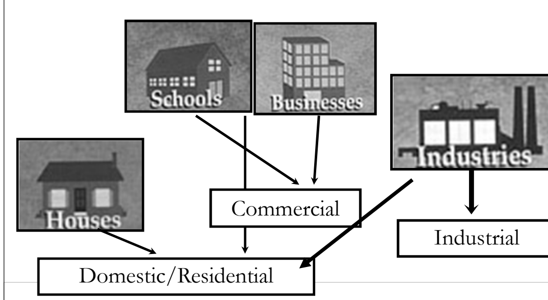


## Presentation Overview

WASTEWATER
WHAT IS IT AND HOW DO WE TREAT IT?
VARYING CONTAMINANTS
POTENTIAL NEGATIVE AFFECTS
LABORATORY MEASUREMENTS

## Sources of Wastewater

Defined: Used water and water-carried solids



## Typical Water Use

- 125 - 150 gallons per day per bedroom
  - Assumes 2 people per bedroom
- 50-80 gallons/person/day
- Annual estimates of use
  - Per person per year = 28,000 gal
  - Typical home ~ 3 persons = 82,000 gal/yr
  - 250 homes in a township = 20 million gallons/year

## Where Does it Come From?

- Water use:
  - Bathroom ~ 64%
    - Toilet = 27%
    - Bathing = 19%
    - Faucets = 8%
  - Laundry = 22%
  - Kitchen = 10%
  - Leaks = 14%

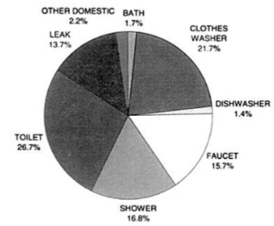
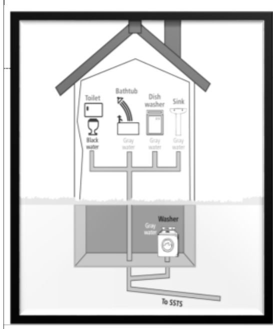



Figure 5.5 Indoor per capita water use percentage including leakage, 1,188 study homes

1,188 homes, Total gpcd = 69.3

Mayer, et al. Residential End Uses of Water. 1999.

## Wastewater Treatment




**ALL WASTEWATER MUST BE TREATED:**
**GREYWATER**
**BLACKWATER**

## So What's in Graywater?

**TABLE 4-1** Chemical and Microbial Quality of Untreated Graywater from Individual and Combined Sources

| Parameter | Bathroom | Laundry | Kitchen Sink and Dishwasher | Graywater Combined (excludes kitchen water) |
|---|---|---|---|---|
| **Physical** | | | | |
| Temperature (°C) | 29 | 28-32 | 27-38 | |
| Turbidity | 28-240 | 14-210 | | 15-140 |
| Total suspended solids (TSS), mg/L | 54-200 | 120-280 | 240-2,400 | |
| Total dissolved solids (TDS), mg/L | 140-1,300 | | | 310-930 |
| Electrical conductivity (µS/cm) | 82-250 | 190-1,400 | | |
| **Chemical** | | | | |
| pH | 6.4 – 8.1 | 8.1-10 | 6.3-7.4 | 6.7-7.6 |
| Alkalinity | 24-67 | 83-200 | 20-340 | 150-200 |
| $BOD_5$ (mg/L) | 26-300 | 48-380 | 1,000-1,500 | 125-250 |
| COD (mg/L) | 100-630 | 13-720 | 3.8-1,400 | 250-430 |
| Total organic carbon (mg/L) | 30-100 | 100-280 | 600-880 | |
| Sodium absorption ratio | | | | 2.3 - 6 |
| Boron (mg/L) | | | | 0.1-1.6 |
| Chloride (mg/L) | 9.0-19 | 9.0-90 | | 22-34 |
| TN (mg/L) | 5-17 | 6-21 | 0.3-74 | 0.6-5.2 |
| TP (mg/L) | 0.1-4 | 0.1->100 | 68-74 | |
| $PO_4$ (mg/L) | 0.94-49 | 4-170 | 13-32 | 4-35 |
| $NH_4$ (mg/L) | <0.1-15 | 0.04-11 | 0.005-6 | 0.15-3.2 |
| $NO_3$ (mg/L) | 0.28-6.3 | 0.4-2 | 0.3-5.8 | 0-4.9 |
| Anionic surfactants (mg/L) | 21 | 92 | 6 | |
| **Microbial** | | | | |
| Total coliform/100 mL | $10^{2.7}$-$10^{7.4}$ | $10^{1.9}$-$10^{5.2}$ | $10^{7}$-$10^{9}$ | $10^{7.2}$-$10^{8.8}$ |
| *Pseudomonas aeruginosa*/100 ml | | | | 1.99 x $10^{4}$ |
| *E. coli*/100 mL | $10^{1.6}$-$10^{3.4}$ | $10^{1.5}$-$10^{3.9}$ | $10^{5.4}$-$10^{9}$ | |
| *Cryptosporidium spp.* | no detection | no detection | | |

## What is NOT Sewage

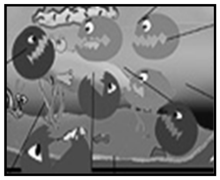
- Clear water
  - Sump pumps
  - Water softener recharge water and other water treatment device clean water
  - Treated water (hot tubs and pools)
- What to do with it?
  - On surface or below surface in separate trench
  - Do not but on neighbors property or into lake, river or stream
  - Recommended setback from wells is 20 ft

## Sewage Constituents

- Organic Loading
  - Biochemical Oxygen Demand (BOD)
  - Total suspended Solids (TSS)
  - Fat, Oils and Grease (FOG)
- Pathogens
  - Fecal Coliform
  - Viruses
- Nutrients
  - Phosphorus
  - Nitrogen
- Chemicals

## Biological Treatment in Septic Systems

- Uses the microorganisms present
- Different applications
- Biological population and processes dependent on system conditions
  - Aerobic
  - Facultative
  - Anaerobic



## Biological Treatment Processes (cont.)

- Biological oxidation
  - Bacteria break down organic matter into water and $CO_2$
  - Reduces BOD, pathogens
  - Works most efficiently in aerobic conditions

## All Systems Need Healthy Bugs

Range

DO | pH | Temp

## Anaerobic Microbes

- Anaerobic bacteria grow in absence of free oxygen, $O_2$
- Most anaerobic organisms are bacteria
- Anaerobic treatment processes split oxygen bound,
  - Ex. $SO_4$: → $H_2S$, $NO_3$ → $N_2$
- Common condition in:
  - Septic tanks
  - Processing tanks
  - Constructed wetlands
  - Other saturated environments

## Anaerobes Cont'd

- They are not able to get as much energy from their food
- Advantages:
  - Microbes that do not require oxygen are able to live in places where aerobes cannot survive, such as the human gut, and many other places where oxygen is in low supply
  - For pathogenic microbes (those that cause disease), this ability is a huge advantage, allowing anaerobic pathogens to cause disease in areas of the body that are not exposed to oxygen

## Anaerobic Digestion



ORGANIC MATTER → GASES + HUMUS

$CO_2$
$CH_4$
$H_2S$
$NH_3$

## Denitrification – Anaerobic Microbes


## Aerobic Microorganisms

- Aerobic bacteria require $O_2$ to live and grow
- Aerobic bacteria manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium
  - The ammonium is further converted by bacteria into nitrate
- Common condition in
  - Soil treatment systems
  - Media filters
  - ATUs

## Microbes as Workhorses

- Microorganisms are used
  - aerobic process is 10 - 20 times faster than anaerobic
  - to convert colloidal and dissolved carbonaceous organic matter into various gases and into cell tissue
    - gases evolve (CO2, N2, and others)
    - new cells can be settled – thus carbon is removed
  - break other nutrients out of organic compounds
    - nitrogenous compounds
    - phosphorous species

## Organics, Microbes & Oxygen

- Bioavailable organic compounds provide food and energy to microbes
  - Naturally-occurring microorganisms consume food, and create more microorganisms
  - The more microorganisms, the more food consumed
  - The more food consumed, more dissolved oxygen is required

## Basic Equation – Carbon Removal

$$\text{Organic Carbon} + O_2 \xrightarrow[\text{microorganisms}]{\text{aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

$$+ O_2 \xrightarrow[\text{microorganisms}]{\text{new aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

$$+ O_2 \xrightarrow[\text{microorganisms}]{\text{new aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

## Respiration

## Processes Occurring Under Aerobic Conditions

- Nitrification: Transformation of $NH_4$ to $NO_3$
- Nutrient reduction
- Pathogen removal
- TSS and BOD reduction

## Facultative Microbes

- Can develop in the presence of oxygen but does not require it
- The concentrations of oxygen and fermentable material in the environment influence the organism's use of aerobic respiration vs. fermentation to derive energy
- If given the choice they prefer to have access to oxygen, in order to get the maximal amount of energy from metabolizing their food

## Microbes Minimal Requirements

- Appropriate oxygen supply
- Temperature must be life-sustaining
- pH needs to be controlled
- Steady supply of food to maintain stable microbial population
- Limited biocides

## Oxygen States - Dissolved

- Dissolved
  - Free $O_2$
  - Oxygen that has been incorporated into water
  - Oxygen source for aerobic and facultative microbes
  - Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide

## Dissolved Oxygen (DO)

- Concentration of $O_2$ dissolved in water
  - Measure with meter and probe or colorimetric kit in field
  - DO expressed as mg/L
  - DO low in septic tank <1 mg/L
  - DO >2 mg/L from advanced treatment systems

## Amount of Dissolved Oxygen

- Organic material
  - If oxygen is available, organic material requires oxygen to decompose
  - Organic material may also decompose in the absence of oxygen
  - More organic material requires more DO, and will tend to deplete water of DO
- Oxygen demand
  - The oxygen demand is the amount of oxygen required to aerobically oxidize a material

## Organic Solids

- What?
  - Digested and undigested animal and vegetable material
  - Synthetic (artificial) organic compounds
  - Laundering and bathing
- Impacts?
  - Requires oxygen to be broken down
    - Biochemical Oxygen Demand (BOD)
  - Lowers water quality in lakes, rivers, and streams
- How treated?
  - Removed and stored in septic tank
  - Effluent screen helps reduce further
  - Serves as food source for good soil bacteria in soil treatment system

## Biochemical Oxygen Demand

- Biochemical oxygen demand (BOD) is the amount of oxygen used by organisms during the breakdown of organic material
- BOD is considered an indirect measure of the organic content of a sample

## Chemical Oxygen Demand

- Another means of measuring oxygen demand needed to oxidize organics and reduced nitrogenous compounds
- Faster than BOD
- Always higher than BOD
  - COD is much higher than BOD in raw wastewaters
  - COD:BOD ratio is usually less than 2:1 in treated effluents
- COD:BOD ratio is dependent on circumstances and reduces with treatment

## DO ranges for Microbes

| Ideal Dissolved Oxygen Range in Wastewater | | | |
|---|---|---|---|
| **Microbes** | **Anaerobe** | **Facultative** | **Aerobe** |
| **Low DO (mg/L)** | 0 | 0 | 0.5 |
| **High DO (mg/L)** | 0.5 | 5 | 5 |
| **Typical (mg/L)** | 0-0.3 | 0-1 | 1-3 |

## Where Does DO Come From?

- Source water
- Groundwater
- Passive from air
- Active forced into system

## Total Suspended Solids (TSS)

- Measures both organic and inorganic solids which have not settled out (lint, dirt, etc)
- Typical home is <60 mg/l
- Settled in the tank & filtered in soil

## Where Does TSS Come From?

- Organic matter (garbage disposal)
- Toilet paper
- Lint
- Dirt
- Other solids

## Garbage Disposal

- Problems:
  - Adds more solids
  - Undigested food
  - Chopped into small pieces
  - More water
- Recommendation:
  - Don't install one
  - Don't use it if you have one
  - Recommended to add
    - 50% more septic tank capacity with multiple compartments
    - Effluent screen and alarm on outlet of septic tank
- INCREASES THE NEED FOR CARE and MAINTENANCE

## Measuring TSS

- Run sample thru 0.45 micron filter
- Solids remaining on filter are SS
- Solids passing through are dissolved

## Relationships in Biomat


## Fats, oils, & grease

- Fats, oils, & grease
- Fats are animal based and solid at room temperature
- Oil are vegetable based and liquid at room temperature
- Grease is petroleum & burnt fats and oils
- Typical home is <20 mg/l
- Must be collected in glass jar

## Fats

- Origin: Animal fats
- State: solid at room temperature
- Treatment: separate into scum, microbial degrade (4 times more energy than BOD)

## Oils

- Origin: Vegetable or plant
- State: liquid or solid at room temperature
- Treatment: separate into scum, microbial degrade (12 times more energy than BOD)


## Grease

- Origin: Petroleum product
- State: solid or liquid at room temperature
- Treatment: separate into scum, toxic to microbial activity
- Can be toxic


## Temperature

- Typical range:  48 – 70˚F
- Typical value: 59˚F
- Low end concerns
  - Microbes become dormant below 41°F
  - Nitrification impacted by temps below 50°F
  - Harmful bacteria and viruses live longer in cold soils
- High end concerns
  - < 74o
  - Fats solidify

## Temperature Influences

**Sample collected on a Saturday afternoon, temperature 102°**

**Temperature has dropped to 95°**

## Temperature and Growth

- Growth rates increase with increasing temperature
- Growth rates approximately double for a 50 °F rise in temperature
- Temperature extremes may interfere with metabolic processes or harm the organisms

## What Influences Temperature

- Water temperature
- Holding time
- Air temperature
  - Venting

## Pathogens

- Fecal Coliform – indicator of potential viruses/bacteria that is easy to measure and is found in the feces of all warm blooded animals
- Treatment
  - Absorption
    - Bacteria have positive change and soil has negative so attracted to each other
  - Filtered
    - Soil is sticky
  - Killed Off

## Wastewater - Organisms

- Source
  - Human waste
  - Laundering/bathing
  - Food waste
- Concern - Human health

| Amounts | Range | Typical |
|---|---|---|
| Total Coliform Bacteria | $10^8 – 10^{10}$ | $10^9$ CFU/100mL |
| Fecal Coliform Bacteria | $10^6 – 10^8$ | $10^7$ CFU/100mL |

CFU = colony-forming unit

## Pathogens

- What?
  - Virus, Bacteria, Helmiths (worms), Protozoa
- Impacts?
  - Human health
- How treated?
  - Difficulty living in oxygen rich environments
  - Removal and die off in soil treatment system

## How are Pathogens Treated?

- Unsaturated soil
- Oxygen present = Aerobic environment
- Bacteria come to eat food, develop biomat
- Biomat provides unsaturated flow

## Phosphorus (P)

- From:
  - Urine
  - Food
  - Household detergents
- Laboratory analysis for total phosphorous
- Impacts?
  - Weed & algal growth in lakes, ponds, and streams
  - P is limiting factor for most aquatic ecosystems
  - Small amount of a P input results in large growth of algae

## Phosphorus (P) Treatment

- P attaches to other minerals (iron and aluminum) in the soil
- It then can't move
- P will move if the soil moves (erosion)
- Some of the P is used by the vegetation
- Soils have limited amount of phosphorus attachment locations
- How much depends on soil characteristics

## Nitrogen

- From:
  - Urine and food breakdown
  - Household cleaners and chemicals
- Impacts:
  - Drinking water quality, weed and algal growth in costal environments

## Nitrogen

- Nitrogen starts as ammonia
- In an aerobic environment it is transformed to Nitrate during the nitrification process
- Nitrate generally moves with water
- Advanced treatment systems can be used to reduce nitrate if they return to an anaerobic environment in the denitrification process

## Biological Nitrification

- Organically bound nitrogen is released when the organic compound is oxidized
  - released as the ammonium cation (NH4+)
- Nitrification is a two-step autotrophic process
  - the conversion from ammonium to nitrate

**Step 1:** $NH_4^+ + 3/2O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^{2-} + 2H^+ + H_2O$

**Step 2:** $NO^{2-} + 1/2O_2 \xrightarrow{\textit{Nitrobacter}} NO^{3-}$

## Biological Nitrification

- During this energy yielding reaction
  - some of the $NH_4^+$ is synthesized into cell tissue giving the following overall oxidation and synthesis reaction:

$$1.00NH^+ + 1.89O_2 + 0.08CO_2 \xrightarrow[\textit{Bacteria}]{\textit{Autotrophic}} 0.98NO_3^- + \underbrace{0.016C_5H_7O_2N}_{\textit{new bacterial cells}} + 0.95H_2O + 1.98H^+$$

  - Nitrifiers use $CO_2$ instead of organic carbon as their carbon source for cell synthesis and for the conversion of $NH_4^+$ to $NO_3^-$-N.

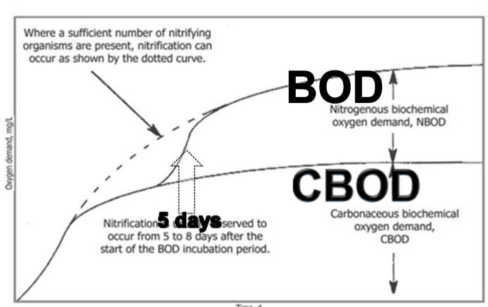



Figure 3: Carbonaceous and Nitrogenous Biochemical Oxygen Demand
Adapted from Metcalf and Eddy (1991)

## Total Nitrogen Measurements

- TKN+ Nitrate = Total N
- TKN = Organic N + $NH_4^+$
  - Organic N
    - found in cells of all living things (proteins, peptides, amino acids)
    - principle compound in feces and urine
      - 70% in urine
    - not available to plants until bacterial conversion to inorganic form
  - Ammonium N ($NH_4^+$)
    - immediately available for plant uptake
    - positively charged, binds to soil particles
    - converted to $NO_3^-$ in aerobic conditions
    - volatilizes to atmosphere as $NH_3$
- Nitrate N ($NO_3^-$)
  - immediately available for plant uptake
  - stable over a wide range of conditions
  - negatively charged, not held by soil
  - high potential for leaching to groundwater
  - converted to $N_2$ in anaerobic conditions

## Chemicals

- What?
  - Cleaners
  - Medications
- Impacts?
  - Aquatic food chain, species reproduction, drinking water quality
- How treated?
  - Stored in tank until pumped which can cause toxic affects
  - Often removed in septic tank and soil treatment system
- More on this in presentation tomorrow

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## Questions – septic.umn.edu