Evaluation of Methods to Control Phosphorus in Areas Served by

Onsite Septic Systems

- The State of the Art -

George Heufelder, M.S., R.S. and Keith Mroczka Massachusetts Alternative Septic System Test Center a unit of Barnstable County Department of Health and Environment

Executive Summary

Phosphorus presents a unique challenge to watershed managers where residences are served by onsite septic systems due to dearth of available treatment technologies and the role that phosphorus plays in the eutrophication of many freshwater ecosystems. Three efforts were conducted to summarize the state of the art regarding phosphorus management from onsite septic systems and make recommendations for further research. Foremost, an open solicitation resulted in the testing of three technologies that attempt to remove phosphorus. Tests were conducted at the Massachusetts Alternative Septic System Test Center in Massachusetts (MASSTC) during 2002 – 2003. Secondly, data collected at that facility since 1999 from standard septic tank-soil absorption systems and various advanced treatment units were used to gain a better understanding of factors that promote phosphorus reduction. These analyses also allowed the formation of recommendations to standard septic system designs to enhance phosphorus removal. Finally, a literature review regarding technologies not directly tested as well as alternative approaches to phosphorus management was conducted. These efforts were coincident with a project of the National Decentralized Resources Capacity Development Project (Etnier et al. 2005) that was charged with the evaluation of phosphorus management in the micro-scale, and the reader is encouraged to also read this document, since the technologies reported on herein are placed in evaluation matrices comparing them with various other phosphorus management strategies.

Three technologies were directly tested for their ability to remove phosphorus. A Waterloo BiofilterTM, that demonstrated efficacy for removing nitrogen in previous testing, was modified with a small experimental module of hematite-coated wood chips. This modification exhibited only limited increase in phosphorus removal (~29%) compared with this system without the experimental module (~11%). PhosphexTM, a patented upflow filter following a recirculating sand filter and containing basic oxygen furnace slag exhibited >99% total phosphorus (TP) removal, however the discharge pH was >11, which precludes discharge to the groundwater under Massachusetts Department of Environmental Protection regulations. Attempts to buffer the pH of this unit were unsuccessful with the exception of a short period following its passage through peat. PhosRidTM, a treatment system with a unique configuration that manipulates the valence state of iron to optimize its combination with phosphorus removed >99% of TP following passage through a final sand filter. This system continues to undergo research and development at MASSTC and has proceeded to the Pilot Approval stage in the Commonwealth of Massachusetts.

Extensive datasets collected since 1999 were examined for evidence of any phosphorus removal by advanced treatment units that purport to remove nitrogen. Four systems were specifically researched: FASTTM, AmphidromeTM, Waterloo BiofilterTM and a non-proprietary recirculating sand filter. In addition data from a standard septic tank-soil absorption system and a drip dispersal system (GeoflowTM) were also reviewed. Examination of the data support the following recommendations for the modification of standard septic system designs to enhance phosphorus removal: maximize the vertical separation between the bottom of the soil absorption system and the groundwater (even at the cost of lessening the horizontal distance to a surface water), distribute the effluent over the soil by pressure distribution where possible, locate the soil absorption system in the upper soil horizons if possible (drip dispersal systems are optimal), select areas where the soil chroma are darker (toward the reddish hues) where possible, select for finer soils in soil absorption systems where possible (taking care to determine the appropriate loading rate). Finally, the data strongly suggest that when advanced treatment units are used, they should disperse the effluent by pressure distribution or drip dispersal to attain maximum phosphorus retention on the receiving soil.

A literature review of other alternative onsite septic systems was conducted and included manufactured units (WallaxTM, RUCKTM, sequencing batch reactors), constructed wetland (various designs), peat, filter beds using adsorbents (various designs), selective resins, and hybrid techniques that incorporate principles from two or more of these techniques. Although the principles involved in many of these techniques have a sound theoretical basis, none has clearly demonstrated a long term history of success for phosphorus removal. Of these referenced techniques, constructed wetlands and the use of manufactured materials for phosphorus adsorption such as Filtralite® in various configurations is the subject of promising recent and continuing research.

Diversion techniques for phosphorus management include composting and urine separation and, in looser context, the containment of blackwater in tight tanks. These strategies endeavor to prevent phosphorus from entering the waste stream, hence obviating the need to treat or remove it. In many instances, diversion techniques anticipate the possibility of recycling the nutrient component of the wastes. This strategy is being investigated in a number of foreign countries but there are limited data to this date on their overall success.

Certain "soft" measures are also useful in an overall phosphorus management strategy. These include prohibitions on phosphorus-containing cleaners, prohibitions on garbage grinders, design modifications for standard septic systems discussed above, and a public outreach and education program regarding sources of phosphorus and its implication.

Areas of research that offer the most promise for an onsite solution were identified and include:

- Investigations on the improvement of the configuration of elements involved in the reductive iron dissolution principle,
- Investigations regarding feasible configurations of adsorptive media that may allow for their retrieval and subsequent recycling of phosphorus,
- The identification of technical, regulatory, and cultural barriers for the reuse of "spent" media containing bioavailable phosphorus,
- Confirming the efficacy of drip dispersal technology in the treatment for phosphorus including the identification of mechanisms involved (plant uptake, soil sorption, precipitation of solid phosphate compounds) and the relative importance of each.
- Continued research of exchange resins, and

Development of guidelines for standard septic system designs that describe methods to enhance phosphorus removal.

Phosphorus in wastewater presents unique challenges and opportunities. If regarded foremost as a nuisance contaminant that only requires treatment, research efforts for treatment of phosphorus are dominated by the challenges of addressing of the solid end products of the manipulated phosphorus chemistry. A burgeoning effort in certain countries, however, is recognizing the opportunity to recover a valuable nutrient from the wastewater stream using diversion techniques. While this effort's major challenge was once overcoming the obvious public health issues, it is now also challenged by the readjustment of attitudes toward recycling of any component of human waste. We identify the determination those barriers, (sociological, financial, practical and regulatory) that impede any serious consideration of phosphorus source diversion as a means to address the phosphorus management issue in areas not served by municipal sewer as a priority research need. It is only by performing some investigation in these areas that wastewater management plans can be complete in their presentation to the public regarding the economic and ecological advantages and disadvantages of their full range of options.

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Authors' note

The efforts described here respond to the need for information on phosphorus management techniques in areas where the onsite septic system is the predominant method of wastewater disposal. These efforts were coincident with a project of the National Decentralized Resources Capacity Development Project (Etnier et al. 2005) that was charged with the evaluation of phosphorus management in the micro-scale. The reader is encouraged to obtain and read this report¹, as it complements efforts reported on herein. In particular some of the technologies tested under support from this project are discussed and placed in various evaluation matrices along with additional phosphorus management techniques. Coordination with these efforts was purposeful and enhanced the overall comprehensiveness this project. This project was supported by a grant issued under the Federal Clean Waters Act Section s.319. Mention of any product or procedure in this report does not constitute an endorsement by the Environmental Protection Agency, the Massachusetts Department of Environmental Protection or Barnstable County. Opinions expressed herein do not necessarily reflect the opinions or policies of these agencies.

1.0 Introduction

Phosphorus is essential to life. Even a casual view of any basic biology book reveals the importance of this element in life's energy pathways, genetic replication and other vital processes. It is eliminated from the body in feces and urine and thus becomes part of the domestic wastewater stream. In addition to use in metabolic pathways, phosphates are also used in detergents due to their ability to keep fine dirt particles in



suspension and to emulsify grease and oils. Following the 1970's their use in laundry detergents was restricted in recognition of its substantial impact on the ecology of freshwater receiving waters. To that point, laundry wastewater was the major source of phosphate in domestic wastewater. In its natural form, phosphorus is usually present as a phosphate: the element itself joined with four oxygen atoms.

In comparison to the occurrence of other natural requirements for biota (carbon, nitrogen oxygen and sulfur) phosphorus is the least abundant and most commonly limits biological productivity in temperate-climate freshwaters. In some instances, even relatively small amounts of phosphorus released from wastewater into freshwater aquatic systems can cause over eutrophication. Eutrophication itself is a natural process in which natural runoff and leachate of nutrients is assimilated into an ecosystem, moving it through stages of succession. When excessive anthropogenic sources nutrients enter the ecosystem by these means, undesirable changes to the

¹ Report available online at <u>http://www.ndwrcdp.org/</u> or from the National Small Flows Clearinghouse, P.O.Box 6064, Morgantown, W.V. 26506-6065 Tel: (800) 624-8301.

ecosystem can result including excessive algae growth, the impairment of water quality for recreational use, and even fish kills. This condition is referred to as over-eutrophication.



Figure 1-1 Diagrammatic Representation of a portion of the phosphorus cycle.

Freshwater Body

The recognition of the importance of phosphorus to aquatic ecosystems and the understanding that phosphates are an inevitable constituent of wastewater has led to the implementation of phosphorus-removal technologies in many larger municipal treatment plants, particularly those that discharge to surface waters. In areas served by onsite septic systems however, it has been generally assumed that options for phosphorus removal are limited or non-existent. The purpose of this report is twofold. Foremost, we describe selected technologies that were tested for their efficacy in phosphorus removal and synthesize data from other phosphorus removal technologies reported elsewhere. In addition, we discuss other management options for phosphorus, including "soft" measures, or means to prevent phosphorus from entering the wastewater stream, and their feasibility of offering meaningful management for phosphorus in watersheds.

1.1 The Search for Sustainable Phosphorus Management

The removal of phosphorus from wastewater presents a unique challenge. While nitrogen can be removed from wastewater by manipulation through its gaseous phase and allowing it to passively exit the system, treatment strategies to remove phosphorus all involve solid byproducts that must be considered. In general phosphorus removal involves the processes of adsorption, chemical precipitation, or the incorporation into biomass.

A concept that should be incorporated into the management of phosphorus is that of "sustainable" strategies. Phosphorus is a valuable nutrient that, if properly managed, may offer opportunities for recycling into locations where productivity is desired. With this in mind, the overall and optimal

phosphorus removal strategies should be those that maintain phosphorus in a bioavailable state. Although this goal can be accomplished in some of the onsite wastewater treatment strategies discussed below, alternative measures such as prevention of the entry of phosphorus to the wastewater stream, are also viable options for overall management of this nutrient and should be considered. While this report is not exhaustive in the treatment of this subject, the reader is referred herein to a number of documents useful in this regard.

This report details efforts supported under the Federal Clean Waters Act 319(b) grants program. It is meant to summarize the efficacy of a number of technologies tested by the Massachusetts Alternative Septic System Test Center during 1999-2002 for nutrient removal (primarily focusing on nitrogen, but for which phosphorus data were collected), as well as describing the results of a focused solicitation for technologies purporting to remove phosphorus (2002 - 2006). Additionally, a survey of the literature was conducted in order to report on those technologies not tested under this grant.

Phosphorus Removal by Standard Septic Systems 2.0

2.1.1 Phosphorus Removal in a Standard Septic Tank

Standard septic systems are generally comprised of a septic tank and a soil absorption system (SAS). The septic tank is a watertight unit that discharges to the SAS after providing various residence times to allow for the anaerobic digestion of waste and the settling of solids. Few authors have reported the removal efficiency of the septic tank portion of a standard septic system (Etnier et. al., 2005) and this author reports on the difficulty in determining this value from the published literature. Examining data of the Massachusetts Alternative Septic System Test Center (MASSTC), from three 1500 gallon single compartment septic tanks processing 330 gallons per day domestic wastewater and operating for over two years, we found that the removal efficiency of the septic tank was 6.4-8.7% (Table 2-1).

the Massachusetts Alternative Septic System Test Center, 1999-2002. Wastewater loading was 330 gallons/day.						
		Septic	Septic	Septic		
	Influent	Tank 1	Tank 2	Tank 3		
Mean (Total Phosphorus mg/L)	5.2	4.8	4.9	4.8		
Median	5.3	4.7	4.7	4.8		
Observations	65	63	62	63		
Percent Removal (Total Phosphorus)		8.7%	6.4%	7.1%		

1 1 5 0 0

These data contrast findings of Pell and Nyberg (1989) who found up to a 48% reduction in phosphorus in a three part septic tank in steady state (after 78 days). A single set of observations of the three MASSTC septic tanks following approximately 14 days of operation does suggest that during the initial operation phosphorus removal can be substantial. The three tanks observed removed 61%, 58% and 59% of the total phosphorus during a two week start-up period.

However, the long term phosphorus removal efficiency of these septic tanks was less than 10%. The likely mechanism for removal of phosphorus in septic tanks is its accumulation in the biomass of the sludge. Since this value appears to reach a steady state following a brief start-up period, it does not appear that requiring excessive pumping of septic tanks² is particularly efficacious as a phosphorus management tool unless pumping is conducted repeatedly following the start up period (every 2-3 weeks).

2.1.2 Potential for Enhancing Phosphorus Removal in a Standard Septic Tank

Perhaps the oldest and best understood process for the removal of phosphorus from wastewater is the precipitation of phosphorus with iron or aluminum salts. By 1975, 135 cities in the United States were using aluminum sulphate (alum) to precipitate phosphorus (Ockershausen 1975). Many authors report relative success at removing phosphorus from wastewater streams using alum (Viraraghavan et. al. 1979, Galonian and Aulenbach, 1973). Similarly, by adding alum to the septic tank each time system's toilet was flushed Brandes (1977) was able to remove 85% of the phosphorus in the onsite setting. These and subsequent authors working with both municipal and onsite applications found, however that alum addition presents other technical challenges. These include the increased production of sludge, alteration of the pH, and adverse impacts on wastewater biota through direct toxicity or inhibition. Thus, the apparent efficacy of simply adding alum to a septic tank to remove phosphorus needs to be balanced by the need to increase the frequency of sludge removal from the septic tank, as well as considering the effect that direct toxicity might have on the biota of the septic tank and soil absorption system, and the facilities receiving the removed sludge.

2.1.3 Phosphorus Removal in Soil Absorption Systems

The removal efficiency of a soil absorption system (SAS) for phosphorus depends on a number of factors including soil texture, mineral content, pH, cation exchange capacity (CEC), configuration of the soil absorption components, and its vertical position relative to surface vegetation.

Three standard leaching trenches were operated for nearly two years at MASSTC. These trenches had an effective bottom width of 36 inches and an effective sidewall height of 24 inches and had a minimum of 18 inches of cover. The hydraulic loading rate of the trenches was 0.74 gal/day/sq ft. which is calculated using effective bottom area and sidewall. Trenches were 17 ft. long. Mean total phosphorus concentration to the SAS (exiting the septic tank) was 4.8 mg/L (Standard Deviation = 0.8, observations = 191). Total phosphorus concentration following 5 ft. of passage through medium sand was 2.6 mg/L (Standard Deviation= 0.4, n= 49), which approximates a 47% reduction. This removal remained relatively stable over the two years, with no indication of reduced efficiency to that point.

Operation of a drip disposal system at MASSTC that discharged directly from a septic tank, offered a unique opportunity to compare the two dispersal modes (standard trenches vs. drip dispersal) under controlled conditions. Each system was underlain by the same medium sand. The testing duration for the drip technology was for two years concurrent with the standard trenches. Drip technology was installed in triplicate, with identical components. Similar to the standard trench design, wastewater was apportioned into fifteen equal doses on a schedule

² The term "septic tank" here refers to their use in context of a standard septic tank-leachfield system as opposed to the term sometimes applied to tight tanks or holding tanks.

designed to mimic the pattern of wastewater use in a typical residence: 40% of daily flow prior to 09:00 AM; 25% of flow during midday; 35% of flow in the evening.

A polyethylene liner at about 10 feet below grade collected all leachate from the three technology replicates. In the Geoflow® installation, leachate from the dripline traveled a vertical distance of approximately 9 feet through medium sand before reaching liner and the sump. In the conventional trenches for soil disposal of septic tank leachate, this vertical distance was approximately 6.5 feet before reaching the liner (Figure 2-1). In addition, the final cover for the drip system was approximately 6-10 inches, including a layer of soil in connection with commercially-grown sod.

Figure 2-1 Schemata of standard soil absorption system and drip dispersal system installed at The Massachusetts Alternative Septic System Test Center.



Installation of Standard Soil Absorption System at MASSTC

Installation of drip disposal system at MASSTC



The data suggest a significant impact by the mode of delivery and surface orientation of the drip disposal unit (Figure 2-2), with the majority of levels in the drip dispersal sump < 1 mg/L TP.



Although the data leave in question whether the increased phosphorus removal may be caused by the additional sand passage before the collection point (9 ft. compared with 6.5 ft.), an inspection of phosphorus data from pan collection devices placed 6 inches and 18 inches beneath the drip irrigation lines indicate that 36-62% of the phosphorus is removed within 6 inches below the drip dispersal network. This compares with approximately 24% phosphorus removal at an elevation of 24 inches below the standard trenches.

Thus, it appears from inspection of data from two years of operation that phosphorus removal can be enhanced by drip dispersal systems. Following the first 18 months of operation a gradual increase in the total phosphorus was noted beneath the drip disposal system. We are unsure however whether this increase reflects a true reduction in the ability of the system under normal conditions to reduce phosphorus or whether the observation was the result of the release of biologically bound phosphorus following an infestation of army worms (*Pseudaletia unipuncta*). In the summer of 2001 large portions of the above-ground sod biomass was consumed during this infestation. This infestation was also concurrent to observations of increased nitrogen in the collection devices, which lend support to the theory that the increases in phosphorus may be related solely to this event.

2.1.5.1 Drip Disposal Soil Absorption System Issues

Since drip disposal units are not common in the Commonwealth, there are a number of issues about which the reader might have questions. The reader is directed toward excellent research

reported by the American Society of Agricultural Engineers (ASAE) in their Proceedings from the Ninth National Symposium on Individual and Small Community Sewage Systems (March 11-14th, 2001, Fort Worth Texas) in which was devoted an entire section of reports on various aspects of drip disposal. For design guidance, the reader is directed to peer-reviewed work conducted with support from the Electric Power Institute in 2004³.

The two key questions commonly asked regarding drip disposal technology relate to its use in cold climates and the necessity of pretreatment. Authors in the previously cited ASAE report concur that properly installed drip disposal systems demonstrate reliability even in cold climates (Wisconsin was specifically referenced). Although pretreatment with drip disposal is commonly thought to be a prerequisite, authors from the ASAE report and others concur that, again with proper design considerations, advanced treatment prior to drip disposal is not required in many situations. In fact, during testing at MASSTC, drip disposal units were tested on septic tank effluent with no additional treatment. Presently (as of April, 2006), drip dispersal proponents are in review for approvals by the Commonwealth of Massachusetts for use without pretreatment.

2.1.4 Potential for Enhancing Phosphorus Removal in a Standard Soil Absorption System

Although the principles involved in the removal of phosphorus within soil absorption systems are not completely understood, there are general principles that, if applied, offer the opportunity to enhance phosphorus treatment in the standard septic system. These principles are as follows:

- Finer textured soil offers greater ability to adsorb phosphorus compared with coarse sands.
- The removal of phosphorus in any soil absorption system is related to the volume of soil that the percolating effluent is exposed to.
- The more aerobic and non-reducing unsaturated-zone environments have a higher capability to remove phosphorus.
- Soils containing a higher content of metal oxides (i.e. iron and aluminum in acidic soils and calcium in basic soils) have a greater ability to sequester phosphorus.
- Shallower placements of the soil absorption system offer the ability of plant-root penetration and hence offer another mechanism and opportunity for phosphorus removal.
- Phosphorus is more mobile under saturated conditions, especially if those conditions are reducing conditions.

The following sections describe design characteristics that might be modified and are within the present regulatory latitude of the Commonwealth of Massachusetts to maximize the removal of phosphorus within the soil absorption system.

³ Available by contacting EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord California, (800) 313-3774, press 2 or internally x5379, (925), 609-9169.

2.1.5 Enhancing Phosphorus Removal in a Standard Soil Absorption System by Considering Design Parameters

The Commonwealth of Massachusetts allows considerable latitude in the design of standard septic systems in features that can be used to enhance phosphorus removal. Before discussing these possibilities, however, it should be understood that despite broad acceptance of these principles, it is also generally understood that the ability of soils to remove phosphorus by adsorption is finite. Although the measures discussed below generally enhance phosphorus removal, quantifying the cost effectiveness of delaying what may be inevitable must be done on a case by case basis with site-specific information at hand.

2.1.5.1 Site Selection as a Means of Enhancing Phosphorus Removal

Septic system design requirements in the Commonwealth of Massachusetts begin with a site evaluation, including soil evaluation and percolation tests. In general, when sites are evaluated and when given a choice, the system designer prefers siting the system where percolation rates are the fastest. Areas of "slower" soils are avoided because the soil absorption system size is inversely related to the percolation rate (the slower the percolation rate, the larger the required soil absorption system). The incentive here is to save the client money and avoid larger excavations. In areas where phosphorus removal is desired, this practice of locating systems in the "fastest" soils needs to be reconsidered. Slower percolating soils generally contain finer soil particle sizes that enhance phosphorus removal, while "faster" soils adsorb less phosphorus.

The present allowance in Massachusetts to use the "B" layer for construction of septic systems actually facilitates phosphorus removal (see revisions 310 CMR 15.000 – April 2006). The B layer often contains accumulations of clay, iron, aluminum and other materials that sorb and/or complex with phosphorus, making it less mobile. Additionally the vertical location of the B layer makes nutrients available to plants, thus sequestering phosphorus even more effectively. Accordingly, in areas where phosphorus removal is desired, the use of the B layer for construction of soil absorption systems should be encouraged.

Another site characteristic that is sometimes open to choices by the system designer is the vertical distance to groundwater. In this feature, the maximum distance to groundwater is desirable to enhance phosphorus removal. The principle is that effluent exposure to oxidized forms of iron and aluminum that occur in the vadose or unsaturated zone is conducive to phosphorus retention. The greater the travel path prior to reaching saturated conditions, the greater the exposure to metallic oxides. As a practical matter, it is difficult to assign the relative premium of increased vertical separation and increased horizontal setbacks from a freshwater body. Many towns in the Commonwealth of Massachusetts have increased the horizontal setback between soil absorption systems and water bodies to 100 feet or greater (only 50 ft. is required under the state regulation). As a general principle, vertical separation should hold the higher value. If, for instance, an applicant can obtain an increase of one foot vertical separation from groundwater, Boards of Health should consider relaxing, to some extent, their horizontal setback requirements that exceed 50 ft. This principle is also efficacious for the removal of pathogens.

A final aspect of site selection process that may present choices to a system designer is mineral content of the soil as indicated by color. Massachusetts incorporates the Munsell® Color determination as part of the soil evaluation procedure. If given choices on developing sites, the designer should use those areas where the receiving soils have redder hues. Etnier et al. 2005

suggest colors 7.5 YR and redder generally indicate soil material with higher phosphorus retention ability compared with other hues. In situations where the soil absorption system is to be installed in fill, if possible, sand having the darker chroma would be desirable since the darker (toward reddish) hues usually indicate metallic oxides that can bind with phosphorus. The addition of this specification to fill requirements would significantly enhance phosphorus removal for systems in fill.

2.1.5.2 Design Features as a Means of Enhancing Phosphorus Removal

Certain design features of a soil absorption system have substantial influence on the phosphorus retaining ability of the standard septic system. Perhaps the most influential aspect of the soil absorption system is the method of septic tank effluent delivery. It is well accepted that the phosphorus retaining ability of a soil absorption system is directly related to the extent of exposure of the septic tank effluent to the soil particle surfaces. It is also understood that pressure distribution of the effluent maximizes this aspect of treatment by distributing to and hence utilizing more of the potential phosphorus binding sites on the soil particle surfaces. In most situations therefore, pressure distribution of effluent provides better overall phosphorus removal and should be incorporated into septic system design whenever feasible. Pressure distribution also minimizes saturated flow conditions than can occur under gravity distribution, thus preventing reduced conditions in the leach field that might promote migration of phosphorus to the groundwater.

Literature reviewed by Etnier et al (2005) also indicates that phosphorus retention is enhanced by the narrow trench. Narrow trenches theoretically expose septic tank effluent to more soil particle surfaces as the trenches pond and divert effluent through their sidewall area. This is in comparison to the leaching bed design where an entire area (often rectangular) is excavated and perforated pipe is laid in a network that superficially resembles the same network laid in trenches. The difference is that in trench designs, native material is situated between the distribution lines and the sidewall of the trench is used in treatment as opposed to acceptable fill material which is generally coarse aggregate with little phosphorus binding ability. These authors believe however, that the efficacy of a trench design vs. bed design is only beneficial when the trench is located in the upper soil horizons where plant roots are allowed contact with wastewater. This is particularly true in the Commonwealth of Massachusetts where current standard trench designs require that trench spacing be three times the effective width or depth of the trench when the reserve area is located between trenches. In this situation any sidewall advantage is negated since the soil-wastewater interface of a bed design is similar if not larger in area than the trench design.

2.1.5.3 Materials Substitution and "Doping" as a Means of Enhancing Phosphorus Removal

Materials substitution refers the practice of substituting materials commonly available for use in a soil absorption system with materials that can enhance phosphorus removal. In the Commonwealth of Massachusetts, there is only one accepted practice that can broadly be considered for this purpose. Presently, tire chips, as a replacement for stone aggregate, do offer some possibility for phosphorus retention. A report by Sengupta and Miller (2000) on a project at MASSTC did indicate that following approximately four months of wastewater flow to two tire chip leaching trenches, the ortho-phosphate levels beneath the trenches were less than the control gravel trench. The purported mechanism of phosphorus retention is the complexing of phosphorus with the exposed iron of the steel-belted tire fragments. While the main intent of these authors was to demonstrate that tire-chip aggregate did not leach any contaminants of

concern, it does appear that tire chips may offer at least some additional benefit for phosphorus removal for at least the short-term. These results concur with Richter and Weaver (2003) and others who found that tire chips sequester phosphorus in constructed wetlands wastewater treatment systems. In general, since the availability of iron from the exposed steel belts is finite, phosphorus removal in systems that incorporate shredded tires, whether as aggregate, filter media or constructed wetlands substrate would be expected to eventually diminish in this ability.

"Doping" refers to the practice of mixing materials into the receiving soil in the SAS that will enhance the absorption of phosphorus. The addition of metallic oxides, for instance, to sand fill being used in a soil absorption system can theoretically enhance phosphorus removal efficiency. Doping is not widely considered for a number of reasons. Foremost, is the unknown effect the doping material might exert as it complexes with phosphorus. Of prime concern is the effect that the complexed material might have on the hydraulic characteristics of the fill material. In addition, assuming that doping became a strategy of choice, this would imply that at some point, when the material used became saturated with phosphorus, it would have to be replaced. In general, the state of knowledge in this field is not developed, and only few demonstration sites have been conducted.

3.0 Phosphorus Removal by Advanced Onsite Treatment Septic Systems

3.2 Advanced Onsite Systems Purported to Remove Nitrogen

The advanced onsite septic system market has evolved over recent years from providing advanced treatment for the removal of Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) to providing systems focused on removing nutrients. The former systems were developed to overcome limiting or difficult soil conditions, while the latter recognize other concerns such as nitrogen release to drinking water aquifers and marine embayments. The Massachusetts Alternative Septic System Test Center (MASSTC) research efforts under the Environmental Protection Agency's Environmental Technology Initiative (ETI) offer a unique opportunity to determine whether those systems designed to remove nitrogen concurrently attenuate phosphorus. Below we examine data from three technologies tested under the ETI program. The results of nitrogen testing for these technologies are available in report from the website http://buzzardsbay.org/etiresults.htm. The three technologies reported are FAST (Bio-Microbics, Inc. 8450 Cole Parkway Shawnee, KS 66227), Amphidrome (F.R. Mahony & Associates, Inc. 273 Weymouth Street Rockland, MA 02370), and the Waterloo Biofilter (Waterloo Biofilter Systems, Inc. P.O. Box 400 143 Dennis Street Rockwood, ON N0B 2K0 Canada). The comparison is first made between these systems and a standard septic tank as determined at the distribution box prior to the discharge to the soil absorption system. The Amphidrome[™], MicroFAST[™], and Waterloo Biofilter[™], removed 22.5% (range 19.7-28.4%), 19.7 % (range 18.5-20.8%) and 11.4% (range 8.5-12.7%) of the total phosphorus respectively compared with the standard septic tank removal of 6.4-8.7% total phosphorus (Figure 3-1).

It is interesting to note that despite the superior phosphorus removals in the advanced treatment units themselves compared with a septic tank, the composite removal of the advanced units with their respective leaching trenches was inferior to the standard septic with identical soil absorption systems (Figure 3-2). This author believes that this again underscores the importance of effluent delivery systems to the overall process of phosphorus removal in a septic system. Amphidrome, which had the greatest phosphorus removal in the treatment unit, exhibited the least overall Figure 3-1 Comparison of total phosphorus removal among three advanced treatment units and a standard septic tank as measured prior to the soil absorption system. Mean provided with 95% Confidence Interval. Data collected 1999-2001.



Figure 3-2 Comparison of total phosphorus removal among three advanced treatment units and a standard septic tank as measured as measured at a point 6.5 ft below the soil absorption trenches. Mean provided with 95% Confidence Interval. Data collected 1999-2001.



phosphorus removal in conjunction with the SAS. This technology discharged its entire daily wastewater load after treatment during one 20 minute time period. This practice, since altered by the manufacturer, likely resulted in a highly saturated and localized flow path within our test cells. As a result, less of the soil particle surface area beneath this system is utilized for phosphorus sorption. The situation is exacerbated by the fact that the effluent quality (generally less than 30 mg/L Biochemical Oxygen Demand [BOD] and Total Suspended Solids [TSS]) does not allow for a biological mat or restrictive layer to facilitate the spreading out and evening of distribution of effluent across the soil absorption system. In contrast, the standard septic tankleach trench system distributes the septic tank effluent to comparatively more soil particles by the following mechanism. In the standard system, biological growth is encouraged by the organic loading, since comparatively less organic material is removed in the pretreatment of the septic tank vs. an advanced treatment unit. This growth progressively restricts flow across the soil interface and encourages new areas in the soil absorption system to be exploited. The area where biological growth restricts the passage of effluent across the soil-effluent interface is commonly referred to as the "biomat." It is this feature, in a standard septic tank-leachfield system that promotes unsaturated flow and the diversion of effluent to previously unexposed soil surfaces in the soil absorption system as the system matures. These principles are represented diagrammatically in figure 3-3.

Figure 3-3 Diagrammatic representation of the differences in wastewater dispersal between standard septic systems and advanced treatment units. A) A standard septic system showing progression of the biomat. B) Effluent applied from an advanced treatment unit showing a much reduced area of application and the resulting relatively saturated flow for extended periods.





3.3 Advanced Onsite Systems to Remove Phosphorus

Initially, proponents of five technologies expressed interest in attempting to demonstrate phosphorus removal from onsite wastewater. One company (Krafta Compact Clarifier) was no longer in existence at the time of actual project initiation. The purveyor of one technology, WallaxTM, decided to withdraw their letter of intent to participate when the project initiated. Three advanced treatment units were tested under support from this project, the modified Waterloo BiofilterTM, PhosphexTM, and Phos-RidTM.

3.3.1 Modified Waterloo BiofilterTM

The Waterloo BiofilterTM is an advanced onsite treatment system with a proven efficacy for removing portions of BOD, TSS, bacterial indicators, and nitrogen from wastewater in an onsite setting. As tested at MASSTC for nitrogen removal, septic tank effluent was recirculated over the top of the filter media, and approximately 50% of the percolate was returned to the septic tank (see reports from ETI and ETV referenced earlier). Later tests were performed by diverting the effluent through a matrix of Hematite (Fe₂O₃) - coated wood chips mixed with foam filter medium (Figure 3-4). Theoretically, the wood chips were used to reduce the oxygen or nitrate to remove nitrogen. The hematite and oxyhydroxides were to adsorb the dissolved phosphates. The unit was small (approximately 20 liters) and experimental.

The modified Waterloo Biofilter removed an average of 29% (median 27%) of total phosphorus (Figure 3-5) over the period tested. This compares with 11% removal of total phosphorus observed in the standard un-modified Waterloo Biofilter in 1999-2001. While the modification demonstrated some success, the effluent mean concentration of 4.2 mg/L total phosphorus still exceeds levels generally considered necessary to prevent undesirable environmental consequences.



Figure 3-5 Phosphorus removal by a modified Waterloo Biofilter™, measured at the Massachusetts Alternative Septic System Test Center 12/19/2001 – 1/19/2003. Raw data in Appendix 1. ** A single set of values observed in September 25, 2002 are considered laboratory errors and are excluded from this graph. 9 8 Influent Mean 5.9 mg/L Total Phosphorus (mg/L) - Effluent Mean 4.2 mg/L 7 6 5 4 3 2 1 0 $2^{19201} + 1^{19202} + 1^{9202$ Date

3.3.2 PhosphexTM

The PhosphexTM system as tested at MASSTC was comprised of a septic tank, recirculating sand filter and an upflow filter (Figure 3-6). The upflow filter was a concrete tank filled with basic oxygen furnace (BOF) slag, which is a waste material from the production of steel. BOF slag contains various oxides and silicates of iron, calcium, magnesium, and aluminum. Mineralogical analysis shows removal of phosphate to be sorption and subsequent precipitation of low solubility calcium-phosphate minerals such as hydroxyapatite (Ca₅(PO₄)₃OH).



Flow enters the system via the septic tank and flows into a pump chamber. From the pump chamber, wastewater is directed to the recirculating sand filter. A portion of the wastewater is diverted to the upflow filter containing the PhosphexTM media. Following passage through the upflow filter, the wastewater is discharged to a soil absorption system.

Results from the initial six months of sampling suggest that this technology can achieve near complete removal of phosphorus (Figure 3-7). From December 1, 2001- April 10, 2002 the detection limit for total phosphorus was 0.5 mg/L (reported as 0.25 mg/L or one half the detection limit). During this time no phosphorus was detected in the effluent at the detection limit. In order to quantify the effluent concentrations, a laboratory was located that could achieve better detection limits. From April 24, 2002- June 2, 2002, the mean total phosphorus concentration of total phosphorus in the discharge of the PhosphexTM was 0.08 mg/L (n=5). Despite impressive phosphorus removal efficiencies, however, the effluent did show a very high pH at the discharge point (mean = 11.25) during this period.



In an attempt to moderate the pH from the PhosphexTM filter itself, the vendor of this system retrofitted the discharge of this system with a cylindrical downflow filter filled with sphagnum peat moss. This was presumably due to the typical acidic nature of peat percolate and hence its theoretical ability to neutralize the basic discharge from the PhosphexTM unit itself.

An attempt to moderate the very base pH effluent showed mixed benefit (Figure 3-8). From August to early November, 2002 the pH of the combined system exhibited pH < 7.0. Following these dates, however, the pH showed a significant increase (> pH 9.0) through March 2003. Although following these dates, the pH showed a downward trend, the interim fluctuations and the changes to the physical characteristics of the peat caused the vendor to conclude that this method of pH adjustment was not sustainable using sphagnum peat moss. It was evident that the installation of the peat filter following the PhosphexTM did not significantly affect its ability to remove phosphorus (Figure 3-9). During the period August 21, 2002 – February 26, 2003, total phosphorus assays were performed on only the total system effluent (PhosphexTM + peat filter). These data show comparable phosphorus removal to periods when the PhosphexTM operated without the peat filter.





We conclude that the Phosphex[™] system has the potential for the removal of phosphorus to levels below 0.5 mg/L total phosphorus. In the Commonwealth of Massachusetts, however, the regulatory issue of effluent pH would have to be addressed. Presently, the Department of Environmental Protection policies suggest that a change in pH of three to four units as exhibited by the Phosphex[™] would not be allowed. This is likely due to the unknown effects the effluent might have on the soil substrate used for treatment/disposal, and further, the long-term effects on the receiving groundwater. The attempt to moderate the pH with sphagnum peat demonstrated some success, however this strategy would add to the complexity of the system operation and maintenance and there is a question regarding the sustainability of this practice. The peat in our tests began to show significant changes in physical characteristic and some changes were evident in its permeability (as evidenced by ponding on top of the peat).

The high efficiency of this system to remove phosphorus may warrant further research into means for moderating the pH at the discharge, however as configured without such devices it does not appear to be an onsite option for this region. The principle involved, that of complexing phosphorus with oxides of iron and calcium, has also been proved effective in constructing reactive barriers that intercept groundwater plumes contaminated with wastewater (Baker et. al. 1998) and may find some applications in broader areas where onsite septic system plumes can be defined.

3.3.3 PhosRidTM

PhosRidTM is a treatment process for phosphorus that proceeds from the work of Robertson (2000) and others based on a process called <u>r</u>eductive <u>i</u>ron <u>d</u>issolution (RID). In this passive process, an iron (Fe[III]) rich porous media is placed in direct contact with unoxidized sewage, such as effluent of a septic tank. The iron present reacts with the carbon in the sewage and is reduced to Fe[II] by the following process:

$$CH_2O + 4Fe(OH)_3 + 7H^+ \rightarrow 4Fe^{2+} + HCO_3^- + 10H_2O$$

The ferrous iron in solution reacts with soluble phosphates and may precipitate out as vivianite (hydrated iron phosphate as below) or other minerals.

$$3Fe^{2+} + 2PO_4^{3-} + 8H_2O \rightarrow Fe_3(PO_4) \cdot 8H_2O$$
 (vivianite)

As the effluent passes through the system to aerobic components, such as the leachfield, Fe[III]-P solids such as strengite⁴ may be formed by the reaction:

$$\mathrm{Fe}^{3+} + \mathrm{PO}_{4}^{3-} + 2\mathrm{H}_{2}\mathrm{O} \rightarrow \mathrm{Fe}_{3} (\mathrm{PO}_{4}) \cdot 2\mathrm{H}_{2}\mathrm{O} \text{ (strengite)}$$

At first glance, it may appear that the PhosRidTM strategy for removing phosphorus is much like the standard addition of ferric chloride (FeCl₃) or alum to precipitate the phosphorus. The difference, however is that the iron-rich porous media (containing for instance ferric hydroxide – Fe(OH)₃) is slowly dissolved by the sewage under reducing conditions in the septic tank effluent and is utilized for phosphorus adsorption as it is produced. Thus the wastewater stream itself "triggers" the release of the phosphorus treatment, reducing the need for accurately dosing

⁴ The formation of vivianite and strengite are only two possible reactions that may occur. In reality phosphorus may form a wide range of secondary minerals when wastewater and iron is present.

amounts of other precipitants such as ferric chloride or alum. Another difference between a simple alum addition and the RID is that the deposition of the iron-phosphorus compounds takes the form of secondary mineral grains and grain coatings as opposed to a low density flocculant that increases the sludge production (Robertson, 2000).

The PhosRid[™] as being developed for onsite system applications, attempts to arrange septic system components to take advantage of the reactive properties of iron with phosphorus, while avoiding the precipitation of iron-phosphorus compounds in components that are inaccessible or expensive to replace (such as the leachfield). Instead of discharging iron-phosphorus compounds that might precipitate in the presence of oxygen to the soil absorption system where they might alter the porosity of the media, the reduced effluent is first passed through an accessible sand filter component. The system schema is presented in Figure 3-10.



Sand or other media that serves as the oxygen-rich areas where iron-phosphorus compounds (such as strengite) can precipitate, will presumably be designed as accessible for replacement at specified intervals.

As configured at MASSTC, the PhosRid[™] system was undergoing continuing development. Its initial configuration was such that wastewater flows were variously split so that the capacities of each unit could be determined (Figure 3-11). It should be noted, however, that following testing

done under support from this grant, the proponent of this technology implemented many changes in loading and maintains participation in further research and development of this technology.



The RID process proceeds on the theory that reducing conditions in septic tank effluent will solubilize iron that is made available in the RID media. The available iron complexes with phosphorus (which is present as phosphate). The availability of the iron was evident in the RID media effluent (See raw data Appendix 3) at concentrations above the septic tank effluent, suggesting that iron from the media was indeed being reduced by the wastewater. Robertson (2000) found that wastewater with lower redox potential exhibited higher ability to mobilize the iron in his substrate. He associated this with the "freshness" of the sewage, with aged sewage exhibiting higher (hence less conducive to iron mobilization) redox potentials. Considering this hypothesis, initial trials at MASSTC supported under this grant, may have been conducted with less than optimal conditions. The two-compartment tank used for its convenience (it was in place prior to the initiation of the project and the proponent decided to take advantage of its use), likely produces an effluent that has a higher redox potential due to better internal processing of sewage and better wastewater stabilization (as evidenced by lower BODs). Following the collection of data reported here, the proponent replaced the two compartment tank with a standard single compartment tank. Results from these trials are not available at the time of this report.

During the initial three months, the total phosphorus reductions as measured just after the RID media show significant reductions (Figure 3-12). However following this initial period, reductions in phosphorus do not appear significant.



This contrasts with the reductions in total phosphorus following the sand filter element of the system (Figure 3-13). During those periods when concurrent samples were taken, total phosphorus levels were generally below our detection limit of 0.5 mg/L.



Data suggest that this technology has potential to remove phosphorus to levels below 0.5 mg/L. However, significant design features must be determined. The proponent of this technology, Lombardo Associates, Inc. (49 Edge Hill Road, Newton, MA 02467-1170) has been conducting significant research and development efforts at MASSTC and continues to do so as of March, 2006.

At present, this technology has a Piloting Approval by the Massachusetts Department of Environmental Protection. This allows up to 15 systems to be installed and monitored. The approval documentation refers to an "oxygenation filter" which is the sand filter referenced above. The approval, however allows this filter to be composed of "any sand, textile or foam filter approved by the Department." Details on the approval and an illustration of a standard configuration can be found on the Massachusetts DEP website http://www.mass.gov/dep/water/wastewater/w035467.doc.

3.2.4 Wallaх^{тм}

As previously stated, the United States purveyor of the Wallax[™] System (Aquapoint, Inc. 241 Duchaine Blvd. New Bedford, MA 02745) initially indicated interest in participating in these testing efforts, but withdrew their interest when the project began. Their advertising material states that the Wallax is a modular phosphorus precipitation system designed to achieve <1mg/l total phosphorus. This author found no data from third party organizations in North America to confirm the ability of this unit to achieve this level of treatment. A report from the Baltic Marine Environment Protection Commission (Baltic Sea Environment Proceedings Number 36 – Seminar on Nutrients Removal from Municipal Wastewater, 4-6 September, 1989, Tampere, Finland) suggests that levels of phosphorus approximating 0.8 mg/L can be achieved. This report also noted that the sludge removal from the unit would be projected at 4-5 times per year. Other Norwegian sources of data may be available.

At present there are no known pilot facilities using this technology in the Commonwealth of Massachusetts, and its application for onsite systems could not be confirmed. A diagram of the system can be viewed at the Aquapoint Company's website <u>http://www.aquapoint.com</u> or in the previously cited Baltic Sea report. Reportedly two Wallax systems have been installed in the State of New York, but no data from these systems are yet available (John Lefreniere, Aquapoint, personal communication).

3.2.5 Sand and Modified Sand Filters

Sand has long been used as a filter media for wastewater. It is variously placed and configured in onsite wastewater treatment systems from simply underlining disposal beds to being placed within containment structures through which wastewater percolates. In these structures, there is usually a sump-type collection system to either direct the effluent toward a disposal field (referred to as a single-pass or intermittent sand filter) or recirculate a number of times through the filter medium (referred to as a recirculating sand filter). Depending on the mineral content of the sand on its surface, the filter may remove significant amounts of phosphorous until adsorption sites become saturated. Many sands, particularly in Massachusetts, are coated with iron oxides which serve as binding sites for phosphorus. Between March 2000-April 2002, two recirculating sand filters were tested at MASSTC. Two different designs were used. Both designs incorporated the use of a 1500-gallon single compartment septic tank which discharged by gravity to a 1000gallon pump chamber. In the first design, all percolate from the pump chamber returned again to the pump chamber. A "Mickey Mouse" or buoyant ball valve was used to direct effluent toward the discharge when the level in the pump chamber was high. In the second design, the bottom of the sand filter container was equipped with a dam that directed approximately 80% of the filter percolate back to the pump chamber, allowing approximately 20% of the percolate to go to discharge. The sand used was 1-2 mm with a uniformity coefficient of less than 2.0 and had a

very light color indicating the absence of iron oxides. Flow schemata for each system are presented in Figure 3-14.

The results of both recirculating sand filters (RSF) were similar, indicating a 27-28% reduction in total phosphorus compared to the septic tank influent (Figure 3-15).



Figure 3-15 Comparison of total phosphorus (mg/L) at the discharge of two recirculating sand filters operated at the Massachusetts Alternative Septic System Test Center between March 2000 - April 2002.



The data suggest that the ability of the sand filters diminishes over time as the mean Total Phosphorus (TP) during the first eight months was 3.1 mg/L for the first eight months of operation (both RSF exhibited the same average discharge value), while the mean discharge concentrations in the final 15 months was 4.1 mg/L TP and 4.2 mg/L TP in filters #1 and #2 respectively. In an attempt to improve the performance of RSF#2, in May, 2002 we obtained a light expanded clay aggregate (LECA) and placed it in 4" diameter troughs beneath the lateral distribution pipes atop the sand filter. We operated the sand filter identically to the March 2000 - April 2002 period until July 2003. The results suggest that there was no significant change in the removal of TP during that period, as the mean TP concentration at the discharge was 4.1 mg/L (compare with 4.2 mg/l from March 2002 - April 2003 Figure 3-16).

Our results compare with Gold et. al. (1992) who found that over two years a recirculating sand filter removed 32% of TP.

Figure 3-16 Total phosphorus concentrations at the discharge from a modified recirculating sand filter operated at the Massachusetts Alternative Septic System Test Center from March 2002- April 2003. Modification included a 4-in diameter trough of light expanded clay aggregate beneath distribution laterals. RSF#1 unmodified and presented for comparison.



3.2.5.1 RUCK Filters

A modification of the sand filter is the RUCK System. This system has undergone some design changes since its inception, but is basically comprised of alternating layers of sand of various textures which receive blackwater (toilet wastes) from a septic tank by gravity. Following passage through the sand filter, the percolate drains into a vessel receiving greywater (shower, cleansing sinks and laundry wastes) from the facility served (Figure 3-17A). More recent modifications are used that do not separate the gray and blackwater, but use a supplemental source of carbon for denitrification (Figure 3-17B).



Laak (1988) reports that the original design removed 100% of the applied total phosphorus. Data from two operating RUCK CFT filters installed in Massachusetts and reported by Etnier (2005) indicate phosphorus removal rates as high as 90%. These data, however are limited to systems only in operation up to four years.

In summary, limited data suggests that the RUCK System has significant potential for the removal of phosphorus, however the theoretic basis upon which phosphorus is removed in the system, suggest that there is a finite adsorption capacity to the system. Is it likely that, similar to standard sand filters, the adsorption capability will be highly dependent on materials used in the filter itself and their adsorption properties. While the manufacturers of the system hypothesize that adsorption in the RUCK is enhanced by the low pH levels (Etnier, 2005), even this quality does not impart an indefinite sorption capability to the medium.



3.3 Constructed Wetlands

Constructed Wetland

Figure 3-18 Schemata of a constructed wetland showing phosphorus pathways.

Constructed wetland is a broad term used to describe a man-made complex of substrate, vegetation, animal life and water. In the context of onsite wastewater treatment, these wetlands are usually contained within an impervious liner and receive wastewater at one end and discharge to a soil absorption system at the discharge end. The influent to a constructed wetland can be highly treated wastewater (such as from an advanced treatment system) or primary treated wastewater from a settling or septic tank. There are numerous designs available for constructed wetlands, and many states from Texas to Minnesota allow their use. The ultimate goal of a constructed wetland is to mimic the principles of natural wetlands in order to convert the undesirable constituents in wastewater into more "desirable" forms of biomass or to cycle certain components of the wastewater(i.e. nitrogen) through to their gaseous phase.

The literature on constructed wetlands treatment is voluminous and is beyond the scope of this report. For a more complete discussion of constructed wetlands and their efficacy for treating domestic wastewater, the reader is directed toward comprehensive texts such as Hammer (1989) and others. Annotations from representative research papers are also presented in the reference section. What follows is a discussion of constructed wetlands as the concept relates to onsite septic systems, with particular emphasis on the principles that encourage phosphorus removal. At the outset, it should be understood however, that many of the principles involved in phosphorus attenuation to exploit its various geochemical and biochemical processes are not completely understood.

There is no commonly-accepted classification of constructed wetlands, however two broad classifications are generally recognized; the surface flow and subsurface flow wetland. As the name implies, surface flow wetlands are those which apply the wastewater at the surface (above ground) and allow the flow horizontally on the surface toward the discharge point. It is unlikely that this mode of operation can be made consistent with the health requirements of an onsite septic system, at least in the Commonwealth of Massachusetts. This is due to the feature of exposed effluent at the surface. This condition might encourage the proliferation of disease vectors (mosquitoes and various flies) as well as provide unintended disease-organism exposure routes. Due to these factors, we restrict our discussion to the second broad class of constructed wetland, the subsurface flow wetland (SSFW).

As this name also implies, a subsurface flow wetland is one in which the influent is introduced and maintained below the surface and allowed to flow either horizontally, vertically or a combination of vertically then horizontally toward a discharge point (Figure 3-19). The vegetation used in subsurface flow constructed wetlands (SSFW) must be tolerant of saturated conditions and hence are typically species that are found in natural wetlands. Substrate composition is also an essential consideration in SSFW since the porosity of the medium must be maintained.

3.3.1 Achieving Phosphorus Reductions in Constructed Wetlands

Considerable differences are reported regarding key elements of a SSFW that are actually responsible for phosphorus reductions. Some authors (Richter and Weaver, 2003, and Drizo et.al. 1999) suggest that substrate types account for the majority of the phosphorus uptake, while others (Pullin and Hammer, 1991, Alder, 1996, Breen, 1990, Couillard, 1994 and others) suggest means by which phosphorus removal can be optimized by plant uptake. Still other authors (Burgoon et. al. 1991) suggest that the interactions between the roots and the substrate can ultimately affect the retention ability of the substrate itself. A synthesis of all the literature reviewed (see annotated bibliography in references section) provides no single design available for SSFW that offers predictable results for phosphorus reduction and there are few generalizations that assist in designing SSFW for this purpose.

Substrate selection for SSFW should be based on two basic requirements. Foremost, substrate should be uniform in size and maintain a high porosity. Bowmer (1987) reported significant reductions in treatment capacity if the media allows preferential flow or "dead zones" where wastewater is occluded. Substrates containing metal oxides or calcium carbonates should be selected whenever possible, since they offer the best opportunities for phosphate adsorption. Richter and Weaver (2003) suggested that tire chips may be a suitable substrate in SSFW due to



Figure 3-19 Schemata of sub-surface flow constructed wetlands showing differences between vertical flow and horizontal flow wetlands.

the high porosity and the exposed iron (from steel-belted radial tires) available for complexing with phosphate. In addition, studies cited in Etnier (2005) indicate that constructed wetlands packed with lightweight aggregates have been constructed and removed up to 98% of the applied phosphorus. The majority of studies however report on SSFW using various size gravels as substrate.

Studies regarding plant selection for phosphorus reduction frequently include the genera Typha (cattails), Phragmites, and Scirpus (Alder et. al 1996, Burgoon et. al 1991, Brix and Schlerup 1989, Brix 1994, Henneck et. al. 2001, House et. al. 1994, and others). Some species of these genera are particularly tolerant of polluted conditions.

As previously stated, the exact mechanism for phosphorus reductions in any particular SSFW are complex and dependent on a number of factors including loading rate, loading method, operational mode of the wetland (vertical vs. horizontal flow), media type used, plant species used, establishment of plants, season and others. As the wetland becomes established, the microbial community that develops in the root zone may play a substantial role in facilitating plant uptake by providing microenvironments where phosphorus is re-mineralized and made available for plant uptake. When designing for plant uptake of phosphorus, appropriate harvesting methods for both plant biomass and peat/litter accretions must be planned. If this is not occasionally performed, above ground biomass may simply recycle its phosphorus onto the wetland, which may reach a saturation point for phosphorus assimilation.

In summary, constructed wetlands for wastewater treatment have intrinsic appeal due to the incorporation of processes that resemble natural wetlands. The literature reveals considerable variation in performance of these systems relative to treatment for phosphorus due to the range of variables in design, materials availability and plant types used. In general, there are no "off the shelf" onsite designs that hold promise for sustainable and significant phosphorus reductions. Designs that might emerge and rely on plant uptake for the major mechanism of phosphorus

removal, must incorporate harvesting and proper disposition of the harvested biomass as part of a long term maintenance plan. The use of lightweight aggregates made of expanded clay may hold promise for enhancing constructed wetland design due to their ability to adsorb phosphorus and the medium's possible reuse after replacement.

3.4 Peat

Peat is partially fossilized plant matter that is formed in wetland where the rate of accumulation of plant matter exceeds that of decomposition (Couillard,1994). The lignin and cellulose components of peat have many polar functional groups which impart a high adsorption capacity for transition metals and polar organic molecules. Peat has commonly been used to remove a wide range of impurities from wastewater since the 1970's. The use of peat in onsite domestic wastewater treatment is relatively recent. A number of proprietary modular peat filters exist on the market, and in some instances a layer of peat has been integrated into the soil absorption system. There is little theoretic basis for predicting phosphorus removal in raw peat. The polar nature of peat components demonstrates a high cation exchange capacity (i.e., ionic metal species – Fe³⁺, Cu²⁺, Zn²⁺ etc.), but a low anion exchange capacity. Phosphates are anionic. The mechanism for removal of phosphorus in peat is first the "loading" of the peat with metallic cations, and then the attraction of phosphate anion to the metallic cation and the subsequent formation of insoluble complexes.

Reports on the efficacy of peat for phosphorus removal are varied (Couillard,1994). Nichols and Boelter (1982) reported perhaps the greatest success in removing phosphorus with peat in an onsite setting, removing 99% of the phosphorus during the five year study using a 40 cm deep bed of reed-sedge peat. A few notable aspects of this study bear mention. Foremost, the authors attribute the retention of phosphorus in the initial years to a high iron, aluminum and ash content of the peat. Secondly, these authors note that, as the peat bed vegetation matured, it provided progressively higher percentage (22.1% in year one to 54% in year five) of the total removal. A final aspect of this study which bears mention is the fact that higher phosphorus accumulation was observed near the sprinkler head distribution points. The authors concluded that more phosphorus adsorption may have resulted if more even influent distribution to the peat bed was applied.

Studies using sphagnum peat (Rock et al. 1984, Brooks et. al. 1984, Geerts et al. 2001 and studies cited in Couillard, 1994) report removal values for phosphorus ranging from 96% (Brooks et. al. 1984) to 10% or less. In the most controlled study by Geerts et. al (2001), levels approximating 42% removal of total phosphorus are reported.

Collectively, the studies reviewed indicate some potential for phosphorus removal using peat; however the exact engineering specifications are not determined. If peat soil absorption systems or in-line peat modules were to be developed for phosphorus removal, the following modifications would appear to be advantageous based on the studies reviewed.

- The peat should be amended to some extent with aluminum or iron.
- The distribution system atop the peat should be uniform (in lined bed systems, pressure distribution is recommended).
- In-ground bed should be planted with species of grasses that have maximum phosphorus uptake.
- Vegetation atop peat beds should be harvested.

In summary, the collective studies using peat for the removal of phosphorus are not promising, despite this media's proven efficacy for removing other wastewater constituents. Sustained long term phosphorus removal has not been demonstrated; however principles revealed in the published studies do suggest that phosphorus removal in peat systems can be enhanced. At this time, there are no commercially available units or accepted engineering practices for non proprietary designs that guarantee phosphorus removal to levels generally accepted as necessary to provide protection for freshwater ecosystems (< 1.0 mg/l at discharge).

3.5 Filter Beds

A hybrid treatment means having some of the qualities if a lined-filter and those of a disposal bed is the concept of a filter bed (Figure 3-20 after Rystad and Sortehaug, 2004). In this system, the filter bed receives pretreated effluent from a biofilter (apparently a packed bed filter situated atop



the bed of Filtralite®) and flows laterally toward a collection point. The sizing of the filter bed depends on the level of phosphorus removal desired. If concentrations less than 1 mg/L TP are desired, the bed should be designed for a 2-3 week detention time. These authors report that a combination of theory and experience indicate that the media must be replaced every 15-20 years. The authors also report that initial investigations suggest that the material can then be used as a fertilizer, making the phosphorus available as a soluble fertilizer.

Results from the four countries in which this design was installed under funding from the Nordic Industrial Fund (Norway, Denmark, Sweden and Finland) are not yet available, and hence the long term efficacy of this system design is not yet known. The project was initiated in 2002 and was scheduled to end in 2005.
Filtralite[™] may be the material referenced as "Filtralite-P" by Ayers (2000) who demonstrated considerable success for removing phosphorus when placed beneath drip dispersal system in Florida. Thus is appears that in addition to being configured as above, this material is being investigated by others for phosphorus removal in varied configurations for onsite septic systems.

3.6 Sequencing Batch Reactors

Sequencing batch reactors (SBR) are wastewater treatment units that treat wastewater in discrete portions; sequencing them through various steps in a treatment train. The concept, commonly used in large treatment plants, has been downsized to onsite applications and there are at least two manufacturers that distribute onsite SBRs in Massachusetts. One such unit, the AmphidromeTM, is reported on previously herein.

In context of larger wastewater treatment systems, many authors report on the ability of certain organisms to accumulate phosphorus at levels that exceed their metabolic requirements (Bernardes and Klapwijk 1996, Cech et. al. 1994, Christensson et. al. 1998, Kerrn-Jepersen and Henze 1993, and Randall and Hill 1997). By sequencing the wastewater flow through anaerobic and aerobic paths in a sequencing batch reactor, an operator can induce this hyper-accumulation of phosphorus within certain bacteria. By directing the biomass containing the bacteria toward a collection point, it can be removed in the sludge, and dewatered. The resulting waste could be composted with other wastes and serve as a soil amendment.

Although sequencing batch reactors have been adapted and downsized for onsite septic system use, these authors found no commercially available product that made claims regarding the reduction of phosphorus via. hyper-accumulation. A similar process was investigated by Ayers (2000), however those authors discontinued testing before success was demonstrated due to the lack of manufacturer support for the onsite systems. We conclude that this mechanism for phosphorus control at the onsite level is not presently available. It is not inconceivable, however, to conclude that encouraging enhanced phosphorus accumulation in certain bacteria could be integrated into an onsite sequencing batch treatment unit.

3.7 Selective Resins

One novel strategy that may hold promise for the removal of phosphorus from wastewater is ion exchange. In this technology, treated effluent is exposed to an exchange resin which adsorbs phosphate. Wang and Sievers (2004) reported favorably on the feasibility of using this type of exchange resin in an onsite setting. One major problem reported by these authors included competition for phosphate binding sites by the bicarbonate ion. In our setting (southeastern Massachusetts), this would not be as problematic since our results indicate that simple sand filtration removes nearly all of the bicarbonate alkalinity in a very short vertical distance (2 ft.) following the initiation of nitrification. Researchers at the University of Massachusetts have made initial inquiries to MASSTC for field testing a unit that uses an ion exchange, which may be the subject of further reports. To this date, however, we have found no commercially available system purporting to remove phosphorus from wastewater in an onsite setting using this strategy.

3.8 Diversion

Diversion, in context here, refers to diverting all or part of a wastewater stream in order to remove a contaminant. The topic of wastewater phosphorus diversion is treated more extensively in Etnier et al. (2005) and is only reviewed in a cursory manner here. We discuss below three ways in which a phosphorus component on wastewater can be diverted: urine separating toilets, composting toilets, and separation of graywater and blackwater with the use of a tight tank for the blackwater.

3.8.1 Urine diversion

Regardless of acceptance of the means to do so, it is estimated that 33-43% of the total phosphorus loading and 50% of the nitrogen loading from domestic wastewater could be removed by diverting urine from the waste stream (Etnier 2005 and others). Urine separation can be achieved by the use of a specially designed toilet equipped with two separate bowls having a porcelain wall between them. By proper positioning during use, urine separation can be achieved with urine and feces exiting or draining from the toilet into different locations. Sweden has been the center of research for urine separating toilets. Following separation, urine can be collected, processed and possibly used as a fertilizer supplement.

A review of ongoing programs in Europe and Asia reveals that a primary impetus for consideration of urine separation is the cost of wastewater treatment and the recognition of the nutrient loads contributed by urine. In addition, we recognize that many of the emerging pharmaceutical contaminants originate in urine.

While urine separation as a strategy for nutrient management is relatively new, the technology is basically simple. To date, however, this strategy has not gained widespread acceptance due to both unresolved regulatory issues as well as public awareness/acceptance. These authors believe that the strategy of urine separation bears further consideration. Although there may be significant cultural and public acceptance barriers, the mere relative contributions of urine to nutrient and pharmaceutical contamination to wastewater streams should compel a thorough cost-benefit and feasibility analysis. The existing programs worldwide, although not sensitive to the unique cultural differences that might exist between areas, should be thoroughly researched as to their applicable comparisons.

In short, despite the obvious cultural aversion for doing anything with body wastes other than disposal, urine contains nutrients that we as a culture spend millions of dollars treating in our wastewater. As a body waste, urine is relatively innocuous compared with feces regarding pathogen content and is amenable to collection of nutrients in concentrated form. Given both these properties of urine and the possible reprocessing capability into a usable product, it appears incumbent upon wastewater managers to investigate urine separation as a possible tool in the overall management of nutrients to our watersheds.

3.8.2 Composting Toilets

Composting toilet technology refers to a wide variety of technologies that have as their common feature the collection and retention of feces that is retained in a chamber and allowed to aerobically decompose over time. In some models, a bulking material such as sawdust or woodchips is added. Air is conveyed across the waste and vented in various manners to where

possible odors would not be offensive. A discussion of various models and strategies is again provided in Etnier et al. (2005). Urine in the waste can either be separated or is evaporated in the process of composting.

In order for composting to act as a meaningful control for phosphorus, the compost and any remaining liquid fraction not evaporated (commonly called "tea") must be managed properly. Proper management merely includes measures that prevent the entry of the nutrients into the groundwater or surface waters in locations that would encourage over eutrophication. As with urine management, compost may offer, under certain circumstances, an opportunity to obtain nutrients as fertilizer for those locations where productivity is desired (agriculture, silvaculture, or nursery operations).

Composting toilet technology faces many of the cultural barriers posed by urine separation. Similar to urine separation, however, the costs of traditional large wastewater treatment technology and advanced onsite treatment technology should compel a serious consideration of this technology and a meaningful attempt to address the public aversions as well as the infrastructural support requirements. Infrastructural support features include collection and transport, processing locations and the development of markets for the final compost product.

3.8.3 Tight Tanks for Blackwater

At least one town in Massachusetts is seriously considering the possibility of using blackwater tight tanks to address nutrient loading issues (Richard Ray, Health Agent, Town of Nantucket, personal communication). This strategy involves the use of microflush toilets (often vacuum flush toilets) that reduce the overall volume of blackwater to less than 3 gallon/person/day. Graywater in these situations is disposed of by traditional means (septic tank – soil absorption system). The serious consideration of tight tanks must presuppose that there is a treatment facility within a feasible distance that can accommodate the tight tank pumping. These wastes will presumably be highly concentrated and require a means of blending with more dilute wastes prior to entering the treatment process train.

The efficacy of this strategy for both phosphorus and nitrogen management is obvious. Nutrient discharge to the groundwater is foregone and hence only the graywater contributions remain. As with any strategy that requires regular and vigilant intervention (such as pumping or collecting), the costs and infrastructure requirements need to be considered. In these authors' opinions, however, the option of tight tanking of blackwater in certain situations for phosphorus control should not be dismissed out of hand. In certain situations, this may be the most economically feasible option, particularly for seasonally-used residences.

4.0 Soft Measures

"Soft measures" are those strategies that prevent phosphorus from entering the wastewater stream and that require very little money or resources to implement. Under that definition, some of the design modifications discussed in Section 2.1 can be considered "soft". There is, however, an additional series of measures that require very little inconvenience, and yet can make significant differences in phosphorus reductions from wastewater. These soft measures include: reduction in the use of phosphorus-containing dishwashing liquid, disallowing garbage grinders (or alternately maintaining vigilance in enforcing present prohibitions), and educating the public regarding sources of phosphorus in wastewater. Recently, the Town of Brewster requested the support of local boards of health in a petition to large retail stores to limit the sale of phosphorus-containing cleaning products. This recognizes the fact that this product was not the subject of the same restrictions as laundry detergents.

5.0 Summary and Conclusions

Three new and innovative approaches to phosphorus removal were investigated. The first technology involved a small experimental add-on to a trickling filter which removed an average of 29% of the phosphorus compared to 11% removal for the trickling filter without the add-on unit. The second system tested under this project was an upflow filter of basic oxygen furnace slag (a by-product of steel production) referred to as PhosphexTM. The system was very successful in removing >99% total phosphorus; however the extremely high pH (11-12) of the resulting effluent could not be moderated with techniques attempted. The principle of reductive iron dissolution (Robertson, 2000) was incorporated into the third design investigated. This septic system configuration also involving a pre-leachfield sand filter and reduced total phosphorus levels to < 0.5 mg/L after the sand filter. This configuration, called PhosRidTM continues to undergo research and development to date. Although the later two technologies have significant practical challenges to overcome, we conclude that they have possibilities for use in the onsite setting.

In addition to new technologies, phosphorus data from five technologies investigated during 1999-2002 for nitrogen reduction were analyzed for phosphorus removal. Three technologies, AmphidromeTM, MicroFASTTM, and Waterloo BiofilterTM removed 22.5% (range 19.7-28.4%), 19.7% (range 18.5-20.8%) and 11.4% (range 8.5-12.7%) of the total phosphorus respectively. A standard septic tank removed 6.4-8.7% total phosphorus. Significant was the fact that when the soil absorption system is considered in conjunction with these technologies, the standard septic system removes more phosphorus than all systems compared. A drip disposal system removed nearly 93% of the total phosphorus until an insect infestation removed all above-ground vegetation over the emitters. The review of data from these technologies support the conclusion that maximum exposure of effluent to soil particle surfaces maximizes the phosphorus retention of the soil, with all other factors being equal. The limited removal of phosphorus in the systems themselves is not adequate to meet the generally-accepted goal of < 1.0 mg/L TP.

Data analyses in conjunction with a literature reviewed suggested ways to optimize phosphorus removal in standard septic systems by design modifications. In general, maximizing the distribution area of the effluent, maintaining a maximum vadose zone, locating the dispersal pipes in the upper soil horizons and selecting soils with redder hues where possible are all methods of enhancing phosphorus removal.

Sand filters and modified sand filters provide phosphorus removal dependent on the materials used in the filter itself. Sands with metal oxides adsorb phosphorus; however they gradually deplete their ability to do so over time. The RUCK, a stratified sand filter reportedly removed 100% of the phosphorus (Laak, 1988) and a modification of the RUCK called the RUCK CFT removed over 90% of the total phosphorus (Etnier, 2005), however the datasets in these reports are limited.

Constructed wetlands are highly variable in design and correspondingly are reported to exhibit a wide range of phosphorus removal. Some reports indicate media used is the prime determinant of phosphorus removal, while others place more importance on the type of vegetation planted. In

general, those designs that maximize root exposure to effluent, maximize residence time, use materials with phosphorus adsorption qualities, and use uniform media size to minimize "dead zones", achieve better results. It should be understood that many of the mechanism for phosphorus removal in wetlands are not fully understood.

A variety of lesser known technologies were reported on from the literature.

- Peat, while used extensively for removal of certain contaminants, exhibits only limited ability to remove phosphorus. However the ability of peat beds to remove phosphorus can be enhanced by amending the peat with metal oxides and maintaining vegetation on top of the filter for biological uptake.
- Filter beds, a combination of advanced treatment and lateral flow through a bed of light expanded clay aggregate (LECA) is the subject of considerable research in four Nordic Countries. Although they purportedly remove >90% phosphorus, limited data were available to provide a reliable assessment of this technology.
- A well documented ability to sequester phosphorus in phosphorus-accumulating bacteria has been used in municipal plants to remove phosphorus, but to date no application of this principle in the onsite setting has been demonstrated.
- Selective resins have been the subject of limited research, but may hold some promise in certain areas such as Cape Cod, since the waters generally are devoid of the bicarbonate ion which generally interferes with the exchange-resin process. This is the subject of a proposal by researchers at the University of Massachusetts.

Diversion techniques include those methods that prevent phosphorus from entering the waste stream. These include urine diversion and composting toilets. These techniques serve primarily to "package" the waste for easier disposition. Urine diversion and composting toilets may offer the ability to reuse the nutrient content of human wastes for useful purposes (fertilizer supplements or soil amendment), but cultural barriers would have to be overcome and necessary infrastructure would have to be developed. These technologies are the focus of research in some Scandinavian countries and in China.

Tight tanks for use in collecting blackwater may prove to be an economically viable solution in certain areas, particularly if combined with micro flush toilets to minimize overall volume. Again, this strategy merely avoids the mixture of human waste with excessive water and hence "packages" the waste for easier handling. This strategy is being considered in areas where seasonal use of homes is prevalent. With overall reduction in blackwater volumes to less than three gallons per capita per day, this strategy may prove economically feasible in many areas.

Finally, we examined "soft" measures to reduce phosphorus inputs to a watershed. These include policies or measures that alter the phosphorus inputs. The regulation of phosphorus in various cleaning products, for instance, is a simple measure that can have a significant impact in some cases. Another soft measure referenced is the prohibition of garbage grinders which add phosphorus to the wastewater stream that could otherwise be diverted.

6.0 Research Needs

The research needs for phosphorus treatment can assume two major and somewhat different paths depending on how a culture views or values phosphorus. If phosphorus in wastewater is viewed primarily as a nuisance contaminant only to be removed, then those strategies that are expedient

will be emphasized in research. Phosphorus chemistry allows the formation of fairly predictable chemical complexes and accordingly research goals under this assumption then become focused on facilitating the formation of solid end products in a manner such that their accumulation does not inhibit hydraulic conductivity of the soil absorption systems. Alternately, the formation of solid end products are managed or encouraged where such that the end products can be conveniently collected and disposed of. On the other hand, some cultures are coming to recognize that phosphorus is a valuable nutrient in finite supply that is used in the production of food supplies. Increasingly, worldwide there is a burgeoning movement to research acceptable ways to return wastewater phosphorus to the production cycle without compromising public health objectives. Both these "philosophies" of phosphorus treatment recognize that preventing phosphorus from entering the wastewater stream is beneficial, and hence a third level of research deals specifically with hard and soft measures to meet that objective.

There is little doubt that the ultimate goal for the treatment of phosphorus or any element, in wastewater should be its recovery, where possible, for useful purposes. These authors realize, however, that in some situations, this approach is not practical or feasible. Accordingly, and recognizing the need for research in both approaches, the following research needs have been identified.

Continue the research and development of onsite septic systems that show promise in reducing phosphorus by precipitation/sorption.

At least two alternative septic systems investigated in this report show promise for successful and significant reductions in phosphorus. Certain technical challenges exhibited in our test facility setting need to be researched and overcome before these systems can be widely used.

Development of filter media for adsorption of phosphorus that offers the potential for recycling of phosphorus into desired productivity trains.

Some studies reviewed investigated media, such as expanded clay or shale aggregates as a filter media to sequester phosphorus. Initial studies suggest that these types of media, once saturated with phosphorus, can be used as a soil amendment, releasing phosphorus for nutritional requirements of plants. Research to identify the qualities of media to maximize this feature needs to be conducted.

Determine the configurations of filter elements that facilitate replacement of media.

Media used in filter elements eventually reach saturation at which time replacement is required. Research is needed to determine configurations of media beds that facilitate the removal and replacement of media that are economically feasible and least disruptive.

Identify regulatory barriers for the use of "spent" absorptive media in horticulture and/or agriculture.

Absorptive media retains phosphorus for subsequent biological uptake in desired areas. Media that has exposed to wastewater, however, also has the potential for conveying pathogens. If absorptive media is to become a means for recycling of wastewater-derived phosphorus, regulatory barriers to its use must be identified and environmental and public health concerns must be addressed.

Continue to research ion exchange resins as a means of removing phosphorus. In particular, those resins that allow the desorption of phosphorus in forms that allows its recycling should be emphasized.

Determine the optimal soil absorption system designs that will facilitate phosphorus retention in the soil for plant uptake.

Our research suggests that drip dispersal systems can prevent phosphorus leaching to groundwater by a combination of soil retention and biological uptake. Other surface oriented dispersal systems should be research for similar efficacy. In addition, grasses and shallow rooted plants that maximize biological uptake should be researched.

Determine appropriate composting strategies in areas where dispersal systems are employed to encourage biological uptake.

Once biological uptake by plants is encouraged in any type of system (drip dispersal, constructed wetlands, irrigation), proper disposition of harvested plants is necessary if the management of phosphorus is to be effective.

Determine the feasibility of source separation and use.

Given the relative concentration of phosphorus in human urine and feces, and considering the relative ease of separating this source from the waste stream, it is incumbent on any resource manager to explore options for the separation, collection and either disposal or processing this source for reuse. Culturally in the United States, the task of encouraging acceptance of this management strategy is daunting. Using the acceptance of composting toilets as a predictor of the acceptance of urine separating toilets would conclude only minimal use of urine separating toilets, even if permitting barriers were relieved. Nevertheless facing more expensive options, incentives may exist to overcome cultural aversions to reuse of human wastes.

Relative to source separation strategies (composting toilets, urine separation), there are a variety of research needs including sociological aspects of the problem. It is beyond the scope of this paper to identify all of the specific research necessary to encourage a sociological shift, but these authors do believe that cultural aversions at some point must be challenged. An effective way to do this may be to explore all possible economic incentives. Phosphorus is used extensively in the fertilizer industry and at some point the costs of its recovery from mineral deposits need to be compared with cost associated with phosphorus recovery from compost or urine. It is a fact that human wastes, with proper processing, can be rendered harmless relative to disease organism transmission. It is also a fact that many other countries view human waste as a resource. In the United States, with the exception of certain products such as dried pelletalized biosolids (i.e. Melorganite®) our culture is slow to accept the use of human derived biosolids. Sustainable phosphorus management, however, must undoubtedly develop creative new ways to reintroduce once-digested phosphorus back into the live cycle of desirable productivity.

Annotated Bibliography and References

* Indicates references used in text. Other references presented for reader review

*Alder P. R., S. T. Summerfelt, D. M. Glenn and F. Takeda. (1996) Evaluation of a wetland system designed to meet stringent phosphorus discharge requirements. *Water Environment Research* 68 (5), 836-840.

In this study, a wetland system was created and managed to increase plant removal of influent phosphorus. Over 3 months, 5 cm troughs were harvested every 2 weeks. These systems had diurnal and harvest cycle variations in phosphorus removal, but did removal 90% of the phosphorus. The systems studied maximized the contact between the effluent containing phosphorus and the plant roots. Design recommendations are given to maximize phosphorus removal. Approximately 50% of the P removed was in the form of bi-weekly glass clippings.

*Ayres Associates. (2000). Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project – Phase II Addendum. *Report to Florida Department of Health Onsite Sewage Program under HRS Contract #C0013*. Ayres Associates, Madison Wisconsin.

Authors examined the performance of three materials underneath a drip dispersal system; locally available sand, an expanded clay aggregate LECATM (later replaced with Filtralite-P), and crushed brick. Filtralite provided the most consistent phosphorus reduction. Crushed brick failed due to short circuiting of the effluent.

*Baker M. J., D. W. Blowes and C. J. Ptacek. (1998) Laboratory development of permeable reactive mixtures for the removal of phosphorus from onsite wastewater systems. *Environmental Science & Technology* 32 (15), 2308-2316.

Mixtures of silica sand, limestone, and 5% and iron or calcium oxide were tested first in the laboratory and then the 2 most successful in the field. The 2 most successful removed over 90% of the phosphorus over a 4 year period and were activated alumina or the by-product of steel manufacturing.

*Bernardes R. S. and A. Klapwijk. (1996) Biological nutrient removal in a sequencing batch reactor treating domestic wastewater. *Water Science & Technology* 33 (3), 29-38.

The paper details the strategy for operating a sequencing batch reactor to remove phosphorus from wastewater. The phosphate levels dropped most dramatically during the aerobic stage that followed an anaerobic stage.

*Bowmer K. H. (1987) Nutrient removal from effluents by an artificial wetland: Influence of rhizosphere aeration and preferential flow studied using bromide and dry tracers. *Water Research* 21 (5), 591-599.

The author documented the presence of "dead zones" in a constructed wetland where the flow through the system is blocked and retention times are highly variable. Implications to the performance of the system in removing phosphorus are discussed. The author used dye tracer added to the wetland to show shorter retention times than expected.

*Brandes, M. (1977) Effective phosphorus removal by adding alum to septic tank. *Journal Water Pollution Control Federation 49* (11), 2285-2296.

By dosing alum to the septic tank every time the toilet was flushed, the author was able to remove 85% of the total phosphorus from the septic tank effluent. The rate of P accumulation in the septic tank sludge was 4.3% before the alum was added and 84.9% after dosing at a rate of 246.8 mg alum/l. The phosphorus was found to accumulate in the sludge and the sludge accumulation was greater than before the alum was added.

*Breen, P. F. (1990) A mass balance method for assessing the potential of artificial wetlands for wastewater treatment. *Water Research* 24 (6), 689-697.

Over a 50 day period phosphorus absorption was measured in wetland system, which was wetland plants and gravel in 10 L plastic buckets. Removal rates for phosphorus were 99%. The system was designed to maximize root contact and most of the phosphorus was taken up in the above ground plant biomass. Plant uptake was reported as the major uptake mechanism.

*Brix H. (1994) Use of constructed wetlands in water pollution control: historical development, present status, and future perspectives. *Water Science & Technology* 30 (8), 209-223.

Performance of 104 surface flow wetlands and 70 free surface flow wetlands are reviewed. The article reviews the principle means of phosphorus removal in free surface flow wetlands systems as adsorption, complexation, and precipitation reactions with aluminum, iron, calcium and clay particles, and peat accretion (accumulation of organic matter). Of these, the author contends that peat accretion is the most sustainable. A summary of the appropriate uses for each wetland system is included.

*Brix H. and H. H. Schlerup (1989) The use of aquatic macrophytes in water-pollution control. *Ambio* 18 (2), 100-107.

This is a good basic review of the different classes of constructed wetlands and the mechanisms for pollution removal.

*Brooks J. L., C. A. Rock, and R. A. Struchtemeyer (1984) Use of peat for on-site wastewater treatment: II. Field Studies *Journal of Environmental Quality* 13 (4), 524-530.

Sphagnum peat in a gravel lined trench removed over ninety percent of the phosphorus in this Maine study. The authors mention, however the undetermined effects of dilution and passage through a small distance of mineral soil prior to the sampling location might have had on results. The weather and dosing method had no significant difference for the removal efficiencies.

*Burgoon P. S., K. R. Reddy, T. A. DeBusk, and B. Koopman (1991) Vegetated submerged beds with artificial substrates. II: N and P removal. *Journal of Environmental Engineering* 117 (4), 408-424.

Over 6 months 4 plant species (Typha, Phragmites, Scirpus, and Sagittaria) in 2 substrates (gravel and plastic beads) were studied at a variety of hydraulic loading rates. The article suggests that the mechanism for phosphorus removal is complex and not completely understood. The media with the highest specific surface area removed more phosphorus. There is a suggestion that interaction with the plant root zone affects the retention of phosphorus on the media.

*Cech J. S., P. Hartman and M. Macek (1994) Bacteria and protozoa population dynamics in biological phosphate removal systems. *Water Science & Technology* 29 (7), 109-117.

A laboratory sequencing batch reactor was used to study the competition between phosphorus accumulating bacteria, other bacteria, flagellates and ciliates. The paper indicates that creating conditions that cause the proliferation of certain flagellates and ciliates may result in lower phosphorus reduction because these organisms prey primarily on the phosphorus accumulating bacteria which decreases phosphorus removal after the first two weeks.

Cheung K. C., T. H. Venkitachalam and W. D. Scott (1994) Selecting soil amendment materials for the removal of phosphorus. *Water Science & Technology* 30 (6), 247-256.

Phosphorus sorption capacities of a number of different soils and some industrial wastes are reported on. Results suggest that alkaline fly ash may be a promising amendment to coarse sand for phosphorus removal. Loamy sand had the greatest phosphorus sorption possibilities and the ability to handle high infiltration rates in this batch study on soil characteristics.

*Christensson M., E. Lie, K. Jönsson, P. Johansson, and T. Welander (1998) Increasing substrate for polyphosphate-accumulating bacteria in municipal wastewater through hydrolysis and fermentation of sludge in primary clarifiers. *Water Environment Research* 70 (2), 138-145.

An anaerobic condition was created to create more volatile fatty acids (such as acetic acid) in the first trial of an activated sludge reactor. This is hypothesized to increase the level of biological phosphorus removal due to the fact that volatile fatty acids are essential substrates for polyphosphate-accumulating bacteria.

*Couillard D. (1994) Review: The use of peat in wastewater treatment *Water Research* 28(6), 1261-1274.

Good review of the use of peat in wastewater treatment (6 papers have results summarized). The author underscores the importance of the nature of the peat in determining/predicting treatment. Also, the importance of plants on top of the peat is referenced and accounts for > 50 % of the phosphorus removal.

*Coupal B. and J. M. Lalancette (1976) The treatment of waste waters with peat moss. *Water Research* 10, 1071-1076.

The author reports of the efficacy of peat in removing phosphate; however the peat is compressed afterwards to remove the various contaminants like squeezing a sponge. No long term in-place data are presented.

Deinema H., L. H. A. Habets, J. Scholten, E. Turkstra, and H. A. A. M. Webers (1980) The accumulation of polyphosphate in Acinetobacter spp. *FEMS Microbiology Letters* 9, 275-279.

The paper describes acinetobacter spp. as a bacteria that can take up and accumulate phosphate under certain conditions and when supplied a carbon source.

Dévai I., L. Felföldy, I. Wittnet and S. Plósz (1988) Detection of phosphine: new aspects of the phosphorus cycle in the hydrosphere. *Nature* 333, 343-345.

This paper documents the presence of phosphine, a phosphorus containing gas, during certain wastewater processes. Under certain conditions, bacteria can be induced to produce phosphine which must be figured into the overall phosphorus budget of the system.

Dolan T. J., S. E. Bayley, J. Zoltek Jr. and A. J. Hermann (1981) Phosphorus dynamics of a Florida freshwater marsh receiving treated wastewater. *Journal of Applied Ecology* 18, 205-219.

This one year study showed that phosphorus in effluent of a marsh was not significantly different from the control and that the effluent phosphorus concentrations were 97% less than the concentration in the applied effluent. Most of that phosphorus was held in the soil and the above ground plant parts during the growing season and afterwards. This Florida marsh is on a peat based soil and the growth of the peat has potential for more phosphorus retention.

*Drizo, A., C. A. Frost, J. Grace., and K. A. Smith. (1999) Physio-chemical screening of phosphate-removing substrates for use in constructed wetland systems. *Water Research.* 33(17):3595-3602.

This study investigated the criteria for substrates that enhance phosphorus removal from wastewater. Seven substrates were investigated: bauxite, shale, burnt oil shale, limestone, zeolite, light expanded clay aggregates and fly ash. The criteria examined included pH, cation exchange capacity (CEC), hydraulic conductivity, porosity, specific surface area, particle size distribution, and phosphate absorption capacity. The authors concluded that shale had the best combination of all properties for use in constructed wetlands.

*Etnier, C., D. Braun, A. Grenier, A. Macrellis, R. J. Miles, and T. C. White. (2005) Micro-Scale Evaluation of Phosphorus Management: Alternative Wastewater Systems Evaluation. Project No. WU-HT-03-22. Prepared for the National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO, by Stone Environmental, Inc., Montpelier, VT.

This report contains numerous references and resources regarding phosphorus management for areas using onsite wastewater treatment. Technologies are placed in a useful set of matrices that help in their evaluation. In addition, "soft" measures for controlling phosphorus are discussed. The report is available online at http://www.ndwrcdp.org/.

Forbes, Margaret, K. R. Dickson, T. D. Golden, P. Hudak, and R. D. Doyle. (2004) Dissolved phosphorus retention of light-weight expanded shale and masonry sand used in subsurface flow wetlands. *Environmental Science and Technology*.38, 892-898.

Comparing the two substrates, the authors concluded that only the expanded shale would be suitable for retaining phosphorus in a subsurface flow constructed wetland.

*Galonian, G.E. and D. B. Aulenbach (1973) Phosphate removal from laundry wastewater. Journal Water Pollution Control Federation 45 (8), 1708-1717.

Calcium, alum, and iron were all shown to be effective ways to remove phosphorus from laundry wastewater. Calcium needs a pH of 9.5-10 and the other two chemicals need a pH of 5.0-6.0.

*Geerts Monson S.D., B. McCarthy, R. Axler, J. Henneck, S. Heger Christopherson, J. Crosby, and M. Guite (2001) Performance of peat filters in the treatment of domestic wastewater in Minnesota. *9th National symposium on individual and small* community sewage systems, ASAE, St. Joseph, Missouri. 446-457.

Peat systems with the variables of types of peat, dosing system, amount of compaction, and modular vs. in-ground were tested in a cold Minnesota environment. In-ground peat filters with pressure distribution and low compaction were the most effective with a non-seasonally effected removal of approx 45% phosphorus.

*Geerts S. M. and B. McCarthy (1999) Wastewater treatment by peat filters. *Focus 10,000* 10, 16-20.

This article reports on the contaminant removal ability of peat systems. It suggests limited ability of peat systems described to reduce phosphorus.

*Gold A. J., B. E. Lamb, G. W. Loomis, J. R. Boyd, V. J. Cabelli, and C. G. McKiel (1992) Wastewater renovation in buried and recirculating sand filters. *Journal of Environmental Quality* 21, 720-725.

The authors report on the performance of mature buried and recirculating sand filters. After two and a half years of operation a recirculating sand filter removed 32% of the phosphorus and the buried sand filter reduced 0.9%. Occasionally, discharge levels were higher than influent levels, presumably due to occasional die off of microbial biomass.

Gonçalves R. F., F. N. Nogueira, L. LeGrand, and F. Rogalla (1994) Nitrogen and biological phosphorus removal in submerged biofilters. *Water Science & Technology.* 30 (11), 1-12.

An operational procedure is presented that enables biological phosphorus removal to be performed using submerged filters. A set of 5 biofilters with a polystyrene bead media are set on anaerobic and aerobic alternating cycles with a continuous wastewater feed to optimize the amount of volatile fatty acids utilized during the anaerobic periods. Sixty to seventy percent of the phosphorus was removed.

Gray, Shalla, J. Kinross, P. Read, and A. Marland. (2000). The nutrient assimilative capacity of maerl as a substrate in constructed wetland systems for waste treatment. *Water Research*. 34(8):2183-2190.

The study evaluated calcified seaweed as a substrate for constructed wetlands treating wastewater. The authors concluded that maerl compared favorably with other novel substrates such as iron slag and shale, for the removal of phosphorus in constructed wetlands.

*Hammer, Donald (ed.). 1989. Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, Michigan. 831pp.

Contains the proceedings of the First International Conference on Constructed Wetlands for Wastewater Treatment, held in 1988. This is a good synthesis of wetland technologies to that date.

Harman J., W. D. Robertson, J. A. Cherry, and L. Zanini (1996) Impacts on a sand aquifer from an old septic system: nitrate and phosphate. *Ground Water* 34 (6), 1105-1113.

The plume of a septic system that has been used for 44 years is investigated. The paper indicates that the unsaturated zone beneath the system is a major determinant of overall reduction and that the plume of phosphorus can migrate in the saturated zone.

*Henneck J., R. Axler, B. McCarthy, S. M. Geerts, S. H. Christopherson, J. Anderson, and J. Crosby (2001) Onsite treatment of septic tank effluent in Minnesota using SSF constructed wetlands: performance, costs and maintenance. *ASAE symposium on individual and small community systems, Fort Worth, TX.*

Three constructed wetlands in Minnesota were planted mostly cattails and removed phosphorus during the first 2 years of operation and then performance was reduced. This is most likely due to substrate saturation. Summer removal was much greater than in winter (15-30% greater).

Ho G.E., K. Mathew and R. A. Gibbs (1992) Nitrogen and phosphorus removal from sewage effluent in amended sand columns. *Water Research* 26 (3), 295-300.

Over 90% of the phosphorus was removed from the experimental columns with red mud in 10 cycles which lasted about one month each. Primary effluent increased the removal efficiency by reducing infiltration rates.

Ho G.E., K. Mathew and P. Newman (1989) Leachate quality from gypsum neutralized red mud applied to sandy soils. *Water, Ail, & Soil Pollution* 47, 1-18.

The paper investigates the ability of bauxite refining residue (red mud) and waste gypsum applied to local sandy soil to remove phosphorus. Various management strategies to address neutralization and other issues are discussed.

*House C. H., S. W. Broome and M. T. Hoover (1994) Treatment of nitrogen and phosphorus by a constructed upland-wetland wastewater treatment system. *Water Science & Technology* 29 (4), 177-184.

This author reports the results of a constructed wetland at a single family residence. The system was comprised of a mounded system (removed 86% of the phosphorus) and three cells of a constructed wetland. The sand in the mound contained marl that helps remove phosphorus by calcium and magnesium phosphates. The plants in two of the cells removed phosphorus, with (Phragmites sp.) removing more than the Typha sp. plot.

Howard-Williams C. (1985) Cycling and retention of nitrogen and phosphorus in wetlands: a theoretical and applied perspective. *Freshwater Biology* 15, 391-431.

The paper reviews many major issues regarding wetlands and the nutrient pathways through a wetland.

*Kerrn-Jepersen J. P. and M. Henze (1993) Biological phosphorus uptake under anoxic and aerobic conditions. *Water Research* 27 (4), 617-624.

This paper demonstrated the possibility of two sets of phosphorus removing bacteria, one aerobic and the other anaerobic. It shows that in the laboratory sets of aerobic and anaerobic cycles have cumulative removal efficiencies. It demonstrates that nitrate and oxygen can be used as electron acceptors. Also acetate was shown to help the anaerobic reaction.

Khalid R. A., W. H. Patrick Jr., and R. D. DeLaune (1977) Phosphorus sorption characteristics of flooded soils. *Soil Science Society of America Journal* 41, 305-310.

Approximately 89% of the absorption of P in anaerobic Louisiana soils can be explained by the iron concentration and 35% of the absorption in aerobic soils is due to iron. The paper underscored the importance of iron in the soils as determining the phosphorus removal.

Körner S. and J. E. Vermaat (1998) The relative importance of *Lemna bibba L.*, bacteria and algae for the nitrogen and phosphorus removal in duckweed-covered domestic wastewater. *Water Research* 32 (12), 3651-3661.

The uptake of phosphorus by the duckweed was minimal at both high and low phosphorus concentrations in this small scale three day lab study. The microbes and soil removed most of the phosphorus with overall removal between 63 and 99%.

*Laak, R. (1988) Passive removal of nitrogen and phosphorus using an alternative on-site wastewater system. In *Alternative Waste Treatment Systems* (Edited by R. Bhamidimarri), 14-21. Elsevier Applied Science, London.

A RUCK system with a 3 layer aerated sand filter, greywater separated in a second septic tank and a complex series of in-drains in the leaching field removed 100 % of the phosphorus from a residential home.

Monnett G. T., R. B. Reneau Jr. and C. Hagedorn (1996) Evaluation of spray irrigation for on-site wastewater treatment and disposal on marginal soils. *Water Environment Research* 68 (1), 11-18.

Spray-irrigation was added to the end of secondary treatment (septic tank/sand filter or aeration package treatment) in marginal soils. Over the 20 months of the study the phosphorus levels in the water run-off remained very low (>95% removal).

*Nichols D. S. and D. H. Boelter D.H. (1982) Treatment of secondary sewage effluent with a peat-sand filter bed. *Journal of Environmental Quality* 11 (1) 86-92.

For 8 years a peat sand filter planted with rough-stalked bluegrass and moved weekly during use provided tertiary treatment for a campground in Northern Minnesota. With a maximum application rate of .625 cm/hr applied with sprinklers the peat bed removed

over 90% of the phosphorus. During the start up period, the authors believe that the high Fe, Al, and ash content of the peat contributed to the ability to retain phosphorus. In later years the bluegrass accounted for 45% of the phosphorus removal.

Nichols, D. S. (1983) Capacity of natural wetlands to remove nutrients from wastewater. Journal Water Pollution Control Federation 55 (5), 495-503.

This review of wetland nutrient removal concluded that low nutrient and hydraulic loading rates are necessary. Non-growing season failure of the wetland was discussed. The author maintains that the major uptake mechanism is the elements in the soil.

Nierengarten, P. and M. Gross (2001) Chemical phosphorus removal in a recirculating textile filter system. Proceedings of the Tenth Annual Conference of the National Onsite Wastewater Recycling Association. Virginia Beach, Virginia.

Authors report on the success of adding alum to remove phosphorus from textile filter effluent to 0.6 Mg/L. The textile filter itself removed very little phosphorus. The authors believe that proper dosing and limestone buffering will overcome problems of low alkalinity and low pH. They suggest that monthly maintenance would be required, and sludge pumping every 3-5 years.

Noah M. (2000) Phosphorus overload in receiving waters Small Flows Quarterly 1 (1), 22-23.

This article reports on the results of two demonstration projects. The first, attempted to use drip irrigation over a bed of crushed-brick media for adsorption of phosphorus. This system saturated very quickly and the efficiency for removing phosphorus diminished. The second study used an upflow filter of iron rich sand after a recirculating sand filter, but hydraulically clogged.

*Ockershausen R. W. (1975) Alum vs. phosphate-wastewater treatment. *Water & Sewage Works* 7, 80-81.

The paper describes the efficacy of adding alum to wastewater for the removal of phosphorus. By 1975, 135 cities in the US were using alum to remove phosphorus. Alum has the added benefit of reducing BOD and SS.

Park J. K., J. Wang and G. Novotny (1997) Wastewater characterization for evaluation of biological phosphorus removal. *Wisconsin Department of Natural Resources Research Report 174*.

The report describes how to use a public domain computer program to model activated sludge wastewater characteristics in order to achieve biological phosphorus removal. A large section on the benefits of using COD measurement over BOD measurement is included.

Parker D. S., L. S. Romano and H. S. Horneck (1998) Making a trickling filter/solids contact process work for cold weather nitrification and phosphorus removal. *Water Environment Research* 70 (2), 181-188.

A trickling filter, activated sludge, rotating contactor, and aerated filter were compared for ability to remove phosphorus. Modifications to the aerated filter was most efficient overall including the phosphorus objectives and are discussed.

*Pell M. and F. Nyberg (1989) Infiltration of wastewater in a newly started pilot sand-filter system: I. Reduction of organic matter and phosphorus. *Journal of Environmental Quality* 18, 451-457.

This research was performed to monitor the treatment of wastewater in sand filters designed to a described standard. The paper describes the progressive reduction in the ability of the sand filter to remove phosphorus over time.

Peterson C.E., Reneau R.B. Jr. and Hagedorn C. (1998) Soil and minespoil fill as media for renovation of nitrogen and phosphorus in domestic wastewater. *Water, Ail, & Soil Pollution* 102, 361-375.

The study compared the efficiency of mine spoil and soil columns for nitrogen and phosphorus removal. The mine spoil columns retained less phosphorus. The authors theorized that the pH of the mine spoil may have affected the solubility of the phosphorus and resulted in lower P removal rates.

Porter P.S. and Sanchez C.A. (1992) The effect of soil properties on phosphorus sorption by everglades histosols. *Soil Science* 154 (5), 387-398.

A mathematical relationship between the histosol soil of the everglades and phosphorus absorption was found to include ash, pH, carbonates, PW and total and extractable Ca.

Pullin B.P. and Hammer D.A. (1991) Aquatic plants improve wastewater treatment. *Water Environment & Technology* 3, 36-40.

Comparisons were made between four species of plants and their suitability for constructed wetlands. The Typha species had the largest water quality tolerance (cattail) but the lowest biomass. S.cypernius (woolgrass) has the highest root mass and S. validus has the highest stem surface area. Implications of the findings are discussed.

*Randall A. A., L. D. Benefield, and W. E. Hill (1997) Enhanced biological phosphorus removal: The variation in location and form of intracellular phosphate induced by different substrates and observed with ³¹P-NMR. *Advances in Environmental Research* 1 (1), 58-73.

Biological removal of phosphorus was studied in context of a sequencing batch reactor. The manipulation of cellular metabolism and its implication to phosphorus storage by the cell is discussed. Although acetate increased the level of phosphorus uptake, methanol did not affect it, and glucose increased it, there was no change in form or location of phosphorus within the cell.

Reneau R. B. Jr., C. Hagedorn, and M. J. Degen (1989) Fate and transport of biological and inorganic contaminants from on-site disposal of domestic wastewater. *Journal of Environmental Quality* 18, 135-144.

Low pressure distribution and low hydraulic loading rates are recommended for the greatest phosphorus removal. This summary points out that soil absorption sites with iron, aluminum, and calcium can regenerate with time. The theorized mechanism for this regeneration is presented.

*Richter A. Y., and R. A. Weaver (2003) Treatment of domestic wastewater by subsurface flow constructed wetlands filled with gravel and tire chip media. *Environmental Technology*, 24(12)1561-1567.

"The only clear difference between medium types in wetland performance was for P. Soluble P in the effluent averaged 1.6 ± 1.0 mg l-1 in the tire chip-filled wetlands and 4.8 ± 3.2 mg l-1 in the gravel-filled wetlands. Most likely, Fe from exposed wires in shredded steel-belted tires complexed with to create an insoluble compound. Tire chips may be a better fill medium for SFCWs than gravel

because of higher porosity, lower cost, and greater reduction of P in effluent".

Richardson C. J. (1985) Mechanisms controlling phosphorus retention capacity in freshwater wetlands. *Science* 228 (4706), 1424-1427.

Richardson argues that aerobic terrestrial soils high in aluminum are more efficient at removing phosphorus than peat and other freshwater wetland soils.

*Robertson W. D. (2000) Treatment of wastewater phosphate by reductive dissolution of iron. *Journal of Environmental Quality* 29, 1678-1685.

Iron rich media is placed in direct contact with unoxidized sewage and hence Fe(III) is reduced to soluble Fe(II) (Reductive iron dissolution). Fe(II) can then bind with phosphorus to precipitate out as vivianite, or as the effluent is subsequently oxidized precipitate as strengite. RID media which is screened B-horizon sediment from several locations in central Ontario removed phosphorus from a seasonal cottage during a 4 month trial. Twenty percent of the total volume of iron in the RID media was used to bind with phosphorus in the soil matrix forming secondary solids.

*Rock C. A., J. L. Brooks, S. A. Bradeen and R. A. Struchtemeyer (1984) Use of peat for onsite wastewater treatment: I. Laboratory evaluation. *Journal of Environmental Quality* 13 (4), 518-523.

Authors report limited phosphorus removal from the anaerobic peat systems in this short-term laboratory study.

*Rystad, V. and O. J. Sortehaug (2004). High phosphorus removal in low maintenance filter beds in the Nordic Countries. *Onsite Wastewater Treatment X, Proceedings of the Tenth National Symposium on Individual and Small Community Sewage Systems, at Sacramento, California.* ASAE, St. Joseph, MI. pp. 547-551.

Describes a filter bed design presently being researched in Nordic Countries which purports to remove >90% of influent phosphorus using an expanded clay aggregate. There is a prefilter before discharge to a lined bed.

Sengupta, S. and H. Miller (2000). Investigation of Tire Shred for Use in Residential Subsurface Leaching Field Systems: A Field Scale Study. Technical Report #32. Chelsea Center for Recycling and Economic Development, University of Massachusetts, Lowell. 33 p.

This report describes studies conducted at the Massachusetts Alternative Septic System Test Center on the use of shredded tires for aggregate. Although not specifically purported to remove phosphorus, some phosphorus removal was observed.

Sikora J., M. G. Bent, R. B. Corey, and D. R. Keeney (1976) Septic nitrogen and phosphorus removal test system. *Ground Water* 14 (5), 309-314.

Calcite and dolomite columns were exposed to household sewage to test their phosphorus removal properties. After 6 weeks the sand columns lost their ability to remove phosphorus. Also considerable slime growth blocked absorption sites. During the removal period, the calcite was superior because of the greater abundance of Ca carbonate.

Smolders G. J. F., J. van der Meij, M. C. M. van Loosdredcht, and J. J. Heijnen (1995) A structured metabolic model for anaerobic and aerobic stochiometry and kinetics of the biological phosphorus removal process. *Biotechnology & Bioengineering* 47(3), 277-287.

Biological phosphorus removal can be described with 2 anaerobic equations and 4 aerobic. The anaerobic uses up acetate to store PHB intercellularly and gives off phosphate. The aerobic uses phosphate to store phb as biomass and glycogen (for maintenance).

USEPA. (2000) Wastewater technology fact sheet: Free water surface wetlands. *EPA* 832-F-00-024.

This fact sheet focuses on the advantages of a free water surface wetland over conventional technology and mentions that a large amount of land is necessary to treat phosphorus. A significant disadvantage to wetlands treatment is mentioned; that being that phosphorus, metals and some persistent organics are bound in the wetland sediments and accumulate over time.

*Viraraghavan T., R. C. Landine, and E. L. Winchester (1979) Oxidation ditch plus alum take phosphorus away. *Water & Sewage Works* 10, 54-57.

A sewage treatment plant in New Brunswick had success using alum to remove phosphorus in an oxidation ditch system.

Wakatsuki T., H. Esumi, and S. Omura (1993) High performance and N & P-removable onsite domestic waste water treatment system by multi-soil-layering method *Water Science & Technology* 27 (1), 31-40.

Brick-like layers of zeolite were added to the soil contained iron pellets. This system removed phosphorus for over a year. The amount of aeration supplied by tubes in the zeolite greatly affected the reduction with 6 hours being the optimal time in this system.

Wang, J. and D. M. Sievers (2004) Phosphorus removal from wastewater by column adsorption. Onsite Wastewater Treatment X, Proceedings of the Tenth National Symposium on Individual and Small Community Sewage Systems, at Sacramento, California. ASAE, St. Joseph, MI. pp. 263-272.

Reports on a new class of ion exchange polymer and its possible applications in the onsite septic system setting. Resin efficiency was reported at 0.008mg P removed per mg of resin. The problem of bicarbonate alkalinity is discussed, since this anion competes with phosphate for binding sites.

Wathugala A. G., T. Suzuki and Y. Kurihara (1987) Removal of nitrogen, phosphorus and COD from waste water using sand filtration system with *Phragmites australis*. *Water Research* 21 (10), 1217-1224.

Over 4 months, Phragmites was grown in pots and given different concentrations of P. The controls without plants became saturated and the highest loaded pot also stopped removing phosphorus at the end of the 4 months. The other 3 loading rates (5-20mg/L) removed over 90% of the P. More P was in the top layers of soil in the planted pots than the controls, and they hypothesized that Phragmites aerated this area to increase P uptake.

Yeoman S., T. Stephenson, J. N. Lester, and R. Perry (1998) The removal of phosphorus during wastewater treatment: A review. *Environmental Pollution* 49, 183-233.

A good and review of both the mechanisms for phosphorus removal and the different ways in which wastewater treatment plants can deal with phosphorus, including both chemical and biological processes. Over 200 references.

APPENDIX 1

RAW DATA FROM ASSAYS TAKEN AT THE WATERLOO BIOFILTER™ RETROFITTED IN AN ATTEMPT TO ACHIEVE PHOSPHORUS REMOVAL

Data from 6/23/99 - 7/17/2001 collected during a testing protocol for nitrogen removal during which phosphorus data were concurrently collected. These assays were performed by University of Massachusetts School for Marine Science and Technology. These data are presented for comparison with dates following (12/19/01 - 1/29/03) when the system was retrofitted in an attempt to achieve phosphorus reductions.

A1 DB – indicates distribution box after treatment from which composite samples were collected. "QA" following this designation indicates a duplicate sample for quality assurance purposes.

DC WEST – indicates the western end of the influent dosing channel from which the influent is supplied to the Waterloo Biofilter

Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)
6/23/1999	A1 DB	7.65	471	150	3.8	5.4
7/7/1999	A1 DB	7.32	349	48	3.7	4.8
7/21/1999	A1 DB	7.28	359	57	4.5	4.8
8/11/1999	A1 DB	7.28	407	50	4.3	4.8
8/11/1999	A1 DB QA	7.36	424	50	4.1	4.5
8/30/1999	A1 DB	7.26	412	55	4.4	5.3
9/22/1999	A1 DB	7.36	418	54	4.1	4.4
10/13/1999	A1 DB	7.29	388	63	4.1	4.1
11/3/1999	A1 DB	7.49	446	106	4.0	4.1
11/18/1999	A1 DB	7.12	446	65	4.0	4.0
12/21/1999	A1 DB	7.21	438	65	4.1	4.3
1/12/2000	A1 DB	7.35	462	84	4.4	4.6
2/2/2000	A1 DB	7.09	462	50	3.3	
2/16/2000	A1 DB	7.25	462	65	4.2	
3/1/2000	A1 DB	7.34	476	171	3.8	4.1
3/15/2000	A1 DB	7.28	404	80	4.2	4.7
3/28/2000	A1 DB	7.41	523	78	3.9	4.5
4/11/2000	A1 DB	7.35	464	74	5.2	5.8
5/2/2000	A1 DB	7.38	467	70	4.2	
5/17/2000	A1 DB	7.40	417	67	4.2	5.4
5/31/2000	A1 DB	7.52	450	80	4.6	5.3
6/14/2000	A1 DB	7.46	427	104	4.7	5.1
6/28/2000	A1 DB	7.27	499	82	5.6	5.8
7/12/2000	A1 DB	7.02	419	60	5.0	5.0
7/12/2000	A1 DB QA			59	5.0	5.3
7/26/2000	A1 DB	7.38	426	89	5.2	5.4
8/9/2000	A1 DB	7.38	512	99	4.6	
8/23/2000	A1 DB	7.36	490	403	3.9	4.2
9/6/2000	A1 DB	7.77	469	89	3.6	3.6
9/20/2000	A1 DB	7.59	402	89	3.8	3.8
10/3/2000	A1 DB	7.38	455	88	4.4	4.4
10/17/2000	A1 DB	7.60	451	96	3.6	3.9
10/30/2000	A1 DB	7.45	385	69	4.0	4.2
11/14/2000	A1 DB	7.18	362	53	3.0	3.5
11/28/2000	A1 DB	7.31	390	73	3.5	3.6
12/12/2000	A1 DB	7.23	465	59	3.2	3.2
12/26/2000	A1 DB	7.26	419	82	3.5	3.7
1/9/2001	A1 DB	7.05	456	84	3.7	4.0

Standard Waterloo Biofilter Configuration (no Phosphorus Removal Media)

Cont.						
Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)
1/23/2001	A1 DB	7.09	433	83	4.1	4.2
2/6/2001	A1 DB	7.36	450	88	3.8	3.8
2/20/2001	A1 DB	7.29	438	100	3.8	3.8
2/20/2001	A1 DB QA	7.35	454	100	3.9	4.0
3/13/2001	A1 DB	7.17	591	92	2.7	4.0
3/27/2001	A1 DB	7.39	400	92	3.9	4.1
4/10/2001	A1 DB	7.56	419	89	4.3	4.3
4/24/2001	A1 DB	7.41	422	68	4.5	4.7
5/8/2001	A1 DB	7.21	412	70	5.0	5.3
5/22/2001	A1 DB	7.30	388	62	4.9	4.9
6/5/2001	A1 DB	7.37	393	85	4.5	4.6
6/19/2001	A1 DB	7.22	373	74	5.4	
7/2/2001	A1 DB	7.14	401	85	6.9	7.1
7/17/2001	A1 DB	6.95	399	78	4.9	5.0
7/17/2001	A1 DB QA	6.97	406	75	4.9	4.9
Mean		7.32		85	4.2	4.5
Median		7.33		78.4	4.1	4.5
Count		52.00		53	53	48
Std Dev.		0.16		49.88	0.71	0.73
95% CI		0.04		13.4	0.19	0.21

Standard Waterloo Biofilter Configuration (no Phosphorus Removal Media) Cont.

Waterloo	Waterloo Biofilter Retrofit With Phosphorus Removal Media								
Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)			
12/19/2001	A1 DB	6.91	444	40	3.8	4.0			
1/3/2002	A1 DB	7.10	424	36	4.0	3.8			
1/3/2002	A1 DB QA	7.09	425	36	4.0	4.1			
1/16/2002	A1 DB	7.06	523	36	4.3	4.5			
1/30/2002	A1 DB	6.89	526	38	4.3	4.6			
2/13/2002	A1 DB	7.16	462	66	4.1	3.9			
2/27/2002	A1 DB	7.07	445	48	4.3	4.0			
3/13/2002	A1 DB	7.10	417	64	3.2	3.4			
3/13/2002	A1 DB QA			68	3.2	3.2			
3/27/2002	A1 DB	7.29	394	78	3.2	3.3			
3/27/2002	A1 DB QA	7.22	399	78	3.1	3.4			
4/10/2002	A1 DB	7.30	419	78	3.9	3.7			
4/24/2002	A1 DB	7.29	442	90	4.2	4.7			
5/8/2002	A1 DB	7.15	399	69	4.3	4.4			
5/22/2002	A1 DB	7.23	390		4.0	5.4			
6/5/2002	A1 DB	7.49	394	72	4.4	4.1			
6/5/2002	A1 DB QA	7.50	396	72	4.4	4.5			
6/19/2002	A1 DB	7.25	388	98	3.5	4.0			
7/3/2002	A1 DB	7.44	394	84	4.6	4.5			
7/3/2002	A1 DB QA			84	4.6	3.9			
7/17/2002	A1 DB	7.39	388	72	3.3	4.2			
7/31/2002	A1 DB	7.48	379	84	3.7	4.2			
7/31/2002	A1 DB QA	7.47	378	85	3.8	4.1			
8/14/2002	A1 DB	7.34	391	77	3.6	4.2			
8/28/2002	A1 DB	7.54	406	80	4.1	4.3			
9/11/2002	A1 DB	7.33	386	62	4.5	3.3			
9/25/2002	A1 DB	7.54	350	70	0.1	1.2			
10/9/2002	A1 DB	7.62	380	81	4	4.2			
10/23/2002	A1 DB	7.40	399	90	4	4.6			
11/6/2002	A1 DB	7.20	403	86	3.9	4			
11/20/2002	A1 DB	7.25	363	70	4	4.1			
12/4/2002	A1 DB	7.29	374	78	4	4.1			
12/18/2002	A1 DB	7.37	360	76	3.9	4.3			
12/30/2002	A1 DB	7.18	391	86	4.3	4.3			
12/30/2002	A1 DB QA	7.17	391	78	4.3	4.8			
1/15/2003	A1 DB	7.29	443	102	3.9	4.6			
1/15/2003	A1 DB QA	7.29	526	164	3.7	5.7			
1/29/2003	A1 DB	7.42	466	118	4.6	3.6			
Mean		7.28		76	3.9	4.1			
Median		7.29		78	4.0	4.1			
Count		36.00		37	38	38			
Std Dev.		0.17		23.91	0.76	0.71			
95% CI		0.06		7.70	0.24	0.23			

INFLUE	INFLUENT for Waterloo Biofilter									
Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)				
12/19/2001	DC WEST	7.40	485	• • • /	2.9	5.5				
1/2/2002	DC WEST	7.43	529	199	3.9	5.9				
1/3/2002	DC WEST	7.43	529	198	3.9	5.9				
1/15/2002	DC WEST	7.62	640	189	4.0	6.1				
1/16/2002	DC WEST	7.62	640		4.0	6.1				
1/29/2002	DC WEST	7.48	578	189	3.9	6.2				
1/30/2002	DC WEST	7.48	578	180	3.9	6.2				
1/30/2002	DC WEST QA	7.52	574	192	3.8	6.4				
2/12/2002	DC WEST	7.43	578	192	4.2	5.5				
2/13/2002	DC WEST	7.43	578		4.2	5.5				
2/26/2002	DC WEST	7.45	514	189	4.0	5.7				
2/27/2002	DC WEST	7.45	514		4.0	5.7				
3/12/2002	DC WEST	7.30	590	189	4.3	8.3				
3/13/2002	DC WEST	7.30	590		4.3	8.3				
3/26/2002	DC WEST	7.40	503	184	3.9	5.9				
3/27/2002	DC WEST	7.40	503		3.9	5.9				
4/9/2002	DC WEST	7.39	571	193	3.9	5.8				
4/10/2002	DC WEST	7.39	571		3.9	5.8				
4/10/2002	DC WEST QA	7.42	565		4.0	5.8				
4/23/2002	DC WEST	7.39	572	198	3.6	5.9				
4/24/2002	DC WEST	7.39	572		3.6	5.9				
5/7/2002	DC WEST	7.39	513		4.0	5.8				
5/22/2002	DC WEST	7.24	518	196	3.7	5.5				
5/22/2002	DC WEST	7.24	518	196	3.7	5.5				
6/5/2002	DC WEST	7.28	552	178	4.0	5.8				
6/5/2002	DC WEST	7.28	552	178	4.0	5.8				
6/19/2002	DC WEST	7.42	528	200	3.1	5.5				
6/19/2002	DC WEST QA	7.45	529	188	3.1	5.3				
7/3/2002	DC WEST	7.31	534		3.6	4.5				
7/17/2002	DC WEST	7.48	527	188	3.1	5.2				
7/17/2002	DC WEST QA				3.1	5.1				
7/31/2002	DC WEST	7.48	490	170	3.7	4.2				
8/14/2002	DC WEST	7.22	513	186	3.9	6.3				
8/14/2002	DC WEST QA	7.28	511		3.9	6.3				
8/28/2002	DC WEST	7.44	536	172	3.7	5.9				
9/11/2002	DC WEST	7.39	502	166	4.0	4.3				
9/25/2002	DC WEST	7.47	476	178	0.1	1.4				

INFLUE	INFLUENT for Waterloo Biofilter									
Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)				
10/9/2002	DC WEST	7.36	503	242	3.7	6.4				
10/23/2002	DC WEST	7.40	556	180	4.0	7				
11/6/2002	DC WEST	7.30	522	166	3.9	6.2				
11/20/2002	DC WEST	7.20	500	170	3.2	5.3				
12/4/2002	DC WEST	7.33	511	174	3.5	5.7				
12/18/2002	DC WEST	7.32	481	160	3.7	6.8				
12/18/2002	DC WEST QA	7.38	481	162	3.6	6.7				
12/30/2002	DC WEST	7.35	491	162	3.8	5.3				
1/15/2003	DC WEST	7.37	518	168	3.7	5.7				
1/29/2003	DC WEST	7.32	527	164	4.2	5				
Mean		7.36		181.33	3.67	5.71				
Median		7.39		178	3.85	5.8				
Count		37.00		27	38	38				
Std Dev.		0.08		17.18	0.68	1.10				
95% CI		0.02		6.48	0.22	0.35				

APPENDIX 2

RAW DATA FROM ASSAYS TAKEN AT THE PHOSPHEX™, RAW WASTEWATER INFLUENT AND THE RECIRCULATING SAND FILTER USED AS INFLUENT FOR THE PHOSPHEX

DC EAST – indicates the eastern end of the influent dosing channel from which the influent is supplied to the recirculating sand filter which subsequently serves as influent to the Phosphex

Date	Location	pН	Sp Cond(uS)	Alkalinity(mgl)	PO4(mg/L)	TP (mg/L)
12/19/2001	PHOSPHEX	11.97	1609	340	0.1	0.25
12/19/2001	PHOSPHEX QA			227	0.1	0.25
1/3/2002	PHOSPHEX	12.09	1390	318	0.1	0.25
1/16/2002	PHOSPHEX	12.52	1249	824	0.1	0.25
1/30/2002	PHOSPHEX	12.12	1342	280	0.1	0.25
2/13/2002	PHOSPHEX	12.00	1056	194	0.1	0.25
2/13/2002	PHOSPHEX QA			216	0.1	0.25
2/27/2002	PHOSPHEX	11.88	1009	170	0.1	0.25
2/27/2002	PHOSPHEX QA	11.85	988	164	0.1	0.25
3/13/2002	PHOSPHEX	11.72	961	310	0.1	0.25
4/3/2002	PHOSPHEX	11.75	568	130	0.1	0.25
4/10/2002	PHOSPHEX	11.53	896	172	0.1	0.25
4/24/2002	PHOSPHEX	11.70	609	158	0.1	0.10
5/8/2002	PHOSPHEX	11.57	719	106	0.1	0.08
5/8/2002	PHOSPHEX QA	11.61	720	90	0.1	0.09
5/22/2002	PHOSPHEX	11.48	694		0.1	0.10
6/5/2002	PHOSPHEX	11.43	678	158	0.1	0.06
6/19/2002	PHOSPHEX	11.49	600	168	0.0	0.07
6/18/2003	PHOSPHEX	10.39	544	139		
7/16/2003	PHOSPHEX	10.63		140		
8/13/2003	PHOSPHEX	10.43		112		
9/10/2003	PHOSPHEX	10.55	565			
10/8/2003	PHOSPHEX	10.14	646	102		
11/12/2003	PHOSPHEX	9.24	622			
12/10/2003	PHOSPHEX	9.90	616			
1/7/2004	PHOSPHEX	9.94	424			
Mean		11.25			0.0	0.19
Median		11.55			0.1	0.25
Count		24.00			18.0	18.00
Std Dev.		0.86			0.0	0.08
95% CI		0.35			0.0	0.04

PHOSPHEX TREATMENT SYSTEM AS ORIGININALLY CONFIGURED FOR PHOSPHORUS REMOVAL

Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP (mg/L)
8/20/2002	PEAT EFF	5.00	317			
8/21/2002	PEAT EFF	5.21	342	2	0.1	0.36
8/28/2002	PEAT EFF	6.39	426	6	0.1	0.18
8/28/2002	PEAT EFF QA	6.44	424	9	0.1	0.14
9/11/2002	PEAT EFF	5.83	389	3	0.1	0.17
9/25/2002	PEAT EFF	5.75	313	5	0.1	0.14
10/9/2002	PEAT EFF	6.19	340	5	0.1	0.07
10/23/2002	PEAT EFF	6.30	347	16	0.1	0.04
10/23/2002	PEAT EFF QA	6.23	345	6	0.1	0.12
11/6/2002	PEAT EFF	6.73	383	20	0.1	0.25
11/20/2002	PEAT EFF	8.06	321	36	0.1	0.04
12/4/2002	PEAT EFF	9.56	389	48	0.1	0.25
12/4/2002	PEAT EFF QA	9.55	387	46	0.1	0.25
12/18/2002	PEAT EFF	9.92	350	51	0.5	0.25
12/30/2002	PEAT EFF	9.65	363	54	0.1	0.01
1/15/2003	PEAT EFF	10.38	423	52	0.1	0.01
1/29/2003	PEAT EFF	9.82	397	54	0.1	0.25
1/29/2003	PEAT EFF QA	9.79	391	58	0.1	0.25
2/12/2003	PEAT EFF	9.69	687	62	0.1	0.05
2/26/2003	PEAT EFF	9.62	546	66	0.1	0.06
3/12/2003	PEAT EFF	9.54	577			
3/26/2003	PEAT EFF	7.42	424			
4/9/2003	PEAT EFF	9.60	410			
4/23/2003	PEAT EFF	9.73	577			
5/7/2003	PEAT EFF	9.49	553			
6/4/2003	PEAT EFF	8.84	492			
6/18/2003	PEAT EFF	8.69	536	128		
7/16/2003	PEAT EFF	7.85	519	132		
9/10/2003	PEAT EFF	7.99	592			
10/8/2003	PEAT EFF	7.86	680	100		
11/12/2003	PEAT EFF	7.77	662			
12/10/2003	PEAT EFF	7.79	595			
1/7/2004	PEAT EFF	7.73	726			
Mean		8.68			0.1	0.14
Median		9.17			0.1	0.12
Count		26.00			13.0	13.00
Std Dev.		1.21			0.1	0.11
95% CI		0.46			0.1	0.06

PHOSPHEX TREATMENT SYSTEM WITH FINAL PEAT FILTER FOR pH ADJUSTMENT

			Sp			ТР
Date	Location	pН	Cond(uS)	Alkalinity(mgl)	PO4(mg/L)	(mg/L)
1/2/2002	RSF2 EF	7.23	408	75.5	3.9	3.8
1/3/2002	RSF2 EF	7.23	408	74	3.9	3.8
1/15/2002	RSF2 EF	7.10	435	348.5	3.8	3.7
1/16/2002	RSF2 EF	7.10	435	61	3.8	3.7
	RSF2 EF					
1/16/2002	QA			63	3.8	3.8
1/29/2002	RSF2 EF	6.99	510	60.5	4.1	4.5
1/30/2002	RSF2 EF	6.99	510	60	4.1	4.5
2/12/2002	RSF2 EF	6.94	409	42.5	4	3.9
2/13/2002	RSF2 EF	6.94	409		4	3.9
2/26/2002	RSF2 EF	6.80	470	40.5	4	3.9
2/27/2002	RSF2 EF	6.80	470		4	3.9
3/12/2002	RSF2 EF	6.59	435	28	4.2	4.1
3/13/2002	RSF2 EF	6.59	435		4.2	4.1
4/3/2002	RSF2 EF	6.72	390	38	4.1	4.3
4/9/2002	RSF2 EF	6.80	433	47	4.4	4.2
4/10/2002	RSF2 EF	6.80	433		4.4	4.2
4/23/2002	RSF2 EF	6.75	452	83.5	4.9	5.4
4/24/2002	RSF2 EF	6.75	452		4 9	5.4
5/7/2002	RSF2 EF	6.99	438		4.5	4 7
57772002	RSF2 EF	0.77	150		1.0	,
5/22/2002	QA	6.74	415		4.4	4.4
5/22/2002	RSF2 EF	6.67	418		4.4	4.6
6/5/2002	RSF2 EF	7.01	421	62	4.8	5.1
6/19/2002	RSF2 EF	6.84	426	74	4.3	5.1
8/28/2002	RSF2 EF	6.57	469	30	4.3	4.7
9/11/2002	RSF2 EF	6.95	424	23	4.6	2.2
	RSF2 EF					
9/11/2002	QA	6.96	424	34	4.6	3.1
9/25/2002	RSF2 EF	7.07	371	36	3.5	1.7
	RSF2 EF					
9/25/2002	QA	7.08	368	34	3.5	4
10/9/2002	RSF2 EF	7.07	404	46	4.2	4.1
	RSF2 EF					
10/9/2002	QA	7.11	398	46	4.1	4.1
10/23/2002	RSF2 EF	6.91	424	38	4	4.4
11/6/2002	RSF2 EF	6.86	419	44	3.7	3.6
11/20/2002	RSF2 EF	7.07	365	50	3.6	3.7
11/20/2007	RSF2 EF					
11/20/2002	QA	7.10	364	46	3.5	3.8
12/4/2002	RSF2 EF	7.26	398	48	3.5	3.8
12/18/2002	RSF2 EF	7.17	366	14	3.7	3.7

RECIRCULATING SAND FILTER SERVING AS INFLUENT FOR PHOSPHEX SYSTEM

(Cont.)						
			Sp			TP
Date	Location	pН	Cond(uS)	Alkalinity(mgl)	PO4(mg/L)	(mg/L)
12/30/2002	RSF2 EF	7.05	374	26	4.1	4.1
1/15/2003	RSF2 EF	7.12	432	28	3.9	1.9
1/29/2003	RSF2 EF	7.21	468	75	4.8	4.7
2/12/2003	RSF2 EF	6.76	625	30	4.1	3.9
2/26/2003	RSF2 EF	6.94	361	24	3.8	4.1
3/12/2003	RSF2 EF	6.15	450	92	3.5	3.5
	RSF2 EF					
3/12/2003	QA	6.04	497	22	3.5	3.5
3/26/2003	RSF2 EF	6.76	509	34	3.5	3.7
	RSF2 EF					
4/9/2003	QA	6.67	377	22	4	4.2
4/9/2003	RSF2 EF	6.67	378	22	4	4.3
4/23/2003	RSF2 EF	6.82	473	57	3.5	3.8
5/7/2003	RSF2 EF	6.75	532	38	4.1	4.6
5/21/2003	RSF2 EF	5.96	551	24	4.1	4.3
6/4/2003	RSF2 EF	6.85	458	38	4.7	5.1
6/18/2003	RSF2 EF	7.24	511	78	4.2	4.9
Mean		6.87		52.49	4.07	4.05
Median		6.93		42.50	4.10	4.10
Count		40		33	40	40
Std Dev.		0.28		50.11	0.39	0.73
95% CI		0.09		17.10	0.12	0.23

RECIRCULATING SAND FILTER SERVING AS INFLUENT FOR PHOSPHEX SYSTEM

INFLUE	INFLUENT FOR PHOSPHEX (via recirculating sand filter)								
			Sp		Í	TP			
Date	Location	рН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	(mg/L)			
12/19/2001	DC EAST	7.30	463		2.8	5.5			
1/2/2002	DC EAST	7.42	554	209	3.8	5.2			
1/3/2002	DC EAST	7.42	554	200	3.8	5.2			
1/15/2002	DC EAST	7.59	636	192	4.0	6.2			
1/16/2002	DC EAST	7.59	636		4.0	6.2			
1/29/2002	DC EAST	7.48	583	186	3.9	6.5			
1/30/2002	DC EAST	7.48	583		3.9	6.5			
2/12/2002	DC EAST	7.39	558	193	4.2	5.7			
2/13/2002	DC EAST	7.39	558		4.2	5.7			
2/26/2002	DC EAST	7.46	529	190	3.9	5.7			
2/27/2002	DC EAST	7.46	529		3.9	5.7			
3/12/2002	DC EAST	7.29	587	193	4.2	8.0			
3/13/2002	DC EAST	7.29	587		4.2	8.0			
3/26/2002	DC EAST	7.33	506	186	3.8	6.2			
3/27/2002	DC EAST	7.33	506		3.8	6.2			
4/9/2002	DC EAST	7.40	577	190	3.9	5.7			
4/10/2002	DC EAST	7.40	577		3.9	5.7			
4/23/2002	DC EAST	7.42	578	52	3.7	5.7			
4/24/2002	DC EAST	7.42	578		3.7	5.7			
	DC EAST								
4/24/2002	QA	7.45	575		3.7	6.0			
5/7/2002	DC EAST	7.45	526		3.9	6.1			
5/22/2002	DC EAST	7.24	437	192	3.7	5.9			
5/22/2002	DC EAST	7.24	437	192	3.7	5.9			
6/5/2002	DC EAST	7.44	538	178	3.8	6.2			
6/5/2002	DC EAST	7.44	538	178	3.8	6.2			
6/19/2002	DC EAST	7.37	502	206	2.9	5.5			
8/28/2002	DC EAST	7.41	520	172	3.7	3.7			
9/11/2002	DC EAST	7.40	504	172	4.1	3.0			
9/25/2002	DC EAST	7.44	470	168	0.1	1.8			
10/9/2002	DC EAST	7.35	515	264	3.7	6.0			
10/23/2002	DC EAST	7.43	540	196	3.9	7.2			
11/6/2002	DC EAST	7.24	468	166	3.8	6.1			
11/20/2002	DC EAST	7.28	503	168	3.2	5.0			

INFLUEN	T FOR PHO	SPHE	X (via reciro	culating sand fil	ter - Contir	nued)
			Sp	0		TP
Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	(mg/L)
12/4/2002	DC EAST	7.29	521	163	3.5	5.7
12/18/2002	DC EAST	7.34	476	162	3.6	7.3
12/30/2002	DC EAST	7.16	494	164	3.8	5.4
1/15/2003	DC EAST	7.34	454	162	3.7	5.7
1/29/2003	DC EAST	7.45	416	168	4.2	4.3
2/12/2003	DC EAST	7.71	782	164	3.7	5.5
	DC EAST					
2/26/2003	QA	7.58	732	158	3.4	5.0
2/26/2003	DC EAST	7.63	813	162	3.4	5.1
3/12/2003	DC EAST	7.53	555	166	3.2	5.2
3/26/2003	DC EAST	7.49	615	178	4.4	6.2
4/9/2003	DC EAST	7.58	515	174	3.8	5.5
4/23/2003	DC EAST	7.10	613	160	4.1	6.6
5/7/2003	DC EAST	7.49	681	178	3.9	5.8
5/21/2003	DC EAST	7.45	576	148	2.8	4.0
6/4/2003	DC EAST	7.31	612	166	4.2	7.1
6/18/2003	DC EAST	7.18	701	200	4.2	6.0
7/2/2003	DC EAST	7.26	693	206	4.5	5.7
7/16/2003	DC EAST	7.27	660	190	4.0	9.1
7/23/2003	DC EAST	7.27	567	168	3.2	5.2
7/30/2003	DC EAST	7.38	593	160	2.9	4.7
8/13/2003	DC EAST				4.2	8.6
9/10/2003	DC EAST	7.28	592	184	3.4	4.8
10/8/2003	DC EAST	7.45	689		3.6	5.4
12/10/2003	DC EAST	7.39	649	180	3.9	4.8
Mean		7.39		177	3.7	5.8
Median		7.40		178	3.8	5.7
Count		39.00		34	40.0	40.0
Std Dev.		0.12		28	0.6	1.2
95% CI		0.04		9	0.2	0.4

APPENDIX 3

RAW DATA FROM ASSAYS TAKEN AT THE PHOSRID™ PHOSPHORUS REMOVAL UNIT

For reference



A – Data for influent characteristics can be obtained from Appendix 2 "DCEAST"

B – Denoted in this appendix as "D3 DB" is the septic tank effluent from a two compartment 1500 gallon septic tank (500 gallon-1000 gallon).

C – Referred to in this appendix as "RID EFF" and refers to effluent from the RID media tank prior to entry into the sand filter media (variously called the "oxygenation chamber" in the Massachusetts DEP Piloting Approval)

D – Referred to in this appendix as "RID SAND" and refers to the effluent from the sand filter after passing through the septic tank and the RID media chamber.

****The proponent of this technology has performed supplemental sampling using a different laboratory to achieve lower detection limits. These data have not been made available.

Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)	Iron
9/11/2002	RID EFF	7.85	696		0.5	0.75	0.8
9/25/2002	RID EFF	7.69		234	0.05	0.41	15
10/9/2002	RID EFF	7.63	599	252	0.05	1	5.7
10/23/2002	RID EFF	7.25	587	244	0.05	1.6	14.8
11/6/2002	RID EFF	7.44	569	228	0.05	3	14.1
11/20/2002	RID EFF	7.44	489	204	0.2	1.4	0.2
12/4/2002	RID EFF	7.37	566	230	0.05	5.2	13
12/18/2002	RID EFF	7.64	501	204	0.7	3.5	6.4
12/30/2002	RID EFF	7.48	529	210	0.9	4	7.8
1/15/2003	RID EFF	7.43	581	220	1.3	4.2	
1/29/2003	RID EFF	7.32	564	210	2	3.7	6.4
2/12/2003	RID EFF	7.43	796	210	1.6	4	4.4
2/26/2003	RID EFF	7.5	556	154	2.3	3.9	4.5
3/12/2003	RID EFF	7.61	623	208	1.8	4.5	5.2
3/26/2003	RID EFF	7.56	688	228	1.8	4.9	2.7
4/9/2003	RID EFF	7.55	555	244	1.3	4.2	4
4/23/2003	RID EFF	7.51	747	230	2.7	3.9	2.8
5/7/2003	RID EFF	7.44	793	248	3.4	4.6	1.4
5/21/2003	RID EFF	7.57	770	248	3.2	4.1	0.67
6/4/2003	RID EFF	7.40	692	232	3.7	5.4	8.4
6/18/2003	RID EFF	7.24	793	270	3.5	4.3	0.3
7/2/2003	RID EFF	7.08	766	266	2.4	4.7	
7/16/2003	RID EFF	7.11	746	240	3.7	7.3	6.3
7/30/2003	RID EFF	7.22	755	258	4.3	5.3	
8/13/2003	RID EFF			270	4.2	5.2	
8/27/2003	RID EFF	7.33	651	270	4.8	5.2	
9/10/2003	RID EFF	6.42	1669	126	0.5	0.9	79.8
9/24/2003	RID EFF	7.26	698	220	0.5	3.6	
10/8/2003	RID EFF	7.33	773	242	1.5	4.7	8.4
6/30/2004	RID EFF	7.66	1514		0.5	2.2	3.9
11/6/2002	RID EFF QA	7.47	535	232	0.05	2.8	
2/12/2003	RID EFF QA	7.51	796	214	1.3	4	
3/26/2003	RID EFF QA	7.75	668	232	1.8	4.8	
Mean		7.42		228.32	1.72	3.74	9.04
Median		7.44		232.00	1.50	4.00	5.45
Count		32		31	33	33	24
Std Dev.		0.25		30.92	1.45	1.59	15.73
95% CI		0.09		10.88	0.50	0.54	6.29

PHOSRID Effluent Following Passage through a Septic Tank and the RID Media Tank

Date	Location	pН	Sp Cond(uS)	Alkalinity(mg/L)	PO4(mg/L)	TP(mg/L)	Iron
9/13/2002	RID SAND	7.12	1433		0.05	0.25	
9/25/2002	RID SAND	7.23	1317		0.05	0.25	1.1
10/9/2002	RID SAND	7.23	963		0.05	0.26	0.5
10/23/2002	RID SAND	7.48	530		0.05	0.25	0.2
11/6/2002	RID SAND	7.26	535		0.05	0.25	0.5
11/20/2002	RID SAND	7.49	507		0.05	0.25	12.9
12/4/2002	RID SAND	7.26	395		0.05	0.25	0.1
12/18/2002	RID SAND	7.45	328		0.5	0.25	0.3
12/30/2002	RID SAND	7.30	335		0.05	0.031	0.05
6/30/2004	RID SAND	7.04	1346		0.7	1.7	6.7
Mean		7.29			0.16	0.37	2.48
Median		7.26			0.05	0.25	0.50
Count		10			10	10	9
Std Dev.		0.15			0.24	0.47	4.44
95% CI		0.09			0.15	0.29	2.90

PHOSRID Effluent Following Passage through a Septic Tank, RID Media Tank and Sand Filter

PHOSRID Influent

Date	Location	pН	Sp Cond(uS)	Oxid-Red Pot.	PO4(mg/L)	TP(mg/L)	Iron
9/11/2002	D3 DB	7.46	586		3.9	16	0.5
9/25/2002	D3 DB	7.52	499	-116	3.6	4.9	0.5
10/9/2002	D3 DB	7.32	576	-80.6	4.5	5.3	0.8
10/23/2002	D3 DB	7.37	591	27.2	4.4	5.5	0.4
11/6/2002	D3 DB	7.29	544	54.8	5.5	4.3	0.7
11/20/2002	D3 DB	7.18	508	-32.2	4	5	0.5
12/4/2002	D3 DB	7.36	567	13.4	4.3	5.6	0.7
12/18/2002	D3 DB	7.44	494	56.6	4.2	5.3	0.7
12/30/2002	D3 DB	7.24	523	163	4.4	5.4	0.5
1/29/2003	D3 DB	7.22	563	50.3			0.7
2/12/2003	D3 DB	7.29	809	17.1			0.6
2/26/2003	D3 DB	7.29	501	-96	3.1	3.8	1.1
3/12/2003	D3 DB	7.44	503	-181.3	3.8	5.1	0.5
3/26/2003	D3 DB	7.38	641	-190.1	3.5	5	0.5
4/9/2003	D3 DB	7.39	518	-323.8	4.2	5.6	0.7
4/23/2003	D3 DB	7.38	659	-207.5	3.7	4.6	0.6
5/7/2003	D3 DB	7.23	745	-191.3	4.4	5	0.5
5/21/2003	D3 DB	7.05	673	-278	3.8	4.6	0.4
6/4/2003	D3 DB	7.12	646	-428.6	5.5	5.9	0.4
6/18/2003	D3 DB	6.96	739	-324	4.8	5.7	0.9
6/30/2003	D3 DB	6.8	740				1
7/7/2003	D3 DB	6.86	651		4.5	4.3	0.6
7/16/2003	D3 DB	6.09	752	-425.3	4.2	7.2	1
8/13/2003	D3 DB	7.17	729		4.8	4.9	0.6
9/10/2003	D3 DB	7.18	692		4.3	4.8	0.5
10/8/2003	D3 DB	7.13	745		4.2	5.3	0.3
11/12/2003	D3 DB	7.18	784		4.8	5.8	0.5
12/10/2003	D3 DB	7.24	708		4.2	5.2	0.4
1/7/2004	D3 DB	7.3	675		4.3	5.6	0.7
2/11/2004	D3 DB	7.26	511		2.2	3.1	0.4
4/21/2004	D3 DB	7.13	644		4.1	4.5	0.9
5/12/2004	D3 DB	7.26	445		3.9	5.4	0.07
6/30/2004	D3 DB	6.99	584		4.9	5.5	1
Mean		7.20			4.20	5.47	0.61
Median		7.24			4.20	5.25	0.60
Count		33			30	30	33
Std Dev.		0.26			0.65	2.12	0.23
95% CI		0.09			0.23	0.76	0.08

APPENDIX 3

RAW DATA FROM ASSAYS TAKEN AT TWO RECIRCULATING SAND FILTERS AND RAW WASTEWATER INFLUENT

First PO4 and TP Assayed at University of Massachusetts Dartmouth, School for Marine Science and Technology. "County" samples assayed at Barnstable County Department of Health and the Environment subcontract laboratory.

Recirculating Sand Filter #1

D.(т.,:		Sp		DO4(/1)	TP	PO4	TP
Date	Location	рн	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	(m/L)	(County)	(County)
3/15/2000	RSF1 EF	7.50	513	169	2.2	2.4		
3/28/2000	RSF1 EF	7.86	611	173	2.5	3.9		
4/11/2000	RSF1 EF	7.68	612	171	2.0	3.1		
5/2/2000	RSF1 EF	7.09	478	83	1.8	2.5		
5/17/2000	RSF1 EF	6.88	475	37	2.2	2.7		
5/31/2000	RSF1 EF	6.76	478	53	2.5	2.7		
6/14/2000	RSF1 EF	6.82	449	66	3.0	3.2		
6/28/2000	RSF1 EF	7.03	490	70	3.1	3.2		
7/12/2000	RSF1 EF	6.73	457	94	3.0	3.5		
7/26/2000	RSF1 EF	6.89	515	89	2.9	2.9		
8/9/2000	RSF1 EF	7.16	530	122	3.3			
8/23/2000	RSF1 EF	7.16	543	333	3.2	3.2		
	RSF1 EF							
8/23/2000	QA	7.17	542	72	3.2	3.3		
9/6/2000	RSF1 EF	7.08	534	96	3.4	3.4		
0/6/2000	RSF1 EF	7.00	52.4	C A	2.4	2.5		
9/6/2000	QA DOELEE	7.08	534	64	3.4	3.5		
9/20/2000	RSF1 EF	7.03	501	90	3.3	3.9		
10/3/2000	RSF1 EF	6.98	565	67	3.4	3.4		
10/17/2000	RSF1 EF	6.79	566	77	2.8	2.8		
10/30/2000	RSF1 EF	7.01	504	66	3.1	3.4		
11/14/2000	RSF1 EF	7.20	486	46	2.4	2.5		
11/28/2000	RSF1 EF	7.10	464	46	2.3	2.5		
12/12/2000	RSF1 EF	6.82	484	42	3.3	3.4		
12/26/2000	RSF1 EF	6.92	463	51	3.4	3.4		
1/9/2001	RSF1 EF	6.46	498	52	3.7	4.1		
1/23/2001	RSF1 EF	6.36	460	46	3.7	3.7		
2/6/2001	RSF1 EF	6.56	450	45	3.5	3.5		
2/20/2001	RSF1 EF	6.49	480	45	4.8	3.7		
3/13/2001	RSF1 EF	6.46	570	42	3.2	3.4		
3/27/2001	RSF1 EF	6.58	382	33	3.6	3.9		
	RSF1 EF							
3/27/2001	QA	6.57	385	32	3.6	3.5		
4/10/2001	RSF1 EF	6.33	453	42	3.7	3.8		
4/24/2001	RSF1 EF	6.89	413	23	3.3	3.9		
5/8/2001	RSF1 EF	6.72	421	60	4.1	4.2		
5/22/2001	RSF1 EF	6.80	403	77	4.4	4.4		
6/5/2001	RSF1 EF	7.06	410	76	4.1	4.2		
6/19/2001	RSF1 EF	7.30	399	99	4.5			
	RSF1 EF							
6/19/2001	QA	7.38	407	99	4.5			
7/2/2001	RSF1 EF	6.95	421	90	5.0	5.1		
7/17/2001	RSF1 EF	6.65	482	79	4.2	4.3		

Recirculating Sand Filter #1 (Continued)

Appendices

Date	Location	рH	Sp Cond(uS)	Alkalinitv(mg/L)	PO4(mg/l)	TP (m/L)	PO4 (County)	TP (County)
7/31/2001	RSF1 EF	6.88	472	66	4.2	4.3	(county)	(county)
8/14/2001	RSF1 EF	6.80	498	94	3.7			
8/28/2001	RSF1 EF	7.15	489	91	3.6			
9/11/2001	RSF1 EF	6.86	463	40	3.5	3.7		
9/25/2001	RSF1 EF	6.84	480	44	3.7	3.9		
10/9/2001	RSF1 EF	6.86	458	49	4.1	4.1		
10/23/2001	RSF1 EF	6.70	481	37	3.5			
11/6/2001	RSF1 EF	6.66	462	37	3.9	4.2		
	RSF1 EF							
11/6/2001	QA	6.87	455	36	3.8	4.1		
11/19/2001	RSF1 EF	7.16	420	35	3.6	3.8		
12/4/2001	RSF1 EF	6.67	402	55	3.8	3.9		
12/18/2001	RSF1 EF	7.06	406	50	3.6	4.3		
1/2/2002	RSF1 EF	6.97	402	56	4.0	4.4		
1/15/2002	RSF1 EF	6.94	458	350	4.0	4.4		
	RSF1 EF							
1/15/2002	QA	6.92	457	346	4.0	4.4		
1/29/2002	RSF1 EF	6.89	529	47	3.9	4.3		
2/12/2002	RSF1 EF	6.87	426	35	3.7	4.1		
2/26/2002	RSF1 EF	6.77	430	43	3.6	3.7		
3/12/2002	RSF1 EF	6.58	455	36	4.1	4.2		
3/26/2002	RSF1 EF	6.95	412	37	3.9	5.2		
4/9/2002	RSF1 EF	6.86	437	192	3.9	4.1		
4/23/2002	RSF1 EF	6.71	466	216	4.3	4.7		
	RSF1 EF							
4/23/2002	QA	6.75	462	52	4.3	4.9		
5/7/2002	RSF1 EF	7.03	448		4.3	4.7		
4/2/2003	RSF1 EF	6.66	447	76			4.3	4.8
4/9/2003	RSF1 EF	6.81	389	70			4.4	4.4
4/16/2003	RSF1 EF	6.57	536	66			4.1	4.0
4/23/2003	RSF1 EF	6.69	537	58			4.3	4.7
5/7/2003	RSF1 EF	6.50	528	81			4.6	4.9
5/21/2003	RSF1 EF	6.65	485	82			4.5	4.3
6/4/2003	RSF1 EF	6.75	446	58			4.6	4.4
6/18/2003	RSF1 EF	6.66	480	86			4.0	4.1
7/2/2003	RSF1 EF	6.59	453	82			4.5	3.5
7/16/2003	RSF1 EF	6.29	527	80			5.0	5.6
7/30/2003	RSF1 EF	6.59	490	89			3.9	4.2
8/13/2003	RSF1 EF			66			4.8	4.2
8/27/2003	RSF1 EF	6.74	439	85			3.5	4.0
9/10/2003	RSF1 EF	6.73	523	68			3.7	3.4
9/24/2003	RSF1 EF	6.55	525	58			3.4	3.5
10/8/2003	RSF1 EF	6.53	555	44			3.9	4.1

Recirculating Sand Filter #2

			Sn				PO4	ТР
Date	Location	рН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	ТР	(County)	(County)

Appendices

3/15/2000	RSF2 FF	8.05	545	162	2.0	28		
3/28/2000	RSF2 EF	8.27	575	162	2.3	3.2		
4/11/2000	RSF2 EF	8.23	587	171	2.7	2.7		
5/2/2000	RSF2 EF	7 85	483		2.0	2.9		
5/17/2000	RSF2 EF	7.09	470	48	2.0	1.2		
5/31/2000	RSF2 EF	7.17	472	37	2.8	2.9		
6/14/2000	RSF2 EF	7.33	429	39	2.9	3.2		
6/28/2000	RSF2 EF	7.29	502	58	3.8	4.1		
7/12/2000	RSF2 EF	7.23	449	73	2.9	3.7		
7/26/2000	RSF2 EF	6.89	515	53	3.1	3.1		
8/9/2000	RSF2 EF	7.42	529	77	3.4			
8/23/2000	RSF2 EF	6.91	542	107	3.4	3.5		
9/6/2000	RSF2 EF	7.74	531	61	3.5	3.5		
9/20/2000	RSF2 EF	7.59	473	54	3.7	3.8		
10/3/2000	RSF2 EF	7.65	528	50	3.5	3.6		
	RSF2 EF							
10/3/2000	QA	7.60	526	49	3.7	3.8		
10/17/2000	RSF2 EF	7.77	530	52	2.9	3.0		
10/30/2000	RSF2 EF	7.68	475	57	2.4	2.8		
	RSF2 EF							
10/30/2000	QA	7.71	476	56	2.4	2.6		
11/14/2000	RSF2 EF	7.58	430	42	2.3	2.5		
11/28/2000	RSF2 EF	7.36	484	64	2.8	2.9		
12/12/2000	RSF2 EF	7.46	481	61	3.4	3.5		
12/26/2000	RSF2 EF	7.36	455	42	3.5	3.5		
	RSF2 EF							
12/26/2000	QA	7.36	452	43	3.4	3.6	 	
1/9/2001	RSF2 EF	6.99	483	29	3.4	4.7		
1/23/2001	RSF2 EF	6.72	453	35	3.2	3.5		
2/6/2001	RSF2 EF	6.83	434	23	3.3	3.5		
2/20/2001	RSF2 EF	6.81	322	26	3.6	3.7		
3/13/2001	RSF2 EF	6.78	574	31	3.4	3.6		
3/27/2001	RSF2 EF	6.84	393	21	3.4	3.7		
4/10/2001	RSF2 EF	6.50	437	20	3.7	4.1		
4/24/2001	RSF2 EF	6.55	430	45	3.3	5.5		
5/8/2001	RSF2 EF	6.95	440	44	4.4	4.6		
5/22/2001	RSF2 EF	7.42	370	59	5.0	5.1		
6/5/2001	RSF2 EF	7.34	405	71	4.1	4.1		
	RSF2 EF							
6/5/2001	QA	7.39	398	72	3.9	4.1		
6/19/2001	RSF2 EF	7.24	390	61	4.5			
7/2/2001	RSF2 EF	7.35	416	54	4.8	4.9		
			Sp				PO4	ТР
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Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	ТР	(County)	(County)
7/17/2001	RSF2 EF	6.73	456	248	4.2	4.2		
7/31/2001	RSF2 EF	6.84	426	60	4.0	4.1		
8/14/2001	RSF2 EF	7.06	457	65	3.6			
	RSF2 EF							
8/14/2001	QA	7.05	457	65	3.5			
8/28/2001	RSF2 EF	7.22	495	85	3.5			
9/11/2001	RSF2 EF	7.26	452	67	3.8	3.8		
9/25/2001	RSF2 EF	6.99	427	75	3.8	3.9		
10/9/2001	RSF2 EF	7.70	545	59	3.9	4.0		
10/23/2001	RSF2 EF	7.08	456	52	3.4			
11/6/2001	RSF2 EF	7.17	436	45	3.8	4.1		
11/19/2001	RSF2 EF	7.32	433	57	3.9	4.3		
	RSF2 EF							
11/19/2001	QA	7.32	412	58	3.8	4.1		
12/4/2001	RSF2 EF	6.90	360	60	3.7	4.0		
12/18/2001	RSF2 EF	7.01	398	58	3.6	4.0		
1/2/2002	RSF2 EF	7.23	408	76	4.0	4.1	3.9	3.8
	RSF2 EF							
1/2/2002	QA	7.25	407	77	3.6	4.1		
1/3/2002	RSF2 EF	7.23	408	74			3.9	3.8
1/15/2002	RSF2 EF	7.10	435	349	3.6	4.2	3.8	3.7
1/16/2002	RSF2 EF	7.10	435	61			3.8	3.7
1/1//0000	RSF2 EF						2.0	2.0
1/16/2002	QA DGE2 FF	(00	510	63	2.0	4.2	3.8	3.8
1/29/2002	RSF2 EF	6.99	510	61	3.8	4.3	4.1	4.5
1/30/2002	RSF2 EF	6.99	510	60		1.0	4.1	4.5
2/12/2002	RSF2 EF	6.94	409	43	3.7	4.0	4.0	3.9
2/13/2002	RSF2 EF	6.94	409			• •	4.0	3.9
2/26/2002	RSF2 EF	6.80	470	41	3.6	3.8	4.0	3.9
2/26/2002	KSF2 EF	6.86	112	40	27	3.0		
2/20/2002	QA RSE2 EE	6.80	443	40	3./	5.0	4.0	2.0
2/2//2002	NOF2 EF	6.50	4/0	20	2.0	4.0	4.0	5.9 1 1
3/12/2002	RSF2 EF	0.39	433	28	5.9	4.0	4.2	4.1
3/12/2002	OA	6.62	444	29	41	41		
3/13/2002	RSF2 EF	6.59	435				4.2	41
3/26/2002	RSF2 EF	6.96	403	33	3.6	38		1
4/3/2002	RSF2 EF	6 72	390	38	2.0	2.0	4 1	43
4/9/2002	RSF2 EF	6.80	433	47	41	43	4.4	4.2
4/10/2002	RSF2 EF	6.80	433	т <i>і</i>	1.1		4.4	4.2
4/23/2002	RSF2 FF	6.75	452	84	4 5	48	4 9	5.4
4/24/2002	RSF2 FF	6.75	452		т.Ј	7.0	4.9	5.4
1/21/2002	101 2 DI	0.75	732	1		1	т.)	J.T

Recirculating Sand Filter #2 (Continued)

$\begin{array}{c c c c c c c c c c c c c c c c c c c $				Sp				PO4	ТР
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	ТР	(County)	(County)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	5/7/2002	RSF2 EF	6.99	438	• • • /	4.1		4.5	4.7
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		RSF2 EF							
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	5/7/2002	QA	7.02	437		4.1	5.0		
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	5/22/2002	RSF2 EF	6.67	418				4.4	4.6
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		RSF2 EF							
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	5/22/2002	QA	6.74	415				4.4	4.4
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	6/5/2002	RSF2 EF	7.01	421	62			4.8	5.1
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	6/12/2002	RSF2 EF	7.10	428					
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	6/19/2002	RSF2 EF	6.84	426	74			4.3	5.1
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	8/28/2002	RSF2 EF	6.57	469	30			4.3	4.7
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	9/11/2002	RSF2 EF	6.95	424	23			4.6	2.2
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		RSF2 EF							
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	9/11/2002	QA	6.96	424	34			4.6	3.1
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	9/25/2002	RSF2 EF	7.07	371	36			3.5	1.7
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	0 10 5 10 0 0 0	RSF2 EF	- 00	2.00	2.4			2.5	1.0
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	9/25/2002	QA	7.08	368	34			3.5	4.0
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	10/9/2002	RSF2 EF	7.07	404	46			4.2	4.1
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	10/0/2002	RSF2 EF	7.11	209	16			4.1	4.1
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	10/9/2002	QA DSE2 EE	/.11	398	40			4.1	4.1
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	10/23/2002	RSF2 EF	0.91	424	38			4.0	4.4
11/20/2002 RSF2 EF 7.07 365 50 3.6 3.7 RSF2 EF 7.10 364 46 3.5 3.8 12/4/2002 RSF2 EF 7.26 398 48 3.5 3.8 12/4/2002 RSF2 EF 7.26 398 48 3.5 3.8 12/4/2002 RSF2 EF 7.17 366 14 3.7 3.7 12/30/2002 RSF2 EF 7.12 432 2.8 3.9 1.9 1/29/2003 RSF2 EF 7.12 432 2.8 3.9 1.9 1/29/2003 RSF2 EF 6.76 625 30 4.1 3.9 2/12/2003 RSF2 EF 6.76 625 30 4.1 3.9 2/26/2003 RSF2 EF 6.15 450 92 3.5 3.5 3/12/2003 QA 6.04 497 22 3.5 3.5 3/12/2003 QA 6.67 378 22 4.0 4.3 4/9/2003 RSF2 EF 6.67 377 22 <t< td=""><td>11/6/2002</td><td>RSF2 EF</td><td>6.86</td><td>419</td><td>44</td><td></td><td></td><td>3./</td><td>3.6</td></t<>	11/6/2002	RSF2 EF	6.86	419	44			3./	3.6
IntroductionIntroductionIntroductionIntroduction11/20/2002QA7.10364463.53.812/4/2002RSF2 EF7.26398483.53.812/18/2002RSF2 EF7.17366143.73.712/30/2002RSF2 EF7.10374264.14.11/15/2003RSF2 EF7.12432283.91.91/29/2003RSF2 EF7.21468754.84.72/12/2003RSF2 EF6.76625304.13.92/26/2003RSF2 EF6.15450923.53.5NSF2 EF6.15450923.53.53/12/2003QA6.04497223.53.53/26/2003RSF2 EF6.76509343.53.74/9/2003RSF2 EF6.67378224.04.3RSF2 EF6.67377224.04.24/9/2003QA6.67377224.04.24/9/2003QA6.67377224.04.24/9/2003RSF2 EF6.75532384.14.65/7/2003RSF2 EF6.75532384.14.65/1/2003RSF2 EF5.96551244.14.55/1/2003RSF2 EF5.96551244.14.5	11/20/2002	RSF2 EF	7.07	365	50			3.6	3.7
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	11/20/2002	KSF2 EF	7 10	364	16			2.5	2.8
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	12/4/2002	QA DSE2 EE	7.10	208	40			2.5	2.0
12/16/2002RSF2 EF7.17366143.73.7 $12/30/2002$ RSF2 EF7.05 374 264.14.1 $1/15/2003$ RSF2 EF7.12432283.91.9 $1/29/2003$ RSF2 EF7.21468754.84.7 $2/12/2003$ RSF2 EF6.76625304.13.9 $2/26/2003$ RSF2 EF6.76625304.13.9 $2/26/2003$ RSF2 EF6.15450923.53.5 $RSF2$ EF6.15450923.53.5 $3/12/2003$ QA6.04497223.53.5 $3/26/2003$ RSF2 EF6.76509343.53.7 $4/9/2003$ RSF2 EF6.67378224.04.3 $4/9/2003$ QA6.67377224.04.2 $4/23/2003$ RSF2 EF6.82473573.53.8 $5/7/2003$ RSF2 EF6.75532384.14.6 $5/7/2003$ RSF2 EF6.75551244.14.6 $5/21/2003$ RSF2 EF5.96551244.14.5	12/4/2002	RSF2 EF	7.20	266	40			2.7	2.7
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	12/18/2002	RSF2 EF	7.17	274	26			3.7	J.7
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	1/15/2002	RSF2 EF	7.03	374	20			4.1	4.1
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	1/13/2003	RSF2 EF	7.12	432	28			5.9	1.9
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	1/29/2003	KSF2 EF	/.21	468	/5			4.8	4./
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	2/12/2003	RSF2 EF	6.76	625	30			4.1	3.9
3/12/2003 RSF2 EF 6.15 450 92 3.5 3.5 RSF2 EF	2/26/2003	RSF2 EF	6.94	361	24			3.8	4.1
RSF2 EF 6.04 497 22 3.5 3.5 3/12/2003 RSF2 EF 6.04 497 22 3.5 3.5 3/26/2003 RSF2 EF 6.76 509 34 3.5 3.7 4/9/2003 RSF2 EF 6.67 378 22 4.0 4.3 RSF2 EF 6.67 377 22 4.0 4.2 4/9/2003 QA 6.67 377 22 4.0 4.2 4/23/2003 RSF2 EF 6.82 473 57 3.5 3.8 5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	3/12/2003	RSF2 EF	6.15	450	92			3.5	3.5
3/26/2003 RSF2 EF 6.76 509 34 3.5 3.7 3/26/2003 RSF2 EF 6.76 509 34 3.5 3.7 4/9/2003 RSF2 EF 6.67 378 22 4.0 4.3 RSF2 EF 4/9/2003 QA 6.67 377 22 4.0 4.2 4/23/2003 RSF2 EF 6.82 473 57 3.5 3.8 5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	3/12/2003	KSF2 EF	6.04	107	22			3.5	35
3/20/2003 RSF2 EF 6.70 309 34 3.3 3.7 4/9/2003 RSF2 EF 6.67 378 22 4.0 4.3 RSF2 EF 4.0 4.3 4/9/2003 QA 6.67 377 22 4.0 4.2 4/23/2003 RSF2 EF 6.82 473 57 3.5 3.8 5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	3/26/2003	DSE2 EE	6.76	500	22			3.5	3.5
4/9/2003 RSF2 EF 6.67 378 22 4.0 4.3 RSF2 EF 4.0 377 22 4.0 4.2 4/9/2003 QA 6.67 377 22 4.0 4.2 4/23/2003 RSF2 EF 6.82 473 57 3.5 3.8 5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	3/20/2003	NSF2 EF	6.67	279	34			3.3	3.7
A/9/2003 QA 6.67 377 22 4.0 4.2 4/23/2003 RSF2 EF 6.82 473 57 3.5 3.8 5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	4/9/2003	RSF2 EF	0.07	5/8	22			4.0	4.3
4/23/2003 RSF2 EF 6.82 473 57 3.5 3.8 5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	4/9/2003	OA	6.67	377	22			4.0	4 2
5/7/2003 RSF2 EF 6.75 532 38 4.1 4.6 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	4/23/2003	RSF2 FF	6.87	Δ73	57			3.5	3.8
5///2003 RSF2 EF 5.96 551 24 4.1 4.3 5/21/2003 RSF2 EF 5.96 551 24 4.1 4.3	5/7/2003	RSF2 FF	6.75	537	38			<u> </u>	<u> </u>
J/21/2003 R012 EF J.70 JJ1 Z4 4.1 4.3 (440000 D0D0 EF COS 450 20 1	5/21/2003	RSF2 FF	5.06	551	24			т.1 Л 1	т.0 / 2
. 6/4/2003 ERSE2 FE T 6 85 T 458 T 38 T T A 7 T 5 T	6/4/2003	RSF2 FF	6.85	458	24			4.1 4.7	4 .5 5 1

Recirculating Sand Filter #2 (Continued)

			Sp			ТР	PO4	ТР
Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	(m/L)	(County)	(County)
6/9/1999	DC EAST	7.40	509	185	3.5	5.4		
6/23/1999	DC EAST	7.32	492	187	3.6	5.1		
7/7/1999	DC EAST	7.18	431	169	3.8	4.9		
7/21/1999	DC EAST	7.47	602	193	3.9	5.5		
8/11/1999	DC EAST	7.33	570	201	4.5	5.7		
8/30/1999	DC EAST	7.36	537	172	3.6	6.0		
9/22/1999	DC EAST	7.42	534	158	3.2	5.1		
10/13/1999	DC EAST	7.25	460	184	3.2	4.9		
11/3/1999	DC EAST	7.30	550	179	3.1	4.2		
11/18/1999	DC EAST	7.36	579	185	3.2	5.1		
12/14/1999	DC EAST	7.33	531	168	3.5	4.9		
12/21/1999	DC EAST	7.39	556	242	3.7	5.7		
1/12/2000	DC EAST	7.42	588	183	3.8	5.3		
2/2/2000	DC EAST	7.30	514	152	3.5			
2/16/2000	DC EAST	7.52	532	162	2.9			
2/23/2000	DC EAST			165	2.8			
3/1/2000	DC EAST	7.45	572	147	3.0	5.3		
3/8/2000	DC EAST	7.17	563	168	3.9	5.6		
3/15/2000	DC EAST	7.27	570	209	3.4			
	DC EAST							
3/15/2000	QA	7.32	600	176	3.5	6.0		
3/28/2000	DC EAST	7.55	531	159	3.1	5.3		
4/11/2000	DC EAST	7.49	584	168	3.1	5.2		
4/19/2000	DC EAST	7.78	556	162	3.6			
5/2/2000	DC EAST	7.38	552	162	3.6	7.4		
5/11/2000	DC EAST	7.33	531	150	2.6	4.0		
5/17/2000	DC EAST	7.42	570	161	2.8	5.2		
5/31/2000	DC EAST	7.37	564	170	2.7	5.0		
6/14/2000	DC EAST	7.09	600	130	3.9	5.7		
	DC EAST							
6/14/2000	QA	7.09	600	51	3.7	5.7		
6/28/2000	DC EAST	7.28	657	158	3.3	4.3		
7/12/2000	DC EAST	7.02	532	59	2.8	3.9		
7/26/2000	DC EAST	7.39	675	192	4.2	5.9		
8/9/2000	DC EAST	7.25	608	168	3.2			
8/23/2000	DC EAST	7.25	638	150	3.2	4.9		
9/6/2000	DC EAST	7.45	599	140	3.0	3.8		
9/20/2000	DC EAST	7.41	547	138	3.2	5.3		
	DC EAST							
9/20/2000	QA	7.38	545	136	3.4	5.1		
10/3/2000	DC EAST	7.28	607	141	3.6	4.9		

Recirculating Sand Filter Influent

			Sp			ТР	PO4	ТР
Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	(m/L)	(County)	(County)
10/17/2000	DC EAST	7.28	525	178	2.6	4.7		
10/30/2000	DC EAST	7.35	461	156	2.8	3.4		
11/14/2000	DC EAST	7.66	482	163	3.1	5.2		
11/28/2000	DC EAST	7.49	550	184	3.2	5.2		
12/12/2000	DC EAST	7.51	569	182	3.0	4.3		
12/26/2000	DC EAST	7.42	547	183	3.6	6.1		
1/9/2001	DC EAST	7.63	561	181	3.8	5.6		
1/23/2001	DC EAST	7.47	523	185	3.7	4.8		
2/6/2001	DC EAST	7.49	785	182	3.4	5.0		
2/20/2001	DC EAST	7.42	517	186	3.4	4.9		
	DC EAST							
2/20/2001	QA	7.43	519	186	3.6	5.2		
3/13/2001	DC EAST	7.39	972	168	3.6	5.6		
3/27/2001	DC EAST	7.50	821	177	3.6	5.5		
	DC EAST	/						
3/27/2001	QA	7.51	830	177	3.5	5.6		
4/10/2001	DC EAST	7.58	499	183	3.9	5.0		
4/24/2001	DC EAST	7.48	546	192	3.3	4.2		
5/8/2001	DC EAST	7.44	516	174	3.3	4.8		
5/22/2001	DC EAST	7.41	499	173	3.9	4.1		
6/5/2001	DC EAST	7.44	536	184	3.3	4.8		
6/19/2001	DC EAST	7.43	525	185	3.3			
7/2/2001	DC EAST	7.39	550	181	3.2	4.7		
7/17/2001	DC EAST	7.31	536	188	3.5	4.2		
7/31/2001	DC EAST	7.39	474	167	2.8	3.7		
8/14/2001	DC EAST	7.25	540	179	3.4			
	DC EAST							
8/14/2001	QA	7.28	534	180	3.2			
8/28/2001	DC EAST	7.57	500	180	2.8			
0/20/2001	DC EAST			190	2.0			
8/28/2001	QA DC FAST	7.25	501	180	3.0	4.2		
9/11/2001	DCEAST	7.55	521	192	3.3	4.5		
9/25/2001	DCEAST	/.10	505	183	3.4	4./		
10/9/2001	DCEAST	7.25	540	184	3.8	4.8		
10/23/2001	DCEASI	7.21	5/4	183	2.8	()		
11/6/2001	DCEAST	7.07	477	184	3.3	6.0		
11/19/2001	DC EAST	7.42	505	179	3.2	5.6		
11/10/2001	DC EASI	7 11	165	100	2 2	5 /		
12/4/2001	DCEAST	7.44	505	102	2.6			
12/4/2001	DCEAST	7 20	162	100	5.0 2.7	7.5	20	5 5
12/10/2001	DCEASI	7.30	403	500	۷.۱	5.1	2.0	5.5
12/19/2001	DULASI	7.50	403				∠.0	5.5

Recirculating Sand Filter Influent (Continued)

			Sp			ТР	PO4	ТР
Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	(m/L)	(County)	(County)
1/2/2002	DC EAST	7.42	554	209	3.7	6.2	3.8	5.2
1/3/2002	DC EAST	7.42	554	200			3.8	5.2
1/15/2002	DC EAST	7.59	636	192	3.7	7.7	4.0	6.2
1/16/2002	DC EAST	7.59	636				4.0	6.2
1/29/2002	DC EAST	7.48	583	186	3.4	6.6	3.9	6.5
	DC EAST							
1/29/2002	QA	7.49	584	188	3.4	7.4		
1/30/2002	DC EAST	7.48	583				3.9	6.5
2/12/2002	DC EAST	7.39	558	193	3.4	5.6	4.2	5.7
2/13/2002	DC EAST	7.39	558				4.2	5.7
2/26/2002	DC EAST	7.46	529	190	3.3	5.6	3.9	5.7
2/27/2002	DC EAST	7.46	529				3.9	5.7
3/12/2002	DC EAST	7.29	587	193	4.3	6.6	4.2	8.0
3/12/2002	DC EAST	7.37	535	182				
3/13/2002	DC EAST	7.29	587				4.2	8.0
3/26/2002	DC EAST	7.33	506	186	3.9	5.0	3.8	6.2
3/27/2002	DC EAST	7.33	506				3.8	6.2
4/9/2002	DC EAST	7.40	577	190	3.5	5.5	3.9	5.7
	DC EAST							
4/9/2002	QA	7.43	574	193	3.4	5.8		
4/10/2002	DC EAST	7.40	577				3.9	5.7
4/23/2002	DC EAST	7.42	578	52	3.4	5.8	3.7	5.7
4/24/2002	DC EAST	7.42	578				3.7	5.7
	DC EAST							
4/24/2002	QA	7.45	575				3.7	6.0
5/7/2002	DC EAST	7.45	526		3.7		3.9	6.1
5/22/2002	DC EAST	7.24	437	192			3.7	5.9
5/22/2002	DC EAST	7.24	437	192			3.7	5.9
6/5/2002	DC EAST	7.44	538	178			3.8	6.2
6/5/2002	DC EAST	7.44	538	178			3.8	6.2
6/19/2002	DC EAST	7.37	502	206			2.9	5.5
8/28/2002	DC EAST	7.41	520	172			3.7	3.7
9/11/2002	DC EAST	7.40	504	172			4.1	3.0
9/25/2002	DC EAST	7.44	470	168			0.1	1.8
10/9/2002	DC EAST	7.35	515	264			3.7	6.0
10/23/2002	DC EAST	7.43	540	196			3.9	7.2
11/6/2002	DC EAST	7.24	468	166			3.8	6.1
11/20/2002	DC EAST	7.28	503	168			3.2	5.0
12/4/2002	DC EAST	7.29	521	163			3.5	5.7
12/18/2002	DC EAST	7.34	476	162			3.6	7.3
12/30/2002	DC EAST	7.16	494	164			3.8	5.4

Recirculating Sand Filter Influent (Continued)

			Sp			ТР	PO4	ТР
Date	Location	рН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	(m/L)	(County)	(County)
1/15/2003	DC EAST	7.34	454	162			3.7	5.7
1/29/2003	DC EAST	7.45	416	168			4.2	4.3
2/12/2003	DC EAST	7.71	782	164			3.7	5.5
2/26/2003	DC EAST	7.63	813	162			3.4	5.1
	DC EAST							
2/26/2003	QA	7.58	732	158			3.4	5.0
3/12/2003	DC EAST	7.53	555	166			3.2	5.2
3/26/2003	DC EAST	7.49	615	178			4.4	6.2
4/9/2003	DC EAST	7.58	515	174			3.8	5.5
4/23/2003	DC EAST	7.10	613	160			4.1	6.6
5/7/2003	DC EAST	7.49	681	178			3.9	5.8
5/21/2003	DC EAST	7.45	576	148			2.8	4.0
6/4/2003	DC EAST	7.31	612	166			4.2	7.1
6/11/2003	DC EAST	7.29	608	166				
6/18/2003	DC EAST	7.18	701	200			4.2	6.0
7/2/2003	DC EAST	7.26	693	206			4.5	5.7
7/16/2003	DC EAST	7.27	660	190			4.0	9.1
7/23/2003	DC EAST	7.27	567	168			3.2	5.2
7/30/2003	DC EAST	7.38	593	160			2.9	4.7
8/13/2003	DC EAST						4.2	8.6
9/10/2003	DC EAST	7.28	592	184			3.4	4.8
10/8/2003	DC EAST	7.45	689				3.6	5.4
12/10/2003	DC EAST	7.39	649	180			3.9	4.8
2/11/2004	DC EAST	7.44	492				2.3	4.0
8/4/2004	DC EAST	7.31	509	180			4.1	
8/11/2004	DC EAST	7.28	598	170			3.5	7.0
8/18/2004	DC EAST	7.42	629	190			3.6	6.1
8/25/2004	DC EAST	7.38	492	160			3.0	4.7
9/1/2004	DC EAST	7.38	463	150			3.4	6.8
9/8/2004	DC EAST	7.31	506	180			3.3	6.0
9/15/2004	DC EAST	7.32	401	170			3.1	5.7
9/22/2004	DC EAST	7.45	545	180			3.3	5.1
9/29/2004	DC EAST	7.32	428	160			3.7	6.6
10/27/2004	DC EAST	7.31	575	180			3.8	6.2
11/3/2004	DC EAST	7.39	555	170			3.4	5.0
11/10/2004	DC EAST	7.38	656	170			4.1	6.4
2/16/2005	DC EAST	7.23	516	150			3.3	6.2
3/9/2005	DC EAST	7.27	554	130			4.1	7.2
3/23/2005	DC EAST	7.50	644	170			3.9	6.2
4/6/2005	DC EAST	7.43	533	180			4.3	6.2

Recirculating Sand Filter Influent (Continued)

			Sp			ТР	PO4	ТР
Date	Location	pН	Cond(uS)	Alkalinity(mg/L)	PO4(mg/l)	(m/L)	(County)	(County)
5/11/2005	DC EAST	7.35	534				4.1	6.6
5/18/2005	DC EAST	7.19	493	100			3.9	5.9
5/25/2005	DC EAST	7.38	573	190			4.3	6.0
6/15/2005	DC EAST	7.32	497	180			4.2	6.9
7/6/2005	DC EAST	7.40	531	210			5.3	8.0
7/13/2005	DC EAST			150			3.6	5.7

Recirculating Sand Filter Influent (Continued)