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Pipeline

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Small Community Wastewater Issues Explained to the Public

Phosphorus and Onsite Wastewater Systems

In the previous Pipeline *we discussed the role of nitrogen in onsite wastewater systems, its effect on the environment, and how to reduce nitrogen discharges. In this issue of* Pipeline *we discuss phosphorus, the other major nutrient of concern found in residential wastewater, and what happens to phosphorus in the environment and in onsite wastewater systems. Phosphorus has not generally been considered to be a major problem for onsite systems. However, because of the site-specific nature of onsite wastewater treatment, in some cases it does create problems. This* Pipeline *discusses situations where and why it may be a problem and what the options are for controlling phosphorus.*

Phosphorus and the environment: The back story

Phosphorus is an essential nutrient for sustaining all life and is present in every cell in every living organism. It is an indispensable part of the important, but generally underappreciated, adenosine triphosphate molecule, which stores energy and releases it as needed for cellular activity. Phosphorus is also a key component in the structure of DNA. In vertebrates phosphorus is found in teeth and bones. It is one of the major nutrients necessary for healthy plant growth, where it plays key roles in photosynthesis and a variety of other functions such as healthy root development and seed formation.

Because of its high chemical reactivity, phosphorus is rarely found in its elemental state in nature. Phosphorus atoms frequently combine with three oxygen atoms to form a composite phosphate ion with a negative three charge. The phosphate ion can then combine with other atoms and molecules to form a variety of compounds. We often use the terms phosphorus and phosphate interchangeably but a phosphorus atom is a part of the phosphate ion.

As with carbon and nitrogen, phosphorus has a natural cycle in the environment. It is present in rocks and in the soil. As rocks weather, phosphorus is released that becomes available for incorporation into soil and for uptake by plants. Phosphorus in soil that is not taken up by plants is subject to erosion by both wind and rain, and eventually finds its way into streams and rivers in a dissolved form or as components of suspended sediment. Considerable biological recycling of phosphorus occurs both in terrestrial and aquatic environments—animals consume plants containing phosphorus and excrete wastes containing phosphorus that then becomes available for use by other plants, animals, and microbes.

Ultimately, phosphorus ends up in the oceans where, after more biological

recycling by marine plankton and other organisms, it is deposited on the ocean floor. Over periods of millions of years ocean sediments become compressed and consolidated into layers of rock. These ocean-floor rock layers eventually are subject to geologic uplift into above-sea-level mountains that are again subject to weathering and erosion, completing the cycle. Because we are talking about geologic time scales, the phosphorus cycle is much, much slower than either the carbon or the nitrogen cycle. This is at least partly because phosphorus does not naturally exist in a gaseous state to any significant extent. As a result there is no atmospheric cycling of phosphorus between the terrestrial and marine environments as there is with carbon and nitrogen.

The key role of phosphorus in enhancing plant growth was scientifically verified less than 200 years ago. Before that farmers, without knowing exactly how or why it helped, had learned to add substances that contained phosphorus to croplands. Historically these were mainly animal manures, plant residues, or human waste products. Within the last 100 years, however, the mining of phosphate-bearing rock deposits that are then industrially processed has been the main source of agricultural phosphorus fertilizers. About 80 to 90 percent of the mined phosphate rock is made into fertilizer with the remainder being used in food and beverages, detergents, industrial processes, and animal feeds. The availability of mass amounts of phosphate fertilizer contributed to the "Green Revolution" that dramatically increased global food production, in turn allowing global population to increase from about 1.6 billion people in 1900 to more than seven billion people today.

However, because phosphate rock deposits are formed only over long geologic time periods, from the human perspective, phosphorus is a finite resource that is being rapidly consumed. Accelerated mining and consumption of phosphate rock have essentially turned the phosphorus cycle into a one-way transfer of phosphorus from the land to the ocean bottoms. The phosphorus is not destroyed, but it is dispersed to the ocean floor where recovery is economically not feasible.

Because the easily accessible, high-quality phosphate rock deposits are being depleted there have been discussions in the past 10 years of phosphorus production peaking and declining, which raises concerns about the ability to keep the world fed. Others believe that new deposits of phosphorus will be discovered and made available averting any potential global food security crisis. It is likely, however, that newly discovered deposits will require more energy to mine, process, and purify. As a result, regardless of it relative availability, phosphorus is expected to become a more expensive resource in the near future.

As with nitrogen, the dramatic increase in the agricultural use of phosphorus during the past 100 years has brought some unintended, negative consequences. Phosphorus is not a selective fertilizer. When soil that contains phosphorus is eroded by wind or rain, phosphorus ends up in streams

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and lakes where it can stimulate biological activity beyond normal levels, a condition referred to as eutrophication. This often results in the overabundant growth of undesirable algae, referred to as a harmful algal bloom.

The frequency and severity of harmful algal blooms in lakes and rivers is increasing globally.

Undesirable or harmful algal blooms create a number of problems besides being unsightly. Individual algae are short-lived and as they die and decompose they consume dissolved oxygen. Low-oxygen conditions, referred to as hypoxia, can lead to fish kills, loss of other aquatic life, and noxious conditions. Algal blooms can also shade out native rooted aquatic plants and negatively shift the ecological balance in aquatic environments.

Certain types of algae called cyanobacteria, also referred to as blue-green algae, produce potent toxins that are harmful to humans and aquatic life. Blooms of cyanobacteria have become increasingly more frequent in freshwater lakes in the U.S. in the last 20 years. Because cyanobacteria can fix nitrogen from the atmosphere, they can bloom in water bodies that are low in nitrogen if sufficient phosphorus is present. The toxins can be ingested by swimmers and boaters who are in direct contact with the water. However, under certain conditions the toxins can also become aerosolized and inhaled by others at a distance from their source. The toxins can be removed from drinking water sources but at an added cost.

It is generally accepted that phosphorus is usually the limiting nutrient when it comes to eutrophication of freshwater resources and nitrogen is usually the limiting nutrient in offshore waters and estuaries. The limiting nutrient is the nutrient in least supply relative to its demand and controls the amount of biological growth taking place. Concentrations of total phosphorus in the range of 0.02 to 0.03 mg/l have been shown to stimulate algal growth in many North American freshwater lakes.

In the 1960s, widespread eutrophication of lakes and rivers attributed to phosphate pollution became a public concern leading to 27 states passing full or partial bans on laundry detergents containing phosphate. Detergent manufacturers voluntarily phased out the use of phosphates in laundry detergents nationally in 1994. More recently, attention has focused on dishwasher detergents containing phosphates. Because automatic dishwashers were not as common in the 1960s, dishwasher detergents were not included in the initial bans. In response to 16 states passing bans limiting phosphates in dishwashing detergents, in 2010 the detergent industry greatly reduced the use of phosphates in domestic dishwasher detergents nationally from 8.7 percent to no more than 0.5 percent. Phosphates are still present in consumer products such as some hair dyes, toothpastes, mouth washes, liquid hand soaps, and shampoos.

Although phosphate bans and other actions taken to control phosphate have helped, the continued application of phosphate fertilizers and animal manures along with population growth means that phosphate contamination continues to be an issue. Currently, the U.S. Environmental Protection Agency estimates more than 100,000 miles of streams; about 2.5 million acres of lakes, reservoirs, and ponds; and 800 square miles of bays and estuaries have poor water quality due to excess nutrients including phosphorus.

This satellite image shows the extent of a blue-green algae bloom in the western section of Lake Erie in 2011. An unusually wet spring, which generated high levels of nutrients in runoff, followed by warmer weather contributed to the worst algal bloom in Lake Erie since the 1960s.

Photo credit: MERIS/NASA; processed by NOAA/NOS/NCCOS

Phosphorus in Wastewater

Phosphorus in wastewater is categorized as either inorganic or organic phosphorus. Inorganic phosphorus includes relatively simple forms of phosphates referred to as reactive or ortho-phosphates consisting of one phosphate ion and zero to three hydrogen ions, depending on the pH level. Condensed phosphates or polyphosphates, also categorized as inorganic, are somewhat more complex chemical structures with more than one phosphorus atom linked together in each molecule. Most polyphosphates originate in detergents and other cleaning products and eventually decompose into ortho-phosphates. Organic phosphorus includes phosphorus incorporated into undigested food residue and dead and living bacteria that are present in feces. Some organic phosphorus is also present in uneaten food scraps that are part of the wastewater stream.

Phosphorus in water and wastewater is typically measured as total phosphorus, which includes both inorganic and organic forms of phosphorus. The concentration of total phosphorus in raw wastewater is quite variable from household to household. A 2008 survey of 17 residences in three regions of the U.S. found total phosphorus concentrations ranging from 0.2 to 32 mg P/l with a median value of 10.4 mg/l. A 1991 study estimated that the average person in the US generates about 2.7 grams of phosphorus per day with approximately 59 percent of the phosphorus coming from toilets; 37 percent from sinks, showers, and appliances; and four percent from kitchen garbage disposals. Due to the 1994 ban on phosphates in laundry detergents and the 2010 ban affecting dishwashing detergents the average amount generated per person has decreased and it has been estimated that as much as 75 percent of phosphorus may now be contained in toilet wastewater.

For toilet wastes, approximately two-thirds of the phosphorus is contained in urine, with the remainder found in feces. The total amount of phosphorus excreted varies from person to person depending on diet and other factors. The approximately two-to-one ratio between the amount of phosphorus found in urine to that in feces, however, is fairly consistent.

On a national basis the majority of phosphorus released to the environment by human activity comes from agriculture. Current data are not available. However, a 1984 study estimated that 72 percent came from agriculture, split evenly between fertilizer application and manure application. Five percent came from wastewater treatment plants and the remaining 22 percent came from all other non-point sources, including onsite wastewater systems.

Agriculture and domestic wastewater are closely connected when it comes to phosphorus. Phosphorus applied by farmers ends up in the foods we eat. Any excess phosphorus our bodies don't need is excreted and ends up in our wastewater. Our wastewater is now being viewed by many as a potential source of phosphate and other nutrients to be recycled for agricultural use. As the availability of easily mined, high-quality rock phosphate declines and the need to make agriculture more sustainable becomes more apparent, wastewater will increasingly be seen more as a resource and less as a waste product.

What happens to phosphorus in onsite wastewater systems?

The concern with phosphorus in onsite systems is that the concentration of phosphorus in wastewater is usually hundreds of times higher than that needed to stimulate algal growth in surface water. Fortunately, compared to other wastewater constituents, phosphorus is not very mobile. In most cases, phosphorus is effectively retained in the soils below drainfields (or soil absorption systems), preventing much phosphorus from being released to streams and lakes. As a result phosphorus from onsite wastewater systems has historically been lightly regulated and added treatment for phosphorus reduction is still rare. The science underlying how phosphorus is retained by soils, however, is complex and varies with soil types.

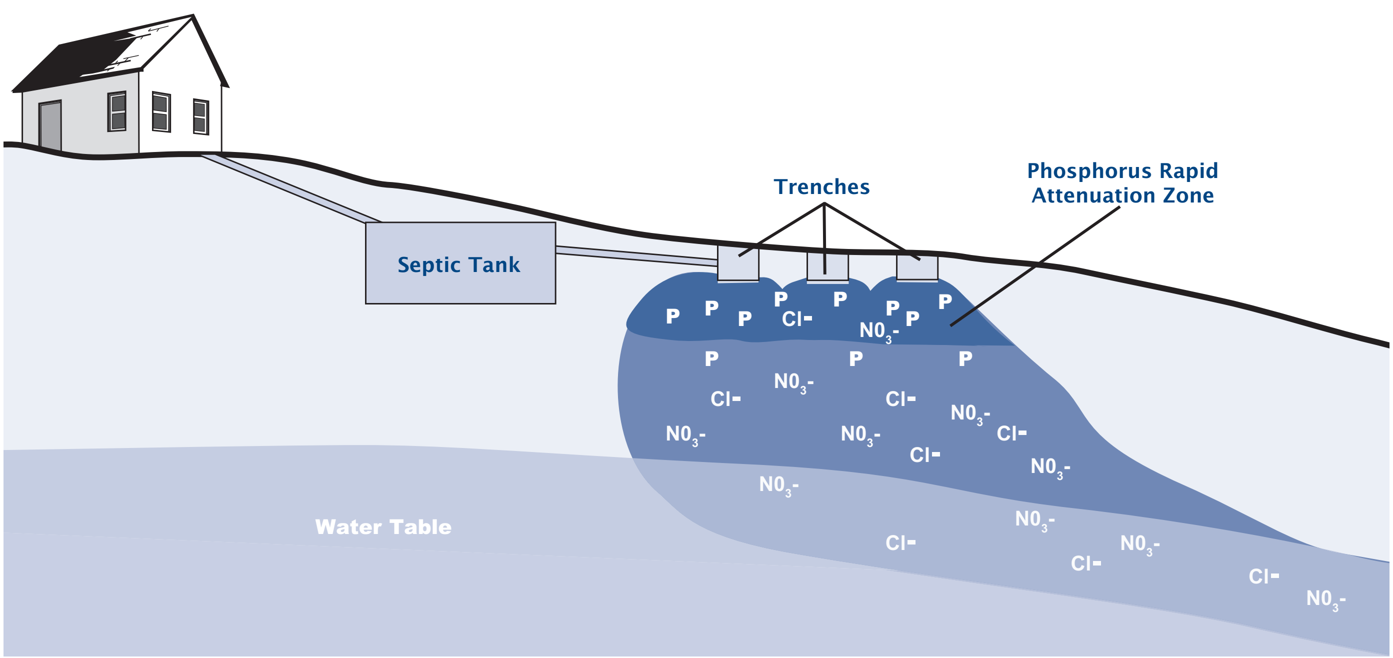
Some phosphorus is removed as the wastewater flows through the septic tank. Some studies have estimated that as much as 20 to 30 percent of phosphorus becomes part of the settled solids in the septic tank. A 2008 study indicated less than six percent removal of phosphorus occurs in septic tanks, however. The concentration of total phosphorus in septic tank effluent, the liquid exiting the septic tank, varies widely from household to household but the median value is approximately 10 mg/l.

As the wastewater leaves the septic tank and is dispersed to the unsaturated soil beneath the drainfield, phosphorus is retained due to two chemical processes: precipitation and adsorption. Precipitation occurs when negatively charged phosphate anions react chemically with positively charged cations to form a solid mineral that is immobilized in the soil. Common cations that react with phosphate to form minerals are iron (both Fe^{+2} and Fe^{+3}), aluminum (Al^{+3}), and calcium (Ca^{+2}). Phosphate also reacts with oxides of iron, aluminum, and calcium to form stable phosphate-metal complexes.

The extent to which precipitation occurs in soil depends on a number of factors including soil pH, the oxidation/reduction status of the soil, the relative availability of cations to react with phosphate, and whether a soil is calcareous or non-calcareous. Calcareous soils are soils of marine origin that have a significant calcium carbonate content and tend to be alkaline in nature. Non-calcareous soils tend to be acidic rather than alkaline. Cations such as iron and aluminum that can react effectively with phosphate are generally more available in non-calcareous soils. Although phosphate reacts with calcium in calcareous soils, it is more effectively immobilized by iron and aluminum in non-calcareous soils.

The other way phosphate is immobilized is through adsorption. Adsorption occurs when phosphate anions are attracted to and bind to positively charged mineral particle surfaces. Binding by adsorption is not as strong as precipitation reactions and is considered more reversible. Adsorption is limited by the number of adsorption sites available. The capacity for precipitation is also finite but can continue as long as cations are available and there is space in the soil for the precipitating solid.

As with precipitation, adsorption is more effective in acidic environments than alkaline environments. Adsorption



In many onsite wastewater systems, phosphorus (P) is effectively immobilized within the first two or three feet of soil below drainfield trenches. This area has been referred to as the Phosphorus Rapid Attenuation Zone or Phosphorus Enrichment Zone. This is in contrast to the plume associated with other more mobile wastewater constituents such as nitrate (NO_3^-) and chloride (Cl^-). The extent of movement of phosphorus varies from system to system but is almost always less than that of NO_3^- and Cl^-.

relies on negatively charged phosphate anions being attracted to positively charged surfaces including aluminum and iron oxides and hydroxides and clay minerals. The surface charge of the minerals can vary under different conditions. In alkaline conditions, such as in calcareous soils, the net surface charge is more likely to be negative in which case little or no adsorption is likely to occur.

Precipitation and adsorption quickly and effectively retard the movement of phosphorus in many drainfield soils to the extent that there is a zone of phosphorus enrichment or accumulation within the first meter below the drainfield lines. This zone, which includes the biomat, has been referred to as the Phosphorus Rapid Attenuation Zone.

Precipitation and adsorption are less effective once any remaining phosphorus reaches groundwater. The movement of phosphorus in groundwater is still slower however than the movement of more mobile, less reactive anions such as nitrate and chloride. Studies that have plotted the movement of groundwater plumes of septic system contaminants almost always show a considerably longer plume for nitrates and chlorides compared to phosphate, even in situations where conditions for phosphate immobilization may not be ideal. The extent to which phosphorus migration is retarded is variable and site-specific.

Nevertheless, there are circumstances where phosphorus from onsite wastewater systems can contribute to pollution of lakes or streams. Some of the factors that contribute to problem sites include:

- Calcareous soils;
- Coarse-grained soils such as sandy and gravelly soils that allow rapid flow rates;
- Households that generate more wastewater than their septic systems were designed to handle;
- Drainfields with thin soils, shallow bedrock, or high water tables;
- Systems with drainfields close to lakes or streams;
- Areas where onsite systems are densely sited;
- Systems where the septic tank effluent is not uniformly distributed across the drainfield; or
- Older or substandard systems such as cesspools, which may be in direct contact with groundwater during part of the year.

Problem areas often occur due to the combination of multiple factors. For example, numerous lake-front communities with closely sited homes, with drainfields in sandy or gravelly soils close to the lake shore have experienced problems with noxious algal blooms. In cases such as these, where drainfield soils are not capable of immobilizing phosphorus, some additional action may be necessary in order to restore lake water quality.

Phosphorus Reduction Options

A number of options can be used in situations where phosphorus from onsite wastewater systems has been identified as a problem. These options can be categorized as source diversion, advanced treatment, and drainfield modifications. Because concern with phosphorus from onsite wastewater systems is fairly recent treatment approaches are continuing to evolve.

Source Diversion

Because 60 to 75 percent of phosphorus is contained in toilet wastewater, referred to as blackwater, removing the blackwater from the wastewater stream can greatly reduce the amount of phosphorus discharged from an onsite system. This has been achieved through the use of composting toilets, urine-diverting toilets, and holding tanks. The remaining wastewater in the household from other fixtures goes to the septic system or a grey water system.

Composting toilets collect toilet waste in a chamber below the toilet. The system is designed so that the contents compost or decompose biologically into a humus-like material that needs to be removed periodically. There are a wide variety of models of composting toilets available including ones that use a small amount of flush water and are able to evaporate off any excess liquid that might interfere with the composting process. Because most composting toilets capture all of the blackwater they can potentially remove as much as 75 percent of the phosphorus,

The fully composted material must occasionally be removed by a service provider or the homeowner. Some states have rules regarding the acceptable disposal of the composted material. Appropriate use or disposal of the compost is necessary so that the phosphorus problem is not simply transferred from one location to another.

Urine-diverting toilets remove urine from the wastewater stream to then be disposed of separately. These toilets are constructed with a barrier in the bowl that separates urine from solid toilet waste.

Urine is deposited in the front chamber and feces and toilet paper in the rear chamber. The front chamber has a separate line that allows urine to be collected in a storage tank. The urine can be processed for use as either a liquid or a solid fertilizer. Because urine contains about two-thirds of the phosphorus in blackwater, urine diversion has the potential to remove 35 to 50 percent of phosphorus from residential wastewater. The effectiveness of the toilet at diverting urine depends upon the correct use of the toilet by the users.

Urine-diverting toilets are not common in the U.S. at this time. However, they have been successfully used in other countries, particularly in planned communities in Europe. Their use in the U.S. has been limited by their unfamiliarity and the lack of a well-established system to collect, process, and reuse the urine agriculturally. However, urine harvesting is beginning to draw more interest in the U.S. and this is expected to increase as the benefits of capturing the nutrients in urine for agricultural use becomes more evident.

In some cases, households may be permitted to divert their toilet waste to a holding tank. The contents of the tank must be periodically pumped and transported to a wastewater treatment plant. Many health departments view holding tanks as a last-resort option and because of the cost of regular pumping this is an expensive option. With the use of a micro-flush toilet the intervals between pumping can be extended helping to reduce costs.

Advanced Treatment

Although advanced treatment systems for phosphorus reduction in onsite systems are still uncommon in the U.S., a number of units are available commercially. A variety of approaches to phosphorus reduction have been made but the most common method has been through the use of reactive media filters. These are modular units that are installed between the septic tank and the drainfield.

Media filters, such as sand or gravel filters, have been used for decades to provide an additional level of wastewater treatment for onsite systems. The difference with phosphorus removal systems is that a medium or combination of media are added that react specifically to immobilize phosphorus. Typically, the media contain some combination of iron, aluminum, or calcium compounds and the reactions are similar to the adsorption and precipitation reactions that occur in soil. The goal is to enhance and maximize the reactions in a more controlled environment.

The types of media used have been categorized as natural, manufactured, and industrial by-products. Natural media include iron-rich soils and peat, which may be supplemented with additional materials to increase their affinity for phosphorus. Other natural materials that have been tested include limestone, bauxite (aluminum ore), bentonite (a type of clay), and lignocellulose fibers, among others.

Manufactured materials include light-weight clay aggregates, which have been processed to expand the clay structure to provide greater surface area. Phosphorus removal for systems using light-weight aggregates have achieved greater than 90 percent phosphorus removal in test facilities. Filtralite® and Utelite® are two brands of manufactured clay aggregates that have been used for phosphorus removal media.

A wide variety of industrial by-products have been investigated for use in reactive media filters including different types of blast furnace or steel fur-

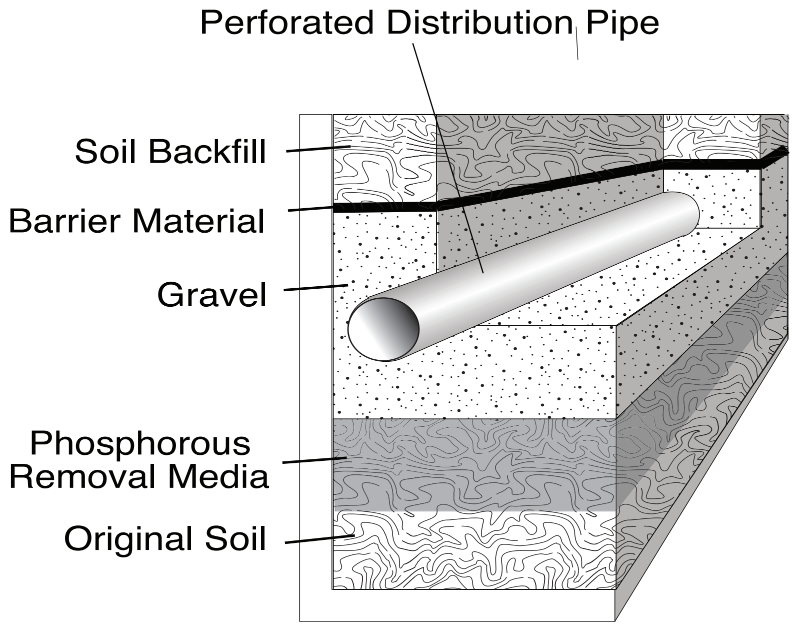
Separating urine from the wastewater of residences or public facilities through the use of urine-diverting toilets or urinals can potentially reduce phosphorus loading to onsite wastewater systems by as much as 50 percent.

nace slags and alkaline fly ash from coal-fired power plants. The composition of industrial slags varies depending on the type of industrial process that generated the slag. A high rate of phosphorus removal has been documented using some slags. However, a drawback with some slags is that they generate a high pH in the water exiting the filter, which means an extra treatment step may be needed to neutralize the pH before final dispersal.

Recently there has been much interest in the use of nano-materials for phosphorus removal. As the overall surface area of a medium increases the number of attachment sites for phosphorus also increases. Because of the extremely small size of nano-particles, the total surface area exposed is greatly increased, potentially giving these materials a much higher capacity for phosphorus removal than other media. Iron-based nano-materials have been coated onto base media and have also been incorporated into resins that can be regenerated once their phosphorus removal capacity has been reached. As with other media, because the demand for phosphorus removal is fairly recent, research and knowledge of the effectiveness and economic practicality of different media are continually developing.

Drainfield Modifications

Because phosphorus related problems from septic systems have been perceived as rare, proposed sites for septic systems are seldom evaluated for their capacity to immobilize phosphorus. However, in the future, especially in sensitive watersheds or in the vicinity of an impaired water body, it is likely that soils may be evaluated more frequently for their ability to capture phosphorus.



A number of media have been suggested for use in drainfield trenches to capture phosphorus. The medium is added between the bottom of the drainfield line and the trench bottom. A suitable medium must have a high capacity to immobilize phosphorus and sufficient permeability. Since it will eventually need to be replaced it should have as long a lifespan as possible.

In soils that are determined to have an inadequate or marginal capacity, in addition to advanced treatment, modification of the drainfield may also be considered.

One modification that has been suggested for marginal soils is timed, pressurized dosing of septic tank effluent to equalize flow over the entire drainfield. This eliminates the localized, saturated flow conditions that often occur after surge flows in conventional gravity-flow systems. Another suggestion has been the use of shallow dispersal options, especially the use of drip distribution systems in which the effluent is dispersed within the root zone of plants, which can then biologically take up phosphorus and incorporate it into plant tissue. These are more effective if any resulting non-woody plants are occasionally harvested to prevent localized phosphorus accumulation.

Research is also being conducted on adding a layer of material with a high capacity for immobilizing phosphorus to the drainfield. These materials would be added to the drainfield trenches between the drainlines and the original soil. Numerous materials have been considered including replacing gravel used in drainfields with limestone or tire chips. The effectiveness of tire chips comes from exposure of the iron present in steel belts. Many of the media that have been suggested for use in reactive media filters such as imported iron or aluminum-rich soils, industrial slag, or clay aggregates may also be candidates for incorporation into drainfield trenches.

The criteria for these types of drainfield amendments include a sufficient capacity to immobilize phosphorus and a texture that allows flow that is slow enough to provide adequate contact time but not so slow as to cause excessive ponding. Because the material will eventually need to be replaced it is important that the material have a long lifespan so the need for replacement is infrequent. It is preferable if the spent material can be reused for horticultural or agricultural purposes. Cost considerations are, as always, a factor as well.

Because the need for better control of phosphorus from onsite wastewater systems is a slowly emerging issue, the options for dealing with it are also continuing to develop. As the need to better protect water resources and rehabilitate nutrient-impaired water bodies becomes more necessary it is likely that additional options for phosphorus control will also become available in the future.

References

Cucarella, Victor and Gunno Renman. 2009. "Phosphorus Sorption Capacity of Filter Materials Used for On-site Wastewater Treatment Determined in Batch Experiments—A Comparative Study." Journal of Environmental Quality, 38: 381-392. Accessed at: https://www.agronomy.org/publications/jeq/abstracts/38/2/381

Etnier, Carl et al. 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. Accessed at: http://www.ndwrcdp.org/research_project_WU-HT-03-22.asp

Glibert, Patricia, et al. 2005. "The Role of Eutrophication in the Global Proliferation of Harmful Algal Blooms." Oceanography, Vol. 18, No. 2. Rockville, MD. Accessed at: http://www.chnep.wateratlas.usf.edu/upload/documents/Eutrophication-AndHABs.pdf

Lombardo, Pio. 2006. *Phosphorus Geochemistry in Septic Tanks, Soil Absorption Systems, and Groundwater*. Lombardo Associates, Inc., Newton, MA. Accessed at: http://www.lombardoassociates.com/pdfs/060410-P-Geochemistry-FINAL-LAI-Version.pdf

Lowe, Kathryn et al. 2009. Influent Characteristics of the Modern Waste Stream from Single Sources. Water Environment Research Foundation, Alexandria, VA. Accessed at: http://www.ndwrcdp.org/documents/04-dec-1/04dec01web.pdf

Smil, Vaclav. 2000. "Phosphorus in the Environment: Natural Flows and Human Interferences." Annual Review of Energy and the Environment. 25:53-88. Accessed at: http://www.vaclavsmil.com/wp-content/uploads/docs/smil-article-2000-aree2000-2.pdf

Robertson, W.D. et al. 1998. "Review of Phosphate Mobility and Persistence in 10 Septic System Plumes." Groundwater, Vol. 36, No. 6. Accessed at: http://info.ngwa.org/gwol/pdf/982964321.PDF

Rosemarin, Arno. 2011. "Peak Phosphorus and the Eutrophication of Surface Waters: A Symptom of Disconnected Agricultural and Sanitation Policies" in *On the Water Front: Selections from the 2010 World Water Week in Stockholm*, J. Lundqvist (ed.). Stockholm Water Institute. Accessed at: http://www.worldwaterweek.org/documents/Resources/Best/2010/2011_OTWF_Arno_Rosemarin.pdf

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