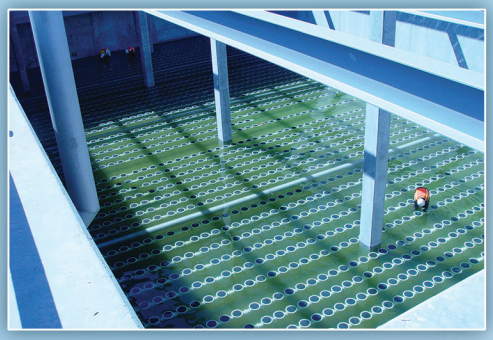
EPA
United States
Environmental Protection
Agency

Emerging Technologies

for Wastewater Treatment and In-Plant Wet Weather Management



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Emerging Technologies

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Cover photos, top to bottom:

Butler Drive Water Reclamation Facility, Peoria, AZ (Arizona Water Infrastructure Finance Authority)

Orange County Water District, Groundwater Replenishment, CA (Tetra Tech)

Ypsilanti Community Utilities Authority Biosolids Incineration System, MI (Tetra Tech)

Richardson Treatment Plant, sampling influent water, Loma Linda, CA (Tetra Tech)

Background photo: James E. Anderson Reverse Osmosis Water Treatment Plant, Port St. Lucie, FL (Tetra Tech)

Preface

The U.S. Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of environmental laws, the Agency strives to formulate and implement actions leading to a balance between human activities and the ability of natural systems to support and sustain life. To meet this mandate, the Office of Wastewater Management (OWM) provides information and technical support to solve environmental problems today and to build a knowledge base necessary to protect public health and the environment in the future.

This publication has been produced, under contract to the U.S. EPA, by the Tetra Tech Corporation, and it provides current state of development as of the publication date. It is expected that this document will be revised periodically to reflect advances in this rapidly evolving area. The original publication was published in February 2008 with document number EPA 832-R-06-006. This publication is the first update and has a new document number, EPA 832-R-12-011, March 2013. Except as noted, information, interviews, and data development were conducted by the contractor. Some of the information, especially related to emerging technologies, was provided by the manufacturer or vendor of the equipment or technology, and could not be verified or supported by full scale case studies. In some cases, cost data were based on estimated savings without actual field data. When evaluating technologies, estimated costs, and stated performance, efforts should be made to collect current and up to date information.

The mention of trade names, specific vendors, or products does not represent an actual or presumed endorsement, preference, or acceptance by the U.S. EPA or Federal Government. Stated results, conclusions, usage, or practices do not necessarily represent the views or policies of the U.S. EPA.

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Overview

In 2008, there were 14,780 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 1440 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. With few exceptions, the CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2008, nearly 37 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment. In many cases, this is due to more stringent water quality based requirements.

This document updates the original 2008 publication "Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management" EPA 832-R-06-006 and provides information on four of the five categories of development regarding emerging wastewater treatment and in-plant wet weather management technologies. Information in the form of technology fact sheets on established technologies is not included. The five categories are:

1. Research – Technologies in the development stage and/or have been tested at a laboratory or bench scale only.

2. Emerging – Technologies that have been tested at a pilot or demonstration scale, or have been implemented at full scale in 3 or fewer installations or for less than 1 year.

3. Innovative – Technologies that have been implemented at full scale for less than five years, or have some degree of initial use (i.e., implemented in more than three but less than 1 percent [150] of US treatment facilities).

4. Established – Technologies that have been used at more than 1 percent (150) of US treatment facilities or have been available and widely implemented for more than five years. (Note: Fact sheets for established technologies are outside the scope of this document and, therefore not included.)

5. Adaptive Use – Some wastewater treatment processes have been established for years, but their use has not been static. In some cases, an established technology may have been modified or adapted resulting in an emerging technology. In other cases, a process that was developed to achieve one treatment objective is now being applied in different ways or to achieve additional treatment objectives. During the operation of treatment systems using these established technologies, engineers, and operators have altered and improved their efficiency and performance. This document includes established technologies that have undergone recent modifications or are used in new applications.

This document also provides information on each technology, except for “established”, its objective, its description, its state of development, available cost information, associated contact names, and related data sources. For each technology, this document further evaluates technologies against various criteria, although it does not rank or recommend any one technology over another. In some cases, the only available information is from the vendor or researcher, and has not been independently verified. Research needs are also identified to guide development of innovative and emerging technologies and improve established ones.

Knowledge about technologies tends to evolve. The information provides a snapshot at a point in time; what is understood at one point in time may change as more information develops. This includes knowledge about operating mechanisms as well as the relative and absolute costs and features of a particular technology. Inquiries into the current state of knowledge are an important step when considering implementation of any technology.

Chapter 1

Introduction and Approach

1.1 Introduction

In 2008, there were 14,780 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 1440 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (known as the Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. The CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2008, nearly 37 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment.

To meet the challenge of keeping progress in wastewater pollution abatement ahead of population growth, changes in industrial processes, and technological developments, EPA is providing this document to make information available on recent advances and innovative techniques. This document updates the original 2008 publication “Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management” EPA 832-R-06-006.

The goal of this document is straight forward—to provide a guide for persons seeking information on innovative and emerging wastewater treatment technologies. The guide lists new technologies, assesses their merits and costs, and provides sources for further technological investigation. This document is intended to serve as a tool for wastewater facility owners/utilities, operators, planners, and consultants.

New technologies typically follow a development process that leads from laboratory and bench-scale investigations to pilot studies, and to initiate use or “full-scale demonstrations” before the technology is considered established. Not all technologies survive the entire development process. Some fail in the laboratory or at pilot stages; others see limited application in the field, but poor performance, complications, or unexpected costs may cause them to lose favor. Even technologies that become established may lose favor in time, as technological advances lead to obsolescence. In short, technologies are subject to the same evolutionary forces present in nature; those that cannot meet the demands of their environment fail, while those that adapt to changing technological, economic and regulatory climates can achieve long-standing success and survival in the market.

Some wastewater treatment processes have been established for many years, but that does not mean that they are static. During the operation of treatment systems using these established technologies, engineers and operators have altered and improved efficiency and performance. In other cases, established technologies applied to one aspect of treatment have

been modified so that they can perform different objectives. Often, better performance can be achieved by linking established processes in innovative ways. This document includes established technologies that have undergone recent modifications or are used in new applications (adaptive use). These technologies are evaluated in the chapters alongside the innovative, emerging, and research technologies.

1.2 Approach

To develop this reference document, the investigators sought information from a variety of sources, identified new technologies, prepared cost summaries, where information was available, for all technologies, and evaluated technologies deemed to be innovative. This method is described below and in Figure 1-1.

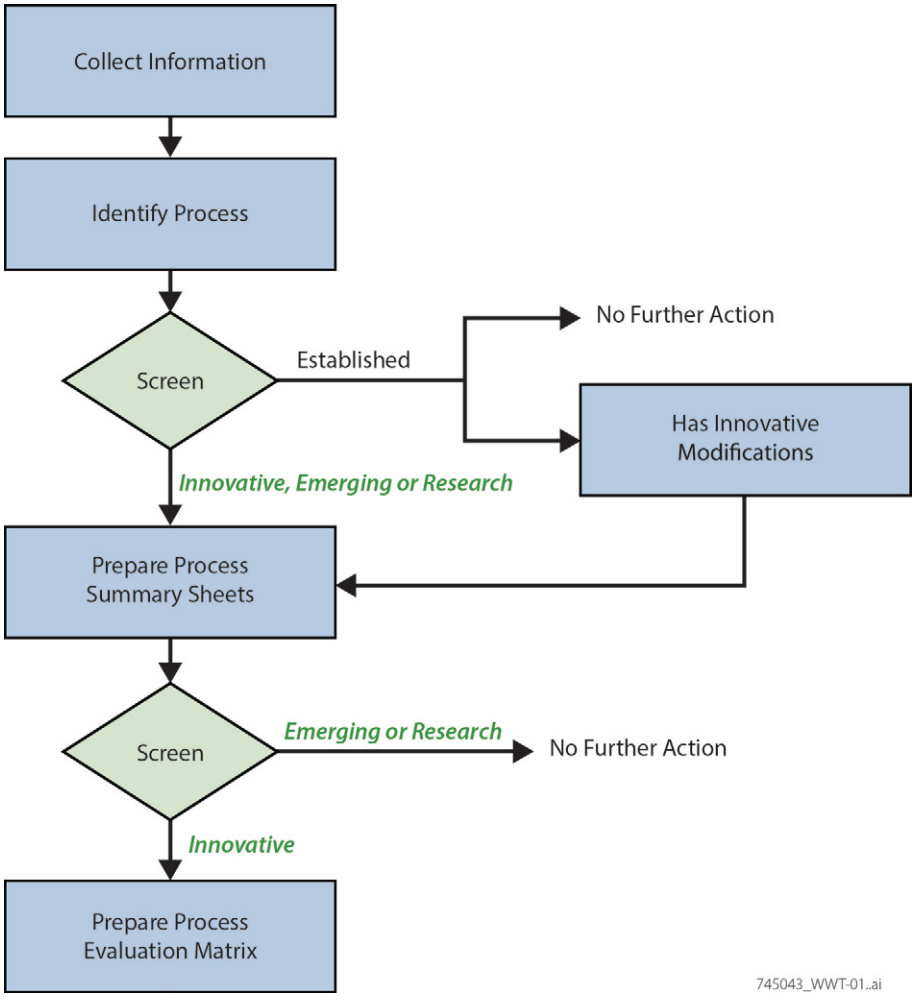

Figure 1.1—Flow Schematic for Document Development

1.2.1 Information Collection and New Process Identification

The collection of information and identification of new technology provided the foundation for subsequent work. To identify new treatment process technologies, investigators gathered information and focused on relevant Water Environment Federation (WEF) and American

Society of Civil Engineers (ASCE) conference proceedings, as well as monthly publications from these and other organizations such as International Water Association (IWA).

"Gray" Literature – Vendor-supplied information, Internet research, and consultants' technical reports comprise the information collected in this category.

Expert Panel – A panel of industry experts including those from technical associations, consulting practice, utilities, and academia was organized to identify emerging wastewater treatment technologies.

Technologies identified through search of the above sources were screened to determine their classification as described below.

1.2.2 Initial Screened Technologies

This project focuses on emerging technologies that appear to be viable, but have not yet been accepted as established processes in the United States. Specific screening criteria used to define the state of development for processes are described in the following paragraphs. This screening resulted in:

- 3 research technologies
- 22 emerging technologies
- 31 innovative technologies
- 7 adaptive use technologies

Research – These technologies are in the development stage and/or have been tested at laboratory or bench scale. New technologies that have reached the demonstration stage overseas, but cannot yet be considered to be established there, are also considered to be research technologies with respect to North American applications.

Emerging – Technologies that have been tested at a pilot or demonstration scale, or have been implemented at full scale in 3 or fewer installations or for less than 1 year.

Innovative – Technologies that meet one of the following criteria were classified as innovative:

- They have been tested as a full-scale demonstration.
- They have been available and implemented in the United States for less than five years.
- They have some degree of initial use (i.e., implemented in less than 1 percent of municipalities (150) throughout the United States).
- They are established technologies from overseas.

Established – In most cases, these processes are used at more than 1 percent of full-scale facilities (150) in North America; but there are some exceptions based upon specific considerations. The established category may include technologies that are widely used although introduced more recently in North America. Due to the extensive number of established technologies and variations in each technology, established technologies are only listed in this report. None are described in depth in this document and Technology Summary Sheets are not provided for established technologies.

Adaptive Use – In some cases, an established technology such as the UCT (University of Cape Town) process may have been modified or adapted, resulting in an emerging technology such as the Modified UCT. In other cases, a process like Actiflo® was developed to remove solids from wet weather flows but is now also being used to polish final effluent.

The focus of this document is on Innovative Technologies along with preliminary information on Emerging and Research Technologies. Early in the development process (the laboratory stage or few full scale installations), data are usually insufficient to prove or disprove general technology viability at full scale. Available information on these Emerging or Research technologies is presented in this document. Technologies on the other end of the developmental scale, those defined as Established in North America, are excluded from the detailed assessments on the assumption that they are proven, although still relatively new.

The differentiation between technologies established in Europe or Asia and those that have reached similar status in the United States can be critical since technologies that have been applied successfully in other countries have not always flourished here in the United States. Because the viability of imported technologies is not guaranteed, established processes from overseas are classified as innovative technologies for this project, unless they are proven in North American applications.

Some technologies fall into a “gray area” between the Research and Innovative categories. Technologies that fall into this category are incorporated into the Emerging category. The screening assessment is summarized by chapter in Tables 1.1 through 1.5.

- Table 1.1 summarizes the treatment technologies for Chapter 2 – Physical/Chemical Treatment Processes.
- Table 1.2 summarizes the treatment technologies for Chapter 3 – Biological Treatment Processes.
- Table 1.3 summarizes the treatment technologies for Chapter 4 – In-Plant Wet Weather Management Processes.
- Table 1.4 summarizes the treatment technologies for Chapter 5 – Process Monitoring Technologies.
- Table 1.5 summarizes the treatment technologies for Chapter 6 – Energy Conservation Measures.

All the cost estimates provided in this document contain a certain degree of expert judgment or educated analysis concerning the various cost elements that comprise the estimates. This is true when cost estimates are based on limited or no information where in some cases little more than process type, location, and plant capacity are known. Therefore, cost estimates are at best order-of-magnitude level per American Association of Cost Engineers (AACE) International classification. However, numerous peripheral factors could also interfere with the accuracy of the order-of-magnitude level cost estimates. Considering these facts, the reader should keep in mind that site-specific applications and local requirements should be considered to increase the accuracy of cost estimates provided in this document.

Knowledge about technologies tends to evolve. The information provides a snapshot at a point in time; what is understood at one point in time may change as more information develops. This includes knowledge about operating mechanisms as well as the relative and absolute

costs and features of a particular technology. Inquiries into the current state of knowledge are an important step when considering implementation of any technology.

1.2.3 Development of Technology Summary Sheets

Technologies categorized as research, emerging, innovative, or adaptive use are each summarized on an individual Technology Summary sheet. Each process generally includes the following information:

Objective – Description of the goal of the technology.

State of Development – Where and how the technology has been applied (i.e., resulting in being placed in the corresponding category: research; emerging; innovative; or adaptive use).

Description – A brief overview of the technology.

Comparison to Established Technologies – Advantages and disadvantages of innovative, emerging, and research technologies are compared to more commonly used technologies.

Available Cost Information – Approximate range of capital and operations and maintenance costs, and assumptions made in developing them (when reliable information was available).

Vendors Name(s) – Name, address, telephone numbers, web address, and other contact information for equipment manufacturers and suppliers.

Installation(s) – Name, address, telephone numbers, and other contact information for utilities and facilities where the technology has been used (full or pilot scale).

Key Words for Internet Search – Because this document is not intended to provide a comprehensive list of vendors for these technologies, key words have been added to aid the reader in finding additional vendors and current product information on the Internet.

Data Sources – References used to compile the technology summary. Specific citations to data sources are provided as appropriate within the individual technology summary sheets that were prepared for this update (noted at the top of the sheet as “prepared 2012”). Data not cited should be assumed to be provided by the technology vendor. Technology summaries labeled as “updated 2012” or “prepared 2008” include data from the listed sources but it may not be cited within the text.

Table 1.1—Summary of Treatment Technologies
Chapter 2 – Physical/Chemical Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (technology summaries not included)									
Adsorption									
Activated Alumina Media						●			
Granular-Activated Carbon (GAC)		●		●	●				
Granular Iron Based Media		●							
Powdered Activated Carbon (PAC)		●			●				
Disinfection									
Ozone							●		
Chlorine/Chlorine Dioxide/Liquid Chlorine/Dechlorination							●		
Halogens (Bromine)							●		
UltraViolet (UV) Disinfection							●		
Flocculation									
Nutrient Removal									
Air Stripping			●			●			
Chemically Enhanced Primary Treatment		●			●				
Denitrification Filters		●		●	●				
Ion-Exchange			●			●			
Chemical Precipitation*									
– Alum Addition		●			●				
– Iron Salts Addition		●			●				
– Zeolite					●				
Solids Contact Clarifier for P Removal		●	●		●				
Oxidation									
Chemical Oxidation									
– Chlorine/Hypochlorite/Chlorine Dioxide						●	●		
– Hydrogen Peroxide						●	●		

Table 1.1—Summary of Treatment Technologies
Chapter 2 – Physical/Chemical Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
– Hydroxyl Radical						●	●		
– Oxygen (Atomic and Molecular)						●	●		
– Ozone						●	●		
Advanced Oxidation Processes									
– Catalytic Oxidation						●	●		
– Fenton's Reagent (H_2O_2 + Ferrous Ion)						●	●		
– Photo Catalysis (UV + TiO_2)						●	●		
– Supercritical Water Oxidation						●	●		
Preliminary/Primary Treatment									
Advanced Grit Removal System (AGRS)									
– HEADCELL™					●				
– GRITKING™					●				
– PISTAGRIT™					●				
– HYDROGRIT™					●				
Grit Removal									
– Traveling Bridge					●				
Screening									
– Fine Screening					●				
– Micro Screening					●				
– Rotary Screening					●				
– Step Screening					●				
– Microsieves		●			●	●			
Solids Removal									
Dissolved Air Flotation (DAF) Treatment/Settling					●				
Filtration through Media									
– Automatic Backwash Filters (ABW®)		●			●				
– Cloth Media									
○ Disc Filter (DF)		●			●				

Table 1.1—Summary of Treatment Technologies
Chapter 2 – Physical/Chemical Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
○ Drum Filter			●			●				
○ Diamond-Shaped Filters			●			●				
– Pulsed Bed Filter			●			●				
– Silica Media (One- and Two-Stage)										
○ Conventional Downflow			●			●				
○ Deep-Bed Downflow Filters			●			●				
○ Deep-Bed Upflow Continuous Backwash Filters			●			●				
Filtration through Membranes										
– Electrodialysis						●	●			
– Microfiltration			●			●	●			
– Ultrafiltration			●			●	●			
Innovative Technologies	**Summary on page**									
Nutrient Removal										
Blue PRO™ Reactive Media Filtration	2-6		●			●				
Phosphorus Recovery (Struvite or Calcium Phosphate Precipitation)	2-8		●	●	●					
Solids Removal										
Compressible Media Filtration (CMF)	2-10	●	●			●				
Magnetite Ballasted Sedimentation	2-14		●			●				
Multi-stage Filtration	2-16		●			●				
Nanofiltration and Reverse Osmosis	2-18		●			●	●			
Adaptive Use Technologies	**Summary on Page**									
Disinfection										
Microwave Ultraviolet (UV) Disinfection	2-20							●		
Solids Removal										
Ballasted High Rate Clarification										

Table 1.1—Summary of Treatment Technologies
Chapter 2 – Physical/Chemical Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
(BHRC) Processes										
– Actiflo® Process	2-22		●			●				
– Densadeg® Process	2-24		●			●				
Emerging Technologies	**Summary on page**									
Disinfection										
Alternative Disinfectants	2-26									
– PAA - Peracetic acid								●		
– BCDMH								●		
Nutrient Removal										
Ammonia Recovery Analyzer	2-29						●			
Oxidation										
Blue CAT™	2-31		●			●	●			
Preliminary/Primary Treatment										
Salsnes Filter	2-33	●								
Research Technologies										
None at this time										

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (technology summaries not included)									
Anaerobic Processes									
Anaerobic Attached Growth System									
– Upflow Packed-Bed Attached Growth Reactor	●								
– Upflow Attached Growth Anaerobic	●								
– Expanded-Bed Reactor (Anaerobic Expanded Bed Reactor [AEBR])	●								
– Downflow Attached Growth Process	●								
Anaerobic Contact Process									
– Anaerobic Sequencing Batch Reactor (ASBR)	●								
– Upflow Anaerobic Sludge Blanket (UASB)	●								
– ANaerobic FLuidized Bed Reactor (ANFLOW)	●								
BOD Removal and Nitrification									
Biolac-Aerated Lagoon	●		●						
Complete Mix-Activated Sludge (CMAS) Process	●		●						
Contact Stabilization	●		●						
Conventional Extended Aeration	●		●						
Countercurrent Aeration System (CCAS™)	●		●	●					
Cyclic Activated Sludge System (CASS™)	●		●	●					
Facultative and Aerated Lagoons	●		●						
High-Purity Oxygen (HPO)	●		●						
Intermittent Cycle Extended Aeration System (ICEAS™)	●		●	●					
Kraus Process	●		●						
Oxidation Ditch/Aerated Lagoons	●		●						
Sequencing Batch Reactor (SBR)	●		●	●					
Staged Activated-Sludge Process	●		●						
Step Feed	●		●						

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Biofilm Processes									
Biological Aerated Filters (BAF)									
– Biofor®	●		●	●					
– Biostyr®	●		●	●					
Fluidized Bed Bioreactor (FBBR)	●		●						
Integrated fixed-Film Activated Sludge (IFAS)									
– IFAS – Submerged Mobile Media	●		●						
– IFAS – Submerged Fixed Media	●		●						
Moving-Bed Bio Reactor (MBBR) Process	●		●	●					
Rotating Biological Contactor (RBC)	●		●						
Submerged Rotating Biological Contactor (SRBC)	●		●						
Trickling Filter (TF)	●		●						
Trickling Filter/Solids Contactor (TF/SC)	●		●						
Nitrogen Removal									
Bardenpho® (Four Stage)	●		●	●					
Biodenitro™	●		●	●					
Denitrification Filter				●	●				
Ludzack-Ettinger	●		●	●					
Modified Ludzack-Ettinger (MLE)	●		●						
Orbal™ Process	●		●						
Schreiber™ Process	●		●						
Simultaneous Nitrification denitrificatioN (SNdN) Process	●		●						
Step Feed (Alternating Anoxic and Aerobic)	●		●						
Wuhrman	●		●						
Nitrogen and Phosphorus Removal									
Anaerobic/Anoxic/Oxic (A2/O)	●	●	●	●					
Bardenpho® (Five Stage)	●	●	●	●					

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)	Summary on page	Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Johannesburg Process		●	●	●	●					
Step Feed BNR Process		●		●	●					
University of Cape Town (UCT)		●	●	●	●					
Virginia Initiative Plant (VIP)		●	●	●	●					
Phosphorus Removal										
Phoredox (Anaerobic/Oxic [A/O])		●	●							
Phostrip		●	●							
Membrane Processes										
Membrane Bioreactor (MBR)										
– Tubular		●	●	●		●				
– Hollow-Fiber		●	●	●		●				
– Spiral Wound		●	●	●		●				
– Plate and Frame		●	●	●		●				
– Pleated Cartridge Filters		●	●	●		●				
Innovative Technologies	**Summary on page**									
Bioaugmentation										
Bioaugmentation	3-7									
– External Bioaugmentation		●		●	●					
– Seeding from Commercial Sources of Nitrifiers		●		●	●					
○ In-Pipe Technology		●		●	●					
○ Trickling Filter and Pushed Activated Sludge (TF/PAS) Process		●		●	●					
○ Seeding from External Dispensed Growth Reactors Treating Reject Waters (Chemostat Type)		●		●	●					
○ In-Nitri® Process		●		●	●					

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
○ Immobilized Cell-Augmented Activated Sludge (ICASS) Process		●		●	●					
○ Seeding from Parallel Processes		●		●	●					
○ Seeding from Downstream Process		●		●	●					
– In Situ Bioaugmentation										
○ DE-nitrification and PHosphate accumulation in ANOXic (DEPHANOX) Process		●		●	●					
○ Bio-Augmentation Regeneration/Reaeration (BAR) Process		●		●	●					
○ Bio-Augmentation Batch Enhanced (BABE) Process		●		●	●					
○ Aeration Tank 3 (AT3) Process		●		●	●					
○ Main stream AUtotrophic Recycle Enabling Enhanced N-removal (MAUREEN) Process		●		●						
○ Regeneration DeNitrification (R-DN) Process		●		●	●					
○ Centrate and RAS Reaeration Basin (CaRRB) Process		●		●	●					
Nitrogen Removal										
Deammonification (Sidestream)	3-16	●		●	●					
Nitritation and Denitritation (Sidestream)	3-19	●		●	●					
Small Site										
Deep-Shaft Activated Sludge/ VERTREAT™	3-22	●								

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Solids Minimization										
Cyclic Metabolic Environment	3-23	●	●	●	●					
Solids Settleability										
Magnetite Ballasted Activated Sludge	3-25	●	●	●	●	●				
Adaptive Use Technologies	**Summary on page**									
Nitrogen and Phosphorus Removal										
Biological-Chemical Phosphorus and Nitrogen Removal (BCFS) Process	3-27	●	●	●	●					
Modified University of Cape Town (MUCT) Process	3-29	●	●	●	●					
Westbank Process	3-30	●	●	●	●					
Phosphorus Removal										
Modified Anaerobic/Oxic (A/O) Process	3-31	●	●	●	●					
Emerging Technologies	**Summary on page**									
Membrane Processes										
Membrane Biofilm Reactor (MBfR)	3-32	●	●	●		●	●			
Vacuum Rotation Membrane (VRM®) System	3-34	●	●			●				
Nitrogen Removal										
OpenCel Focused Pulse	3-35				●					
Nitrogen and Phosphorus Removal										
Integrated Fixed-film Activated Sludge (IFAS) with Biological Phosphorus Removal	3-36	●		●	●					
Solids Minimization										
Multi-Stage Activated Biological Process (MSABP™)	3-37	●		●	●					
Solids Settleability										
Aerobic Granular Sludge Process (AGSP)	3-38	●	●	●	●					

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes (continued)

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Research Technologies	**Summary on page**									
Anaerobic Processes										
Anaerobic Migrating Blanket Reactor (AMBR®)	3-41	●								
Anaerobic Membrane BioReactor (An-MBR)	3-43	●	●							
Electricity Generation										
Microbial Fuel Cell (MFC) Based Treatment System	3-45	●	●							

Table 1.3—Summary of Treatment Technologies
Chapter 4 – In-Plant Wet Weather Management Processes

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (technology summaries not included)										
Treatment										
Dispersed Air Flotation			●			●				
Dissolved Air Flotation (DAF)			●			●				
Enhanced Clarification/High Rate Clarification (HRC)										
Ballasted Flocculation (Actiflo® and Microsep®)			●			●				
Lamella Plate Settlers			●			●				
Screening						●				
Vortex Separation						●				
Innovative Technologies	**Summary on page**									
Treatment										
Compressible Media Filtration (CMF)	4-4		●			●				
Continuous Deflection Separator (CDS)	4-8					●				
TRASHMASTER™ Net Capture System	4-10					●				
Treatment Shaft	4-11					●				
Storage										
HYDROSELF® Flushing Gate	4-13					●				
Tipping Flusher®	4-15					●				
Adaptive Use Technologies										
BioActiflo Process	4-19	●				●				
Emerging Technologies	**Summary on page**									
Treatment										
Alternative Disinfectants (PAA; BCDMH)	4-16							●		
Research Technologies										
None at this time										

Table 1.4—Summary of Treatment Technologies
Chapter 5 – Process Monitoring Technologies

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (technology summaries not included)										
Microbial Activity										
Dissolved Oxygen Analyzer										●
Oxidation Reduction Potential (ORP) Probe										●
Solids Retention Time (SRT) Controller										●
Solids										
Sludge Blanket Level Detector									●	
Total Suspended Solids Analyzer									●	
Water Quality										
Online Cl_2 Residual									●	
pH Probes									●	
Innovative Technologies	**Summary on page**									
Microbial Activity										
Fluorescence In Situ Hybridization (FISH) for Filamentous and Nitrifying Bacteria	5-4									●
Microtox®/Online Microtox®	5-5									●
Nicotinamide Adenine Dinucleotide (NADH) Probes	5-6									●
Online Respirometry	5-7									●
Solids										
Microwave Density Analyzer	5-8								●	●
Water Quality										
Nutrient Analyzers, Probes, and Electrodes	5-9								●	●
Adaptive Use Technologies										
None at this time										

Table 1.4—Summary of Treatment Technologies
Chapter 5 – Process Monitoring Technologies (continued)

Technology and Advancements (Listed in process flow sequence)		Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Emerging Technologies	**Summary on page**									
Microbial Activity										
Biological Micro-Electro-Mechanical Systems (BioMEMS)	5-12									●
FISH for Phosphorus Accumulating Organisms (PAOs)	5-13									●
Handheld Advanced Nucleic Acid Analyzer (HANAA)	5-14									●
Immunosensors and Immunoassays	5-15									●
Water Quality										
Photo-electro Chemical Oxygen Demand (PeCOD™)	5-16									●
Research Technologies										
None at this time										

Table 1.5—Summary of Treatment Technologies
Chapter 6 – Energy Conservation Measures

Technology and Advancements (Listed in process flow sequence)	Summary on page	Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (technology summaries not included)										
Aeration										
Adjustment of Submergence of Mechanical Aerators			●	●						
Bioprocess Intelligent Optimization System (BIOS)			●						●	
Cycling Mechanical Aerators On and Off			●						●	
Fine-Pore Aeration Diffusers			●							
High Speed (Gearless) Turbo Blowers			●							
Mixing										
Hyperbolic Mixers				●						
Pumping										
NEMA Premium® efficiency motors		●								
Variable Frequency Drives (VFDs)		●								
Other Processes										
Incineration Heat Recovery [Applications: N/A]										
Innovative Technologies	**Summary on page**									
Aeration										
Automated SRT/DO Control	6-4		●						●	
Dual Impeller Aerator (mechanical mixing)	6-4		●	●						
Integrated Air Flow Control	6-6		●						●	
Single-stage Centrifugal Blowers with Inlet Guide Vanes and Variable Diffuser Vanes	6-8		●							
Mixing										
Intermittent Mixing	6-10			●					●	
Pulsed Large Bubble Mixing	6-11				●					
Pumping										
Pump Control Optimization	6-12	●							●	
Adaptive Use Technologies										
None at this time										

Table 1.5—Summary of Treatment Technologies
Chapter 6 – Energy Conservation Measures (continued)

Technology and Advancements (Listed in process flow sequence)	Summary on page	Applications								
		C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Emerging Technologies										
Aeration										
Critical Oxygen Point Control	6-13		●						●	
Membrane Air Scour Alternatives	6-14		●						●	
Ultra-fine Bubble Diffusers	6-16	●	●	●						
Disinfection										
Automated Channel Routing for UV Disinfection	6-18							●	●	
Low Pressure High Output Lamps for UV Disinfection	6-19							●		
Other Processes										
Solar Drying of Sewage Sludge	6-20					●				
Research Technologies										
None at this time										

1.2.4 Evaluation of Technologies

Technologies defined as innovative in the initial screening were subjected to a detailed evaluation. Each technology was evaluated with respect to the descriptive and comparative criteria described below. Descriptive criteria include:

- **State of Development** – Describes the stage of development for each technology, ranging from bench scale development to full-scale operations.
- **Applicability** – Qualitatively assesses in which market the technology is designed to be used.
- **Effluent Reuse** – Describes the reuse of treated effluent as specifically direct, indirect, potable and/or nonpotable.
- **Benefits** – Considers the potential benefits gained (e.g., capital or operational savings) from implementation of the technology.

Designations for each descriptive criterion are presented in Table 1.6.

Table 1.6—Descriptive Evaluation Criteria

Criterion	Designation	Description
State of Development	B	Bench scale
	P	Pilot scale
	I	Full-scale industrial applications
	M	Full-scale municipal applications
	O	Full-scale operations overseas
	N	Full-scale operations in North America
Applicability	I	Industrywide
	F	Few plants
	S	Primarily small plants
	L	Primarily large plants
Effluent Reuse	Dp	Direct potable
	Dn	Direct nonpotable
	Ip	Indirect potable
	In	Indirect nonpotable
Potential Benefits	C	Capital savings
	I	Intense operational demand
	O	Operational/Maintenance savings
	S	Shock load capacity
	W	Wet weather load capacity
	E	Effluent quality

Comparative criteria include:

- **Impact on Existing Facilities or Other Processes** – Describes whether or not the technology requires the involvement of extensive design changes, and the degree to which the existing facilities will be disturbed.
- **Complexity** – Considers the installation, startup, and shutdown methods for the technology.

Air/Odor Emissions – Considers if the process has impacts on air and odor emissions for the facility.

- **Energy** – Considers the amount of energy required to adequately maintain the process and if any energy saving is possible.
- **Footprint** – Considers how the footprint helps to identify the land needed to expand a facility for increased capacity.
- **Retrofitting** – Considers if the process can be used to modify old treatment plants without extensive reconstruction.

The above criteria compared individual technologies with other technologies in the same category, and were scored positive, neutral/mixed, or negative.

The criteria and ratings were applied to each innovative technology and the results are presented in matrix format. Where available information was insufficient to rate a technology for a criterion, no rating is given. The project team and reviewers assessed each technology based on the limited information gathered and their collective judgment, experience, and opinions. Results of the evaluation are presented in subsequent chapters.

1.3 Reference Document Format and Use

The remainder of the reference document is divided into chapters based upon general technologies, one chapter is dedicated to each of the following categories:

- Chapter 2 – Physical/Chemical Treatment Processes
- Chapter 3 – Biological Treatment Processes
- Chapter 4 – In-Plant Wet Weather Flows Management Processes
- Chapter 5 – Process Monitoring Technologies
- Chapter 6 – Energy Conservation Measures
- Chapter 7 – Research Needs

Where appropriate to more than one category, a single technology may be included in more than one chapter; for example, the *Alternative Disinfectants (PAA; BCDMH)* technology fact sheet appears in both Chapter 2 and Chapter 4. Each chapter provides an overview of the appropriate technologies, discusses the state of development for each, presents an evaluation matrix for innovative technologies, and concludes with a Technology Summary Sheet for each research, emerging, innovative, and adaptive use technology included in that chapter.

The technology summaries and evaluation matrices are the cornerstones of each chapter, providing a broad overview of the innovative technologies. Neither the summaries nor the

matrices should be considered definitive technology assessments. Rather, they should be considered stepping stones to more detailed investigations.

Appendix A contains applicable trade associations.

Appendix B contains a list of acronyms and abbreviations.

This document will be updated from time to time. Technologies were reviewed in late 2011 to early 2012.

1.4 Chapter References

Hunter, P. and Lewis, S., Top Ten Biggest Wastewater Treatment Plants, Engineering News Record, April 2, 2012.

U.S. EPA, Clean Watershed Needs Survey 2008 Report to Congress, EPA 832-R-10-002, Office of Water, 2010.