

PHOSPHORUS CONTROL AND CAPTURE TECHNOLOGIES – AN INTRODUCTION

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Abstract

In the author's mind, phosphorus reclamation in wastewater is a more critical issue than nitrogen reduction is. Both nitrogen and phosphorus are essential nutrients to living things. Typically, phosphorus is the most limiting nutrient in fresh water environments, such as rivers, ponds and lakes. Salt waters (oceans and estuaries) are usually nitrogen limited. Phosphorus is an essential component in important biological macromolecules, including adenosine tri phosphate (ATP), adenosine di phosphate (ADP) and Deoxyribo Nucleic Acid (DNA). Phosphorus is relatively scarce in the Earth's crust and its distribution is limited. No countries in North America have significant phosphorus rock reserves, but multiple countries in Northern Africa and the middle east control vast areas with mineable phosphorite rock reserves. The biogeochemical cycle of phosphorus plays out over geological time, meaning it will take many thousands of years before measurable changes in phosphorus ore location occurs. Phosphorus can be removed from wastewater by pollution prevention (changing product formulations to not include phosphorus), diverting plumbing flows with significant reclaimable phosphorus and using electrochemical methods to sequester phosphorus into a variety of minerals using various cations.

Introduction

Why is phosphorus worth worrying about? To begin, the word phosphorus means “bringer of light” in ancient Greek. The element earns that name because one type of phosphorus, white phosphorus, gives off a faint glow overnight as it oxidizes to become red phosphorus. Elemental phosphorus was first isolated from urine as white phosphorus in 1669 by Hennig Brand (Krafft 1969). Phosphorus is an essential element found in animals, plants and microbes. Organism growth and reproduction in specific water bodies can be limited by the amount of phosphorus dissolved in those waters. There is a wide variation in the amount of phosphorus in the earth's crust and substantial phosphate ore reserves are plentiful in just a few places on the planet. Phosphorus is scarce in the earth's crust. The unequal distribution of phosphorus ore makes it critical that phosphorus be managed with care, especially in countries with limited phosphorus reserves.

The Phosphorus atom and its chemistry

Some folks call phosphorus “the forgotten nutrient” because so much attention is given to nitrogen. Let's now go over some basic information about the atom phosphorus and its chemistry. Atoms are made up of three different subatomic particle types: positively-charged protons, neutrons with

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Basic chemistry boils down to atoms altering their outermost shell electron patterns to make them identical to that found in a noble gas. The prime directive is to lose or gain electrons during interactions with other atoms until all the atoms' outermost electron shells are full. For phosphorus specifically, the goal is to add (or take) three electrons from other atoms. Doing this would give the electrons around the outermost shell of the phosphorus atom the same pattern as the noble gas argon. Note the number of other subatomic particles protons and neutrons are not changed. If gaining electrons isn't a workable option, the phosphorus atom may lose (or give up) 5 electrons, completely emptying its M shell. If this were to happen the remaining electrons in the K shell would have the same pattern as the noble gas neon.

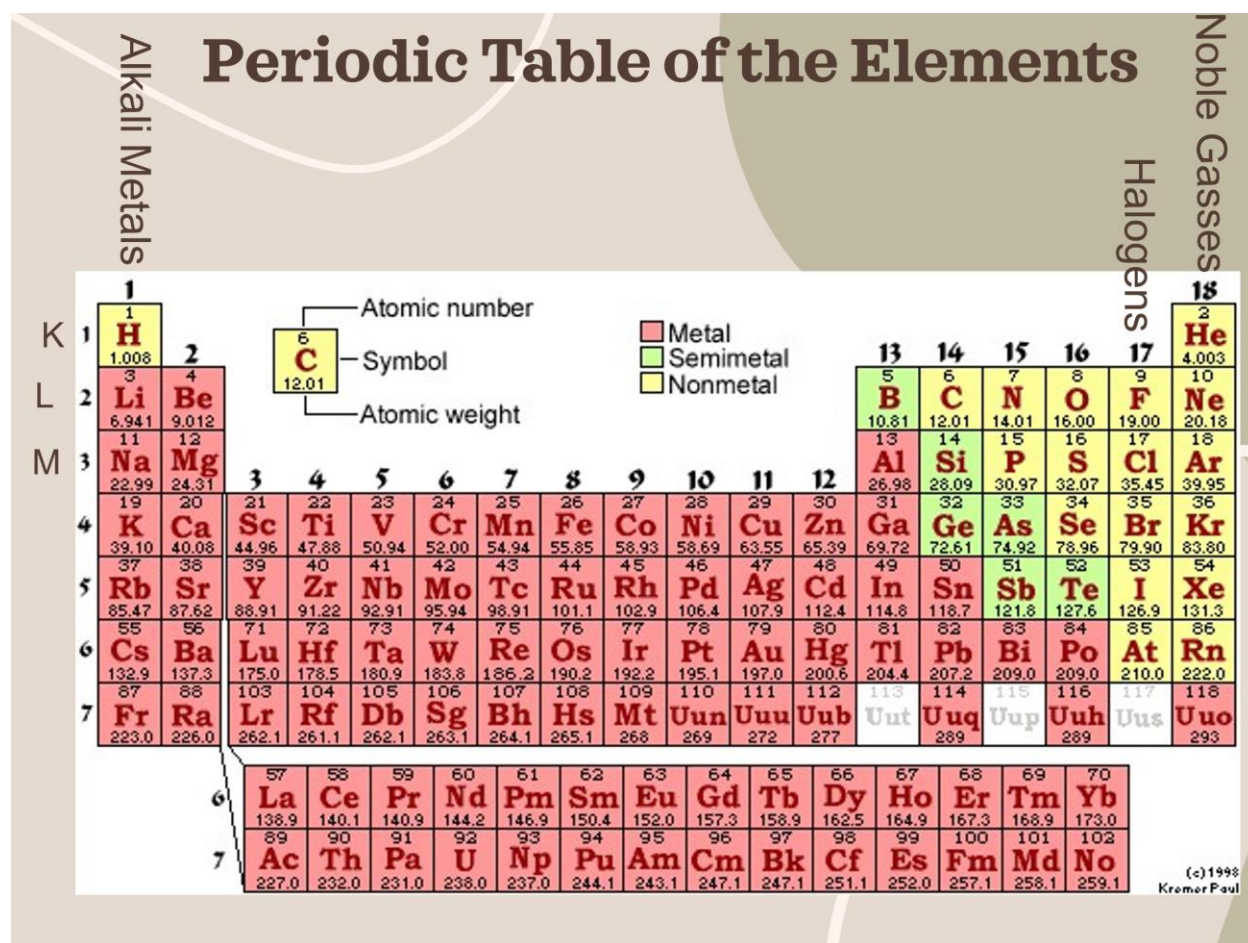


Figure 2 Periodic Table of the Elements

Note that in order for phosphorus to gain three electrons, both sulfur and chloride stand in its way. Oxygen (one row up and to the right) is a common element on earth and is also a fierce competitor for taking electrons from atoms further away from the noble gasses than it is. Based on oxygen's position in the periodic table, it would like to take two additional electrons if at all possible. Then it's new electron configuration would be identical to neon's. If oxygen is one of the atoms in a compound, it is much more likely that oxygen would take electrons from any atoms further away

from noble gases than it is. The takeaway is that if oxygen and phosphorus create a compound, oxygen will take electrons from phosphorus, and not the other way around.

The atom phosphorus is an extremely reactive element. It is never encountered on earth without other atoms also being present. The compound orthophosphate is shown on Figure 3. Ortho means straight or right as in correct. Orthophosphate is the least complicated phosphorus compound. It contains one phosphorus atom centrally located and surrounded by 4 oxygen atoms. The compound has the geometry of a tetrahedron. One of the oxygen atoms forms a double bond with phosphorus (two parallel lines directly above P in the drawing). That means this oxygen atom took two electrons from phosphorus, Two was the optimum number for oxygen to take generally. The other oxygen atoms take one electron each of the three remaining electrons in the outer shell of phosphorus because one is better than none. This reaction leaves a negative charge on three oxygen atoms and an overall charge of negative 3. By far and away phosphorus on our planet is found in a phosphate configuration.

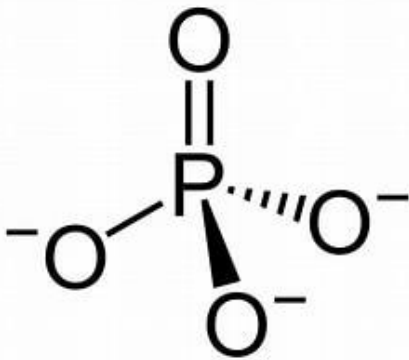


Figure 3 Orthophosphate anion

An ion is defined as an atom or molecule that has gained or lost one or more of its valence (fancy term for outer shell) electrons giving it a net positive or net negative electrical charge. In other words, there is an imbalance between the number of protons (positively charged particles in the nucleus) and electrons (negatively charged particles orbiting the nucleus). Orthophosphate has a charge of minus three. An attraction exists between anions and cations because they carry opposite electrical charges. You will never be confused about the type of ion by recognizing the plus sign in the word ca⁺tion,

Biological importance of phosphorus

Phosphate is found in several important large biological molecules called macromolecules. DNA – the acronym stands for deoxyribo nucleic acid. DNA holds the genetic code of most plants and animals. RNA – the acronym for ribonucleic acid is the genetic material found in most bacteria. RNA is also used by plants and animals for cellular communication with mitochondria (the engines of the cell). ATP is short for adenosine tri phosphate. ATP releases energy inside the cell and as the chemical transforms to a lower energy state it loses a phosphate molecule and becomes adenosine diphosphate. An analogy of ATP and ADP, consider a stiff spring with a hook near the

spring's attachment point on the wall. If the spring is compressed and locked in a position with a hook, it is in an ATP state (ready to release energy). Put your back against the spring, then release the hook. Energy will be released into pushing you away from the wall. It has now transformed to ADP. ADP is analogous to a released spring. If conditions in the cell are favorable, the cell will store energy for future use by combining ADP with another available phosphate molecule to re-make ATP. ATP slash ADP is then the energy currency of the cell. Phospholipids are used in creating the cell wall. This wall is semi-permeable. It allows waste materials to exit the cell and food, water and nutrients to enter.

Adequate levels of phosphorus are needed in our diets (Calvo & Uribarri, 2013). Daily values of phosphorus intake for humans are 700 to 1,650 mg per day. Note that the maximum value is more than twice the minimum value. This wide range of phosphorous intake rates can cause problems for certain people in the population. People with kidney disease will have trouble removing excess phosphorus from their blood. These individuals must carefully monitor and limit their phosphorus intake. Phosphorus is important in building strong bones and teeth. It helps us produce, use and store energy in our cells. Phosphorus is used to repair and replace aging cell walls in our bodies.

Urination is the predominant route that excess phosphorus as phosphate takes when it is excreted by people (Noe-Hays et al., 2020). The second most amount of phosphate exits with feces. Most people unintentionally consume more phosphate than they need. This higher than necessary intake is not a problem if one's kidneys are functioning properly.

The phosphorus cycle is the biogeochemical cycle that tracks the movement of phosphorus through the lithosphere (the rocky shell of our planet), the hydrosphere (waters on the earth's surface and in clouds) and the biosphere (the global ecological system). Unlike many other elements' biogeochemical cycles, the atmosphere does not play a role in the movement of phosphorus. Consequently, the phosphorus cycle is primarily examined by studying the movement of phosphate (PO_4^{3-}) through terrestrial and aquatic ecosystems. In the long-term global cycle, the major transfer is driven by tectonic movement over geological time and weathering of phosphate containing rock such as apatite. Phosphate moves quickly through plants and animals. The processes that move phosphorus through the soil and the ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles in existence. Humans have caused major changes to the global phosphorus cycle primarily through the mining and subsequent shipping of phosphorus minerals for use in plant fertilizer and other industrial products. The United States was a major exporter of phosphate rock up until the 1980's when deposits in peninsular Florida were exhausted.

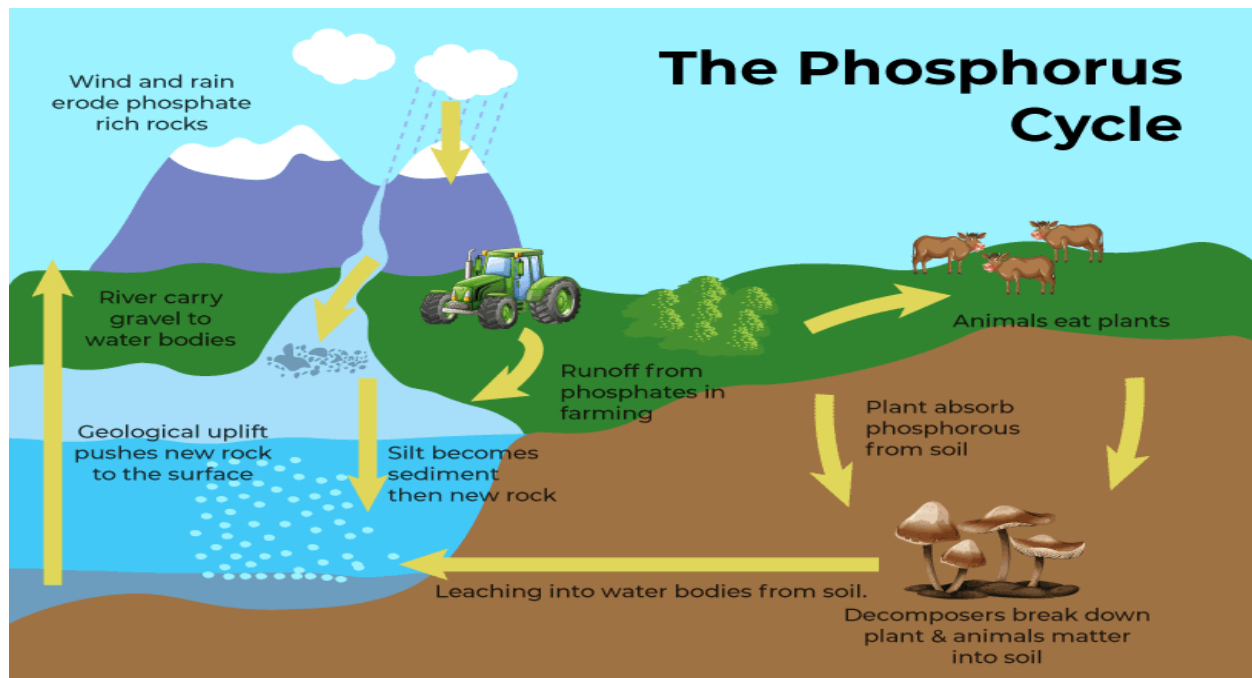


Figure 4. The Phosphorus Cycle

Limiting Nutrients and Redfield Ratios

A limiting nutrient is one that is in such short supply that it limits the potential for growth and reproduction in an ecosystem. Before we get ahead of ourselves, what are nutrients in general? They are chemicals that provide nourishment, and are essential for growth and maintenance of life. Nutrients are the substances that keep living things alive. 25 of the 118 elements found on the periodic table are labelled essential for life. Of these, just four: carbon, oxygen, hydrogen and nitrogen make up 96% of the human body. Science fiction writers call earthlings carbon-based life forms, and we truly are. More generally speaking, all organisms from plants to microbes to various animals use six essential elements: carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur. In an aqueous, by that I mean watery environment, hydrogen and oxygen are readily available for chemical reactions through their dissociation into two hydrogen molecules and one oxygen molecule. Sulfur is a very abundant macro mineral. Sulfur is predominantly found in volcanic areas, mines containing various other minerals such as pyrite and galena, in natural gas and in foods. Carbon, nitrogen and phosphorus have the potential to be limited in certain environments. We will focus on these three nutrients in the next few slides. NOTE that the element that is in shortest supply relative to its need by living things, we will call the limiting nutrient.

All organisms (plants, microbes and animals) use nutrient elements to build essential molecules. In an analogy to a summertime lemonade stand, if you only have 30 lemons, it doesn't matter how much extra water, ice and sugar you have available, you can only make a specific amount of lemonade. The limiting ingredient is the one you will run out of **first**. The same usage limitation is true in the world's oceans. Alfred Redfield in 1934 discovered through extensive oceanographic sampling that the base of the food chain (floating, photosynthesizing, single celled algae called

phytoplankton) extracted 1 atom of phosphorus for every 16 atoms of nitrogen and for every 106 atoms of carbon. Remarkably, these numbers were consistently found in **all** the earth's oceans. These numbers are called Redfield ratios (Redfield, A., 1934).

Redfield ratios can be used to predict which nutrient will be limiting based on water sampling data. A water sample shows that 500 moles of carbon, 74 moles of nitrogen and 4 moles of phosphorus are present. A mole is a standard scientific unit for measuring large quantities of very small entities such as atoms giving a chemically measurable amount of an element. Take each mole value and divide it by its corresponding Redfield ratio. The lowest value indicates which nutrient will run out **first**.

$$\text{Carbon } 500/106 = 4.72 \quad \text{Nitrogen } 74/16 = 4.63 \quad \text{Phosphorus } 4/1 = 4.0$$

In this case, phosphorus is the limiting nutrient. If additional phosphorus were released into the water, the food chain would expand, because extra carbon and nitrogen currently not being used would go into making additional phytoplankton.

If 5 moles of phosphorus were found in this water instead of 4, how much additional phytoplankton would be produced?

$$\text{Carbon } 500/106 = 4.72 \quad \text{Nitrogen } 74/16 = 4.63 \quad \text{Phosphorus } 5/1 = 5.0$$

Answer – to the point where nitrogen would replace phosphorus and become the limiting nutrient.

Table 1 Limiting nutrient for eutrophication by water type

Water Type	Location Description	Eutrophication by	Eutrophication effects
Fresh Water	Temperate streams, lakes, rivers and reservoirs	Phosphorus almost exclusively	Uncontrolled algal blooms, Reduced water clarity, fish kills
Brackish (mixed) Water	Estuaries	Both nitrogen and phosphorus (location specific)	Harmful algal blooms, habitat degradation
Salt Water	Oceans, seas	Nitrogen typically	Uncontrolled blue-green algal growth, dead or hypoxic zones

Eutrophication is how algae, phytoplankton or other plants react to the increase in the concentration of phosphorus, nitrogen, and other plant nutrients in an aquatic ecosystem such as a lake, estuary or ocean. Excessive plant growth makes eutrophic waters murky and may support fewer large animals, such as fish and birds, than non-eutrophic waters. The table points out that fresh waters are typically phosphorus-limited. There are, however, exceptions to this rule. For instance, the salt waters surrounding the Florida Keys are phosphorus limited. Oceans are typically nitrogen limited. Brackish water (a blend of salt and fresh waters located close to the coast) are a toss-up with respect to which limiting nutrient controls growth. The effects of eutrophication are listed in the right-hand column of the table. Because phosphorus is a limiting nutrient in fresh

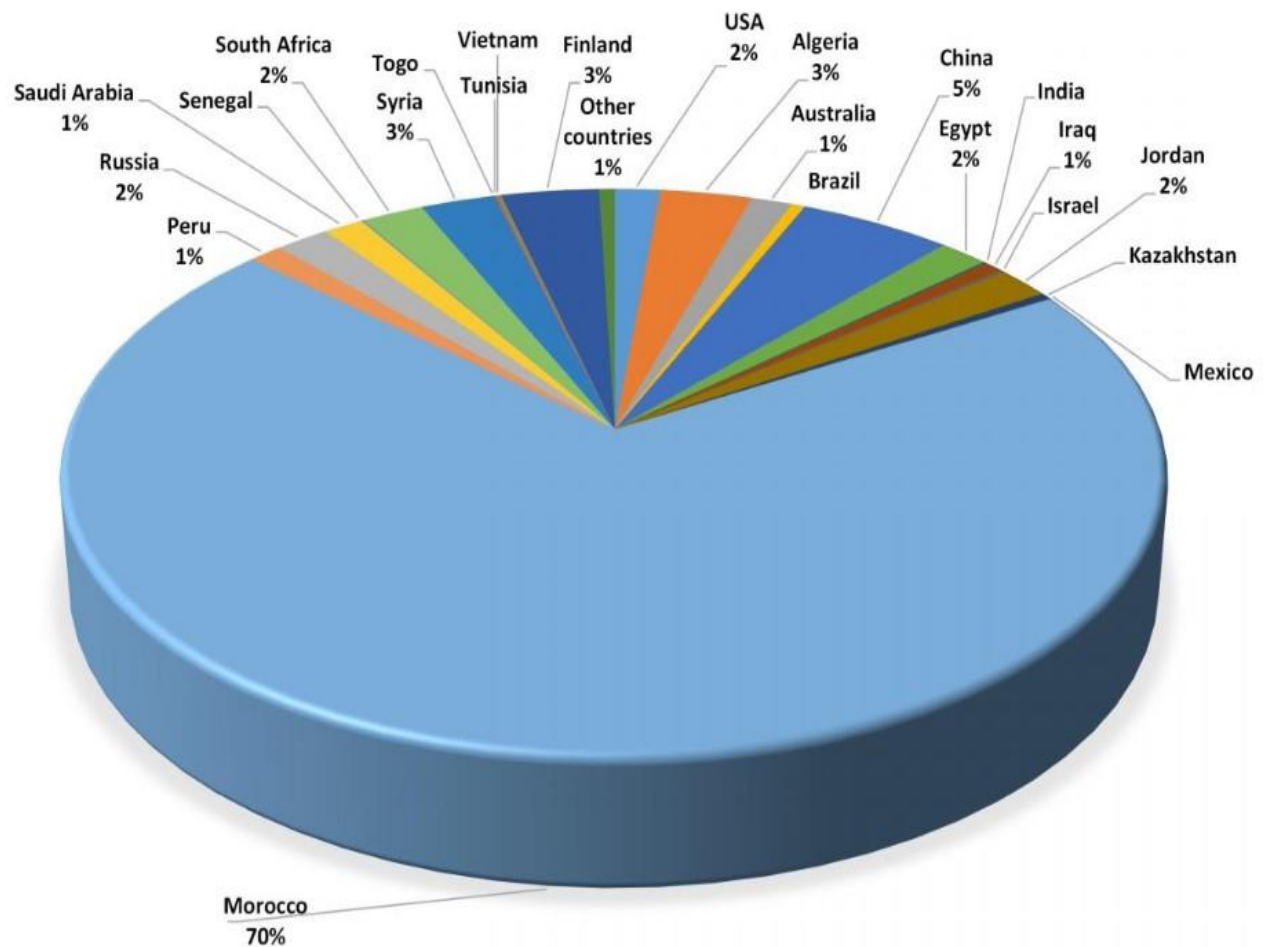
water, and uncontaminated fresh water is critical to human health and environmental quality, we really should be concerned about phosphorus-based eutrophication.

Uses/sources of phosphorus

Phosphate is found in numerous household goods. The vast majority of mined phosphate is used in manufacturing plant fertilizer. Phosphate is essential in producing steel, fine china and specialized glasses, such as those used in welding or around lasers.

Historically laundry detergents and dishwashing products contained phosphorus. It was used primarily as a builder. A builder in a detergent serves to tie up cations such as calcium and magnesium ions, which otherwise interfere with the surfactant (wetting agent). Builders, by tying up calcium, magnesium, iron and manganese improving overall washing performance. Phosphates are excellent builders, but can cause eutrophication in temperate fresh waters. The soap and detergent association sought alternative builders to phosphorus. Once they had them tested and were certain they were appropriate alternatives, manufacturers voluntarily stopped adding phosphate to their products. This case is a classic example of pollution prevention. When phosphorus is removed from a product, it never enters the wastewater stream (Knud-Hansen, C., 1994).

So, where is phosphate found in nature. Phosphorite rock is a sedimentary rock. The chemical formula for phosphorite pentoxide is P_2O_5 . There are two phosphorus atoms in this compound. Think back to earlier in the paper. How many electrons are in phosphorus' outer shells? (5). So, two phosphorus atoms would have twice that many electrons in its outer shell (or 10). How many oxygen atoms are there? 5. How many electrons does oxygen need to reach a noble gas electron configuration? 2 two times five is ten. Phosphorite pentoxide is very stable material because all the atoms present have achieved a noble gas configuration. It is so stable it forms a rock. The rock contains between 4 percent to 20 percent phosphorite pentoxide. Marketed phosphorite rock is sold in an enriched in phosphate or beneficiated state. Methods of beneficiation occurs through washing, screening, de-liming, magnetic separation or flotation of raw phosphorite rock.



In: Rosemarin, 2016

Figure 5. Global distribution of phosphate rock reserves

The world's phosphate ore reserve totals nearly 69.5 billion tons (2019), but its distribution is markedly uneven. There are “haves” and “have-nots” in the world when it comes to phosphate ore. More than 80% of the world's phosphate rock reserves are located in Northern African and Middle Eastern countries. Morocco and the Western Sahara are the world's richest countries in phosphate resources, with reserves of 50 billion tons in 2019, accounting for nearly 72 percent of the world's total. In the United States, after multiple decades of phosphate mining and shipping, the states of Florida, North Carolina, Idaho and Utah still contain about 2% of the world's phosphate rock reserves.

Recycling/recovery of phosphorus

Based on the limited amount of phosphorus reserves found in North America, it is clear that single uses of phosphate will have to end. The first two options to consider are urine diverting toilets and waterless urinals. These options allow the recovery and potential reuse of a valuable nutrient by never letting phosphates enter the wastewater stream. The third option, phosphorus removal and reclamation technologies use the manipulation of the phosphate anion by adding cations such as iron, aluminum, potassium, magnesium, sodium and calcium to encourage the formation of

precipitates from the waste stream. Once the phosphorus has precipitated the technology's job is not over. It must then capture the solid end products that can then be harvested and returned for agricultural reuse.

A dry (or waterless) toilet is also known as a compost toilet. A small hole in a separate forward-facing compartment sends urine to a water tight container one floor beneath the toilet. Urine diversion flush toilets are similar in appearance to a standard flush toilet, except for the addition of a diversion basin in the bowl. The toilet bowl has two sections so that the urine can be separated from the other wastes. The urine flows into a storage tank for future reuse or processing, while the feces are flushed with water to be treated by sewer or decentralized systems. Urine contains most of the nitrogen and most of the phosphorus generated by the residents. These nutrients can be applied by farmers to agricultural lands after pasteurization of the product or can be alternately directly applied in home gardens.

Urine diversion is only practical because urine itself is so concentrated in nutrients. Urine makes up only one percent of the liquid flow coming from a residence. But taking urine out of the waste stream eliminates up to 80% of the nitrogen found in wastewater (the range is 70 to 80%) and 65% of the phosphorus found in wastewater (range is 50 to 65%), Noe-Hays et al., 2020.

The cross section drawing of a flushing urine diversion toilet (Figure 6 next page) provides the missing information to understanding how these devices work. Note the built-in trap is connected to a urine transfer pipe leading to a urine storage tank. The tank can be emptied by a liquid vacuum truck and the contents treated by pasteurization prior to land application. A useful rule of thumb is a human will excrete around 125 gallons of urine per year (44 ounces or 5.5 cups a day).

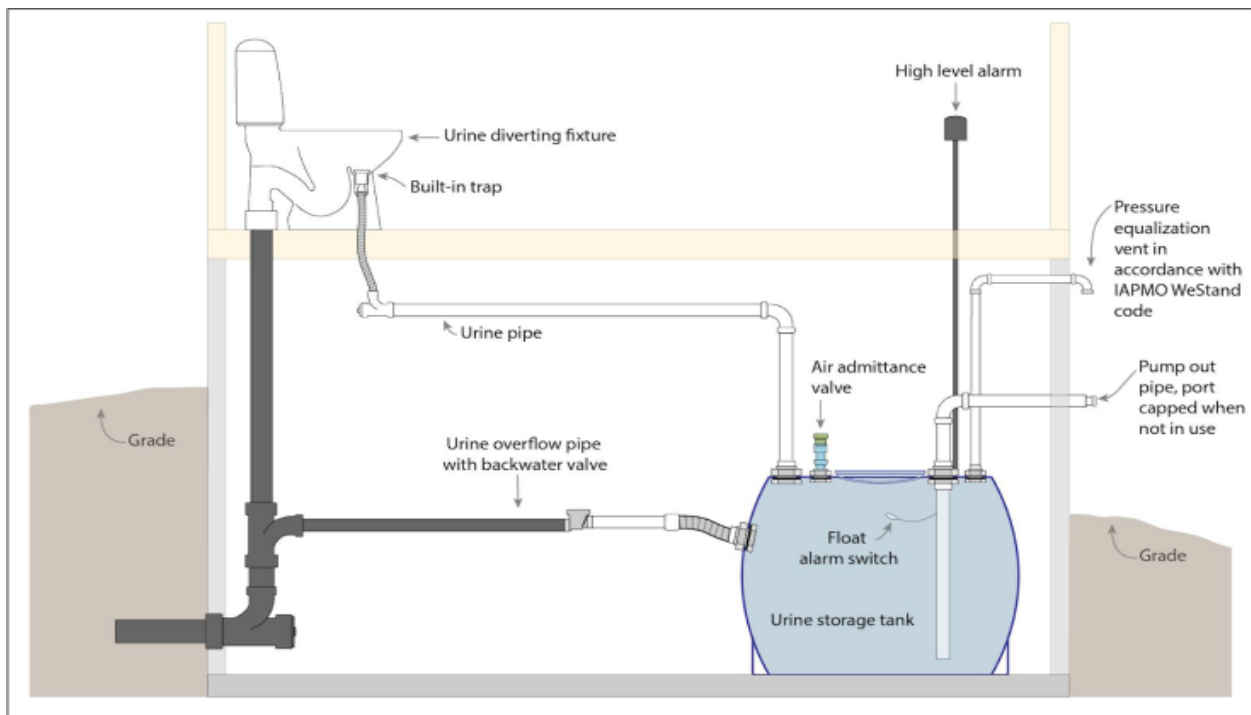


Figure 6 Cross section view of flushing urine diversion toilet. IN: Noe-Hays et al., 2020

Most waterless urinals use a liquid sealer and rely on a density differential between the sealant and urine to control objectionable odors. The sealant is less dense than urine, which passes through the sealant. The sealant creates an odor barrier between the liquid waste and the urinal bowl. Liquid-seal urinals feature two different designs: cartridge and integrated drain trap. The cartridge design uses various types of disposable cartridge inserts that fit into the custom-designed urinal base. The cartridge might simply slide into the base, or it might require a special tool for insertion and removal. The cartridge typically contains half a liter of water and is topped with a liquid sealant. This cartridge collects sediment and directs the flow of liquid waste to the drain while blocking odors. Urine will eventually flow out of the urinal and into a drain pipe. The pipe may be attached to a sewer or flow into a septic tank or be containerized for future reuse.

Large municipal wastewater plants have been removing phosphorus from wastewater for decades. These types of treatment systems are complex and expensive, and take advantage of frequent operator visits. These advantages are generally not available and are impractical for a small system. Precipitation creates a sludge byproduct rich in phosphorus that still has to be dealt with. Chemical addition requires chemical storage, metering pumps, and control systems to ensure the proper dose of chemical is being added. Often pH has to be controlled as well. Adsorption reactions also concentrate phosphorus and those adsorbents have to be regenerated and phosphorus collected must be moved to a final disposal point. Biological phosphorus removal requires multiple tanks and recycle lines to initiate the process. In many cases, volatile fatty acids are added to enhance the biological removal process. Again, another chemical feed system to deal with. One last method used by large systems for phosphorus removal is land application either through the liquid fraction or biosolid spreading. In these cases, the phosphorus is applied at a rate that is taken up by the crop being grown. This rate is called the agronomic rate. While these methods are effective at managing phosphorus, they do require large acreages of land. Also, the wastewater or biosolids cannot be applied year-round in temperate climates so storage or an alternate disposal method must be used when the crops are not actively growing. These types of systems are generally not practical for small systems. Nevertheless, some small-flow solutions are now available to this market sector.

The removal of phosphorus from wastewater can be performed using physico-chemical methods, biological treatment, and/or combinations of both. Many large-scale centralized system techniques are well established. However, translating such technologies to effective use at smaller scales has rarely been done and, as such, there is little information regarding the implementation and-or success of such systems. Small-scale treatment plants are different in that they may be less accessible than larger urban facilities; influent flows tend to be much more variable and subject to wider seasonal fluctuations; they are less closely managed and monitored; and wastewater composition often differs from urban sources (Bunce et al., 2018).

Conventional onsite systems are not designed to remove nutrients, but that does not mean that certain conventional systems remove nutrients naturally. Depending upon the soil type beneath

the soil treatment area, some irreversible phosphorus precipitation is possible. An average family (2 to 3 people) generates 6 to 9 grams of phosphorus per day, simply from human excretion as urine and feces. Aging systems pose a greater risk for contributing phosphorus into the environment because the finite phosphorus precipitation sites have been saturated (used) earlier in the system's life.

Phosphorus' reactive nature allows designers to enhance phosphorus capture by precipitation of phosphate rich minerals. Phosphorous is favored to form compounds with the cations aluminum, iron and calcium. In a filtration option, water is dripped over or through lightweight expanded clay aggregate Lightweight Expanded Clay Aggregates (LECA) with naturally high levels of aluminum, iron or calcium. Electrochemical solutions are also available. An iron or aluminum electrode is slowly dissolved into the wastewater using direct electric current. The phosphorus can form crystalline minerals mentioned earlier (in particular Struvite and Vivianite) in the treatment unit. These minerals permanently capture the phosphate molecule.

Constructed wetlands are relatively simple to construct and maintain. Professional maintenance is recommended for the systems. Constructed wetland systems should be operated by hard-working people with green thumbs. These systems are comparatively easier to operate, so less technical operator training is needed than other system types. The systems consist of shallow ponds planted with aquatic vegetation. There are three types of constructed wetland available. Free water surface (looks like a natural wetland), vegetated submerged (shown on the next slide with horizontal flow) and vertical flow vegetated submerged constructed wetlands, which are popular in Europe. Plants rely on naturally-occurring microbial biological physical and chemical processes to treat wastewater. Ruminants are cows, horses, and other animals with multiple stomachs needed to extract nutrition from cellulose.

Lightweight expanded clay aggregates are one type of lightweight or low-density aggregate. Air bubbles become entrained in the clay pellets when heated to 1200 degrees Celsius in a rotary kiln. Certain clays have naturally high concentrations of aluminum, iron or calcium. These LECAs are designated LECA-P.

PhosRid™ is a trademarked treatment process for phosphorus removal that proceeds from the research of Robertson (2000) and others based on a process called reductive iron dissolution (RID). In this passive process, a Ferric iron (Fe³⁺) rich porous media is placed in direct contact with unoxidized sewage, such as the effluent of a septic tank. The iron present reacts with the carbon in the sewage and is reduced to ferrous iron Fe²⁺. The ferrous iron in solution reacts with soluble phosphates and may precipitate out as vivianite (hydrated iron phosphate) or other phosphorus rich minerals (Heufelder & Mroczka, 2004).

The RUCK System is a modified sand filter. This system is 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 that also receives

greywater (shower, sinks and laundry wastes) from the facility served. The theoretic basis upon which phosphorus is removed in the system, suggest that there is a finite adsorption capacity to the system. The system was invented by Rein Laak a professor from the University of Connecticut to primarily reduce nitrogen levels. The system uses in-drains that provide air to the filter so it stays aerobic. Laak (1986) reported that the pH in the aerobic sand filter (under construction here) drops to below 4 as the sand begins to treat wastewater. Laak felt this low pH was responsible for increased phosphorus adsorption in the sand. He reported the average phosphorus concentration in Ruck system effluent was 5 mg/L, which was a great achievement in the 1980's. Currently, the total phosphorus concentration target in surface streams leading to lakes is 0.5 mg/L and 0.1 mg/L in flowing fresh water streams.

The Phos-4-Fade phosphorus removal filter (Fig 7) is a non-mechanical solution that can be easily installed as part of any onsite wastewater treatment system. Flow enters the inlet chamber of the Phos-4-Fade filter where it then moves downward and passes into the media chamber through transfer ports. Concrete support channels direct flow beneath the media where evenly spaced apertures provide uniform dispersal of flow. Progressively sized layers of primary and secondary filtration media further distribute the flow to the adsorptive media layer (primary is the red bag, secondary is the green bag, adsorptive media is loose). As the flow passes through the adsorptive media, final polishing takes place as Phosphorus adheres to the porous media surfaces.

NORWECO PHOS-4-FADE® PHOSPHORUS REMOVAL FILTER

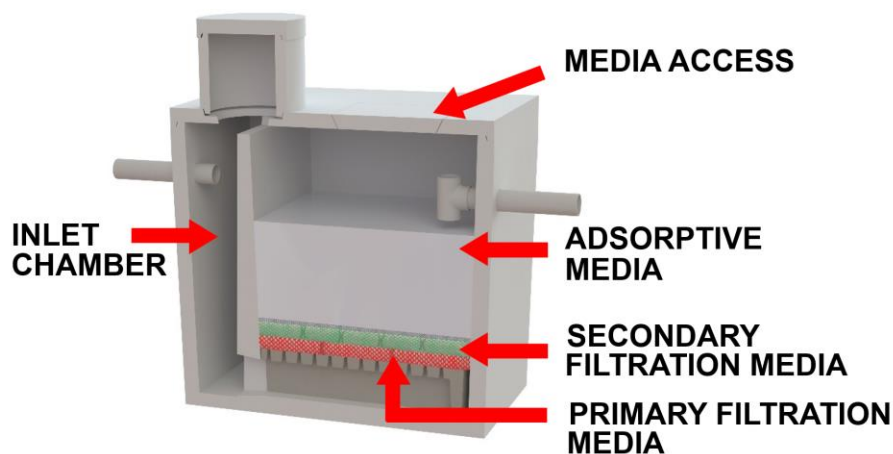


Figure 7 Cutaway view of Norweco Phos-4-fade filter with critical information highlighted

The Phos-4-Fade filter can be quickly and easily installed downgradient from any onsite wastewater treatment system. The innovative adsorptive media technology begins working

immediately upon start-up. Completely non-mechanical, the filter requires no electricity and operates continuously with minimal maintenance. A single riser extends to grade from the tank to allow inspection and service of the filter contents. The Phos-4-Fade filter is user friendly, easy to install and maintain, and provides effective total phosphorus removal for any onsite wastewater treatment system. Components are backed by a one-year limited warranty and lifetime exchange program. Media replacement will normally be required at two-to-five-year intervals.

Another product innovation, Norweco's Phos-4-Fade tablets are formulated to provide a slow and consistent release of aluminum sulfate for the removal of phosphorus from wastewater, stormwater and process water. Phos-4-Fade tablets contain 93% aluminum sulfate as an active ingredient. Aluminum sulphate is a coagulant that bonds with phosphorus in its natural form of phosphate. These combined particles settle to the bottom of the treatment system tankage or lagoon. For maximum effectiveness, Phos-4-Fade tablets should be incorporated into the treatment process in conjunction with clarification but prior to a chlorine contact tank or mixing chamber. Phos-4-Fade tablets can be utilized with Norweco's Bio-Dynamic tablet feeders, with field constructed feed systems or in conjunction with the various brands of pressure type feeders available in the marketplace.

A favored approach in industry to remove phosphorus is the injection of chemical coagulants in liquid or solid form into the wastewater flow. Removal of phosphorus occurs by precipitation and chemical adsorption. A significant fraction of phosphorus precipitates in the form of insoluble crystals with the metal coagulating agent, while the remaining phosphorus is adsorbed by the flocs of metal hydroxides formed during dissolution. Thus, the injection of coagulant into a mixed basin makes it possible to form both flocs and particles decantable in a subsequent separation step. The principle of electrocoagulation requires the passage of a low electrical current between two electrodes (an anode and a cathode) submerged in order to release (put in solution) the required dose of cations. The Premier tech DpEC system is based on the principle of primary phosphorus capture process using a solid cation source.

Electro-coagulation (EC) unit

- Uses aluminum electrodes
- Operates on command

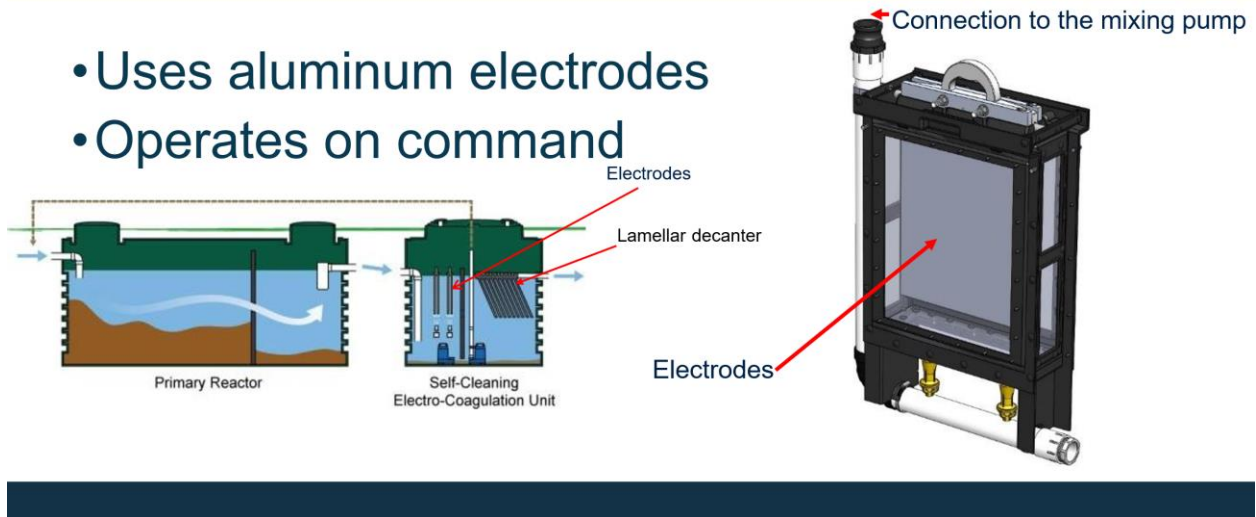


Figure 8 Cross section view of electro-coagulation unit and cross section view of two tanks

Raw wastewater is first sent to the primary reactor. This reactor allows sedimentation of particles and allows storage of sludge. The primary reactor also receives recirculate from the electrocoagulation unit. The recirculation loop consists of a pump located in the lamellar decanting basin, whose operation is coordinated with the treatment system feed pump. Each pair of electrodes is installed in a mesh basket allowing the free circulation of water, while confining particles created around the electrodes. A stirring pump ensures vigorous mixing of the water, increasing the speed of the water fivefold and increasing its turbulent energy. The DpEC effluent then passes through a filtration component, such as a Ecoflo Biofilter or compact Sand Filter Bed system, where the aluminum-phosphate minerals are filtered out of the effluent.

The Premier Tech Water Environment DpEC can be used for both retrofits and new installations at individual homes. The DpEC technology is certified under the CAN/BNQ 3680-600 for either configuration shown on Table 3. The DpEC unit itself achieves 92% total phosphorus removal. The Ecoflo biofilter contributes additional total phosphorus capture for a total of 99%. A sand filter bed contributes even more total phosphorus capture for a total of 99.4% using a hydraulic loading rate of 1.84 gallons per square foot per day.

Table 3. DpEC CAN/BNQ Certification results

Parameters	Influent primary reactor	Effluent EC	Effluent Ecoflo Biofilter	% Removal	Classification
TSS (mg/L)	231 ± 65	33 ± 23	2 ± 2	99.5%	BIV
CBOD ₅ (mg/L)	188 ± 63	53 ± 23	2.0 ± 0.1	98.6%	BIV
P total (mg/L)	5.1 ± 1.7	0.4 ± 0.4	0.1 ± 0.1	99%	PII
FC (log)	6.4 (2,272,815)	4.8 (62,773)	<0.3 (<2)	> 6	DIII
pH	8.0	8.2	7.5	n/a	
n	159	159	159	n/a	

TSS (mg/L)	231 ± 65	33 ± 23	1 ± 1	99.6%	BIV
CBOD ₅ (mg/L)	188 ± 63	53 ± 23	2 ± 1	99.1%	BIV
P total (mg/L)	5.1 ± 1.7	0.4 ± 0.4	0.04 ± 0.02	99.4%	PII
FC (log)	6.4 (2,272,815)	4.8 (62,773)	1.7 (51)	4.5	DIII
pH	8.0	8.2	7.5	n/a	
n	159	159	159	n/a	

The Waterloo Biofilter EC-P from Waterloo Biofilter Systems (Figure 9) captures phosphorus from residential and commercial wastewater streams using an electrochemical process. These EC units can be used for both retrofits and new installations at individual homes. The EC technology can be used in combination with advanced treatment units or following conventional septic systems. The EC-P is simple to install and can be configured to the level of phosphorus removal desired. The system requires no liquid chemical addition, does not appreciably increase sludge production and uses very little energy. Electrodes typically last for up to two years before requiring replacement. More than 98 percent of phosphorus can be removed from effluent before it enters groundwater supplies. Through electrochemistry the Waterloo EC-P removes phosphorus by the precipitation of iron-phosphate minerals. A natural iron electrode is installed in the septic tank or in a small tank immediately thereafter. A low current is applied to the electrode. Iron is dissolved into the sewage stream where it reacts with phosphate to form highly stable and insoluble iron-phosphate minerals. The Waterloo EC-P effluent is then passed through a filtration component,

such as a Waterloo Biofilter treatment unit, sand filter, or other unsaturated media filter or conventional leach field, where the iron-phosphate minerals are filtered out of the effluent preventing phosphorus from reaching groundwater.



Figure 9. Field installation of Waterloo Biofilter EC-P

Conclusion

Phosphorus is an important element and nutrient in our world for many different reasons. It limits the growth of fresh water aquatic plants in temperate climates. It is found in many commercial products, and in macromolecules essential for life. The biogeochemical cycle of phosphorus plays out over geological time, meaning it will take many thousands of years before measurable changes in phosphorus ore location occurs. Phosphate rock reserves are found primarily in northern Africa and the Middle East. The creation and use of phosphate-free detergents (both laundry and dishwashing) marks a pollution prevention success. Another pollution prevention opportunity is just beginning with the growing use of urine diversion toilets and waterless urinals. Modest phosphorus reclamation can be achieved by constructed wetlands, LECA-P and RUCK systems.

Newer decentralized phosphorus capture technologies exploit the attraction between cations and anions to create stable precipitate minerals to prevent phosphorus from leaching into groundwater.

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