Urine source separation offers solution to nutrient overload

Nations faced with the challenge of expanding wastewater treatment capacity could find promise in a sustainable alternative – NoMix technology – and supplement to traditional wastewater infrastructure. ***Judit Lienert*** *and* ***Tove Larsen*** *of the Swiss Federal Institute of Aquatic Science and Technology (Eawag) report on the Novaquatis project that demonstrated how separate collection and treatment of urine could significantly improve water pollution control and increase nutrient recycling worldwide.*

In a 2004 report, the United Nations Environment Programme (UNEP) warned that nutrient overload could pose a greater threat to fish stocks than overfishing. Excessive nutrients, particularly nitrogen and phosphorus, lead to the proliferation of algae, which create oxygen-depleted "dead zones." These "dead zones" developed when large amounts of oxygen are consumed from the decomposition of short-lived algae, particularly in coastal waters. Consequently, fish die in anaerobic zones too large for a quick escape. The number of marine dead zones worldwide increased by 33% since 2004.

Conventional sewer networks and treatment facilities cannot adequately solve the problem of nutrient overload. In 1990, humans excreted 21 million tonnes of nitrogen worldwide, with only 6% being removed at wastewater treatment plants. Compared with the 48 million tonnes of nitrogen per year flowing into coastal waters from the world's continents, this amount is substantial. Since then, the global population has grown by 25% and migration to coastal cities continues to increase.

NoMix technology, developed through the Novaquatis project at Eawag in Switzerland, provides one solution to this growing problem. Between 80% to 90% of the nitrogen excreted by humans is contained in urine. If urine was separately collected and the nitrogen eliminated – or possibly recovered and used in agriculture – this system would surpass the efficiency of nutrient removal at most of the world's wastewater treatment plants.

NoMix in Switzerland

Urine source separation makes the wastewater management system as a whole more flexible and efficient, particularly energy-efficient. More emphasis can then be placed on eliminating problematic substances other than nutrients at treatment facilities. Furthermore, the construction of new plants is less costly if large tanks are no longer required for nutrient removal. This design change frees up financial resources to redirect towards household-level measures, such as investments in NoMix technology.

> ***"This finding means that urine source separation can reduce the environmental risks associated with pharmaceuticals and hormones of human origin in wastewater by an estimated 50%, and decrease the nutrient load on wastewater treatment plants."*** *– Judit Lienert, Eawag*

In Switzerland and other countries with a well-developed sewerage and wastewater treatment infrastructure, it remains to be seen how far the introduction of the NoMix technology is a viable option. Generations of water pollution control experts have addressed the nutrient issue in the United States, financed with public funds, yet nutrient removal remains a problem. In Switzerland certain problems have yet to be resolved. In the case of Lake Greifen, for example, reduction targets specified for phosphorus have not been achieved despite modern technology. The problem is caused by sewer overflows during rain events when wastewater is released to Lake Greifen without prior treatment. Reaching the phosphorus targets would entail building large stormwater tanks, which would be excessively expensive.

The urban wastewater management sector will face new challenges in the future that could lead to major cost increases, assuming that current technologies can handle problems caused by micropollutants and climate change. For example, drier summers in Central Europe could result in less diluted wastewater in rivers, so ammonia and nitrite toxicity could once again become an issue in the region. If the frequency of brief, intense downpours increases, as already recorded in Denmark, combined sewer overflows will also increase, with wastewater being discharged untreated into rivers and streams. The NoMix technology could help to tackle all three problems – phosphorus inputs, micropollutants, and climate change.

NoMix in China

In countries with limited wastewater treatment facilities, the NoMix technology offers a sustainable alternative and supplement to the establishment and expansion of wastewater treatment plants, particularly in coastal cities.

Lake Dianchi used to be the source of drinking water for the city Kunming, China, but is now polluted with excessive phosphorus. ***Photo by Eawag***

Part of the Novaquatis project involved studying the wastewater situation in Kunming, China, the sister city of Zurich, Switzerland, where an estimated 2000 tonnes of phosphorus per year enters Lake Dianchi; wastewater supplies 75% of the phosphorus.

Lake Dianchi used to be the source of the city's drinking water, but excessive nutrient levels have heavily polluted the water. The lake can naturally absorb only 60 tonnes of phosphorus per year. The traditional end-of-pipe strategy, even with a massive expansion of the sewer system and modern wastewater treatment plants, could not possibly reduce nutrients to the required amount. Experts from Eawag and Kunming found that source control measures, such as urine source separation and agricultural measures, were indispensable. Local officials were very receptive to the idea of urine source separation and prepared to adopt new approaches. Given the rapid expansion of cities such as Kunming – by 2020 the population is expected to grow from 2.4 to 4.5 million – measures could also be implemented much more quickly than in Switzerland. This new application in China promises to open up an attractive market for NoMix technology produced on an industrial scale. Separate urine collection can also save water because it avoids the use of more than 20 L of drinking water to dilute a liter of urine. Waterfree urinals require no water (obviously) and certain NoMix toilets require very little flushing water for urine drainage.

Agricultural fertilizers

Urine processing methods can eliminate nutrients. The methods suitable for this purpose (e.g. biological treatment) are similar to those used at sewage plants; however nutrients in urine are present in a highly concentrated form in contrast to heavily

diluted wastewater. Consequently, process engineering can be more flexible and the facilities required are much smaller.

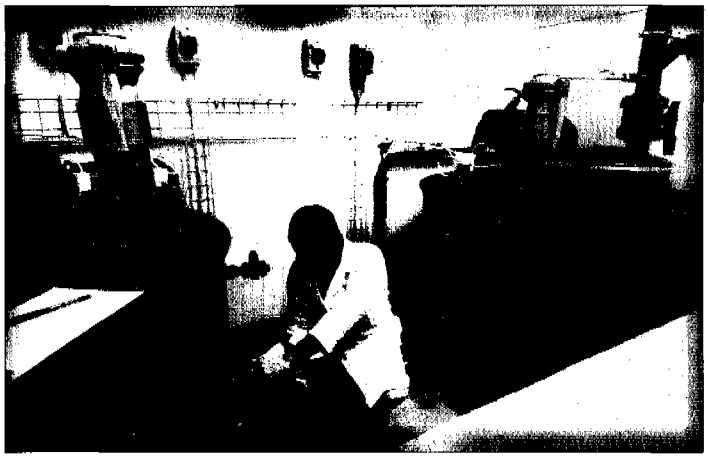
Another use is to recover nutrients from urine for recycling as agricultural fertilizers. For this purpose, micropollutants such as medicines and hormones must be removed from urine, so several removal methods were tested. For example, precipitation with magnesium recovered 98% of the phosphorus in urine. The product struvite ($MgNH_4PO_4$) is an attractive fertilizer in powder form, free of pharmaceuticals and hormones.

Nanofiltration and electrodialysis are other methods of separating nutrients from possible pollutants. The utilities agency (AIB) of Canton Baselland, Switzerland, uses a combination of electrodialysis and ozonation to process urine collected at the Cantonal Library in Liestal. In 2006, the Research Institute of Organic Agriculture (FiBL) successfully tested the fertilizer produced in this pilot project overseen by Eawag. Its effectiveness on fodder maize was similar to that of artificial mineral fertilizer and significantly better than that of slurry or commercial organic fertilizers. In Switzerland, nutrients from human urine could serve as substitutes for at least 37% of the nitrogen and 20% of the phosphorus demand that is currently met by imported artificial fertilizers.

The NoMix technology thus opens up novel process engineering options for wastewater management, which can be flexibly applied depending on the goal. In most cases, however, the methods have yet to be implemented in practice – in larger-scale pilot plants or in subsequent development by companies seeking to market the technology. At Eawag, meanwhile, engineers' efforts will be focused on developing methods for treating small volumes of urine that are applicable in decentralized systems.

Reducing pharmaceuticals

Eawag researchers working on the Novaquatis project developed ecotoxicological and chemical analytical methods to evaluate the quality of the urine-based fertilizer product. A newly developed ecotoxicological battery can also determine the overall effect of the methods by testing samples before and after processing. Tests performed showed that the treatment methods tested remove different pharmaceutical substances to different extents. For example, the efficiency of the bioreactor was found to be inadequate, while struvite precipitation proved to be highly efficient: the micropollutants studied were almost completely eliminated. Nanofiltration removed 50% to 90% of the toxicity and ozonation removed 55% to 99%, depending on the ozone dose.



Storage tanks for urine collected separately from women and men for research purposes by Eawag. ***Photo by Eawag***

Medicines and hormones enter wastewater via human urine to widely varying levels. The average rate of urinary excretion is 60% to 70% for 212 active substances ingested, which are found in 1409 pharmaceutical products. The remaining fraction found in wastewater is excreted in faeces.

A screening method was developed in the Novaquatis project to assess the environmental risks associated with excreted pharmaceuticals. The hazards posed to the aquatic environment were investigated for 41 commonly used medicines. Urine accounts for the entire ecotoxicological hazard in the case of 25% of all active substances, and for at least half in the case of another 40%. This finding means that urine source separation can reduce the environmental risks associated with pharmaceuticals and hormones of human origin in wastewater by an estimated 50%, and decrease the nutrient load on wastewater treatment plants.

Acceptance levels

The Swiss public approves of NoMix technology, as indicated by surveys carried out in pilot projects in public buildings. These involved 1750 people who used the NoMix toilets at their workplace (Eawag), vocational college, and at the BL Cantonal Library in Liestal. Altogether, 70% to 80% of respondents thought that urine source separation was a good idea, and an estimated 80% rated NoMix systems as equivalent or superior to conventional toilets with regard to design, hygiene, and odor. More than 80% would be prepared to move into an apartment fitted with a NoMix toilet. Many users of NoMix toilets are willing to adapt their behavior; for example, the urine source separation system requires all users – including men – to sit down to urinate, and 72% of respondents actually did so. Urine-based fertilizers also meet with approval: three quarters of the 501 people surveyed at the BL Cantonal Library would buy vegetables grown with a fertilizer of this kind. In a survey of farmers, 57% approved of the idea of urine-based fertilizers.

In public and office buildings, sanitary facilities are cleaned and maintained by service personnel. In all three pilot projects, NoMix toilets and waterless urinals required more efforts than conventional models. In certain waterless urinals, for example, a cartridge has to be periodically replaced. In NoMix toilets, blockages caused by urine scale need to be prevented, e.g. by flushing the urine drain regularly with a weak citric acid solution. This makes the installation of NoMix toilets in a household setting more problematic. Not everyone is prepared to accept the additional cleaning efforts required. Other drawbacks of NoMix toilets may also cause greater inconvenience in a private bathroom: children in particular find it difficult to adopt the required sitting position. In Switzerland, the small Eawag pilot project only involved four households, but the objections raised are confirmed by experience abroad – e.g. a project in which 88 apartments in Linz, Austria, were fitted with NoMix toilets.

Further development of NoMix toilets is thus essential before they can be installed on a large scale. Major investments are only likely to be made by sanitary technology companies if a sizeable market exists; however, a global market could rapidly emerge if the potential of the NoMix system to resolve water pollution problems is recognized.

Challenges

The NoMix toilet operates according to a simple principle: wastes collected at the back of the bowl are flushed into the sewers with water in the normal manner. In the front compartment, urine is collected and drained with a small amount of flushing water – or undiluted – into a local storage tank. Two difficulties remain. What can be done about the precipitation of salts that can block narrow pipes and siphons after only a few thousand usages? And how is urine to be transported to the treatment facility? Technical ingenuity is needed to find solutions for both of these problems.

Decentralized measures appear promising. Blockages could be solved by developing NoMix appliances in which the unavoidable build-up of precipitates takes place in a replaceable unit integrated into the toilet – as is currently the case in a number of water-free urinals. The need for transport can be avoided if urine is treated close to the source such as in a user-friendly unit located in the basement or in the toilet. If the system is to be implemented in practice, however, further research and development will be required, essentially involving cooperation with wastewater professionals and the sanitary technology industry.

Novaquatis has clearly shown that NoMix technology merits further development, yet plenty of work remains for Eawag in research and practical implementation. Engineers need to develop processing methods that allow urine to be treated in compact, decentralized units as near to the source as possible. A "urine machine" of this kind must be a stable, low-maintenance device – much like a modern coffee machine. In addition, social scientists and local experts in developing and emerging countries need to cooperate in order to introduce NoMix as a mass-use technology to solve water pollution problems.

Publications on the Novaquatis project include a Final Report (English, German) and an issue of Eawag News. Further information and links to all the relevant publications are available at:
www.novaquatis.eawag.ch