EVALUATION OF RAPID INFILTRATION BASIN SYSTEMS (RIBS) FOR WASTEWATER DISPOSAL: PHASE I

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ILLUSTRATIONS

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Acronyms used in this report

AS	Activated Sludge
BC	Beaver Creek
BCF	Breeder's Crown Farm
BOD	Biochemical Oxygen Demand
CE	Colonial Estates
CH	Cape Henlopen State Park
COD	Chemical Oxygen Demand
col/100 ml	Colonies per 100 Milliliters
DE	Delaware
DGS	Delaware Geological Survey
DNREC	Delaware Department of Natural Resources and Environmental Control
EA	Extended Aeration
FG	Forest Grove
GWRM	Ground Water Recharge Mapping
IT	Imhoff Tank
LBWD	Land Based Wastewater Disposal
LSA	Landis Sewerage Authority
MA	Massachusetts
MD	Maryland
µg/L	Micrograms per Liter
mg/L	Milligrams per Liter
N	Nitrogen
NC	North Carolina
NH4	Ammonia
NJ	New Jersey
NO3	Nitrate
O&M	Operation and maintenance
OD	Oxidation Ditch
OP	Ortho-Phosphorus
P	Phosphorus
RBC	Rotating Biological Contactor
RIBS	Rapid Infiltration Basin Systems
SBR	Sequencing Batch Reactor
SMWW	Standard Methods for Examination of Water and Wastewater
SWA	Southwood Acres
SC	Stonewater Creek
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	U.S. Environmental Protection Agency
WBP	West Bay Park
WTP	Winslow Township
WWTP	Wastewater Treatment Plant

INTRODUCTION

This technical report documents an evaluation of rapid infiltration basin systems (RIBS) in Delaware. The report contains review and comparison of regulations regarding RIBS in Delaware, Florida, and states in the northeastern U.S. region. Influent and effluent samples were collected from ten advanced wastewater treatment systems that operate in conjunction with RIBS. A performance evaluation of the treatment plants utilized by these systems was completed through analytical testing of the collected samples. Effluent data were obtained from the Non-Hazardous Waste Sites database provided by the Delaware Department of Natural Resources and Environmental Control (DNREC). Effluent data from other states were provided by the respective governing state environmental agencies. Performance evaluations of the treatment processes that discharge to RIBS were ascertained by examining the occurrence of exceedences of concentrations of regulated pollutants in effluent samples.

Purpose and Scope

Southern New Castle, Kent, and Sussex Counties are undergoing rapid urban development. An increasing number of communities in these areas are implementing community-wide land-based disposal systems for treated wastewater. Land based wastewater disposal (LBWD) is the controlled application of treated effluent to soil to achieve treatment of constituents. When operated properly, disposal of treated effluent by RIBS may be advantageous in many aspects. RIBS may recharge the ground-water, provide further treatment to the treated effluent, and reduce degradation of stream-water quality.

The population of Southern Delaware is projected to increase 20% by 2020 (Delaware Population Consortium, 2006). This increase in population is accompanied by a rise in proposed residential subdivisions (Delaware Population Consortium, 2006). The costs of constructing new or upgrading existing public wastewater treatment facilities can be daunting, especially for states where budgets are limited. As a result, many states, including Delaware, are more receptive to privately funded and operated LBWD systems.

In Delaware, many streams are subject to the EPA's Total Maximum Daily Load (TMDL) restrictions which set a limit on the amount of a pollutant that can be discharged into a water body without compromising water quality. With the combination of TMDL restrictions and budget concerns, many planned subdivisions have proposed RIBS for wastewater disposal. In January 2006, DNREC initiated new guidelines for design and operation of large LBWD systems which included RIBS. Although RIBS have been used for waste water disposal and ground water recharge for the last twenty-five years in arid areas it is a relatively uncommon method for wide use in Delaware. Therefore, the performance of RIBS and potential impacts of RIBS on the receiving environment are generally unknown for Delaware.

One of the benefits of RIBS is that they will recharge ground water. However, because RIBS operate at higher loading rates compared to spray irrigation and other LBWD systems, RIBS also pose risks for altering ground-water flow patterns and causing large volumes of ground water to become contaminated. This can especially be true in instances where a site has characteristics that are inappropriate for RIBS or the pre-treatment of the wastewater are inadequate.

Contamination of ground water is a major concern in Delaware as ground water is the most important natural source of fresh water for the state, with thirteen major aquifers providing more than 100 million gallons of water everyday (Wheeler, 2003). Almost all of the fresh water used south of the Chesapeake and Delaware Canal is obtained from ground water (Talley, 1985). Ground water is also the source of about 70% of fresh water stream flow (Johnston, 1976). Concerns for ground-water contamination have developed as decades of inadequate agricultural and wastewater disposal practices have led to serious eutrophication problems in surface water and nitrate contamination in ground water. Four decades of studies have reported that nitrate is a major ground-water contaminant in Delaware as a result of decades of agricultural and wastewater disposal activities (Miller, 1972; Robertson, 1977; Talley, 1985; Ritter and Chirnside, 1984; Andres, 1991, Hamilton et al., 1993; Denver et al., 2004). More than 90% of the water bodies in DE are polluted mostly with pathogens and nutrients which originate from non-point sources and are extremely difficult to control (Denver et al., 2004; USEPA, January 2002).

The type of concern for ground-water contamination varies by location. For example, three hydraulically connected aquifers, the Mt. Laurel, Rancocas, and Columbia aquifers, are major sources of water for domestic and public wells in Southern New Castle County. As a result ground-water contamination caused by land application of wastewater might adversely impact nearby domestic or public wells in one or more of these aquifers. In the Inland Bays region of Delaware, because of the connection of ground and surface waters, contamination of ground water will eventually impact streams.

This project aims to evaluate the risks and benefits of RIBS for Delaware in two main parts. Completed Phase-I was planned to perform a thorough literature search on RIBS and to evaluate the performances of existing RIBS and wastewater treatment plants in conjunction to them.

The objectives of Phase-I were as follows:

1. Evaluate the siting criteria and performance of RIBS in the northeastern United States (including Delaware) and wastewater treatment systems that may be used in conjunction with RIBS.

2. Review and compare existing DNREC permitted RIBS and associated wastewater treatment systems with different treatment processes and their effluent data.

3. Review and compare operation and maintenance procedures used for other RIBS in the Mid-Atlantic States and identify key elements of operation and maintenance protocols for RIBS in Delaware.

4. Evaluate the performance of existing wastewater treatment systems in Delaware that may be used with RIBS.

5. Evaluate existing and planned RIBS sites for future field study.

Completion of these objectives was essential to address some of the questions regarding the siting, compliance and pre-treatment requirements for RIBS. This work will also provide a strong foundation for the second phase of the project during which physical and biogeochemical effects of RIBS on the receiving environment - aquifer, streams, nearby wells, and surface waters - will be investigated.

One of the main goals of the first phase of the project is to provide appropriate scientific information to DNREC to improve existing guidelines and regulations for on-site wastewater treatment and disposal systems. This is to be accomplished by evaluating the current practices for RIBS design, operation and maintenance and environmental compliance monitoring in Delaware and comparing them with those of nearby states. Recommendations will be provided to DNREC for permitting/monitoring of RIBS, ground water and wastewater facilities discharging to the RIBS.

Previous Assessments

For hundreds of years, it has been common practice for people to dispose of their wastewaters directly into surface waters, although land application of wastewater is a long standing practice for many communities (William and Belford, 1979; Bastian, 2005; Williams, 2006; Reed et al., 1984). However, with increasing environmental awareness, local governments are required not only to treat their wastewaters, but also to find efficient and beneficial disposal options for wastewater.

Land Based Wastewater Disposal

In their most basic form, current LBWD practices are basically the controlled application of wastewater to soil to achieve further treatment. As one of the land application methods, RIBS is a land treatment system that resembles intermittent sand filtration. It is also known as soil-aquifer treatment since pre-treated wastewater that is applied to the basins is further treated by physical, chemical, and biological mechanisms as it percolates through the soil and reaches to the ground water (Crites and Tchobanoglous, 1998). Some of the benefits of RIBS are listed below:

- Direct discharge of wastewater effluent to the surface waters is eliminated
- Wastewater effluent is potentially further treated through filtration, adsorption and biological degradation.
- Ground water can be replenished through the discharge of reclaimed water to the RIBS.
- The process is not constrained by seasonal changes.
- Economically more feasible since they do not require much land

Being one of the oldest, simplest ground-water recharge methods, RIBS have been used in the United States, especially in relatively arid, fast-developing, water-short west and southwest areas where water reuse and ground-water recharge are vital. Some of these systems are shown in Table 1. Major wastewater constituents can effectively be removed by the rapid infiltration process. Organic pollutants, solids and suspended solids are mostly removed initially by filtration and later by microbial biodegradation. Adsorption of remaining organic compounds takes place in the soil; therefore loading rate is a very important parameter to be able to prevent clogging the basin with excessive organic material and solids (Matsumoto and California Water Resources Center, 2004).

Table 1. Selected RIBS in the United States

Location	**Hydraulic Loading Rate, ft/yr**
Brookings, South Carolina	40
Calumet, Michigan	115
Darlington, South Carolina	92
Fresno, California	44
Hollister, California	50
Lake George, New York	190
Orange County, Florida	390
Tucson, Arizona	331
West Yellowstone, Montana	550

(Crites, Middlebrooks and Reed, 2006; Asano et al., 2006)

With the increase in environmental consciousness and knowledge, monitoring land application sites to prevent any contamination of ground water has been receiving more attention from government agencies, research institutes and the public. The long term impacts of RIBS on receiving environments in different regions of the United States have been studied by many researchers (Sumner and Bradner, 1996; Aulenbach and Clesceri, 1980; Quanrud et al., 2003).

The most common contaminants from RIBS that might reach to the surface or ground-water sources are nutrients (nitrogen, phosphorus), solids, pathogens and organic compounds. Nitrogen and phosphorus can be present in soil and wastewater in many forms depending on the redox potential of the environment. Most of the nitrogen species in the water resources can have adverse effects on living organisms (Stumm and Morgan, 1996). Nitrogen in water is commonly found as nitrate (NO_3), which is the most oxidized form of nitrogen. High nitrate concentrations in drinking water were found strongly associated with a serious and potentially fatal condition commonly referred to as “blue baby” syndrome since it particularly affects infants (Knobeloch et al., 2000; Masters, 1998). The Safe Drinking Water Act limits nitrate-N concentration to 10 mg/L for public water supplies (USEPA, June 2003). However while this federal regulation ensures the safety of public water sources, it does not apply to private wells. Thus a site specific, systematic and detailed research on potential effects of RIBS on the receiving environment is crucial.

RIBS can provide effective natural nitrogen reduction in treated wastewater through a series of chemical and biological reactions. Removal of nitrogen strongly depends on environmental conditions such as oxygen availability and temperature. Higher nitrogen removal rates are usually achieved when ammonia in influent wastewater is fully oxidized to nitrate. Particle size, mineral content, adsorption capacity and biological activity of the soil, treatment processes used to treat the wastewater and operation strategies all play important roles in nitrogen removal (Matsumoto and California Water Resources Center, 2004; Sumner and Bradner, 1996). Since these parameters differ from site to site, so do the removal efficiencies. For instance while the total nitrogen removal rate for RIBS in Colton, California can go up to 78%, it is around 50% for Reedy Creek RIBS in Orange County, Florida. The importance of operation strategies in nitrogen removal was reported by Bouwer (1974), who measured almost no nitrogen removal when short and frequent flooding periods (2 days flooding, 5-10 days drying) were used; however nitrogen removal went up to 30% with longer flooding periods (10 days flooding, 2 weeks drying). Although optimum schedules should be developed for individual RIB systems, soil profiles generally become mostly aerobic with a short and frequent flooding schedule, which then limits nitrate to nitrogen conversion. Similarly, no nitrogen will be removed if the flooding periods are extremely long since the lack of oxygen will prevent nitrate formation.

One of the well studied land application sites is in Cape Cod, Massachusetts. Disposal of secondarily treated wastewater for more than 60 years into RIBS created a contaminated ground water plume 6000 m long, 30 m thick and more than 1000 m wide (Repert et al., 2006). Dissolved nitrogen (mainly nitrate and ammonium), phosphorus, dissolved organic and inorganic carbon, chloride, boron, organic nitrogen and nitrite are reported as main pollutants in the effluent discharged into the RIBS. Although land application of wastewater ceased in 1995, the core of the plume remained anoxic and its size and shape have not changed for about 10 years (Repert et al., 2006; Savoie et al., 2006). The Cape Cod case shows that years of disposing treated effluent at high loading rates to a limited area may have irreversible negative impacts on ground water.

Domestic and industrial wastewaters also usually contain a variety of organic compounds including pharmaceuticals, personal care products, and widely used household and industrial chemicals (Cordy et al., 2004; Conn et al., 2006; Aufdenkampe et al., 2006). Since these chemicals (i.e., emerging contaminants) can partially be removed during treatment by existing wastewater treatment technologies, they might reach the environment through surface water discharge or land application of the effluent (Conn et al., 2006). Some of the emerging contaminants have been found to be toxic and are persistent in the environment. It was reported that antiepileptic drugs carbamazapine and primidone were detected in the ground water after eight years of ground water recharge of treated effluent (Drewes et al., 2003). Another recent research project revealed that barbiturates and sedative hypnotics used mostly during mid-1960s in veterinary medicine, have been detected in ground-water samples. Additional biotic and abiotic tests did not show any degradation either under aerobic conditions or hydrolysis, which means that once released into the aquatic environment barbiturates stay stable in the environment for decades (Peschka et al., 2006).

Delaware Permitting Practices

Currently in Delaware, RIBS are covered under “Regulations Governing the Design, Installation and Operation of Onsite Systems” (DNREC, 2004). However, very little specific information regarding design and operation of RIBS is present in the regulations. Instead, specifics are covered in “Guidelines for Preparing Preliminary Ground-Water Impact Assessments for Large On-site Wastewater Treatment and Disposal Systems” (State of Delaware, December 2005) and “Large System Siting, Design and Operation Guidelines” (DNREC, 2006). These guidelines are intended to minimize the impact of large systems such as trenches, beds, drip lines, sand mounds, and RIBS on the receiving environment (DNREC, 2006). According to the guidelines, if generated wastewater volume exceeds 20,000 gallons per day, it must be treated to meet secondary treatment standards which require total nitrogen levels of discharged effluent wastewater to not exceed 10 mg/L. Additionally, all disinfected wastewater being sent to any basin should not exceed 200 col/100 ml of fecal coliform. Monthly average Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) concentrations in the effluent should not exceed 30 mg/l each.

However, permits for some sites are written to allow DNREC and the operator some leeway in meeting guidelines. For example, total nitrogen concentration of effluent at Breeder’s Crown wastewater treatment plant shall not exceed 25 mg/L. This is due to Breeder’s Crown wastewater treatment plant was subject to the Regulations Governing the Design, Installation and Operation of Onsite Systems (DNREC, 2004). It was stated that until the existing permit expires, a site can only be subject to the regulations or guidelines that they were permitted under (Hilary Moore, DNREC, personal correspondence).

Besides effluent limits, the Delaware guidelines take site characterization, design considerations, construction, monitoring requirements, and operation and maintenance into consideration. RIBS are suggested to have minimum separation/buffer distances from sensitive receptors (Table 2). Depending on the soil structure, some sites might require excavation of the basin and replacement of natural material with engineered fill.

In the guidelines (DNREC, 2006), vegetation is not recommended for RIBS, however, any existing vegetation should be regularly maintained and grass cuttings removed from the basins. As a part of the routine maintenance, RIBS are required to be periodically scarified to remove any accumulated solids and organic materials that may clog the basin and lower the infiltration rate. Details for RIBS maintenance are given in the guidelines (DNREC, 2006).

Table 2. Buffer distances for RIBS in Delaware and other states. Note that more stringent buffer distances may be required in some states according to flow rate.

	DE	**MD**	**FL**	**NC**	**NJ**	**MA**
Ground Water	2 ft	10 ft	3 ft	4 ft	4 ft	4 ft
Surface Water	100 ft	100 ft	100 ft	200 ft	200 ft	100 ft
Property Line	50 ft	50 ft	100 ft	200 ft	100 ft	25 ft
Public Well	150 ft	100 ft	500 ft	100 ft	400 ft	400 ft
Private Well	100 ft	100 ft	500 ft	100 ft	400 ft	100 ft

(DNREC, 2006; *Pye et al.,1988;State of Maryland, 2003; State of New Jersey, 2002; Florida Department of Environmental Protection, 2005; North Carolina Department of Environment and Natural Resources Division of Water Quality, 2006; State of Massachusetts, 1984)*

Wastewater Treatment Technologies

Wastewater collected from residences, industries and institutions has to be returned to receiving waters or to be land applied or reused. However the level of treatment prior to discharge will determine the impact of effluent on receiving environments.

Wastewater contains a variety of materials ranging in size and density. Coarse particulate materials are usually removed during the treatment process. Typical domestic wastewater contains 350-1200 mg/L total solids, 100-350 mg/L total suspended solids, 280-860 mg/L total dissolved solids and 5-20 mg/L settleable solids (Crites and Tchobanoglous, 1998). Usually 60 percent of the suspended solids in municipal wastewater are settleable and can be removed during treatment (Tchobanoglous and Stensel, 2003). If the effluent is land applied, part of the remaining suspended solids are removed by filtration or entrapment. Alternating flooding-drying cycles during land application allow the removed solids to desiccate or degrade. However, in a RIBS application, dried solids need to be removed from the surface of the application area or the area should be scraped routinely to prevent clogging and hydraulic failure. Inadequate procedures for removing solids can also increase risk of ground-water contamination with certain bacteria (Tchobanoglous and Stensel, 2003).

When biodegradable organics are released into a body of water, microorganisms break them into smaller organic and inorganic molecules to meet their carbon and energy requirements. If this process takes place under aerobic conditions, the amount of oxygen consumed by microorganisms is called Biological Oxygen Demand (BOD). Highly oxygen demanding pollutants might cause environmental disasters by depleting all oxygen in the receiving environment. Therefore, BOD is the most widely used parameter to determine the level of organic pollution in wastewaters and surface waters.

Pollutants in nature can be degraded both biologically and chemically. Chemical Oxygen Demand (COD) is used to determine the amount of oxygen required to oxidize pollutants chemically. While microorganisms are used to degrade the organics in a BOD test, a strong chemical oxidizing agent, commonly potassium dichromate, is used to oxidize the organics in a COD test. However, since an inert chemical is used to degrade pollutants, a COD test does not adequately simulate an aquatic environment (Masters, 1998). As a result, BOD has always been a more important measure of the strength of organic pollution. However, in the course of this project effluent samples were analyzed for COD since chemical degradation takes place in the natural environment and some of the complex organic substances are hard to oxidize biologically but they can be oxidized chemically.

In addition to carbonaceous organics, oxygen is also required for biodegradation of noncarbonaceous matter, such as ammonia. The oxidation of ammonium to nitrate consumes at least 40% of the total oxygen requirement of an ordinary biological wastewater treatment. In biological treatment systems competition between heterotrophic bacteria and nitrifying bacteria (*Nitrosomonas, Nitrobacter*) takes place for oxygen, which is normally the limiting factor for the conversion of organic matter and ammonium. In most cases slow-growing nitrifying bacteria are out-competed by heterotrophic bacteria and they die off due to lack of oxygen. Therefore, mostly any biological treatment system without a separate nutrient removal unit is insufficient to meet the oxygen requirement of the system (Henze et al., 1997). However, it was recently reported that a better nutrient reduction also leads removal of pharmaceuticals and personal care products (Cristen, 2006). For complete nitrogen removal, nitrate has to be reduced to nitrogen gas by denitrifying bacteria (*Flavobacteria, Bacillus, Micrococcus*) under anoxic conditions. When oxygen is completely depleted by heterotrophic and nitrifying bacteria, facultative bacteria may start using nitrate as an oxygen source and produce nitrogen gas (Tchobanoglous and Stensel, 2003; Russell, 2006).

Although both nitrogen and phosphorus are essential nutrients for the growth of plants and other biological organisms, they can be harmful when present in surface water. Excess nitrogen and phosphorus could trigger a chain of reactions resulting in algal blooms, accelerated plant growth and death of certain fish and animals. Depending on the season, either nitrogen or phosphorus can be the limiting nutrient in a water body. Phosphorus may have dramatic impacts on surface waters even at very low concentrations, especially when it is the limiting nutrient in controlling eutrophication. A typical untreated domestic wastewater contains 4-15 mg/L total phosphorus (Crites and Tchobanoglous, 1998). To protect water resources, controlling phosphorus concentrations in treated effluent prior to discharge into RIBS has been a concern for land-application programs. However, Delaware currently does not have any statewide phosphorus restrictions for ground water.

During wastewater treatment, phosphorus and nitrogen removal do not occur simultaneously. Phosphorus can not be removed until the nitrate, as the preferable oxygen donor, is gone. In practice, phosphorus is removed by sequencing the wastewater into reactors where the appropriate environmental conditions are supplied. A group of bacteria use volatile fatty acids as carbon sources and they release phosphorus into the system. If the anaerobic conditions are followed by aerobic conditions, the bacteria uptake more phosphorus than they release. Finally, phosphorus is removed from the system by the removal of wastewater sludge containing phosphorus accumulating microorganisms (Crites and Tchobanoglous, 1998; Tchobanoglous and Stensel, 2003).

Biological characteristics of treated wastewater are major concerns in controlling diseases caused by human originated pathogenic organisms. Among the pathogenic organisms the ones that are more abundant and easy to test for are usually used as indicator organisms for human fecal contamination. An ideal indicator organism must be present whenever the target pathogenic organism is present (Tchobanoglous and Stensel, 2003). Since coliform bacteria are found in the human intestinal track, they have been used as indicators of contamination with pathogenic organisms associated with human feces. Another group of indicator organism is Enterococci, which are found in the intestines of humans and animals but are also important pathogens responsible for serious infections (Fraser, 2006). Although the enterococci are generally found in lower numbers than fecal coliform, they exhibit better survival in sediment, sea and estuarine waters. As a more stable group of indicators, enterococci can be successfully used in the risk assessment of such environments (Tchobanoglous and Stensel, 2003; Jin et al., 2004).

Treatment Practices Observed During This Study

During the first phase of this project, we have seen five different treatment processes that are utilized by wastewater treatment plants in conjunction with RIBS. The most commonly used in Delaware is the rotating biological reactor (RBC). First introduced in West Germany in 1960 and nearly a decade later in the US, RBCs are a type of secondary treatment process. This process involves the convergence of a biological medium and wastewater in order to remove pollutants prior to discharge. An RBC consists of a series of closely spaced circular disks that are partially submerged (40%) in a tank containing wastewater. The plastic disks are typically 3.6m in diameter and attached to a horizontal shaft that slowly rotates at about 1.0 to 1.6 revolutions per minute. As the RBC rotates, the film of microorganisms that grows on the surface area of the disks is exposed to the atmosphere providing aeration and facilitates the biological degradation of the wastewater pollutants (Masters, 1998; Tchobanoglous and Stensel, 2003).

The second type of treatment process used is activated sludge (AS). This process, whose name is derived from the fact that settled sludge containing microorganisms, is returned to the reactor to amplify biomass availability and accelerate the reactions, is a suspended-culture system that has been in use since the early 1900s. In a conventional activated sludge process, raw or settled sewage flows into a large, concrete tank along with a mixed population of microorganisms. The mixture (mixed liquor) then enters an aeration tank, where the wastewater and organisms are mixed together with a large quantity of air. Aeration provides oxygen to make biological degradation of wastes occur at a faster rate. After about 6 to 8 hours of aeration, the mixture flows into a large settling tank where the biomass slowly settles out of suspension and the settled flocculant microorganisms are removed from the effluent stream. The settled microorganisms (activated sludge) are then recycled to the head of the aeration tank to be remixed with wastewater. Because new activated sludge is continually being produced, some is removed or "wasted" from the process. The rest is recycled to the aeration tank. The effluent from a properly designed and operated activated-sludge plant is of high quality, usually having BOD and TSS concentrations of equal to or less than 10 mg/L (Crites and Tchobanoglous, 1998).

The remaining treatment processes observed are all modifications or variations of the activated sludge process. The most common of these is the sequencing batch reactor (SBR). During the late 1950's and early 60's, the improvement of new equipment and technologies led to an increased interest in SBRs in the United States. Enhanced aeration devices and computer control systems have made SBRs a practical choice over the conventional activated-sludge system. The SBR equipment is a variation of the activated sludge process, and is unique in its ability to act as an equalization basin, aeration basin and clarifier within a single reactor using a timed control sequence; whereas, a conventional activated sludge system relies on multiple tanks or basins (Al-Rekabi, Qiang and Qiang, 2007; USEPA Office of Water, 1999).

Sequence batch reactors are basically a set of tanks that operate on a fill-and-draw basis. The cycle for each tank in a typical SBR is divided into five discrete time periods: Fill, React, Settle, Draw and Idle. It begins with the Fill cycle; Wastewater enters each partially filled tank, containing biomass, which is acclimated to the wastewater constituents during preceding cycles. Once the reactor is full, it behaves like a conventional activated sludge system, but without a continuous influent or effluent flow. The aeration and mixing is discontinued after the biological reactions are complete, the biomass settles, and the treated supernatant is removed. The period between Draw and Fill is termed Idle. Despite its name, this "idle" time can be used effectively to settle sludge. (Barbato, 2006)

Like SBRs, the extended aeration process (EA) is comparable to the conventional activated sludge process except that it operates in the endogenous respiration phase of the growth curve, which requires a low organic loading and long aeration time. Similarly, oxidation ditches (OD) typically operate in an extended aeration mode with long detention and solids retention times. The oxidation process originated in the Netherlands in 1954 and there are currently more than 9,200 municipal oxidation ditch installations in the United States (USEPA, 2000). The oxidation ditch consists of a ring or oval shaped channel and is equipped with mechanical aeration devices. Screened wastewater enters the ditch, is aerated, and circulates at about 0.8 to 1.2 ft/s (0.25 to 0.35 m/s) to maintain the solids in suspension. When designed and operated for nitrogen removal, nitrification to less than 1 mg/L ammonia nitrogen is consistently achieved. The main advantage of the oxidation ditch is the ability to achieve removal performance objectives with low operational requirements and operation and maintenance costs. However, compared to other modifications of the activated sludge process, effluent suspended solids concentrations associated with oxidation ditches are relatively high. Additionally, ODs require large land area that can prove to be costly. (USEPA, 2000; Crites and Tchobanoglous, 1998)

The final type of treatment process observed in Delaware is the Imhoff Tank (IT). Patented in 1906 and first used in operation in Essen, Germany in 1908, the Imhoff Tank is one of the oldest and simplest treatment processes. It was developed to address the deficiencies of septic tanks. It prevents the remixing of removed solids while promoting the decomposition of these solids within the same tank. In addition, it provides an effluent acceptable for further treatment. Basically, an Imhoff Tank consists of a twostory tank in which sedimentation is accomplished in the upper compartment and anaerobic digestion is accomplished in the lower compartment. Imhoff tanks are still used occasionally because they are simple to operate, there is no mechanical equipment to maintain, and do not require highly skilled supervision (Crites and Tchobanoglous, 1998; Seeger, 1999).

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METHODS

Methodology of this study consists of two main parts. The first part relates to the literature search, site visits to the selected advanced wastewater treatment plants with RIBS, influent and effluent sampling, laboratory analysis, collection of effluent quality data from nearby states, data processing, and interpretation. The second part relates to the assessment of current RIBS regulations and operation/maintenance strategies.

Site Visits, Sampling, and Analysis

Permitting agencies in DE, NJ, MA, and NC provided data on the types of treatment systems currently in use, the assessments conducted regarding the reliability of those systems, and any existing information regarding effluent quality monitoring of effluent and/or well monitoring data. The DNREC NonHaz database provided data on the permitted flow, pretreatment method, effluent quality, monitoring and inspection records on existing permitted RIBS in Delaware. All operating RIBS in Delaware were visited. The selection of treatment plants in nearby states was done based on their location, capacity, and treatment and discharge (e.g., RIBS discharge) methods. A list of treatment plants visited is given in Table 3.

During site visits in Summer 2007, RIBS sites were photographed, wastewater samples were collected , and the plant operators were interviewed. Listed below are some of the questions that plant managers were asked:

- What type of treatment processes are being used in this facility?
- What is the average daily flow rate of wastewater coming to the system?
- Is the plant operating at its design capacity?
- How long has the plant been in operation?
- What is currently being done with the treated effluent?
- What type of discharge method is used?
- How often are influent and effluent samples analyzed?
- What is done with wastewater sludge? Is it hauled or is it land applied?
- How is the quality of effluent in general?
- Is the effluent disinfected prior to RIBS application?
- If RIBS are used for effluent discharge, how many RIBS are there in the site?

- How long have they been in operation?
- What is the flooding/drying and RIBS rotation schedules?
- What type of maintenance do RIBS require? (i.e. scoring, excavating, mowing, vegetation removal)
- How is the vegetation on RIBS being taken care of? How often?
- Have you ever had any operational or maintenance problems? How did you solve them?
- Are there any monitoring or observation wells at the site? How many?

Table 3. Advanced treatment plants visited in Delaware and New Jersey

Facility	Treatment Type	Effluent Sampling Method	Capacity (GPD)	Location
Beaver Creek	SBR	24hr Composite	81,600	DE/Sussex
Breeder's Crown Farm	RBC	Grab	18,600	DE/Kent
Cape Henlopen State Park	Imhoff Tanks	Grab	80,000	DE/Sussex
Colonial Estates	Activated Sludge	Grab	16,000	DE/Sussex
Heron Bay	SBR	Grab	50,000	DE/Sussex
Forest Grove	RBC	Grab	39,835	DE/Kent
Southwood Acres	RBC	Grab	51,914	DE/Kent
Stonewater Creek	SBR	24hr Composite	225,000	DE/Sussex
West Bay Park	RBC	Grab	92,520	DE/Sussex
Hammonton	Oxidation Ditch	Not Sampled	1,600,000	NJ
Landis Sewerage Authority	Activated Sludge	Grab	12,200,000	NJ
Winslow	Oxidation Ditch	Grab	2,600,000	NJ

Duplicate 500 ml samples were placed into polyethylene bottles for both influent and effluent. On-site conductivity and pH measurements were performed with portable AP50 pH/Ion/Conductivity instrument (Denver Instrument Company, Arvada, Colorado). Samples were immediately placed in ice and transported to the Water Quality Laboratory at the University of Delaware within 2-3 hours. A list of analyses that were performed at the Water Quality Laboratory is given in Table 4.

Table 4. Wastewater analysis and analytical methods

Parameter	**Method**	**Comments**
Biological oxygen demand (BOD)	SMWW[1] 5210B Winkler titration	5 day BOD
Chemical oxygen demand (COD)	SMWW 5220D	Colorimetric
Total suspended solids (TSS)	SMWW2540 B,C,D,E	Gravimetric
Total dissolved solids (TDS)	SMWW2540 B,C,D,E	Gravimetric
Total Kjeldahl nitrogen (TKN)	SMWW4500C	Acid digestion
Nitrate-Nitrogen (NO3-N)	SMWW4500 NH_4 B,C	Nitrate method
Ammonia-Nitrogen (NH4-N)	SMWW4500 NH_4 B,C	Nitrate method
Ortho-Phosphorus (OP)	SMWW 4500E	Colorimetric-ascorbic acid; Acid digestion
Dissolved Total-Phosphorus (TP)	SMWW 4500E	Filtration; Colorimetric-ascorbic acid; Acid digestion
Total Coliform	SMWW 9222D, 9230C	Membrane filtration

Source: Clesceri et al., 1998

Removal rates of nitrogen, phosphorus, biological oxygen demand (BOD), chemical oxygen demand (COD) and solids were calculated for different treatment plants in Delaware by using the analysis results of influent and effluent wastewater samples taken from these sites. Total nitrogen concentrations were calculated by adding the analysis results of Kjeldahl-nitrogen, nitrate-nitrogen and nitrite-nitrogen. Results were used to evaluate the performances of different wastewater treatment technologies that are most commonly used or proposed for use in Delaware. To assess the level of compliance with generally accepted treatment standards (Tchobanoglous and Stensel, 2003), drinking water nitrate limits (USEPA, 2003), and Delaware Large System Regulations (DNREC, 2006) exceedence frequencies were determined for a total of 49 treatment plants in DE, NJ, NC, and MA. Effluent quality data in DNREC's NonHaz Database was combined with our analysis results to be used in evaluation of exceedences. Each state's effluent data for different wastewater quality parameters including BOD, TSS, Total Nitrogen, Nitrate, and Indicator Organisms were used in the data analysis.

Comparison of State Regulations on Land Application of Wastewater

Another task of this project is to evaluate the siting criteria (depth to water table, presence or absence of restricting zones, proximity to wells and water bodies) and existing regulations or guidelines used in permitting and monitoring RIBS in Delaware and other states.

Our comparison of state programs that regulate RIBS focuses on states that have generally similar climatic and hydrogeologic conditions. States that characteristically have humid climate and aquifers hosted by unconsolidated to weakly consolidated sedimentary deposits were chosen. In addition, our survey is somewhat limited to those states with enough Internet presence to allow us to find the programs and regulations pertaining to RIBS. Despite extensive internet research, limited effluent data was obtained for the states of New York, Maryland, Pennsylvania. Subsequent correspondence and telephone conversations with officials from these states yielded little additional information concerning current regulations with regards to RIBS. It is possible that there are other states for which we have not been able to locate the programs and regulations pertaining to RIBS.

RESULTS AND DISCUSSION

State Regulatory Programs and Technical Criteria

The regulatory approaches of states fit what we refer to as a decision tree system. That is, sites are evaluated by multiple series of criteria and the result of each evaluation step determines a different set of permitting evaluation criteria and decisions. Categories of compliance requirements of other states for RIBS are summarized as follows.

- Buffer zone distances
- Effluent limits (Biological Oxygen Demand/Total Suspended Solids/Total Nitrogen/Coliform)
- Pretreatment requirements
- Distance to water table
- Monitoring well requirements
- Storage capacity
- Flow rate

All states appear to have minimum setback requirements from property boundaries, wells, depth to ground water, and water courses that will prohibit the use of RIBS (see Figures 1-6). No RIBS are allowed if these criteria can not be met. Almost all states have the prerogative to evaluate each RIBS on a case by case basis.

Flow rate appears to be used a major factor in determining the specific design and operation requirements for RIBS. For example, Delaware and New Jersey use an expected effluent flow rate of 20,000 gpd to prescribe if primary rather than secondary treatment is needed before discharge to the infiltration basins. It is following this step in the decision tree that states have the greatest differences in their regulatory requirements for the larger systems. These requirements fall into the categories of site exploration, effluent quality limitations, and effluent and ground-water monitoring.

USEPA guidance documents and several texts state that an unsaturated zone between the base of the infiltration basin and the water table is needed to allow for nitrogen removal from effluent (Crites and Tchobanoglous, 1998; Crites, Middlebrooks and Reed, 2006; USEPA, 1985; USEPA, 1999). These documents explain that biogeochemical mediated reactions in the N removal process include mineralization or nitrification of organic N (to ammonium), sorption of ammonium, nitrification of ammonium, and denitrifcation. Increasing thickness of vadose zone provides a margin of safety to guard against N contamination of ground water should effluent quality fail to meet regulations, guidelines, or permit requirements.

If the unsaturated zone is thin and the effluent contains substantial quantities of N, there is significant risk that substantial amounts of N, in the forms of organic N, ammonium, or nitrate will reach the water table. These chemical constituents will travel down gradient with ground-water flow where they will eventually discharge to a body of surface water and/or be pumped by a water supply well. To reduce this risk related USEPA documents indicate there has to be careful balancing of expected effluent quality (including inevitable treatment problems) against thickness of the vadose zone when developing rules for thickness of the vadose zone under RIBS (USEPA, 1985; USEPA, 1999). We also agree with USEPA guidance (USEPA, 2004) suggestions that expected water supply and environmental uses of the shallow aquifer have to be considered when developing vadose zone thickness requirements.

States have reacted to the USEPA guidance for determining vadose zone thickness requirements in different ways. Amongst the states with RIBS regulations that we surveyed, vadose zone thickness requirements range from as little as two feet (Delaware) to 10 feet (Maryland). In every state, the regulations do not contain explanations for how the distance requirements were determined, however, we expect that the requirements reflect a balance between need for wastewater treatment capacity to serve development, environmental protection, and expected uses of ground water.

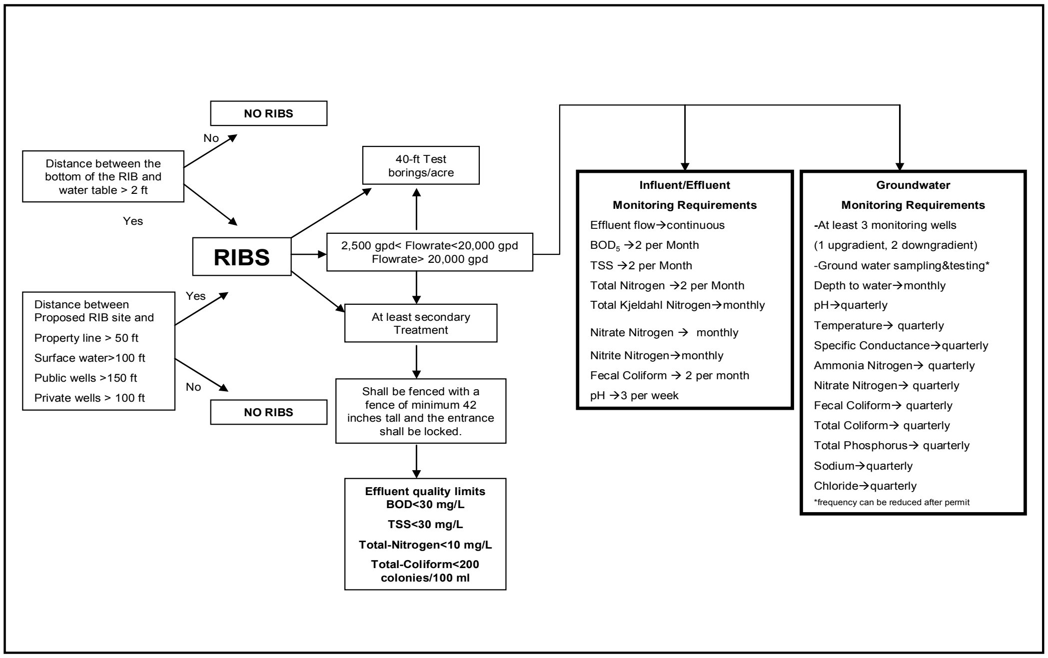


Figure 1. Regulations, major permitting criteria and monitoring requirements for RIBS in Delaware (State of Delaware, 2005; DNREC, 2006).

Currently, Delaware's "Large System Siting, Design and Operation Guidelines" require only two (2) feet separation distance between RIBS site and ground water table. It should be noted that in this report, the 2-foot separation regulation refers to the distance between the base of the infiltration bed and the mounded water table. Should effluent not meet standards, further treatment of contaminants in treated effluent by filtration and adsorption is negligible with the current two feet to ground water rule. There is significant risk of contamination to ground water in Delaware, especially in Sussex and Kent Counties where the water table is found at shallow depths.

Separation distances between RIBS and environmentally sensitive receptors such as wetlands, surface waters and potable water supply wells are listed in the Delaware guidelines (see Table 2). However, to be more protective of public and environmental health, many other states requires greater separation distances or use travel time criteria to minimize the risk of contamination to sensitive receptors. Travel-time criteria, because they are based on site-specific hydrogeologic conditions, provide a custom fit level of protection for each site. It is important to note that travel-time criteria are used in Delaware's source water protection program.

One requirement in the State of North Carolina may be appropriate for Delaware. North Carolina requires treatment plants in some areas of the state to have additional storage for wastewater should the plants have treatment upsets or malfunctions. This requirement provides an extra margin of safety in areas where ground-water contamination caused by discharge of poorly treated effluent poses significant risk of harm to sensitive receptors.

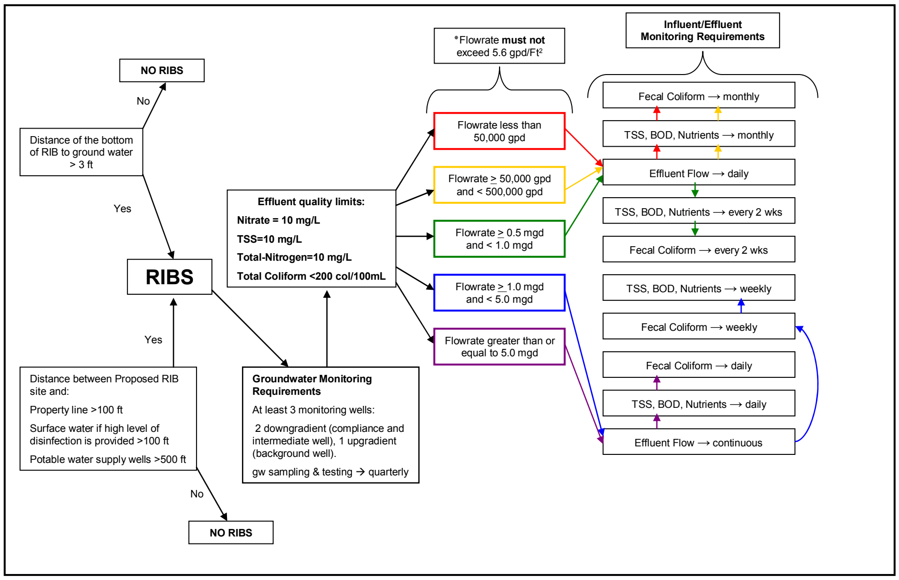


Figure 2. Regulations, major permitting criteria and monitoring requirements for RIBS in Florida (Florida Department of Environmental Protection, 2005).

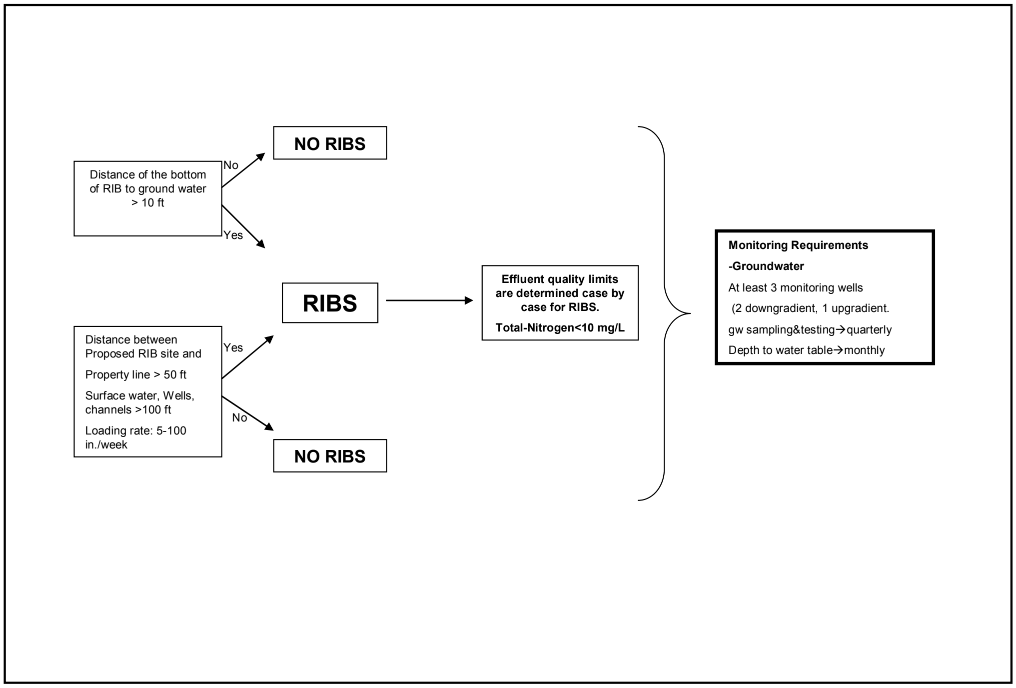


Figure 3. Regulations, major permitting criteria and monitoring requirements for RIBS in Maryland (State of Maryland, 2003).

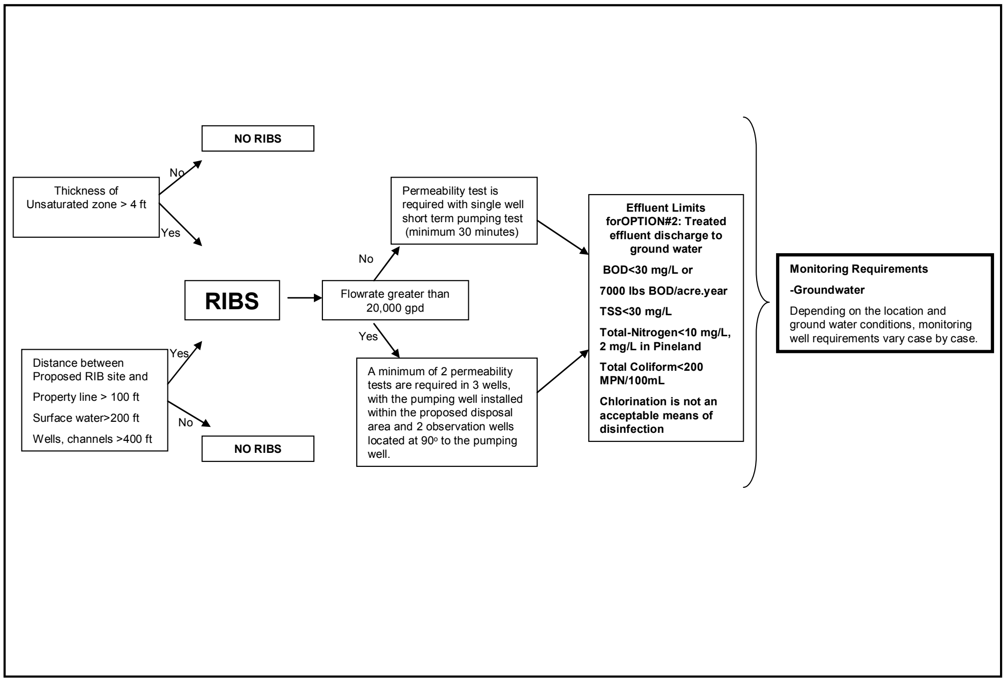


Figure 4. Regulations, major permitting criteria and monitoring requirements for RIBS in New Jersey (State of New Jersey, 2002; State of New Jersey, 2005).

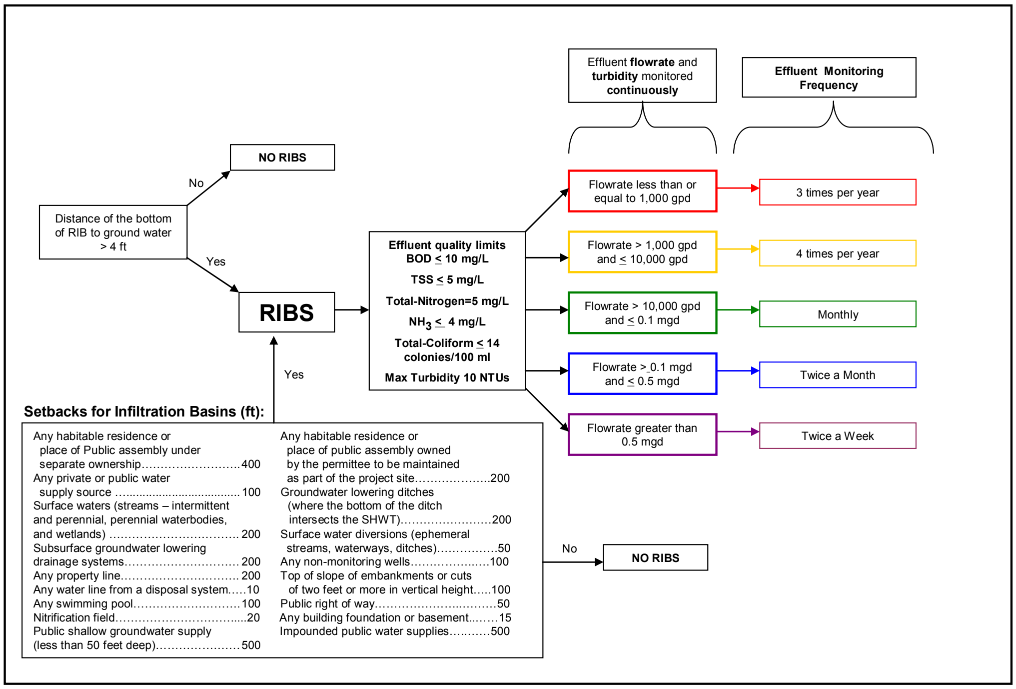
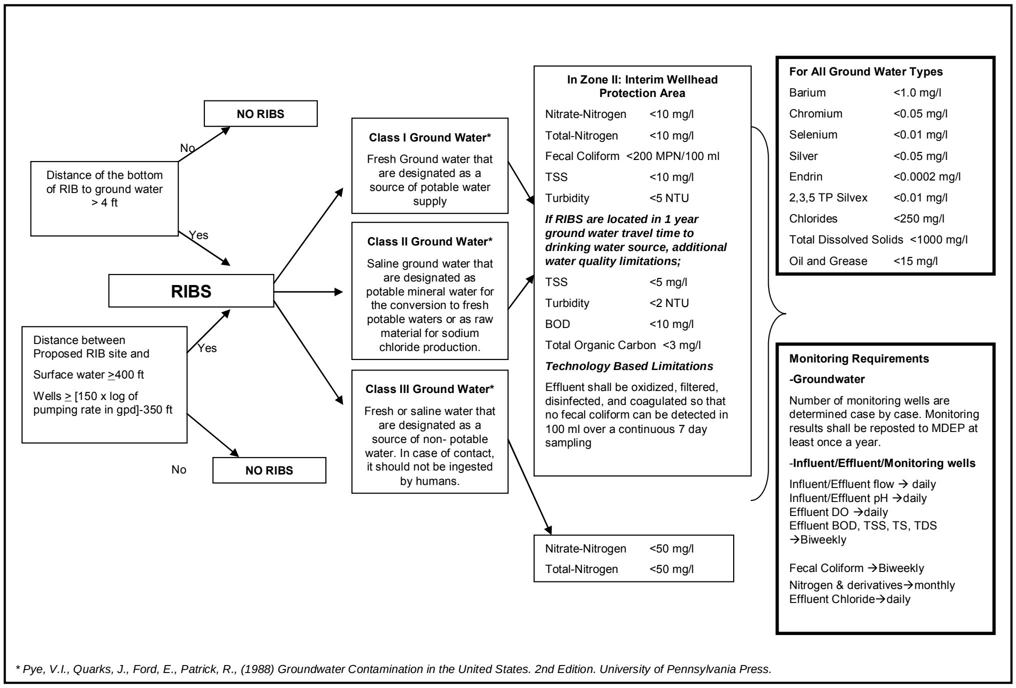


Figure 5. Regulations, major permitting criteria and monitoring requirements for RIBS in North Carolina (State of North Carolina, 2006).



** Pye, V.I., Quarks, J., Ford, E., Patrick, R., (1988) Groundwater Contamination in the United States. 2nd Edition. University of Pennsylvania Press.*

Figure 6. Regulations, major permitting criteria and monitoring requirements for RIBS in Massachusetts (State of Massachusetts, 1984).

Effluent Characterization and Treatment Plant Performance – Delaware and New Jersey

Our results show that on the date of sampling seven out of 10 treatment plants were able to remove at least 90% of the biodegradable organic load out of the influent wastewater with their existing advanced treatment processes (see Figure 7). Analysis results of the influent/effluent samples taken from LSA and WTP were also included in this section. Although three of the effluent BOD concentrations were found close to the effluent BOD limit of 30 mg/L given in Large System Siting, Design and Operation Guidelines, only one of the treatment plants did not meet requirement (DNREC, 2006). Treatment plants with activated sludge process have achieved the highest average BOD removal rates (98%). They are followed by OD, SBR, IT and RBC, respectively. Most of the treatment plants that were visited are residential, small community treatment plants which mostly receive domestic wastewater. High BOD removal efficiencies also point out that most of the pollutants in the wastewaters are easily biodegradable organic substances. Both New Jersey plants were able to reduce BOD levels below effluent BOD limit of 30 mg/L.

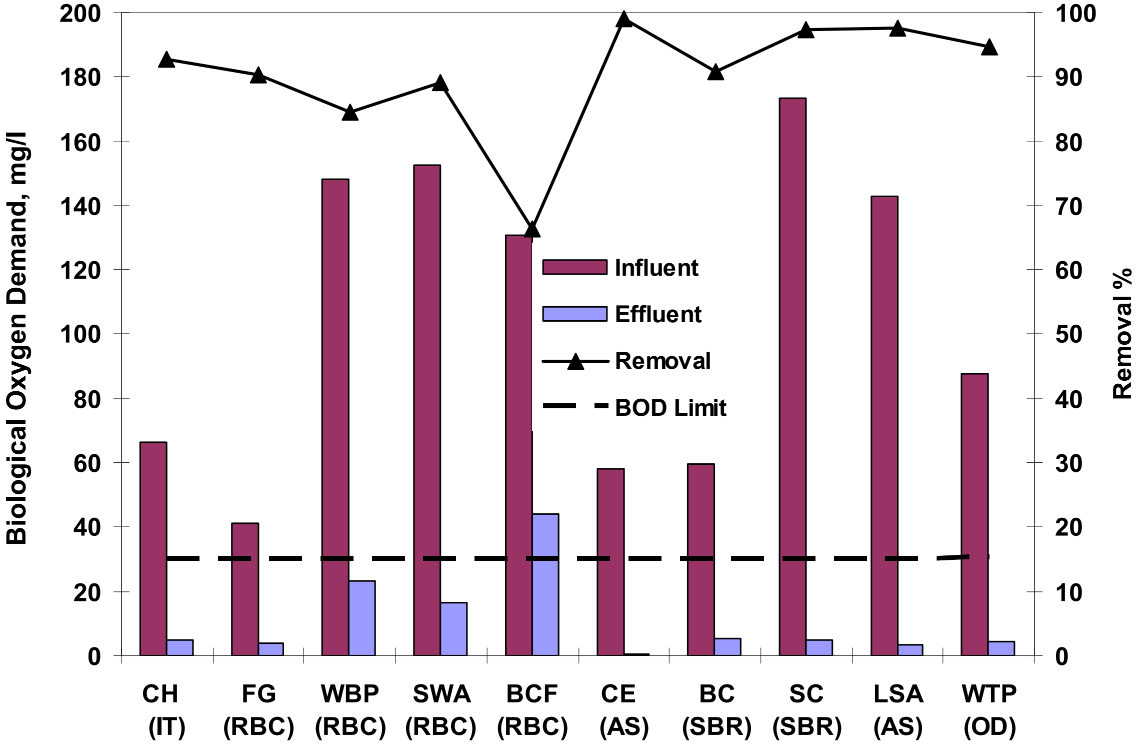


Figure 7. Concentrations of Biological Oxygen Demand in the influent and effluent samples from different wastewater treatment plants and percent removal rates.

Influent and effluent wastewater sample analysis results showed that COD removal rates (see Figure 8) are slightly lower than those for BOD. Almost complete COD removal is measured in both of the treatments plants in NJ. Although not particularly stated in the guidelines, usually 40-100 mg/L COD effluent is acceptable for land application of wastewater applications (Tchobanoglous and Stensel, 2003). Effluent COD concentrations of two of 10 treatment plants were found out of the concentration range given above. However since BOD results of these plants were well below guideline limits, it can be concluded that some of the organic matter in these wastewaters was resistant to biodegradation and could only be degraded chemically, which ultimately required more oxygen than biological degradation.

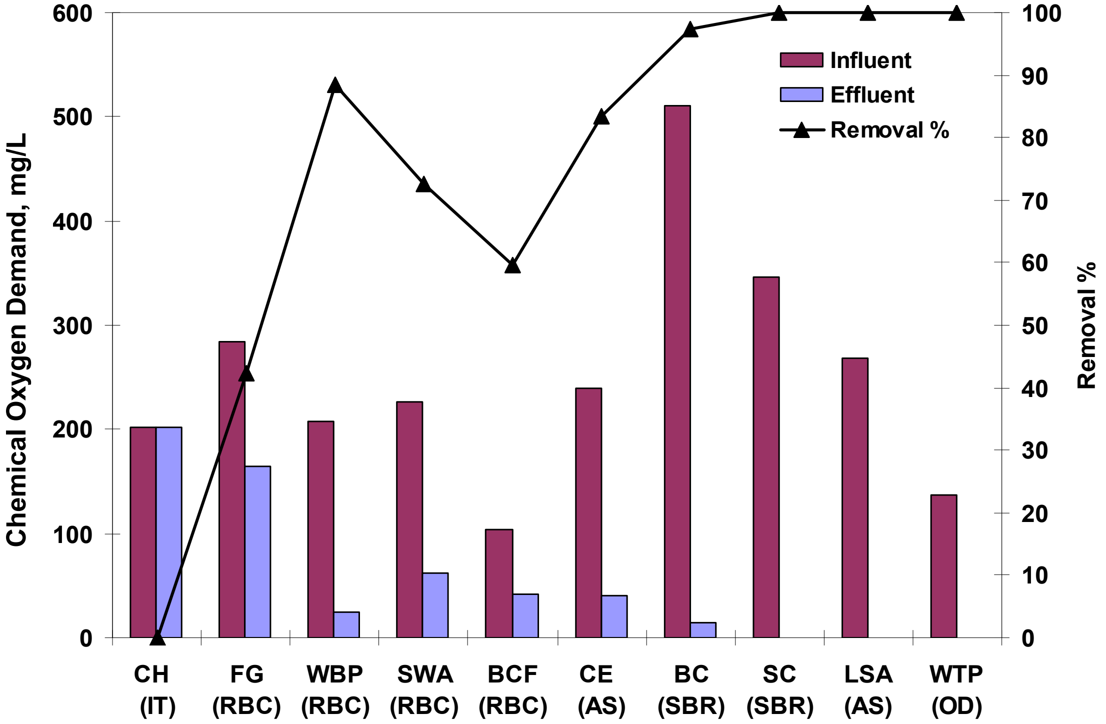


Figure 8. Concentrations of Chemical Oxygen Demand (COD) in the influent and effluent samples from different wastewater treatment plants and percent removal rates.

Only one out of 10 effluent samples was found well above the guideline TSS limit of 30 mg/L for both Delaware and New Jersey.(DNREC, 2006; State of New Jersey, 2002) (see Figure 9). The highest TSS concentration of 112 mg/L was measured in the effluent of Forest Grove Wastewater Treatment Plant. This site uses (RBC) as the main biological treatment process. During our visit to Forest Grove in July 2007, floating solids were observed at the surface of the secondary clarification tank. The main reason for the high solids concentration in the effluent is thought to be ongoing denitrification at the bottom of the clarification tanks due to the anoxic conditions. As the nitrogen gas is produced by denitrification, it rises to the surface, and resuspends settled solids. Among the sites we have visited, high solids concentrations were reported as a common problem in the treatment plants that use the same tanks for biological treatment and nutrient removal with insufficient aeration. In that aspect, results also showed that the SBR process is the most efficient in TSS removal.

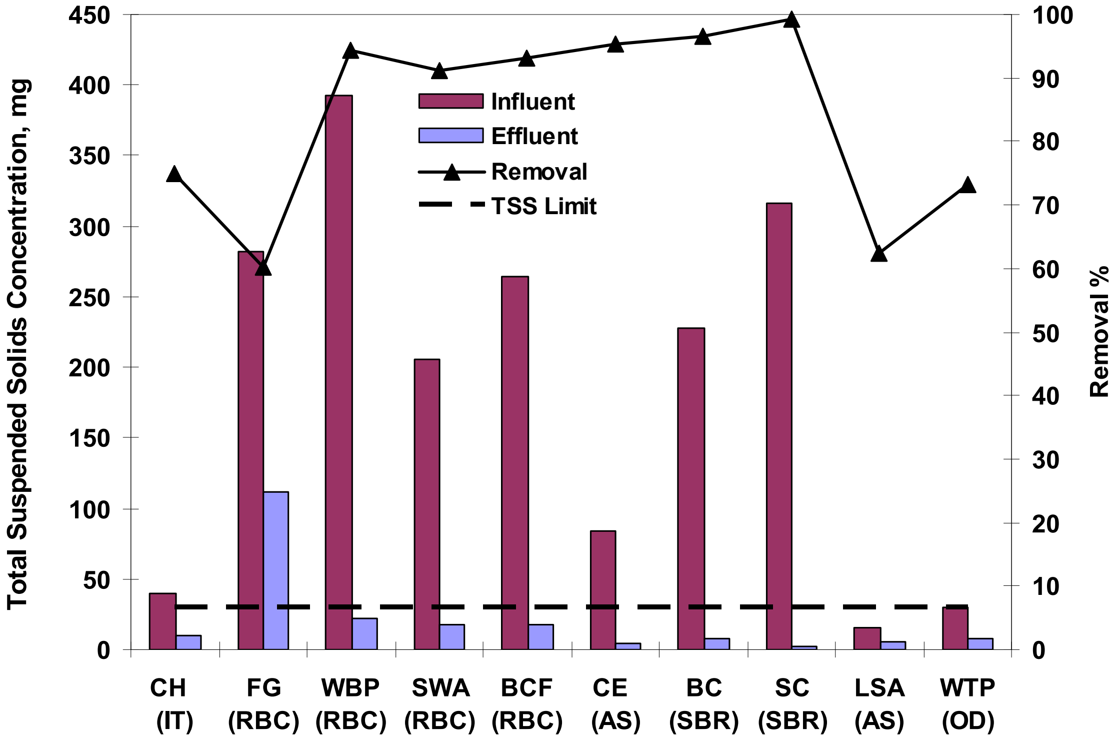


Figure 9. Total Suspended Solids concentrations in the influent and effluent samples and percent removal rates.

Besides treatment processes, seasonal temperature differences might play an important role in TSS concentration. During summer months, despite its state-of-the-art design and operation, and also TSS concentrations below limit, LSA in Vineland, New Jersey experiences algae growth problems in their chlorine contact/equalization tanks especially during summer months (Dennis Palmer, Landis Sewerage Authority, personal communication). Since algae increase the solids concentration, the effluent is used only for spray irrigation during April through October to prevent clogging of RIBS. This type of algae growth problem was not observed in any of the treatment plants that we visited in DE.

When the nitrogen removal efficiencies of different treatment processes were compared, SBRs were found to be the most efficient treatment processes (see Figure 10). Only two of eight treatment plants in Delaware have met the effluent total-N requirement, which is listed as 10 mg/L in the guidelines (DNREC, 2006). However, it should be noted that among the sites we visited, only four of the eight treatment plants (BC, SC, SWA and WBP) have nutrient reduction process.

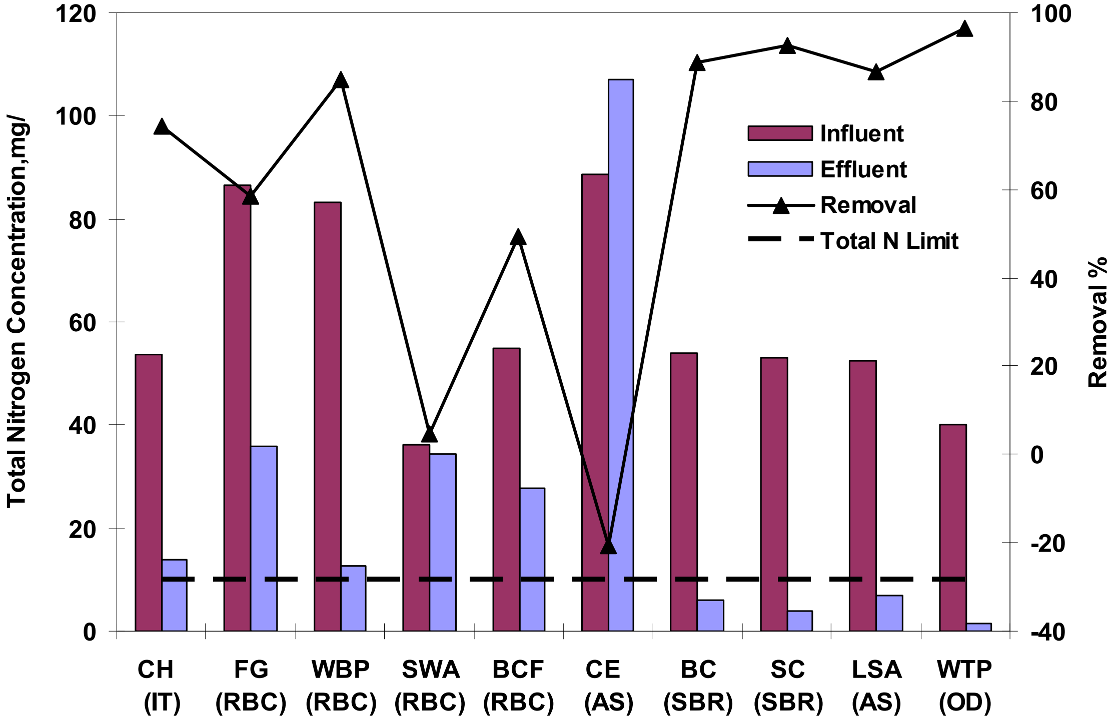


Figure 10. Concentrations of Total Nitrogen in the influent and effluent samples from different wastewater treatment plants and percent removal rates.

As far as the types of treatment processes are concerned, results showed that conventional secondary wastewater treatment is inadequate in nutrient removal. Higher nitrogen concentrations in the effluent for Colonial Estates Treatment Plant were due to incomplete nitrogen removal which results in an increase in ammonia concentration as a by-product. That means the oxidation process of ammonium to nitrate is not complete due to the lack of dissolved oxygen caused by insufficient aeration in the system. It was reported that high dissolved oxygen concentrations during aeration also leads to reduction of excess sludge production (Kulikowska, Klimiuk and Drzewicki, 2007). The higher performances of SBR processes in overall nutrient removal are mostly due to the intermittent oxygen supply, which provide aerobic and anoxic conditions when necessary for a complete nitrogen removal. Since the nutrients are concentrated in the sludge, timely removal of excess sludge from the system prevents resolubilization of nitrogen and phosphorus back into the water (Tchobanoglous and Stensel, 2003).

The removal rates of total phosphorus were found significantly lower than any other parameters discussed earlier. As mentioned previously, phosphorus removal is directly related with the nitrogen removal efficiency of a treatment process. Despite being relatively lower, phosphorus removal performances of the treatment plants exhibited trends similar to those with nitrogen removal (see Figure 11). Interestingly, higher phosphorus concentrations were measured in the effluent samples of FG and BCF than their influent samples. Since the phosphorus removing bacteria first release their extracellular phosphorus into the system and then uptake more than they released, higher phosphorus concentrations in the effluent indicate an incomplete phosphorus removal.

Overall, poor nutrient removal performances of the treatment plants were found strongly related with the RBC units which are used as their main biological treatment process. The highest phosphorus removal (100%) was observed at Stonewater Creek Treatment Plant which utilizes a SBR system.

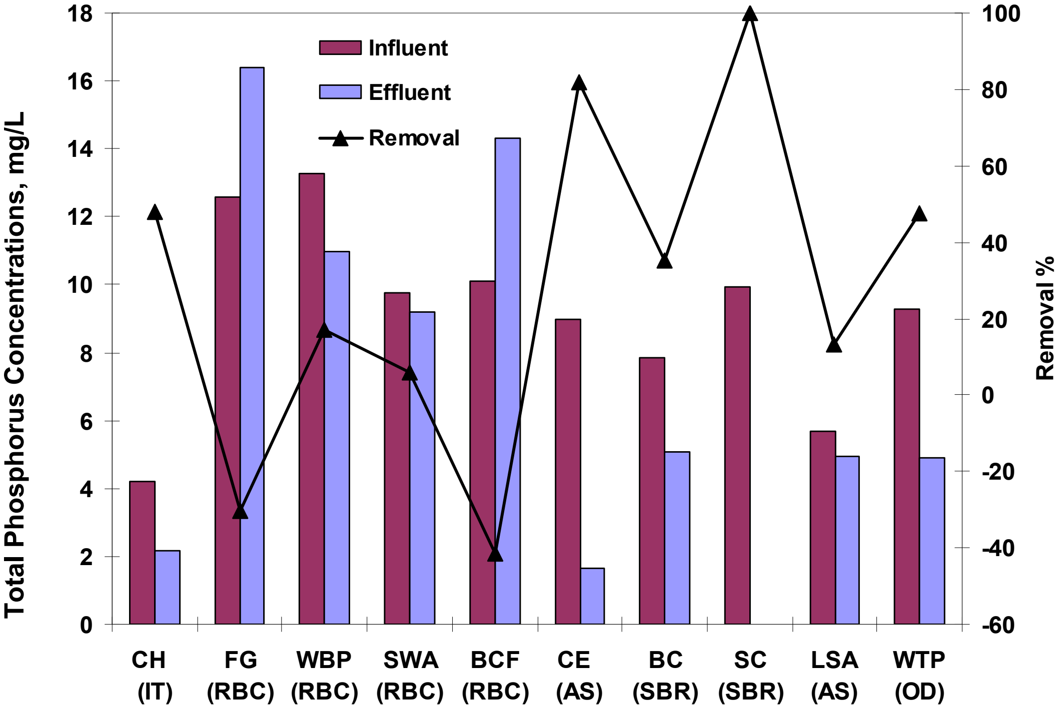


Figure 11. Total Phosphorus concentrations in the influent and effluent samples and percent removal rates.

In Delaware, guidelines state that all wastewater shall undergo disinfection, preferably ultraviolet, prior to being sent to the infiltration basins (DNREC, 2006). The fecal coliform concentration is required to be lowered below 200 colonies/100 ml by disinfection. In this research, indicator organism concentrations were found above limits in five out of seven of the effluent samples taken from wastewater treatment plants in Delaware (see Figure 12). This was an anticipated result since among all the treatment plants visited in Delaware, Cape Henlopen State Park Wastewater Treatment Plant was the only site which disinfects the treated effluent prior to RIBS discharge. Up to 100% virus or bacteria removal might be achieved via filtration especially in areas where depth to ground water is high. However ground water is more susceptible to microbiologic contamination when the water level is in close proximity to the land surface, which is a commonly occurring condition in southern Delaware (Martin and Andres, 2008). Therefore, proper pre-treatment and disinfection of wastewater prior to RIBS discharge is particularly important for Delaware.

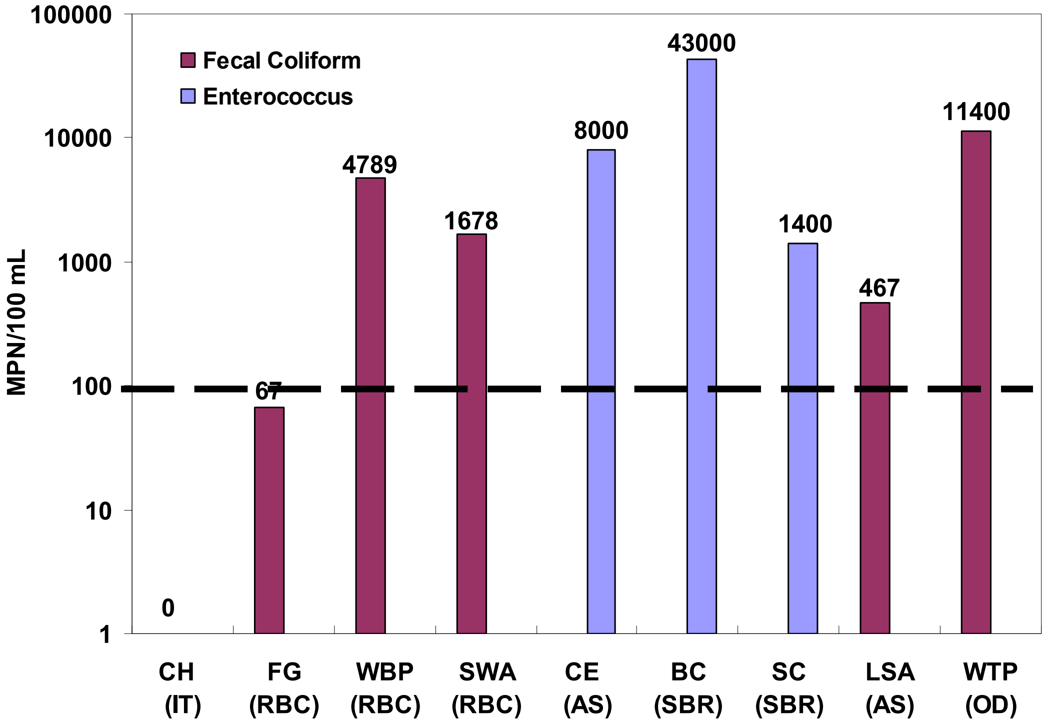


Figure 12. Indicator organism concentrations in the effluent samples

Effluent Characterization and Treatment Plant Performance - All States

The treatment types, effluent quality parameters and percent exceedences from wastewater treatment plants from four states, are given in Table 5 and results are illustrated in Figures 13 and 14. This analysis has been a very significant part of the first phase of this project in terms of summarizing years' of effluent quality data from four states (DE, NJ, MA, NC).

Analysis of nitrogen data is complicated by differing analytical schedules and sampling frequencies and differing effluent quality requirements. For example, some of the treatment plants in Delaware are still subject to a 25 mg/L Total N effluent limit and as a result, nitrate is not measured as frequently as Total N. Conversely, Total N is not measured for EA plants in North Carolina. We have attempted to aggregate the data using the following assumptions. Total N is set equal to nitrate for North Carolina plants that use EA and OD treatment processes and for SBR plants in other states that report only nitrate concentrations. The effect of this assumption is that if a plant exceeds a 10 mg/L nitrate-nitrogen limit it will also exceed a 10 mg/L Total N limit. There is a possibility of a false negative in cases where an EA or OD plant that is experiencing treatment upset discharges poorly treated effluent with high Total N but little nitrate.

Twenty four out of 49 evaluated treatment plants utilize the EA process, most of which are located in North Carolina. In comparison to other treatment methods, extended aeration has the highest representation in the data analysis (Figure 13). However, most of the EA data sets did not include total nitrogen values. More than three-fourths of them exceeded the 10 mg/L nitrate-nitrogen limit multiple months per year (Figure 14). This is expected because a conventional EA process increases the oxidation of ammonia in the influent to nitrate but does not include a denitrification step prior to discharge. Given that EA plants consistently fail to meet nitrate standards, they would pose a significant risk of causing high nitrate concentrations in ground water, especially in areas with a shallow (<10 ft) depth to ground water. Less than 5% of the treatment plants with EA process exceeded the TSS, coliform, and BOD limits. These results indicate the effectiveness of sufficient aeration for the removal of organics and suspended solids.

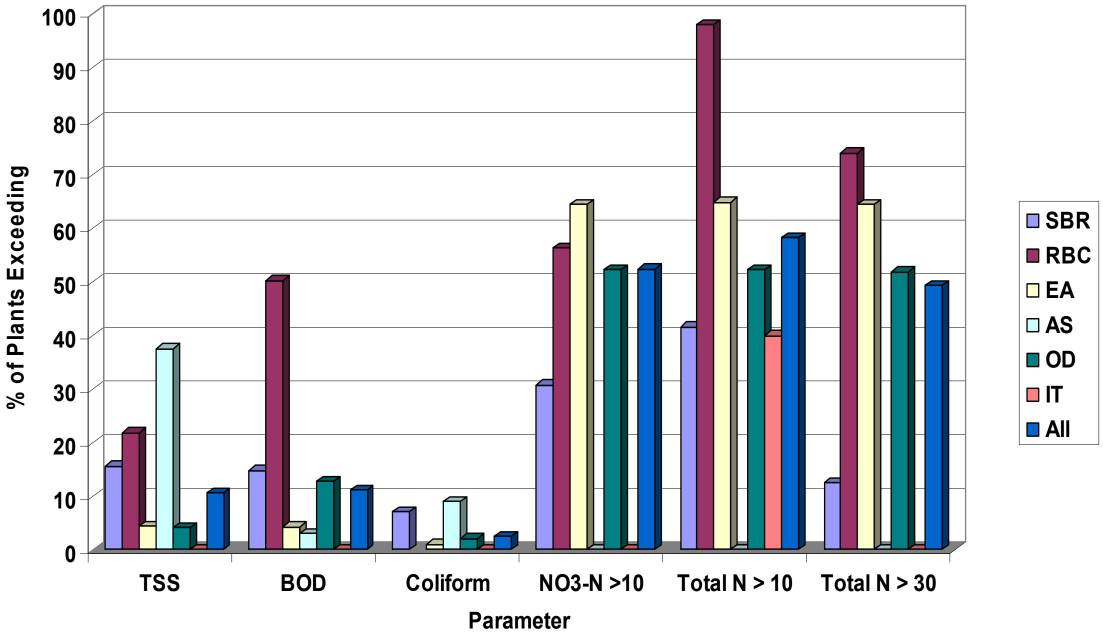


Figure 13. Comparison of parameter exceedences based on treatment processes.

Eleven treatment plants with SBR were evaluated in the project. These facilities appear to behave somewhat similarly to EA facilities (Figure 13). However, percent limit exceedences for TSS, BOD and Total Coliform were higher for SBR plants than EA plants. Compared to RBC, EA and OD, intermittent oxygen supply in SBR process leads to lower but still significant occurrences of limit exceedences for nitrate. SBR plants do not appear to be exceeding a TN limit of 30 mg/L. Although the SBR process appears to be more efficient than other processes in nitrate and total-nitrogen removal the data indicate that SBR plants have difficulties consistently meeting the nitrate standard (Figure 14). This is a concern for Delaware, where nitrate contamination of ground water poses risk to sensitive receptors.

When all of the treatment methods are considered, less than 10% of the treatment plants exceeded the limits for TSS, BOD and Total Coliform limits. Nearly three-fourths of the treatment plants exceeded the effluent nitrate limits at least one month per year. Figure 14 shows that a significant proportion of the EA and SBR plants exceed the nitrate limit more than six months of the year. As expected, Total N with a 10 mg/L limit was the second most exceeded effluent quality parameter. When the Total N limit is increased to 30 mg/L, the overall exceedence percentage decreased slightly more than two times. The long-term effects of the nitrate and Total N exceedences on ground-water quality and sensitive receptors down flow of RIBS receiving poorly treated effluent need to be investigated further.

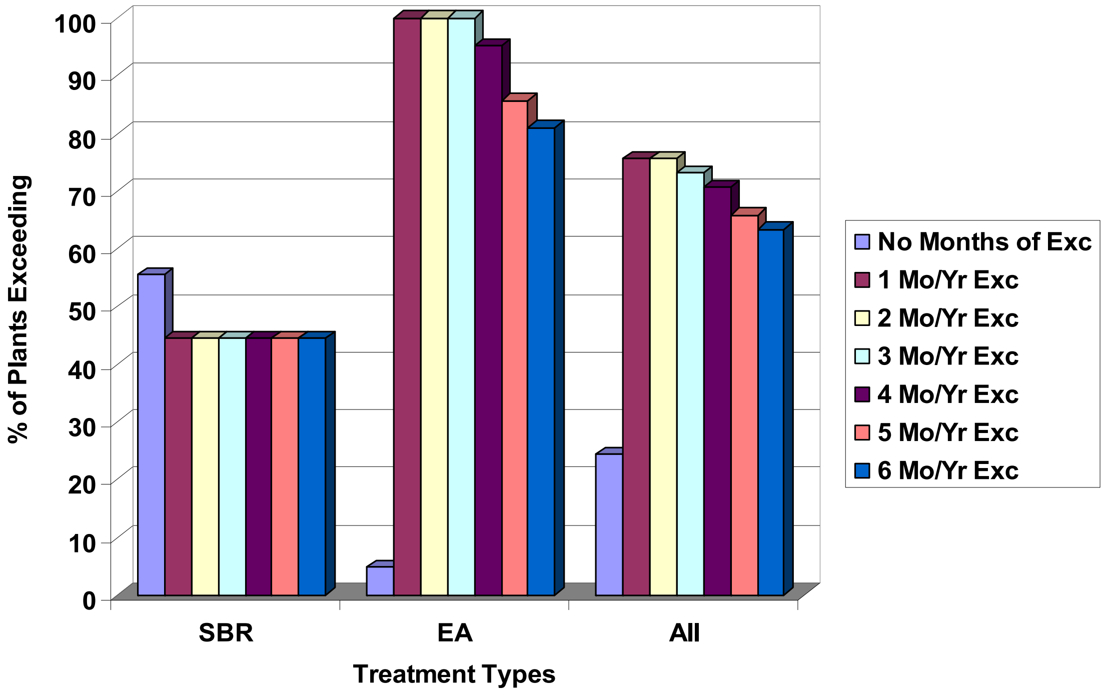


Figure 14. Comparison of frequencies of nitrate exceedences. Mo/yr Exc = months per year exceedence.

In the data set there are five treatment plants that use oxidation ditches (OD), three of which are in NC and two of them are in NJ. Despite not having TSS and BOD records for Winslow and Hammonton Wastewater Treatment Plants, analysis with existing data showed that the percent TSS and BOD limits exceedences of OD plants are lower than those of RBC and SBR plants. Similar to EA sites, the majority of OD sites do not have records for total nitrogen. Therefore, total nitrogen exceedence percentages for both EA and OD sites may not be representative of actual results. Total coliform exceedence of OD sites are the second lowest among all the treatment processes. As mentioned earlier, since microorganisms tend to attach to the small solid particles in the wastewater, efficient solids removal leads to a better pathogen removal.

Table 5. List of treatment facilities evaluated in this study and their percent exceedences of effluent quality limits. Exceedences of BOD (30 mg/L), and suspended solids (30 mg/L) in effluent are determined relative to concentrations expected from secondary treatment (Tchobanoglous, G., and Stensel, H.D., 2003, p. 8), for total nitrogen (30 mg/L) relative to concentrations expected from tertiary wastewater treatment (Tchobanoglous, G., and Stensel, H.D., 2003, p. 1377) and for nitrate-nitrogen (10 mg/L) relative to the USEPA standard for drinking water (USEPA, 2003) and DNREC (2006). Results are significant for evaluating risk of ground-water contamination in Delaware's hydrogeologic setting, but do not indicate compliance or lack of compliance with state regulations or specific permits.

				Total Suspended Solids		**Nitrate**		**Biochemical Oxygen Demand**		**Total Coliform**		**Total Nitrogen (>10mg/L)**		**Total Nitrogen (>30mg/L)**	
NonHazID/ Permit ID	**Name**	**State**	**Type**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Month s Exceed**	**# Months Exceed**	**% Months Exceed**
19	Bethany Bay	DE	SBR	2	9.52	8	61.54	2	10.00	no data	no data	13	59.09	4	18.18
27	Cape Henlopen	DE	IT	0.00	0.00	0.00	0.00	0	0.00	0	0.00	2	40.00	0	0.00
193	Colonial Estates	DE	AS	2	40.00	no data	no data	0	0.00	no data	no data	no data	no data	no data	no data
218	Forest Grove MHP	DE	RBC	4	16.67	no data	no data	15	62.50	no data	no data	11	100.00	11	100.00
261	South Wood Acres	DE	RBC	12	40.00	1	20.00	19	63.33	no data	no data	8	100.00	5	62.50
268	Breeder's Crown	DE	RBC	0	0.00	4	80.00	3	60.00	no data	no data	5	100.00	4	80.00
284	Stonewater Creek	DE	SBR	0	0.00	12	54.55	0	0.00	no data	no data	14	63.64	2	9.09
285	Heron Bay	DE	SBR	0	0.00	3	75.00	0	0.00	no data	no data	5	100.00	0	0.00
297	Beaver Creek	DE	SBR	0	0.00	0	0.00	0	0.00	no data	no data	3	37.50	0	0.00
336	West Bay Park	DE	RBC	4	30.77	9	69.23	2	15.38	no data	no data	12	92.31	7	53.85
370	Mobile Gardens MHP	DE	Septic	6	46.15	no data	no data	5	38.46	no data	no data	4	100.00	0	0.00
21	Barnstable WWTP	MA	AS	8	72.73	0	0.00	1	9.09	2	18.18	0	0.00	0	0.00
24	Edgartown WWTF	MA	EATF	1	9.09	0	0.00	0.00	0.00	0	0.00	1	9.09	0	0.00
200	Surfside	MA	SBR	6	54.55	no data	no data	8	72.73	no data	no data	no data	no data	no data	no data
201	Siasconset WWTP	MA	SBR	0	0.00	0	0.00	1	8.33	0	0.00	0	0.00	0	0.00
656	Town of Acton WWTF	MA	SBR	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
657	Devens WWTF	MA	SBR	0	0.00	0	0.00	0	0.00	2	18.18	0	0.00	0	0.00
677	Town of Plymouth WWTF	MA	SBR	7	58.33	0	0.00	6	50.00	0	0.00	2	28.57	0	0.00
WQ0000165	Sands Villas	NC	SBR	0	0.00	6	85.71	1	1.79	1	1.82	-	-	-	-

Table 5. Continued

				Total Suspended Solids		**Nitrate**		**Biochemical Oxygen Demand**		**Total Coliform**		**Total Nitrogen (>10mg/L)**		**Total Nitrogen (>30mg/L)**	
NonHazID/ Permit ID	**Name**	**State**	**Type**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**
WQ0000224	Point Emerald Villas WWTF	NC	EATF	2	3.57	6	60.00	1	1.79	0	0.00	-	-	-	-
WQ0000889	PCS Phosphate Co-Onsite Fac	NC	OD	0	0.00	11	73.33	0	0.00	0	0.00	-	-	-	-
WQ0000910	The Village at Nags Head	NC	EATF	2	3.70	5	45.45	0	0.00	0	0.00	-	-	-	-
WQ0000986	Island Beach & Racquet Club Condos	NC	EATF	9	16.07	34	94.44	19	34.55	0	0.00	-	-	-	-
WQ0002042	Clarion Hotel-Nags Head Beach	NC	EATF	0	0.00	2	28.57	2	4.00	1	2.04	-	-	-	-
WQ0002128	Pebble Beach Condos WWTF	NC	EATF	2	3.51	13	92.86	0	0.00	0	0.00	-	-	-	-
WQ0002314	Windward Dunes WWTF	NC	EATF	0	0.00	2	33.33	0	0.00	1	2.08	-	-	-	-
WQ0002829	KDHWWTP	NC	EATF	0	0.00	3	50.00	1	1.85	2	3.77	-	-	-	-
WQ0003044	Dunescape Villas WWTF	NC	EATF	3	5.26	10	71.43	3	5.26	1	1.75	-	-	-	-
WQ0003067	Ocean Bay Villas & Ocean Glen Condos	NC	EATF	2	3.45	45	78.95	0	0.00	0	0.00	-	-	-	-
WQ0003271	Hestron Park WWTF	NC	EATF	0	0.00	8	61.54	0	0.00	1	1.79	-	-	-	-
WQ0003437	Queens Court WWTF	NC	EATF	6	10.91	12	92.31	5	8.93	2	3.57	-	-	-	-
WQ0004059	Atlantic Station WWTF	NC	EATF	5	8.77	8	61.54	2	3.51	1	1.75	-	-	-	-
WQ0004230	A Place at the Beach III WWTP	NC	EATF	0	0.00	12	92.31	1	1.82	0	0.00	-	-	-	-
WQ0005173	Cape Royall Dolphin	NC	EATF	5	8.77	14	100.00	3	5.26	2	3.51	-	-	-	-
WQ0006254	Corolla Light No. 1	NC	EATF	1	1.85	7	50.00	1	1.92	0	0.00	-	-	-	-

Table 5. Continued

				Total Suspended Solids		Nitrate		Biochemical Oxygen Demand		Total Coliform		Total Nitrogen (>10mg/L)		Total Nitrogen (>30mg/L)	
NonHazID/ Permit ID	**Name**	**State**	**Type**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**	**# Months Exceed**	**% Months Exceed**
WQ0006863	Genesis Condos WWTF	NC	EATF	0	0.00	11	78.57	4	7.14	0	0.00	-	-	-	-
WQ0007103	Sound Of The Sea SBR WWTF	NC	EATF	3	5.36	12	60.00	0	0.00	0	0.00	-	-	-	-
WQ0007256	Baycliff	NC	EATF	2	3.70	1	33.33	2	3.64	0	0.00	-	-	-	-
WQ0009772	Monteray Shores	NC	EATF	0	0.00	9	75.00	1	1.85	2	3.70	-	-	-	-
WQ0011030	The Arboretum & Ocean Greens WWTF	NC	EATF	3	5.56	6	60.00	1	1.82	0	0.00	-	-	-	-
WQ0011313	Peppertree Resort WWTF	NC	OD	5	8.77	37	86.05	13	22.81	3	5.26	-	-	-	-
WQ0013027	Sea Isle Plantation North WWTF	NC	EATF	9	16.07	14	100.00	8	14.29	0	0.00	-	-	-	-
WQ0014550	Camp Don Lee-Arapahoe WWTP De	NC	SBR	21	50.00	no data	no data	9	20.45	10	22.73	-	-	-	-
WQ0018420	Ocean Club WWTF	NC	OD	2	3.85	1	100.00	8	15.38	2	3.85	-	-	-	-
WQ0018992	Southwinds Condos WWTF	NC	EATF	0	0.00	11	78.57	0	0.00	0	0.00	-	-	-	-
WQ0020084	The Villas Condominums	NC	EATF	0	0.00	3	50.00	2	4.17	0	0.00	-	-	-	-
46421	Hammonton WTPF	NJ	OD	no data	no data	0	0.00	no data	no data	1	1.52	0	0.00	0	0.00
47091	Winslow TWP WWTP	NJ	OD	no data	no data	no data	no data	no data	no data	0	0.00	1	1.79	0	0.00
46537	Landis WWTP	NJ	AS	0	0.00	no data	no data	0	0.00	0	0.00	0	0.00	0	0.00

RBC	Rotating Biological Contactor	4	**IT**	Imhoff Tank	1	**AS**	Activated Sludge	3
SBR	Sequencing Bach Reactor	11	**OD**	Oxidation Ditch	5	**EATF**	Extended Aeration	24

Four out of 49 treatment plants evaluated use the Rotating Biological Contactor (RBC) process, all of which are located in Delaware. As can be seen in Figure 13, treatment plants with RBC process have the very high limits exceedences for Nitrate, BOD, and Total N. These results agree with our laboratory analyses of effluent samples taken from treatment plants with RBCs. As mentioned before, during our site visits, it was observed that RBC sites had lower treatment performances in compared to other treatment processes. DNREC's Non-Hazardous Waste Sites Database does not have Total Coliform records for the treatment plants evaluated in this project. Therefore, none of the RBC sites have effluent coliform records. However, effluent sample analysis results showed that all four RBC sites in Delaware have effluents with pathogen concentrations above guideline effluent limits of 200 colonies/100 ml. This would be a immediate health risk should the RIBS have hydraulic problems and prolonged periods with effluent ponded in the RIBS.

Three treatment plants that use the Activated Sludge (AS) process were evaluated in the project. However, one treatment plant located in Delaware does not have any records of nitrate, total coliform or total nitrogen analyses. The only information on the effluent quality is the laboratory analysis results of the effluent samples that were taken during our site visit. Results obtained from the dataset showed that facilities with AS have the highest TSS percent limit exceedences. One of the most common reason of high TSS problems in biological treatment units, especially in clarifiers, is called "sludge rising"(Tchobanoglous and Stensel, 2003). Anoxic conditions in the settled sludge layer trigger denitrification and can lead to the sludge layer becoming buoyant and floating to the surface along with the nitrogen gas. Increasing the frequency of sludge collection tends to reduce the sludge detention time in the clarifiers, and can help reduce TSS problems. Another reason for low effluent quality in AS plants might be foaming, which is caused by certain types of filamentous bacteria, particularly *Microthrix parvicella* and *Nocardia* (Tchobanoglous and Stensel, 2003). Since these organisms are hydrophobic, they attach to the air bubbles and cause foam formation by stabilizing air bubbles. Spraying chlorine on the foaming surface, reducing the oil and grease content in the wastewater and adding cationic polymer are some of the common solutions used to prevent foaming.

The only treatment plant with an IT process evaluated in this project is located in Cape Henlopen State Park in Delaware. This treatment plant was built in 1941 and upgraded in 1980s. Performance of the IT plant was evaluated based on the laboratory test results of influent/effluent samples taken from the treatment plant and the effluent quality records obtained from DNREC. Total Nitrogen is the only parameter exceeded by this plant. Because CH is an old and small facility this is an unexpectedly good performance for such a simple process. Unlike other treatment facilities visited in Delaware, this site disinfects the treated effluent prior to RIBS discharge. Disinfection with chlorine gas lowers the total coliform concentration below guideline limits of 200 Col/100 mL.

Records indicate that RIBS in CH have been in operation since 1983. Due to more than 25 years of land application of treated wastewater, this site was chosen to conduct a field research during the second phase of this project to investigate the impacts of RIBS on the environment. The field research will consist of installation and sampling of geologic test borings and monitoring wells near and down flow of the RIBS, and sampling of treatment plant influent, effluent, and sludge.

CONCLUSIONS AND RECOMMENDATIONS

Results of the first phase of this research have shown that while RIBS technology has the potential to be a beneficial alternative to surface discharge and a means to recharge ground water, RIBS are appropriate only where and when the possible adverse environmental impacts are minimized by using appropriate site selection criteria and by meeting the requirements listed in guidelines or regulations. Because the costs associated with remediating or mitigating ground-water problems, and because RIBS technology is not simple, Delaware's regulations, policies, and guidelines should be stringent, and yet flexible enough to protect public and environmental health from the use of RIBS. Establishing good policies will not only improve the decision making process during permit application and review but also minimize the short and long term impacts of RIBS on the receiving environment.

The most common and serious treatment problems in treatment plants located in Delaware and neighboring states are high nutrient and pathogen concentrations in WWTP effluent. Years of application of treated effluent with high nutrient, pathogen, and organic content to RIBS will result in significant risks for environmental and public health problems. Although a simple disinfection unit can solve the pathogen problem in the effluent, reducing high nutrient concentrations below regulatory limits may require more significant and costly actions such as modifying treatment processes or upgrading treatment plants. Considering the high costs associated with fixing treatment plants, additional permitting safeguards are needed to limit the risks of serious widespread ground-water contamination resulting from poorly performing WWTPs.

In Delaware, discharge of poorly treated effluent to RIBS creates a risk for nutrient and pathogen contamination of ground water. The shallow Columbia aquifer is the receiving water body for the effluent at risk for contamination. The risk of serious ground-water contamination is most significant in areas where the water table is shallow, as is the case over much of Sussex and Kent Counties. In these areas, effluent discharged into RIBS will undergo much less additional renovation before reaching the water table. The risk of serious ground-water contamination in areas with a deep water table is not yet certain. Because the Columbia aquifer serves as a major source of potable water and streamflow, site selection should be done in full consideration of the risk of damage to all users of this resource. In cases where depth to ground water and distance from sensitive receptors are adequate, RIBS design, construction, and operation need to be done in a way to minimize risk of contamination of ground water.

Conditions in FL and NJ, states with lesser depth to ground water requirements, illustrate these concepts well. The Florida rule (3 foot thickness) reflects that state's significant investment in water reclamation to serve irrigation users and to control salt water intrusion from sea level canals (USEPA, 2004). The NJ rule in part reflects the use of RIBS to augment and manage quality of baseflow in streams draining the Pinelands, where a majority of the RIBS are located. Further, several of the larger RIBS in NJ have replaced direct surface water discharges that had impaired water quality and habitats. The 10 foot depth to ground water rule in Maryland reflects the need to maintain water quality in the shallow aquifer that serves as a significant source of potable water supply as well as the primary source of streamflow. These concerns are similar to those in Delaware.

Control of nitrogen in wastewater effluent is of special concern in Delaware. Nitrate contamination of shallow ground water has been a significant problem over large areas of Delaware and Delmarva for decades (Denver et al., 2004; Miller, 1972; Robertson, 1977; Ritter and Chirnside, 1982; Bachman, 1984; Andres, 1991). These studies have documented that oxic conditions in the shallow aquifer favor persistence and transport of nitrate over great distances (kilometers) and time scales (decades). These and many additional studies, including but not limited to Andres (Andres, 1992; Hamilton et al., 1993; Pellerito et al., 2006; Bachman and Ferrari, 1995) have documented that nitrate has led to contamination of domestic and public water supply wells and significantly contributes to the water quality and eutrophication problems experienced in many bodies of surface water.

In this regard, Delaware's "Large System Siting, Design and Operation Guidelines" (DNREC, 2006) requirement for a two foot separation distance between the bottom of the infiltration basins and water table needs urgent attention. Nearly four decades of research in Delaware have shown that infiltration of water containing high concentrations of total nitrogen and/or nitrate into the ground creates conditions where ground-water contamination by nitrate is certain, and contamination by other compounds present in the water is a significant risk. We strongly recommend that advanced treatment with nitrogen removal, engineering, operational, and siting controls be used with RIBS to limit the discharge of nitrate and other contaminants to the water table. As seen in other states, combinations of redundant engineering controls on the quality of effluent discharged to the ground, and advanced effluent and ground-water monitoring can reduce risks for contamination. We also recommend that the fixed buffer distances between RIBS and streams and wells be more rigorously defined to account for disposal rate, engineering controls, and site specific characteristics of the aquifer. This last concept is similar to that used in the Source Water Protection Program.

Phosphorus impacts on ground water due to RIBS have not been specifically studied in Delaware. Because proposed TMDLs in Delaware have phosphorus requirements, and phosphorus in ground water will eventually reach streams, this issue warrants further attention.

At this time there are no regulations that have been specifically developed for RIBS and as a result there have been a variety of design and site characterization approaches taken by permit applicants. Regulations developed from technically-based assessment of RIBS in the region and consideration of Delaware-specific hydrogeologic and water resources issues would provide the state with clear and consistent expectations for RIBS siting, design, and performance. In turn, regulations would help designers, operators, and owners of RIBS to provide wastewater disposal systems that are environmentally sound and protective of public health.

Evaluation of site visit and treated effluent data showed that overall operation and maintenance practices also play important roles in the performance of treatment plants. The most efficiently working WWTPs are usually the ones with a good management system in place. The Landis Sewerage Authority (LSA) is an example of one of the best managed and operated WWTP and LBWD facilities. The knowledgeable, well organized management of LSA appears to be proactive in responding to monitoring data and anticipating the effects of seasonal or operational changes on effluent quality and on their RIBS and spray irrigation sites. In addition, LSA staff recognizes that spray irrigation is the preferable LBWD method for their facility. On the other hand, among the treatment plants we visited, the ones with fewer or part-time personnel, apparent safety hazards, visible problems with the treatment units (i.e. solids floating in the tanks, foaming) have the lower treatment efficiencies and problems with functioning of the RIBS.

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