ANTIDEGRADATION ALTERNATIVES FOR MUNICIPAL SEWAGE TREATMENT

December, 2010

Prepared for:

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1.0 INTRODUCTION

While the technology of wastewater treatment has made advances in treatment methodology in many areas, antidegradation laws are requiring communities to re-examine sewage treatment systems to find alternative treatment methods that further reduce pollutant loadings to water bodies. The purpose of this study is to compile operational, cost, design, and performance parameters on treatment alternatives for conventional municipal sewage treatment in order to demonstrate the feasibility of advanced and innovative methods and to assist decision makers in meeting antidegradation requirements.

Applied Ecological Services, Inc. (AES) was retained by Prairie Rivers Network (PRN) on behalf of the Mississippi River Collaborative (MRC) to develop a report that examines both the economic and technical feasibility of state of the art treatment alternatives for new or expanding municipal sewage treatment facilities. The product is to be used to present operators with environmentally sound sewage treatment alternatives that are feasible and cost effective to implement. AES has teamed with Environmental Consulting & Technology, Inc. (ECT) and Natural Water Solutions, LLC (NWS) in the creation of this document.

The intended audience of this document is operators of systems that treat excess of 10,000 gallons per day (gpd), or 100 persons served. The alternatives provided herein are divided into those applicable to medium sized systems (10,000 gpd to 1 million gallons per day- mgd, or 100 to 10,000 persons served) and large sized systems (greater than 1 mgd, or 10,000 persons served). A discussion on small system alternatives has also been included. The treatment alternatives presented will examine removal technologies for TSS, BOD, ammonia, total nitrogen, nitrate, total phosphorus, and pathogens.

Flow figures used for this comparison are the traditional units of 100 gallon per capita (person) per day. Over the past 10 to 15 years municipalities and industries are improving their collection system maintenance and practicing more water efficient methods of use. Thus we are seeing flow numbers often in the neighborhood of 65 gallons per capita per day.

Included in this document are a report text, an antidegradation matrix for municipal sewage treatment, and a matrix listing effluent characteristics of treatment alternatives. The purpose of the antidegradation matrix is to provide brief criteria on treatment alternatives for medium to large systems. The effluent characteristics matrix is a listing of achievable water quality results for the treatment alternatives listed in the antidegradation matrix. The report text should be consulted for additional detail on each system as well as brief descriptions of small system alternatives and a list of references used in the preparation of this document.

Wastewater Treatment Overview

As all operators know, the final decisions on plant expansions are made by elected officials and/or appointed boards, all of whom rarely understand the mechanisms that control treatment efficiencies. For that reason, this report includes the following synopsis of wastewater treatment.

The purpose of wastewater treatment is to remove the contaminants from wastewater with the objective that it is treated enough to be released back into the environment. The treatment is achieved through physical, chemical and biological processes that occur naturally. Wastewater treatment facilities aim to accelerate such processes. Treatment can occur on-site, near the location where the wastewater is generated, or it can be transported to a facility (municipal treatment facility) through a network of pipes. Collection and discharge of wastewater is typically regulated by standards established at the local, state or federal level.

Conventional wastewater treatment can involve preliminary, primary, secondary and tertiary treatment. Preliminary treatment is used to remove large objects such as rocks, sticks, and trash from the wastewater, normally through the use of bar racks and screens. Another component to preliminary treatment involves the removal of grit, sand, stones, and small debris from the wastewater. In primary treatment, the wastewater is collected and held so that solids are allowed to settle and oils and greases are allowed to float. The remaining wastewater is then sent to secondary treatment where mico-organisms digest the biological matter within the wastewater. Typically, the settled solids from primary and secondary treatment are sent to an anaerobic digester as part of secondary treatment to reduce the quantity and stabilize the solids. Anaerobic digestion is a biologic process that occurs by microorganisms in the absence of oxygen. Anaerobic activity reduces the volume of organic solids and by-products are carbon dioxide gas and methane which can be captured and utilized. Any additional treatment in addition to primary and secondary is tertiary treatment.

Disinfection of Effluent

The report and matrices focus on nutrient s (nitrogen and phosphorus constituents), ammonia, BOD, and TSS removal. It is important to note that wastewater treatment facilities often have bacterial discharge standards and disinfection of the effluent is required to reduce the number of microorganisms discharged to the receiving water (stream, groundwater, lakes, or oceans). Methods of effluent disinfection include chlorination (chlorine or sodium hypochlorite), ozonation, and ultraviolet light (UV). The effectiveness of disinfection depends on the quality of the effluent water (suspended, BOD, pH, etc.), which is determined by the level of treatment. Highly treated wastewater is more readily disinfected to meet the bacterial standards.

Chlorination has been the most common form of wastewater disinfection due to its low cost and long-term history of effectiveness. However, the use of chlorine by treatment plants is currently decreasing due to safety concerns: chlorine released to the atmosphere can be toxic to people; combination with organics can produce chloramines or other compounds that are carcinogenic; residual chlorine is toxic to aquatic species. A dechlorination step is needed to remove residual chlorine before discharge to the receiving water.

Ozone (O_3) is generated by passing oxygen through a high voltage potential. Ozone is very unstable, reactive, and oxidizes most organic material it comes in contact with, including many pathogenic microorganisms, BOD, and TSS. Ozone produces few disinfection by-products compared to chlorine but it also has safety concerns. It is highly poisonous if released accidently, and as an oxidizer there is an explosive hazard when released. The high cost of the ozone generation equipment and the requirements for special operators are further limitations on its use.

In the last twenty years UV disinfection has become more common given concerns about the impacts of chlorine in chlorinating residual organics in the wastewater or chlorinating organics in the receiving water. UV is safer than either ozone or chlorine for the wastewater treatment operators and the public.

2.0 MEDIUM AND LARGE SYSTEM TREATMENT ALTERNATIVES > 10,000 GPD

The alternatives presented within this section are applicable to systems greater than 10,000 gpd.

The alternatives presented are separated into the following categories:

- Non-Discharging Alternatives- systems other than those considered surface water discharging by US EPA.
- Enhanced Treatment of conventional technology through modification of the treatment system to increase removal of effluent constituents
- Advanced Innovative Treatment Technologies- used to extend the treatment of conventional secondary treatment systems
- Conventional Alternatives- systems that are widely accepted and used.
- Seasonal Discharging Alternatives- surface water discharging during certain seasons.

DEDICATED & SEASONAL LAND APPLICATION NONDISCHARGING

System Size	Pollutants Addressed		
☑ Small	☑ Ammonia	☑ TSS	☑ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☑ TN
☑ Large			

Description
Dedicated Land Application or Seasonal Application Systems typically utilize one of three application techniques: Drip Irrigation, Spray Irrigation and Overland Flow. Spray irrigation with center pivot equipment is the more commonly used technique. The land application itself provides a tertiary method of treatment and is used in conjunction with primary and secondary treatment. Dedicated application systems are used in warm areas where the soil is not frozen in the winter. A dedicated system in a warm area is usable year around. Seasonal systems are more common in the Midwest and North where the soil freezes in the winter. A seasonal system is used during spring to fall and effluent generated during winter months is typically stored in a holding lagoon for application after winter.

During Spray and Drip Irrigation the wastewater is distributed evenly on a vegetated plot of land where it is treated. During an Overland Flow application, the wastewater is distributed along the top contour of a gently sloping site. The water flows down the slope and is treated by the plants and infiltrates into the soil as it flows past. Generally the irrigation systems are designed to have no discharge from the land application. Application fields will have a collection point where runoff from an application field can be checked and released if the quality is acceptable. The performance of dedicated land application treatment is difficult to generalize as it is dependent on the type of vegetation and soil characteristics of the area where the water is being applied. Costs of these systems are dependent upon the capital needed to purchase the irrigation equipment, the amount of land required for application (a Seasonal system may require a constructed lagoon to hold the effluent over winter), the degree of pre-treatment to settle and remove solids prior to application, and the possible need for pathogen treatment prior to land application.

Typical Applications
Deep, well-drained and permeable soils are best suited for reclaimed water irrigation. Soils with good tilth in the surface layer facilitate the infiltration and percolation of water and prevent surface runoff. Good permeability in the subsoil layers fosters biological activity in the root zone that maximizes nutrient and water utilization by the growing plants. Adequate depths to bedrock and the seasonally high water table are required (> 4 feet).

Critical Design Parameters
- Hydraulic and nutrient loading of the site
- Pre-treatment
- Land Area and topography

Effluent Characteristics
The effluent characteristic will be a function of the pretreatment method and effectiveness, the type of vegetation and soil characteristics of the area of application. Generally, land application can provide good removal of BOD, TSS and Phosphorus. During the growing season, Ammonia can be removed as well.

Cost Considerations

- *Capital*- The capital cost of a Land Application System may require larger land areas, though land need not be purchased in all cases. Pre-treatment is often required prior to application and this could require additional plant facilities.
- *O&M*- Operation and Maintenance costs will include the costs for manual labor required for inspection and maintenance, power for operation, and materials used for the pre-treatment and irrigation system.

Benefits

- Because reclaimed water is being used to irrigate, there are potable water savings.
- Can provide source of irrigation water for off-site users.
- Nutrients are being recycled to plants.
- Potential water source to use for ground water recharge.
- Non-discharge can preserve in-stream water quality.

Limitations

- Large area of land may be required, but can land apply a portion of effluent reducing requisite land mass.
- Requires pre-treatment
- Requires buffer to control human contact

Related Technologies

- Reclaimed water reuse

RAPID INFILTRATION BASIN ENHANCED TREATMENT

<u>System Size</u>
☐ Small
☑ Medium
☐ Large

<u>Pollutants Addressed</u>
☐ Ammonia ☑ TSS ☑ Nitrate
☑ BOD/DO ☑ Phosphorus ☐ TN

Description
Rapid infiltration Basins (RIBs) consist of a shallow vegetative basin overlying highly permeable soils. Treated wastewater enters the basin and continues treatment (polishing) as if flows through the soils. In some instances the wastewater can be collected by an under drain system for additional treatment. RIBs are typically used in medium size systems; however the key is suitable soil conditions. RIBs can provide quality reclaimed water groundwater recharge; however, seasonal storage is often required. In colder climates, there is a lower rate of treatment during the winter and, therefore, the water must be detained for longer periods to compensate. Additionally, the wastewater entering a RIB must be pre-treated, so pre-treatment costs must be considered.

Typical Applications
RIBS require highly permeable soils with no underlying constraints that could result in ground water contamination.

Critical Design Parameters
- Soil characteristics of underlying soils
- Hydraulic loading rate
- Lack of groundwater close to the infiltration basin
- No bedrock or highly fractured (Karst limestone) rock close to bottom of the infiltration basin

Effluent Characteristics[15]
Most Rapid Infiltration Basins discharge directly to the groundwater and do not have a discharge to surface water. Some RIB treatment facilities capture seepage from the applied water in under drains. The effluent quality from the under drain is represented by the following characteristics:
BOD: < 5mg/L (95% reduction)
TSS 1 mg/L
Nitrate: < 5 mg/L (40%-90% reduction)
P: < 1 mg/L (90 - 99% reduction)

Cost Considerations
- *Capital-* The underlying soil characteristic can affect the cost. The permeability of the soil will govern the size of the basin(s), and therefore the cost.
- *O&M-* The RIB will require periodic roto-tilling and vegetation removal.

Benefits
- Groundwater Recharge and reuse.
- Wildlife habitat in the basin vegetation.
- Can be integrated into trail and park developments for interesting diversity of plantings and wildlife.

Limitations

- Land area needed and no traffic is allowed in or around the RIB.

Related Technologies

- Groundwater Injection (not often practiced). With higher levels of treatment we will see this more and more in use and corresponding changes in regulations to allow.

System Size
☐ Small
☑ Medium
☑ Large

Pollutants Addressed
☑ Ammonia ☑ TSS ☐ Nitrate
☑ BOD/DO ☑ Phosphorus ☐ TN

Description
Traditional activated sludge plants do not address Ammonia, and can be modified to do so. This is achieved by extending the aeration provided and the detention time or by increasing the amount of biomass within the facility. Examples of modified activated sludge plants include:

- Integrated Fixed Film in Activated Sludge Systems (IFAS) - In the IFAS, additional surface area within the facility is provided by adding media in the aeration chambers to increase the surface available for microbial growth.
- Membrane Bioreactor (MBR) - Combines activated sludge treatment with a membrane liquid-solid separation process. The membrane acts as a micro-filter or ultra-filtration layer and the biomass growing on the membrane actively removes solids thereby lessening or eliminating the need for final clarification.

Typical Applications
Use to enhance removal of nitrogen, TSS, BOD, and phosphorus over conventional activated sludge plants using small footprint chambers containing the media or the membrane. Their removal efficiency produces high quality effluent which could be valuable for water reuse systems.

Critical Design Parameters

- Biomass effective area available on the media or membrane.
- Aeration delivery system design.
- Influent characteristics.

Effluent Characteristics

Ammonia: <2 mg/L
BOD: 10-30 mg/L
TSS: 10-30 mg/L
TN: little reduction
Nitrate: little reduction
P: 2.5 – 6 mg/L (15-20% reduction)

Cost Considerations

- *Capital*- The systems require additional mechanical controls .
- *O&M*- Cost of energy to operate the aeration system

Benefits

- Increase in solids retention time (SRT) with enhanced nitrification.
- More stable microbial populations which are less effected by hydraulic or organic shock loads than conventional activated sludge systems.
- Reduction in sludge production versus conventional activated sludge systems.

Limitations

- Membranes can be affected by grease or grit.
- High peak flow rates can cause problems. Work best with consistent flow rates.
- Fouling.

Related Technologies

- Conventional Activated Sludge.
- Oxidation ditches
- Sequencing Batch Reactors

MODIFIED LUDZACK ETTINGER (MLE) ADVANCED INNOVATIVE

System Size	Pollutants Addressed		
☐ Small	☑ Ammonia	☑ TSS	☑ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☑ TN
☑ Large			

Description

The purpose of the Modified Ludzack-Ettinger (MLE) process is to remove nitrogen from wastewater. The MLE process consists of two zones, an anoxic zone and an aerobic zone. The wastewater enters the system and is mixed with return sludge (settled) recycling from the clarifier and the aeration tank effluent liquor. Both of these streams are high in nitrate (NO_3). The microorganisms from the return sludge use the nitrogen from the aeration tank effluent liquor, consume ('eat") carbon in the influent wastewater, and convert the nitrate to nitrogen gas in the anoxic reaction (no dissolved oxygen).

Typical Applications

The MLE process may be used with any other activated sludge treatment system. It is commonly used upstream of an oxidation ditch.

Critical Design Parameters

- Recycle ratio for control over nitrogen removal
- Type of pre-treatment
- Adequate influent carbon (soluble food value)
- Effluent requirements

Effluent Characteristics

Ammonia: 0-2 mg/L
BOD: 10-20 mg/L
TSS: 10-20 mg/L
TN: 5-8 mg/L
Nitrate: 3-6 mg/L
P: 2-6 mg/L (15- 35% reduction)

Cost Considerations

- *Capital -* Because of the small footprint, the cost of land is not an issue. The capital cost associated with the MLE include all of the equipment required such as blowers, diffusers, valves, mixers, pumps, decanters and a control panel as well as the tanks, earthwork, and installation.
- *O&M* – Additional energy is required for aeration and a slight increase in operator monitoring time for proper system control.

Benefits

- Offers control over the amount of total nitrogen removed based on the recycling ratio.

Limitations

- Temperature dependent.
- Uncontrolled filamentous growth of biomass can occur
- Recycle volume monitoring to assure good reduction

Related Technologies

The Bardenpho process is the MLE process with two additional zones. The third zone is an anoxic zone. In the fourth zone, re-aeration helps removes nitrogen gas and increases the DO of the wastewater. The Bardenpho process can decrease the nitrogen concentrations to 3 to 5 mg/L (Nutrient Control Design Manual: State of Technology Review Report, EPA, 2009).

BARDENPHO PROCESS — ADVANCED INNOVATIVE

System Size
☐ Small
☑ Medium
☑ Large

Pollutants Addressed
☑ Ammonia ☑ TSS ☑ Nitrate
☑ BOD/DO ☑ Phosphorus ☑ TN

Description
The Bardenpho process is the MLE process with two additional zones. The third zone is an anoxic zone and aeration occurs in the fourth zone to remove nitrogen gas and increase the DO of the wastewater.

Typical Applications

Critical Design Parameters
- Recycle ratio for control over nitrogen removal
- Type of pre-treatment
- Adequate influent carbon (soluble food value)
- Effluent requirements

Effluent Characteristics
The Bardenpho process can decrease the total nitrogen concentrations to 3 to 6 mg/L (Nutrient Control Design Manual: State of Technology Review Report, EPA, 2009).
Ammonia: 0-1 mg/L
BOD: 10-20 mg/L
TSS: 10-20 mg/L
TN: 3-6 mg/L
Nitrate: 1-7 mg/L
P: 2-6 (15-35% reduction)

Cost Considerations
- *Capital-* . The capital cost associated with Bardenpho includes large tanks with earthwork, and installation along with all the equipment required such as blowers, diffusers, valves, mixers, pumps, decanters and control panel.
- *O&M-* Additional energy aeration and more operator time needed to monitor the system to maintain the proper recirculation ratios. Possible methanol additions to optimize biologic activity.

Benefits
- Offers control over the amount of total nitrogen removed based on the recycling ratio.

Limitations
- Can be carbon limiting for biologic growth. Addition of methanol can overcome this issue.

Related Technologies
- Modified Ludzack Ettinger (MLE)
- Oxygen ditch with nitrogen removal.

OXIDATION DITCH WITH NITROGEN REMOVAL   ADVANCED INNOVATIVE

System Size	Pollutants Addressed		
☐ Small	☑ Ammonia	☑ TSS	☑ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☑ TN
☐ Large			

Description
An oxidation ditch consists of a long channel equipped with aeration within which wastewater is continuously circulated. The oxidation ditch can be designed to include nitrogen removal. This can be done through the addition of the Modified Ludzack-Ettinger process to the system, or modifications to the ditch to encourage nutrient removal between the anoxic and aerobic zones within the ditch. Pre-treated wastewater entering the ditch is aerated and mixed with return sludge from a secondary clarifier. The wastewater is circulated through the ditch and passes through multiple aerations zones. These zones result in a high DO just downstream of the aerators (where nitrification can occur) and a low DO just upstream of the operators (allowing for denitrification). The wastewater is then sent to a separate clarifier.

Typical Applications
The MLE process may be used with any other wastewater treatment system. Because it requires a large amount of land, oxidation ditches are applicable for small rural communities.

Critical Design Parameters
- Retention time
- BOD loading

Effluent Characteristics
When an oxidation ditch is designed for nitrogen removal, effluent concentrations can be less than 1 mg/L. (EPA Wastewater Technology Fact Sheet Oxidation Ditches, 2000).
Ammonia: 0-1 mg/L
BOD: 10-20 mg/L
TSS: 10-20 mg/L
TN: 3-6 mg/L
Nitrate: 2- 5 mg/L
P: 2-6 mg/L (15 – 35% reduction)

Cost Considerations
- *Capital*- The land required for an oxidation ditch can be significant and can contribute significantly to the cost.
- *O&M*- Oxidation ditches can provide lower operation and maintenance costs in relation to other secondary treatment systems.

Benefits
- Easy to maintain and operate
- Produces less sludge than other systems
- Can be operated efficiently

Limitations

- Requires a large area
- TSS concentrations can be high compared to other systems
- Takes about one to two years to optimize, after which the system is quite reliable.

Related Technologies

- Modified Ludzack Ettinger (MLE)
- Bardenpho Process.

SANITAIRE'S ICEAS PROCESS — ADVANCED INNOVATIVE

System Size	Pollutants Addressed		
☐ Small	☑ Ammonia	☑ TSS	☑ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☑ TN
☑ Large			

Description
The Intermittent Cycle Extended Aeration System offered by Sanitaire is a modified version of the sequencing batch reactor (SBR). In this system the wastewater flows into the reactor continuously, and thus the need for additional reactors or methods for flow receipt is eliminated. This is achieved within a single reactor containing two zones. The first zone allows the inflow to be aerated and mixed allowing the biological reactions to occur. The flow enters the second zone where settling occurs. After settlement the clear water is discharged and sludge is collected for additional treatment.

Typical Applications
Because of their small footprint, the ICEAS is used when space is limited.

Critical Design Parameters
- Influent characteristics
- Effluent requirements
- Number of basins
- Number of cycles
- Aeration equipment

Effluent Characteristics
SBRs can achieve good removal rates for BOD, TSS, Nitrogen and Phosphorus:
Ammonia: 0.5-5 mg/L
BOD: <10mg/L
TSS: <10mg/L
TN: 3-5 mg/L
Nitrate: 3-6 mg/L
P: 0.3-2 mg/L
(EPA Wastewater Technology Fact Sheet Sequencing Batch Reactors, 1999)

Cost Considerations
- *Capital*- Because of the small footprint, the cost of land is not an issue. The capital cost associated with the SBRs include all the equipment required such as blowers, diffusers, valves, mixers, pumps, decanters and control panel as well as the tanks, earthwork, installation. Furthermore, additional treatment may be required as part of the system.
- *O&M*- Because the primary and secondary clarifiers are included within the SBR, the cost associated with those is eliminated.
- *Modifications to progress from TSS/BOD removal to nitrogen and/or phosphorus removal are easily made with the addition of mixer(s), and programming changes.*

Benefits

- Less area required
- Easily modified for nutrient removal if required in the future
- Greater operator control allow for increased flexibility in treating variable wastewater influents
- Primary and secondary clarification within one reactor is possible (reducing cost and space)

Limitations

- Potential for sludge disposal during decant phase

Related Technologies

- Modified Ludzack Ettinger (MLE)
- Bardenpho Process.
- Oxygen ditch with nitrogen removal.

A^2/O PROCESS ADVANCED INNOVATIVE

System Size	Pollutants Addressed		
☐ Small	☑ Ammonia	☑ TSS	☑ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☑ TN
☑ Large			

Description

The A^2/O is a modification to the sequencing batch reactor (SBR) that utilizes anaerobic/anoxic/aerobic biologic treatment zones to enhance removal of nitrogen and phosphorus in SBR plant. In this system the wastewater flows through a series of reactors where the oxidation state is controlled continuously to encourage microbial growth specific to its condition. This promotes uptake of additional phosphorus from the effluent in each stage which results in higher removal of Phosphorus. The nitrogen is subject to stages of nitrification followed by denitrification with additional nitrogen removed by the diverse microbial mass produced by the system. Often a carbon source such as methanol is required to maximize denitrification by the A^2/O process. Internal recycle within the system to promote removal can be used. Nitrogen removal to less than 3 mg/l is achievable with careful operation and methanol addition.

Typical Applications

The A^2/O process requires limited space and less energy than other SBR systems. It also is capable of giving good removal of nitrogen and phosphorus (best with additional filtration and metal salt precipitation).

Critical Design Parameters

- Influent characteristics
- Effluent requirements
- Number of basins
- Number of cycles
- Possible addition of a carbon source (methanol) for the anaerobic stage

Effluent Characteristics

SBRs with A^2/O processes can achieve good removal rates for BOD, TSS, Nitrogen and Phosphorus:
Ammonia: 0-1 mg/L
BOD: 10-20 mg/L
TSS: 10-20mg/L
TN: 6-8 mg/L
Nitrate: 1-7 mg/L
P: 1-2 mg/L (lower concentrations achievable with metal salt addition)
(EPA Wastewater Technology Fact Sheet Sequencing Batch Reactors, 1999)

Cost Considerations

- *Capital-* Because of the small footprint, the cost of land is not an issue. The capital cost associated with the SBRs include all the equipment required such as blowers, diffusers, valves, mixers, pumps, decanters and control panel as well as the tanks, earthwork, installation. Furthermore, additional treatment may be required as part of the system.
- *O&M-* Because the primary and secondary clarifiers are included within the SBR, the cost associated with such clarifiers is eliminated.
- *Modifications to progress from TSS/BOD removal to nitrogen and/or phosphorus removal are easily made with the addition of mixer(s) and programming changes.*

Benefits

- Less area required.
- Easily modified for nutrient removal
- Operator control
- Primary and secondary clarification within one reactor is possible (reducing cost and space)

Limitations

- Potential for sludge disposal during decant phase

Related Technologies

- Modified Ludzack Ettinger (MLE)
- Bardenpho Process.
- Oxygen ditch with nitrogen removal
- Sanitaire's ICEAS Process

System Size
☐ Small
☑ Medium
☑ Large

Pollutants Addressed
☑ Ammonia ☑ TSS ☑ Nitrate
☑ BOD/DO ☑ Phosphorus ☑ TN

Description
Advanced nutrient removal beyond that achieved by the various sequencing batch reactor (SBR) processes. Post filtration of effluent after metal salt addition can significantly reduce the phosphorus effluent levels for an SBR advanced innovative system. Post denitrification of effluent (after complete nitrification has been established) can significantly reduce the nitrogen effluent levels for an SBR advanced innovative system. Several variations on processes utilizing post metal salt addition/filtration and post denitrification have been developed and used throughout the world on new plants or added to conventional treatment plants for increased nitrogen and phosphorus removal from wastewater. Both processes also lower the BOD and TSS in the effluent.

Typical Applications
Added to existing plants to meet more stringent discharge limits for nutrients.

Critical Design Parameters
- Influent characteristics
- Effluent requirements

Effluent Characteristics
Nutrient removal technologies can achieve excellent removal rates for Nitrogen and Phosphorus and the following concentrations are achievable:

Post Filtration with Metal Salt
Ammonia: Little Effect
BOD: 2-5 mg/L
TSS: 2-5 mg/L
TN: Little Effect
Nitrate: Little Effect
P: 0.03-1 mg/L

Post Denitrification Filter
Ammonia: 0-1 mg/L
BOD: 10 mg/L
TSS: 10 mg/L
TN: 3-5 mg/L
Nitrate: 1-2 mg/L
P: Little Effect

Cost Considerations
- *Capital-* The capital costs associated with the nutrient removal technology include all the equipment required such as blowers, diffusers, valves, mixers, pumps, decanters and control panel as well as the tanks, earthwork, installation.
- *O&M-* increased operator monitoring and active management required.

***Bene*fits**

- High removal of nutrients.

Limitations

- Additional basin *a*nd filtration areas required for most systems.

Related Technologies

- Modified Ludzack Ettinger (MLE)
- Bardenpho Process.
- Oxygen ditch with nitrogen removal.
- Sanitaire's ICEAS Process (SBR)
- A^20 Process

ACTIVATED SLUDGE PLANTS — CONVENTIONAL

System Size	Pollutants Addressed		
☐ Small	☑ Ammonia	☑ TSS	☐ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☐ TN
☑ Large			

Description

The activated sludge process is a secondary treatment process within which a mixture of wastewater and sludge solids is aerated. The wastewater and sludge mixture (mixed liquor) is first aerated in an aeration tank. From there the wastewater enters a secondary clarifier where the solids settle. The organisms, using the oxygen, reduce the organic content of the sewage. There are many configurations for an activated sludge system. For the purposes of this comparison we are talking about the use of conventional complete mix activated sludge process with diffused aeration into the wastewater or use of efficient mechanical aerators. Hydraulic retention times (HRT) of 8 to 12 hours are compared. Examples of other activated sludge process systems are: step feed aeration, pure oxygen, extended aeration, oxidation ditch, or contact stabilization.

Typical Applications

Commonly used as secondary treatment at many existing facilities

Critical Design Parameters

- Amount of oxygen supplied to the system
- Hydraulic retention time (size)
- Degree of preliminary and/or primary treatment
- Amount and duration of wet weather flow

Effluent Characteristics

Ammonia: little reduction
BOD: 10-50 mg/L
TSS: 15-60 mg/L
TN: little reduction
Nitrate: little reduction
P: 2.5-6 mg/L (15-20% reduction)

Cost Considerations

- *Capital*- Require tanks with mechanical aeration equipment
- *O&M*- Cost of energy to operate the aeration system

Benefits

- Active oxygen addition is used so units are smaller than other systems since surface area for oxygen diffusion into the wastewater is not required.

Limitations

- Requires energy to operate the aeration system, which can increase operation costs

Related Technologies

- Oxidation ditches
- Sequencing Batch Reactors

SEQUENCING BATCH REACTOR CONVENTIONAL

System Size
☐ Small
☑ Medium
☑ Large

Pollutants Addressed
☑ Ammonia ☑ TSS ☐ Nitrate
☑ BOD/DO ☑ Phosphorus ☑ TN

Description

A Sequencing Batch Reactor (SBR) is simply a single tank operated in a cyclic manner first as an aeration chamber, then as a mixing tank without aeration (anoxic) and then as a clarifier. Pre-treated (primary settled)wastewater fills the reactor, where it is aerated and mixed which increases the oxygen within the wastewater, allowing the aerobic bacterial population to grow which increases the consumption of wastes. In addition to consuming typical constituents (BOD/TSS), the process can be operated to reduce nutrients in the effluent. During the aeration process, the nitrogen from ammonia is converted into nitrate and a portion of the phosphorus is consumed by and becomes part if the bacterial cell wall and contents. When the biological reactions are complete, the aeration is turned off and a mixer is turned on, allowing the aerobic bacteria to continue to multiply until the dissolved oxygen is depleted. At this point, the anaerobic bacteria flourish, extracting the oxygen molecule from the nitrate (NO_3) thereby converting the nitrogen into nitrogen gas. After this step, mixing is stopped, air is turned on for a short time, and then turned off again and the sludge formed by the bacteria is allowed to settle to the bottom of the tank. . Portions of the sludge are then removed for dewatering and/or disposal. And, separately, the treated supernatant (clear water) is removed for discharge.

Typical Applications

Because of a small footprint, the SBR is used where land is not available.

Critical Design Parameters

- Influent characteristics
- Effluent requirements
- Number of basins
- Number of cycles
- Aeration equipment

Effluent Characteristics

SBRs can achieve good removal rates for BOD, TSS, Nitrogen and Phosphorus:
Ammonia: 5-8 mg/L
BOD: 10mg/L
TSS: 10mg/L
TN: Little reduction
Nitrate: little reduction
P: 1-2 mg/L
(EPA Wastewater Technology Fact Sheet Sequencing Batch Reactors, 1999)

Cost Considerations

- *Capital-* Because of the small footprint, the cost of land is not an issue. The capital cost associated with the SBRs include all the equipment required such as blowers, diffusers, valves, mixers, pumps, decanters and control panel as well as the tanks, earthwork, installation.
- *O&M-* Because the primary and secondary clarifiers are included within the SBR, the cost associated with these is eliminated. *A*dditionally, controls can be efficient and allow for consistent operation.

Benefits

- Less area required
- Easily modified for nutrient removal if required in the future
- Greater operator control allows for increased flexibility in treating variable wastewater influents
- Primary and secondary clarification within one reactor is possible (reducing cost and space)
- Short term wet weather can be handled nicely with SBRs. Programming allows for "storm" modes of operation whereby aeration is shortened and decant (discharge) is increased for the higher flows

Limitations

- Potential for sludge disposal during decant phase
- Prolonged wet weather will require equalization tanks.

Related Technologies

- Activated sludge plants
  - Conventional
  - Extended air plants.

OXIDATION DITCH CONVENTIONAL

System Size	Pollutants Addressed		
☐ Small	☑ Ammonia	☑ TSS	☐ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☑ TN
☑ Large			

Description
An oxidation ditch consists of a long channel equipped with aeration within which wastewater is continuously circulated. Pre-treated wastewater entering the ditch is aerated and mixed with return sludge from a secondary clarifier. The wastewater is circulated through the ditch and passes through multiple aerations zones. These zones result in a high DO just downstream of the aerators and a low DO just upstream of the operators. The wastewater is then sent to a separate clarifier.

Typical Applications
Because it requires a large amount of land, oxidation ditches are applicable for small rural communities.

Critical Design Parameters
- Retention time
- BOD loading

Effluent Characteristics
Ammonia: 5-8 mg/L
BOD: 10-30 mg/L
TSS: 10-30 mg/L
TN: little reduction
Nitrate: little reduction
P: 2.5-6 mg/L (15% to 20% reduction)

Cost Considerations
- *Capital*- The land required for an oxidation ditch can be significant and can contribute significantly to the cost.
- *O&M*- Oxidation ditches can provide lower operation and maintenance costs in relation to other secondary treatment systems.

Benefits
- Easy to maintain and operate
- Produces less sludge than other systems
- Can be operated efficiently

Limitations
- Requires a large area
- TSS concentrations can be high compared to other systems

Related Technologies
- Activated sludge plants
  - Conventional
  - Extended air plants.

CHEMICAL SETTLING WITH METAL SALTS (CHEMCIAL PHOSPHATE REMOVAL) CONVENTIONAL

System Size	Pollutants Addressed		
☑ Small	☐ Ammonia	☑ TSS	☐ Nitrate
☑ Medium	☑ BOD/DO	☑ Phosphorus	☐ TN
☑ Large			

Description

Chemical settling with metal salts is used to remove phosphate from wastewater. The method is also called chemical phosphate removal. Chemical phosphate removal is achieved by treating the wastewater with a chemical that promotes phosphate precipitation. The precipitated compounds are then disposed of as sludge. The chemicals used are one of the following metals: Calcium, Iron, and Aluminum. These are most commonly used as salts in the following forms: alum, sodium aluminate, ferric chloride, ferric sulfate, ferrous sulfate and ferrous chloride.

Typical Applications

Chemical phosphate removal can be used in conjunction with many other wastewater treatment systems. For example it can be used within the Modified Ludzack Ettinger process, or within any conventional biological system. In some instances it precedes or follows other systems as a stand-alone process.

Critical Design Parameters

- Treatment with which chemical phosphate removal is being used

Effluent Characteristics

Ammonia: little reduction
BOD: 15 mg/L
TSS: 15 mg/L
TN: little reduction
Nitrate: little reduction
P: 0.5-1.0 mg/L (<0.3 with Bio P followed by chemical phosphate removal by effluent filter

Cost Considerations

- *Capital*- The cost of this method is dependent on the type and amount of the chemical, and its availability.
- *O&M*- Increases the solids volume in the secondary clarifier and metal salts in the solids may cause upset of the biologic activity if introduced into anaerobic digesters.

Benefits

- Well established technology
- Some of the chemicals can be inexpensive, resulting in an effective economical treatment
- Can be low maintenance

Limitations

- It can be difficult to obtain low required phosphorus concentrations with chemical treatment alone.
- Chemicals used in the treatment do not fully react and are wasted and disposed of as sludge.
- Depending on chemicals being used, operator safety may be a concern
- Some chemicals and their application point in the process can significantly increase the amount of sludge.
- UV disinfection can be interfered with when excessive iron is used.
- Performance is effected by pH

Related Technologies

Chemical precipitation for the removal of metals, in-organics, suspended solids, fats, oils, and greases

LAGOONS SEASONAL DISCHARGE

System Size
☑ Small
☑ Medium
☐ Large

Pollutants Addressed
☑ Ammonia ☑ TSS ☑ Nitrate
☑ BOD/DO ☑ Phosphorus ☑ TN

Description
Lagoons are ponds used as a conventional method to treat municipal waste through the use of aquatic vegetation and microorganisms. They can be non-aerated (facultative), aerated, or anaerobic.

Facultative lagoons are approximately 4 to 8 foot deep earthen lagoons used to treat raw, screened or primary treated wastewater. In many cases the system consists of multiple lagoon cells. Dissolved oxygen, present at the water surface from the atmosphere and algal respiration, supports aerobic organisms, while sludge at the bottom of the lagoon supports the anaerobic organisms. Commonly, these types of lagoons are discharged seasonally.

Aerated lagoons are mechanically aerated to maintain minimum oxygen content. Similar to facultative lagoons, many aerated lagoon systems consist of multiple lagoon cells. Aerated lagoons can be up to 20 feet in depth and, therefore, require less land area that facultative lagoons.

Anaerobic lagoons are deeper than 8 feet with less surface area to limit oxygen transfer and create conditions for anaerobic activity. A combination with aerobic and anaerobic lagoons could be used to promote nitrogen removal by nitrification then denitrification with soluble phosphorus removal occurring by microbial growth.

Typical Applications
Lagoons can be an inexpensive system for a small community and in rural areas where land cost is not an issue.

Critical Design Parameters
Facultative
- Liner may be required based on soil conditions
- Number of cells to maximize system effectiveness
- Detention time based on climate
- Usually shallow, thus more land area needed

Aerated
- Liner may be required based on soil conditions
- Number of cells to maximize system effectiveness
- Detention time based on aeration intensity
- Settling basin for TSS removal

Anaerobic
- Usually combined with an aerobic lagoon in series to provide additional nitrogen removal
- Liner may be required based on soil conditions
- Detention time based on climate
- Usually deeper, thus less land area needed

Effluent Characteristics

Facultative Lagoon
Ammonia: 2.4-10 mg/L
BOD: 30 mg/L
TSS: 150 mg/L

TN: Little Effect
Nitrate: Little Effect
P: 1.5-3.5 mg/L

Aerated and Mixed Lagoon
Ammonia: more effective than facultative
BOD: 15 mg/L
TSS: 20-60 mg/L
TN: Little Effect
Nitrate: Little Effect
P: Less effective than facultative

Facultative is moderately effective at Ammonia removal, but it is difficult to predict. Removal rates are based on the temperature, pH and detention time of the system. This is not consistent during colder seasons. Aerated lagoons must be designed appropriately to provide enough dissolved oxygen for nitrification.
Facultative lagoons are far less effective in TSS removal and can exceed 150 mg/L based on algal concentrations. TSS in aeration lagoons ranges from 20 to 60 mg/L and can depend on the design of the settling basin.

In facultative lagoons, the photosynthesis occurring with the algae causes fluctuation in oxygen and pH levels throughout a 24 hour period. Precipitation of phosphorus can occur seasonally, as well as re-release from the benthos (settled microorganisms and decomposing vegetation) seasonally.

Cost Considerations

- *Capital-* Costs can vary for facultative and aeration lagoons as it depends on land required, earthwork, and inlet and outlet structures. For aeration lagoons, the cost of aeration equipment must be considered. Based on soil conditions, the material and installation cost for a liner must be considered. Anaerobic lagoons have a small surface area to minimize oxygen diffusion but a greater depth to maintain anaerobic conditions. Typically excavation for anaerobic lagoons is still less than facultative and aerated lagoons.
- *O&M-* Most facultative and anaerobic lagoons rely on gravity flow and, therefore, operation and maintenance is minimum. The system must be inspected and sludge must be cleaned out (dredged) periodically. Aeration lagoons have cost associated with the power, operation and maintenance of the aeration equipment. Anaerobic lagoons will have higher cleanout costs for solids removal, when needed, due to their greater depth.

Benefits

Facultative

- Easy operation

Aerated

- Can discharge throughout the winter in colder climates

Limitations

Facultative

- Poor TSS and ammonia removal.
- Land area requirement.
  - Area required determined by organic loading rate and hydraulic detention time (HDT)
  - Typical min. recommendation – 4' deep (max), 40 lb/BOD/ac/d loading rate, 30 day HDT
- Objectionable odors can result.
- Seasonal discharge in colder climates
- Sludge requires periodic removal
- Mosquitoes can be a problem
- Burrowing animals may be a problem with dikes

- Long detention times, especially in northern climates

Aerated
- Land area requirement less than facultative due to active aeration.
  - Area required determined by organic loading rate and hydraulic detention time (HDT)
  - Typical min. recommendation – 4' deep (max), 40 lb/BOD/ac/d loading rate, 19 day HDT
- Sludge requires periodic removal
- Mosquitoes can be a problem
- Borrowing animals may be a problem with dikes
- Requires energy input

Anaerobic
- Land area requirement lowest for all lagoons.
  - Area required determined by organic loading rate and hydraulic detention time (HDT)
  - Typical min. recommendation – 8' deep (max), 175-2000 lb/BOD/ac/d loading rate, 20 day HDT
- Objectionable odors can result.
- Mosquitoes can be a problem
- Burrowing animals may be a problem with dikes
- Long detention times, especially in northern climates

Related Technologies
- Activated sludge system
- Constructed Wetland biosystems using subsurface (anaerobic) flow and surface (aerobic) flow units in series.

3.0 SMALL SYSTEM TREATMENT ALTERNATIVES <10,000 GPD

As explained above, this document focuses on systems greater than 10,000 gpd; however, a discussion regarding smaller systems is warranted. The effluent quality of large scale wastewater treatment facilities has improved dramatically over the past decades. The same cannot be said for many of the smaller scale facilities, which includes treatment on individual parcels. Because the population continues to develop beyond the urban core, these sources are a growing portion of the pollutant load in our waterways. One specific challenge is reducing the effluent discharge volumes in areas that cannot accept the flow (notable wetlands, impermeable clay soil, and areas with high water tables.) Equally important is nutrient control from these smaller facilities. The following is a discussion of treatment alternatives for such systems:

2.1 Conventional Septic Systems

A conventional septic system for a small facility consists of a septic tank and a septic field. Wastewater enters the first chamber of the septic tank where solids settle and oils and grease float. Often the remaining liquid then flows into a second chamber where additional settling occurs. The water flows into the septic field that consists of a trench filled with sand or gravel within which perforated pipe is placed. Conventional systems are typically only used for single family residences. The governing factor in the performance of a trench system is the size and material of the trenches and the underlying soils. Fewer of these systems are being used because of the limited suitability of soils and the tendency not to be sustainable in the long term. Often replacement sites are necessary in zoning codes.

2.2 Mound System

A mound system is an alternative to explore when sites have soil conditions with slow permeability and/or the water table is high and a conventional septic system would not allow for proper treatment of the wastewater and is typically only used for single family residences. A mound system consists of a conventional septic tank, a dosing chamber from which the wastewater is pumped and distributed to the mound. The mound itself is made up of sands and aggregates and a pipe network for wastewater distribution, all covered with a layer of soil and vegetated. It provides secondary treatment and also provides dispersal of the treated water to soil horizon for further polishing and treatment. The governing factor in the performance of a mound system is the size and material of the mound and the underlying soils. The cost of the system is more than a conventional system because of the cost for the dosing chamber and the mound.

2.3 Dedicated Land Application

Dedicated Land Application or Surface Application Systems typically result in three techniques: Drip Irrigation, Spray Irrigation and Overland Flow. The land application itself provides a tertiary method of treatment and is used in conjunction with primary and secondary treatment. During Spray and Drip Irrigation the wastewater is distributed evenly on a vegetated plot of land where it is treated. During an Overland Flow, application of the wastewater is distributed along the top contour of a gently sloping site. The water flows down the slope and is treated by the plants and infiltrates into the soil as it flows past. Generally the irrigation systems are designed to have no discharge from the land application. Application fields will have a collection point where runoff from an application field can be checked and released if the quality is acceptable. The performance of dedicated land application treatment is difficult to generalize as it is dependent on the type of vegetation and soil characteristics of the area where the water is being applied. Costs of these systems are generally high due to the amount of land required, the degree of pre-treatment needed to settle and remove solids prior to application, and the possible need for pathogen treatment prior to land application. All three types of irrigation can be used in small systems. Additional detail for the use of dedicated land application for medium and large systems is included in subsequent sections of this report.

2.4 Unlined Wetland System

An unlined wetland system for wastewater treatment maintains a subsurface flow within a pervious media that supports wetland vegetation, or surface flow through and across soil with wetland vegetation. The flow through nature of the system provides the physical, chemical and biochemical reactions to treat the wastewater. An unlined system provides distribution as well, depending on the characteristics of the underlying soils. These systems can be used for systems up to 60,000 gpd (EPA Wastewater Technology Fact Sheet. Wetlands: Subsurface Flow, 2000). The wetland systems are efficient in removing BOD and TSS. They can be efficient in removing nitrogen and phosphorus based on detention time. Unlined wetland systems can be economical to construct and operate in relation to their mechanical counterparts. Cost of land, however, must be considered.

2.5 Evapotranspiration

Evapotranspiration (ET) is the process of uptake of water within the soil by evaporation and plant transpiration. For wastewater treatment, evapotranspiration is used to dispose of treated wastewater. In most ET systems, the wastewater is transported from the treatment facility through distribution pipes to an area planted with water tolerant plants. The system is normally lined, or consists of impermeable soils. ET systems are applicable for arid climates and are often expensive due to their large size and special material requirements.

2.6 Water Recycling or Re-Use

Wastewater can be divided into two categories: black water or grey water. Black water is wastewater from toilets, while grey water is wastewater coming from all other plumbing fixtures. If separated from black water, grey water can be treated by filtration prior to reuse to flush toilets or used with minimal treatment for irrigation purposes. This technique can be used for single family residences and small managed communities. Grey water re-use is applied frequently in some foreign countries. Technology providers are currently beginning to tap into the United States market with particular interest in areas where water is costly and/or scarce. Re-use can be applied in small systems as well as large. There are some large systems that are unique in their use of large quantities of water that does not need to be of drinking quality. Examples can include paper mills or irrigation (i.e. golf courses).

2.7 Subsurface Flow Wetland with Re-Circulating Sand Filter with Recycle

A re-circulating sand filter (RSF) can be used in conjunction with a subsurface flow wetland to provide tertiary treatment. After solids are removed, typically through a septic tank, and then treated in the subsurface flow wetland, the wastewater is distributed over the top of an open sand filter where the water percolates through the sand filter and is collected by under-drains. A portion is dispersed, while the rest is returned back to the wetland. The RSF provides treatment (aerobic) via the microorganisms within the sand filter, reduces BOD and TSS, while converting ammonia to nitrate. A system such as this can be used for small communities up to 20,000 gpd. Working together, the wetland and sand filter provide for efficient removal of BOD, TSS, and Nitrogen and can provide very good effluent quality. Subsurface flow wetlands with re-circulating sand filter with recycle can be economical to construct and maintain. Cost considerations include cost of land and sand filter media cost.

2.8 Enhanced Aerobic Treatment Unit (ATU)

An Aerobic Treatment Unit (ATU) is similar to a traditional septic system, but uses an aerobic treatment process. The system consists of an aeration compartment where oxygen is mixed with the wastewater with an air blower or compressor. With the presence of oxygen, the aerobic bacteria break down some of the solids within the wastewater. An ATU is used in conjunction with pre-treatment by screening, grit removal, and primary settling operations and once treated by the ATU the wastewater is sent for dispersal. ATUs are typically used for single family residences or small communities up to 20,000 gpd. An ATU is efficient in reducing BOD, TSS and Ammonia and can be retrofitted with controls that aid in the reduction of Total Nitrogen. These systems increase the capital costs and tend to have higher ongoing O&M costs.

2.9 Subsurface Flow Wetland with ATU with Recycle

A subsurface flow wetland with ATU with recycle will be of similar configuration to the subsurface flow wetland with re-circulating sand filter with recycle. Both the subsurface flow wetland and ATU are described above. This system is applicable to a similar size community, provides similar effluent characteristics and similar costs as the subsurface flow wetland with re-circulating sand filter with recycle.

2.10 Re-Circulating Sand Filter with Anaerobic Up Flow or Peat Filter

After being pre-treated the wastewater is distributed over the top of an open sand filter (aerobic component) where the water percolates through the sand filter and is collected by under-drains where a portion of it is dispersed to an up flow or peat filter, while the rest is sent back to the top of the sand filter. The sand filter traps suspended solids which reduces BOD and the organic nitrogen and ammonium is converted to nitrates. The up flow filter or peat filters (anaerobic component) offer additional nitrogen removal by denitrification. A system such as this can be used for small communities up to 20,000 gpd

2.11 Chemical Settling with Metal Salts

Chemical settling with metal salts is used to remove phosphate from wastewater. The method is also called chemical phosphate removal. Chemical phosphate removal is achieved by treating the wastewater with a chemical that promotes phosphate precipitation. The precipitated compounds are then disposed of as sludge. The chemicals used are one of three of the following metals: Calcium, Iron, and Aluminum. These are most commonly used as salts in the following forms: alum, sodium aluminate, ferric chloride, ferric sulfate, ferrous sulfate and ferrous chloride. The cost of this method is dependent on the type and amount of the chemical, and its availability.

2.12 Soil Horizon Dispersal

Soil horizon dispersal is often combined with or "following" a mound system or a trench system in that it provides secondary treatment and dispersal. In Soil Horizon Dispersal the wastewater is usually pretreated to secondary or higher standards, and then dispersed to the soil promoting its flow horizontally through the soil horizon for "polishing" treatment. It, unlike the mound system, can be used for small communities, up to 20,000 gpd. The governing factor in the performance of soil horizon dispersal is the degree of pretreatment and characteristic of the underlying soils. The cost is dependent on the soil conditions and the degree of pretreatment.

4.0 CONCLUSIONS

Antidegradation requirements and impending numeric nutrient criteria are helping drive advances in wastewater treatment for the removal of ammonia, BOD, TSS and nutrients, and will continue to do so as more states implement their antidegradation rules and adopt water quality standards for nitrogen and phosphorus.

Operator experience and published literature indicate that existing innovative treatment technology can produce wastewater that meets nutrient removal goals. Concentration levels of 1.0 mg/L monthly average for phosphorus and total nitrogen of 6-8 mg/L annual average are readily achievable at most locations with the treatment technology available. Several POTW's in the nation and around the world have achieved effluent limits of nitrogen of less than 3 mg/L and phosphorus levels near or less than 0.1 mg/L. Each site and its wastewater are unique and require flexibility for operators and the owners (public or private) to choose the best technology for their situation. As nutrient removal requirements become more stringent, the cost of the advanced innovative technologies will decrease and newer variations to the processes currently used will undoubtedly evolve to enhance nutrient removal.

As affected communities plan upgrades or new treatment plants, both operators and regulators need performance and operational data to determine how to incorporate enhanced and innovative treatment technologies in order to prevent unnecessary degradation and to meet nutrient standards. Operators around the world have used these processes and variations thereto to enhance pollutant removal. The number of variations to the basic process is limited only by creative innovation applied by operators.

The attachments to this report compile the performance, operational, and cost data in matrices that can be used as guides in determining what each alternative (enhanced innovative and conventional) I is capable of achieving in the removal of nutrients, BOD, ammonia, and TSS.

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APPENDIX A:

Effluent Characteristics of Technology Alternatives for Municipal Sewage Treatment

Effluent Characteristics of Technology Alternatives for Municipal Sewage Treatment[1]
December, 2010

Typical Wastewater Constituent Influent Characteristics (mg/L)	12-50[13]	20-85[13]	0[14]	180-300	180-300	3-7[13]
	Achievable Effluent Characteristics by the Technology (mg/L)					
Treatment Technology (medium & large POTW)	Ammonia nitrogen	Total nitrogen	Nitrate nitrogen	BOD	TSS	Total phosphorus
Non-discharging Alternatives						
Dedicated Land Application	Ref[2]	Ref[2]	Ref[2]	30	30	Ref[2]
Advanced Innovative Treatment Technologies						
Modified Ludzack Ettinger (MLE)	0-2	5-8	3-6 Ref[7]	10-20	10-20	2-6
Bardenpho Process	0-1	3-6	1-7	10-20	10-20	2-6
$A^2/0$	0-1	6-8	1-7	10-20	10-20	1-2 (without metal salt addition)
Oxidation Ditch with Nitrogen Removal	0-1	3-6 (3-5 TN w/mixed liquor recycle)	2-5	10-20	10-20	2-6 (15 to 35% reduction)
Sequencing Batch Reactor (Sanitaire's ICEAS process)	0.5-5	3-5	3-6 (w/anoxic stage & mixer)	<10	<10	0.3-2 (requires metal salt addition)
Post filtration with metal salt addition (after advanced innovative above)	na Ref[3]	na Ref[3]	na Ref[3]	2-5	2-5	0.03-1
Post Denitrification(after advanced innovative above with full nitrification)	0-1	3-5	1-2	10	10	na Ref[4]
Enhanced Treatment Technologies (above Conventional)						
Modified Activated Sludge Plants	<2	20-80 Ref[6]	na Ref[5]	10- 30	10- 30	2.5-6
Seasonal Discharging Alternatives						
Lagoons - Facultative	2.4-10	20-80 Ref[6]	na Ref[5]	20-30	150	2-7
Lagoons - Aerated and Mixed	more effective than facultative	20-80 Ref[6]	na Ref[5]	15	20-60	more effective than facultative
Conventional Alternatives						
Activated Sludge Plants	little to some reduction	20-80 Ref[6]	na Ref[5]	10-50	15-60	2.5-6
Sequencing Batch Reactors (SBR)	5-8	20-80 Ref[6]	na Ref[5]	10	10	1-2
Oxidation Ditch	5-8	20-80 Ref[6]	na Ref[5]	10-30	10-30	2.5-6
Metal Salt Precipitation (incorporated in secondary system)	na Ref[3]	na Ref[3]	na Ref[3]	15	15	0.5-1

1. Effluent characteristics depend on many factors & plant operation. The table assumes favorable influent conditions & high operator management. The values reflect optimal effluent levels for the technology.

2. This is a non d=discharging alternative, therefore nutrient concentrations are not applicable. Agronomic application rates will need to be honored, however there is no surface water discharge.

3. The nitrogen series remain unchanged by metal salt addition. Metal salts are used to remove P.

4. Post denitrification is designed to remove nitrate. Often some phosphoric acid is added to assure that there is enough P to sustain microorganism metabolism.

5. Activated sludge plants are not designed to remove nitrate. There is no reduction. Often there is a slight increase. The increase depends on how much ammonia is converted.

6. The facility is not designed for removal of nitrogen (oxic/anoxic cycles), therefore there is little change through system. The starting total nitrogen is in the 20-80 mg/L range.

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14. Nitrate is typically zero entering a municipal wastewater treatment facility. Once ammonia is converted, Nitrate is generated and can typically get in the range of 2 to 12 mg/l if no denitrification occurs.

APPENDIX B:

Anti-Degradation Alternatives Matrix for Municipal Sewage Treatment

Anti-Degradation Alternatives Matrix for Municipal Sewage Treatment
December, 2010

Treatment	Achievable Effluent Characteristics (mg/L)						Critical Design Parameters	Estimated Costs[17] ($ per million gallons treated)		Benefits	Limitations	Examples
	Ammonia Nitrogen	Total Nitrogen	Nitrate-N	BOD	TSS	Phosphorus		Capital ($/mgd)	Operation and Maintenance ($/million gallons treated)			
Typical Wastewater Constituent Influent Characteristics	12-50[13]	20-85[13]	0[14]	180-300	180-300	3-7[13]						
Medium Systems (10,000 gpd - 1 mgd)												
Non-discharging Alternatives												
Dedicated Land Application	ref[16]	ref[16]	ref[16]	30	30	ref[16]	Hydraulic and nutrient loading of the site. Follows conventional secondary systems Pre-treatment Land Area	$0.70 mil. per mgd or $70 per person per mgd (land (160 Ac): $400K (irr sys with 1/4 sect center pivot) + $150K (holding pond) + $150K	$500+ [2] (annual) $1096 (annual 2006-08 Muskegon, MI irrigation system cost only)	Savings on potable water Nutrients recycled to plants groundwater recharge preservation of in stream water quality	Large land area may be required Requires significant pre-treatment Requires buffer area Potential nitrogen leaching	Often use center pivot irrigation. Pauls Valley, Oklahoma and Muskegon County, MI (11,000 acres).
Seasonal Land Application	ref[16]	ref[16]	ref[16]	30	30	ref[16]	Hydraulic and nutrient loading of the site. Follows conventional secondary systems Pre-treatment Land Area	$1.0 mil. per mgd or $100 per person per mgd (land (160 Ac): $400K (irr sys with 1/4 sect center pivot) + $150K (holding pond) + $450 k (excav costs)	$500+[2] (annual) $1096 (annual 2006-08 Muskegon, MI irrigation system cost only)	Savings on potable water Nutrients recycled to plants	Large land area may be required Requires significant pre-treatment Requires buffer area Potential nitrogen leaching	Often use center pivot irrigation. Pauls Valley, Oklahoma and Muskegon County, MI (11,000 acres); Fox Mills, IL; City of Plano, IL; Village of Cortland, IL
Advanced Innovative Treatment Technologies												
Modified Ludzack Ettinger (MLE)	0-2 (Ammonium converted to nitrates by nitrification)	5-8	3-6 (Limited reduction of nitrates by denitrification)	10-20[2]	10-20[2]	2-6 (15 to 35% reduction)	Recycle ratio for control over nitrogen removal Pre-treatment Effluent requirements	$2.5 - 5.0 mil. per mgd or $250 - $500 per person per mgd[8] (upgrade to plant)	$773,000 - per year per mgd or $78 per person per year[8]	Provides control over amount of nitrogen removal through recycle ratio. Removes some Nitrate, thus total nitrogen is reduced more than just a nitrification system.	Requires more energy because of mixed liquor recycle	Orlando, Fl (>1 mgd) Maryland-Cambridge, Seneca, Freedom District, Conococheaque, Cox Creek, Back River and Aberdeen, Ref[21]
Bardenpho Process	0-1	3-6	1-7	10-20[2]	10-20[2]	2-6 (15 to 35% reduction)	Needs to have an adequate amount of carbon (food) in the influent to obtain high denitrification	$2.2 mil. per mgd or $220 per person per mgd[8] (upgrade to plant)	$930,000 - per year per mgd or $93 per person per year[8]	Proven process, excellent ammonia reduction with good total nitrogen removal with denitrification.	Often limited by amount of carbon (food) available in the influent. This can be overcome with methanol addition, thus added costs.	Maryland: Maryland Correctional Institute
A^2/O	0-1	6-8	1-7	10-20[2]	10-20[2]	1-2 without metal salt addition	Must be properly sized and may need a fermentor to provide volatile fatty acids (VFAs)	$17 mil. per mgd or $1700 per person per mgd[9] (50K gpd package plant)	$1.2 mil. per year per mgd or $1200 per person per mgd[9] (50K gpd package plant)	Proven process, can achieve total N < 3 mg/l with careful operation and methanol addition. When combined with effluent filtration and metal salt addition, Total P can achieve very low values.	Often need to add methanol and install fermenters. Solids upsets will discharge total P [18]. Often post filtration needed to achieve consistent P discharge.	Maryland: Frederick, Ballenger, Westminster, and Sod Run.
Oxidation Ditch with Nitrogen Removal	0-1	3-6 (< 5 Tot N if mixed liquor recycle employed)	2-5	10-20[2]	10-20[2]	2-6 (15 to 35% reduction)	Retention Time BOD loading may require mixed liquor recycle	$8 mil. per mgd or $800 per person per mgd	$850,000 per year per mgd or $85 per person per year	low operational and maintenance requirements (compared to other conventional treatments) produces less sludge than other systems	requires large land area TSS concentrations can be high compared to other systems requires more electricity than conventional	Hartland, MI, Cedarburg, WI
Sequencing Batch Reactor (Sanitaire's ICEAS process)	0.5-5	3-5	3-6 (requires anoxic system and mixer to get low numbers)	<10[1]	<10[1]	0.3-2[1] (requires metal salt addition)	Influent characteristics Effluent requirements Number of basins Number of cycles Aeration equipment	$5.8 mil. per mgd or $583 per person per mgd (Cedar Grove)	$0.5 mil. per year per mgd or $50 per person per year	Clarification, Treatment and Secondary clarification achieved in one reactor Minimal footprint Easily modified for nutrient removal Operator control	Sophisticated timing and controls (more maintenance) Potential for discharging sludge with clear water	Harmony Grove-Okee, WI Cedar Grove, WI
Post filtration with metal salt addition (after advanced innovative above)	ref[19]	ref[19]	ref[19]	2-5	2-5	0.03-1	Multi media filter with backflush (solids removal)	$1.5 mil. - $5.1 mil. per mgd or $150-$510 per person per mgd	$22,700-$69,000 per year per mgd or $2.70-$6.90 per person per year[9]	Proven Technology and well understood	Need the differential head to support hydraulic flow, often added as a retrofit to meet more stringent standards, thus low lift pumps are often necessary to elevate the water flow	Hillsboro, Oregon; Rock Creek, TX (includes tertiary Alum addition followed by filtration).[9]
Post Denitrification Filter (after advanced innovative above with full nitrification)	0-1	3-5	1-2	10	10	ref[20]	Anoxic Environment, carefully controlled, phosphoric acid addition if required and methanol addition as required	$1.46 - $3.2 mil. per mgd or $146 - $320 per person per mgd[11,12]	$286,000 (100K gpd) - $800,000 (25K gpd) per year per mgd or $28.60 - $80.00 per person per year[12]	Allow for good control of denitrification and results in very low BOD and TSS effluent. Often used in Chesapeake Bay area to achieve stringent requirements	Need the differential head to support hydraulic flow, often added as a retrofit to meet more stringent standards, thus low lift pumps are often necessary to elevate the water flow. Post denitrification system filter uses larger media and doesn't hold solids as effectively as smaller media systems.	Arlington County, VA (large plant), Maryland analyses and case study[11]

Medium Systems (10,000 gpd - 1 mgd)

Treatment	Achievable Effluent Characteristics (mg/L): Ammonia Nitrogen	Total Nitrogen	Nitrate-N	BOD	TSS	Phosphorus	Critical Design Parameters	Estimated Costs[17] ($ per million gallons treated): Capital ($/mgd)	Operation and Maintenance ($/million gallons treated)	Benefits	Limitations	Examples
Typical Wastewater Constituent Influent Characteristics	12-50[13]	20-85[13]	0[14]	180-300	180-300	3-7[13]						
Enhanced Treatment Technologies (above Conventional)												
Modified Activated Sludge Plants	< 2	ref[14] Little change	ref[14] Little change	10-30	10-30	2.5-6 (15 to 20% reduction)	Mean cell residence time (sludge age) generally >15 days, good solids settling or removal, temperature sensitive. Usually aeration hydraulic retention time >16 hours, often 24 to 36 hours.	$0.42 mil. - $ 1.45 mil. per mgd or $42 - $145 per person per mgd9	$46,000 - $145,000 per year per mgd or $73 per person per year[9]	Proven technology and well understood	Soft water may need alkalinity added, will need about 4 times as much aeration than a non-nitrifying plant.	City of LaSalle, IL (1 mgd); Pingree Grove, IL using MBR; Traverse City, MI using MBR;
Seasonal Discharging Alternatives												
Lagoons- Facultative	2.4-10[6]	ref[14] Little change	ref[14] Little change	30[6]	150[6]	1.5-3.5[6]	Liner based on soil conditions Number of cells for effectiveness Detention time based on climate	$4.4 mil. per 1 mgd or $440 per person per mgd	$175,000 per year per mgd or $17.50 per person per year	Inexpensive alternative for small rural towns Easy operation	Large area required Potential odors Seasonal discharge Mosquitoes and burrowing animals a concern Long detention times	Lagoons are used throughout the US and Canada primarily for medium or small systems. Fewer are being constructed because of their poor cold weather performance. Barneveld, Merrimac, and Brownsville, Wisconsin
Lagoons- Aerated and Mixed	More effective than facultative	ref[14] Little change	ref[14] Little change	15 (<95% 5))	20-60[5]	less effective than facultative	Liner based on soil conditions Number of cells for effectiveness Detention time and aeration intensity Downstream polishing required	$6.8 mil. per 1 mgd or $684 per person per mgd (19000 gpd WWTP)	$200,000 per year per mgd or $20.00 per person per year (19000 gpd WWTP)	Can discharge throughout the winter in colder climates	Large area required, though not as much as facultative Mosquitoes and burrowing animals a concern Requires energy input long detention times	
Rapid Infiltration Basin (RIB) (Seasonal method of returning treated wastewater to the ground water environment)	ref[16]	ref[16]	ref[16]	ref[16]	ref[16]	ref[16]	Soils are critical, typically sand and gravels, or otherwise porous soil structures. Typically sized for so many gallons per square foot of surface area. Requires berm of several feet in height. Requires several units so that they may be dosed	$1.5 mil. per 1 mgd or $150 per person per mgd [9]	$25,000 per year per mgd or $2.50 per person per year	This is a sustainable (seasonal) means of returning water back to the ground water where most water is drawn, if soils will allow and wastewater effluent to infiltrate meets State Discharge Standards for Total Nitrogen (varies from State to State, typically 3 to 5 mg/l Total N) and Total P (varies from State to State, but can be from 0.03 to 0.5 mg/l). Valuable method to combat salt water intrusion into ground water in coastal areas.	Requires very high treatment standards for both N and P, along with a discharge of typical advanced treatment effluent standards for TSS. BOD, and fecal coliform reduction. UV would be the preferred disinfection method	Hartland, MI, Orlando, Fl
Conventional Alternatives												
Activated Sludge Plants	ref[14] Little to some reduction	ref[14] Little change	ref[14] Little change	10-50[2]	15-60[2]	2.5-6 (15 to 20% reduction)	Hydraulic detention time, aeration & clarification capacity	$7.2 mil. per mgd or $722 per person per mgd	$730,000 per year per mgd or $73 per person per year	Cost Effective, well understood, can often take short term overloading during wet weather.	Cannot take long term overloads.	Many Locations throughout the US and the world.
Sequencing Batch Reactors (SBR)	5-8[1]	ref[14] Little to some reduction	ref[14] Little change	10 [1]	10 [1]	1-2[1]	Influent characteristics Effluent requirements Number of basins Number of cycles Aeration equipment	$6.5 mil. per mgd or $650 per person per mgd	$292,000 - $730,000 per year per mgd or $29 to $73 per person per yr[1]	Clarification, Treatment and Secondary clarification achieved in one reactor Minimal footprint Easily modified for nutrient removal Operator control	Sophisticated timing and controls (more maintenance) Potential for discharging sludge with clear water	Aqua Aerobics Design in Abilene, KS (1.5 mgd capacity, 2008 construction cost = $9.4 million) and Marissa, IL (0.6 mgd).
Oxidation Ditch	5-8	ref[14] Little to some reduction	ref[14] little to no change, may increase	10-30	10-30	2.5-6 (15 to 20% reduction)	Retention Time; BOD Loading; Hydraulic retention time (HRT) of aeration basin.	$7.2 mil. per mgd or $722 per person per mgd	$730,000 per year per mgd or $73 per person per year	low operational and maintenance requirements (compared to other conventional treatments) produces less sludge than other systems	requires large land area TSS concentrations can be high compared to other systems	Many Locations throughout the US and the world. Hartland, MI and Cedarburg, WI.
Metal Salt Precipitation (incorporated in secondary system)	ref[19] Little change	ref[19] Little change	ref[19] Little change	15	15	0.5-1.0 (<0.3 with Bio P removal + chemical phosphate removal + effluent filter)	Activated Sludge treatment with a metal salt (chemical phosphate removal) being used. Often added to aeration tank, settling in secondary clarifier.	$0.25 mil. per mgd or $25 per person per mgd	$31,000 per year per mgd or $3.10 per person per year	Well established technology Chemicals can be inexpensive Can be low maintenance	Difficult to obtain low phosphorus concentrations with chemical treatment alone Can increase the amount of sludge Operator safety can be a concern and personal protection equipment is used, training is required	Many Locations throughout the US and the world. Collinsville, IL, Racine, WI, and Bayfield, WI.
Disinfection	ref[15]	ref[15]	ref[15]	ref[15]	ref[15]	ref[15]	Retention time; Dosage; if UV- Lamp Intensity	500 gpm ozone contact vessel system - capital cost = $400,000[23]	500 gpm ozone contact vessel system - annual O&M cost = $20,000[23]	Use of chlorine for disinfection and sulfur dioxide for disinfection are proven technologies but are slowly losing favor (see limitations). Ozone is rarely used (see limitations). UV uses less space on a plant site, uses electricity only, and is effective with disinfecting a wastewater that is clear and <30 mg/l TSS. Easy to operate and maintain.	Chorine and Sulfur Dioxide are chemicals that require special handling, storage, and personnel protection measures. Ozone is a strong oxidant and like above, requires personnel protection measures. Emergency plans are costly and public notification required. UV requires clear effluent and some problems have occurred from overuse of ferric chloride (coats lamps).	UV: Cedarburg, WI; Wayne County- Wyandotte, MI ; UV: Stookey TWP Main STP, IL

	Treatment	Achievable Effluent Characteristics (mg/L)						Critical Design Parameters	Estimated Costs[17] ($ per million gallons treated)		Benefits	Limitations	Examples
		Ammonia Nitrogen	Total Nitrogen	Nitrate-N	BOD	TSS	Phosphorus		Capital ($/mgd)	Operation and Maintenance ($/million gallons treated)			
	Typical Wastewater Constituent Influent Characteristics	12-50[13]	20-85[13]	0[14]	180-300	180-300	3-7[13]						
Large Systems (> 1 mgd)	**Non Discharging Alternatives**												
	Dedicated Land Application	ref[16]	ref[16]	ref[16]	30	30	ref[16]	Hydraulic and nutrient loading of the site. Follows conventional secondary systems Pre-treatment Land Area	$0.70 mil. per mgd or $70 per person per mgd (land (160 Ac) = $400K, irr sys (1/4 sect center pivot) = $150K, holding pond excav= $150K)	$500+2 (annual) $1096 (annual 2006-08 Muskegon, MI irrigation system cost only)	Savings on potable water Nutrients recycled to plants groundwater recharge preservation of in stream water quality	Large land area may be required Requires significant pre-treatment Requires buffer area Potential nitrogen leaching	Often use center pivot irrigation. More prevalent in drier areas and areas with sandy subsoil. Pauls Valley, Oklahoma and Muskegon County, MI (11,000 acres).
	Advanced Innovative Treatment Technologies												
	Modified Ludzack Ettinger (MLE)	0-2 (Ammonium converted to nitrates by nitrification)	5-8	3-6 (Limited reduction of nitrates by denitrification)	10-20[2]	10-20[2]	2-6 (15 to 35% reduction)	Recycle ratio for control over nitrogen removal Pre-treatment Effluent requirements	$1.4 mil. per mgd or $140 per person per mgd[10] (140 mgd plant)	$92,000 per year per mgd or $9 per person per mgd[10] (140 mgd)	Provides control over amount of nitrogen removal through recycle ratio, Removes some Nitrate, thus total nitrogen is reduced more than just a nitrification system.	Requires more energy because of mixed liquor recycle	Orlando, Fl (>1 mgd); Maryland- Cambridge, Seneca, Freedom District, Conococheaque, Cox Creek, Back River and Aberdeen. Denver, CO[10]
	Bardenpho Process	0-1	3-6	1-7	10-20[2]	10-20[2]	2-6 (15 to 35% reduction)	Needs to have an adequate amount of carbon (food) in the influent to obtain high denitrification	$1.4 - $2.6 mil. per mgd or $140 - $220 per person per mgd[8]	$180,000 - per year per mgd or $18 per person per year[8]	Proven process, excellent ammonia reduction with good total nitrogen removal with denitrification.	Often limited by amount of carbon (food) available in the influent. This can be overcome with methanol addition, thus added costs.	Maryland: Ballenger and Hurlock
	A^2/O	0-1	6-8	1-7	10-20[2]	10-20[2]	1-2 without metal salt addition	Must be properly sized and may need a fermentor to provide volatile fatty acids (VFAs)	$400,000 per year per mgd or $400 per person per mgd[8] (upgrade to plant)	$30,000 - per year per mgd or $3 per person per year[8]	Proven process, can achieve total N < 3 mg/l with careful operation and methanol addition. When combined with effluent filtration and metal salt addition, Total P can achieve very low values.	Often need to add methanol and install fermenters. Solids upsets will discharge total P. Often post filtration needed to achieve consistent P discharge.	Maryland: Frederick, Ballenger, Westminster, and Sod Run. Village of Mokean, IL. Triangle WWTP Durham, NC. Little Patuxent, MD[8]
	Oxidation Ditch with Nitrogen Removal	0-1	3-6 (< 5 Tot N if mixed liquor recycle employed)	2-5	10-20[2]	10-20[2]	2-6 (15 to 35% reduction)	Retention Time BOD loading	$1.7 mil. per mgd or $170 per person per mgd[8]	$165,000 - per year per mgd or $16.5 per person per year[8]	low operational and maintenance requirements (compared to other conventional treatments) produces less sludge than other systems	requires large land area TSS concentrations can be high compared to other systems	Ashland, OR and Princeton, IN.
	Sequencing Batch Reactor (Sanitaire's ICEAS process)	0.5-5	3-5	3-6 (requires anoxic system and mixer for low numbers)	<10 [1]	<10 [1]	0.3-2[1] (requires metal salt addition)	Influent characteristics Effluent requirements Number of basins Number of cycles Aeration equipment	$2.3 mil. per mgd or $227 per person per mgd (Jefferson City, MO)	$0.5 mil. per year per mgd or $50 per person per year	Clarification, Treatment and Secondary clarification achieved in one reactor Minimal footprint Easily modified for nutrient removal Operator control	Sophisticated timing and controls (more maintenance) potential for discharging sludge with clear water Need metal salt addition to achieve total P removal	Jefferson City, MO
	Post filtration with metal salt addition (after advanced innovative above)	ref[19]	ref[19]	ref[19]	2-5	2-5	0.03-1	Multi media filter with backflush (solids removal)	$1.5 mil. - $5.1 mil. per mgd or $150-$510 per person per mgd. [9]	$22,700-$69,000 per year per mgd or $2.70-$6.90 per person per year[9]	Proven Technology and well understood	Need the differential head to support hydraulic flow, often added as a retrofit to meet more stringent standards, thus low lift pumps are often necessary to elevate the water flow	Hillsboro, Oregon; Rock Creek, TX (includes tertiary Alum addition followed by filtration). [9]
	Post Denitrification Filter (after advanced innovative above with full nitrification)	0-1	3-5	1-2	10	10	ref[20]	Anoxic Environment, carefully controlled, phosphoric acid addition if required and methanol addition as required	$1.46 - $3.2 mil. per mgd or $146 - $320 per person per mgd[11,12]	$286,000 (100K gpd) - $800,000 (25K gpd) per year per mgd or $28.60 - $80.00 per person per year[12]	Allows for good control of denitrification and results in very low BOD and TSS effluent. Often used in Chesapeake Bay area	Need the differential head to support hydraulic flow, often added as a retrofit to meet more stringent standards, thus low lift pumps are often necessary to elevate the water flow	Arlington County, VA (large plant), Maryland analyses and case study[11]
	Enhanced Treatment Technologies (above Conventional)												
	Modified Activated Sludge Plants	<2	ref[14] Little change	ref[14] Little change	10-30	10-30	2.5-6 (15 to 20% reduction)	Mean cell residence time (sludge age) generally >15 days, good solids settling or removal, temperature sensitive. Usually aeration hydraulic retention time >16 hours. Could have MBR instead of clarifiers.	$1.45 mil. per mgd or $145 per person per mgd[8], $3 mil. per mgd or $300 per person per mgd (Delphos)	$180,000 - per year per mgd or $18 per person per year[8]	Proven technology and well understood	Soft water may need alkalinity added, will need about 4 times as much aeration than a non-nitrifying plant.	Delphos, OH. MBR plant (Enviroquip).

	Treatment	Achievable Effluent Characteristics (mg/L)						Critical Design Parameters	Estimated Costs[17] ($ per million gallons treated)		Benefits	Limitations	Examples
		Ammonia Nitrogen	Total Nitrogen	Nitrate-N	BOD	TSS	Phosphorus		Capital ($/mgd)	Operation and Maintenance ($/million gallons treated)			
	Typical Wastewater Constituent Influent Characteristics	12-50[13]	20-85[13]	0[14]	180-300	180-300	3-7[13]						
Large Systems (> 1 mgd)	**Conventional Alternatives**												
	Activated Sludge Plants	ref[14] Little to some reduction	ref[14] Little change	ref[14] Little change	10-50 [2]	15-60 [2]	2.5-6 (15 to 20% reduction)	Design for wet weather flow. Hydraulic detention time, aeration & clarification capacity	$6 mil. per mgd or $600 per person per mgd	$292,000 - $730,000 per year per mgd or $29 to $73 per person per year[1]	Cost Effective, well understood, can often take short term overloading during wet weather.	Cannot take long term overloads.	Many Locations throughout the US and the world. Edwardsville, IL, Waukesha, WI, Beaver Dam, WI, and Decatur, IL.
	Sequencing Batch Reactors (SBR)	5-8[1]	ref[14] Little to some reduction	ref[14] Little change	10 [1]	10 [1]	1-2[1]	Influent characteristics Effluent requirements Number of basins Number of cycles Aeration equipment	$1.2 mil. per mgd or $120 per person per mgd[8]	$130,000 - per year per mgd or $13 per person per year[8]	Clarification, Treatment and Secondary clarification achieved in one reactor Minimal footprint Easily modified for nutrient removal Operator control	Sophisticated timing and controls (more maintenance) Potential for discharging sludge with clear water	Many Locations throughout the US and the world. Pima, AZ, Pekin, IL, and Madison, WI.
	Oxidation Ditch	5-8	ref[14] Little to some reduction	ref[14] Little to no change, may increase	10-30	10-30	2.5-6 (15 to 20% reduction)	Retention Time; BOD Loading; HRT of aeration basin.	$6 mil. per mgd or $600 per person per mgd	$292,000 - $730,000 per year per mgd or 29.20 to 73 per person per year[1]	low operational and maintenance requirements (compared to other conventional treatments) produces less sludge than other systems	requires large land area TSS concentrations can be high compared to other systems	Many Locations throughout the US and the world. Hartland, MI and Cedarburg, WI.
	Metal Salt Precipitation (incorporated in secondary system)	ref[19] Little change	ref[19] Little change	ref[19] Little change	15	15	1	Activated Sludge treatment with a metal salt (chemical phosphate removal) being used. Often added to aeration tank, settling in secondary clarifier.	$0.25 mil. per mgd or $25 per person per mgd	$31,000 per year for 1 mgd or $3.10 per person per year	Well established technology Chemicals can be inexpensive Can be low maintenance	Difficult to obtain low phosphorus concentrations with chemical treatment alone Can increase the amount of sludge Operator safety can be a concern	Wyandotte, MI and Collinsville, IL.

1. EPA (1999). Wastewater Technology Fact Sheet Sequencing Batch Reactors. Office of Water. Washington, D.C. EPA 832-F-99-073
2. EPA (2002). Onsite Wastewater Treatment Systems Manual. Office of Water and Office of Research and Development. Washington, D.C. EPA 625-R-00-008. BOD and TSS achievable limits referenced in the manual are 20 mg/L each. Various operators have been able to achieve limits approaching 10 mg/L for their particular system.
3. EPA (2000). Wastewater Technology Fact Sheet Oxidation Ditches. Office of Water. Washington, D.C. EPA 832-F-00-013
4. EPA (1981). Process Design Manual for Land Treatment of Municipal Wastewater. Center for Environmental Research Information. Cincinnati, OH EPA 625-1-81-013
5. EPA (2002). Wastewater Technology Fact Sheet Aerated, Partial Mix Lagoons. Office of Water. Washington, D.C. EPA 832-F-02-008
6. EPA (2002). Wastewater Technology Fact Sheet Facultative Lagoons. Office of Water. Washington, D.C. EPA 832-F-02-014
7. EPA (2009). Nutrient Control Design Manual State of Technology Review Report. Office of Water and Office of Research and Development. Washington, D.C. EPA 625-R-09-012
8. EPA (2007). Biological Nutrient Removal Processes and Costs. Office of Water and Office of Research and Development. Washington, D.C. EPA 823-R-07-002
9. Hartman, P. and Cleland, J.(2007). Wastewater Treatment Performance and Cost Data to Support an Affordability Analysis for Water Quality Standards. Prepared by ICF international for Montana Department of Environmental Quality. May 31, 2007.
10. University of Colorado Boulder(2009). The Robert W. Hite Treatment Facility South Complex Secondary Treatment Upgrade Evaluation. Denver, CO. October 12, 2009.
11. EPA (2007). Wastewater Technology Fact Sheet Denitrifying Filters. Office of Water. Washington, D.C. EPA 832-F-07-014
12. Foess, G. W., Steinbrecher, P., Williams, K., and Garrett, G. (1998). Cost and Performance Evaluation of BNR Processes. Florida Water Resources Journal. December, 1998.
13. Sedlak, R., Phosphorus and Nitrogen Removal from Municipal Wastewater, Principles and Practice, Second Edition (1991)
14. Nitrate is typically zero entering a municipal wastewater treatment facility. Aeration and biologic activity (nitrification) converts ammonium nitrogen to nitrates.
15. Disinfection typically has little effect on nutrients and wastewater characteristics. Common practice today is chlorination followed by dechlorination, Ultraviolet Light (UV), and on occasion ozone addition. Main objective is the reduction of pathogenic microorganisms (disease causing).
16. This is a method of returning the treated water to the environment. This includes groundwater as well as evaporation, even evapotranspiration. Thus the removal or alteration of nutrients is not the primary objective and in some cases the values may go down, up or remain unchanged. But see Antideg Alternaties for Municipal Sewage Treatment.
17. Capital costs cover the cost of materials & labor to construct the facily and bring it on-line. Generally it does not factor in the land costs for the treatment site O&M costs include repair items, labor, expendables, utilities, any chemicals.
18. The biomass that makes up the activated sludge has retained phosphorus in the cell wall and inner cell contents. Thus if a plant upset caused solids to pass through to the effluent, a P excursion is likely.
19. The addition of metal salts does not change the soluble ammonium or nitrate present in the effluent. The additional biomass settled by the metal salt would remove some additional organic nitrogen in the BOD and TSS resulting in a slightly lower total nitrogen concentration.
20. Denitrification does not change the phosphorus present in the biomass.
21. NRDC, et al before US EPA. (2007). Petition for Rulemaking under Clean Water Act. Secondary Treatment Standards for Nutrient Removal.
22. Clarkson, W. (1991) Land Treatment of Wastewater. Civil Engineering Class Text Oklahoma State University, Stillwater, OK.
    Calculation assumptions - application 4"/week, nitrogen leaching >10mg/L, dedicated and seasonal system applies 30 weeks/year, 160 acres with center pivot req'd for 1 MGD, hold pond - dedicated system 6 month capacity, holding pond seasonal requires 1 month capacity
23. EPA (1999). Wastewater Technology Fact Sheet Ozone Disinfection. Office of Water. Washington, D.C. EPA 832-F-99-063