Chapter 4

Alternatives for Centralized and Satellite Wastewater Treatment Facilities and Sites

CHAPTER 4

ALTERNATIVES FOR CENTRALIZED AND SATELLITE WASTEWATER TREATMENT FACILITIES AND SITES

4.1 INTRODUCTION

A. **Purpose**. The purpose of this chapter is to identify technologies and sites that can be used by the Town of Barnstable as part of one or more new satellite wastewater treatment and discharge facilities, or as part of an upgrade and expansion of the Hyannis Water Pollution Control Facility. The recommended technologies will be considered for further detailed evaluation as part of the next phase of the project. Wastewater treatment alternatives are divided into the following groups:

1. Overview of Barnstable's existing municipal wastewater treatment facilities.
2. Secondary/Advanced treatment technologies.
3. Technologies to treat Total Organic Carbon to less than 3 mg/L.
4. Technologies to treat total nitrogen to less than 3 mg/L.
5. Phosphorus removal technologies.
6. Effluent disinfection.
7. Residuals management.
8. Satellite treatment facilities.
9. Identification of potential satellite treatment sites.
10. Alternatives for treatment system expansion and upgrade at the Hyannis WPCF.

Each group of alternatives is presented and screened in a separate section of this chapter. Treated water recharge alternatives are discussed in Chapter 5.

4.2 OVERVIEW OF BARNSTABLE'S EXISTING MUNICIPAL WASTEWATER TREATMENT FACILITIES

A. **Introduction.** The Town of Barnstable Department of Public Works (DPW) operates two centralized and satellite treatment facilities: The Hyannis Water Pollution Control Facility (WPCF) and, the Marstons Mills Wastewater Treatment Facility (WWTF). (The Town also operates the Red Lily Pond Cluster System which was discussed in Chapter 3.) These wastewater treatment systems were described in detail in the Needs Assessment Report and are briefly reviewed in this chapter to provide background on these two existing Town municipal wastewater treatment facilities.

B. **Hyannis WPCF.** The Hyannis WPCF is located on Bearse's Way in Hyannis and treats wastewater collected from Hyannis and Barnstable villages. The treated water is recharged at sand infiltration beds at the Bearse's Way site. The Hyannis WPCF has treatment capacity to treat 4.2 million gallons per day (mgd) on a maximum month basis and currently treats a flow of 1.94 mgd during the maximum month (typically July or August). The remaining capacity is reserved for planned sewer extensions approved by the 2007 Wastewater Facilities Plan. The Hyannis WPCF is illustrated in Figure 4-1.

The Hyannis WPCF has been upgraded and expanded several times since it was constructed in 1936. It is now classified as an advanced secondary treatment process and has consistently met the discharge limits required by MassDEP and the Sole Source Aquifer regulations. The total nitrogen concentration of the treated water recharged at the site has averaged 5 mg/L over the past three years, and this is excellent nitrogen removal performance. The treatment facilities represent a large investment in wastewater infrastructure, and a large percentage of the facilities have been constructed with state and federal grants and low-interest loans.

The MassDEP regulations have recently changed, and the Hyannis WPCF will need to meet a Total Organic Carbon (TOC) limit of 3 mg/L in the future, particularly if the facility is expanded. This regulatory change could require additional treatment upgrades.

The Hyannis WPCF is located in the Lewis Bay watershed and may need to provide additional nitrogen removal to meet the nitrogen TMDL for that water body.

C. **Marstons Mills WWTF.** This satellite treatment facility, located at the West Villages Elementary School and Horace Mann Charter School complex, serves these two schools as well as The Villages subdivision located on Osterville-West Barnstable Road. The Marstons Mills WWTF was originally constructed in 1994 when the Charter School (previously a Middle School) was constructed, and it was originally operated by a contract operator as overseen by the Town's School Department. The early treatment performance of the Marstons Mills WWTF did not meet the discharge limits set by MassDEP due to the following issues:

- The schools have very irregular wastewater flows and loadings due to the intermittent land use of the schools.
- Several system components were not well designed for the intermittent wastewater flows.
- System operations were not well budgeted by the School Department.

The Marstons Mills WWTF was upgraded and expanded in 2005, and additional wastewater flow was connected to the WWTF from The Villages subdivision. This additional flow evened out the past intermittent flows that are typical of a school complex of this size. Since the upgrade and improved operation provided by the Towns Department of Public Works Water Pollution Control Division (the same group that operates the Hyannis WPCF), the WWTF has performed well and has met the MassDEP discharge limits. The nitrogen concentration of the treated water has averaged less than 4 mg/L for the past year. The Marstons Mills WWTF is illustrated in Figure 4-2.

MassDEP has recently changed its discharge regulations and, similar to the Hyannis WPCF, the Marstons Mills WWTF will need to increase treatment performance (particularly if it is expanded) to meet a new limit of 3 mg/L TOC.

4.3 SECONDARY/ADVANCED WASTEWATER TREATMENT TECHNOLOGIES

A. **Introduction.** Wastewater treatment facilities include the following system components: (1) preliminary treatment; (2) primary treatment; (3) flow equalization; (4) secondary/advanced treatment alternatives; (5) effluent filtration; and (6) effluent disinfection. These system components are described below, and treatment alternatives are described in detail and screened. These system components are also illustrated on Figure 4-3.

B. **Preliminary Treatment.** Preliminary treatment is designed to remove large and abrasive objects and solids from wastewater and is usually the first process of a treatment facility. The removal of these objects prevents damage to treatment equipment such as pumps, valves, and pipelines.

Bar screens are used to remove large objects and the material removed is referred to as "screenings". Grit removal facilities are utilized to remove sand and other abrasive materials from the wastewater to prevent excessive wear on moving equipment and minimize heavy deposits in pipelines and channels.

C. **Primary Treatment.** Primary treatment is a process to remove settleable solids from the wastewater flow. The solids are removed by gravity settling and can be collected using mechanical equipment or by periodically pumping the tank. Primary treatment methods often include primary clarification for larger facilities and large septic tanks for smaller facilities.

Primary clarification involves the use of circular or rectangular tanks with mechanical equipment for collection and removal of solids and scum. As wastewater flows through the tank, solids settle to the bottom of the tank and the scum floats to the top of the tank; both are then collected and removed by mechanical equipment.

D. **Flow Equalization.** Flow equalization is used to even out the daily flow fluctuations at a treatment facility. Most municipal wastewater is produced during two to three hours in the morning and evening when water usage is highest. Flow equalization utilizes one or more storage tanks to store the wastewater during these flow peaks, and pump it evenly into the treatment process throughout the day.

E. **Secondary/Advanced Treatment Concepts and Configurations.** Secondary treatment processes are designed to remove dissolved and suspended solids from wastewater, reducing the biological oxygen demand (BOD) and total suspended solids (TSS) concentrations. Advanced treatment processes typically remove nutrients such as nitrogen and phosphorous. The most common and typically least expensive secondary and advanced treatment processes are biological processes. This section focuses on biological processes because they are the most used and efficient processes for wastewater treatment. This section also discusses physical and chemical processes that can enhance the performance of the biological processes.

Biological treatment of wastewater utilizes microorganisms to transform solids and organic matter into biological cell mass, carbon dioxide, and nitrogen gas. Biological processes provide an environment for microbial growth using nutrients, BOD, and TSS in the wastewater as a food source. Microorganisms are removed from the wastewater as sludge (also called biosolids); and carbon dioxide and nitrogen gas are released to the atmosphere.

Biological processes are classified as aerobic, anoxic, or anaerobic processes. Aerobic processes are those which occur only in the presence of oxygen; anoxic processes occur when there is minimal oxygen but sufficient nitrate-nitrogen for biological respiration; and anaerobic processes occur when there is no oxygen or nitrate present.

Biological processes are also classified by the physical configuration used for promoting microbial growth. The following sections provide a brief description of the three major types of biological processes:

1. **Suspended Growth Processes.** Suspended growth processes are biological processes which maintain a concentrated supply of microorganisms suspended in the wastewater. The mixture of microorganisms, organic solids, and water are collectively referred to as mixed liquor suspended solids (MLSS). Decomposition of solids and organic matter is achieved by combining wastewater and MLSS in a contact tank. The microorganisms grow and consume the solids and organic material. The microorganisms multiply and are later separated from the treated water to be reused in the process. Excess biological growth is removed from the process as sludge. The microorganisms are typically separated from the treated water in settling tanks or through various separation processes.

2. **Attached Growth Processes.** Attached growth processes utilize an inert medium of plastic, stone, sand, or other material on which the microorganisms grow and multiply. The wastewater is brought in contact with the microorganisms (also called biomass) on the medium, and the biomass consumes the solids and organic material to produce more biomass. Attached growth processes (also known as fixed-film processes) include trickling filters, rotating biological contactors (RBCs), aerated biological filters, packed beds, fluidized beds, and moving

bed biofilm reactors (MBBR). These process names identify the configuration of the support medium.

3. **Plant and Biological Treatment Systems.** Plant and biological treatment systems utilize plant materials as well as microbiological populations for wastewater treatment. They have not been widely applied for nitrogen removal and are not as well defined in terms of predicted performance and design criteria as the more conventional systems. They typically have large land area requirements. These treatment systems include hydroponic systems (like Solar Aquatics) and constructed wetlands. These systems rely on naturally occurring plants, aquatic life, and sunlight to remove contaminants.

F. **Nitrogen Removal Processes and Performance Conditions.** Nitrogen removal from wastewater is an established technology, but it requires larger process tanks and skilled operation. Nitrogen removal includes the two steps of nitrification and denitrification. Nitrification converts ammonia-nitrogen to nitrate-nitrogen and denitrification converts nitrate-nitrogen into nitrogen gas which is released to the atmosphere.

Biological Nitrogen Removal (BNR) processes have typically been designed to meet the drinking water standard of 10 mg/L total nitrogen. As a result (when they are operated well), they will produce a treated water with an average total nitrogen concentration of 5 to 7 mg/L. The Hyannis WPCF and the Marstons Mills WWTF are BNR processes and produce treated water with average nitrogen concentration of approximately 5 mg/L.

The coastal ponds and estuaries in the planning area are much more sensitive to nitrogen impacts than drinking water supplies used for human consumption. Concentrations above 0.4 mg/L total nitrogen in these estuaries will cause water quality impacts as compared to the human health threats that occur above the drinking water standard of 10 mg/L total nitrogen. As a result, a greater nitrogen removal performance level is required to protect and remediate current water quality problems in the estuaries.

Enhanced Nitrogen Removal (ENR) systems are BNR systems designed with additional components to consistently produce a treated water of 3 mg/L total nitrogen on average. This performance level is considered by the regulatory agencies as the limit of best available wastewater technology for nitrogen removal, and this level of performance (at a minimum) must be considered for treatment facilities that recharge to watersheds of impacted marine waters.

Also, it is noted that the nitrogen that remains after an ENR process may not be as readily degradable or bioavailable. Therefore, it may not be as much of a threat to the estuaries as the current septic system nitrogen that is very bioavailable and is causing nutrient enrichment of the estuaries.

Due to the regulatory nature of the nitrogen TMDLs, nitrogen removal performance may need to be lower than 3 mg/L. There are drinking water and industrial technologies that can be used to treat to lower levels, though they are not typically used for municipal wastewater treatment. The most appropriate of these technologies are considered in the following sections of this chapter.

G. **Physical/Chemical Processes.** These can be used for wastewater treatment and nitrogen removal, but have received limited application for municipal wastewaters because biological processes tend to be more efficient and cost effective. Physical/chemical processes are reviewed here in an effort to be complete in our identification of treatment processes and to provide background on processes that will be considered for effluent polishing as discussed later in this chapter.

1. **Ion Exchange.** Ion exchange is an ion-specific process that can be used to remove specific nitrogen, carbon, or other contaminants and involves the use of columns or beds containing resins that will exchange one ion for another. The column is operated until the resin is exhausted and breakthrough occurs, at which time the bed must be regenerated with a concentrated alkaline solution to remove the ions. The spent regenerant must then be treated and disposed of, or processed for recovery and reuse. To avoid plugging of the resin, influent pretreatment and filtration must be provided ahead of the ion exchange column.

Full-scale applications have shown that the process is labor intensive and costly, requires frequent maintenance, and presents safety and corrosion concerns due to the handling of caustic acid and salt solutions. It is considered later in this chapter for the polishing steps of removing nitrogen and total organic carbon TOC to levels below 3 mg/L.

2. **Ammonia Stripping.** Ammonia stripping and related processes, such as steam stripping and ammonia stripping at elevated temperatures, consists of adding lime or other alkaline compounds to raise the pH of the wastewater stream to a high level and passing the stream through a tower with countercurrent air flow to strip out the ammonia gas. The stripped ammonia is then released to the atmosphere, which can create odor problems or may not be considered environmentally acceptable. The air stream must then be passed through an air scrubber to recover the ammonia in the form of ammonium sulfate. Ammonia stripping does not remove organic nitrogen, nitrites, or nitrates, and thus would not be able to consistently achieve the expected nitrogen removal limits without other processes. Ammonia stripping is highly temperature dependent and more suited to warm climates. Stripping efficiency is greatly reduced at cold temperatures. Full-scale applications have encountered serious scaling problems in the towers. Ammonia stripping and related processes are more suited to industrial applications with low volume, high-strength ammonia streams, or specific applications, such as digester supernatant streams. Chemical dosages are dependent on the volume of flow and the ammonia concentration; therefore, this process becomes more cost effective at increased ammonia concentrations. This technology is not considered further.

3. **Breakpoint Chlorination.** Breakpoint chlorination involves the dosing of wastewater with high concentrations of chlorine to convert ammonium-nitrogen to other forms. Organic nitrogen and nitrates are not removed by breakpoint chlorination. It would be difficult to meet total nitrogen limits using this process. Many other reactions occur and dissolved solids are generated. Dechlorination is required due to the large dosages of chlorine required to achieve breakpoint. This technology is not considered further.

H. **Secondary/Advanced Treatment Processes.** The following is a summary of biological and advanced processes that can be used for treatment of wastewater flows.

1. **Suspended Growth Biological Treatment Alternatives.**

a. **Background Information.** Suspended growth systems for nitrogen removal have been widely investigated, developed, and implemented in the last four decades. As a variation of the activated sludge process, suspended growth systems provide additional tankage volume for 1) longer solids retention times for nitrification and 2) anoxic conditions for denitrification. A variety of systems are available, including single-sludge versus multiple-sludge systems. Within the single-sludge category, further process classifications can be defined, such as:

1) Multiple-stage processes for nitrogen and phosphorus removal.
2) Multiple-stage processes for nitrogen removal.
3) Multiple-phase/cyclical aeration.
4) Oxidation ditches.
5) Sequencing batch reactors (SBRs).

Some systems have been developed to meet more stringent effluent limitations for nitrogen by providing multiple anoxic zones, and some systems have been developed to remove both phosphorus and nitrogen with an emphasis on optimizing phosphorus removal.

The applicability of the various processes for Barnstable is dependent on the level of treatment required; the possible need to remove phosphorus; reliability and flexibility; environmental concerns; public acceptance; and cost effectiveness.

b. **Single-Sludge Systems.** Single-sludge systems combine carbonaceous BOD removal, nitrification, and denitrification in a single mixed liquor by providing aeration tankage with one set of clarifiers. Consequently, the activated sludge (single-sludge) returned to the aeration tankage from the clarifiers contains a concentrated mixture of microorganisms to accomplish all three processes. BOD removal and nitrification are accomplished simultaneously in the aerobic zones. Denitrification is accomplished in anoxic zones, which are mixed but not aerated to maintain a low dissolved oxygen level. Single or multiple anoxic zones or phases can be provided depending on the features of the various processes and/or level of treatment required. A higher level of nitrogen removal can be achieved with longer solids retention times (SRTs) and two or more anoxic zones, which result in increased aeration tankage. The major process variations or classifications of single-sludge systems follow.

1) **Multiple-stage Processes for Nitrogen and Phosphorus Removal.** Figure 4-4 represents a process schematic of a multiple-stage process developed

to achieve both nitrogen and phosphorus removal. Influent wastewater or primary effluent first enters an anaerobic zone, followed by an anoxic zone and aerated zone. BOD removal and nitrification is achieved in the aerobic portion. Mixed liquor from the end of the aerobic zone is recycled to the head of the anoxic zone to achieve denitrification of nitrates (generated in the aerobic zone) to nitrogen gas. A high recycle rate is required (200 to 400 percent of influent flow) to return a sufficiently large fraction of nitrates to achieve good denitrification efficiency. Return activated sludge (RAS) is returned to the head of the anaerobic or anoxic zone. If returned to the anoxic zone, then another internal recycle is required to pump mixed liquor from the anoxic zone to the upstream anerobic zone. The anaerobic zone is utilized to achieve phosphorus removal. Anaerobic conditions are used to stress the bacteria; phosphorus is released but later taken up by the bacteria during synthesis in higher proportions than normal synthesis, known as biological uptake or luxury uptake of phosphorus. A side benefit of the anaerobic zone is that it acts as a "selector" which has been shown to improve settleability characteristics of the sludge. Process variations have been developed, including the A^2/O process; the four-stage Bardenpho process; University of Capetown (UCT) process; and the Virginia Initiative Plant (VIP).

The Bardenpho process, which utilizes dual anoxic zones, is capable of achieving a total nitrogen limit of 3 to 5 mg/l on average, and 3 mg/L to meet enhanced nitrogen removal (ENR) requirements when followed by filtration. The A^2/O process, which has a single anoxic zone, can achieve 5 to 7 mg/l total nitrogen. The VIP and UCT processes are similar in that they were developed to optimize phosphorus removal. By providing multiple recycles for various zones, it is possible to achieve increased phosphorus removal. Although the UCT and VIP processes have dual anoxic zones, they have not been capable of reliably meeting a total nitrogen limit of 3 to 5 mg/l on average.

Multi-stage processes to remove nitrogen and phosphorus have the following advantages:

- Can reliably achieve various levels of nitrogen removal.

- Well developed, investigated, and implemented with established design criteria and features.
- Nutrient removal accomplished in a single set of aeration tankage and clarifiers.
- No significant environmental or public acceptance concerns.
- Proprietary systems are available with process guarantees by the vendors.
- Anaerobic zone acts as a selector to improve sludge settleability.

They have the following disadvantages:

- Inclusion of biological phosphorus removal can result in complex operational and process control demands.
- High energy usage due to aeration requirements and recycle pumping.
- High capital costs for new tankage.

2) **Multiple-stage Processes for Nitrogen Removal.** Figure 4-5 illustrates the process schematic for two multi-stage nitrogen removal alternatives: the Modified Ludzack-Ettinger (MLE) process, which contains a single anoxic zone for pre-denitrification, and the four-stage Bardenpho process with two anoxic zones (one for pre-denitrification and the second for post-denitrification). These processes are very similar to those discussed in the first section, but without the anaerobic zone for phosphorus removal.

The MLE process utilizes an internal recycle following the nitrification (aerobic) zone to return nitrates to the anoxic zone for denitrification. The recycle rate determines denitrification efficiency. The Hyannis WPCF utilizes a MLE Process.

The four-stage Bardenpho process is similar, but follows the nitrification zone with a second anoxic zone and a post-aeration zone. The second anoxic zone provides additional denitrification to achieve a higher level of nitrogen removal. Post-aeration is necessary to remove nitrogen gas formed during denitrification and to provide dissolved oxygen ahead of the clarifiers so that settling performance is not hindered.

A carbon source is required to allow denitrification to occur. In the first anoxic zone, BOD in influent wastewater or primary effluent provides the necessary carbon source for denitrification. In the second anoxic zone, due to the low BOD concentration remaining at that stage of treatment, either an external carbon source must be provided or carbon available from the products of endogenous respiration must be utilized. If an external source is utilized, such as methanol, a high rate of denitrification can be achieved, but residual methanol must be removed. This process is referred to as the enhanced MLE (eMLE). Without an external source (Bardenpho), the denitrification rate is very low and the volume of the second anoxic zone must be substantially increased.

The MLE process is well proven and can reliably achieve an effluent total nitrogen level of 5 to 7 mg/l on average. The Bardenpho system can meet an effluent limit of 3 to 5 mg/l total nitrogen, but requires additional tankage due to the additional zones and more conservative design criteria, and it may require the addition of an external carbon source, such as methanol, and removal of residual methanol. The Bardenpho system can achieve an effluent total nitrogen of 3 mg/L on average if the effluent is filtered to remove fine suspended solids that contain small amounts of nitrogen. At this performance level (3 mg/L), it is classified as an Enhanced Nitrogen Removal (ENR) treatment process.

Multiple-stage processes for nitrogen removal have the following advantages:

- Can reliably achieve 3 to 5 mg/l or 5 to 7 mg/l total nitrogen on average.
- Well developed, investigated, and implemented with established design criteria and features.
- No significant environmental or public acceptance concerns.

They have the following disadvantages:

- Operational requirements require skilled staff to control the process.
- High energy usage with aeration requirements and recycle pumping.
- High capital costs for new tankage.

3) **Multiple-Phase/Cyclical Aeration.** Figure 4-6 illustrates two processes that utilize multiple phases for nitrogen removal in lieu of dedicated zones. Alternating aerobic/anoxic conditions are created within the same zone or tankage. The first process is cyclical nitrogen removal (CNR), also called cyclical aeration, which can be used with mechanical aerators, submerged turbines, or diffused air. Timers are used with mechanical aerators to turn the aerators on and off, thereby creating alternating aerobic conditions for nitrification and anoxic conditions for denitrification. Preferably, there should be at least three compartments in series; the final compartment is aerated continuously. Step feeding of influent flow can be utilized to provide a carbon source for denitrification in downstream compartments but even without step feed, wastewater carbon flows forward negating the need for a nitrate recycle to return nitrates to a dedicated anoxic zone. Internal recycle of nitrified effluent is not required since nitrification and denitrification occur within the same zone, although recycle can be provided for operational flexibility. Mixing is desirable during the aerator off cycle to provide good solids contact for denitrification. CNR can also be used with diffused aeration systems by providing electrically operated valves on the air headers or drop legs for each compartment to turn the air on and off. The Hyannis WPCF used the CNR process for nitrogen control with surface aeration from 1988 to 2001 at which time it was converted to a MLE process with diffused aeration.

Another multiple-phase system is the Schreiber process, which utilizes a circular tank and a rotating bridge with aeration diffusers. As the bridge rotates, aerobic conditions are created by aerating that portion of the tank, which gradually loses DO until anoxic conditions prevail, thereby creating alternating aerobic/anoxic phases in all portions of the tank. Internal recycle of nitrified effluent and step feeding are not required.

Multiple-phase processes can achieve a nitrogen level of 8 to 10 mg/l in the effluent. These processes are well proven at operating installations. In terms of screening criteria, these processes would be very similar to the multiple-stage processes discussed, with some additional advantages and disadvantages. The CNR process and Schreiber process, however, do differ in those situations involving retrofits of existing activated sludge plants. The CNR process can generally be retrofitted to existing tankage with minor modifications. The Schreiber process requires new tankage, and therefore, is more suited to new plants or plants without existing aeration tanks.

Multiple-phase processes have the following advantages:

- Can reliably achieve 8 to 10 mg/l total nitrogen.
- Well-proven technology.
- No significant environmental or public acceptance concerns.
- Schreiber process is provided with process guarantee by the vendor.
- Internal recycle pumping of nitrified effluent is not required.
- Cycles can be varied to increase or decrease cycle times, thereby providing operational flexibility in optimizing the process.

Multiple-phase processes have the following disadvantages:

- Operational requirements are intensive to control the process.
- Energy usage is moderate.
- High capital costs for new tankage.
- The settling characteristics of the sludge is not as good as multi phase processes with dedicated anoxic zones.

4) **Membrane Bioreactors.** Membrane Bioreactors or MBRs are activated sludge processes that are typically configured as MLE or 4-Stage Bardenpho processes for nitrogen removal. MBR's utilize membrane filter modules (instead of settling tanks) to separate the treated water from the suspended solids. They can provide an even higher qulaity effluent; typically 3 mg/L total

nitrogen for a Bardenpho configuration with methanol addition. The membranes require special controls and cleaning procedures to provide long term performance. Figure 4-7 illustrates how the membrane system and associated equipment is used to replace the settling tanks.

The MBR process has the following advantages:

- No final settling tanks are required.
- Effluent can potentially be reused for non-potable uses such as toilet flushing or irrigation because of the high degree of particulate removal.
- Can increase capacity of existing tankage by allowing a higher biomass concentration in the aeration tank.

MBR processes have the following disadvantages:

- Capital costs for the tankage and membrane facilities are high.
- Membrane replacement costs are high.

5) **Oxidation Ditches.** Figure 4-8 illustrates a generic process schematic for an oxidation ditch. Oxidation ditches were developed to minimize operational requirements and maintenance. Ditches have large surface areas and one or more fixed aerators, located at strategic points to provide aeration and mixing as well as propulsion of flow around the tank. Wastewater flows in a continuous, circuitous path around the ditch with a high internal recycle rate to provide a complete mix flow regime. Ditches are designed to provide long solids retention time with no primary settling tank. Since aeration is provided at key points in the loop, aerobic conditions are created downstream of the aerator, while anoxic conditions generally exist upstream of the aerator. Consequently, nitrogen removal is achieved.

Various systems have been developed for nitrogen removal to take advantage of this inherent characteristic of oxidation ditches. Among these are the Carrousel, Orbal, and Bi-denitro processes. Pre- and post-anoxic tanks are often used with the oxidation ditches to further promote nitrogen removal.

Oxidation ditches require larger land areas due to their large volume requirements.

Oxidation ditches have the following advantages:

- Requires minimal operator attention.
- Can achieve high level of nitrogen removal (3 to 5 mg/L when configured as a Bardenpho process and 5 to 7 mg/L configured as a MLE process).

They have the following disadvantages:

- Large land area is required for new tankage.
- Large capital costs associated with new tankage.

6) **Sequencing Batch Reactors.** Sequencing batch reactors (SBR) consist of batch-type processes utilizing fill-and-draw operation (as illustrated in Figure 4-9) in a self-contained system. Equalization, aeration, anoxic reaction, and settling are accomplished in a single basin. Continuous operation can be achieved by providing several SBR basins, such that each basin is intermittently fed and in a different phase of the cycle. The various phases include fill, react, settle, draw, and idle. Wastewater is added during the fill cycle with and without aeration. During the react phase, nitrification and denitrification reactions are completed by alternating the aeration cycle. The next phase is settling for liquid/solids separation, followed by decanting of clarified effluent in the draw phase. During the idle phase, sludge wasting is performed while the basin is waiting to begin the next cycle. The length of the cycles can be varied to achieve the desired degree of treatment. Internal recycle and return of activated sludge is not required. A number of manufacturers have developed proprietary processes and equipment to enhance nitrogen removal, treatment efficiency, and simplify operations.

The following is a listing of some of the more widely marketed systems:

a) **Aqua SBR.** Utilizes a proprietary floating mixer, effluent decanter, and microprocessor control system.

b) **Omniflow.** Utilizes a patented control system for aeration phases to optimize nitrification and denitrification cycles.

c) **CASS.** Cyclic Activated Sludge System is similar to other SBRs, but utilizes a proprietary selector reactor to improve settling characteristics.

d) **ICEAS.** Intermittent Cycle Extended Aeration System is a modified batch system. Continuous influent flow is provided during all cycles to reduce the valving and headworks requirements compared to non-continuous flow SBRs. ICEAS also utilizes a patented anoxic selector.

A high level of nitrogen removal can be achieved due to the ability to retain the reactor contents as desired. Since settling occurs in the same basin, separate final settling tanks are not required.

SBRs have the following advantages:

- Batch operation allows reactor contents to be retained until desired effluent quality is achieved.
- RAS and internal recycles are not required.
- Settling occurs under totally quiescent conditions with no influent flow (except for ICEAS), eliminating short circuiting.
- All phases are provided in a single basin, eliminating the need for separate final clarifiers, therefore they typically have lower capital costs.
- Highly flexible operationally with ability to adjust cycle times.

They have the following disadvantages:

- A sophisticated control system with valves, timers, probes, and level sensors is required to control intermittent feeding, cycle times, phases, and process performance.
- Downstream equalization typically required for cost-effective design of filtration and disinfection processes.
- Volume of reactor must be increased to allow for cycle times and use of basin for settling.
- High operations costs due to increased pumping.

c. **Multiple Sludge Alternatives.** Multiple sludge systems have also been utilized for nitrogen control. Two-sludge and three-sludge systems are illustrated in Figure 4-10. Contrary to single-sludge systems where processes are combined in a single step, multiple sludge systems separate process functions by utilizing intermediate clarifiers. A two-sludge system combines BOD removal and nitrification in one step, followed by suspended growth denitrification in a second step, each with its own clarifiers. Methanol or other carbon source addition is required for denitrification due to the lack of influent BOD available following the first step. A three-sludge system further separates BOD removal and nitrification, as well as denitrification, thereby requiring a third set of clarifiers.

Multiple sludge systems can achieve a high level of nitrogen removal and were often the process of choice used while single-sludge systems were under development. The thought was that by separating the processes, each process could be better controlled, compared to combining two or more processes. However, due to the limited solids production which occurs in nitrification and denitrification, process control of the solids inventory is more difficult. The need for one or two sets of intermediate clarifiers increases capital costs. The multiple steps result in higher hydraulic head losses. O&M costs are typically greater due to the additional clarifiers and process control requirements for each of the separate phases.

Multiple sludge systems have the following advantage:

- Individual processes can be controlled to maximize nitrogen removal.

They have the following disadvantages:

- More difficult and complex operational control requirements with two or more separate processes.
- Less benefit of BOD reduction and alkalinity generation with post-denitrification compared to single-sludge systems with predenitrification.
- More sludge production with separate-stage BOD removal.
- Larger land area is required for intermediate clarifiers compared to single-sludge systems.
- Methanol addition required with post-denitrification, increasing O&M costs.
- High capital costs associated with extensive new tankage.

2. Attached Growth Biological Treatment Alternatives.

a. **Background Information.** Attached growth systems are wastewater treatment systems where the biological growth occurs on a solid medium that comes in contact with the wastewater. The systems are used for BOD removal, nitrification and/or denitrification. BOD removal and nitrification can be provided by trickling filters, rotating biological contactors (RBCs), aerated biological filters, packed beds, and fluidized beds. Denitrification can be provided by RBCs, packed beds, and fluidized beds. A special type of attached growth system located in an activated sludge, known as an Integrated Fixed Film Activated Sludge (IFAS) process, is generally used for nitrification but could also be considered for denitrification. Fixed-film enhancement involves the placement of media, such as small plastic elements, sponges, or hanging rope-like strands, into suspended growth systems, thereby increasing the capacity of such systems by providing surface area for microbial growth of organisms, which increases the effective solids content in the reactor.

b. **Rotating Biological Contactors.** RBCs are attached growth systems that function as described previously. When RBCs are used for nitrogen removal, a separate submerged (anoxic) RBC follows the partially submerged (aerobic) RBC to provide denitrification and remove nitrogen to the 5 to 7 mg/L total nitrogen range. Methanol must be added to the anoxic RBC to assist nitrogen removal. This RBC process configuration is illustrated in Figure 4-11.

RBCs have the following advantages:

- The technology is used extensively for small treatment facilities and is well accepted by MassDEP.
- Energy requirements are low.
- Operational requirements are low.

They have the following disadvantages:

- Must be preceded by primary treatment.
- Must be followed by a final settling tank.
- Capital costs are high.
- Cold weather performance is a concern and the tanks must be covered.
- There is minimal process control and flexibility for high seasonal flows.

c. **Denitrifying Filters.** Denitrification filters are a form of Biologically Active Filters (BAFs) which are operated anoxically for denitrification. They would follow the BOD removal and nitrification phase to provide separate-stage denitrification. A high level of nitrification would be necessary prior to the filters to achieve a low level total nitrogen discharge in the treated water. The general types of denitrification filters include: downflow packed bed systems, upflow media beds, continuous backwash filters, and wood chip beds.

- Downflow packed bed systems are actually deep bed sand filters operated to encourage attached microorganisms to denitrify. Methanol addition is typically used to provide the carbon source needed for denitrification. The packed beds also act as effluent filters to remove suspended solids and improve effluent quality. Periodically, the beds must be backwashed similar to sand filters and must be bumped with backwash for a few seconds to release nitrogen gas which accumulates in the filter media and increases headloss through the media. Figure 4-12 presents a generic schematic for denitrifying filters. Downflow systems include proprietary systems such as the TETRA denitrification filter.

- Upflow media bed filters include filters that use either media that is heavier than water (Degremont Biofor) or a floating plastic media (Kruger Biostyr). Denitrifying microorganisms attach to the media as nitrified effluent flows upward through the media. Reactor sizes and area requirements are small due to the highly effective biomass concentration in the column. Methanol addition is typically used to provide the carbon source needed for denitrification.
- Continuous backwash filters consist of a column of sand media in which the nitrified wastewater is introduced at the bottom. The wastewater flows upward as the media flows downward and is discharged over a weir at the top. An air lift pump induces the flow which recirculates the media from top to bottom and back. The media in this type of filter is continuously cleaned as it recirculates and thus a separate backwash cycle is not required. An example is the Parkson Dynasand Filter.
- Wood chip beds are a new approach to denitrifying filters that was developed for individual on-site systems but have since been used for a small number of small treatment plant applications. They are comprised of wood chips (or other forms of waste wood) impregnated with alkaline material. They do not need supplemental carbon addition because the wood chips provide the organic carbon for the denitrifying bacteria. Similar to other filters, they can provide a high level of nitrogen removal. Unlike other denitrifying filters, they do not provide much process control with respect to backwash or organic carbon feed rates. The wood chip beds do need to be replaced after time; and because they are such a new developing technology, the replacement time is unknown (10 to 20 years has been estimated). They include the proprietary system NITREX®.

Denitrifying filters have the following advantages:

- Reliable technology to meet a total nitrogen limit of 3 mg/L.
- Familiar technology, as it is similar to other types of effluent filters.
- No significant environmental or public acceptance concerns.
- Potential for air emissions is minimal, as filters are typically enclosed in buildings.

They have the following disadvantages:

- Moderate capital costs for new facilities and building enclosure.
- High O&M costs.
- Large headloss, necessitating pumping of effluent.
- Methanol addition and stripping are required for all but the wood chip filters.
- Wood chip filters provide little process control.

d. **Biological Aerated Filters (BAF)**. BAFs consist of submerged filter media which allow biological growth on the media. The filters act as deep upflow beds with air injected either below the bed or at an intermediate point, depending on the treatment process. They are used mainly for BOD and TSS removal and nitrification of ammonia. A denitrifying filter is an anoxic form of the BAF and would typically follow an aerobic BAF for nitrogen removal. A primary clarifier is typically required as a pretreatment step before the flow goes to the BAF. Figure 4-13 is a diagram of the BAF system manufactured by Kruger as the BIOSTYR System.

BAFs have the following advantages:

- Reliable technology for BOD and TSS removal and some nitrogen removal.
- Potential for air emissions is minimal, as filters are enclosed in a building.

They have the following disadvantages:

- High capital costs for primary treatment and the BAF.
- Cold effluent wastewater temperatures may impact the nitrification process.

e. **Amphidrome.** The Amphidrome process is an attached growth, sequencing batch-type process designed for nitrogen removal at small treatment facilities. It uses relatively complex controls to circulate the water being treated back and forth through filter media as aerobic and anoxic conditions are cycled. Figure 4-14 illustrates the configuration of this process.

The Amphidrome process has the following advantages:

- No final settling tanks are required.
- Tanks are typically placed below ground; therefore, visual impacts are minimal.
- Allows secondary treatment and nitrogen removal in a single reactor.
- Potential for air emissions is minimal, as filters are enclosed and below ground.

The Amphidrome process has the following disadvantages:

- It is a relatively new treatment configuration and there are few large installations to assess long-term performance.
- Large headloss and below-grade installation requires effluent pumping.
- Treatment flow is complicated and relies on automatic controls.

f. **Integrated Fixed-film Activated Sludge (IFAS®) Technologies.** IFAS® technologies involve the addition of media for fixed-film growth in activated sludge aeration basins to increase the nitrification capacity. Depending on the type of media, IFAS® can also be used for denitrification. Figure 4-15 presents a generic schematic for the fixed-film activated sludge technologies.

Sponge-type media, or plastic media, are freely suspended by mixing in the aeration basin. The media is contained within the aeration basin by screens. Sponge media is typically returned to the head of the media zone by an airlift pump to prevent accumulation at the downstream screen. Another type of system, called Ringlace, utilizes ropes or strands of plastic material which are mounted in racks and placed in the aeration tank. The racks can be fixed or mounted on moveable rails to allow relocation of the racks to provide access to the air diffusers. Submerged RBCs and other types of large plastic media can also be used for fixed-film enhancement.

These systems have been thoroughly investigated and results have shown that they are highly effective and can be combined in various single-sludge treatment schemes to improve nitrogen removal performance.

Fixed-film enhanced systems have the following advantages:

- Can be utilized in variety of treatment schemes.
- Shown to be highly effective in enhancing nitrification.
- Provides flexibility in operation and process control.

They have the following disadvantages:

- Pilot testing may be required if wastewater has unusual characteristics.
- High material costs.
- Control of growths, such as nematodes, may be required (rope and sponge media).
- Replacement and maintenance of media is required (rope and sponge media).

IFAS® systems are not a process by themselves, but enhance other processes and therefore must be included in the evaluation of other process schemes designed to meet the desired level of treatment.

3. Plant and Biological Systems.

a. **Hydroponic Systems.** Hydroponic systems involve the use of marshes, sunlight, and naturally occurring plants, bacteria, and fish to remove nitrogen. Such systems are experimental and would need pilot testing. These systems have not yet demonstrated that a high level of nitrogen removal can be reliably achieved on a large or long-term scale. Approval of such systems by regulatory agencies at this stage of development is unlikely without extensive pilot testing.

b. **Constructed Wetlands.** Constructed wetlands consist of an artificial biofilter (receiving water and vegetation) to treat surface and subsurface water flow. Vegetation used in treatment includes duckweed, water hyacinths, cattails, rushes, and reeds. Vegetation must be harvested to effectively manage the system. Removal and disposal of the vegetation is a significant consideration in the design and operation of wetland systems. Backup systems are required due to natural seasonal and decay cycles and to provide active treatment sites while harvesting. Treatment efficiency in northern climates may be subject to seasonal variations, thereby necessitating large storage basins. A diagram of a constructed wetland system is shown on Figure 4-16.

c. **Solar Aquatics.** Solar aquatic systems utilize greenhouses, fish tanks, wetlands, etc. for wastewater treatment. Wastewater is first allowed to settle to remove large solids and is then treated in stages with different types of living organisms, usually plants or algae. Sunlight is required to supply light to the plants and heat for the overall system. The final effluent is then discharged to a leaching area. A diagram of a solar aquatics system for large wastewater flows is included as Figure 4-17. Energy requirements are the main disadvantage when compared with other plant and biological systems.

d. **Lagoons.** Lagoons are lined aerated ponds and could be considered for nitrification; however, they have a number of inherent limitations. Typically, lagoons have a detention time of several days; consequently, they are too large to be well mixed, and active microorganisms are deposited on the bottom of the lagoon. There is insufficient contact of the nitrifiers with wastewater to obtain efficient nitrification.

Cold weather operation results in reduced performance due to decreased microbial activity. With long detention times, lagoon temperatures are less than those for activated sludge processes. Mixing and recirculation of effluent can be provided to improve performance; however, a large land area is required, public nuisances and odors are a concern.

An aerated lagoon cannot be used for denitrification; therefore, a second process would be required, following the lagoons.

Facultative lagoons with algal harvesting have the potential to remove nitrogen. The surface layers must be aerobic to achieve nitrification and the bottom layers and deposits must be anoxic and anaerobic to achieve denitrification. The algal biomass must be removed from lagoon effluent or will increase effluent solids levels above permit limits, necessitating effluent filtration or other effluent polishing steps. Solids accumulations in the bottom of the lagoon and pass-through of solids in final effluent have been a recurring problem with such systems in the past. Operation in winter in northern climates is a major design concern due to the reduction in microbial activity and lack of process control to manage the system.

Plant and biological treatment systems have the following advantages:

- Appropriate for small rural communities.
- Typically require little operational control.
- Relies on use of natural ecosystems.
- Minimal energy requirements (except for Solar Aquatics).
- Processes can have high public acceptance and appeal due to their use of plant material.

Plant and biological treatment systems have the following disadvantages:

- Large land area requirements due to long wastewater retention times.
- Cold weather performance is questionable.
- Design information and performance data are limited.
- Nitrogen removable efficiency is not readily predictable or controllable.

- Harvesting and disposal of vegetation is required.
- Prefiltration or effluent polishing may be required.
- Pilot testing may be required.

I. **Screening of Secondary/Advanced Treatment Technologies.** The screening of secondary/advanced treatment technologies is based on the description of each technology, its respective advantages and disadvantages, and the screening criteria established in Chapter 2 of this report. A summary of secondary/advanced treatment technologies with respect to the screening criteria is included in Table 4-1.

Of the physical/chemical processes only Ion exchange will be considered for specific effluent polishing processes for total organic carbon removal and nitrogen removal below 3 mg/L. The other physical/chemical processes have a history of operational problems; safety concerns with chemical handling; prefiltration and/or disposal of residual streams is required; and costly operation and maintenance requirements.

Multiple-stage, single-sludge, biological processes with and without phosphorus removal can meet various levels of nitrogen removal and have been well investigated, developed, and widely implemented. Each of the multiple-stage processes has inherent advantages and disadvantages. Phosphorus removal would increase capital and O&M costs compared to other processes and should be used if the treated water recharge is upgradient of sensitive freshwater ponds and/or lakes.

Of the multiple-stage, single-sludge systems, the Bardenpho process is recommended for further evaluation to meet the ENR total nitrogen limit of 3 mg/L (after final filtration), and the MLE process is recommended for further evaluation to meet the 5 to 7 mg/L total nitrogen BNR performance level.

Multiple-phase/cyclical aeration system can reliably achieve an effluent nitrogen concentration of 8 to 10 mg/l, as has been previously demonstrated at the Hyannis WPCF; but is not recommended for new facilities or for use at the Hyannis WPCF. Dedicated anoxic zones provide simpler operation and a sludge that has better settling characteristics.

RBCs are less desirable due to their requirement for primary treatment, necessity to cover equipment due to cold weather, high capital costs, and limited process control. Thus, this process is not considered for larger centralized facilities. They may be used for smaller satellite systems.

SBRs perform all treatment phases in a single basin, are highly flexible in operation, and can achieve consistent nitrogen removal to the range of 5 to 10 mg/L on average and 3 mg/L on average when they are followed by denitrification filters. SBRs should be retained for further evaluation for use at new facilities.

Amphidrome systems have limited installations for small treatment facilities. They have a complicated flow path that leads to reliance on automatic controls. They should only be considered for small satellite systems.

Membrane Bioreactors (MBRs) utilize MLE and bardenpho process configurations to provide reliable nitrogen removal and provide a well filtered effluent that can be used for various reuse applications (irrigation and toilet flushing). The effluent is also well suited as an influent to reverse osmosis or nano filtration processes for Total Organic Carbon removal or nitrogen removal to less than 3 mg/L because the MBR process uses microfiltration of ultrafiltration membranes to separate the treated water from the process liquids. MBR will be retained for further evaluation.

Oxidation ditches provide good nitrogen removal when using additional pre- and post-anoxic tanks (MLE or Bardenpho processes) designed for additional nitrogen removal. They can achieve enhanced nitrogen removal to 3 mg/L on average when they are followed by filtration. The system provides relatively easy operation, but the large tankage requirements have higher capital costs. Use of oxidation ditches will be retained for further evaluation.

The plant and biological systems of Solar Aquatics, hydroponic systems, and lagoons have high land area requirements and questionable nitrogen removal performance in cold climates. These systems will not be considered for further evaluation.

BAFs are typically used to provide BOD and TSS removal and nitrification of the ammonium in the wastewater. It would need to be followed by a denitrification filter, which would then denitrify the full nitrate load because minimal denitrification is achieved in the BAFs. This technology takes up minimal space and is useful at treatment plant sites that have no room for expansion or where only nitrification is needed. BAFs also have high capital costs. Due to the factors listed above, this process should only be considered to increase the treatment capacity at the Hyannis WPCF in the current treatment footprint.

Denitrification filters provide denitrification and filtering of a previously nitrified effluent. They can be used to denitrify the full nitrate load when they are preceded by a BAF or an activated sludge, extended aeration process; or they can be used to denitrify (polish) a greatly reduced nitrate load when they are preceded by one of the nitrification and denitrification processes previously described. They can be smaller in size, have lower capital costs, and use less methanol when they are used to polish a previously nitrified and denitrified effluent. This process should be evaluated further for combination with single sludge BNR processes.

4.4 TECHNOLOGIES TO ACHIEVE LESS THAN 3 MG/L TOTAL ORGANIC CARBON

A. **Introduction.** As discussed in the Draft Needs Assessment Report (Chapter 3 Regulatory Issues), in March of 2009, the Commonwealth of Massachusetts' Groundwater Discharge Permit Program (314 CMR 5.00) was modified to include additional water quality requirements for treated waters recharged to Zone II areas. (Zone II areas are land areas that could contribute groundwater to public water supply wells.) The revised regulations include new limitations on total organic carbon (TOC) concentrations. The TOC concentration must be less than 3 mg/l for recharges with a travel time (to the public water supply well) greater than 2 years, and must be less than 1 mg/L for recharges with travel times of 2 years or less. Also, all recharges utilizing recharge directly into the saturated zone must have TOC concentrations less than 1 mg/L.

The need to treat municipal wastewater to meet low concentrations of total organic carbon (TOC) is a relatively new phenomenon, particularly in the Northeastern United States. As a result, there is little local experience with pilot or full-scale municipal systems. Nationwide, TOC concentrations in treated water have typically been used as a bulk measure of organic contamination in reclaimed municipal water intended for reuse. In this sense, TOC concentrations are being used as a surrogate measurement for the presence of such contaminants of emerging concern (CECs) as endocrine disrupting compounds (EDCs), pharmaceuticals and personal care products (PPCPs), and other organic compounds commonly found in treated water.

Where wastewater treatment has typically focused on other measures of organics removal such as biological oxygen demand (BOD) and chemical oxygen demand (COD), TOC has long been targeted for removal from drinking water supplies due to its role in the formation of disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs), some of which are suspected human carcinogens. Drinking water regulations include both limitations on acceptable concentrations of DBPs in finished water as well as TOC removal objectives for source waters with elevated TOC concentrations. As a result, much of the information related to TOC removal through unit treatment processes has been developed in support of meeting regulations for drinking water and water reuse, particularly direct or indirect potable reuse.

It is important to understand the differences between TOC found in natural source waters and TOC found in treated water. Organic matter found in treated water is typically higher in total concentration, lower in humic acid, more polar, and higher in nitrogen than organic matter found in natural source waters. In addition, higher concentrations of biologically-available organic matter are observed in treated water than in natural source waters. As a result, technologies utilized to remove TOC from natural source waters may perform differently when utilized to reduce TOC concentrations in treated water.

Another important consideration in determining the most appropriate technique for removing TOC is its solubility. Dissolved organic carbon (DOC) is the portion of TOC which passes through a 0.45 µm membrane filter. The DOC/TOC ratio can be used as a guide to assist in determining the most effective approach to TOC removal. If the DOC/TOC ratio is low, indicating that a significant portion of the organics present are in particulate form, then physical separation processes such as sedimentation and filtration would be expected to be effective in reducing TOC concentrations. Conversely, if the DOC/TOC ratio is high, indicating that the organics are largely in solution, coagulation, adsorption, and membrane filtration may be required to achieve significant removal (EPA 1999).

Several pilot- and full-scale municipal installations nationwide have evaluated a variety of TOC removal techniques for their ability to remove organic carbon. Much of the data collected have focused on the ability of unit processes to selectively remove EDCs, PPCPs, and other CECs. The body of data regarding approaches to meeting TOC regulations for treated water continues to grow. An annotated bibliography of the key research and case studies in this topic is attached in Appendix 4-1. The following sections present alternatives for meeting the TOC limitations of 3.0 mg/L and 1 mg/L. It should be noted that, as the scientific community develops a better understanding of the toxicity and occurrence of specific CECs, it is anticipated that new regulations will be promulgated focusing on specific CECs, rather than or in addition to TOC as a whole. Currently, efforts are underway at the State and Federal levels to gather the information necessary to directly regulate EDCs and other CECs directly. It is recommended that the selected technology either be capable of removing specific EDCs and other CECs of potential concern, or be easily adapted to comply with new regulatory requirements.

B. **Technologies to Achieve Less Than 3 mg/L TOC.** The technologies described below were evaluated to reduce effluent TOC to meet the requirement of 3 mg/L.

1. **Coagulation and Filtration.** TOC removal through coagulation and filtration involves altering the physical or chemical properties of suspended particles to increase their agglomeration, creating larger flocs, which are more readily separated from solution by sedimentation and/or filtration. Figure 4-18 illustrates the main components of this treatment process. In drinking water applications, chemical coagulants such as aluminum sulfate (alum), ferric chloride, and ferric or ferrous sulfate are typically added to increase floc formation, increasing sedimentation rates. This process can be used to remove particulate carbon; in addition, some coagulants react with dissolved organics, rendering them insoluble. In drinking water applications, TOC removal is routinely increased through implementation of enhanced coagulation, in which chemical coagulants are optimized for organics removal (EPA 1999).

Coagulation and filtration processes have the following advantages:

- Simple, well-understood process with few mechanized systems.
- Requires minimal operator attention.
- Operation and maintenance costs are typically low, with the exception of chemical costs.

They have the following disadvantages:

- Large land area is required for new sedimentation basins.
- Typically higher capital costs for the large new basins.

- Chemical storage and handling requirements.

Anticipated removal efficiencies:

- TOC: Good
- EDCs: Good

2. **Adsorption.** Activated carbon may be used to adsorb soluble organics including carbon and nitrogen compounds. Granular activated carbon (GAC), biological activated carbon (BAC), and powdered activated carbon (PAC) are commonly used adsorption technologies.

a. **Granular Activated Carbon.** Granular activated carbon is a well-tested approach for TOC removal, traditionally used in drinking water applications. GAC can be used in either a downflow or upflow contactor. Figure 4-19 illustrates a GAC contactor. Downflow contactors are the simplest configuration, though upflow contactors have been applied in cases with very long contact times (greater than 120 minutes) and high concentrations of suspended solids. GAC systems typically require pretreatment (such as coagulation, filtration, or softening) to prevent filter clogging. In addition, the GAC adsorption effectiveness decreases over time, with effluent TOC concentrations increasing over time. Once the effluent concentration has reached a threshold limit, the GAC column must be taken offline to allow the GAC to be replaced. Spent GAC may be disposed of or regenerated either on or off-site. Purchase of GAC can be costly, and GAC disposal may be difficult, particularly if the spent GAC is considered a hazardous waste. Disposal is typically only cost-effective for applications under 500 lb/day. For application between 500 lb/day and 2000 lb/day, off-site regeneration is usually cost-effective. For applications greater than 2,000 lb/day, onsite regeneration may be a cost-effective – yet complex – alternative.

GAC adsorption processes have the following advantages:

- Relatively simple process.
- Requires minimal operator attention.
- Can achieve high level of organics removal.

They have the following disadvantages:

- Moderate land area is required for new GAC contactors.
- Efficacy decreases with time until GAC requires costly regeneration or replacement.
- Pretreatment required to minimize potential for clogging of GAC contactors.
- Requires offsite disposal and replacement.
- High operation and maintenance costs.

Anticipated removal efficiencies:

- TOC: Excellent
- EDCs: Good

b. **Biological Activated Carbon.** An alternative to traditional GAC filtration is the use of biological activated carbon (BAC) filtration. In this process, instead of replacing or regenerating spent GAC, the GAC is allowed to become biologically active. Over time, microorganisms adhere to pores in the GAC media, essentially covering the GAC media with a biofilm. TOC removal is achieved through biodegradation by miroorganisms in the biofilm, rather than through adsorption onto GAC. BAC filtration processes are typically less effective than virgin GAC; however, operation and maintenance costs are significantly reduced, as carbon replacement frequency is reduced by an order of magnitude. BAC filtration efficacy can be significantly improved by adding an oxidation step prior to BAC filtration to cleave large organic molecules, making them more bioavailable. Because contact by a strong oxidant increases the bioavailability of organic molecules, GAC filters located downstream of a strong oxidation process tend to readily convert to BAC filtration processes. As a result BAC is frequently implemented following ozonation. Due to the significant capital and operating costs associated with ozone usage, hydrogen peroxide addition has been identified as a preferred oxidation process prior to BAC. This configuration is illustrated on Figure 4-19.

BAC filtration processes downstream of strong oxidation processes (e.g., ozonation or hydrogen peroxide addition) have the following advantages:

- Very simple processes.
- Low operation and maintenance costs.
- Requires minimal operator attention.
- Can achieve moderate level of organics removal.
- Offsite disposal and replacement requirement much lower than for GAC.

They have the following disadvantages:

- Moderate land area is required for new BAC contactors.
- Preoxidation step can require chemical handling and storage.
- Less TOC removal than virgin GAC.

Anticipated removal efficiencies:

- TOC: Good
- EDCs: Good

c. **Powdered Activated Carbon.** Powdered Activated Carbon (PAC) is typically added in a rapid mix step, and settles out in the sedimentation stage. PAC capacity for TOC removal increases with contact time up to seven days; therefore, the contact time provided by typical settling basins is insufficient to produce effective removal. PAC is often used with membrane processes. PAC is frequently combined with microfiltration or ultrafiltration to improve performance by increasing organics removal and decreasing membrane fouling. TOC removals between 13 and 85 percent and DOC removals between 13 and 76 percent have been documented (EPA 1999). The major components of a PAC treatment system are illustrated on Figure 4-20.

PAC adsorption processes have the following advantages:

- Can achieve high level of organics removal.

They have the following disadvantages:

- Moderate process complexity.
- Requires offsite disposal and replacement.
- Requires microfiltration or ultrafiltration for optimal removal.

Anticipated removal efficiencies:

- TOC: Excellent
- EDCs: Good

3. **Membrane Filtration.** Membrane processes can remove TOC through filtration and adsorption. Organic molecules greater in size than the membrane pores are rejected based on size exclusion. Membranes may also remove TOC through surface adsorption, though this mechanism is undesirable as it has been shown to cause irreversible fouling.

Pressure-driven membrane processes are typically grouped into the following categories (in order of decreasing pore size): microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Figure 4-21 illustrates the relative pore sizes of these four membrane types. NF and RO have very small pore sizes, and are extremely effective at reducing TOC concentrations through size exclusion. MF and UF have shown limited efficacy in TOC removal due to their relatively large pore size. As a result, nanofiltration and reverse osmosis appear most promising. Figure 4-22 illustrates the main components of membrane filtration.

Membrane treatment with RO and NF membranes is a relatively energy-intensive process. A recent report prepared by the Water Research Foundation (formerly American Water Works Association Research Foundation) through a tailored collaboration with the WateReuse Foundation compared the effectiveness of several NF and ultra-low pressure RO (ULPRO) membranes for treating recycled water. The study found that rejection of TOC by NF membranes varies significantly (~50% - >90%) by membrane. In addition, while high rejection NF membranes exhibited higher flux rates than ULPRO membranes initially, these flux rates quickly dropped to those commonly observed for ULPRO membranes. The report found that the potentially significant savings resulting from lower energy requirements of NF membranes as compared to RO membranes can only be achieved using "loose" NF membranes, which are significantly less effective at rejecting TOC. These lower rejection membranes would not be suitable for achieving the low TOC concentrations required for groundwater recharge. The study found that, for the high rejection NF membranes tested, pressure, flux, and energy usage were comparable to that of commonly used ULPRO membranes. In the pilot tests conducted, feed pressures averaged approximately 900 kPa (130 psi) at 85 percent recovery. This corresponded to an electrical consumption of 0.37 kWh/m^3 (1.4 kWh/kgal) of permeate generated. For an electrical cost of $0.12 /kWh, this would equal approximately $0.05/m^3 of permeate produced using either the ULPRO or high rejection NF membrane.[1] As a result, NF membranes used to achieve groundwater recharge TOC requirements are unlikely to generate significant cost savings over RO membranes.

Both RO and NF membranes reject a vast majority of contaminants, though precise rejection values vary by membrane manufacturer. However, RO membranes are typically more effective at rejecting compounds of lower molecular weight, including some forms of TOC and total dissolved solids (TDS), than NF membranes. Because RO membranes typically reject a higher percentage of TDS than NF membranes, RO concentrate is expected to have a higher TDS concentration than NF membrane reject.

When utilizing RO or NF prior to groundwater recharge, concentrate disposal poses a potentially significant issue. On Cape Cod, where ocean discharge is generally not considered a viable alternative, membrane concentrate would need to be recharged to groundwater. However, in addition to TDS, membrane concentrate contains the TOC removed from the treated effluent; re-combining streams directly would negate the TOC removal benefit of the membrane treatment.

One way of addressing this issue is to remove TOC from the concentrate stream prior to recombining the concentrate with the permeate for discharge. The TOC contained in the concentrate stream is expected to be recalcitrant, as it is present in the treated wastewater following biological treatment. One way to degrade recalcitrant TOC in the concentrate stream is to expose the concentrate stream to an advanced oxidation process, in which hydroxyl radicals cleave larger TOC molecules into smaller, more easily biodegraded molecules (advanced oxidation processes are described in further detail in subsequent sections). The concentrate stream can then be returned to the biological treatment process for further TOC degradation. In

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[1] Drewes, Jorg E., et al. Comparing Nanofiltration to Reverse Osmosis for Treating Recycled Water. Awwa Research Foundation and WateReuse Foundation Tailored Collaboration. AwwaRF, 2008.

this arrangement, it is important to consider the concentration of TDS in the concentrate stream. Recycling a concentrate stream high in TDS could interfere with the biological process. As a result, the fraction of flow passing through the RO or NF membrane must be limited based on the concentration of TDS in the membrane concentrate to assure that the concentrate stream can be recycled without negatively effecting the biological process. Figure 4-23 illustrates a treatment flow schematic using this type of side stream treatment and GAC treatment for a smaller side stream.

Because concentrate TDS is an important consideration in the use of RO and NF membranes where concentrate must be recharged, membranes should be selected to maximize TOC rejection while minimizing TDS rejection. NF membranes typically provide greater flexibility in limiting TDS rejection; as a result, NF membranes may provide a slight advantage over RO membranes for this application. However, there are few large-scale programs utilizing NF to treat recycled water, and RO is a more proven technology for this application.

Advantages and disadvantages of nanofiltration and reverse osmosis are presented below.

NF and RO processes have the following advantages:

- Small land requirements for membrane filtration compared to traditional methods.
- Can achieve extremely high level of organics removal.
- Capital costs are relatively low.

They have the following disadvantages:

- Potential for membrane fouling without adequate pretreatment.
- Post-treatment required for water chemistry stabilization.
- Chemical storage and handling requirements for pre- and post-treatment chemicals.
- Special considerations are needed for concentrate (reject water) disposal and/or recharge.
- Operation and maintenance costs are typically high for high-pressure membranes.

Anticipated removal efficiencies:

- TOC: Excellent
- EDCs: Excellent

4. **Ion Exchange.** TOC can be removed through ion exchange, in which water comes into contact with a charged resin, and dissolved molecules from the source water replace resin molecules. Ion exchange resins can be classified as anionic or cationic, depending upon the resin charge. Ion exchange removes organic molecules from solution by attracting charged functional groups, causing the molecule to adhere to the resin.

An ion exchange approach that has recently attracted attention for its TOC removal capabilities, relatively low cost, and small footprint is the Magnetic Ion Exchange (MIEX) process, under patent by Orica Watercare of Australia. MIEX has been shown to be particularly effective at DOC removal.

The MIEX process is a continuous ion exchange process using a patented magnetized ion exchange resin designed for DOC removal from drinking water supplies. In this process, negatively charged DOC is exchanged with chloride ions on the MIEX resin surface, with resin particles suspended in a continuously stirred tank reactor. MIEX systems use smaller resin beads than conventional ion exchange resin beads, and include a magnetic component dispersed within the resin particles. The magnetic component allows the resin to rapidly settle into large, fast settling particles, increasing resin recovery rates and reducing recovery times.

The majority (90 – 95%) of settled resin is recycled back to the contactor as a concentrated suspension, with the remainder continuously diverted to a resin regeneration system. The resin which is removed for regeneration, and resin lost due to carryover from the separator, is replaced by fresh resin.

Regeneration is achieved by contacting spent resin with concentrated brine solution. Adsorbed molecules on the spent resin are replaced by chloride ions, and the previously adsorbed molecules are released into the brine solution for disposal. This process is illustrated on Figure 4-24.

MIEX processes have been shown to reduce DOC concentrations by as much as 70% in municipal drinking water applications.

MIEX DOC removal processes have the following advantages:

- Small footprint.
- Can achieve high level of DOC removal.
- Capital and operating costs are relatively low.

They have the following disadvantages:

- Removal efficiency depends upon TOC speciation (dissolved and polar qualities).
- Brine disposal required.
- Relatively complex process (compared with conventional processes).

Anticipated removal efficiencies:

- TOC: Excellent (DOC)
- EDCs: Good

5. **Advanced Oxidation Processes (AOPs).** AOPs break down the chemical bonds in organic molecules that make them difficult to be degraded biologically. Once these bonds have been broken, the organic compounds can be further metabolized by the biological or adsorption processes. AOPs are often utilized as a polishing step to destroy particularly recalcitrant organic compounds present in low initial concentrations.

There are several different AOPs. Three commonly used approaches are discussed below.

- Ultraviolet (UV) light: Organic compounds can be degraded using UV light through a process known as direct photolysis. In this process, organic molecules absorb the energy provided by the UV light, which causes the bonds to disassociate. This approach is typically used only in ultrapure applications with extremely low TOC starting concentrations (< 1 mg/L).

- UV + ozone or peroxide. The use of UV in combination with a secondary oxidant is a more applicable approach to oxidizing TOC at concentrations found in recycled water. In this approach, organic molecules in the recycled water are oxidized by hydroxyl (OH-) radicals, which are formed when UV light comes into contact with a strong oxidant such as peroxide or ozone. Hydroxyl radicals are very strong oxidants which attack the chemical bonds of the organic molecules.
- Ozone + peroxide. Similar to UV + secondary oxidant, the use of ozone in combination with a secondary oxidant such as peroxide results in formation of hydroxyl radicals, which oxidize organic molecules in the treated water.

A 1999 Study conducted by the Water Research Foundation (formerly the American Water Works Research Foundation) evaluating the efficacy of advanced oxidation processes for TOC removal in two drinking water sources concluded that the combination of UV and peroxide provided similar benefits to ozonation, with less complicated technology (Spietel et al). Removal of TOC by ozone and peroxide did not provide significantly greater removal than ozone alone. As a result, of the AOPs evaluated, UV + peroxide appears to be most promising. Advantages and disadvantages of UV + peroxide are presented below.

UV + peroxide processes have the following advantages:

- Small land requirements for inline UV and chemical injection.
- Can achieve high level of organics removal.
- Capital costs are relatively low for UV systems.

They have the following disadvantages:

- Relatively complex process.
- Requires operator attention and training.
- Chemical storage and handling requirements.
- Operation and maintenance costs are typically high for UV.

Anticipated removal efficiencies:

- TOC: Excellent

- EDCs: Excellent

C. **Screening of Technologies to Achieve Less Than 3 mg/L TOC.** The screening of technologies to achieve less than 3 mg/L TOC is based on the description of each technology and its respective advantages and disadvantages. A summary of TOC removal technologies with respect to the screening criteria is included in the Table 4-2.

Coagulation and Filtration processes are well-understood processes that are relatively simple to operate. They carry significant land requirements for new sedimentation basins, and typically have relatively high capital costs, though operations and maintenance costs are limited to coagulant costs. Enhanced coagulation followed by filtration may be sufficient to achieve the TOC limitation of 3.0 mg/L, but would not be effective for CEC removal, and significant process modifications would be required to meet new, targeted regulations. As a result, this alternative is not retained for further evaluation.

GAC Adsorption is a relatively well-studied, straightforward adsorption process. GAC contactors require a relatively large area, and GAC replacement and disposal costs are high. GAC is a proven technology to achieve high levels of organics removal and moderate CEC removal. A GAC adsorption process would be capable of meeting future regulations with minor modifications. As a result, GAC is retained for further evaluation.

BAC Adsorption is similar to GAC adsorption, with reduced GAC replacement and disposal requirements but reduced TOC and CEC removal efficiency. Due to its reduced removal efficiency, BAC is not retained for further evaluation.

PAC Adsorption is a relatively complex process requiring operator attention and training. While there is a relatively small land requirement, PAC carries moderately high capital costs and high carbon replacement and disposal costs. PAC is capable of achieving high organics removal efficiency, though performance issues have been reported, likely due to its operational complexity; as a result, this alternative is not retained for further evaluation.

Membrane Filtration, specifically nanofiltration or reverse osmosis, is a fairly complex process requiring operator training and attention. Membrane processes carry relatively small land requirements, but do require pre- and post-treatment processes, with associated chemical storage and handling requirements. Membrane processes can also be moderately energy-intensive processes, though they consistently achieve very high degrees of organics removal and CEC removal. It is expected that a membrane process would be capable of meeting potential future regulations without modification. NF and RO processes are retained for further evaluation.

Ion Exchange (MIEX) is a relatively complex process requiring operator training and attention. MIEX processes have the benefits of requiring a relatively small land area, moderate capital costs and relatively low operations and maintenance costs. They have been shown to achieve a high degree of organics removal, but their ability to remove CECs is unproven. While MIEX processes have received substantial attention for their efficacy in removing DOC, they are less proven than other available technologies and are not retained for further evaluation.

Advanced Oxidation, specifically UV+Peroxide, is a complex process requiring operator training and attention, and chemical storage and handling. This process requires a relatively small land area, and carries relatively low capital costs. The energy requirements of the UV reactor coupled with chemical costs generate moderate operations and maintenance costs. This alternative is expected to achieve a moderate degree of organics and CEC removal, and has the potential to meet future regulations with only minor modifications. This technology is typically utilized as a polishing step following other advanced treatment approaches, or as a side steam treatment step treating a smaller flow of refractory organics, and is less proven as a primary TOC removal step than other available technologies. As a result, it is not retained for further evaluation as a primary TOC removal step; but is recommended for further evaluation as a side stream treatment or polishing step.

D. **Technologies to Achieve Less Than 1 mg/L TOC.** As described previously, the revised Massachusetts Groundwater Discharge Permit Program imposes a TOC limitation of 1.0 mg/L for recharge in a Zone II with less than a two year travel time, as well as for recharge in a Zone II with a travel time of greater than two years in the absence of soil aquifer treatment (e.g., direct recharge to the saturated zone).

While a variety of technologies exist to achieve 3.0 mg/L of TOC, there are fewer technologies capable of achieving TOC concentrations as low as 1.0 mg/L. Coagulation and filtration and BAC would not be capable of reducing TOC to below 1.0 mg/L. While GAC or PAC treatment may be capable of achieving 1.0 mg/L of TOC, use of GAC to remove TOC to such low levels would require frequent, costly media replacement, as effluent TOC concentrations increase as adsoptive capacity is exhausted. MIEX has been shown to reduce TOC to concentrations below 1.0 mg/L in some drinking water applications; however, in these cases, initial TOC concentrations were lower than those typically found in recycled waters. In addition, MIEX preferentially removes polar dissolved organic carbon; if a significant percentage of nonpolar, undissolved TOC is present in recycled waters, MIEX would not be effective for TOC removal. Advanced oxidation can theoretically mineralize TOC to carbon dioxide; however, mineralization of TOC in recycled waters to concentrations below 1.0 mg/L would be cost-prohibitive. As discussed previously, advanced oxidation is usefull and feasible for side stream treatment and for final polishing; and it will be retained for further evaluation. Of the technologies currently available, the most reliable means of achieving a limit of 1.0 mg/L would be NF or RO membrane treatment which will be retained for further evaluation.

4.5 TECHNOLOGIES TO ACHIEVE LESS THAN 3 MG/L TOTAL NITROGEN

A. **Introduction**. There is a significant amount of experience with removing nitrogen to Biological Nitrogen Removal (BNR) levels of 5 to 7 mg/L on average, and to Enhanced Nitrogen Removal (ENR) levels of 3 mg/L on average. The need to treat municipal wastewater to levels below 3 mg/L total nitrogen is rare and thus there is little experience with full-scale municipal systems.

It is important to understand the limitations of removing nitrogen to levels below 3 mg/L. The nitrogen that remains in the treated water following ENR treatment processes consists of three forms: ammonia, oxidized nitrogen (typically nitrate), and organic nitrogen. In a system that is fully nitrifying, the ammonia will be less than 1 mg/L, perhaps as low as 0.2 to 0.5 mg/L. If the system has performed very well with denitrification, nitrate in the effluent should be less than 1 mg/L. Both ammonia and nitrate are soluble, so filtration will not reduce them further. Organic nitrogen consists of both a soluble and a particulate form. The particulate form of organic nitrogen is associated with any biological floc that escapes in the effluent and is generally proportional to the level of suspended solids in the effluent. If filtration is provided, then the particulate organic nitrogen is removed but not completely. Soluble organic nitrogen is typically 1.0 to 1.5 mg/L in the effluent of a domestic wastewater treatment plant. The soluble organic nitrogen can be higher in treatment plants that receive waste from industries such as textile or dye plants or that receive a significant amount of septage. Thus, as the various forms of nitrogen in a filtered effluent are added together, the concentration approaches 3 mg/L as a limit unless some additional, more advanced treatment steps are taken to remove them.

B. **Technologies Used to Achieve Less Than 3 mg/L TN.** The technologies described below reduce the total nitrogen in the treated water by removing one of the three remaining fractions of nitrogen in one of several ways:

1. **Adsorption.** Activated carbon may be used to adsorb soluble organics including carbon and nitrogen compounds. There are several processes to accomplish this, as previously discussed in relation to TOC removal. Granular activated carbon (GAC) filters are available as either downflow gravity filters or pressure filters. Biological Activated Carbon (BAC) filters are GAC filters where the influent is oxidized and to the filters support an attached biological growth. Powdered activated carbon (PAC) can be added to a stage of the activated sludge process to adsorb the organics while also retaining them in the process for possible further biological treatment.

2. **Advanced Oxidation Processes (AOP)**. As discussed with respect to TOC removal processes, AOPs work on the principle of breaking down the chemical bonds in the organic nitrogen (as well as other organic compounds) that make it difficult for the compound to be oxidized biologically. Once these bonds are broken down, the ammonia compound will be further metabolized by the ENR processes. There are two main types of AOPs. The first relies strictly on UV light and is referred to as direct photolysis. The organic compound absorbs the energy provided by the UV light, which causes the bonds to disassociate. The second type, which is more applicable, utilizes a combination of UV light and some type of oxidant, such as hydrogen peroxide or ozone. The UV light and oxidant produce hydroxyl (OH^-) radicals, which are very strong oxidants and will attack the bonds.

3. **Ion Exchange.** Specialized ion exchange media (similar to the MIEX process discussed earlier for TOC removal) has been used to remove ammonia and nitrate ions. The media can be added as a slurry or can be used in a packed column. There are several commercial applications of this technology. The media is typically regenerated with a caustic salt water solution.

4. **Membrane Filtration.** Reverse osmosis and/or nanofiltration membrane filtration is effective in removing additional organic nitrogen because the membranes are capable of blocking some of the higher molecular weight organic compounds. Microfiltration and ultrafiltration are typically used as a pretreatment step for reverse osmosis or nanofiltration. They are also used for phosphorus removal after chemical precipitation.

C. **Summary.** These technologies are identified and described at this stage in the project to provide understanding on how additional technologies could be added to an ENR treatment system and/or TOC removal system to achieve lower levels (less than 3 mg/L) of total nitrogen in the treated water. These are not conventional wastewater treatment technologies for nitrogen removal and would add greater costs to an overall system. These processes are also represented in the group of technologies used for TOC removal to less than 3 mg/L. All of these technologies (except BAC treatment) will be retained for further evaluation if treatment to less than 3 mg/L total nitrogen is needed. These systems would typically need to be piloted with the treated water that would be coming from the ENR process to optimize the design of the system and to gain regulatory approval.

4.6 CONSIDERATIONS ON TREATMENT ALTERNATIVES FOR PHOSPHORUS

Recent studies have indicated that phosphorus discharged upgradient of freshwater ponds can migrate through the soil with the groundwater to the ponds and cause nutrient enrichment in the ponds. Before these studies were completed, the conventional judgment was that the phosphorus became bound to the soil particles and did not migrate with the groundwater. If treated water recharge is to occur upgradient of a freshwater pond, phosphorus removal from the water may be required.

Phosphorus removal from wastewater is currently required for many regions of the United States. The treatment processes are well understood and phosphorus removal to 0.2 mg/L total phosphorus in the treated water is commonly attained at centralized treatment plants through a combination of biological treatment (such as the Bardenpho multiple-stage process), chemical precipitation through the addition of iron or aluminum salts, and filtration and/or membrane treatment. New or upgraded treatment facilities should be planned and designed to accommodate the potential need to remove phosphorus in the future.

4.7 DISINFECTION ALTERNATIVES

A. **Introduction.** This section presents several alternatives for disinfection which will be required by MassDEP and should be considered as part of a new centralized wastewater treatment facility in Barnstable or an upgraded/expanded Hyannis WPCF.

B. **Chlorination.** Chlorination can be provided by the addition of a number of chemicals, including sodium hypochlorite, calcium hypochlorite, gaseous chlorine, bromine chloride, and chlorine dioxide. Use of either sodium hypochlorite or calcium hypochlorite for disinfection is very similar and involves storage and feeding of hypochlorites in solution form. Hypochlorites are hazardous and corrosive, but these chemicals are safer than gaseous chlorine with respect to storage and overall management.

All chlorine compounds can combine with organic material and produce trihalomethanes, which are suspected carcinogens. The USEPA and MassDEP have established a drinking water standard of 0.1 ppm for trihalomethanes. Testing conducted on Cape Cod using treatment plant effluent disinfected with sodium hypochlorite does not indicate the formation of trihalomethanes above 0.1 ppm. At the same time, there may be public perception of a public health concern for disinfection with chlorine compounds.

Sodium hypochlorite is the preferred method of chlorination and it is the current disinfection process at the Hyannis WPCF. It has the following advantages:

- The process can be controlled for feed dosages and chlorine residual.
- Minimal energy use.
- Low O&M costs.

Use of chlorination for disinfection has the following disadvantages:

- A large contact tank is needed.
- There may be potential public perception of groundwater contamination with trihalomethanes.
- The storage and handling of sodium hypochlorite can be a safety hazard.
- Sodium hypochlorite has a limited shelf life.

C. **Ozone.** Ozone has been found to be highly effective in disinfection and has few potential adverse environmental impacts on receiving waters and water supplies. Ozone must be generated on site, which normally involves the use of high voltage electrodes and pure oxygen. Ozone is then transferred from the gas phase to the liquid phase with diffusers and closed contactors. The off-gases from the contactor must be treated thermally to destroy excess ozone, which is toxic.

Ozone presents less environmental concern than chlorination because ozone rapidly dissipates to oxygen after application, leaving no ozone residual and adding dissolved oxygen to the treated water. Ozone can, however, produce toxic mutagenic and/or carcinogenic compounds. Unlike chlorine, ozone does not produce a disinfection residual concentration that can be measured and used as an indication of satisfactory disinfection.

The cost to produce ozone on site is high, resulting from the high capital cost of generation equipment and high energy requirements. Ozonation is labor intensive because the system is complex and difficult to operate and maintain.

Disinfection with ozone has the following advantages:

- Ozone adds dissolved oxygen to the treated water.
- Fewer adverse environmental impacts as compared to chlorination.

It has the following disadvantages:

- Ozone is toxic, even though it rapidly dissipates to oxygen.
- High capital costs associated with generating equipment.
- High energy usage to generate ozone.
- Complex operation and maintenance.
- High O&M costs.
- Can produce toxic mutagenic and/or carcinogenic compounds.
- Destruction of off-gases from the ozone contactors is required.
- Does not produce a monitorable residual.

D. **Ultraviolet Radiation (UV).** Unlike the previous alternatives, UV radiation provides disinfection without the use of chemicals. UV light provides radiation which penetrates bacterial cell walls and viruses and kills them or prevents them from reproducing. No toxic residuals are produced. The UV bulbs are contained in racks or modules which are submerged in channels. Required contact time with the bulbs is short.

Suspended solids in the treated water can interfere with disinfection efficiency by preventing light transmission in the water; therefore, a high quality treated water is required prior to the UV disinfection. The UV bulbs become dirty over time and must be periodically removed and cleaned, which is accomplished by dipping the rack of bulbs in cleaning solution or utilizing a submerged mechanical wiper blade system. The bulbs must be periodically replaced, which adds to the O&M costs; however, UV disinfection has been found to be cost competitive with chlorination.

UV disinfection has the following advantages:

- No adverse environmental impacts.
- Minimal space requirements due to the required short contact time.
- Ease of operation and maintenance.
- Cost competitive with other disinfection techniques.
- Well-proven effectiveness.

It has the following disadvantages:

- Suspended solids, turbidity, and color can interfere with the effectiveness of disinfection.
- High quality treated water is required prior to UV disinfection.
- Periodic cleaning and replacement of bulbs is required.
- Does not produce a monitorable residual.

E. **Screening of Disinfection Alternatives.** Table 4-3 presents a matrix summary of the disinfection alternatives for further evaluation. UV radiation is recommended as the preferred disinfection alternative for new treatment facilities based on minimal adverse impacts on the environment; ease of operation; cost competitiveness; and reduced risk to operations staff and the environment due to the absence of chemical transportation or storage requirements.

Sodium hypochlorite is not retained for new facilities due to potential liabilities associated with the transportation and storage of hypochlorite. Use of sodium hypochlorite can be continued at the Hyannis WPCF as long as treated water monitoring does not indicate the formation of trihalomethanes. Ozonation is not recommended for further evaluation due to its high costs, complex operation, and the fact that it may potentially produce toxic compounds.

4.8 RESIDUALS MANAGEMENT

A. **Introduction.** The purpose of this section is to identify and screen alternatives that could be used to properly treat and dispose of residuals from new wastewater treatment processes. Residuals are byproducts of wastewater treatment and are often difficult to handle, expensive to dispose of, and can be a source of odors. The following is a description of the various types of residuals associated with municipal sanitary wastewater:

1. **Septage.** Septage is comprised of wastewater solids that accumulate in septic tanks, tights tanks, and cesspools, and includes sludge, scum, and liquids.

2. **Trap Grease.** Trap grease is the material that is periodically pumped out of restaurant grease traps and is a combination of solid floatable grease, settleable solids, and water. Trap grease is difficult to handle, difficult to dispose of, and should be isolated from wastewater treatment processes because it fouls piping, valves, and other treatment equipment.

3. **Screenings and Grit.** Screenings and grit are byproducts of treating wastewater, septage, and trap grease. Screenings are large solid objects removed from wastewater in bar screens during preliminary treatment. Grit consists primarily of sand and gravel and is also typically removed during the preliminary treatment process. Removing screenings and grit from wastewater and sludge treatment processes is important to prevent damage to pumps, valves, and pipelines.

4. **Sludge.** Sludge (also called biosolids) is the organic material removed from wastewater treatment processes. Wastewater sludge is solid material that settles by gravity in a

primary wastewater treatment process, or is a combination of microorganisms and organic material generated in secondary/advanced treatment processes and effluent polishing processes. Sludge is produced as a liquid and typically has a solids concentration of 5,000 to 20,000 mg/L (0.5 to 2 percent total solids). It is typically thickened and disposed of at regional disposal facilities at a concentration of 5 percent total solids. Also, it can be dewatered and disposed of at regional disposal facilities as a sludge cake at a concentration of 20 to 25 percent total solids. It can also be dewatered and composted to produce a soil conditioner material of approximately 35 to 50 percent total solids.

B. Septage and Trap Grease Treatment and Disposal Alternatives.

1. **Current Practices.** Septage and trap grease are collected from Town residences and commercial establishments, and transported to the Hyannis WPCF, where they are treated. (The Draft Needs Assessment Report, Chapter 4, provides a detailed description of the septage treatment process at the Hyannis WPCF.) Septage treatment at the WPCF makes the best use of existing facilities and provides reliable service and flexible operation. Septage and trap grease should continue to be routed to the existing WPCF to avoid the cost of managing these residuals at a new facility.

C. **Screenings and Grit Disposal.** Screenings and grit are typically generated at the headworks of wastewater treatment facilities. Screenings and grit from a new wastewater treatment facility would most likely be combined and disposed at an approved location. The Town of Bourne landfill is permitted to receive this material and is the most likely disposal location for screenings and grit.

D. **Sludge Processing Alternatives.** Sludge is a byproduct of secondary/advanced wastewater treatment processes and must be treated properly to avoid odors, reduce disposal costs, and minimize potential risks to human health. The manner in which sludge is treated can have significant impacts on the liquid stream treatment performance and the efficiency of nitrogen removal. This is because of the interdependency of the liquid and solids streams through return flows and recycle streams. Sludge processing alternatives are divided into the following categories:

- Sludge thickening

- Sludge dewatering
- Sludge stabilization and composting
- Sludge disposal

1. **Sludge Thickening.** Sludge thickening is a process to concentrate sludge by removing a portion of the liquid fraction. Sludge thickening reduces transportation and disposal costs and facilitates additional sludge treatment processes, including dewatering and stabilization/composting. Sludge thickening can be accomplished by several processes. The simplest thickening process involves storing sludge in an aerated tank and periodically stopping aeration to allow sludge to settle and excess liquid to be decanted. Other thickening processes utilize equipment such as filters, gravity belts, centrifuges, and rotating drums. Thickening with these types of mechanical equipment (mechanical thickening) often requires a covered process building, odor control facilities, and additional process equipment such as feed pumps and piping. Mechanical thickening also typically requires the addition of chemicals, such as polymer, to condition the sludge and facilitate the thickening process. The Hyannis WPCF currently uses gravity belt thickeners which were determined to be the most cost effective and manageable sludge thickening alternative in the 2007 Wastewater Facilities Plan.

2. **Sludge Dewatering.** Sludge dewatering is a physical process used to reduce the water content of thickened sludge. Dewatered sludge, also known as sludge cake, has the consistency of moist sawdust and requires less volume for storage or transportation to a disposal site. Dewatering processes include belt filter presses, rotary fan presses, centrifuges, and plant and frame presses.

3. **Sludge Stabilization/Composting.** Sludge is stabilized to reduce pathogens, odors, and the potential for the sludge to biologically decay. Sludge stabilization processes can be used prior to or following sludge dewatering. Common sludge stabilization technologies include composting, digestion, alkaline stabilization, and heat treatment and drying.

    a. **Composting.** Composting is a biological sludge stabilization process that destroys pathogens, reduces the water and organic solids content of dewatered sludge, and produces a granular, soil-like material. Sludge composting processes typically include the following three steps:

1) Dewatered sludge is mixed with a bulking agent such as wood chips, yard waste, or sawdust.

2) The mixture is aerated or regularly mixed, which increases the temperature of the mixture, killing pathogens and degrading the volatile solids of the sludge.

3) The composted material is cured and stored for distribution.

Finished compost can be distributed to the public if it meets criteria established by MassDEP regulations. Composting is typically most successful if the sludge to be composted has already been digested because the material is partially stabilized, there is less potential for generation of odors, and the sludge is easier to handle. Although composting provides a beneficial reuse of sludge, it is usually not cost effective for low sludge flows. Sludge composting facilities often consist of large covered structures to shelter the compost machinery and odor control facilities. Land areas and capital costs are usually relatively high for composting facilities.

b. **Digestion.** Digestion is a biological stabilization process that reduces the number of pathogens and the overall solids content of sludge through the use of microorganisms. The microorganisms feed on the organic material in the sludge and are utilized in two types of sludge digestion processes: anaerobic digestion and aerobic digestion. Digested sludge can be dewatered, composted, or disposed of at a regional facility. Anaerobic digestion produces methane gas that can be used as a fuel source.

Anaerobic and aerobic sludge digestion processes typically include two or more large covered tanks. Thickened sludge is fed into the tanks where anaerobic or aerobic microorganisms decompose the sludge. Mixing and aeration equipment is required to improve the digestion process and maintain either an anaerobic or aerobic environment. The digestion process also requires covered buildings to protect process equipment and odor control facilities. Sludge digestion is not cost effective for small sludge flows.

c. **Alkaline Stabilization.** Alkaline stabilization is a process in which dewatered sludge is combined with an alkaline material, such as cement kiln dust or lime, to raise the pH, raise the temperature, and reduce the water content of the sludge. Raising the pH and temperature of the sludge creates an environment which is hostile for pathogen growth and reproduction. Alkaline stabilization, like composting, can produce a material that meets MassDEP's requirements for distribution to the public.

The primary market for an alkaline stabilized sludge is the agricultural industry. The alkaline stabilized sludge has alkalinity and nutrients that are useful for growing corn and other crops; however, this type of agricultural market does not exist on Cape Cod. The facilities required for alkaline stabilization include enclosed areas for storing alkaline materials, processing the sludge-alkaline material mixture, and storing the final product. Equipment requirements include screw conveyors for transferring the alkaline materials, a mixing unit that combines dewatered sludge and alkaline material, and a drying process for the blended material. Land area requirements and capital and operations costs are comparable to those of a composting facility. Alkaline stabilization is typically not cost effective for small sludge flows in areas where there is not a market for the final product.

d. **Heat Treatment and Drying.** Heat treatment and drying are thermal stabilization processes that involve heating sludge under pressure to disinfect and dry the sludge. The resulting material is easier to dewater and may be dried to produce a powdered or pelletized product, which can be used as a fertilizer or soil conditioner.

These processes generally have high capital costs, high level of complexity, high energy usage and operation costs, and can be poorly received by the public due to air emissions.

Sludge stabilization has the following advantages:

- Certain processes, such as composting and alkaline stabilization, produce a material that can be distributed to the public, providing a beneficial reuse of the sludge and potential reduction of transportation and disposal costs.
- Processes are often easily expanded to accommodate increased sludge flows.

- These processes produce a sludge that is easy to dispose of because the sludge material is biologically more stable and less likely to decompose and generate odors.
- Anaerobic digestion produces methane gas which, if produced in large enough volumes, can be used as a supplementary energy source.

Sludge stabilization has the following disadvantages:

- The demand for a composted or alkaline-stabilized product is unknown and may be minimal due to the relatively low number of agricultural areas in Cape Cod and Eastern Massachusetts.
- Stabilization processes, particularly thermal processes, generate odors and require the construction of odor control facilities.
- High land area requirements to provide space for equipment and materials.
- Composting, alkaline stabilization, and heat treatment alternatives require extensive permitting and monitoring for MassDEP and USEPA approval prior to distribution of the finished material.
- Energy use for mixing and processing equipment would be high, resulting in high O&M costs.
- Requires high level of skill for operation and maintenance of the complex machinery.

E. Sludge Disposal Alternatives.

The sludge disposal/reuse evaluation is provided on the following pages. A diagram identifying potential sludge residual processing alternatives is included as Figure 4-25.

1. **Thickening and Disposal at a Regional Facility.** This alternative would involve the transportation and disposal of thickened sludge at a regional facility. This would require the construction of sludge storage and thickening facilities. The thickened sludge would be transported to a regional facility for disposal (i.e., Woonsocket, RI or Worcester, MA). The Hyannis WPCF currently uses this method of sludge disposal which was determined to be the most cost effective as part of the 2007 Wastewater Facilities Plan.

This alternative has the following advantages:

- Use of one common sludge processing facility at the Hyannis WPCF or new facilities at a new WWTF.
- Minimizes capital costs and equipment operational costs.

This alternative has the following disadvantages:

- May require transportation of unthickened sludge to the Hyannis WPCF which would increase traffic.

2. **Sludge Dewatering and Disposal at a Regional Facility.** Using this alternative, the Hyannis WPCF or a new facility would dewater the sludge and dispose of the sludge cake at a regional facility.

This alternative has the following advantages:

- Disposal costs for sludge cake are less than those for thickened liquid sludge.
- Thickened sludge could be received and processed at the Hyannis WPCF.

This alternative has the following disadvantages:

- Belt filter presses or centrifuges are the most common and economical dewatering processes, but they are more expensive than simple thickening equipment.
- There are few regional disposal facilities that accept sludge cake and the cost savings with sludge cake disposal do not offset the higher cost to produce it.
- The sludge dewatering process provides a greater potential for release of odors.

3. **Sludge Dewatering, Composting, and Distribution to the Public.** This alternative involves the construction of sludge dewatering and composting facilities, with the primary goal to produce a material that could be distributed to the public. Although it is unknown if there would be sufficient demand for sale of these materials in Barnstable, experience indicates that the public will pick up and use the material if it is free and of good quality.

Composting and distribution of compost would have the following advantages:

- The Town would not have to pay for sludge disposal.
- Beneficial reuse is provided.
- The Town has more control over sludge disposal and is not dependent on a regional sludge disposal facility.
- Sludge generated and thickened at multiple facilities could be dewatered and composted at one centralized location.

This alternative would have the following disadvantages:

- Construction and O&M costs are typically highest for this alternative.
- Regular sampling, analysis, and reporting to MassDEP is required.
- The potential for odors is increased and adjacent property owners may not welcome this type of process.
- High land area is required.
- It would be necessary to continue to transport sludge to this facility from either the existing WPCF or a new WPCF.

4. **Land Application of Sludge.** This alternative involves the thickening and/or dewatering of sludge and subsequent spreading of sludge (in very controlled application rates) onto and into the land. The land is then seeded with an agricultural crop to utilize the sludge's nutrients and turn it into soil material. This type of sludge disposal is common in the Midwestern United States, where there are large farms that welcome the nutrients. It has also been used in other places to produce inexpensive topsoil for the construction of landfill caps. (In 1996, the Barnstable landfill cap utilized approximately 5 years of sludge production from the Hyannis WPCF for use in the cap topsoil layer saving large sums of money.) Land application of sludge is not recommended for Barnstable because there are no large agricultural lands nearby that could use (or want) the sludge. Also, sludge contains significant amounts of nitrogen, which typically does not lend itself to application in Barnstable and the many watersheds to sensitive coastal estuaries.

5. **Screening of Sludge Disposal/Reuse Alternatives.** The screening of sludge disposal/reuse alternatives is based on the description provided for each alternative, its

advantages and disadvantages, and the screening criteria established in Chapter 2 of this report. A summary of sludge disposal/reuse alternatives and a side-by-side comparison of screening criteria are included in Table 4-4.

Sludge thickening is a relatively simple process with minimal operation, maintenance, and energy requirements and is retained for further evaluation. Thickened sludge can be disposed of at a number of regional facilities. Sludge could also be collected and transported to the existing WPCF for thickening and disposal with the sludge generated at that facility.

Sludge dewatering and disposal at a regional facility is not retained for additional evaluation, as the required land area will either be site restrictive or cost prohibitive. There is also a greater potential for odor generation.

Sludge composting has high capital and O&M costs due to construction of a covered building, high land area requirements, and the purchase and operation of complicated machinery. Public interest may be high in Barnstable due to a desire to reuse the sludge, but public acceptance is expected to be low due to the potential for odors, visual impacts both during and after construction, and a minimal market for distribution of the finished product. Performance and reliability are a major concern for composting facilities based on the poor performance of the two municipal composting facilities on Cape Cod (and the one at the Otis AFB WWTF), which were all shut down due to economic factors and the generation of odors.

Based on the evaluation of these alternatives, disposal of thickened sludge is believed to be the most practical sludge disposal alternative and is recommended for further integration into the management plans and detailed evaluation.

F. **Ongoing Evaluations for Sludge Minimization at the Hyannis WPCF.** The Town of Barnstable Department of Public Works (DPW) Water Pollution Control Division (WPCD) currently pays approximately $480,000 per year for sludge disposal. This represents approximately 30% of the total WPCD annual budget. In an effort to minimize this annual cost, the Hyannis WPCF is investigating various methods to minimize the amount of sludge that is produced and needs off-site disposal or reuse.

There are several proprietary processes that vendors have claimed can minimize sludge production and save annual sludge disposal costs. These processes all rely on mineralizing the organic component of the sludge to carbon dioxide.

They use different biological, chemical, and filtration processes to mineralize the sludge organic content.

The following processes were investigated to learn if they are viable processes and if they have proven performance with municipal WWTFs similar to the Hyannis WPCF:

- AFC Process marketed by PMC Biotec Co. of Exton, PA.
- Autothermal Thermophilic Aerobic Digestion (ATAD) marketed as TermAer™ by Thermal Processes Systems Inc. of Crown Point, IN.
- Cannibal® System as marketed by Siemans Corp.
- Biolysis® Process marketed by Infilco Dégremont.
- KADY BLS™ Process.

The first three processes were determined to be viable processes that are being actively marketed and supported. The most promising of these three processes is the AFC Process which had a full scale installation at the Seabrook, New Hampshire WWTF that claimed to have an 80% sludge minimization rate. Site visits were made to the WWTF and the sludge minimization process appeared to be working well. PMC Biotec Co. proposed to perform a bench scale pilot study with sludge from the Hyannis WPCF. In 2009, the process at the Seabrook WWTF was discontinued after odor complaints and operational problems, and Barnstable DPW has not proceeded with the pilot study.

The Town plans to continue to observe the progress of this emerging technology as a way to minimize its sludge disposal costs. Once full scale processes have proven the technology, the Town should proceed with pilot study to determine if the technology would be successful at the Hyannis WPCF.

4.9 SATELLITE WASTEWATER TREATMENT FACILITIES INCORPORATING NITROGEN REMOVAL

Satellite treatment facilities incorporating nitrogen removal are designed to treat and discharge wastewater flows greater than 10,000 gpd and are typically of a size less than 300,000 gpd. These treatment systems serve many properties and require a wastewater collection system as well as a treated water recharge system.

Satellite treatment facilities typically utilize processes that are compact in size and more mechanized than individual and multiple-home, on-site-type systems. These facilities can produce a treated water that meets the Class I permitted standards of 30 mg/L BOD_5, 30 mg/L TSS, and 10 mg/L nitrate-N. They typically produce average total nitrogen concentrations in the 5 to 7 mg/L range. When properly designed and operated, they can provide even better treatment.

A satellite treatment facility typically incorporates aspects of both the individual home I/A systems discussed in Chapter 3 and the larger scale centralized processes discussed previously in this chapter. A satellite system can either scale up an individual-home I/A technology for a larger flow scheme, or scale down one of the processes discussed in this chapter for a slightly smaller flow. For example, the Town-operated Marstons Mills WWTF utilizes an RBC (fixed film process) followed by a denitrification filter as discussed earlier in this chapter.

The general treatment processes are discussed further in this section.

A. **Regulatory Impacts and Treatment Standards.** Wastewater discharges greater than 10,000 gpd require a groundwater discharge permit under the Massachusetts Groundwater Discharge Permit Program and the Reclaimed Water Permit Program and Standards described in 314 CMR 5.00 and 20.00, respectively. These regulations were discussed in the Draft Needs Assessment Report. *"Guidelines for the Construction, Operation, and Maintenance of Small Treatment Facilities with Land Disposal"* have been published by MassDEP specifically governing these types of treatment facilities. These guidelines provide detailed design criteria for treatment and discharge facilities.

B. **System Components for Satellite Wastewater Treatment Facilities.** Several system components are common to all satellite wastewater treatment facilities. These components are required by MassDEP's design guidelines or are required as part of a well-equipped treatment facility that can be easily operated and maintained during its design life. The main components of a satellite wastewater treatment facility are very similar to the components necessary for a larger municipal (centralized) facility as illustrated in Figure 4-3 and are briefly described below.

1. **Primary Clarifiers.** Primary clarifiers are settling tanks that reduce the organic loading to the treatment process by removing settleable solids and floatable material. The raw wastewater flows through the clarifier (typically large septic tanks for satellite wastewater treatment facilities) and the solids settle to the bottom, where they are collected and removed for disposal. MassDEP's design guidelines require the installation of primary clarifiers on all small wastewater treatment facilities (some suspended growth processes, such as an SBR, may be an exception to this requirement).

2. **Flow Equalization.** Flow equalization is required to provide steady and relatively consistent daily wastewater flows and associated loadings to a satellite wastewater treatment facility. A flow equalization tank stores the variable flows that occur periodically during the day, and equalization pumps convey a relatively constant flow from the equalization tank to the biological treatment process.

3. **Biological Nitrogen Removal Process.** This process utilizes a large concentrated population of microorganisms to treat the wastewater. As discussed previously, these processes are categorized by the physical configuration used to promote microbial growth, such as suspended growth, attached growth, or a combination. Similar to larger municipal facilities, satellite treatment facilities may require chemical addition to accomplish the biological processes.

4. **Secondary Clarifiers.** Secondary clarifiers are an integral component of some of the more common fixed film and suspended growth nitrogen removal processes. These clarifiers are used to separate the biological solids (sludge) from the treated water, and they operate similarly to the previously described primary clarifiers.

5. **Effluent Filtration.** This is typically required by MassDEP following the biological nitrogen removal process. This process filters the treated water to remove most remaining particulate matter. The facilities include sand or other media filters and the necessary pumps and

reservoirs to periodically backwash the filters and pump the dirty backwash water back to the biological treatment process. Depending on the technology/process chosen, effluent filtration is provided as part of the standard design or is not required due to the treatment process.

6. **Disinfection.** Disinfection may be required prior to recharging the treated water to the groundwater. Disinfection can be accomplished by any of the disinfection methods discussed previously. Disinfection is not typically required when subsurface leaching fields are used for recharge unless it occurs within a Zone II. Disinfection may be required when sand infiltration beds (open to the atmosphere), well injection, or recharge to a surface water body are used.

7. **Treated Water Recharge Facilities.** As with any treatment system, whether individual on-site systems, cluster systems, satellite systems, or large municipal systems; treated water needs to be recharged somewhere. Two methods are commonly used, including sand infiltration beds and subsurface leaching, although there are other options that are discussed in detail in Chapter 5. When sand infiltration beds are used, the treated water is piped to a sand bed, where the water percolates into the ground through the open sand surface. Maintenance of the beds is relatively easy and solids can be removed from the top of the sand beds. The sand beds are usually sized based on a hydraulic loading rate of 5 gpd/ft^2 of bed area for sandy soils, but this loading rate must be verified with soil analysis and hydrogeologic investigations. When subsurface leaching is used, the water is piped to a subsurface perforated drain field, where it percolates into the ground. Maintenance of these systems is more difficult because the leaching field is not exposed to the surface and solids cannot be easily removed. The leaching fields are generally sized based on a hydraulic loading rate of 2.5 gpd/ft^2 of leaching area. Leaching fields have the advantage of being able to be located under a parking lot or other large open area that may have another use; therefore, it could potentially require little or no additional space. The selection of treated water recharge facilities must be performed on a site-by-site basis.

8. **Support Structures.** An operations building is required to shelter process equipment, store supplies, and operate and maintain the various treatment processes.

C. Biological Nitrogen Removal Processes.

1. **General.** Biological treatment processes are divided into two general classifications: suspended growth processes and attached film processes. A third classification especially for

satellite treatment facilities, involves a combination of one of the two processes with a physical process such as filtering.

Suspended growth processes use the concentrated microorganism population suspended in the wastewater via mechanical mixing or injection of compressed air. Carbonaceous removal, nitrification, and denitrification are accomplished in one or more tank compartments during the process, and the microorganisms are settled from the wastewater to be reused in the process or are removed for disposal. Typical suspended growth processes for satellite treatment facilities include general processes such as sequencing batch reactors or activated sludge processes.

Fixed film processes utilize a concentrated microbial population that adheres to a supporting media. The wastewater is circulated through tank compartments that contain the microorganism-coated media. At the end of the process, the wastewater is typically settled or filtered to remove any microorganisms that have sloughed from the media. Typical fixed film processes for satellite treatment facilities include rotating biological contactors, recirculating sand filters, and I/A systems such as Bioclere, Amphidrome, and FAST systems.

The advantages and disadvantages for the various systems and processes were discussed either previously in this chapter or in Chapter 3. The same advantages and disadvantages discussed in those sections would also apply here.

2. **Additional processes.** A denitrification filter, such as NITREX, can be added to any of these systems to achieve additional denitrification of a nitrified effluent.

D. **Residual Treatment and Disposal for Satellite Treatment Facilities.** Satellite wastewater treatment facilities typically do not have sludge treatment or processing facilities. Liquid sludge is usually transported off site for treatment and disposal at a larger facility. The Hyannis WPCF would be the probable destination for the sludge produced by a new small wastewater treatment facility, or the sludge could be shipped directly to a regional disposal facility such as the Upper Blackstone Water Pollution Control Facility. A small quantity of screenings could be produced at a small wastewater treatment facility, and these screenings would be expected to be disposed of as a special waste in a regional landfill.

E. **Sizing and Land Area Considerations for Satellite Treatment Facilities.** The land area required for a satellite wastewater treatment facility is determined by three primary factors:

1. Land area needed for process equipment and operations building.
2. Land area needed for treated water recharge facilities, such as sand infiltration beds or leaching beds.
3. The necessary buffer area to visually screen the facility from neighboring properties.

The land area of the process equipment and operations buildings is approximately the same for the different biological nitrogen removal processes identified. The RBC process may require slightly more area and the SBR process may require slightly less area, but these incremental increases are small when compared to the land area requirements for treated water recharge facilities and buffer area. Treated water recharge area requirements are based on the use of sand infiltration beds that require the least space and are the easiest to maintain. As previously mentioned, subsurface leaching beds have a larger area requirement, but may have an advantage if they can be located under a parking area or other open space that has a multiple use. The buffer areas required for a particular small wastewater treatment facility will depend on the site selected and the neighboring properties. The buffer areas estimated are based on a separation distance of 100 feet between the property boundary and the process facilities. This separation distance is greater than the distances required by MassDEP's guidelines, but would allow space for a driveway access and sufficient planting to provide a visual screen from adjoining properties. Even greater space is often needed to gain approval from neighboring residential properties.

Typical land area requirements for small wastewater treatment facilities to treat wastewater flows of 10,000, 35,000, and 110,000 gpd (typical flows that might be expected for cluster systems in the planning area) are 1.8, 2.8, and 3.7 acres, respectively. Diagrams indicating a typical plan view of wastewater treatment systems for these flows are included as Figures 4-26, 4-27, and 4-28, respectively. Pertinent examples of satellite and small WWTFs are presented in the following paragraphs.

As discussed earlier in this chapter, the Town owns and operates the Marstons Mills WWTF which is a satellite wastewater treatment facility serving the West Villages Elementary School, the Horace Mann Charter School, and a neighboring residential area called the Village at

Marstons Mills. This satellite wastewater treatment system and the space it requires is illustrated in Figure 4-2.

The Town of Falmouth recently completed a satellite wastewater treatment system for the New Silver Beach area of North Falmouth that has the following characteristics and sizes:

- 60,000 gpd maximum-day capacity.
- Serves approximately 220 homes and the North Falmouth Elementary School.
- A treatment facility building with a SBR treatment system (0.15 acres) on a fenced site with buffer area and parking (1.2 acres).
- Subsurface leaching facilities under a new soccer field at the elementary school. The leaching facilities are approximately 1.2 acres in size.
- This facility was designed for BNR treatment requirements and should produce treated water at 5 to 7 mg/L on average.

This satellite facility is illustrated on Figure 4-29.

There are two privately owned WWTFs in Barnstable as discussed in the Draft Needs Assessment Report. They are both sized for approximately 20,000 gpd and they serve the Cotuit Landings Stop & Shop WWTF that is typical of a small private WWTF. It uses MBR treatment technology and performs well at nitrogen removal to meet the discharge limit of 10 mg/L total nitrogen and an average performance of 5 to 7 mg/L total nitrogen. Most of the tankage is underground to minimize building costs and space. Leaching fields are located under the parking lot. This type of compact installation makes operation and maintenance more difficult than a more conventional municipal Satellite WWTF such as the Marstons Mills WWTF or the New Silver Beach WWTF.

F. **Evaluation of Satellite Wastewater Treatment Facilities for Use in Barnstable.** Satellite wastewater treatment systems incorporating RBCs, SBRs, Amphidrome, MBRs, FAST, MBR, Nitrex and Bioclere treatment components provide a variety of treatment alternatives with good levels of wastewater nitrogen removal. These systems allow for operator control and flexibility, typically take up a small area for the treatment process (not including the treated water recharge area), and can handle a range of flows.

On the other hand, they typically are not designed to treat to the Enhanced Nitrogen Removal (ENR) standards of 3 mg/L total nitrogen on average because they are not of a size to make this level of treatment attainable at a feasible cost. As a result, they typically discharge approximately two times the nitrogen (6 mg/L versus 3 mg/L on average) as a larger ENR facility. Satellite treatment facilities will need to be carefully sited to minimize impacts to neighboring properties and to the receiving waters where they recharge.

4.10 IDENTIFICATION OF WASTEWATER TREATMENT SITES

Satellite treatment systems receive wastewater flow from many properties and would need to be sited in the neighborhoods and/or regions of the town that they serve. They may recharge the treated water at the same site where they are located or they could pump the treated water to a remote infiltration site.

Available sites in Barnstable were reviewed to initiate the identification of satellite treatment sites as well as potential treated water recharge sites. This review process and the sites identified is summarized in Chapter 5 with the treated water recharge sites identified.

4.11 ALTERNATIVES FOR TREATMENT SYSTEM EXPANSION AND UPGRADE AT THE HYANNIS WPCF.

A. **Introduction.** The Hyannis WPCF currently treats approximately 1.94 mgd on a maximum month basis, and is designed for a maximum month flow of 4.2 mgd. The existing capacity and condition of the Hyannis WPCF was evaluated in detail in the Draft Needs Assessment Report. The evaluation found that the Hyannis WPCF has recently been upgraded and expanded to the 4.2 mgd capacity, and it is performing well, meeting its discharge limit of 10 mg/L total nitrogen and producing average nitrogen concentrations of 5 mg/L. The Hyannis WPCF is illustrated in Figure 4-1.

The capacity of a WWTF is determined by the smallest capacity of its component treatment processes. The aeration tanks have the smallest capacity at 4.2 mgd followed by the secondary clarifiers at 4.4 mgd (maximum month) capacity. The other unit processes have greater capacity that would become limiting at approximately 6 mgd. From Figure 4-1 it is seen that there is space for an additional aeration tank to the north west of the three existing aeration tanks (called

MLE Aeration Treatment Tanks on Figure 4-1), but there is no additional space for a new secondary clarifier near the other secondary clarifiers. Any increase in capacity will require a TOC removal process as part of the upgrade; therefore, any strategy for increasing the plant capacity that also contributes to or lends itself to TOC removal is seen as advantageous.

The following paragraphs summarize an evaluation of alternatives for treatment system expansion and upgrade at the Hyannis WPCF. Figure 4-31 illustrates potential areas for new facilities within the existing treatment footprint and outside the existing treatment footprint at the existing sand beds.

B. **Alternatives to Increase Capacity – Existing Footprint.** Several alternatives exist to increase the plant capacity without expanding the existing nitrogen removal process footprint into the current sand bed area. These options may require new tankage, buildings, or structures, but the area required can be limited to the available open space of the existing plant footprint. TOC removal processes will require additional space that cannot be fit into the existing plant footprint and are considered separately.

1. **Nitrogen Removal Expansion Options for BNR.** There are several options to increase the existing plant capacity and treat to BNR levels without expanding outside the existing plant footprint.

a. **Add an Additional Aeration Tank.** The most obvious upgrade to expand capacity on the existing site is the construction of one additional aeration tank, (No. 4) identical in size to tanks 1-3 currently on the site. This tank would be located to the north of the current tank number 3 and incorporate the same Modified Ludzack-Ettinger (MLE) process that is currently utilized at the facility. The current site is configured for such an addition, with pipe stubs and distribution box space allocated for its construction. As such, this option is likely to have the least impact on the existing facility such as retrofits of existing structures. One additional aeration tank would increase the capacity to 5.6 mgd on a maximum month basis. The operation of this tank would be identical to the current operations. The additional aeration tank would not provide capacity above 5.6 mgd, and would not allow provisions for enhanced nutrient removal. Because this process is simply a continuation of existing treatment, it does not address TOC removal needs.

The addition of Aeration Tank No. 4 has the following advantages:

- Site already configured for fourth tank
- Same operation as current facility
- No retrofitting of existing structures

It has the following disadvantages:

- Cannot provide capacity above 5.6 mgd without expansion outside the current footprint
- Does not address TOC removal
- Does not address clarifier capacity

2. **Add Membrane Bioreactor Technology.** The facility could install membrane bioreactor (MBR) technology in the existing tankage to increase capacity. MBRs (detailed in previous text) can increase the capacity of existing tankage by increasing the mixed liquor suspended solids concentration. A further benefit, given the existing plant setup, is that MBRs do not require final settling tanks, so the existing secondary clarifiers could be converted to secondary/advanced treatment tankage, further increasing capacity. The capacity of the facility would be expanded both because of the increased MLSS concentration, and by utilizing additional process tankage. Also, with the addition of the MBR, the overall treatment process could be reconfigured for methanol addition to treat to lower nitrogen levels. Also, MBRs are often used as a pretreatment step for many TOC removal processes.

However, MBRs tend to be costly both to install and to maintain. They are also more complicated to operate and often require substantial instrumentation to function efficiently. MBRs require chemicals (some of which are not currently used on site) to be included in the treatment process to clean the membrane filters. An additional building would have to be built to house new process equipment associated with the MBRs.

The addition of MBRs in the existing tankage has the following advantages:

- Could significantly increase capacity

- Can treat to lower nitrogen levels in same footprint
- Can be utilized as part of a TOC removal process

It has the following disadvantages:

- Relatively high costs – capital and O&M
- Relatively more complex mechanical operation and instrumentation maintenance
- Will require new building to house new equipment
- Additional chemical usage

C. **Add BioMag® System Technology.** The BioMag® system is an emerging proprietary technology that operates on some of the same principles as an MBR. Historically, the limiting factor on treatment capacity has been final clarifiers and the ability of the solids to settle in the clarification step. BioMag® circumvents this problem by introducing magnetite into the biological process. The magnetite powder (which has a high specific gravity) binds up with biological growth in the clarifiers, significantly decreasing the settling time. The magnetite is then recovered from the sludge before being reintroduced to the aeration system. Because the solids settle so readily, the solids concentration can be increased substantially within the aeration tanks. Similar to the MBR concept, an elevated MLSS concentration will provide additional treatment capacity in the same footprint. BioMag® pilot studies have demonstrated that the process is able to double the capacity of the existing clarifiers. Therefore, at a given flow, the MLSS concentration can be doubled so that the plant can accept two times the flow. While there are no installations that use BioMag® as part of a TOC removal process, it is possible that it could be utilized in this regard similar to MBRs. A BioMag® process diagram is included as Figure 4-32.

The operation of the BioMag® system would be simple as compared to MBRs, though it does require additional processes compared to present operations. As with an MBR, a building would have to be constructed to house some of the new equipment. Initial studies have shown that BioMag is less costly than MBRs at a given location, though the large scale facilities with long-term operational histories do not exist. The BioMag® system relies on a commodity (magnetite) which is relatively inexpensive but does have to be handled and delivered periodically. Similar to the alternative for the addition of MBR technology, the addition of BioMag® technology could include process reconfiguration to include methanol addition to treat to lower nitrogen levels.

The addition of the BioMag® technology has the following advantages:

- Could significantly increase capacity
- Can treat to lower nitrogen levels in same footprint with the addition of methanol
- Studies show lower cost than MBR
- Can likely be utilized as part of TOC removal process

It has the following disadvantages:

- Will require new building to house new equipment
- Relatively new technology, therefore there are few full-scale installations
- Relies on the delivery and usage of magnetite
- Proprietary technology

D. **Add IFAS® Technology.** Integrated Fixed Film Activated Sludge (IFAS®) technology was reviewed earlier in the chapter and utilizes an attached growth process in conjunction with activated sludge. A media (plastic, rope, sponge, etc.) would be placed in the existing aeration tanks to increase the effective MLSS and tank capacity similar to MBR and BioMag® technology. This process would not require a new process building. While it does increase the treatment capacity of the aeration tanks, IFAS® does not improve clarifier capacity, so any increase in capacity is limited to the current secondary clarifier capacity. As was the case for the additional aeration tank, IFAS® would not contribute to a TOC removal process.

The addition of the IFAS® technology would have the following advantages:

- Could significantly increase capapcity
- Similar to current operations
- Would not require new buildings for equipment

It has the following disadvantages:

- Does not address clarifier capacity
- Does not contribute to TOC removal

Table 4-5 summarizes the advantages and disadvantages of the four alternatives noted. Based on the criteria listed, construction of MBRs or conversion to BioMag® appear the most feasible. The other options do not contribute in any way to TOC removal, and would require the construction of additional clarifiers which would require expansion outside the existing treatment footprint, as evaluated below. If the existing footprint is to be maintained, MBRs or BioMag® should be evaluated in greater detail. When these are configured for BNR, these alternatives are referred to as B1 (BNR with MBR) and B2 (BNR with BioMag®).

1. **ENR Processes.** Each of the options presented for BNR above could be configured for ENR by constructing additional process tankage with methanol addition as an anoxic selector following the existing treatment train. However, with space limited, the same issues arise, and MBRs and BioMag® appear the most advantageous. In order to utilize these two processes in ENR configuration, one of the clarifiers or a portion of the aeration tanks would have to be dedicated as an anoxic zone, with methanol addition to facilitate additional denitrification. These alternatives are referred as E1 (ENR with MBR) and E2 (ENR with BioMag®).

E. **Alternatives to Increase Capacity Outside the Existing Treatment Footprint.** In addition to the alternatives to increase plant capacity inside the existing treatment footprint listed above, there is the ability to expand capacity outside the existing footprint. The most obvious location for such an expansion would be to utilize the area west of the existing septage building, currently used as effluent sand beds.

In theory, any nitrogen removal secondary treatment processes described earlier in the chapter could be utilized as part of a plant upgrade. However, we have selected treatment alternatives that maintain the current gravity flow-through (i.e. not batch), single sludge operations of the existing system. These options are selected to maintain one treatment protocol throughout the facility to avoid the undue burden of widely divergent treatment protocols across different portions of the same site. Further, we have selected treatment options that contribute to or are easily used with a TOC removal step that will need to be included with a facility expansion. And with space no longer being a limiting factor we have screened out IFAS® or BioMag® technology which are typically only used at constrained sites. Figure 4-31 illustrates the current sand bed area that could be utilized for process tankage and TOC removal equipment.

1. **BNR Processes.** Based on the criteria outlined above, there are two BNR expansions that appear feasible. Each of these options must be able to treat to BNR nitrogen levels and prepare the waste stream for further treatment in the TOC removal process.

    a. **MLE and Clarifier(s).** This option would copy the current setup of the facility and reproduce the necessary MLE-configured aeration tank(s) and clarifier(s) to facilitate expansion of the facility. With additional space available, the size of the two processes can be customized as needed to meet the sizing needs. Some form of pumping and return will be required to allow the flow to be split and then returned for disinfection and pumping to recharge effluent. This alternative is referred to as B3.

    b. **MBR.** New membrane bioreactor tanks could be configured for BNR. The process tankage could be sized as needed for the plant upgrade. Similar to Alternative B3, some form of pumping and return will be required to allow the flow to be split and then returned for disinfection and pumping to recharge effluent. This alternative will be referred to as B4.

2. **ENR Processes.** ENR processes offer a bit more flexibility, as these options lend themselves better to TOC removal.

    a. **MLE, Clarifier, Dentrifying Filters.** This alternative would consist of an MLE tank, clarifier, and denitrifying filter to treat to ENR standards. The denitrifying filters contribute to TOC removal by lowering the solids concentration in addition to producing improved effluent nitrogen levels. This alternative will be referred to as E3.

    b. **Bardenpho, Clarifier, Tertiary Filters.** This alternative is identical to the one above, but treats to lower nitrogen levels in the main process. The tertiary filters provide suspended solids removal for additional nitrogen removal and as a pretreatment step for TOC removal. This alternative will be referred to as E4.

c. **MBR, with Bardenpho Configuration.** This alternative would mimic the BNR option, but with a Bardenpho configuration to attain ENR standards. This alternative is referred to as E5.

3. **Consideration for TOC Removal.** As was the case for the plant expansion options within the existing treatment footprint, some of the alternatives for expansion into the sand bed areas would contribute to the TOC removal options. For example, MBR treatment avoids membrane treatment as a pretreatment requirement for reverse osmosis. Thus if RO is utilized, an MBR process upstream would reduce costs. Treatment processes that utilize only a sand filter or clarification would need membrane treatment preceding an RO process.

4. **Alternative Summary.** The various alternatives are summarized in Table 4-6. Each of these alternatives should be evaluated in more detail to determine the technical feasibility given the site conditions, and the relative cost of each.