Wastewater Basics 101

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Wastewater Basics 101

• Target audience
  – policy makers, leaders, and planners
  – People who have a water quality agenda

• This presentation discusses the fundamentals of converting wastewater back to water
  – How do we (humans) interact with the hydrologic cycle
Wastewater Basics 101

• Major Focus
  – What *is* in wastewater and how do we get *it* out
  – Organic matter, nitrogen, & phosphorus

• Minor Focus
  – Individual and small community wastewater treatment systems
    • Wastewater basics are universal
    • Independent of scale
Wastewater

• By definition (for today’s purpose)
  – Water that has constituents of human and/or animal metabolic wastes
  – Water that has the residuals from cooking, cleaning and/or bathing

• Thus,
  – Domestic wastewater
    • Our focus is wastewater that comes from a home
Wastes and Water

• The more water you have,
  – The more wastewater you generate
  – Romans knew that water carried away the smell
Wastes and Water

• If water is not available
  – Then wastewater is not generated
  – The original low-flush toilet
Carriage Water

• There is no other substance that can transport wastes like water can
  – it cleans the inside of our body
  – it cleans the outside of our body
  – it carries away our metabolic wastes

• In high population densities
  – water is the best means to collect and transport waste away
Water is the Universal Solvent

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Water is Dense and has Viscosity

• Water is heavy
  – provides for buoyancy
  – provides for inertia forces

• Water is viscous
  – can suspend items
  – can erode surfaces
So, our Chore is to Get Wastes out of Water

- Is it difficult to get waste out of water?
  - Yes, but we have a lot of help available to us
  - Our team includes
    - Gravity
    - The sun
    - Billions of microorganisms
    - And, the soil
Wastewater

• By weight
  – Is 99.9% water
  – It is the 0.1% that we have to remove

• That 0.1% contains
  – Organic matter
  – Microorganisms (a few of which are pathogenic)
  – Inorganics compounds
Major Measures of What’s in Water

• Oxygen Demand
  – Biochemical oxygen demand
  – Chemical oxygen demand

• Indicator organisms
  – Fecal coliform
  – Escherichia coli **(E Coli 0157:H7 is the really bad boy)**

• Solids content
  – Total suspended solids
  – Total dissolved solids
Other Measures of What’s in Water

• Chemical analyses
  – Ammonia & nitrate
  – Total & reactive phosphorus
  – pH
  – Alkalinity

• Volatile compounds
  – Dissolved gases
  – Odors
Oxygen Demand

- Indictor of mass of dissolved oxygen needed by microorganisms to degrade organic and some inorganic compounds
  - High BOD/COD is indirect indicator of the organic content
  - Ammonia is inorganic and creates an oxygen demand
    - As it is converted to nitrate
Aerobic Biotransformation

- Dissolved oxygen is consumed in the process of converting organic matter into inorganic matter.

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

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

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

• Contains more than
  – Carbon, hydrogen, and oxygen

• Can also contains
  – Nitrogen
  – Phosphorus
  – Sulfur
  – Many other compounds
Degradation of Organic Matter

• Releases these other compounds
  – Typically in an inorganic form

• For example
  – Nitrogen becomes ammonia/ammonium
    • Creates an additional oxygen demand
  – Phosphorus becomes ortho-phosphate
Nitrogen Cycle

• Nitrogen is a component of protein
  – As proteins are degraded, nitrogen is released
  – Nitrogen converts to ammonia/ammonium
  – Process of ammonification

\[
\text{Organic-N} + \text{Microorganisms} \rightarrow \text{NH}_3/\text{NH}_4^+
\]
Biological Nitrification

• Ammonia/ammonium is then converted to nitrite and nitrate
  – Nitrification
  – Oxygen demand

• Nitrification is a two-step autotrophic process
  – the conversion from ammonium to nitrate

  **Nitrosomonas**

  Step 1: \( \text{NH}_4^+ + \frac{3}{2}\text{O}_2 \rightarrow \text{NO}_2^{-} + 2\text{H}^+ + \text{H}_2\text{O} \)

  **Nitrobacter**

  Step 2: \( \text{NO}^2- + \frac{1}{2}\text{O}_2 \rightarrow \text{NO}_3^{-} \)
Okay, Let’s go Back to the Bigger Picture

• We focused on oxygen demand
  – We have wastewater with organic matter
  – And other stuff

• However, the first treatment step
  – Is liquid/solid separation
  – Very inexpensive energy source
  – Very large return on investment
    • In terms of treatment
Preliminary/Primary Treatment

• Gravity as a treatment method

• Floaters and Sinkers (go ahead and giggle)
  – Based on buoyancy
    • Water is very dense – many waste products float
      – Paper products
      – Fats, oils, grease
    • Some organic solids are more dense than water and sink
      – Bacterial cells
      – Food wastes
Small System Primary Treatment
Basic Assumptions

• 50% reduction in oxygen demand
  – Because organic solids remain in tank
  – Creates an accumulation in the tank
     • That is either very slow to degrade
     • Or will not degrade

• Tremendous reduction in suspended solids

• Minimal biotransformation
  – Anaerobic environment
Now, Let’s Remove the Remainder of the Oxygen Demand

• Secondary treatment
  – the second major process
  – Provide dissolved oxygen to aerobic microorganism to finish the job

• Two questions
  – How much land is available?
  – How much energy are you willing to purchase?
Providing Dissolved Oxygen

• Air is only 21% (+/-) oxygen
  – Have to move a lot of air through water to transfer the oxygen
  – Oxygen readily dissolves into water

• Passive – large footprint, low energy
  – Moving air over water allows for transfer

• Mechanical – small footprint, much energy
  – Moving air through water for enhanced transfer
Secondary Treatment Devices

- The soil
  - Attached growth
  - Passive aeration
  - Low loading rate
  - Excessive growth of biosolids is problematic

- Trickling filters
  - Attached growth
  - Passive aeration
  - Biosolids can slough

- Activate sludge
  - Suspended growth
  - High loading rate
  - Activated sludge is the biosolids
  - Mechanical aeration
Okay, Inventory Time

• After secondary treatment and clarification
  – We have reduced oxygen demand
    • Oxidized the organic carbon
    • Converted organic nitrogen to nitrate
  – Clarified the effluent
  – Put a hurt on the microbial population

• If nutrients are not an issue
  – We can now disinfect if surface discharged
If Nutrients are an Issue

• Tertiary treatment – the third major process
  – Nutrient removal
  – Some references include disinfection

• Nitrate and phosphate
  – Required nutrients for plant growth
  – Excessive plant growth
    • Creates an oxygen demand
    • Crowds out other aquatic organisms
Denitrification

- $\text{NO}_3^-$ can be reduced,
  - under anoxic conditions, to $\text{N}_2$ gas through heterotrophic biological denitrification
  - Two issues
    - Anoxic conditions
    - Heterotrophic bacteria
Anoxic Conditions

• Classical definition
  – Very low concentration of dissolved molecular oxygen (i.e., anaerobic)
    • Forces the use of chemically-bound oxygen
  – Dissolved organic carbon is available
    • Heterotrophic bacterial use organic carbon as food source
Biological Denitrification

- Totally cool process
  - Nitrate has oxygen
  - Through reduction/oxidation processes
    - Oxygen is pulled from nitrate ion
    - Nitrogen evolves as a gas form

\[
\text{Heterotrophic Bacteria} \\
\text{NO}_3^- + \text{Organic Matter} \rightarrow \text{N}_2 + \text{CO}_2 + \text{OH}^- + \text{H}_2\text{O}
\]
Operational Issues

• Here is the rub
  – we consumed the organic carbon in the previous step
  – Under aerobic conditions

• Thus, our process must
  – Remove dissolved oxygen
  – Add organic carbon back into solution
Recirculation

• Recirculate a fraction of the
  – Secondary treated water back through primary treatment

• Assumptions
  – Nitrates are formed during secondary treatment
  – Organic carbon is available in primary treatment
  – Raw wastewater is anaerobic
Phosphorus Removal

• Chemical treatment
  – Phosphate is an anion: \( \text{PO}_4^{3-} \)
  – Cations can be added to bind with phosphate
    • \( \text{Ca}^{2+} \)
    • \( \text{Al}^{3+} \)
    • \( \text{Fe}^{3+} \)
  – Naturally occurs in soil systems
    • Except sandy soils
  – Each form an insoluble precipitant
Phosphorus Removal

• Biological Methods
  – Encourage the luxurious uptake of phosphorus within microbial cells
  – Harvest the cells before the excess phosphorus is released
  – Requires very controlled conditions
Future Wastewater Treatment

• Pharmaceuticals and Personal Care Products
  – what other “stuff” goes down the drain with our wastes
  – medicines, hormones, antibacterial soaps
  – many of these products are not removed with traditional means.

• Will we call this “quaternary treatment”?
So, the Ultimate Question.....

• At what point does wastewater become water?
  – are you willing to consume recycled water?
    • you are consuming recycled water
    • it’s called the hydrologic cycle
  – but, the cycle is getting smaller
    • civilization will have to adapt to the notion of their being a direct connection between the wastewater treatment plant and the water treatment plant
Questions?