# Nitrate Removal for On-Lot Sewage Treatment Systems: The POINT™ System

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## 1.0 INTRODUCTION

### 1.1 OVERVIEW OF THE PROBLEM

Nitrate-nitrogen ($NO_3$-N) in groundwater is becoming a ubiquitous problem, particularly in rural and suburban areas where domestic water supplies are obtained from individual on-lot water supply wells. Nitrate in groundwater can come from natural sources such as soil, bedrock and organic material; however, the overwhelming loading of nitrate originates from anthropogenic sources, particularly agricultural practices and residential on-lot sewage treatment systems (a.k.a. "septic systems"). As residential subdivisions expand into previously undeveloped or agricultural areas, homeowners, developers, planners and township regulators are increasingly challenged with balancing sustained growth with a safe drinking water supply. Prevalent concerns are with high-density developments that utilize on-lot drinking water supply wells that draw from the same groundwater which is being impacted by the conventional nitrate-yielding on-lot septic systems. Unfortunately, the current solution implemented by most municipalities under the State's (PA) sewage planning permit process is to require larger developable lot sizes, which only encourages sprawl.

On-lot septic systems contribute a significant nitrate load to groundwater: a problem that can be addressed through innovative nitrate treatment within the septic systems. This paper provides a detailed description of the POINT™ (Passive Organic In-situ Nitrate Treatment) System; a passive, in-situ biological treatment system that augments traditional on-lot septic systems to effectively reduce nitrate levels in the effluent to below drinking water standards. This simple and cost effective technology can help prevent groundwater degradation and can easily be installed and operated for the life of the septic system with little or no maintenance.

### 1.2 MAGNITUDE OF THE PROBLEM

Of the estimated 11.8 million residents of Pennsylvania (U.S. Census Bureau, 2000), more than one third use on-lot sewage treatment systems (PSATS, 1998) and groundwater as their sewage disposal and primary source of drinking water, respectively (Hamlet, 1995). Drinking water containing elevated nitrate has been attributed to several adverse health effects and can be particularly severe or fatal to small infants through a condition known as methemoglobinemia, or blue baby syndrome. The U.S. Environmental Protection Agency (USEPA) currently sets a limit or maximum

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contaminant level (MCL) under the Safe Drinking Water Act for nitrate in public drinking water supplies of 10 milligrams per liter (mg/L) reported as nitrate-nitrogen ($NO_3$-N). Median nitrate concentrations above 10 mg/L $NO_3$-N are commonly reported in groundwater beneath unsewered residential subdivisions, with levels in excess of 130 mg/L $NO_3$-N (MPCA, 1999; Yates, 1985) in some cases. Once in groundwater, nitrate attenuates very slowly and can persist for years or decades, and improving the water quality becomes expensive or even technically infeasible (Nolan, 1996).

## 1.3 SOLUTIONS TO THE PROBLEM

Three primary means of addressing the nitrate-in-groundwater problem exist: 1) isolation distance, 2) on-lot sewage treatment system density, and 3) treatment. Most states, including Pennsylvania, require a minimum separation distance between the septic system and drinking water supply wells to minimize the septic system effluent contaminants, including nitrate, from entering the adjacent drinking water supply. However, nitrate in groundwater does not generally degrade and is principally reduced through dilution from the natural recharge of infiltrating precipitation. Therefore, location of on-lot sewage treatment systems vis-à-vis adjacent drinking water supply wells has little bearing on nitrate concentrations from other sources, especially when multiple sources of nitrate are located in close proximity to one another (e.g., high-density developments).

The second approach to controlling nitrate in groundwater is to balance the input of nitrate into the groundwater with the amount of dilution that occurs. This is accomplished by controlling the density of development per area, most commonly by requiring minimum lot sizes or open space. Most municipalities require minimum lot sizes, which typically range from ½ to 1 acre (Yates, 1985). Several recent studies involving groundwater sampling beneath unsewered residential communities suggest lot sizes larger than 1 acre may be needed (Brown, 1987; Yates, 1985). The Pennsylvania Department of Environmental Protection (PADEP) reports a lot size of 1.4 acres is needed for each sewage treatment system based on empirical studies and/or statewide generalizations (PADEP, 1997). On a macro-scale, this minimum lot size policy often results in more land being destroyed per unit (i.e., sprawl).

The third and most effective means of addressing the nitrate issue, and the focus of this paper, is to reduce the nitrate concentration in the on-lot sewage treatment system effluent. In many impacted groundwater areas (e.g., farmland, overdeveloped areas), prior to any development, the groundwater can already be impacted above the drinking water standard of 10 mg/L $NO_3$-N. In these cases, isolation distance and dilution through increased lot size do not solve the problem and the only alternative is to install on-lot sewage treatment systems that reduce the amount of nitrate discharged from the system. Several treatment technologies have been proposed to reduce this nitrate concentration from on-lot sewage treatment systems. Most of these technologies have resulted in only marginal nitrate reductions or have shown to be economically or technically impractical in individual on-lot settings. The POINT™ System presented herein overcomes the economic and technical shortcomings of the previously-developed technologies as discussed below.

# 2.0 ORIGIN AND FATE OF NITROGEN

## 2.1 NITROGEN IN THE TRADITIONAL SEWAGE TREATMENT SYSTEM

Liquid and solid waste generated in the household is partially treated in a traditional on-lot sewage treatment system in stages. Untreated household waste, which contains urea ($CON_2H_4$) and organic nitrogen, is first discharged to a septic tank. In the septic tank, the solid and liquid phases are separated through gravity settling. The liquid material is converted to ammonia ($NH_3$) and ammonium ($NH_4^+$) via anaerobic bacteria and the solid material settles to the bottom of the tank for eventual degradation and/or removal. Following the separation and primary treatment stage, the liquid is discharged either by gravity or by pump to the absorption field. In the absorption field, the ammonia nitrogen in the waste water is quickly converted sequentially to nitrite ($NO_2^-$) and then nitrate ($NO_3^-$) through biological aerobic nitrification processes within the shallow soil horizon. Conventional on-lot sewage treatment systems are a cost effective means of treating the solids, organic pollutants and microorganisms in waste water; however they are not specifically designed to remove nitrogen and it (the nitrogen) tends to pass directly through the absorption field with the liquid effluent and into the receiving (groundwater) (Mooers, 1996; MPCA, 1999).

## 2.2 DENITRIFICATION

Once nitrogen is in an aqueous nitrate form, it is generally stable except under concurrent anoxic and carbonaceous conditions, which support the biological conversion of nitrate to nitrogen gas in a process known as denitrification. Unlike nitrifying microorganisms which can only use oxygen as an electron acceptor, denitrifying bacteria are capable of using nitrate as an electron acceptor in the absence of oxygen (dissimalatory denitrification). If given a preference, the microorganisms prefer oxygen as the terminal electron acceptor due to its higher energy yield, therefore, for denitrification to occur, an anoxic environment must be present. When the microorganisms reduce (break apart) the nitrate ($NO_3^-$) to liberate the oxygen, nitrogen gas ($N_2$) and nitrous oxide ($N_2O$) are produced and harmlessly lost to the atmosphere. Denitrification also requires the presence of an organic carbon source (electron donor) for microbial metabolism. In traditional large-scale wastewater treatment plants employing a denitrification step, the carbon source is normally methanol or raw wastewater, both of which contain organic carbon.

These two concurrent conditions are not generally present in on-lot sewage treatment systems where unsaturated sandy soils are needed for proper filtration and percolation. In the POINT™ System, natural organic substrates such as sawdust, peat, and culm are used as the carbon source and the engineered mixture, content and placement of the organic layer create the appropriate anoxic conditions.

## 3.0 CURRENT NITRATE REMOVAL METHODS

Several individual on-lot nitrate treatment systems have been proposed in recent years in response to the growing concern over nitrate in groundwater. To date, none of these systems have proven to consistently reduce nitrate nor have they been approved for use in Pennsylvania via Alternate Guidance or PA Title 25, Chapter 73. The following is a brief overview of some of the commonly accepted nitrate treatment systems. This overview is not meant to be exhaustive or technically detailed but rather is meant to establish a comparative baseline by which to compare and evaluate the POINT™ System. Information used to summarize these technologies was collected from publicly- and readily-available sources.

### 3.1 TRADITIONAL TREATMENT METHODS

Several traditional treatment methodologies have been developed and implemented to treat nitrate either in wastewater or drinking water applications. These treatment methodologies are normally applied to large wastewater flow conditions (e.g., municipal) or to remove nitrate from drinking water. Some of the methodologies are as follows:

- Biological Denitrification – Biological denitrification is the most common means of removing nitrate from large-flow wastewater conditions. Following conversion of ammonia to nitrate in a precursor process, the nitrate is exposed to an anoxic and carbon-rich environment. The organic carbon is normally supplied by recirculating some of the wastewater sludge to the anoxic treatment vessel or by introducing an external carbon source such as ethanol, methanol, glucose, lactic acid, or acetic acid are added. Biological treatment in this form is very expensive, labor- and equipment-intensive, and not well suited for individual on-lot sewage treatment system applications.
- Ion Exchange – Ion exchange is a reversible chemical reaction whereby an ion in the fluid to be treated is replaced with a different ion on the exchange media. This process is similar to a water softener, also known as a cation exchange unit. In the case of nitrate, however, the process is an anion exchange unit as nitrate is negatively charged. As with a water softener, the exchange medium requires frequent regeneration, whereby the captured nitrate is eventually washed away, and there is generally a limited amount of resins with high selectivity for nitrate. Ion exchange is typically limited to drinking water applications and not wastewater treatment.
- Reverse Osmosis – Reverse osmosis (RO) uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. The downside to RO is the low selectivity of the membranes used for nitrate treatment and the generation and disposal of the reject fluid, not to mention the O&M cost of such a process. RO is typically limited to drinking water applications and not wastewater treatment.

## 3.2 NEW OR INNOVATIVE TREATMENT SYSTEMS

Several new nitrate treatment technologies have been developed over the years. The following is a literature search summary of some commonly-tried technologies when nitrate removal is required:

- Recirculation – In this process, a portion of the fluid waste stream from an aerobic treatment unit, in most cases a sand filter, is returned to the septic tank where the anoxic and carbon-rich environment biologically converts the nitrate to nitrogen gas (denitrification). These systems require installation of an additional treatment unit (sand filter), additional piping and pumps, and only treat a portion of the waste water. USEPA reports an average total nitrogen removal of between 40 and 50 percent (USEPA, 2002)
- FAST® - This technology involves installation of a large (5' x 2' x 4') fixed-film reactor vessel within an existing or new septic tank to provide both nitrification and denitrification within the vessel and the septic tank. The supplier claims a nitrogen removal rate of 70%; however, pilot-scale studies have shown average removal rates of about 55% (Costa, et. al.). The downside of this technology is the capital cost of the unit, the septic tank volume reduction resulting from the vessel, the aesthetics and additional power demands from the electric blower unit, the low nitrate removal efficiency, and the technology's performance fluctuations due to ambient temperatures. Recent experience by PADEP indicates that this process is not approved for nitrate treatment.
- RUCK – The RUCK system is a sand filter and denitrification unit where black water is sent to the septic tank, then to a sand filter (the RUCK filter). Sand filter effluent and gray water are discharged to a second septic tank where anaerobic conditions create denitrification. This effluent is then sent to a traditional absorption area. Total nitrogen removal rates are reportedly in the 40-80% range (Winkler, 2000). The downside to this system is the need for two additional treatment units (the RUCK filter and the second septic tank), necessary pumps and piping, and separate household plumbing for the grey and black water.
- Waterloo Biofilter – The Waterloo Biofilter is a trickling filter (fixed-film) using medium-density foam blocks in an above-ground or below-ground structure (the biofilter). This structure is placed between the traditional septic tank and the absorption field and operates primarily in aerobic conditions. Data from previous studies as well as manufacturer's literature report wide ranges in nitrogen removal from 21% (Winkler, 2000) to as high as 60% (Costa, et. al.) with slightly higher rates (~65%) when in conjunction with additional recirculation or denitrification components. As with the other treatment technologies, this technology requires additional capital and O&M costs for the additional treatment units and provides only marginal decreases in nitrogen levels.
- Wetlands – Both surface and subsurface flow wetlands have been designed and implemented in pilot and full-scale applications to treat for nitrate using

sequential nitrification and denitrification. Wetlands systems have not garnered widespread approval mainly due to the land area they consume and the aesthetics of such a system (e.g., the "swamp" perception). Wetlands are also susceptible to performance fluctuations based on seasonal ambient temperatures.

- Peat Filter – Peat filters are trickling filters using peat moss as the filter media. Effluent from the primary septic tank is discharged to the peat filter, followed by discharge to the soil absorption area. Total nitrogen removal rates of between 35% and 70% have been reported (McKee, 1998). Removal efficiencies of up to 70% in aerobic conditions provide support for the potential denitrification when in the presence of organics, most likely occurring in micro-environments within the peat pore spaces. The downsides of this technology are the need for the additional treatment vessel, the required O&M performed by the manufacturer, and the need for periodic substrate replacement.
- NITREX – NITREX uses "nitrate-reactive media" (wood by-products) to promote denitrification. The nitrate-reactive medium is contained in a tank, or in larger cases a lined excavation. Pretreatment is required to convert ammonia to nitrate prior to entry into the NITREX system. This technology is reportedly sensitive to low temperatures and has a higher capital cost due to the need for additional treatment vessels (pre-treatment and NITREX units).

All of the above-listed systems have at least one significant downside; whether it be costly, overly burdensome from an O&M standpoint, inefficient nitrate removal, or inapplicable to site-specific conditions (e.g., size, new plumbing). Conversely, the POINT™ System presented herein does not require additional treatment units, is in-situ and passive, and uses recycled products as its primary treatment medium.

# 4.0 POINT™ SYSTEM OVERVIEW AND BACKGROUND

## 4.1 SYSTEM OVERVIEW

The POINT™ System consists of a traditional two-chamber septic tank, distribution network, and a modified absorption area consisting of two layers for the sequential treatment of traditional wastewater parameters and nitrate. Like a conventional septic system, the upper layer consists of natural soil that is excavated for installation of the underlying nitrate treatment layer and then replaced. This layer is generally 2 feet thick and provides treatment of the traditional treatment parameters (e.g., total suspended solids [TSS], biological oxygen demand [BOD], nutrients, pathogens, and miscellaneous parameters). The nitrate treatment layer consists of a one to two foot thick layer of natural soil or imported material augmented with carbon-rich material for biological nitrate treatment (denitrification). Figure 1 provides a cross-section of a typical system. Effluent from the septic tank is distributed to the modified absorption area through a series of perforated pipes similar to a traditional system. Treatment occurs as the effluent travels by gravity through the traditional absorption area and the carbon-rich layer. The effluent is nitrate-reduced as it leaves the absorption area. Nitrogen gas generated from the denitrification is harmlessly lost to the atmosphere as it migrates upward through the air voids in the absorption field.

## 4.2 REGULATORY SUPPORT

It should be noted that USEPA recognizes passive in-situ biological denitrification as a viable treatment process for removal of nitrate in onsite wastewater treatment systems. Specifically, USEPA's Onsite Wastewater Treatment Systems Technology Fact Sheet 9 [Enhanced Nutrient Removal – Nitrogen] (USEPA, 2002) states that "The use of beds of carbon-rich materials below [subsurface wastewater infiltration system] leach lines could be a promising concept if the hydraulic matching problems are solved and the bed service life can be extended for 10 years or more." Both of these design considerations have been addressed by the author on previous applications and are discussed (along with several other aspects of the treatment system) in the following sections.

USEPA's Onsite Wastewater Treatment System Manual provides further support and justification for a denitrification system with an organic-rich component in the following statements: "…nitrogen removal below the infiltration field can be enhanced by placing the system high in the soil profile, where organic matter in the soil is more likely to be present,…" and "Denitrification can also occur if ground water enters surface water bodies through organic-rich bottom sediments." (USEPA, 2002).

PADEP has evaluated several "experimental" on-lot sewage treatment technologies over the years; some of which have included denitrification technologies. It appears from personal discussions and review of multiple sources that there is not a PADEP-approved (i.e., "alternate") technology for the treatment of nitrate in spite of several experimental systems which have undergone evaluation. In fact, PADEP has recently established a Technology Verification Protocol (TVP) for evaluation of on-lot sewage treatment technologies which it believes warrant evaluation. Any evaluations conducted on the POINT™ System will be performed in accordance with the TVP.

## 4.3 TECHNICAL JUSTIFICATION

Treatment schemes similar to the POINT™ System have been studied and field-tested by the author and other researchers for treatment of high-nitrate water and for other parameters with similar treatment removal mechanisms as nitrate. This information is summarized below as technical justification for the POINT™ System.

### 4.3.1 Denitrification Applications

***Permeable Reactive Barriers (Australia, New Zealand)***

Permeable reactive barriers, or PRBs, are trenches excavated below the groundwater table and perpendicular to the groundwater flow direction to intercept impacted groundwater. The PRBs are filled with a reactive medium to treat the groundwater as it passes through the PRB. Several PRBs have been installed in recent years, but only a handful are known to exist for the treatment of nitrate-impacted groundwater. Two such pilot-scale PRBs, one in Australia and one in New Zealand, used sawdust as the reactive medium. Both showed successful reduction in groundwater nitrate concentrations from upgradient of the PRB to downgradient (Fahrner, 2002: Schipper, circa 2001).

***Subsurface On-site Waste Water Treatment System (Canada)***

An on-site wastewater treatment system was installed in 1996 below a parking lot of a restaurant in Ontario, Canada. The system contained (top to bottom) polyethylene leaching chambers over a sand filter bed. Sawdust was added to one-half of the bed as a comparison to the unaugmented half. Results show a significant reduction in nitrate at the bottom of the augmented half (effluent $NO_3$=0.6 mg/L) as compared to the unaugmented half (8.6 mg/L) (St. Marseille, 2001).

***Nitrate-Containing Landfill Leachate: Pilot Test (Canada)***

A three-year pilot-scale field trial was conducted using a two-layer absorption area to treat landfill leachate containing high levels of ammonia. The absorption area contained a 95 centimeter (cm) thick (3.1 feet) layer of unsaturated sand underlain by a 20 cm (0.66 feet) thick layer of coarse hardwood sawdust. The pilot-system was able to sequentially convert ammonium to nitrate in the upper layer followed by nitrate to nitrogen gas within the sawdust layer. Average total nitrogen removal was 89% over the life of the test, with a third-year average of 96% (Robertson, 1999).

***In-situ Denitrification Field Trials (Canada)***

Three field trials using a variety of configurations to examine oxygen diffusion and nitrate reduction using different porous media were installed at sites in Canada. Two of the field trials used organic layers below leaching fields and one was a cut-off wall

(PRB). The two sites involving horizontal layers included an organic layer augmented with 15% sawdust and the PRB was constructed of a sand/sawdust mixture (20% sawdust). The results of these trials that are germane to the POINT™ System are four-fold: 1) coarse silt to fine sand will remain saturated via surface tension, 2) augmentation of such a layer with organics helps retain saturation levels, 3) nitrate reduction due to denitrification in an organic-augmented layer occurs rapidly, and 4) 15% organic augmentation is adequate to support denitrification over the life of the test (Robertson, 1995).

4.3.2 Similar Treatment Applications

Organic media such as peat moss, sawdust, hay, and brewery waste have been used in several passive and semi-passive treatment systems, including those researched, designed, and implemented by the primary author. In the primary author's experience, the systems have involved using sawdust as an organic substrate to promote an anaerobic environment conducive to sulfate-reducing bacteria (SRB). SRB are similar to the denitrifiers in that both require an anaerobic (anoxic) environment and a constant carbon source for metabolism. The SRB technology has been successfully applied to acid mine drainage (AMD) and metals-removal projects in a similar fashion as the POINT™ System.

Specific applications by the primary author have included: 1) Pilot study for metals removal from a wastewater influent whereby a 35-foot by 35-foot basin was constructed, filled with an organic treatment media (sawdust and manure), and operated for 3 months to successfully demonstrate metals removal using SRB in an anaerobic environment (AGC, 2004), and: 2) Column study for acid mine drainage whereby a sawdust-based substrate was successful in supporting the biological activity in an anaerobic environment, thus buffering the acidity and removing metals from the influent (Hagerty, 2002).

These systems, and many others not directly associated with the author, have been designed and implemented to provide an anaerobic, carbon-rich environment for the promotion of biological activity similar to the POINT™ System. In addition, these systems have been developed with similar long-term hydraulic and longevity design constraints as those associated with proposed nitrate treatment systems.

## 5.0 POINT™ SYSTEM CONSIDERATIONS

The following sections provide a technical review of the physical and biological characteristics of the POINT™ system.

### 5.1 CARBON SOURCE

Several sources of carbon are available for denitrification. In the POINT™ System, manufacturing byproducts such as sawdust or culm are normally used since they are high in carbon content and would otherwise be waste products. When evaluating carbon sources for use in biological degradation, the carbon is typically expressed in terms of its relative ratio to nitrogen; known as the carbon-to-nitrogen (C:N) ratio. Most sources list sawdust as the highest C:N ratio, at between 400 and 600. Sawdust generally contains about 0.1% nitrogen. Assuming sawdust has an average C:N ratio of 500:1 and 0.1% nitrogen, the sawdust is approximately 50% carbon, or about 1,000 pounds (lbs) of carbon per ton of sawdust (Jenkins, 1999: MDOC, 1994).

### 5.2 SYSTEM LONGEVITY

The logical follow-up question to Section 5.1 is, how long will the carbon source in the sawdust last before it requires replacement? EPA's Technology Fact Sheet 9 (USEPA, 2002) provides a design benchmark of 10 years for this type of technology to be viable, although the authors believe that applicable systems should last 20 years or more. As shown below, under normal operating conditions, the organic-carbon component is expected to last for more than 100 years. To calculate the longevity of the carbon component, the following assumptions are provided:

- Nitrate concentration into carbon layer - 45 milligrams per liter (mg/L) (PADEP, 1997)
- Daily flow rate into the absorption area - 500 gallons per day (gpd) assuming 4 bedroom residential dwelling (PADEP, 2004)
- Percolation rate - 30 minutes per inch (mpi)
- Factor of Safety (FS) added to perc rate - 1.5, or a design rate of 45 mpi (see Section 5.4.1 for explanation of FS)
- Denitrification layer thickness – two (2) feet
- Stoichiometry: $5CH_2O + 4NO_3^- \rightarrow 5CO_2 + 2N_2 + 3H_2O + 4OH^-$
- Dry bulk density of sawdust - 20 pounds per cubic foot (pcf) (Robertson, 1999: Hagerty project experience)
- 50% carbon content sawdust (by weight) (Jenkins, 1999: MDOC, 1994)

Using these assumptions results in a carbon longevity of 279 years. In reality, all of the carbon in the sawdust may not be available for metabolism and the denitrification layer is not 100% organic. Even so, a conservative FS of 4 (2 for carbon availability and 2 for 50% soil/50% organic mix) would maintain the longevity over 50 years, which is more than twice the typical life expectancy of a normal on-lot sewage treatment system and more than five times the EPA design benchmark.

As additional evidence of the ample longevity of the carbon source, the author's experience with SRB systems, which also use sawdust as the carbon source, has indicated that longevity is not an issue. One such SRB system has been in operation since 1996 with no visible signs of substrate breakdown or physical reduction. Furthermore, long-term performance evaluations of field-scale studies referenced earlier indicate only minimal carbon consumption, on the order of less than 0.5% per year (Robertson, 2000).

## 5.3 ANAEROBIC PROPERTIES AND SATURATION

A primary consideration in the effectiveness of any denitrification system is for the treatment unit, in this case the organic-augmented layer, to contain a low level of oxygen for the promotion of anaerobic microbial activity. Three common characteristics of the POINT™ System, infiltration zone organic loading, soil-water holding capacity, and depth of organic layer, ensure that the organic layer remains in an anoxic environment for denitrification to occur. Each of the characteristics is discussed below.

### 5.3.1 Infiltration Zone Organic Loading

It is well understood that the infiltration layer of a traditional on-lot sewage treatment system is responsible for the removal or reduction of the organic load (BOD) in the wastewater and also the conversion of ammonium to nitrate. Both of these processes are oxygen-demanding, and as such, DO levels a couple of feet into the infiltration layer are typically low. EPA recognizes this condition when it states "Anaerobic conditions are created when the applied oxygen demand exceeds what the soil is able to supply by diffusion through the vadose zone." (USEPA, 2002). Furthermore, research has provided data supporting the same conclusion. For example, field pilot studies conducted in the early 1990's concluded that "[g]reatest $O_2$ declines were noted immediately below the weeping tiles indicating that this was the zone where oxidation of effluent organic matter and $NH_4^+$ was most intense." (Robertson, 1995). Similarly, data cited by EPA in its Onsite Wastewater Treatment System Manual show total removal of BOD (93.5 mg/L to <1 mg/L) within the first two feet of the absorption area, indicating that $O_2$ was consumed in this region (USEPA, 2002). These observations and studies confirm that, even when properly designed, anaerobic conditions are likely to occur in the lower portions of an absorption area following treatment for BOD and $NH_4^+$ in the upper layers of an absorption area.

It is also believed that the iron content in substrates assists denitrification possibly via increased oxygen consumption rates (McFarland, 1996). This theory will be evaluated further with respect to its impact on the absorption area's overall characteristics and effectiveness of the treatment system.

### 5.3.2 Soil-Water Holding Capacity

It is well documented that a soil layer containing a high amount of moisture generally has a low level of DO and does not allow the diffusion of oxygen (e.g., re-aeration from the surface to the underlying soil). The presence of organics such as sawdust within the soil increase the soil's water holding capacity. These high-moisture conditions in turn create (and maintain) anaerobic conditions for denitrification. Field studies previously cited provide data whereby sawdust-augmented soil layers were placed at a prescribed depth within a septic system absorption area. Discrete DO and moisture content measurements were then taken above and below the sawdust-augmented layer, and in all cases, significant reductions in DO were experienced within and directly below the augmented layer (Robertson, 1995).

Other studies have indicated that, even when water samples from organic soil layers indicate aerobic conditions, denitrification still occurs due to microenvironments within soil pores containing denitrifying microorganisms in intra-aggregate water-filled pores (Fahrner, 2002).

### 5.3.3 Depth of Organic Layer

The depth of the denitrification treatment layer will normally be at least 4 feet below the ground surface. At this depth, oxygen diffusion from the surface (atmosphere) to the subsurface is limited. This is supported by EPA literature that states "The maximum depth [of the infiltration surface] should be limited to no more than 3 to 4 feet below grade to adequately re-aerate the soil and satisfy the daily oxygen demand of the applied wastewater." (USEP, 2002). Additionally, EPA states "Maximum delivery of oxygen to the infiltration zone is most likely when soil components are shallow…" (USEPA, 2002).

These observations and data provide further evidence of the ability of an organic-augmented layer directly below a traditional septic system absorption area to maintain anaerobic conditions and thus provide denitrification.

## 5.4 REACTION RATES AND HYDRAULICS

On-lot sewage treatment system design is based on the anticipated flow from an individual dwelling and the ability of the absorption area to accept this flow on a daily basis. To determine this ability, a percolation (or "perc") test is conducted in the proposed absorption area to determine the rate of infiltration, and hence the required absorption area. Perc rates are based on the average rate of drop in water levels in a series of test holes within the proposed absorption area and are expressed in terms of minutes per inch (mpi). This average perc rate can be expressed as the absorption area's hydraulic capacity. When determining the denitrification layer dimensions, hydraulic capacity is evaluated in two ways; 1) the ability of the organic layer to accommodate the daily flow without impacting the overall perc rate of the system, and 2) the required residence time of water within the organic layer to allow for complete denitrification. Each of these design characteristics is discussed below.

### 5.4.1 Hydraulic Capacity

As stated previously, EPA's Onsite Wastewater Treatment Systems Manual states that "The use of beds of carbon-rich materials below [subsurface wastewater infiltration system] leach lines could be a promising concept if the hydraulic matching problems are solved…" These hydraulic problems have been successfully addressed by the author on other similar projects (i.e., SRB projects). In reality, it is not a "matching" problem but rather a flow restriction issue. Specifically, the hydraulic properties of the overlying re-compacted soil and the underlying denitrification layer do not have to be matched, but they have to be designed such that the denitrification layer is more permeable than the overlying soil, thus creating a free-flowing system. It is only when the underlying denitrification layer is less permeable than the overlying soil layer that hydraulic failures occur. In this case, the failures would result in a collection of water at the soil/organic interface which would create the potential for an anaerobic zone into the overlying recompacted soil zone. In most cases, the grain size of the organic amendments in the denitrification layer is greater than the grain size of the overlying virgin soil. When larger-grained material is added to a soil, the permeability increases. Therefore, adding the organic amendments to the soil will create a more permeable denitrification layer, which will not cause system hydraulic flow problem.

As with a traditional system, the POINT™ System is first designed using the data from the perc test to determine the size of the absorption area. The average perc rate is increased by 1.5 (FS) to account for potential temporary hydraulic conductivity loss due to excavation and replacement of the absorption area to install the denitrification layer. It is believed that the 1.5 FS is a conservative approach to accommodate the short-term potential of the recompacted soil layer to temporarily decrease in hydraulic conductivity until a steady-state, higher conductivity is re-established. Post-installation perc tests may be conducted to confirm that the factor of safety adequately overcame the temporary permeability reductions, if any.

### 5.4.2 Residence Time

Residence time is defined as the time a given quantity of water resides in a treatment unit. In traditional wastewater treatment, residence time is calculated by dividing the volume of the treatment unit by the flow rate of effluent into the unit. This assumes that influent flow equals effluent flow (steady state) and that the treatment unit remains full. In on-lot sewage treatment systems including the POINT™ System, these assumptions do not always hold. Rather, residence time is a direct function of the hydraulic conductivity of the treatment media, in this case the organic layer for denitrification.

Several residence times from several column, pilot, and full-scale studies referenced above were evaluated. When calculated using hydraulic conductivity as the controlling factor, the residence times ranged from 3 to 9 hours for adequate removal of nitrate. Based on the assumptions from Section 5.2 for an average absorption field, and applying a porosity of 0.4 to determine seepage velocity, the residence time for a two-foot thick organic layer would be 7.2 hours. This is well within the range of successful residence times from other studies and indicates that the denitrification layer will adequately denitrify the effluent in a 2 foot thick layer.

### 5.4.3 Fill Stabilization

Disturbance of the absorption area for installation of the denitrification layer is not consistent with PADEP's on-lot sewage disposal system design standards. Specifically, disturbance of the absorption area is not permitted. However, PADEP acknowledges the soil disturbance as a temporary condition in §73.12(b) (Site location) where it states "Absorption areas or spray fields may not be placed in or on fill unless the fill has remained in place for a minimum of 4 years to allow restoration of natural permeability." Therefore, it is expected that the disturbed soil will return to pre-disturbed hydraulic conditions, or equilibrate at some other rate, relatively shortly after the installation of the system.

PADEP's Experimental Guidance Document (PADEP, 2003) provides several provisions for the early evaluation of "controlled fill" prior to the 4-year period. These provisions, both during placement of the POINT™ System and during the evaluation period, will be followed in any future pilot or full-scale applications, as appropriate, including the use of a certified Sewage Enforcement Officer (SEA) and a certified soil scientist. The TVP will be the final determination on testing and monitoring procedures.

In the event that the disturbed fill condition is not acceptable to the governing agency, the POINT™ System can be installed using several PADEP-approved treatment units. For example, a free access sand filter (§73.162(b)) or a subsurface sand filter (§73.54) can be modified with the denitrification layer to be consistent with PADEP regulations.

### 5.5 pH

Two primary pH concerns are typically raised when considering a system similar to the POINT™ System. First, one needs to confirm that microbial denitrification is not overly sensitive to pH fluctuations from the incoming effluent. Second, one should confirm that the denitrification process does not cause unacceptable pH conditions to the receiving body. Research indicates that denitrification operates optimally in the 6.0 to 8.0 pH range, which is typical of on-lot sewage treatment systems, therefore, denitrification efficiencies are not expected to be compromised by pH.

Impacts on the receiving body as a result of denitrification are not expected based on the byproducts of the reaction. As shown in Section 5.2, the denitrification reaction produces alkalinity ($OH^-$). This alkalinity is expected to be beneficial based on the slightly acidic nature of groundwater in many areas of Pennsylvania. Additionally, nitrification, which occurs directly above the denitrification layer, produces minor amounts of acidity ($H^+$) which will then be buffered by the denitrification process.

### 5.6 Temperature

Temperature fluctuations and their impact on treatment efficiencies are often a concern in biological treatment scenarios. This is witnessed in some of the treatment technologies listed in Section 3.2 where treatment efficiencies are reduced in winter months. This is not the case for the POINT™ System as the denitrification layer is normally positioned greater than 4 feet below ground surface in a horizon that does not experience significant temperature fluctuations. Furthermore, several researchers have shown that biological denitrification, although more rapid at higher temperatures, will still occur at acceptable rates down to as low as 0°C (Brown, 2002). As the geothermal temperature 4 to 5 feet below ground surface is about 55°F and stable, denitrification in the POINT™ System should be effective and stable.

## 5.7 Traditional Treatment Parameters

The following section is provided in support of how the POINT™ System will be able to maintain the removal efficiencies of a traditional on-lot sewage treatment system while still treating for nitrate. Generally, the traditional treatment parameters consist of solid constituents (total suspended solids [TSS]), organic substances (typically measured in terms of biological oxygen demand [BOD]), nutrients (primarily nitrogen and phosphorous), pathogens (bacteria and viruses), and miscellaneous parameters (surfactants, inorganics [metals], toxic organics). Each grouping is summarized below including how the POINT™ System will continue to treat the traditional parameters.

### 5.7.1 Solid Constituents

Solid constituents consist of large to small diameter particulate which generally settle out in a properly-sized septic tank. Particulate remaining in the septic tank effluent is generally small (in most cases colloidal) and is measured in terms of TSS. The POINT™ System employs the same septic tank design parameters as a traditional septic system, therefore, no increase or decrease in the removal efficiency would be experienced at this stage. It is generally accepted that the remaining TSS which is introduced into the absorption area is removed to acceptable levels within the first 1 foot of the infiltrative surface (EPA, 2002: OSU, 2002). As the top portion of the POINT™ System will be compacted native soil, TSS is expected to continue to be easily removable within the first foot of soil under the distribution piping.

### 5.7.2 Organic Substances

A host of organic substances, most dissolved, are present within septic tank effluent which is delivered to the leaching field. These substances collectively create an oxygen demand on the receiving body. Primarily through biological activity in upper portions of the absorption area soil, the organic matter is normally removed within the first two feet of soil. This is supported by case studies cited by EPA (EPA, 2002: Anderson et al., 1994) and also by OSU (OSU, 2002). As the top portion of the POINT™ System will be compacted native soil, BOD is expected to continue to be easily removable within the first two feet of soil under the distribution piping.

### 5.7.3 Nutrients

Nitrogen removal is not normally achieved in a traditional on-lot sewage treatment system. Instead, nitrogen is simply converted from organic nitrogen to ammonia (septic tank) to nitrate (absorption field). The POINT™ System provides significant nitrogen removal as detailed above.

The other main nutrient constituent is phosphorous. Phosphorous is removed in the absorption area primarily via adsorption and secondarily via precipitation (EPA, 2002).

The adsorptive capacity of soil is highly dependent on several soil characteristics. An increase in organic matter in soil increases the adsorptive capacity for phosphorous (Florida, 2003), therefore, the POINT$^{TM}$ System's denitrification layer is expected to increase the phosphorous removal rate over traditional on-lot sewage treatment systems.

### 5.7.4 Pathogens

Pathogens in on-lot sewage treatment systems generally include bacteria and viruses. Bacteria are normally removed by filtration (physical) in the first 1-2 feet of soil. The bacteria then typically do not survive long due to the hostile environment unlike the host environment (EPA, 2002). Viruses are smaller than bacteria and are removed by adsorption, also then followed by mortality due to hostile conditions. Both of these removal mechanisms are a function of the adsorption area soil of a traditional on-lot sewage disposal system. The POINT$^{TM}$ System is installed in a similar fashion and therefore should not impact its ability to remove pathogens at a similar rate as a traditional system.

## 6.0 CONCLUSIONS

Groundwater degradation by nitrate is an increasingly-important regulatory issue. Unfortunately, the current approach to addressing the issue is inversely proportional to land preservation goals, resulting in more land destruction per acre to achieve density requirements established for nitrate. A more balanced approach is to *limit* the discharge of nitrate to groundwater, as opposed to spreading it out. The POINT™ System is a passive, in-situ method of reducing the mass of nitrate discharged to groundwater while continuing to treat sewage at levels consistent with current technology. This system is conceptually simple, easy to install, has a long operating life, and requires little or no maintenance. With advanced on-lot sewage treatment systems such as the POINT™ System, land planners, developers, and regulators will have a much-needed tool to reduce nitrates to the environment while balancing development and land preservation.

The technology in the POINT™ System has been shown through bench- and pilot-scale testing to be effective at reducing nitrate concentrations by more than 90% via denitrification. As with any innovative technology, additional data and full-scale trials will be beneficial to confirm the effectiveness of the technology and to develop design standards for future installations. These data collection activities will be pursued through partnerships with regulatory agencies and their respective assessment protocols, such as PADEP's Technology Verification Protocol (TVP).

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