Emerging ISSUES

Urine Diversion

An Option for Wastewater Nutrient Management

As the increasing pollution of lakes, streams, and coastal waters by excess nutrients becomes more evident, there has been a recent corresponding increase in the search for solutions. For nutrients that originate in wastewater, one option that is beginning to draw some attention in the U.S. is urine diversion. Also known as urine harvesting or source separation, it has been used successfully in a number of developed and developing countries. European countries—Sweden in particular—have been installing and studying urine diversion systems since the early 1990s.

There is a long history of human urine and feces being used agriculturally by preindustrial cultures. That use was largely curtailed with the development of modern sanitation systems, which improved public health but resulted in the loss of nutrients. Urine diversion is a contemporary attempt to recycle nutrients without jeopardizing public health.

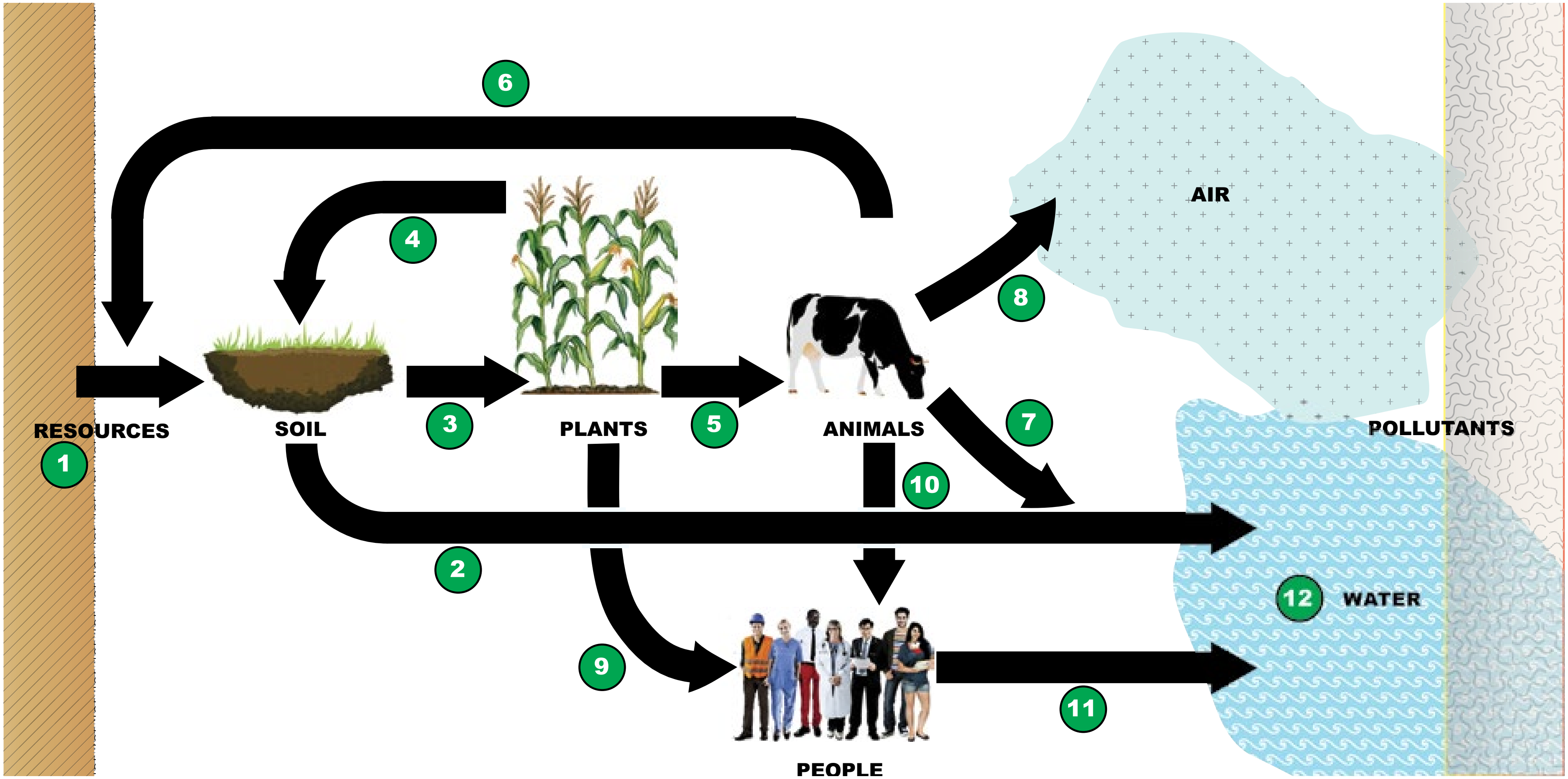
Urine diversion involves separating urine from the wastewater stream at the point of excretion and reusing the urine as an agricultural fertilizer. The interest in this approach centers on the fact that urine makes up only about one percent of the typical residential wastewater stream but contains about 80 percent of the nitrogen, 55 percent of the phosphorus, 60 percent of the potassium, plus smaller amounts of other nutrients including sulfur, calcium, and magnesium. Nitrogen and phosphorus are the two nutrients most responsible for the over-enrichment of freshwater and coastal waters causing the proliferation of harmful algae blooms, negative changes in aquatic plant and animal life, and loss of fisheries. Residential wastewater is not the only source of these nutrients but it is a contributor and decreasing the amount of nutrients released in wastewater is necessary to protect and rehabilitate our aquatic resources.

The reuse of urine as an agricultural fertilizer provides a number of auxiliary benefits. Currently, most nitrogen fertilizer is synthesized by reacting atmospheric nitrogen gas with hydrogen gas and catalysts—an energy-intensive process. Urea, the organic form of nitrogen in fresh urine converts naturally to the plant-available nutrient ammonia with little or no needed energy input, depending on how it is processed. Thus, the use of urine as a fertilizer potentially offers significant energy savings.

The production of phosphorus fertilizer relies on the mining of phosphate-bearing rock. High-quality phosphate rock deposits are currently found in only a small handful of countries and there is growing concern about the prospect of phosphorus shortages within this century. Recycling urine is seen as one way to reduce the demand on rock phosphate, which is a non-renewable resource.

Urine diversion also has the potential to help conserve water. As much as 30 percent of water currently used in U.S. residences is used to flush toilets. Most urine-diverting (UD) toilets use a very small amount of water, about one tenth of a liter, to flush urine. Because about 80 percent

Continued on page 3



Although they are intimately connected, with regard to nutrient management, the U.S. agricultural production and human sanitation systems are currently run as separate, parallel, linear systems. Nutrients in the form of nitrogen and phosphorus fertilizers are applied to agricultural soils (1). Because of the difficulty of accurately matching fertilizer application with the optimal plant uptake, fertilizers are frequently applied in excess. Some excess nutrients move from the soil to surface water through groundwater or through erosion of soil by wind and rain (2). Plants incorporate some nutrients into plant tissue (3). Some plant residues containing nutrients may be recycled back to the soil (4). Plant materials are fed to farm animals (5). Some nutrients are incorporated into meat, milk, or other animal products but most end up in manure, which may be recycled as fertilizer (6). Nutrients in manure may escape animal facilities in surface water runoff or in groundwater (7). Ammonia gas (NH_3) present in animal urine can evaporate into the atmosphere and then return to the soil and water as dry particles or in rain droplets (8). Excess nutrients that end up in downstream waters can create a spectrum of pollution-related problems (12).

The human sanitation system is directly connected to the agricultural system through the consumption of plant (9) and animal (10) products by people. Because human adults need only small amounts of dietary nitrogen and phosphorus, most of the nutrients are excreted into residential wastewater (11). The majority of U.S. wastewater treatment plants do not remove nutrients from the wastewater. And, very few of those plants that do remove nutrients do so in a way that allows for their reuse as agricultural fertilizers. As a result, as nutrients move through the agricultural and sanitation systems, largely in one direction, they are transformed from crucial agricultural resources to water pollutants. Excess nutrients in surface water have led to low oxygen conditions negatively affecting aquatic plant and animal life and economically damaging the fishing and recreational industries.

Continued from page 1.

of toilet flushes are used to flush only urine this could result in a sizable savings in water used compared to conventional toilets. In public buildings, urine can also be collected using waterless urinals.

What's involved in urine diversion?

A urine diversion system can be divided into three parts: (1) collection, (2) storage, and (3) reuse.

Collection Fixtures
Because the urine is diverted at the point of excretion, urine diversion involves the use of alternative collection fixtures, including toilets. There are a variety of UD toilet designs. In developed countries, these designs usually involve the incorporation of a partitioned bowl. The front section collects urine and the back section collects feces and toilet paper.

The urine collected in the front section is flushed with a small amount of water, although some models use no water for the urine flush. The back bowl can be connected to a conventional sewer with a standard flush evacuation or it can be connected to a chute that feeds a storage container where feces and paper are collected for dehydration and eventual composting.

In situations where eventual composting of the solids is planned, urine separation provides an additional benefit. Composting of feces is more manageable when it is not mixed with urine. The mixture of the feces and urine produces a heavier, more malodorous sludge that can be avoided if the urine is separated.

The front section of a UD toilet contains a seal to control urine odors. There are a variety of odor seal designs depending on the manufacturer. For flush UD toilets, the back section uses a U-bend water seal to control odors, the same as that used in conventional toilets.

As mentioned, in public buildings urine can be collected from men's restrooms using waterless urinals. Waterless urinals are already in use in the U.S. for water conservation purposes. They have not, however, been connected to urine collection systems to any great extent. Some proponents of urine diversion see public buildings such as schools, highway rest stop facilities, and stadiums as prime targets for urine diversion systems because they produce a wastewater flow that is rich in urine.

Urine-diverting toilets have a vertical barrier in the bowl that separates urine (front section) from other toilet waste. Low-flow and waterless urinals can also be used to divert and collect urine from men's restrooms.

Like UD toilets, waterless urinals usually incorporate some method of odor control. Waterless urinals marketed in the U.S. typically use a liquid sealant that floats on top of the urine contained in the trap. Urine can penetrate the sealant, which may be a biodegradable vegetable oil or aliphatic alcohol. To remain effective the sealant needs to be replenished on a regular basis. The length of time between maintenance varies depending on level of use.

Piping and Storage
UD systems use piping to connect toilets and urinals to storage tanks. Recommended pipe materials are polyvinyl chloride and polyethylene. Metal pipes are not recommended to prevent metal contamination of the urine. Pipes should extend almost to the bottom of the storage tank. This allows a liquid seal to form around the pipe and minimize odors venting upwards.

Hard crystalline precipitates and some soft sludge can form in sections of pipe where liquid moves slowly. To minimize precipitation, a combination of sufficient slope and pipe diameter is necessary. For larger systems the slope can be as small as one percent with pipe diameters no less than two inches. For single-family systems the diameter can be as small as ¾ of an inch but the slope should be no less than four percent. Ninety degree bends in piping are discouraged.

Urine storage can be both short-term and long-term. Short-term storage is usually located near where the urine is generated. Tanks can be made of polyvinyl chloride, polypropylene, polyethylene, fiber-glass or reinforced concrete. Short-term tanks should provide enough storage to provide a comfortable interval between urine removal episodes.

Long-term storage is used to disinfect the urine (more on this later) and for issues of agricultural timing. Fertilizers are not applied to land year-round so some long-term storage is necessary for times when fertilizer is not needed. In addition to the tank materials mentioned above, plastic bladders have also been used for long-term storage.

Storage tanks should be unventilated to prevent the loss of ammonia gas. Pressure equalization can be provided to allow urine to replace the air in the tank head-space by use of a small hole or valve. In cases where the tank is emptied by pumping, sufficient allowance must be made for temporary pressure equalization to prevent potential vacuum-collapse of the tank.

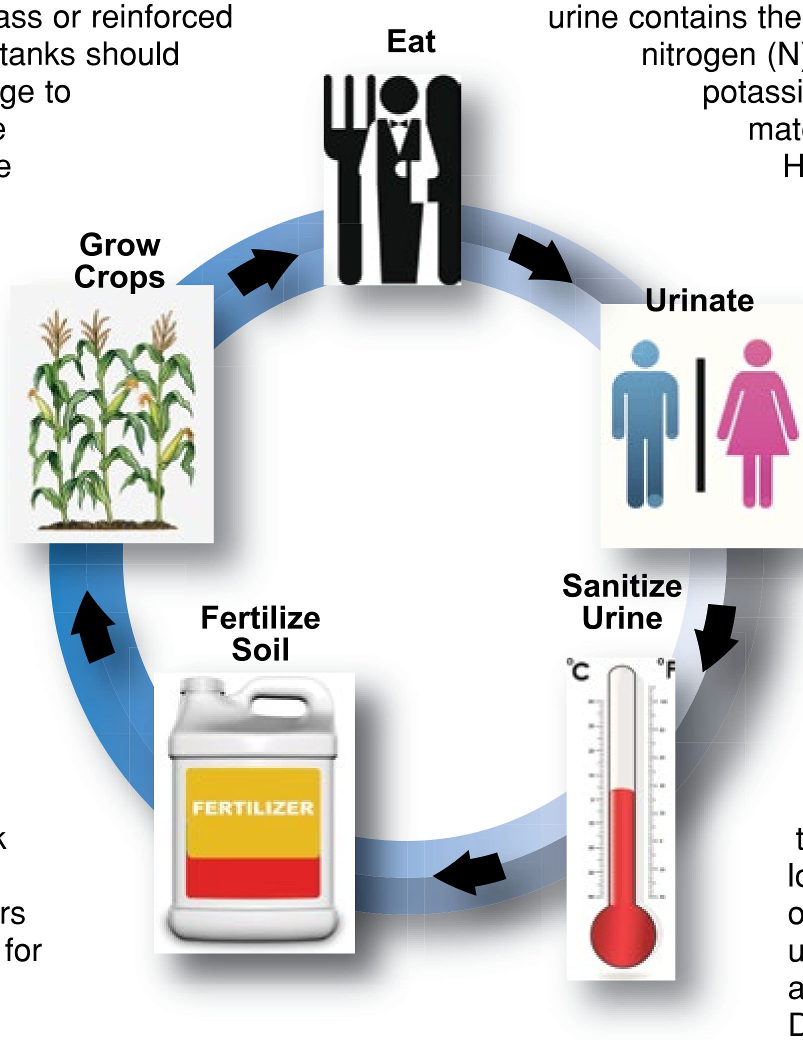
Agricultural Reuse

Beneficial reuse, in which urine is used to replace synthesized or mined fertilizers, is crucial to the success of a UD system. Without responsible reuse, nutrients are just being transferred to a different location.

Urine can be applied directly to agricultural soils as a liquid or processed into solid pellets. Liquid urine contains the three macro-nutrients nitrogen (N), phosphorus (P), and potassium (K) in an approximate NPK ratio of 11/1/2.5. However, because urine is 95 percent water it is relatively dilute so the cost of transporting urine can be an issue.

Some farmers already have equipment for spreading liquids so applying urine to agricultural land is not a major problem. Like any fertilizer, farmers need to apply urine in a way that nutrients are not lost unnecessarily. Most of the nitrogen in stored urine is in the form of ammonia/ammonium. Dissolved ammonia can evaporate to the atmosphere as ammonia gas representing lost nutrients. Farmers (and gardeners) can mini-

Continued on page 6



Recycling urine for agricultural fertilizer converts the current linear pathways of nutrient flow into a single closed cycle. While some loss of nitrogen to the environment is unavoidable, human urine recycling has the potential to reduce nutrient pollution, conserve water and energy, and reduce dependence on synthesized fertilizers.

RICH EARTH INSTITUTE

FERTILIZER FROM URINE Clean Rivers. Sustainable Farms.

Rich Earth Institute Pioneers Urine Reuse Research in the U.S.

The Rich Earth Institute, located in Brattleboro, Vermont, operates the first legally authorized and publicly documented community-scale human urine reuse project in the U.S. Starting in 2012, they have collected urine from as many as 170 donors in the Brattleboro area.

Rich Earth sanitizes and applies the collected urine as an agricultural fertilizer with the cooperation of local farmers. With funding from a USDA Sustainable Agriculture Research and Education Partnership grant, the Institute conducts testing of the urine and the soil after application for the presence of nutrients, heavy metals, and pathogens. Using randomized block trials, they have documented increased hay production from the application of urine at different dilution rates and levels of application.

The organization has also experimented with the use of a solar unit to pasteurize urine, which reduces the amount of storage time needed to sanitize the urine. In 2014, Rich Earth will be further experimenting with incorporating a heat exchanger into their pasteurization unit and conducting an EPA-funded study looking at the fate of pharmaceuticals in urine when it is applied to crop soils. More information on their project is available at www.richearthinstitute.org

As part of the Rich Earth Institute project, Seth True, of Best Septic, pumps from a 275 gallon collection tank. A family of three can fill a tank this size in eight months.

The Rich Earth Institute has experimented with solar pasteurizers to reduce the amount of storage time needed to sanitize the urine. The pictured unit was designed to sanitize 50 gallons of urine by heating it to 70° C (158° F) for 30 minutes.

Continued from page 4.

mize the loss of ammonia gas by turning the soil after application of liquid urine or by applying the urine in the evening when temperatures are less conducive to evaporation.

Urine can be processed in various ways to produce solid fertilizers in pellet form. The addition of magnesium to the urine results in the precipitation of a crystalline compound called struvite, $Mg(NH_4)(PO_4)\cdot 6H_2O$. This is the same material that precipitates in collection pipes but by adding an optimal amount of magnesium, in the form of magnesium oxide, much higher rates of phosphate precipitation are achieved. Calcium and potassium are also present in the resulting crystals in smaller amounts. Struvite is recognized as a slow-release fertilizer and has a history of agricultural use. The reaction to produce struvite is neither particularly complex nor energy-intensive.

Struvite precipitation, however, does not recover all of the nitrogen present in urine. To maximize nitrogen recovery, zeolites have been used successfully. Zeolites are natural minerals that have the ability to exchange some ions without altering their basic structure. One type of zeolite, clinoptilolite, has a high affinity to adsorb ammonium ions (NH_4^+). Struvite precipitation and zeolite adsorption of ammonia can be conducted simultaneously to produce a solid fertilizer that recovers almost all of the phosphorus and 60 to 80 percent of the nitrogen from urine. The resulting fertilizer is equivalent in quality and effectiveness to conventional commercial fertilizers.

Experiments have also been conducted with cyclical freezing and thawing of urine. Under controlled conditions this can result in concentrated urine with no loss of nutrients but in a volume that is as much as four times less than the original volume. Processing of urine, either as a concentrated liquid or into solids can help overcome the cost issues of transporting dilute liquid urine.

Obstacles to Urine Diversion

Although urine diversion offers a number of advantages as a method of managing nutrients in wastewater, it is not without obstacles to being implemented. These concerns can be classified as hygienic concerns, and user and institutional concerns.

Hygienic Concerns

The safety of using urine as a fertilizer may be the primary concern of many people, who may be unaware that urine and feces do not present the same level of risk to public health. In healthy individuals, urine is sterile. Some pathogens may be passed in the urine of infected people but for most of the resulting illnesses, contact with urine is not considered to be the main route of transmission. An exception is Schistosomiasis, a disease caused by parasitic worms, whose eggs may be transmitted in urine. This disease, however, is limited mainly to Africa and is not found in the U.S.

A bigger concern is the possibility of contamination of urine with feces, which have a much higher likelihood of containing pathogens. Even with some expected fecal contamination, diverted urine will have a much lower concentration of micro-organisms than the mixture of urine and feces in conventional toilet wastewater.

Urine also has the convenient property of being somewhat self-sterilizing during storage. The pH of freshly excreted urine varies between 5 and 7.5. However, as the nitrogen in the fresh urine, mostly in the form of urea, is converted to ammonia the pH rises to about 9. The combination of the higher pH and the concentration of ammonia effectively kills most micro-organisms during storage. In fact, some standard indicators of fecal contamination, such as *E. coli,* are eliminated so rapidly that they are not useful as indicators when dealing with urine.

The factors, beside pH and ammonia concentration, that affect the efficiency of the sanitizing process include temperature, storage time, and the amount of dilution of the urine. Higher temperatures and longer storage time lead to more complete sterilization, while higher dilution delays the sterilization process. Temperature appears to be the most critical factor. The organisms that appear most resistant to inactivation are viruses and some helminths (microscopic worms), whose eggs are especially resistant. For both, little or no inactivation occurs at low temperatures (4° C) but effective inactivation occurs within two months of storage at higher temperatures (24°–34° C), provided the urine is diluted by no more than one to one.

It is worth noting that, for single families that divert urine for use as fertilizer exclusively in their family garden, storage for the purpose of sterilization is not considered necessary. This is because for most illnesses spread by microbes, it is assumed that family members are more likely to be exposed by person-to-person contact with family members than by contact with urine. It is still recommended that urine application be stopped one month before harvesting.

Another area of hygienic concern is the presence in urine of compounds such as hormones and pharmaceuticals and their metabolic byproducts. Although it varies from compound to compound, it is estimated that about two-thirds of these types of compounds that are excreted are present in urine, with the remainder in feces.

While more research is needed on this topic, some scientists believe that these organic compounds are more likely to be effectively decomposed in a soil environment than in an aquatic environment, where they are mostly now being discharged. This is because shallow soil environments have a much higher density and diversity of micro-organisms capable of degrading organic compounds and are more oxygenated than aquatic environments.

The public health risk of applying human urine to soil needs to be evaluated within the context that animal manure and urine now being produced and applied to farm land by modern farming methods also contains hormones and pharmaceuticals, including antibiotics, frequently in concentrations much higher than in human urine.

User and Institutional Concerns

Most remaining obstacles to the implementation of urine diversion have to do with its unfamiliarity. While the use of some components of urine diversion systems, such as the use of waterless urinals by males, require no behavioral changes, some minor adjustments are necessary. Some people, both male and female, may not intuitively know how a UD toilet is supposed to be used. Studies conducted in Europe show that there was less acceptance and more fecal cross-contamination of UD systems in public buildings and schools than in systems serving residents of single households and planned eco-villages. This indicates that some education is necessary for new users about not just how UD toilets are used, but also why they are being used.

Similarly, although having a urine collection tank onsite that needs to be occasionally pumped is also unfamiliar, it is not a major change. Many people in rural and suburban areas already have septic tanks that need intermittent pumping. Urine collection tanks can be installed underground outside of the house so that pumping can be conducted without entering the house.

Institutional obstacles also exist because urine diversion is not currently a significant part of the U.S. wastewater infrastructure. As a result, urine diversion collection systems are not included in plumbing codes. Also, if diverted urine were to be used agriculturally in a more widespread way, it is likely that some level of regulation would be expected. There are, however, currently no guidelines in the U.S. on the agricultural use of human urine and some confusion exists about how it should properly be regulated.

Another obstacle is that the U.S. centralized wastewater treatment sector currently is heavily committed to the model that all treatment takes place at the end of the pipe. Diverting some fraction of the wastewater stream at the point of excretion rather than removing it at the treatment plant would require a major change in philosophy.

Currently, the majority of public wastewater treatment plants in the U.S. are not able to remove nutrients. And, almost all of those plants that do have nutrient removal capabilities use processes that remove nutrients in such a way that they cannot be reused for fertilizer. However, the technology is becoming available to remove nutrients in reusable forms from wastewater at the treatment plant. As that technology becomes more affordable it is likely that such end-of-pipe treatment would be favored over urine diversion. However, there are many other circumstances, such as in areas that rely mostly on decentralized wastewater treatment systems, where urine diversion may some day soon become one more option available for managing nutrients.

References

Fam, Dena et al. 2010. "Institutional Challenges to System Innovation in Wastewater Management—The Case of Urine Diversion in Sweden." Institute of Sustainable Futures, University of Technology. Sydney, Australia. Accessed at: *http://www.academia.edu/4881684/Sustainable_innovation_in_wastewater_management_lessons_for_nutrient_recovery_and_reuse_Sustainable_innovation_in_wastewater_management_lessons_for_nutrient_recovery_and_reuse*

Ganrot, Zsófia. 2005. Urine Processing for Efficient Nutrient Recovery and Reuse in Agriculture. Doctoral Thesis, Department of Environmental Science and Conservation, University of Gothenburg. Gothenburg, Sweden. Accessed at: *http://www.gu.se/english/research/publication/?publicationId=116739*

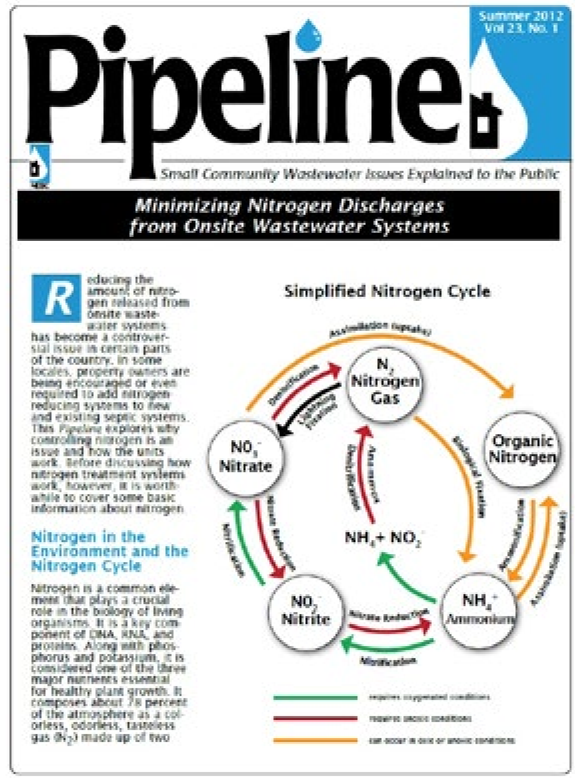
Kvarnström, Elisabeth et al. 2006. "Urine Diversion: One Step Towards Sustainable Sanitation." Stockholm Environmental Institute. Stockholm, Sweden. Accessed at: *http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf*

Schönning, Caroline. 2001. "Urine Diversion—Hygienic Risks and Microbial Guidelines for Reuse. Swedish Institute for Infectious Disease Control. Solna, Sweden. Accessed at: *http://www.who.int/water_sanitation_health/wastewater/urineguidelines.pdf*

von Münch, Elisabeth et al. 2011. "Technology Review of Urine Diversion Components." Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Eschborn, Germany. Accessed at: *http://www2.gtz.de/dokumente/bib-2011/giz2011-0270en-urine-diversion.pdf*

More Information

The National Environmental Services Center (NESC) newsletter *Pipeline* covers onsite wastewater issues in detail. Review more than 50 topics at: *www.nesc.wvu.edu/pipeline.cfm*. Nitrogen and phosphorus concerns may be of particular concern to those interested in urine diversion. Learn more with these NESC items:


Pipeline

Summer 2012
Vol 23, No. 1

Small Community Wastewater Issues Explained to the Public

Minimizing Nitrogen Discharges from Onsite Wastewater Systems

Reducing the amount of nitrogen released from onsite wastewater systems has become a controversial issue in certain parts of the country. In some locales, property owners are being encouraged or even required to add nitrogen-reducing systems to new and existing septic systems. This *Pipeline* explores why controlling nitrogen is an issue and how the units work. Before discussing how nitrogen treatment systems work, however, it is worthwhile to cover some basic information about nitrogen.

Nitrogen in the Environment and the Nitrogen Cycle

Nitrogen is a common element that plays a crucial role in the biology of living organisms. It is a key component of DNA, RNA, and proteins. Along with phosphorus and potassium, it is considered one of the three major nutrients essential for healthy plant growth. It composes about 78 percent of the atmosphere as a colorless, odorless, tasteless gas (N_2) made up of two

Minimizing Nitrogen Discharges from Onsite Wastewater Systems
http://www.nesc.wvu.edu/pdf/ww/publications/pipline/PL_SU12.pdf

Phosphorus and Onsite Wastewater Systems
www.nesc.wvu.edu/pdf/WW/publications/pipline/PiL_SU13.pdf

Phosphorus: Essential Nutrient Can Pose Problems for Wastewater Treatment
http://www.nesc.wvu.edu/pdf/DW/EmergingIssues/EmergingIssues2.pdf