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Recirculating Packed-Bed Media Filters

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Background

- Packed-bed recirculating media filters
  - Two problems with the name
    - the media doesn’t recirculate
    - and the process does not filter
- Common process for small-system wastewater treatment
  - passive aeration
  - low maintenance
  - larger footprint
  - withstands shock loadings

Primary Goals

- Use aerobic microorganisms to provide:
  - removal of biodegradable organics
  - removal suspended solids
  - convert nitrogen species to nitrate
- Use anaerobic microorganisms to convert nitrate into nitrogen gas

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

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

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

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

Biological Nitrification

- Organically bound nitrogen is released when the organic compound is oxidized
  - released as the ammonium cation (NH_4^+)
- Nitrification is a two-step autotrophic process
  - the conversion from ammonium to nitrate

Nitrosomonas

Step 1: $NH_4^+ \; + \; 3/2O_2 \; \rightarrow \; NO_2^{2-} \; + \; 2H^+ \; + \; H_2O$

Nitrobacter

Step 2: $NO^{2-} \; + \; 1/2O_2 \; \rightarrow \; NO^{3-}$

From Academic Curriculum chapter: *Onsite Nitrogen Removal.* By Stewart Oakley

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.

Biological Denitrification

- When an adequate carbon source is available, the principal problem associated with denitrification is the achievement of anoxic conditions.

- The dissolved oxygen concentration controls whether or not the denitrifying bacteria use NO_3^- or O_2 as the electron acceptor.

- Dissolved oxygen must not be present above certain maximum levels or the denitrifying bacteria will preferentially use it for oxidation of organic matter rather than NO_3^-.

- As a result, the design of anoxic zones is one of the most important factors in denitrification processes.

Biological Denitrification

Heterotrophic Denitrification

Wastewater as the Carbon Source

- The following unbalanced equation illustrates the process when wastewater or bacterial cell material is used as the carbon source:

$$\underset{\textit{organic matter}}{COHNS} + NO_3^- \xrightarrow{\textit{Heterotrophic Bacteria}} N_2 + CO_2 + \underset{\textit{bacterial cells}}{C_5H_7O_2N} + OH^- + H_2O + \text{end products}$$

Providing Dissolved Oxygen

- Aerobic treatment systems take advantage of natural processes by providing plenty of DO
  - high-rate carbon removal and ammonification
  - occupies a small-footprint
  - requires energy to maximize oxygen transfer
  - biological reactor

Aerobic to Anaerobic

- If dissolved oxygen is consumed faster than aeration, then anaerobic conditions occur
  - anaerobic microbes will continue the organic carbon degradation process
    - but at a much slower rate than aerobic microbes
  - Maintaining anaerobic conditions in a process designed to provide aerobic conditions is difficult

Microbes as Workhorses

- Microorganisms are used
  - to convert colloidal and dissolved carbonaceous organic matter into various gases and into cell tissue
    - gases evolve (CO_2, N_2, and others)
    - new cells can be settled – thus carbon is removed
  - break other nutrients out of organic compounds
    - nitrogenous compounds
    - phosphorus species

Optimizing a Natural Process

- Bioreactors are built to maximize the production of beneficial end-products
  - alcohols (beer)
  - insulin
  - other medications
- And
  - convert wastewater into secondary-quality effluent

Microbial Metabolism

- Chemical Activities Performed by Cells
  - Catabolism
    - biochemical process that degrades substrate (food) down to end-products with the release of energy
    - energy is held in chemical form for future use
  - Anabolism
    - biochemical process that synthesizes new cells.
    - energy from catabolism is used to drive the process

Catabolism

- Fermentation
  - first step in biodegradation
    - does not depend on presence of oxygen
  - both aerobic and anaerobic microbes use this step
    - this is why methane and alcohol production must be anaerobic
    - however, anaerobic microbes cannot further oxidize the VFA

$$\underset{\text{organic compounds}}{\text{COHNS}} \xrightarrow[\text{microbes}]{\text{heterotrophic}} \begin{bmatrix} \text{volatile} \\ \text{fatty} \\ \text{acids} \end{bmatrix} + CO_2 + H_2O + CH_4 + \text{energy} + \text{residuals}$$

Catabolism

- Respiration
  - second step for aerobic microbes
    - simple organic compounds can be oxidized to carbon dioxide and water
  - requires the presence of dissolved oxygen

$$\begin{bmatrix} \text{volatile} \\ \text{fatty} \\ \text{acids} \end{bmatrix} + O_2 \xrightarrow[\text{microbes}]{\text{aerobic}} \text{energy} + CO_2 + H_2O + \text{residuals}$$

Anabolism

- Building of Cell Protoplasm
  - energy from fermentation and/or respiration is used to assemble the characteristic chemical components of cells from simple precursors
    - precursors provide carbon, hydrogen, nitrogen and other elements found in cellular structure
    - chemical energy in adenosine triphosphate (ATP)

$$\underset{\text{precursors}}{\text{simple}} \xrightarrow[\text{energy}]{\text{microbes}} \underset{\text{new cells}}{C_{60}H_{87}N_{12}O_{23}P}$$

Endogenous Respiration

- Aerobic Degradation of Cellular Material
  - microbes are organic compounds
  - under substrate-limiting conditions, microbes will feed on each other at a higher rate than new microbes can be formed

$$\underset{\text{cellular material}}{C_{60}H_{87}N_{12}O_{23}P} + O_2 \xrightarrow[\text{microbes}]{\text{aerobic}} CO_2 + H_2O + PO_4 + NH_3 + \text{residuals}$$

Environmental Effects

- Microbes need more than organic carbon, dissolved oxygen and water
  - temperature must be life-sustaining
  - need steady supply of food to maintain stable microbial population
  - pH needs to be monitored
    - low alkalinity can cause large changes in pH
  - Be careful with biocides
    - acid drain cleaner
    - antibiotics

Summary

- Aerobic treatment of wastewater
  - takes advantage of a natural process
  - process can be easily engineered into a biological reactor for high-rate wastewater treatment
  - Carbon is transformed into cell mass and into carbon dioxide
- Anaerobic treatment of wastewater
  - Conversion of nitrate to nitrogen gas
  - Sacrifice some carbon removal for nitrogen removal

Technology Case Studies: Recirculating Media Filters

- Questions
  - how does the effluent from a packed-bed recirculating media filter respond to diurnal changes in organic loading?
  - does this variation in loading effect the denitrification process?
  - do weekend loadings differ from weekdays in terms of final effluent quality?

Packed-Bed Media Biological Reactor

Based on Trickling Filter Technology

However, There are Big Differences

- Trickling filter
  - high flow rate per surface area & deep
  - large pores between media particles
  - generation of biosolids, which must be collected
- Packed-bed recirculating media filter
  - low flow rate per surface area & shallow
  - small media particles, small pores
  - slow build-up of biosolids

Investigated System

- Blount County, Tennessee
- Subdivision
  - STEG
  - approximately 80 homes
    - three bedroom pre-manufactured housing

Wastewater Infrastructure

- Lift station
  - collects all the water from STEG
  - transfers water to recirculating packed-bed media filter
- Hines-Pickney sand filter
  - 10,000 gallon per day
  - volume moved through filter is approximately five times the daily inflow
- Subsurface drip irrigation dispersal

Specifications

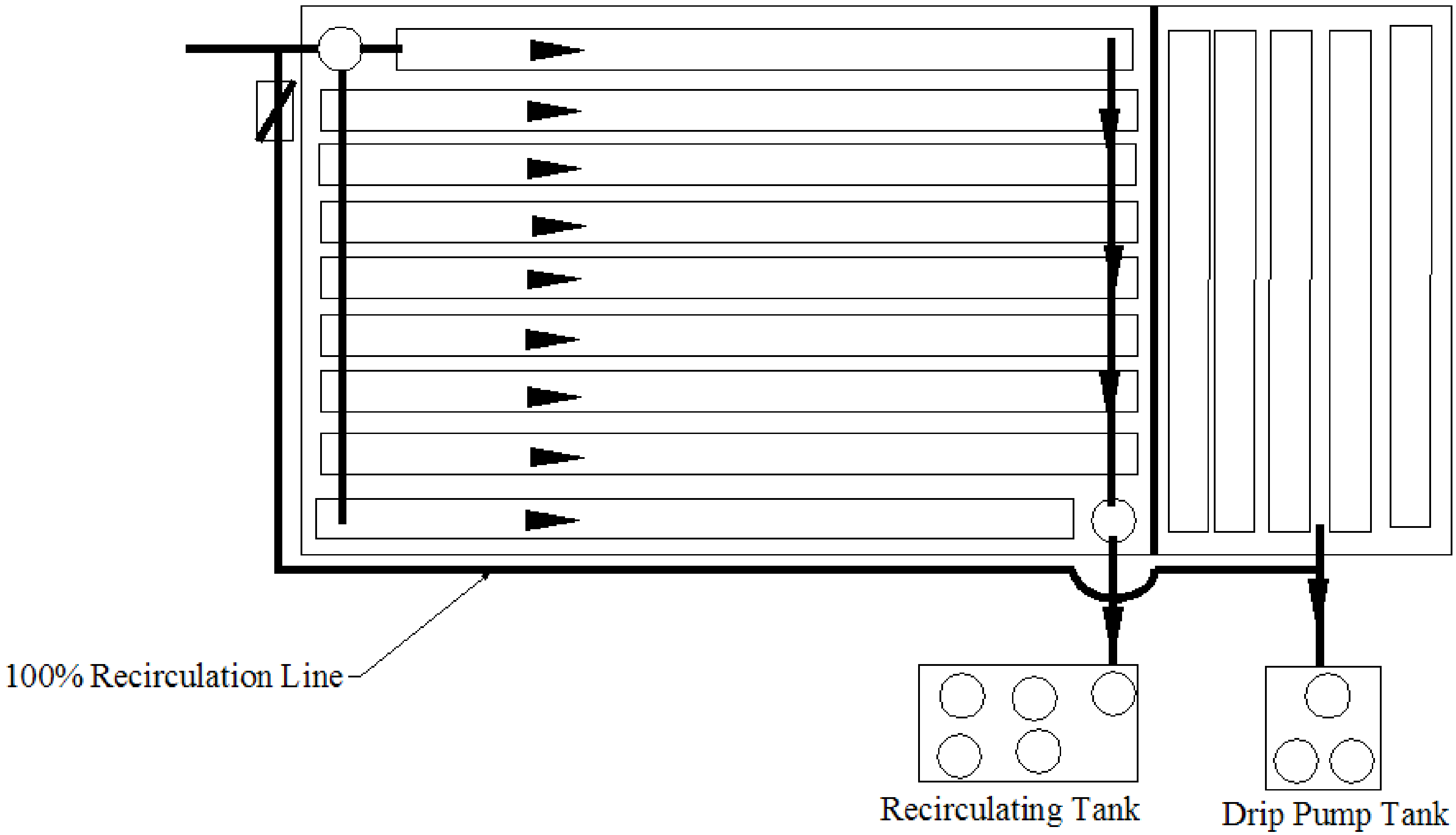
- 2,000 square feet of top surface area
  - 5 gallons per day per square foot
- 4 feet deep
  - bottom layer – 12” of open vaults
  - transition layer – 6” larger gravel
  - treatment media – 24” of fine gravel
  - cap over distribution laterals – 6” larger gravel

Specifications

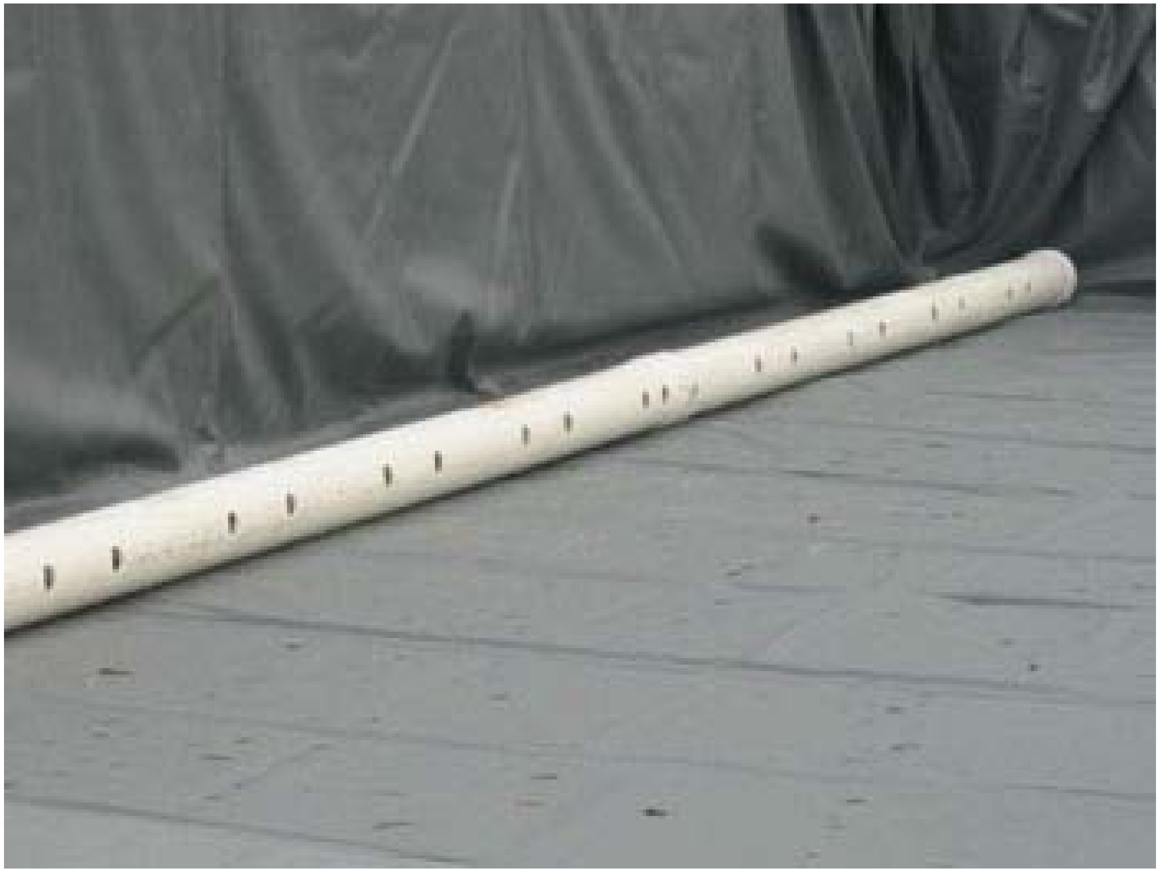
- Effluent distribution across top of media
  - low pressure system with orifices on 15” by 15” centers
  - four major zones, each with 4 subzones
- Recirculation and final pass
  - three zones recirculates
  - fourth zone drains to drip system dose tank

Liner and Divider Wall

Typical Flow Diagram



Distribution Pipe



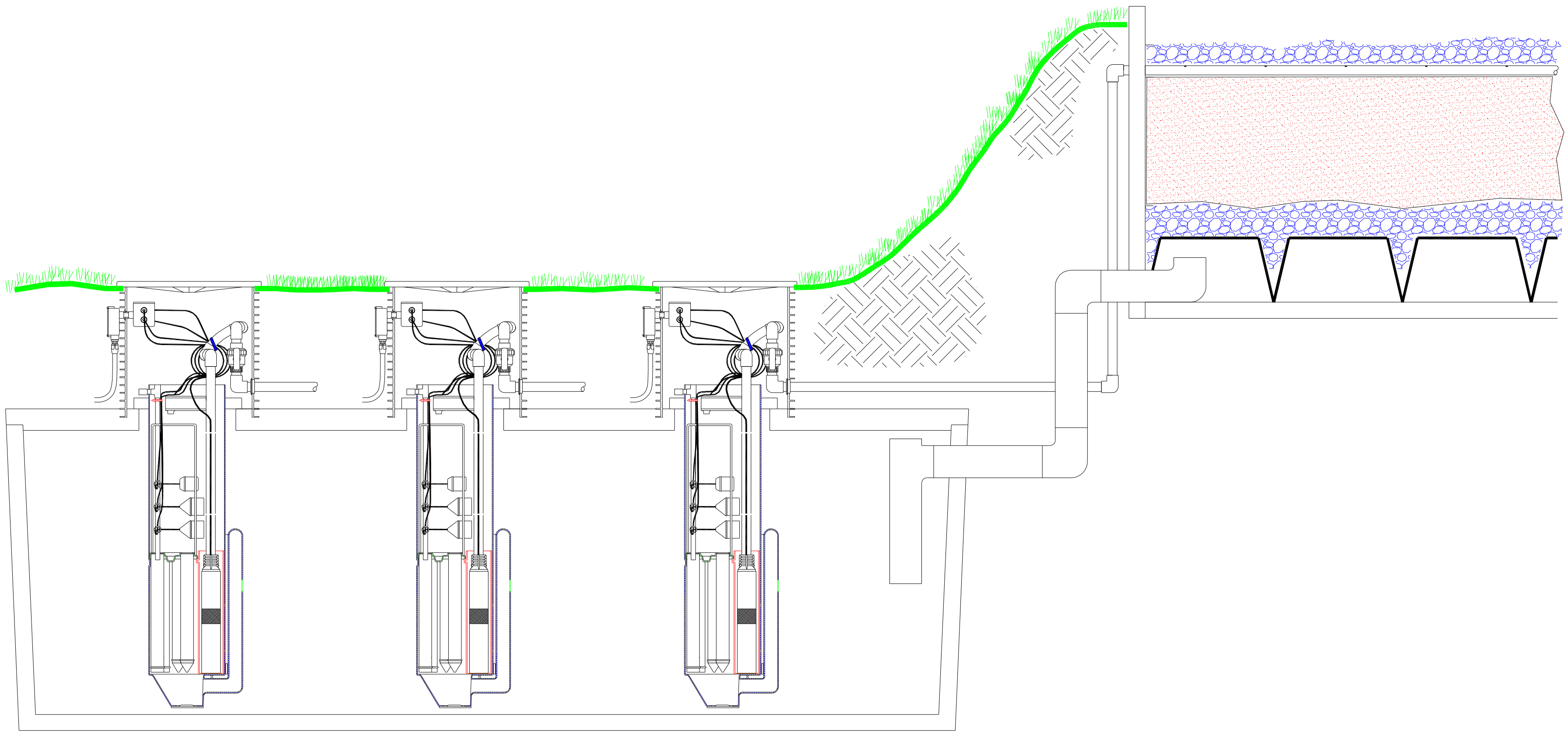
Chambers for Open Storage Beneath Media

Gravel over Chambers
Media over Gravel

Media Cap and Distribution Laterals

Recirculation Tanks and Dose Tanks

Recirculation Tank and Media Filter



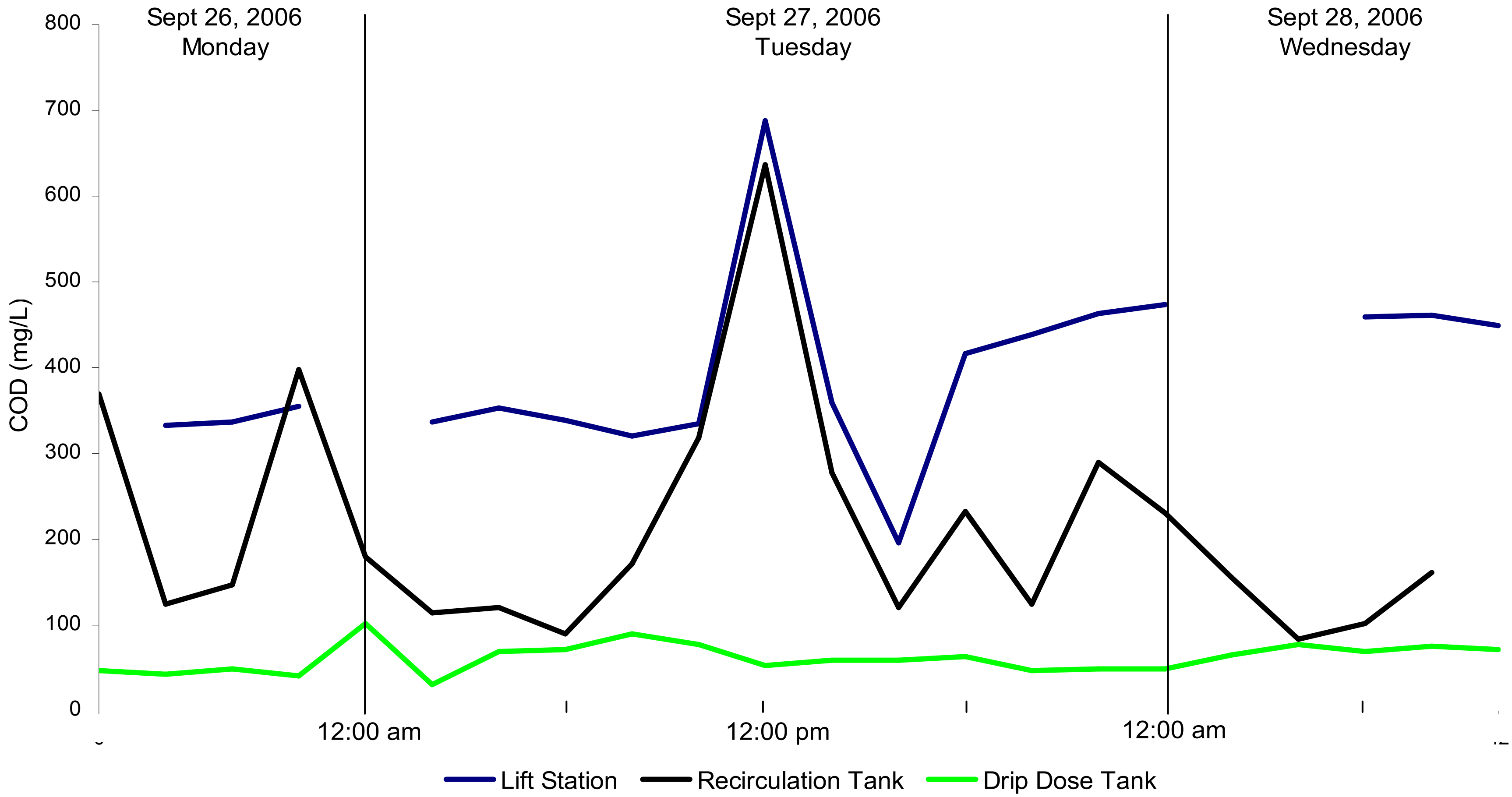
Treatment Capabilities

Question: Does diurnal variation of influent produce diurnal variation in final effluent ?

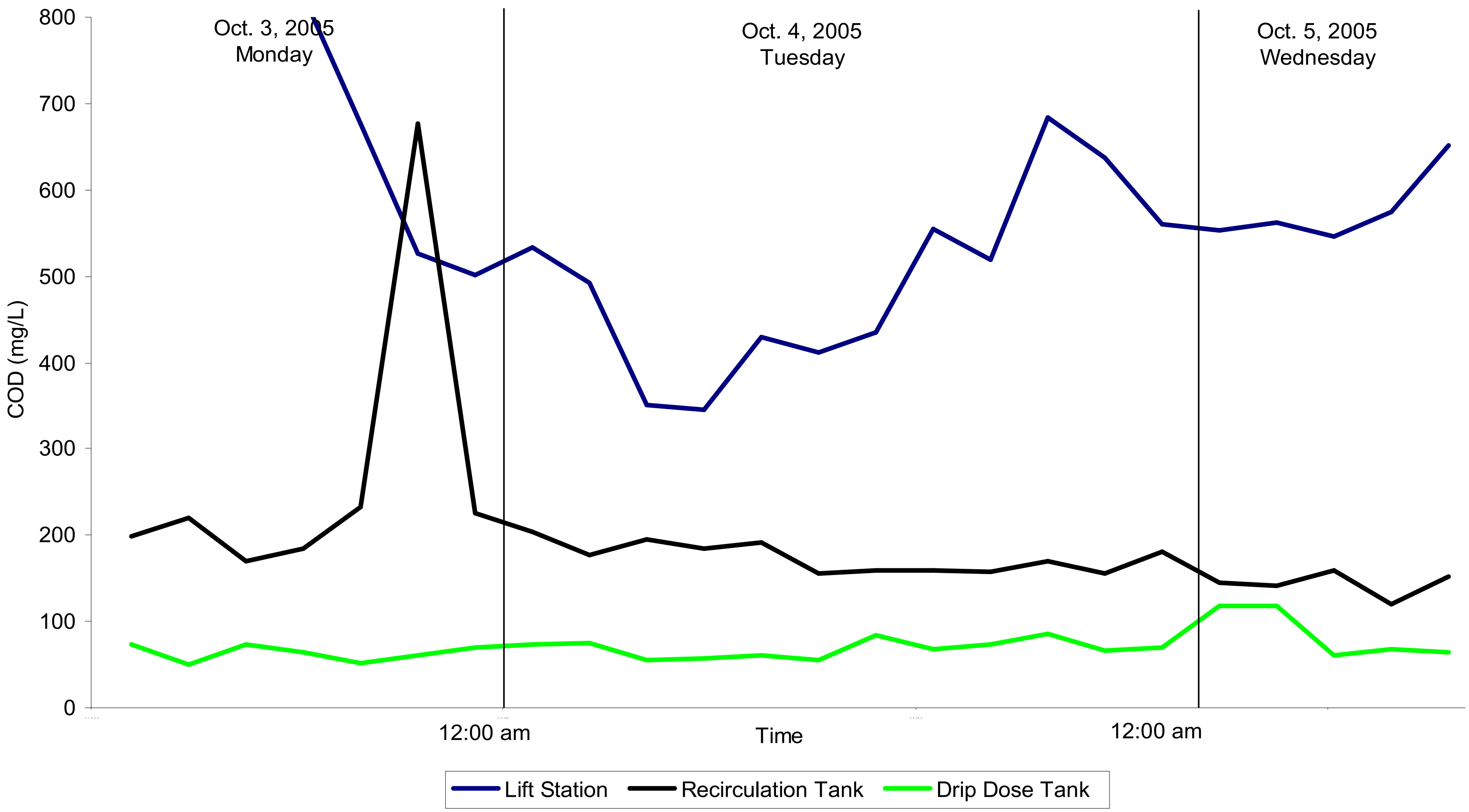
Sampling

- ISCO automatic samplers
  - programmed to take a 750 ml sample every two hours
  - can hold 24 samples, thus two days
- Three samplers
  - lift station tank
  - recirculation tank
  - drip dose tank

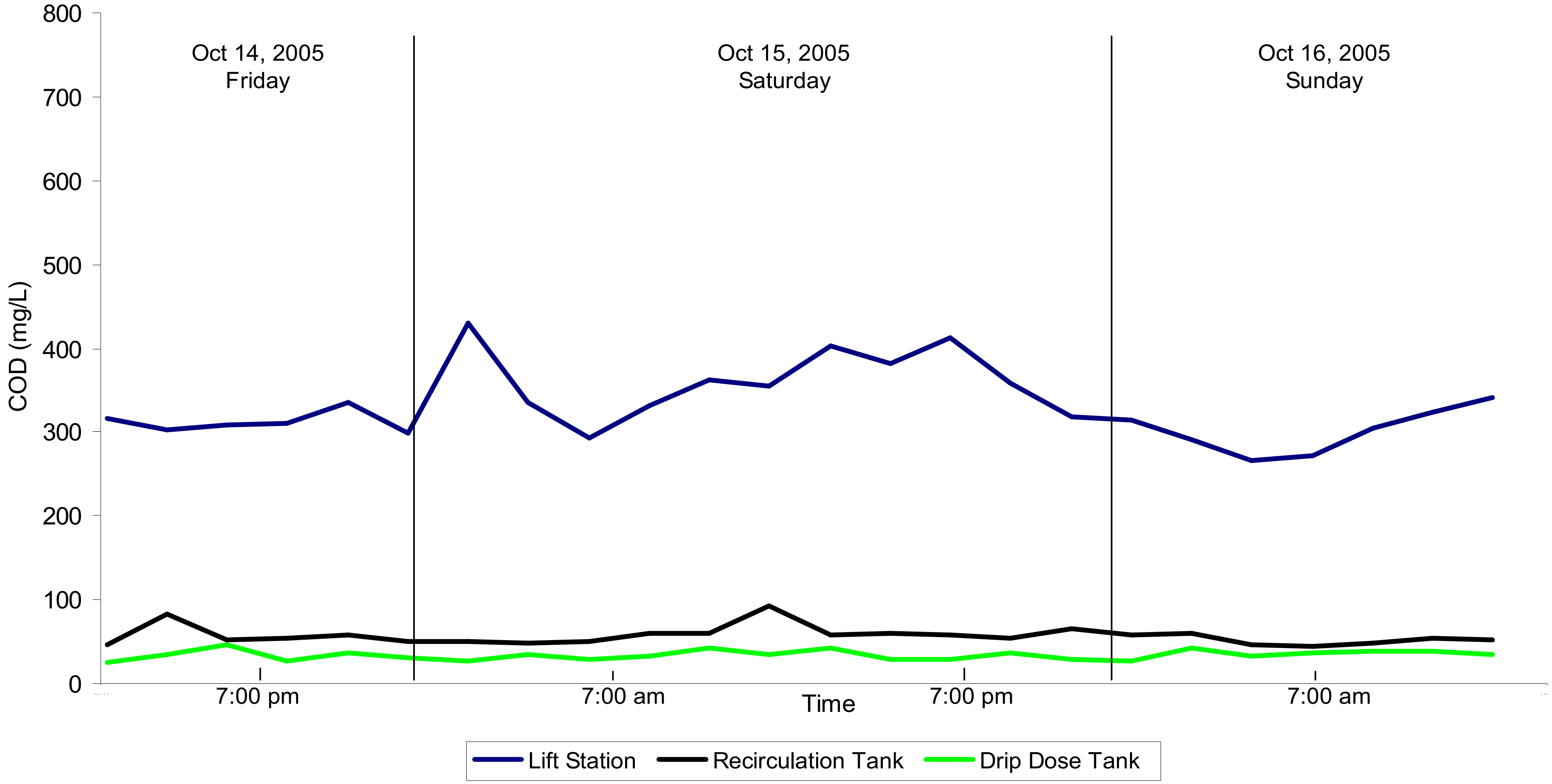
COD and Time (1st Set)



COD and Time (2nd Set)

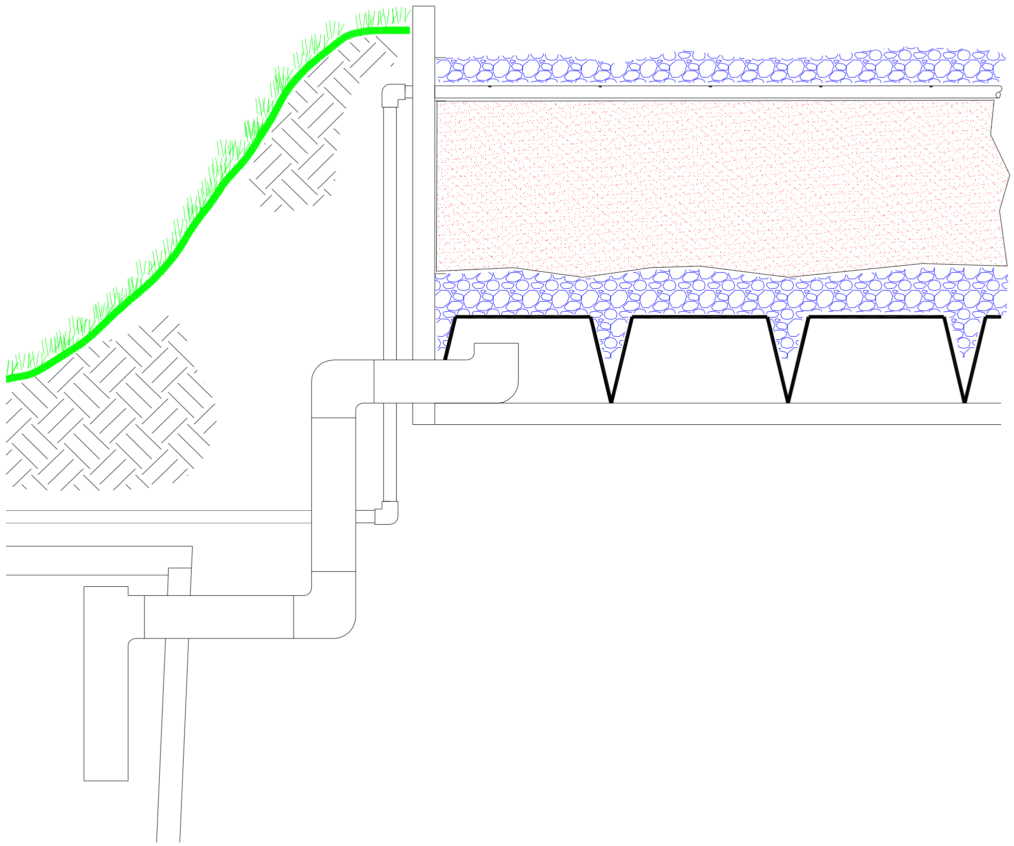


COD and Time (Weekend)

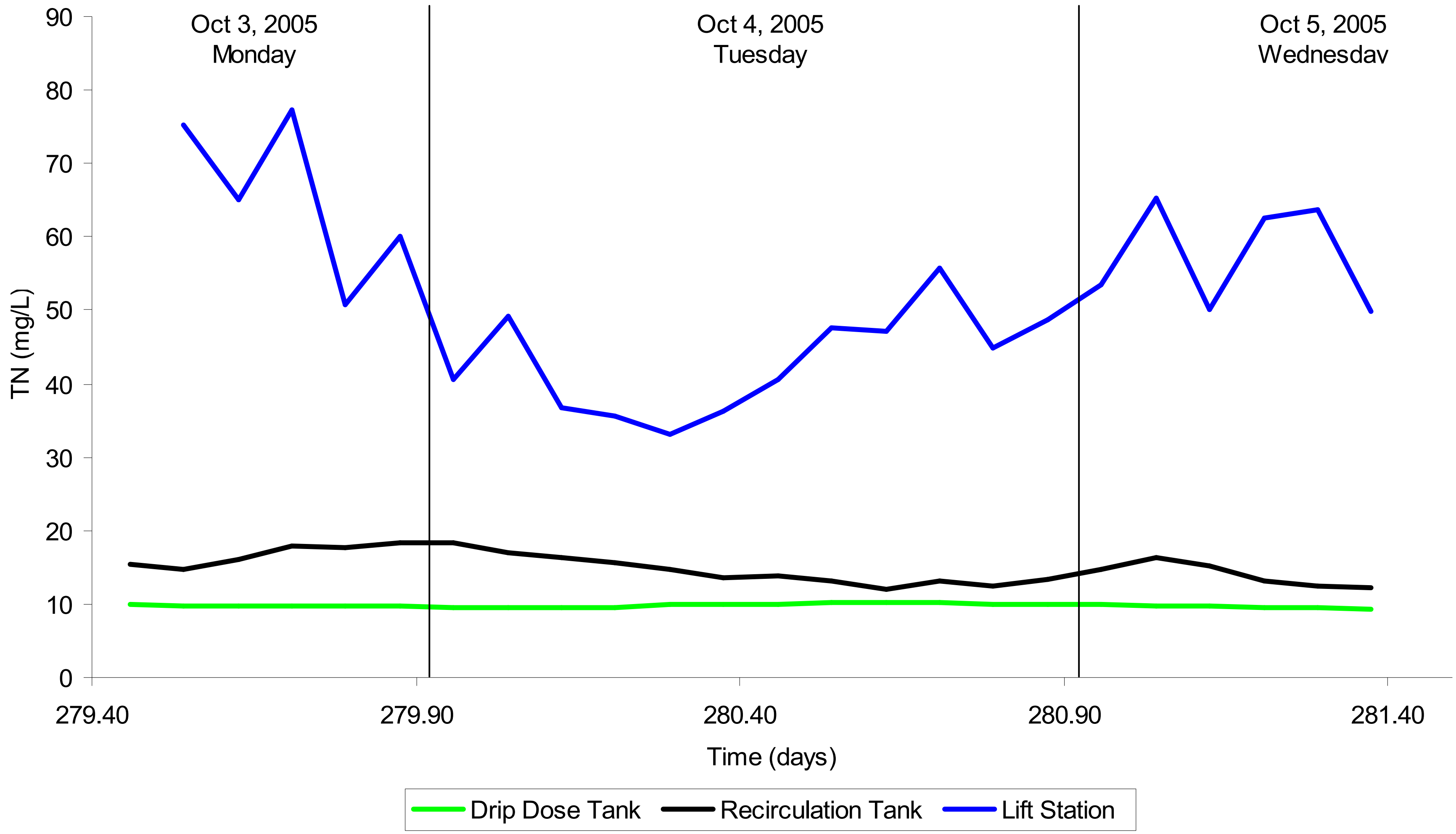


For Nitrogen Removal…

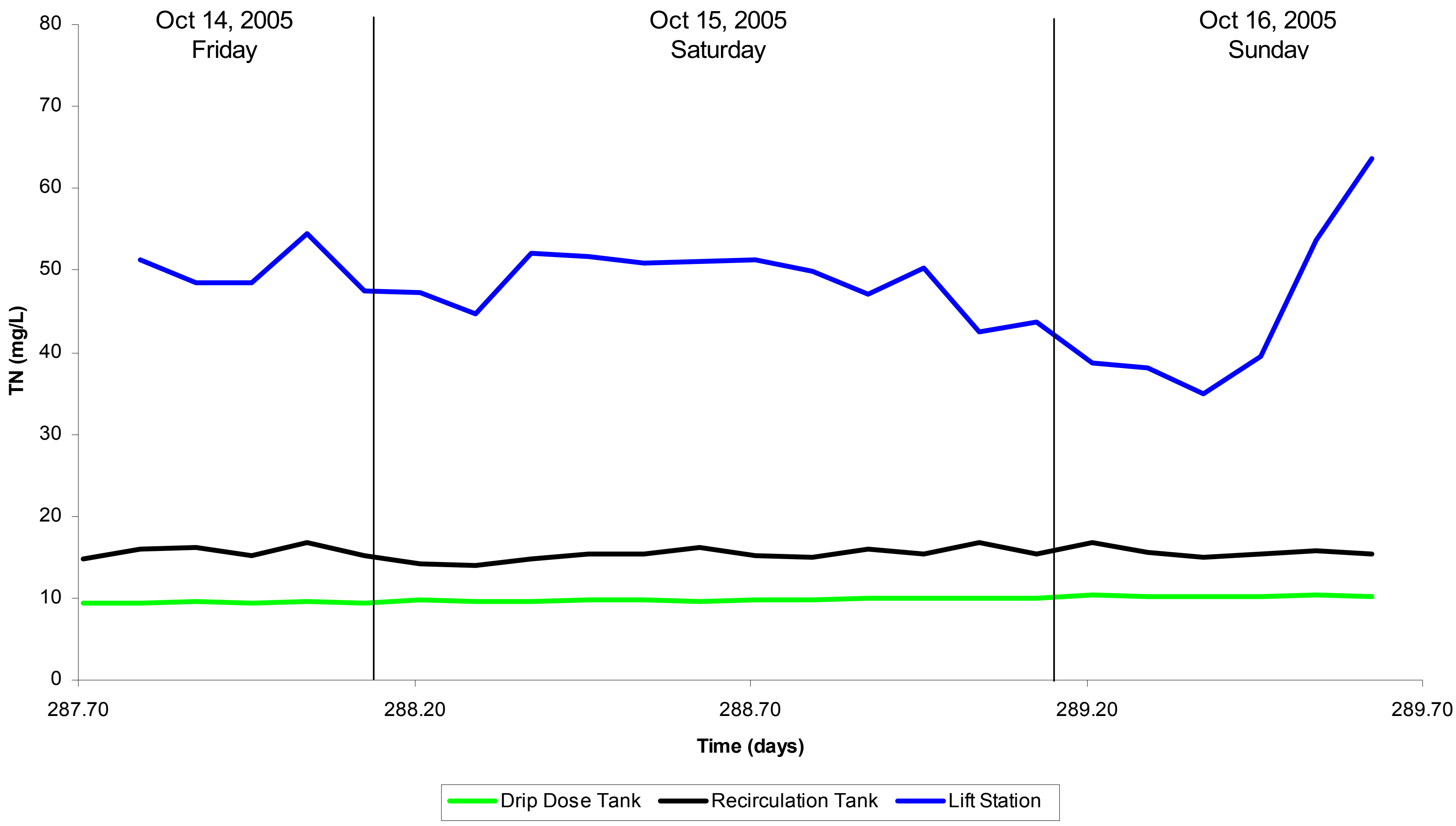
- Need aerobic conditions for nitrification and anaerobic conditions for denitrification



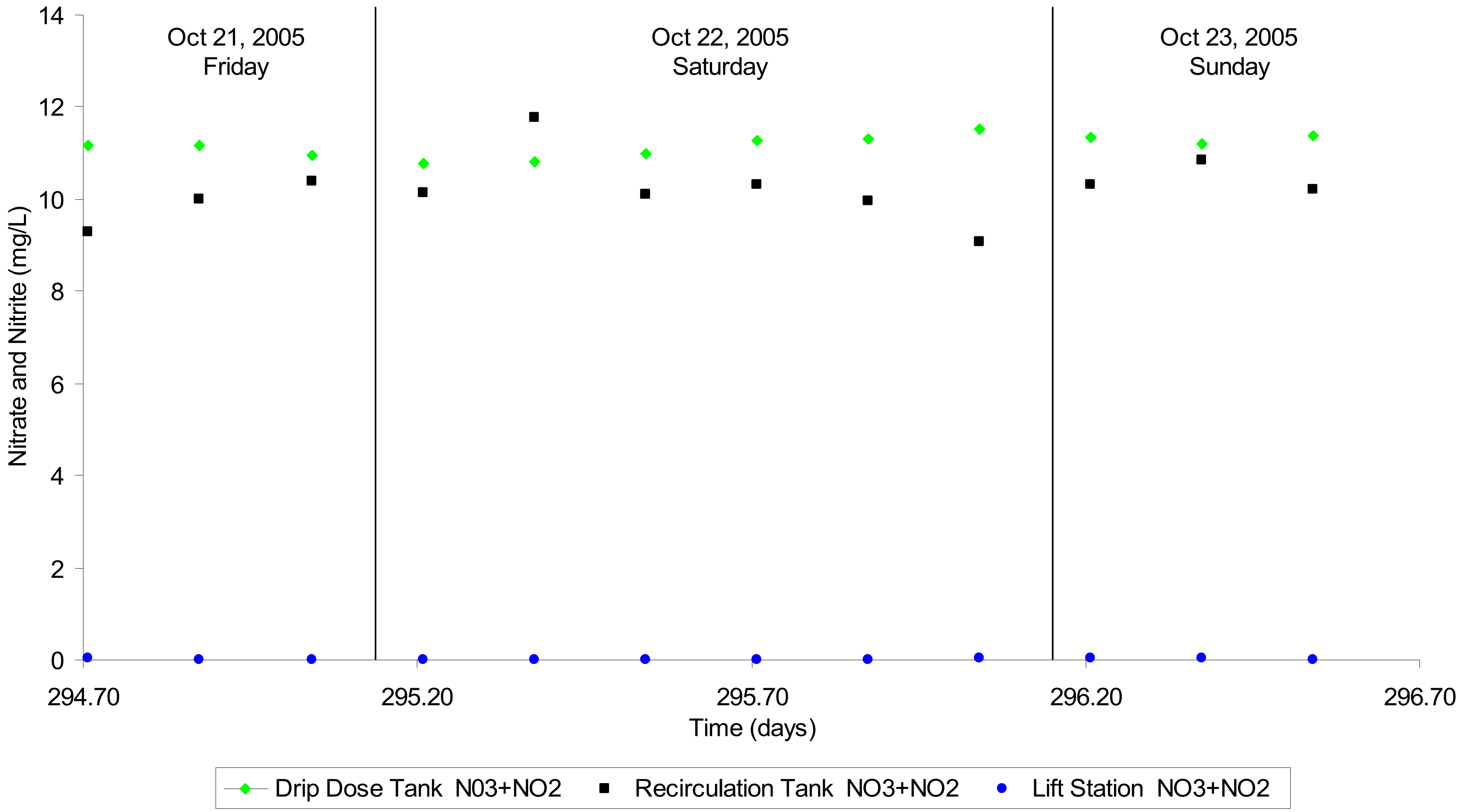
Nitrogen Removal (TN)



Total Nitrogen and Time (Weekend)



Nitrification and Denitrification



Preliminary Conclusions

- Sufficient buffering and mixing within system to handle variations in influent strength to produce very constant effluent
- Nitrification was not really a question
- Denitrification is occurring
  - can it be optimized?

Next Phase

- Measure dissolved oxygen at various locations
  - does the recirculation tank maintain anaerobic conditions?
    - with all the recirculation, is the organic strength high enough to consume the D.O.?
  - could recirculation be suspended during low flows to allow more denitrification to take place?
  - at what cost to carbon removal?

Cuss and Discuss Time

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